Fishery Data Series No. 07-83

Inriver Abundance and Distribution of Spawning Susitna River Sockeye Salmon *Oncorhynchus nerka*, 2006

by

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December 2007

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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INRIVER ABUNDANCE AND DISTRIBUTION OF SPAWNING SUSITNA RIVER SOCKEYE SALMON *ONCORHYNCHUS NERKA*, 2006

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December 2007

This investigation was partially financed by the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under Project F-10-22, Job No. S-2-38.

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

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This document should be cited as:
Yanusz, R., R. Merizon, D. Evans, M. Willette, T. Spencer, and S. Raborn. 2007. Inriver abundance and distribution of spawning Susitna River sockeye salmon Oncorhynchus nerka, 2006. *Alaska Department of Fish and Game, Fishery Data Series No. 07-83, Anchorage.*

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ABSTRACT

The escapement of sockeye salmon *Oncorhynchus nerka* to the Susitna River is not well known. The Susitna River sockeye salmon stock is managed based on a combined sonar and fish wheel escapement estimate at river kilometer (rkm) 7 on the Yentna River, a major tributary of the Susitna River. During 1999-2005, Yentna River sockeye salmon escapement estimates were below the sustainable escapement goal 5 of 7 years. In 2006, capture-recapture experiments using passive integrated transponder (PIT) tags, fish wheels, and weirs were conducted to estimate sockeye salmon escapement in the entire Susitna River independent of the combined sonar and fish wheel estimate. Radiotelemetry was used primarily to identify spawning areas throughout the Susitna River drainage, and was also used to estimate sockeye salmon abundance. Three abundance estimates of sockeye salmon ≥400 mm (mideye-to-fork length) passing Sunshine (on the mainstem Susitna River at rkm 116) derived for the entire season were 93,161, 107,000, and 128,105 fish. The abundance estimate of 107,000 fish (95% CI = 49,180-164,820) passing Sunshine, based on Flathorn (Susitna River at rkm 31) PIT-tag releases, had the most evidence for meeting the abundance model conditions, and was not significantly different (P = 0.65) from the estimate of 93,161 fish (95% CI = 80,053-106,268) based on radio tags recovered at Larson and Byers lakes. The third estimate could not be statistically compared because the variation could not be accurately quantified. Two abundance estimates of sockeye salmon ≥400 mm (mideye-to-fork length) were derived for the Yentna River at rkm 7: 417,750 fish (95% CI = 261,930-573,570) for 29 July onward based on PIT tags and 311,197 fish (95% CI = 252,000-391,000) for the entire season based on radio tags. The two estimates could not be statistically compared because the time periods were different. The Yentna abundance estimate using PIT tags had the most evidence for meeting the abundance model conditions, but it still had weaknesses. The counts from four weirs in the Yentna River drainage showed that the true sockeye salmon abundance in the Yentna River was at least 126,218 fish, so the Yentna sonar and fish wheel estimate of 92,896 fish in 2006 was biased low. The terminal distribution of radio-tagged sockeye salmon suggests that most fish spawned in major lake systems and the remainder in various tributaries without lakes throughout the Susitna River drainage. Radio-tag tracking showed no sockeye salmon spawning downstream of Yentna or Sunshine in 2006. Recommendations for 2007 include estimating sockeye salmon abundance using only radio tags, deploying them from Yentna and Sunshine, and using weirs on the major lakes as the recapture locations.

Key words: sockeye salmon, *Oncorhynchus nerka*, Susitna River, Yentna River, escapement, abundance, capture-recapture, fish wheel, weir, radiotelemetry, passive integrated transponder (PIT) tag

INTRODUCTION

The Susitna River sockeye salmon *Oncorhynchus nerka* run is a major contributor to the sockeye salmon run in Upper Cook Inlet (UCI). Management of the Susitna River sockeye salmon run is based on a combined sonar-fish wheel estimate of the escapement to the Yentna River, a tributary that is a major producer of sockeye salmon (Shields 2007; Westerman and Willette. 2007). The sockeye salmon escapement to the entire Susitna River drainage is estimated to be 1.95 times the Yentna escapement (Tobias and Willette 2004). The basis for this expansion factor is a combination of capture-recapture estimates of the sockeye salmon passing Sunshine (Susitna River at river kilometer (rkm) 116) and sonar-fish wheel estimates of the sockeye salmon passing Yentna (Yentna River, rkm 7) and Susitna Station (Susitna River, rkm 37) during 1981-1985 (Fox 1998). The current sustainable escapement goal of 90,000-160,000 for Yentna River sockeye salmon was set by the Alaska Department of Fish and Game (ADF&G) in 2002 (Hasbrouck and Edmundson. 2007).

Between 1999 and 2005, estimated sockeye salmon escapements were below the sustainable escapement goal 5 of 7 years. As a result, ADF&G, with participation from the Cook Inlet Aquaculture Association (CIAA), decided to estimate the sockeye salmon escapement in the entire Susitna River drainage in 2006 using capture-recapture techniques that were independent of the sonar-fish wheel estimate. The independent escapement estimate may allow: (1) estimation of the total annual run of Susitna River sockeye salmon when escapement estimates and genetics-based, stock-separation catch estimates are combined, (2) evaluation of the accuracy of the Yentna River sockeye salmon sonar-fish wheel estimate, and (3) proportional estimates of the Yentna River contribution to the entire Susitna River sockeye escapement.

There were two primary objectives for this study in 2006. The first objective was to estimate the inriver abundance of adult sockeye salmon (escapement) migrating upstream of Flathorn (Susitna River, rkm 31), Yentna, and Sunshine using capture-recapture experiments (Figure 1). The second objective was to identify sockeye salmon spawning areas in the Susitna River drainage using radiotelemetry.

STUDY AREA

The Susitna River drainage comprises 49,210 km^2 and originates in the Alaska Range north of Anchorage (Figure 1). It flows generally south from the Alaska Range for approximately 400 km before entering UCI west of Anchorage. There are three major tributaries within the drainage and numerous sockeye salmon nursery lakes. The largest tributaries are the Yentna, Chulitna, and Talkeetna rivers. Most of the sockeye salmon produced within the Talkeetna drainage are thought to come from Larson and Stephan lakes. Numerous small lakes contribute to sockeye salmon production in the Chulitna drainage, but Byers Lake is thought to have the greatest production potential (King and Walker 1997). The Yentna drainage has at least 12 lakes known to support sockeye salmon, of which Chelatna, Shell, Hewitt, and Judd are thought to provide the most production potential (King and Walker 1997).

METHODS

Two-event capture-recapture experiments were used to estimate the abundance of adult sockeye salmon (Seber 1982). The experimental design allowed abundance estimates to be generated for the entire Susitna drainage, the mainstem Susitna drainage only, or only the Yentna drainage, through the combination of three marking strata and four recapture strata:

	Marking Strata	Recapture Strata	Abundance Model
1	Flathorn fish wheels	Yentna and Sunshine fish wheels	Pooled or stratified estimate for entire Susitna drainage
2	Flathorn fish wheels	Weirs in the upper Yentna and mainstem Susitna drainages	Pooled or stratified estimate for entire Susitna drainage
3	Yentna fish wheels	Weirs in the Yentna drainage	Pooled or stratified estimate for Yentna drainage summed with 4 below to estimate entire Susitna drainage
4	Sunshine fish wheels	Weirs in the mainstem Susitna drainage	Pooled or stratified estimate for mainstem Susitna drainage summed with 3 above to estimate entire Susitna drainage

MARK EVENTS-PIT TAGS

Four fish wheels at Flathorn were operated daily from 3 July through 17 August 2006 (Table 1), with operating times distributed throughout each day. One fish wheel was operated on each bank of the two channels at the Flathorn site (Figure 2). Each fish wheel was operated with a picket weir to direct migrating salmon offshore and into the fish wheel. Each fish wheel had 2x2-m baskets that were adjusted as needed to fish ≤0.3 m from the river bottom.

All uninjured sockeye salmon ≥400 mm (mideye-to-fork (MEF) length) captured at Flathorn were injected with a 7-mm passive integrated transponder (PIT, manufactured by BioMark™) tag, had their adipose fin removed (to identify PIT-tagged fish), were measured MEF length, had their sex determined by inspection of external characteristics, and then released. Scales for age determination and an axillary process for genetic stock identification were also taken from a subsample of captured sockeye salmon. The results of the genetic stock identification are reported in Habicht et al. (2007). PIT-tag codes were collected using a Destron Fearing 2001F tag reader. All other salmon species captured in the fish wheels were counted and released.

Two fish wheels were operated at both Yentna (the location of the sonar site) and Sunshine, one on each bank (Figure 1). Fish wheels were operated daily at Yentna from 7 July through 18 August and at Sunshine from 8 July through 18 August. Picket weirs were operated at both fish wheels for the entire season at Yentna, and one weir was operated for part of the season at Sunshine (Table 1). Sampling shifts at both sites were scheduled so that breaks did not exceed 4 hours, and the start times of the shifts systematically rotated so that all times of day were sampled over the course of each week. The fish wheels at Yentna and Sunshine were used to recapture fish marked at Flathorn. In addition, a subsample of unmarked sockeye salmon ≥400 mm MEF length received a PIT tag, an upper left operculum punch, was measured MEF length, and had their sex determined by inspection of external characteristics. Scales for age determination and an axillary process for genetic stock identification were also taken from a subsample of captured sockeye. Sockeye salmon released without PIT tags at the Yentna and Sunshine fish wheels received an upper right operculum punch to allow detection of fish that held downstream of the wheels while recovering, and thus were subject to duplicate sampling. PIT-tag codes were collected using a Destron Fearing 2001F tag reader. All other salmon species captured in the fish wheels were counted and released.

Whenever possible, sockeye salmon were taken immediately out of the fish wheel live box, tagged, and released. Fish wheels were checked and any sockeye salmon captured were tagged at least every 2 hours at Flathorn, and every 30 minutes at Sunshine and Yentna during sampling shifts. All efforts were made to minimize capture and handling-induced stress. When sampling shifts were done the fish wheels were stopped to avoid holding-induced mortality.

RADIO-TAG DEPLOYMENT

There were 250 sockeye salmon marked with PIT tags and inserted with radio transmitters: 100 at Flathorn and 75 each at Yentna and Sunshine. At each site, the number of radio tags applied each day was determined preseason based on the historical sockeye salmon run timing, as measured by fish wheel catch on both banks combined. At Yentna, the pre-determined number of radio tags applied on a given day was apportioned between banks (north and south) in proportion to the previous day's bank-specific fish wheel catch, irrespective of time, sex, or size on each bank. At Flathorn and Sunshine, the pre-determined number of radio tags applied on a given day were applied to every *n*th fish, where *n* was equal to the previous day's total sockeye salmon catch divided by the total number of tags to deploy on the current day, irrespective of bank, fish wheel, sex, or size.

Radio transmitters used were manufactured by Advanced Telemetry Systems, Inc. (ATS) and operated on several frequencies within the 151.000 to 151.999 MHz range. Each frequency had several different transmitting patterns ("pulse codes"), resulting in 250 uniquely-identifiable transmitters. The transmitters were 42x17 mm, cylinder-shaped, equipped with a 30-cm antenna, and weighed 14 g in air. The minimum battery life of the transmitters was 90 days. Each transmitter was equipped with an activity monitor as a mortality indicator. The activity monitor changed the signal pattern to an inactive mode (Eiler 1995) if the transmitter was inactive for 4 hours.

The radio tag was inserted through the fish's mouth into the stomach using a plastic tube (0.7-cm diameter) until the tag was no longer visible. The fish were not anesthetized during tag insertion and were immediately released after processing. Small sockeye salmon (<400 mm MEF length) were not radio tagged.

Every fish with a radio tag also received a PIT tag, was measured MEF length, had its sex determined from external characteristics, received a secondary mark (adipose finclip at Flathorn or an upper left operculum punch at Yentna and Sunshine), and had its left axillary process removed and preserved for genetic analysis.

Recovery Events-Flathorn PIT Tags at Yentna and Sunshine

The number of marked and unmarked sockeye salmon examined at Yentna and Sunshine were recorded each time the fish wheel live boxes were checked. If a secondary mark from the Flathorn marking event (adipose finclip) was observed, the fish was scanned for a PIT tag and examined for a radio tag (i.e., an antenna protruding from the mouth).

Between 28 July and 11 August, mid-channel and nearshore drift gillnetting was conducted at Sunshine and Yentna to determine the relative abundance of sockeye salmon in these areas. Successive drifts were made in sampling lanes at specified distances from shore. Monofilament drift gillnets were 9 to 27-m long and 5 to 10-m deep, with 11.88-cm stretch mesh.

Recovery Events-PIT Tags at Weirs

CIAA counted sockeye salmon passing through weirs at Chelatna, Hewitt, Shell, and Judd lakes in the Yentna drainage, and Byers and Larson lakes in the mainstem Susitna drainage (Figure 1). Automated, electronic, PIT-tag detection and recording systems were set up to scan all fish for PIT tags at the Chelatna, Judd, and Larson lake weirs using rectangular 30x50-cm PIT-tag antennas affixed to the upstream gate on the live box at each weir. Hand-held PIT-tag detection systems were used at Hewitt, Shell, and Byers lakes.

At weirs with automated PIT-tag detection systems, the PIT-tag readers were maintained and tag detection tests were conducted each day during operation. Prior to counting each day, tag detection tests were conducted to estimate the PIT-tag detection rate at the weir. Detection tests consisted of passing 50 PIT tags contained in plastic vials through an antenna twice per day (100 tests per day). The vials were filled with water such that they were neutrally buoyant and would naturally move through all regions of the detection field.

At Hewitt, Shell, and Byers lakes, a dip net was used to examine a sample of fish that passed upstream of the weir. Fish with secondary marks (adipose finclips from Flathorn and upper left operculum punches from Yentna and Sunshine) were examined with a hand-held PIT-tag detector to obtain the PIT-tag number.

MEF length, scale (age determination), sex, and secondary mark information were collected from fish samples passing through each weir. Trap loads or dip net loads of fish were sampled systematically at each weir. An axillary process was also collected for genetic stock identification.

RADIO-TAG RELOCATION

Radio-tagged sockeye salmon movement upriver was tracked at 11 remote tracking stations and by aerial surveys throughout the Susitna River drainage. Tracking stations were placed along primary travel corridors on the mainstem Susitna River and major tributaries (Table 2; Figure 3). Tracking station equipment consisted of an ATS Model 4500 receiver and data logger, a satellite uplink (Campbell Scientific, Logan, Utah), and a self-contained power system. The equipment was housed in an enclosure and attached to a 9-m mast.

An ATS Model 200 antenna switch was coupled with two antennas at each tracking station. One antenna was oriented downstream, and the other upstream. Signal strength and time of reception were recorded separately for each antenna and provided information on direction of travel. “Reference” radio tags were continuously detected at each station to assure proper station operation. Information was recorded at 10-minute intervals.

The ATS receiver detected radio-tagged fish and recorded signal strength, activity pattern of the transmitter (active or inactive), date, time, and location of each fish in relation to the station (i.e., upriver or downriver from the site). Radio-tagged fish were considered to have passed a tracking station when the recorded signal strength indicated the transition from the downriver antenna to the upriver antenna. The first tracking stations were located approximately 5 km upriver from the tagging sites.

Migration rates for radio-tagged sockeye salmon were calculated using the date and time fish passed between tracking stations. Fish tracked to terminal reaches of the drainage were classified as distinct spawning populations. The terminal reaches were also assumed to be the spawning reaches.

Because tracking sites were located in isolated areas, data were transmitted every hour by satellite uplink to a geostationary operational environmental satellite system and relayed to a receiving station near Washington, D.C. (Eiler 1995; Appendix A1). Data transmissions were monitored during the field season via the internet.

Each station was visited periodically and data were downloaded as a comma-delimited file to a handheld computer using a Microsoft™ compatible custom program. Each record in the file contained site code, download date and time, radio frequency and pulse code, date and time of detection, antenna number, and signal strength.

A fixed-wing aircraft was used to conduct aerial surveys of the Susitna River drainage. The aircraft was equipped with a computer-controlled receiver and two, 4-element Yagi receiving antennas, one mounted on each side of the aircraft and oriented forward. Tracking receivers contained an integrated global positioning system to identify and record locations. Automatically recorded data included: date and time of decoding, frequency and pulse code, latitude and longitude, signal strength, and activity mode of each decoded transmitter. Data were also recorded on a form during the survey as a backup to the automated recording system and to track the number of radio tags detected during each survey.

DATA ANALYSIS-ESTIMATION OF ABUNDANCE

Abundance of sockeye salmon migrating into the Susitna River drainage was estimated as the sum of estimates from two-event, closed population, capture-recapture experiments, with each experiment representing a separate component of the entire run. Chapman's modification of the Petersen model (Seber 1982) was used to estimate abundance $\hat{N}$ for each experiment (stratum) such that:

$$\hat{N} = \frac{(M+1)(C+1)}{(R+1)} - 1 \tag{1}$$

where M is the number of fish captured and marked during event "1," C is the number of fish inspected for marks during event "2," and R is the number of C that possessed marks applied during event 1. The variance of the abundance estimate was estimated as:

$$\text{var}(\hat{N}) = \frac{(M+1)(C+1)(M-R)(C-R)}{(R+1)^2(R+2)}. \tag{2}$$

Each experiment represented a stratum of the population defined by time and location to meet conditions for producing an accurate estimate of abundance.

The general conditions necessary for Equation 1 to provide an accurate estimate of abundance are described in Seber (1982) as follows:

(a) every fish in a stratum has an equal probability of being marked in event 1, or every fish in the same stratum has an equal probability of being inspected for marks in event 2, or marked fish are mixed completely with unmarked fish in the stratum between events; and

(b) there are no mark-induced behaviors (including tag-induced mortality); and

(c) fish did not lose their marks between events and all marks are recognizable; and

(d) there is no immigration or mortality (emigration) between events.

To test whether condition *a* was met, two chi-square tests were performed with the following null hypotheses: (1) proportions of marked fish in samples from event 2 were constant over recovery strata (e.g., time strata at recovery fish wheels); and (2) the probability of recapture in event 2 was constant over marking strata (e.g., time strata at marking fish wheels). If the null hypothesis of either test was not rejected, the pooled abundance estimate (Equation 1) was considered sufficient; otherwise, a temporally or spatially stratified estimate was considered using the Stratified Population Analysis System (SPAS) software program (Arnason et al. 1996).

