Fishery Data Series No. 11-19

Inriver Abundance and Distribution of Spawning Susitna River Sockeye Salmon *Oncorhynchus nerka*, 2007

by

Richard J. Yanusz,

Richard A. Merizon,

T. Mark Willette,

David G. Evans,

and

Ted R. Spencer

May 2011

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

Symbols and Abbreviations

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

Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Measures (fisheries)

fork length	FL
mid eye to fork	MEF
mid eye to tail fork	METF
standard length	SL
total length	TL

Mathematics, statistics

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

FISHERY DATA SERIES NO. 11-19

INRIVER ABUNDANCE AND DISTRIBUTION OF SPAWNING SUSITNA RIVER SOCKEYE SALMON *ONCORHYNCHUS NERKA*, 2007

by
Richard J. Yanusz
Alaska Department of Fish and Game, Division of Sport Fish, Palmer

Richard A. Merizon
Alaska Department of Fish and Game, Division of Sport Fish, Palmer

T. Mark Willette
Alaska Department of Fish and Game, Division of Commercial Fisheries, Soldotna

David G. Evans
Alaska Department of Fish and Game, Division of Sport Fish, Research and Technical Services, Anchorage

and

Ted R. Spencer
Alaska Department of Fish and Game, Division of Commercial Fisheries, Anchorage

Alaska Department of Fish and Game
Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska, 99518-1565

May 2011

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

Richard J. Yanusz
Alaska Department of Fish and Game, Division of Sport Fish
1800 Glenn Highway, Suite 4, Palmer, AK 99645-6736, USA

Richard A. Merizon
Alaska Department of Fish and Game, Division of Sport Fish
1800 Glenn Highway, Suite 4, Palmer, AK 99645-6736, USA

T. Mark Willette
Alaska Department of Fish and Game, Division of Commercial Fisheries
43961 Kalifornsky Beach Road, Suite B, Soldotna, AK 99669-8276, USA

David G. Evans
Alaska Department of Fish and Game, Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, AK 99518-1565, USA
and
Ted R. Spencer
Alaska Department of Fish and Game, Division of Commercial Fisheries
333 Raspberry Road, Anchorage, AK 99518-1565, USA

This document should be cited as:
Yanusz, R. J., R. A. Merizon, T. M. Willette, D. G. Evans, and T. R. Spencer. 2011. Inriver abundance and distribution of spawning Susitna River sockeye salmon Oncorhynchus nerka, 2007. Alaska Department of Fish and Game, Fishery Data Series No. 11-19, Anchorage.

TABLE OF CONTENTS

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

LIST OF APPENDICES

Appendix **Page**

ABSTRACT

In 2007, a capture-recapture experiment was conducted using radio tags, fish wheels, and weirs to estimate the sockeye salmon *Oncorhynchus nerka* escapement to the Susitna River. Radio tags were used as the mark in the abundance experiment and to identify spawning locations of adult sockeye salmon ≥400 mm mid eye to fork of tail. Two separate abundance estimates were calculated; one for the Yentna River system upstream of Yentna sonar (Yentna rkm 7) and one for the Susitna River system upstream of Sunshine (Susitna rkm 116). The abundance estimate for sockeye salmon passing Sunshine was 87,883 (95% CI 79,712-96,054). A pooled-Petersen estimate of the abundance of sockeye salmon passing Yentna sonar was 239,849 (95% CI 205,955-273,743). The Yentna abundance estimate likely includes some bias, due to violation of the assumption of equal closure between banks, possible lagging of radiotagged fish, and changes in fish wheel capture probability through time, possibly 25% high to 15% low. Twenty-seven percent of the sockeye salmon escapement into the entire Susitna River went to the Susitna River system above Sunshine, while the remaining 73% went to Yentna River. Forty-nine percent (unweighted) of sockeye salmon radiotagged at the north bank and 39% (unweighted) radiotagged at the south bank at Yentna sonar had final locations not associated with major lakes, while 29% in the Susitna River system above Sunshine had final locations not associated with a major lake, and were assumed to spawn at those locations. The Bendix sonar-fish wheel estimate of the sockeye salmon escapement passing the Yentna sonar (79,901 fish) was biased low, as it was less than the sum of the weir counts in the Yentna River system (94,359 fish).

Key words: sockeye salmon, *Oncorhynchus nerka*, Susitna River, Yentna River, escapement, abundance, capture-recapture, fish wheel, weir, radiotelemetry, spawning

INTRODUCTION

The Susitna River is a major contributor to the sockeye salmon *Oncorhynchus nerka* run in upper Cook Inlet (UCI). In 2007, management of the Susitna River sockeye salmon run was based on a combined Bendix sonar-fish wheel estimate of the escapement to the Yentna River, a major tributary of the Susitna River (Shields 2007; Westerman and Willette 2010; Figure 1). With this method, the sockeye salmon escapement to the entire Susitna River drainage is estimated to be 1.95 times the Yentna River escapement (Tobias and Willette 2004). The basis for the expansion factor is a combination of capture-recapture abundance estimates of sockeye salmon passing Sunshine (Susitna River at river kilometer [rkm] 116) and Bendix sonar-fish wheel estimates of sockeye salmon passing Yentna (Yentna River, rkm 7) and Susitna Station (Susitna River, rkm 37) during 1981-1985 (Fox 1998). The sustainable escapement goal (SEG) range in effect in 2007 was 90,000-160,000 Yentna River sockeye salmon.

Between 1999 and 2005, estimated sockeye salmon escapements for the Yentna River were below the SEG range of 90,000-160,000 Yentna River sockeye salmon for 5 of 7 years (Hasbrouck and Edmundson 2007). Part of the Alaska Department of Fish and Game (ADF&G) response to this situation was to examine the accuracy of the Yentna River sonar-fish wheel escapement method and relate it to the sockeye salmon escapement in the entire Susitna drainage. ADF&G, with participation from the Cook Inlet Aquaculture Association (CIAA), began a study in 2006 to estimate the sockeye salmon escapement in the entire Susitna River drainage using capture-recapture experiments that were independent of the sonar-fish wheel estimate. The independent escapement estimates were designed to allow: (1) estimation of the total annual run of sockeye salmon to the entire Susitna River drainage by summing the escapement estimates with genetics-based, stock-separation catch estimates, (2) evaluation of the accuracy of the Yentna River sockeye salmon sonar-fish wheel estimate, and (3) estimation of the proportion the Yentna River system contributes to the sockeye salmon escapement in the entire Susitna River drainage.

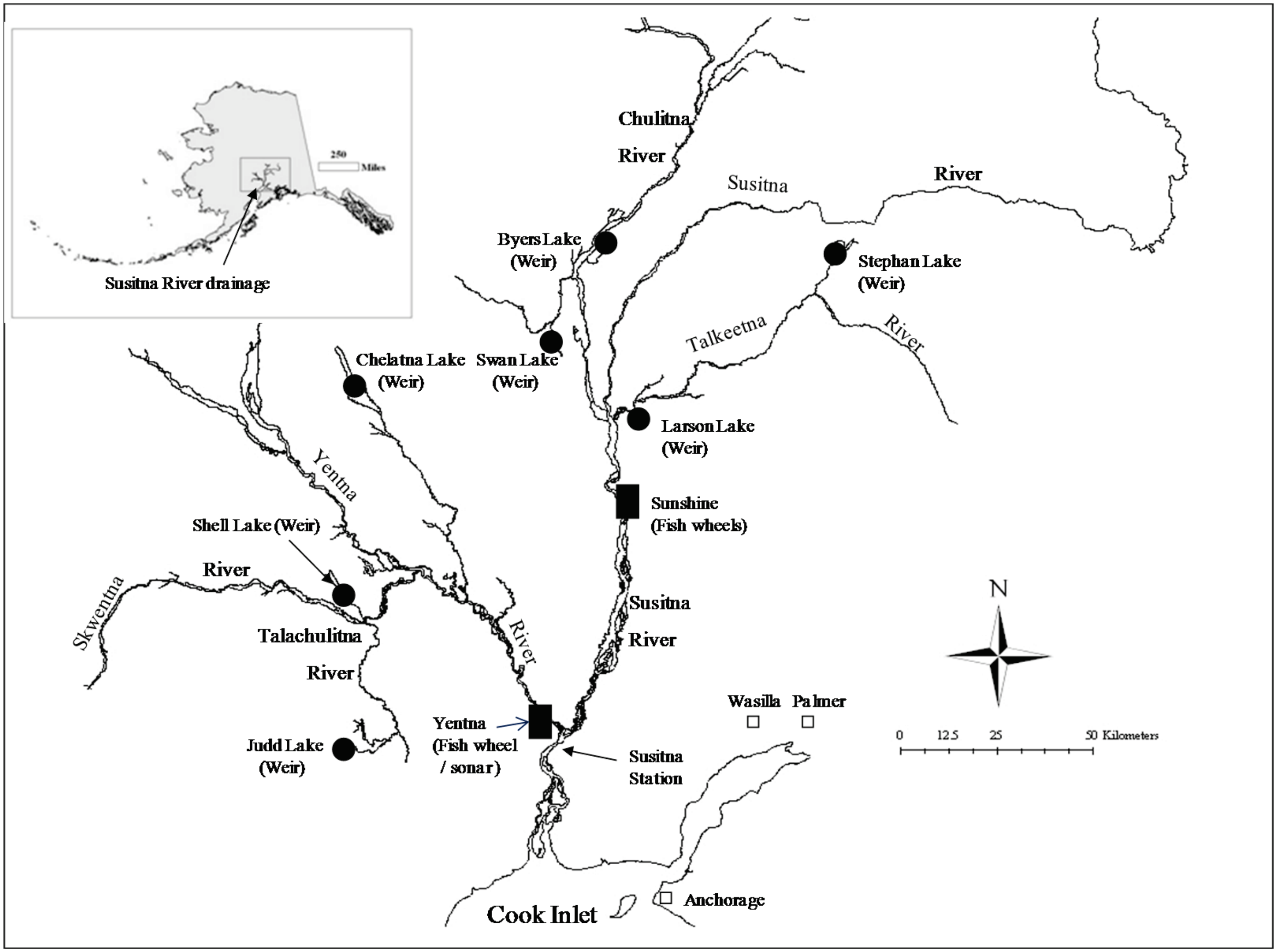


Figure 1.–Locations of fish wheels, sonar, and weirs in Susitna River drainage, 2007.

In 2006, fish wheels at three sites and weirs at seven lakes were used to capture and recapture sockeye salmon marked with passive integrated transponder (PIT) tags, radio tags, and finclips. Abundance estimates of sockeye salmon for the Yentna River system and the Susitna River system above Sunshine were generated, but had unresolved uncertainties due to possible tag loss, poor tag detection, tagging effects, and low sample sizes (Yanusz et al. 2007). Many new spawning locations were documented throughout the Susitna River drainage.

The objectives in 2007 were to estimate the inriver abundance of adult sockeye salmon migrating upstream of Yentna and Sunshine (escapement) using capture-recapture experiments (Figure 1) and to identify additional sockeye salmon spawning areas throughout the Susitna River drainage using radiotelemetry.

STUDY AREA

The Susitna River drainage comprises 49,210 km^2 and it originates in the Alaska Range north of Anchorage (Figure 1). Susitna River flows generally south from the Alaska Range for approximately 400 km before entering upper Cook Inlet west of Anchorage. The largest tributaries are the Yentna, Chulitna, and Talkeetna rivers, and there are numerous sockeye salmon nursery lakes. Most of the sockeye salmon produced within the Talkeetna River system are thought to come from Larson and Stephan lakes. Many small lakes contribute to sockeye salmon production in the Chulitna River system, but Byers and Swan lakes are believed to be the major producers. The Yentna River system has at least 12 lakes known to support sockeye salmon, of which Chelatna, Shell, Hewitt, and Judd lakes are thought to provide the most production potential (King and Walker 1997).

METHODS

ABUNDANCE

Separate, two-event, capture-recapture experiments were used to estimate the abundance of adult sockeye salmon (Seber 1982) for the Susitna River system upstream of Sunshine and the Yentna River system.

Capture Events

Two fish wheels, one on each bank, were operated at both Yentna (the location of the sonar site) and Sunshine (Figure 1). Each fish wheel had 2 × 2 m baskets that were adjusted as needed to fish ≤ 0.3 m from the river bottom. Picket weirs, installed between the fish wheel and the river bank, were operated at Yentna and Sunshine for the entire season (Table 1). At Sunshine, fish wheels were fished for two, 3-h periods spaced 5 h apart during daylight hours, for a total of 6 h of effort per day. The start of fishing time for the fish wheels each day was systematically rotated, so that over the course of 5 d most daylight hours were sampled. At Yentna, to be consistent with the historic sonar-fish wheel methods, fish wheels were operated for three, 2-h periods selected from within 3 periods each day: 0600-1200, 1200-1800, and 1800-2400, for a total of 6 h of effort per day. At both fish wheel capture sites it was assumed that there was no substantial diel variation in the stock composition of fish passage.

Table 1.–Dates of operation for sockeye salmon fish wheels by location in Susitna River drainage, 2007.

	River kilometer (rkm)				Dates of operation			
				River banks	Fish wheel weir		Fish wheel	
Location [a]	Susitna R	Yentna R	Site name	fished	Installed	Removed	Started	Stopped
Lower Susitna River tributary -								
Susitna-Yentna river confluence,	45 [b]	0						
Yentna River sonar/fish wheels	na	7	Yentna	North bank	7/6	8/16	7/7	8/16
				South bank	7/6	8/16	7/7	8/16
Lower Susitna River -								
mainstem fishwheels,	116	na	Sunshine	West bank	7/9	8/20	7/10	8/20
about 12 km below the George				East bank	7/9	8/20	7/10	8/20
Parks Highway bridge (rkm 128) [b]								

Note: na = not applicable.

[a] Thompson et al. (1986) defined "lower Susitna River" as the river reach between Susitna River confluence at Cook Inlet (river mile [RM] 0.0 [river kilometer (rkm) 0.0]) and the Susitna-Chulitna river confluence (RM 98.6 [rkm 158.7]) near Talkeetna.

[b] rkm conversion from river miles (RM) presented in Thompson et al. (1986).

Fish wheels were checked at least once per hour during each sampling shift. Only uninjured sockeye salmon ≥400 mm mid eye to fork of tail length (METF) were radiotagged. Sockeye salmon <400 mm METF[1] were not radiotagged because these smaller fish may not have the same capture probability at fish wheels or weirs as the larger fish. To minimize handling effects, sockeye salmon receiving a radio tag were taken directly out of the fish wheel basket as they were captured and tagged immediately. Sockeye salmon found in the live box at the beginning of a fish wheel visit were counted and released. Radio tags were applied to every subsequent fish caught while the crew was present until the 1 in 10 ratio was achieved. Every 10th sockeye salmon caught thereafter while the crew was present was radiotagged. Radiotagged fish were also measured for METF, sex was determined from external morphological characteristics[2], and a tissue sample (left axillary process) was collected from each using standard ADF&G Genetics Conservation Lab procedures[3] and preserved in ethanol for later genetic assay. To minimize holding time no anesthesia was used, fish were held in tubs with fresh river water, and fish were restrained in padded cradles during tagging. No scales were collected from radiotagged fish in order to minimize stress. Handling time of radiotagged fish averaged <1.5 min.

The radio transmitters used were manufactured by Advanced Telemetry Systems, Inc.[4] (ATS™) and operated on 19 frequencies within the 150.000 to 150.999 MHz range. Each frequency had 50 different transmitting patterns (i.e., pulse codes), resulting in 950 uniquely identifiable transmitters. All transmitters were 42×17 mm cylinders equipped with a 30 cm antenna, and each weighed 14 g. The minimum battery life of the transmitters was 90 d. 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 24 h. Radio tags were inserted through the esophagus and into the upper stomach of the fish using a 10 mm diameter, 30 cm long plastic tube.

