Fishery Data Series No. 08-49

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

by

Jan M. Conitz

October 2008

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

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Measures (fisheries)

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

Mathematics, statistics

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

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The Federal Subsistence Board, managed by U.S. Fish and Wildlife Service Office of Subsistence Management, approved the Falls Lake Sockeye Salmon Stock Assessment Project (Study Number FIS04-607). The project was funded by the U.S. Forest Service, and is 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 report fulfills contract obligations for Sikes Act Contracts AG-0109-C-06-0018 and AG-0109-C-06-0011.

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

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ABSTRACT

The number of sockeye salmon that returned to spawn in Falls Lake has been estimated in the recent six year period, 2001–2006, and these estimates were compared with weir counts obtained during an earlier sockeye assessment program in 1981–1989. Estimates in 2001–2005 were produced using a combination of in-season escapement counts and mark-recapture studies, but in 2006, only the mark-recapture study was conducted. In all years, the age composition of the sockeye spawning population was estimated from samples taken at the weir or on the spawning grounds. The estimated size of the sockeye spawning population in 2006 was 8,800 fish, larger than in all previous years in which it was measured, but generally consistent with existing information about this sockeye run, including early commercial fishery records. The subsistence harvest of Falls Lake sockeye salmon was not independently estimated in 2006, but returned permits indicated a total harvest of about 1,500 fish. In 2006 as in 2005, over 50% of sockeye salmon in the spawning population had two freshwater years (ages 2.2 and 2.3), whereas in 2001–2004 most of the sockeye salmon in the escapement had reared in the lake for only one year (ages 1.2 and 1.3). The alternation between years in proportions of fish with one and two freshwater years among returning adults seems to be characteristic of this system.

Key words: Sockeye salmon, *Oncorhynchus nerka*, subsistence, Falls Lake, Kake, escapement, spawning populations, mark-recapture, age composition

INTRODUCTION

Falls Lake on the east side of Baranof Island produces small but consistent runs of sockeye salmon (*Oncorhynchus nerka*), supporting an active subsistence fishery based in the village of Kake (Figure 1). Recent research including key respondent interviews with Kake elders indicates that the *Keex'kwaan*, the Tlingit regional group occupying the area, have harvested fish from the Falls Lake sockeye run over a period of at least several hundred years (Goldschmidt et al. 1998; Turek et al. 2006). Before European-American contact, this sockeye salmon system was controlled by the leader of a clan or house group, and an extended family group most likely lived seasonally at a fish camp or semi-permanent village near the creek (Turek et al. 2006; Betts and Wolfe 1992).

The introduction of the commercial fishing industry into the area in the late 1800s forced changes in social organization and control and use of salmon resources upon the *Keex'kwaan*, like other Tlingit and Haida groups in Southeast Alaska. By the early 1900s, most of the *Keex'kwaan* people were living year-round in the village of Kake, and the seasonal harvesting cycle increasingly revolved around commercial fishing, with many Kake residents participating as boat owners, fishermen, crew, and cannery workers (Turek et al. 2006; Betts and Wolfe 1992; Firman and Bosworth 1990). People continued to use fish camps on a more limited seasonal basis, including the one at Falls Lake, until around the end of World War II. Subsistence was designated as a separate fishery and put under a permit system in 1961, shortly after Alaska statehood (Turek et al. 2006).

Directed commercial harvest on the Falls Lake sockeye salmon stock occurred between 1913 and 1922, with annual harvests ranging from about 1,000 to 10,000 fish, and averaging about 3,600 fish (Rich and Ball 1933). Directed harvest of this stock was discontinued after the 1920s, but Falls Lake sockeye salmon undoubtedly continued to be caught in mixed stock, primarily purse seine fisheries in Chatham Strait. Since Alaska statehood, commercial harvest of sockeye salmon in the subdistricts of lower Chatham Strait (District 109; Figure 1) increased gradually as incidental catch in the purse seine fisheries. In the 1990s and 2000s, incidental sockeye salmon harvests in this area increased more than four-fold from previous decades, mainly due to contributions from fisheries on the east side of Chatham Strait, particularly Kingsmill Point to Washington Bay (Subdistrict 109-51). High incidental sockeye salmon harvests also occurred from southeast Baranof Island to the area around Red Bluff Bay (Subdistricts 109-10 and -20) during the 1990s but have subsequently declined to pre-1990s levels (ADF&G Div. of Commercial Fisheries database, 2008). In the 2000s, commercial fisheries managers have used adjustments to fishing areas and dates in an effort to protect the Falls Lake and Gut Bay Lake sockeye salmon runs (B. Davidson, ADF&G Div. of Commercial Fisheries, personal communication 2006). However, the specific contribution of the Falls Lake stock in any commercial harvest is unknown, because individual stocks are not generally identified in these fisheries.

