Fishery Data Series No. 07-74

Falls Lake and Kutlaku Lake Subsistence Sockeye Salmon Projects 2005 Annual Report

by

Jan M. Conitz

December 2007

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

Symbols and Abbreviations

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

Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Measures (fisheries)

fork length	FL
mideye-to-fork	MEF
mideye-to-tail-fork	METF
standard length	SL
total length	TL

Mathematics, statistics

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

FISHERY DATA REPORT NO. 07-74

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The Federal Subsistence Board, managed by U.S. Fish and Wildlife Service Office of Subsistence Management, approved the Falls Lake Subsistence Sockeye Salmon Project (Study Number FIS04-607) and the Kutlaku Lake Subsistence Sockeye Salmon Project. The projects were funded by the U.S. Forest Service, and are cooperative projects 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 report partially fulfills contract obligations for Sikes Act Contracts 53-0109-4-0025 and 53-0109-4-0026.

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

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ABSTRACT

In 2005, we estimated a spawning population of about 3,000 sockeye salmon (*Oncorhynchus nerka*) in Falls Lake, using two independent mark-recapture studies. This population size was similar to what we found in 2004, and in mid-range of escapements observed in previous years. The sockeye harvest of about 1,100 fish was lower than in the four preceding years, possibly as a result of an extended midseason closure designed to protect the early season escapement. However, reduced harvest could also reflect a short or long term shift in use and effort patterns among Kake fishers rather than lack of fish or opportunity. Age-2.3 sockeye salmon made up an unusually high percentage of the escapement in Falls Lake in 2005, and altogether, fish with two freshwater years made up about 55% of the escapement, somewhat higher than in previous years' observations. In Kutlaku Lake, we estimated about 4,500 fish in the main inlet stream and 3,100 fish in a secondary inlet stream using mark-recapture methods, which together represented very roughly 64% of all spawners, according to visual survey results. We extrapolated a total spawning population of about 12,000 sockeye salmon from the mark-recapture estimates and the rough percentage of the total population they represented. This rough estimate was similar in magnitude to those for 2002 and 2003. A more consistent sampling schedule and addition of sampling in the secondary inlet stream improved our overall estimate in 2005. Most sockeye salmon returning to Kutlaku Lake had only one year of freshwater growth, consistent with age estimates in the Kutlaku Lake escapement since 1982.

Key words: Sockeye salmon, *Oncorhynchus nerka*, subsistence, Falls Lake, Kutlaku Lake, Bay of Pillars, Kake, spawning, escapement, mark-recapture, zooplankton

INTRODUCTION

Falls Lake on Baranof Island and Kutlaku Lake on Kuiu Island produce small runs of sockeye salmon which are a major element in the seasonal subsistence cycle of people from Kake. Harvest of sockeye salmon and other food resources was carried out in small, seasonal fish camps around the mouths of productive streams, including Falls and Kutlaku Creeks, 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).

Both subsistence fisheries have been the subject of regulatory actions in recent years. In 2002, Kake residents and Alaska Department of Fish and Game (ADF&G) fishery managers negotiated to increase the daily possession limit for sockeye salmon to 50 fish at Falls Creek, in order to avoid the necessity for repeat trips (B. Davidson, ADF&G fisheries management biologist, letter to Organized Village of Kake, March 2002). ADF&G fishery managers have also adjusted the season dates at Falls Creek in an attempt to protect the earlier-returning parts of the sockeye run. Although very little subsistence fishing is currently occurring at Kutlaku Creek, Kake residents successfully proposed that the Federal Subsistence Board close this area to non-subsistence users. However, because of the very light harvest activity there and lack of evidence of any conservation concern for this sockeye run, ADF&G Division of Sport Fish has initiated an effort to rescind the closure (C. Swanton, ADF&G Division of Sport Fish, personal communication 2006).

We have estimated escapement and subsistence harvest of sockeye salmon returning to Falls Lake since 2001, using a weir in 2001 and 2002 and mark-recapture methods in all years, and direct interviews of participants in the subsistence fishery. We also conducted assessments of sockeye fry and smolt and zooplankton prey populations in an attempt to determine relationships between juvenile sockeye production and prey abundance in this system (Conitz and Cartwright *In prep*; Conitz and Cartwright 2003, 2005; Conitz et al. 2002). Falls Lake sockeye salmon escapements, juvenile populations, prey populations, and water chemistry measures were previously estimated in the 1980s during a fertilization study (Conitz et al. 2002).

Study of Kutlaku Lake sockeye salmon included mark-recapture estimates of spawning populations in 2002 and 2003, fry population estimates in 2001 and 2002, and zooplankton population estimates in 2001–2003 (Conitz and Cartwright 2003, 2005). ADF&G field technicians also visited Kutlaku Lake in most years from 1982 through 2001 to collect scale (age), sex, and length (ASL) samples from sockeye spawning populations (Appendix A.2 in Conitz and Cartwright 2003). Field notes and sketch maps from these sampling trips provide some information about timing, rough abundance, and location of sockeye spawning areas in Kutlaku Lake over this 20-year time period.

Additionally, ADF&G Division of Commercial Fisheries maintains a record of subsistence harvest by fishing site, including the Bay of Pillars (Kutlaku Creek) and Falls Creek. 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).

Sampling at Falls Lake in 2005 was similar to that in 2004, except in 2005 we did not sample sockeye smolt. We continued to count salmonids entering Falls Lake via the fish ladder and to sample for escapement age, sex, and length composition estimates, and we again used two different mark-recapture methods to estimate the sockeye spawning population in the lake. Subsistence harvest was estimated from on-site surveys as in previous years. We also continued to sample zooplankton to estimate species composition and abundance, and to measure profiles of light intensity and temperature in the water column.

In Kutlaku Lake, we estimated the sockeye spawning population using mark-recapture studies and visual surveys in the lake, and we estimated the age, sex, and length composition of the spawning population. One mark-recapture study focused on the sub-population spawning in the main inlet stream, which we previously estimated in 2002 and 2003. In addition, we attempted to estimate the size of another spawning group in the lake in order to strengthen the comparison with visual surveys.

OBJECTIVES

1. Estimate the subsistence harvest of sockeye salmon from the Falls Lake terminal area using an on-site survey, so that the estimated coefficient of variation is less than 15%.
2. Estimate the escapement of sockeye salmon into Falls Lake with mark-recapture studies, marking fish at a trap at the top of the fish ladder and sampling for marked fish on the spawning grounds, so that the estimated coefficient of variation is less than 15%.
3. Estimate the size of the Falls Lake sockeye spawning population within a defined study area on spawning grounds, so that the estimated coefficient of variation is less than 15%. Use observer counts to determine the proportion of the total spawning population that was available for sampling in the study area, and expand the study area estimate to a rough population estimate for the whole lake.
4. Measure light and temperature profiles and estimate zooplankton species composition, size, and abundance in Falls Lake throughout the season using established ADF&G limnological sampling procedures.
5. In Kutlaku Lake, estimate the number of sockeye spawners in the main inlet stream and other spawning areas so that the coefficient of variation is less than 15%. Use observer counts to determine the proportion of the total spawning population that was available for sampling in the study area, and expand the study area estimate to a rough population estimate for the whole lake.
6. For the sockeye spawning populations in both lakes, estimate the age, length, and sex composition 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.

METHODS

STUDY SITES

Falls Lake

Falls Lake (lat 56°49.5'N, long 134°42.2'W) is located on the east side of Baranof Island (Figure 1), just south of Red Bluff Bay and within the central Baranof metasediments subsection (Nowacki et al. 2001). It lies in a steep mountain cirque basin at an elevation of about 20 m, and drains a watershed area of about 1,650 km^2. The continental ice sheets of the Pleistocene Ice Age never overrode the upper elevations of the steep angular mountains in this area, but abundant precipitation formed smaller alpine glaciers, which carved the landscape and persist today. Frequent landslides, debris torrents, and avalanches sweep down the steep slopes, forming colluvial and alluvial fans around the bases of the mountains (Nowacki et al. 2001).

