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Inriver Abundance and Migration Characteristics of Kuskokwim River Chinook Salmon, 2015

by

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and

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May 2017

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

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$\log_2$, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

FISHERY DATA SERIES NO. 17-22

INRIVER ABUNDANCE AND MIGRATION CHARACTERISTICS OF KUSKOKWIM RIVER CHINOOK SALMON, 2015

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ABSTRACT

A 2-sample mark–recapture experiment was conducted to estimate the abundance and upriver migration characteristics of adult Chinook salmon *Oncorhynchus tshawytscha* returning to the Kuskokwim River in 2015. Tagging occurred downriver from all known spawning tributaries, except the Eek River. All fish were marked with a dorsally attached spaghetti tag, and a subset of spaghetti tagged fish was also fitted with a radio tag to evaluate assumptions of the abundance estimator and monitor upriver movement. Radiotagged fish were tracked throughout the study area using a network of telemetry stations and a series of aerial telemetry surveys. Seven escapement monitoring weirs were operated upriver from the tag site and served as recapture locations for tagged fish. Inriver abundance of Chinook salmon upstream of rkm 67 was 115,541 fish (95% CI: 105,370–125,346). Radiotagged Chinook salmon traveling to upriver tributaries were captured and tagged earlier in the run compared to tagged fish migrating to middle river tributaries. Chinook salmon returning to lower river tributaries were captured and tagged throughout the entire run.

Key words: Chinook salmon, *Oncorhynchus tshawytscha*, mark–recapture, radiotelemetry, abundance estimation, run timing, swim speed, Kuskokwim River

INTRODUCTION

Kuskokwim River fisheries managers require accurate estimates of Chinook salmon *Oncorhynchus tshawytscha* abundance and detailed information about fish migration as they pass through harvest areas to manage subsistence and commercial fisheries. The Kuskokwim River supports a large run of Chinook salmon that averages nearly 240,000 fish (1976–2015; Liller and Hamazaki 2016). Historically, annual run sizes have been adequate to support an unrestricted subsistence fishery. The Kuskokwim River subsistence fishery is one of the largest in the State of Alaska, accounts for 50% or more of the statewide subsistence harvest of Chinook salmon (Fall et al. 2015), and harvests an average (1976–2015) of 31% of the total annual run (range: 8%–56%; Liller and Hamazaki 2016). There is no directed commercial fishery for Kuskokwim River Chinook salmon, but Chinook salmon are harvested incidentally during chum and sockeye salmon fisheries. Since about 2010, Kuskokwim River Chinook salmon productivity has declined and annual run sizes have been inadequate to meet escapement and subsistence harvest needs. In response, fisheries managers have implemented strategies to reduce harvest in order to achieve escapement goals. Harvest reduction efforts have included complete closures of commercial fisheries and unprecedented restrictions to the subsistence fishery.

Declining productivity has been documented for many Chinook salmon stocks across Alaska, including the Kuskokwim River, creating social and economic hardships. In 2012, the Alaska Department of Fish and Game (ADF&G), in conjunction with Federal agencies and academia, identified gaps in stock assessment data that prevented them from fully addressing questions that arose from the statewide decline in the abundance of Chinook salmon. In response, the ADF&G Chinook Salmon Research Team was formed and developed a research plan with recommended studies to address questions identified in the gap analysis (ADF&G Chinook Salmon Research Team 2013). The core of the plan was aimed at understanding stock-specific variability in productivity. The Kuskokwim River was 1 of 12 indicator stocks chosen by the Chinook Salmon Research Team to index statewide Chinook salmon productivity and abundance trends.

Currently, total annual abundance of Kuskokwim River Chinook salmon is estimated using a statistical run reconstruction model that uses previously defined relationships between estimates of total abundance and indices of abundance from a range of monitoring projects (Bue et al. 2012). Accurate abundance estimates require that the run reconstruction model is scaled appropriately. The run reconstruction model is currently scaled using estimates of total run size from 2003 to 2007, a period of average and record high returns (Bue et al. 2012; Schaberg et al. 2012). Since 2010, the annual Chinook salmon run size has been below average, including record low run sizes in 2010, 2012, and 2013 (ADF&G Chinook Salmon Research Team 2013; Liller and Hamazaki 2016). The Chinook Salmon Research Team recommended additional independent estimates of total abundance to evaluate model performance in low abundance years, which could be used if necessary to rescale the model for improved abundance estimation. As such, a 3-year mark–recapture study was initiated for 2014, 2015, and 2016.

Methods used in 2015 were modified substantially compared to those used in 2014 and prior years (2003–2007). In particular, the tag site was moved from its original location near the community of Kalskag (rkm 270) downriver near the mouth of the Kuskokwim River (rkm 67). The feasibility of this new tagging location was evaluated in 2014 (Clark et al. 2014) and results indicated a high likelihood of success compared to previous attempts to tag in the Lower Kuskokwim River (ADF&G 1967; Marino and Otis 1989). Tagging fish near the mouth of the Kuskokwim River had several advantages. First, the location change simplified the process of estimating total run by eliminating the need to use untested habitat-based methods to estimate escapement to unmonitored tributaries (see Schaberg et al. 2012). Second, the new tag location was downriver from the Kwethluk and Tuluksak Rivers allowing us to collaborate with U.S. Fish and Wildlife Service (USFWS) to use those existing weirs as additional recapture sites for tagged fish. The additional recapture effort was expected to result in a more precise estimate of total run size. Third, moving the tag site downriver provided a first opportunity to monitor Chinook salmon run timing and swim speed through the lower portion of the Kuskokwim River where most harvest occurs.

The gillnet mesh size used to capture adult Chinook salmon was also changed from previous tagging studies. In 2015, we decided to use only 7.5 in mesh gillnets, based on recommendations from the 2014 Lower River feasibility study (Clark et al. 2014) and 2014 mark–recapture study (Head et al. 2017). Those studies used 8.0 in and 7.5 in mesh gillnets, both of which were shown to be selective for large Chinook salmon. It is possible that we could capture Chinook salmon across the range of fish sizes and in proportion to abundance by using smaller gillnet mesh sizes or a range of complementary mesh sizes. However, we chose not to pursue those options in 2015 for 3 reasons. Most importantly, repeated Chinook salmon tagging studies have demonstrated that the suite of weirs used as recapture sites is not selective for fish size (e.g., Stuby 2007; Head et al. 2017), and as such, any selectivity during the tagging event would not bias the abundance estimate. Second, we expected the catch of non-Chinook salmon species to increase substantially if smaller mesh sizes were used. Finally, using a single gillnet size was an attempt to increase crew efficiency by avoiding complicated net rotation schedules and simplifying net maintenance.

We also improved our ability to evaluate potential biases in 2015 by incorporating a new recapture weir into the study design. This decision was heavily influenced by an unprecedented and large percentage (21%) of radiotagged Chinook salmon tracked to headwater tributaries upriver from McGrath (rkm 753) in 2014 compared to prior years (average 5%, 2002–2007). We believe the tag distribution in 2014 accurately reflects an increased escapement of Chinook salmon to headwater tributaries, which is best explained by salmon fishery closures during the early portion of the run (Lipka et al. 2016) when those fish were most abundant (Head et al. 2017). Fishery managers implemented early season harvest restrictions again in 2015; therefore, we expected a relatively large escapement to headwater tributaries. A weir was installed on the Salmon River (Pitka Fork) to evaluate the ratio of marked and unmarked fish for the subset of Chinook salmon that return to the headwaters. The Salmon River was chosen based on 7 years of telemetry studies that consistently demonstrated its importance as a headwater spawning tributary (Stuby 2007; Head et al. 2017).

This report documents the activities and results of the 2015 study.

OBJECTIVES

1. Estimate the abundance of adult Chinook salmon in the Kuskokwim River for all waters upriver of rkm 67, such that the bounds of the 95% confidence interval are within ±25% of the estimated abundance.
2. Evaluate the stock-specific run timing of Chinook salmon migrating past the Lower Kuskokwim River tag site located at rkm 67.
3. Evaluate the stock-specific migration speed of Chinook salmon as they travel from rkm 67 to rkm 753.

METHODS

STUDY AREA

Estimates of abundance are germane to all waters upriver of rkm 67 (Figure 1). The study encompassed an area draining approximately 108,000 km^2. Due to the migratory nature of Chinook salmon, sampling and tracking efforts encompassed the entire Kuskokwim River drainage upriver from the tag site.

Initial capture and tagging of Chinook salmon occurred at rkm 67 near the confluence of the Johnson and Kuskokwim rivers (Figure 1). This area was chosen because it is downriver from all but 1 Chinook salmon spawning tributaries (i.e., Eek River) and downriver from where approximately 90% of subsistence harvest occurs. The river channel near the tagging area was 3.7 km wide and tagging occurred along a section of the mainstem that was approximately 13 km long. The tagging area was divided into 2 spatially exclusive sites to facilitate the use of 2 tagging crews (Figure 2). Within each tagging site (i.e., lower and upper), 2 drift zones were used to capture fish at the start of the season. Early season exploration lead to the establishment of 9 total drift zones, 5 in the lower and 4 in the upper site (Figure 2). The use of multiple drift zones was an attempt to distribute effort throughout the channel and over a wide range of tidal stages. The depth of drifts zone ranged from 6.1–9.1 m for most sand bar locations, and from 9.1–12.2 m at most bank locations. Maximum river depth was 25 m near the vicinity of the tag site.

Recapture of tagged Chinook salmon occurred at 7 weirs located on important spawning tributaries within the lower, middle, and upper portions of the Kuskokwim River drainage (Figure 1). Weirs located on the Kwethluk (rkm 216) and Tuluksak (rkm 248) rivers indexed Chinook salmon spawning tributaries in the Lower Kuskokwim River. Middle Kuskokwim River tributaries were indexed with weirs installed on the Salmon (Aniak drainage; rkm 404), George (rkm 453), Tatlawiksuk (rkm 568), and Kogrukluk (Holitna drainage; rkm 710) rivers. A weir on the Salmon River (Pitka Fork drainage; rkm 880) indexed Chinook salmon migrating to the headwaters tributaries upriver from McGrath.

A total of 18 stationary telemetry towers were used to monitor the movement of and determine final fate of radiotagged Chinook salmon (Figure 1). One telemetry station located at rkm 112 (hereafter referred to as T01) was used to identify radiotagged fish that successfully migrated upriver from the tagging location. A distance of 45 rkm separated the tagging location and T01 to allow radiotagged fish adequate time to recover from capture and tag stress. An additional 9 telemetry stations were located along the mainstem Kuskokwim River from the bifurcation of the mainstem Kuskokwim River and Kuskokuak Slough (rkm 124) to McGrath (rkm 753). A telemetry station was also located at each of the 7 weir recovery sites. Lastly, 1 telemetry tower was placed within the lower reaches of the Kwethluk River (7 rkm upstream from the confluence) to help distinguish between tagged salmon escaping into the Kwethluk River versus the nearby Kisaralik and Kasigluk Rivers.