Because condition *a* is relevant to attributes other than when and where salmon are captured, the possibility of size selective sampling was investigated. The hypothesis that fish of different sizes were captured with equal probability in the first event was tested using a Kolmogorov-Smirnov (K-S) two-sample test ($\alpha = 0.05$) to compare size distributions of fish captured in the second event with that of recaptured fish. The hypothesis that fish of different sizes were captured with equal probability in the second event was tested using a K-S two-sample test ($\alpha = 0.05$) to compare size distributions of marked and recaptured fish. If size selectivity was found in both events, then the mark-recapture estimate was stratified by size. Condition *b* was tested using radiotelemetry. The proportion of radio-tagged fish that did not resume upstream migration after tagging was assumed to be an estimate of tag-induced mortality, and the number of marked fish in the first event was adjusted accordingly. The tag loss component of condition *c* was assessed using double marks. The tag detection component of condition *c* was assessed from daily tag detection tests at weirs, but it was not assessed at fish wheel recapture sites. Condition *d* was assumed to be met for fish tagged at all sites because there were no other sources of salmon entering the river upstream of these sites (immigration), and there were no large, inriver salmon fisheries in the Susitna River (mortality and emigration), and the entire Susitna drainage was the study area, so no fish could leave the study area (emigration).

Strata were defined to ensure conditions *a-d* were met within each stratum, and then estimates across relevant strata were summed to provide an estimate for the relevant drainage. Estimated variances were likewise summed. Drift gillnetting at Yentna and Sunshine provided evidence that most sockeye salmon passed by these sites near shore and were available to the fish wheels. Evidence of mortality (emigration) between events would indicate estimated abundance is germane to event 1 (the downstream event). Evidence of immigration (recruitment) would indicate estimated abundance is germane to event 2 (the upstream event). When recruitment and mortality do not occur simultaneously, Equation 1 provides a consistent estimate of abundance.

A Darroch model was used to estimate the abundance of sockeye salmon passing Sunshine using Larson Lake weir as the recapture site. SPAS software developed specifically for stratified mark-recapture experiments was used for the analysis (Arnason et al. 1996). There were three temporal tagging strata (20 July-26 July, 27 July-31 July, 1 August-13 August) and three temporal recovery strata (22 July-30 July, 31 July-4 August, 5 August-17 August) initially established. A lag of 4 days was used between tagging and recovery strata to account for the mean migration time between Sunshine and the Larson Lake weir.

The χ^2 and G^2 goodness-of-fit statistics were computed to evaluate model fit (Arnason et al. 1996). The factors considered when evaluating strata to pool were: (1) eliminate strata with expected recaptures of <5, (2) pool adjacent strata with similar initial capture or recapture probabilities, and (3) minimize the standard error of the estimate. When a large change occurred in the G^2 statistic or standard error (i.e., greater than 1 SE) during pooling, the abundance estimate was considered questionable and dropped (Arnason et al. 1996). Strata were also dropped if the number of tags released or recaptured was small. This was necessary to minimize the number of cells with <5 recaptures expected.

While not designed for this purpose, radiotelemetry data were used to estimate the abundance of sockeye salmon migrating past Yentna and Sunshine. The Yentna abundance estimate was based on radio-tagged sockeye salmon that passed the lower Yentna tracking station, the sockeye salmon weir counts at Judd and Shell lakes, and the radio tags detected above the Judd and Shell lake weirs. Similarly, the Sunshine abundance estimate was based on radio-tagged sockeye salmon that passed the Sunshine tracking station, the sockeye salmon weir counts at Larson and

Byers lakes, and the radio tags detected above the Larson and Byers lake weirs. For each estimate, the stream reaches above the weirs were considered distinct recovery strata that enabled testing for deviations of equal probability of capture at the marking sites. A chi-square test of the null hypothesis of equal marked proportions among recovery strata was conducted to test this assertion. If the null hypothesis was not rejected, the pooled Petersen method was used to estimate the total abundance of sockeye salmon derived from radio-tag recoveries (Seber 1982). Because the sample size was relatively small, an inverse cube root transformation of the estimate was used to calculate the confidence interval (Arnason et al. 1991).

DATA ANALYSIS-DISTRIBUTION OF RADIO TAGS

A weighted terminal distribution of radio-tagged sockeye salmon was calculated to allow tags from all tagging sites to be pooled. The tags applied at Yentna and Sunshine were weighted by the proportion of the total tags applied at Flathorn that migrated up each drainage. A weighted terminal distribution of radio-tagged sockeye salmon within the Yentna and mainstem Susitna drainages was also estimated to adjust for the disproportional application of radio tags in relation to fish wheel catch. The tags applied at Yentna and Sunshine were weighted by the catch per hour of sockeye salmon during each week at each tagging site (Willette et al. 2003).

RESULTS

ABUNDANCE-FISH WHEEL TO FISH WHEEL

Capture-recapture conditions were sufficiently met such that sockeye salmon abundance passing Sunshine was estimated using three different data sets, and sockeye salmon abundance passing Yentna was estimated using two different data sets (Table 3). At Flathorn, 4,441 sockeye salmon were caught in the four fish wheels, of which 3,872 were marked and PIT tagged (Table 4). Generally low numbers of PIT-tagged sockeye salmon were recaptured at the Yentna and Sunshine fish wheels, with no valid recaptures at Yentna before 29 July.

Instead of one pooled-abundance estimate for Flathorn, two completely separate fish wheel to fish wheel estimates were constructed, one for the mainstem Susitna River and one for the Yentna River, based on PIT-tag and radio-tag migration patterns and travel times. All but 1 of the 149 PIT-tag recaptures from the Flathorn fish wheels in the eastern channel were recaptured in the mainstem Susitna drainage, at either the Sunshine fish wheels or the Larson Lake weir (Table 5). Thus, the Flathorn eastern two fish wheels were used as the capture event and the Sunshine fish wheels as the recapture event for the mainstem Susitna drainage abundance estimate. All but 2 of the 112 PIT-tag recaptures from the Flathorn fish wheel on the west bank of the western channel were recaptured in the Yentna drainage, at either the Yentna fish wheels or the Chelatna or Judd lake weirs (Table 5). Consequently, only the westernmost Flathorn fish wheel was used as the capture event and the Yentna fish wheels as the recapture event for the Yentna drainage abundance estimate. PIT and radio-tagged fish released from the fish wheel on the east bank of the west channel at Flathorn were recaptured at sites up both the Yentna and Susitna drainages, so PIT tags applied at that fish wheel were excluded from the analyses. It was assumed that fish following the east bank of the west channel at Flathorn entered their respective drainages and intermixed sufficiently with the marked fish from the other wheels at Flathorn before reaching any of the recapture sites.

Relocations of radio-tagged sockeye salmon indicated little or no mortality between sampling events, suggesting part of condition *b* was met (see *Spawning Distribution and Migration Timing* below). Of the 38 fish at Yentna and the 19 fish at Sunshine that were missing an adipose fin, all contained a PIT tag, thus meeting condition *c*.

The abundance estimate of 107,000 (95% CI = 49,180-164,820) sockeye salmon ≥400 mm MEF length at Sunshine for the season was based on 11 recaptures of 680 sockeye salmon marked at the east channel fish wheels at Flathorn and 1,892 unmarked sockeye salmon caught at Sunshine (Tables 6 and 7). Transit times of PIT-tagged fish between Flathorn and Sunshine were relatively uniform (Figure 4), with a median of 4.75 days and an average of 5.4 days (SD = 2.0 days). The uniform migration rates permitted precise stratification of the data by season (Table 6). The tagged fraction at Sunshine increased over time, but was not significant ($P = 0.12$). Similar recapture rates early (0.014) and late (0.017) in the season indicated that probabilities of capture at Sunshine did not vary appreciably during the season (Table 6). K-S tests also showed no evidence of size selectivity in either of the fish wheel events ($P = 0.99$ in both cases). Thus, abundance of sockeye salmon passing Sunshine was estimated without stratifying by size or season using PIT-tagged sockeye salmon released at the east channel Flathorn fish wheels and recaptured at the Sunshine fish wheels. Most fish at Sunshine were believed to pass up the east bank because few (35) sockeye salmon were caught in the west fish wheel at Sunshine (Table 6) and only one was caught during 3 hours of drift gillnetting.

The abundance estimate of 417,750 (95% CI = 261,930-573,570) sockeye salmon ≥400 mm MEF length up the Yentna River using PIT-tagged fish marked at the westernmost Flathorn fish wheel and recaptured at the Yentna fish wheels is a minimum estimate because no valid recaptures from Flathorn occurred before 29 July in the Yentna River fish wheels (Tables 8 and 9). Only four fish were captured at Yentna before 29 July that had a missing adipose fin, but the PIT tags were either shed, the fish were not scanned, or the tags did not appear in the Flathorn PIT-tag database. Therefore, there is no abundance estimate before 29 July at Yentna. Of the 112 fish caught and marked in the westernmost fish wheel at Flathorn and subsequently recaptured upstream, all but 2 were recaptured in the Yentna River and its tributaries (Table 5). Of these recaptured fish, 38 were caught in the Yentna fish wheels. All 38 were caught 29 July or later and all were marked at Flathorn on or after 28 July. The location and period for which the Yentna estimate is germane is therefore Flathorn beginning 28 July or, equivalently, Yentna beginning 29 July. At Yentna, 3,572 sockeye salmon were caught in the fish wheels before 29 July and 7,146 from 29 July onward (Table 8). A completely stratified Petersen model was used to estimate abundance beginning 29 July at Yentna because proportions of marked fish and probabilities of recapture changed between two time strata (”early” and ”late,” $P < 0.05$) within the period at Yentna beginning 29 July. The early time stratum at the Yentna fish wheels covered 29 July through 5 August and the late time stratum covered 6 August through 18 August. Transit times of recaptured fish between Flathorn and the Yentna fish wheels were relatively uniform (median of 0.81 and average of 1.6 days, SD = 2.0; Figure 4), indicating that a pooled Petersen estimate could be calculated for each of the early and late strata beginning 29 July. The estimates (and variances) from the early and late strata were summed to provide the estimate for the period beginning 29 July at Yentna.

No stratification by fish size was indicated because fish recaptured beginning 29 July had a similar size distribution as the marked population for that time ($P = 0.34$). However, size distribution of sockeye salmon caught at the west bank of the west channel fish wheel at Flathorn was skewed to fish smaller than those caught at Yentna ($P = 0.015$) beginning 29 July. Most catches of salmon other than sockeye salmon (coho *O. kisutch*, chum *O. keta*, and pink salmon

O. gorbuscha) occurred before 29 July. In 11.4 hours of drift gillnetting between the fish wheels on the Yentna River, only 6 sockeye salmon were caught, and all were netted a few feet offshore of the north bank fish wheel.

ABUNDANCE-FISH WHEEL TO WEIR

An estimated 128,105 sockeye salmon ≥400 mm MEF length migrated past Sunshine, based upon PIT-tag releases at the Sunshine fish wheels and recaptures at the Larson Lake weir. Of the 1,425 sockeye salmon PIT-tagged at Sunshine from 20 July to 13 August, 543 were recaptured at the Larson Lake weir. Daily PIT-tag detection test rates ranged from 85 to 100% with 100% detection on 12 of 18 days. The number of recaptured sockeye salmon with tags was not adjusted for tag detection. However, the PIT-tag detection system was not operational 21 July–30 July due to an electronic problem with the antenna. Therefore, the number of tagged sockeye recaptured during this time was estimated assuming the recapture probability was the same as the 31 July to 4 August period. The final model pooled recapture strata for the periods beginning 22 July and 31 July (Table 10). The G^2 statistic for this model indicated no significant difference ($P = 0.51$) between observed and fitted recaptures. Capture probability declined slightly between the two temporal strata used in the analysis ($P < 0.01$). If the actual number of tags passing the weir before 31 July was greater than estimated, the population estimate would be biased high. However, the marked fraction also increased over time at the weir ($P < 0.01$). If this was due to tagged fish lagging behind untagged fish, the population estimate could be biased high. The mean migration time for PIT-tagged fish from Sunshine to Larson Lake weir was 4.37 days (SE = 2.2 days). Confidence intervals were not reported for this abundance estimate because of the extrapolation of recaptures into earlier strata.

The Larson Lake weir was the only weir in the mainstem Susitna drainage that provided enough PIT-tag data for analysis, so there is no information on the probability of capture at Sunshine for other stocks, which would help assess condition *a*. However, few sockeye salmon were caught on the west bank at Sunshine and none were captured by gillnetting there or in the center of the river, suggesting that most sockeye at Sunshine migrated along the east bank. This migration pattern makes it likely that different stocks were tagged equally, if not at the same rate through time. Radio-tagging results, while sparse, show timing of sockeye salmon at Stephan Lake (about 80 km upstream of Larson Lake) had a similar median tagging date at Sunshine (about 27 July) to those of Larson Lake origin.

The abundance of sockeye salmon passing Flathorn was not estimated using data from Larson Lake weir because there was an unequal capture probability between banks in the east channel at Flathorn. The tendency for PIT-tagged sockeye salmon from the western fish wheel of the eastern channel at Flathorn to travel to Larson Lake was about 1.5 times greater than for fish tagged at the eastern most fish wheel. This suggested some stock separation among banks at Flathorn. Without confidence that fish were PIT-tagged proportionally among banks at Flathorn, the Larson Lake weir was not used as a recapture event.

The capture-recapture experiment for the Yentna drainage using PIT tags released from the Flathorn or Yentna fish wheels and recaptured at the Chelatna and Judd lake weirs did not meet the conditions necessary for an accurate estimate. At both weir sites, the number of PIT-tagged sockeye salmon passing through the weirs was substantially less than expected, based on the number of radio-tagged fish in each lake. Of the 1,296 fish PIT-tagged at Yentna, 1.5% were detected at Chelatna and 1.5% were detected at Judd Lake. Yet, of the 140 radio-tagged sockeye salmon migrating past the lower Yentna tracking station, 17.9% were detected in Chelatna Lake and 17.9% were detected in Judd Lake. During the 9 August aerial telemetry survey, 15 radio-tagged fish were detected in Chelatna Lake, but only 2 (13%) of the PIT tags that should have been in these fish were detected passing through the weir. However, the Chelatna Lake weir was only operated between 27 July and 10 August due to flooding, so some fish may have entered the lake prior to weir operation. Also on the 9 August aerial survey, one radio-tagged fish was detected in Judd Lake while the PIT tag injected into this fish was not detected passing through the weir. Daily PIT-tag detection tests at both lakes indicated that tag detection was generally above 90% (Appendices B1 and B2).

Because the number of sockeye salmon moving through the Judd Lake weir during the last 3 days of operation was 1.2%, 0.3%, and 0.2% of the final weir count (Appendix B1), salmon passage through the weir appeared nearly complete when the weir was removed on 21 August. Yet, during an aerial telemetry survey on 28 August, 10 of 24 (42%) radio-tagged fish that eventually entered Judd Lake were below the weir.

A hand-held PIT-tag antenna was used at the Shell Lake weir, but did not produce enough recaptures for analysis. Hewitt Lake weir was operated from 30 July until 10 August, when flooding stopped operations prematurely, and not enough fish were examined to be useful.

ABUNDANCE-RADIOTELEMETRY

There were an estimated 93,161 (95% CI = 80,053–106,268) sockeye salmon ≥400 mm MEF length that migrated past Sunshine, based on radio tags detected in Larson and Byers lakes. The data from these two lakes were pooled because marked proportions did not differ ($\chi^2 = 0.07$, df = 1, $P = 0.79$) between recapture locations (condition *a*). The marked sample ($n = 107$) consisted of 32 fish radio tagged at Flathorn and 75 fish radio tagged at Sunshine (Table 11). The terminal destination of these fish was determined from aerial surveys. A paired comparison test indicated that the Sunshine estimate based upon PIT-tag releases at Flathorn was not different from the Sunshine estimate based upon radio tags detected in Larson and Byers lakes ($P = 0.65$).

An additional estimate of the sockeye salmon passing Yentna was calculated using radio tags detected in Judd and Shell lakes. Using these data, there were 311,197 (95% CI = 251,568–391,264) sockeye salmon ≥400 mm MEF length that migrated past Yentna. The data from these two lakes were pooled in the analysis, because marked proportions did not differ ($\chi^2 = 3.12$, df = 1, $P = 0.08$) between recovery strata (condition *a*). The marked sample ($n = 140$) consisted of 66 fish radio tagged at Flathorn and 74 fish radio tagged at Yentna (Table 12). The terminal destination of 135 of these fish was determined from aerial surveys. The other five fish were detected migrating upstream past the fixed radiotelemetry station at Skwentna, but were not located during subsequent aerial surveys. There were two radio-tagged fish located in Shell Creek during the last aerial survey on 5 October that were assumed to have moved up into Shell Lake.

The abundance estimate at Yentna based on Flathorn PIT-tag releases was substantially greater than the radio-tag estimate at Yentna, but a statistical comparison could not be made because the PIT-tag estimate was only for the period after 28 July at Yentna. However, a comparable radio-tag abundance estimate was constructed by assuming a constant travel time for radio-tagged fish from Flathorn (or Yentna) to each of the weirs (this is essentially what was assumed for the single Petersen estimate using radio tags) and stratifying the estimate by time (before 29 July and 29 July onward at Yentna). Travel time was assumed to be 13 days from Flathorn to Judd Lake (from the PIT-tag data), 12 days from Yentna to Judd Lake (from the PIT-tag data), 9 days from

Flathorn to Shell Lake (based on the relative distance from Flathorn to Judd Lake vs. Flathorn to Shell Lake), and 8 days from Yentna to Shell Lake. These travel times resulted in all radio-tagged fish passing by their respective weirs while the weirs were still in operation, which allowed abundance estimates to be calculated. The stratification dates for the count at each weir are different because the travel time was different to each, and only the date of marking for the radio tags was known. The variety of possible estimates for the period before 29 July at Yentna was fairly consistent when both weirs were used for the recovery: 205,424 when only Flathorn radio tags were used and 202,025 when only Yentna radio tags were used (Table 13). The results were similar at Yentna for 29 July onward, with an estimate of 94,506 using Flathorn radio tags and about 97,206 using Yentna radio tags. From these analyses there are comparable estimates between Flathorn PIT tags (417,750; 95% CI = 262,000-574,000) and Flathorn radio tags for 29 July onward (94,506; 95% CI = 50,000-139,000).

Radio-tag abundance estimates of the sockeye salmon migrating past Sunshine and Yentna may be biased due to unequal probabilities of capture among individuals in the capture events (condition *a*). At Flathorn, 98% of the radio-tagged fish that migrated up the Yentna River were tagged in the west channel, and 91% of these were tagged on the west bank. Similarly, 82% of the radio-tagged fish that migrated up the Susitna River were tagged in the east channel. At Sunshine, all of the radio tags were applied on the east bank. At Yentna, 93% of the radio tags were applied on the south bank.

