Fishery Data Series No. 17-47

Inriver Abundance and Migration Characteristics of Kuskokwim River Chinook Salmon, 2016

by

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and

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November 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. 17-47

2016 INRIVER ABUNDANCE AND RUN TIMING OF KUSKOKWIM RIVER CHINOOK SALMON

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November 2017

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This document should be cited as follows:
Smith, N. J., and Z. W. Liller. 2017. Inriver abundance and migration characteristics of Kuskokwim River Chinook salmon, 2016. Alaska Department of Fish and Game, Fishery Data Series No. 17-47, Anchorage.

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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 2016. Tagging occurred downriver from all known spawning tributaries, except the Eek River. A total of 621 Chinook salmon were marked with radio and spaghetti tags, of which 527 continued upriver migration and were used to estimate abundance. Radiotagged fish were tracked throughout the study area using a network of telemetry stations and a series of aerial telemetry surveys. Upriver escapement monitoring weirs served as 7 recapture locations, representing lower, middle, and upper river tributaries. A total of 21,590 Chinook salmon were evaluated for tags, and total tag recoveries was estimated at 94. Inriver abundance of Chinook salmon upstream of rkm 67 was 120,000 fish (95% CI: 99,304–147,502). 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. Chinook salmon swam at a median speed of 36 rkm/day (range: 31–41 rkm/day) through all portions of the mainstem Kuskokwim River upstream from Bethel.

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

INTRODUCTION

Alaska Department of Fish and Game (ADF&G) 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 within the Kuskokwim River. The Kuskokwim River supports a run of Chinook salmon that averages nearly 240,000 fish (Liller 2017). 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 of 30% of the total annual run (range: 8–56%; Liller 2017). 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 has experienced a downturn in productivity and annual run sizes have been inadequate to meet escapement and subsistence harvest needs. In response, fisheries managers have implemented strategies to reduce harvest for the purpose of achieving 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 (ADF&G Chinook Salmon Research Team 2013). In 2012, 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 (ADF&G Chinook Salmon Research Team 2013). 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. The core of the plan was stock-specific and aimed at understanding 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 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, 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 2017). The Chinook Salmon Research Team recommended additional 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.

ADF&G, through the Chinook Salmon Research Initiative, funded a 3-year mark–recapture study to estimate the total run size of Kuskokwim River Chinook salmon between 2014 and 2016. In 2014, total abundance was estimated for all waters upriver from rkm 294 (Head et al. 2017) and estimates of lower river escapement and harvest will be needed to reconstruct total run size. In 2015, tagging operations were moved downriver to rkm 67, and for the first time, the mark–recapture abundance estimate represented the entire Chinook salmon run, except those fish returning to the Eek River and those fish harvested downriver from the tag site (Smith and Liller 2017). The new tag location probably monitors more than 90% of the total run, based on historical information about subsistence harvest downriver (Shelden et al. 2016), escapement to the Eek River (Schaberg et al. 2012), and total run size (Liller 2017). Given the apparent success of the new tag site, the lower river tag site was used again to estimate the abundance of Chinook salmon in 2016.

In 2016, we intended to replicate the 2015 study design (Smith and Liller 2017) exactly, but changes were necessary to address prolonged high water events that hindered visual detection of tagged fish at several recapture locations. Tagging operations commenced 2 days earlier in 2016 in an attempt to increase coverage of the entire Chinook salmon run. As in 2015, all captured Chinook salmon were given an external spaghetti tag that would serve as the primary mark. A subset of all spaghetti tagged fish was also fitted with a radio tag to evaluate the assumptions of the abundance estimator and monitor upriver fish movement. All Chinook salmon passing upriver of recapture weirs were visually inspected for external spaghetti tags. However, unlike the 2015 season, recapture operations in 2016 were affected by high water during much of the season. At all locations, accurate visual observations of passing Chinook salmon were still possible, but positive identification of the external tag was dramatically reduced at times. Furthermore, the Kwethluk River weir was inundated with high water for most of the Chinook salmon season and there was a high level of uncertainty in the estimates of missed passage at that location. We decided that visual tag recapture information and estimates of missed passage were unreliable for obtaining an unbiased estimate of abundance. External tag deployment, harvest, and recapture information are provided for completeness (Appendices A1–A3). Instead abundance estimates in 2016 were based on observed weir counts and radio tags recaptured during operation periods only. Recapture of radiotagged fish was achieved through telemetry methods that were not affected by high water. This report is focused on radiotelemetry methods and results only.

