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Falls Lake Subsistence Sockeye Salmon Project: 2007 and 2008 Annual Reports

By

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December 2009

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

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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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ABSTRACT

The 2007 and 2008 Falls Lake sockeye salmon (*Oncorhynchus nerka*) stock assessment was an ongoing project that has run continuously since 2001. In 2007, the project was reduced to a mark-recapture study on the spawning grounds, and age composition developed from scale samples taken during the mark-recapture study. In 2008, the full season of project activities resumed: fish were counted and marked as they migrated into a trap at the top of a fish ladder, the sampling crew conducted an on-site harvest survey of the subsistence fishery, and the sampling crew collected limnology readings and zooplankton samples. The estimated sockeye escapement for 2007 was 2,900 fish, which, compared to 2006, was closer to the long-term average. The dominant age class in 2007 was age 1.3, from Brood Year 2002. However, but the sample size used to determine age composition was less than optimal. For 2008, the estimated sockeye escapement was 750 fish, the lowest on record. The estimated subsistence harvest of about 1,700 sockeye salmon (based on interviews of fishermen on the grounds) exceeded the escapement by more than 2 times. The dominant age classes in 2008 were age 1.2 (Brood Year 2004) and 2.2 (Brood Year 2003), again determined from a very small sample. Zooplankton densities and biomass were low but within the ranges observed in previous years. In light of the intensive fishing that can occur on this small sockeye run, continued monitoring of the escapement and subsistence harvest seems essential, to provide the basic data needed to make informed management decisions.

Key words: Sockeye salmon, *Oncorhynchus nerka*, subsistence, Falls Lake, escapement, mark-recapture, age composition, limnology, Southeast Alaska

INTRODUCTION

Falls Lake, located on the east side of Baranof Island, produces small but consistent runs of sockeye salmon (*Oncorhynchus nerka*), that support an active subsistence fishery based in the village of Kake (Figure 1). The Tlingit regional group occupying the area, known as the *Keex'kwaan*, traditionally harvested fish from Falls Lake for hundreds of 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 (Betts and Wolfe 1992; Turek et al. 2006). Kake residents kept seasonal fish camps at the Falls Lake outlet at least through the 1940s. Present-day Kake residents now travel the distance of about 50 km from Kake, across the exposed waters of lower Chatham Strait, to day-fish for sockeye salmon at Falls Lake. Because of the long, exposed crossing and lack of suitable anchorages around Falls Lake, most subsistence fishermen try to travel from Kake during good weather and harvest their season's supply of sockeye salmon in a single day.

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. 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.

The intensity of subsistence fishing around Falls Lake in recent years has prompted discussion and proposals at both state and federal fisheries meetings, as well as some management adjustments. In 2002, Kake residents and 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, *personal communication*). 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. Sockeye salmon return to the

mouth of Falls Lake starting in late June or early July. They often spend several weeks schooled up around the creek mouth before ascending the falls into the lake, and when weather and tides are favorable for fishing, they are especially susceptible to harvest. Most sockeye salmon are unable to ascend the lower falls when the tide is low, and once they are able to enter Falls Creek, the upper falls immediately presents another partial barrier to their migration into the lake. A fish pass was constructed in the upper part of the outlet stream in 1986 by the U.S. Forest Service to aid salmon passage.

Escapement counting and other biological studies including a lake fertilization study were conducted at Falls Lake through most of the 1980s (summarized in Conitz et al. 2002). The current sockeye salmon stock assessment program was started in 2001, providing a series of escapement and harvest estimates, as well as limnological information and estimates of juvenile sockeye populations (Conitz et al. 2002; Conitz and Cartwright 2003; Conitz and Cartwright 2005; Conitz and Cartwright 2007; Conitz 2007; Conitz 2008). Sockeye salmon escapement counts in the 1980s, ranging from about 1,000 to 6,000 fish, were remarkably similar to escapement estimates in the 2000s, which ranged from about 1,000 fish to a high of over 8,000 fish in 2006 (Conitz 2008). Subsistence sockeye salmon harvests have been robust throughout most of this period. Harvest estimates were provided only by permit holders' reports on their returned permits beginning in the early 1980s through 2001. From 2001 to 2005, on-site surveys and direct interviews with fishermen were used to estimate harvest. In the earlier period, permit holders reported annual sockeye salmon harvests from under 100 to about 1,200 fish; reported harvests increased substantially in the 1990s. From 2001 to 2005, estimated harvests of about 1,000 to 3,000 sockeye salmon were calculated from the on-site surveys (Conitz 2008).

In 2006, due to a change in funding priorities, the project was reduced to mark-recapture estimation and adult sockeye salmon age-sex-length sampling only; the scope of the 2007 project was similarly reduced. In 2007, an open-population Jolly-Seber method was used to estimate the sockeye salmon population in the main spawning areas of the lake; age-sex-length sampling and visual counts were conducted in conjunction with the mark-recapture sampling. Sufficient resources were available in 2008 to resume some of the previous project activities and provide a more reliable, inseason-based escapement estimate, a harvest estimate, and information about the lake habitat. In 2008, a trap was installed at the top of the fish ladder on the outlet creek, where all sockeye salmon and other fish that ascended the falls via the fish ladder were counted, and a portion of the sockeye salmon were marked and sampled for age-sex-length data. Visual surveys and mark-recapture sampling on the spawning grounds, limnological measurements, zooplankton sampling, and an on-site subsistence harvest survey in the salt water fishing areas were also conducted in 2008.

OBJECTIVES

2007 OBJECTIVES

1. Estimate the size of the Falls Lake sockeye salmon spawning population using an open-population Jolly-Seber method with sampling on the spawning grounds, so that the estimated coefficient of variation is less than 15%. Use observer counts to estimate the proportion of the total spawning population that was included in the mark-recapture sampling area, and expand the Jolly-Seber estimate by that proportion to obtain a rough estimate of total spawning population.

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

2008 OBJECTIVES

1. Estimate the subsistence harvest of sockeye salmon from the fishing area around the mouth of the Falls Lake outlet 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 a standard, 2-sample mark-recapture study, 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. 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.
4. Estimate the age, length, and sex composition of sockeye salmon in the Falls Lake spawning population, with a target sample size of 600 fish, so that the estimated coefficient of variation for the 2 major age classes is 10% or less.

METHODS

STUDY SITE

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 ha. 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 2 main inlet streams, originating in hanging glaciers and steep mountain falls, have formed large alluvial fans at their lower ends, which support 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; a shallow sill separates the main basin from a smaller basin near the outlet (Figure 2). A very short outlet stream plunges over 2 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. Spawning occurs mainly in the lower reaches and around the mouths of the 2 largest inlet streams, which enter 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; 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*). The 2006 and 2007 mark-recapture and the 2008 second-event sampling areas centered on the 2 largest inlet streams; limnology sampling stations were located at the deepest points of the 2 main basins of the lake, as in previous years (Figure 2).

