Fishery Data Series No. 16-35

Abundance and Spawning Distribution of Susitna River Chum *Oncorhynchus keta* and Coho *O. kisutch* Salmon, 2011

by

Peter M. Cleary

Richard J. Yanusz

Jack W. Erickson

Daniel J. Reed

Raye Ann Neustel

and

Nicole J. Szarzi

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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

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Peter M. Cleary
Richard J. Yanusz
Jack W. Erickson
Daniel J. Reed
Raye Ann Neustel
and
Nicole J. Szarzi

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

Jack W. Erickson,
Alaska Department of Fish and Game, Division of Sport Fish,
333 Raspberry Road, Anchorage, AK 99518-1565, USA

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

Raye Ann Neustel,
Alaska Department of Fish and Game, Division of Sport Fish,
333 Raspberry Road, Anchorage, AK 99518-1565, USA

and

Nicole J. Szarzi, retired,
Alaska Department of Fish and Game, Division of Sport Fish,
3298 Douglas Place, Homer, AK 99603- 8027, USA

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ABSTRACT

In 2009, the Alaska Department of Fish and Game began a 4-year spawning distribution and abundance estimation study in response to concerns over the status of the Susitna River chum (*Oncorhynchus keta*) and coho (*O. kisutch*) salmon stocks. This report summarizes results of mark–recapture abundance and distribution assessments completed during 2011. Four fish wheels were used to capture and tag chum and coho salmon with dart tags at river mile (RM) 22 in the Susitna River in July and August 2011. Two fish wheels were used at RM 7 in the Yentna River and 2 fish wheels were used at RM 34 in the mainstem Susitna River to sample salmon for tags. Estimated abundance of chum salmon was 1,473,969 (SE 123,933) fish for the mainstem Susitna River and 278,063 (SE 42,780) fish for the Yentna River. Estimated abundance of coho salmon was 131,878 (SE 24,146) fish for the mainstem Susitna River and 84,677 (SE 9,981) fish for the Yentna River. A total of 734 radio tags were placed in chum and coho salmon. Their movements were tracked using 6 ground tracking stations, 7 aerial surveys of the mainstem Susitna River, 6 aerial surveys of the Yentna River, and 3 drainagewide aerial surveys. All but 31 of the radio tags were relocated, and 635 (86.5%) were assigned a putative spawning location. Both chum and coho salmon exhibited bank orientation at the tagging site.

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 stocks contribute to commercial and sport harvests in upper Cook Inlet (UCI). The 1966–2011 average commercial harvest in UCI was 446,027 chum salmon and 301,596 coho salmon (Shields and Dupuis 2013). Annual sport harvests from the Susitna River averaged 2,569 chum and 36,606 coho salmon from 1998 to 2011 (calculated from tables in Oslund et al. 2013).

From 1981 through 1985, fishery studies were conducted for a proposed Susitna River hydroelectric project. To estimate abundance, chum and coho salmon data were collected from the Yentna River at river mile (RM) 6.2 (Yentna Site) from 1981 through 1984, at the Sunshine Site (RM 80 of the Susitna River) from 1981 through 1985, and at the Flathorn Site (RM 22 of the Susitna River) 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 Susitna River drainagewide coho salmon estimate of 663,000 fish was generated using mark–recapture techniques (Willette et al. 2003). During that study, 179 coho salmon were radiotagged in Cook Inlet and tracked to the Susitna River drainage. Results of this study provided the first drainagewide spawning distribution information for coho salmon.

User groups have been concerned over the status of coho and chum salmon stocks in the Susitna River and have brought the issue before the Alaska Board of Fisheries (BOF). At the 2008 BOF meeting, there were 69 proposals to modify commercial fishing regulations in UCI and 2 proposals for sport fishing regulations in the Susitna River, demonstrating the importance of the fisheries. In addition, the BOF issued resolution 2008-253-FB to the Alaska Legislature supporting funding for fisheries research. 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 4-year spawning distribution study (2009–2012) using radio telemetry. In 2010, ADF&G added an abundance estimation component. The objectives for 2011 were to use mark–recapture techniques and radiotagging to 1) estimate inriver abundance of adult chum and coho salmon above the Flathorn Site, 2) identify chum and coho salmon spawning locations throughout the Susitna River drainage by fishwheel tagging site, and 3) estimate the proportions of chum and coho salmon spawning in 15 major tributaries (or groupings of minor tributaries).

STUDY AREA

The Susitna River watershed, the fourth largest drainage in the state of Alaska, is 49,210 km^2 and originates in the Alaska Range north of Anchorage (Figure 1). The Susitna River 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 have clear water, whereas others are glacially turbid (Sweet et al. 2003). The largest tributaries are the Yentna, Chulitna, and Talkeetna rivers, and there are numerous small lakes (King and Walker 1997).

METHODS

ABUNDANCE

Abundances of chum and coho salmon were estimated using 2-sample mark–recapture techniques.

Marking Events

Four fish wheels were operated in 2011 at the Flathorn Site (RM 22 Susitna River): 1 on each bank and 2 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. The Division of Sport Fish (SF) crews operated fish wheel (FW) 2, 3, and 4 from 6 July through 29 August 2011. On 11 August, SF assumed operations of FW 1 when the Division of Commercial Fisheries (CF) concluded a separate study on fish wheel selectivity.

SF crews, working two 7.5-hour 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 9-hour shifts each day, operated FW 1 until reaching the goal of 18 h/d of 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 11 August. All fish wheels operated each day except when repairs were needed or high water events occurred.

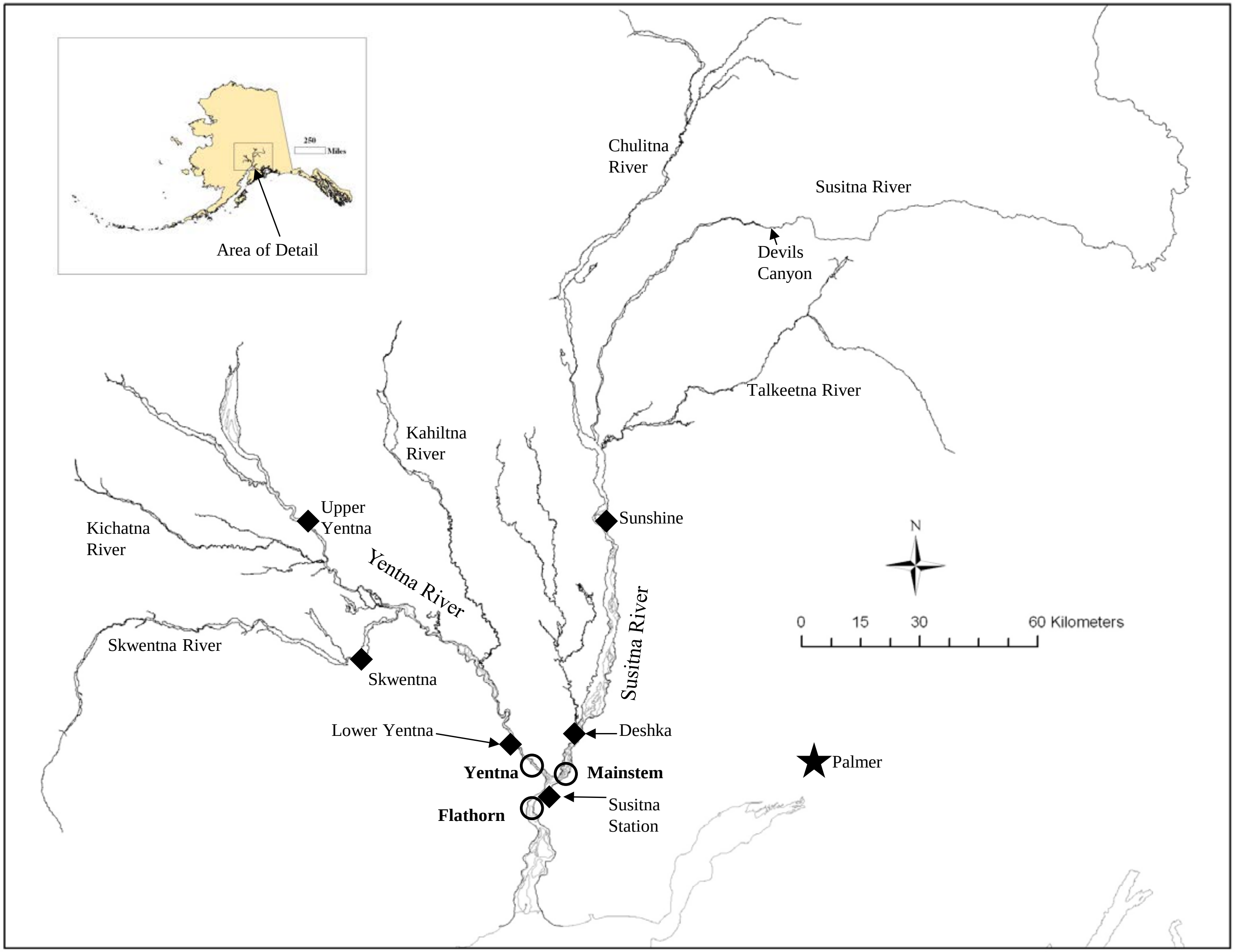

Figure 1.–Locations of Flathorn, Mainstem, and Yentna fish wheel sites (circles) and fixed radiotracking stations (diamonds) in the Susitna River drainage, 2011.

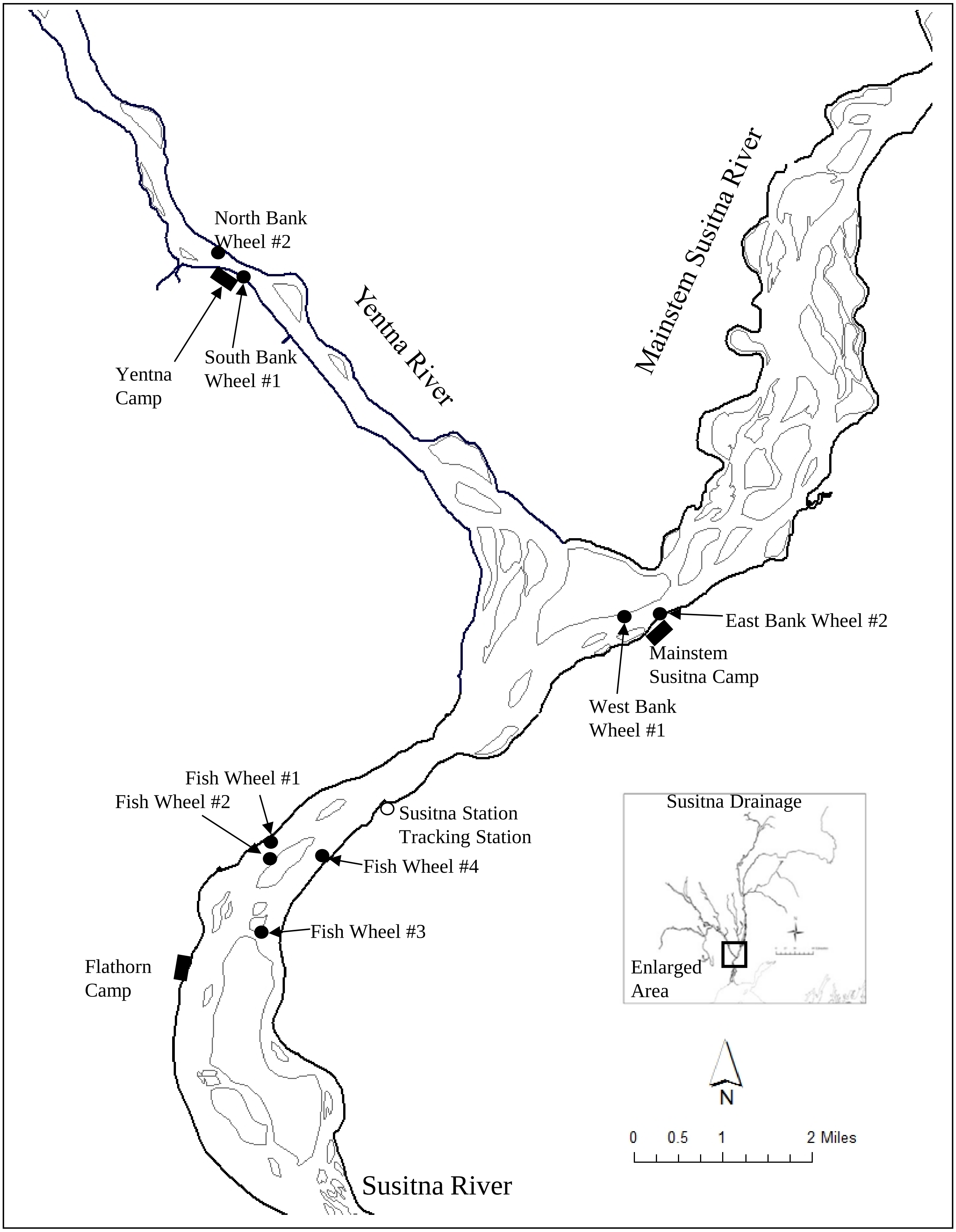

Figure 2.–Location of Flathorn, Mainstem, and Yentna fish wheels (circles); Flathorn, Mainstem, and Yentna field camps (rectangles); and a radiotracking station (open circle).

Fish wheels were constructed of aluminum, with two 6.5 ft × 6.6 ft 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 a live box. Live boxes measured 8 ft long, 2 ft wide, and 3 ft deep, with plywood sides with holes for water exchange. The configuration of the fish wheel axle, baskets, and floats allowed the baskets to reach a maximum depth of 6.5 ft. Fish wheels were secured to the riverbank and held offshore with poles to reach sufficient current and depth to spin the baskets. The axle height was adjusted so that the baskets swept as close to the river bottom as possible. Picket weirs were installed between the fish wheel and the riverbank on each wheel to direct migrating salmon away from the bank and towards the fish wheel baskets.

Throughout the season at all FWs 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, 6-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, the adipose fin was removed from dart-tagged salmon as a secondary mark to detect tag loss and at FW 1 when SF began tagging fish. 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. For this reason, the CF crew did not remove the adipose fin on dart-tagged salmon during the selectivity study. 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.

Recapture Events

Yentna River

Two fish wheels were operated by CF on the Yentna River at RM 6.2 (Yentna Site) as part of an annual sonar project to assess sockeye salmon abundance and run timing. The fish wheels were similar to the Flathorn Site fish wheels except the maximum fishing depth was 4.5 ft. For tag recovery, the fish wheels were operated from 7 July 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 captured fish were identified, counted, recorded, and inspected for the presence of a yellow dart tag. If a tag was discovered, the tag number was recorded, and the end of the tag with the number was cut off and saved. When CF was sampling, chum and coho salmon lengths were taken in proportion to the previous day's fish wheel catch on each bank using the sampling rate of 3% for coho salmon and 18% for chum salmon. When SF was sampling, METF length was measured for the first 3 of each untagged chum and coho salmon captured at each wheel by each shift for a total of up to 12 chum salmon and up to 12 coho salmon every day.

Mainstem Susitna River

At the mainstem Susitna River recapture site (RM 30; Mainstem Site), 2 fish wheels were operated by SF for 12 h/d each (6 h/shift for 2 shifts) from 6 July through 31 August. The fish wheels were similar in construction to those at the Flathorn Site. All captured fish were counted, recorded, and inspected for the presence of a yellow dart tag. Additionally, all chum and coho

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

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 3 of each untagged chum and coho salmon captured at each wheel by each shift for a total of up to 12 chum salmon and up to 12 coho salmon each day.

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:

1) Assumption I—the population is closed to births, deaths, immigration, and emigration.

   Considering the short distance between the first-event site at Flathorn and the 2 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 the Flathorn Site. The subsample of chum and coho salmon that was 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, which was then used to adjust the number of valid marks downward appropriately.