Untagged sockeye salmon captured at Yentna and Sunshine fish wheels were sampled for scales (for age determination), sex, and METF (ASL). At Sunshine, the left axillary process was also clipped from each ASL-sampled fish[3] and stored in bulk in ethanol for genetic assay. ASL samples at Sunshine were collected in a batch at the beginning of each day's shift. ASL sampling at Yentna followed the ADF&G Division of Commercial Fisheries historical ASL sampling procedures, collected in proportion to the previous day's sonar estimate of sockeye salmon abundance, to achieve a minimum total sample of 500 scales over the season (*Unpublished* ADF&G Division of Commercial Fisheries operational plan for upper Cook Inlet commercial [salmon] catch and escapement sampling obtained from T. Tobias, Fishery Technician, ADF&G, Soldotna). At Yentna, the left axillary process was clipped and preserved from only radiotagged fish[3], as this provided sufficient samples for genetic analysis.

For age determination, one scale was removed from the preferred area and scales were placed on labeled gum cards (Clutter and Whitesel 1956). In the laboratory, the gum cards were impressed in heated acetate cards and the ages determined from examining the scale circuli patterns under magnification.

---

1 Sockeye salmon <400 mm METF are usually "jacks." Jacks are male sockeye salmon that spend only one winter at sea before they return to freshwater. Historically, jacks make up about 1% of the Susitna River sockeye salmon run.

2 . Coloration, body and fin shape, and jaw morphology are secondary sexual characteristics used to differentiate the sex of live Pacific salmon.

3 Source: ADF&G. 2007. Sampling non-lethal finfish tissues for DNA analyisis. Genetics Conservation Lab, Anchorage. http://www.adfg.alaska.gov/static/fishing/PDFs/research/salmon_sampling_instructions.pdf (Accessed 15 March 2007).

4 Product names used in this publication are included for completeness but do not constitute product endorsement.

Recapture Events

CIAA counted sockeye salmon passing through weirs at Chelatna, Shell, and Judd lakes in the Yentna River system, and Byers, Swan, Stephan, and Larson lakes in the Susitna River system above Sunshine (Figure 1). An automated radiotelemetry station was placed adjacent to each weir as the method to count the number of radiotagged fish. See "Radio Tag Distribution and Migration Timing" below for details.

ASL data were collected throughout the runs from samples of sockeye salmon trapped at each weir. All sockeye salmon within each trap load were sampled to minimize selection bias. The left axillary process was collected from a sample of sockeye salmon at Byers, Swan, and Stephan lakes and preserved in ethanol for later genetic assay by ADF&G. Genetic samples were collected from Byers, Swan, and Stephens lakes because they have smaller runs and the ADF&G Genetics Conservation Lab did not have enough baseline samples. Chelatna, Shell, and Judd lakes have larger runs and genetic samples were not collected at these lakes because ADF&G already has an adequate baseline for them.

Estimation of Abundance

Abundance of sockeye salmon migrating into the entire Susitna River drainage was estimated as the sum of two, independent, 2-event, closed population, capture-recapture experiments. Each experiment represented a separate component of the entire run, one being the migration past the Yentna sonar site and the other the migration past Sunshine. The following applies to each experiment.

If assumptions *a*-*d* below were met then Chapman's modification of the Petersen model (Seber 1982) was used to estimate abundance $\hat{N}$ for an experiment 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:

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

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

(a) every fish has an equal probability of being marked in event 1, or every fish has an equal probability of being inspected for marks in event 2, or marked fish are mixed completely with unmarked fish 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 address the equal catchability provision of condition *a*, fish wheels were run concurrently on both banks throughout the migration. The fish wheels were run 6 h/d on each bank at each site, with starting times staggered within daylight hours through the season to improve the chances that each component of the run was exposed to marking. Fish wheels tend to capture more sockeye salmon as more fish pass by, resulting in self weighting of tag deployment over time. Drift gillnetting in the middle of the river and close to the fish wheels at Sunshine provided insight into whether there were mid-channel segments of the population that the fish wheels did not access. Drift gillnetting was not done at Yentna in 2007 because previous drift gillnetting results showed very low numbers of sockeye salmon offshore (Yanusz et al. 2007).

To test whether condition *a* was met, two chi-square (χ^2) tests were performed with the following null hypotheses: (1) the ratios of marked to unmarked fish in samples from event 2 were constant over recovery strata (time or weir), and (2) the ratio of re-captured versus not recaptured fish was constant over marking strata (time or bank). If the null hypothesis of either test was not rejected, the pooled abundance estimate (Equation 1) was considered sufficient, with consideration of the caveats described in Schwarz and Taylor (1998); otherwise, a temporally or spatially partially stratified estimate was considered using the Stratified Population Analysis System (SPAS) software program (Arnason et al. 1996). Banks and weirs comprised natural spatial strata with respect to tagging and recovery, respectively. The χ^2 and G^2 goodness of fit statistics provided by SPAS were used to evaluate model fit in the partially stratified analysis (Arnason et al. 1996). The factors considered when evaluating strata to pool were: (1) no strata with expected recaptures of <5, (2) pooling adjacent strata with similar initial capture or recapture probabilities, and (3) minimizing 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).

The ratio of fish wheel catch of all salmon species to the DIDSON (dual frequency identification sonar) count of all species of salmon (Yentna only) over time for each bank was also visually examined to indicate if the fish wheels on each bank fished with consistent efficiency. This ratio assumes the sonar is counting at least a certain proportion of the passage of all salmon species.

An adipose finclip given to fish tagged on the west bank at Sunshine allowed some assessment of bank-to-bank movement (mixing).

With respect to the provision in condition *a* of equal inspection probabilities for event 2, the probability of capture for fish entering each of the weirs while operating was 1.0 (or close to it), while the probability of recapture of those fish in areas other than the lakes with weirs was zero. Equal inspection probabilities for event 2 were therefore precluded as a function of the design of the experiment and the Chapman-Petersen estimate relied on equal capture probabilities at the fish wheels.

Because the equal probability of capture provision of 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 event 1 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 event 2 was tested using a K-S two-sample test ($\alpha = 0.05$) to compare size distributions of marked and recaptured fish.

Condition *b* was tested using radiotelemetry. The proportion of radiotagged fish that did not resume upstream migration after tagging was assumed to be an estimate of tag induced mortality. Tagged fish failing to resume upstream migration were culled (i.e., censored) from the study. Bank effects on the tendency for radiotagged fish to sustain upstream migration after tagging were tested with a 2×2 χ^2 test of independence between bank of marking and migration status (up or down). Gross effects of tagging on fish behavior were examined through ground surveys of areas where multiple radio tags were detected in areas other than the lakes with weirs. These surveys allowed documentation of the presence of untagged spawning sockeye salmon and collection of axillary process clips from spawning salmon to augment the genetics baseline.

The tag loss component of condition *c* was indistinguishable from tag induced mortality as it manifested itself in downstream or stationary radio relocations and was accounted for on that basis. The tag detection component of condition *c* was addressed by using redundant methods (stationary receivers plus aerial surveys) and by comparing the number of tags deployed versus the number detected. 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), there were no large, inriver sockeye salmon fisheries in the Susitna River (mortality and emigration), and the entire Susitna River drainage was the study area, so no fish could leave the study area (emigration). Movement between the two experiments was monitored by radio-telemetry.

RADIOTAG DISTRIBUTION AND MIGRATION TIMING

River Tracking Stations

Radiotagged sockeye salmon movement upriver was tracked at 11 river tracking stations placed on the major tributaries throughout the Susitna River drainage (Table 2; Figure 2). The Flathorn tracking station was placed below both tagging sites to monitor fish migrating downstream after tagging.

Tracking station equipment consisted of an ATS™ Model 4500 receiver and data logger and a self contained power system. A satellite uplink (Campbell Scientific, Logan, Utah) was used for all of the river tracking stations except Sunshine. 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 min intervals.

Table 2.–Locations of tracking stations used to monitor the movements of radiotagged Susitna River sockeye salmon, 2007.

	Tracking station			Distance (km) from:		
		Type			Previous	
Area description	Name	River	Weir	Saltwater	station	
Susitna River drainage:						
Lower Susitna R mainstem	Flathorn	X		40.0	na	
Lower Susitna R tributary						
Yentna R mainstem	Lower Yentna River	X		58.1	18.1	[a]
Yentna R tributary	Kahiltna River	X		93.7	35.6	
Kahiltna R drainage lake	Chelatna Lake		X	184.9	126.9	
Yentna R tributary	Skwentna River	X		138.5	80.4	
Skwentna R drainage lake	Shell Lake		X	151.5	13.0	
Yentna R tributary	Talachulitna River	X		144.9	6.4	
Talachulitna R drainage lake	Judd Lake		X	221.2	76.3	
Yentna R tributary	Kichatna River	X		147.3	89.2	
Yentna R mainstem	Upper Yentna River	X		156.0	98.0	
Lower Susitna R mainstem	Sunshine	X		128.3	88.3	[a]
Susitna R tributary	Talkeetna River	X		156.6	28.3	
Talkeetna R drainage lake	Larson Lake		X	170.9	14.3	
Talkeetna R tributary lake	Stephan Lake		X	245.2	88.6	
Susitna R tributary	Chulitna River	X		170.7	42.4	
Chulitna R drainage lake	Byers Lake		X	210.3	39.6	
Chulitna R tributary lake	Swan Lake		X	216.5	45.8	
Middle Susitna R[b] mainstem	Middle Susitna River	X		165.0	36.7	

Note: na = not applicable.

[a] Distance from previous station calculated from Flathorn (rkm 40).

[b] Historically the "middle Susitna River" has been defined as the river reach between Susitna-Chulitna river confluence (RM 98.6 [rkm 158.7]) and Devils Canyon (RM 152.0 [rkm 244.6])(Thompson et al. 1986).

The ATS™ receiver detected radiotagged 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). Radiotagged 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.

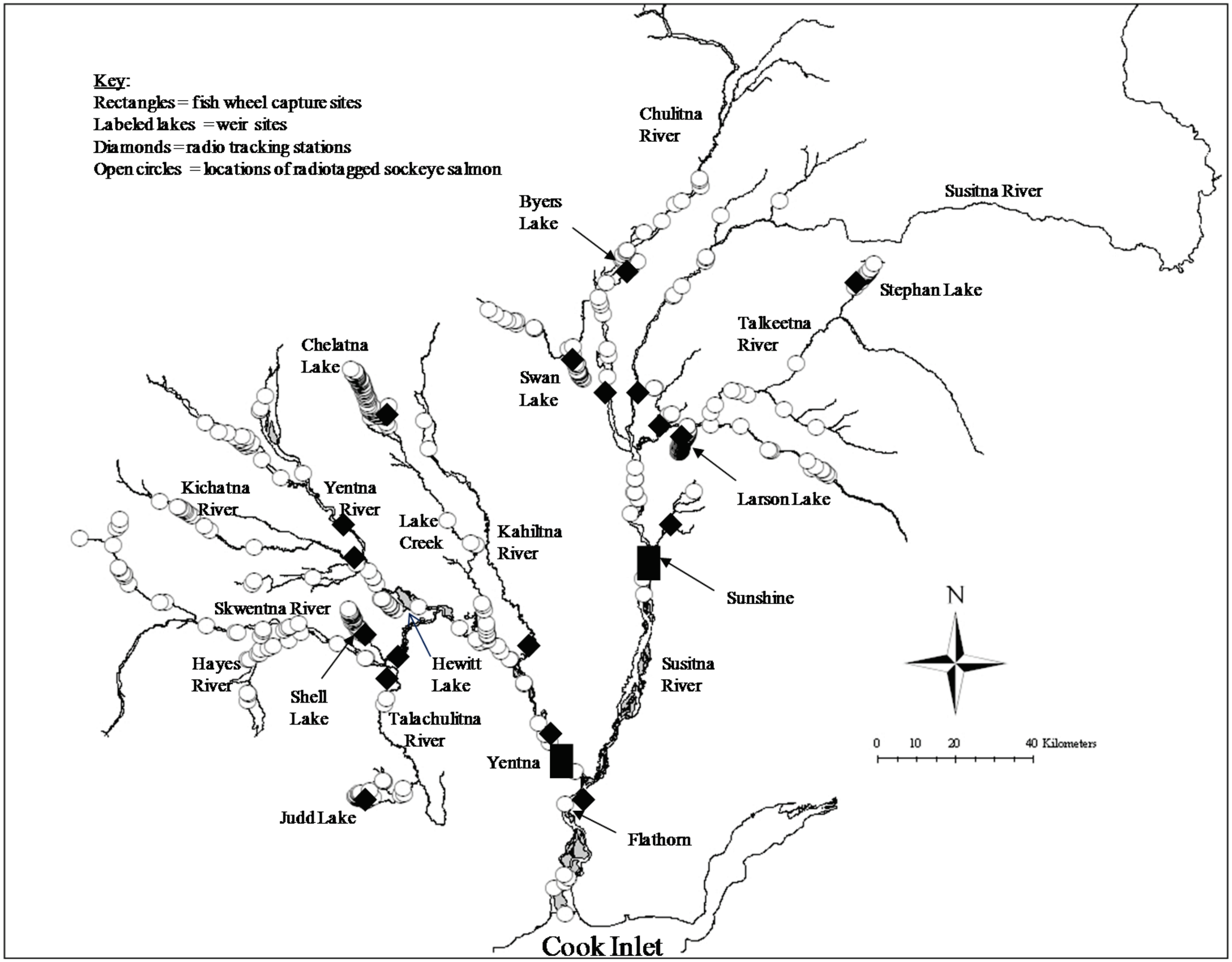


Figure 2.–Locations of fish wheel capture sites, weirs, and radiotracking stations in Susitna River drainage, and the terminal distribution of radiotagged sockeye salmon based on aerial surveys, 2007.

Because most of the river tracking stations 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). Data transmissions were monitored during the field season via the internet. Tracking stations easily accessible by road or boat were visited every 1–2 weeks, and data were downloaded as a comma delimited file to a laptop computer using Microsoft™ compatible software from ATS™. After the field season, data from the isolated stations were also downloaded this way. Each record in the files contained the site code, download date and time, radio frequency and pulse code, date and time of detection, antenna number, and signal strength.

Weir Tracking Stations

Radiotagged sockeye salmon movement upriver and into lakes was also tracked at seven weir stations (Table 2; Figure 2). These stations were similarly equipped to river stations except for a shorter, 3 m mast and no satellite uplink.

Since many of the weir sites were located close to a lake's outlet, determining passage time was occasionally difficult. While the signal strength of radiotagged sockeye salmon arriving at weirs was very high, some fish lingered just below or just above the lake outlet. The lack of a rapid drop off in signal strength due to this lingering behavior made the transition from the lower antenna to the upper antenna difficult to determine for those individuals. When necessary, aerial surveys and later tracking records for affected fish were compared when selecting a date of fish passage into each lake.

Each weir station was visited every 7-10 d and data from weir station receivers were downloaded as a comma delimited file to a laptop computer. This information was stored in the Palmer and Anchorage ADF&G offices for postseason analysis.