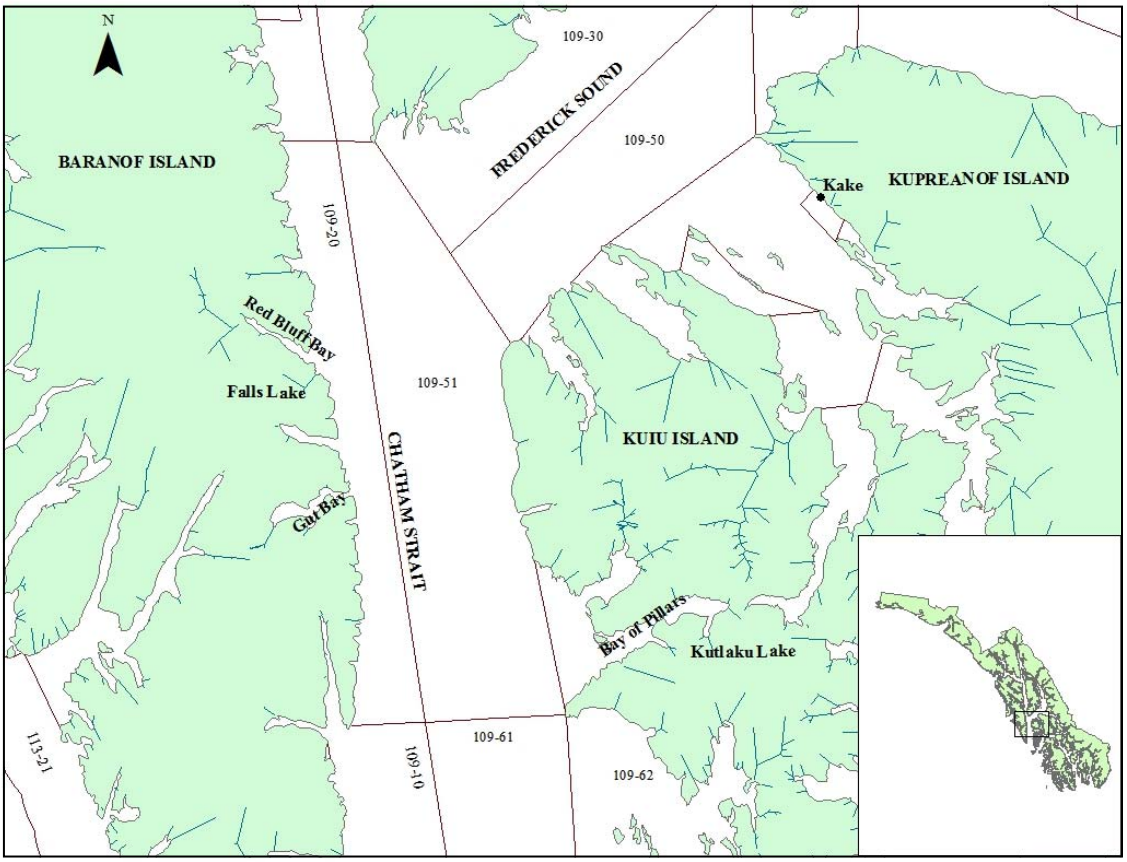

Figure 1.–Map showing the location of Falls Lake on Baranof Island, in relation to the village of Kake, in Southeast Alaska (inset). Commercial fishing districts in waters adjacent to the study site are also shown.

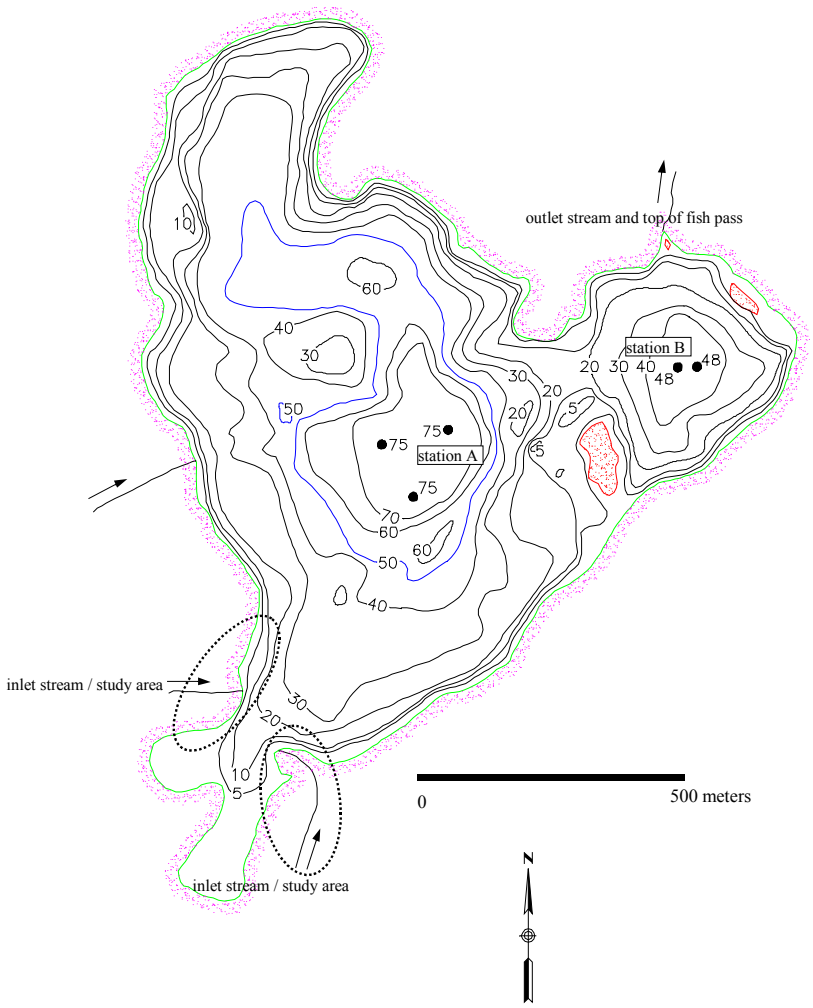

Figure 2.–Bathymetric map of Falls Lake, showing 10 m depth contours, limnology sampling stations A and B, and mark-recapture study areas.

SOCKEYE SPAWNING POPULATION ESTIMATE IN 2007

Mark-Recapture Study

Field Operations

The crew sampled fish in the main spawning areas with a beach seine or dipnets. Sampling began as soon as sockeye salmon were observed in the spawning areas, and 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.

In the first sampling event, all live sockeye salmon were marked with an opercular punch and a t-bar tag. During subsequent sampling events, all live sockeye salmon were checked for opercular punches and tags. Unmarked fish were tagged and marked with a specific opercular punch (e.g., square, round, triangle, etc.) for that sampling event. Tag numbers were recorded for all live fish caught in a given sampling event, both for initial captures and recaptures. Fish were sampled

without replacement during a given sampling event, but each recapture of a marked fish in subsequent sampling events was recorded. The opercular punch served as a primary mark to identify the fish to the sampling event in which it was captured and marked, even in the event of tag loss. The tag number data were used to construct an individual capture history for each fish, by sampling event. A "1" denoted a sampling event in which a fish with a given tag number was captured, and a "0" denoted a sampling event in which the fish with that tag number was not captured (Pollock et al. 1990). In the event of tag loss, capture histories were reconstructed by means of the opercular punch mark(s) present.

The crew attempted to sample fish in all the main spawning areas of Falls Lake and its 2 main inlet streams. In order to account for additional sockeye spawners in areas not sampled, visual surveys were conducted at the time of each sampling event. At least 3 observers counted sockeye 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 sockeye salmon have been observed. Two counts were recorded, a total count for the entire lake system, and a count for just those areas where sampling was conducted. The proportion of fish included in the mark-recapture estimate was then estimated as the average proportion of fish in the sampling areas at each sampling event, weighted by the estimated spawning population size (i.e., total count) at each event.