2) Assumption II—there is 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 include fresh seal bites or other scars that penetrated into the muscle, capture injuries such as torn opercula or broken snouts, or being dropped in the boat while handling.

   Also, the subsample of chum and coho salmon instrumented with radio tags and then 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 the Flathorn Site.

3) Assumption III—tagged fish do not lose their marks between sampling events and all marks are 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 Site were examined for the presence of an adipose fin.

4) Assumption IV—at least 1 of the following 3 conditions must be met:
    a) All chum and coho salmon have the same probability of being caught in the first event.
    b) All chum and coho salmon have the same probability of being captured in the second event.
    c) Marked fish mix completely with unmarked fish between samples.

In these experiments, it was unlikely that marked and unmarked fish mixed completely. Furthermore, although fish wheels were operated throughout the run, probabilities of capture of both chum and coho salmon were expected to vary as their migration progressed. For example, 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. Size-biased sampling was detected during both first and second sampling events for both chum and coho salmon. As a result, data sets for each species were stratified into 2 size strata.

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. Tests were conducted for each size stratum for each species. The test for complete mixing (Test I in Appendix A2) was not performed. We assumed the complete mixing condition was violated geographically because of a strong tendency for bank orientation by chum and coho salmon at the Flathorn tagging site that was detected during the 2009 radiotelemetry study (Merizon et al. 2010), the 2010 mark–recapture experiments (Cleary et al. 2013), and in the data presented in this report. The complete mixing condition cannot be satisfied temporally due to experimental design and the timing of movements of fish being investigated.

Given that temporal or geographic heterogeneity in probability of capture was detected during both sampling events (violation of Assumption IV), abundances within size strata for both chum and coho salmon were estimated using the model developed by Darroch (1961). 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 ratios of marked to unmarked fish were homogeneous within strata and different between strata. Temporal categories comprised groupings of sample data collected by week, and geographic categories comprised fish wheel sites.

Length data were not available for a small number of marked chum and coho salmon. Because complete size stratification of the data was required prior to temporal and geographic stratification, the probabilities that individual marked fish of unknown length were in each size stratum were estimated. The probability that fish *f* was in size stratum *z* was estimated as follows:

$$\hat{p}_{f,z} = \frac{n_{w,d,z}}{n_{w,d}} \tag{1}$$

where

$\hat{p}_{f,z}$ = the estimated probability that fish *f* was in size stratum *z*,

$n_{w,d}$ = the number of fish of known length tagged at wheel *w* on day *d*, and

$n_{w,d,z}$ = the number of fish in $n_{w,d}$ in size stratum *z*.

Within each size stratum *z*, the number of marked fish released in each first-event geographical-temporal (G-T) stratum *s*, was estimated as follows:

$$\hat{M}_{(\mathrm{Rel})z,s} = M_{(\mathrm{Rel},kn-l)z,s} + \sum_{f=1}^{F} I(z,s)\hat{p}_{f,z} \tag{2}$$

where

$I(z,s)$ = 1 if fish *f* was in G-T stratum *s* within size stratum *z*; 0 otherwise. Note that G-T strata can differ within each size stratum,

$M_{(\mathrm{Rel},kn-l)z,s}$ = the number of marked fish of known length ($_{kn\text{-l}}$) released ($_{\mathrm{Rel}}$) in size stratum *z* in G-T stratum *s*, and

F = number of marked fish of unknown length.

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 the Flathorn Site but spawned below that tagging site or those harvested by anglers). Fates of radiotagged fish were used to estimate losses of marked fish from the experiments. Within each size stratum, for each first-event G-T stratum, the number of valid marks entering the experiment was estimated as follows:

$$\hat{M}_{z,s} = \hat{M}_{(\mathrm{Rel})z,s}\,\hat{p}_{z,s} \tag{3}$$

where

$\hat{p}_{z,s}$ = the estimated proportion of valid marks in size stratum *z* in G-T stratum *s*.

Fates of radiotagged fish were used to estimate

$$\hat{p}_{z,s} = \frac{n_{(\mathrm{Sp})z,s}}{n_{z,s}} \tag{4}$$

where

$n_{z,s}$ = the number of radiotagged fish released in size stratum *z* in G-T stratum *s*, and

$n_{(\mathrm{Sp})z,s}$ = those fish in $n_{z,s}$ that traveled upstream from the marking site to a spawning area ($_{\mathrm{Sp}}$).

During second-event sampling, fish inspected for marks were subsampled for length data throughout the second-event sampling period at each site. However, sampling was not proportional to numbers of fish inspected over time, and length composition varied over time. To estimate the number of fish inspected for marks within each size stratum, length composition data were stratified into V = 6 (coho) or V = 7 (chum) time periods for each second-event sampling site. Within each site *u*, for each time period *v*, we estimated the probability that a sampled fish was a member of a size stratum *z*:

$$\hat{p}_{u,v,z} = \frac{n_{u,v,z}}{n_{u,v}} \tag{5}$$

where

$\hat{p}_{u,v,z}$ = the estimated probability that a fish sampled in (*u*,*v*) was in size stratum *z*,

$n_{u,v}$ = the number of fish sampled for length at site *u* during time period *v*, and

$n_{u,v,z}$ = the number of fish in $n_{u,v}$ in size stratum *z*.

Within each size stratum, for each of *t* second-event G-T strata, we estimated the number of fish inspected for marks:

$$\hat{C}_{t,z} = \sum_{u=1}^{3}\sum_{v=1}^{V} I(t,u,v)C_{u,v}\,\hat{p}_{u,v,z} \tag{6}$$

where

$I(t,u,v)$ = 1 if site *u* and time period *v* were germane to second-event G-T stratum *t* and 0 otherwise, and

$C_{u,v}$ = the number of fish inspected for marks at site *u* (*u* = 1 to 3 corresponding to Mainstem, North Yentna, and South Yentna sites) during time period *v*.

Temporal breaks between the *t* second-event G-T strata were constrained to correspond with temporal breaks between the *v* size composition strata for each second-event sampling site. During the model selection process when different second-event G-T stratum breaks were considered, different breaks between the *v* size composition strata were also considered to allow flexibility in choosing temporal breaks between the *t* second-event G-T strata, but homogeneity was maintained within each of the *v* size composition strata.

During both the chum and coho salmon mark–recapture experiments, data were lost for several recaptured fish. Specifically, the dart tag number of these marked fish was not recorded or data sheets containing these data were lost. For these particular fish, if they were detected during second-event sampling, the site and date were recorded, but information was not available to identify the fish wheel and date where these recaptures were marked or, in most instances, to identify the size strata in which these recaptures belonged. In the few cases when length data were taken, these fish could be assigned to the appropriate size stratum and second-event G-T stratum within each size stratum. For recaptures without size data, *u* and *v* were known and the probabilities that individual fish were within a particular size stratum were estimated using Equation 5. Within a size stratum, the numbers of recaptured fish within each second-event G-T stratum for which the first-event G-T stratum was unknown were estimated as follows:

$$\hat{r}_{(\mathrm{Unk}),t,z} = G_{(kn-l)t,z} + \sum_{u=1}^{3}\sum_{v=1}^{V} I(t,u,v)G_{u,v}\,\hat{p}_{u,v,z} \tag{7}$$

where

$I(t,u,v)$ = 1 if site *u* and time period *v* were germane to second-event G-T stratum *t* and 0 if otherwise,

$G_{(kn-l)t,z}$ = the number of recaptured fish without tag data, but of known length, in second-event G-T stratum *t* within size stratum z, and

$G_{u,v}$ = the number of recaptured fish at site *u* during time period *v* without tag or length data.

Within each size stratum, the probabilities that individual fish in each $\hat{r}_{(u)t,z}$ were marked in each of the *s* first-event G-T strata were estimated using the counts of recaptures with complete data:

$$\hat{p}_{(t)s,z} = \frac{r_{(k)s,t,z}}{r_{(k)\bullet,t,z}} \tag{8}$$

where

$r_{(k)s,t,z}$ = the number of recaptures with complete data that were known ($_k$) to have been marked in stratum *s* and recaptured in stratum *t* in size stratum *z*,

and where

$$r_{(k)\bullet,t,z} = \sum_{i=1}^{s} r_{(k)i,t,z} . \tag{9}$$

The total number of recaptures marked in first-event stratum *s* and recaptured in second-event stratum *t* was estimated as follows:

$$\hat{r}_{s,t,z} = r_{(k)s,t,z} + \hat{r}_{(\mathrm{Unk})t,z}\hat{p}_{(t)s,z} . \tag{10}$$

Initial modeling was conducted using the computer program SPAS (Arnason et al. 1996) after rounding $\hat{M}_{z,s}$, $\hat{C}_{t,z}$, and $\hat{r}_{s,t,z}$ values to the nearest integers. For both chum salmon size strata, admissible models were identified that contained 6 first-event strata and 6 second-event strata. For coho salmon size strata, admissible models were identified that contained 3 and 4 first-event strata and an identical number of second-event strata. These “square” models allowed for computation of an analytical solution using matrix algebra described in Seber (1982). Actual values for $\hat{M}_{z,s}$, $\hat{C}_{t,z}$, and $\hat{r}_{s,t,z}$ were used in the analytical model to provide estimates of abundance within each size stratum for both chum and coho salmon.

Variances and 95% confidence intervals for abundance estimates were estimated using bootstrap methods (Efron and Tibshirani 1993). For each bootstrap realization, recaptures with complete information were modeled as a multinomial process within first-event stratum *s* with parameters ($M_{(\mathrm{Rel},kn-l)z,s}$, $\hat{p}_{(s)1,z}, \ldots \hat{p}_{(s)t,z}$, $\hat{p}_{(s)nr,z}$) where

$$\hat{p}_{(s)i,z} = \frac{r_{(k)s,i,z}}{M_{(\mathrm{Rel},kn-1)z,s}} \tag{11}$$

for *i* = 1 to *t*, and

$$\hat{p}_{(s)nr,z} = 1.0 - \sum_{i=1}^{t} \hat{p}_{(s)i,z} \ . \tag{12}$$

Bootstrap variability in the process described in Equations 1 and 2 was modeled as a binomial processes with parameters ($n_{w,d}$, $\hat{p}_{f,z}$). Bootstrap variability in the process described in Equations 3 and 4 was modeled as a binomial processes with parameters ($n_{z,s}$, $\hat{p}_{z,s}$). Bootstrap variability in the process described in Equations 5–7 was modeled as a binomial processes with parameters ($n_{u,v}$, $\hat{p}_{u.v,z}$). Bootstrap variability in the process described in Equations 8–10 was modeled as a multinomial processes with parameters ($r_{(k)\bullet,t,z}$, $\hat{p}_{(t)1,z}$,… $\hat{p}_{(t)s,z}$).

For each bootstrap realization, the analytical s × t Darroch (1961) model was then used to generate estimates of abundance for each size stratum that were summed to provide an overall estimate of abundance for that bootstrap realization. One million bootstrap realizations were generated for each experiment. The standard error for each parameter estimate was calculated as the standard deviation of the bootstrap distribution for that parameter. Ninety-five percent confidence intervals for each parameter were estimated as the values at 2.5 and 97.5 percentage points of the bootstrap distribution for that parameter.

SPAWNING DISTRIBUTION

Radiotelemetry techniques were used to estimate the spawning distribution of chum and coho salmon.

Radiotag Application

During the abundance experiment 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 and the total catch by species 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.

A set number of radio tags was deployed each 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 RM 6.2 of the Yentna River was used to determine the number of tags to be distributed each day over the season. Within a particular day, an equal number of radio tags was deployed among all 4 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 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 10 frequencies within the 150.000 to 151.999 MHz range. Each frequency had up to 100 different transmitting patterns (i.e., pulse codes), resulting in 1,000 uniquely identifiable transmitters. Transmitters were 42 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 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.

Radiotag Relocation

Tracking Stations

The migrations of radiotagged chum and coho salmon were tracked at 6 stations placed on major tributaries throughout the Susitna River drainage (Figure 1, Table 1). The Susitna Station tracking station was placed 3.1 RM above the Flathorn tagging site. 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 river drainages, 2011.

		Distance (RM) from	
Drainage	Tracking station	Saltwater	Previous station
Susitna River	Susitna Station	24.9	–
	Deshka River	39.6	13.5
	Sunshine	79.7	38.3
Yentna River	Lower Yentna River	36.1	11.4
	Skwentna River	86.0	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 weatherproof container attached to the base of a 9 m mast.

An ATS Model 200 antenna switch was coupled with 2 antennas at each tracking station. One antenna was oriented downstream and the other upstream. Signal strength and time of reception were recorded separately for each antenna and provided information on direction of travel. "Reference" radio tags were continuously detected at each station to assure proper station operation. Information was recorded at 10-minute intervals.

The ATS receiver detected 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.

Tracking stations were visited every 14–21 days to check on the condition of the equipment and to 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 (Figure 1). The aircraft was equipped with an ATS Model 4500 or 4520C receiver and data logger and two 4-element Yagi receiving antennas, 1 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.

Estimation of Spawning Distribution

The diagnostic procedures for estimating abundance (Appendix A1) indicated size-biased sampling during both events for both chum and coho salmon, requiring stratification of all data into length strata, with independent estimates of abundance for each stratum for each species. Furthermore, the diagnostic procedures (Appendix A2) indicated that probability of capture was not uniform over time or between marking sites (fish wheels) for both chum and coho salmon within size strata. To minimize bias, spawning distribution for each species was first estimated within each of the *s* first-event G-T strata (described above) within each size stratum. 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:

$$\hat{p}_{l,s,z} = \frac{n_{l,s,z}}{n_{s,z}} \tag{13}$$

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

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

$$\hat{N}_l = \sum_{z=1}^{2} \sum_{s=1}^{s_z} \hat{N}_{s,z}\,\hat{p}_{l,s,z} \tag{14}$$

where $\hat{N}_{s,z}$ is the number of fish passing and remaining above the Flathorn Site estimated in first-event G-T stratum *s* for size stratum *z* from the Darroch (1961) models described above. The proportion of salmon spawning in each location was estimated as follows:

$$\hat{p}_l = \frac{\hat{N}_l}{\sum_{z=1}^{2} \sum_{s=1}^{s_z} \hat{N}_{s,z}}. \tag{15}$$

Variances and 95% confidence intervals for spawning distribution estimates were estimated using bootstrap methods (Efron and Tibshirani 1993). For each bootstrap realization, bootstrap variability in the process described in Equations 13 and 14 was modeled as a multinomial process with parameters ($n_{s,z}$, $\hat{p}_{l,s,z}$,… $\hat{p}_{l,s,z}$).

For each bootstrap realization, the analytical $s \times t$ Darroch (1961) model was then used to generate an estimate of abundance for each size stratum that was summed for all size strata to provide an overall estimate of abundance for that bootstrap realization. One million bootstrap realizations were generated for each experiment. The standard error for each parameter estimate was calculated as the standard deviation of the bootstrap distribution for that parameter. Ninety-five percent confidence intervals for each parameter were estimated as the values at 2.5 and 97.5 percentage points of the bootstrap distribution for that parameter. Bootstrap modeling exercises to estimate uncertainty (variances) for abundance and spawning distribution were conducted concurrently for each species.

RESULTS

ABUNDANCE

Chum Salmon

During the first event in the mark–recapture experiment, a total of 22,934 chum salmon were captured in 4 fish wheels at the Flathorn Site (RM 22 of the Susitna River) from 7 July to 29 August 2011. Radio tags, which were used to estimate losses of marked fish from the experiment, were deployed on 382 chum salmon distributed across the run. A total of 51,120 chum salmon were inspected for marks at fish wheels at the Yentna Site (RM 6.2 of the Yentna River) and at the Mainstem Site (RM 30 of the Susitna River) (Tables 2 and 3). Of these, 817 were recaptured marked fish and 50,303 were unmarked (Tables 2 and 3). Data recording errors and data loss during the second-event sampling resulted in incomplete information for 47 recaptured marked fish.