Radiotagging Chinook salmon near the mouth of the Kuskokwim River provided a unique opportunity to monitor migration characteristics for groups of Chinook salmon returning to all major tributaries and to monitor swim speeds throughout the entire Kuskokwim River mainstem. Historical data regarding migration timing and speed are from fish tagged in the middle river

(Pawluk et al. 2006; Stuby 2007; Schaberg et al. 2010; Head et al. 2017). The 2015 tagging study was the first opportunity to evaluate migration timing and travel speed through the lower river (Smith and Liller 2017). Results from 2015 confirmed that fish bound for more distant tributaries had an earlier migration timing compared to fish traveling to less distant locations. Surprisingly, there was no noticeable pattern among fish returning to lower and middle river tributaries. In 2015, Chinook salmon traveled a median of 41 rkm per day regardless of the tributary of return. The 2015 swim speed was faster than those reported from earlier studies conducted in the middle river (Schaberg et al. 2010), but similar to what has been observed for Chinook salmon returning to other large river systems like the Yukon River (Eiler et al. 2015).

This report presents the activities and results for the final year of Chinook salmon abundance estimation and the second year of Chinook salmon migration timing and speed through the lower portion of the Kuskokwim River.

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 the tagging site located at 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 just downriver from the confluence of the Johnson and Kuskokwim rivers at rkm 67 (Figure 1). This area was chosen because it is downriver from all Chinook salmon spawning tributaries, except the 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 tagging sites to facilitate the use of 2 tagging crews (Figure 2). At the start of the capture and tagging season, 4 drift zones in the upper tagging site and 5 drift zones in the lower tagging site were used to capture and tag fish. Exploration of the tagging sites led to the establishment of a sixth drift zone in the lower river site (Figure 2). Drifts zone depths ranged from 6.1 to 9.1 m at most sand bar locations, and from 9.1 to 12.2 m at most bank locations. Maximum depth was 25 m.

Recapture of tagged Chinook salmon occurred at 7 weirs located on 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 17 telemetry towers were used to monitor the upstream migration of radiotagged fish (Figure 1). A single telemetry station located at rkm 112 (hereafter referred to as T01) was used to identify radio tags that successfully migrated upriver from the tagging area. A distance of 44 rkm separated the tagging location and T01 to allow radiotagged fish adequate time to recover from capture and tagging induced stress. An additional 8 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 765). A telemetry station was also located at each of the 7 weir recovery sites. Lastly, 1 telemetry tower was placed 7 rkm upstream from the mouth of the Kwethluk River 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 26 and continuing until July 23. 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 D/K 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.

A total of 621 Chinook salmon that passed the physical examination were given a primary mark consisting of a uniquely coded esophageal radio tag (Advanced Telemetry Systems, Inc.)[1]. Radio tag size was varied to ensure that tags did not exceed 2% of the fish's body weight (Cooke et al 2012). A model F1840B tag (20 grams total weight) was used for fish with a mideye to tail fork (METF) length between 450 mm and 550 mm. 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 (Stuby 2007). In addition to a radio tag, all radiotagged Chinook salmon were given a secondary mark consisting of a uniquely numbered spaghetti tag (Model FT-4; Floy Tag and Manufacturing, Inc.). 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 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.

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 radiotagged Chinook salmon that continued upriver past the tag site was estimated using telemetry and harvest information. 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. The subset (n_{rup}) of radiotagged fish that migrated upriver past the tag site 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 ($p_{up} = n_{rup}/n_r$). The number of fish that successfully entered the marked population (M') was estimated as $n_r \cdot p_{up}$.

Telemetry Tracking

Radiotagged Chinook salmon were tracked as they migrated up the Kuskokwim River using a network of 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 3 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 radio tagged fish passing the receiver site without being detected.