Analysis

The sockeye salmon spawning population in Falls Lake was estimated with a Jolly-Seber model for open populations (Pollock et al. 1990), with an adjustment for spawning salmon populations (Schwarz et al. 1993). 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. This model requires the following assumptions:

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

The model incorporates the following parameters:

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

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

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

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

The following statistics were also used in the model:

m_i = number of marked fish captured in the ith event (i=1, 2, …, s);

u_i = number of unmarked fish captured in the ith event (i=1, 2, …, s);

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

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

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

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

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

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

$$\hat{N}_i = \frac{(n_i+1)\hat{M}_i}{m_i+1}; \tag{2}$$

$$\hat{\phi}_i = \frac{\hat{M}_{i+1}}{\hat{M}_i - m_i + R_i}; \tag{3}$$

$$\hat{B}_i = \hat{N}_{i+1} - \hat{\phi}_i(\hat{N}_i - n_i + R_i). \tag{4}$$

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

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

When recruitment and mortality are assumed to occur uniformly between sampling events, the maximum likelihood estimator for B_i^* is,

$$\hat{B}_i^* = \hat{B}_i \frac{\log(\hat{\phi}_i)}{\hat{\phi}_i - 1}. \tag{5}$$

$\hat{B}_0$, $\hat{B}_1$, and $\hat{B}_{s-1}$ are confounded parameters and cannot be estimated without further assumptions (Schwarz et al. 1993). However, by assuming no new recruitment into the spawning population just before the last sampling event, $\hat{B}_{s-1}$ can be set to zero. The number of fish alive in the population at the second sampling event, N_2, was estimated as,

$$\hat{N}_2 = \hat{B}_0 \phi_1 + \hat{B}_1. \tag{6}$$

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

$$\hat{N}_2 \frac{\log(\hat{\phi}_1)}{\hat{\phi}_1 - 1}. \tag{7}$$

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

$$\hat{N} = \hat{N}_2 \frac{\log(\hat{\phi}_1)}{\hat{\phi}_1 - 1} + \sum_{i=2}^{k-1} \hat{B}_i^*. \tag{8}$$

A non-parametric bootstrap technique was used 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 (biometrician, ADF&G Div. of Commercial Fisheries, Region 2). The procedure works by resampling the observed experimental data to create a series of "pseudo-experiments," according to the following algorithm.

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

ADULT POPULATION AGE AND SIZE DISTRIBUTION–BOTH YEARS

To estimate the size, sex, and age structure of the respective spawning populations in Falls Lake, about 600 length, sex, and scale samples were collected from adult sockeye salmon on the

spawning grounds. Length of each fish was measured from mid-eye to tail fork, to the nearest millimeter. 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 fish with one freshwater and 3 ocean years; Koo 1962). Associated standard error was estimated using standard statistical techniques and assuming a binominal distribution (Thompson 1992).

SUBSISTENCE HARVEST ESTIMATE IN 2008

In 2008, subsistence fishing at Falls Lake was open from June 1 through July 13, and again from July 23 to August 15. 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 from 0500 to 2300 daily, between July 1 and August 31. 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 2 or more boats were leaving at the same time, one boat was randomly selected using a coin toss. The participant that was 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,

$$\hat{H} = \frac{M}{m} \sum_{j=1}^{m} h_j \tag{9}$$

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

$$\mathrm{var}(\hat{H}) = (1 - \frac{m}{M}) M^2 \frac{\sum_{j=1}^{m} (h_j - \bar{h})^2}{m(m-1)} \tag{10}$$

.If all boat-parties within 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 SPAWNING POPULATION ESTIMATE IN 2008

Mark-Recapture Study

Fish Trap and Field Operations

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 July 1 through August 31, 2008.

A stratified, 2-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, which allowed 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 approximately weekly 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. The crew conducted visual surveys around the lake prior to each sampling event, using the same methods as in 2007 and previous years. Because of the mark-recapture estimation method used, an expansion factor based on visual survey counts in a designated study area was not needed.

Analysis

At the end of field operations, 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 2-sample Petersen method is a simple model for estimating animal populations based on a first sample, in which all live animals captured are marked, and a second sample at some later time, in which the numbers of marked and unmarked animals are counted (Seber 1982, p. 59; Pollock et al. 1990). Stratified mark-recapture models, which extend the 2-sample Petersen method over 2 or more sampling occasions or events in both the marking (first) and mark-recovery (second) samples, are widely used for estimating salmon populations as they enter their natal streams or spawning areas (Arnason et al. 1996). 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 assumptions of equal probability of capture required by the Petersen model are as follows: 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 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." If neither test statistic—or only one of them—was significant, the fully pooled estimate was accepted. If both test statistics were significant, we looked for a full or partial stratification, following the guidelines and suggestions in Arnason et al. (1996) that would better satisfy the assumptions.

A parametric bootstrap procedure was used 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.

LIMNOLOGY SAMPLING IN 2008

Light and Temperature Profiles

Field technicians recorded underwater light intensity at 0.5 m intervals from just below the surface, to the depth where measured intensity was one percent of the surface light reading, using an electronic light sensor and meter (Protomatic). The natural log (ln) of the ratio of light intensity just below the surface to light intensity at depth z (I_0/I_z) was calculated for each depth. The vertical light extinction coefficient (K_d) was estimated as the slope of $\ln(I_0/I_z)$ versus depth. The euphotic zone depth (EZD) was defined as that depth at which light (photosynthetically available radiation, 400–700nm) was attenuated to one percent of the intensity just below the lake surface (Schindler 1971), and was calculated using the equation, EZD = 4.6205/ K_d (Kirk 1994).

Field technicians measured temperature in degrees centigrade (ºC) 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 5-meter intervals.

Secondary Production

Field technicians collected zooplankton samples, which were then sent to the Near Island Lab (ADF&G in Kodiak) for further analysis. Zooplankton density and biomass were estimated by species, to roughly quantify the amount of prey available to sockeye fry rearing in Falls Lake.

One zooplankton sample was collected at each station on each sampling date using a vertical tow. A 0.5-m diameter, 153-um mesh, 1:3 conical net was pulled either from a depth of 2 m above the lake bottom or from a depth of 50 m (whichever was shallowest), at a constant speed of 0.5 m per sec. The net was rinsed to collect the organisms in the net bucket, the contents of the bucket were rinsed into a bottle, and all specimens were preserved in a solution of neutralized 10% formalin (Koenings et al. 1987).

In the laboratory, technicians sub-sampled each zooplankton tow, and counted organisms in the sub-samples by species or genus (Koenings et al. 1987). Average counts by taxon in the sub-samples were expanded by the volume proportion of the sub-sample to estimate the number of individuals by taxon in the whole sample. The density of individuals in the water column for each m^2 of lake surface area was the estimated number of zooplankters in the sample divided by the area, in m^2, of the net opening. Body lengths of individuals in each taxon were measured and averaged. The mean length by taxon and sampling date, weighted by density of the taxon at each sampling date, was averaged for a seasonal mean body length. The seasonal mean biomass (weight per m^2 surface area) was estimated by converting the seasonal mean length to weight, based on known length-weight relationships for each taxon, and multiplying by the seasonal mean density (Koenings et al. 1987). Total seasonal mean zooplankton biomass and density were estimated by summing seasonal means across all species.