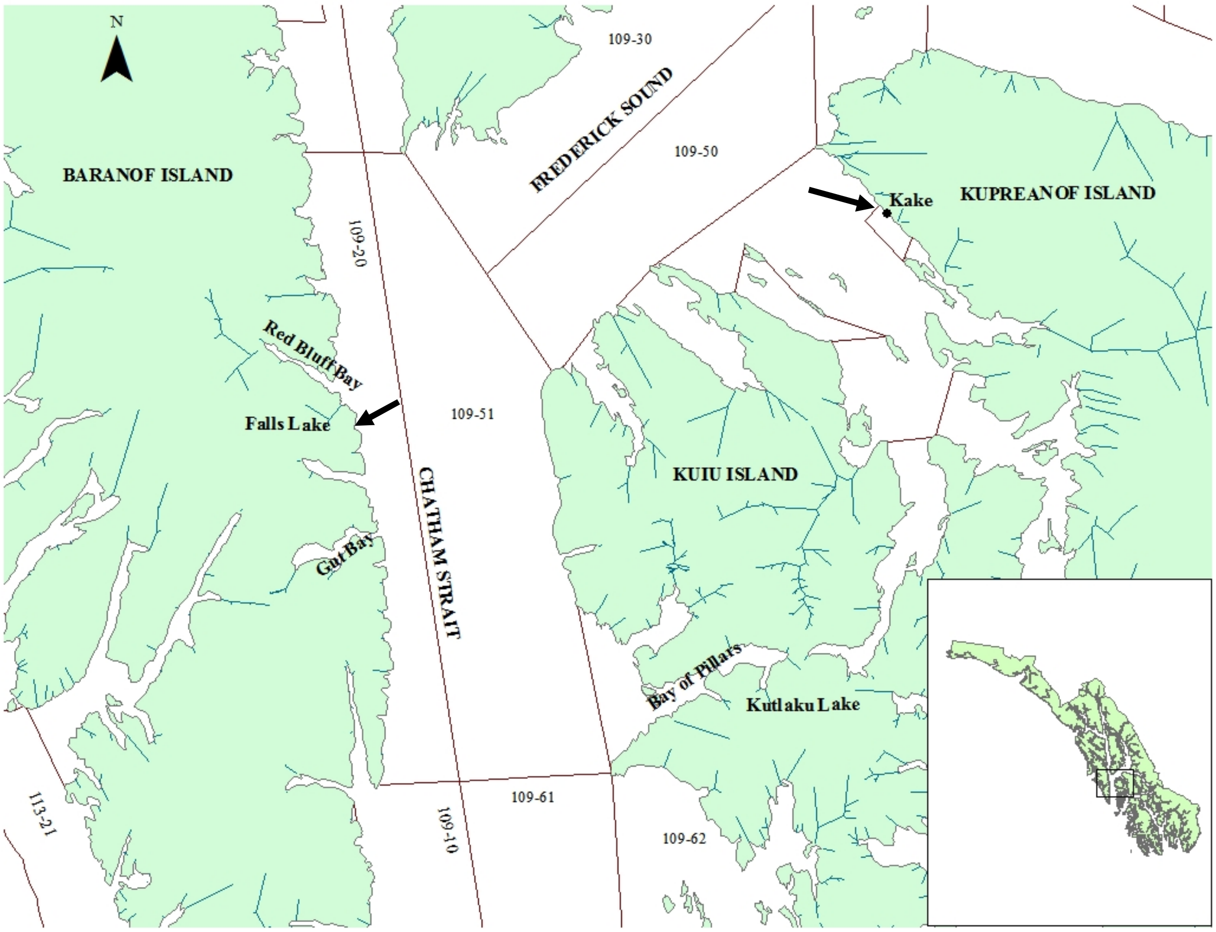

Figure 1.–Map with arrows showing the location of Falls Lake on Baranof Island and the village of Kake on Kupreanof Island, in Southeast Alaska (inset). Commercial fishing districts in waters adjacent to the study site are also shown.

According to ADF&G records, sockeye salmon harvest in the permitted subsistence fishery at Falls Lake increased more than two-fold in the 1990s (Table 1). However, the subsistence harvest estimates in the 1980s and 1990s were based solely on returned permits and not independently validated. Especially during the earlier period, when the permit system was fairly new, some fishers may have failed to report or even to obtain a permit at all. During the 1980s, the Bay of Pillars and Gut Bay were far more commonly used by Kake residents for subsistence sockeye salmon fishing than Falls Creek (Firman and Bosworth 1990). However, by 2000, Falls Creek was the place where most Kake residents obtained their subsistence sockeye salmon. In 2001–2005, the ADF&G subsistence sockeye salmon project crew conducted independent harvest surveys at Falls Creek, and I estimated the harvests from this survey data and compared them with harvest totals reported by permit holders. The estimated harvests, based on the surveys, were higher than the reported harvests by 8–46% in four out of five years, lower by 21% in one year, and higher on average by 23% over all five years (Table 2). Note that the number of participants interviewed in the surveys was generally less than the number of permits reporting, most likely because most groups fishing at Falls Lake fished for more than one permit.

Table 1.–Reported subsistence harvest of sockeye salmon from the area around the mouth of Falls Creek, from 1985 to 2005. Harvest totals were obtained from permit-holders' reported catches after the season and were not independently verified (ADF&G Div. of Commercial Fisheries database 2008).

Year	Number of permits reporting	Total reported sockeye harvest
1985	2	17
1986	3	30
1987	3	30
1988	24	338
1989	26	350
1990	16	149
1991	10	122