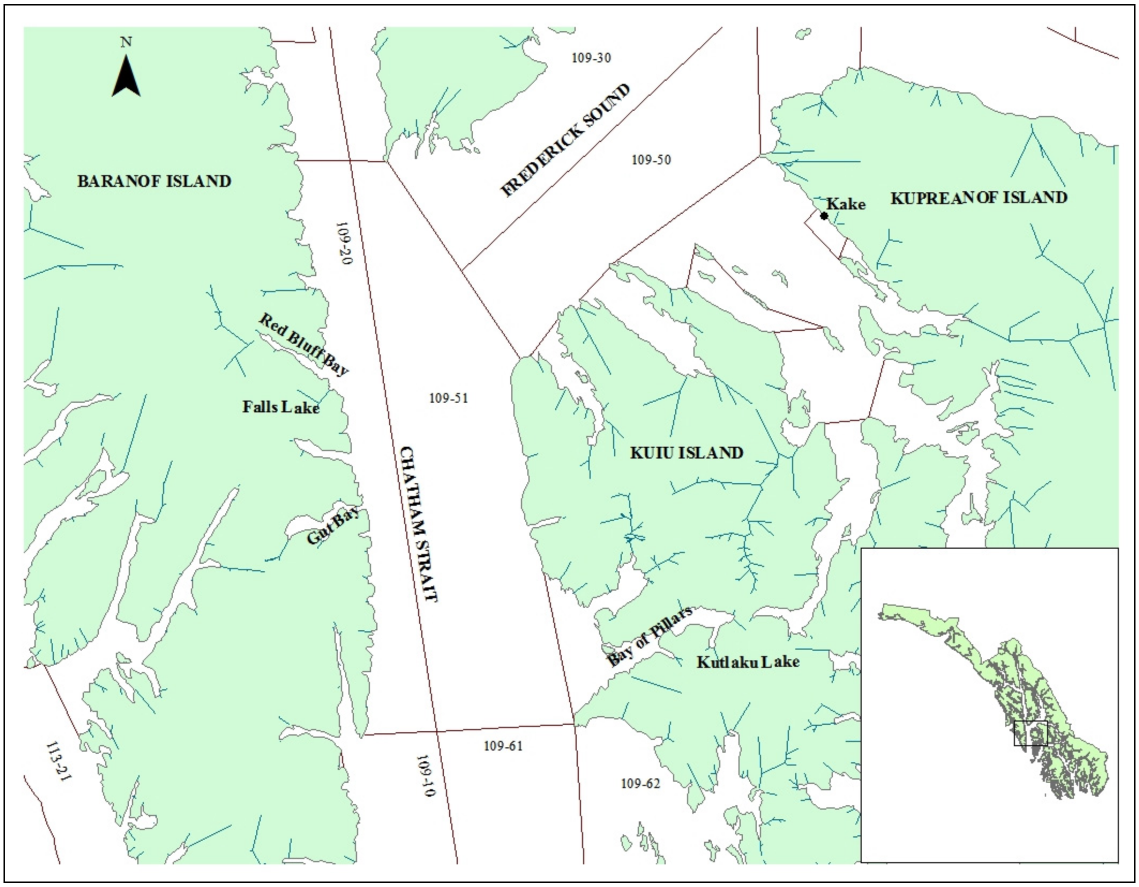

Figure 1.–Map showing the location of Falls Lake on Baranof Island, and Kutlaku Lake on Kuiu Island, in relation to the village of Kake, in Southeast Alaska (inset). Commercial fishing districts in waters adjacent to the study sites are also shown.

Falls Lake's two main inlet streams, originating in hanging glaciers and steep mountain falls, have formed large alluvial fans at their lower ends, supporting productive old-growth spruce forest and willow and alder thickets. Both stream channels are dynamic, with rapid changes apparent from flooding, beaver activity, and forest succession. The southwest inlet stream is sometimes cloudy with glacial silt; the west-southwest inlet stream is usually clear. Falls Lake has a surface area of about 95 ha, an average depth of 32 m. The large main basin in the center of the lake reaches a maximum depth of 75 m and is separated by a shallow sill from a smaller and shallower basin near the outlet (Figure 2). A very short outlet stream plunges over two falls directly into Chatham Strait. Falls Lake is organically stained and oligotrophic. Nutrient and chlorophyll levels, measured in the 1980s, were low and levels of dissolved ions and other water chemistry parameters were typical of lakes along the southeast Alaska coast (Conitz et al. 2002). Sockeye (*Oncorhychus nerka*) and coho (*O. kisutch*) salmon ascend the falls and spawn in the lake or inlet streams, mainly in the lower reaches and around the mouths of two largest streams entering the southwest corner of the lake. Both streams have partial or complete migration barriers a short distance upstream from the lake. Pink salmon (*O. gorbuscha*) spawn in the lower section of the outlet stream, but most eggs are probably washed out because suitable gravel is lacking and flow is periodically high; a very small number of pink salmon ascend the falls. The lake supports resident and anadromous populations of Dolly Varden char (*Salvelinus malma*), as well as sticklebacks (*Gasterosteus aculeatus*), and a few sculpins (*Cottus cognatus*). A fishpass was constructed in the upper part of the outlet stream in 1986 by the U.S. Forest Service to aid salmon migration. Mark-recapture study areas centered around the two main inlet streams at the southwest corner of the lake, and limnology sampling stations were located at the deepest points of the two main basins of the lake as in previous years (Table 1 and Figure 2).

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

Waypoint ID	Description	Latitude	Longitude
FALLS1	Mouth of main inlet stream	56.819217	134.708067
FALLS2	East end, beach study area	56.821783	134.708383
FALLS3	West end, beach study area	56.819367	134.711967
FALLSA	Limnology Station A	56.823250	134.694000
FALLSB	Limnology Station B	56.825067	134.695133

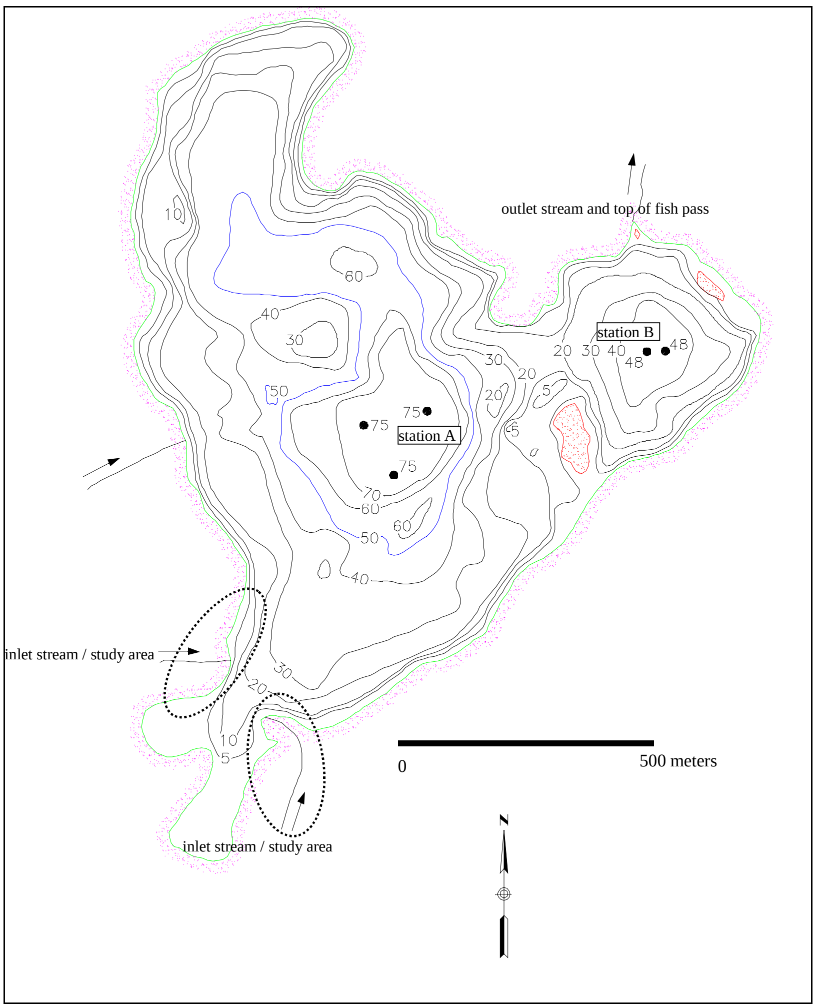

Figure 2.–Bathymetric map of Falls Lake, showing 10 m depth contours, location of trap at top of fishpass on the lake outlet, mark-recapture study areas, and two permanent limnology-sampling stations (A and B).

Kutlaku Lake

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. The rounded mountains in this area were heavily eroded and 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 3). 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, pink, and chum salmon, and anadromous or resident Dolly Varden char and cutthroat trout (*O. clarki*) are 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 2.