MARK–RECAPTURE ABUNDANCE ESTIMATION

A Petersen closed population 2-sample mark–recapture study design (Chapman 1951; Seber 1982) was used to estimate the total inriver abundance of Chinook salmon upstream of rkm 67.

First Event Sampling

Two 3-person fishing crews captured adult Chinook salmon as they migrated upriver past the tag site. Sampling was conducted 7 days per week throughout the entire Chinook salmon run, from May 28 until July 24. One crew was assigned to the lower and 1 crew to the upper tagging site, for the duration of the study. Each crew fished for approximately 8 hours each day with effort distributed among the twice daily incoming tides starting just after slack tide. Tide schedule predictions were based on a 1-hour earlier adjustment from the Bethel district in the Western Alaska edition of the Alaska tide book. At the start of each tide, effort was distributed evenly among drift zones (Figure 2) until it was determined where fish capture was most successful. Increased sampling effort was allocated to more productive zones throughout the remainder of the shift. Each crew worked 6 days per week, alternating days off.

Drift gillnets were used to capture medium to large size adult Chinook salmon. Gillnets had a stretched mesh size of 7.5 in (19.1 cm) and were 45 meshes deep (8.6 m). The nets were constructed of multi-fiber monofilament (MT83 twine and shade 66 Green) with a K/D knot type. Size 11 closed cell foam floats were used with a 7/16″ cork line. The lead line was size 95. The mesh was hung at a 2:1 ratio for a finished length of 25 fathoms (45.7 m).

Strict handling, tagging, and release methods were used to minimize fish stress. When it was suspected that a fish was captured in a drift gillnet, the net was retrieved to the boat. Captured Chinook salmon were immediately removed from the net, placed in a tote containing fresh river water, and immobilized in a soft mesh cradle. A physical examination was performed on all captured Chinook salmon. The examination ranked fish on a scale of 1–4, with 1 being good condition with no injuries, 2 having minor injuries, 3 having major injuries, and 4 being deceased. Only fish that receive a rank of 1 or 2 were tagged. Chinook salmon were released immediately following tagging.

All Chinook salmon that passed the physical examination were given a primary mark consisting of a uniquely numbered spaghetti tag (Model FT-4; Floy Tag and Manufacturing, Inc.)[1], and a subset of 623 Chinook salmon also received an esophageal radio tag (Advanced Telemetry Systems). Spaghetti tags were attached approximately 1 cm below and 2–3 fin rays anterior to the posterior insertion of the dorsal fin following standard methods. Radio tags were deployed in proportion to run strength based on a schedule developed from historic run timings observed at

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

the Bethel test fishery (BTF) located 39 rkm upriver from the tag site. Inseason run timing information from the BTF was used to modify the deployment schedule to mimic actual run timing observed. Each radio tag was distinguishable by a unique frequency and encoded pulse pattern. Two sizes of radio tags were used to ensure that tags did not exceed 2% of the fish's body weight (Cooke 2012). A model F1840B tag (20 grams total weight) was used for fish with mideye tail fork (METF) length between 450 and 550 mm inclusive. A larger model F1845B tag (24 grams total weight) was used for fish with a METF length greater than 550 mm. Insertion of radio tags followed standard methods (e.g., Stuby 2007).

At the time of tagging, tag information and biological data was recorded for all captured Chinook salmon. Data included the spaghetti tag number, radio tag frequency and code, length (mm; METF), sex, and fish condition. Sex was determined by visually examining secondary sexual characteristics. All non-target species captured were recorded and released.

The number of spaghetti tagged Chinook salmon that continued upriver past the tag site was estimated using information from radiotagged fish. The number of radiotagged fish that continued upriver past the tag site (n_{rup}) was equal to the sum of the fish harvested between the tag site and T01 and those fish that moved and remained upriver past T01. That subset (n_{rup}) of radiotagged fish out of the total number of radiotagged fish released at the tag site (n_r) formed the estimated proportion of tagged fish that were available for recapture, $p_{up} = n_{rup}/n_r$. Then, the number of spaghetti tagged fish that successfully entered the marked population above the tagging site (M') out of the total number of fish that received a spaghetti tag (M) was estimated as $M \cdot p_{up}$. All fish harvested downriver from the tag site and those that did not resume migration past the tag site were culled from the experiment.

Telemetry Tracking

Radiotagged Chinook salmon were tracked as they migrated up the Kuskokwim River using a network of 10 stationary tracking towers (Figure 1). Each stationary tower was equipped with an ATS model 4500 receiver that had an integrated data logger. The receiver, 2 deep-cycle 12V batteries, and associated components were securely housed in a lockable weather resistant steel box. Two 4-element Yagi antennas were mounted on a mast elevated 2–10 m above the ground. The tower was powered by a 95W solar panel. The receiver was programmed to receive from both antennas simultaneously and scan through the list of tag frequencies at 6 s intervals. When a signal of sufficient strength was encountered, the receiver paused for up to 12 s on each antenna to decode and record tag information. The relatively short cycle period minimized the chance of radiotagged fish passing the receiver site without being detected.

A series of 23 aerial telemetry tracking flights were performed between June 6 and August 25 to assist with monitoring upriver movement and determine a final fate (Table 1). Tracking surveys were conducted with a fixed wing aircraft, pilot, and surveyor(s) who operated a R4500 data logger(s). Scan time for each frequency was 2 seconds. A single H-antenna was mounted on each wing strut, and the surveys conducted from August 24 through August 27 also utilized a C-type antenna attached to the bottom of the aircraft. The H-type antenna provided directional detection of fish to the left or right side of plane. The C-type antenna was used to increase detection of tagged fish directly below the plane. Surveys were flown at approximately 120 km/h at an altitude between 100 and 300 m above the center of the river. Once a radio tag was detected, the surveyor prompted the data logger to record georeferenced tag information.

The combination of stationary and aerial telemetry tracking methods were used to monitor movement, determine the final fate of radiotagged Chinook salmon, and test mark–recapture assumptions. The Kuskokwim drainage was stratified into 10 subareas upriver from rkm 112 using the network of 10 towers along the mainstem (Table 2; Figure 3). A process of elimination approach was used to assign fish to a subarea and determine a final fate (Liller et al. 2011). Chinook salmon were assumed to be in a tributary if stationary tower records confirmed their presence in a subarea and they were not detected in the mainstem during the aerial tracking survey. A single tracking tower was located at each of the 7 recapture weirs to determine the number of radiotagged Chinook salmon that passed upriver. Aerial survey flights were flown upriver from each weir to confirm the passage of radiotagged fish through the recapture weirs, in the unlikely event that a tagged fish passed the tower undetected.

Harvest Mortality

Harvest mortality of tagged fish was evaluated using a volunteer tag lottery. The lottery was advertised using mailers sent to rural businesses and tags were clearly labeled with contact information. Fishermen were encouraged to call in tags caught in the subsistence fishery by advertising 4 monthly prizes of $200 awarded to 1 randomly selected participant who reported tag information during June, July, August, and September. We also held a grand prize drawing at the end of the study and awarded a $500 prize to 1 participant selected at random from all participants. Participants reported the date and location of harvested fish along with tag color, tag number, and presence or absence of a radio tag.

Radiotelemetry methods were also used to determine if a radiotagged fish may have been harvested, but was not reported through the lottery system. A radiotagged fish was assumed to have been harvested if it was identified in the same location within 1 km of a village or active fish camp for 3 or more aerial tracking flights.

Second Event Sampling Methods

Recapture sampling occurred at 7 tributary escapement monitoring weirs located upstream of the tagging location. At each weir, sampling began on approximately June 15 and continued until approximately September 20. Operational dates have been shown to encompass the entire Chinook salmon escapement at each weir (Blain et al. 2016; Webber et al. 2016a and 2016b). Recapture samples collected at each of the 7 weir locations (C_i) consisted of all Chinook salmon observed passing upstream of weir i (i = 1,…, 7) during operable periods. The total recapture sample (C) was $\sum(C_i)$. Only fish directly counted at the weir were included in the sample; estimates of missed passage were not used.

All Chinook salmon were visually inspected for spaghetti tags as they passed weir locations. Two methods were used to visually inspect and record external tags. Alaska Department of Fish and Game staff physically recaptured tagged fish as they passed weirs located on the Salmon (Aniak drainage), George, Tatlawiksuk, and Kogrukluk, and Salmon (Pitka drainage) rivers. When a tagged fish was recaptured at the weir, tag number, presence of a radio tag, sex, and condition of the fish were recorded. Weirs operated by the USFWS on the Kwethluk and Tuluksak rivers utilized video technology to enumerate passing Chinook salmon (Webber et al. 2016a and 2016b). Presence of a tag and tag color was visible to observers who reviewed recorded footage of fish passing the weir, but tag numbers were only recorded for a small subset fish recaptured during scheduled age, sex, and length sampling periods. Video data was reviewed both inseason and postseason and compared to data from the nearby telemetry tower to confirm that all tagged fish were identified.

The number of tag recaptures was adjusted to account for incomplete reporting by weir crews. The number of radiotagged Chinook salmon that passed upriver of each weir was known from telemetry tower and air survey records. However, we acknowledge that some portion of the fish that only received an external spaghetti tag may have passed upriver through the weir without being observed. Radiotelemetry data was used to estimate the probability that a tagged fish was observed as it passed through the weir during operational periods. Recapture sites were grouped p (p = 1, 2, and 3) based on enumeration method and crew experience. The number of radiotagged fish detected by the telemetry towers located at the weir sites (n_{rp}) and the total number of radio tags documented by weir staff (n_{sp}) was used to estimate the detection probability $p_{sp} = n_{sp}/n_{rp}$ for each group. Then the detection probability and the number of spaghetti tag only recaptures (r_p) was used to estimate total number of non-radiotagged fish that passed the weirs (R_p) as r_p/p_{sp}. The expected total number of recaptures (R') was then estimated as $\sum(R_p+n_{rp})$.

Groups were defined as follows for the purpose of estimating detection probability. The Kwethluk and Tuluksak River weirs were grouped because these projects were operated by USFWS and observations of fish was with a video camera which provided a horizontal (side) view of all Chinook salmon passing the weir. The Salmon (Aniak), George, Tatlawiksuk and Kogrukluk River weirs were grouped because they are operated by ADF&G and staff visually observe passing Chinook salmon by looking down into the water column through a viewing window. All of the staff working at these 4 weirs in 2015 had prior experience recapturing tagged salmon. The Salmon (Pitka Fork) weir was also operated by ADF&G and used the same methods as other ADF&G projects, but the crew had no prior experience recapturing tagged salmon.

