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Abundance and Spawning Distribution of Susitna River Chum *Oncorhynchus keta* and Coho *O. kisutch* Salmon, 2010

by

Peter M. Cleary

Richard A. Merizon

Richard J. Yanusz

and

Daniel J. Reed

March 2013

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

Symbols and Abbreviations

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Weights and measures (metric)	
centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm
Weights and measures (English)	
cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd
Time and temperature	
day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s
Physics and chemistry	
all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

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

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. 13-05

ABUNDANCE AND SPAWNING DISTRIBUTION OF SUSITNA RIVER CHUM *ONCORHYNCHUS KETA* AND COHO *O. KISUTCH* SALMON, 2010

By
Peter M. Cleary, Richard A. Merizon, and Richard J. Yanusz
Alaska Department of Fish and Game, Division of Sport Fish, Palmer
and
Daniel J. Reed
Alaska Department of Fish and Game, Division of Sport Fish, Nome

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

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Peter M. Cleary,
Alaska Department of Fish and Game, Division of Sport Fish,
1800 Glenn Hwy., Suite 2, Palmer, AK 99645-6736 USA

Richard A. Merizon,
Alaska Department of Fish and Game, Division of Sport Fish,
1800 Glenn Hwy., Suite 2, Palmer, AK 99645-6736 USA

Richard J. Yanusz,
Alaska Department of Fish and Game, Division of Sport Fish
1800 Glenn Hwy., Suite 2, Palmer, AK 99645-6736 USA

and

Daniel J. Reed
Alaska Department of Fish and Game, Division of Sport Fish
103 E. Front St., Nome, AK 99762-1148 USA

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ABSTRACT

Because of recent concerns over the status of the Susitna River chum (*Oncorhynchus keta*) and coho (*O. kisutch*) salmon stocks, the Alaska Department of Fish and Game began a four-year spawning distribution study in 2009. In 2010, a mark–recapture component was added to the study. Four fish wheels were used to capture and tag chum and coho salmon with dart tags at river mile 22 in the Susitna River in July and August, 2010. Two fish wheels were used at river mile 6.2 in the Yentna River and two fish wheels were used at river mile 30 in the mainstem Susitna River to sample salmon for tags. Estimated abundance of chum salmon was 151,127 (SE 37,564) fish for the mainstem Susitna River and 205,869 (SE 30,256) fish for the Yentna River. Estimated abundance of coho salmon was 73,640 (SE 25,153) fish for the mainstem Susitna River and 122,777 (SE 22,697) fish for the Yentna River. A total of 719 radio tags were placed in chum and coho salmon. Their movements were tracked using 13 ground tracking stations and four drainage-wide aerial surveys. All but five of the radio tags were relocated and 633 (88.5%) were assigned a putative spawning location. Both chum and coho salmon exhibited bank orientation at the tagging site. Chum salmon appeared to utilize predominately mainstem spawning locations while coho salmon appeared to utilize primarily tributary locations for spawning.

Key words: chum salmon, coho salmon, abundance, mark–recapture, Susitna River, Yentna River, spawning distribution, fish wheel, radio telemetry

INTRODUCTION

The Susitna River chum (*Oncorhynchus keta*) and coho (*O. kisutch*) salmon contribute to commercial and sport harvests in upper Cook Inlet (UCI). The 1966–2006 average commercial harvest in UCI was 313,000 coho salmon and 478,000 chum salmon (Shields 2007). Annual sport harvests from the Susitna River averaged 40,767 coho salmon and 2,893 chum salmon from 1998 to 2007 (Ivey et al. 2007; Jennings et al. 2010).

From 1981 through 1985, fishery studies were conducted for a proposed Susitna River hydroelectric project. Chum and coho salmon data were collected from the Yentna River at river mile (RM) 6.2 from 1981 through 1984, at the Sunshine site (RM 80) from 1981 through 1985, and at the Flathorn site (RM 22) in 1984 and 1985. With the exception of the Yentna site, which used sonar, all other estimates were generated using mark–recapture techniques. The 1981–1985 average chum salmon abundance estimate for fish that migrated upstream of the Sunshine site was 419,540; for the Yentna site, the 1981–1984 estimated average was 21,225 chum salmon; and for the Flathorn site, the 1984–1985 estimated average was 564,750 chum salmon. Average coho salmon estimates for the same years were 19,500 fish at the Yentna site, 42,440 fish at the Sunshine site, and 133,750 fish at the Flathorn site (Barrett et al. 1985; Thompson et al. 1986).

In 1981, the first radiotagging study was conducted when 11 chum and 10 coho salmon were radiotagged at Talkeetna (RM 103) and at Curry (RM 120) (ADF&G 1981). In 2002, a new Susitna drainage-wide coho salmon estimate of 663,000 fish was generated using mark–recapture techniques with tagged coho salmon in Cook Inlet. (Willette et al. 2003). During that study (Willette et al. 2003), 179 coho salmon were radiotagged in Cook Inlet and tracked into the Susitna River drainage, providing the first drainage-wide spawning distribution information for coho salmon.

The status of coho and chum salmon stocks in the Susitna River has been an issue brought before the Alaska Board of Fisheries (BOF) by user groups. The BOF issued resolution 2008-253-FB to the Alaska Legislature supporting funding for fisheries research. At the 2008 BOF meeting, there were 69 proposals to modify commercial fishing regulations in UCI and two proposals for sport fishing regulations in the Susitna River, demonstrating the dynamic nature of the fisheries. The Matanuska–Susitna Borough issued a resolution on 15 January 2008 requesting the Alaska

Department of Fish and Game (ADF&G) declare Susitna River chum salmon a "stock of concern," enumerate salmon escapements, and set escapement goals for all salmon in northern Cook Inlet. The Alaska State Legislature issued Legislative Resolve Number 51 in 2008 establishing the Cook Inlet Salmon Task Force to examine "conservation and allocation issues."

In 2009, ADF&G initiated a four-year spawning distribution study (2009–2012) using radio telemetry. In 2010, ADF&G added an abundance estimation component. The objectives for 2010 were to 1) estimate inriver abundance of adult chum and coho salmon above the Flathorn site and 2) identify chum and coho salmon spawning locations throughout the Susitna River drainage.

STUDY AREA

The Susitna River watershed is 49,210 km^2 and originates in the Alaska Range north of Anchorage (Figure 1). It is the fourth largest drainage in the state of Alaska. It flows generally south from the Alaska Range for approximately 400 km before entering UCI west of Anchorage. Some tributaries that originate in the Alaska or Talkeetna Mountain ranges are clear while others are glacially turbid (Sweet et al. 2003). The largest tributaries are the Yentna, Chulitna, and Talkeetna rivers, and numerous small lakes (King and Walker 1997).

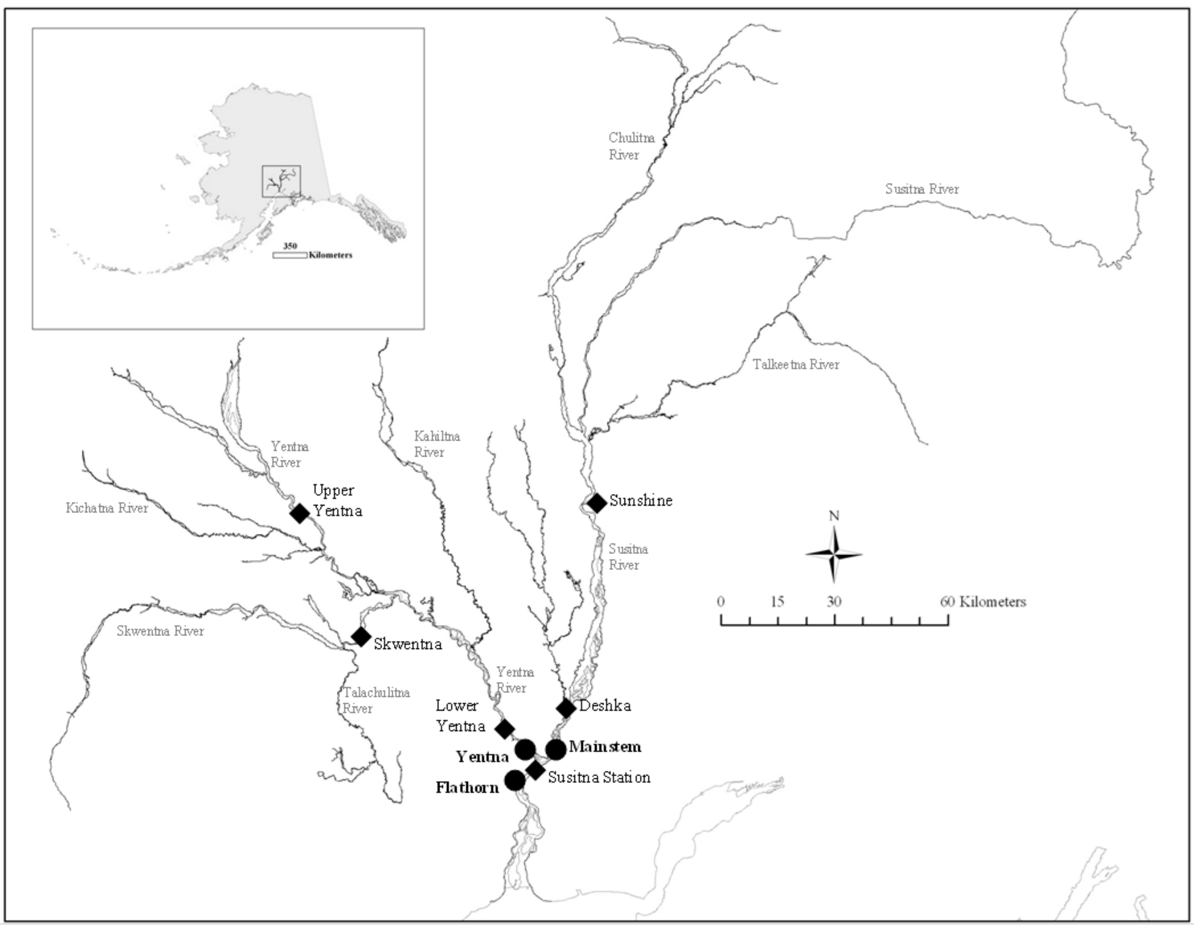

Figure 1.–Location of Flathorn, Mainstem, and Yentna sites (circles) and fixed radiotracking stations (diamonds) in the Susitna River drainage, 2010.

METHODS

ABUNDANCE

Marking Events

Four fish wheels were operated in 2010 at the Flathorn site: one on each bank and two on islands in the Susitna River (Figure 2). These sites were selected because they are upstream of a highly braided area and downstream of the confluence with the Yentna River. Each fish wheel had 2 m × 2 m baskets that were adjusted as needed to fish close to the river bottom. Picket weirs were installed between the fish wheel and the river bank on each wheel to direct migrating salmon away from the bank and towards the fish wheel baskets.

The Division of Sport Fish (SF) crews operated fish wheels (FW) 2, 3, and 4 from 6 July through 30 August 2010. On 12 August, SF assumed operations of FW 1 when the Division of Commercial Fisheries (CF) concluded a study on fish wheel selectivity. During the CF study, all captured coho, chum, sockeye (*O. nerka*), and pink (*O. gorbuscha*) salmon were marked with an external tag and a subsample of coho and chum salmon, distributed over time and among the four tagging wheels, were marked with a radio tag and subsequently tracked to spawning locations (Unpublished, "Yentna Fish Wheel Selectivity Study FY11 Operational Plan," Mark Willette, ADF&G Division of Commercial Fisheries Biologist).

SF crews, working at least two 7.5-h shifts each day, operated FWs 2–4 during daylight hours until reaching the goal of 12 h/d of effort per fish wheel. CF crews, working two nine-hour shifts each day, operated FW 1 until reaching the goal of 18 h/d effort because more tagged fish were needed for the CF selectivity study. Effort at FW 1 was reduced to 12 h/d when the SF crew replaced the CF crew on 13 August. All fish wheels operated each day except when repairs were needed or high water events occurred.

Fish wheels were constructed of aluminum, with two 6-ft wide baskets webbed with knotted nylon 1.5-inch (square measure) mesh. Captured fish descended the basket chute and exited via an aluminum-framed fabric "slide" and dropped into the live box. Live boxes measured 8 ft long, 2 ft wide, and 3 ft deep, with plywood sides with holes for flow. The configuration of the fish wheel axle, baskets, and floats allowed the baskets to reach a maximum depth of 4.5 ft. Fish wheels were secured to the river bank and held offshore with poles to reach sufficient current and depth to spin the wheels. The axle height was adjusted so that the baskets swept as close to the river bottom as possible. At the Flathorn site, all captured chum and coho salmon at least 400 mm from mid eye to tail fork (METF) and in good condition were marked with an individually numbered, yellow, six-inch-long dart tag (either model FT-1-94 from Floy Tag, Seattle, WA, or model PDA from Hallprint, Australia[1]). All tagged fish were measured for METF length. At FWs 2–4 only, the adipose fin was removed from dart-tagged salmon as a secondary mark to detect tag loss. At FW 1, no secondary mark was used. The CF selectivity study at FW 1 tagged 4 species of salmon and required that all species be treated identically; additional handling, such as removing the adipose fin from only chum and coho salmon, might have introduced extra handling effects. Also, the crews at the Yentna recovery site were expected to handle many thousands of fish of all species, precluding accurate inspection of fish for a missing adipose fin.

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

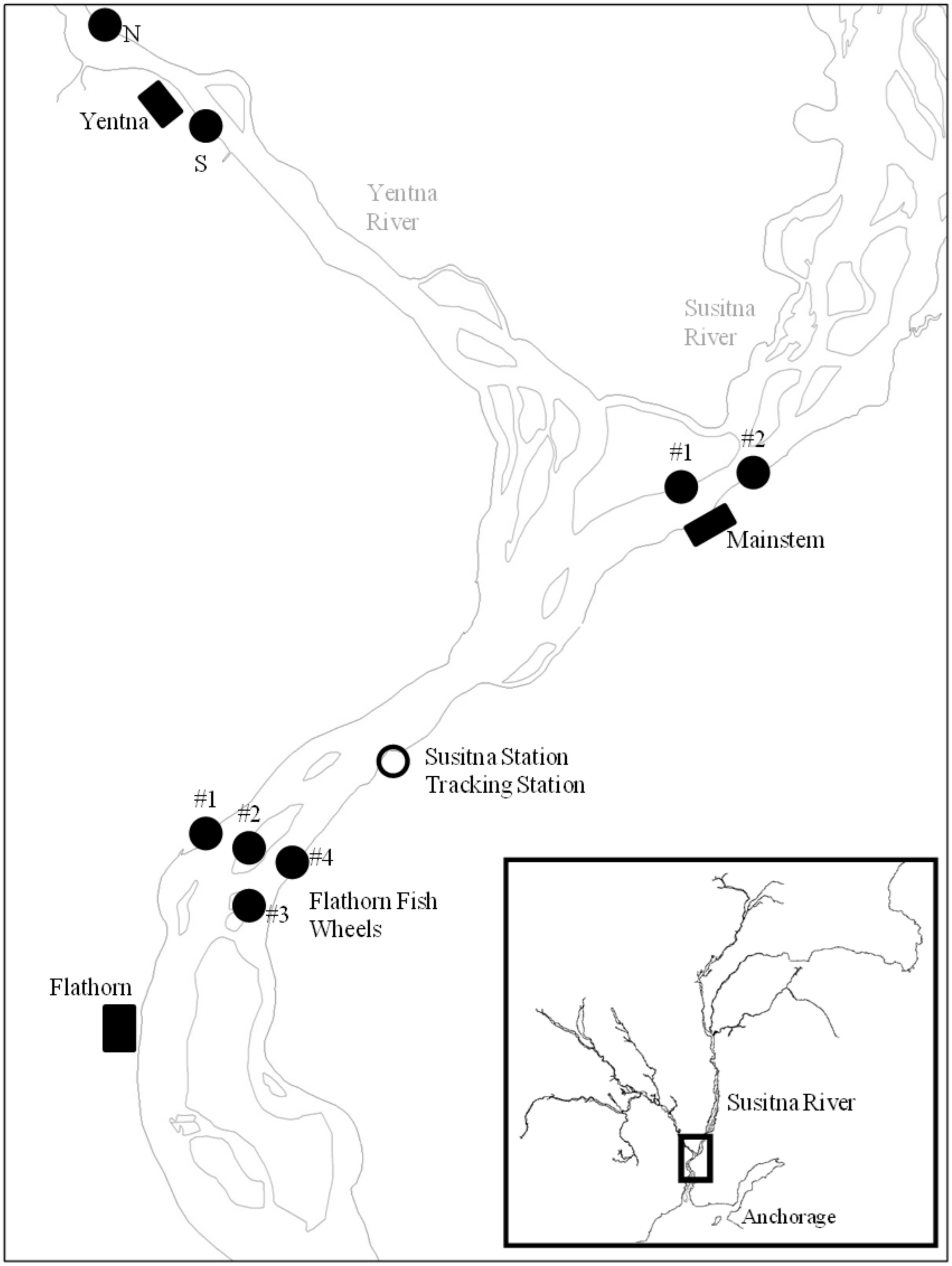

Figure 2.–Location of Flathorn, Mainstem, and Yentna fish wheels (circles), and Flathorn, Mainstem, and Yentna field camps (rectangles), and a radiotracking station (open circle), 2010.