Table 2.–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

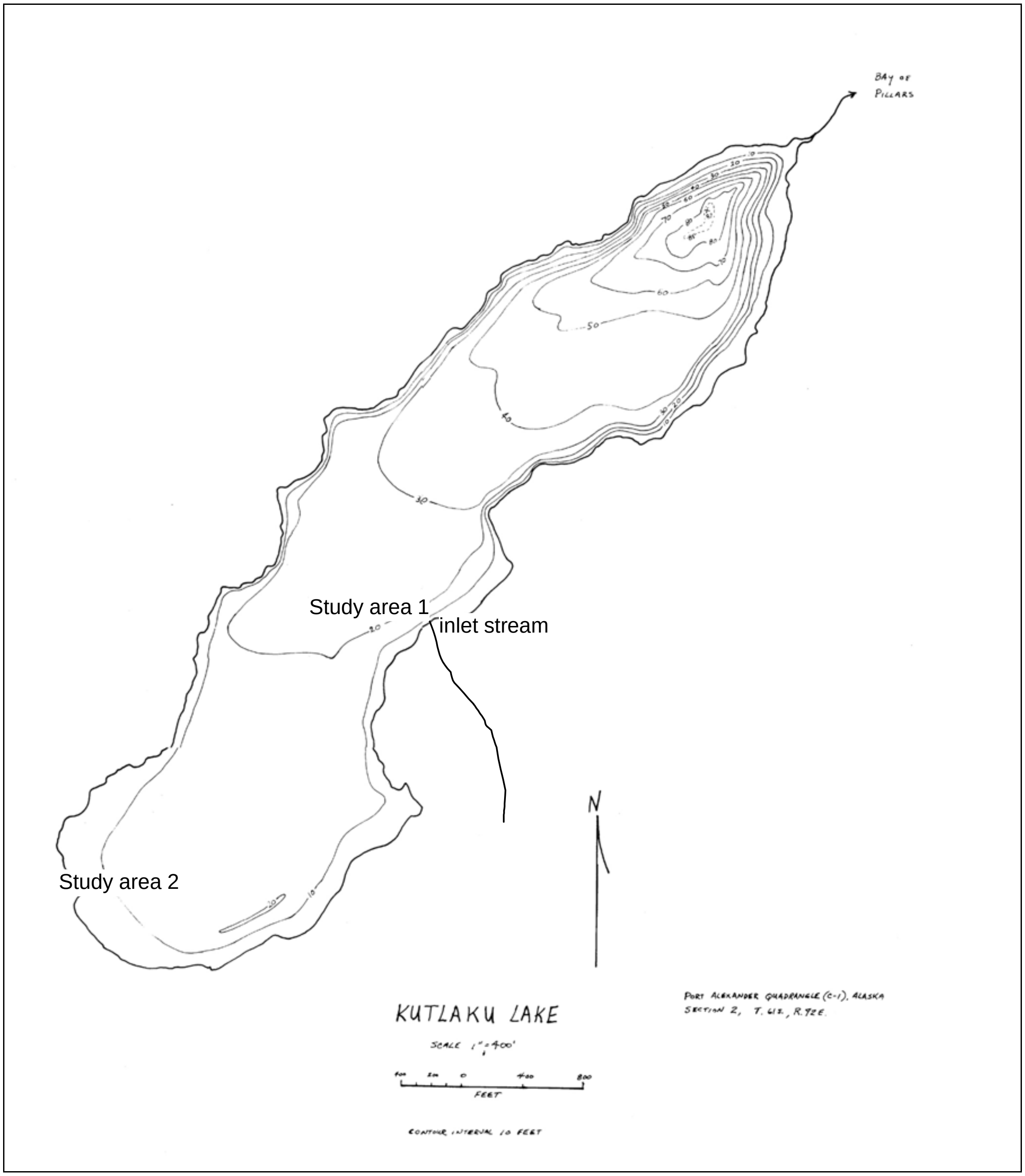

Figure 3.–Bathymetric map of Kutlaku Lake, the main inlet stream and mark-recapture study areas. Depth contours are in intervals of 10 ft (approximately 3 m).

FALLS LAKE HARVEST ESTIMATE

In 2005, subsistence fishing was open at Falls Lake from 1 June through 13 July, closed from 14 through 22 July, and open again from 23 July to 15 August. Sport fishing was open the entire season from May through September.

Given the low number of participants in the fishery, samplers were able to monitor the fishing area during the entire sampling period from 0500 to 2300 daily, between 20 June and 31 August. Both subsistence and sport fisheries were monitored. Fishery participants were contacted as they entered the area, counted by gear type (subsistence seine, subsistence gillnet, subsistence dipnet, or sport rod), and asked to complete an interview before leaving the area. Data collected during each interview included angler effort (rod or net hours) and harvest by species. If the technician was unable to interview a participant because two or more boats were leaving at the same time, one boat was randomly selected using a coin toss. The participant not selected, or any participant the crew was unable to interview for other reasons, was recorded as a missed interview.

Equations for estimating harvest, catch, and effort in each harvest survey were those for a one-stage direct expansion (access point, completed-trip interview) survey (Cochran 1977). This design was appropriate because the crew could accurately count all boats in the fishery and interview participants in most boats after they completed fishing. The primary sampling units were boat-parties within days. For each gear group, let h_j denote harvest on boat j, m denote number of boat-parties interviewed, and M denote number of boat-parties counted. The harvest, for a given gear group, was estimated as,

$$\hat{H} = \frac{M}{m} \sum_{j=1}^{m} h_j \ .$$

Letting $\bar{h}$ denote the mean harvest per boat, the variance of the harvest by stratum (gear group) was estimated as,

$$\mathrm{var}(\hat{H}) = (1 - \frac{m}{M}) M^2 \frac{\sum_{j=1}^{m} (h_j - \bar{h})^2}{m(m-1)} \ .$$

If all boat-parties in a gear group were interviewed, the one-stage design collapsed into a complete census, and we estimated harvest of each species by simply summing the harvests reported by all the boat-parties. The total harvest estimate of each species for the season was the sum of harvests for all gear groups, and estimated variance of the total harvest estimate was the sum of variances for all gear groups. The coefficient of variation (CV) for each estimate was the square root of the variance divided by the estimate.

SOCKEYE ESCAPEMENT ESTIMATES

Adult Trap Counts and Mark-Recapture Study (Falls Lake)

Migrating fish ascending the Falls Lake fish ladder were channeled into a 1.25 m x 1.25 m x 2.5 m box frame trap above the ladder (Conitz et al. 2002). All fish entering the trap were identified by species, counted, and passed upstream. The trap was operated continuously from 21 June through 30 August 2005.

A stratified, two-sample mark-recapture study was used to estimate sockeye salmon escapement into Falls Lake (Arnason et al. 1996). All sockeye salmon passed through the trap 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 the crew to monitor for tag loss. Following the season, tag numbers applied at the weir were stratified by tagging date into nine strata of one week each.

Six recapture events were conducted on the spawning grounds at five to ten day intervals throughout the spawning period. Fish were sampled in the main spawning areas around the mouths and in the channels of both inlet streams. Tags were applied to all unmarked fish in these samples, and each fish also received an opercular punch to identify the sampling event in which it was caught. A member of the crew recorded tag numbers of all newly captured and recaptured fish, along with sampling date and location. Following the season we compiled tag number data into electronic tables, and used database software to sort tag numbers by sampling event and count sample sizes and numbers of recaptured fish in each sample. Newly captured or recaptured fish were only counted on the first sampling event in which they were encountered. We accounted for tag loss in this study by recording recaptures of sockeye salmon with a clipped adipose fin but no tag. Because all tagged fish were marked with adipose clips, fish with lost tags could still be identified as recaptures and included in the recapture data, although the initial capture strata of such fish were unknown. We apportioned all recaptures of fish with lost tags to initial capture strata based on proportions of all fish marked at the trap in each stratum.

The two-sample Petersen method is a simplistic model for estimating total escapement based on the total number of fish marked as they move into the lake (first sample), the total number of fish subsequently sampled for marks on the spawning grounds (second sample), and the number of marks recovered in the second sample (Seber 1982, p. 59; Pollock et al. 1990). Stratified mark-recapture models extend the two-sample Petersen method over two or more sampling occasions or 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 there can be substantial variation in biological parameters such as daily immigration or mortality rates. A fundamental assumption of the Petersen and related mark-recapture models is that capture probabilities for individual animals are equal (Pollock et al. 1990). Briefly stated, the three assumptions of equal probability of capture required by the Petersen model are: 1) all fish have an equal probability of capture in the first sample (marking), 2) all fish have an equal probability of capture in the second sample (mark-recovery), and 3) fish mix completely between the first and second sample. Generally, if one or more of these assumptions is met, the marking and recovery strata can be pooled, thereby providing the most precise estimate. However, if none of the assumptions are met, the pooled estimate can be badly biased (Arnason et al. 1996).

We used the Stratified Population Analysis System (SPAS) software to aid in analyzing and interpreting our mark-recapture results (Arnason et al. 1996; for details, refer to http://www.cs.umanitoba.ca/~popan/). SPAS calculates Darroch and "pooled Petersen" estimates, and provides two goodness-of-fit tests to compare observed and expected capture probabilities in the marking (first) and mark-recovery (second) samples (Arnason et al. 1996). The test of the assumption of complete mixing is incorporated into the test for equal probability of capture in the second sample. We considered a test statistic with p-value ≤ 0.05 as "significant." In the event that both test statistics were significant, we looked at sample sizes and capture probabilities in each marking and mark-recovery stratum, and considered any natural events such as flooding or failures of our technicians to follow the sampling design. We then checked the Darroch estimate for possible problems, such as a failure of the SPAS program to converge to a solution, or an estimate much larger or smaller than the pooled Petersen estimate. We searched for a partial pooling scheme that led to non-significant test statistics and an absence of other diagnostic problems, with the fewest number of strata, and selected the Darroch or pooled Petersen estimate following the guidelines and suggestions in Arnason et al. (1996).

We used a parametric bootstrap procedure to estimate the standard error and construct the 95% confidence interval for 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.

Spawning Grounds Mark-Recapture Study and Visual Surveys (Falls Lake)

To obtain a second, independent estimate of the Falls Lake sockeye spawning population size, we used the Jolly-Seber model for open populations (Pollock et al. 1990), with an adjustment for spawning salmon populations (Schwarz et al. 1993). The crew sampled fish in the main spawning areas with a beach seine or dipnets. Sampling began as soon as sockeye salmon moved into the spawning areas, and a second event followed a few days after the first such that mortality would be at or near zero between these two events. We then sampled at approximately ten-day intervals until the number of available spawners declined and it was apparent that few or no new fish were entering the spawning areas. Tags were applied to all unmarked fish in these samples, with an opercular punch to identify the sampling event in which the fish was caught. Fish that had already been tagged at the weir were treated as if they were tagged on the first sampling event in which they were encountered on the spawning grounds. A crew member recorded tag numbers of all newly-marked and previously-marked fish, along with sampling date and location.

Following the season we compiled tag number data into electronic tables, and used database software to sort tag numbers by sampling event. We constructed an individual capture history for each fish, denoting a sampling event in which the fish was captured with a “1” and a sampling event in which the fish was not captured with a “0” (Pollock et al. 1990). From capture histories of fish with multiple recaptures, we were also able to look for incidence of spawners moving between different spawning areas. To account for lost tags, we reconstructed capture histories up to the most recent recapture by noting patterns of primary opercular punch marks or fin clips. If a particular pattern of primary marks with a lost tag was not seen in a later recapture, we could assume no more recaptures of that fish and complete its capture history with zeros for all subsequent sampling events. Each fish with a lost tag was also associated with an apparent capture history, consisting of a capture (1) in the event prior to the event in which the lost tag was noted, with no recaptures (all zeros) for subsequent events. If we were able to reconstruct and add a capture history for a fish with a lost tag, we also deleted the apparent capture history.