The tests for size-biased sampling (Appendix A1) indicated that size selectivity occurred during both the second-event sampling (P = 0.013; Figure 3) and the first sampling event (P < 0.001; Figure 4). Data were apportioned into 2 size strata: chum salmon less than 562.5 mm METF length and chum salmon greater than or equal to 562.5 mm METF length. Subsequent diagnostic tests and parameter estimates were conducted separately for each of these strata.

Table 2.–Capture-recapture matrix used for Darroch (1961) models to estimate abundance of chum salmon less than 562.5 mm METF length spawning upstream from the Flathorn Site in the Susitna River, 2011.

First-event stratum			Recaptures at second-event strata							
		Est. valid	Yentna Site event days			Mainstem Site event days				
FW	Days	marks	188–220	221–224	225–245	188–211	212–222	223–244	Total	Not recaptured
1										
	188–210	1,155	45	13	0	0	1	0	59	1,096
	211–222	2,352	12	176	15	1	4	1	209	2,144
	223-241	938	0	28	40	0	0	0	68	870
2–4										
	188-209	3,205	13	1	0	31	7	0	51	3,153
	210-218	3,097	3	6	2	5	53	20	91	3,006
	219-241	3,885	0	9	11	0	7	83	109	3,776
Est. total valid marks		14,632	73	233	68	37	73	104	587	14,045
Est. unmarked			1,396	4,182	4,129	2,715	5,444	13,500	31,366	
Est. inspected for marks			1,468	4,415	4,197	2,752	5,516	13,604	31,953	

Note: FW means fish wheel. Abundance of all spawning chum salmon in the Susitna River in 2011 was estimated as 1,752,031 (SE 131,144).

Table 3.–Capture-recapture matrix used for Darroch (1961) models to estimate abundance of chum salmon greater than or equal to 562.5 mm METF length spawning upstream from the Flathorn Site in the Susitna River, 2011.

		Recaptures at second-event strata							
	Est. valid	Yentna Site event days			Mainstem Site event days				Not
First-event stratum	marks	188–219	220–226	227–245	188–216	217–224	225–245	Total	recaptured
FW1									
Days 188–210	406	12	7	0	1	0	0	20	386
Days 211–225	695	1	63	1	0	5	1	72	624
Days 226–241	69	0	0	5	0	0	0	5	64
FW 2–4									
Days 188–211	2,171	4	1	0	15	15	0	35	2,136
Days 212–223	2,055	0	7	0	2	78	3	91	1,964
Days 224–241	161	0	2	0	0	0	5	7	154
Est. total marked	5,557	17	81	6	18	98	9	230	5,328
Est. unmarked		1,419	3,651	1,151	2,630	6,854	3,232	18,937	
Est. inspected for marks		1,436	3,732	1,158	2,648	6,952	3,241	19,167	

Note: FW means fish wheel. Estimated abundance of all spawning chum salmon in the Susitna River is 1,752,031 (SE 131,144).

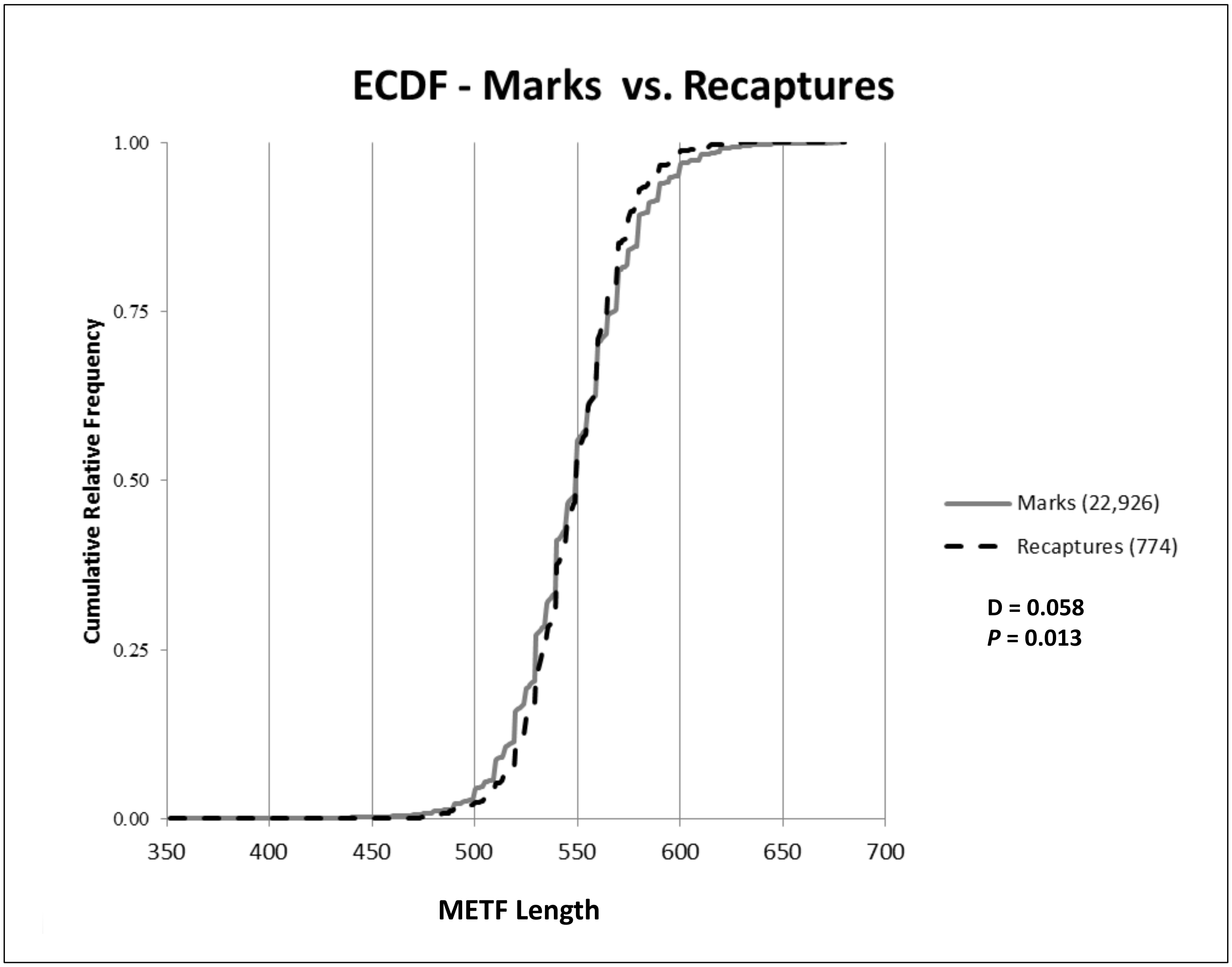

Figure 3.–Empirical cumulative distribution functions (ECDF) of length of all chum salmon marked during first-event sampling at the Flathorn Site and all recaptures during second-event sampling.

Note: The Kolmogorov-Smirnov test results for equal probability of capture based on METF length during second-event sampling were D = 0.058, *P* = 0.013. Six of the 22,934 marked chum salmon were not measured, and data collection errors resulted in missing lengths for 2 additional fish. Length measurements were available for 774 of 817 recaptured chum salmon.

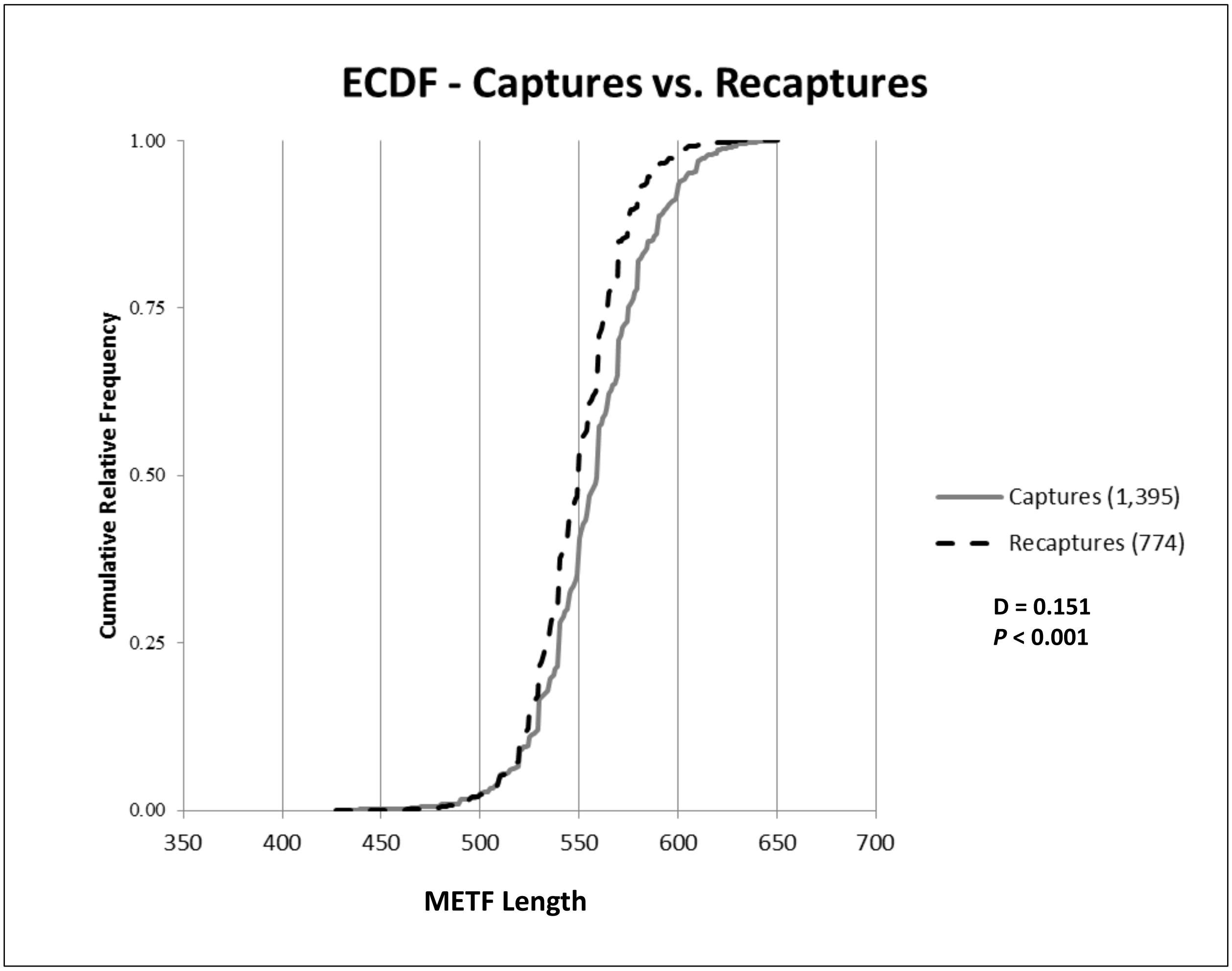

Figure 4.–Empirical cumulative distribution functions (ECDF) of pooled length of all chum salmon inspected for marks during the second-event sampling and all recaptured coho salmon during second-event sampling for fish wheels at the Mainstem Site and the Yentna Site.

Note: The Kolmogorov-Smirnov test results for equal probability of capture based on METF length during first-event sampling were D = 0.151, $P < 0.001$. Length measurements were available for 774 of 817 recaptured chum salmon.

Temporal and geographical variation in probability of capture (Appendix A2) was detected for both size strata during both second (Tables 4 and 5) and first (Table 6 and 7) sampling events. As a result, the partially stratified model described by Darroch (1961) was necessary for estimating abundance (Table 6).

Table 4.–Results used in test for equal probability of capture (H_o) during the second-event sampling for Susitna River chum salmon less than 562.5 mm METF length, 2011.

	Area and time where marked					
	Fish wheel 1 event days			Fish wheels 2–4 event days		
	188–210	211–222	223–241	188–209	210–218	219–241
Marks [a]	1,325	2,557	1,000	3,694	3,568	4,159
Recaptured [b]	56	195	65	49	89	107
Not recaptured	1,269	2,362	935	3,645	3,479	4,052

Note: Results of test for temporal (event days) and geographical (fish wheel) variation were $\chi 2 = 234.181$, $P < 0.001$; H_o was rejected.

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

[b] Known recaptures only; not adjusted for recaptures of unknown length or marking strata.

Table 5.–Results used in test for equal probability of capture (H_o) during the second-event sampling for Susitna River chum salmon greater than or equal to 562.5 mm METF length, 2011.

	Area and time where marked					
	Fish wheel 1 event days			Fish wheels 2–4 event days		
	188–210	211–225	226–241	188–211	212–223	224–241
Marks [a]	541	904	69	2,775	2,144	190
Recaptured [b]	17	61	5	33	87	6
Not recaptured	524	843	64	2,742	2,057	184

Note: Results of test for temporal (event days) and geographical (fish wheel) variation were $\chi 2 = 82.771$, $P < 0.001$; H_o was rejected.

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

[b] Known recaptures only; not adjusted for recaptures of unknown length or marking strata.

Table 6.–Results used in test for equal probability of capture (H_o) during the first-event sampling for Susitna River chum salmon less than 562.5 mm METF length, 2011.

	Area and time where inspected					
	Yentna Site event days			Mainstem Site event days		
	188–220	221–224	225–245	188–211	212–222	223–244
Inspected [a]	1,468	4,415	4197	2752	5516	13,604
Marked [b]	69	216	67	35	74	102
Unmarked	1,399	4,199	4,130	2,717	5,442	13,502

Note: Results of test for temporal (event days) and geographical (recapture sites) variation were $\chi 2 = 413.806$, $P < 0.001$; H_o was rejected.

[a] Estimated within size stratum using size composition data from each site.

[b] Known recaptures only; not adjusted for recaptures of unknown length..

Table 7.–Results used in test for equal probability of capture (H_o) during the first-event sampling for Susitna River chum salmon greater than or equal to 562.5 mm METF length, 2011.

	Area and time where inspected					
	Yentna Site event days			Mainstem Site event days		
	188–219	220–226	227–245	188–216	217–224	225–245
Inspected [a]	1,436	3,732	1,158	2,648	6,952	3,241
Marked [b]	14	68	6	17	97	9
Unmarked	1,422	3,664	1,152	2,631	6,855	3,232

Note: Results of test for temporal (event days) and geographical (recapture site) variation were $\chi2 = 52.479$, $P < 0.001$; H_o was rejected.

[a] Estimated within size stratum using size composition data from each site.

[b] Known recaptures only; not adjusted for recaptures of unknown length.

During inspection of 34,714 chum salmon during second-event sampling at the mainstem Susitna River fish wheels, all fish found with a missing adipose fin had retained a yellow dart tag. Therefore, loss of dart tags during the experiment was estimated to be 0.0%.

The estimated number of chum salmon spawning upstream of the Flathorn Site in the Susitna River drainage in 2011 was 1,752,031 (SE 131,144) with a 95% confidence interval of 1,556,974 to 2,073,042 fish.

Coho Salmon

During the first event of the mark–recapture experiment, a total of 6,668 coho salmon were captured and tagged at the Flathorn Site from 9 July to 29 August 2011. Radio tags were deployed on 352 coho salmon distributed across the run. During second-event sampling, 9,179 coho salmon were inspected for marks at fish wheels at the Yentna Site and at the Mainstem Site (Tables 8 and 9). Of these, 328 were recaptured marked fish and 8,851 were unmarked (Tables 8 and 9). Data recording errors and data loss during the second-event sampling resulted in incomplete information for 13 recaptured marked fish.

The tests for size-biased sampling (Appendix A1) indicated that size selectivity occurred during both the second-event sampling (P = 0.019; Figure 5) and the first-sampling event (P = 0.002; Figure 6). Data were stratified into 2 size strata: coho salmon less than 472.5 mm METF length and coho salmon greater than or equal to 472.5 mm METF length. Subsequent diagnostic tests and parameter estimates were conducted separately for each of these strata.