Radio tags were applied relatively early in the sockeye salmon run at Yentna, as indicated by fish wheel catch per hour (CPUE; Figure 5). Radio-tagged fish in Judd and Shell lakes also exhibited a relatively early run timing past Yentna (Figure 5). These fish were therefore more likely to receive a tag than the majority of fish migrating later in the run, and may not have been representative of all Yentna stocks. Similar conditions occurred at Sunshine. However, weighting the number of tags recaptured at each weir by weekly catch per hour in fish wheels at tagging sites did not substantially change the tag recapture numbers (7-21% difference; Appendix C1). Thus, the radio-tag abundance estimates may be biased low because of higher capture probabilities in the marking event for fish migrating to recovery strata, but the error appears to be small.

Although capture probabilities may have varied among individuals in the marking event, radio-tagged fish still may have mixed with the untagged fish. Ninety-five percent of the Flathorn PIT tags recaptured at Sunshine crossed the channel from the opposite bank or from the west channel at Flathorn. Conversely, only 23% of the Flathorn PIT tags recaptured at Yentna crossed the channel from the opposite bank. The relatively short distance between Flathorn and Yentna may have limited mixing.

Uncertainty regarding the final destination of some radio-tagged fish introduced uncertainty into the abundance estimates. Abundance estimates using radiotelemetry are based on the assumption that surveys adequately determine the final destination of radio-tagged fish, and that all radio-tagged fish eventually reach their final spawning site. The erratic behavior of some radio-tagged fish suggests there was a tagging effect, but none could be verified. Tagged fish detected in the lakes were assumed to be part of the lake population even if they were later detected below the lake. This assumption seemed reasonable because salmon typically move downstream after spawning. However, two radio-tagged fish detected in Shell Lake or Shell Creek on 28 August were later detected 10.5 km upstream of Shell Creek in the Skwentna River on 5 October. These fish were assumed to be destined for the Skwentna River and not Shell

Lake, because they moved a substantial distance upstream in the Skwentna River. Two radio-tagged fish included in the recovery strata at Shell Lake were detected in Shell Creek below the weir during the last aerial survey on 5 October. These fish were assumed to be destined for Shell Lake, but this was not verified. Both of these fish were tagged at Yentna during the third week in July, and their apparent late arrival into Shell Creek suggests that tagging may have affected their behavior. Five tagged fish that migrated upstream past the tracking station at Skwentna were not located during subsequent aerial surveys, so it is possible these fish entered Judd or Shell lakes undetected.

SPAWNING DISTRIBUTION AND MIGRATION TIMING

Between 8 July and 18 August 2006, 250 sockeye salmon were radio tagged at the Flathorn, Yentna, and Sunshine fish wheel sites combined (Table 14). All but one radio-tagged fish moved upriver (Table 15). Ten (4.0%) radio-tagged fish were not assigned to a spawning location, and one (0.4%) was never relocated. The fates of these 11 fish were unknown.

Comparison of sockeye salmon CPUE in fish wheels and the number of radio tags applied each week indicated that the radio-tagging schedule was skewed earlier than the sockeye salmon run timing (Figure 5). However, when CPUE was compared with the timing of radio-tagged sockeye salmon migrating upstream (Figure 5), the run timing of tagged fish was earlier than untagged fish to a lesser extent at Sunshine than at Yentna. There were no differences ($P > 0.05$) between the lengths of radio-tagged fish and PIT-tagged fish at any of the fish wheel sites.

A probable spawning location was identified for the majority of radio-tagged fish. Of the 250 radio-tagged fish, 239 (96%) could be assigned to a final spawning location or smaller tributary. For the 10 fish not assigned to a spawning location, 3 were tagged at Flathorn, 4 at Yentna, and 3 at Sunshine:

1. For the Flathorn fish, one fish passed the Yentna (no other information available) and the other two fish moved only 5-10 km upriver before stopping in the Susitna mainstem. An inactive transmitter mode (mortality indicator) was detected during aerial surveys after 13 days for one fish and after 32 days for the other two fish.
2. For the four Yentna fish, two moved at least 85 km up the Yentna River before migrating back down to the Susitna River near Flathorn. A third fish traveled upstream of the lower Yentna before moving back down the Susitna River and into Cook Inlet where a mortality indicator signal was detected 8 days later. The fourth fish migrated up the Yentna River near the mouth of the Skwentna River (60 km). A mortality indicator signal was detected 44 days later, but the location did not appear to be a spawning site.
3. All 3 Sunshine fish migrated at least 80 km further up the Susitna River mainstem (confirmed during aerial flights) but were not associated with a spawning area.

One fish tagged at Flathorn migrated up the Yentna River (23 km) before turning back and continuing its migration up the Susitna and Chulitna rivers to a small lake near Swan Lake.

Aerial surveys were conducted over the mainstem Susitna drainage on 2 August, 26 August, 1 September, 11 September, and 6 October 2006, and over the Yentna drainage on 9 August, 28 August, 7 September, and 5 October 2006. These surveys located 242 (96.8%) radio-tagged fish between tracking stations and upriver of tracking stations on terminal tributaries. All fish locations were corroborated by available tracking station records.

Radio-tagged sockeye salmon traveled throughout the Susitna River drainage (Table 16; Figure 3). There were 100 fish radio tagged at Flathorn, of which 66 migrated up the Yentna River and 34 continued up the mainstem Susitna River (Table 17). Of the 66 tagged fish that migrated up the Yentna River, 65 were recorded in terminal tributaries: 24 tags in the Skwentna River mainstem (or smaller tributaries), 23 tags in the Yentna River mainstem (or smaller tributaries), 12 tags in the Talachulitna River drainage, 5 tags in the Kichatna River drainage, and 1 tag in the Kahiltna River drainage (Table 18, Figure 6). Of the 34 tagged fish that migrated up the Susitna River, 23 traveled to the Talkeetna River drainage and 9 to the Chulitna River drainage. There were 75 fish radio tagged at Sunshine, and 72 were tracked to terminal tributaries including 65 in the Talkeetna River drainage and 7 in the Chulitna River drainage (Table 18).

Radio-tagged fish detected by the tracking stations were also detected during aerial surveys. All fish radio tagged at Flathorn and Sunshine were detected by tracking stations located immediately upstream. Only one fish tagged at Yentna was not detected by the tracking station located immediately upstream. All 9 tagged fish passing the upper Yentna tracking station were recorded, as were the 2 Kahiltna fish passing the Kahiltna tracking station, the 32 Flathorn-tagged fish passing the Sunshine tracking station, the 6 tagged fish passing the Kichatna tracking station, and the 86 tagged fish passing the Skwentna tracking station.

Although not installed until 26 July, the Talachulitna tracking station recorded 28 of 33 fish that were later found upstream during aerial surveys. Some sockeye salmon that were radio-tagged early could have passed prior to that time. The Chulitna tracking station only recorded 9 of 16 fish later found upstream during aerial surveys, but the station was not functional until 4 August and was vandalized on 22 August, resulting in lost data. To minimize future vandalism, information about the project is now posted at each station (Appendix A1). The electronics at the Talkeetna tracking station were destroyed and the data lost by a flood on 19 August. After the electronics were replaced only two late-tagged fish were recorded. The upper Susitna tracking station did not record any fish passage. Three fish were recorded upstream of the upper Susitna tracking station during the aerial surveys on 2 August, but the station was not activated until 3 August.

The weighted terminal distribution of radio-tagged sockeye salmon indicated that 66.9% of the run spawned in lakes and 33.1% spawned in streams. Of those fish spawning in lakes, 84.4% spawned in Larson, Chelatna, Shell, and Judd lakes (Figure 7).

The terminal distribution also indicated that sockeye salmon were strongly bank oriented at the tagging sites. For the Flathorn fish wheels, all sockeye salmon tagged at the west bank of the west channel fish wheel went up the Yentna River and all those tagged at the east bank of the east channel fish wheel continued up the Susitna River. Sockeye salmon tagged at the Flathorn west bank of the east channel and east bank of the west channel fish wheels were located in both drainages. The majority of sockeye salmon were radio tagged at the west bank of the west channel fish wheel at Flathorn (Table 17), the south fish wheel at Yentna, and the east fish wheel at Sunshine.

Most sockeye salmon passing by Flathorn exhibited similar run timing, although some differences by stock were observed. The Talkeetna River and Skwentna River stocks were present throughout the return, but the Talkeetna River stocks peaked the week beginning 16 July and the Skwentna River stocks peaked beginning 23 July (Figure 8). Sockeye salmon in the

Yentna and Talachulitna River displayed a timing pattern similar to the Skwentna River, while Chulitna River sockeye salmon more closely patterned the Talkeetna River timing.

The response of radio-tagged fish was to delay resuming upriver movement or to slow swimming speeds immediately after release. Flathorn fish movement averaged 5.6 km/day past the tracking station immediately upstream of the tagging site (Table 19). Yentna fish averaged 3.4 km/day and Sunshine fish averaged 4.4 km/day. Movement rates for Flathorn fish after passing the initial tracking station averaged 11.2 km/day for mainstem Susitna-bound fish and 13.6 km/day for Yentna-bound fish and an overall average of 12.8 km/day (Table 20). For Flathorn fish recorded at upriver stations, the overall average speed was 11.1 km/day (Table 21). While some stocks were slower, the sample sizes were small. The tagged Yentna and Sunshine fish combined averaged 10.5 km/day (Table 22).

DISCUSSION

ABUNDANCE

Capture-recapture abundance estimates of sockeye salmon escapement could only be generated separately for the Yentna and mainstem Susitna rivers. All three estimates for Sunshine were similar, and the Flathorn to Sunshine PIT-tag estimate of 107,000 fish (95% CI = 49,180-164,820) had the most evidence for meeting the necessary conditions for the capture-recapture experiment (Table 3). Results were more complicated and wide-ranging for the Yentna abundance estimates. All necessary conditions for each Yentna capture-recapture experiment with PIT tags or radio tags either were not met or could not be fully evaluated. The Yentna experiment that used the Flathorn to Yentna PIT tags during 29 July–18 August had the most evidence for meeting the necessary conditions, but this estimate (417,750 fish; 95% CI = 261,930-573,570) is not for the entire season, is imprecise (relative precision = 37%), and has small sample sizes (39 total recaptured PIT tags at Yentna) that give the statistical tests low power.

Because neither immigration nor emigration occurred (condition *d*), the abundance estimates for Yentna and Sunshine are germane at Flathorn. Radiotelemetry did not document any sockeye salmon spawning sites between Flathorn and Sunshine. With radio tags inserted in 34 sockeye salmon ascending the mainstem Susitna River from releases at Flathorn, there was only a 3% chance of finding no radio tags below Sunshine if 10% of the mainstem Susitna spawning population spawned below Sunshine. Therefore, the Sunshine estimate should be representative of the mainstem Susitna River.

Only 11 PIT-tag recaptures were available for analyses at the Sunshine fish wheels. The low number of recaptures provided a relatively imprecise abundance estimate (relative precision = 54%) and low power to test assumptions. Heterogeneous probability of capture at Sunshine is a possibility given the variation in fish wheel effort at that site (Table 7). For example, if the stratification dates at Flathorn/Sunshine are shifted by a few days, then the recapture rates differ among strata, showing the sensitivity of the analysis to the number of recaptures.

The Flathorn to Yentna fish wheel estimate using PIT tags has possible weaknesses. First, by relying on the marks only applied at the Flathorn westernmost fish wheel, the assumption is that the probability of capture at Yentna is relatively constant within the two temporal strata used for 29 July onward, or fish mixed completely within each temporal stratum. Second, assuming tag detection rates and probability of marked fish before 29 July equal those for 29 July onward, the estimated probability of observing no tags before 29 July at Yentna (in 3,572 fish examined) is close to 0. One possibility is that the marked fraction before 29 July is lower than that estimated for 29 July onward. However, the marked fraction that would yield a reasonable chance of no tags at Yentna before 29 July would lead to unrealistically high abundance estimates before 29 July (Figure 9). Third, tag detection may have been <100% for 29 July onward. The lack of expected tag recoveries at Yentna before 29 July described above was associated with peak catches of sockeye and other species in the fish wheels (Table 9), suggesting that adipose fin clips might have been overlooked because of the large numbers of fish handled. If tag detection was <100% for 29 July onward as well, then the abundance estimate may be biased high. However, all sockeye salmon at Yentna were individually handled, minimizing the risk of overlooking an adipose fin clip.

The aerial surveys conducted while the Chelatna and Judd lake weirs were in operation provided an opportunity to evaluate detection of the PIT tags in radio-tagged fish passing through those weirs. Although this method was limited, it suggests that the relatively low number of PIT-tag recaptures at these lakes may have been due to poor PIT-tag detection or PIT-tag loss (condition *c*). While the tag detection tests at the lakes showed that the PIT detectors generally worked well, it may be that PIT-tag detection in fish was not mimicked by the daily tests. Radio tags also may have interfered with PIT-tag detection. Although the radio-tag manufacturer (ATS) stated there would be no interference between the two tag types within these frequency ranges, electromagnetic fields and metal in the PIT-tag antenna field can reduce PIT-tag detection. Therefore, further tests should be conducted to evaluate whether radio tags interfere with PIT-tag detection.

PIT-tag recapture probabilities at weirs were inversely related (P = 0.014) to the distance fish traveled from the tagging site to the weirs (Table 23). This was not due to variable PIT-tag detection among weirs, because fish tagged at near and distant sites were passing through each weir at roughly the same time. Because tag mortality estimated from radio-tagged fish was low, this relationship is likely due to either tag loss or tagged fish lagging behind untagged fish, and thus not reaching the distant weirs before they were removed. Willette et al. (2003) estimated that tag retention in adult sockeye salmon tagged with 11-mm PIT tags and recaptured in gillnets was 98%. Because the sockeye salmon in this study were tagged with smaller PIT tags (7 mm) and were not recaptured in a net (i.e., less handling), it seems unlikely that tag loss could account for the observed relationship. Instead, aerial tracking of radio-tagged sockeye salmon suggested that tagged fish were lagging behind untagged fish, because substantial numbers of radio-tagged fish were found downstream of weirs after the run of untagged fish had tapered off. Underwood et al. (2004) found that recapture probabilities of radio-tagged chum salmon captured in fish wheels were inversely related to distance traveled. Although Underwood et al. (2004) attributed the relationship to handling mortality, our data suggest that tagging may also reduce the migration speed of salmon. Transit times of fish with PIT tags and radio transmitters were generally slower than fish with just PIT tags. For example, median travel time from Flathorn to Sunshine was 4.75 days for PIT tags and 8 days for radio tags, and from Flathorn to Yentna, 0.81 and 1.91 days, respectively. Transit times from Sunshine to Byers and Larson lake weirs, and between the Yentna fish wheels and the Yentna drainage weirs, were less regular than transit times from Flathorn to fish wheels upstream.

Tag loss and poor tag detection are two sources of error typically associated with capture-recapture experiments (part of condition *c*) that likely did not significantly bias the radio-tag abundance estimates. Only one radio-tagged fish lost its tag or the tag was not activated before release, and this fish was excluded from the experiment. All of the radio-tagged fish that migrated upstream past the tracking stations at Yentna and Sunshine were later located in the recovery strata or elsewhere within the drainage, so tag loss and poor tag detection probably did not bias the estimate. Although radio-tagging was skewed toward an earlier run timing, the timing of radio-tagged fish at the lower Yentna tracking station was closer to the run timing of untagged sockeye salmon, estimated using species-apportioned DIDSON sonar (Maxwell et al. *In prep*), indicating that tagged fish lagged behind and provided some temporal mixing with the incoming run (Figure 5).

Unequal probability of capture among stocks migrating up different banks may have been a significant source of error. Todd et al. (2001) found that 63% of dart-tagged sockeye salmon recaptured at Judd Lake (a south-side tributary of the Yentna River) were tagged on the south bank at Yentna, and 83% of sockeye salmon recaptured at Chelatna Lake (a north-side tributary) were tagged on the north bank at Yentna. If fish destined for Judd and Shell lakes (south-side tributaries) tended to migrate along the south bank at Yentna, they may have had a higher probability of being tagged, causing the radio-tag abundance estimates to be biased low. However, Todd et al. (2001) also found otolith-marked fish originating from fry releases at Chelatna Lake were caught on both banks (65% south bank; 35% north bank) at Yentna. In a separate part of that study, 75% of sockeye salmon tagged and released downstream of the Yentna fish wheels were recaptured on the opposite bank. The prevalence or consistency of bank affiliation by sockeye salmon during migration in the Susitna River drainage is not well understood.

The run timing of sockeye salmon in 2006, specifically in the Susitna River, was especially late (Shields 2007; Westerman and Willette. 2007). Heavy rainfall and flooding in mid to late August contributed to an earlier than desired removal of the fish wheels and weirs. This combination of events may have led to incomplete weir counts. The weir counts are the census of untagged fish in some of the abundance experiments, and would bias the radio-tag abundance estimates low.

Species-apportioned sonar estimates of the sockeye salmon abundance passing Yentna in 2006 were 92,896 (Bendix sonar; Shields 2007) and 160,452 (DIDSON sonar; Maxwell et al. *In prep*), which are significantly lower than the capture-recapture abundance estimates for the Yentna drainage (Table 24). Mid-channel drift gillnetting captured few sockeye salmon, suggesting that the nearshore range of the sonar was appropriate for enumerating sockeye salmon. If the species apportionment using the fish wheel catches was not representative of the species composition in the river, it may explain some of the abundance discrepancies. The abundance estimates for other species at Yentna were high enough to substantially affect sockeye salmon abundance estimates. Based on Bendix sonar counts there were 282,920 pink salmon, 11,745 chum salmon, 130,952 coho salmon, and 557 Chinook salmon.

A total of 126,218 sockeye salmon were enumerated passing the four weirs upstream of the Yentna sonar site (Table 24 and Appendix B2). It was expected that the weir counts would be less than the capture-recapture abundance estimates or the sonar counts, because historical aerial surveys (Fox 1998) and this year's radiotelemetry found sockeye salmon in many additional locations in the Yentna drainage. The weir counts are also a minimum count because flooding prevented operating all of the weirs for the entire season, and the late runs may not have been complete when most weirs were removed. As shown by the Yentna weir counts, the end-of-season Bendix sonar estimate of 92,896 fish was biased low in 2006.

SPAWNING DISTRIBUTION AND MIGRATION TIMING

This was the first study to use radiotelemetry to follow sockeye salmon in the Susitna River on a comprehensive scale. In 2006, 34 probable spawning locations were identified and given specific names, but several other probable spawning sites with fewer tagged fish were left unnamed. The terminal distribution of about one-third of the radio-tagged sockeye salmon was in rivers or sloughs, suggesting that a sizeable portion of spawning does not occur in lake systems. Additionally, on-the-ground tracking would be required to document that these are actual spawning sites.

After an initial delay, radio-tagged sockeye salmon appeared to consistently migrate upstream, although migration speed declined with distance traveled. While handling time for a radio-tagged fish is longer than a fish receiving only a PIT tag, most (95.6%) fish appeared to continue upriver to spawning areas. In some cases, radio-tagged fish appeared to lag behind the untagged population passing through weirs, indicating that tagging reduced their migration speed. Operation of fixed radiotelemetry stations at weirs and more frequent aerial surveys would provide the data needed to determine if tagging affected migration speed.