Data Analysis

The Jolly-Seber model extends the Schnabel method (Seber 1982, p. 130) to open populations. Population size is estimated at the time of each sample, and the number of new animals entering the population is estimated between sampling events, for *s* sampling events. In using this model we must assume:

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

We designated the following parameters:

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

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

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

B_i= total number of new fish entering the population before the first event, and between the ith event and $(i+1)^{th}$ event, and still in the population at time of $(i+1)^{th}$ event (i=0, 1, …, s-1); and B_0 is the number of fish that entered the population before the first event and are still alive at the time of the first event;

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

We also designated the following statistics:

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

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

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

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

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

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

The following unbiased estimators were recommended by Seber (1982:204):

$$\hat{M}_i = m_i + \frac{(R_i + 1)z_i}{r_i + 1};$$

$$\hat{N}_i = \frac{(n_i + 1)\hat{M}_i}{m_i + 1};$$

$$\hat{\phi}_i = \frac{\hat{M}_{i+1}}{\hat{M}_i - m_i + R_i};$$

$$\hat{B}_i = \hat{N}_{i+1} - \hat{\phi}_i(\hat{N}_i - n_i + R_i).$$

Seber (1982:204) recommended that m_i and r_i should be greater than 10 for satisfactory performance of these bias-adjusted estimators.

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

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

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

$$\hat{N}_2 = \hat{B}_0\phi_1 + \hat{B}_1.$$

So a reasonable estimate of the number of fish that entered the system before the first sampling event and between the first and second sampling events, including those that entered the system and died before and between these sampling events, is,

$$\hat{N}_2 \frac{\log(\hat{\phi}_1)}{\hat{\phi}_1 - 1}$$ (Schwarz et al. 1993).

We then estimated the super-population, or total escapement, as

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

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

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

Visual Surveys

Mark-recapture sampling was conducted in specific places, designated as the study area (Table 1 and Figure 2), within the main spawning areas of the Falls Lake system. Although the areas sampled comprise most of the available sockeye spawning habitat in Falls Lake, we adjusted our total spawning population estimate to account for the few spawners present outside of the study area. We determined the proportion of the total spawning population available for sampling in the study area, using visual survey counts. Just before each sampling event, at least three observers counted sockeye spawners from a skiff motoring slowly around the lake perimeter, and by walking up the spawning streams. The survey encompassed the entire lake and each inlet stream to the upper extent that fish have been observed. Observers recorded a total count of sockeye spawners in all areas, and also a count of just those spawners within the study area. We used mean counts between all observers, and divided the count for the study area by the total count, to estimate the proportion of fish within the study area at each sampling event. The proportion of fish in the study area over the entire season was estimated by taking the mean of proportions in the study area at each sampling event, weighted by the estimated spawning population size at each event.

Spawning Grounds Mark-Recapture Study and Visual Surveys (Kutlaku Lake)

At Kutlaku Lake, we used mark-recapture methods to estimate a portion of the sockeye spawning population, and visual surveys to approximate the proportion of the sockeye spawning population encompassed by this estimate. We extrapolated the mark-recapture estimate of spawners within the sampling area to a spawning population estimate for the whole lake on the basis of the proportion of fish counted in the sampling area. The primary sampling area was the main inlet stream along the south side of the lake (Figure 3), where we also conducted mark-recapture sampling in two previous years (2002 and 2003). We also attempted to obtain an estimate of at least one beach spawning group, but we found no spawners in the second study area used in 2003 (Conitz and Cartwright 2005) and we found no other place suitable for sampling beach spawners. However, the crew leader identified a secondary inlet stream at the southwest end of the lake in which sockeye salmon were spawning, and so we conducted mark-recapture sampling for a second estimate in that area.

We used a stratified, two-sample mark-recapture procedure (Arnason et al. 1995), as described for the Falls Lake mark-recapture estimate, to estimate escapement in each of the two inlet streams in Kutlaku Lake. Over several sampling events, sockeye salmon were sampled and marked (first sample) as they schooled up around the mouth of each inlet stream before going upstream to spawn. Once sockeye salmon entered the streams to spawn, they were sampled with dipnets (second sample), over several sampling events. Fish marked in each event were assigned to a stratum by sampling date, identified with a distinct opercular punch shape: stratum 1—round, stratum 2—triangle, stratum 3—square. The left operculum was marked in fish sampled at the main inlet stream, and the right operculum was marked in fish sampled in the secondary inlet stream. Because these two spawning groups were separated in both space and time, we did not anticipate any significant problems with misidentification due to mixing of the two groups. Marking samples were divided into three strata (22 August, 1 September, and 12 September) at the mouth of the main inlet stream, and two strata (12 September and 25 September) at the mouth of the secondary inlet stream. Live fish and carcasses sampled in the recapture phase were examined for marks; the number of each mark type and the number of unmarked fish were recorded. All live fish and carcasses sampled in the recapture phase were given a secondary mark to prevent re-counting. Sample sizes were as large as practical but avoided multiple same-day recaptures. Recapture samples were divided into three strata (1 September, 11 September, and 26 September) in the main inlet stream, and two strata (26 September and 4 October) in the secondary inlet stream.

Data analysis was exactly the same, using the SPAS software, as described under Adult Trap Counts and Mark-Recapture Study for Falls Lake above.

Adult Population Age and Size Distribution

About 600 length, sex, and scale samples were collected from adult sockeye salmon at the Falls Lake trap to estimate the size, sex, and age structure of the population. Fish were selected systematically (e.g. every fifth fish) to prevent selection bias, throughout the entire run. At Kutlaku Lake, the crew attempted to collect 600 samples from sockeye salmon on the spawning grounds during mark-recapture sampling. Samples were distributed across sampling trips and study areas so as to represent all parts of the spawning population to the extent possible. 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). For the Falls Lake samples, the weekly proportions in each age class, and the mean proportion in each age-sex group weighted by total trap count per week, were estimated. For the Kutlaku Lake samples, the proportions in each age-sex group were estimated from the entire sample. Associated standard error was estimated using standard statistical techniques and assuming a binominal distribution (e.g. Thompson 1992). Mean lengths by age and sex were likewise estimated from weekly means weighted by the total trap count per week for Falls Lake, and as simple means from the entire sample for Kutlaku Lake.

LIMNOLOGY SAMPLING (FALLS LAKE)

Limnology sampling was conducted on four dates in Falls Lake in 2005, beginning in early May and repeated at approximately six-week intervals through late September. Light and temperature measurements were taken only at Station A. Zooplankton samples were collected from two 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. Measurements were made at one-meter intervals to the first 10 m or the lower boundary of the thermocline (defined as the depth at which the change in temperature decreased to less than 1ºC per meter). Below this depth, measurements were made at five-meter intervals to 50 m.

Secondary Production

Zooplankton samples were collected at two stations using a 0.5 m diameter, 153 μm mesh, 1:3 conical net. Vertical zooplankton tows were pulled from 50 m at station A, and two meters from the bottom at station B, 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). Each zooplankton tow was sub-sampled in the laboratory, and technicians identified to species or genus, counted, and measured organisms in the sub-samples (Koenings et al. 1987). Density (individuals per m^2 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

FALLS LAKE HARVEST ESTIMATE

The Falls Lake crew counted a total of 30 participants in the subsistence and sport fisheries at Falls Creek in 2005 and they interviewed all participants (Table 3). Nineteen subsistence participants harvested a total of 879 sockeye salmon, and 11 sport fishers harvested 66 sockeye salmon, plus smaller numbers of four other species of salmon. Because participants from all boats counted were interviewed, the total harvest estimates are censuses, without sampling error. However, the estimate of 945 sockeye salmon (Table 3) may have some non-sampling error or bias because it is lower than the total harvest of 1,134 sockeye salmon reported by permit holders in 2005 (ADF&G Div. of Commercial Fisheries database 2006).

Table 3.–Number of participants (boats) in subsistence and sport fisheries and numbers of salmon harvested at Falls Creek in 2005, determined from on-site surveys.

Fishery type	Boats counted	Missed interviews	Total harvest by species				
			Sockeye	Coho	Chum	Pink	Chinook
Gillnet	14	0	303	1	99	104	6
Seine	4	0	518	30	0	27	0
Dipnet	1	0	58	0	0	0	0
Sport	11	0	66	1	0	7	5
Total	30	0	945	32	99	138	11

Overall, more sockeye salmon were harvested during the late season, from 23 July to 15 August, but subsistence fishers using gillnets harvested all of their sockeye salmon in the early season, between 25 June and 13 July. As expected, seine gear netted the highest average number of sockeye salmon per hour fished and gillnets the lowest, among subsistence fishers. Sport fishers harvested an average of one sockeye salmon per hour (Table 4).

Table 4.–Daily and seasonal harvest of sockeye salmon at Falls Creek by gear type, showing subtotals for the early season, mid season closure, and late season subsistence fishing periods, and a summary of hours fished and average sockeye harvest per hour by gear type.