1992	34	550
1993	51	1,002
1994	51	911
1995	56	976
1996	70	1,229
1997	69	987
1998	62	1,101
1999	75	1,020
2000	59	798

Table 2.–Subsistence harvest of sockeye salmon from the Falls Creek area from 2001 to 2005, comparing permit-holders' reported harvest totals with estimates generated from on-site surveys of the fishery (Conitz et al. 2002; Conitz and Cartwright 2003, 2005, 2007; Conitz 2007).

	By permit returns		By on-site survey		
Year	Total reported harvest	Number of permits reporting	Estimated harvest	Number of participants interviewed	Percentage difference[a]
2001	1,300	84	1,900	35	46%
2002	1,800	62	2,600	42	44%
2003	2,400	63	2,600	28	8%
2004	2,100	65	2,900	33	38%
2005	1,134	44	900	30	-21%

[a] Difference between estimated harvest and reported harvest, as percentage of reported harvest.

Escapement of sockeye salmon into Falls Lake has been estimated annually during two periods, first in 1981–1989, and more recently in this study starting in 2001. The ranges of estimated escapement during these two periods were remarkably similar. In the earlier period, a simple weir count was used, and ranged from 1,114 to about 5,789 fish (Conitz et al. 2002). From 2001 to 2005, escapement was estimated using a weir or trap at the top of the fish ladder in conjunction with a mark-recapture study, and the estimates ranged from 1,100 to 5,700 sockeye salmon (Table 3; Conitz et al. 2002; Conitz and Cartwright 2003, 2005, 2007; Conitz 2007). The subsistence harvest increased steadily from 2001 to 2004, but the escapement and total number of fish returning to Falls Creek generally increased during that period also. The number of fish harvested exceeded the number in the escapement only in 2002. The pattern of increasing subsistence harvests and run sizes changed in 2005, with a substantially lower subsistence harvest and a smaller total number of fish returning to Falls Creek than in the two previous years. Perhaps Kake residents responded to the smaller sockeye salmon run by fishing elsewhere, or perhaps they simply harvested fewer fish overall for some other reason.