Aerial Surveys

A fixed-wing aircraft (Cessna 185) was used to conduct aerial surveys of the entire Susitna River drainage. The aircraft was equipped with an ATS™ Model 4500 receiver and data logger and two, 4-element Yagi receiving antennas, one mounted on each side of the aircraft and oriented forward. Aerial receivers contained an integrated global positioning system (GPS) 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. At the Palmer or Anchorage ADF&G office, data were downloaded as a comma delimited file to a desktop computer using Microsoft™ compatible software from ATS™. Data for each survey were imported to Microsoft™ Excel and sorted by frequency, pulse code, and time. For each tag, the location with the greatest signal strength was chosen as the most likely location of the tagged fish. 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.

Estimation of Spawning Distribution

Assuming the population migrating past each fish wheel tagging site (Yentna or Susitna) was proportionally tagged, the proportion of the population destined for location i was estimated as:

$$\hat{p}_i = \frac{r_i}{r} \tag{3}$$

where:

r_i = Number of radio tags out of r assumed to have spawned in location i, and

r = Number of radio tags released from the marking site that retained upstream migration and was tracked to a final destination.

An estimate of the variance of $\hat{p}_i$ is given by:

$$\text{var}(\hat{p}_i) = \frac{\hat{p}_i(1-\hat{p}_i)}{(r-1)}. \tag{4}$$

If the assumption of proportional tagging was not met, bank specific distributions using the equations above were estimated, but with r being the number of radio tags released from a specific bank at the marking site that resumed upstream migration and was tracked to a final destination.

When a stratified estimator was subsequently used that yielded precise estimates of bank specific abundance (Susitna River system above Sunshine only), the distribution data were weighted accordingly to yield a drainage-wide distribution. The weighted distributions for area i were estimated as follows:

$$\hat{p}_i = \hat{p}_{iW}\frac{\hat{N}_W}{\hat{N}_W + \hat{N}_E} + \hat{p}_{iE}\frac{\hat{N}_E}{\hat{N}_W + \hat{N}_E} \tag{5}$$

where

$\hat{p}_{iW}$ = Proportion of tags applied on the west bank that migrated to area i; similarly for $\hat{p}_{iE}$

$\hat{N}_W$ = Darroch-derived estimate of abundance on the west bank; similarly for $\hat{N}_E$.

Estimation of the variance of $\hat{p}_i$ is complicated by covariances among the components in Equation 5. The standard error of the (weighted) distribution proportion $\hat{p}_i$ in Equation 5 was derived through simulation. For the west wheel component of each simulation, 23 radio tags were distributed among the categorized sites (eight of them) as a multinomial random variable; the multinomial 'p' parameter vector (length = 8) was taken as the set of proportions of the 23 tags found in the 8 areas in 2007. For the east wheel component, 270 tags were distributed similarly. Bank-specific Darroch least squares estimates were then calculated from each set of generated recaptures according to the formulas in Schwarz and Taylor (1998). A simulated set of $\hat{p}_{iW}$ and $\hat{p}_{iE}$ was then calculated and Equation 5 used to calculate a simulated $\hat{p}_i$. The standard error of $\hat{p}_i$ was then taken as the sample variance of the simulated $\hat{p}_i$'s over all simulations.

Estimation of Migration Timing and Rates

Run timing analysis for a given final location i within a river system was based on the time radio tags destined for location i passed the marking site. Since the fish wheel capture and marking sites in the Yentna River system and the Susitna River system above Sunshine differed with respect to how far upstream each was located, run timing of stocks within but not between drainages could be compared. Standard summary statistics (mean, median, variance) of the timing data were calculated for each location.

Migration rates for radiotagged sockeye salmon were calculated using the date and time fish passed between tracking stations, along with river distance between them.

Drift Gillnetting at Sunshine

This effort provided data on the relative abundance of sockeye salmon migrating offshore and adjacent to shore versus those being caught in fish wheels. The section of the river fished was from approximately 200 m upstream of the furthest upstream fish wheel to approximately 200 m downstream of the furthest downstream fish wheel. Within this section of the river, drift tracks and stationary setnet sites were recorded using a GPS, water depths measured with a single beam, transom mounted transducer, and precise distance from shore measured with a laser range finder. Drift gillnetting was terminated if: (1) the net became snagged on the bottom or was not fishing properly, (2) the end of the study area was reached, or (3) approximately 4 fish were believed to be captured in the net. Attempts were made to completely fish all areas between each fish wheel; however, due to unpredictable current patterns, riverine debris, or shallow water, certain areas were too hazardous or not conducive for drift gillnetting. Start and stop fishing times were recorded for each drift gillnet set. Gillnets were 25 m long, and either 5 or 10 m deep, depending upon the water depth at the fishing site. Each net was hung from a floating corkline with 4.75 in stretch-measure mesh multifilament netting. Every attempt was made to release all other captured fish alive.

RESULTS

In 2007, fish wheels were operated from 7 July to 16 August at Yentna and from 10 July to 20 August at Sunshine, during which each fish wheel operated for an average of 6.0 h/d (Appendices A1-A2). At Yentna, a total of 3,588 sockeye salmon were caught among two fish wheels, of which 356 were radiotagged (Appendix A1). At Sunshine, 3,139 sockeye salmon were caught among two fish wheels, of which 311 were radiotagged (Appendix A2). Ten radiotagged fish from the Yentna releases and 4 from the Sunshine releases were assumed to be injured by the tagging process and these tags were censored from the set of marks used in the capture-recapture estimates (Table 3); 10 of these tags were recorded passing the receiver at Flathorn and 4 did not sustain any significant upstream migration beyond the marking site. There were consequently 54 marks available for recapture from Yentna north bank fish wheel, 292 marks available for recapture from Yentna south bank fish wheel, 284 marks available for recapture from Sunshine east bank fish wheel, and 23 marks available for recapture from Sunshine west bank fish wheel.

At Yentna, 8 Chinook *O. tshawytscha*, 1,923 coho *O. kisutch*, 3,834 pink *O. gorbuscha*, and 457 chum *O. keta* salmon were caught by the two fish wheels (Appendix A1). At Sunshine, 34 Chinook, 2,587 coho, 2,679 pink, and 3,123 chum salmon were caught by the two fish wheels (Appendix A2).

Tissue samples were collected from 331 radiotagged sockeye salmon at Sunshine and 356 radiotagged sockeye salmon at Yentna. An additional 925 sockeye salmon tissue samples were collected at Sunshine.

Table 3.–Capture, marking, and recapture of Susitna River sockeye salmon, 2007.

Capture		Marking			Recapture						
					Yentna R system			Susitna R system above Sunshine			
Site	Fish wheel	Initial number captured & marked [a]	Discounted marks [b]	Final number of analyzed marks [c]	Chelatna Lk[d] weir	Judd Lk weir	Shell Lk weir	Byers Lk weir	Larson Lk weir [e]	Stephan Lk weir	Swan Lk weir
Yentna	North bank	56	2	54	24	3	3				
	South bank	300	8	292	56	90	26				
	Total	356	10	346	80	93	29				
	Weir count				10,104	57,392	26,863				
	Marked:Unmarked ratio				0.01	[f]	[f]				
Sunshine	East bank	288	4	284				2	164	23	12
	West bank	23	0	23				1	1	0	7
	Total	311	4	307				3	165	23	19
	Weir count							1,701	47,924	4,124	5,509
	Marked:Unmarked ratio							[f]	[f]	0.01	[f]

[a] Marked = radiotagged.

[b] These censored radiotagged fish where removed from the set of marks used in the abundance and distribution estimates. Marks were discounted if the radiotagged fish were never detected by a tracking station after being tagged, if they moved downstream (i.e. detected by the river tracking station at Flathorn), of if they failed to move upstream after being radiotagged.

[c] These uncensored radio tags were used in the capture-recapture estimates.

[d] Radio recoveries are for entire season; weir counts relevant to 5 August 2007.

[e] Does not include - 1 radiotagged sockeye salmon that entered Larson Lake after the weir was removed or 1 radiotagged sockeye salmon that was tagged at Yentna.

[f] Marked:Unmarked ratio is less than 0.00.

Full picket weirs were operated at Judd, Shell, and Chelatna lakes in the Yentna River system from 9 July to 14 September (Appendices A3 and A4). During that period, 10,871 sockeye salmon were counted through the Chelatna weir, 57,392 through the Judd weir, and 26,863 through the Shell weir, for a total of 94,359 in the Yentna River system. The Chelatna weir was flooded from 5 August to 21 August, during the likely peak of the run, making the count substantially biased low.

In the Susitna River system above Sunshine, full picket weirs were operated at Byers, Larson, and Stephan lakes, and a net blocked Swan Lake, from 4 July to 11 September (Appendices A3 and A4). For the full season, 1,701 sockeye salmon were counted through the Byers Lake weir, 47,924 through the Larson Lake weir, 4,124 through the Stephan Lake weir, and 5,509 through the Swan Lake net, for a total of 59,258 in the Susitna River system above Sunshine. The net at Swan Lake was installed later than planned (6 August), but only seven fish were counted in the first 8 days of operation, so it appears few, if any, immigrants were missed. Tissue samples were collected from 139 sockeye salmon at Byers Lake, 200 at Swan Lake, and 196 at Stephan Lake.

Of the 346 uncensored radio tags released at Yentna sonar, 202 (58%) were detected passing through either Chelatna (80), Judd (93), or Shell (29) lake weirs and 210 (68%) of the 307 uncensored radio tags released from Sunshine were detected passing through Byers (3), Larson (165), Stephan (23) and Swan (19) lake weirs (Table 3). A total of 412 of the 653 uncensored radio tags (63%) passed through the weirs in 2007. One radio tag released from the Yentna site passed through the Larson Lake weir.

ESTIMATION OF ABUNDANCE-SUSITNA RIVER SYSTEM ABOVE SUNSHINE

The assessment of condition *a*, the "Mixing Test," which tests for equality of recaptured:not recaptured ratios over tagging strata (banks), was significant (P = 0), while the "Equal Proportions" test, which tests the hypothesis of equal marked:unmarked ratios over recovery sites (weirs) was not significant (P = 0.12; Table 3). Schwarz and Taylor (1998) point out that a non significant "Equal Proportions" test is a sufficient condition for a consistent pooled Petersen estimator if it can also be assumed that there was equal closure over the tagging strata (banks), i.e., if an equal proportion of the population in each tagging stratum moved to recovery strata. When the recapture strata are censused, as in this case (weirs), the hypothesis of equal closure is equivalent to the hypothesis tested by the "Mixing Test" above, which was significant. Therefore, a partially stratified estimator by bank was needed to estimate abundance on the Susitna River system above Sunshine.

A K-S test of length distribution from weir samples versus length distribution of recaptured fish was not significant (P = 0.4), suggesting probability of capture during marking was not different according to size. The K-S test of lengths from marked fish versus lengths of recaptured fish was also not significant (P = 0.9), suggesting probability of capture in the recapture event was not according to size, i.e., that the passage through the weirs was representative of the population by size. No difference was found in the length distributions of fish radiotagged by bank (P = 0.8); mean lengths of radiotagged fish on the east and west banks at Sunshine were 545 mm (SE = 2.2) and 541 mm (SE = 6.9), respectively, although overall length distributions among untagged fish ($\geq$ 400 mm) did differ between banks (K-S test: P = 0.001, mean east bank length 539 mm, mean west bank length 531 mm). The age-1.2 versus age-1.3 composition also did not differ significantly between banks (P = 0.99). Approximately 60% of the sampled untagged sockeye salmon at Sunshine were age-1.3 and 22% were age-1.2 (Table 4). As a result of these tests, the abundance estimate for the Susitna River system above Sunshine was not stratified by size.

Only three sockeye salmon were caught in about 1.5 h of drift gillnetting effort off shore of the fish wheels at Sunshine, suggesting only a small fraction of the migrating sockeye salmon were not available to the fish wheels, and no adjustment was made to the analysis.

Table 4.–Percent age composition of Susitna River sockeye salmon sampled in 2007.

		Age class					
Location		Age 1.2	Age 0.3	Age 1.3	Age 2.2	Age 2.3	Total
Yentna River - mainstem	Percent	19.4	3.7	62.8	6.5	7.6	100.0
(Yentna fish wheels)	Sample size[a]	69	13	223	23	27	355
Susitna River - mainstem	Percent	22.3	3.4	60.3	5.2	8.8	100.0
(Sunshine fish wheels)	Sample size[a]	158	24	426	37	62	707
Combined	Percent	21.4	3.5	61.1	5.6	8.4	100.0
	Sample size[a]	227	37	649	60	89	1,062

[a] Units = number of sockeye salmon.

Regarding the possibility of effects of radiotagging on subsequent behavior (condition *b*), the rate of movement of radiotagged fish between the tagging site and the first tracking station on the mainstem Susitna River and the rate between subsequent upstream stations was compared. For fish radiotagged on the east bank (rkm 122.1; Table 5) and subsequently detected upstream of the Sunshine station (rkm 128.3) and the Talkeetna stations (rkm 156.6), the median movement rate was 11.4 km/d from the tagging site to the Sunshine station and 17 km/d between the Sunshine station and the Talkeetna station (Table 5). The median travel rates were significantly different (Wilcoxon Signed Rank test; $P < 0.001$, n = 237 fish). For the west bank, the trend was reversed, with fish traveling faster to the first tracking station than to a subsequent station. Fish radiotagged on the west bank (rkm 119.95) and subsequently detected upstream at the Sunshine station (rkm 128.3) and the Chulitna station (rkm 170.7), the median movement rate was 9.7 km/d from the tagging site to the Sunshine station and 5.0 km/d between the Sunshine station and the Chulitna station. The median travel rates were significantly different (Wilcoxon Signed Rank test; $P < 0.005$, n = 21 fish). Stratification by time was not used because (a) the potential effects of tagging on migration rates would confound any variation in movement rate and (b) the experiment was designed to self weight with respect to probability of capture over time, within a bank.

At Sunshine, fish that were captured in the west fish wheel and marked with an adipose finclip and released, were not recaptured in the east fish wheel, suggesting fish on the west bank did not cross over to the east bank on their way upstream. Very few radio tags (4) were censored from the Susitna River system above Sunshine experiment, showing conditions *c* and *d* were largely met.

Table 5.–Migration rates of radiotagged Susitna River sockeye salmon between tagging site and upstream tracking stations, 2007.

	Bank	Tag	Upstream migration				Distance	Travel time (d)			Median speed	Nu
Location	origin	group[a]	From	rkm	To	rkm	(km)	Median	Min	Max	km/d	o
Yentna River	North	E	North fish wheel	54.3	Lower Yentna Station	58.1	3.81	0.3	0.1	1.9	11.8	
	North	E	Lower Yentna Station	58.1	Chelatna Station	184.9	126.87	7.1	4.6	13.6	17.9	
	South	F	South fish wheel	52.8	Lower Yentna Station	58.1	5.27	0.8	0.2	3.5	7.1	
	South	F	Lower Yentna Station	58.1	Skwentna Station	138.5	80.44	6.1	0.8	21.2	13.3	
	South	G	South fish wheel	52.8	Lower Yentna Station	58.1	5.27	0.8	0.2	3.4	6.5	
	South	G	Lower Yentna Station	58.1	Talachulitna Station	144.9	86.83	6.5	1.2	17.8	13.3	
	South	H	South fish wheel	52.8	Lower Yentna Station	58.1	5.27	0.6	0.2	3.3	8.6	
	South	H	Lower Yentna Station	58.1	Kichatna Station	147.3	89.22	14.0	4.8	23.1	6.4	
	South	H	South fish wheel	52.8	Lower Yentna Station	58.1	5.27	0.5	0.2	3.1	11.0	
	South	H	Lower Yentna Station	58.1	Chelatna Station	184.9	126.87	6.5	4.8	15.3	19.5	
Susitna River	East	A	East fish wheel	122.1	Sunshine Station	128.3	6.15	0.5	0.0	6.1	11.4	
	East	A	Sunshine Station	128.3	Talkeetna Station	156.6	28.31	1.7	0.9	37.6	17.0	
	East	B	East fish wheel	122.1	Sunshine Station	128.3	6.15	1.3	0.1	5.6	4.9	
	East	B	Sunshine Station	128.3	Upper Susitna Station	165.0	36.66	3.9	2.1	38.7	9.4	
	East	C	East fish wheel	122.1	Sunshine Station	128.3	6.15	1.1	0.1	6.5	5.6	
	East	C	Sunshine Station	128.3	Chulitna Station	170.7	42.38	6.2	2.9	24.7	6.9	
	West	D	West fish wheel	120.0	Sunshine Station	128.3	8.34	0.9	0.4	5.1	9.7	
	West	D	Sunshine Station	128.3	Chulitna Station	170.7	42.38	8.5	4.2	24.7	5.0	

[a] Denotes sets of radio tags that accomplished these From/To migrations.