	Daily and seasonal sockeye harvest by gear type				
	Beach seine	Gillnet	Dipnet	Sport	All gear
25 Jun	0	8	0	0	8
1 Jul	0	3	0	0	3
2 Jul	0	80	0	0	80
6 Jul	0	107	0	0	107
8 Jul	5	45	0	0	50
11 Jul	0	0	0	18	18
13 Jul	0	60	0	3	63
Subtotal, early season (1 Jun–13 Jul)	5	303	0	21	329
16-Jul	-	-	-	18	18
22-Jul	-	-	-	3	3
Subtotal, mid season closure (14–22 Jul)	0	0	0	21	21
27 Jul	63	0	0	12	75
29 Jul	200	0	0	0	200
1 Aug	0	0	0	12	12
2 Aug	0	0	0	0	0
3 Aug	0	0	0	0	0
4 Aug	0	0	0	0	0
7 Aug	250	0	0	0	250
11 Aug	0	0	58	0	58
Subtotal, late season (23 Jul–15 Aug)	513	0	58	24	595
Season total harvest	**518**	**303**	**58**	**66**	**945**
Total hours fished	22.0	61.6	3.0	55.5	142.1
Average harvest per hour fished	24	5	19	1	7

SOCKEYE ESCAPEMENT ESTIMATES

Adult Trap Counts and Mark-Recapture Study (Falls Lake)

Sockeye salmon entered Falls Lake through the fish ladder beginning 1 July 2005. The peak period of sockeye escapement was the week between 22 and 29 July, with a smaller peak around 5 August. The peak daily escapements coincided with small peaks in water level, while the larger peaks in water level were associated very low or zero sockeye escapement (Figure 4). Trap operation ended on 30 August; a few more sockeye salmon may have entered the lake after that date, but the run had tapered off to a very low level and typically ends early in September. The total count for the season was 1,930 sockeye salmon, representing an unknown fraction of total escapement. Coho and a few chum salmon and Dolly Varden char also entered Falls Lake via the fish ladder (Appendix A).

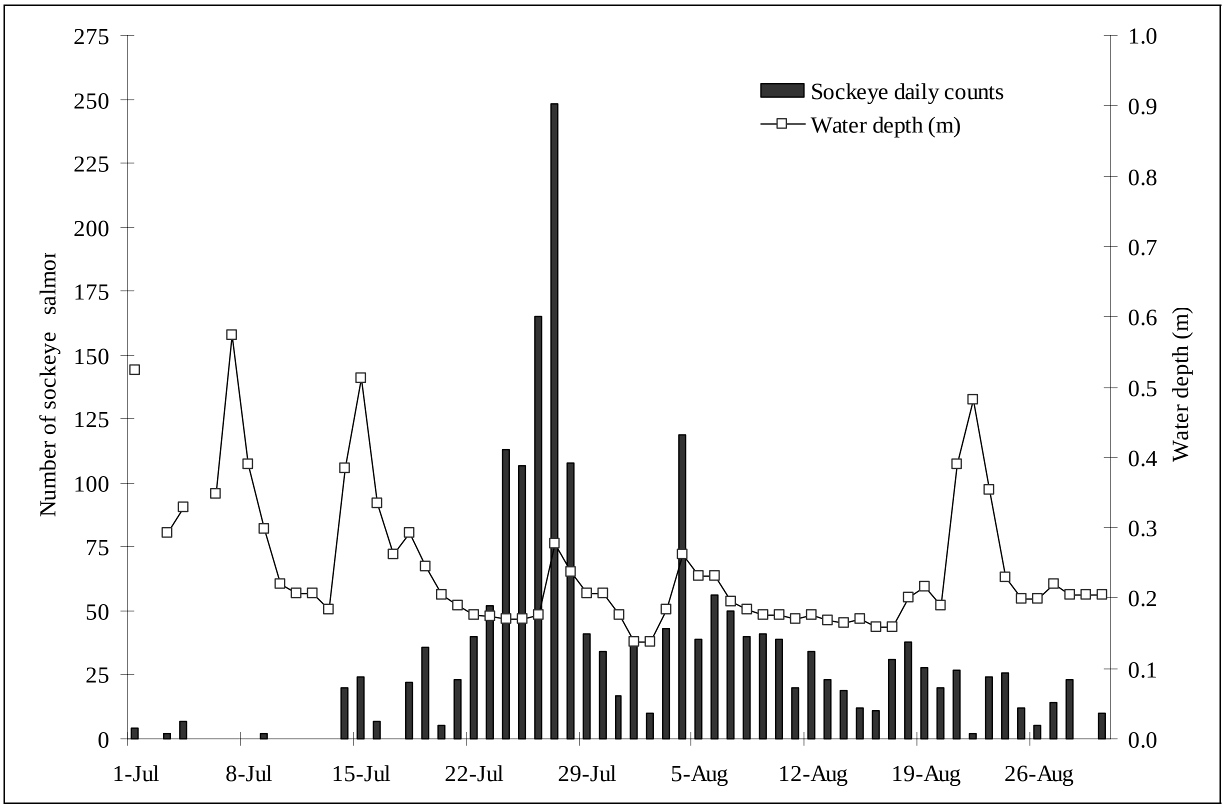

Figure 4.–Daily counts of sockeye salmon passed through the trap at the top of the fish ladder and water depth at the outlet of Falls Lake, 2005.

We estimated that about 3,400 sockeye salmon (CV=2%; 95% confidence interval 3,300–3,600) escaped into Falls Lake to spawn. The crew tagged 1,927 out of the 1,930 sockeye salmon passed through the trap for the mark-recapture study. Tagged fish were divided into strata based on the week in which they were tagged. Over the six sampling events between 25 August and 2 October, the crew sampled 1,232 sockeye salmon and recaptured 695 fish that were tagged at the trap (Table 5). Test statistics for “complete mixing” (X^2=41.3, p-value<<0.01, 9 df) and “equal proportions” (X^2=8.7, p-value=0.12, 5 df) led to the conclusion there was insufficient evidence of bias to reject the pooled Petersen estimate.

Table 5.–Numbers of fish marked and recaptured and sample sizes, by week of marking at the trap and date of sampling on the spawning grounds at Falls Lake 2005.

Marking stratum (week)	Number marked	Recaptures by sampling date						All recaps	Proportion recaptured by marking stratum
		25 Aug	30 Aug	9 Sep	14 Sep	23 Sep	2 Oct		
26 Jun–2 Jul	4	1	0	0	0	0	0	1	0.29
3–9 Jul	11	2	1	0	0	0	0	3	0.31
10–16 Jul	51	7	2	2	2	0	1	15	0.29
17–23 Jul	178	25	15	10	6	1	0	58	0.32
24–30 Jul	817	122	52	47	42	16	10	288	0.35
31 Jul–6 Aug	319	54	23	22	21	10	4	135	0.42
7–13 Aug	244	34	17	19	16	6	4	96	0.39
14–20 Aug	161	13	9	20	19	6	7	74	0.46
21–27 Aug	109	1	1	7	4	2	0	14	0.13
28 Aug–3 Sep	33	0	0	6	3	1	0	11	0.34
Totals	1,927	259	120	135	113	42	26	695	
Total sampled		430	211	261	191	85	54	1,232	
Proportion of marked fish in recapture samples		0.60	0.57	0.52	0.59	0.49	0.48		

Spawning Grounds Mark-Recapture Study and Visual Surveys (Falls Lake)

Using the Jolly-Seber method, we estimated a sockeye spawning population within the sampling or study area of about 2,900 fish (CV=6%; 95% confidence interval 2,500–3,200). The six sampling event dates were the same as those listed for the Petersen mark-recapture estimate in Table 5. We sampled and constructed capture histories for 1,222 sockeye salmon, showing 856 (70%) fish tagged and not seen again and the remainder recaptured at least once (Table 6). These totals were adjusted to include records for fish with lost tags for which capture histories could be unambiguously reconstructed from their primary marks (fin clip and opercular punches). An additional 35 records of lost tags, comprising 16 pairs and one set of three records, could not be resolved (i.e. fish in each pair may or may not have been the same individual). Therefore, the effective tag loss rate in this experiment was about 1–3% (17–35 fish out of a total of 1,239–1,257 unique fish sampled on the spawning grounds).

Table 6.–Summary of capture-recapture histories of sockeye salmon sampled on the Falls Lake spawning grounds, 2005. Capture histories are denoted with a "1" for a sampling event in which the fish was caught and released and a "0" for a sampling event in which the fish was not caught, in consecutive order over six sampling events. The number of fish with each observed capture history, and the subtotal in each category, are shown.

Capture-recapture category	Capture history	Number of fish
Captured only once	100000	271
	010000	160
	001000	161
	000100	138
	000010	72
	000001	54
Subtotal		856
Recaptured next event	110000	38
	011000	19
	001100	47
	000110	37
	000011	13
Subtotal		154
Recaptured once, after next event	101000	36
	100100	39
	100010	7
	100001	4
	010100	14
	010010	3
	010001	1
	001010	26
	001001	8
	000101	8
Subtotal		146
Recaptured more than once	111100	1
	111011	1
	111000	1
	110100	3
	110010	2
	101100	13
	101011	1
	101010	2
	100111	2
	100110	3
	100101	1
	100011	2
	011100	4
	011010	3
	010110	3
	001111	4
	001110	9
	001101	2
	001011	1
	000111	8
Subtotal		66
Total		**1,222**

Sampling encompassed most of the sockeye spawning areas in Falls Lake in 2005. Visual surveys indicated that over 90% of sockeye spawners were present in the sampling area at each sampling event, and over the season, a weighted average of about 95% of all sockeye spawners in Falls Lake were present in the mark-recapture study area (Table 7). Adjusting the spawning grounds mark-recapture estimate by the seasonal proportion of fish in the study area gave a whole lake spawning population estimate of about 3,000 sockeye salmon.