Recapture Events

Yentna River

Two fish wheels were operated by CF on the Yentna River at RM 6.2 as part of an annual sonar project. The fish wheels were similar to the Flathorn fish wheels, and the maximum fishing depth was 4.5 ft. For tag recovery, the fish wheels were operated through 2 September from 0400 to 0830 hours, 0930 to 1400 hours, 1400 to 1830 hours, and 1930 to 2400 hours daily, for a total effort of 18 h/d/fish wheel. All fish captured were identified, counted, recorded, and inspected for the presence of a yellow dart tag; tag numbers were recorded.

Mainstem Susitna River

At the mainstem Susitna River recapture site (RM 25.5), two fish wheels were operated by SF for 12 h/d each (6 h/shift for two shifts). The fish wheels were similar in construction to those at the Flathorn site. All fish captured were counted, recorded, and inspected for the presence of a yellow dart tag. Additionally, all chum and coho salmon were examined for an adipose fin to document tag loss. Tag numbers were recorded from recaptured salmon and the numbered end of the tag was removed and saved. Length data were collected daily from the first three of each untagged chum and coho salmon captured at each wheel by each shift.

Abundance Estimation

Mark–recapture experiments were designed so that Chapman's modification to the Petersen estimator (Chapman 1951) could be used to estimate abundance of chum or coho salmon passing the Flathorn tagging site. For these estimates of abundance to be unbiased, certain assumptions must be met (Seber 1982). These assumptions, expressed in the circumstances of this study, along with their respective design considerations and test procedures were as follows:

- Assumption I: the population was closed to births, deaths, immigration, and emigration.

  Considering the short distance between the first event site at Flathorn and the two second-event sampling sites just upstream, and the life history of these species, there should have been no recruitment between sampling events. First event sampling (marking) began prior to any significant passage of fish past the tagging sites and continued until run passage dropped to near zero.

  It was anticipated that some salmon, particularly coho salmon, might travel upstream to the Flathorn site and be vulnerable to tagging, but later spawn in tributaries below Flathorn. The subsample of chum and coho salmon captured at the fish wheels and instrumented with radio tags was tracked and used to estimate the proportions of each species exhibiting this type of behavior, and to adjust the number of valid marks downward appropriately.

- Assumption II: there was no trap-induced behavior.

  There is no explicit test for this assumption because the behavior of unhandled fish cannot be observed. We attempted to meet this assumption by minimizing holding and handling time of all captured fish. Any obviously stressed or injured fish were not tagged. Examples of stress were fresh seal bites that penetrate into the muscle, capture injuries such as torn opercula or broken snouts, or being dropped in the boat while tagging.

Also, the subsample of chum and coho salmon instrumented with radio tags and tracked was used to estimate handling mortality, specifically the proportion of fish marked at each wheel that failed to continue upstream after being handled and were not found in tributaries below Flathorn.

- Assumption III: tagged fish did not lose their marks between sampling events and all marks were recognizable.

  We attempted to estimate tag loss for only part of the abundance experiments. For reasons described in the methods, fish tagged with darts in the CF fish wheel selectivity study did not receive a secondary mark. However, the adipose fin of dart-tagged fish from FWs 2, 3, and 4 was removed to make a secondary mark. Only chum and coho salmon captured at the mainstem Susitna site were examined for the presence of an adipose fin.
- Assumption IV: one of the following three conditions was met:
  1) All chum and coho salmon had the same probability of being caught in the first event.
  2) All chum and coho salmon had the same probability of being captured in the second event.
  3) Marked fish mixed completely with unmarked fish between samples.

In these experiments, it was unlikely that marked and unmarked fish mixed completely. Fish wheels were operated continuously during the run; however, probabilities of capture of both chum and coho salmon were expected to vary as their migration progressed. Fluctuations in water levels at both first and second event sampling sites can affect the efficiency of fish wheels, resulting in variation in probability of capture over time. Also, the probabilities of capture were expected to vary between fish wheel sites during both first and second events due to differences in channel morphology and water flow (Yanusz et al. 2007).

Equal probability of capture was evaluated by time, area, and length of fish. The procedures for analyzing length data for statistical bias due to gear selectivity are described in Appendix A1. Unfortunately, length data collected during second event sampling at the Yentna fish wheels were not consistent with length data collected during first event sampling at Flathorn, precluding the ability to test for size-biased sampling during the first event. As a result, only second event sampling was tested for size bias. Further, lack of second event length data precluded the ability to fully stratify the data by size, if size-biased sampling were detected.

Contingency table analyses recommended by Seber (1982) and described in Appendix A2 were used to detect significant temporal or geographic violations of assumptions of equal probability of capture. The test for complete mixing (Test I in Appendix A2) was not performed. We assumed the complete mixing condition was violated geographically because a strong tendency for bank orientation by chum and coho salmon at the Flathorn tagging site was demonstrated during the 2009 radiotelemetry study (Merizon et al. 2010) and in the 2010 data presented here. The complete mixing condition cannot be satisfied temporally, due to experimental design and the timing of movements of fish being investigated.

Abundances for both chum and coho salmon were estimated using the model developed by Darroch (1961) because temporal or geographic heterogeneity in probability of capture was detected during both sampling events. The contingency tables described in Appendix A2 were also analyzed to identify 1) first event strata (individual or contiguous groupings of temporal or geographic categories) where probability of recapture during the second event was homogeneous within strata and different between strata, and 2) second event strata where the marked:unmarked ratios were homogeneous within strata and different between strata. Temporal categories consisted of groupings of sample data collected by week, and geographic categories included fish wheel sites.

Prior to estimating abundance, it was necessary to adjust the number of marks deployed to account for fish lost due to handling as well as for fish that were not part of the populations being investigated (i.e., those that were vulnerable to capture at Flathorn but spawned below that tagging site). Fates of radiotagged fish were used to estimate losses of marked fish from the experiments. Contingency table analyses were used to test for homogeneity of loss rate over time and between tagging locations (fishwheels). Based on these analyses, mark loss strata were identified such that estimated loss rates were homogeneous within strata and different between strata. The mark loss strata were not necessarily consistent with first event strata identified based on homogeneity or probability of capture, described above. Adjusting marks for each of the first event strata required application of estimates of mark loss from 1 to 3 of the mark loss strata. For each first event stratum, the number of valid marks entering the experiment was estimated as follows:

$$\hat{M}_i = \sum_{k=1}^{K_i} M_{ik} \hat{p}_k , \tag{1}$$

where

$\hat{M}_i$ = the estimated number of valid marks in the experiment in first event stratum *I*,

M_{ik} = the number marks deployed in first event stratum *I* within mark loss stratum *k*, and

$\hat{p}_k$ = the estimated proportion of valid marks in mark loss stratum *k*.

Fates of radiotagged fish were used to estimate the following:

$$\hat{p}_k = \frac{n_{v,k}}{n_k}, \tag{2}$$

where

n_k = the number of radiotagged fish released in mark loss stratum *k*, and

$n_{v,k}$ = the portion of n_k that traveled upstream from the marking site to a spawning area.

Initial modeling was conducted using the computer program SPAS (Arnason et al. 1996), after rounding $\hat{M}_i$ values to the nearest integer. For both chum and coho salmon, admissible models were identified that contained four first-event strata and four second-event strata. These “square” models allowed for computation of an analytical solution using matrix algebra described in Seber (1982). Actual values for $\hat{M}_i$ were used in the analytical model to provide estimates of abundance for both chum and coho salmon.

Variances and 95% credible intervals for abundance estimates were estimated using Bayesian methods (Carlin and Louis 2000). Using Markov chain Monte Carlo (MCMC) methodology provided in WinBUGS software (Gilks et al. 1994), posterior distributions were generated for $\hat{p}_k$, $\hat{M}_i$, and recaptures by first and second event strata. The parameter p_k was modeled as a binomial random variable using observed values, as described in equation (2). Posterior distributions for $\hat{M}_i$ were then calculated using equation (1). Recaptures were modeled independently for each first event stratum. Recaptures by each second event stratum and marks not recaptured were modeled as a multinomial distribution with M_i components using observed data from each first event stratum. Total numbers of fish inspected for marks within each second event stratum were modeled as scalar values using observed data. The analytical 4 × 4 Darroch (1961) model was then used to generate posterior distributions for estimates of abundance. Posterior distributions for abundance by first and second event strata were also collected, as well as arithmetic combinations of strata estimates. Approximately 40,000 posterior distributions were used to generate credible intervals. Standard errors for abundance estimates were calculated as standard deviations of the posterior distributions for those estimates.

SPAWNING DISTRIBUTION

Radio Tag Application

During the marking event, fish wheels were checked at least once an hour during sampling shifts. Only uninjured chum and coho salmon greater than or equal to 400 mm METF length were radiotagged but the total catch was recorded. To minimize handling effects, coho salmon receiving a radio tag were either: 1) taken directly out of the fish wheel basket as they were captured or 2) taken out of the fish wheel live box if the hold time did not exceed 1 h (Yanusz et al. 1999; Carlon and Evans 2007). There was no hold time restriction for chum salmon that otherwise met the tagging criteria.

Tags were deployed systematically, with a fixed number of tags deployed per day by fish wheel and species. Average historical run timing (1981–1984) of chum and coho salmon at the ADF&G sonar and fish wheel camp at Yentna River (RM 6.2) was used to distribute radio tags by day over the season. Within a day, an equal number of radio tags were deployed among all four fish wheels.

All radiotagged fish were measured for METF length, a dart tag was applied adjacent to the dorsal fin, and a tissue sample (left axillary process) was collected, preserved in ethanol, and stored at the ADF&G Gene Conservation Lab in Anchorage, Alaska, for later genetic assay. To minimize capture and handling-induced stress during tagging, no anesthesia was used, fish were held in water-filled tubs, and fish were restrained in padded cradles. Handling time of radiotagged fish averaged less than 1.5 minutes.

The radio transmitters used in this project were manufactured by Advanced Telemetry Systems, Inc. (ATS, Isanti, Minnesota) and operated on 18 frequencies within the 150.000 to 151.999 MHz range. Each frequency had up to 100 different transmitting patterns (e.g., pulse codes), resulting in 800 uniquely identifiable transmitters. Transmitters were 50 mm × 17 mm long, equipped with a 30-cm antenna, and weighed 14 g in air. The battery capacity rating of the transmitters was 126 d. Each transmitter was equipped with an activity monitor as a mortality indicator. The activity monitor changed the signal pattern to an inactive mode (ATS, Isanti, Minnesota) 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.

Radio Tag Relocation

Tracking Stations

The movement of radiotagged chum and coho salmon upriver was tracked at 13 river tracking stations placed on major tributaries throughout the Susitna River drainage (Figure 1; Table 1). The Susitna Station tracking station was placed 5.0 km above the Flathorn fish wheels. If a radiotagged fish migrated above this “gateway” station, it officially entered the experiment.

Table 1.–Locations of tracking stations used to monitor the movements of radiotagged chum and coho salmon in the Susitna and Yentna rivers drainages, 2010.

		Distance (RM) from	
Drainage	Tracking station	Saltwater	Previous station
Susitna River	Susitna Station	24.9	–
	Deshka	39.6	13.5
	Sunshine	79.7	38.3
Yentna River	Lower Yentna River	36.1	11.4
	Skwentna River	86	49.9
	Upper Yentna River	99.5	63.2

Tracking station equipment consisted of an ATS Model 4500C receiver and data logger and a self-contained power system. The equipment was housed in a waterproof 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.

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 station was located approximately 3.1 RM upriver from the tagging site.

Tracking stations were visited every 14–21 days to check on the condition of the equipment and download the radio receivers. Stations in the lower drainage (Susitna Station and Lower Yentna) were at risk of overwriting due to the large number of passing radio tags. Data files were downloaded using a Windows-based program on a field laptop. Data files were then saved to the ADF&G Palmer local area network.

Aerial Surveys

A fixed-wing aircraft was used to conduct aerial surveys of the entire Susitna River drainage below Devil’s canyon. The aircraft was equipped with an ATS Model 4520C receiver and data logger and two 4-element Yagi receiving antennas, one mounted on each side of the aircraft and oriented forward. Receivers contained an integrated global positioning system to identify and record latitude and longitude. Automatically recorded data included date and time of decoding, frequency and pulse code, latitude and longitude, signal strength, and activity mode of each decoded transmitter. Data were also recorded on a form during the survey as a backup to the automated recording system and to track the number of radio tags detected during each survey.

Estimation of Spawning Distribution

The diagnostic procedures for estimating abundance, as described in Appendix A2, indicated that probability of capture was not uniform over time or between marking sites (fish wheels) for both chum and coho salmon. To minimize bias, spawning distribution was first estimated within each of the four first-event strata (described above) determined for each species. Results from the strata for each species were then combined to provide estimates of spawning distribution.

For each first event stratum, radiotagging data were used to estimate spawning distribution as follows:

$$\hat{p}_{l,s} = n_{l,s} / n_s \,, \tag{3}$$

where $\hat{p}_{l,s}$ is the estimated proportion of salmon from stratum *s* spawning in location *l*, n_s is the number of fish radiotagged in stratum *s* that travelled to a spawning location, and $n_{l,s}$ is the number of fish from n_s that travelled to location *l*.

The total number of salmon spawning in location *l* was estimated as follows:

$$\hat{N}_l = \sum_{s=1}^{4} \hat{N}_s \, \hat{p}_{l,s} \,, \tag{4}$$

where $\hat{N}_s$ is the number of fish passing the Flathorn site estimated in first event stratum *s* from the Darroch (1961) model described above. The proportion of salmon spawning in each location was estimated as follows:

$$\hat{p}_l = \hat{N}_l \Big/ \sum_{s=1}^{4} \hat{N}_s \,. \tag{5}$$

Variances and 95% credible intervals for the terms were estimated using Bayesian methods (Carlin and Louis 2000). Posterior distributions for the $\hat{p}_{l,s}$ were generated using Markov chain Monte Carlo (MCMC) methodology provided in WinBUGS software (Gilks et al. 1994). Within each first event stratum *s*, the $\hat{p}_{l,s}$ terms were modeled as a multinomial distribution with n_s components using observed data. Approximately 40,000 posterior distributions were used to generate credible intervals. Standard errors for estimates of spawning distribution were calculated as standard deviations of the posterior distributions for those estimates. MCMC modeling efforts to estimate uncertainty (variances) for abundance and spawning distribution were conducted concurrently for each species.