Data Analysis

Chapman's modification of the Petersen estimator (Chapman 1951; Seber 1982) was used to estimate total abundance of Chinook salmon upstream of rkm 67:

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

Variance of the mark–recapture estimate was estimated by a parametric bootstrap simulation with 1,000 replicates (Efron 1982). Each uncertain parameter, M', p_{sp}, and R' associated with the tagging and recapturing processes was modeled, denoted in subsequent equations with an asterisk (*). With each bootstrap replicate, denoted with subscript (b), a probable value for each parameter was drawn from an assumed distribution and a bootstrap estimate of simulated abundance was calculated using Equation 1.

The number of spaghetti tagged fish that moved upstream of the tag site was assumed to have a binomial distribution (BN), and was modeled as $M^*_{(b)} \sim BN(M, p_{up})$.

Estimating the number of recaptures was accomplished by monitoring a subset of spaghetti tagged fish fitted with radio tags. The estimation process relied on 3 steps. Because the estimated number of fish that only had spaghetti tags at each weir was predicated on the detection probability of fish that also had radio tags, the detection probability of radio tags at each weir group ($p^*_{(b)sp}$) was modeled as a binomial variable, $p^*_{(b)sp} \sim BN(n_{rp}, p_{stp})/n_{rp}$. The second step modeled radio tag movement variability among recapture locations by separating the proportion of spaghetti tagged fish with a radio tag, p_i , into 8 classes i (i = 0,…, 7; Table 3). The number radio tags recovered at each weir site was assumed to have a multinomial distribution, and was modeled as $R^*_{(b),i} \sim multi\ (n_{rm}, p_i)$. Lastly, the results from the first 2 steps were used to model the total number of spaghetti tagged fish that were recovered as $R^*_{(b)} = \sum R^*_{(b)i} + \sum r_p / p^*_{(b)sp}$.

The average bootstrap estimate of simulated abundance $\overline{N}^*_{(b)}$ calculated as $(\Sigma N^*_{(b)})/1{,}000$ was used to approximate variance of the mark–recapture estimate, using the following equation:

$$v(\hat{N}) = \frac{\sum_{(b)} (N^*_{(b)} - \overline{N}^*_{(b)})^2}{B-1} \ . \qquad (2)$$

Data modeling and hypothesis testing were used to determine whether this study met the critical assumptions of the Petersen estimator (Chapman 1951; Seber 1982). The requirement for a closed population was addressed by conducting tag and recapture operations throughout most of the Chinook salmon run and culling fish that did not continue upriver after being tagged. Harvest does occur throughout the mark–recapture study area, but we assumed that tagged and untagged fish were harvested at the same rate. The assumption that tagged fish behave the same as untagged fish could not be formally evaluated, but we attempted to minimize behavioral effects by limiting holding time of captured fish and tagging only healthy fish. The requirement that fish retain their tag and are recognized during the second sample event was addressed by estimating the proportion of fish that were observed at each weir and adjusting the number of recaptures with this proportion. The assumption that all fish had an equal probability of capture in the first or second sample was evaluated using radiotagged fish and by following recommendations of Seber (1982; Appendix A1). A chi-square goodness-of-fit test was used to evaluate equal probability of capture and recapture.

Sex and length selectivity biases that may have occurred during the capture and recapture events were explored using contingency table analysis and a Kolmogorov-Smirnov test. Comparisons of the marked (*M*) and recaptured (*R*) populations for sex and length used standard chi-square and Kolmogorov-Smirnov tests, respectively. However, tests involving fish examined during the second event (*C*) were modified to account for the fact that sex and length composition of fish examined in the second event was estimated and the number of samples collected at each site was not proportional to abundance. The sex composition of the recapture sampling event (*S*) was estimated by weighting the sex ratio (*s*) observed at each weir i (i = 1,…, 7) by the escapement at that weir (C_i), so that $S = \sum C_i * s_i$. A chi-square test of independence was used to test the hypothesis of no difference in the sex composition between the first and second sampling event. In order to evaluate length bias, an empirical cumulative distribution function for the second sampling event was modeled. The count (l) of samples collected at each discrete length m (m = 333…, 1,005) was expanded by the total escapement (C_i) at each recapture weir, and the expanded count of lengths was summed across all weir locations as:

$$F_m = \sum \left(\frac{l_{mi}}{\sum l_{mi}} * C_i \right) . \qquad (2)$$

The estimated count of fish by length in the recapture sample was converted to a cumulative distribution and compared to cumulative length distribution of the marked sample using a

Kolmogorov-Smirnov goodness-of-fit test (Appendix A2). All statistical tests were considered significant at $\alpha = 0.05$.

RUN TIMING

Run timing past the tag site was evaluated for all tagged fish assigned to a tributary within Subareas 2, 3, and 5–10 (Table 2; Figure 3). Sub-areas 1 and 4 were not included because no salmon tributaries drain into those sections. Tag dates recorded at the lower river site were summarized using the median, central 50%, central 80%, and range for fish returning to each subarea. Date summaries were portrayed graphically for comparison and trend identification.

MIGRATION RATE

Radiotelemetry data was used to determine the total time it took for each radiotagged Chinook salmon to travel between successive locations (i) along the mainstem Kuskokwim River. Elapsed time was estimated between the tag site ($i = 0$) and tower T01 and then sequentially between all 10 successive tower locations ($i = 1,\ldots, 10$). The date/hr/min (t) at which each fish was released at the tag site was known. The date/hr/min that each fish passed tower i was approximated using the first detection by the upriver antenna. The estimated total elapsed time (T') between locations was estimated as t_i-$t_{(i-1)}$ and reported in days. The distance (d) between each location i was determined using ArcGIS software. A migration rate was determined for each fish as T_i'/d_i. Radiotagged fish assigned to Subareas 2, 3, and 5–10 were pooled by subarea and a median migration rate and interquartile range was calculated.

RESULTS

MARK–RECAPTURE

The estimated abundance of Chinook salmon upstream of rkm 67 was 115,541 fish (95% CI: 105,370–125,346; Table 4). The abundance estimate includes all fish that were harvested or escaped upriver from the tag site at rkm 67. The bounds of the 95% confidence interval were ±9% of the estimated abundance, which met the predetermined objective criteria of ±25% (Robson and Regier 1964).

A total of 1,213 Chinook salmon were captured at rkm 67. Of all fish captured, 85% were determined to be healthy with no visible injuries (condition 1) and 14% displayed minor wounds (condition 2), and only 1% displayed major wounds (condition 3) or were deceased (condition 4). A total of 1,193 (98%) Chinook salmon were spaghetti tagged (Table 5), and subset of 623 fish also received a radio tag. Chinook salmon were captured on the first day of operation (Table 5). Catches steadily increased and peaked at 76 Chinook salmon on June 18. After June 18, catches slowly decreased until the last day of sampling. Catches remained around 1% or less per day of the total season's catch during the last 16 days of operation. No Chinook salmon were caught during the final day of operations (July 24).

Final fate was determined for all 623 radiotagged Chinook salmon (Table 6). A total of 81 (13%) radiotagged fish failed to migrate and remain upriver from the tag site. Of those, 44 did not resume upriver migration, 34 continued upriver past T01 but later swam back downriver out of the study area, and 3 fish were harvested downriver from the tag site. A total of 542 radiotagged fish were used to estimate abundance. Of those, 505 (93%) radiotagged Chinook salmon migrated and remained upriver from T01 whereas 37 (7%) fish were harvested between the tag site and T01. A total of 411 (76%) radiotagged fish were located in a spawning tributary, 60 (11%) were located in the mainstem Kuskokwim River, and 34 (6%) were harvested in the subsistence fishery upriver from T01.

A total of 122 tagged Chinook salmon were reported harvested in local subsistence fisheries (Table 7). Of those, 48 (39%) were fish tagged with only a spaghetti tag and 74 (61%) were also tagged with a radiotag. Only 2% of tagged fish were harvested near Tuntutuliak (rkm 32) which is downriver from the tag site. Nearly 90% were harvested in the lower portion of the Kuskokwim River (i.e., lower 200 rkm) and 51% were harvested between Napakiak (rkm 87) and Bethel (rkm 106).

The number of spaghetti tagged Chinook salmon that continued upriver after being released at rkm 67 was estimated using radiotelemetry and harvest reports. The probability that a tagged fish migrated and remained upriver from T01 (p_{up}) was estimated to be 0.87 (Table 8). Therefore, the total number of spaghetti tagged fish was reduced by 13% to account for fish that did not continue upriver past the tag site. The total estimated marked population after correction (M') was 1,038 spaghetti tags (Table 8).

Total observed escapement (C) from all 7 weirs was 29,802 Chinook salmon (Table 9). A total of 216 tagged Chinook salmon was observed by weir crews during operational periods, of which 121 had only a spaghetti tag and 95 had both a spaghetti and radio tag. The probability that a spaghetti tagged fish was observed passing through the weirs varied depending on crew experience and counting method (Table 9). The lowest detection probability (0.79) was observed at the Salmon (Pitka Fork) River weir. The Kwethluk and Tuluksak weirs had a detection probability of 0.84. The remaining 4 weirs had a detection probability of 0.90. Total estimated tag recoveries (R') were 267 tags after adjusting for tagged fish that passed weirs undetected (Table 9).

Conditions for an unbiased estimate of abundance were achieved. The ratio of marked and unmarked radiotagged Chinook salmon at each weir was not significantly different, which provides support for the assumption of equal probability of capture (Table 10; $\chi^2 = 7.802$, $p = 0.1675$). Additionally, temporal radio tag deployment and recapture ratios were not significantly different (Table 11; $\chi^2 = 11.27828$, $p = 0.08010$), which indicates the probability of a tagged fish being recaptured did not differ over the course of the study. Large sample sizes were available for detecting length biases (Table 12). There was evidence that the first sampling event disproportionately selected larger fish; however, there was no length selectivity during the second event (Table 13; Figure 4). As a result, population composition parameters for length data are best represented by data collected from the weirs. Sex assignment at the tagging location was unreliable based on postseason validation. Comparisons between the sex assignment of fish at the tagging and recapture locations revealed a 24% error rate at the tagging location. As a result, tests for sex selective sampling are not presented.

RUN TIMING

Chinook salmon sub-stocks overlapped considerably as they passed upriver of the tag site, but general run timing patterns were elucidated (Tables 14 and 15; Figure 5). Headwater stocks typically showed up sooner than middle and lower river stocks. Headwaters fish made up 67% of the catch during the first week of operations (May 28–June 7), their contribution to the weekly catch decreased throughout the run, and they comprised 5% or less of the catch by week 5

(June 29–July 5). Fish returning to middle and lower river tributaries generally displayed similar run timing with median catch dates of June 21 and June 20 respectively (Table 14). The contribution of middle and lower river sub-stocks to the weekly catch increased throughout the run, but fish returning to the middle river were generally 2–4 times more abundant. Chinook salmon bound for middle river tributaries made up 50%–95% of the weekly catch between June 8 and July 24 (Table 15). During that same time, fish bound for lower river tributaries made up 17%–33% of the weekly catch.