Table 7.–Visual survey counts of sockeye salmon in the spawning areas of Falls Lake, and the number and proportion of sockeye spawners observed within the mark-recapture study areas at each sampling event.

	Sockeye salmon counted		
Date	**Study areas**	**Whole lake**	**Proportion in study area**
24-Aug	741	752	0.98
29-Aug	877	912	0.96
8-Sep	1,098	1,158	0.95
13-Sep	1,077	1,149	0.94
22-Sep	782	824	0.95
1-Oct	325	359	0.91
Season weighted average proportion			0.95

Spawning Grounds Mark-Recapture Study and Visual Surveys (Kutlaku Lake)

We estimated that about 4,500 sockeye salmon (CV=9%; 95% confidence interval 3,800–5,600) entered Kutlaku Lake's main inlet stream to spawn. A total of 708 sockeye spawners was sampled and marked at the mouth of the main inlet stream between 22 August and 12 September 2005. Between 1 and 26 September, 555 sockeye spawners were sampled in the stream for marks, with 86 marks recovered (Table 8). Test statistics for "complete mixing" (X^2=38.6, *p*-value<0.01, 2 df) and "equal proportions" (X^2=1.3, *p*-value=0.54, 2 df) showed insufficient evidence of bias to reject the pooled Petersen estimate.

Table 8.–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 2005.

Marking date	**Number marked**	**Number recaptured in stream, by sampling date**			**Total recaptures by marking date**
		1 Sep	**11 Sep**	**26 Sep**	
22 Aug	231	31	8	4	43
1 Sep	203	0	35	1	36
12 Sep	274	0	0	7	7
Total marked	708				
Total recaptures by sampling date		31	43	12	86
Total number sampled for marks		183	272	100	555

We estimated a spawning population in the secondary inlet stream of about 3,100 sockeye salmon (CV=6%; 95% confidence interval 2,800–3,600). Between 12 and 25 September, 895 sockeye spawners were sampled and marked at the mouth of the secondary inlet stream, and between 26 September and 4 October, 522 sockeye spawners were sampled for marks in the stream, where 148 marked fish were recaptured (Table 9). Test statistics for "complete mixing" (X^2=10.4, *p*-value<<0.01, 1 df) and "equal proportions" (X^2=2.6, *p*-value=0.11, 1 df) showed insufficient evidence of bias to reject the pooled Petersen estimate.

Table 9.–Numbers of sockeye spawners marked and numbers of fish sampled for marks and numbers of recaptures at the secondary inlet stream in Kutlaku Lake in 2005.

Marking date	Number marked	Number recaptured in stream, by sampling date		Total recaptures by marking date
		26 Sep	4 Oct	
12 Sep	633	85	36	121
25 Sep	262	0	27	27
Total marked	895			
Total recaptures by sampling date		85	63	148
Total number sampled for marks		328	194	522

Visual survey counts confirmed the timing and relative sizes of spawning populations in both inlet streams and were used to estimate the proportion of the total sockeye spawning population that was sampled in these two streams. The proportion of spawners in the two inlet streams declined steadily through the season; however, the peak counts in the two streams roughly coincided with the peak counts for the whole lake (10 and 25 September; Table 10). The number of spawners in the main inlet stream (Stream 1) declined sharply after the 10 September peak count, while numbers continued to rise between 10 and 25 September in the secondary inlet stream (Stream 2) and in the lake as a whole. The sum of the pooled Petersen mark-recapture estimates of sockeye spawners in the two inlet streams was about 7,600 fish, and expanding by the overall weighted average proportion of fish in the two streams yielded a total spawning population estimate of about 11,800.

Table 10.–Visual survey counts of sockeye spawners in the two inlet streams where mark-recapture studies were conducted in Kutlaku Lake in 2005, compared with sockeye counts for the whole lake on each sampling date. The proportion of fish in both streams was used to expand the combined mark-recapture estimate (both streams) to a whole lake spawning population estimate.

Date	Sockeye counts (visual estimates)			Proportion in both streams
	Stream 1	Stream 2	Total	
22-Aug	72	0	73	0.99
31-Aug	378	50	506	0.85
10-Sep	927	739	2,028	0.82
25-Sep	317	1,099	2,058	0.69
3-Oct	50	565	1,280	0.48
19-Oct	0	30	617	0.05
Season weighted average proportion				0.64

Adult Population Age and Size Distribution

Falls Lake

Surprisingly, sockeye salmon with two freshwater years dominated the escapement in 2005, and the oldest group, age-2.3 fish, made up the highest percentage of all fish sampled (Table 11). Age-1.2 fish were the next most abundant group, followed by age-2.2, then age-1.3 fish. We estimated that about 55% of the returning sockeye spawners in 2005 were fish that had spent two years in Falls Lake as juveniles. The age-2.3 fish had the largest mideye to fork length, averaging 545 mm (Table 12). Those fish with three ocean years (age-2.3 and age-1.3) were 50–60 mm longer, on average, than those with two ocean years (age-2.2 and age-1.2). The additional year of freshwater growth in each of these groups did not correspond to larger size in the adults.

Table 11.–Age composition of adult sockeye salmon in the Falls Lake escapement by sex, 2005. Percentages in each age group were weighted by weekly counts through the trap. Estimated numbers in each age class, based on total estimated escapement (3,000 fish) are also shown.

Brood Year	**2002**	**2001**	**2000**	**2001**	**2000**	**1999**	
Age	**1.1**	**1.2**	**1.3**	**2.1**	**2.2**	**2.3**	**Total**
Male							
Sample size	1	66	64	2	42	120	294
Percent	0%	13%	12%	0%	8%	20%	53%
Female							
Sample size	-	89	29	-	78	67	264
Percent	-	16%	5%	-	15%	11%	47%
All fish							
Sample size	1	155	93	2	120	187	558
Percent	0%	29%	17%	1%	23%	31%	
Standard error	-	2%	2%	0%	2%	2%	
Estimated number in escapement	5	870	510	11	690	930	

Table 12.–Mean fork length (mm), weighted by weekly trap counts, of sockeye salmon in Falls Lake escapement by sex and age class. All fish were sampled between 3 July and 27 August 2005.

Brood year						
Age	**1.1**	**1.2**	**1.3**	**2.1**	**2.2**	**2.3**
Male						
Weighted mean length	390	486	542	374	489	546
SE (mean length)	-	4	3	6	5	2
Number sampled	1	66	64	2	42	120
Female						
Weighted mean length	-	485	530	-	488	543
SE (mean length)	-	2	6	-	3	3
Number sampled	-	89	29	-	78	67
All fish						
Weighted mean length	390	487	539	374	487	545
SE (mean length)	-	2	3	6	3	2
Number sampled	1	155	93	2	120	187

No striking pattern emerged in the weekly age composition of the escapement. However, during the two weeks with the highest sockeye counts through the trap, 24–30 July and 31 July–6 August, age-1.2 fish represented the highest percentage of the weekly counts. In the last three weeks of trap counts, age-2.3 fish represented the highest percentage of weekly counts (Table 13).

Table 13.–Sockeye age composition by week in the Falls Lake 2005 escapement. Percentages are based on the number of fish sampled and the number of fish passed through the trap at the top of the fish ladder each week between 3 July and 27 August 2005.

Week beginning	Estimated percentage of weekly escapement, by age class						Trap count
	1.1	1.2	1.3	2.1	2.2	2.3	
3-Jul	0%	17%	33%	0%	0%	50%	11
10-Jul	3%	28%	10%	0%	28%	31%	52
17-Jul	0%	34%	17%	0%	27%	22%	178
24-Jul	0%	33%	17%	1%	24%	24%	817
31-Jul	0%	31%	21%	0%	28%	20%	322
7-Aug	0%	17%	20%	0%	19%	44%	247
14-Aug	0%	24%	12%	0%	11%	53%	159
21-Aug	0%	19%	11%	0%	15%	56%	111

Kutlaku Lake

Only four age classes were observed in the Kutlaku Lake sockeye escapement in 2005, and nearly 70% of the fish sampled from the escapement were age 1.2 (Table 14). Almost 10% of the sampled fish were age-1.1 jacks, and almost 70% of all fish sampled were male. Only 413 fish, out of a total of 499 fish sampled, could be aged. The smaller sample size provides less certainty that the age-sex composition of the sample represents the true age-sex composition of the spawning population.

Age-1.3 fish, with three ocean years, had the largest mean fork length, 548 mm (Table 15). Age-1.2 fish, with two ocean years, averaged about 70 mm shorter than their counterparts with three ocean years, but were slightly larger than their age-2.2 counterparts.

Table 14.–Age composition of adult sockeye salmon in the Kutlaku Lake escapement by sex, 2005.

Brood year	2002	2001	2000	2000	
Age	**1.1**	**1.2**	**1.3**	**2.2**	**Total**
Male					
Sample size	40	191	51	5	287
Percent	9.7%	46.2%	12.3%	1.2%	69.5%
Female					
Sample size		92	30	3	125
Percent		22.3%	7.3%	0.7%	30.3%
All fish					
Sample size	40	284	81	8	413
Percent	9.7%	68.8%	19.6%	1.9%	
Standard error	1.5%	2.3%	2.0%	0.7%	

Table 15.–Mean fork length (mm) of sockeye salmon in Kutlaku Lake 2005 escapement by sex and age class.