The partially stratified abundance estimate for sockeye salmon in the Susitna River system above Sunshine is 87,883 fish (SE = 4,169). Bank specific abundance estimates are 78,130 fish (SE = 5,816) for the east bank and 9,752 fish (SE = 4,636) for the west bank (SPAS goodness of fit statistic $P = 0.08$). The probabilities of capture on the east and west banks were an estimated 0.36% and 0.24%, respectively. The completely pooled Petersen estimate, by comparison, is 86,288 fish (SE = 3,319), while a partially stratified estimate calculated after dropping the Byers stratum (due to low recoveries) is 85,555 (SE = 4,051).

ESTIMATION OF ABUNDANCE-YENTNA RIVER SYSTEM

A high water event in 2007 resulted in the Chelatna Lake weir becoming inoperable from 5 August through 21 August. The radiotracking station at the Chelatna Lake weir continued to operate and detect radiotagged fish moving into the lake through the entire season. Therefore, the abundance estimate used only the Judd and Shell lake weir data. Schwarz and Taylor (1998) show that a partially stratified estimate remains consistent after deletion of recovery strata as long as the number of recovery strata are greater than or equal to the number of tagging strata. This condition is met with the Judd and Shell lake weirs as recovery strata and the north and south banks as the tagging strata.

The "Mixing Test," which tests for equality of recaptured:not-recaptured ratios over tagging strata (banks) was significant ($P = 0$), while the "Equal Proportions" test, which tests the hypothesis of equal marked:unmarked ratios over recovery sites (weirs) was not significant ($P = 0.07$, Table 3). As described above, a non significant "Equal Proportions" test is a sufficient condition for a pooled Petersen estimator to be consistent if it can also be assumed that there is equal closure over the tagging strata (banks), i.e., if an equal proportion of the population in each tagging stratum moves to recovery strata. When the recapture strata are censused, as in this case (weirs), the hypothesis of equal closure is equivalent to the hypothesis tested by the "Mixing Test" above, which was significant. Partial stratification by bank appeared necessary for an unbiased abundance estimate for the Yentna River system.

Stratification of the Yentna River system abundance estimate by fish length was not necessary. Length distribution of fish from weir samples versus length distribution of recaptured fish were not significantly different ($P = 0.17$), suggesting probability of capture during marking was not different among different size groups. Length distribution from marked fish versus length distribution of recaptured fish were also not significantly different ($P = 0.85$), suggesting probability of capture in the recapture event was not different among different size groups, i.e., that the passage through the weirs was representative of the population by size. There was no difference in the length distributions of fish radiotagged by bank ($P = 0.3$); mean lengths of radiotagged fish on the north and south banks at Yentna were 538 mm (SE = 6.7) and 546 mm (SE = 2.8), respectively. Overall length distribution among untagged fish ($\geq$400mm) also did not differ significantly (K-S test, $P = 0.48$). The mean north bank length was 530 mm, and the mean south bank length was 536 mm.

Approximately 63% of the sampled, untagged sockeye salmon at Yentna were age-1.3 and 19% were age-1.2 (Table 4). The age-1.2 versus age-1.3 composition also did not differ significantly between banks ($P = 0.60$).

Regarding the possibility of effects of radiotagging on subsequent behavior (condition *b*), the rate of movement of radiotagged fish between the tagging site and the first tracking station on the Yentna River system and the rate between subsequent upstream stations was examined. For fish radiotagged on the north bank (rkm 54.25 from salt water; Table 5) and subsequently detected upstream at both the lower Yentna station (rkm 58.1 from salt water) and the Chelatna station (rkm 184.93 from saltwater), the median movement rate was 11.8 km/d from the tagging site to the lower Yentna station and 17.9 km/day between the lower Yentna station and the Chelatna station (Table 5). The median travel rates were significantly different (Wilcoxon Signed Rank test; $P < 0.005$, n = 24 fish). For fish radiotagged on the south bank (Yentna rkm 52.79 from saltwater) and subsequently detected upstream at the lower Yentna (rkm 58.06 from salt water) and the Skwentna stations (rkm 138.5 from salt water), the median movement rate was 7.1 km/d from the tagging site to the Yentna station and 13.3 km/d between the lower Yentna station and the Skwentna station. The median travel rates were significantly different (Wilcoxon Signed Rank test; $P < 0.001$, n = 169 fish).

Very few radio tags (10) were censored from the Yentna experiment, showing conditions *c* and *d* were sufficient at Yentna. Movement between banks was not assessed, as the wheels are located nearly across the river from each other, and there are no large sand bars between the wheels (like at Sunshine) that salmon might follow to change banks.

As described above, the "Mixing" and "Equal Proportions" tests suggested use of the partially bank-stratified estimate based on the Judd and Shell weirs alone. This estimate is, however, very imprecise (395,624 fish; SE = 173,962) and is considered of little value. The pooled Petersen estimate of abundance (239,849, SE = 17,293) is more precise than the partially bank-stratified estimate, although some bias probably exists in the estimate due to lack of equal closure between the tagging strata. The SPAS simulation module was used to investigate the bias that may be incurred by using the pooled Petersen estimate. Each simulation dataset was established by specifying (a) movement probabilities using information based on radio tags released by bank that passed through each of the weirs, (b) weir counts based on those observed in 2007, (c) abundances passing the north and south banks, and (d) number of radio tags deployed by bank, taken as the number applied in 2007. The abundances and their distribution by bank differentiated each simulation dataset (Table 6). The pooled Petersen estimate was biased low, depending on how the abundance by bank in the simulation was structured. The further the ratio of north:south bank simulated abundance veered from the observed, bank-specific, fish wheel catches, the more biased the estimator became, reaching about -15% when the true abundance was structured as 300,000, in a 1:2 ratio for the north:south banks. The observed fish wheel catch ratio was approximately 1:5 for the north:south banks, which was associated with a bias of only -0.5%. This is not an estimate of the bias in the Pooled Petersen estimate, but an approach to put bounds on possible bias by entertaining reasonable scenarios of abundance, movement probabilities, etc.

The ratio of fish wheel catch (all species) to the DIDSON sonar total count was examined as a way to evaluate whether tags were applied in proportion to abundance over time (Figures 3-4). Using maximally-selected χ^2 values (Clark 1991), 29 July was identified as a temporal cutpoint, where the ratio of the total fish wheel catch to DIDSON sonar total count was 0.025 for the period 7-28 July and 0.039 for the period 29 July-16 August (0.039), a 56% increase.

Table 6.–Simulation data sets used to investigate bias in the pooled Petersen abundance estimate (PPE) for Yentna River sockeye salmon.

Bank	True abundance	Marks released	Probability of capture at fish wheel	Movement probability		Mean simulated PPE total abundance	bi
				Judd Lake weir [a]	Shell Lake weir[b]		
North	100,000	54	0.00054	0.05	0.05		
South	200,000	292	0.00146	0.28	0.10		
Total	300,000					255,811	
North	50,000	54	0.00108	0.05	0.06		
South	200,000	292	0.00146	0.29	0.11		
Total	250,000					241,558	
North	50,000	54	0.00108	0.04	0.05		
South	250,000	292	0.00117	0.23	0.09		
Total	300,000					298,372	

[a] Judd Lake weir count was set at 60,000 sockeye salmon for this simulation.

[b] Shell Lake weir count was set at 25,000 sockeye salmon for this simulation.

Fish wheel capture probabilities for all species therefore appeared to increase during the season, indicating the need for temporal stratification at the tagging site, accompanied by necessary stratification at the weirs (see Schwarz and Taylor [1998] for discussion on lack of consistency of the partially stratified estimate when the number of tagging strata exceeds the number of recovery strata). Temporally stratifying the weir data is problematic, however, because of the evidence that tagging delays fish migration and recovery patterns at the weirs across time may be contaminated by these effects of tagging. To investigate the potential effect of tag-induced delays abundance estimates from two scenarios were compared. The first scenario was a temporal stratification of the south bank tagging stratum, delineated by 29 July, the point at which fish wheel catchabilities apparently changed, and the Judd and Shell lake weir data into two strata, assuming a 14 d travel time between fish wheels and weirs. The second scenario involved identical stratum definitions but with any tags from the early tagging stratum that were recovered in a late weir stratum moved into the early weir stratum. This action corrected all potentially tag-delayed fish. The abundance estimate from the first scenario was about 10% lower than the estimate from the second scenario. Tag-induced lagging would appear to bias the temporally stratified estimate downwards by less than 10%. This result allowed examination of the influence of temporal stratification by comparing a temporally stratified estimate with the pooled Petersen estimate. Stratifying the tagging event (both banks) at 29 July and the weir strata 14 d later, yields an abundance estimate of 185,364 (SE=22,707). This estimate is about 22% lower than the pooled Petersen estimate. Ideally, a temporal and bank-stratified estimate would be calculated; tag recoveries are too sparse to yield a reliable estimate, however.

The flooding of the Chelatna Lake weir led to significant effects on the abundance estimate. The weir was the only recovery area on the north side of the drainage, and 80 radio tags were recovered at that weir over the entire season. The highly variable, partially stratified estimate described above, based on only the Judd and Shell lake weirs, is likely partly due to the fact the north bank tagging effort was nullified by the loss of Chelatna Lake weir data; 80% of the tags on the north bank moved to Chelatna Lake. Given the complete record of radiotag recoveries at the Chelatna Lake weir, some "what-if" scenarios were examined, assuming reasonable weir counts for the flooded period of the Chelatna Lake weir operation. The weir count up until the flooding event was 10,104 fish. There was a declining trend in the counts when the weir flooded, and when the weir was reinstalled on 22 August, the counts were zero. Two total weir counts for the Chelatna Lake weir of 20,000 and 30,000 fish were modeled. Incorporating the Chelatna Lake weir recoveries into the analysis (Judd, Shell, and Chelatna as recovery events), the “Mixing Test” passes easily: 56% of the north bank tags were recovered and 59% of the south bank tags were recovered. The pooled Petersen estimates under these scenarios are 179,541 fish (SE = 8,088) and 196,607 fish (SE = 8,859) for the 20,000 and 30,000 total Chelatna Lake weir count scenarios, respectively.

SPAWNING DISTRIBUTION AND MIGRATION TIMING

River Tracking Stations

All radiotagged fish were recorded moving upriver and traveled throughout the Susitna River drainage (Table 7). Of the 667 radiotagged fish, 615 (92.2%) could be assigned to a final location or smaller tributary (Table 8). The terminal distribution indicated that sockeye salmon were strongly bank oriented at the tagging sites.

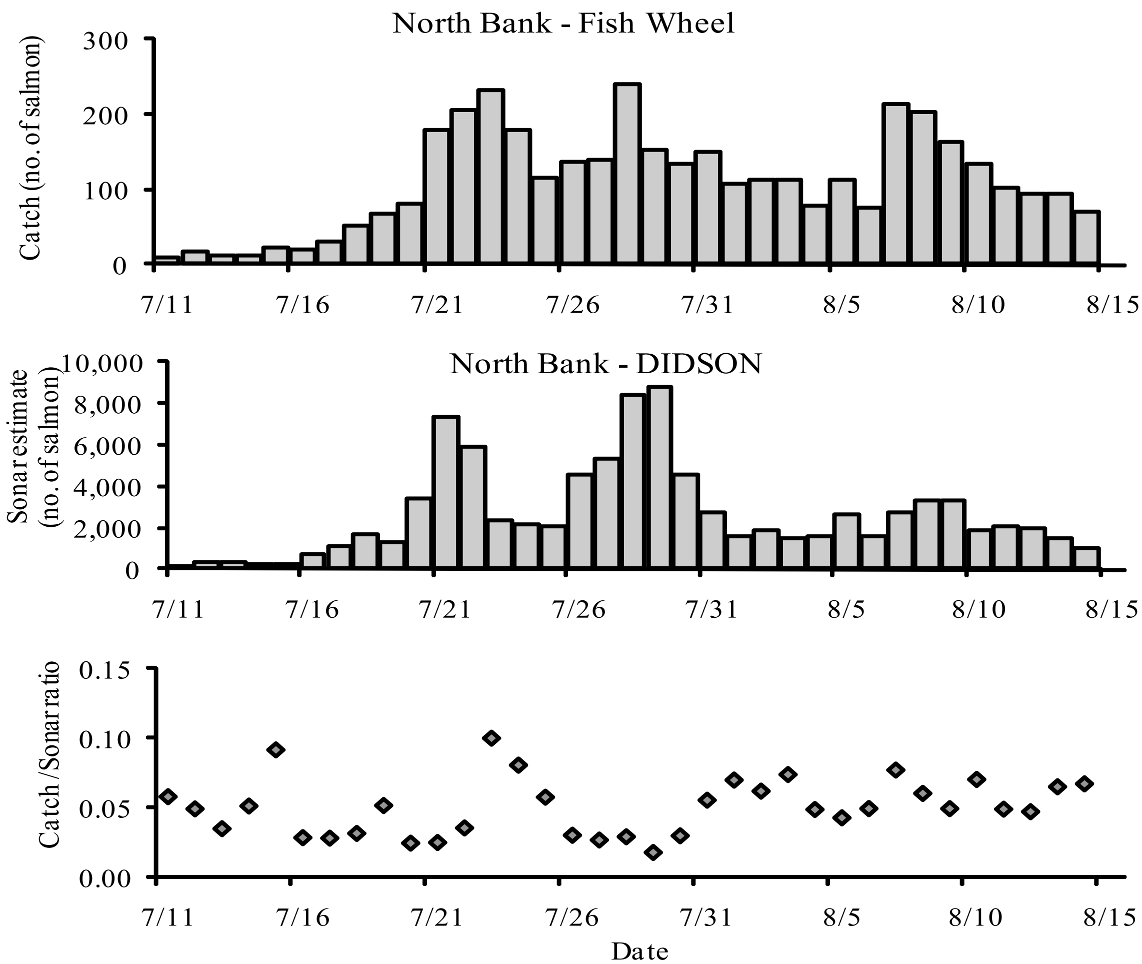


Figure 3.–Fish wheel catches, DIDSON sonar estimates, and the catch:sonar ratio for all salmon species at Yentna River north bank, 2007.