A series of 27 aerial telemetry tracking flights were performed between June 1 and August 23 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 s. A single H-antenna was mounted on each wing strut, and the surveys conducted August 22 and August 23 also utilized a C-type antenna

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

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 per hour at an altitude between 100 m 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 radio tagged Chinook salmon, and test mark–recapture assumptions. The Kuskokwim River drainage was stratified into 9 subareas upriver from rkm 112 using the network of 9 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.

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 located 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 $\sum(C_i)$. Estimates of missed passage were not used.

The number of recaptures (R_i) at each weir (i) consisted of all radiotagged fish that were detected passing the tracking tower located at each weir during operational periods. The number of tag recaptures was adjusted to account for radio tag loss. The proportion of fish that retained the radio tag (p_{rt}) was estimated using the total number of spaghetti tags observed by weir staff (n_o), and the subset of those tagged fish that were also detected upriver of the weir by the telemetry tower located at the weir site or during aerial surveys (n_{rt}), where $p_{rt} = n_{rt}/n_o$. That proportion was used to expand the number of recaptures ($\sum R_i$) to account for those fish that lost their radio tag and were not detected. The estimated number of recaptures (R') was $\sum R_i/p_{rt}$.

To evaluate radio tag loss, Chinook salmon were visually inspected for spaghetti tags as they passed weir locations. External tag identification and reporting was accomplished using 2 methods. ADF&G 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 U.S. Fish and Wildlife Service (USFWS) on the Kwethluk and Tuluksak rivers utilized video technology to enumerate passing Chinook salmon (Webber et al. 2016a and 2016b). Therefore, presence of a radio tag was only recorded for a small subset of fish recaptured during scheduled age, sex, and length sampling periods.

Data Analysis

Abundance Estimation

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

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

Variance Estimation

Variance of the mark–recapture estimate was estimated by a parametric bootstrap simulation with 1,000 replicates (Efron 1982). Each uncertain parameter M', p_{up}, p_{rt}, 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 radiotagged fish that moved upstream of the tag site was assumed to have a binomial distribution (BN), and was modeled as $M^*_{(b)} \sim BN(n_r, p_{up})$.

The proportion of tagged fish that entered the marked population ($p_{i,}$) was separated into 8 classes (i = 0,…, 7; Table 3). Tagged fish were assumed to be distributed among these classes by a multinomial distribution, and the number in each class (R_i) was modeled by $R^*_{(b),i} \sim multi(M^*_{(b)}, p_i)$. The proportion of tagged fish that retained their radio tag was modeled as a binomial process, $p^*_{(b)rt} \sim BN(n_o, p_{rt})/n_o$. The total number of fish recovered was then modeled as $R^*_{(b)} = (\sum R^*_{(b)i}) / p^*_{(b)rt}$. 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:

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

The 95% confidence interval was determined from the 2.5 and 97.5 percentiles of the bootstrap distribution. The bounds of the 95% confidence interval relative to the abundance estimate were evaluated using the following equation and reported as a percentage:

$$\left(\frac{1.96\sqrt{\hat{v}}}{\hat{N}}\right)*100 \ . \qquad (3)$$

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 double tagging and estimating the proportion of fish that retained their radio tag and adjusting the number of recaptures with this proportion. The assumptions that all fish had an equal probability of capture in the first sample or second sample, or that tagged fish mixed completely with untagged fish was evaluated following recommendations of Seber (1982; Appendix B1). 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 = 362…, 1,030) 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:

$$F_m = \sum\left(\frac{l_{mi}}{\sum l_{mi}} * C_i\right) . \qquad (3)$$

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 B2). All statistical tests were considered significant at $\alpha = 0.05$.