Brood year Age	2002 1.1	2001 1.2	2000 1.3	2000 2.2
Male				
Mean length (mm)	345	476	555	474
SE (mean length)	4	2	4	16
Number sampled	40	191	51	5
Female				
Mean length (mm)		477	534	447
SE (mean length)		3	4	11
Number sampled		92	30	3
All fish				
Mean length (mm)	345	476	548	464
SE (mean length)	4	2	3	11
Number sampled	40	284	81	8

LIMNOLOGY SAMPLING (FALLS LAKE)

Light and Temperature Profiles

The depth of the euphotic zone in Falls Lake decreased steadily through the season in 2005, from 14.0 m in late May to 6.5 m in late September (Table 16). The thermocline had already begun to form in Falls Lake by the first sampling date, 27 May, and it persisted between 7 and 10 m through the summer months. By the last sampling date, 22 September, temperature stratification was disappearing (Figure 5).

Table 16.–Euphotic zone depths for Station A in Falls Lake in 2005.

Date	Depth (m)
27 May	14.0
10 Jul	11.5
5 Aug	9.4
22 Sep	6.5
Seasonal mean	10.1

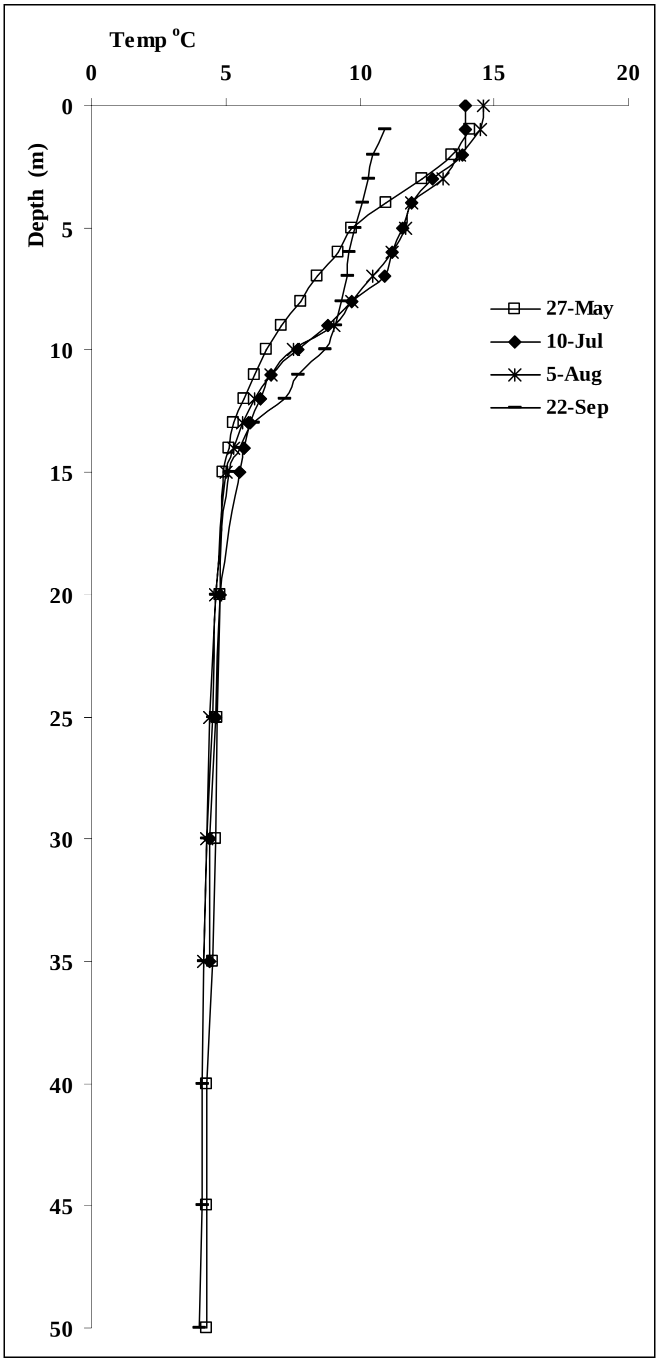

Figure 5.–Water column temperature profiles for Falls Lake at four sampling dates from 27 May to 22 September 2005.

Secondary Production

Zooplankton samples from Station A produced much higher estimates of seasonal mean density and biomass than the samples from Station B. However, the copepod *Diaptomus* dominated the biomass (68% of total) estimated from Station A samples due to its larger mean size (Table 17). Aside from *Diaptomus*, the largest contributor to both numbers and biomass of zooplankton at both stations was the small cladoceran *Bosmina*. Small numbers of the preferred prey *Daphnia* were present in samples from both stations, increasing late in the season.

Table 17.–Zooplankton species composition, numerical density, mean body length, and mean biomass in Falls Lake in 2005. 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.

Taxon	Density (number per m^2), by date					Percent of total number	Weighted mean length (mm)	Seasonal mean biomass ($mg \cdot m^{-2}$)	Percent of total biomass
	5/28	7/10	8/5	9/22	Seasonal mean				
Station A									
Epischura	4,670	8,660	764	212	3,577	6%	0.71	6	4%
Diaptomus	4,415	23,434	27,764	14,221	17,459	31%	1.19	122	68%
Ovig. Diaptomus	0	0	255	1,698	488	1%	1.50	7	4%
Cyclops	8,321	15,792	10,188	2,123	9,106	16%	0.72	16	9%
Copepod nauplii	1,613	3,057	1,274	849	1,698	3%			
Bosmina	7,726	20,122	19,868	23,136	17,713	32%	0.38	23	13%
Ovig. Bosmina	1,189	0	255	637	520	1%	0.33	1	0%
Daphnia longiremis	255	509	1,528	3,396	1,422	3%	0.71	3	2%
Ovig. D. longiremis	0	0	0	637	159	0%	0.85	1	0%
Daphnia rosea	0	0	0	212	53	0%	0.80	0	0%
Holopedium	85	0	0	0	21	0%	0.50	0	0%
Immature Cladocera	764	2,292	2,547	8,490	3,523	6%			
Seasonal mean totals					**55,740**			**179**	
Station B									
Epischura	2,377	3,396	0	0	1,443	9%	0.69	2	15%
Diaptomus	1,953	509	170	42	669	4%	0.85	2	12%
Cyclops	4,670	5,434	594	340	2,760	18%	0.59	3	21%
Copepod nauplii	1,953	2,717	1,528	509	1,677	11%			
Bosmina	4,075	8,830	7,981	6,071	6,739	44%	0.31	6	37%
Ovig. Bosmina	255	170	85	297	202	1%	0.34	0	1%
Daphnia longiremis	255	170	1,104	1,274	701	5%	0.68	1	9%
Ovig. D. longiremis	0	170	509	170	212	1%	0.80	1	4%
Daphnia rosea	0	0	0	42	11	0%	0.78	0	0%
Holopedium	170	170	170	0	128	1%	0.50	0	2%
Immature Cladocera	85	1,868	425	594	743	5%			
Seasonal mean totals					**15,283**			**16**	
Seasonal mean totals, between stations					**35,511**			**97**	

DISCUSSION

Abundance of sockeye spawners in Falls Lake was similar in 2005 to the previous year, and remained in the middle of the range of previous escapement estimates for this system (Table 18). On the other hand, subsistence harvest, which had increased each year from 2001 to 2004, dropped in 2005 to less than half the level of the previous years (Conitz and Cartwright *In prep*; Conitz and Cartwright 2005, 2003; Conitz et al. 2002). We don't know if the drop in harvest was a response to a smaller number of fish in the marine terminal area, or simply because people chose to fish elsewhere or to not fish at all. The extended mid-season fishing closure may have discouraged some participants who were accustomed to fishing in this area during the third week in July, when sockeye catches are usually at their peak and the weather is generally favorable. Project personnel did not report any complaints from fishers, however, and some people reported harvesting the sockeye salmon they needed at Gut Bay earlier in the season.

Table 18.–Summary of marine terminal area sockeye harvests and escapements for Falls Lake, for all years with estimates or weir counts through 2004. Escapement estimates in 1981–1989 were simply weir counts, and in 2001–2004 they were mark-recapture estimates.

Year	Total terminal area harvest	Estimated escapement
1981	no estimate	1,278
1982	no estimate	1,687
1983	no estimate	1,656
1984	no estimate	3,622
1985	no estimate	2,612
1986	no estimate	no estimate
1987	no estimate	5,789
1988	no estimate	1,114
1989	no estimate	1,989
-	-	-
2001	2,000	2,600
2002	2,600	1,100
2003	2,700	5,700
2004	2,900	3,300
2005	1,100	3,000

Sockeye spawning abundance at Kutlaku Lake was similar to what we estimated in two previous years (Table 19; Conitz and Cartwright 2005). Sockeye harvest totals reported by permit-holders may not be an entirely accurate representation of true subsistence harvest in this fishery, but they do indicate that the magnitude of harvest is relatively small compared with escapement and with harvest from other areas (e.g. Falls Lake). Evidently, the Falls Lake fishery is currently much more popular with Kake residents, a reversal of the pattern seen in the late 1980s and early 1990s (Firman and Bosworth 1990; Appendix A in Conitz and Cartwright 2005). Kake residents have described a traditional system of management and use of sockeye resources in their area whereby people were encouraged to fish in certain systems and refrain from fishing in others depending on the strength of the respective sockeye runs (M. Jackson, Natural Resources Specialist, Organized Village of Kake, personal communication 2003). Although modern socioeconomic factors currently play a large role in determining where people fish (Firman and Bosworth 1990), Kake residents continue to give weight to advice from their elders and community leaders in their subsistence practices. Certainly, one year's change in fishing patterns may not indicate a community wide shift in harvest patterns, but we recognize the possibility that the change in 2005 resulted at least in part from deliberate efforts by the community to manage their harvests for sustainability.