RESULTS

SOCKEYE SPAWNING POPULATION ESTIMATE IN 2007

Mark-Recapture Study

Field Operations

The sampling crew tagged and examined 724 sockeye spawners in the main spawning areas in Falls Lake during 4 sampling events in 2007: August 22, September 12, September 22, and September 28 (Table 1). The gap of 21 days (3 weeks) between the first and second sampling event was not planned. Before the end of the second scheduled sampling event on 29 August, the crew abandoned camp after being harassed by a juvenile brown bear. In early September, the crew was delayed by weather and lingering concerns about how to handle the bear. This gap undoubtedly reduced the number of recaptures from the first sampling event, particularly because the high water would have flushed spawned-out or weaker fish out of the streams and spawning areas, thus making them unavailable to the samplers.

The sampling crew conducted visual surveys on the first 4 sampling trips, including the second trip on 29 August, when mark-recapture sampling was cancelled (Table 2). The greatest number of sockeye spawners was counted on August 29, for both the whole lake and the sampling area. No visual survey was conducted on the last trip on September 28, 2007.

Analysis

The Jolly-Seber estimate of the total number of sockeye salmon spawning in Falls Lake in 2007 was about 2,600 fish (95% confidence interval 1,900–4,400; CV=24%). The gap between the first and second sampling events probably resulted in a disproportionate loss of marked fish during that period, and had an unknown effect on the total estimate. The objective for the coefficient of variation (less than 15%) was not met. Nevertheless, given the total number of fish sampled and compared with previous years' estimates, the estimate appears to be a reasonable representation of the spawning population. The overall weighted proportion of sockeye salmon spawners in the sampling areas for the entire season was 0.89. Expanding the mark-recapture estimate by that proportion gives a rough total spawning population estimate of 2,900 fish.

Table 1.–Summary of capture histories of sockeye salmon sampled on the Falls Lake spawning grounds in 2007.

Description of Capture History[a]		
Verbal	**Digital**	**Number of Fish[b]**
Captured only once; tagged and released	1000	343
	0100	218
	0010	89
	0001	41
Subtotal		**691**
Captured (tagged and released), then recaptured at next event and released	1100	9
	0110	13
	0011	3
Subtotal		**25**
Captured (tagged and released), not recaptured at the next event, then recaptured and released at a later event	1010	1
	0101	6
Subtotal		**7**
Recaptured and released more than once	1101	1
Subtotal		**1**
Total		**724**

[a] Capture histories show one digit for each of 4 sampling events in chronological order: a "1" indicates a sampling event in which the fish was caught, and a "0" indicates a sampling event in which the fish was not caught.

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

Table 2.–Visual counts of sockeye spawners and proportion of spawners in the study area at each sampling date, in Falls Lake, 2007.

Date	Average count within sampling areas	Average count for whole lake	Proportion in sampling areas
22 August	611	844	0.72
29 August	844	859	0.98
12 September	674	674	1.00
21 September	336	380	0.88

ADULT POPULATION AGE AND SIZE DISTRIBUTION IN 2007

Sex and length were recorded and scale samples were collected from 411 adult sockeye salmon on the Falls Lake spawning grounds during the mark-recapture sampling in 2007. A large number of the scales collected could not be aged, leaving only 139 of the sampled fish for which ages could be determined (Table 3). The 2007 age composition is not reliable, due to the small sample size. Age-1.3 fish from Brood Year 2002 were the largest age class in the sample. The sample contained only a few age-2.2 fish from that brood year. As a whole, fish with one freshwater year represented 67% of the sample. Age-2.3 sockeye salmon from Brood Year 2001 were the second largest age class. Adult sockeye salmon that had spent 3 years at sea (age-1.3 and age-2.3) were larger on average than their 2-ocean counterparts (age-1.2 and age-2.2) by 40–50 mm (Table 4).

Table 3.–Age composition of adult sockeye salmon in Falls Lake escapement by sex, 2007.

	Number and Percentage by Brood Year and Age Class					
	2004	2003	2002		2001	
Sampling Stratum	**1.1**	**1.2**	**1.3**	**2.2**	**2.3**	**Total Aged**
Male						
Sample size	1	15	52	0	29	97
Percent	1%	11%	37%	0	21%	70%
Female						
Sample size	0	12	13	3	14	42
Percent	0	9%	9%	2%	10%	30%
All Fish						
Sample size	1	27	65	3	43	139
Percent	1%	19%	47%	2%	31%	—

Table 4.–Mean mideye to fork length (mm) of adult sockeye salmon in Falls Lake escapement, 2007. All fish were sampled on the spawning grounds.

	Mean Length by Brood Year and Age Class				
	2004	2003	2002		2001
Sampling Stratum	**1.1**	**1.2**	**1.3**	**2.2**	**2.3**
Male					
Sample size	1	15	52	0	29
Mean length	410	513	559	0	562
Standard error	—	6.3	2.7	—	4.4
Female					
Sample size	0	12	13	3	14
Mean length	0	500	540	517	554
Standard error	—	5.9	8.6	20.2	5.4
All Fish					
Sample size	1	27	65	3	43
Mean length	410	507	555	517	559
Standard error	—	99.2	2.9	20.2	3.4

SUBSISTENCE HARVEST ESTIMATE IN 2008

In 2008, between June 29 and August 9, sampling technicians counted 20 fishing parties (including both subsistence and sport) in the marine area around the outlet stream of Falls Lake (Table 5). Most of these individuals or groups were interviewed about their catches, but 3 parties left the area without giving an interview. No one fished during the mid-season subsistence closure, or after the first week of August, even though subsistence fishing was open until 15 August, and sport fishing was open the entire season. Large harvests of sockeye salmon were taken both before and after the mid-season subsistence closure, which occurred between July 14 and July 22.

Table 5.–Number of subsistence and sport fishing parties interviewed, missed interviews, and salmon harvest reported in interviews in the Falls Lake area, by week, in 2008.

Week	Dates	Fishing parties counted	Missed interviews	Salmon Harvest Reported in Interviews, by Species				
				Sockeye	Coho	Chum	Chinook	Pink
27-28[a]	29 June–12 Jul	5	0	472	1	31	4	5
29[b]	13–19 Jul	0	na	—	—	—	—	—
30[c]	20–26 Jul	4	0	287	35	13	2	21
31	27 Jul–2 Aug	6	2	478	60	20	0	12
32	3–9 Aug	5	1	302	47	2	0	12

[a] Numbers from weeks 27 and 28 were combined to protect confidentiality of individual harvest data.

[b] Mid-season subsistence fishery closure, 14–22 July.

[c] Subsistence fishing re-opened, following mid-season closure, on 23 July.

An estimated 1,721 sockeye (CV=12%), 145 coho, 85 chum, 9 Chinook and 61 pink salmon were harvested in 2008 (Table 6). Because all fishing parties that were counted but not interviewed (3) were using gillnets, only the gillnet harvests are estimates. The seine and sport harvests are assumed to be total counts, with no corresponding variance estimates. The estimated salmon harvests by beach seine and gillnet were roughly equivalent, but the number of parties using gillnets was double that of fishing parties using beach seines. In other words, about twice as many sockeye salmon were harvested, on average, by a fishing party using a beach seine compared to a fishing party using a gillnet. Beach seines required a larger fishing crew, and some of the beach seine parties had as many as eight people (including children). Gillnets were sometimes fished by a single person. Sport harvest of sockeye salmon was a negligible fraction of the total (<1%); coho salmon was the primary species harvested by sport fishermen, who generally also reported some catch-and-release fishing.