MIGRATION RATE

All sub-stocks displayed similar migration rates through the sequential mainstem reaches (Table 16; Figure 6). It took the various sub-stocks a median of 3.18 days to travel the 45 rkm separating the tag site and T01 at a median rate of 14 (km/day, range 10–16). Upriver migration rate increased nearly three-fold after T01 and remained relatively consistent at 41 km/day (range: 32–45 rkm/day) through all subsequent sections.

DISCUSSION

There is no evidence that the tagging effort missed a substantial temporal component of the Chinook salmon run in 2015. Less than 1% of the Chinook salmon run migrated through the lower river prior to the start of tagging operations, based on information from the upriver Bethel test fishery (BTF; rkm 106; AYKDBMS[2]). Tagging operations continued as planned and on schedule throughout the run. Low catches during last 2 weeks of operations provided a reasonable assurance that the end of the run was well represented. Only 3.3% of the Chinook salmon run passed the BTF location after tagging operations ceased downriver.

Recapture weirs, telemetry tracking stations, and aerial surveys were effective and minimal operational challenges were identified. Only minor instances of missed passage occurred at weirs, with over 99% of the total escapement being observed (Blain et al. 2016). On-site test radio tags confirmed that all telemetry towers operated effectively for 95% of the days that Chinook salmon were actively passing the weir locations (i.e., the radio towers were not operational for about 5% of the season due to technical issues or user error). Extensive, aerial surveys were conducted upriver from each weir location to confirm passage of radio tags and detect any tags that may have passed when the towers were not operational. It is unlikely that any radiotagged fish migrated undetected past the recovery locations. The effectiveness of the escapement monitoring and telemetry tracking efforts provided an opportunity to evaluate a large number of Chinook salmon for tags and correct bias associated with incomplete reporting of tagged fish at the recapture sites.

We were unable to determine why 60 radiotagged fish had a final location in the mainstem Kuskokwim River upriver from T01; however, it is unlikely that our uncertainty substantially influenced the abundance estimate. There are no known Chinook salmon spawning aggregates in mainstem Kuskokwim River. Therefore, tagged fish located in the mainstem likely represent a combination of tag loss, unreported harvested fish, and fish that expired during upriver migration. Tag loss was explicitly evaluated and incorporated into our abundance estimate. Unreported harvest would not affect the abundance estimate as long as tagged and untagged fish

[2] AYKDBMS [Arctic-Yukon-Kuskokwim Database Management System] Home Page. http://sf.adfg.state.ak.us/CommFishR3/WebSite/AYKDBMSWebsite/Default.aspx.

were harvested in similar proportions—which we considered to be a reasonable assumption. In addition to harvest mortality, some degree of natural mortality was expected as fish travel upriver towards spawning grounds (e.g., Cooke et al. 2006), and we assumed that tagged and untagged fish would succumb to natural mortality at similar rates. However, it is plausible that the addition of tagging and handling stress may have resulted in higher en route mortality for tagged fish. As such, we must acknowledge the possibility that a few of these 60 fish could have been bound for monitored tributaries, and if they had not died would have been recaptures. We attempted to account for this type of uncertainty in our variance estimation by modeling recaptures and simulating abundance.

We were able to produce a reliable abundance estimate in the first year using a new study design in large part due to prior planning, inclusion of telemetry methods, and a robust tag recovery platform. Tagging success stemmed from a previous feasibility study that identified optimal tagging locations in the lower river (Clark et al. 2014), which resulted in a relatively large number of Chinook salmon captured and tagged. Our decision to incorporate radiotelemetry methods proved critical for evaluating the new tagging location and estimating the fate of tagged fish. We estimated that a large percentage of the tagged fish was able to continue their upriver migration and was available for recapture. Our ability to utilize the Kuskokwim Area weir program to recapture tagged fish was a particular strength of the study design. Recapture sites were spatially diverse representing lower river tributaries, both north and south draining tributaries in the middle river, and a headwater tributary. The combination of these weirs provided an opportunity to evaluate a large number of fish for tags and added statistical power to evaluate mark–recapture assumptions. The Salmon River weir located within the Pitka Fork upriver from McGrath was newly implemented in 2015, and provided an opportunity to confirm that all components of the run (including headwaters fish) were captured and tagged in proportion to their abundance. The data support our decision to use a pooled Petersen estimator and the estimate met our precision criteria. Our estimate of Chinook salmon abundance upriver from rkm 67 is likely unbiased and the precision is realistic given the challenges to operating a mark–recapture study of this scale.

This report presents the first holistic view of Chinook salmon run timing through the lower portion of the Kuskokwim River. All previously successful tagging studies were conducted in the middle river, near rkm 270. These past studies provided some evidence that fish returning to the tributaries upriver from McGrath had notably earlier migration timing through the middle portion of the Kuskokwim River compared to fish returning to spawn in less distant tributaries (Stuby 2007; Head et al. 2017). Our results indicate that Chinook salmon bound for the headwater tributaries also had earlier migration timing through the lower river. These findings were not surprising and are consistent with run timing patterns documented in other large river systems in Alaska like the Yukon (Eiler et al. 2004) and Copper rivers (Savereide 2004). Although only 1 year of data is available, we were surprised to find that Chinook salmon returning to lower river tributaries didn’t conform to any run timing pattern and were generally present throughout the entire run.

This study also yielded the first reliable estimates of Chinook salmon upriver migration rate throughout the entire Kuskokwim River mainstem. Estimates of Chinook salmon swim speed are available from fish tagged in the middle river and recaptured at upriver weirs (Pawluk et al. 2006; Schaberg et al. 2010), but those estimates are from relatively small samples of external tagged fish and are likely biased low (Schaberg et al. 2010). By using radiotelemetry methods we were able to monitor the migration rate of a much larger number of fish through discrete reaches. Our results indicate that there are considerable variations among individuals, but once Kuskokwim River Chinook salmon passed upriver from Bethel they tended to travel a similar and nearly consistent rate, regardless of which tributary they are returning to. The relatively slow migration rate of 14 km/day between the tag site and Bethel is not representative due to stress incurred during tagging, which has been documented in many tagging studies to cause fish to slow down or even travel downriver for some time (e.g., Bernard et al. 1999). Upriver from Bethel, the average migration rate was approximately 40 rkm/day (range: 30–48), which is similar to what has been observed for Yukon River Chinook salmon spawning in lower and middle river tributaries (28–51 rkm/day) but considerably slower than fish returning to the upper portions of the Yukon River drainage (45–65 rkm/day; Eiler et al. 2015).

Although not the focus of this study, the 2015 mark–recapture results provided some interesting insight into Chinook salmon spawning distribution. Much of our understanding of Chinook salmon spawning distribution comes from 6 years of radiotelemetry conducted from 2002–2007 upriver from the primary harvest areas (Stuby 2007; Schaberg et al. 2012). During this time, there were no restrictions to subsistence harvest and majority of the harvest effort occurred during the early portion of the Chinook salmon run (Hamazaki 2008). The Chinook salmon abundance at that time was above average (Liller and Hamazaki 2016) and only 3–9% of tagged Chinook salmon was tracked to headwater locations upriver from McGrath (Schaberg et al. 2012). In 2015, 23% percent of radiotagged Chinook salmon migrated to areas upriver from the community of McGrath, similar to what was observed in 2014 (21%; Head et al. *2017*). The results of our study indicate that Chinook salmon bound for headwater tributaries have early migration timing relative to other sub-stocks. We believe that the notable increase in tagged Chinook salmon tracked to the headwaters was a result of Chinook salmon conservation measures (e.g., Lipka et al. 2016) implemented during years of below average run size (Liller and Hamazaki 2016). In particular, early season fishery closures were used as a conservation tool in both years, and it is possible that the exploitation of those upriver sub-stocks was reduced or even eliminated. Chinook salmon bound for headwater tributaries may make up a substantially larger component of the total run than previously thought.

RECOMMENDATIONS

Future lower river mark–recapture experiments would be improved by radiotagging all fish. Using radio tags as the primary mark would allow us to determine a final fate for all tagged fish and would eliminate the need to estimate the number of marks and recaptures. Furthermore, since all radiotag recaptures can be positively verified, we would be able to increase the second sample (C) by using estimates of missed passage during brief periods when weirs are not operational. Radiotelemetry was the only viable way to evaluate the potential for recapture biases and monitor migration characteristics for Chinook salmon returning to the Kwethluk and Tuluksak Rivers. These types of evaluations require the ability to determine the date that each fish was tagged. It was not possible to observe the unique spaghetti tag number associated with each tagged fish they passed through either of the video weirs. However, all radiotagged Chinook salmon that passed upriver from both weirs were positively identified using tracking towers and aerial survey methods. Finally, radiotagging all fish increases options for alternative estimation methods in the event that the assumptions of the Petersen estimate are not met (see Liller 2014 for an example of how this consideration was included on the current study).

Future studies should increase outreach to improve awareness of the tagging study and encourage reporting of tagged fish captured in local fisheries. Increased outreach is especially important in lower river communities, where the majority of harvest occurs. Increased resolution of harvested fish would provide a better estimate of the number of fish that successfully migrated upriver from the tag site. We used mailers sent to local businesses to inform area residents about the study and advertise the tag lottery. Alternative methods that may be effective in the future include ads in the local newspapers, radio announcement, and social media. It may be possible to improve reporting by guaranteeing an award for every tagged fish that is harvested and reported. For that approach to be effective, we would have to closely balance the tradeoff between making the per-tag award substantial enough to motivate participation, while still remaining cost effective and not encouraging active targeting of tagged fish. Another alternative is to estimate the reporting rate annually by varying the per-tag award systematically, assuming that the maximum award is reported near 100%, and observing the relative number of tag reports by award category.

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TABLES AND FIGURES

Table 1.–Summary of 2015 aerial telemetry tracking surveys used to locate radiotagged Chinook salmon in the Kuskokwim River.