RESULTS

ABUNDANCE

Chum Salmon

A total of 6,879 chum salmon were captured in four fish wheels at the Flathorn site from 6 July to 30 August 2010, comprising the first event in the mark–recapture experiment. Radio tags were deployed on 375 chum salmon, distributed across the run, which were used to estimate losses of marked fish from the experiment. During second event sampling, 7,486 chum salmon were inspected for marks at fish wheels in the Yentna River and at the mainstem Susitna River site (Table 2). Of these, 160 were recaptured marked fish and 7,326 were unmarked (Table 2).

The test for size-biased sampling (Appendix A1) suggested there may have been size selectivity during second event sampling ($P = 0.052$, Appendix A1). Appropriate length data (METF) were not collected at the Yentna fish wheels during second event sampling, precluding a completely robust test for size-selective sampling during the marking event. However, we did compare the cumulative length frequency distributions of all fish inspected for marks and recaptures at the mainstem Susitna River fish wheel sites. Virtually no evidence of size-biased sampling during the first event was detected ($P = 0.999$, Figure 3), suggesting that data did not need to be stratified by size prior to estimating chum salmon abundance.

Temporal and geographical variation in probability of capture (Appendix A2) was detected during both first ($P < 0.001$) and second ($P < 0.001$) sampling events (Table 2). As a result, the partially stratified model described by Darroch (1961) was necessary for estimating abundance (Table 3).

During inspection of 1,269 chum salmon during second event sampling at the mainstem Susitna River fish wheels, all fish found with missing adipose fins had retained a yellow dart tag. Therefore, loss of dart tags during the experiment was estimated to be 0.0%.

Losses of radiotagged chum salmon, due to handling or fish failing to enter the experimental area, varied between tagging sites and over time ($P = 0.018$, Table 4). Prior to estimating abundance, the number of valid marks within each first event stratum was estimated using proportions of valid marks estimated from radiotagged fish.

Based on the model of Darroch (1961), the estimated number of chum salmon spawning upstream of the Flathorn site in the Susitna River drainage in 2010 was 356,996 (SE 48,723) with a 95% credible interval of 284,573 to 476,270 fish.

Coho Salmon

A total of 4,360 coho salmon were captured and tagged at the Flathorn site from 6 July to 30 August 2010, comprising the first event in the mark–recapture experiment. Radio tags were deployed on 344 coho salmon, distributed across the run, which were used to estimate losses of marked fish from the experiment. During second event sampling, 6,780 coho salmon were inspected for marks at fish wheels in the Yentna River and at the mainstem Susitna River site (Table 5). Of these, 170 were recaptured marked fish and 6,610 were unmarked (Table 5).

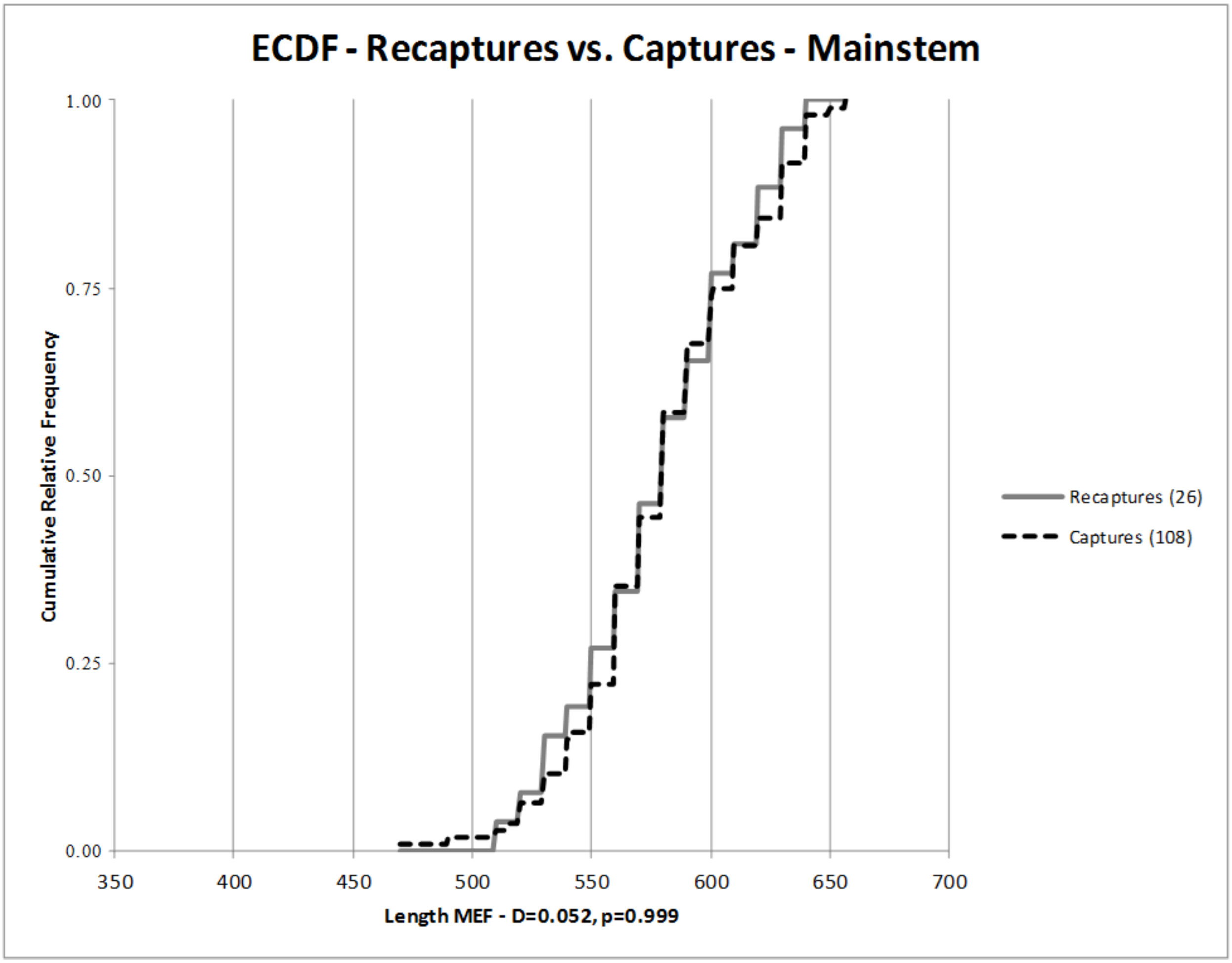

Figure 3.–Empirical cumulative distribution functions (ECDF) of length of all chum salmon inspected for marks and all recaptured chum salmon during second event sampling at mainstem Susitna River fish wheels.

Note: The Kolmogorov-Smirnov test results for equal probability of capture based on METF length during first event sampling were D = 0.052, P = 0.999.

Table 2.–Tests for temporal and geographical variation in probability of capture for Susitna River chum salmon, 2010.

Event	Parameter	Weeks 28–31		Weeks 32–36	
First event[a]					
	Location	Fish wheels 3&4	Fish wheels 1&2	Fish wheels 3&4	Fish wheels 1&2
	Marks[b]	1,892	2,261	975	1,751
	Recaptured	18	49	10	83
	Not recaptured	1,874	2,212	965	1,668
Second event[c]					
	Location	Mainstem	Yentna	Mainstem	Yentna
	Inspected	843	2,460	452	3,731
	Marked	16	22	10	112
	Unmarked	827	2,438	442	3,619

[a] Test of equal probability of capture during first event sampling: $\chi^2 = 68.164$, $P < 0.001$.

[b] Total marks deployed; not corrected for marks lost from experiment.

[c] Test of equal probability of capture during second event sampling: $\chi^2 = 31.748$, $P < 0.001$.

Table 3.–Darroch (1961) model used to estimate abundance of chum salmon spawning upstream from Flathorn in the Susitna River, 2010.

		Recaptures at 2nd event strata				
		Mainstem		Yentna		
1st event strata	Estimated valid marks	Weeks 28–31	Weeks 32–36	Weeks 28–31	Weeks 32–36	Not recaptured
Fish wheels 3 & 4, weeks 28–31	1,704.3	12	1	2	3	1,686.3
Fish wheels 3 & 4, weeks 32–36	899.5	0	7	0	3	889.5
Fish wheels 1 & 2, weeks 28–31	2,035.3	4	0	20	25	1,986.3
Fish wheels 1 & 2, weeks 32–36	1,484.5	0	2	0	81	1,401.5
Unmarked		827	442	2,438	3,619	
Inspected for marks		843	452	2,460	3,731	

Note: estimated abundance = 356,996.1 (SE 48,723)

Table 4.–Test for temporal and geographical variation in rate of mark loss for chum salmon due to handling or failing to enter the experimental area, 2010.

	Fish wheels 1 & 2			Fish wheels 3 & 4		
	Week 29	Weeks 30–32	Weeks 33–36	Week 29	Weeks 30-32	Weeks 33–36
Total radio tags	14	132	48	9	125	46
Lost	1	14	11	3	9	4
Good	13	118	37	6	116	42

Note: the test results for temporal and geographical variation were $\chi^2 = 13.606$, $P = 0.018$.

Table 5.–Darroch (1961) model used to estimate abundance of coho salmon spawning upstream from the Flathorn site in the Susitna River, 2010.

		Recaptures at 2nd event strata					
		Yentna			Mainstem		
1st event strata	Est. valid marks	Weeks 28–30	Weeks 31–32	Weeks 33–36	Weeks 28–36	Total	Not recaptured
Fish wheels 1 & 2, wks 28–29	592.0	15	6	0	0	21	571.0
Fish wheels 1 & 2, wks 30–32	2,212.9	18	75	20	5	118	2,094.9
Fish wheels 1 & 2, wks 33–36	175.9	0	0	20	0	20	155.9
Fish wheels 3 & 4, wks 28–36	740.2	2	1	1	7	11	729.2
Unmarked		2,781	2,578	617	634	6,610	
Inspected for marks		2,816	2,660	658	646	6,780	

Note: estimated abundance = 196,416.6 (SE 32,785).

The test for size-biased sampling (Appendix A1) suggested little evidence for size selectivity during second event sampling (P = 0.354, Figure 4). Appropriate length data (METF) were not collected at the Yentna fish wheels during second event sampling, precluding a completely robust test for size-selective sampling during the marking event. However, we did compare the cumulative length frequency distributions of all fish inspected for marks and recaptures at the mainstem Susitna fish wheel sites. No evidence of size-biased sampling during the first event was detected (P = 0.914, Figure 5). It was not necessary to stratify coho salmon data by size prior to estimating abundance.

Temporal and geographic variation in probability of capture (Appendix A2) was detected during both first ($P < 0.001$) and second ($P < 0.001$) sampling events (Tables 6 and 7). As a result, the partially stratified model described by Darroch (1961) was necessary for estimating abundance (Table 5).

During inspection of 646 coho salmon during second event sampling at the mainstem Susitna River fish wheels, all fish found with missing adipose fins had retained a yellow dart tag. Loss of dart tags during the experiment was estimated to be 0.0%.

Losses of radiotagged coho salmon, due to handling or fish failing to enter the experimental area, varied between tagging sites and over time (P = 0.004, Table 8). Prior to estimating abundance, the numbers of valid marks within each first event stratum was estimated using proportions of valid marks estimated from radiotagged fish.

Based on the model of Darroch (1961), the estimated number of coho salmon spawning upstream of the Flathorn site in the Susitna River drainage in 2010 was 196,417 (SE 32,786) with a 95% credible interval of 153,498 to 281,020 fish (Table 5).

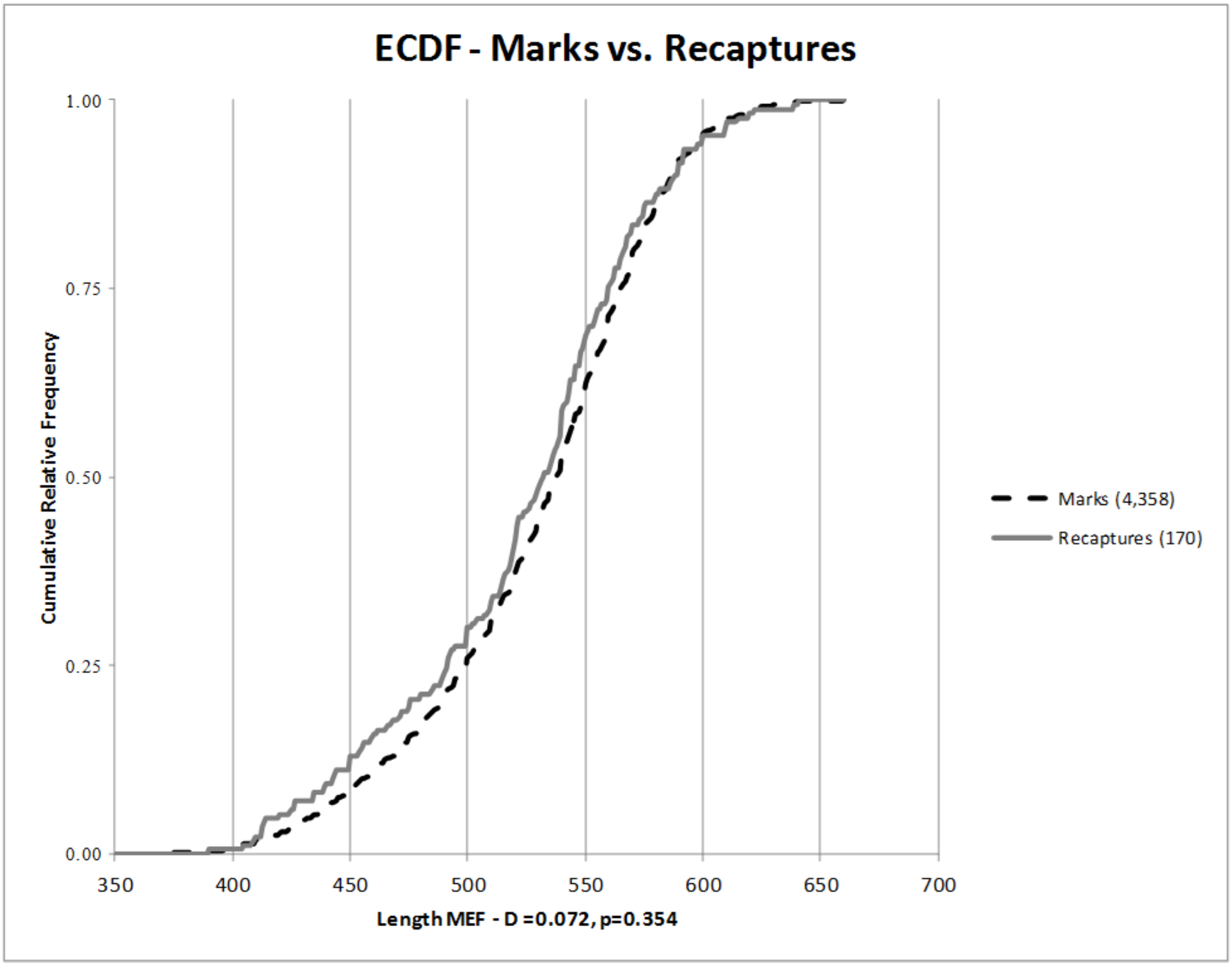

Figure 4.–Empirical cumulative distribution functions (ECDF) of length of all coho salmon marked during first event sampling at the Flathorn site and all recaptures during second event sampling.

Note: The Kolmogorov-Smirnov test results for equal probability of capture based on METF length during second event sampling were D = 0.072, P = 0.354.