Table 8.–Capture-recapture matrix used for Darroch (1961) models to estimate abundance of coho salmon less than 472.5 mm METF length spawning upstream from the Flathorn Site in the Susitna River, 2011.

First-event stratum		Est. valid marks	Recaptures at second-event strata: Yentna Site event days 188–219	Yentna Site event days 220–245	Mainstem Site event days All	Total	Not recaptured
FW 1–2							
	Days 188–204	410	32	4	2	39	371
	Days 205–241	1,179	37	51	4	91	1,088
FW 3–4	All	380	2	1	8	11	369
Est. total valid marks		1,969	71	56	14	141	1,828
Est. unmarked			1,058	845	718	2,622	
Est. inspected for marks			1,129	901	732	2,762	

Note: FW means fish wheel. Estimated total abundance of coho salmon was 216,555 (SE 25,760).

Table 9.–Capture-recapture matrix used for Darroch (1961) models to estimate abundance of coho salmon greater than or equal to 472.5 mm METF length spawning upstream from the Flathorn Site in the Susitna River, 2011.

First-event stratum		Est. valid marks	Recaptures at second-event strata: Yentna Site event days 188–219	Yentna Site event days 220–245	Mainstem Site event days 188–224	Mainstem Site event days 225–245	Total	Not recaptured
FW 1–2								
	Days 188–215	2,060	55	32	7	1	95	1,966
	Days 216–241	1,120	1	61	3	5	70	1,050
FW 3–4								
	Days 188–215	481	2	3	11	0	16	465
	Days 216–241	275	0	0	2	4	6	269
Est. total valid marks		3,936	58	96	23	10	187	3,749
Est. unmarked			2,479	1,703	1,813	235	6,230	
Est. inspected for marks			2,537	1,799	1,836	245	6,417	

Note: FW means fish wheel. Estimated total abundance of coho salmon was 216,555 (SE 25,760).

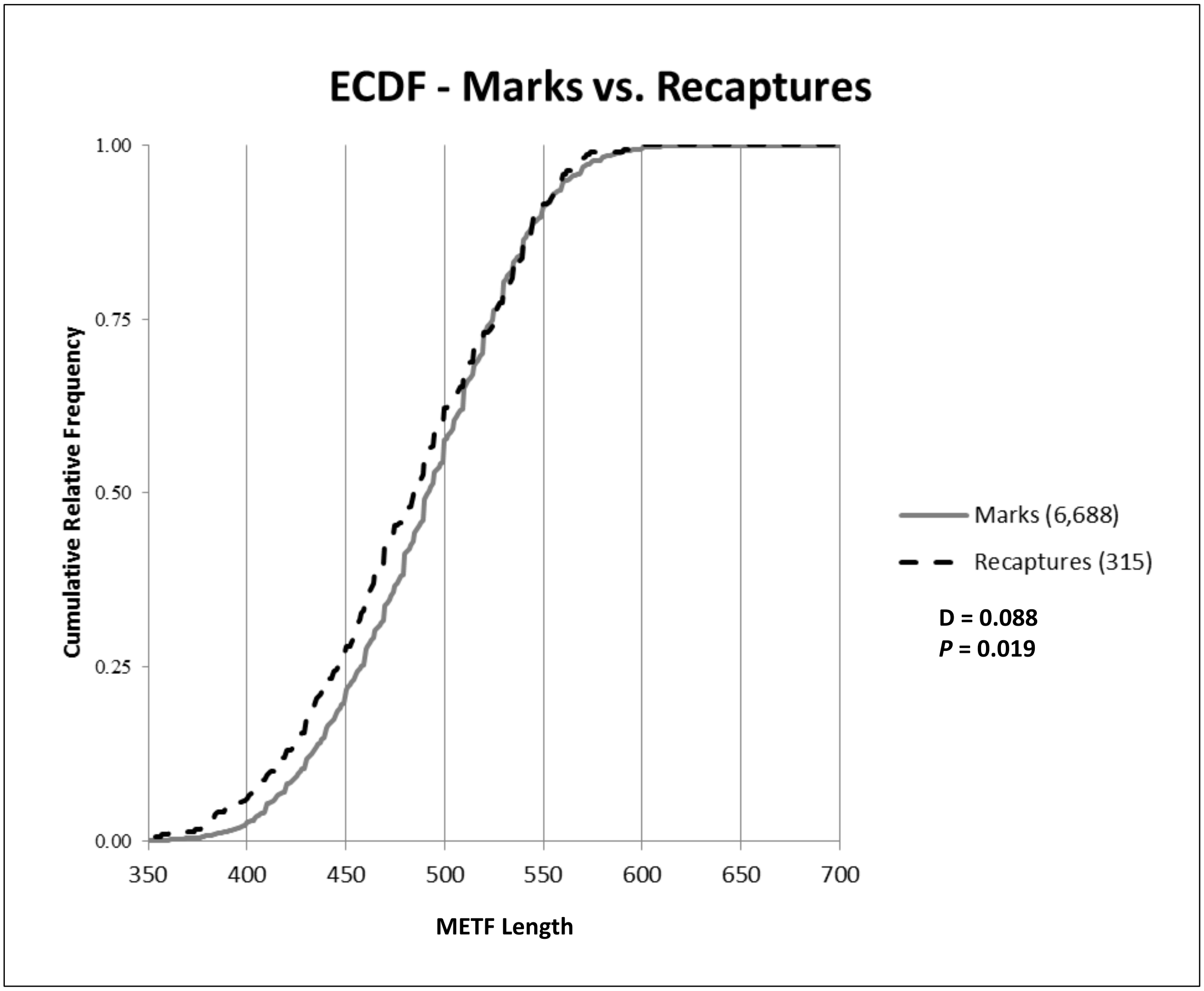

Figure 5.–Empirical cumulative distribution functions (ECDF) of length of all coho salmon marked during first-event sampling at the Flathorn Site and all recaptures during second-event sampling.

Note: The Kolmogorov-Smirnov test results for equal probability of capture based on METF length during second-event sampling were D = 0.088, *P* = 0.019. Length measurements were available for 315 of 328 recaptured coho salmon.

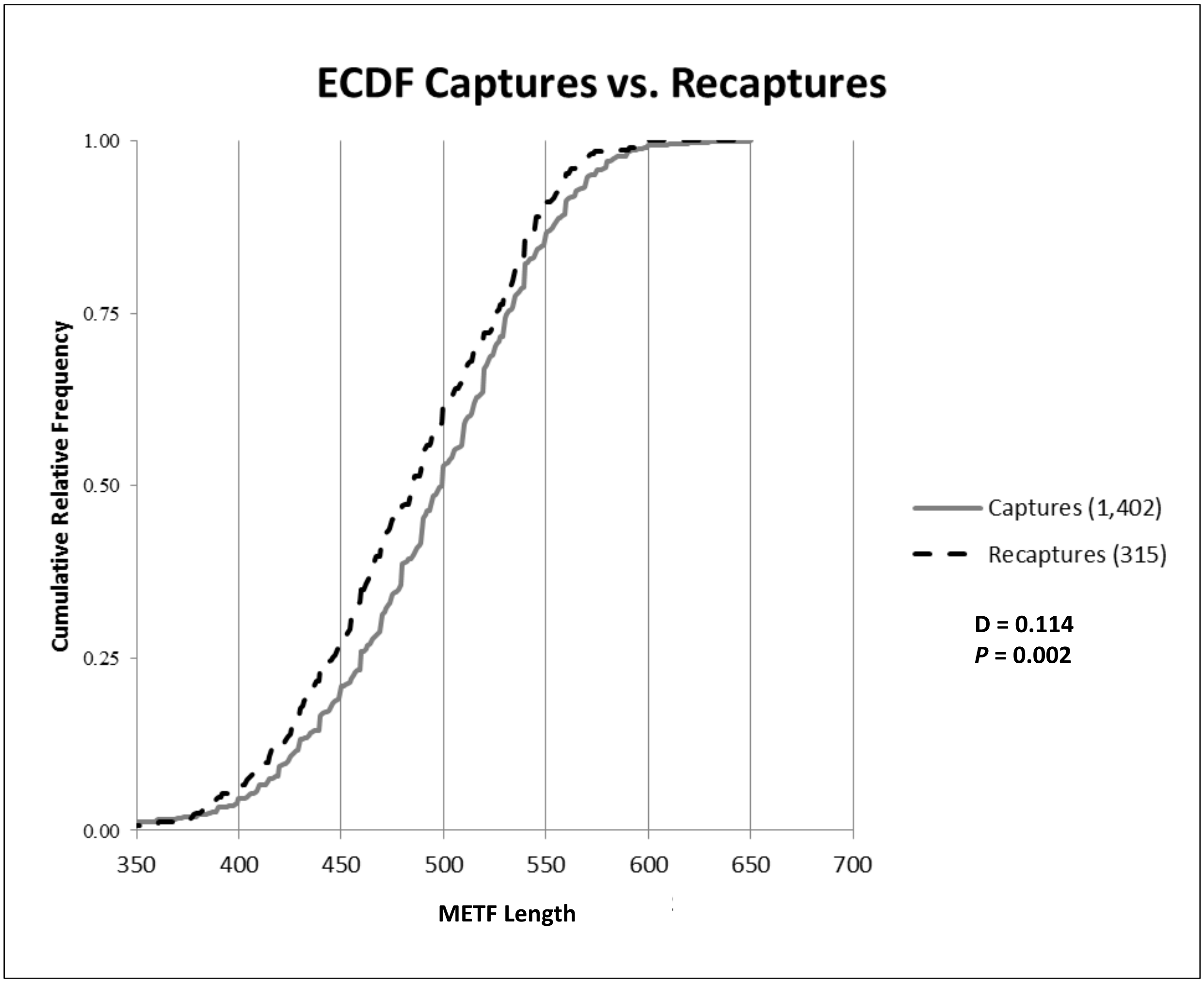

Figure 6.–Empirical cumulative distribution functions (ECDF) of pooled length of all coho salmon inspected for marks during second-event sampling and all recaptured coho salmon during second-event sampling at the Mainstem Site and the Yentna Site fish wheels.

Note: The Kolmogorov-Smirnov test results for equal probability of capture based on METF length during first-event sampling were D = 0.114, $P = 0.002$. Length measurements were available for 315 of 328 recaptured coho salmon.

Temporal and geographical variation in probability of capture (Appendix A2) was detected for both size strata during both second (Tables 10 and 11) and first (Tables 12 and 13) sampling events. As a result, the partially stratified model described by Darroch (1961) was necessary for estimating abundance (Table 5).

Table 10.–Results used to test for equal probability of capture (H_o) during the second-event sampling for Susitna River coho salmon less than 472.5 mm, 2011.

	Area and time where marked		
	Fish wheels 1–2 event days		Fish wheels 3–4 event days
	188–204	205–241	All
Marks [a]	410	1,446	463
Recaptured [b]	38	87	11
Not recaptured	372	1,359	452

Note: Results of test for temporal (event days) and geographical (fish wheel) variation were $\chi 2 = 18.872$, $P < 0.001$; H_o was rejected.

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

[b] Known recaptures only; not adjusted for recaptures of unknown length or marking strata.

Table 11.–Results used to test for equal probability of capture (H_o) during the second-event sampling for Susitna River coho salmon greater than or equal to 472.5 mm, 2011.

	Area and time where marked			
	Fish wheels 1–2 event days		Fish wheels 3–4 event days	
	188–215	216–241	188–215	216–241
Marks [a]	2,301	1,199	544	305
Recaptured [b]	91	66	16	6
Not recaptured	2,210	1,133	538	299

Note: Results of test for temporal (event days) and geographical (fish wheel) variation were $\chi 2 = 11.719$, $P = 0.008$; H_o was rejected.

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

[b] Known recaptures only; not adjusted for recaptures of unknown length or marking strata.

Table 12.–Results used to test for equal probability of capture (H_o) during the first-event sampling for Susitna River coho salmon less than 472.5 mm METF length, 2011.

	Area and time where inspected		
	Yentna Site event days		Mainstem Site event days
	188–219	220–245	All
Inspected [a]	1,130	901	733
Marked [b]	70	52	14
Unmarked	1,060	849	719

Note: Results of test for temporal (event days) and geographical (recapture sites) variation were $\chi 2 = 19.516$, $P < 0.001$; H_o was rejected.

[a] Estimated within size stratum using size composition data from each site.

[b] Known recaptures only; not adjusted for recaptures of unknown length.

Table 13.–Results used to test for equal probability of capture (H_o) during the first-event sampling for Susitna River coho salmon greater than or equal to 472.5 mm METF length, 2011.

	Area and time where inspected			
	Yentna Site event days		Mainstem Site event days	
	188–219	220–245	188–224	225–245
Inspected [a]	2,536	1,799	1,835	245
Marked [b]	56	90	23	10
Unmarked	2,480	1,709	1,812	235

Note: Results of test for temporal (event days) and geographical (recapture sites) variation were $\chi 2 = 53.119$, $P < 0.001$; H_o was rejected.

[a] Estimated within size stratum using size composition data from each site.

[b] Known recaptures only; not adjusted for recaptures of unknown length.

During inspection of 2,813 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%.

The estimated number of coho salmon spawning upstream of the Flathorn Site in the Susitna River drainage in 2011 was 216,555 (SE 25,760) with a 95% confidence interval of 182,995 to 281,825 fish.

SPAWNING DISTRIBUTION

Radiotag Application

In 2011, a total of 22,934 chum salmon captured at fish wheels (FW) operated at the Flathorn Site from 7 July to 29 August were tagged with dart tags; 382 of these were also radiotagged and used in the analyses. A total of 98 radiotagged chum salmon were released from FW 1, 97 from FW 2, 92 from FW 3, and 95 from FW 4. A total of 6,668 coho salmon were captured among the 4 fish wheels between 9 July and 29 August; 352 of these were radiotagged. A total of 98 radiotagged coho salmon were released from FW 1, 90 from FW 2, 72 from FW 3, and 92 from FW 4. Ninety percent (90%) of chum salmon and 85% of coho salmon radio tags were deployed between 19 July and 18 August (Table 14).

Table 14.–Chum and coho salmon radio tags deployed by week at the Flathorn Site on the Susitna River, 2011.

ADF&G statistical week	Dates	Chum salmon	Coho salmon
29	14–16 Jul	12	9
30	17–23 Jul	72	77
31	24–30 Jul	85	79
32	31 Jul–6 Aug	86	77
33	7–13 Aug	80	57
34	14–20 Aug	39	30
35	21–27 Aug	8	21
36	28 Aug–3 Sep	0	2
Total		382	352

Tracking Stations

Tracking stations were installed in the Yentna River drainage between 6 and 7 June and removed between 19 and 20 September 2011. Tracking stations were installed along the Mainstem Susitna River between 6 and 16 June and removed between the 20 and 27 of September 2011. The Susitna Station tracking station was not operational on 2 August and 4–11 August due to an equipment malfunction.

Aerial Surveys

Aerial surveys of the mainstem Susitna River were conducted on 11, 25, and 29 August; 8 and 28 September; and 11 and 13 October. Surveys of the Yentna River drainage were completed on 10 and 26 August, 9 and 29 September, and 5 and 10 October. Additionally, 3 complete drainagewide aerial surveys occurred on 13 September and both 3 and 12 October. These surveys relocated and obtained final locations for 689 individual radiotagged fish (93.9% of the 734 released). All fish locations obtained by aerial survey were corroborated by available records from surface tracking stations. Fifty-four of the 689 tagged fish assigned a final location were never located past the Susitna Station tracking station. Of the 45 fish not assigned a final location, 31 were never detected by either aerial or ground tracking devices, and 14 were harvested by sport anglers (Table 15).

Table 15.–Movement and migration pattern descriptions used to determine the final spawning location of radiotagged salmon relocated during aerial surveys in 2011.