RECOMMENDATIONS

Proposed recommendations for 2007:

1. Eliminate all PIT tagging, and direct monetary savings toward the purchase of radio tags for the capture-recapture abundance experiment.
2. Operate only the Yentna and Sunshine fish wheels as marking sites.
3. Radio tags should be applied in proportion to the actual individual fish wheel catch, i.e., every *n*th fish. This approach will ensure that radio tags are applied in proportion to fish wheel CPUE over time and on each bank. A sufficient number of tags should be purchased to allow for a larger than expected run or, if necessary, reduce the tagging rate inseason.
4. Design the 2007 mark-recapture study as a partially stratified Darroch model, with banks constituting marking strata and lakes with weirs as recapture strata.
5. Operate an additional weir at Stephan Lake off the Talkeetna River.
6. Install radiotelemetry tracking stations at all weirs to monitor radio-tagged sockeye salmon movement through the weirs for the recapture event.
7. Continue extensive drift gillnetting in the center of the river at Sunshine to ascertain mid-river migration.
8. Continue aerial radio-tracking surveys to identify spawning locations.

In addition to providing abundance estimates (when combined with weir counts), extensive radio-tag application will provide precise estimates of sockeye salmon distribution. Precise and representative distribution estimates can be used to estimate sockeye salmon escapement in each tributary to the entire Susitna River drainage, and define the spatial pattern of sockeye salmon production.

ACKNOWLEDGMENTS

The 2006 Susitna River sockeye salmon stock assessment study was a large undertaking by multiple agencies, multiple divisions within ADF&G, and private organizations, which required a high level of development and coordination. Former Commissioner of ADF&G McKie Campbell initiated this study. From the Commercial Fishery Division of ADF&G, D. Lloyd, J. Regnart, L. Fair, L. Seeb, J. Seeb, D. Moore, R. Decino, D. Westerman, J. Berger, S. Palmer, J. Cross, J. Lynch, K. Nyberg, and K. Sechrist contributed to the design and implementation of the study. T. Tobias read the scale ages and K. Rudge-Karic conducted field logistics and data entry. R. Driscoll assisted with the radio tracking. From the Sport Fish Division of ADF&G, K. Hepler, D. Bernard, B. Clark, B. Stratton, J. Hasbrouck, D. Rutz, N. Deslauriers, D. Miller, and M. Hatfield contributed to the design and implementation of the study.

The following seasonal staff at remote field camps provided very long days, dedication, and patience collecting the data. From the Commercial Fisheries Division of ADF&G, Yentna River camp: T. D. Hacken (crew leader), S. Walker (crew leader), K. Dent, T. J. Hancock, S. Andrew, W. Newberry, D. Booth, and J. St. Louis. From the Sport Fish Division of ADF&G, crews at Flathorn camp were M. Bowes (crew leader), P. DiSarro (crew leader), I. Fo, J. Dawkins L. Henslee, and B. Leu, and at Sunshine were A. Lipshultz (crew leader), A. Baer, C. Clemens, and N. Peters. Sport Fish Division staff J. Bullock and S. Kincheloe conducted field logistics, sampling, and field supervision out of Palmer.

From CIAA, G. Frandrei, T. Dodson, G. Smith, and R. Carlson provided design, logistics, and supervision. CIAA field crews were P. Blanche, B. Artwich, N. Rewald; S. Caird, D. Schrandt, and J. Simmon at Chelatna Lake; J. Brinkman and D. Horton at Hewitt Lake; L. Yaegar and N. Fielitz at Shell Lake; M. Johnson and L. Becker at Larson Lake; D. DesRosier and J. Iumarri at Byers Lake; and D. Larsen and J. Hillman at Judd Lake. Technical assistance with computer programming was provided by R. Murray, and for radiotelemetry was provided by N. Christensen, L. Kuechle, A. Mayer, and R. Reichle of ATS. Also, thank you for the support and understanding of the Matanuska-Susitna Advisory Committee and the Matanuska-Susitna Borough.

The following people greatly assisted with the logistical coordination of the field operations: The Talachulitna Lodge, J. Hanson, B. Bryant, L. Teague, C. Norvell, J. Norvell, L. Heater, M. Meechan, Regal Air Service, J. DeCreeft (Northwind Aviation), and D. Glaser (Arctic Wings).

Product names used in this report are included for scientific completeness and do not constitute product endorsement.

REFERENCES CITED

Arnason, A. N., C. W. Kirby, C. J. Schwarz, and J. R. Irvine. 1996. Computer analysis of marking data from stratified populations for estimation of salmonid escapements and the size of other populations. Canadian Technical Report of Fisheries and Aquatic Sciences. 2106. National Research Council, Canada.

Arnason, A. N., C. J. Schwarz, and J. M. Gerrard. 1991. Estimating closed population size and number of marked animals from sighting data. Journal of Wildlife Management 55:716-730.

Eiler, J. H. 1995. A remote satellite-linked tracking system for studying Pacific salmon with radiotelemetry. Transactions of the American Fisheries Society 124:184-193.

Fox, J. 1998. Northern District sockeye salmon stock status, 1998. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2A98-01, Anchorage.

REFERENCES CITED (Continued)

Habicht, C., W. D. Templin, T. M. Willette, L. F. Fair, S. W. Raborn, and L. W. Seeb. 2007. Post-season stock composition analysis of Upper Cook Inlet sockeye salmon harvest, 2005-2007. Alaska Department of Fish and Game, Fishery Manuscript No. 07-07, Anchorage. http://www.sf.adfg.state.ak.us/FedAidpdfs/fms07-07.pdf

Hasbrouck, J. J., and J. A. Edmundson. 2007. Escapement goals for salmon stocks in Upper Cook Inlet, Alaska: report to the Alaska Board of Fisheries, January 2005. Alaska Department of Fish and Game, Special Publication No. 07-10, Anchorage. http://www.sf.adfg.state.ak.us/FedAidPDFs/sp07-10.pdf

King, B. E., and S. C. Walker. 1997. Susitna River sockeye salmon fry studies, 1994 and 1995. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2A97-26, Anchorage.

Maxwell, S. L., T. M. Willette, and A. V. Smith. *In prep*. A comparison of salmon passage rates from two sonars, a dual frequency identification sonar (DIDSON) and Bendix counter, at the Copper, Kenai, and Nushagak rivers. Alaska Department of Fish and Game, Division of Commercial Fisheries, Fishery Manuscript, Anchorage.

Seber, G. A. F. 1982. On the estimation of animal abundance and related parameters, *second edition.* Griffin and Company, Ltd. London.

Shields, P. 2007. Upper Cook Inlet commercial fisheries annual management report, 2006. Alaska Department of Fish and Game, Fishery Management Report No. 07-36, Anchorage. http://www.sf.adfg.state.ak.us/FedAidpdfs/Fmr07-36.pdf

Tobias, T., and T. M. Willette. 2004. An estimate of total return of sockeye salmon to upper Cook Inlet. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2A04-11, Anchorage.

Todd, G. L., S. R. Carlson, P. A. Shields, D. L. Westerman, and L. K. Brannian. 2001. Sockeye and coho salmon escapement studies in the Susitna drainage 1998. Alaska Department of Fish and Game, Commercial Fisheries Division, Regional Information Report 2A01-11, Anchorage.

Underwood, T. J., J. F. Bromaghin, and S. P. Klosiewski. 2004. Evidence of handling mortality of adult Chum salmon caused by fish wheel capture in the Yukon River, Alaska. North American Journal of Fisheries Managementt 24:237-243.

Westerman, D. L., and T. M. Willette. 2007. Upper Cook Inlet salmon escapement studies, 2005. Alaska Department of Fish and Game, Fishery Data Series No. 07-43, Anchorage. http://www.sf.adfg.state.ak.us/FedAidPDFs/fds07-43.pdf

Willette, T. M., R. DeCino, and N. Gove. 2003. Mark-recapture population estimates of coho, pink, and chum salmon runs to upper Cook Inlet in 2002. Alaska Dept. of Fish and Game, Division of Commercial Fisheries, Regional Information Report no. 2A03-20, Anchorage.

TABLES

Table 1.-Dates of operation for the Susitna River sockeye salmon fish wheels and their associated weirs by location, 2006.

		Dates of Operation			
		Fish Wheel	Fish Wheel weir		Fish Wheel
Site	Fish Wheel Location	Started	Installed	Removed	Stopped
Flathorn	West Channel, West Bank	7/3	7/14	8/14	8/17
	West Channel, East Bank	7/4	7/15	8/14	8/17
	East Channel, West Bank	7/4	7/27	8/14	8/17
	East Channel, East Bank	7/5	7/27	8/14	8/17
Sunshine	West Bank	7/17	none installed		8/15
	East Bank	7/8	7/24	8/17	8/18
Yentna	North Bank	7/7	7/7	8/18	8/18
	South Bank	7/7	7/7	8/18	8/18

Table 2.–Location of tracking stations used to monitor the movements of radio-tagged sockeye salmon in the Susitna River, 2006.

		Distance (km)	
Drainage	Tracking Station	From Saltwater	From Previous Station
Susitna	Flathorn	40.0	--
	Sunshine	128.3	88.3
	Talkeetna River	156.6	28.3
	Upper Susitna River	165.0	36.7
	Chulitna River	170.7	42.4
Yentna	Lower Yentna River	58.1	18.1
	Kahiltna River	93.7	35.6
	Skwentna River	138.5	80.4
	Talachulitna River	144.9	6.4
	Kichatna River	147.3	89.2
	Upper Yentna River	156.0	98.0

Table 3.-Assessment of our ability to meet capture-recapture model conditions and estimators used.

Population Estimated	Capture/ Recapture	Tag Type	Conditions Met a	b	c	d	Model	Comments
Mainstem Susitna	Flathorn/ Sunshine	PIT	Yes	Yes	Yes	Yes	Petersen[a]	1 of 149 recaptured Flathorn east channel tags recaptured in Yentna drainage Unequal capture probability between channels at Flathorn Only 11 recaptured tags limited power to tests assumptions
	Sunshine/ Larson	PIT	?	Yes	Partially	Yes	Darroch	PIT detector at Larson inoperable before 31 July; marked fraction after 31 July used for period before 31 July
	Sunshine/ Larson-Byers	Radio	?	Yes	Yes	Yes	Petersen	Tags not applied in proportion to abundance but marked fractions similar between Byers and Larson
Yentna	Flathorn/ Yentna	PIT	Partially	Yes	?	Yes	Stratified Petersen	Estimate only for period 29 July onward at Yentna 2 of 112 recaptured Flathorn west channel, west bank fish wheel tags recaptured in Susitna drainage; Unequal capture probability between banks at Flathorn; Unequal capture probability over time at Yentna; Tag detection questionable due to lack of recaptures before 29 July.
	Yentna/ Judd-Chelatna	PIT	?	?	No	Yes	No estimate	Tag detection questionable; Chelatna weir only operated for 15 days
	Yentna/ Judd-Shell	Radio	?	?	Yes	Yes	Petersen	Tags not applied in proportion to abundance but marked fractions similar between Judd and Shell; possible marking effect on radio tag migration time.
Entire Susitna	Flathorn/ Judd-Chelatna	PIT	?	?	No	Yes	No estimate	Tag detection questionable; Chelatna weir only operated for 15 days
	Flathorn/Larson	PIT	?	Yes	Partially	Yes	No estimate	PIT detector at Larson inoperable before 31 July; unequal capture probability between banks at Flathorn

[a] Petersen Conditions:

a. Equal capture probability in event 1 or 2, or complete mixing.
b. No mark-induced behavior (including mortality)
c. No tag loss and all tags detected
d. No immigration and emigration between events.

Table 4.-Total daily salmon catch, tags applied, fish wheel spin time, and fish wheel revolutions per minute (RPM) at Flathorn, 2006.

	Sockeye Salmon							Total	Daily
	Total	Tags Applied		Other Salmon Species				Fish Wheel Spin Time	Average Fish Wheel
Date	Catch	PIT[a]	Radio	Chinook	Coho	Pink	Chum	(hrs) [b]	RPM [c]
7/3	0	0	0	0	0	0	0	16.0	NA
7/4	1	0	0	0	0	0	0	16.0	NA
7/5	2	0	0	1	0	3	0	37.3	NA
7/6	6	9	0	3	4	1	0	48.1	2.00
7/7	6	7	0	1	7	1	0	29.6	2.00
7/8	0	6	0	NA	NA	NA	NA	4.5	2.00
7/9	7	4	0	1	5	0	3	42.5	2.00
7/10	25	21	0	NA	NA	NA	7	57.9	2.19
7/11	16	14	0	0	3	0	1	55.6	2.43
7/12	9	2	0	0	10	1	1	55.0	2.06
7/13	13	14	1	0	8	4	0	51.7	2.33
7/14	18	15	0	2	23	8	4	64.5	2.04
7/15	23	11	1	2	86	37	25	61.4	2.52
7/16	53	49	3	3	113	82	77	49.3	2.34
7/17	70	45	6	0	78	108	34	45.2	2.25
7/18	97	91	6	1	96	147	8	26.4	2.17
7/19	70	71	4	0	69	49	2	21.5	2.22
7/20	94	67	3	4	50	40	5	38.9	2.66
7/21	120	98	2	0	101	117	12	49.9	2.80
7/22	78	66	2	0	83	131	17	37.8	2.69
7/23	111	95	8	1	119	140	10	38.2	2.43
7/24	93	83	6	0	142	289	6	33.4	2.71
7/25	93	74	7	1	112	260	14	32.5	2.55
7/26	113	94	7	1	93	215	13	34.7	2.35
7/27	154	142	6	0	173	294	5	56.1	2.31
7/28	235	202	7	1	184	364	5	38.9	2.58
7/29	167	142	3	0	150	246	6	35.8	2.45
7/30	145	134	4	0	89	347	11	35.2	2.62
7/31	155	140	2	1	145	266	8	35.9	2.34
8/1	171	151	3	0	130	196	13	36.6	2.44
8/2	243	225	2	1	117	319	27	49.2	2.76
8/3	261	236	1	0	113	247	40	49.7	2.66
8/4	234	205	3	1	87	192	40	48.6	2.81
8/5	229	197	0	1	91	109	25	60.4	2.64
8/6	227	203	3	0	95	145	29	53.7	2.90
8/7	195	166	1	1	71	52	13	39.9	2.89
8/8	118	112	1	0	57	36	18	47.4	2.91
8/9	113	80	1	0	78	45	24	70.8	2.33
8/10	103	97	2	0	68	36	12	70.8	2.60

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Table 4.–Page 2 of 2.

Date	Sockeye Salmon Total Catch	Sockeye Salmon Tags Applied PIT[a]	Radio	Other Salmon Species Chinook	Coho	Pink	Chum	Total Fish Wheel Spin Time (hrs) [b]	Daily Average Fish Wheel RPM [c]
8/11	99	78	1	0	62	24	14	71.8	2.50
8/12	52	47	1	0	28	18	5	63.0	2.86
8/13	127	111	1	0	32	14	4	76.7	2.41
8/14	171	154	1	NA	NA	NA	NA	60.5	2.48
8/15	54	48	0	0	13	3	6	54.2	2.26
8/16	16	20	0	0	4	0	0	38.9	2.17
8/17	54	46	1	0	8	7	8	58.7	2.31
Total	4,441	3,872	100	27	2,997	4,593	552	2,100.2	

[a] Passive Integrated Transponder tag.

[b] Is the daily sum of four fish wheels at Flathorn.

[c] Is the daily average of revolutions per minute for four fish wheels at Flathorn.

Table 5.-Recapture locations of Flathorn passive integrated transponder (PIT) tagged sockeye salmon by fish wheel in 2006.

		Recapture Locations					
		Mainstem Susitna R.		Yentna R.			
Flathorn Fish Wheel	PIT Tags Released	Sunshine Fish Wheels	Larson Weir	Yentna Fish Wheels	Chelatna Weir	Judd Weir	Total
West Channel, West Bank	2,627	1	1	38	51	21	112
West Channel, East Bank	511	7	16	1	9	2	35
East Channel, West Bank	470	10	103	0	1	0	114
East Channel, East Bank	256	1	34	0	0	0	35
Total	3,864	19	154	39	61	23	296

Table 6.-Recapture statistics for Flathorn passive integrated transponder (PIT) tags deployed at east channel fish wheels and recaptured at Sunshine fish wheels in 2006.

	Flathorn PIT Tags Released			Sunshine Catch					
Stratum [a]	East Channel, West bank	East Channel, East bank	Total	East	West	Total	Flathorn Recaptures	Recapture Rate	Marked Fraction
1	142	75	217	944	10	954	3	0.014	0.003
2	319	144	463	913	25	938	8	0.017	0.009
Total	461	219	680	1,857	35	1,892	11		

[a] Flathorn Stratum 1 occurred from 6 July to 27 July 2006, Stratum 2 from 28 July to 13 August 2006.
Sunshine Stratum 1occurred from 11 July to 1 August, Stratum 2 from 2 August to 18 August 2006.

Table 7.-Total daily salmon catch, tags applied, fish wheel spin time, and fish wheel revolutions per minute (RPM) for Sunshine 2006.