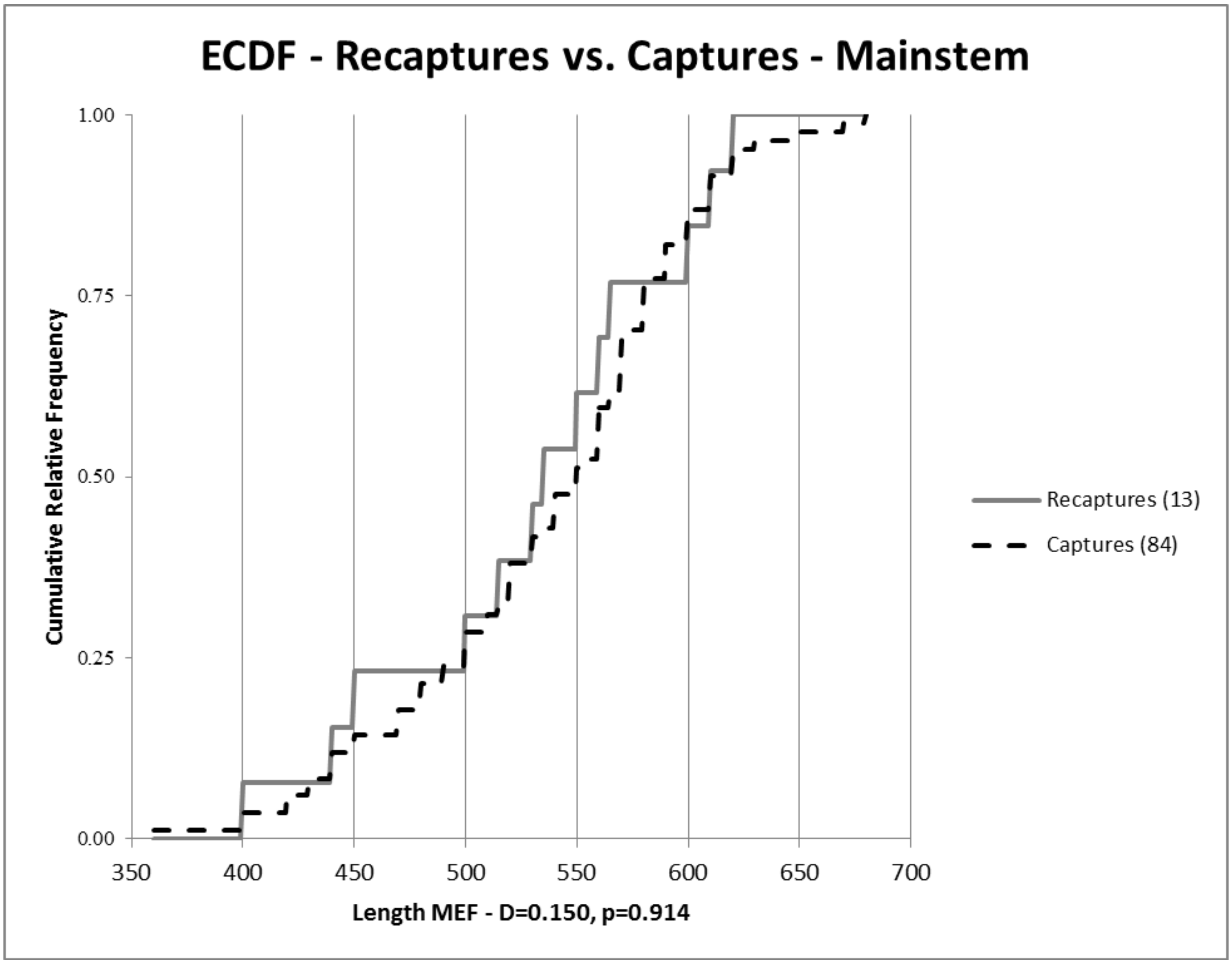

Figure 5.–Empirical cumulative distribution functions (ECDF) of length of all coho salmon inspected for marks and all recaptured coho salmon during second event sampling at the mainstem Susitna River fish wheels.

Note: The Kolmogorov-Smirnov test results for equal probability of capture based on METF length during first event sampling were D = 0.150, P = 0.914.

Table 6.–Test for temporal and geographical variation of capture for Susitna River coho salmon during first event sampling, 2010.

	Fish wheels 1 & 2			Fish wheels 3 & 4
	Weeks 28–29	Weeks 30–32	Weeks 33–36	Weeks 28–36
Marks[a]	722	2,528	210	900
Recaptured	21	118	20	11
Not recaptured	701	2,410	190	889

Note: Results of test for temporal and geographical variation were $\chi^2 = 40.818$, $P = 0.001$.

[a] Total marks deployed; not corrected for marks lost from the experiment.

Table 7.–Test for temporal and geographical variation of capture for Susitna River coho salmon during second event sampling, 2010.

	Yentna			Mainstem
	Weeks 28–30	Weeks 31–32	Weeks 33–36	Weeks 28–36
Inspected	2,816	2,660	658	646
Marked	16	82	41	12
Unmarked	2,781	2,578	617	634

Note: Results of test for temporal and geographical variation were $\chi^2 = 97.719$, $P < 0.001$.

Table 8.–Test for temporal and geographical variation in rate of mark loss for coho salmon due to handling or failing to enter the Susitna River experimental area, 2010.

	Fish wheels 1 & 2			Fish wheels 3 & 4		
	Weeks 29–30	Week 31	Weeks 32–35	Weeks 29–30	Week 31	Weeks 32–35
Total radio tags	50	52	74	49	50	69
Lost	9	1	12	12	3	6
Good	41	51	62	37	47	63

Note: results of test for temporal and geographical variation were $\chi^2 = 16.921$, $P = 0.004$.

SPAWNING DISTRIBUTION

Radio Tag Application

In 2010, a total of 6,879 chum salmon captured at fish wheels operated at the Flathorn site from 6 July to 30 August were tagged with dart tags; 374 of these were also radiotagged and used in the analyses. A total of 98 radiotagged chum salmon were released from FW 1, 95 from FW 2, 90 from FW 3, and 91 from FW 4. A total of 4,360 coho salmon were captured among the four fish wheels; 344 of these were radiotagged. A total of 94 radiotagged coho salmon were released from FW 1, 82 from FW 2, 90 from FW 3, and 78 from FW 4. Ninety percent (90%) of chum salmon and 91% of coho salmon radio tags were deployed between 11 July and 22 August (Table 9).

Table 9.–Chum and coho salmon radio tags deployed by week at the Flathorn site on the Susitna River, 2010.

Week beginning	Dates	Chum salmon[a]	Coho salmon
28	4–10 Jul	0	0
29	11–17 Jul	23	27
30	18–24 Jul	100	72
31	25–31 Jul	68	102
32	1–7 Aug	89	82
33	8–14 Aug	49	47
34	15–21 Aug	32	10
35	22–28 Aug	12	4
36	29 Aug–4 Sep	2	0
Total		375	344

[a] Only 374 radio tags were used in the analysis.

Tracking Stations

Tracking stations were installed in the Yentna River drainage between 14 and 16 June and removed on 13 September 2010. Tracking stations in the mainstem Susitna River were installed between 9 June and 7 July. A power supply problem required rewiring of the Susitna Station tracking station and therefore this station was not operational until 7 July. Tracking stations on the Susitna River were removed between 14 and 21 September 2010.

Of the radiotagged salmon released from the Flathorn site, 18 chum and 17 coho salmon had final locations determined only by ground stations. Five chum and three coho salmon were never relocated by either aerial surveys or ground tracking stations.

Aerial Surveys

Of the 719 radiotagged salmon, 671 final locations were assigned based on aerial surveys and corroborated with ground tracking stations. Aerial surveys were conducted of the mainstem Susitna River on 28 July; 19 August; 12 September; and 4, 5, 9, and 12 October 2010. Surveys of the Yentna River drainage were completed on 28 July; 23 August; 10 and 28 September; and 5 October 2010. Efforts in 2010 yielded four complete drainage-wide aerial surveys. These surveys relocated 685 different radiotagged fish (95.3% of the 719 released). All fish locations obtained by aerial survey were corroborated by available records from surface tracking stations. Of the 34 tags not detected by aerial survey, nine were detected at the Deshka tracking station, one at the Sunshine tracking station, four at the Lower Yentna tracking station, one at the Skwentna Tower, and one at the Upper Yentna Tower. Ten tags never migrated past the Susitna Station tracking station and eight were never detected by either aerial or ground tracking devices.

Spawning Locations

Radiotagged salmon were assigned one of nine movement and migration pattern descriptions. Of the 685 radiotagged salmon relocated by aerial surveys, 44.8% of chum and 58.0% coho salmon displayed progressive and constant upstream movement to their assumed spawning location (Table 10). Aerial survey data were used to assign spawning locations of chum and coho salmon. Tracking station data were used to corroborate these locations and a putative final spawning location was assigned for each fish (Tables 11 and 12).

Of the 370 radiotagged chum salmon, 332 (87.7%) were assigned a putative spawning location (Table 13, Figures 6–10). Of the 341 radiotagged coho salmon, 301 (87.5%) were assigned a putative spawning location (Table 13, Figures 11–15). The Susitna Station gateway tracking station was approximately 3.1 miles upstream from the nearest fish wheel and regarded as the point at which radiotagged salmon entered the experiment. Of the radiotagged fish, 38 chum and 40 coho salmon did not migrate upstream of the Susitna Station and were not assigned a putative spawning location. These include one chum and five coho salmon that were located in Alexander Creek, 14 km downstream of the Flathorn tagging site. Five radiotagged chum and three radiotagged coho salmon were not documented by stationary towers or aerial surveys (Table 13). Fish that were not detected and fish that did not migrate past the Susitna Station were excluded from the experiment and locations were not reflected in the final distribution map for each species.

Table 10.–Movement and migration pattern descriptions used to determine the final spawning location of radiotagged salmon relocated during aerial surveys in 2010.

		Chum salmon		Coho salmon	
Code	Movement description	Number	Percent	Number	Percent
1	Did not migrate upstream of Susitna Station	34	9.5%	41	12.4%
2	Progressive upstream movement through all aerial surveys	160	44.8%	192	58.0%
3	Progressive upstream movement except the last 1–2 aerial surveys, assigned the upstream-most location.	45	12.6%	11	3.3%
4	Initially displayed upstream movement but then displayed downstream movement >2 aerial surveys, assigned upstream-most location.	18	5.0%	2	0.6%
5	A cluster of locations (within 20 miles), assigned a known location in the middle of cluster.	57	16.0%	34	10.3%
6	A cluster of locations except 1 outlier, assigned location in the middle of cluster, unless the outlier was observed during a late season (>15 Sep) survey, then it was assigned the upstream-most location.	4	1.1%	1	0.3%
7	Migrated up river A and then had >2 locations up river B. If strong signal strengths (>120 exist among cluster in river B, then fish was assigned to river B, otherwise river A.	10	2.8%	12	3.6%
8	Single aerial relocation only.	27	7.6%	27	8.2%
9	Sport caught by angler.	2	0.6%	11	3.3%
	Total	357	100.0%	331	100.0%

The final putative spawning locations indicate that chum and coho salmon were strongly bank oriented at the Flathorn tagging site. Of the 84 chum salmon tagged on FW 1 that migrated upstream of the gateway station, 75 (89.3%) migrated up the Yentna River (Figure 7). Of the 87 chum salmon tagged on FW 4 that migrated upstream of the gateway station, 82 (94.3%) migrated up the mainstem Susitna River (Figure 10). Of the 84 coho salmon tagged on FW 1 that migrated upstream of the gateway station, 81 (96.4%) migrated up Yentna River (Figure 12). Of the 69 coho salmon tagged on FW 4 that migrated upstream of the gateway station, 66 (95.7%) migrated up the mainstem Susitna River (Figure 15).

Sport anglers voluntarily returned 18 radio tags found in coho salmon. One fish was harvested in a setnet off Salamantof Beach in Nikiski, Alaska (north Cook Inlet). There were six fish harvested in the Yentna River drainage: three in Lake Creek, one each in Peters and Indian creeks, and one at an unknown location on the Yentna River. There were nine fish harvested in the Susitna River drainage: two in the Deshka River, three in Montana Creek, and one each in Sheep, Alexander, and Little Willow creeks, and Talkeetna River. Two radio tags were returned without name, location, or method of recovery. No radio tags were found in chum salmon harvested during the 2010 fishing season.

Table 11.–Unweighted terminal distribution by fish wheel (number of fish and percent) of radiotagged chum salmon in the Susitna drainage in 2010.

	Fish wheel									
	1		2		3		4		Total	
Location	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
RM 0–24 Susitna[a]	14	14.3%	9	9.7%	11	12.5%	4	4.4%	38	10.3%
Susitna River	4	4.1%	14	15.1%	20	22.7%	31	34.1%	69	18.6%
East Side Parks Hwy[b]	0	0.0%	2	2.2%	6	6.8%	10	11.0%	18	4.9%
Deshka River	0	0.0%	0	0.0%	0	0.0%	2	2.2%	2	0.5%
Talkeetna River	3	3.1%	4	4.3%	18	20.5%	22	24.2%	47	12.7%
Chulitna River	2	2.0%	4	4.3%	17	19.3%	15	16.5%	38	10.3%
Tokositna River	0	0.0%	0	0.0%	2	2.3%	2	2.2%	4	1.1%
Yentna River	15	15.3%	12	12.9%	2	2.3%	2	2.2%	31	8.4%
West Fork Yentna River	5	5.1%	3	3.2%	0	0.0%	0	0.0%	8	2.2%
Kahiltna River	1	1.0%	2	2.2%	0	0.0%	0	0.0%	3	0.8%
Lake Creek	6	6.1%	5	5.4%	1	1.1%	0	0.0%	12	3.2%
Skwentna River	45	45.9%	31	33.3%	9	10.2%	3	3.3%	88	23.8%
Talachulitna River	0	0.0%	2	2.2%	1	1.1%	0	0.0%	3	0.8%
Johnson Creek	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Kichatna River	3	3.1%	5	5.4%	1	1.1%	0	0.0%	9	2.4%
Total[c]	98		93		88		91		370	

[a] RM 0–24 Susitna River radio tags account for all of those radio tags that did not migrate above the "gateway" tracking station (Susitna Station) including those assigned to Alexander Creek.

[b] Includes Willow Creek, Kashwitna River, Sheep Creek, and Montana Creek that drain into the Susitna River along the Parks Highway.

[c] The total does not include five chum salmon never relocated by aerial or ground relocation methods (1 from fish wheel [FW] 1, 3 from FW 2, and 1 from FW 4).

Table 12.–Unweighted terminal distribution by fish wheel (number of fish and percent) of radiotagged coho salmon in the Susitna drainage in 2010.

	Fish wheel									
	1		2		3		4		Total	
Location	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
RM 0–24 Susitna[a]	10	10.6%	11	13.6%	10	11.4%	9	11.5%	40	11.7%
Susitna River	2	2.1%	10	12.3%	19	21.6%	30	38.5%	61	17.9%
East Side Parks Hwy[b]	0	0.0%	1	1.2%	7	8.0%	7	9.0%	15	4.4%
Deshka River	1	1.1%	4	4.9%	14	15.9%	5	6.4%	24	7.0%
Talkeetna River	0	0.0%	1	1.2%	3	3.4%	4	5.1%	8	2.3%
Chulitna River	0	0.0%	2	2.5%	16	18.2%	11	14.1%	29	8.5%
Tokositna River	0	0.0%	3	3.7%	4	4.5%	9	11.5%	16	4.7%
Yentna River	24	25.5%	20	24.7%	5	5.7%	0	0.0%	49	14.4%
West Fork Yentna River	3	3.2%	1	1.2%	0	0.0%	0	0.0%	4	1.2%
Kahiltna River	8	8.5%	5	6.2%	5	5.7%	1	1.3%	19	5.6%
Lake Creek	13	13.8%	4	4.9%	2	2.3%	0	0.0%	19	5.6%
Skwentna River	14	14.9%	9	11.1%	1	1.1%	0	0.0%	24	7.0%
Talachulitna River	8	8.5%	5	6.2%	0	0.0%	1	1.3%	14	4.1%
Johnson Creek	1	1.1%	0	0.0%	0	0.0%	0	0.0%	1	0.3%
Kichatna River	10	10.6%	5	6.2%	2	2.3%	1	1.3%	18	5.3%
Total[c]	94		81		88		78		341	

[a] RM 0–24 Susitna River radio tags account for all of those radio tags that did not migrate above the “gateway” tracking station (Susitna Station) including those assigned to Alexander Creek.