		Chum salmon		Coho salmon	
Code	Movement description	Number	Percent	Number	Percent
0	Never relocated.	14	3.7	17	4.8
1	Did not migrate upstream of Susitna Station.	34	8.9	20	5.7
2	Progressive upstream movement through all aerial surveys.	53	13.9	137	38.9
3	Progressive upstream movement except the last 1–2 aerial surveys; assigned the upstream-most location.	101	26.4	66	18.8
4	Initially displayed upstream movement but then displayed downstream movement >2 aerial surveys; assigned upstream-most location.	13	3.4	6	1.7
5	A cluster of locations (within 20 miles); assigned a known location in the middle of cluster.	90	23.6	43	12.2
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.	55	14.4	29	8.2
7	Migrated up river A and then had >2 locations up river B. If strong signal strengths (>120) existed among cluster in river B, then fish was assigned to river B, otherwise river A.	17	4.5	11	3.1
8	Single aerial relocation only.	2	0.5	12	3.4
9	Caught by sport angler.	3	0.8	11	3.1
	Total	382	100.0	352	100.0

Spawning Locations

Radiotagged salmon were assigned 1 of 9 movement and migration pattern descriptions. Of the 689 radiotagged salmon relocated by aerial surveys, 13.9% of chum salmon and 38.9% of coho salmon displayed progressive and constant upstream movement to their assumed spawning location (Table 15). An additional 26.4% of chum salmon and 18.8% of coho salmon displayed progressive and constant upstream movement except in the last 1 to 2 surveys.

The Susitna Station gateway tracking station was approximately 1.8 miles upstream from the nearest fish wheel and regarded as the point at which radiotagged salmon entered the mark–recapture experiments. Aerial survey and tracking station data were used to assign a putative final spawning location to each chum and coho salmon that migrated upstream of the Susitna Station tracking station (Tables 16–18, Figures 7–16). Of the 382 radiotagged chum salmon, 331 (86.6%, which excludes totals from codes 0, 1, and 9 in Table 15) were assigned a putative spawning location upstream of Susitna Station and were included in the analyses (Tables 16 and 18, Figures 7–11). Of the 352 radiotagged coho salmon, 304 (86.4%, which excludes totals from codes 0, 1, and 9 in Table 15) were assigned a putative spawning location upstream of Susitna Station and were included in the analyses (Tables 17 and 18, Figures 12–16). Of the radiotagged fish, 34 chum and 20 coho salmon did not migrate upstream of the Susitna Station and were not assigned a putative spawning location. An additional 14 radiotagged chum salmon and 17 radiotagged coho salmon were not documented by stationary towers or aerial surveys (Table 15). Fish that were not detected and fish that did not migrate past the Susitna Station were excluded from the mark–recapture experiment and locations were not reflected in the final distribution map for each species.

The final putative spawning locations indicate that chum and coho salmon were strongly bank oriented at the Flathorn tagging site. Of the 85 chum salmon tagged on FW 1 that migrated upstream of the gateway station, 71 (93.5%) migrated up the Yentna River (Figure 8). Of the 82 chum salmon tagged on FW 4 that migrated upstream of the gateway station, 76 (92.7%) migrated up the mainstem Susitna River (Figure 11). Of the 86 coho salmon tagged on FW 1 that migrated upstream of the gateway station, 84 (97.7%) migrated up the Yentna River (Figure 13). Of the 77 coho salmon tagged on FW 4 that migrated upstream of the gateway station, 73 (94.8%) migrated up the mainstem Susitna River (Figure 16).

Sport anglers voluntarily returned 3 radio tags found in chum salmon; 2 were harvested from Little Willow Creek and 1 from Montana Creek. Sport anglers voluntarily returned 11 radio tags found in coho salmon. There were 2 coho salmon harvested in the Yentna River drainage, both from Lake Creek. There were 9 radiotagged coho salmon harvested in the Susitna River drainage: 3 from the Deshka River, and 1 each from Montana, Sheep, Rabideaux, Sunshine, and Willow creeks, and the Talkeetna River.

Table 16.–Unweighted terminal distribution by fish wheel (number of fish and percent) of radiotagged chum salmon in the Susitna River drainage in 2011.

	Fish wheel									
	FW 1		FW 2		FW 3		FW 4		Total	
Location	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
RM 0.0–24.0 Susitna River [a]	8	8.6	8	8.5	9	10.3	9	9.9	34	9.3
RM 24.1–98.0 Susitna River	3	3.2	7	7.4	12	13.8	8	8.8	30	8.2
RM 98.1–154.1 Susitna River	2	2.2	17	18.1	15	17.2	15	16.5	49	13.4
East Side Parks Hwy [b]	1	1.1	15	16.0	11	12.6	13	14.3	40	11.0
Deshka River		0.0		0.0		0.0		0.0	0	0.0
Talkeetna River	3	3.2	27	28.7	28	32.2	28	30.8	86	23.6
Chulitna River	4	4.3	7	7.4	4	4.6	12	13.2	27	7.4
Tokositna River	1	1.1		0.0		0.0		0.0	1	0.3
Yentna River below Skwentna River confl.	7	7.5	2	2.1	2	2.3	2	2.2	13	3.6
Yentna River above Skwentna River confl.	11	11.8	1	1.1	1	1.1		0.0	13	3.6
Kahiltna River	1	1.1	1	1.1		0.0		0.0	2	0.5
Lake Creek	2	2.2	2	2.1		0.0		0.0	4	1.1
RM 0.0–16.0 Skwentna River	7	7.5		0.0	1	1.1		0.0	8	2.2
RM 16.1+ Skwentna River	21	22.6	6	6.4		0.0	3	3.3	30	8.2
Talachulitna River	3	3.2		0.0		0.0		0.0	3	0.8
Johnson Creek	11	11.8		0.0	1	1.1		0.0	12	3.3
Kichatna River	8	8.6	1	1.1	3	3.4	1	1.1	13	3.6
Total [c]	93	100.0	94	100.0	87	100.0	91	100.0	365	100.0

[a] Terminal locations between RM 0 and RM 24 Susitna River account for all radio tags that did not migrate above the “gateway” tracking station (Susitna Station).

[b] Includes Willow Creek, Little 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 14 chum salmon never relocated by aerial or ground relocation methods (5 from FW 1, 2 from FW 2, 5 from FW 3, and 2 from FW 4) and 3 chum salmon harvested by sport anglers.

Table 17.–Unweighted terminal distribution by fish wheel (number of fish and percent) of radiotagged coho salmon in the Susitna River drainage in 2011.

	Fish wheel									
	FW 1		FW 2		FW 3		FW 4		Total	
Location	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
RM 0.0–24.0 Susitna River [a]	6	6.5	5	6.0	2	3.1	7	8.3	20	6.2
RM 24.1–98.0 Susitna River	2	2.2	11	13.1	8	12.5	17	20.2	38	11.7
RM 98.1–154.1 Susitna River		0.0	4	4.8	5	7.8	4	4.8	13	4.0
East Side Parks Hwy [b]		0.0	4	4.8	3	4.7	13	15.5	20	6.2
Deshka River		0.0	8	9.5	16	25.0	7	8.3	31	9.6
Talkeetna River		0.0	10	11.9	9	14.1	8	9.5	27	8.3
Chulitna River		0.0	8	9.5	3	4.7	11	13.1	22	6.8
Tokositna River		0.0	5	6.0	8	12.5	13	15.5	26	8.0
Yentna River below Skwentna River confl.	21	22.8	14	16.7	4	6.3	1	1.2	40	12.3
Yentna River above Skwentna River confl.	12	13.0	1	1.2	1	1.6		0.0	14	4.3
Kahiltna River	13	14.1	3	3.6	1	1.6		0.0	17	5.2
Lake Creek	7	7.6	3	3.6	1	1.6		0.0	11	3.4
RM 0.0-16.0 Skwentna River	5	5.4		0.0		0.0		0.0	5	1.5
RM 16.1+ Skwentna River	8	8.7	3	3.6		0.0		0.0	11	3.4
Talachulitna River	16	17.4	1	1.2	1	1.6	2	2.4	20	6.2
Johnson Creek		0.0	1	1.2	1	1.6		0.0	2	0.6
Kichatna River	2	2.2	3	3.6	1	1.6	1	1.2	7	2.2
Total [c]	92	100.0	84	100.0	64	100.0	84	100.0	324	100.0

[a] Terminal locations between RM 0 and RM 24 Susitna River account for all radio tags that did not migrate above the “gateway” tracking station (Susitna Station).

[b] Includes Goose Creek, 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 17 coho salmon never relocated by aerial or ground relocation methods (4 from FW 1, 3 from FW 2, 5 from FW 3 and 5 from FW 4) and 11 coho salmon harvested by sport anglers.

Table 18.–Terminal distribution summary of radiotagged chum and coho salmon in the Susitna River drainage, 2011.

			Chum salmon		Coho salmon	
Drainage	Region	Nearby tributaries	Number [a]	Percent	Number [b]	Percent
Susitna River						
	Susitna River mainstem (RM 0.0–24.0) [c]		34	9.3	20	6.2
	Susitna River mainstem (RM 24.1–98.0)		30	8.2	39	12.0
		Deshka River			31	9.6
		Willow Creek	14	3.8	9	2.8
		Little Willow Creek	1	0.3		
		Kashwitna River	5	1.4	3	0.9
		Sheep Creek	8	2.2	4	1.2
		Montana Creek	12	3.3	3	0.9
	Talkeetna River		25	6.8	5	1.5
		Chunilna River (Clear Creek)	59	16.2	11	3.4
		Sheep River	2	0.5	5	1.5
		Iron Creek				
		Prairie Creek–Stephan Lake			6	1.9
	Upper Susitna River mainstem (RM 98.0–154.0)		45	12.3	9	2.8
		Tributaries	4	1.1	4	1.2
	Chulitna River		27	7.4	22	6.8
		Byers Creek				
		Tokositna River	1	0.3	26	8.0
		Swan Lake				

-continued-

Table 18.–Page 2 of 2.

Drainage	Region	Nearby tributaries	Chum salmon Number [a]	Chum salmon Percent	Coho salmon Number [b]	Coho salmon Percent
Yentna River						
	Yentna River mainstem below Skwentna River		13	3.6	31	9.6
		Kahiltna River	2	0.5	17	5.2
		Peters Creek			9	2.8
		Lake Creek	4	1.1	11	3.4
		Chelatna Lake				
	Yentna River mainstem above Skwentna River		13	3.6	14	4.3
	Lower Skwentna River mainstem (RM 0.0–16.0)		8	2.2	5	1.5
		Tributaries				
		Shell Creek–Shell Lake				
		Talachulitna River	7	1.9	15	4.6
		Talachulitna Creek– Judd Lake	5	1.4	5	1.5
	Upper Skwentna River mainstem (RM 16.1+)		30	8.2	8	2.5
		Hayes River			3	0.9
	Hewitt Creek–Hewitt Lake					
	Johnson Creek		3	0.8	2	0.6
	Kichatna River		13	3.6	7	2.2
	Total		365		324	

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

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

[c] Terminal locations between Susitna River mainstem RM 0 and RM 24 account for all radio tags that did not migrate above the gateway tracking station (Susitna Station).

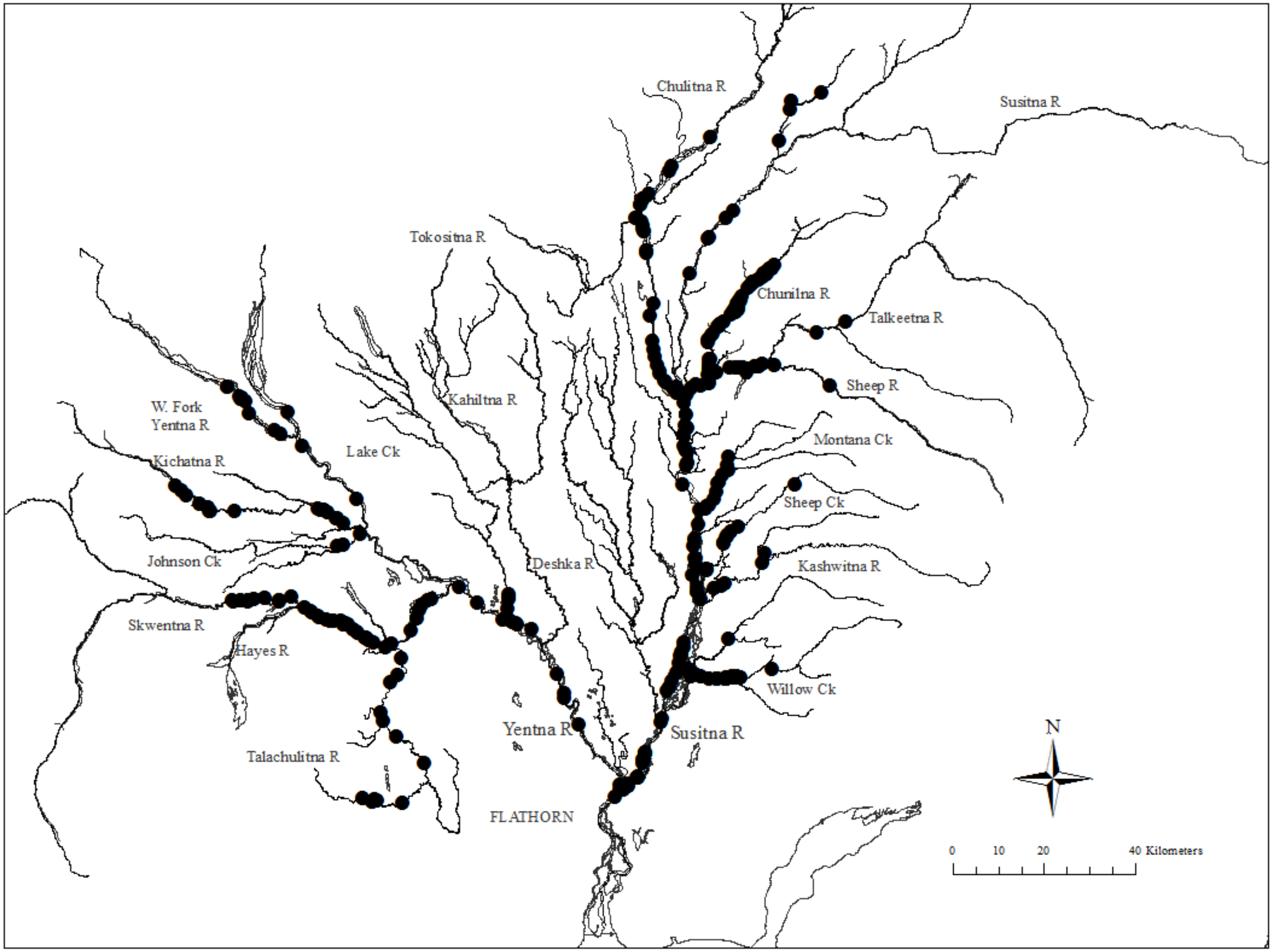

Figure 7.–Final locations of chum salmon radiotagged at all fish wheels in 2011.