Table 19.–Bay of Pillars subsistence sockeye harvest totals reported by permit-holders after fishing, and estimated sockeye escapements into Kutlaku Lake in 2001–2005. Total harvest reported by permit holders may substantially underestimate true harvest.

Year	Total reported harvest	Estimated escapement
2001	130	no estimate
2002	194	10,000
2003	366	8,500
2004	548	no estimate
2005	114	12,000

As in previous years, zooplankton abundance and biomass were very low in Falls Lake, compared with other sockeye-producing lakes in Southeast Alaska (Appendix D in Conitz and Cartwright 2005). In 2005, we observed a higher proportion of sockeye salmon returning to Falls Lake with two freshwater years, predominantly in the oldest, age-2.3 class. In all years from 2001 to 2004 age-2.- fish were estimated to be less than 50% of the escapement, although they made up over 40% of escapement in 2002 and 2003 (Conitz and Cartwright *In prep*; Conitz and Cartwright 2005, 2003; Conitz et al. 2002). When Falls Lake sockeye escapements were sampled during the 1980s, high proportions of age-2.- fish were observed in some years (Appendix B.2 in Conitz et al. 2002). High proportions of fish with two freshwater years may indicate that conditions in the lake during the rearing years of these cohorts were such that many sockeye fry did not attain a large enough size to leave the lake after one year (Koenings and Burkett 1987). The fry population in Falls Lake in 2001 was relatively high (Conitz et al. 2002; Table 28 in Conitz and Cartwright 2005), and included the age-0 fry that returned as age-1.3 and age-2.2 adults in 2005 and the age-1 fry that returned as age-2.3 adults in 2005. Glacial silt from the main inlet stream clouded the lake in 2001 and may have reduced primary and secondary production in the lake that year more than in other years when the lake water remained clearer (Conitz and Cartwright 2005). Although even the largest observed sockeye fry populations in Falls Lake are low compared to fry abundance in other Southeast Alaska sockeye lakes (Appendix E in Conitz and Cartwright 2005), they may nevertheless be limited at this level by the oligotrophic nature and low zooplankton abundance in Falls Lake.

In contrast, nearly all sockeye salmon returning to Kutlaku Lake had only one freshwater year. The dominant age classes of adult sockeye salmon returning to Kutlaku Lake has alternated between age 1.2 and age 1.3 in all years estimated since 1982 (Appendix A.2 in Conitz and Cartwright 2003). The 2005 escapement followed that pattern with approximately 70% at age 1.2. Kutlaku Lake appears to be productive system, and its zooplankton populations were high relative to Falls Lake and moderate in comparison with other Southeast Alaska sockeye lakes, in years when they were measured (Appendix D in Conitz and Cartwright 2005). The high proportion of sockeye males in the 2005 Kutlaku Lake escapement was puzzling but could have been an artifact of sampling.

We have continued to refine and improve our estimation methods for sockeye spawning populations. Our two independent mark-recapture estimates for the Falls Lake sockeye spawning population were close enough to give us confidence that each is reasonably accurate. The pooled Petersen estimate of 3,400 applied to fish as they first entered the lake, while the Jolly-Seber estimate of about 3,000 applied to fish on the spawning grounds. We know that sampling schedules and protocol were followed without problems in 2005, and we were able to sample roughly 95% of fish in the spawning areas. Furthermore, estimation procedures and tests revealed no obvious problems, so we have no evidence of serious bias in either estimate. We are uncertain why the subsistence harvest total compiled from on-site interviews at Falls Lake was lower than the total harvest reported by permit holders. An obvious reason would be failure of crew members to accurately count and record all fishing boats in the Falls Lake marine terminal area. A more subtle reason could be that fishers underestimated their catches during the interviews, but counted and reported them more accurately upon returning to Kake and processing their fish.

We have somewhat more confidence in our sockeye spawning population estimate for Kutlaku Lake in 2005 than in the two previous years in which estimates were attempted. Most importantly, the sampling schedule was closely followed. We continued to use the main inlet stream as the primary mark-recapture study area, as we did in 2002 and 2003, and we added a second study area to increase the proportion of the spawning population that was sampled. Because the spatial pattern of spawning has varied in Kutlaku Lake over the years of our study, we have had to adapt in our selection of the second study area. The second inlet stream which we sampled in 2005 may not be used by sockeye spawners every year, but in 2005 a relatively large proportion of the total lake population did use this stream. The 2005 estimate was similar in magnitude to the estimates in previous years.

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APPENDIX

Appendix A.–Daily and cumulative counts of sockeye and coho salmon[1] entering Falls Lake through the fish ladder, and daily water levels and water and air temperatures, in 2005.

	Sockeye salmon		Coho salmon		Physical data		
Date	Daily	Cumulative	Daily	Cumulative	Water level (mm)	Water temp (°C)	Air temp (°C)
20-Jun	0	0	0	0	-	-	-
21-Jun	0	0	0	0	-	-	-
22-Jun	0	0	0	0	-	-	-
23-Jun	0	0	0	0	-	-	-
24-Jun	0	0	0	0	-	-	-
25-Jun	0	0	0	0	-	-	-
26-Jun	0	0	0	0	-	-	-
27-Jun	0	0	0	0	-	-	-
28-Jun	0	0	0	0	-	-	-
29-Jun	0	0	0	0	-	-	-
30-Jun	0	0	0	0	-	-	-
1-Jul	4	4	0	0	524	16.0	14.0
2-Jul	0	4	0	0	-	-	-
3-Jul	2	6	0	0	293	16.0	12.0
4-Jul	7	13	0	0	329	16.0	14.0
5-Jul	0	13	0	0	-	16.0	13.0
6-Jul	0	13	0	0	347	15.0	12.0
7-Jul	0	13	0	0	573	14.0	13.0
8-Jul	0	13	0	0	390	14.5	14.0
9-Jul	2	15	0	0	299	14.5	12.5
10-Jul	0	15	0	0	219	15.0	12.0
11-Jul	0	15	0	0	207	15.0	16.0
12-Jul	0	15	0	0	207	16.0	16.0
13-Jul	0	15	0	0	183	17.0	14.0
14-Jul	20	35	0	0	384	14.0	13.0
15-Jul	24	59	0	0	512	14.0	13.0
16-Jul	7	66	0	0	335	14.0	13.0
17-Jul	0	66	0	0	262	16.0	15.0
18-Jul	22	88	0	0	293	15.0	14.5
19-Jul	36	124	0	0	244	15.0	14.0
20-Jul	5	129	0	0	204	16.0	12.5
21-Jul	23	152	0	0	189	16.0	15.0
22-Jul	40	192	0	0	177	16.0	16.0
23-Jul	52	244	0	0	174	16.0	17.0
24-Jul	113	357	0	0	171	17.0	19.5
25-Jul	107	464	0	0	171	17.5	15.0
26-Jul	165	629	0	0	177	17.0	12.5
27-Jul	248	877	0	0	277	15.0	14.0
28-Jul	108	985	0	0	238	17.0	15.0

-continued-

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	Sockeye salmon	Coho salmon	Physical data		Sockeye salmon	Coho salmon	Physical data
Date	**Daily**	**Cumulative**	**Daily**	**Date**	**Daily**	**Cumulative**	**Daily**
29-Jul	41	1,026	0	0	207	16.0	14.0
30-Jul	34	1,060	0	0	207	17.0	14.0
31-Jul	17	1,077	0	0	177	17.0	14.0
1-Aug	37	1,114	0	0	137	16.0	12.0
2-Aug	10	1,124	0	0	137	16.0	12.0
3-Aug	43	1,167	0	0	183	16.0	13.0
4-Aug	119	1,286	0	0	262	16.0	15.0
5-Aug	39	1,325	0	0	232	15.0	14.0
6-Aug	56	1,381	0	0	232	15.0	14.0
7-Aug	50	1,431	0	0	195	17.0	20.0
8-Aug	40	1,471	1	1	183	17.0	15.0
9-Aug	41	1,512	1	2	177	19.0	16.0
10-Aug	39	1,551	0	2	177	18.0	19.0
11-Aug	20	1,571	0	2	171	17.0	17.0
12-Aug	34	1,605	0	2	177	18.0	17.0
13-Aug	23	1,628	5	7	168	19.0	19.0
14-Aug	19	1,647	0	7	165	17.0	17.0
15-Aug	12	1,659	0	7	171	17.0	17.0
16-Aug	11	1,670	0	7	158	18.0	17.0
17-Aug	31	1,701	5	12	158	20.0	16.0
18-Aug	38	1,739	3	15	201	19.0	19.0
19-Aug	28	1,767	17	32	216	19.0	15.0
20-Aug	20	1,787	6	38	189	18.0	13.0
21-Aug	27	1,814	22	60	390	16.0	14.0
22-Aug	2	1,816	9	69	482	16.0	13.0
23-Aug	24	1,840	23	92	354	16.0	12.0
24-Aug	26	1,866	7	99	229	17.0	14.0
25-Aug	12	1,878	1	100	198	15.0	15.0
26-Aug	5	1,883	0	100	198	14.0	15.0
27-Aug	14	1,897	8	108	219	14.0	15.0
28-Aug	23	1,920	15	123	204	14.0	17.0
29-Aug	0	1,920	0	123	204	14.0	13.0
30-Aug	10	1,930	2	125	204	15.0	13.0
Totals	1,930		125[1]				

[1]Incomplete count of coho salmon, which continued to enter Falls Lake after 30 August.