Table 6.–Estimated total subsistence and sport salmon harvest in the Falls Lake area, by gear type, in 2008.

Gear	Counted	Interviews	Estimated Harvest by Species (standard error in parentheses)				
			Sockeye	Coho	Chum	Chinook	Pink
Gillnet	10	7	939 (200)	73 (28)	63 (19)	9 (2)	37 (17)
Beach seine	5	5	769 (0)	47 (0)	22 (0)	0	24 (0)
Sport, rod & reel	5	5	13 (0)	25 (0)	0	0	0
Total	20	17	1,721 (200)	145 (28)	85 (19)	9 (2)	61 (17)

SOCKEYE SPAWNING POPULATION ESTIMATE IN 2008

Mark-Recapture Study

Fish Trap and Field Operations

Between July 15 and August 26, 2008, 415 sockeye and 130 coho salmon were passed through the Falls Lake trap (Figure 3). The largest number of sockeye salmon counted through the trap on a single day was 69 fish on 31 July. During the study period, the water depth at the gauge site near the top of the falls fluctuated between a low of 0.21 m and a high of 1.07 m. The high water was unusual for both its height and the time of its occurrence in late July. The flooding and extreme high flows over the falls prevented sockeye salmon from ascending the fish ladder (and most likely any part of the falls), at a time which was normally the peak of the sockeye migration into the lake. A total of 292 sockeye salmon (70% of all the fish using the fish ladder and caught by the trap), were marked as they entered Falls Lake.

Visual surveys were conducted on 5 days in August and September (Table 7). The highest number of sockeye spawners was counted on 21 August, the first survey date. The actual peak of the sockeye migration likely occurred on or after August 21, because the crew was present and checked the lake every few days throughout August for visible spawners. As in previous years, the bulk of sockeye spawning occurred within a 6-week period, between mid-August and the end of September (Conitz and Cartwright 2005; Conitz 2008).

Table 7.–Visual counts of sockeye spawners in Falls Lake in 2008.

Date	Sockeye Count
21-Aug	127
4-Sep	80
11-Sep	46
17-Sep	62
30-Sep	20

Analysis

The marked fish were divided into 2 temporal strata (Table 8). Altogether, 50% of marked fish were recovered. The chi-squared test of complete mixing of marked fish between release and recovery strata was significant (reject; χ^2=5.9, *p*-value=0.02, 1 df). However, the chi-square test of equal probability of capture in the second sample yielded a non-significant result (do not reject; χ^2=7.5, *p*-value=0.19, 5 df). Because a non-significant result for one of these 2 diagnostic tests is evidence that the pooled estimator was appropriate for estimating abundance, we chose to use the pooled-Petersen estimate. The estimated escapement of sockeye salmon into Falls Lake was 750 fish (95% confidence interval, 690–820 fish; CV=4.7%). Assuming this estimate represents the entire Falls Lake escapement, about 55% of the sockeye salmon escapement used the fish ladder to migrate into the lake, rather than directly ascending the falls.

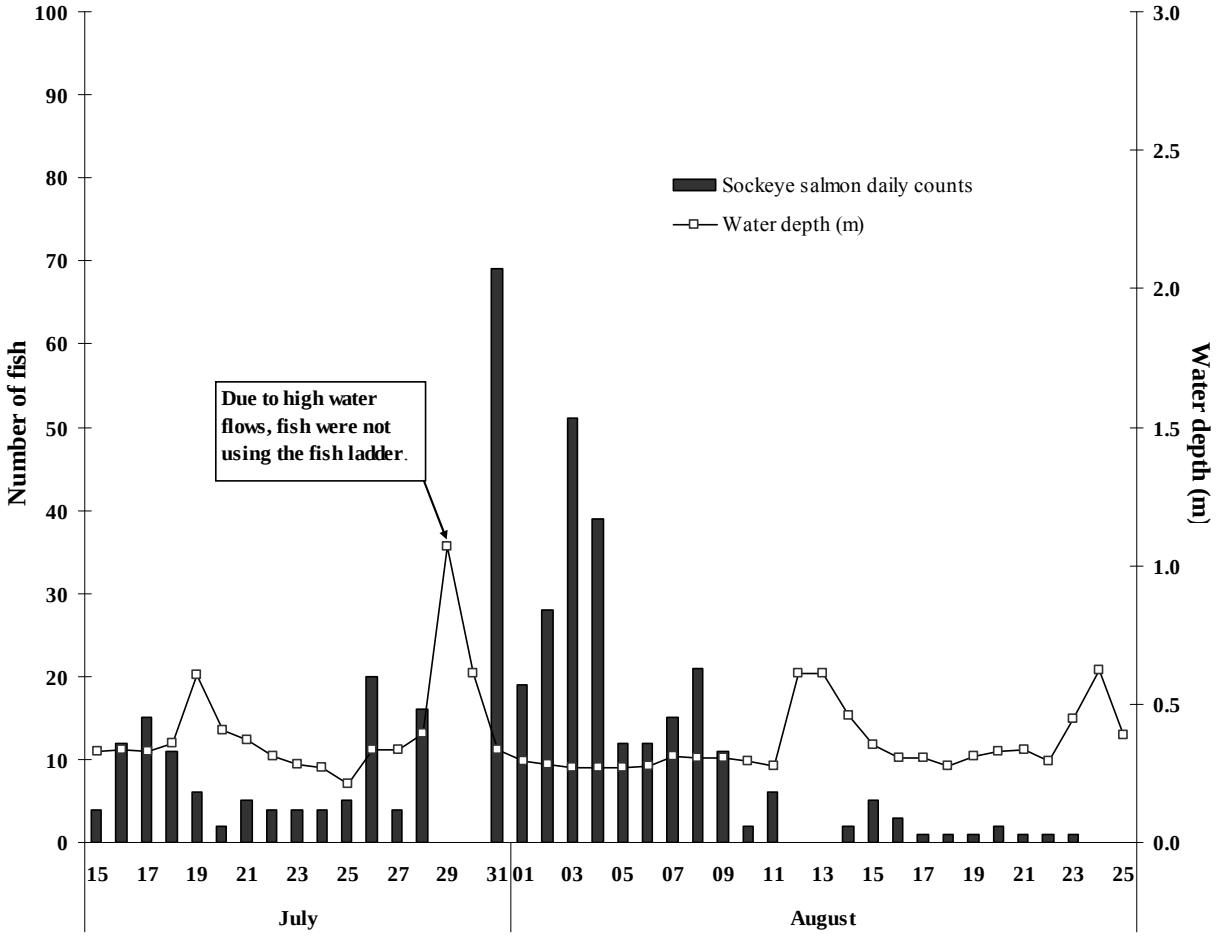

Figure 3.–Daily sockeye salmon escapement counts and water depth levels at the Falls Lake trap.

Table 8.–Sockeye salmon marked and marked fish recovered by strata in the mark-recapture experiment at Falls Lake in 2008.