	Sockeye Salmon			Other Salmon Species				Total Fish Wheel	Daily Average Fish Wheel
	Total	Tags Applied						Spin Time	
Date	Catch	PIT[a]	Radio	Chinook	Coho	Pink	Chum	(hrs) [b]	RPM [c]
7/8	0	0	0	0	0	0	0	3.0	NA
7/9	4	3	0	6	1	0	1	4.8	NA
7/10	0	0	0	10	5	1	4	7.3	NA
7/11	0	0	0	5	6	1	8	7.9	NA
7/12	3	0	0	4	3	1	7	9.6	3.25
7/13	9	2	0	1	3	3	8	8.2	3.25
7/14	8	2	0	2	4	3	17	14.3	3.13
7/15	3	0	0	0	1	2	5	14.3	3.50
7/16	3	1	1	0	2	0	3	14.5	3.75
7/17	12	4	2	2	2	8	6	20.5	3.75
7/18	14	4	1	3	5	9	16	15.7	3.50
7/19	12	1	1	0	17	20	12	26.1	3.00
7/20	34	11	4	0	7	19	6	24.6	3.00
7/21	97	18	7	0	1	30	20	24.4	2.75
7/22	101	28	8	1	7	51	32	25.2	2.77
7/23	35	0	4	0	10	61	27	25.2	2.85
7/24	31	11	5	0	16	179	70	25.2	2.85
7/25	69	58	4	0	18	270	56	23.0	3.02
7/26	66	59	3	1	13	255	58	20.3	3.00
7/27	63	48	6	0	29	524	63	19.5	3.28
7/28	52	51	3	0	51	695	102	19.9	3.02
7/29	88	34	4	0	63	658	110	19.4	2.75
7/30	84	82	6	0	42	691	103	20.7	3.00
7/31	90	71	1	0	40	312	63	16.6	3.25
8/1	80	80	4	0	51	469	76	14.6	3.04
8/2	89	105	3	1	69	670	86	17.6	3.83
8/3	83	94	0	0	118	689	165	18.0	3.40
8/4	87	85	1	0	150	891	256	16.4	3.75
8/5	133	105	2	0	204	377	152	14.8	3.02
8/6	117	106	1	0	247	506	247	18.2	2.73
8/7	107	101	0	0	192	411	243	30.0	2.49
8/8	65	64	0	0	NA	NA	NA	16.5	2.46
8/9	71	71	0	0	290	233	203	19.4	2.75
8/10	54	55	0	0	129	80	81	17.6	3.25
8/11	46	46	1	1	93	36	41	23.3	3.75
8/12	44	44	1	0	194	72	136	23.0	4.50
8/13	4	4	0	0	32	6	50	26.9	5.38
8/14	1	1	0	0	2	1	5	20.4	5.31
8/15	1	1	1	0	5	0	12	15.0	4.25
8/16	7	7	0	0	24	3	94	14.5	3.75
8/17	15	13	0	0	42	0	227	13.0	4.00
8/18	14	13	1	0	16	1	30	13.9	4.06
Total	1,896	1,483	75	37	2,204	8,238	2,901	742.8	

[a] Passive Integrated Transponder tag.

[b] Is the daily sum of two fish wheels at Sunshine.

[c] Is the daily average of revolutions per minute for two fish wheels at Sunshine.

Table 8.-Recapture statistics for passive integrated transponder (PIT) tags deployed at the Flathorn west channel, west bank fish wheel and recaptured at Yentna fish wheels in 2006.

		Flathorn PIT Tags Released	Yentna Catch			Flathorn	Recapture	Marked
Stratum [a]		West Channel, West bank	North	South	Total	Recaptures [b]	Rate	Fraction
1		632	454	3,118	3,572	0	0.000	0.000
2	Early	1,038	540	3,466	4,006	13	0.013	0.003
2	Late	957	474	2,666	3,140	24	0.025	0.008
Total		2,627	1,468	9,250	10,718	37		

[a] Flathorn Stratum 1 occurred from 7 July to 27 July, and Stratum 2 was divided into an Early (28 July to 4 August) and Late (5 August to 17 August) period. Yentna Stratum 1 occurred from 8 July to 28 July, and Stratum 2 was divided into an Early (29 July to 5 August) and Late (6 August to 18 August) period.

[b] Although a total of 38 Flathorn tagged sockeye salmon were recaptured at Yentna only 37 were used in the analysis due to the way the stratum dates were created.

Table 9.-Total daily salmon catch, tags applied, and fish wheel spin time at Yentna. Measurements of revolutions per minute were not collected at Yentna in 2006.

	Sockeye Salmon			Other Salmon Species				Total Fish Wheel Spin Time
	Total	Tags Applied						
Date	Catch	PIT[a]	Radio	Chinook	Coho	Pink	Chum	(hrs) [b]
7/7	30	0	0	11	46	9	7	16.2
7/8	42	2	1	6	87	15	7	22.2
7/9	56	5	0	4	65	14	1	31.6
7/10	79	7	2	1	146	17	7	30.3
7/11	50	6	1	2	73	12	5	35.4
7/12	33	6	0	2	81	29	6	33.4
7/13	34	4	1	5	44	39	8	35.5
7/14	10	5	1	3	83	57	17	31.5
7/15	57	1	1	3	241	162	54	26.7
7/16	111	5	1	2	430	737	55	29.3
7/17	225	14	4	1	463	721	42	33.7
7/18	332	31	3	4	640	768	21	31.1
7/19	223	40	5	2	337	333	35	29.9
7/20	149	26	3	2	235	428	35	28.0
7/21	174	16	3	1	426	1,121	54	28.2
7/22	248	21	3	1	712	1,614	65	28.7
7/23	237	29	2	0	811	3,632	69	32.9
7/24	274	25	5	0	949	3,755	43	32.6
7/25	404	35	3	1	904	3,121	37	32.4
7/26	273	48	4	1	583	2,011	29	27.1
7/27	531	34	3	0	574	2,173	36	31.5
7/28	897	59	3	1	985	2,369	40	29.3
7/29	770	115	2	0	1,170	3,507	40	32.1
7/30	498	89	3	1	553	2,087	28	29.1
7/31	231	64	2	0	391	1,095	20	30.3
8/1	274	28	1	0	282	1,226	53	26.9
8/2	417	34	3	1	267	1,035	74	29.3
8/3	489	50	1	0	314	773	89	29.3
8/4	430	58	2	0	348	663	105	32.8
8/5	237	55	0	3	196	320	58	32.8
8/6	339	31	2	1	180	271	58	31.8
8/7	313	41	2	1	185	247	73	28.3
8/8	165	37	1	0	199	91	43	28.6
8/9	163	24	2	0	175	85	21	29.2
8/10	134	20	1	4	93	51	17	38.7
8/11	259	16	1	0	84	74	14	34.9
8/12	290	31	1	1	247	126	56	29.2
8/13	412	30	1	1	132	NA	29	39.6
8/14	321	51	1	0	46	72	18	31.3
8/15	NA	39	0	NA	NA	NA	NA	28.8
8/16	NA	0	0	NA	NA	NA	NA	0.0
8/17	296	0	0	0	132	60	55	29.5
8/18	211	0	0	0	102	29	47	27.2
Total	10,718	1,232	75	66	14,011	34,949	1,571	1,277.2

[a] Passive Integrated Transponder tag.

[b] Is the daily sum of two fish wheels at Yentna.

Table 10.-Results from a maximum likelihood Darroch abundance estimate of sockeye salmon passing Sunshine in 2006 based upon passive integrated transponder (PIT) tag recaptures at Larson Lake weir (final pooling) and test results for completing pooling. Stratum dates indicate the beginning of each time period.

(A) Detailed results from analyzing PIT tag data: final pooling.

Release		Observed recaptures with fitted values beneath		
Strata	Fish tagged	22 July and 31 July	5 August	Total
20 July	190	92	2	94
		94.9	2.1	97
27 July	289	120	23	143
		117.1	21.9	139
1 August	946	29	329	358
		29	330	359
Total tags[a]		241	354	595
Total untagged		35,359	21,083	56,442
Marked Fraction		0.007	0.017	
Population size		68,571	59,535	128,105
SE (Population size)		3,766	2,691	4,174
Probability (recapture)		0.516	0.354	
SE (Probability recapture)		0.028	0.016	
G^2 test for goodness of fit:		$G^2 = 0.43$, df = 1, $P = 0.51$		

(B) Test results for completing pooling.

	χ^2	df	*P*-value
Test for complete mixing	23.5	2	<0.01
Test for equal proportions	126	1	<0.01

[a] Tag detector not operational 21 July-30 July, recaptures for this period estimated using probability of recapture during 31 July-4 August.

Table 11.-Summary statistics for radio-tagged sockeye salmon detected migrating upstream past a fixed radiotelemetry station 4.2 km above Sunshine and subsequently detected during aerial surveys in Larson and Byers lakes.

	Number Fish	Recovery strata	
Release Stratum	Radio Tagged	Larson	Byers
Sunshine: 18 July – 30 August	107	64	4
Total Untagged		56,445	3,074

Table 12.-Summary statistics for radio-tagged sockeye salmon detected migrating upstream past a fixed radiotelemetry station 4.5 km above Yentna and subsequently detected during aerial surveys in Judd and Shell lakes.

	Number Fish	Recovery strata	
Release Stratum	Radio Tagged	Judd	Shell
Yentna: 14 July - 19 August	140	24	25
Total Untagged		40,633	69,720

Table 13.-Estimates of sockeye salmon abundance $\hat{N}$ using radio tags from the Flathorn or Yentna fish wheels to the Judd and Shell lake weirs.

Stratum	Radio Tags Released	Weir Count at Judd Lake	Radio Tags at Judd Lake	Weir Count at Shell Lake	Radio Tags at Shell Lake	Judd $\hat{N}$	SE[$\hat{N}$]	Shell $\hat{N}$	SE[$\hat{N}$]	Both $\hat{N}$	SE[$\hat{N}$]
1) Flathorn to Judd and Shell, completely stratified											
Before 29 July	46	32,170	7	37,761	8	189,004	57,383	197,201	56,066	205,424	40,459
29 July onward	20	8,463	3	32,039	5	44,435	17,876	112,139	35,818	94,506	22,589
All	66	40,633	10	69,800	13	247,497	65,310	334,047	76,704	308,294	49,391
Summed						233,439	60,102	309,340	66,531	299,930	46,338
2) Yentna to Judd and Shell, completely stratified											
Before 29 July	51	32,170	11	37,761	6	139,407	33,905	280,517	92,253	202,025	37,472
29 July onward	23	8,463	3	32,039	6	50,783	20,728	109,850	32,684	97,206	22,382
All	74	40,633	14	69,800	12	203,169	45,422	402,697	97,845	306,760	46,372
Summed						190,190	39,739	390,367	97,871	299,231	43,648

Table 14.-Weekly and total number of sockeye salmon captured using fish wheels and radio tagged in the Susitna River drainage, 2006.

Statistical Week	Dates	Site			Total
		Flathorn	Yentna	Sunshine	
27	2-8 July	0	1	0	1
28	9-15 July	2	6	0	8
29	16-22 July	27	22	24	73
30	23-29 July	43	22	29	94
31	30 July-5August	15	13	17	45
32	6-12 August	10	9	3	22
33	13-19 August	3	2	2	7
Total	2 July-19August	100	75	75	250

Table 15.-Tracking results for sockeye salmon radio tagged in the Susitna and Yentna rivers during 2006.

Tagging Site	Total Number Tagged	Number Moved Upriver [a]	Percent Moved Upriver
Flathorn	100	100	100
Yentna	75	74	98.7
Sunshine	75	75	100
Total	250	249	99.6

[a] Fish recorded upriver from the tagging sites.

Table 16.-Regional distribution of radio-tagged sockeye salmon in the Susitna River drainage during 2006.

		Flathorn		Yentna		Sunshine	
Drainage	Region	Number of Fish	Percent	Number of Fish	Percent	Number of Fish	Percent
Susitna River	Lower Susitna River MS [a]	2[b]	2	3[c,d]	4	0	0
	Talkeetna River	3	3			3	4
	Tributaries	2	2			5	6.6
	Papa Bear Lake	0	0			2	2.7
	Larson Lake	17	17			47	62.7
	Stephan Lake	1	1			8	10.7
	Upper Susitna River MS	0	0			3[e]	4
	Chulitna River	2[f,g]	2			1	1.3
	Tributaries	0	0			1	1.3
	Byers Lake	3	3			2	2.7
	Swan Lake	4[g]	4			3	4
Yentna River	Lower Yentna River MS [h]	1[i]	1	2[j]	2.8		
	Upper Yentna River MS	5	5	4	5.4		
	Lake Creek	1	1	3	4		
	Chelatna Lake	15	15	10	13.3		
	Johnson Creek	0	1	1	1.3		
	Hewitt Lake	2	2	1	1.3		
	Kahiltna River	1	1	1	1.3		
	Lower Skwentna River MS [k]	1	1	0	0		
	Upper Skwentna River MS	6	6	7	9.3		
	Tributaries	4	3	8	10.7		
	Shell Lake	13	13	13	17.3		
	Talachulitna River	1	1	5	6.7		
	Tributaries	1	1	3[l]	4		
	Judd Lake	10	10	13	17.3		
	Kichatna River	5	5	1	1.3		
	Total	100	100	75	100	75	100

[a] Section of the Susitna River from saltwater to the Susitna-Talkeetna River confluence.

[b] Both fish moved only a short distance above the Flathorn tagging site.

[c] Includes two fish that passed Yentna station then back down to Flathorn.

[d] Includes one fish that passed Yentna station then back down to saltwater.

[e] All three fish were located in Upper Susitna but not assigned a final location.

[f] Includes one fish recorded near Lucy Lake.

[g] Includes one fish also recorded at Lower Yentna station.

[h] Section of the Yentna River from the Susitna-Yentna River confluence to the Yentna-Skwentna River confluence.

[i] Includes one fish that passed Yentna station, no other information available.

[j] Includes one fish tagged at Yentna, no information available, the second fish moved near Skwentna River confluence in Yentna River MS.

[k] Section of the Skwentna River from the Yentna-Skwentna River confluence to the Skwentna-Talachulitna River confluence.

[l] Includes one fish located in Movie Lake.

Table 17.-Recapture locations of Flathorn radio-tagged sockeye salmon by fish wheel in 2006.

		Recapture Locations		
Flathorn Fish Wheel	Radios Released	Mainstem Susitna R.	Yentna R.	Total
West Channel, West Bank	60	1	59	60
West Channel, East Bank	11	5	6	11
East Channel, West Bank	18	17	1	18
East Channel, East Bank	11	11	0	11
Total	100	34	66	100

Table 18.-Terminal distribution (number of fish and percent [in parentheses]) of radio-tagged sockeye salmon in the Susitna River drainage in 2006, by fish wheel.

	Terminal Site															
Tagging Site	Talkeetna River	Larson Lake	Stephan Lake	Chulitna River	Swan Lake	Byers Lake	Yentna River	Chelatna Lake	Hewitt Lake	Kahiltna River	Skwentna River	Shell Lake	Talachu-litna River	Judd Lake	Kichatna River	Total
Flathorn:																
West Channel, West Bank Fish Wheel																
	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	6 (6.2)	11 (11.3)	2 (2.1)	1 (1.0)	10 (10.3)	13 (13.4)	1 (1.0)	10 (10.3)	4 (4.1)	58 (59.8)
West Channel, East Bank Fish Wheel																
	0 (0.0)	0 (0.0)	1 (1.0)	0 (0.0)	1 (1.0)	3 (3.1)	0 (0.0)	4 (4.1)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (1.0)	1 (1.0)	11 (11.3)
East Channel, West Bank Fish Wheel																
	3 (3.1)	11 (11.3)	0 (0.0)	0 (0.0)	1 (1.0)	1[a] (1.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (1.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	17 (17.5)
East Channel, East Bank Fish Wheel																
	2 (2.1)	6 (6.2)	0 (0.0)	1 (1.0)	2[b] (2.1)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	11 (11.3)
Yentna:																
North Bank Fish Wheel																
	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (1.4)	1 (1.4)	0 (0.0)	0 (0.0)	2 (2.9)	0 (0.0)	0 (0.0)	1 (1.4)	0 (0.0)	5 (7.1)
South Bank Fish Wheel																
	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	7 (10.0)	9 (12.9)	1 (1.4)	1 (1.4)	13 (18.6)	13 (18.6)	5 (7.2)	15[d] (21.4)	1 (1.4)	65 (92.9)
Sunshine:																
West Bank Fish Wheel																
	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
East Bank Fish Wheel																
	10[c] (13.9)	47 (65.3)	8 (11.1)	2 (2.8)	3 (4.1)	2 (2.8)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	72 (100.0)
Total	15 (6.3)	64 (26.8)	9 (3.8)	3 (1.2)	7 (2.9)	6 (2.5)	14 (5.9)	25 (10.5)	3 (1.2)	2 (0.8)	26 (10.9)	26 (10.9)	6 (2.5)	27 (11.3)	6 (2.5)	239 (100.0)

[a] In small lake near Byers Lake

[b] Includes one fish in small lake near Swan Lake

[c] Includes two fish near Papa Bear Lake

[d] Includes one fish in small lake (Movie) near Judd Lake

Table 19.-Elapsed time by capture week for radio-tagged sockeye salmon traveling between the tagging area and the tracking station immediately upriver in 2006.

Tagging Site	Week Beginning	Number Tags	Average Days	Average Migration Speed (km/day)
Flathorn	7/2	0		
	7/9	2	2.4	2
	7/16	27	1.3	3.7
	7/23	42[a]	0.7	6.9
	7/30	15	0.7	7.1
	8/6	10	0.5	9.1
	8/13	3	0.4	13.5
	Combined	99	0.8	5.6
Yentna	7/2	0[a]		
	7/9	5[a]	2.8	1.6
	7/16	22	1.2	3.9
	7/23	22	1.4	3.3
	7/30	13	1.2	3.8
	8/6	9	1.1	4.1
	8/13	2	1.2	3.9
	Combined	73	1.3	3.4
Sunshine	7/2	0		
	7/9	0		
	7/16	24	0.9	4.7
	7/23	29	1	4.1
	7/30	17	0.8	5.3
	8/6	3	0.9	4.6
	8/13	2	2	2.1
	Combined	75	1	4.4
Total		247	1	4.4

Note: At Flathorn the average distance from four fish wheels to Flathorn was 4.71 km, at Yentna the average distance from both fish wheels to lower Yentna was 4.54 km, and at Sunshine the average distance from both fish wheels to Sunshine was 4.27 km.

[a] Excluding a radio tagged fish not recorded passing the tracking station.

Table 20.-Movement rates (km/day) of sockeye salmon radio tagged at Flathorn during 2006 based on travel time between the Flathorn tracking station and the lower Yentna and Sunshine tracking stations.

Tracking Station	River	Number of Tags	Distance (km)	Average Number of Days	Average Migration Speed (km/day)
Sunshine	Susitna	32[a,b]	88.3	7.9	11.2
lower Yentna	Yentna	66	18.1	1.3	13.6
Combined		98			12.8

[a] Excluding one radio tagged fish not recorded passing the Flathorn tracking station.

[b] Excluding one radio tagged fish not recorded passing the Sunshine tracking station.

Table 21.-Movement rates (km/day) of sockeye salmon radio tagged at Flathorn during 2006, based on fish passage from Flathorn to the furthest upriver tracking station locations.

Tracking Station	Number of Tags	Distance (km)	Average Number of Days	Average Migration Speed (km/day)
Talkeetna	2	116.6	19.7	5.9
Chulitna	5	130.7	17.7	7.4
Kahiltna	1	53.7	19.3	2.8
Skwentna	36	98.5	7.7	12.8
Kichatna	5	107.3	9.1	11.8
Upper Yentna	5	116	24.3	4.8
Combined	54			11.1

Table 22.-Movement rates (km/day) of sockeye salmon radio tagged at Yentna or Sunshine during 2006 based on fish passage from Yentna or Sunshine to the furthest upriver tracking station locations.