RUN TIMING

Run timing past the tag site was evaluated for all radiotagged fish returning to Subareas 2 and 4–9 (Figure 3) using all available telemetry (tower and aerial) and recapture (weir and tributary harvested tag returns) information. Subareas 1 and 3 were not included because no Chinook salmon tributaries drain into those sections. Tag dates recorded at the lower river site were summarized using the median, central 50%, and central 80% of 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 each successive pair of tower locations (i = 1,…, 9) moving sequentially upriver. The date, hour, and minute (t) at which each fish was released at the tag site was known. The date, hour, and minute 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 and 4–9 were pooled by subarea and a median migration rate and interquartile range (IQR) was calculated.

RESULTS

MARK–RECAPTURE

The estimated abundance of Chinook salmon upstream of rkm 67 was 120,000 fish (95% CI: 99,304–147,502); Table 4). The bounds of the 95% confidence interval were ±20% of the estimated abundance, which met the predetermined objective criteria of ±25% (Robson and Regier 1964).

Chinook salmon were captured on the first day of operation (Table 5). Catches steadily increased and peaked at 70 fish on June 16. After June 16, catches slowly decreased until the last day of sampling. Catches remained around 4 fish or less per day during the last 13 days of operation. Only 1 fish was captured on the final day of operation (July 23). A total of 1,532 Chinook salmon were captured, of which 621 were radiotagged.

Final fate was determined for all 621 radiotagged Chinook salmon (Tables 6 and 7). A total of 94 (15%) radiotagged fish failed to migrate and remain upriver from the tag site. Of those, 70 did not resume upriver migration, 17 continued upriver past T01 but later swam back downriver out of the study area, and 7 fish were harvested downriver from the tag site. A total of 527 radiotagged fish were used to estimate abundance. Of those, 469 (89%) radiotagged Chinook salmon migrated and remained upriver from T01, whereas 58 (11%) fish were harvested between the tag site and T01. A total of 399 (76%) radiotagged fish were located in a spawning tributary, 24 (5%) were located in the mainstem Kuskokwim River, and 46 (9%) were harvested in the subsistence fishery upriver from T01. The probability that a tagged fish migrated and remained upriver from the tag site (p_{up}) was estimated to be 0.85 (Table 8).

Total observed escapement (C) from all 7 weirs was 21,590 Chinook salmon (Table 9). A total of 91 radiotagged Chinook salmon passed telemetry tracking stations located at the 7 recapture weirs during operational periods. In total, 73 external tags were physically observed by weir crews, of which, 71 had a radio tag. Therefore, radio tag retention was estimated to be 97% and total tag recoveries (R') was adjusted to 94 tags (Table 9).

Conditions for an unbiased estimate of abundance were achieved in 2016. The marked fraction of radiotagged Chinook salmon at each weir was not significantly different, which provides support for the assumption of equal probability of capture (Table 10; $\chi^2 = 5.63$, $p = 0.3435$). Additionally, temporal radio tag deployment and recapture ratios were not significantly different (Table 11; $\chi^2 = 2.963$, $p = 0.706$), 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. Therefore, tests for sex selective sampling are not presented.

RUN TIMING

Chinook salmon substocks overlapped considerably as they passed upriver of the tag site, but general run timing patterns were elucidated (Tables 14 and 15; Figure 5). The median tag date for fish returning to upriver tributaries was June 15, which was 10 days earlier compared to fish returning to middle river tributaries and 11 days earlier than fish returning to lower river tributaries. Headwaters fish made up 50% of the catch during the first week of operations (May 26–June 5). Their contribution to the weekly catch decreased throughout the run, and they made up an average of 5% of the weekly catch beginning June 20. Fish returning to middle and lower river tributaries displayed similar run timing with median catch dates of June 25 and June 26 respectively (Table 14). Middle river substocks increased from 45% of the total catch during week 1 to 72% during week 4 (June 20–June 26) before leveling off at an average of 70% of the total catch for the remainder of the season. The composition of lower river substocks generally increased throughout the run, representing 5% of the total catch during the first week and 33% during the last week of the season.

MIGRATION RATE

All substocks displayed similar migration rates through the sequential mainstem reaches (Table 16; Figure 6). It took the various substocks a median of 4.4 days to travel the 45 rkm separating the tag site and T01 at a median rate of 10 (km per day, range: 9–15). Upriver migration rate increased after T01 and remained relatively consistent at a median of 36 km per day (range: 31–41 rkm per day) through all subsequent sections.