		Mainstem[a]		
Date	Agency	Start	End	Tributary
6/6	USFWS	Fowler Island	Tuluksak	–
6/8	USFWS	Fowler Island	Tuluksak	–
6/10	ADF&G	Lomavik Slough	Aniak	–
6/12	USFWS	Fowler Island	Tuluksak	–
6/15	USFWS	Eek River	Tuluksak	Tuluksak River
6/17	USFWS	Eek River	Tuluksak	Tuluksak River
6/19	USFWS	Eek River	Tuluksak	Kwethluk and Kisaralik rivers
6/22	USFWS	Eek River	Tuluksak	Kwethluk and Kisaralik rivers
6/26	ADF&G	Eek River	Tuluksak	Kwethluk and Kisaralik rivers
6/29	USFWS	Eek River	Tuluksak	Kwethluk and Kisaralik rivers
7/1	ADF&G	Aniak	McGrath	Aniak and Holitna rivers
7/2	USFWS	Fowler Island	Tuluksak	Kwethluk Kisaralik, and Tuluksak rivers
7/6	USFWS	Fowler Island	Tuluksak	Kwethluk Kisaralik, and Tuluksak rivers
7/9	USFWS	Fowler Island	Tuluksak	Kwethluk Kisaralik, and Tuluksak rivers
7/13	USFWS	Fowler Island	Tuluksak	Kwethluk Kisaralik, and Tuluksak rivers
7/16	USFWS	Fowler Island	Tuluksak	Kwethluk Kisaralik, and Tuluksak rivers
7/23	ADF&G	Aniak	Crooked Creek	Holokuk and Oskawalik rivers
7/29	USFWS	Fowler Island	Tuluksak	Kwethluk Kisaralik, and Tuluksak rivers
8/10	USFWS	Fowler Island	Tuluksak	Kwethluk Kisaralik, and Tuluksak rivers
8/19	ADF&G	-	-	Aniak River
8/21	ADF&G	Fowler Island	Aniak	–
8/24	ADF&G	Aniak	Sleetmute	George, Takotna, Middle-Fork, Pitka Fork, and Tonzona rivers
8/25	ADF&G	Sleetmute	McGrath	George, Holitna, Hoholitna, Tatlawiksuk, and Takotna rivers

[a] Flight path from start to end is flown along the main channel and major side channels of the Kuskokwim River.

Table 2.–Monitored and unmonitored tributaries located within each of the subareas used to classify the final location of radiotagged Chinook salmon in the Kuskokwim River, 2015.

Subarea	Monitored tributaries	Unmonitored tributaries
1	–	–
2	Kwethluk	Kisaralik, Kasigluk
3	Tuluksak	Fog
4	–	–
5	Salmon of Aniak	Aniak (Minus Salmon), Owhat
6	George	Kolmakof, Holokuk, Veahna, Oskawalik, Crooked
7	Kogrukluk of Holitna	Holitna, Vreeland
8	–	Stony
9	Tatlawiksuk	Swift, Nunsatuk, Selatna
10	Salmon of Pitka Fork	Takotna, Middle Fork (Blackwater, Big River, Pitka Fork [Minus Salmon]), South Fork (Tonza), East Fork, North Fork

Table 3.–The 8 mutually exclusive classes used to separate radiotagged Kuskokwim River Chinook salmon for variance estimation, 2015.

Class	Description
p_0	Entered marked population but moved to non-terminal area or harvested
p_1	Moved upstream of Kwethluk River Weir
p_2	Moved upstream of Tuluksak River weir
p_3	Moved upstream of Salmon River (Aniak River) weir
p_4	Moved upstream of George River weir
p_5	Moved upstream of Kogrukluk River weir
p_6	Moved upstream of Tatlawiksuk River weir
p_7	Moved upriver of Salmon River (Pitka Fork) weir

Table 4.–Kuskokwim River Chinook salmon abundance estimate worksheet, 2015.

Number marked (M)[a]	Number examined (C')	Number recovered	Adjusted recovered (R')[b]	Marked fraction	Abundance estimate	L 95% CI	U 95% CI
1,038	29,802	216	267	0.90%	115,541	105,370	125,346

[a] Based on the percentage of radiotagged Chinook salmon that successfully migrated above the rkm 67 tagging location.
[b] Based on detection probability.

Table 5.–Tagged and untagged Kuskokwim River Chinook salmon captured by day at the rkm 67 tagging site, 2015.

Day	Captured	Tagged	Day	Captured	Tagged
5/28	3	3 (3)	6/27[b]	28	28 (10)
5/29[a]	0	0	6/28	43	41 (11)
5/30[a]	0	0	6/29	38	38 (9)
5/31	0	0	6/30[b]	33	32 (8)
6/1	2	2 (2)	7/1	35	35 (8)
6/2	1	1 (1)	7/2	29	27 (6)
6/3	11	11 (11)	7/3[b]	7	7 (7)
6/4[b]	3	3 (2)	7/4	25	22 (7)
6/5	21	20 (20)	7/5	15	14 (6)
6/6	16	16 (16)	7/6	16	16 (5)
6/7	29	29 (29)	7/7[b]	11	11 (5)
6/8[b]	15	15 (15)	7/8	17	17 (5)
6/9	29	29 (29)	7/9	9	9 (5)
6/10	29	28 (28)	7/10[b]	8	8 (4)
6/11[b]	31	31 (20)	7/11	11	11 (3)
6/12	31	30 (19)	7/12	9	8 (3)
6/13	35	34 (20)	7/13	9	9 (2)
6/14	54	54 (21)	7/14[b]	5	5 (2)
6/15[b]	36	36 (35)	7/15	9	9 (5)
6/16	48	47 (40)	7/16	8	8 (5)
6/17	60	60 (31)	7/17	12	12 (10)
6/18	76	76 (18)	7/18[b]	4	4 (4)
6/19[b]	12	12 (12)	7/19	5	5 (4)
6/20	61	61 (17)	7/20	2	2 (2)
6/21	42	41 (30)	7/21	2	2 (1)
6/22	23	23 (17)	7/22	2	2 (1)
6/23[b]	26	26 (12)	7/23	2	2 (0)
6/24	52	51 (14)	7/24[b]	0	0 (0)
6/25	45	45 (12)	Total	1,213	1,193 (623)
6/26	28	26 (11)			

Note: The subset of all tagged fish that received a radio tag is indicated in parentheses.

[a] Days off, when no fishing occurred.

[b] Days when only 1 crew fished.

Table 6.–Fates assigned to Chinook salmon radiotagged in the Kuskokwim River, 2015.

Fate	Fate description		Count
	Radio tags that were not used to estimate abundance		
1	Failed to migrate above rkm 67 tag site		78
2	Harvested downstream of rkm 67 tag site		3
		Total	81
	Radio tags that were used to estimate abundance		
3	Harvested between tag site (rkm 67) and tower T01 (rkm 112)		37
4	Harvested upriver from tower T01 (rkm 112)		34
5	Moved upstream of monitoring weir while in operation		123
6	Moved upstream of weir while out of operation		10
7	Entered non-monitored tributaries		278
8	Did not enter a tributary (mainstem final location)		60
		Total	542

Table 7.–Voluntary reports of tagged Kuskokwim River Chinook salmon harvested in subsistence fishery, 2015.

		Tag type		
Nearest community	rkm	Spaghetti	Spaghetti with radio	Total
Tuntutuliak[a]	32	0	3	3
Napakiak	87	13	16	29
Napaskiak/ Oscarville	97	2	4	6
Bethel	106	10	17	27
Kwethluk	131	5	8	13
Akiachak	143	3	11	14
Akiak	161	3	6	9
Tuluksak	193	3	5	8
Lower Kalskag	259	1	0	1
Kalskag	263	1	2	3
Aniak	307	2	2	4
Crooked Creek	417	2	0	2
Sleetmute	488	2	0	2
Nikolai	941	1	0	1
Total		48	74	122

Note: The location is reported as the nearest community to where the harvest occurred.

[a] Located downstream from the rkm 67 tag site.

Table 8.–Number of spaghetti tagged Kuskokwim River Chinook salmon considered part of marked (M′) population for abundance estimation, 2015.

Total number of radio tags deployed at tag site (n_{rm})	Number of radio tags that successfully migrated upriver from tag site (n_{rup})	Proportion of radio tags that successfully migrated upriver from tag site (p_{up})[a]	Total number of spaghetti tags deployed at tag site (M)	Estimated number of spaghetti tags that migrated upriver of tag site (M′)[b]
623	542	0.87	1,193	1,038

[a] Estimated from radio tag and weir recovery data.

[b] Corrected based on the number of radiotagged Chinook salmon that did not migrate above the rkm 67 tag site.

Table 9.–Number of tagged Kuskokwim River Chinook salmon observed at each upriver recapture site and considered part of capture (C) and recapture (R′) populations for abundance estimation, 2015.

				Tag detection				
Recapture location	Total weir passage (C_i)	Number of radio tags that moved upstream of weir (n_{rp})[a]	Number of radio tags counted by weir staff (n_{sp})	Detection probability of radio tags[b]	Pooled detection probability (P_{sp})[c]	Number of spaghetti tags counted by weir staff (r_p)	Corrected number of spaghetti tags that passed weir (R_p)[d]	Total number of recaptures (R')[e]
Kwethluk River	8,163	36	31	0.86	0.84	37	44	80
Tuluksak River	711	2	1	0.50	0.84	3	4	6
Salmon River (Aniak)	2,292	7	7	1.00	0.90	6	7	14
George River	2,282	13	12	0.92	0.90	4	5	18
Tatlawiksuk River	2,096	8	6	0.75	0.90	8	9	17
Kogrukluk River	7,522	21	19	0.90	0.90	34	38	59
Salmon River (Pitka Fork)	6,736	36	19	0.79[f]	0.79[f]	29	37	73
Total	29,802	123	95			121	144	267

[a] Number of radiotagged Chinook salmon detected by tracking station during weir operational periods. Radio tags were the secondary mark in this study.

[b] Estimated from radio tag and weir recovery data.

[c] Recapture locations with similar methods, crew experience levels, and geographic locations were pooled.

[d] Corrected based on estimates of tag detection.

[e] Radio tags plus corrected spaghetti tags, $\sum(Rp+nrp)$.

[f] Does not include 12 radiotagged Chinook salmon that passed the weir during operational periods while weir staff was not recording tagged fish.

Table 10.–Kuskokwim River Chinook salmon radiotag recovery ratios by site, 2015.

					Chi-square		
Recapture location	Distance (rkm)[a]	Total recaptures[b]	Total untagged	Ratio[c]	X^2	df	*p*-value [d]
Kwethluk River	216	36	8,127	0.0044	0.0518		
Tuluksak River[e]	171	2	709	0.0028	–		
Salmon (Aniak) River	327	7	2,285	0.0031	0.6422		
George River	376	13	2,269	0.0057	1.3677		
Tatlawiksuk River	491	8	2,088	0.0038	0.0491		
Kogrukluk River	633	21	7,501	0.0028	3.2637		
Salmon (Pitka Fork) River	847	36	6,700	0.0054	2.4280		
Total		123	29,679	0.0041	7.80254	5	0.1675

[a] Distance from rkm 67 tagging site.

[b] Total number of radiotagged Chinook salmon that migrated paste each weir during operational periods.

[c] Total number of tag recaptures divided by total number of untagged fish in sample.

[d] The *p*-value criteria is based on an alpha of 0.05

[e] Data from Tuluksak River weir was pooled with Kwethluk River weir due to small sample sizes.

Table 11.–Temporal recovery ratios of radiotagged Kuskokwim River Chinook salmon, 2015.