[b] Includes Willow Creek, Kashwitna River, Sheep Creek, and Montana Creek that drain into the Susitna River along the Parks Highway.

[c] The total does not include three coho salmon never relocated by aerial or ground relocation methods (one from fish wheel [FW] 2 and two from FW 3).

Table 13.–Drainagewide distribution of radiotagged chum and coho salmon in the Susitna River drainage, 2010.

Drainage	Region	Chum salmon		Coho salmon	
		Number[a]	Percent	Number[b]	Percent
Susitna River					
	Susitna River mainstem (RM 0–24)[c]	37	10.0%	35	10.3%
	Alexander Creek	1	0.3%	5	1.5%
	Susitna River mainstem	62	16.8%	47	13.8%
	Deshka River	2	0.5%	31	9.1%
	Willow Creek	4	1.1%	5	1.5%
	Kashwitna River	3	0.8%	3	0.9%
	Sheep Creek	3	0.8%	2	0.6%
	Montana Creek	8	2.2%	4	1.2%
	Talkeetna River	25	6.8%	4	1.2%
	Chunilna River (Clear Creek)	19	5.1%	2	0.6%
	Sheep River	3	0.8%	1	0.3%
	Iron Creek	0	0.0%	0	0.0%
	Prairie Creek / Stephan Lake	0	0.0%	1	0.3%
	Upper Susitna River mainstem	4	1.1%	2	0.6%
	Tributaries	3	0.8%	6	1.8%
	Chulitna River	38	10.3%	29	8.5%
	Byers Lake	0	0.0%	0	0.0%
	Tokositna River	4	1.1%	16	4.7%
	Swan Lake	0	0.0%	0	0.0%
Yentna River					
	Yentna River mainstem	29	7.8%	40	11.7%
	Kahiltna River	2	0.5%	15	4.4%
	Peters Creek	1	0.3%	4	1.2%
	Lake Creek	12	3.2%	19	5.6%
	Chelatna Lake	0	0.0%	0	0.0%
	Lower Skwentna River mainstem	84	22.7%	23	6.7%
	Tributaries	0	0.0%	0	0.0%
	Shell Creek / Lake	0	0.0%	0	0.0%
	Talachulitna River	3	0.8%	8	2.3%
	Talachulitna Creek / Judd Lake	0	0.0%	6	1.8%
	Upper Skwentna River mainstem	0	0.0%	0	0.0%
	Hayes River	4	1.1%	1	0.3%
	Hewitt Creek / Lake	0	0.0%	0	0.0%
	Johnson Creek	0	0.0%	1	0.3%
	Kichatna River	9	2.4%	18	5.3%
	West Fork Yentna River	8	2.2%	4	1.2%
	East Fork Yentna River	2	0.5%	9	2.6%
	Total	370	100.0%	341	100.0%

[a] Five deployed chum salmon radio tags were never detected via either aerial or ground relocation methods.

[b] Three deployed coho salmon radio tags were never detected via either aerial or ground relocation methods.

[c] Susitna River mainstem (RM 0–24) radio tags account for all of those radio tags that did not migrate above the gateway tracking station (Susitna Station). This includes one chum and five coho salmon that were assigned a putative spawning location of Alexander Creek, which is 14 km downstream of the Flathorn tagging site.

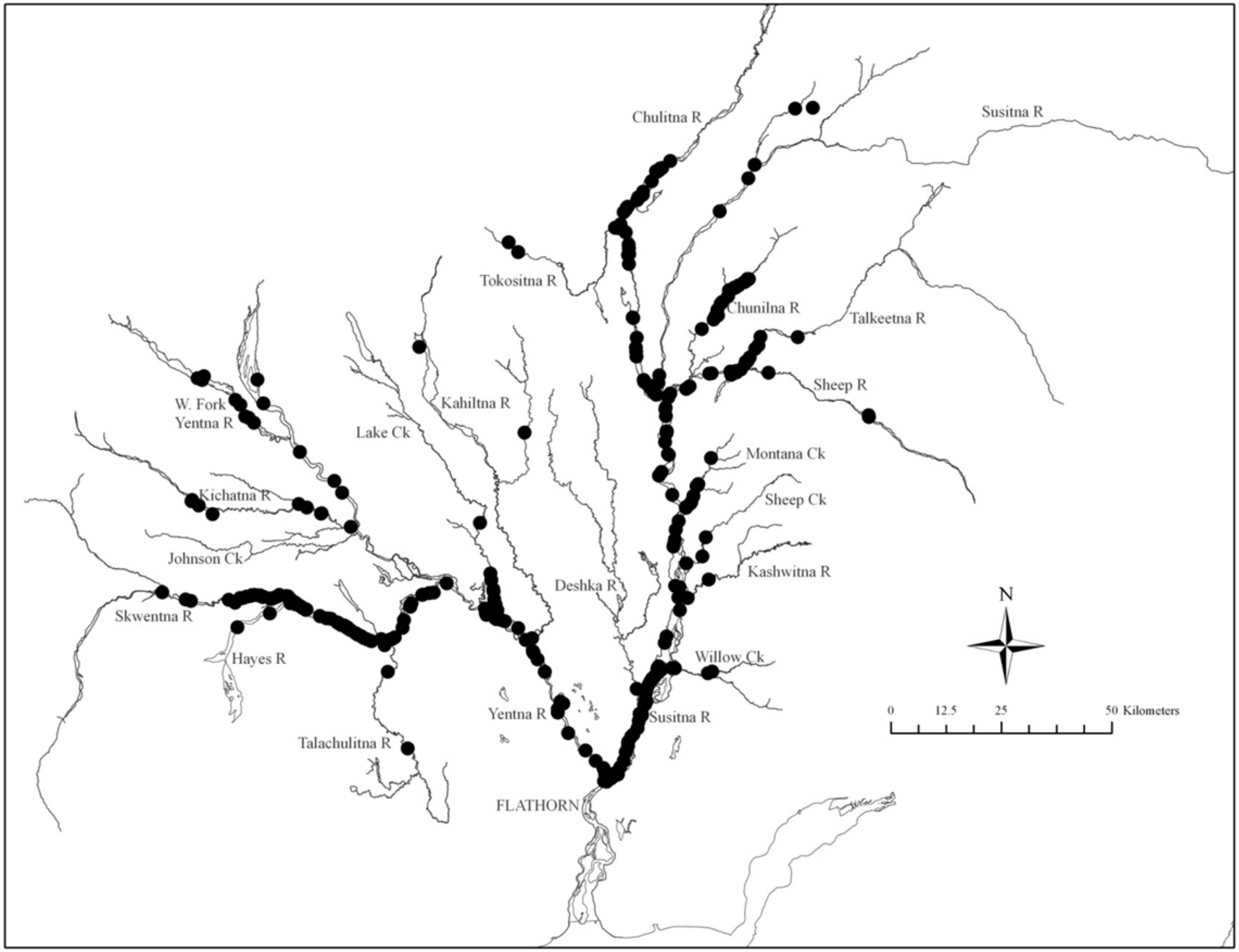

Figure 6.–Final locations of chum salmon radiotagged at all fish wheels in 2010.

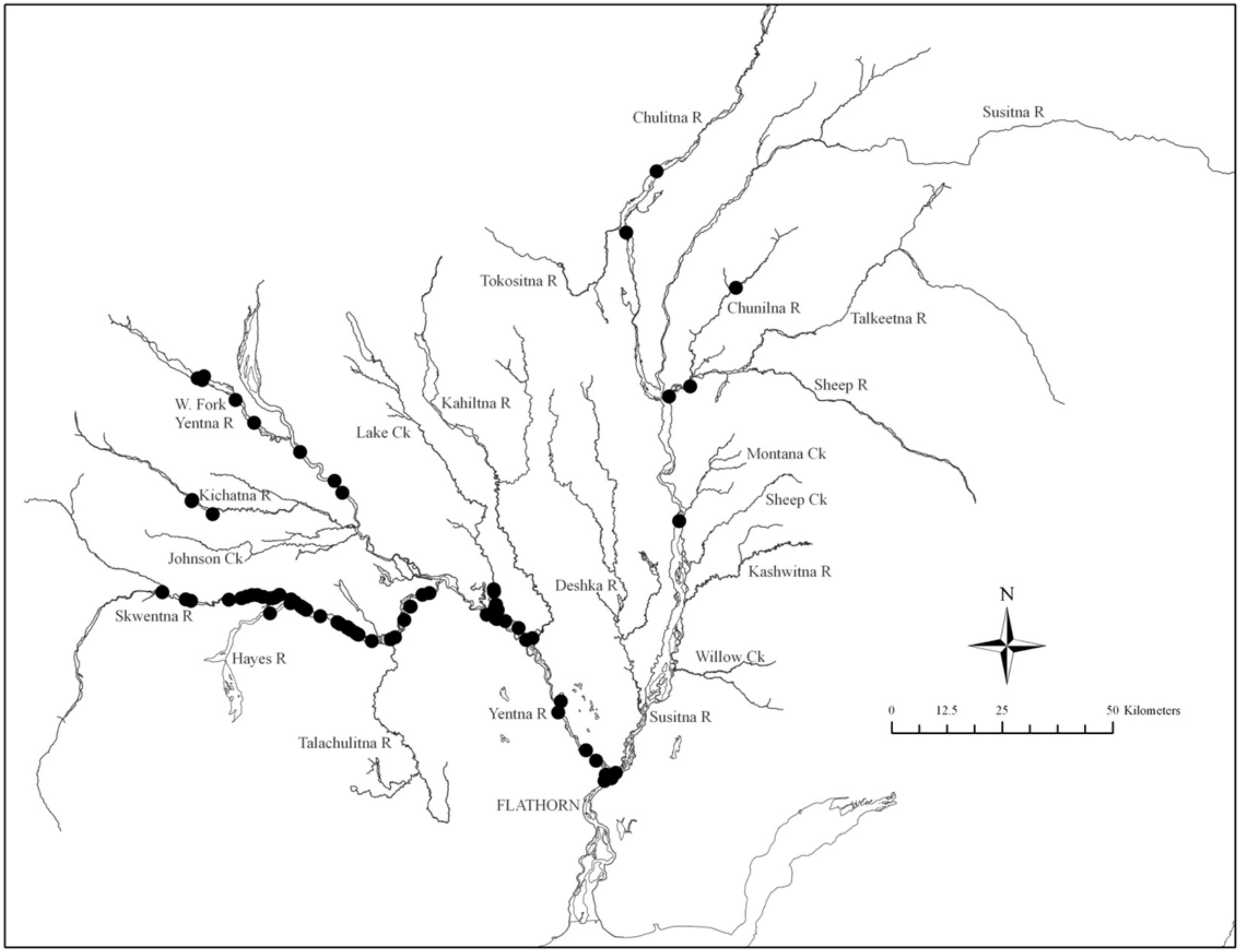

Figure 7.–Final locations of chum salmon radiotagged at FW 1, 2010.

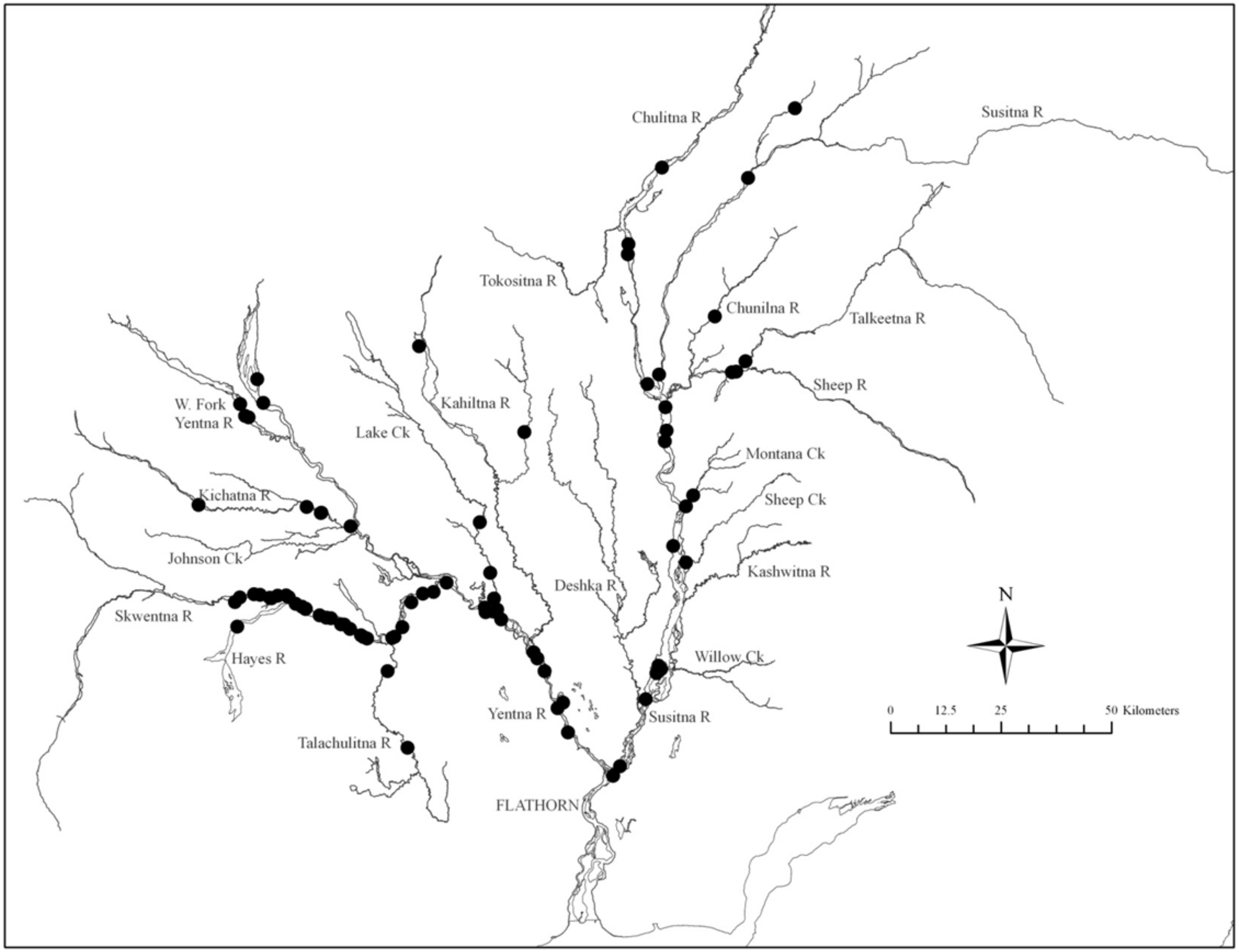

Figure 8.–Final locations of chum salmon radiotagged at FW 2, 2010.