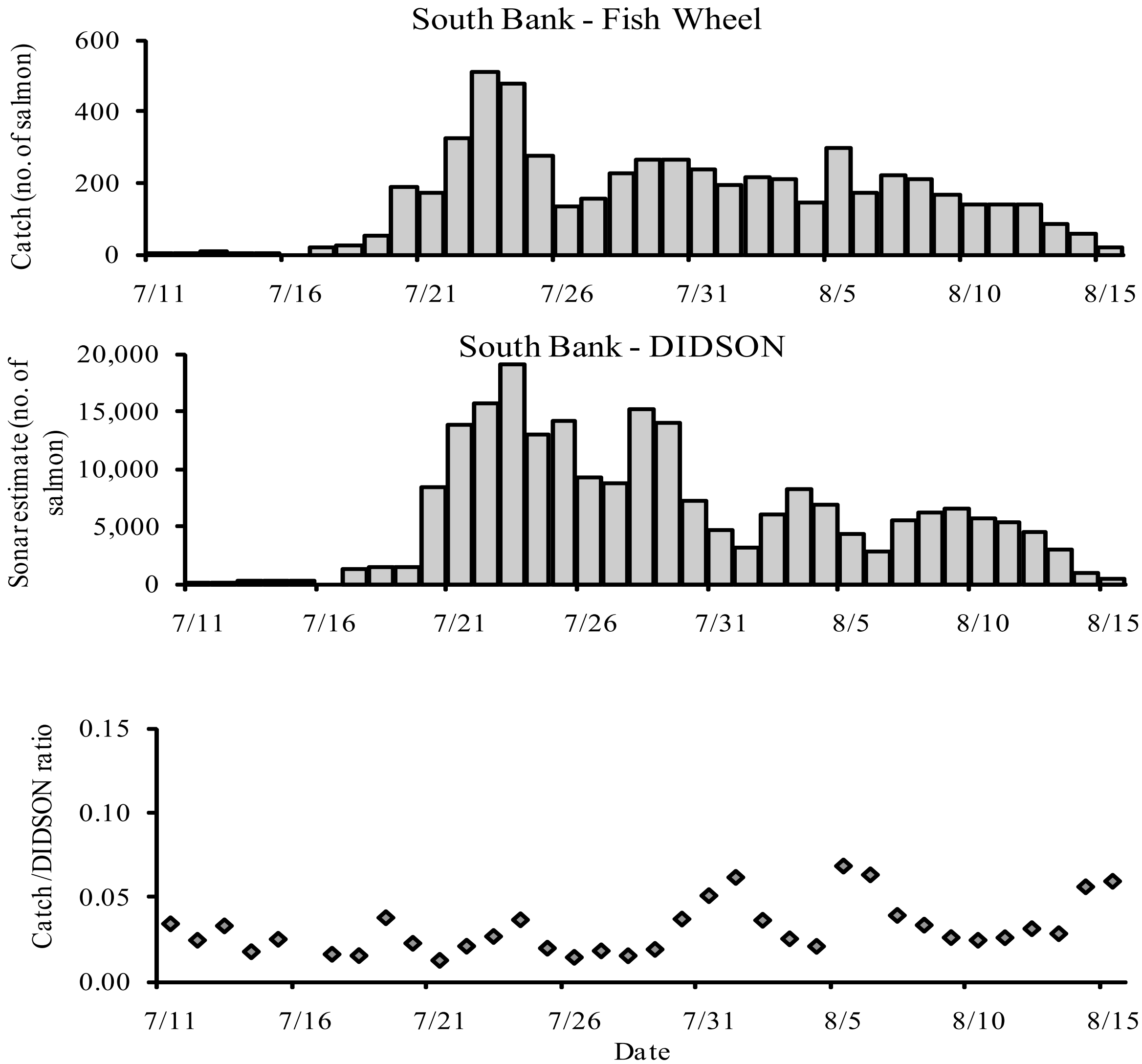


Figure 4.–Fish wheel catches, DIDSON sonar estimates, and the catch:sonar ratio for all salmon species at Yentna River south bank, 2007.

There were 356 fish radiotagged at Yentna, of which 353[5] migrated upstream of the lower Yentna station. Two of the 3 fish not migrating upstream were recorded at the station but did not pass, both migrating down below the tagging site, with 1 recorded near the Susitna River mouth. The radiotracked movements of the third fish showed it swam down the Yentna River and continued up the mainstem Susitna River to Larson Lake. Of the 353 tagged fish that continued up the Yentna River, 56 were tagged on the north bank and 297 on the south bank. Forty-seven (83.9%) of the north bank fish were recorded in terminal tributaries: 5 tags in the Skwentna River mainstem (or tributaries), 32 tags in the Yentna River mainstem (or tributaries), 5 tags in the Talachulitna River system, 3 tags in the Kichatna River system, and 1 tag each in the Kahiltna River system and the Chulitna River system. For the south bank, 274 (92.3%) fish were recorded in terminal tributaries: 67 tags in the Skwentna River mainstem (or tributaries), 92 tags in the Yentna River mainstem (or tributaries), 99 tags in the Talachulitna River system, 13 tags in the Kichatna River system, and 1 tag each in the Kahiltna and Tokositna river systems.

There were 311 fish radiotagged at Sunshine, all of which migrated up the Susitna River past the Sunshine station, with 23 tagged on the west bank and 288 on the east bank. All 23 west bank fish were recorded in terminal tributaries: 1 traveled to the Talkeetna River system and 22 to the Chulitna River system. Of the 288 fish radiotagged at the Sunshine east bank, 271 (94.1%) were tracked to terminal tributaries including 230 in the Talkeetna River system, 32 in the Chulitna River system, 8 in the mainstem Susitna River upstream of Sunshine, and 1 in the Skwentna River system.

Fifty-two (7.6%) radiotagged fish were not assigned to a spawning location. These included 9 caught in sport fisheries, 13 possibly caught in sport fisheries, and 5 returning downstream to the Susitna River mouth. Of the 52 fish not assigned to a spawning location, 35 were tagged at Yentna and 17 at Sunshine:

1. For the 35 Yentna fish, 14 moved 45 km up the Yentna River near the mouth of Lake Creek where 4 were caught in sport fisheries and 10 possibly caught in sport fisheries. Four other fish continued past Lake Creek; 3 of these fish nearly to the Skwentna River mouth, while the 4th was caught in Shell Creek by a sport fisher. Three fish traveled to just below the Lake Creek confluence, while 10 were recorded only a short distance upstream of the Lower Yentna station, with 7 of the 10 turning back downstream and 4 of the 7 continuing down the Susitna River to Cook Inlet. There were no records for 4 fish after passing upstream of the Lower Yentna station.
2. For the 17 Sunshine fish, 7 fish remained in the Susitna River mainstem and were recorded below the Talkeetna River mouth. One fish was recorded off channel, below Talkeetna, and 1 fish turned back downstream below the tagging site at Sunshine. Eight fish moved 34 km past the Talkeetna station near the mouth of Larson Creek where 4 of the 8 were caught in sport fisheries, 2 of the 8 possibly caught in sport fisheries, and 2 of the 8 turning back down the Susitna. One other fish migrated back down to Cook Inlet.

---

[5] This value does not match Table 2 because stricter criteria were used to define fish for the abundance estimate, such as time and distance upstream.

Table 7.–Regional distribution of radiotagged sockeye salmon in the Susitna River drainage during 2007.

		Tagging site			
		Yentna		Sunshine	
Location	Region	Number of fish	Percent	Number of fish	Percent
Yentna River	Lower Yentna River mainstem [a]	22 [b, c]	6		
	Upper Yentna River mainstem	27	8		
	Lake Creek	16 [d]	5		
	Chelatna Lake	80	22		
	Johnson Creek	2	1		
	Hewitt Lake/outlet	11	3		
	Kahiltna River	2	1		
	Lower Skwentna River mainstem [e]	0	0		
	Upper Skwentna River mainstem	19	5		
	Tributaries	24	7	1	0
	Shell Lake/outlet	30 [f]	8		
	Talachulitna River	2	1		
	Talachulitna Creek	6	2		
	Judd Lake	93	26		
	Trinity Lake	3	1		
	Kichatna River	16	5		
Susitna River	Lower Susitna River mainstem [g]			9 [h, i]	3
	Talkeetna River			11 [j]	4
	Tributaries			17	6
	Papa/Mama Bear Lake			3	1
	Larson Lake/outlet	1	0	184 [k, l]	59
	Stephan Lake/outlet			24	8
	Upper Susitna River mainstem			6	2
	Tributaries			2	1
	Chulitna River	1	0	21	7
	Byers Lake			3	1
	Tokositna River	1	0	11	4
	Swan Lake			19	6
	Total	356	100	311	100

[a] Section of Yentna River from Susitna-Yentna River confluence to Yentna-Skwentna River confluence

[b] Includes 2 fish that were recorded at lower Yentna station but no clear passage.

[c] Includes 6 fish that passed Flathorn station down towards Cook Inlet.

[d] Includes 4 fish caught in sport fishery.

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

[f] Includes 1 fish caught in sport fishery.

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

[h] Includes 1 fish that passed Sunshine station then back down.

[I] Includes 1 fish recorded in Montana Creek.

[j] Includes 2 fish that passed Talkeetna station then back down Susitna River mainstem.

[k] Includes 4 fish caught in sport fishery.

[l] Includes 1 fish went back down Susitna River mainstem to Cook Inlet.

Table 8.–Unweighted terminal distribution of radiotagged sockeye salmon in the Susitna drainage by fish wheel in 2007.

Fish wheel location		Yentna River	Chelatna Lake	Hewitt Lake	Kahiltna River	Skwentna River	Shell Lake	Talachulitna River	Judd Lake	Kichatna River	Susitna River	Talkeetna River	Larson Lake	Stephan Lake	Chulitna River	Swan Lake	Byers Lake
Yentna:																	
N bank	No. of fish	4	27[a]	1	1	4	1	1[b]	4	3	0	0	0	0	1	0	0
	Percent	8.5	57.4	2.1	2.1	8.5	2.1	2.1	8.5	6.4	0.0	0.0	0.0	0.0	2.1	0.0	0.0
S bank	No. of fish	25[c,d]	57	10[e]	1	39	28	10[f]	89	13	0	0	1	0	1[g]	0	0
	Percent	9.1	20.8	3.6	0.4	14.2	10.2	3.6	32.5	4.7	0.0	0.0	0.4	0.0	0.4	0.0	0.0
Sunshine:																	
W bank	No. of fish	0	0	0	0	0	0	0	0	0	0	0	1	0	14[h]	7	1
	Percent	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.3	0.0	60.9	30.4	4.3
E bank	No. of fish	0	0	0	0	1	0	0	0	0	8	27[i]	179[j]	24[k]	18[l]	12	2
	Percent	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	3.0	10.0	66.1	8.9	6.6	4.4	0.7
Total	No. of fish	29	84	11	2	44	29	11	93	16	8	27	181	24	34	19	3
	Percent	4.7	13.7	1.8	0.3	7.2	4.7	1.8	15.1	2.6	1.3	4.4	29.4	3.9	5.5	3.1	0.5

Note: Does not include 52 sockeye salmon not assigned to a spawning location.

[a] Includes 4 fish in Lake Creek.

[b] Includes 1 fish in small lake (Trinity) near Judd Lake.

[c] Includes 2 fish in Johnson Creek.

[d] Includes 2 fish in Lake Creek.

[e] Includes 1 fish in Hewitt Creek.

[f] Includes 2 fish in small lake (Trinity) near Judd Lake.

[g] Includes 1 fish in Tokositna River.

[h] Includes 4 fish in Tokositna River.

[I] Includes 3 fish in Papa Bear Lake.

[j] Includes 15 fish in Larson Creek.

[k] Includes 1 fish in Prairie Creek.

[l] Includes 1 fish in Tokositna River.

Very few fish tagged at Sunshine on the mainstem Susitna River ultimately spawned in the Yentna River system and vice versa. One fish radiotagged at Sunshine migrated up the Yentna and Skwentna rivers (over 262 km) to Hayes River and 3 fish, radiotagged at Yentna, traveled up the Susitna River: 1 going to Larson Lake, 1 to the Tokositna River, and 1 to the Chulitna River.

Weir Tracking Stations

Of the 56 fish radiotagged at Yentna north bank fish wheel, 30 (54%) traveled upstream and were detected as they passed weir tracking stations into lakes: 24 into Chelatna Lake, 3 into Judd Lake, and 3 into Shell Lake. Of the 300 fish tagged at the south fish wheel, 174 (58%) fish were recorded passing into lakes: 89 into Judd Lake, 57 into Chelatna Lake, and 28 into Shell Lake (Table 8).

Of the 23 fish tagged at the Sunshine west bank fish wheel, 9 (39.1%) were recorded passing weirs into lakes: 7 tags into Swan Lake, and one each into Byers and Larson lakes. Of the 288 fish tagged at the Sunshine east bank fish wheel, 201 (69%) fish were recorded passing into lakes: 164 into Larson Lake, 23 into Stephan Lake, 12 into Swan Lake, and 2 into Byers Lake.

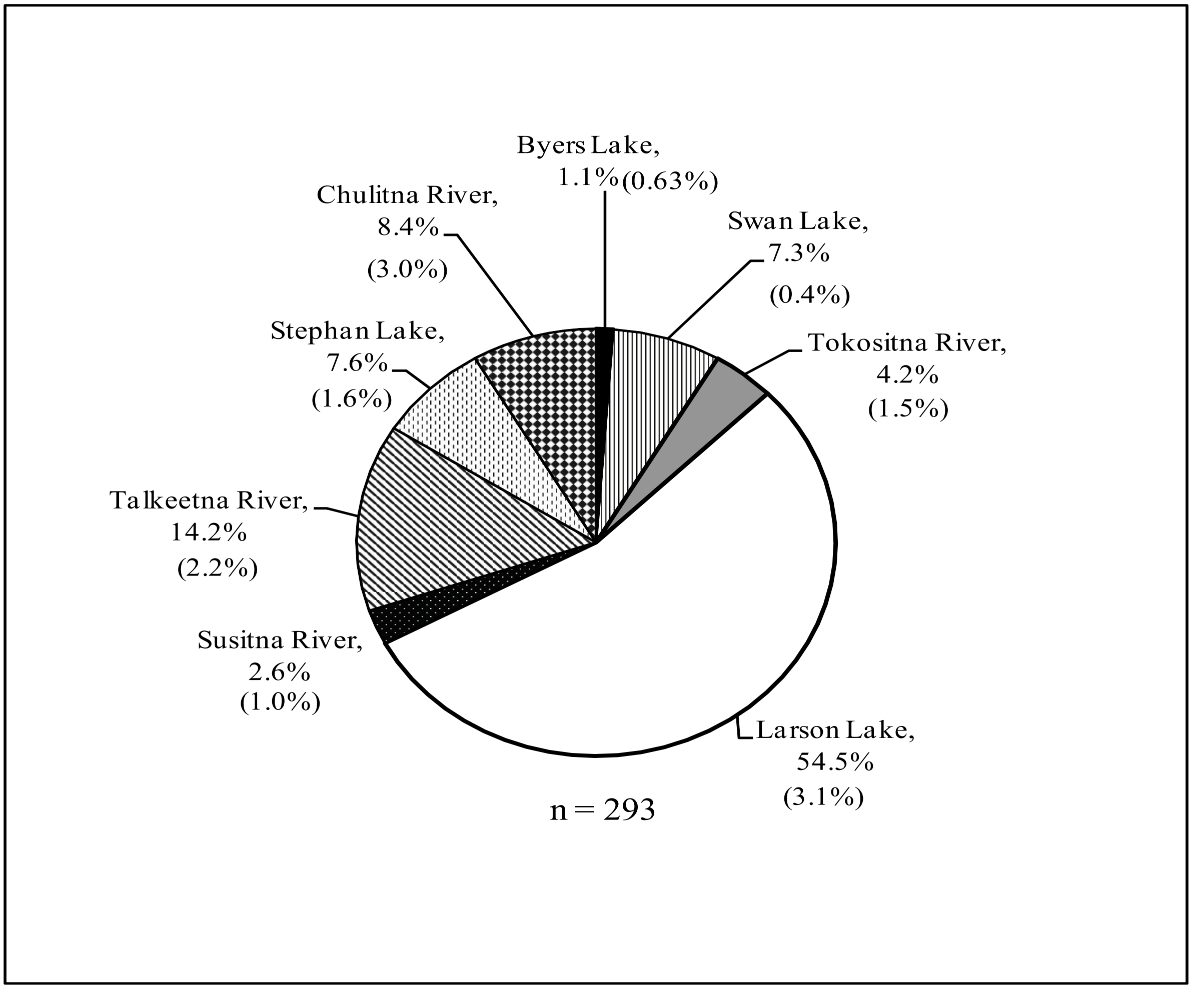
Aerial Surveys

Aerial surveys were conducted over the Susitna River system above Sunshine on 21 August, 22 August, 29 August, 5 September, 27 September, and 3 October 2007, and over the Yentna River system on 21 August, 22 August, 28 August, 6 September, and 29 September 2007. These surveys recorded 632 radiotagged fish (94.8% of the 667 released). All fish locations were corroborated by available tracking station records. Of the 35 fish not recorded by the aerial surveys, 6 were tagged at Sunshine and 29 at Yentna. For the Sunshine fish, 4 were caught in sport fisheries, 1 possibly caught in sport fisheries, and 1 recorded going into Stephan Lake by the weir tracking station. For the Yentna fish, 2 were caught in sport fisheries, 15 were located in lakes by weir tracking stations, and 8 located in Yentna River tributaries by tracking stations. No information was available for 4 fish after passing the lower Yentna station.