Marking Phase (first sample)				Marks Recovered, by Date (Recovery Sample No.)						All Recoveries	
Marking Strata				1	2	3	4	5	6		
No.	Dates	Fish Counted	Fish Marked	22-Aug	30-Aug	4-Sep	11-Sep	17-Sep	24-Sep	Total	Percent of All Marked
1	2 Jul–1Aug	200	129	13	16	9	7	8	0	54	42%
2	2–30 Aug	215	163	10	28	23	15	11	5	91	56%
Total		415	292	23	44	32	22	19	5	145	50%
		Total fish sampled		63	127	77	41	44	21	373	
Percent marked fish in recovery samples				37%	35%	42%	54%	43%	24%	39%	

ADULT POPULATION AGE AND SIZE DISTRIBUTION IN 2008

In 2008, 196 sockeye salmon were sampled for age, sex, and length composition, and 148 were successfully aged from Falls Lake beach seine samples. This was less than one-third of the target goal of 600 samples, thereby making the age composition estimates unreliable. Females comprised over 70% of the aged samples. The 2 largest age classes were 1.2 from Brood Year 2004 and 2.2 from Brood Year 2003; 90% of the samples were assigned to these 2 age classes (Table 9). As with the 2007 age composition, the length of time spent in freshwater and marine environment correlated with the mean lengths of fish at escapement (Table 10).

Table 9.–Age composition of adult sockeye salmon escapement in Falls Lake, by sex for 2008.

	Number and Percentage by Brood Year and Age Class					
	2004	2003		2002		
Sampling Stratum	**1.2**	**1.3**	**2.2**	**1.4**	**2.3**	**Total Aged**
Male						
Sample size	22	8	10	1	1	42
Proportion	14.9%	5.4%	6.8%	0.7%	0.7%	28.4%
SE	2.9%	1.9%	2.1%	—	—	3.7%
Female						
Sample size	49	4	50	0	3	106
Proportion	33.1%	2.7%	33.8%	0	2.0%	71.6%
SE	3.9%	1.3%	3.9%	—	1.2%	3.7%
All Fish						
Sample size	71	12	60	1	4	148
Proportion	48.0%	8.1%	40.5%	0.7%	2.7%	100.0%
SE	4.1%	2.2%	4.0%		1.3%	

Table 10.–Mean mideye-to-fork length of adult sockeye salmon in the 2008 Falls Lake escapement. All fish were sampled on the spawning grounds.

	Mean Length by Brood Year and Age Class				
	2004	2003		2002	
Sampling Stratum	**1.2**	**1.3**	**2.2**	**1.4**	**2.3**
Males					
Sample size	22	8	10	1	1
Mean length (mm)	500.5	549.1	497.6	560.0	560.0
SE (mm)	1.4	2.6	3.9		
Females					
Sample size	49	4	49	—	3
Mean length (mm)	491.0	527.5	496.6	—	523.3
SE (mm)	0.5	9.0	0.5	—	8.4
All fish, by age					
Sample size	71	12	59	1	4
Mean length (mm)	493.9	541.9	496.7	560.0	532.5
SE (mm)	0.4	2.3	0.4	—	6.9

LIMNOLOGY SAMPLING IN 2008

Light and Temperature Profiles

The euphotic zone depth (the depth at which the measured light intensity is 1% of the light intensity at the surface) varied from about 9.1 to 11.7 m at station A in Hetta Lake (Table 11). While a thermocline by our definition (temperature decrease ≥1º C per meter of depth increase) had developed by 21 August (Figure 4), the temperature profiles never developed the classic thermal stratification that would restrict nutrient and oxygen circulation (Wetzel 2001).

Table 11.–Euphotic zone depths at station A in Falls Lake in 2008.

Date	Depth (m)
13 Jun	11.7
21 Aug	9.1
23 Sep	9.4
Seasonal Mean	10.1

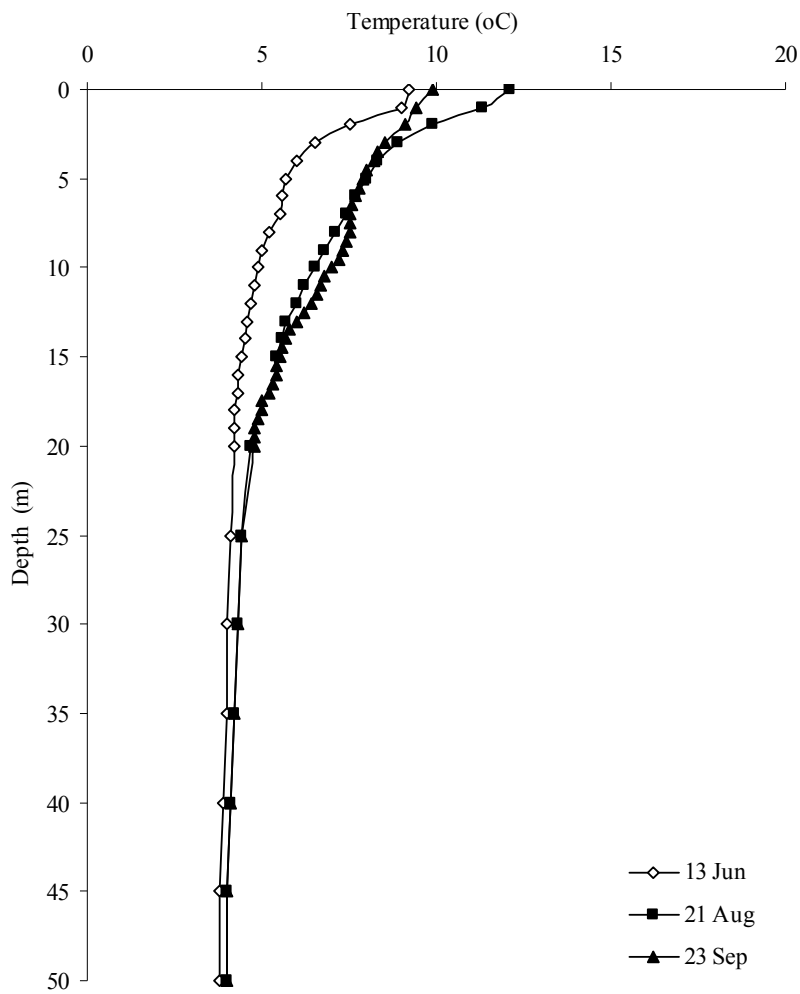

Figure 4.–Water temperature profiles at station A in Falls Lake in 2008.

Secondary Production

Copepods, particularly *Cyclops* sp. far outnumbered the cladocerans in the Falls Lake macrozooplankton assemblage in 2008. The cladoceran *Bosmina*, usually a dominant component of the zooplankton that increases rapidly through the season, remained at low densities throughout the 2008 season (Table 12). The larger cladoceran *Daphnia*, an important but usually much smaller component of the zooplankton, had densities equal to or exceeding *Bosmina* throughout the season. The copepods comprised an even greater proportion of the total zooplankton biomass, due in part to the dominance of the large-bodied *Diaptomus*, which itself comprised over half the zooplankton biomass at Station A (Table 13). Among the cladocerans, *Daphnia* contributed proportionately more to the total zooplankton biomass, due to its larger size relative to the very small-bodied *Bosmina*. Zooplankton density and biomass were much higher, as expected, at Station A, which is in the center of the main basin of Falls Lake and is less influenced by the flow over the falls and outlet stream.