Temporal strata[a]	Not recovered	Recovered	Ratio	Chi-square X^2	Chi-square df	Chi-square *p*-value[b]
5/28–6/7	76	8	0.1053	5.53641		
6/8–6/14	122	30	0.2459	3×10^{-6}		
6/15–6/21	143	40	0.2797	0.51650		
6/22–6/28	69	18	0.2609	0.04919		
6/29–7/5	37	14	0.3784	1.91220		
7/6–7/12	27	3	0.1111	1.79731		
7/13–7/26[c]	26	10	0.3846	1.46667		
Total	500	123	0.2460	11.27828	6	0.08010

[a] Based on operational week; generally 7 days, Monday to Sunday.

[b] The *p*-value criteria is based on an alpha of 0.05

[c] Last 2 weeks were pooled due to low expected tag recoveries.

Table 12.–Number of length samples available from each recapture location used to test for sampling bias of Kuskokwim River Chinook salmon, 2015.

Recapture location	Weir passage	Available samples	Percent sampled
Kwethluk River	8,163	1,003	12%
Tuluksak River	711	196	28%
Salmon (Aniak) River	2,292	157	7%
George River	2,282	195	9%
Tatlawiksuk River	2,096	209	10%
Kogrukluk River	7,522	246	3%
Salmon (Pitka Fork) River	6,736	229	3%
Total	29,802	2,235	7%

Note: The length samples from each weir recapture location were used to estimate escapement length composition.

Table 13.–Results of tests for size selective sampling in the marked (M), captured (C), and recaptured (R) sample populations of Kuskokwim River Chinook salmon using the Kolmogorov-Smirnov test (D).

Sample sizes[a]			Length (mm, METF)				Test for selective sampling: *M* vs. *R*		*C* vs. *R*		*M* vs. *C*	
M	*C*	*R*		*M*	*C*[b]	*R*	D	*p*-value[c]	D	*p*-value[c]	D	*p*-value[c]
			Min	345	333	505						
			Max	994	1,005	953						
1,192	2,235	198	Mean	761	665	761	0.0425	0.9186	0.9101	<0.001	0.9078	<0.001

[a] Includes only fish with a length measurement. Number of marked and recaptured fish differ from those used for abundance estimation because not all fish were measured.

[b] Min and max were obtained by pooling all samples from all recapture sites, and mean is the weighted average where the weights are the number of fish counted through the appropriate weir.

[c] H_o: No difference in length distribution between sample populations at an $\alpha = 0.05$ significance level.

Table 14.–Median tag deployment date at rkm 67 for Kuskokwim River Chinook salmon migrating to known subareas, 2015.

River area	Subarea	Number of tagged fish	Median deployment
Lower River	1	–	–
	2	64	6/21
	3	9	6/16
	Subtotal	73	6/20
Middle River	4	–	–
	5	88	6/24
	6	20	6/17
	7	127	6/22
	8	14	6/30
	9	45	6/17
	Subtotal	294	6/21
Upper River	10	119	6/14
	Total	486	6/20

Note: Includes all Chinook salmon that were tagged with a radiotag and Chinook salmon tagged with only a spaghetti tag that were recaptured at weirs.

Table 15.–Timing past the rkm 67 tag site for radiotagged Kuskokwim River Chinook salmon tracked to lower, middle, and upper river tributaries, 2015.

Date	Operational week	Radio tags	Lower tributaries[a]	Middle tributaries[b]	Upper tributaries[c]
5/28–6/7	1	42	10%	24%	67%
6/8–6/14	2	92	17%	50%	33%
6/15–6/21	3	116	16%	61%	23%
6/22–6/28	4	66	20%	68%	11%
6/29–7/5	5	43	21%	74%	5%
7/6–7/12	6	20	5%	95%	0%
7/13–7/19	7	29	24%	72%	3%
7/20–7/24	8	3	33%	67%	0%

Note: Only radiotagged Chinook salmon that migrated to tributary systems are included. Therefore, the number of radio tags presented is different than the number of radio tags deployed at the rkm 67 tag site.

[a] Radiotagged Chinook salmon that migrated to tributaries in Subareas 2 and 3.

[b] Radiotagged Chinook salmon that migrated to tributaries in Subareas 5 through 9.

[c] Radiotagged Chinook salmon that migrated to tributaries in Subarea 10.

Table 16.–Median travel time (days; IQR) and migration rate (km/day; IQR) of Kuskokwim River Chinook salmon between each successive mainstem telemetry towers, 2015.

Travel time		Subarea								
Mainstem section	Distance (rkm)[a]	2	3	5	6	7	8	9	10	Median
Tag Site - T01	45	4 (2.6-5.8)	4.5 (3.3-5.7)	3.3 (2.4-5.1)	3.1 (2.1-4.2)	3.4 (2.1-4.9)	2.7 (2.4-4.3)	3 (1.9-3.5)	2.8 (1.8-4.1)	3.18
T01-T02	12	0.3 (0.2-0.5)	0.4 (0.3-0.6)	0.3 (0.2-0.3)	0.3 (0.2-0.4)	0.2 (0.2-0.3)	0.4 (0.3-0.4)	0.3 (0.2-0.4)	0.3 (0.2-0.4)	0.30
T02-T03	32		0.9 (0.8-2)	0.8 (0.6-1)	0.8 (0.7-0.9)	0.7 (0.6-0.9)	0.7 (0.7-1)	0.7 (0.6-0.9)	0.8 (0.6-1.1)	0.77
T03-T04	74			1.9 (1.7-2.4)	2 (1.7-2.4)	1.7 (1.6-1.9)	2 (1.8-2.1)	1.7 (1.6-2.3)	1.9 (1.6-2.5)	1.92
T04-T05	68			2 (1.6-2.4)	1.6 (1.6-2.5)	1.7 (1.5-2)	1.9 (1.6-2.1)	1.6 (1.5-1.9)	1.6 (1.5-1.8)	1.67
T05-T06	54				1.4 (1.2-1.7)	1.2 (1.2-1.5)	1.5 (1.3-1.5)	1.3 (1.2-1.5)	1.3 (1.2-1.4)	1.27
T06-T07	127					2.8 (2.6-3.2)	3 (2.8-3.3)	2.8 (2.5-3.6)	2.7 (2.5-3.2)	2.81
T07-T08	35						0.9 (0.9-1)	0.9 (0.9-1.2)	0.9 (0.8-1.1)	0.92
T08-T09	47							1.5 (1.3-1.7)	1.4 (1.2-1.6)	1.46
T09-T10	205								5 (4.6-5.5)	-
Migration rate		2	3	5	6	7	8	9	10	Median
Tag Site - T01	45	11 (8-17)	10 (8-13)	13 (9-19)	14 (11-21)	13 (9-21)	16 (10-19)	15 (13-23)	16 (11-24)	14
T01-T02	12	40 (24-52)	29 (22-49)	48 (38-55)	37 (33-52)	50 (39-59)	35 (29-44)	42 (31-53)	42 (31-55)	41
T02-T03	32		34 (16-42)	41 (32-52)	40 (36-45)	48 (38-56)	44 (32-47)	43 (35-51)	39 (30-51)	41
T03-T04	74			38 (32-45)	37 (31-45)	44 (40-48)	37 (36-41)	43 (32-47)	39 (30-47)	39
T04-T05	68			34 (29-42)	42 (28-43)	40 (34-46)	36 (33-43)	42 (36-47)	42 (38-46)	41
T05-T06	54				39 (32-44)	44 (37-47)	36 (35-43)	43 (36-47)	43 (39-47)	43
T06-T07	127					45 (40-49)	42 (39-46)	45 (36-50)	47 (40-52)	45
T07-T08	35						38 (34-40)	38 (30-40)	39 (33-44)	38
T08-T09	47							31 (28-36)	33 (29-39)	32
T09-T10	205								41 (37-45)	-
	Median [b]	-	32	40	39	45	37	43	41	41

[a] Length of each mainstem section defined by the location of telemetry towers.

[b] Median of migration rate for all sections upriver from T01.

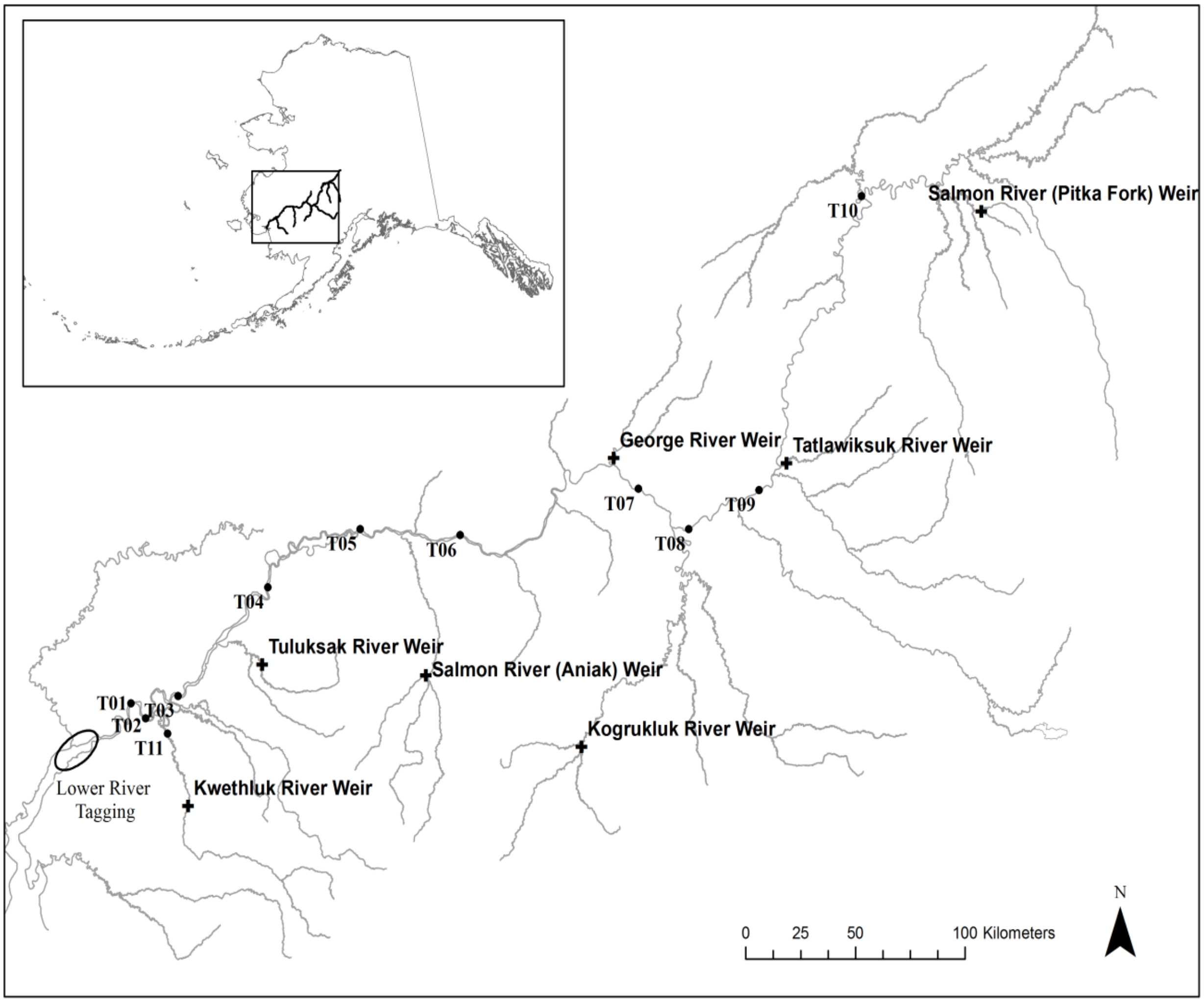

Figure 1.–Location of the tagging site, telemetry towers (black circles), and escapement monitoring weirs (black crosses) used to tag, track, and recapture Kuskokwim River Chinook salmon, 2015.