Spawning Distribution and Migration Timing

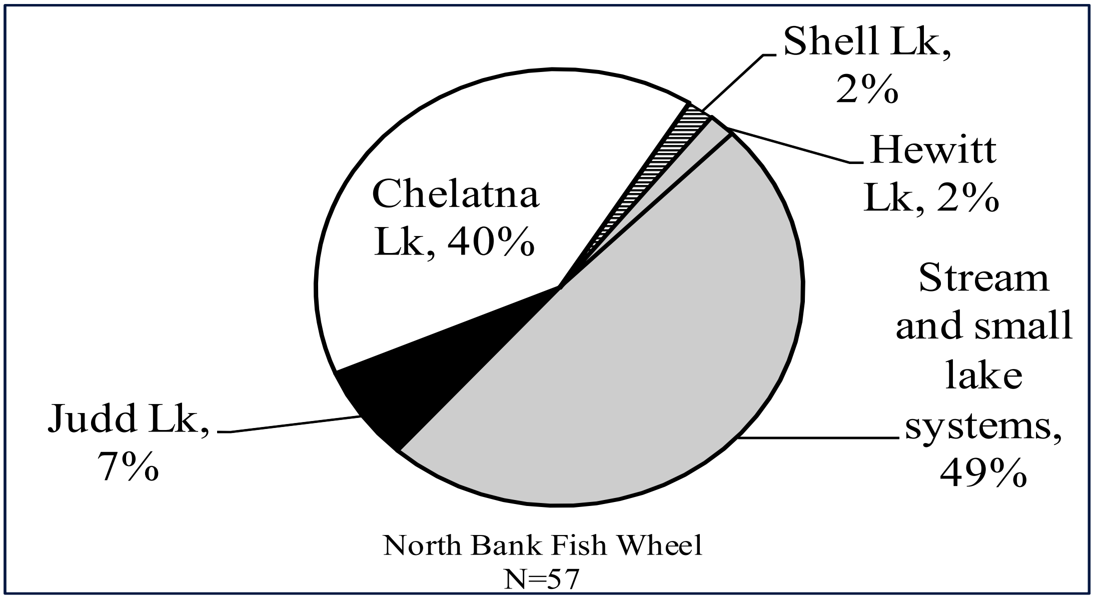
About 28% of the unweighted terminal distribution of all radio tags deployed were in rivers or sloughs in 2007, suggesting that a sizeable portion of spawning does not occur in lake systems. The unweighted terminal distribution indicated that sockeye salmon were strongly bank oriented at the tagging sites (Table 8).

The heterogeneous marked:unmarked ratios for sockeye salmon observed among all the weirs indicates that the radiotag distributions within the Yentna River system and the Susitna River system above Sunshine require weighting to generate unbiased estimates of the true spawner distribution. For the Susitna River system above Sunshine, the abundance-weighted distribution showed 54% (SE = 3.1%) of the spawners went to Larson Lake, and 29% were in tributaries without a major lake (Figure 5). The lack of an acceptable abundance estimate for the Yentna River system limits the description of spawner distribution to unweighted distributions according to bank tagged, to reduce bias caused by heterogeneous capture probabilities (Figure 6). Substantial percentages of fish tagged on either the north or south bank were not located in a lake (49% from the north bank and 39% from the south bank).

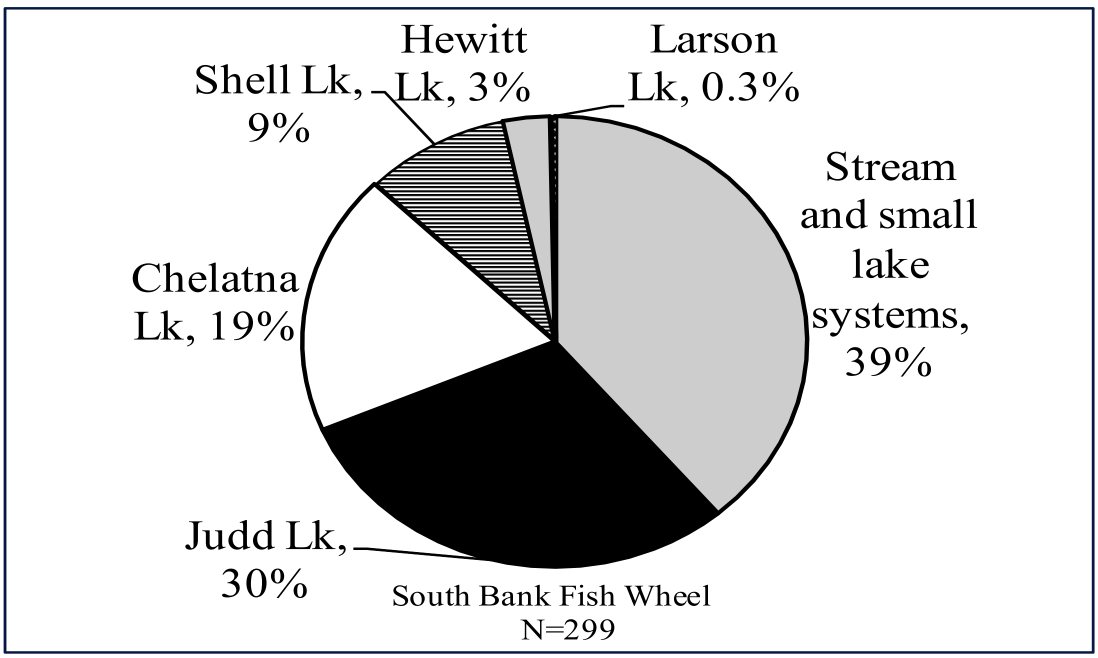


Note: SE in parentheses.

Figure 5.–Weighted terminal distribution of sockeye salmon in the Susitna River system above Sunshine, 2007.



North Bank Fish Wheel
N=57



South Bank Fish Wheel
N=299

Note: Percentages indicate the fraction of the total number of fish tagged at each fish wheel that moved upriver to each terminal area.

Figure 6.–Unweighted terminal distribution of sockeye salmon radiotagged at Yentna River fish wheels, 2007.

The unweighted terminal distribution of most sockeye salmon passing by tagging sites exhibited similar run timing, although some differences by stock were observed. The Larson Lake stock was present throughout the run, peaking at the fish wheels the week beginning 29 July (Sunday through Saturday; Figure 7), with a median run-timing of 2 August. Tokositna River and Swan Lake (median run timing of 4 August) stocks peaked the week beginning 22 July, while Sheep River run timing coincided with that of Larson Lake. Stephan Lake (median run timing of 2 August) and Chulitna River stocks peaked the week beginning 5 August.

For Yentna stocks, Judd Lake represented the largest component, peaking the week beginning 22 July (Figure 8), with a median run timing at the Yentna tagging site of 28 July. A peak for Chelatna Lake (median run timing of 31 July), Shell Lake (median run timing of 31 July), and the Skwentna and Kichatna rivers also coincided with Judd Lake for the week beginning 22 July, but also exhibited a second peak the week beginning 5 August. Hewitt Lake and Talachulitna River stocks peaked the week beginning 29 July, while the Yentna stock peaked the week beginning 5 August.

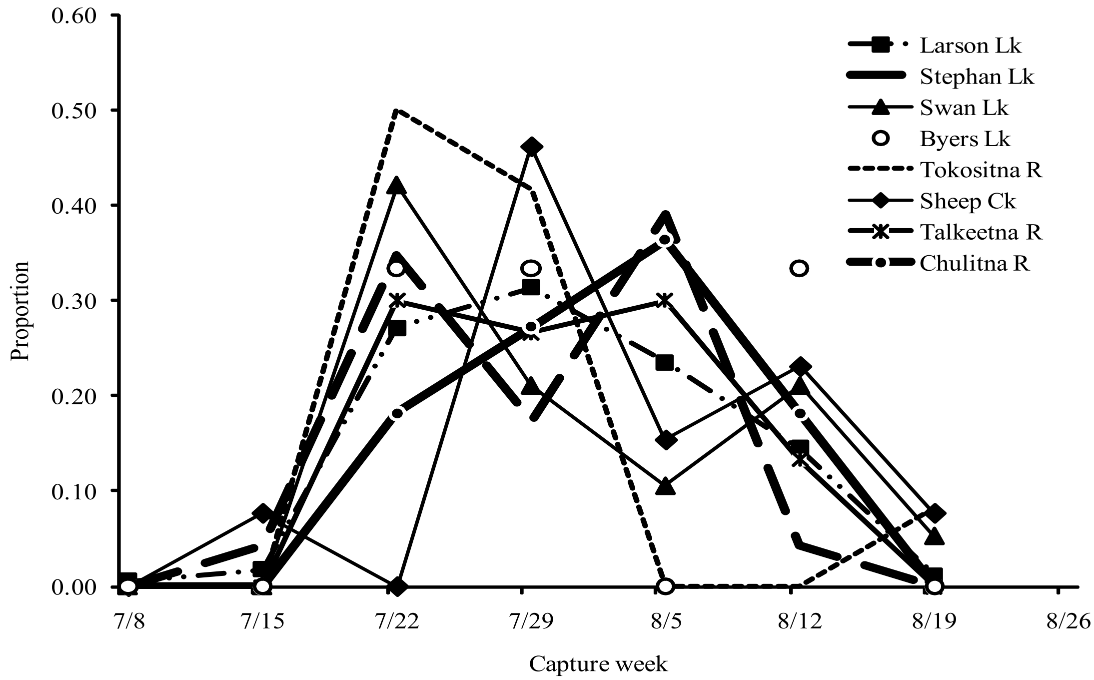
Ground surveys were conducted to collect tissue samples from spawning sockeye salmon for the genetic baseline. Sites visited were Moose Creek, Kichatna River, and Spink Creek on 27 August; Birch Creek and Papa Bear Lake on 28 August; Johnson Creek and Trimble River on 17 September; and Canyon Creek and a small tributary of the Skwentna River on 20 September. Tissue samples were collected at all of the sites that were visited. Observations by field crewmembers documented tens to hundreds of sockeye salmon at each location. These observations are consistent with the assumption that radiotagged fish were associated with actual spawning sites.

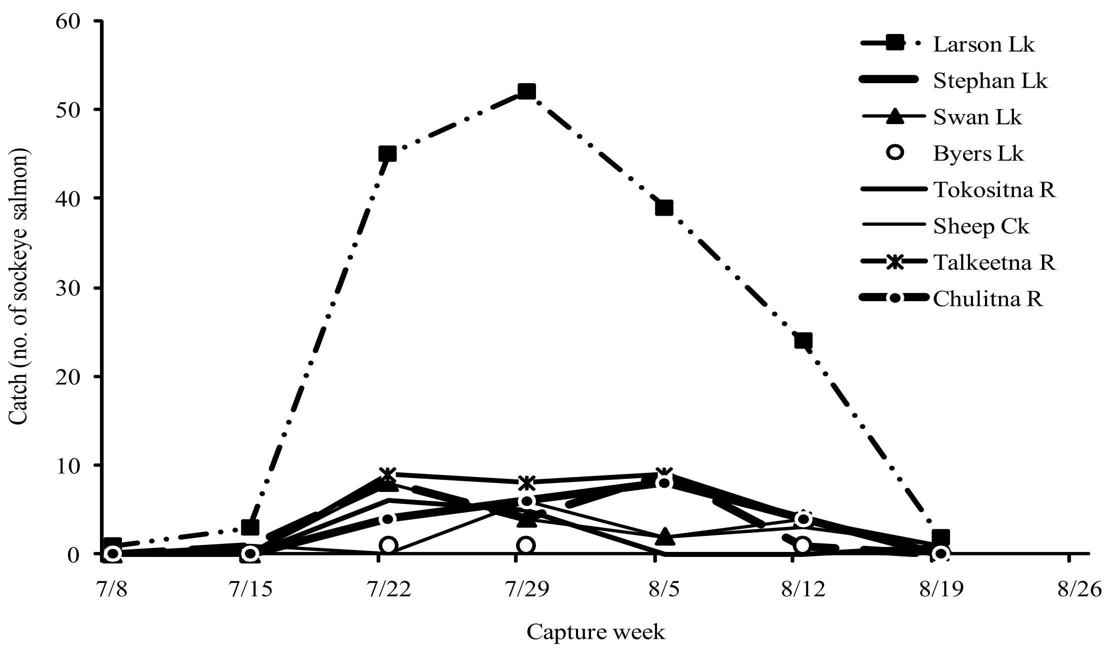
DISCUSSION

ABUNDANCE

Capture-recapture abundance estimates of the sockeye salmon escapement in the Yentna River system and the Susitna River system above Sunshine were generated by design in 2007. Necessary conditions were met in the Susitna River system above Sunshine for a partially stratified estimator to produce an inriver abundance estimate of 87,883 fish (SE = 4,169), with a 95% CI of 79,712 to 96,054 fish, for a 95% relative precision of 9.3%.