Table 12.–Numerical density of macrozooplankton, sampled at Stations A and B in Falls Lake, 2008.

Taxon by Sampling Station	**Macrozooplankton Density (number/m^2), by Date**				**Seasonal Mean**	**Percent of Total Seasonal Mean Density**
	14 Jun	**24 Jul**	**21 Aug**	**23 Sep**		
Station A						
Epischura sp.	42	7,811	340	340	2,133	10%
Diaptomus sp.	0	11,207	7,472	2,717	5,370	26%
Cyclops sp.	42	9,170	12,056	8,406	7,461	36%
Copepod nauplii	2,590	7,981	1,274	1,019	3,216	16%
Bosmina sp.	467	849	1,358	1,358	1,008	5%
Daphnia longiremis	552	849	1,189	1,274	1,040	5%
Daphnia rosea	127	0	85	0	53	0%
Chydorinae sp.	0	340	0	0	85	0%
Immature Cladocera	0	849	679	85	403	2%
Total macrozooplankton					**20,791**	
Station B						
Epischura sp.	42	509	0	0	138	2%
Diaptomus sp.	0	679	170	170	255	4%
Cyclops sp.	42	5,434	6,877	340	3,173	52%
Copepod nauplii	1,910	4,245	509	212	1,719	28%
Bosmina sp.	340	340	679	297	446	7%
Daphnia longiremis	509	0	170	297	244	4%
Daphnia rosea	—	—	—	—	—	—
Chydorinae sp.	—	—	—	—	—	—
Immature Cladocera	0	170	340	0	127	2%
Total macrozooplankton					**6,102**	
Seasonal mean total macrozooplankton, between stations					**13,447**	

Table 13.–Seasonal mean body length and estimated biomass, weighted by numbers (density) per sampling date, of zooplankton sampled at stations A and B in Falls Lake in 2008.

Taxon by Sampling Station	Seasonal means, weighted by density per sampling date		Percent of total biomass
	Length (mm)	Biomass ($mg \cdot m^{-2}$)	
Station A			
Epischura sp.	0.75	4.3	9%
Diaptomus sp.	1.04	26.1	58%
Cyclops sp.	0.67	11.7	26%
Bosmina sp.	0.33	1.0	2%
Daphnia longiremis	0.65	1.9	4%
Daphnia rosea	1.14	0.3	1%
Chydorinae sp.	0.23	0.0	0%
Total zooplankton		**45.3**	
Station B			
Epischura sp.	0.67	0.2	4%
Diaptomus sp.	0.86	0.7	14%
Cyclops sp.	0.57	3.5	68%
Bosmina sp.	0.31	0.4	8%
Daphnia longiremis	0.57	0.3	6%
Daphnia rosea	—	—	—
Chydorinae sp.	—	—	—
Total zooplankton		**5.1**	
Mean total biomass, between stations		**25.2**	

DISCUSSION

In light of its importance as a subsistence resource, long-term consistent monitoring of the Falls Lake sockeye stock is vital to its proper management. This is especially true because the run is quite vulnerable to overharvest, due to timing and capture methods in the subsistence fishery, the physical configuration of the marine fishing area, and the partial barrier of 2 falls on the lake outlet stream. On-site harvest surveys have provided a more accurate accounting of harvests than returned subsistence permits (Table 14). If the on-site harvest estimates tracked the numbers on returned subsistence permits more closely, then the returned permit reports could be considered a surrogate or index for the harvest estimate. Unfortunately, our short time series does not show a close correspondence. Even with on-site harvest survey estimates, we may be underestimating catches by the most successful participants. In the 2008 harvest survey, the boat party reporting the largest single sockeye harvest (400 fish) admitted they had just guessed at, rather than accurately counted, their catch. This one harvest comprised almost a quarter of the total estimated harvest. A decision to omit the on-site harvest estimates in both 2006 and 2007, in part to reduce costs, was reconsidered by ADF&G management and research program staff in 2008. The size of the 2008 subsistence harvest, in comparison with the escapement, amply demonstrated the importance of obtaining more accurate, on-site harvest data. A marine harvest over twice as large as the escapement certainly exceeded the informal targets used by fisheries managers in the absence of formal escapement goals. Nevertheless, with harvest and escapement data collected in season, managers can use information about size and timing of individual harvests and daily escapement numbers to further refine season opening and closing dates and other policies in the Falls Lake fishery.

Table 14.–Comparison of subsistence sockeye harvest estimates, between returned subsistence permits, and on-site harvest surveys.

	By Permit Returns		By On-Site Survey		
Year	**Total Reported Harvest**	**Number of Permits Reported**	**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	2,700	28	8%
2004	2,100	65	2,900	33	38%
2005	1,134	48	900	30	-21%
2006	1,507	53	—	—	—
2007	820	26	—	—	—
2008	1,021	42	1,700	24	49%

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

Table 15.–Estimated estimates of escapement, harvest, and total return, of Falls Lake sockeye salmon, 1981–2008.

Year	**Method of Escapement Estimation**	**Estimated Escapement**	**On-Site Harvest Estimate**	**Estimated Total Return**
1981	Weir count only	1,278	—	—
1982	Weir count only	1,687	—	—
1983	Weir count only	1,656	—	—
1984	Weir count only	3,622	—	—
1985	Weir count only	2,612	—	—
1986[a]	—	—	—	—
1987	Weir count only	5,789	—	—
1988	Weir count only	1,114	—	—
1989	Weir count only	2,055	—	—
Average, 1981–1989		**3,000**	—	—
2001	Weir count and mark-recapture	2,600	1,900	4,500
2002	Weir count and mark-recapture	1,100	2,600	3,700
2003	Partial count (fish ladder) and mark-	5,700	2,700	8,400
2004	Partial count (fish ladder) and mark-	3,300	2,900	6,200
2005	Partial count (fish ladder) and mark-	3,400	900[b]	4,300[b]
2006	Mark-recapture on spawning grounds,	8,800	—	—
2007	Mark-recapture on spawning grounds,	2,600	—	—
2008	Partial count (fish ladder) and mark-recapture	750	1,700	2,350
Average, 2001–2008		**3,600**	**2,100**	**5,700**

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

[b] Actual number likely higher, due to violation of assumptions for on-site survey in 2005.

Table 16.–Selected summary measures of water column temperatures, euphotic zone depth (EZD), and seasonal mean zooplankton biomass and density in Falls Lake, in the 1980s and 2000s. Shading indicates years in which Falls Lake was artificially fertilized.