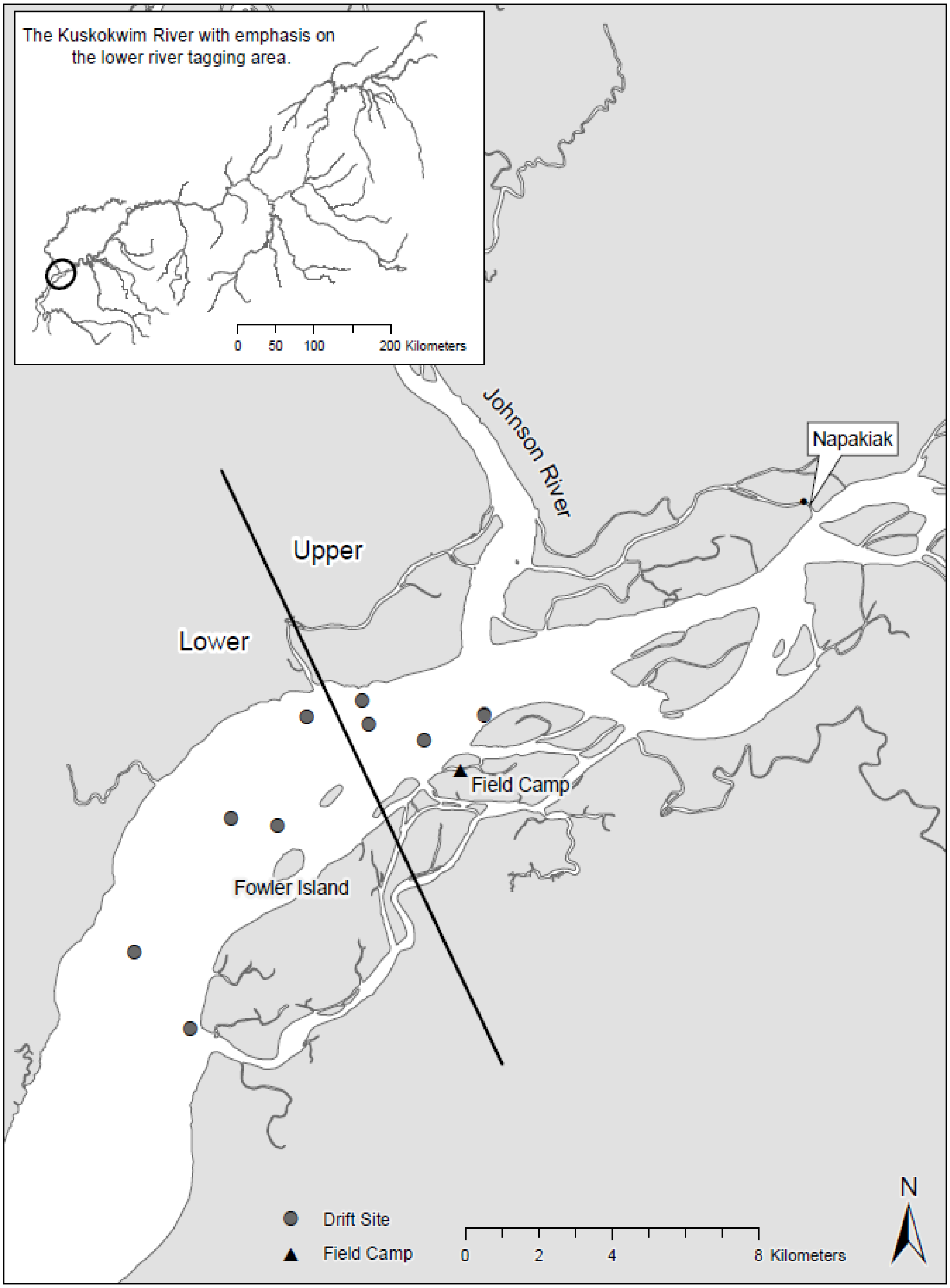

Figure 2.–Location of Kuskokwim River Chinook salmon tagging sites (upper and lower), drift zones (circles), and field camp (triangle), 2015.

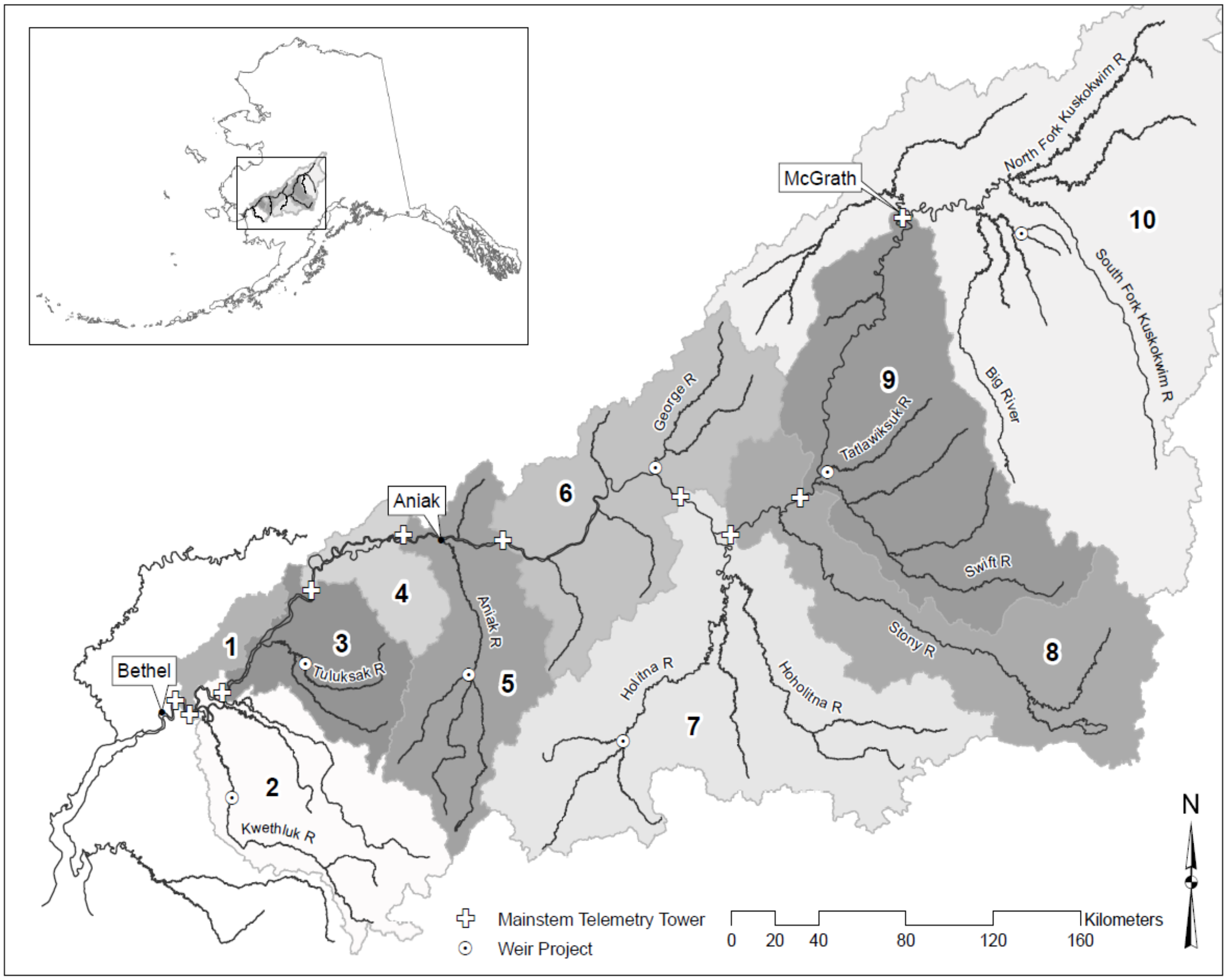

Figure 3.–Subareas used to classify the final location of radiotagged Chinook salmon in the Kuskokwim River, 2015.

Note: White crosses represent telemetry tracking towers and white circles are escapement monitoring weirs.