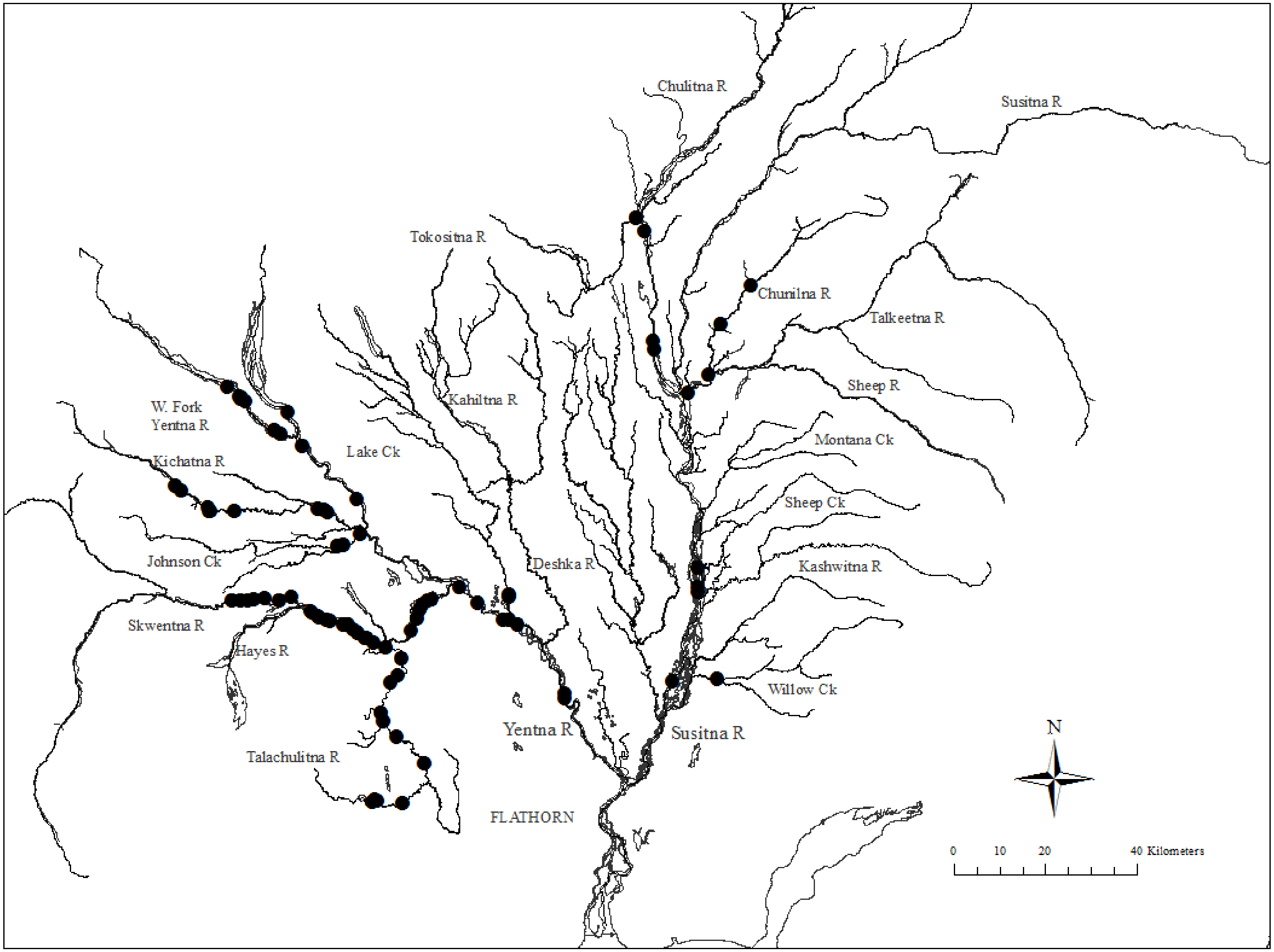

Figure 8.–Final locations of chum salmon radiotagged at FW 1, 2011.

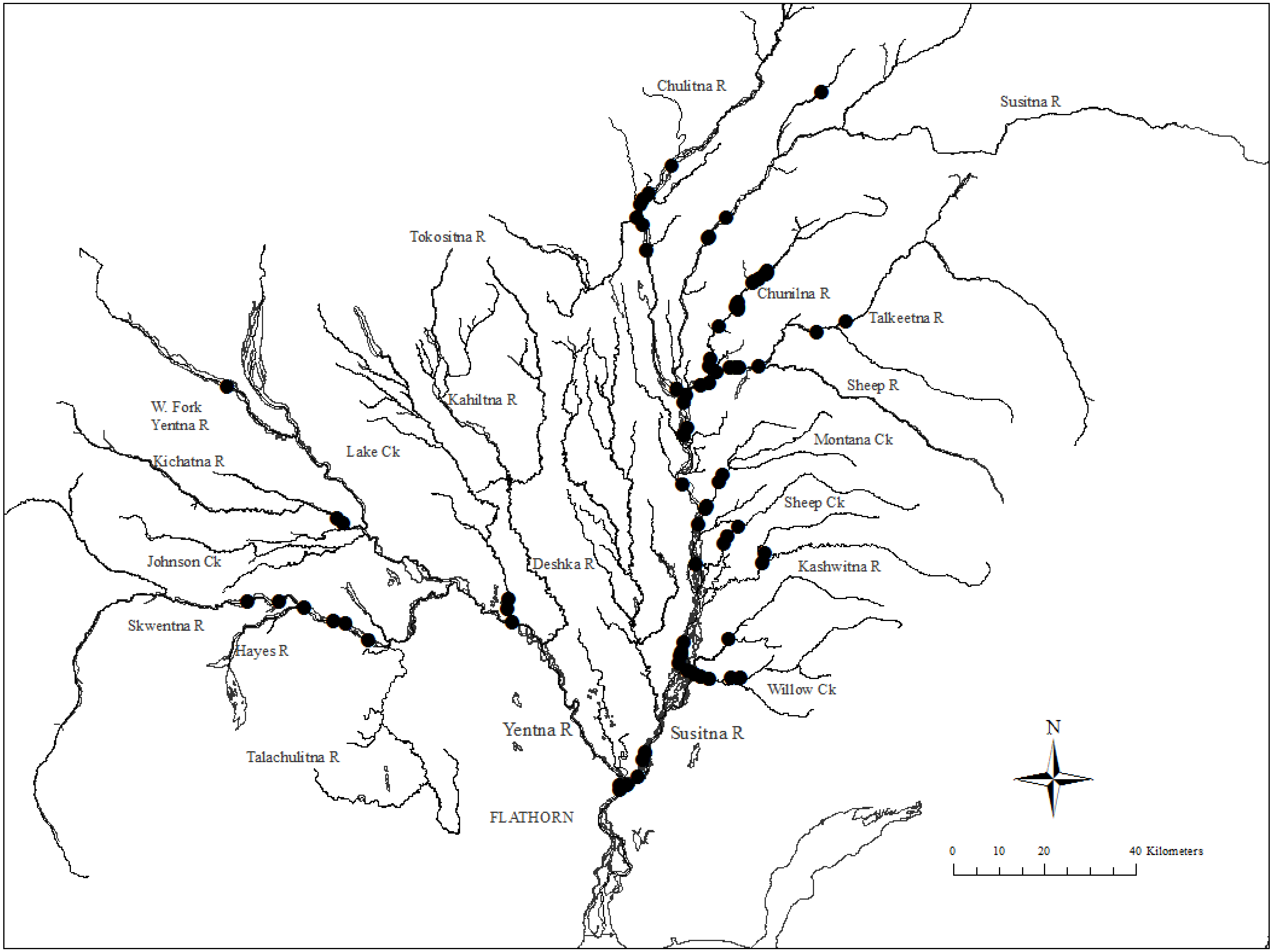

Figure 9.–Final locations of chum salmon radiotagged at FW 2, 2011

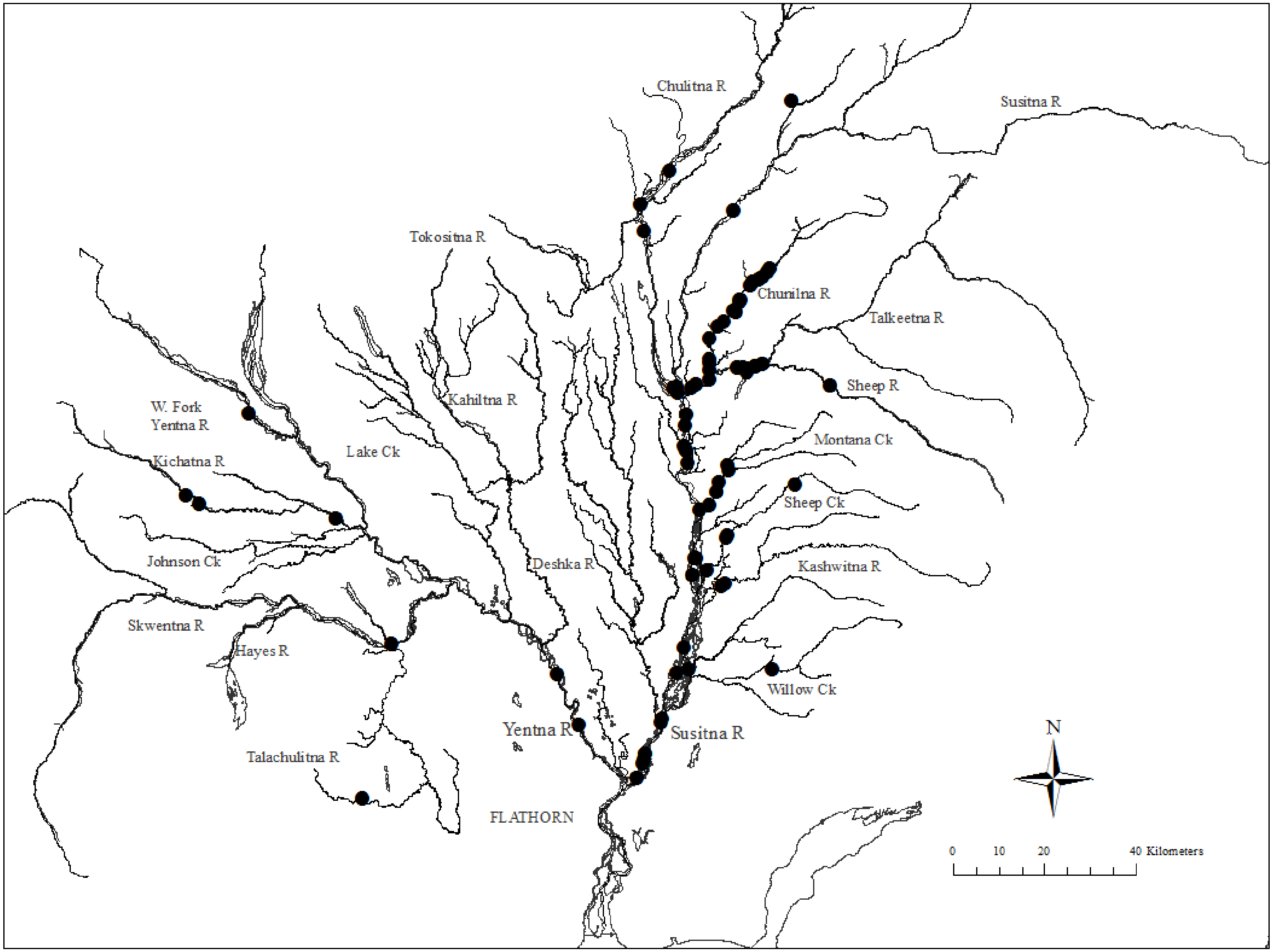

Figure 10.–Final locations of chum salmon radiotagged at FW 3, 2011.

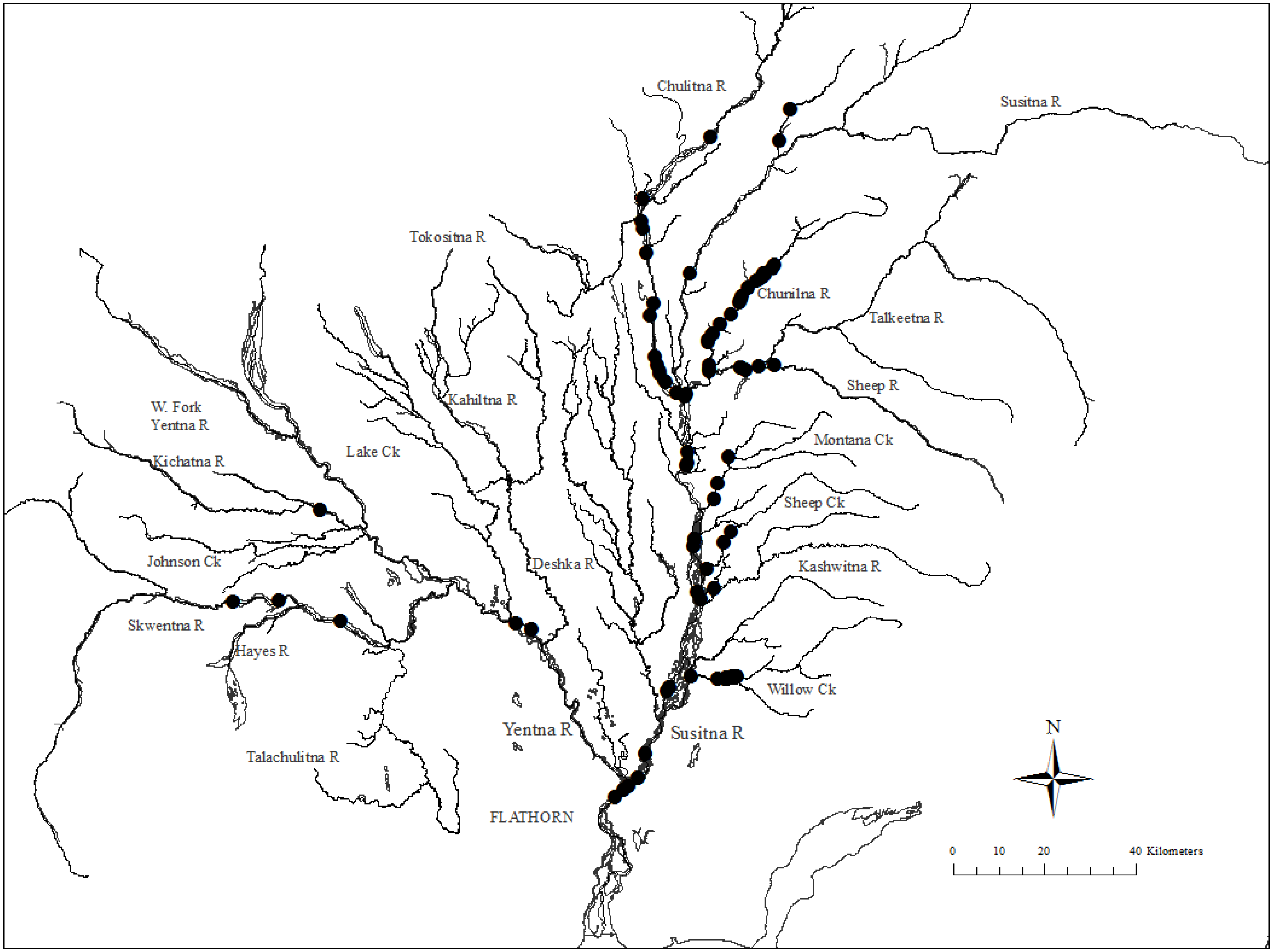

Figure 11.–Final locations of chum salmon radiotagged at FW 4, 2011.