Tagging Site	Tracking Stations	Number of Tags	Distance (km)	Average Number of Days	Average Migration Speed (km/day)
Sunshine	Talkeetna	0	28.3		
Sunshine	Chulitna	4	42.4	5.9	7.2
Yentna	Kahiltna	1	35.6	4.3	8.2
Yentna	Skwentna	49	80.4	7.1	11.3
Yentna	Kichatna	1	89.2	8.1	11
Yentna	Upper Yentna	4	98	19	5.2
Combined		59			10.5

Table 23.-Passive integrated transponder (PIT) tag recapture probabilities and distance between fish wheel tagging sites and weir recapture sites.

Tagging Site	Weir Site	Distance from Tagging Site (km)	Recapture Probability
Flathorn	Judd	136.3	0.0079
Yentna	Judd	118.2	0.0147
Flathorn	Chelatna	123.5	0.0193
Yentna	Chelatna	105.4	0.0154
Flathorn	Larson	108.8	0.1877
Sunshine	Larson	40.5	0.3624

Table 24.-Comparison of sockeye salmon escapement estimates in the Susitna drainage, 2006. In the Yentna drainage sockeye salmon were counted at weirs on Judd, Shell, Hewitt, and Chelatna lakes, and in the upper Susitna drainage weirs were operated on Byers and Larson lakes.

			Escapement Estimate		
Population Estimated	Capture/Recapture Site	Method	Point	Lower 95% CI	Upper 95% CI
Mainstem Susitna	Sunshine/Larson-Byers	Radio Tag	93,161	80,053	106,268
Mainstem Susitna	Flathorn/Sunshine	PIT Tag	107,000	49,180	164,820
Mainstem Susitna	Sunshine/Larson	PIT Tag	128,105	-	-
Mainstem Susitna (lakes with weir)	-	Weir[a]	59,519	-	-
Yentna	Yentna/Judd-Shell	Radio Tag	311,197	251,568	391,264
Yentna (29 July onward)	Flathorn/Yentna	PIT Tag	417,750	261,930	573,570
Yentna	-	Bendix Sonar [b]	92,896	-	-
Yentna	-	DIDSON Sonar [c]	160,452	-	-
Yentna (lakes with weir)	-	Weir[a]	126,218	-	-

[a] *Source*: Cook Inlet Aquaculture Association. Soldotna, Alaska. Accessed 10 October, 2006. http://www.ciaanet.org/content_sub.asp?SUB_ID=14&CAT_ID=6.

[b]Shields 2007

[c]Maxwell et al. *In prep*

FIGURES

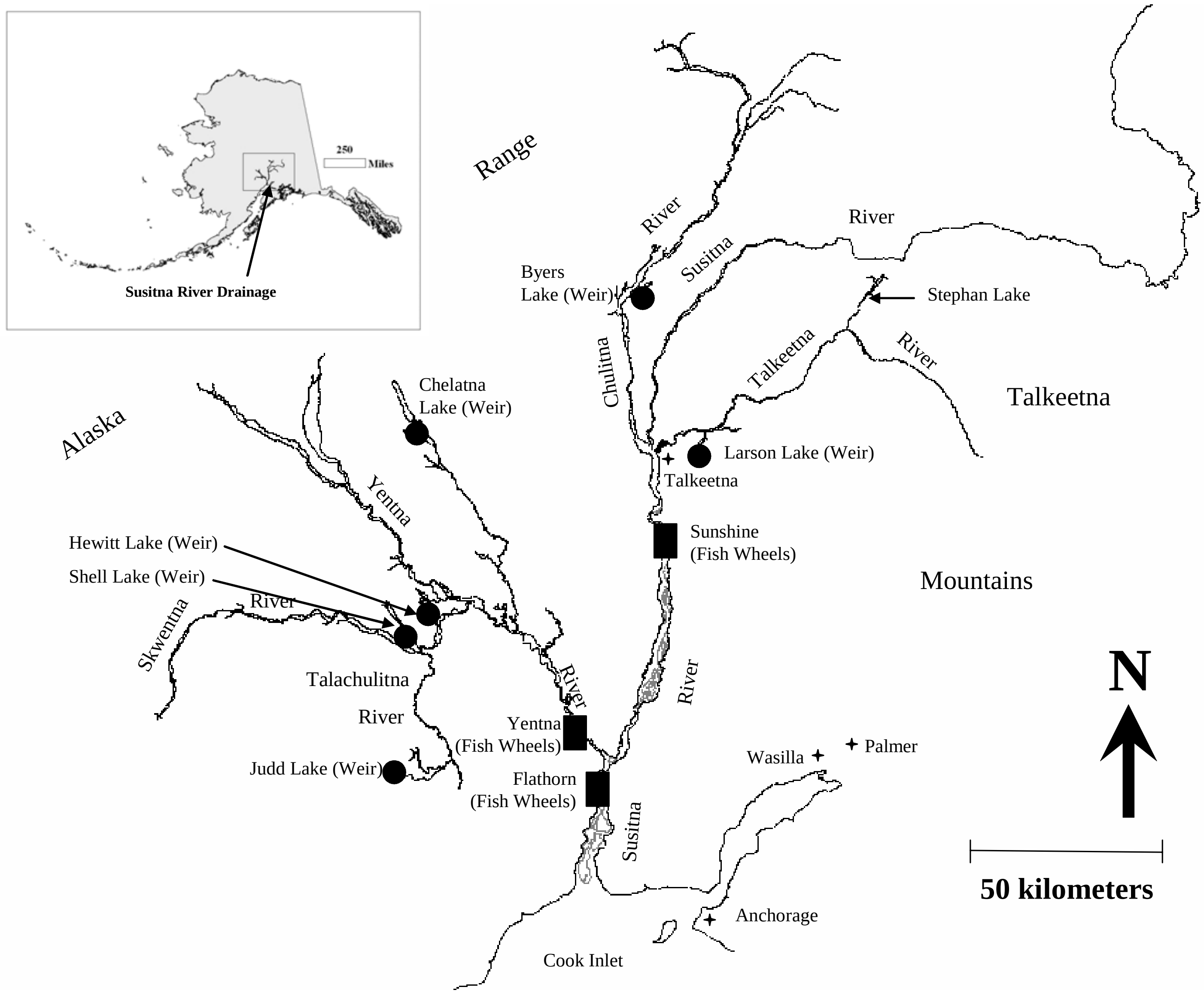


Figure 1.-Susitna River drainage with fish wheel (rectangles) and weir (circles) locations, 2006.

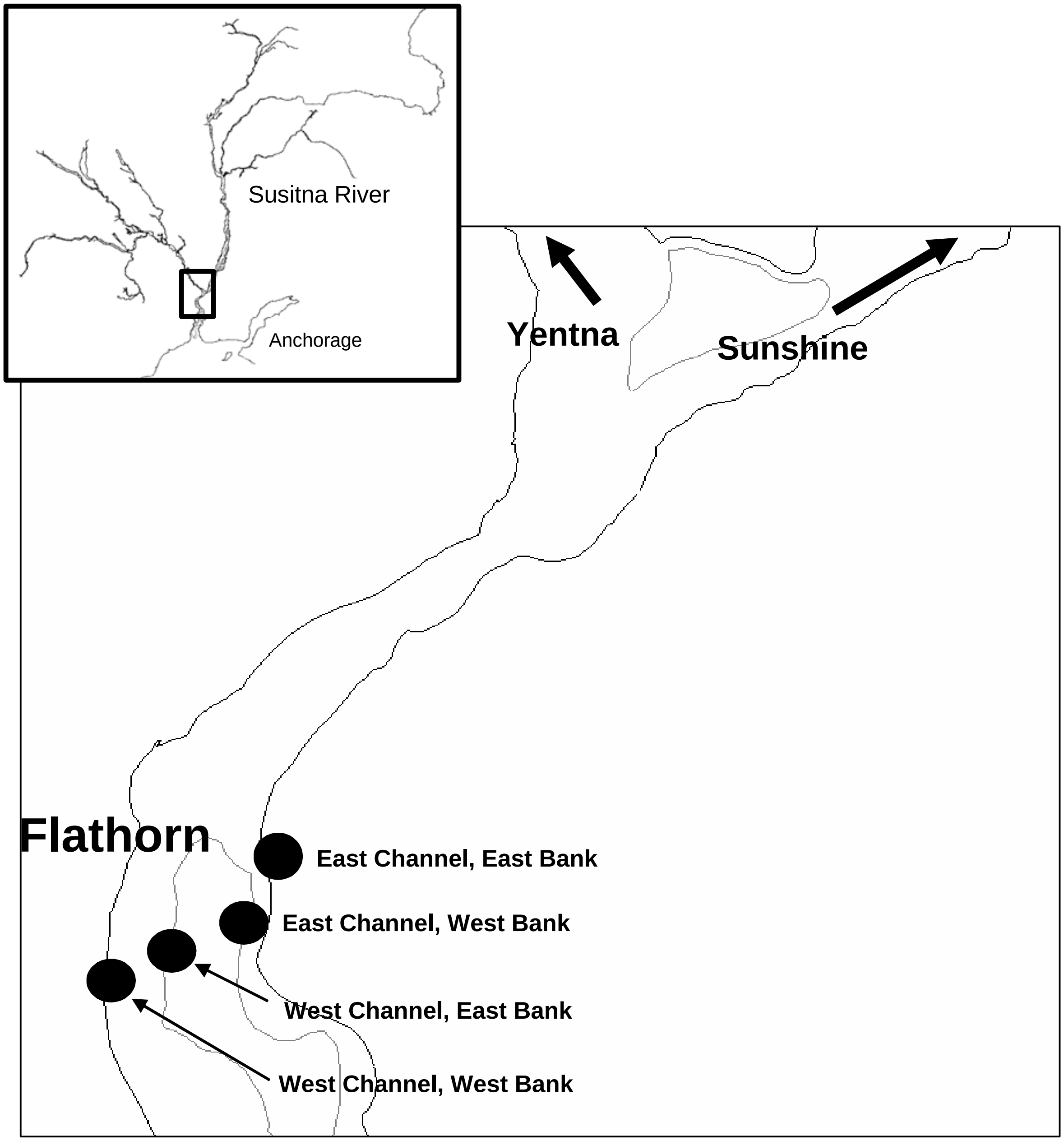


Figure 2.-Location of the four fish wheels on the lower Susitna River at Flathorn, 2006.

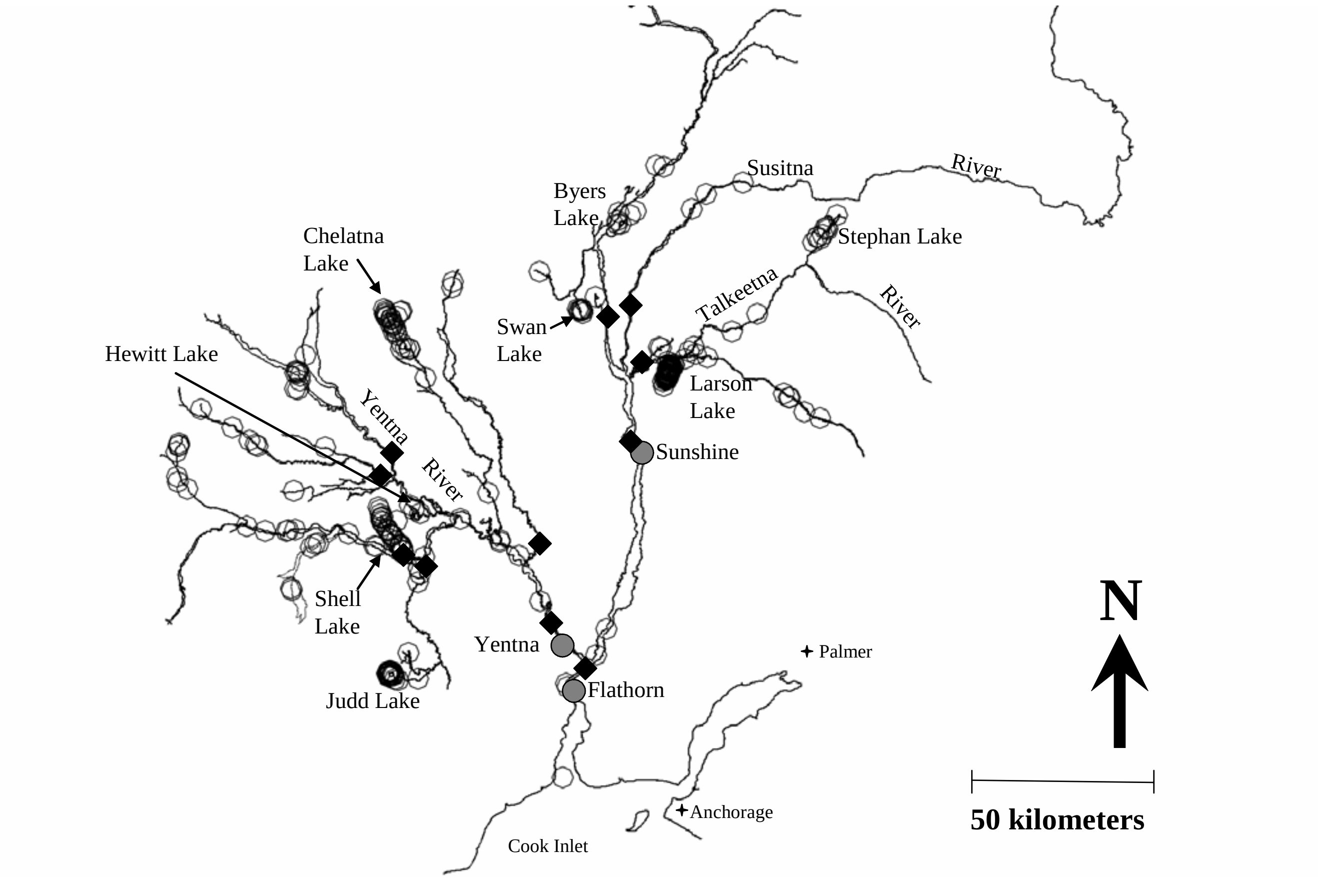
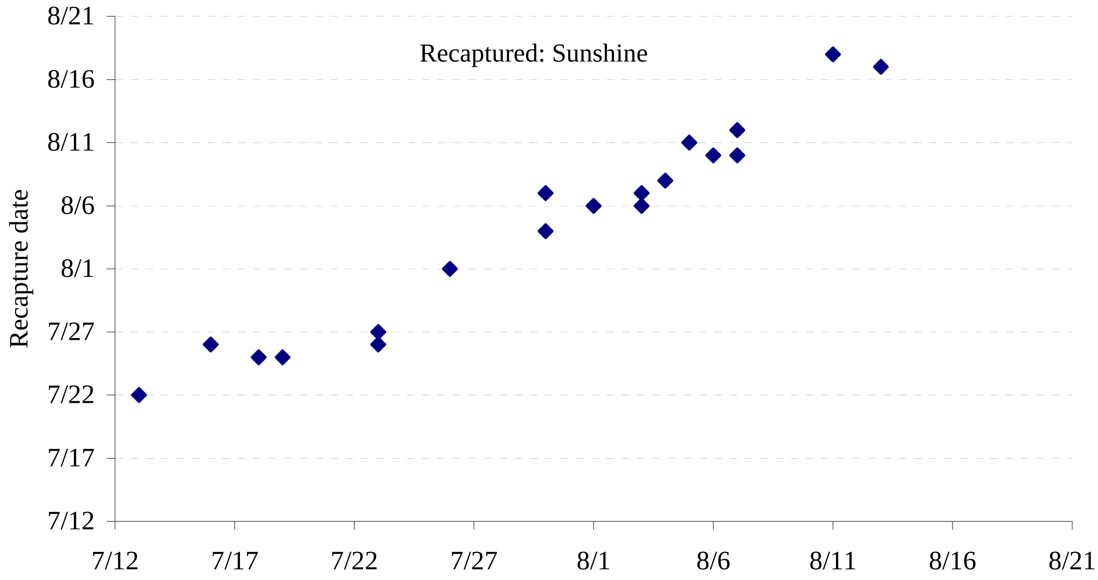


Figure 3.-The Susitna River drainage, the 3 fish wheel marking sites (solid circles), 11 remote radio tracking stations (solid diamonds), and the spawning locations of radio-tagged sockeye salmon (open circles) based on aerial surveys, 2006.



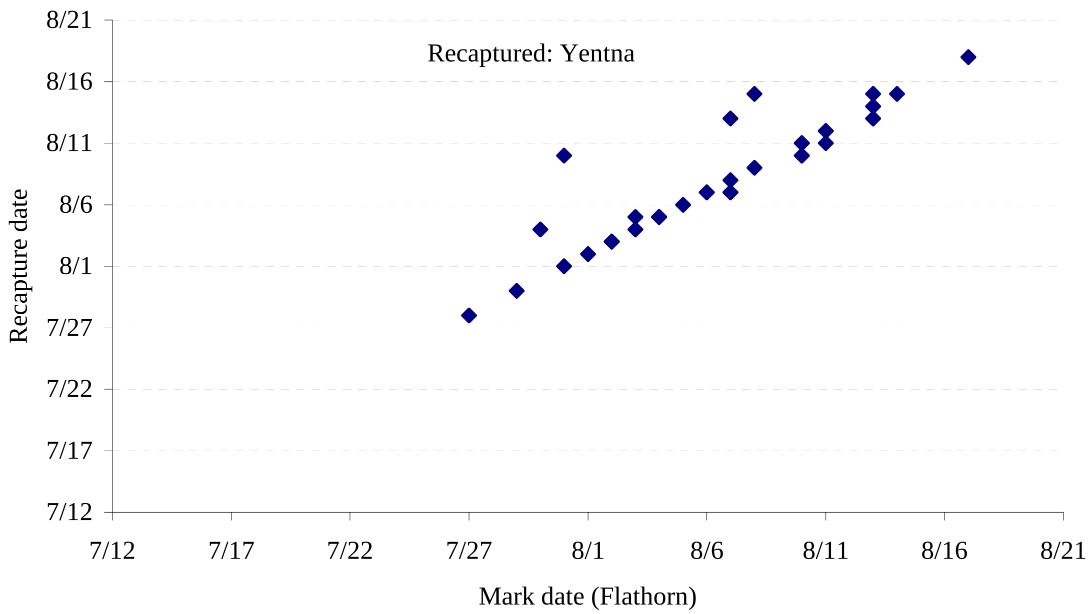


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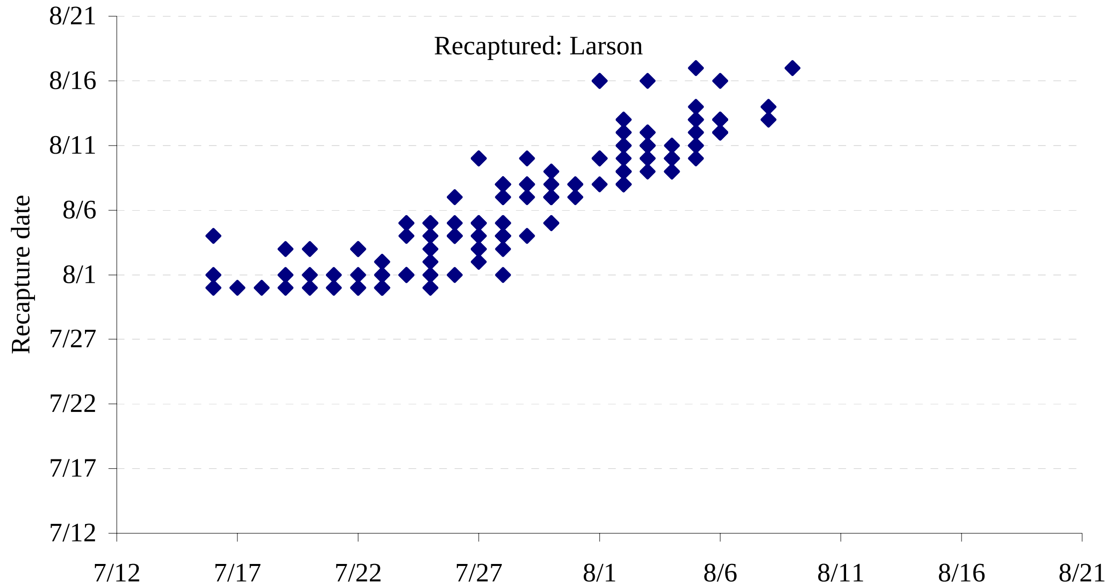
Figure 4.-Travel time of PIT-tagged sockeye salmon from Flathorn to Yentna and Sunshine, and to Larson, Chelatna, and Judd Lake weirs, 2006.