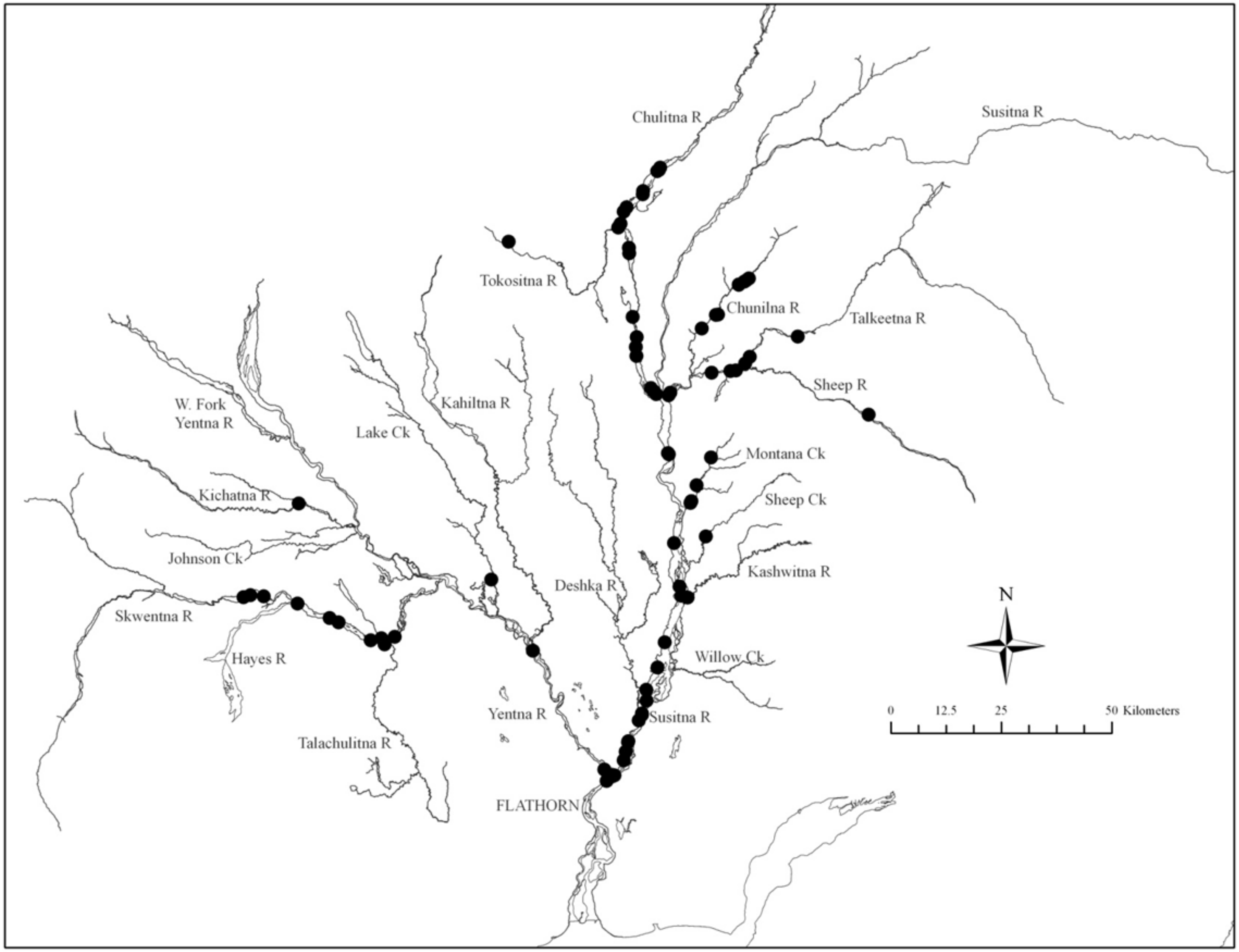

Figure 9.–Final locations of chum salmon radiotagged at FW 3, 2010.

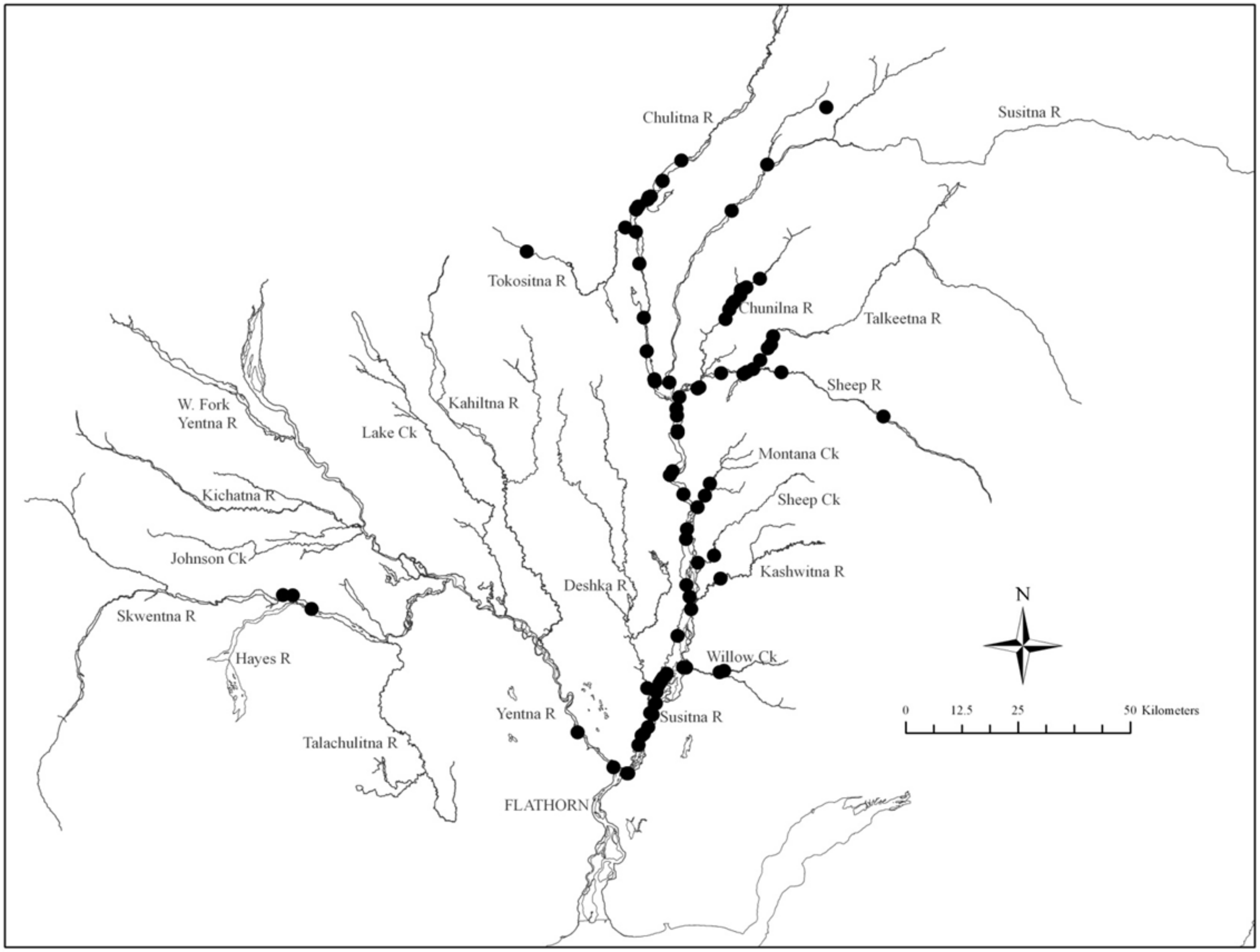

Figure 10.–Final locations of chum salmon radiotagged at FW 4, 2010.

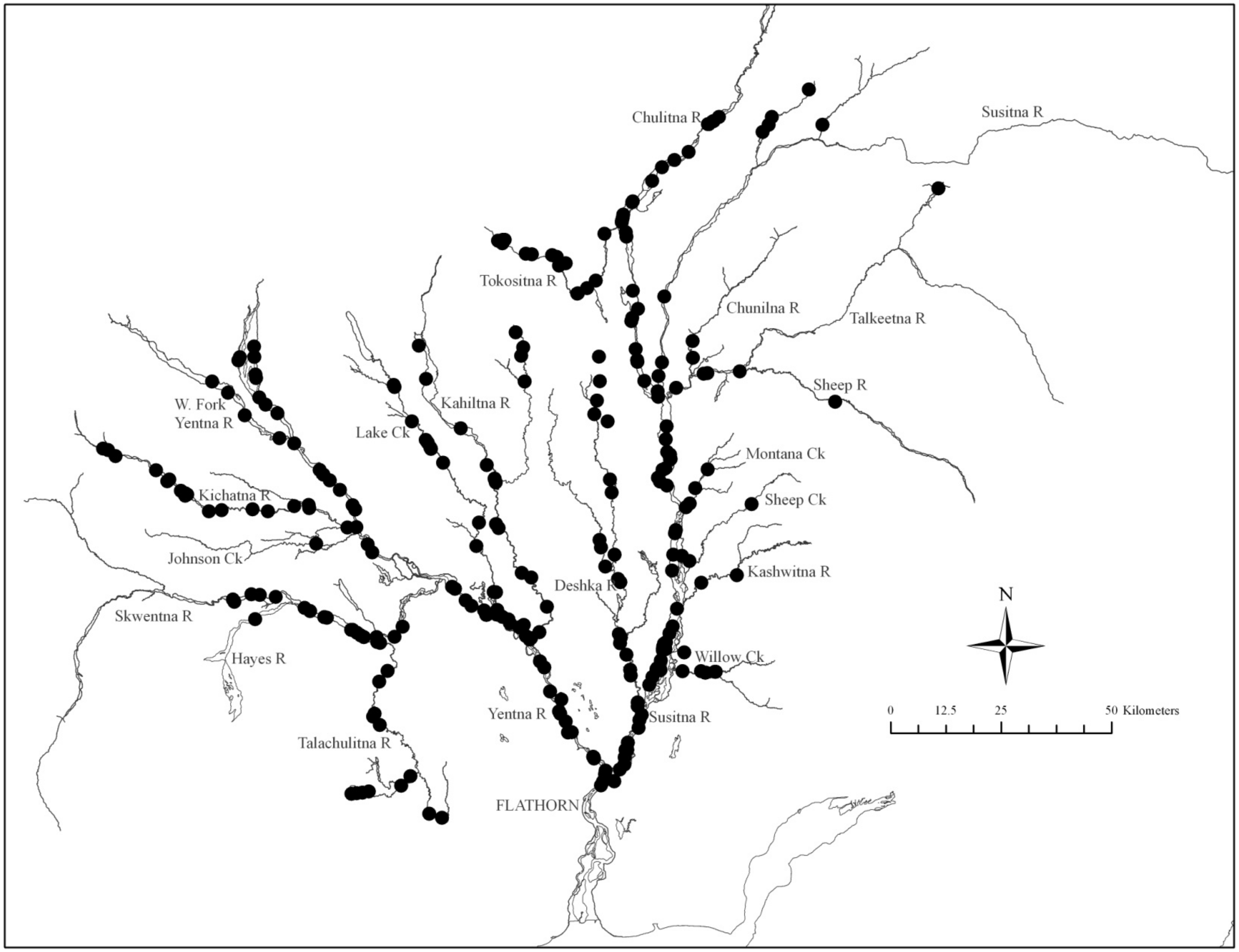

Figure 11.–Final locations of coho salmon radiotagged at all fish wheels in 2010.

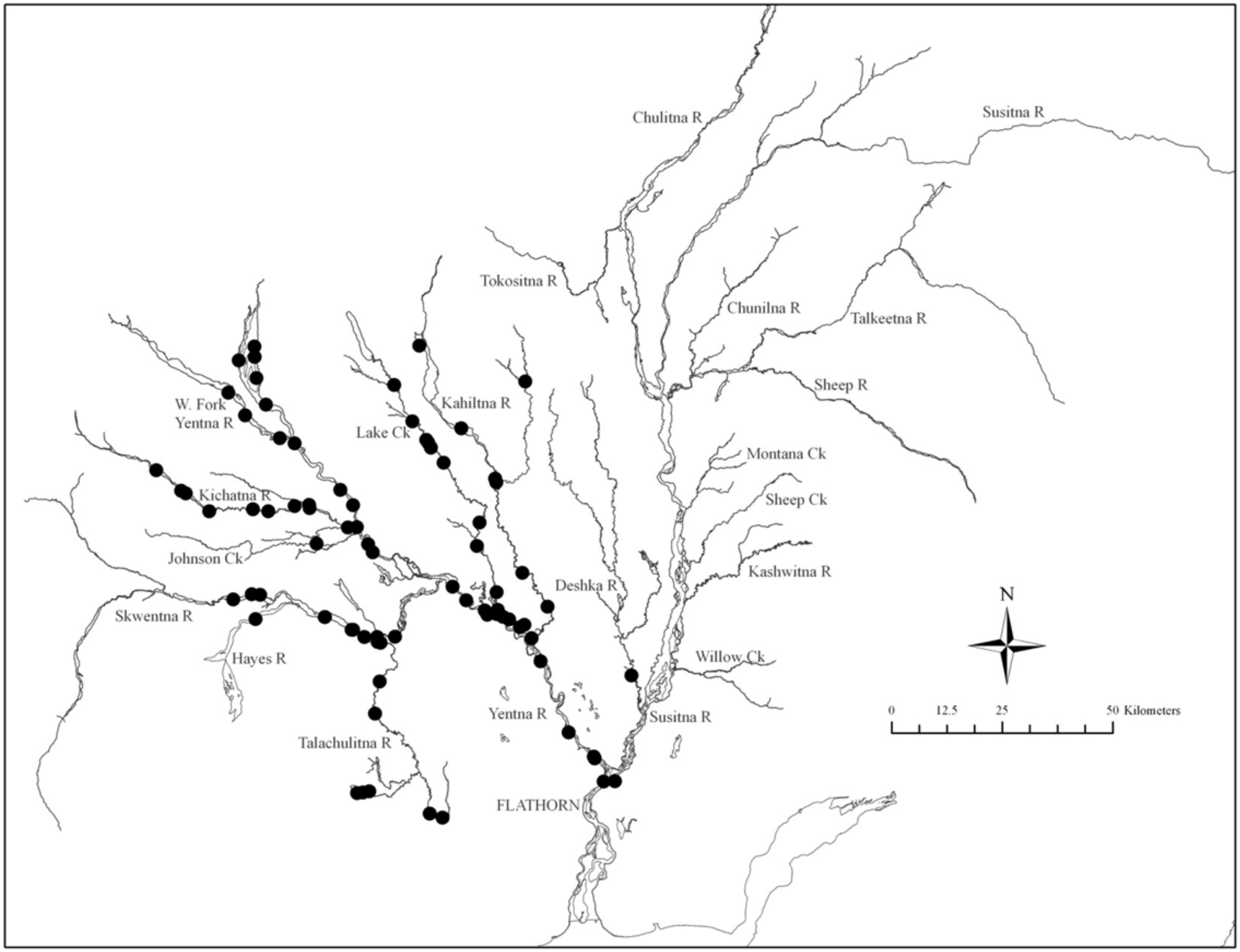

Figure 12.–Final locations of coho salmon radiotagged at FW 1, 2010.