Table 3.–Estimated subsistence harvest of sockeye salmon in the terminal marine area at the mouth of Falls Creek, sockeye escapement into Falls Lake, and total number of sockeye salmon returning to the Falls Lake system (subsistence harvest plus escapement) from 2001 to 2005.

Year	Subsistence harvest	Escapement	Total number returning
2001	2,000	2,600	4,600
2002	2,600	1,100	3,700
2003	2,700	5,700	8,400
2004	2,900	3,300	6,200
2005	900[a]	3,400	4,300

[a] Estimated harvest in 2005 was lower than the total harvest of 1,134 sockeye salmon that was reported on returned subsistence permits.

The managers of the Falls Lake subsistence fishery have responded to the new information gathered in this study, as well as to Kake community needs and requests, by implementing several changes. In 2002, the possession limit for sockeye salmon was increased to 50 fish for the Falls Lake area, in order to make the long and potentially hazardous trip from Kake more cost-effective (B. Davidson, ADF&G Div. of Commercial Fisheries, letter to Henrich Kadake, OVK, March 2002). A closed area was also extended around the mouth of Falls Creek to protect sockeye salmon waiting below the intertidal falls, where entry by migrating salmon into the creek depends upon tide and water level in the creek. Because we observed in 2001 that the entire subsistence sockeye salmon harvest was taken before any fish escaped into the lake, a mid-season closure, during approximately the third week in July, was implemented in 2002. this closed period was lengthened, in conjunction with a later season closing date, in 2005. In addition, commercial fishing boundaries have been moved farther away from the Falls Creek area in order to protect the Falls Lake sockeye salmon run (B. Davidson, ADF&G Div. of Commercial Fisheries, personal communication 2002).

In 2006, this project conducted only a mark-recapture study and age-sex-length sampling in the spawning areas of the lake; other parts of the project were eliminated, at the request of the funders, in order to shift priority funding to another project. Comparisons were made in previous years between several different mark-recapture methods and complete or partial escapement counts at the lake outlet, so the stand-alone mark-recapture estimate in 2006 can be evaluated in the context of the prior years' information.

OBJECTIVES

1. Estimate the size of the Falls Lake sockeye salmon 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.
2. Estimate the age, length, and sex composition of the sockeye salmon in the spawning population at Falls Lake, based on a sample size of 600, so that the estimated coefficient of variation for the two major age classes is 10% or less.

METHODS

STUDY SITE

Falls Lake (lat 56^{o}49.5'N, long 134^{o}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).

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 and an average depth of 32 m. The large main basin in the center of the lake reaches a maximum depth of 75 m 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 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 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 on the two main inlet streams at the southwest corner of the lake were the same as in previous years (Figure 2).