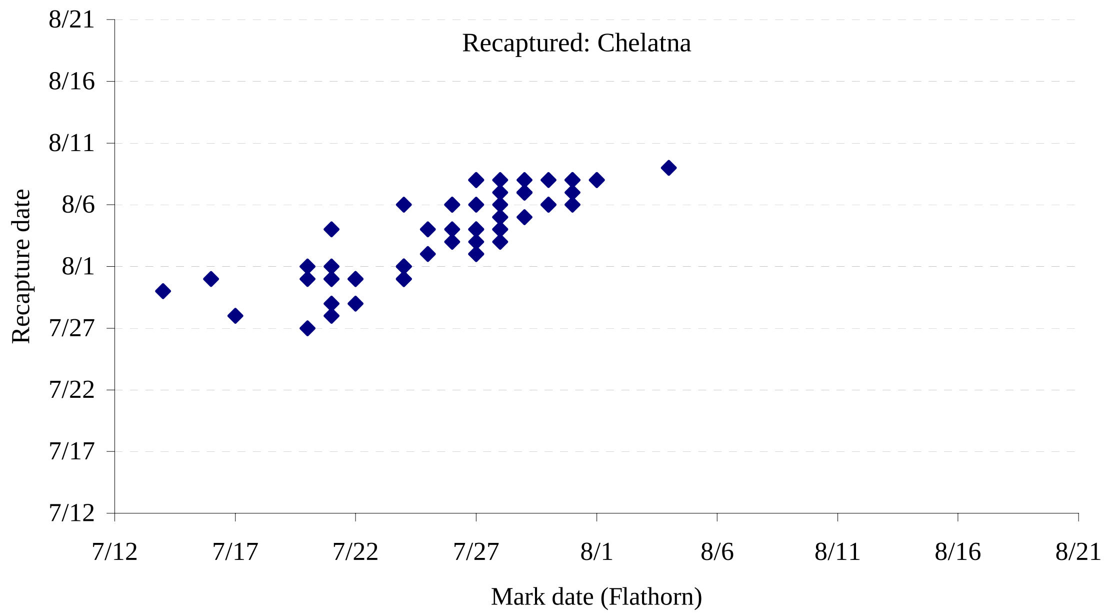


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Figure 4.-Page 2 of 3.

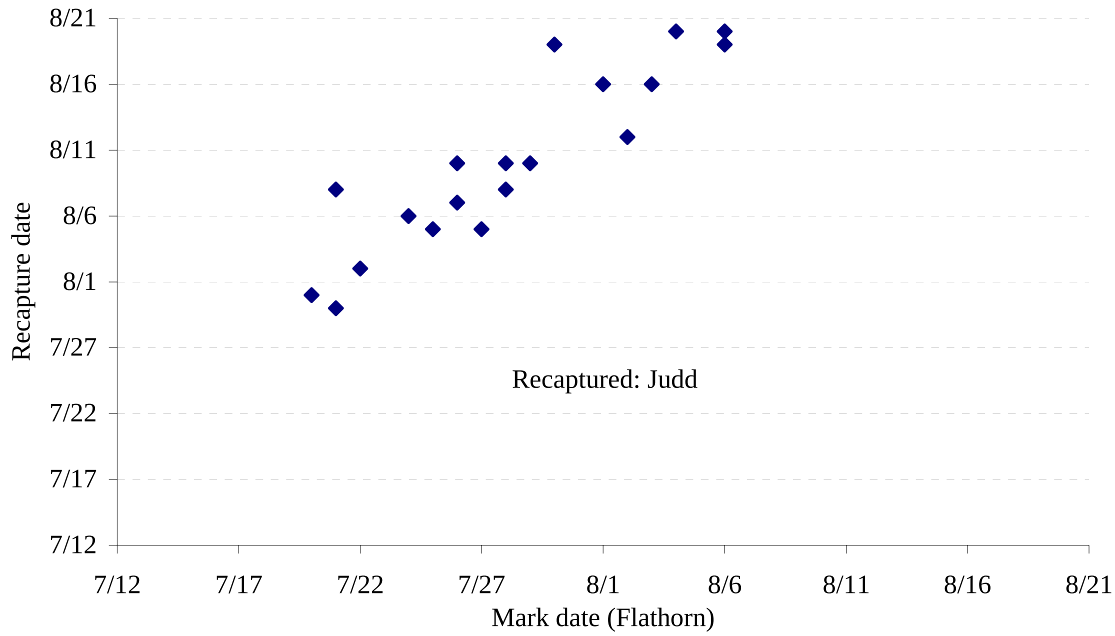


Figure 4.-Page 3 of 3.

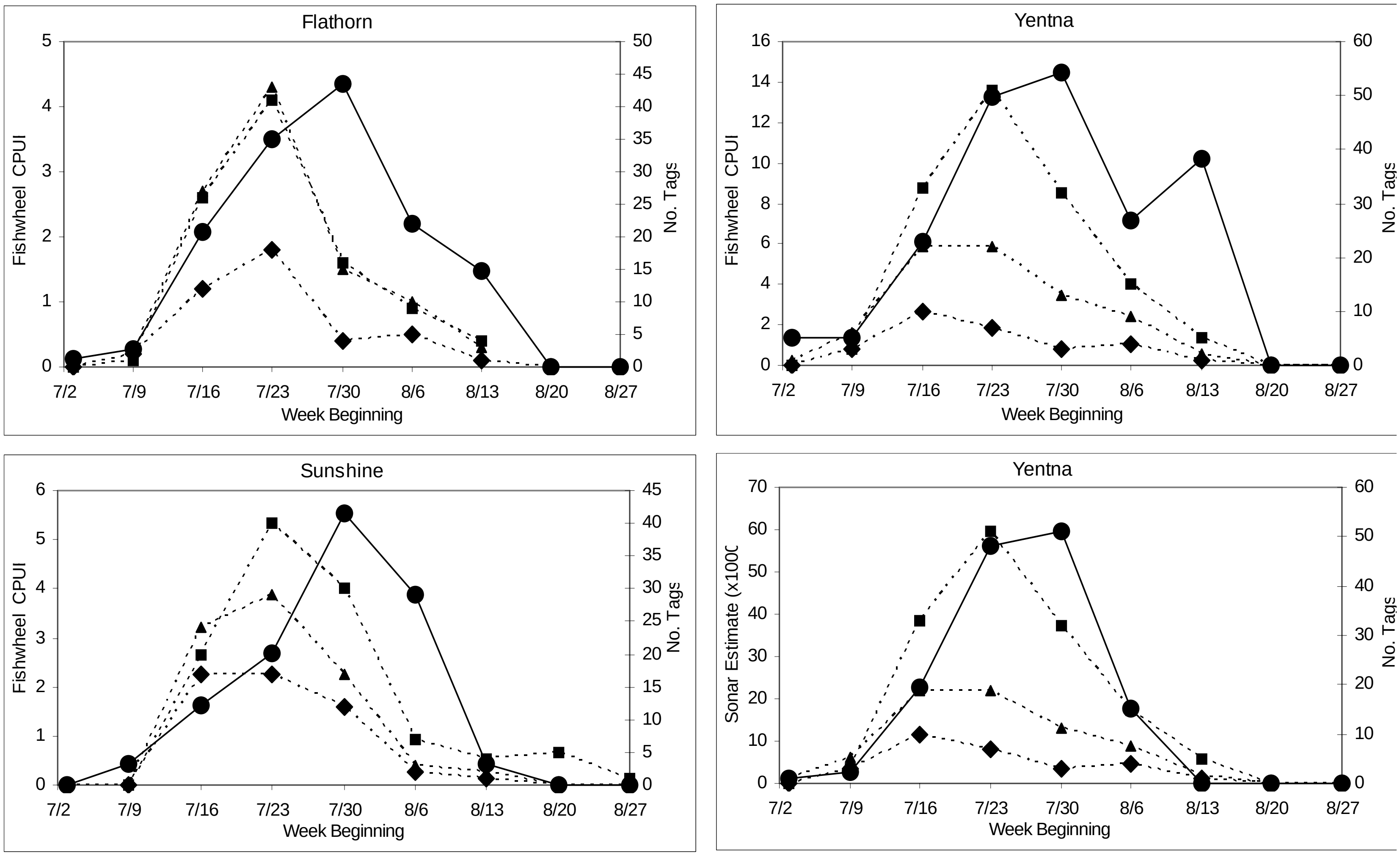


Figure 5.-Comparison of (1) number of radio tags applied to sockeye salmon (solid triangles), (2) number of radio tags applied to sockeye salmon that were subsequently detected in Judd, Shell, Larson, and Byers lakes (solid diamonds), and (3) number of radio-tagged sockeye salmon detected migrating past fixed radiotelemetry stations immediately upstream of tagging sites (solid squares) with sockeye salmon catch per hour (CPUE) in fish wheels (solid circles) at Flathorn, Sunshine, and Yentna.

Note: The lower right panel provides a comparison of the DIDSON sonar estimate (solid circles) for the number of sockeye salmon migrating past the Yentna sonar site (Maxwell et al. *In prep*) with data sets 1-3.

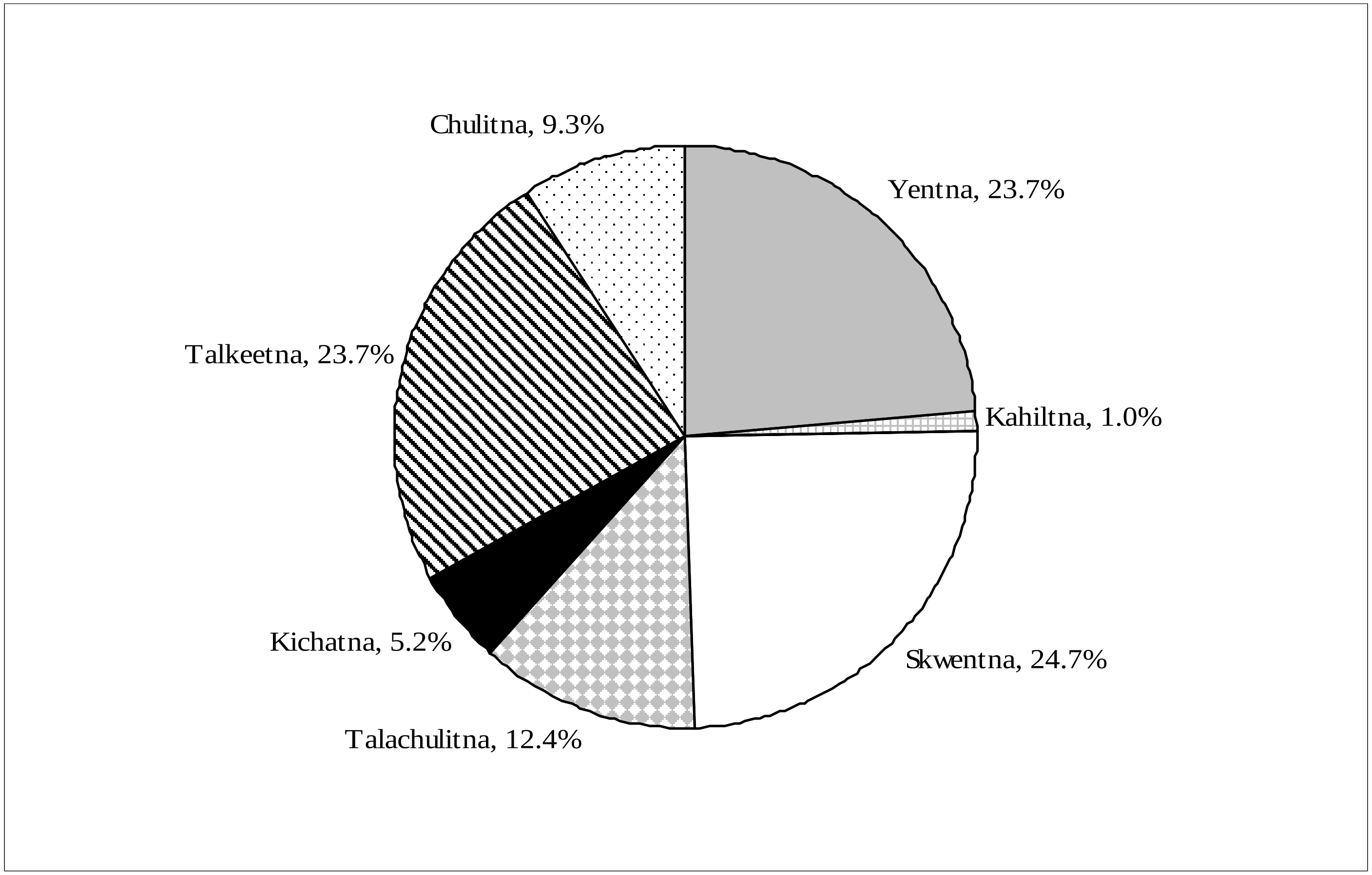


Figure 6.-Terminal distribution of sockeye salmon radio tagged in the lower Susitna River at Flathorn in 2006. Percentages indicate the fraction of the total number of fish that moved upriver to each terminal site.

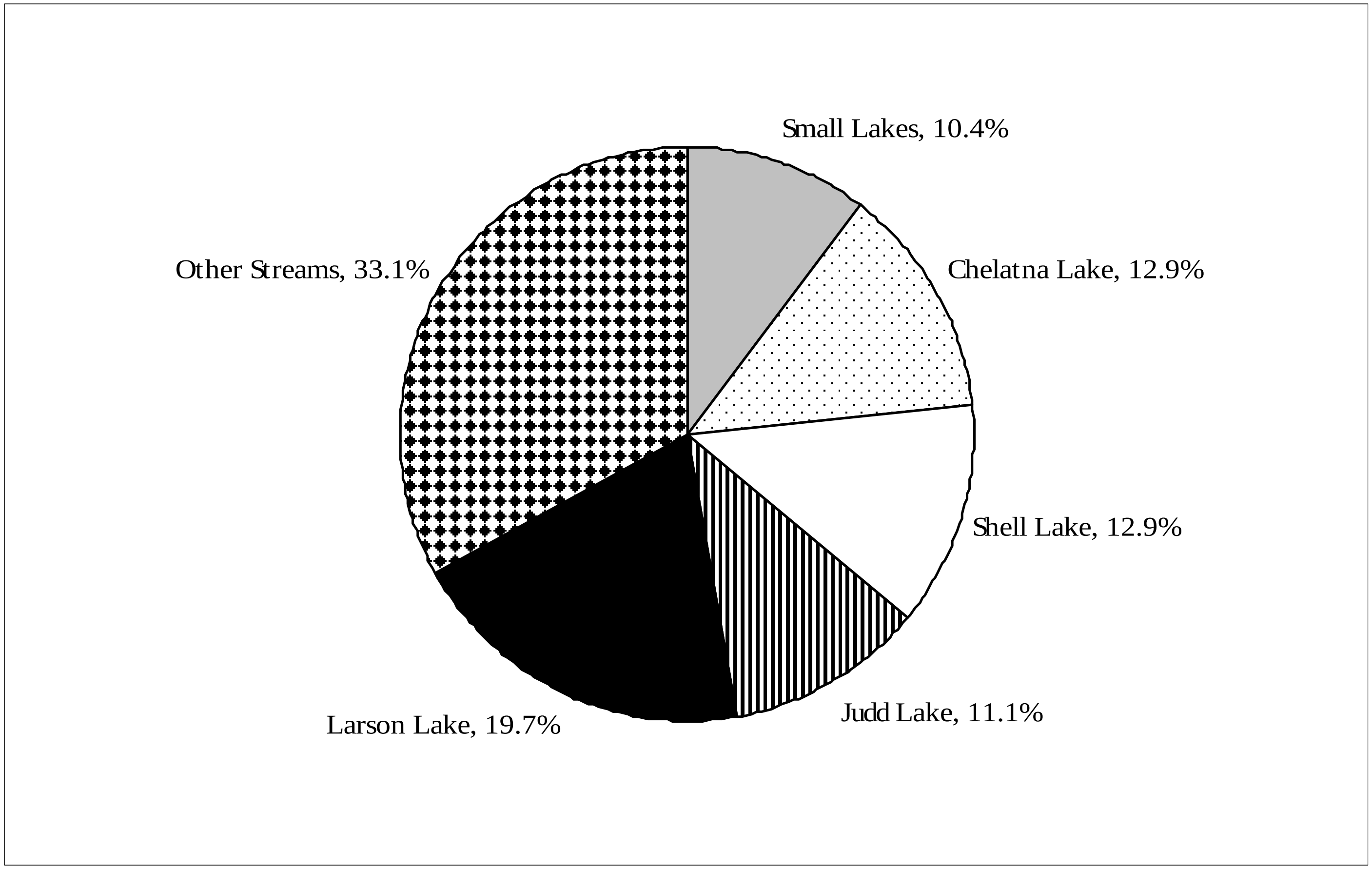


Figure 7.-Weighted terminal distribution of sockeye salmon radio tagged at Flathorn, Yentna, and Sunshine sites in 2006. Percentages indicate the fraction of the total number of fish that moved upriver to each terminal site. Yentna and Sunshine tag data were weighted by the fraction of the total number of Flathorn site radio tags that moved up the Susitna and Yentna drainages.