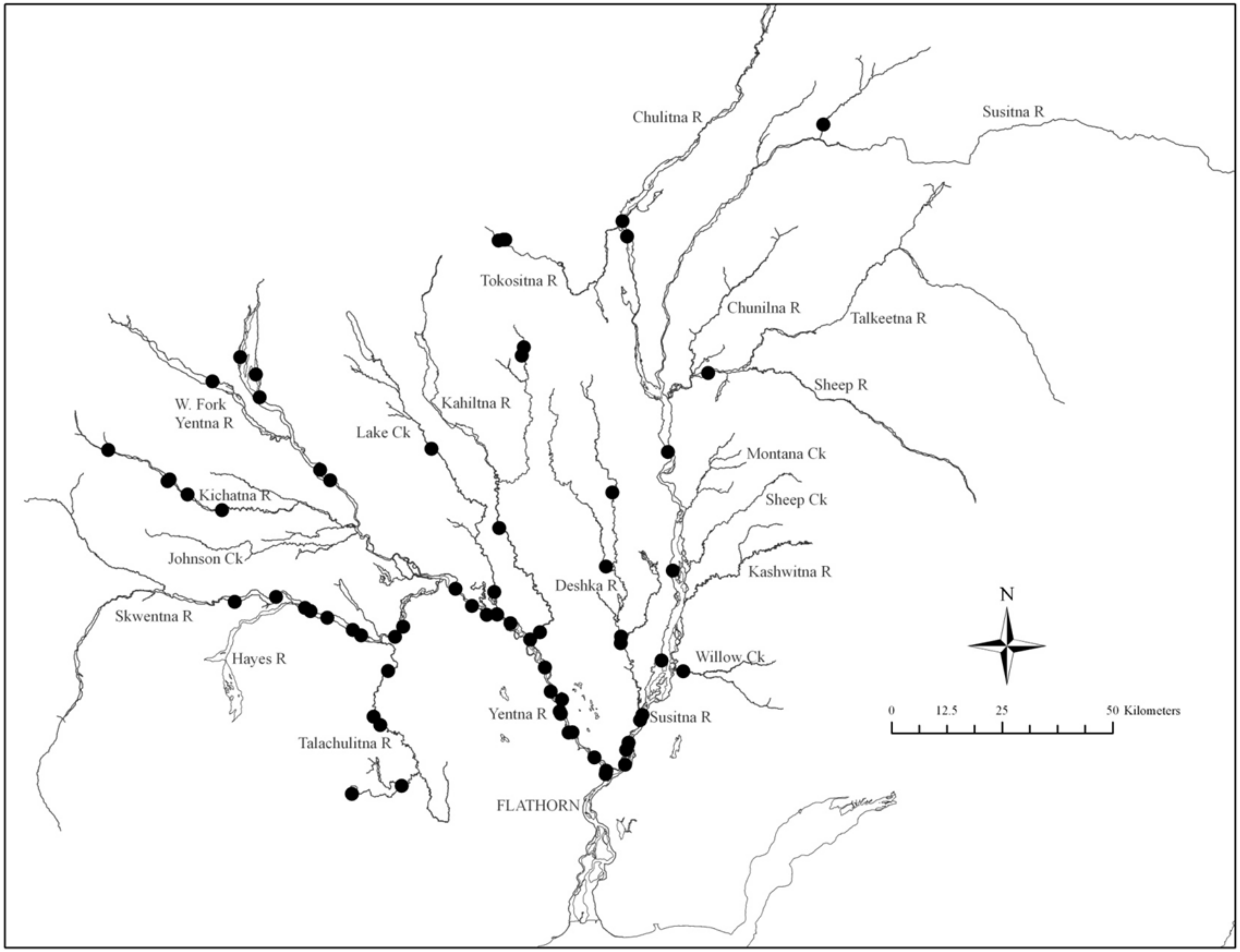

Figure 13.–Final locations of coho salmon radiotagged at FW 2, 2010.

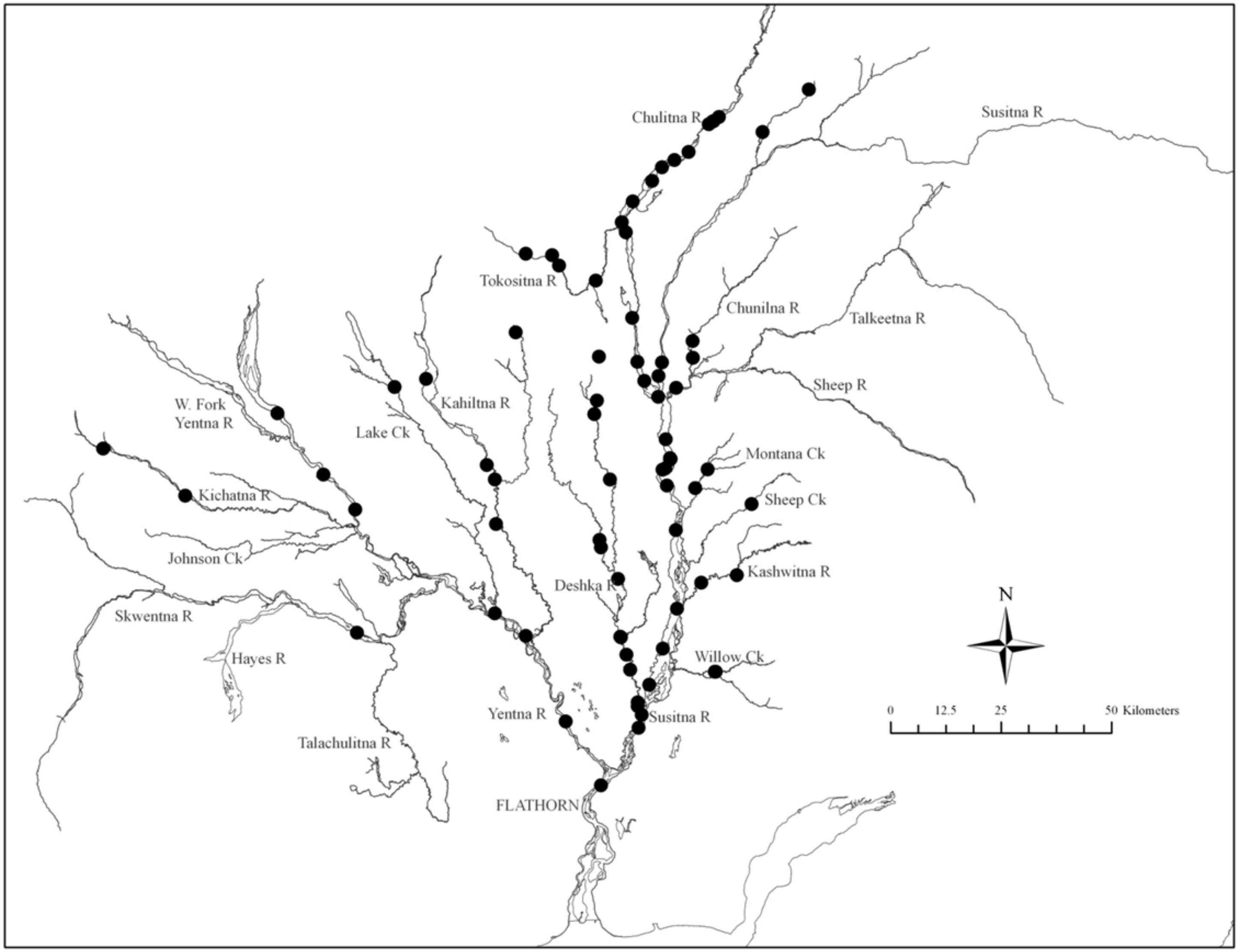

Figure 14.–Final locations of coho salmon radiotagged at FW 3, 2010.

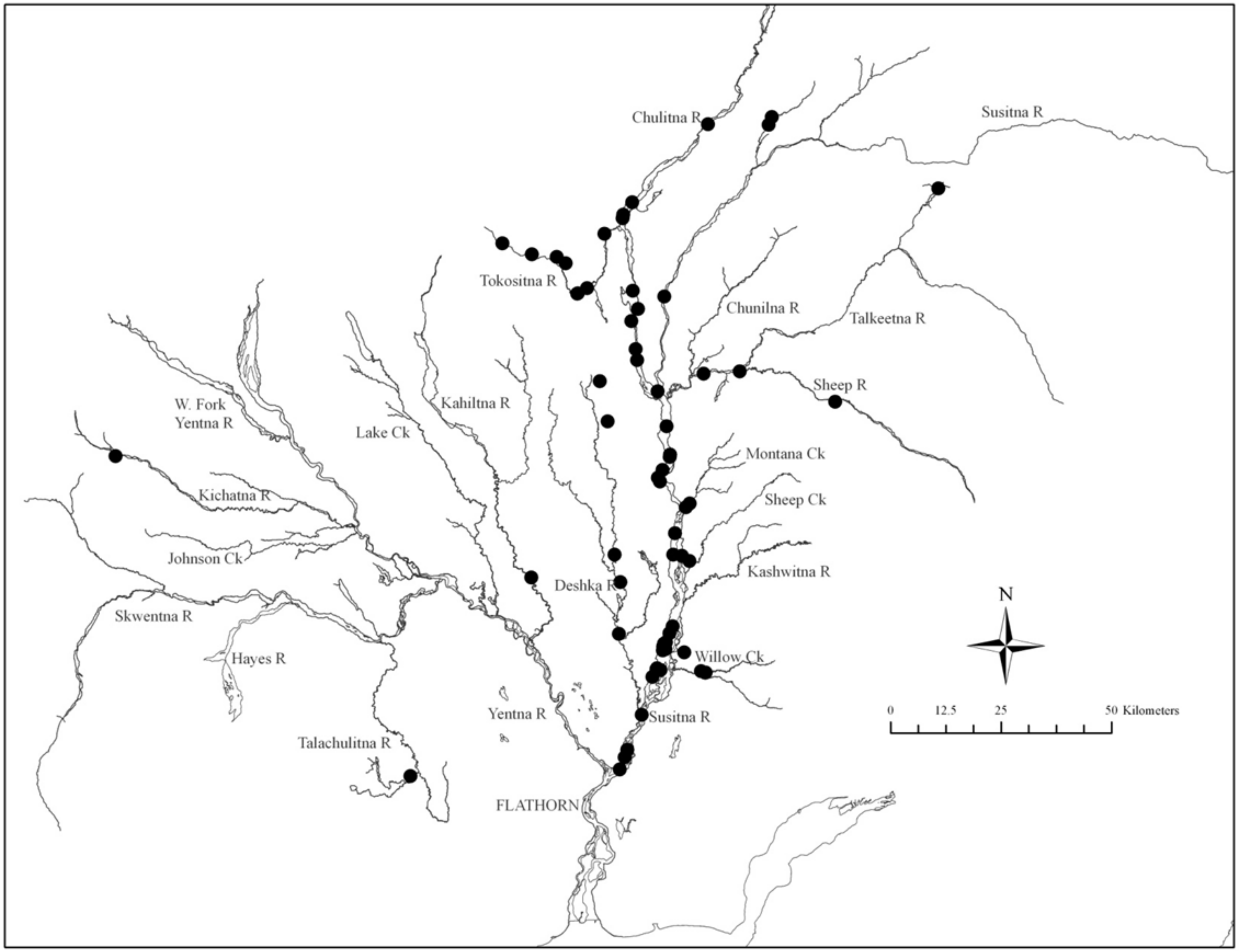

Figure 15.–Final locations of coho salmon radiotagged at FW 4, 2010.

Estimated Distribution of Spawning Salmon

Chum Salmon

Results from the mark–recapture experiment indicate that radio tags were not deployed in chum salmon proportional to passage over the course of the run. To estimate abundance of spawning salmon in different tributaries within the Susitna River drainage, the distribution of spawners was first estimated within first event strata used in the mark–recapture model and then summed across strata. The estimated abundance of radiotagged chum salmon was effectively weighted by estimated passage within each first event strata (Table 14).

Table 14.–Estimated abundance, number of radio tags deployed, and relative weights (number of spawners per tag) used to estimate abundance within first event strata for chum salmon spawning upstream from the Flathorn tagging site in the Susitna River, 2010.

1st Event strata	Estimated abundance	Estimated SE	Radio tags deployed	Relative weight spawners/tag
Fish wheels 3 & 4, weeks 28–31	51,570	36,600	83	621.3
Fish wheels 3 & 4, weeks 32–36	52,717	25,216	81	650.8
Fish wheels 1 & 2, weeks 28–31	244,187	42,283	89	2,743.7
Fish wheels 1 & 2, weeks 32–36	8,523	9,689	79	107.9

An estimated 151,127 (SE 37,564) chum salmon spawned in tributaries of the Susitna River above the mouth of the Yentna River in 2010. The number of chum salmon spawning in the Yentna River drainage in 2010 was estimated to be 205,869 (SE 30,526) fish (Table 15).

Table 15.–Chum salmon spawning distributions, based on weighted abundance (Table 14), in the Susitna River, 2010.

Location	Estimated abundance	SE	Intervals 95% lower	Intervals 95% upper
Susitna River above the Yentna River	151,127	37,564	103,911	251,314
RM 24–97 mainstem Susitna River	52,880	14,046	34,119	89,060
Deshka River	1,272	1,302	144	4,940
Eastside Susitna River	12,940	6,395	5,521	30,250
Talkeetna River	36,682	12,469	21,103	69,496
RM 97–152 mainstem Susitna River	8,110	4,289	2,517	18,730
Chulitna River	39,243	12,459	22,716	71,206
Yentna River	205,869	30,256	150,499	268,455
Yentna River mainstem	21,086	6,889	10,992	37,898
Yentna R. mainstem below Skwentna R.	18,126	6,291	9,081	33,519
Yentna R. mainstem above Skwentna R.	2,959	2,642	258	10,009
Kahiltna River	8,231	4,611	1,539	19,047
Lake Creek	9,715	4,679	3,340	21,349
Skwentna River	131,777	22,372	90,272	178,002
Talachulitna River	6,109	3,872	1,014	15,751
Upper Yentna Tributaries	28,951	8,908	13,798	48,027

Coho Salmon

Results from the mark–recapture experiment indicate that radio tags were not deployed in coho salmon in proportion to passage over the course of the run. Radiotagged coho salmon were effectively weighted by estimated passage within each first event strata from the mark–recapture experiment (Table 16).

Table 16.–Estimated abundance, number of radio tags deployed, and relative weights (number of spawners per tag) used to estimate abundance within first event strata for coho salmon spawning upstream from the Flathorn tagging site in the Susitna River, 2010.

1st Event strata	Estimated abundance	Estimated SE	Radio tags deployed	Relative weight spawners/tag
Fish wheels 1 & 2, weeks 28–29	89,213	28,720	11	8,110.3
Fish wheels 1 & 2, weeks 30–32	49,556	15,195	116	427.2
Fish wheels 1 & 2, weeks 33–36	1,177	1,330	27	43.6
Fish wheels 3 & 4, weeks 28–36	56,470	25,418	147	384.1

An estimated 73,640 (SE 25,153) coho salmon spawned in tributaries of the Susitna River above the mouth of the Yentna River in 2010. The number of coho salmon spawning in the Yentna River drainage in 2010 was estimated to be 122,777 (SE 22,697) fish (Table 17).

Table 17.–Coho salmon spawning distributions, based on weighted abundance (Table 16), in the Susitna River, 2010.

			Intervals	
Location	Estimated abundance	SE	95% lower	95% upper
Susitna River above the Yentna River	73,640	25,153	42,590	139,753
RM 24–97 mainstem Susitna River	19,256	7,601	10,330	39,120
Deshka River	9,051	3,827	4,500	19,019
Eastside Susitna River	5,805	2,944	2,450	13,413
Talkeetna River	3,116	1,748	1,129	7,631
RM 97–152 mainstem Susitna River	3,543	1,759	1,365	8,071
Chulitna River	32,868	14,376	15,056	70,524
Yentna River	122,777	22,697	89,067	178,817
Yentna River mainstem	20,763	9,270	9,128	45,320
Yentna R. mainstem below Skwentna R.	16,961	9,093	6,544	41,262
Yentna R. mainstem above Skwentna R.	3,802	1,523	1,232	7,215
Kahiltna River	15,158	8,932	5,336	39,360
Lake Creek	22,630	12,124	7,707	54,108
Skwentna River	17,509	8,794	6,145	39,520
Talachulitna River	19,770	12,070	5,423	50,456
Upper Yentna Tributaries	26,947	11,918	11,280	56,870

DISCUSSION

The 2010 abundance estimates indicated approximately 64% of chum salmon and 59% of coho salmon migrated to areas in the Susitna River upstream of the Yentna River confluence. The remaining 36% of chum salmon and 41% of coho salmon migrated to the Yentna River drainage. It was assumed that radiotagged fish that migrated past the “gateway” Susitna Station tracking station ended their migration at spawning sites. However, verifying that radiotagged fish spawned was cost prohibitive and impractical because of turbid water conditions and a large geographic area. Putative spawning sites selected by chum and coho salmon in 2010 were similar to those selected in 2009 (Merizon et al. 2010) and 1981 (ADF&G 1981). Approximately 58% of chum salmon appeared to use mainstem sites (Susitna, Yentna, and Skwentna rivers mainstems) versus 43% of coho salmon. Few chum salmon (8, 2.3%) were documented in the Kahiltna, Deshka, and Tokositna rivers. However 18% (62) of radiotagged coho salmon were documented in these rivers (Table 13).