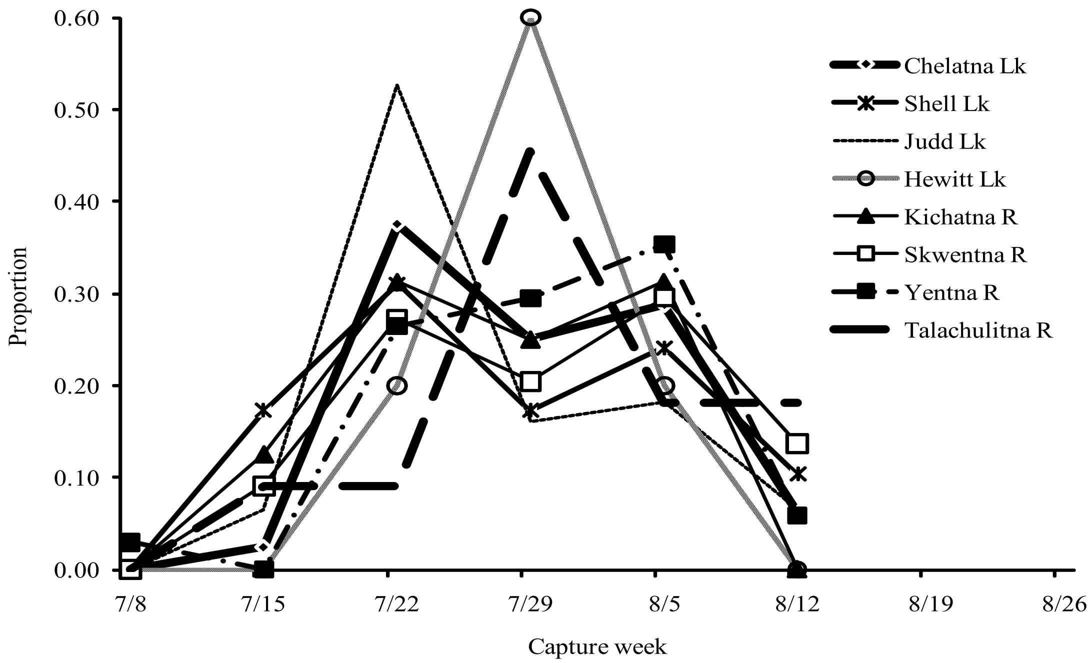
The August flood of the Chelatna weir in 2007 compromised the Yentna data set such that a precise and unbiased abundance estimate could not be generated for Yentna sockeye salmon. The partially stratified estimate using just the Shell and Judd lakes data is too imprecise to be useful (95% CI relative precision is 86%), and other estimators using simulations or presumed values yield apparently reasonable estimates, but there is no objective criteria to select the most accurate. The pooled Petersen estimate of 239,849 fish (SE 17,293, 95% CI 205,955 to 273,743, relative precision 14%) is the only estimator that can be used without simulating data, and will be considered the 2007 sockeye salmon escapement passing Yentna, despite not meeting condition *a* at the tagging strata. Scenarios to examine how biased the estimate may be due to unequal closure by bank, temporal variation in tagging rate, lagging, and incomplete weir counts suggest the pooled Petersen estimate may be biased 25% high to 15% low.

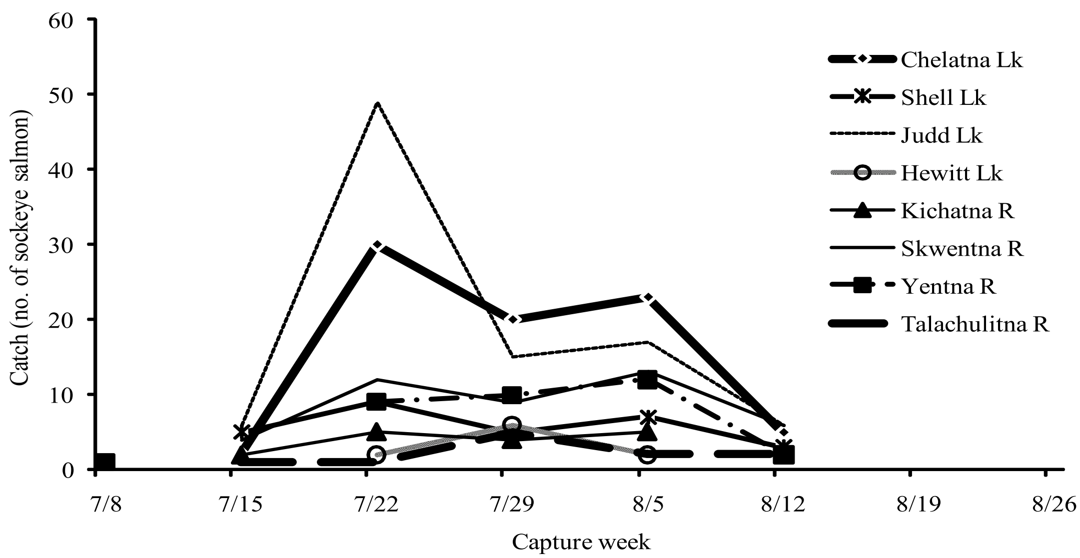




Note: Dates shown are the beginning date of each 7-day capture week (Sunday through Saturday).

Figure 7.–Run timing by capture week of radiotagged sockeye salmon passing the Sunshine tagging site to terminal reaches of the Susitna River drainage, 2007.





Note: Dates shown are the beginning date of each 7-day capture week (Sunday through Saturday).

Figure 8.–Unweighted run timing by capture week of radiotagged sockeye salmon passing the Yentna tagging site to terminal reaches of the Yentna drainage, 2007.

Combining the Yentna River system and the Susitna River system above Sunshine abundance estimates generates a sockeye salmon escapement estimate of 327,732 (SE = 17,788) fish for the entire Susitna River drainage, with the Yentna River system contributing 73% and the Susitna River system above Sunshine contributing 27%.

The 2007 study had several design changes from the 2006 study that were successful. The two-experiment design in 2007 allowed for more economical operations by omitting all fish wheels on the lower Susitna River at Flathorn. The radiotagging at Flathorn in 2006 showed no tagged fish spawning in the Susitna River tributaries between Flathorn and the Susitna-Yentna river confluence and that only one radiotagged fish moved between the Susitna-Yentna river confluence and the Susitna River system above Sunshine (Yanusz et al. 2007). While four fish switched river systems in 2007, it was still a very strong indication that the sockeye salmon in these two river systems are almost totally separate populations, and the 2-experiment design is appropriate (condition *d*). The 2006 results suggested that the data analysis would require stratification during tagging (by bank), and the 2007 results confirmed this. Stratifying the abundance estimate by bank was successful for the Susitna River system above Sunshine, and appears likely that it would have succeeded for the Yentna River system if the Chelatna weir had not flooded. In 2006, crews applying PIT tags often could not keep pace with fish wheel catches during the height of the migration and had to stop the fish wheels periodically to catch up (Yanusz et al. 2007). The 2006 run was therefore likely not tagged proportionally. In 2007, only radio tags were used and they were applied at a much lower rate. Tagging crews were therefore able to avoid being overwhelmed by catches during the peak of the run, improving the chance of tagging proportionally. Tag detection and tag loss was not an issue in 2007 because only radio tags were used, and by design all were tracked. Any substantial tag detection or loss problems would have been obvious and quantifiable (condition *c*). In 2006 it appeared there were likely non-lethal effects of radiotagging on behavior (condition *b*), since radiotagged fish were slower to reach their destination than PIT tagged fish (Yanusz et al. 2007). Handling time was reduced in 2007 by tagging fish as they were caught, instead of allowing fish to collect in the fish wheel live box. Any increased travel times for tagged fish should have had less effect on the 2007 estimate, because the weirs were operated for the duration of the 2007 run. But, we still assumed that any sub-lethal effects do not prevent radiotagged fish from passing through the weirs; if this assumption was violated the abundance estimates would be biased high.

The Bendix sonar-fish wheel estimate of the sockeye salmon abundance passing Yentna in 2007 was 79,901 fish (Shields 2007) and the DIDSON sonar-fish wheel estimate was 125,146 fish (Fair et al. 2009), which are substantially lower than the pooled Petersen capture-recapture abundance estimate for the Yentna River system (Table 9). Moreover, the Bendix estimate is less than the sum of the passage through the weirs (94,359, Table 9), and this year's spawning distribution showed that the lakes with weirs receive only a portion of the Yentna escapement (about 50% of the north and 60% of the south bank radio tags were detected in lakes with weirs in the Yentna River system). A similar pattern was found in 2006 (Yanusz et al. 2007). 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 if non-representative sampling occurred. Based on Bendix sonar counts there were 66,914 pink salmon, 8,120 chum salmon, 39,957 coho salmon, and 108 Chinook salmon (Westerman and Willette 2010).

Table 9.–Comparison of sockeye salmon escapement estimates in the Susitna drainage, 2007.

		Escapement Estimate		
			Lower	Upper
Population Estimated	Method	Point	95% CI	95% CI
Yentna	Pooled Petersen Capture-Recapture	239,849	205,955	273,743
Yentna	Bendix Sonar-Fish Wheel	79,901 [a]		
Yentna	DIDSON Sonar-Fish Wheel	125,146 [b]		
Yentna (lakes with weir)[c]	Weir	94,359 [d]		
Mainstem Susitna	Partially Stratified Capture-Recapture	87,883	79,712	96,054
Mainstem Susitna (lakes with weir)[e]	Weir	59,258 [d]		

[a] *Source:* Shields (2007).

[b] *Source:* Fair et al. (2009).

[c] In the Yentna River drainage sockeye salmon were counted at weirs on Judd, Shell, and Chelatna lakes.

[d] Source: *Unpublished* 2007 sockeye salmon escapement data from weirs operated at the outlet of select lakes by Cook Inlet Aquaculture Association (CIAA), obtained 22 November 2010 from Nathan Weber, CIAA biologist, Soldotna, Alaska.

[e] In the Susitna River drainage sockeye salmon weirs operated on Byers, Swan, Stephan, and Larson lakes.

SPAWNING DISTRIBUTION AND MIGRATION TIMING

The unweighted terminal distribution of radio tags in 2007 appears consistent with 2006, when 33% of the sockeye salmon escapement apparently spawned in locations other than lakes (Yanusz et al. 2007). Almost all of the apparent spawning sites were identical between 2006 and 2007, in spite of the far greater number of tags deployed in 2007 (667 tags) versus 2006 (250 tags). For the Susitna River system above Sunshine, unbiased estimates showed 29% of sockeye salmon spawned in locations other than lakes (e.g., mainstem river sites, side channels, spring-fed sloughs, etc.) and 54% spawned in Larson Lake. Since the terminal distribution of Yentna River system sockeye salmon spawners could not be weighted, inferences about the true spawning distribution and comparisons to the 2006 spawning distribution are not possible.

There was an initial delay in migration of radiotagged sockeye salmon in three of four cases in 2007, similar to 2006, even with reduced handling time in 2007. However, by operating these weirs several days or weeks past the date when the last radiotagged fish passed through each weir, we believe that all radiotagged fish had sufficient time to reach their final spawning destinations (Appendix A3).

ACKNOWLEDGMENTS

We thank the Commissioner of ADF&G Denby Lloyd for his support. C. Swanton, R. Clark, J. Hasbrouck and J. Erickson from the Sport Fish Division (SFD) in Anchorage and J. Hilsinger, J. Regnart, and L. Fair from Division of Commercial Fisheries (CFD) in Anchorage provided advice and project oversight. From CFD in Soldotna, D. Westerman supervised the Yentna camp, K. Rudge-Karic conducted field logistics and data entry, and T. Tobias read the scale ages. From SFD in Palmer D. Rutz, N. Deslauriers, and D. Miller provided logistical support, J. Cross and R. Driscoll of CFD assisted with the radio tracking and data tabulation. J. Berger from the

ADF&G Gene Conservation Laboratory provided instructions and supplies for collecting tissue samples, and lab staff performed field sampling.

J. Bullock and A. Lipschultz from SFD in Palmer provided field supervision and logistical support for Sunshine and the weirs, downloaded radio receivers, and completed drift gillnetting. L. Vail (crew leader) and K. Egelus of SFD performed the fish wheel sampling at Sunshine. T. D. Hacken (crew leader), S. Walker (crew leader), K. Dent, and R. Maryott from CFD performed the sampling at the Yentna River camp. C. Thompson, B. Tyler, C. Murray, B. Russell, J. Mueller, and D. Malherek assisted with late season weir operations.

G. Frandrei, T. Dodson, P. Blanche, D. Frisbee, and R. Carlson from Cook Inlet Aquaculture Association (CIAA) provided funding, design, logistics, and supervision for the weirs. CIAA field crew personnel were: N. McManus, J. Grew, and J. Hillman at Byers Lake; S. Baker, K. Stone, and N. Troyer at Chelatna Lake; N. Reif and J. Shea at Swan Lake; D. Rapp, L. Shuman, S. Stratton, and K. Yoder at Judd Lake; C. Brandys, A. Jasonowicz, J. Lautenslager, and C. Woodley at Larson Lake; K. Lynn, A. Jones, A. Veller, and N. Weber at Shell Lake; and C. Reece and J. Woodhull at Stephan Lake. Technical assistance with radiotelemetry was provided by N. Christensen, L. Kuechle, A. Mayer, and R. Reichle of Advanced Telemetry Systems, Inc. Also, thank you for the support and understanding of the Matanuska-Susitna Advisory Committee.

The following people greatly assisted with the logistics of the field operations: the Talachulitna Lodge, B. Bryant, J. Hanson, C. Norvell, J. Norvell, M. Meechan, Regal Air Service, Pollux Aviation, and D. Glaser (Arctic Wings).

This project was funded by a Capital Improvement Project from the Alaska State Legislature, the State of Alaska operating budget, and the Wildlife and Sport Fish Restoration program.

REFERENCES CITED

Arnason, A. N., C. W. Kirby, C. J. Schwarz, and J. R. Irvine. 1996. Computer analysis of data from stratified mark−recovery experiments for estimation of salmon escapements and other populations. Canadian Technical Report of Fisheries and Aquatic Sciences 2106.

Clark, R. A. 1991. Stock status of Chena River Arctic grayling during 1990. Alaska Department of Fish and Game, Fishery Data Series No. 91-35, Anchorage. http://www.sf.adfg.state.ak.us/FedAidPDFs/fds91-35.pdf

Clutter, R., and L. Whitesel. 1956. Collection and interpretation of sockeye salmon scales. International Pacific Salmon Commission, Bulletin 9. Westminster, British Columbia, Canada.

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.

Fair, L. F., T. M. Willette, and J. Erickson. 2009. Escapement goal review for Susitna River sockeye salmon, 2009. Alaska Department of Fish and Game, Fishery Manuscript Series No. 09-01, Anchorage. http://www.sf.adfg.state.ak.us/FedAidPDFs/fms09-01.pdf

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. http://www.sf.adfg.state.ak.us/FedAidPDFs/RIR.2A.1998.01.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. http://www.sf.adfg.state.ak.us/FedAidPDFs/RIR.2A.1997.26.pdf

Schwarz, C. J., and C. G. Taylor. 1998. Use of stratified-Petersen estimator in fisheries management: estimating the number of pink salmon (*Oncorhynchus gorbuscha*) spawners in the Fraser River. Canadian Journal of Fisheries and Aquatic Sciences 55:281-296.

Seber, G. A. F. 1982. On the estimation of animal abundance and related parameters, 2nd edition. Griffin and Company, Ltd. London.

Shields, P. 2007. Upper Cook Inlet commercial fisheries annual management report, 2007. Alaska Department of Fish and Game, Fishery Management Report No. 07-64, Anchorage. http://www.sf.adfg.state.ak.us/FedAidpdfs/fmr07-64.pdf

Thompson, F. M., S. N. Wick, and B. L. Stratton. 1986. Adult salmon investigations May – October 1985. Alaska Department of Fish and Game, Susitna Hydro Aquatic Studies Report Series 13, Anchorage.

Tobias, T., and M. Willette. 2004. An estimate of total return of sockeye salmon to upper Cook Inlet, Alaska 1976-2003. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2A04-11, Anchorage. http://www.sf.adfg.state.ak.us/FedAidPDFs/RIR.2A.2004.11.pdf

Westerman, D. L., and T. M. Willette. 2010. Upper Cook Inlet salmon escapement studies, 2007. Alaska Department of Fish and Game, Fishery Data Series No. 10-14, Anchorage. http://www.sf.adfg.state.ak.us/FedAidpdfs/FDS10-14.pdf

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. http://www.sf.adfg.state.ak.us/FedAidpdfs/fds07-83.pdf

APPENDIX A

Appendix A1.–Total daily salmon catch, number of radiotagged sockeye salmon, and fishing effort for both fish wheels combined at Yentna, 7 July to 16 August 2007.