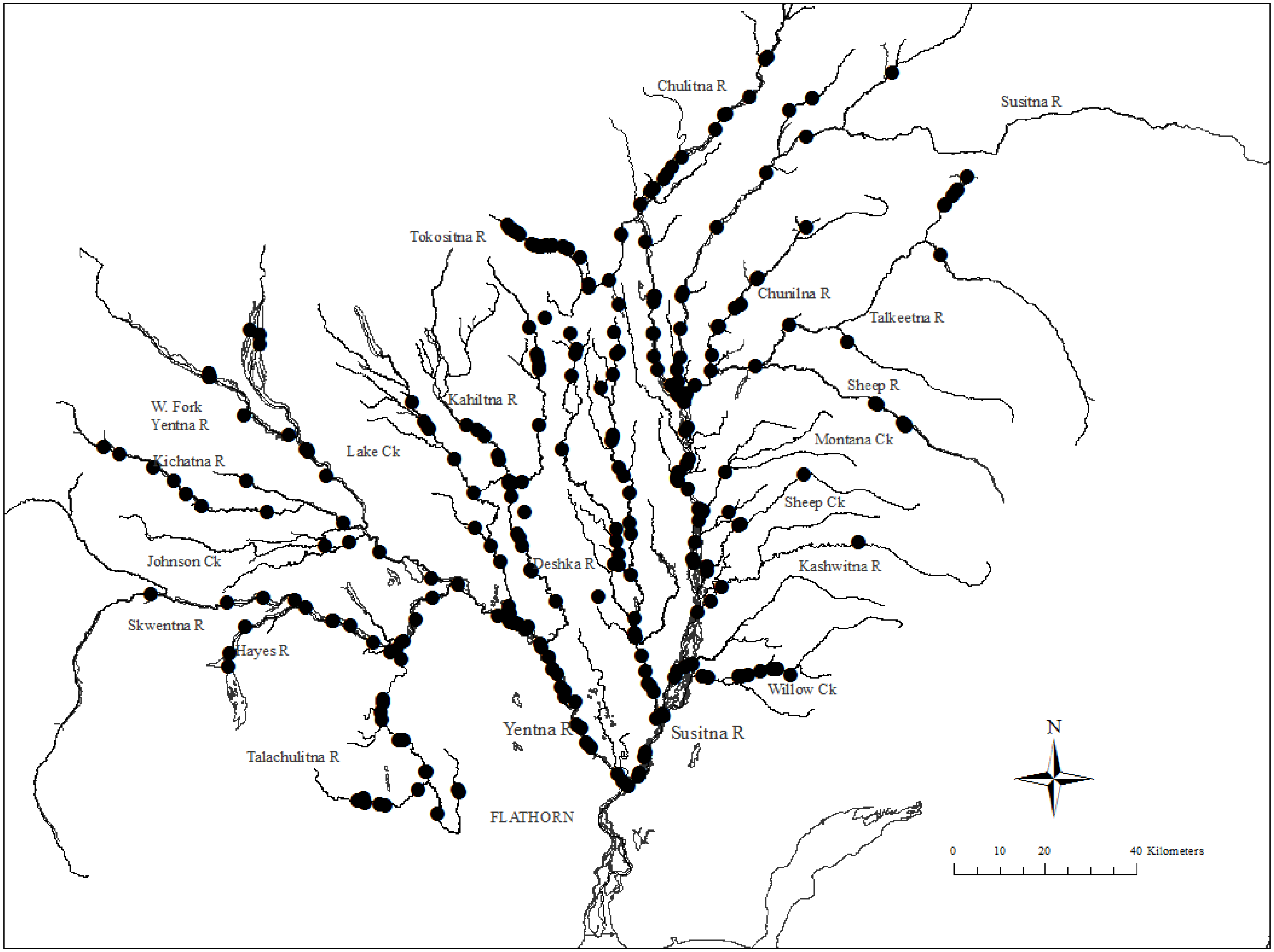

Figure 12.–Final locations of coho salmon radiotagged at all fish wheels in 2011.

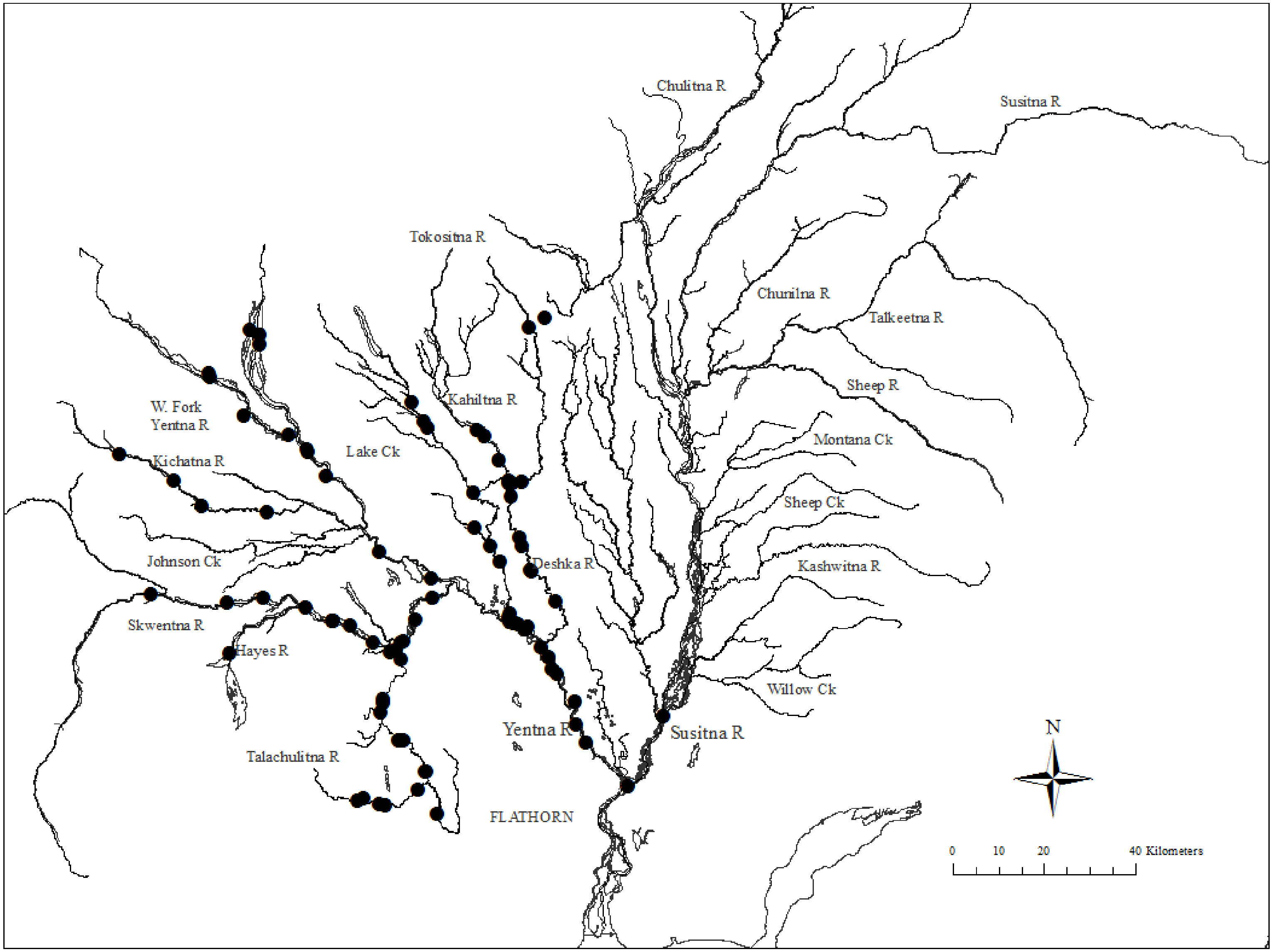

Figure 13.–Final locations of coho salmon radiotagged at FW 1, 2011.

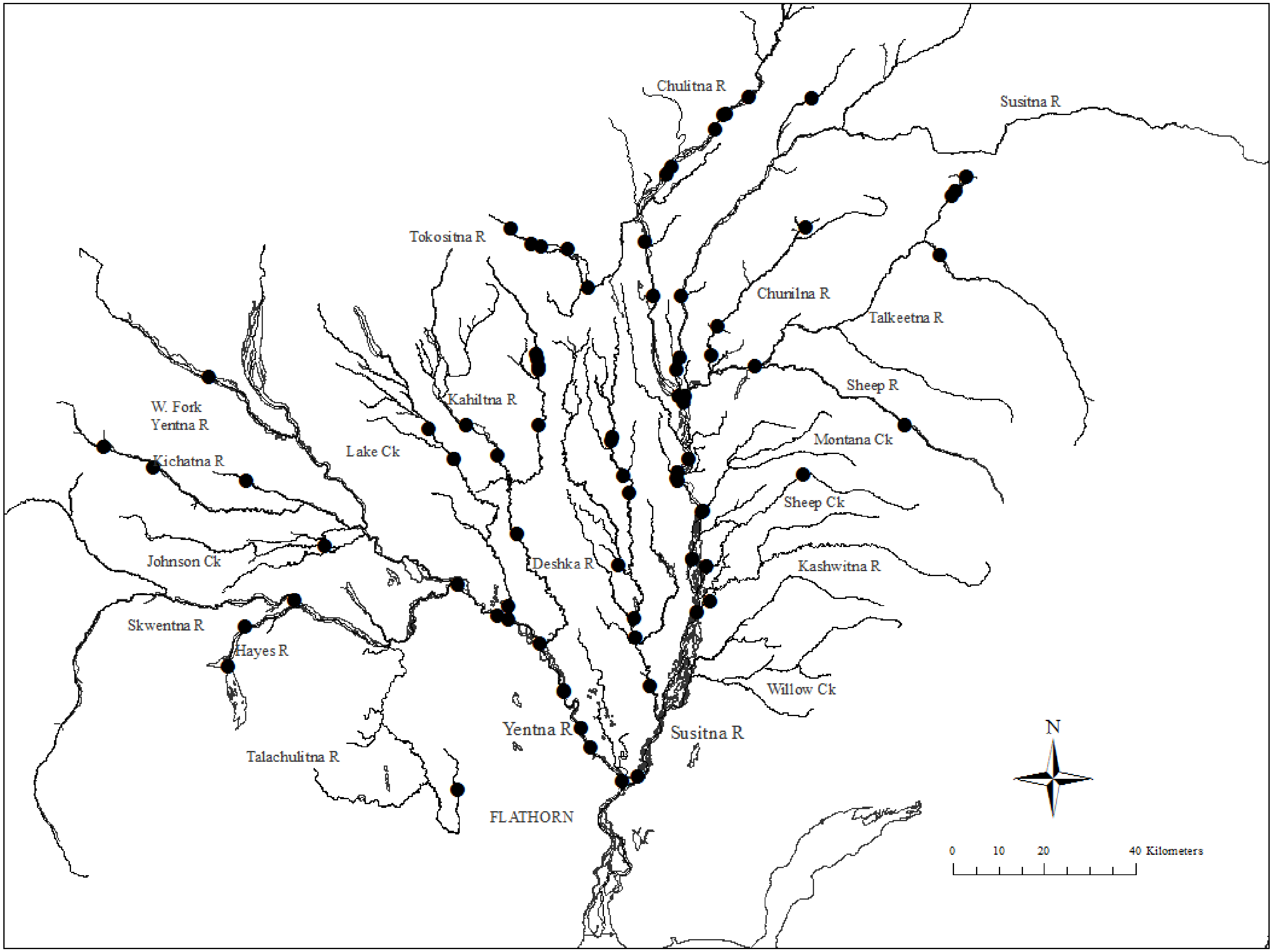

Figure 14.–Final locations of coho salmon radiotagged at FW 2, 2011.

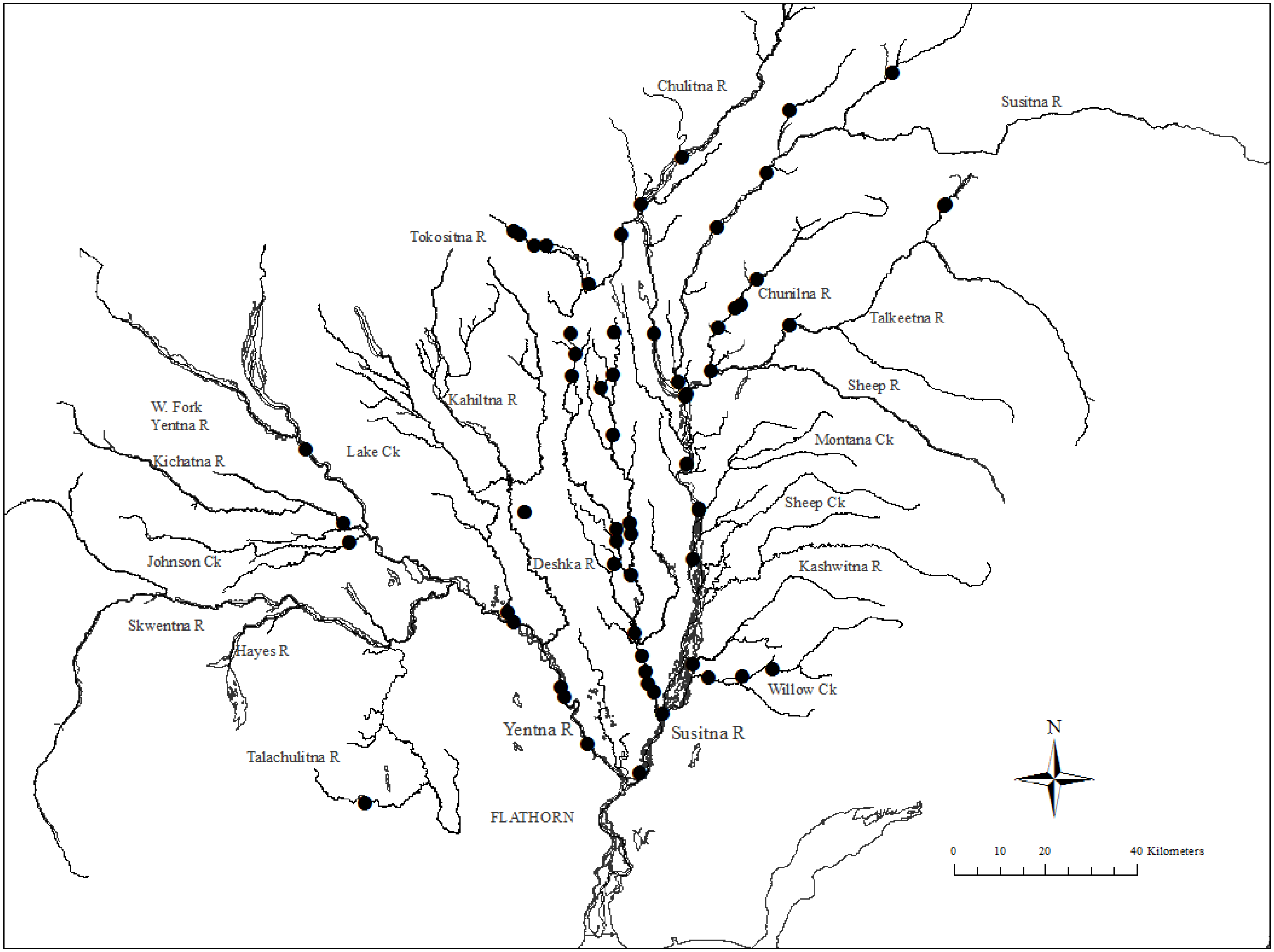

Figure 15.–Final locations of coho salmon radiotagged at FW 3, 2011.