As in the 2009 radiotelemetry study (Merizon et al. 2010), bank orientation (a stock-specific adult migration behavior) was present at the tagging fish wheels for both species (Figures 7–10 and 12–15). Although, it would be best to position the fish wheels where bank orientation is not a concern, the Susitna River downstream of the Flathorn tagging site becomes braided, shallow, and subject to tidal influence. Therefore it is unlikely that fish wheel sites, suitable for capturing migrating chum and coho salmon prior to bank orientation behavior, could be located downstream. The complete mixing condition required in a mark–recapture experiment could not be satisfied temporally in this system due to experimental design and the timing of movements of the fish being investigated. The model we used to estimate abundance for both chum and coho salmon, the partially stratified model described by Darroch (1961), allowed us to minimize bias in our estimates of abundance by accommodating heterogeneity in probability of capture (accompanied by lack of complete mixing) that was detected during both sampling events. The Darroch (1961) model also provides estimates of abundance for each temporal and geographic stratum for each sampling event. For the marking event, there were estimates of passage within each stratum. These estimates were used to weight each radiotagged fish for each first (marking) event stratum based on estimated passage and the number of radio tags deployed within each stratum. Estimates of spawning distribution were calculated based on these weighted observations of radiotagged fish, resulting in estimates of spawning distribution that were adjusted for variation in probability of capture when and where the radio tags were deployed. The imprecision or uncertainty in the weights is propagated through to our estimates of spawner distribution, so that estimates of standard errors associated with spawner distribution reflect the uncertainty about these estimates.

This approach resulted in minimally biased estimates of both abundance and spawner distribution. Bias in these estimates could result from our inability to detect all major sources of capture heterogeneity during the marking event, meaning the selected strata were not accurate. However, the strata were selected based on known logistics and realities in the field and supplemented and supported by the diagnostics tests for equal probability of capture described in Seber (1982).

The diagnostic procedures for estimating abundance, as described in Appendix A2, indicated that probability of capture was not uniform over time or between marking sites (fish wheels) for both chum and coho salmon. Contingency table analyses recommended by Seber (1982) and described here in Appendix A2 were used to detect significant temporal or geographic violations of assumptions of equal probability of capture.

In 2002, coho salmon were radiotagged in salt water in lower Cook Inlet (Willette et al. 2003). The weighted distribution determined for 2010 of radiotagged coho salmon between the Yentna (43%) and Susitna (54%) rivers is consistent with the weighted distributions determined for 2009: 43% and 56% in the Yentna and Susitna rivers, respectively (Merizon et al. 2010). The fraction of coho salmon radiotagged in 2002 was compared among five streams, and did not differ, suggesting homogenous tagging (Willette et al. 2003). In 1998, of the coho salmon caught in fish wheels and radiotagged at the Yentna site, 40% were found in Yentna River mainstem (mainstem plus east and west forks), 30% in Skwentna River, and 10% in Kichatna River (Todd et al. 2001). In 2010, the same areas had 15.5%, 14.8%, and 5.3% of radiotagged coho salmon, respectively, while the remainder of the coho salmon were located in other sites. The dissimilar results could be due to sampling bias in 1998. Chum and coho salmon radiotagged in 1981 in the upper Susitna River displayed patterns of mainstem use and tributary use similar to that in 2010 and 2009 (ADF&G 1981; Merizon et al. 2010).

The 1984, 1985, and 2010, chum and coho salmon mark–recapture projects were conducted using the Flathorn site for tag deployment. Based on these estimates, chum salmon run strength was greatest in 1984 (812,700 fish), followed by 357,000 in 2010 and 316,800 in 1985. Fish wheel mark–recapture coho salmon estimates were greatest in 2010 (196,000 fish), followed by 190,000 in 1984 and 77,000 in 1985. In 2002, coho salmon abundance was estimated at 663,000 fish and was derived by radiotagging coho salmon in Cook Inlet (Willette et al. 2003; Table 18).

Table 18.–Historical Susitna River chum and coho salmon abundance estimates.

		Site[a]			
Species	Year	Flathorn	Yentna	Sunshine	Mainstem Susitna
Chum salmon	1981	NA	19,800[b]	262,900	NA
	1982	NA	27,800[b]	430,400	NA
	1983	NA	10,800[b]	265,800	NA
	1984	812,700	26,500[b]	765,000	NA
	1985	316,800	NA	373,600	NA
	2010	357,000	202,000	NA	155,000
Coho salmon	1981	NA	17,000[b]	19,800	NA
	1982	NA	34,100[b]	45,700	NA
	1983	NA	8,900[b]	15,200	NA
	1984	190,100	18,200[b]	94,700	NA
	1985	77,400	NA	36,800	NA
	2002	NA	305,240	NA	357,991
	2010	196,000	136,000	NA	60,000

Source: 1981–1984 estimates from Barrett et al. (1985); 1985 estimates from Thompson et al. (1986); 2002 estimates from Willette et al. (2003).

[a] The Flathorn site was located at Susitna River RM 22, the Yentna site at Yentna River RM 6.2, the Sunshine site at Susitna River RM 80, and the mainstem Susitna site at Susitna River RM 25.5.

[b] Side scan sonar and fish wheel catch apportionment were used to estimate escapement.

There are a number of factors that can affect the precision of abundance estimates. For fish wheel studies, these include variation in tag deployment and recovery methods, wheel design, changes in bottom morphology at wheel sites, new locations of wheel sites, and water level effects on wheel efficiencies. Like the mark–recapture studies conducted in the 1980s, first event data collected in 2010 for chum and coho salmon were collected at the Flathorn site using fish wheels and second event data were collected upstream using fish wheels, one of which was at RM 6.2 on the Yentna River. However, unlike previous studies, fish wheels were operated in 2010 for tag recovery at RM 25.5 on the lower Susitna River downstream of previous tag recovery sites at Sunshine (RM 80), Talkeetna (RM 103), and Curry (RM 120). In addition to tag recovery data collected at fish wheels during studies in the 1980s, tag data were also collected during surveys of steams and sloughs upstream of the deployment wheels.

The radio telemetry study in 2002 (Willette et al. 2003) indicated Susitna River coho salmon run strength was greater than estimates of run strength for all other years. However the 2002 project did not collect data using fish wheels in the Susitna River. Instead, coho salmon were tagged in Cook Inlet using radio and passive integrated transponder tags and the marked fraction was estimated from radiotracking aerial surveys. The radio tags were tracked after entering the Susitna River and used to apportion the coho salmon escapements among major drainages (Willette et al. 2003; Table 17). Consequently, there is uncertainty when comparing estimates if methods are not consistent across studies and particularly when there are significant standard errors associated with an estimate or different possibilities for bias.

Partial stock assessment data have been collected for chum and coho salmon for many places in the Susitna River watershed (ADF&G, 1981, Barrett et al. 1984; Hoffman and Crawford 1986; Thompson et al. 1986; Willette et al. 2003; Ivey et al. 2007). As this spawning distribution study continues in subsequent years and results become more refined and reliable, the historical data could be viewed in the context of the entire watershed, to make it more useful. Additionally, this study provides genetic baseline samples to better define the stock composition of Susitna River chum and coho salmon runs. Such information could be useful to ADF&G when gauging land use, fishery management, or invasive species impacts to chum and coho salmon stocks.

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APPENDIX A: METHODS FOR DETECTING SIZE- OR SEX-SELECTIVE SAMPLING AND TESTS OF CONSISTENCY

Appendix A1.–Detection of size- or sex-selective sampling during a two-sample mark–recapture experiment and its effects on estimation of population size and population composition.

Size-selective sampling: The Kolmogorov-Smirnov two-sample test (Conover 1980) is used to detect significant evidence that size-selective sampling occurred during the first or second sampling events. The second sampling event is evaluated using the null test hypothesis of no difference by comparing the length frequency distribution of all fish marked during the first event (M) with that of marked fish recaptured during the second event (R). The first sampling event is evaluated by comparing the length frequency distribution of all fish inspected for marks during the second event (C) with that of R. A third test that compares M and C is then conducted and used to evaluate the results of the first two tests when sample sizes are small. Sample sizes are considered "small" if less than 30 for R and less than 100 for M or C.

Sex-selective sampling: Contingency table analysis (χ^2 test) is generally used to detect significant evidence that sex-selective sampling occurred during the first or second sampling events. The counts of observed males to females are compared between M and R, C and R, and M and C using the null hypothesis that the probability that a sampled fish is male or female is independent of the sample. If the proportions by gender are estimated for a sample (usually C), rather than observed for all fish in the sample, contingency table analysis is not appropriate and the proportions of females (or males) are then compared between samples using a two-sample test (e.g., student's t-test).

	M vs. R	C vs. R	M vs. C
Case I:	Fail to reject H_o	Fail to reject H_o	Fail to reject H_o
	Result: There is no size or sex selectivity detected during either sampling event.		
Case II:	Reject H_o	Fail to reject H_o	Reject H_o
	Result: There is no size or sex selectivity detected during the first event but there is during the second event sampling.		
Case III:	Fail to reject H_o	Reject H_o	Reject H_o
	Result: There is no size or sex selectivity detected during the second event but there is during the first event sampling.		
Case IV:	Reject H_o	Reject H_o	Either result possible
	Result: There is size or sex selectivity detected during both the first and second sampling events.		
Evaluation Required:	Fail to reject H_o	Fail to reject H_o	Reject H_o

Result: Sample sizes and powers of tests must be considered as follows:

A. If sample sizes for M vs. R and C vs. R tests are not small and sample sizes for M vs. C test are very large, the M vs. C test is likely detecting small differences that have little potential to result in bias during estimation. *Case I* is appropriate.

B. If sample sizes for M vs. R are small, the *P*-value for M vs. R is not large (~0.20 or less), and sample sizes for C vs. R are not small or the *P*-value for C vs. R is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size or sex selectivity during the second event, which the M vs. R test was not powerful enough to detect. *Case I* may be considered but *Case II* is the recommended, conservative interpretation.

C. If sample sizes for C vs. R are small, the *P*-value for C vs. R is not large (~0.20 or less), and sample sizes for M vs. R are not small or the *P*-value for M vs. R is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size or sex selectivity during the first event, which the C vs. R test was not powerful enough to detect. *Case I* may be considered but *Case III* is the recommended, conservative interpretation.

D. If sample sizes for C vs. R and M vs. R are both small, and both *P*-values for C vs. R and M vs. R are not large (~0.20 or less), the rejection of the null in the M vs. C test may be the result of size or sex selectivity during both events, which the C vs. R and M vs. R tests were not powerful enough to detect. *Cases I, II, or III* may be considered but *Case IV* is the recommended, conservative interpretation.

-continued-

Case I. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated after pooling length, sex, and age data from both sampling events.

Case II. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the first sampling event without stratification. If composition is estimated from second event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the M vs. R test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

Case III. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the second sampling event without stratification. If composition is estimated from first event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the C vs. R test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

Case IV. Data must be stratified to eliminate variability in capture probability within strata for at least one or both sampling events. Abundance is calculated using a Petersen-type model for each stratum, and estimates are summed across strata to estimate overall abundance. Composition parameters may be estimated within the strata as determined above, but only using data from sampling events where stratification has eliminated variability in capture probabilities within strata. If data from both sampling events are to be used, further stratification may be necessary to meet the condition of capture homogeneity within strata for both events. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance.

If stratification by sex or length is necessary prior to estimating composition parameters, then an overall composition parameter (p_k) is estimated by combining within-stratum composition estimates using the following:

$$\hat{p}_k = \sum_{i=1}^{j} \frac{\hat{N}_i}{\hat{N}_\Sigma} \hat{p}_{ik} \text{ and} \tag{1}$$

$$\hat{V}[\hat{p}_k] \approx \frac{1}{\hat{N}_\Sigma^2} \sum_{i=1}^{j} \left(\hat{N}_i^2 \hat{V}[\hat{p}_{ik}] + (\hat{p}_{ik} - \hat{p}_k)^2 \hat{V}[\hat{N}_i] \right) \tag{2}$$

where

J = the number of sex or size strata,

$\hat{p}_{ik}$ = the estimated proportion of fish that were age or size *k* among fish in stratum *i*,

$\hat{N}_i$ = the estimated abundance in stratum *i*, and

$\hat{N}_\Sigma$ = sum of the $\hat{N}_i$ across strata.

Appendix A2.-Tests of consistency for the Petersen estimator (from Seber 1982, page 438).

Of the following conditions, at least one must be fulfilled to meet the assumptions of a Petersen estimator:

1) Marked fish mix completely with unmarked fish between events.
2) Every fish has an equal probability of being captured and marked during event 1.
3) Every fish has an equal probability of being captured and examined during event 2.

To evaluate these three assumptions, the chi-square statistic was used to examine the following contingency tables as recommended by Seber (1982). At least one null hypothesis needs to be accepted in order to satisfy the assumptions of the Petersen model (Bailey 1951, 1952; Chapman 1951) to be valid. If all three tests were rejected, a temporally or geographically stratified estimator (Darroch 1961) was used to estimate abundance.

I.–Test for complete mixing

Area or time where marked	Area or time where recaptured (second event strata)				Not recaptured
	1	**2**	**…**	***t***	$(n_1\text{-}m_2)$[a]
1					
2					
…					
s					

Note: This tests the hypothesis that movement probabilities (θ) from first event strata i (i = 1, 2, ...s) to second event strata j (j = 1, 2, ...t) are the same for all i within each j; H_0: $\theta_{ij} = \theta_j$.

[a] n_1 = number captured in first event; m_2 = number captured in the second event that were marked.

II.–Test for equal probability of capture during the first event

	Area or time where examined (second event strata)			
	1	**2**	**…**	***t***
Marked (m_2)[a]				
Unmarked $(n_2\text{-}m_2)$[b]				

Note: This tests the hypothesis of homogeneity on the columns of this 2-by-t contingency table with respect to the marked to unmarked ratio among time or area designations; H_0: $\Sigma_i a_i \theta_{ij} = kU_j$ where θ = movement probability from first event strata i to second event strata j, k = total marks released/total unmarked in the population, U_j = total unmarked fish in stratum j at the time of sampling, and a_i = number of marked fish released in time or area stratum i.

[a] m_2 = number captured in the second event that were marked.

[b] n_2 = number captured in the second event.

III.–Test for equal probability of capture during the second event

	Area or time where marked (first event strata)			
	1	**2**	**…**	***s***
Recaptured (m_2)[a]				
Not Recaptured $(n_1\text{-}m_2)$[b]				

Note: This tests the hypothesis of homogeneity on the columns of this 2-by-s contingency table with respect to recapture probabilities among time or area designations; H_0: $\Sigma_j \theta_{ij} p_j$ = d where θ = movement probability from time or area stratum i to section j, p_j is the probability of capturing a fish in section j during the second event, and d is a constant.

[a] m_2 = number captured in the second event that were marked.

[b] n_1 = number captured in the first event.