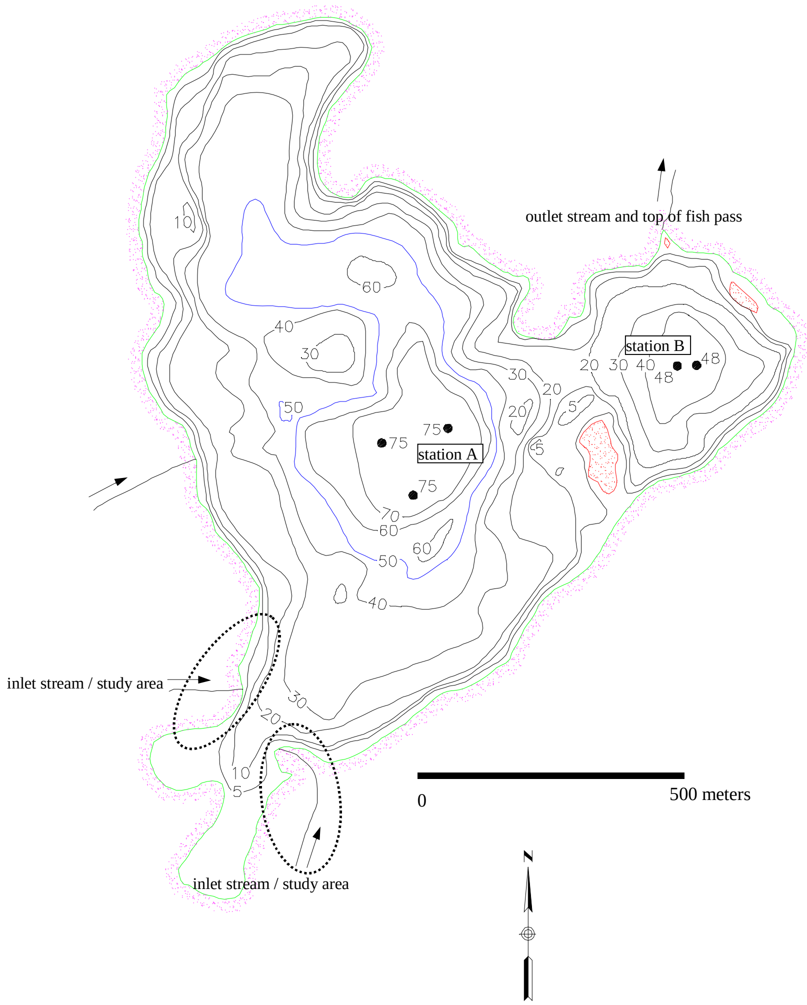

Figure 2.–Bathymetric map of Falls Lake, showing 10 m depth contours and mark-recapture study areas.

Sockeye salmon Escapement Estimate

Mark-Recapture Study

To obtain an estimate of the spawning population of Falls Lake sockeye salmon, I 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. Sampling continued at approximately weekly intervals until the number of available spawners declined and it was apparent that few or no new fish were entering the spawning areas. Numbered t-bar 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. A crew member recorded tag numbers of all newly-marked and previously-marked fish, along with sampling date and location.

Following the season I compiled tag number data into electronic tables, and used database software to sort tag numbers by sampling event. I 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). For fish with lost tags, I could reconstruct 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, I assumed no more recaptures of that fish and completed 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 an initial capture (when the fish was first tagged) and no recaptures (because even though this fish was later recaptured the unique tag number was missing). In each case of a lost tag where a capture history could be reconstructed using the primary marks, the corresponding apparent capture history was removed from the data set.

Visual Surveys

Mark-recapture sampling was conducted within the main spawning areas of the Falls Lake system (Figure 2), but a few groups of fish spawned outside these areas. Consequently, the spawning population estimate applied only to the portion of the total spawning population that was sampled within the study area. To determine the proportion of the total spawning population that was sampled, I used visual survey counts of the total number of sockeye salmon spawners in the lake and of the number of spawners just within the study area. Prior to each sampling event, at least three observers counted sockeye salmon spawners from a skiff motoring slowly around the lake perimeter, and on foot walking up the spawning streams. The survey encompassed the entire lake and each inlet stream to the upper extent that fish have been observed. Fish in the study area were counted separately. After each survey, I divided the mean count (between all observers) for the study area by the mean count for the whole lake (including streams), to estimate the proportion of fish within the study area at that 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 (whole lake count) at each event.

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. The model requires the following assumptions:

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

Parameters were designated as follows:

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). 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).

The following statistics were also designated:

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 used, as recommended by Seber (1982:204):

$$\begin{aligned}\hat{M}_i &= m_i + \frac{(R_i+1)z_i}{r_i+1};\\ \hat{N}_i &= \frac{(n_i+1)\hat{M}_i}{m_i+1};\\ \hat{\phi}_i &= \frac{\hat{M}_{i+1}}{\hat{M}_i - m_i + R_i};\\ \hat{B}_i &= \hat{N}_{i+1} - \hat{\phi}_i(\hat{N}_i - n_i + R_i).\end{aligned} \tag{1}$$