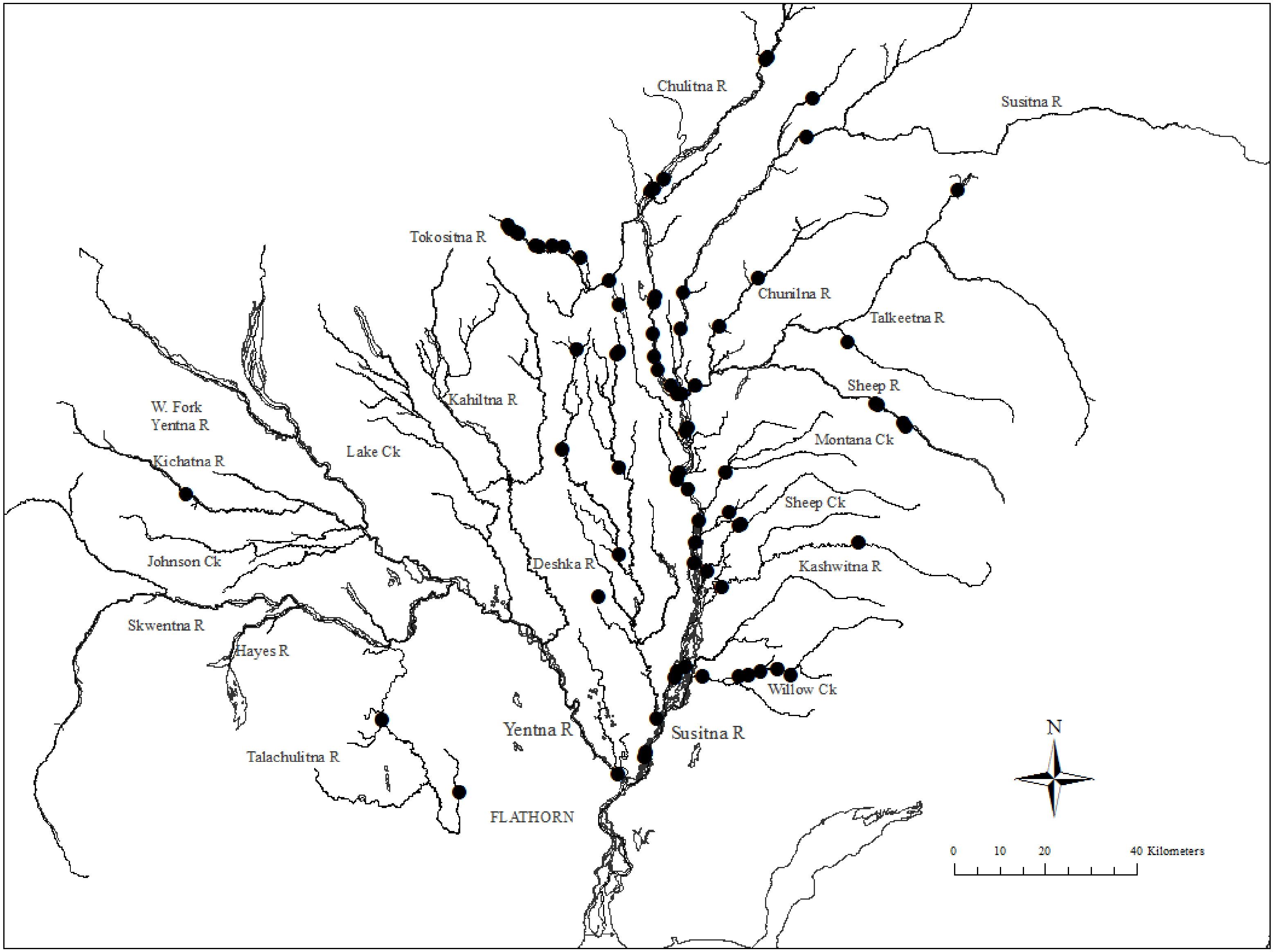

Figure 16.–Final locations of coho salmon radiotagged at FW 4, 2011.

Estimated Distribution of Spawning Salmon

Chum Salmon

Results from the mark–recapture experiment indicated 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 each first-event stratum used in the mark–recapture model and then summed across all first-event strata. The estimated abundance of radiotagged chum salmon was effectively weighted by estimated passage within each first-event stratum (Tables 19 and 20).

An estimated 1,473,969 (SE 123,933) chum salmon spawned in tributaries of the Susitna River above the mouth of the Yentna River in 2011. The number of chum salmon spawning in the Yentna River drainage in 2011 was estimated to be 278,063 (SE 42,780) fish (Table 21).

Table 19.–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 less than 562.5 mm METF length spawning upstream from the Flathorn tagging site in the Susitna River, 2011.

First-event stratum		Estimated abundance	Estimated SE	Estimated radio tags deployed [a]	Relative weight spawners/tag
FW 1	Days 188–210	5,297	6,168	26.73	198.16
	Days 211–222	12,054	9,132	23.00	524.07
	Days 223–241	54,758	16,519	15.79	3,468.52
FW 2–4	Days 188–209	246,321	49,419	52.00	4,736.94
	Days 210–218	226,599	52,787	46.67	4,855.70
	Days 219–241	569,554	86,186	71.42	7,974.92

[a] The number of tags is estimated because there were 5 radiotagged chum salmon for which we had no length data, and therefore we had to estimate which size stratum these fish belonged to in order to calculate expansion factors by marking stratum (see text with regard to Equation 1).

Table 20.–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 greater than or equal to 562.5 mm METF length spawning upstream from the Flathorn tagging site in the Susitna River, 2011.

First-event stratum		Estimated abundance	Estimated SE	Estimated radio tags deployed [a]	Relative weight spawners/tag
FW 1	Days 188–210	27,124	15,704	6.27	4,327.46
	Days 211–225	11,579	10,232	10.00	1,157.89
	Days 226–241	15,121	18,560	3.21	4,706.45
FW 2–4	Days 188–211	361,492	105,974	42.00	8,606.96
	Days 212–223	113,680	39,809	23.33	4,871.99
	Days 224–241	108,452	59,631	10.58	10,248.95

[a] The number of tags is estimated because there were 5 radiotagged chum salmon for which we had no length data, and therefore we had to estimate which size stratum these fish belonged to in order to calculate expansion factors by marking stratum (see text with regard to Equation 1).

Table 21.–Chum salmon spawning distributions, based on weighted abundance (Tables 19 and 20), in the Susitna River, 2011.

Location		Estimated abundance	SE	Intervals 95% lower	95% upper
Susitna River above the Yentna River					
Susitna River mainstem RM 24–98		189,209	40,303	121,708	278,394
Deshka River		0	0	0	0
Eastside Susitna River		242,675	44,282	166,008	339,603
Talkeetna River		548,285	67,592	433,117	698,490
Susitna River mainstem and tributaries RM 98–154		337,014	57,240	240,957	465,366
Chulitna River		156,786	34,882	96,935	233,631
Total		1,473,969	123,933	1,276,921	1,764,849
Yentna River					
Yentna River mainstem					
	Yentna R. mainstem below Skwentna R.	51,801	18,724	20,879	94,129
	Yentna R. mainstem above Skwentna R.	27,016	10,837	9,640	51,723
	Total	78,817	21,390	42,792	126,493
Kahiltna River		4,935	4,740	0	16,490
Lake Creek		13,141	1,216	52,080	56,371
Skwentna River		104,579	25,570	64,393	161,591
Talachulitna River		15,827	9,442	3,548	40,005
Upper Yentna Tributaries		52,696	21,850	21,432	103,388
Total		278,063	42,780	213,620	376,980

Coho Salmon

Results from the mark–recapture experiment indicated 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 stratum from the mark–recapture experiment (Tables 22–23).

Table 22.–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 less than 472.5 mm METF length spawning upstream from the Flathorn tagging site in the Susitna River, 2011.

First-event strata		Estimated abundance	Estimated SE	Estimated radio tags deployed [a]	Relative weight spawners/tag
FW 1–2	Days 188–204	5,273	2,945	14.39	366.36
	Days 205–241	17,683	4,598	22.85	773.74
FW 3–4	All event days	30,687	13,826	33.00	929.91

[a] The number of tags is estimated because there were 5 radiotagged coho salmon for which we had no length data, and therefore we had to estimate which size stratum these fish belonged to in order to calculate expansion factors by marking stratum (see text with regard to Equation 1).

Table 23.–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 greater than or equal to 472.5 mm METF length spawning upstream from the Flathorn tagging site in the Susitna River, 2011.

First-event stratum		Estimated abundance	Estimated SE	Estimated Radio tags deployed [a]	Relative weight spawners/tag
FW 1–2	Days 188–215	85,014	14,015	68.61	1,239.14
	Days 216–241	1,070	4,394	59.15	18.09
FW 3–4	Days 188–215	63,163	23,612	61.00	1,035.46
	Days 216–241	13,664	11,260	45.00	303.64

[a] The number of tags is estimated because there were 5 radiotagged coho salmon for which we had no length data, and therefore we had to estimate which size stratum these fish belonged to in order to calculate expansion factors by marking stratum (see text with regard to Equation 1).

An estimated 131,878 (SE 24,146) coho salmon spawned in tributaries of the Susitna River above the mouth of the Yentna River in 2011. The number of coho salmon spawning in the Yentna River drainage in 2011 was estimated to be 84,677 (SE 9,981) fish (Table 24).

Table 24.–Coho salmon spawning distributions, based on weighted abundance (Tables 23 and 24), in the Susitna River, 2011.

Location	Estimated abundance	SE	Intervals 95% lower	95% upper
Susitna River above the Yentna River				
Susitna River mainstem RM 24–98	25,426	6,661	15,916	41,666
Deshka River	18,686	5,866	10,747	33,191
Eastside Susitna River	15,732	5,271	8,197	28,624
Talkeetna River	22,994	5,866	13,587	36,359
Susitna River mainstem and tributaries RM 98–154	10,785	4,085	4,703	20,581
Chulitna River	38,255	8,886	25,335	59,778
Total	131,878	24,146	100,712	193,164
Yentna River				
Yentna River mainstem				
Yentna R. mainstem below Skwentna R.	18,904	4,635	11,207	29,338
Yentna R. mainstem above Skwentna R.	9,701	3,313	4,051	16,968
Total	28,605	5,762	18,895	41,453
Kahiltna River	16,427	4,119	9,336	25,455
Lake Creek	9,589	3,254	3,769	16,466
Skwentna River	10,079	3,352	4,420	17,503
Talachulitna River	13,687	3,821	7,159	22,095
Upper Yentna Tributaries	6,289	2,624	2,239	12,412
Total	84,677	9,981	67,473	106,704

DISCUSSION

The 2011 Susitna River drainage spawning abundance estimates indicated approximately 84% (1,473,969/1,752,032) of chum salmon and 61% (131,878/216,555) of coho salmon migrated to areas in the Susitna River upstream of the Yentna River confluence (Tables 21 and 24). The remaining 16% of chum salmon and 39% 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 2011 were similar to spawning sites in 1981 (ADF&G 1981), 2009 (Merizon et al. 2010), and 2010 (Cleary et al. 2013). Based on estimated abundances, approximately 54.3% (952,294/1,752,032) of chum salmon appeared to use main channel sites (Susitna, Yentna, and Skwentna rivers), versus 42% (90,627/216,555) of coho salmon (Tables 21 and 24). Few radiotagged chum salmon (3/365, 0.1%) were documented in the Kahiltna, Deshka, and Tokositna rivers (Table 16). However, 23% (74/324) of radiotagged coho salmon were documented in these rivers (Table 17).

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 in Appendix A2 were used to detect significant temporal or geographic violations of assumptions of equal probability of capture.

The partially stratified model described by Darroch (1961) and used to estimate abundance for both chum and coho salmon 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 provided 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 may still exist due to our inability to detect all major sources of capture heterogeneity during the marking event, meaning the selected strata may not accurately compensate for that heterogeneity. However, the strata were selected based on known field conditions and supplemented and supported by the diagnostics tests for equal probability of capture described in Seber (1982).

As in the 2009 (Merizon et al. 2010) and 2010 (Cleary et al. 2013) radiotelemetry studies, bank orientation (a stock-specific adult migration behavior) was present at the tagging fish wheels for both species (Figures 8–11 and 13–16). 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 could be located downstream, suitable for capturing migrating chum and coho salmon prior to bank orientation behavior. 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 weighted abundance distribution determined for radiotagged coho salmon between the Yentna (39%) and Susitna (61%) rivers in 2011 is consistent with the weighted distributions determined for 2009 (43% and 56% in the Yentna and Susitna rivers, respectively; Merizon et al. 2010). In 2002, coho salmon were radiotagged in salt water in lower Cook Inlet and the fraction compared among 5 streams did not differ, suggesting homogenous tagging is possible prior to entering the river (Willette et al. 2003). In 1998, of the coho salmon caught in fish wheels and radiotagged at the Yentna Site, 40% had terminal locations in the Yentna River mainstem (mainstem plus east and west forks), 30% in Skwentna River, and 10% in Kichatna River (Todd et al. 2001). In 2011, the same areas had 25.3%, 10.2%, and 2.2% of radiotagged coho salmon that migrated up the Yentna drainage and tributaries, respectively, while the remaining were located in other sites (Table 18).

The 1984–1985 and 2010–2011 chum and coho salmon mark–recapture projects were conducted using the Flathorn Site for tag deployment to estimate abundance. Based on these estimates, chum salmon run strength was greatest in 2011 (1,752,000), followed by 1984 (812,700), 2010 (357,000), and 1985 (316,800). Fish wheel mark–recapture coho salmon estimates were greatest in 2011 (216,600) followed by 2010 (196,000), 1984 (190,000), and 1985 (77,000). 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 25).

Table 25.–Historical Susitna River chum and coho salmon abundance estimates (nearest hundred).

		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
	2011	1,752,000	278,000	NA	1,474,000
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	305,200	NA	358,000
	2010	196,000	136,000	NA	60,000
	2011	216,600	84,700	NA	131,900

Source: 1981–1984 estimates from Barrett et al. (1985); 1985 estimates from Thompson et al. (1986); 2002 estimates from Willette et al. (2003); 2010 estimates from Cleary et al. (2013).

[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 Site at Susitna River RM 30.0.

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

A number of factors 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 structure at wheel sites, new locations of wheel sites, and water level effects on wheel speed. Like the mark–recapture studies conducted in the 1980s and in 2010, first-event data collected in 2011 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. Similar to 2010 but unlike studies in the 1980s, fish wheels were operated in 2011 for tag recovery at RM 30 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 streams and sloughs upstream of the deployment wheels.

The radiotelemetry study in 2002 estimated a run strength for Susitna River coho salmon that was greater than estimates of run strength for all other years (Table 25). 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 via 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). 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.

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 provided 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 2-sample mark–recapture experiment and its effects on estimation of population size and population composition.

Size-selective sampling

The Kolmogorov-Smirnov 2-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 2 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 2-sample test (e.g., Student's *t*-test).

Test outcomes	M vs. R	C vs. R	M vs. C	Result
Case I	Fail to reject H_o	Fail to reject H_o	Fail to reject H_o	No size or sex selectivity detected during either sampling event
Case II	Reject H_o	Fail to reject H_o	Reject H_o	No size or sex selectivity detected during the first event but there is during the second event
Case III	Fail to reject H_o	Reject H_o	Reject H_o	No size or sex selectivity detected during the second event but there is during the first event
Case IV	Reject H_o	Reject H_o	Either result possible	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	Sample sizes and powers of tests must be considered [a-d]

[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 1 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.

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

$$\hat{p}_k = \sum_{i=1}^{j} \frac{\hat{N}_i}{\hat{N}_\Sigma} \hat{p}_{ik} \text{ and} \tag{A1}$$

$$\hat{V}[\hat{p}_k] \approx \frac{1}{\hat{N}_\Sigma^2} \sum_{i=1}^{j} \left(\hat{N}_i^2 \hat{V}[\hat{p}_{ik}] + \left(\hat{p}_{ik} - \hat{p}_k\right)^2 \hat{V}[\hat{N}_i] \right) \tag{A2}$$

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 (Seber 1982: page 438).

Of the following conditions, at least 1 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 3 assumptions, the chi-square statistic was used to examine the following contingency tables as recommended by Seber (1982). At least 1 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 3 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 recaptured (second-event strata)				Not recaptured
Area or time where marked	1	2	…	t	(n_1-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 is the number captured in first event; m_2 is the 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-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_{ij} is the movement probability from first-event strata i to second-event strata j, k is the total marks released per total unmarked in the population, U_j is the total unmarked fish in stratum j at the time of sampling, and a_i is the number of marked fish released in time or area stratum i. For the Petersen estimator to be unbiased, k must equal total marks released per total unmarked in the population; this condition is satisfied if there is equal closure over tagging strata ($\Sigma_j\theta_{ij}$ = constant), i.e. the proportion of the run in each tagging stratum moving to inspected second-event strata is the same for all tagging strata. The hypothesis can also be satisfied through mixing ($\theta_{ij} = \theta_j.$) but because mixing is unlikely due to the experimental design, the test is one of equal probability of capture in the first event.

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

[b] n_2 is the 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-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_{ij} is the 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. The hypothesis can also be satisfied through mixing ($\theta_{ij} = \theta_j.$), but because mixing is unlikely due to the experimental design, the test is one of equal probability of capture in the second event.

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

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