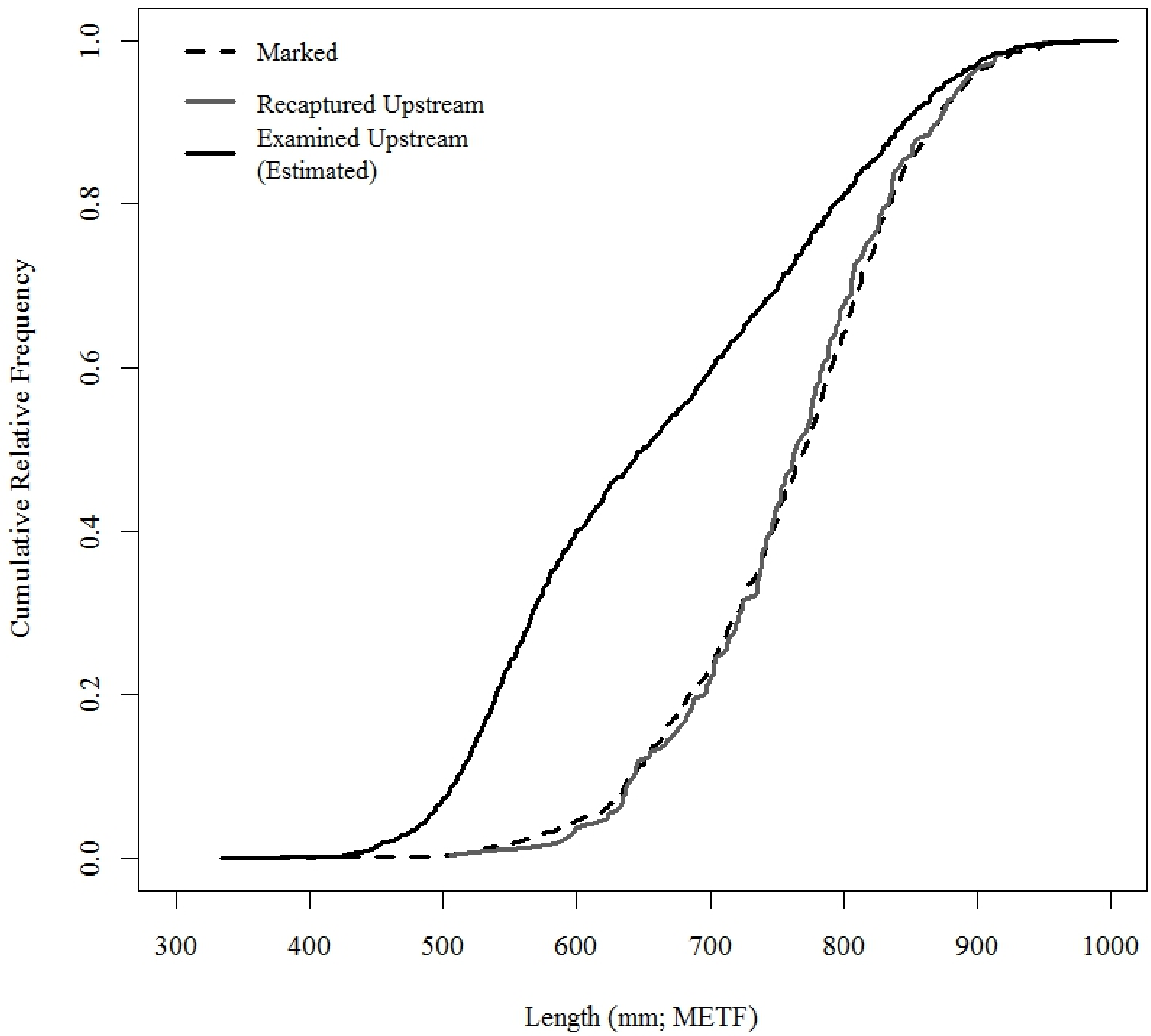

Figure 4.–Cumulative length frequencies of Chinook salmon tagged at rkm 67 (marked) and recovered upstream (recaptured), compared with the estimated length composition of all fish examined at upstream recovery weirs (examined).

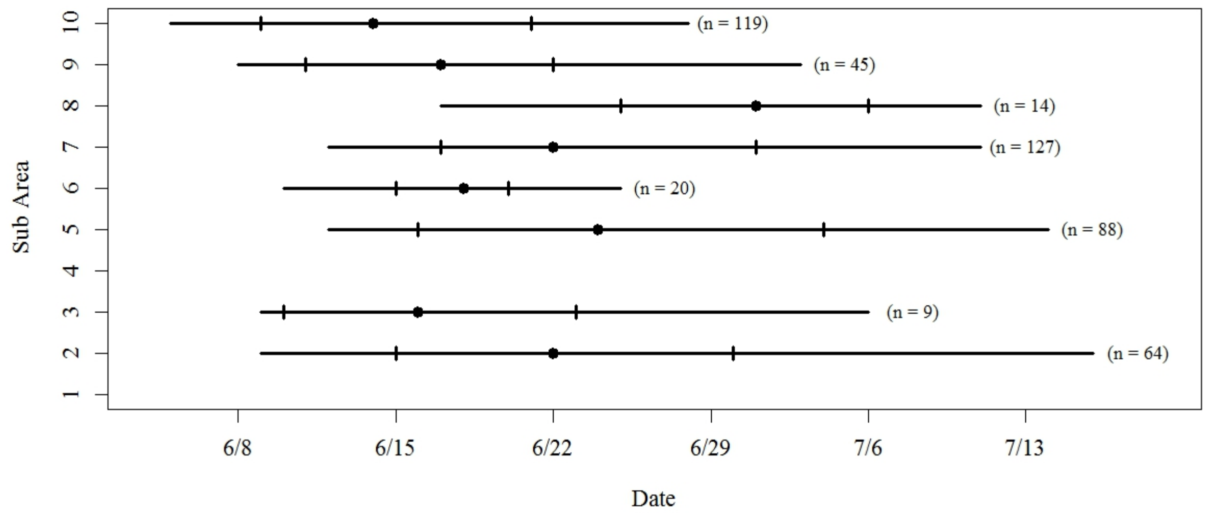

Figure 5.–Tag deployment dates at rkm 67 for Kuskokwim River Chinook Salmon migrating to known subareas, 2015. Median, central 50%, central 80% of tagging dates, and sample sizes (*n*) are shown.

Note: Includes all Chinook salmon that were tagged with a radio tag and Chinook salmon tagged with only a spaghetti tag that were recaptured at weirs.

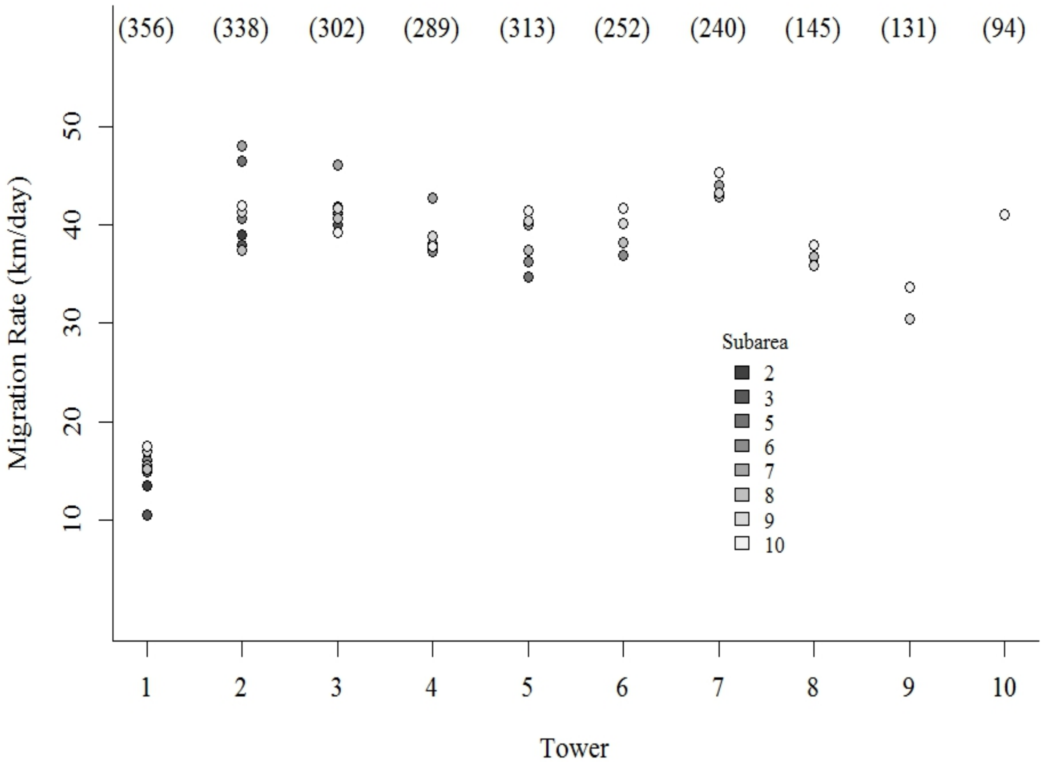

Figure 6.–Median migration rate (km/day) of Kuskokwim River Chinook salmon between each successive mainstem telemetry tower, 2015.

Note: The number of radiotagged Chinook salmon is shown in parentheses.

APPENDIX A: STATISTICAL TESTS FOR ANALYZING DATA FOR SEX AND SIZE BIAS

Appendix A1.–Tests of consistency for the Petersen estimator.

The following conditions are critical 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 the first event; or,
3. Every fish has an equal probability of being captured and examined during the second event.

To evaluate these three assumptions, the chi-square statistic is used to examine the following contingency tables as recommended by Seber (1982). At least one null hypothesis needs to be accepted for assumptions of the Petersen model (Bailey 1951, 1952 as cited in Seber 1982; Chapman 1951) to be valid. If all three tests are rejected, the Petersen estimator is not appropriate.

I.-Test For Complete Mixing[a]

Area/Time Where Marked	Area/Time Where Recaptured				Not Recaptured
	1	**2**	**…**	**t**	$(n_1\text{-}m_2)$
1					
2					
…					
S					

II.-Test For Equal Probability of Capture During the First Event[b]

	Area/Time Where Examined			
	1	**2**	**…**	**t**
Marked (m_2)				
Unmarked (n_2-m_2)				

III.-Test For Equal Probability of Capture During the Second Event[c]

	Area/Time Where Marked			
	1	**2**	**…**	**s**
Recaptured (m_2)				
Not Recaptured (n_1-m_2)				

[a] This tests the hypothesis that movement probabilities (θ) from area or time i (i = 1, 2, ...s) to section j (j = 1, 2, ...t) are the same among sections: H_0: $\theta_{ij} = \theta_j$.

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

[c] This tests the hypothesis of homogeneity on the columns of this 2-by-s contingency table with respect to recapture probabilities among area or time designations: H0: Σjθijpj = d, where pj is the probability of capturing a fish in section j during the second event, and d is a constant.

Appendix A2.–Detection of size and/or sex selective sampling (from Stuby 2007).

Size selective sampling: The Kolmogorov-Smirnov two sample test (Conover 1980 as cited in Stuby 2007) is used to detect significant evidence that size selective sampling occurred during the first and/or second sampling events. The second sampling event is evaluated 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) by using the null test hypothesis of no difference. The first sampling event is evaluated by comparing the length frequency distribution of all fish inspected for marks during the second event (C) with that of R. A third test that compares M and C is then conducted and used to evaluate the results of the first two tests when sample sizes are small. Guidelines for small sample sizes are <30 for R and <100 for M or C.

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

M vs. R	**C vs. R**	**M vs. C**
Case I:		
Fail to reject H_o	Fail to reject H_o	Fail to reject H_o
There is no size/sex selectivity detected during either sampling event.		
Case II:		
Reject H_o	Fail to reject H_o	Reject H_o
There is no size/sex selectivity detected during the first event but there is during the second event sampling.		
Case III:		
Fail to reject H_o	Reject H_o	Reject H_o
There is no size/sex selectivity detected during the second event but there is during the first event sampling.		
Case IV:		
Reject H_o	Reject H_o	Either result possible
There is size/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. 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 which have little potential to result in bias during estimation. *Case I* is appropriate.

B. If a) sample sizes for M vs. R are small, b) the M vs. R *p*-value is not large (~0.20 or less), and c) the C vs. R sample sizes are not small and/or the C vs. R *p*-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size/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.

-continued-

C. If a) sample sizes for C vs. R are small, b) the C vs. R *p*-value is not large (~0.20 or less), and c) the M vs. R sample sizes are not small and/or the M vs. R p-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size/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 a) sample sizes for C vs. R and M vs. R are both small, and b) both the C vs. R and M vs. R p-values are not large (~0.20 or less), the rejection of the null in the M vs. C test may be the result of size/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.

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 type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

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

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

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

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

where:
j = the number of sex/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.