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

I assumed that sampling extended to a time when immigration had ended and 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 new 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, I adjusted $\hat{B}_i$ by a probability distribution approach (Schwarz 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

$$\hat{B}_i^* = \hat{B}_i \frac{\log(\hat{\phi}_i)}{\hat{\phi}_i - 1}. \tag{2}$$

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

$$\hat{N}_2 = \hat{B}_0 \phi_1 + \hat{B}_1. \tag{3}$$

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,

$$\hat{N}_2 \frac{\log(\hat{\phi}_1)}{\hat{\phi}_1 - 1} \text{ (Schwarz et al. 1993).} \tag{4}$$

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

$$N* = \hat{N}_2 \frac{\log(\hat{\phi}_1)}{\hat{\phi}_1 - 1} + \sum_{i=2}^{k-1} \hat{B}_i^*. \tag{5}$$

I 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**.

Adult Population Age and Size Distribution

A target sample size of 600 adult sockeye salmon was set, to estimate the length, sex, and age composition of the Falls Lake sockeye salmon spawning population. 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. To determine age, 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). Associated standard errors were estimated using standard statistical techniques and assuming a binominal distribution (e.g. Thompson 1992).

RESULTS

SOCKEYE SALMON ESCAPEMENT ESTIMATE

Mark-Recapture Study

Over the course of six sampling events (23, 30 August and 5, 14, 21, 30 September) in 2006, a total of 2,405 sockeye salmon was sampled in the Falls Lake study area. The estimated spawning population within the study area was 7,900 sockeye salmon (95% confidence interval 7,200–8,800; CV=5%). About 15% (368 fish) of all fish sampled were captured in more than one sampling event (Table 4). Tag loss was observed in 38 fish out of the 368 recaptures. Using opercular punch marks and assuming each of these fish was only recaptured once after the initial capture and tagging event, I was able to reconstruct capture histories for all these fish, and included them in the estimate. The substantial proportion of recaptures contributed to good precision of the mark-recapture estimate. Nearly 6% (153 fish) were caught after two or more periods between sampling events, including 21 multiple recaptures (Table 4), indicating the residence time for these spawners was reasonably long relative to the sampling intervals.

Visual Surveys

Based on visual survey counts, the proportion of sockeye salmon spawners in the study area compared to all spawners in Falls Lake ranged from 0.82 to 0.95 (Table 5). The average proportion of fish in the study area, weighted by abundance at each sampling date (whole lake count), was 0.90 for the entire spawning period. Assuming the study area estimate of 7,900 fish represented 90% of all sockeye salmon spawning in Falls Lake, the total spawning population estimate was about 8,800 sockeye salmon.

Table 4.–Summary of capture-recapture histories of sockeye salmon sampled on the Falls Lake spawning grounds, 2006. The numbers of fish with each observed capture history, and the total number in each category, are shown.

Capture-recapture category	Capture history[a]	Numbers of fish
Captured only once	100000	506
	010000	402
	001000	453
	000100	471
	000010	177
	000001	29
Subtotal		2,038
Recaptured at next event	110000	53
	011000	53
	001100	52
	000110	25
	000011	10
Subtotal		193
Recaptured once, after next event	101000	47
	100100	26
	100010	2
	100001	1
	010100	47
	010010	11
	010001	2
	001010	9
	000101	8
Subtotal		153
Recaptured more than once	110100	2
	110110	1
	101100	4
	101010	1
	100110	1
	100011	1
	011100	6
	010111	2
	010110	2
	001110	1
	001101	1
Subtotal		22
Total		**2,406**

[a] A "1" denotes a sampling event in which the fish was caught and released, and a "0" denotes a sampling event in which the fish was not caught, in consecutive order for six sampling events: 23, 30 August and 5, 14, 21, 30 September.

Table 5.–Visual counts of sockeye spawners and proportion of spawners in the study area at each sampling date, in Falls Lake, 2006.