			Total Zooplankton Seasonal Means		*Daphnia* Seasonal Means		
Year	**Maximum Temp (°C)**	**EZD (m)**	**Biomass ($mg \cdot m^{-2}$)**	**Density ($number \cdot m^{-2}$)**	**Biomass ($mg \cdot m^{-2}$)**	**Density ($number \cdot m^{-2}$)**	**Length (mm)**
1981	–	8	101	29,413	4	1,986	0.68
1982	–	8.4	45	14,098	3	1,318	0.72
1983	15.3	9.5	115	33,822	5	2,720	0.70
1984	14.5	8.5	123	35,167	3	1,498	0.69
1985	13.5	9.5	15	8,934	4	1,442	0.67
1986	–		25	10,840	5	1,390	0.62
–	–	–	–	–	–	–	–
2001	15.5	9.7	105	27,419	0	216	0.73
2002	14.0	10.3	28	12,521	1	300	0.73
2003	16.8	9.6	29	16,379	2	628	0.69
2004	16.0	13.6	14	18,605	2	1,348	0.6
2005	14.8	10.1	97	35,511	3	1,279	0.73
2006	–	–	–	–	–	–	–
2007	–	–	–	–	–	–	–
2008	12.0	10.1	25	13,447	2	669	0.67
Averages							
1981-1986	14.4	8.8	70.9	22,046	4.0	1,726	0.68
2001-2008	14.9	10.6	49.7	20,647	1.6	740	0.69
All Years	14.9	9.8	60.3	21,346	2.8	1,233	0.69

The very low sockeye escapement in 2008 should be noted, but does not by itself indicate a problem with the population overall. Note that sockeye salmon runs were weak throughout Southeast Alaska in 2008 (Eggers et al. 2008). After the highest recorded sockeye escapement in 2006, the estimated escapement in 2007 decreased considerably, but was closer to the average of escapements estimated between 1981 and 2007 (Table 15). In 2008, escapement of sockeye salmon into Falls Lake fell off even further and was the lowest recorded in all years since 1981. The 2008 escapement was even lower than the 2 other low escapements in 1988 and 2002, by about 50%. Monitoring of the Falls Lake sockeye run, over the 2 time periods (and spanning almost 30 years) provides some evidence of a possible cyclic fluctuation. Because the subsistence harvest is only partially documented, and the commercial harvest is completely unknown, we do not know the percentage of the total return comprised by harvest. Furthermore, the age composition of Falls Lake sockeye salmon varies, such that the timing of stronger and weaker age classes and brood years is complex. Unless escapement remains low in subsequent years, the low escapement in 2008 should not be a cause for concern, despite these sources of uncertainty and the inherent variability in salmon returns.

Zooplankton sampling and seasonal population estimates have been included in the 2008 and past years' projects with the intention of providing additional clues about the productivity of Falls Lake as sockeye rearing habitat. Researchers have attempted to determine whether lake productivity is a limiting factor in sockeye production from this system overall, particularly during the 1980s, when a lake fertilization experiment was conducted (Koenings et al. 1983; Conitz et al. 2002). The zooplankton information available is not continuous, with a gap in the most recent series in 2006–2007, and a 12-year interval between the recent series and the earlier

one in the 1980s (Table 16). The evidence does show low zooplankton standing crops in Falls Lake, compared with other sockeye producing lakes in Southeast Alaska (Conitz and Cartwright 2005, Appendix D). In Falls Lake, the average seasonal mean zooplantkon biomass appears to be lower during the 2000s than in the 1980s, but the average seasonal mean zooplankton density has not been substantially lower in the more recent period (Table 16). The contribution of the cladoceran *Daphnia* may be a better indicator of forage conditions for sockeye fry due to its desirability as prey (Mazumder and Edmundson 2002). Seasonal mean biomass and density of *Daphnia* has been low throughout both time periods, but was substantially below the average in the 2000s. Physical conditions in the lake appear to be mostly unchanged; summary data show the lake may be slightly warmer and clearer in more recent years but the differences are small and may not be significant (Table 16). Falls Lake is an oligotrophic lake with a short growing season and low zooplankton populations may well represent an equilibrium condition with juvenile sockeye populations. Spawning populations in the 2000s have been somewhat larger than in the 1980s and the somewhat lower zooplankton stocks may reflect heavier grazing by the resulting larger sockeye fry populations. Many, and in some years most, of the adult sockeye salmon returning to Falls Lake have 2 years of freshwater growth, another indicator that the lake may be a food limited environment for juvenile sockeye salmon (Conitz 2008). The limited zooplankton sampling that has been conducted through most of the 2000s provides no more than a sketchy indicator of sockeye rearing conditions, in comparison with other years and other Southeast Alaska sockeye lakes. A more complete view of lake conditions for sockeye fry would be provided by more comprehensive and statistically validated sampling in an ongoing annual program, particularly if combined with annual sockeye fry population estimates and smolt emigration estimates.

As with many salmon stock assessment projects, the Falls Lake project provides only a fraction of the information needed to make definitive conclusions about underlying causes of trends in abundance and the overall health and sustainability of this sockeye stock. Including estimates of sockeye fry and smolt, and number of adult fish (if any) harvested in the commercial fishery would help provide a more complete picture. In its current form, the project produces the minimum information necessary for monitoring the health of the sockeye run and making informed management decisions. The large subsistence sockeye harvest in comparison with the lowest escapement on record in 2008 speaks for itself as to the need to continue on-site harvest monitoring.

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APPENDIX

Appendix A.–Daily and cumulative counts of sockeye and coho adult salmon, and physical data (daily water levels, water temperatures, and air temperatures), at the Falls Lake fish trap, in 2008. The trap was operational starting on 1 July 2008, but no fish were counted until 15 July.

	Sockeye salmon		Coho salmon		Physical data		
Date	Daily	Cumulative	Daily	Cumulative	Water level (cm)	Water temp (^{o}C)	Air temp (^{o}C)
7/15	4	4	0	0	33	11.0	15.0
7/16	12	16	0	0	34	11.0	14.0
7/17	15	31	0	0	33	12.0	13.0
7/18	11	42	0	0	36	12.0	14.0
7/19	6	48	0	0	60	10.0	13.0
7/20	2	50	0	0	40	10.0	12.0
7/21	5	55	0	0	37	10.0	12.0
7/22	4	59	0	0	31	9.0	13.0
7/23	4	63	0	0	28	9.0	13.0
7/24	4	67	0	0	27	9.0	12.0
7/25	5	72	0	0	21	10.0	13.0
7/26	20	92	0	0	34	—	—
7/27	4	96	0	0	34	9.5	12.0
7/28	16	112	0	0	40	9.5	11.5
7/29	0	112	0	0	107	—	13.5
7/30	0	112	0	0	61	—	—
7/31	69	181	0	0	34	10.0	12.0
8/01	19	200	0	0	29	10.0	12.0
8/02	28	228	0	0	28	10.0	14.0
8/03	51	279	0	0	27	10.0	13.0
8/04	39	318	0	0	27	11.0	14.0
8/05	12	330	0	0	27	12.0	14.0
8/06	12	342	0	0	27	10.0	15.0
8/07	15	357	3	3	31	12.0	—
8/08	21	378	6	9	31	13.0	15.0
8/09	11	389	0	9	30	11.5	15.0
8/10	2	391	4	13	30	13.0	14.0
8/11	6	397	1	14	27	13.0	14.0
8/12	0	397	1	15	61	—	14.0
8/13	0	397	0	15	61	—	13.0
8/14	2	399	16	31	46	10.0	13.0
8/15	5	404	21	52	35	10.5	13.0
8/16	3	407	14	66	30	10.0	13.0
8/17	1	408	6	72	31	10.0	14.0
8/18	1	409	4	76	28	10.0	12.0
8/19	1	410	6	82	31	11.0	13.0
8/20	2	412	7	89	33	10.5	13.0
8/21	1	413	10	99	34	11.0	12.0
8/22	1	414	7	106	29	10.0	13.0
8/23	1	415	7	113	45	10.0	13.0
8/24	0	415	17	130	62	9.5	12.0
8/25	0	415	0	130	39	10.0	12.0
8/26	0	415	0	130	42	10.0	14.0