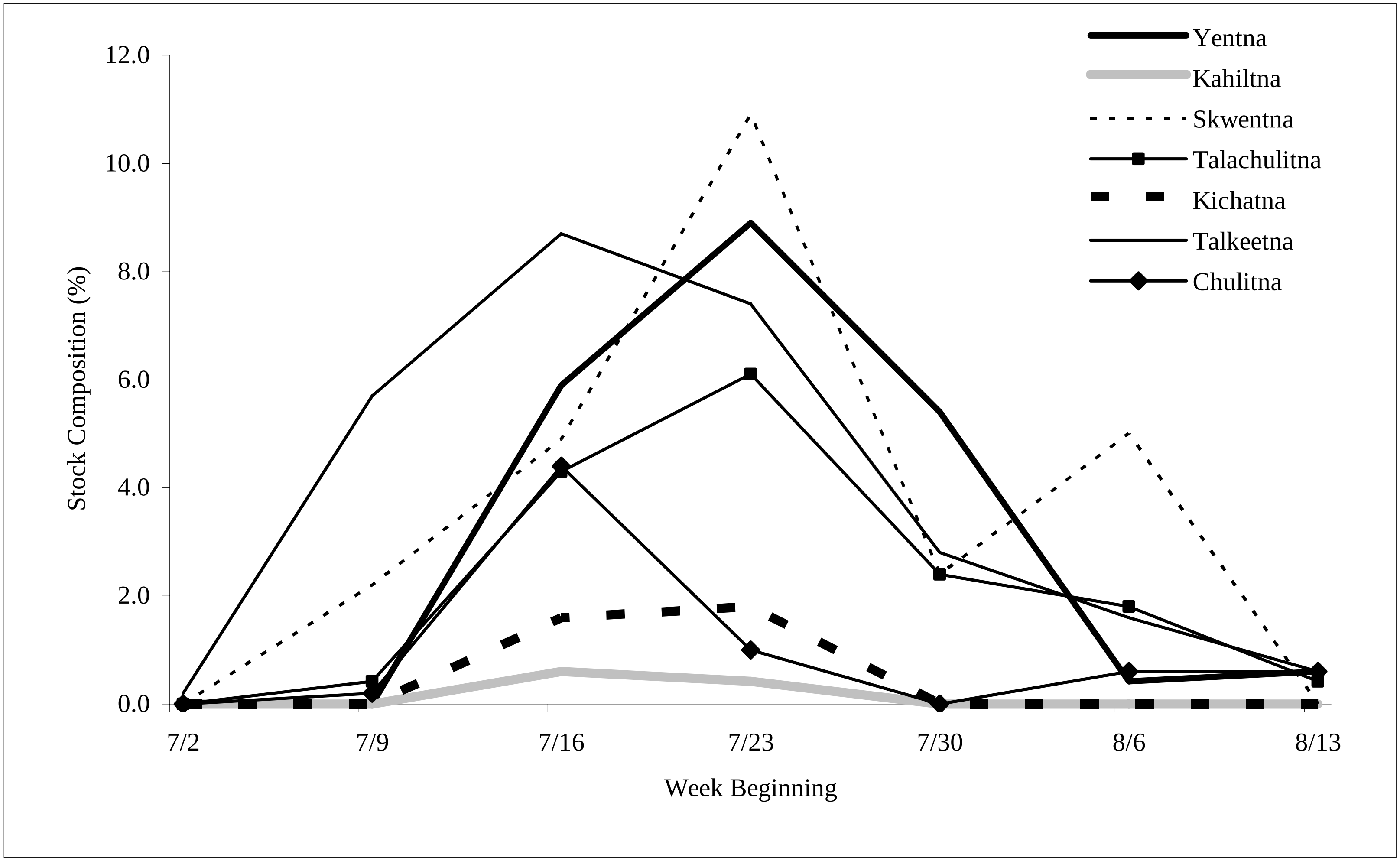


Figure 8.-Run timing by capture week of radio-tagged sockeye salmon passing from the Flathorn tagging site to terminal reaches of the Susitna River drainage in 2006, adjusted for upriver tagging site distances, 1 day at Yentna and 8 days at Sunshine. Yentna and Sunshine tag data were weighted by the fraction of the total number of Flathorn site radio tags that moved up the Susitna and Yentna drainages.

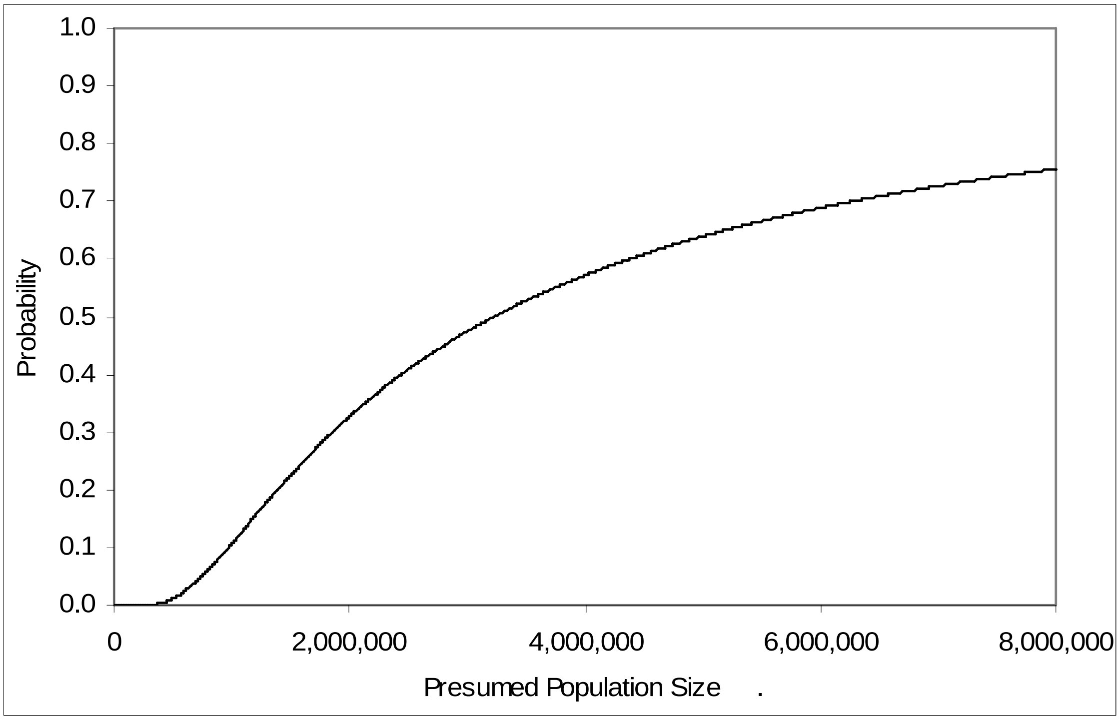


Figure 9.-Probability of detecting zero tags during the period before 29 July at the Yentna fish wheels in relation to presumed sockeye salmon population sizes during that period.

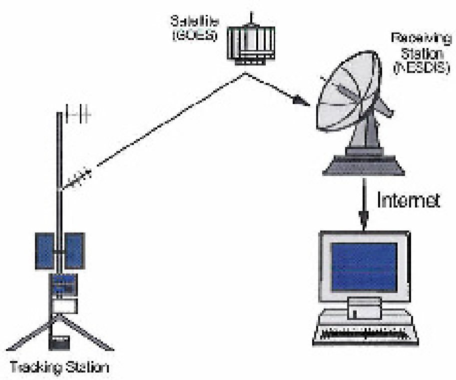
APPENDIX A

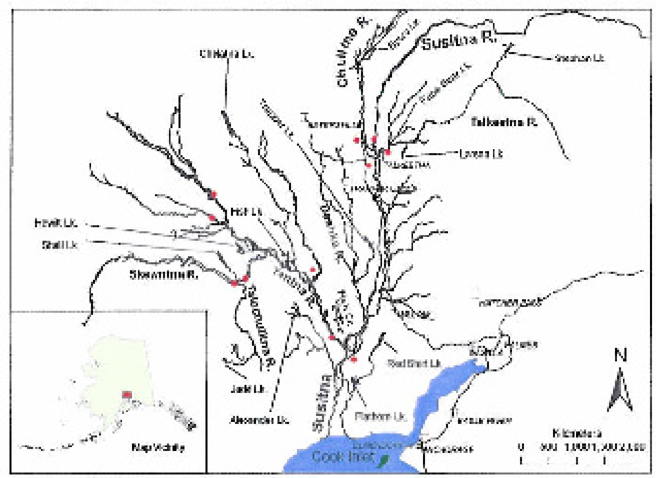
Appendix A1.-Example of project poster placed on tracking stations in 2006.

Susitna River Sockeye Salmon Radio Telemetry Project

This remote tracking station is part of a network of 11 sites that are used to follow the movements of sockeye salmon on their return migration to spawning grounds throughout the Susitna River drainage. Returning adult sockeye salmon are caught near the mouth of the Susitna River and radio tags are inserted in their stomachs. Tracking stations record when the fish moves past the site, and passage records are relayed to a central database. Radio tagged fish can also be tracked from aircraft to locate fish between tracking stations or within spawning tributaries.

This research will provide fishery biologists with a better understanding of the distribution of sockeye salmon in the Susitna River drainage, differences in the migration patterns of distinct stocks, and a yearly estimate of the total adult sockeye salmon population. This knowledge will be used to manage sustainable fisheries of wild sock-eye salmon.





APPENDIX B

Appendix B1.-Daily counts of sockeye salmon, passive integrated transponder (PIT) tag detection rates, and number of PIT tags detected at weirs with automated PIT tag detection systems (Chelatna, Judd, and Larson lakes) during 2006.

Weir Site	Date	Number of Sockeye	PIT Tag Detection Rate	Number PIT Tags Detected
Chelatna	7/27	466	100.0%	2
Chelatna	7/28	337	100.0%	2
Chelatna	7/29	477	100.0%	4
Chelatna	7/30	71	96.0%	1
Chelatna	7/31	1,806	100.0%	10
Chelatna	8/1	1,015	95.0%	8
Chelatna	8/2	568	92.0%	3
Chelatna	8/3	1,027	94.0%	3
Chelatna	8/4	1,918	100.0%	9
Chelatna	8/5	536	99.0%	3
Chelatna	8/6	1,727	98.0%	10
Chelatna	8/7	1,013	98.0%	14
Chelatna	8/8	1,216	87.0%	10
Chelatna	8/9	115	77.0%	1
Chelatna	8/10	923	-	-
Judd	7/20	0	99.0%	0
Judd	7/21	0	100.0%	0
Judd	7/22	0	99.0%	0
Judd	7/23	0	100.0%	0
Judd	7/24	0	98.0%	0
Judd	7/25	92	99.0%	0
Judd	7/26	729	99.0%	0
Judd	7/27	1,042	98.0%	1
Judd	7/28	938	94.0%	6
Judd	7/29	2,141	100.0%	2
Judd	7/30	570	100.0%	3
Judd	7/31	1,802	95.0%	1
Judd	8/1	1,092	93.0%	1
Judd	8/2	4,116	92.0%	2
Judd	8/3	2,596	96.0%	0
Judd	8/4	1,869	87.0%	0
Judd	8/5	2,828	80.0%	2
Judd	8/6	1,584	98.0%	1
Judd	8/7	3,258	83.0%	1
Judd	8/8	3,371	86.0%	3
Judd	8/9	3,416	100.0%	1
Judd	8/10	726	88.0%	4
Judd	8/11	2,797	77.0%	0
Judd	8/12	897	90.0%	1
Judd	8/13	1,297	96.0%	0
Judd	8/14	1,616	76.0%	0
Judd	8/15	632	89.0%	1
Judd	8/16	171	100.0%	2
Judd	8/17	173	88.0%	3

continued

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Weir Site	Date	Number of Sockeye	PIT Tag Detection Rate	Number PIT Tags Detected
Judd	8/18	178	98.0%	1
Judd	8/19	490	82.0%	4
Judd	8/20	121	94.0%	2
Judd	8/21	91	92.0%	0
Larson	7/14	3	-	-
Larson	7/15	0	-	-
Larson	7/16	0	-	-
Larson	7/17	0	-	-
Larson	7/18	0	-	-
Larson	7/19	0	-	-
Larson	7/20	0	-	-
Larson	7/21	1	-	-
Larson	7/22	0	-	-
Larson	7/23	117	-	-
Larson	7/24	284	-	-
Larson	7/25	1,514	-	-
Larson	7/26	1,053	-	-
Larson	7/27	648	-	-
Larson	7/28	2,961	-	-
Larson	7/29	1,580	-	-
Larson	7/30	1,815	-	-
Larson	7/31	5,990	**265.0%**	46
Larson	8/1	5,692	92.0%	53
Larson	8/2	3,202	**103.0%**	33
Larson	8/3	4,138	85.0%	46
Larson	8/4	6,364	91.0%	58
Larson	8/5	2,521	93.0%	54
Larson	8/6	3,482	-	-
Larson	8/7	3,750	86.0%	57
Larson	8/8	4,493	100.0%	100
Larson	8/9	1,636	99.0%	39
Larson	8/10	1,369	**102.0%**	40
Larson	8/11	940	**103.0%**	29
Larson	8/12	1,057	100.0%	55
Larson	8/13	835	**101.0%**	35
Larson	8/14	326	100.0%	8
Larson	8/15	439	**101.0%**	9
Larson	8/16	171	98.0%	19
Larson	8/17	64	**101.0%**	5

Appendix B2.-Daily counts of sockeye salmon through the Judd, Shell, Hewitt, Chelatna, Byers, and Larson Lake weirs, 2006.

	West Side (Yentna River) Lakes					East Side (Susitna / Chulitna Rivers) Lakes		
Date	Judd	Shell	Hewitt [a]	Chelatna [b]	Total	Byers	Larson [c]	Total
7/13	0				0	0		0
7/14	0				0	0	3	3
7/15	0	0			0	0	0	0
7/16	0	0			0	0	0	0
7/17	0	0			0	0	0	0
7/18	0	0			0	0	0	0
7/19	0	0			0	0	0	0
7/20	0	0			0	3	0	3
7/21	0	0			0	0	1	1
7/22	0	0			0	0	6	6
7/23	0	10			10	0	117	117
7/24	0	1,130			1,130	0	284	284
7/25	92	2,334			2,426	0	1,514	1,514
7/26	729	7			736	0	1,053	1,053
7/27	1,042	2,325		517	3,884	0	648	648
7/28	938	704		337	1,979	0	2,961	2,961
7/29	2,141	23		477	2,641	0	1,580	1,580
7/30	570	1,117		71	1,758	1	1,815	1,816
7/31	1,802	1,868	57	1,806	5,533	9	5,990	5,999
8/1	1,092	904	6	1,015	3,017	1	5,652	5,653
8/2	4,116	677	444	568	5,805	14	3,202	3,216
8/3	2,596	0	3	1,027	3,626	2	4,138	4,140
8/4	1,869	14,152	510	1,918	18,449	32	6,364	6,396
8/5	2,828	11,086	948	536	15,398	18	3,521	3,539
8/6	1,584	1,424	134	1,727	4,869	49	3,482	3,531
8/7	3,258	5,011	0	1,013	9,282	132	3,750	3,882
8/8	3,371	2,613	337	1,217	7,538	816	4,493	5,309
8/9	3,416	8,278	0	115	11,809	307	1,636	1,943
8/10	726	7,123	74	928	8,851	811	1,369	2,180
8/11	2,797	0	0		2,797	384	940	1,324
8/12	897	2,896			3,793	54	1,057	1,111
8/13	1,297	451			1,748	31	835	866
8/14	1,616	181			1,797	148	326	474
8/15	632	3,252			3,884	136	439	575
8/16	171	1,567			1,738	123	171	294
8/17	173	0			173		64	64
8/18	178	5			183			
8/19	490	662			1,152			
8/20	121				121			
8/21	91				91			
Total	40,633	69,800	2,513	13,272	126,218	3,071	57,411	60,482

[a] High water halted weir operations between 11 and 13 August. Weir crew was removed from site on 14 August.

[b] Crew arrived on 15 July. Weir installation was post poned until 21 July due to high water. The weir was complete on 26 July and normal operations began 27 July. High water again halted weir operations between 11 and 15 August. The weir crew was removed from site on 16 August.

[c] High water halted operations on 18 August and the weir was removed.

Source: Cook Inlet Aquaculture Association. Soldotna, Alaska. Accessed 10 October, 2006. http://www.ciaanet.org/content_sub.asp?SUB_ID=14&CAT_ID=6.

APPENDIX C

Appendix C1.–Terminal distribution of radio-tagged sockeye salmon within the upper Susitna and Yentna drainages calculated using numbers of radio tags detected migrating upstream past Sunshine and Yentna. The proportion of the total number of tags at each terminal site is indicated, as well as the proportion weighted by the weekly catch per hour in fish wheels at each tagging site.

Upper Susitna drainage

Lake or Stream	Number Tags	Proportion	Weighted No. Tags	Weighted Proportion
Byers Lake	4	0.037	4.4	0.042
Chulitna River	5	0.047	2.7	0.025
Larson Lake	64	0.598	59.6	0.562
Papa Bear Lake	2	0.019	2.8	0.026
Sheep River	7	0.065	5.9	0.055
Stephan Lake	5	0.047	3.7	0.035
Prairie Creek below Stephan Lake	4	0.037	5.4	0.051
Susitna River (Upper)	2	0.019	0.9	0.009
Susitna River (Mainstem)	2	0.019	2.5	0.024
Swan Lake	7	0.065	8.6	0.081
Talkeetna River	5	0.047	9.5	0.090
Total	107	1.000	106.0	1.000

Yentna drainage

Lake or Stream	Number Tags	Proportion	Weighted No. Tags	Weighted Proportion
Chelatna Lake	25	0.179	20.9	0.154
Granite Creek	2	0.014	2.1	0.015
Happy River	3	0.021	3.0	0.022
Hayes River	3	0.021	3.2	0.024
Hewitt Lake	3	0.021	5.7	0.042
Johnson Creek	1	0.007	1.5	0.011
Judd Lake	24	0.171	19.8	0.146
Kichatna River	5	0.036	2.6	0.020
Lake Creek	4	0.029	6.0	0.044
Moose Creek	4	0.029	2.4	0.017
Movie Lake	1	0.007	1.5	0.011
Nakochna River	1	0.007	0.6	0.004
Shell Lake	25	0.179	27.3	0.202
Skwentna River	16	0.114	12.6	0.093
Talachulitna River	8	0.057	12.7	0.094
Trimble River	2	0.014	1.4	0.010
Yentna River	4	0.029	3.5	0.026
Yentna River (W. Fork)	8	0.057	7.1	0.052
Yentna River (E. Fork)	1	0.007	1.5	0.011
Total	140	1.000	135.3	1.000