Date	Average count within study area	Average count for whole lake	Proportion in study area
24 Aug	1,259	1,528	0.82
29 Aug	1,699	1,837	0.92
5 Sep	1,639	1,726	0.95
13 Sep	1,552	1,675	0.93
20 Sep	972	1,160	0.84
30 Sep	447	471	0.95

Adult Population Age and Size Distribution

Scales and sex and length measurements were taken from 506 sockeye salmon sampled on the Falls Lake spawning grounds, falling short of the target sample size of 600 fish. Out of the 506 fish sampled, ages were determined for 365 fish (Table 6). Assuming that this sample represented the full spawning population in 2006, five-year-old sockeye salmon from the 2001 brood year (ages 1.3 and 2.2) comprised 66% of the population. Four-year-old fish from the 2002 brood year made up an additional 27% of the total, with a small remainder (7%) of six-year-old fish from the 2000 brood year. Fish with two freshwater years comprised over 60% of the spawning population, and age-2.2 fish from the 2001 brood year were the largest class represented in the population overall (Table 6). Sockeye salmon with two ocean years, age-1.2 and -2.2, averaged about 495 mm in length, compared with fish with three ocean years, which were on average about 50 mm longer (Table 7). The additional year of freshwater growth added only about 10 mm on average to the length of three ocean fish and none to the two ocean fish.

Table 6.–Age composition of adult sockeye salmon in Falls Lake escapement by sex, 2006. All fish were sampled on the spawning grounds.

Brood Year	**2002**	**2001**	**2001**	**2000**	
Age	**1.2**	**1.3**	**2.2**	**2.3**	**All aged**
Male					
Sample size	61	23	70	13	167
Percent	17%	6%	19%	4%	46%
Female					
Sample size	38	22	127	11	198
Percent	10%	6%	35%	3%	54%
All Fish					
Sample size	99	45	197	24	365
Percent	27%	12%	54%	7%	
Standard error	2.3%	1.7%	2.6%	1.3%	

Table 7.–Mean mideye to fork length (mm) of adult sockeye salmon in Falls Lake escapement by sex and age class, 2006.

Brood Year	**2002**	**2001**	**2001**	**2000**
Age Class	**1.2**	**1.3**	**2.2**	**2.3**
Male				
Average length	498	549	497	562
Standard error	3	5	3	5
Sample size	61	23	70	13
Female				
Average length	494	544	494	548
Standard error	3	4	2	6
Sample size	38	22	127	11
All Fish				
Average length	496	547	495	556
Standard error	2	3	1	4
Sample size	99	45	197	24

DISCUSSION

The estimated population of about 8,800 sockeye salmon was the largest recorded for Falls Lake, exceeding the previous high estimates of about 5,700 fish in 2003 and 1987 (Table 8). No direct estimate of subsistence harvest in the Falls Lake marine terminal area was obtained in 2006, but a total harvest of 1,507 sockeye salmon was reported on returned subsistence permits for Falls Creek (47 permits reporting; ADF&G Div. of Commercial Fisheries database, 2008). This reported harvest total is not directly comparable with harvest estimates from this project for 2001–2005 (Conitz et al. 2002; Conitz and Cartwright 2003, 2005, 2007; Conitz 2007), because it was not independently verified for accuracy. Nevertheless, it represents at least a partial estimate of the sockeye salmon harvested from the Falls Lake run in 2006. (Note that in five years of independent verifications, the estimated harvests were 23% higher, on average, than the total harvests reported by permit holders; Table 2.) The total sockeye salmon run, including subsistence harvest and escapement, exceeded 10,000 fish in 2006. Although somewhat larger than in other recent years, this run size estimate appears to be consistent with other information about the Falls Lake stock. For example, early commercial fishery records from a brief period, 1913–1922, show a maximum sockeye salmon harvest attributed to the Falls Lake stock of 9,615 fish (Rich and Ball 1933).

Table 8.–Estimated escapements of sockeye salmon into Falls Lake during an earlier period of weir operation, 1981–1989, and in this project, 2001–2006, listing method used. High escapement years are shown in bold.