	Fish wheel catch (no. of fish)					Number of radiotagged sockeye salmon	Total fish wheel effort (h) [a]
Date	Chinook salmon	Coho salmon	Pink salmon	Chum salmon	Sockeye salmon		
7/7	1	2	0	0	0	0	11.8
7/8	2	0	0	0	3	0	11.7
7/9	0	0	1	0	3	0	11.8
7/10	0	1	1	0	2	0	11.7
7/11	0	2	6	0	4	1	12.0
7/12	0	3	13	0	3	0	11.7
7/13	0	6	10	0	5	0	12.0
7/14	0	0	12	0	3	0	12.1
7/15	0	3	18	0	1	1	11.9
7/16	0	4	15	0	4	0	11.9
7/17	0	6	32	0	12	1	11.9
7/18	0	10	52	0	10	0	12.1
7/19	1	14	82	5	15	3	12.0
7/20	0	58	128	6	76	7	12.0
7/21	0	73	199	4	94	9	12.0
7/22	0	94	231	4	200	21	12.0
7/23	1	103	318	15	348	35	11.8
7/24	0	106	193	3	348	35	12.1
7/25	0	101	142	7	144	14	11.9
7/26	0	54	126	6	80	7	12.0
7/27	0	84	131	8	73	7	12.1
7/28	0	125	196	11	139	14	12.0
7/29	0	135	203	11	140	13	12.1
7/30	2	98	145	13	139	14	12.1
7/31	0	92	160	14	113	11	12.1
8/1	0	49	124	14	116	12	11.9
8/2	0	80	110	23	118	11	12.2
8/3	0	66	124	16	113	12	12.0
8/4	0	54	68	11	81	8	12.1
8/5	0	67	150	27	157	17	12.0
8/6	0	28	76	16	127	12	12.0
8/7	0	57	186	15	172	17	12.1
8/8	0	75	139	26	173	16	12.1
8/9	1	41	127	22	140	15	12.0
8/10	0	73	88	36	77	8	12.0
8/11	0	31	83	26	95	10	12.0
8/12	0	38	57	16	116	11	12.1
8/13	0	34	47	27	68	7	11.9
8/14	0	35	29	69	34	2	12.0
8/15	0	17	9	4	29	4	12.0
8/16	0	4	3	2	13	1	4.0 [b]
Total	8	1,923	3,834	457	3,588	356	483.2

[a] Is the daily sum of two fish wheels at Yentna. Measurements of revolutions per minute were not collected at Yentna fish wheels in 2007.

[b] Reduced fish wheel effort on the last day of operation.

Appendix A2.–Total daily salmon catch, number of radiotagged sockeye salmon, and the average fishing effort and revolutions per minute (RPM) for both fish wheels combined at Sunshine, 10 July to 20 August 2007.

	Fish wheel catch (no. of fish)					Number of radiotagged sockeye	Total fish wheel effort	Daily average fish wheel
Date	Chinook salmon	Coho salmon	Pink salmon	Chum salmon	Sockeye salmon	salmon	(h) [a]	RPM [b]
7/10	7	0	0	0	1	0	12.0	2.81
7/11	4	0	0	1	2	0	12.1	2.75
7/12	4	1	0	0	3	0	12.0	2.55
7/13	1	2	0	1	6	1	12.4	2.63
7/14	3	1	3	0	3	0	12.0	2.71
7/15	2	1	7	0	6	0	12.0	2.66
7/16	1	0	1	0	7	1	12.0	2.58
7/17	2	0	8	1	1	0	12.1	2.31
7/18	1	3	20	0	9	1	12.2	2.48
7/19	2	1	23	2	12	1	12.1	2.53
7/20	1	2	15	0	12	1	12.3	2.64
7/21	0	4	32	1	11	1	12.3	2.64
7/22	0	0	55	11	62	7	12.2	2.90
7/23	2	1	63	5	78	8	12.2	2.84
7/24	2	0	62	8	113	10	12.2	2.91
7/25	0	4	58	9	128	13	12.1	2.89
7/26	0	9	115	10	160	16	12.0	2.63
7/27	0	20	164	23	144	14	12.1	2.80
7/28	0	17	169	58	189	19	12.0	3.13
7/29	0	14	145	23	103	9	12.1	3.29
7/30	0	15	121	69	181	18	12.3	3.50
7/31	0	16	81	13	149	15	12.0	3.33
8/1	0	26	119	16	150	15	12.2	3.40
8/2	0	53	169	79	156	15	12.0	3.15
8/3	0	52	142	61	94	9	12.0	3.08
8/4	0	102	234	137	151	14	12.4	2.86
8/5	0	82	121	53	119	12	12.3	2.85
8/6	1	38	28	63	105	11	12.0	3.63
8/7	0	147	47	180	94	9	12.8	3.33
8/8	0	128	93	217	75	7	12.0	3.00
8/9	0	120	99	158	74	8	12.0	3.06
8/10	0	112	117	184	91	10	12.3	2.94
8/11	0	161	139	172	169	17	12.2	2.84
8/12	1	218	90	204	124	12	12.1	2.54
8/13	0	161	39	179	74	7	12.0	2.61
8/14	0	85	42	170	101	11	12.1	2.75
8/15	0	86	14	117	57	6	12.1	3.28
8/16	0	120	8	93	30	3	12.0	3.55
8/17	0	126	11	162	22	2	12.0	3.53
8/18	0	221	10	257	32	3	12.0	3.20
8/19	0	246	13	224	19	2	12.2	2.79
8/20	0	192	2	162	22	3	12.1	2.70
Total	34	2,587	2,679	3,123	3,139	311	509.1	

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

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

Appendix A3.–Daily passage of radiotagged sockeye salmon through Judd, Shell, Chelatna, Byers, Larson, Stephan, and Swan lakes weirs, 2007.

	Yentna River system lakes				Susitna River system lakes above Sunshine				
Date	Judd Lake	Shell Lake	Chelatna Lake	Total	Byers Lake	Larson Lake	Stephan Lake	Swan Lake	Total
7/4						install			0
7/5						0			0
7/6						0			0
7/7						0	install		0
7/8						0	0		0
7/9			install			0	0		0
7/10	install		0	0		0	0		0
7/11	0		0	0		0	0		0
7/12	0		0	0		0	0		0
7/13	0		0	0		0	0		0
7/14	0		0	0	install	0	0		0
7/15	0	install	0	0	0	0	0		0
7/16	0	0	0	0	0	0	0		0
7/17	0	0	0	0	0	0	0		0
7/18	0	0	0	0	0	0	0		0
7/19	0	0	0	0	0	0	0		0
7/20	0	0	0	0	0	0	0		0
7/21	0	0	0	0	0	0	0		0
7/22	0	0	0	0	0	0	0		0
7/23	0	0	0	0	0	0	0		0
7/24	0	0	0	0	0	2	0		2
7/25	0	0	0	0	0	2	0		2
7/26	0	0	0	0	0	1	0		1
7/27	0	0	0	0	0	5	0		5
7/28	0	0	1	1	0	7	0		7
7/29	1	0	5	6	0	2	0		2
7/30	1	0	8	9	0	3	0		3
7/31	1	0	4	5	0	3	0		3
8/1	0	0	3	3	0	3	1		4
8/2	0	0	1	1	0	5	0		5
8/3	6	0	2	8	0	3	1		4
8/4	3	0	0	3	0	18	0		18
8/5	4	2	4	10	0	17	2		19
8/6	6	4	1	11	0	7	0	install	7
8/7	4	1	5	10	0	0	3	0	3
8/8	6	0	3	9	0	8	1	1	10
8/9	4	1	1	6	0	11	2	2	15
8/10	2	1	7	10	0	4	2	1	7
8/11	7	0	4	11	0	8	0	0	8
8/12	6	3	7	16	0	7	0	0	7

-continued-

Appendix A3.–Page 2 of 2.

	Yentna River system lakes				Susitna River system lakes above Sunshine				
	Judd	Shell	Chelatna		Byers	Larson	Stephan	Swan	
Date	Lake	Lake	Lake	Total	Lake	Lake	Lake	Lake	Total
8/13	4	6	4	14	0	7	0	0	7
8/14	7	0	7	14	0	7	1	0	8
8/15	3	4	1	8	0	3	2	0	5
8/16	2	1	4	7	0	4	1	0	5
8/17	3	0	1	4	0	7	2	1	10
8/18	4	1	1	6	0	5	1	0	6
8/19	2	0	4	6	0	3	1	2	6
8/20	1	2	2	5	0	3	0	1	4
8/21	2	1	0	3	0	1	2	1	4
8/22	2	0	0	2	0	2	0	0	2
8/23	3	1	0	4	0	3	0	0	3
8/24	1	0	0	1	0	1	0	0	1
8/25	1	0	0	1	0	1	0	0	1
8/26	3	0	0	3	0	2	1	1	4
8/27	1	0	0	1	1	0	0	1	2
8/28	2	0	0	2	2	0	0	0	2
8/29	0	0	0	0	0	0	0	0	0
8/30	0	0	0	0	0	1 - removed	0	2	3
8/31	0	0	removed	0	removed		0	1	1
9/1	0	0		0			0	2	2
9/2	0	1		1			0	1	1
9/3	0	0		0			0	1	1
9/4	0	0		0			0	1	1
9/5	0	0		0			0	0	0
9/6	1	0		1			0	0	0
9/7	0	0		0			0	0	0
9/8	0	0		0			0	0	0
9/9	0	0		0			0	0	0
9/10	0	0		0			removed	0	0
9/11	0	0		0				removed	0
9/12	0	0		0					0
9/13	removed	0		0					0
9/14		removed		0					0
Total	93	29	80	202	3	167 [a]	23	19	212

Note: "Installed" – refers to the date the full picket weir was set up. "Removed" – refers to the date the full picket weir was taken down.

[a] Includes one additional radiotagged sockeye salmon which passed the Larson Lake weir on 3 October 2007.

Appendix A4.–Daily counts of adult sockeye salmon through Judd, Shell, Chelatna, Byers, Larson, Stephan, and Swan lake weirs, 2007.

	Yentna River system lakes				Susitna River system lakes above Sunshine				
	Judd	Shell	Chelatna	Combined	Byers	Larson	Stephan	Swan	Combined
Date	Lake	Lake [a]	Lake [b]	total	Lake	Lake [c]	Lake [d]	Lake [e]	total
7/4						install			0
7/5						0			0
7/6						1			1
7/7						0	install		0
7/8						3	1		4
7/9			install			1	0		1
7/10	install		0	0		0	NA		0
7/11	0		0	0		0	0		0
7/12	0		0	0		2	0		2
7/13	0		0	0		0	NA		0
7/14	0		0	0	install	0	NA		0
7/15	0	install	0	0	0	0	NA		0
7/16	0	0	0	0	0	1	NA		1
7/17	0	0	0	0	0	0	NA		0
7/18	0	0	0	0	0	18	0		18
7/19	0	0	0	0	0	2	0		2
7/20	0	0	0	0	0	14	0		14
7/21	0	0	42	42	0	47	0		47
7/22	0	0	69	69	0	145	0		145
7/23	0	0	177	177	0	262	0		262
7/24	0	0	13	13	0	668	0		668
7/25	4	0	170	174	0	957	0		957
7/26	9	0	73	82	0	926	3		929
7/27	83	0	546	629	0	3,043	3		3,046
7/28	478	0	1,613	2,091	0	3,005	8		3,013
7/29	1,663	0	2,155	3,818	0	1,981	14		1,995
7/30	3,576	0	1,500	5,076	0	2,595	107		2,702
7/31	1,944	0	1,306	3,250	0	1,151	103		1,254
8/1	1,779	0	623	2,402	0	1,292	150		1,442
8/2	2,051	0	1,817	3,868	0	2,385	150		2,535
8/3	3,800	0	NA	3,800	0	2,101	197		2,298
8/4	2,937	0	NA	2,937	0	3,012	250		3,262
8/5	3,524	7,911	NA	11,435	0	3,234	259		3,493
8/6	2,350	3,292	NA	5,642	0	1,037	348	install	1,385
8/7	2,674	759	NA	3,433	0	568	243	2	813
8/8	3,112	793	NA	3,905	0	1,610	148	2	1,760
8/9	3,126	800	NA	3,926	1	2,533	250	NA	2,784
8/10	1,737	921	NA	2,658	155	879	136	0	1,170
8/11	2,093	76	NA	2,169	39	2,122	223	0	2,384
8/12	1,699	1,440	NA	3,139	1	1,695	259	0	1,955

-continued-

Appendix A4.–Page 2 of 2.

	Yentna River system lakes				Susitna River system lakes above Sunshine				
	Judd	Shell	Chelatna	Combined	Byers	Larson	Stephan	Swan	Combined
Date	Lake	Lake [a]	Lake [b]	total	Lake	Lake [c]	Lake [d]	Lake [e]	total
8/13	995	1,442	NA	2,437	177	1,728	17	0	1,922
8/14	2,252	505	NA	2,757	53	1,887	152	0	2,092
8/15	1,717	790	NA	2,507	38	881	NA	40	959
8/16	1,976	178	NA	2,154	62	1,064	51	20	1,197
8/17	2,010	4	NA	2,014	57	1,190	3	246	1,496
8/18	1,663	935	NA	2,598	42	702	109	305	1,158
8/19	876	1,490	NA	2,366	75	1,264	68	359	1,766
8/20	1,188	663	NA	1,851	14	775	22	611	1,422
8/21	1,281	492	NA	1,773	20	125	228	196	569
8/22	1,131	1,228	0	2,359	32	196	37	306	571
8/23	1,016	438	0	1,454	201	155	97	124	577
8/24	388	222	0	610	274	183	89	195	741
8/25	366	175	0	541	50	130	62	865	1,107
8/26	383	123	0	506	45	98	5	245	393
8/27	324	375	0	699	309	126	68	327	830
8/28	271	713	0	984	0	74	33	63	170
8/29	215	198	0	413	26	56	50	363	495
8/30	44	131	0	175	30	removed	39	481	550
8/31	141	158	removed	299	removed		34	89	123
9/1	52	171		223			33	340	373
9/2	52	357		409			17	78	95
9/3	71	4		75			22	33	55
9/4	48	60		108			14	17	31
9/5	70	2		72			8	97	105
9/6	50	5		55			2	7	9
9/7	32	11		43			5	29	34
9/8	85	1		86			3	44	47
9/9	9	0		9			4	9	13
9/10	3	0		3			removed	16	16
9/11	8	0		8				removed	
9/12	36	0		36					
9/13	removed	0		0					
9/14		removed							
Total	57,392	26,863	10,104	94,359	1,701	47,924	4,124	5,509	59,258

Source: *Unpublished* 2007 sockeye salmon escapement data from weirs operated at the outlet of select lakes by Cook Inlet Aquaculture Association (CIAA), obtained 22 November 2010 from Nathan Weber, CIAA biologist, Soldotna, Alaska.

[a] Crews notched 2 beaver dams downstream of Shell Lake on 4 August.

[b] The weir was not operated due to flooding from 5-21 August.

[c] The Larson Lake weir was not operated from 3-4 July while the transition was made between smolt and adult salmon weirs. Eleven sockeye salmon counted prior to 5 July were not included in the abundance estimate.

[d] The weir was not operated on 10, 13-17 July and 15 August due to high water.

[e] The Swan Lake weir was not operated on 9 August because of needed repairs.