Year	Number of sockeye salmon	Method of estimation
1981	1,278	Weir count only
1982	1,687	Weir count only
1983	1,656	Weir count only
1984	3,622	Weir count only
1985	2,612	Weir count only
1986[1]	na[a]	-
1987	**5,789**	Weir count only
1988	1,114	Weir count only
1989	2,055	Weir count only
-	-	-
2001	2,600	Weir count and mark-recapture
2002	1,100	Weir count and mark-recapture
2003	**5,700**	Partial count (fish ladder) and mark-recapture
2004	3,300	Partial count (fish ladder) and mark-recapture
2005	3,400	Partial count (fish ladder) and mark-recapture
2006	**8,800**	Mark-recapture only

[a] Year in which the Falls Lake fish ladder was installed.

The 2006 estimate of escapement was based solely on a mark-recapture study with no in-season escapement count at a weir or fish ladder as in all previous years of study (Table 8). Nevertheless, studies in the five most recent years have shown a reasonable comparison between estimates based on interception of sockeye salmon as they entered the lake (counting and marking), and spawning population estimates which relied only on mark-recapture sampling in the spawning areas (Table 9; Conitz et al. 2002; Conitz and Cartwright 2003, 2005, 2007; Conitz 2007).

Table 9. Comparison of Falls Lake sockeye salmon escapement counts and associated mark-recapture estimates with spawning population estimates from studies on the spawning grounds, 2001–2005.

Year	Sockeye count (full weir or trap only)	Estimated escapement (marking at weir or trap), 95% confidence interval	Estimated total spawning population (sampling in spawning areas), approximate range
2001	2,570 (full weir)	2,500–2,800	1,400–2,400
2002	774 (full weir)	970–1260	700–1,500
2003	2,222 (trap only)	5,100–6,500	3,900–4,800
2004	1,640 (trap only)	3,200–3,500	2,700–3,300
2005	1,930 (trap only)	3,300–3,600	2,600–3,400

In 2006, as in 2005, most of the sockeye salmon that returned to spawn had two freshwater years (Conitz 2007). Over twelve years of sampling between 1982 and 2006, the age composition of the sockeye salmon spawning population has been variably distributed among four major age classes (Table 10). However, sockeye salmon with one freshwater year were dominant (over 50% of total) in eight out of twelve years. The age at which sockeye salmon smolt is related to, though not necessarily exclusively determined by, freshwater growth, and varies widely among populations in different lake systems and between years in a given lake system (Burgner 1991). The fact that in some years, apparently large proportions of Falls Lake sockeye salmon do not smolt until the second year suggests that some conditions in the lake environment are limiting to sockeye salmon growth. Falls Lake is characterized by low zooplankton density, cold temperatures that persist into the summer, and intrusion of glacial silt into the lake water in some years, all of which can inhibit sockeye salmon growth. These conditions, as well as sockeye salmon age at smolting as apparent from adult scale patterns, appear to be similar in the recent period of study to what they were in the 1980s when the lake and sockeye salmon populations were last studied (Koenings et al. 1984).

Table 10.–Age composition of sockeye salmon entering Falls Lake to spawn estimated in twelve years between 1982 and 2006. The dominant age class(es) in each year are highlighted. Only major age classes are shown.

Year	Estimated percentage of escapement by age class			
	1.2	1.3	2.2	2.3
1982	32.9	19.7	29.7	16.7
1983	19.5	50.9	22.8	6.2
1984	5.8	18.2	8.9	60.8
1985	1.7	19.0	22.6	44.0
-	-	-	-	-
1988	47.3	41.6	4.2	6.4
1989	1.6	72.4	20.4	5.6
-	-	-	-	-
2001	6.0	91.0	1.0	2.0
2002	45.6	11.4	22.8	19.7
2003	22.1	34.9	36.9	5.2
2004	37.6	42.4	13.3	6.7
2005	29.0	17.0	23.0	31.0
2006	27.0	12.0	54.0	7.0

Sockeye salmon populations produced in the Falls Lake system are small but appear to be stable over time and capable of supporting the levels of subsistence harvest that have been observed during the most recent period. The small size of this sockeye salmon run makes it intrinsically vulnerable to over-harvesting, but in recent years the modest time and area restrictions in both subsistence and nearby commercial fisheries appear to be allowing for sufficient escapement. Because this sockeye salmon run is a valuable and long-standing subsistence resource for the people of Kake, it should continue to be monitored to ensure escapements remain at a sustainable level.

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