DISCUSSION

There is no evidence that the tagging or recapture efforts missed a substantial temporal component of the Chinook salmon run in 2016. 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 BTF (rkm 106; AYKDBMS[2]). Tagging operations continued as planned and on schedule throughout the run. Low catches during last week of operations provided a reasonable assurance that the end of the run was well represented. Only 2.9% of the Chinook salmon run passed the BTF location after tagging operations ceased downriver. Similarly, daily counts from each recapture weir location confirm that the weirs were installed prior to the arrival of Chinook salmon and operated well after the Chinook salmon run ended (Head and Liller 2017).

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

The use of radiotelemetry techniques proved critical to the success of the 2016 season. The aerial- and ground-based telemetry techniques used allowed us to determine the final fate of all radiotagged fish with high confidence. In particular, telemetry methods made it possible to determine the date and time that most radiotagged fish passed upriver of recapture weir locations. On-site test radio tags confirmed that telemetry towers located at each weir site operated well, with only 2 exceptions. First, the George River weir telemetry tower had 4 days in late June when the tower was out of operation. Second, the upstream facing antenna on the Kogrukluk River weir telemetry tower recorded lower than expected signal strength when fish passed the weir, which made it difficult to identify a precise date and time of passage. However, extensive aerial surveys were conducted upriver from each weir location to confirm passage of radio tags and detect any tags that may have been missed by the towers.

We are confident that all Chinook salmon that retained their radio tag were identifiable and accurately reported in the second event. Retention of radio tags was estimated to be 97% between the tagging and recapture sites. The sample size for investigating tag loss was relatively small (n = 73); however, the power to detect tag loss was probably adequate given that 80% of all recaptured fish were evaluated for tag loss.

The Red Devil tower (i.e., T06; Figure 1) was not operated correctly and only limited data was recorded at this site. The setting used to amplify signal strength was mistakenly set to zero on the R4500 data logger, which effectively prohibited the data logger from detecting tagged fish at distance. The result was that 71% (152 of 215) of radiotagged Chinook were not detected passing the tower. The Red Devil tower formed the upper extent of Subarea 5 and the downriver extent of Subarea 6. An extensive aerial survey flown within the Holitna River combined with information from the Kogrukluk weir and T07 was adequate to confidently assign fish to Subareas 5 and 6. The Red Devil tower complications only affected the final fate of 4 fish. Each fish was assigned to Subarea 5, but it is possible that those fish could have been bound for Subarea 6. The overall effect of these 4 fish fates on our conclusions about run timing and swim speed was negligible.

We were unable to determine why 24 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. The combination of aerial and mainstem telemetry coverage provided sufficient data to confirm that these fish had final locations in the mainstem Kuskokwim River. There are no known Chinook salmon spawning aggregates in mainstem Kuskokwim River. Therefore, tagged fish located in the mainstem probably 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 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 24 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.

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 headwaters 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. High water during much of the season prohibited reliable detection of external tags by the crews; however, this challenge was overcome by using telemetry techniques to determine the number, date and time of recaptures at each weir.

We chose not to use estimates of missed passage at weirs due to the large uncertainty in the Kwethluk River weir estimate. We evaluated the influence of our decision by rerunning the abundance estimate twice, each time using estimates of missed passage and all known radio tags passed the weirs regardless of the operational status of the weir. First, we used the smallest estimate of total passage for each weir based on the 95% confidence intervals as reported by Head and Liller (2017), and we estimated abundance at 97,700. Second, we used the largest estimate of total passage for each weir and estimated abundance at 131,400. The range of estimates was similar to the 95% confidence interval of the reported estimate using only observed passage (95% CI: 99,304–147,502). As such, we feel the reported estimate of abundance is probably unbiased and the precision is realistic given the challenges of operating a mark–recapture study of this scale during a year impacted by high water.

For the second straight year, we were able to evaluate the run timing for a large number of Chinook salmon returning to major subareas and estimate swim speed throughout the majority of the Kuskokwim River mainstem. Overall, run timing patterns observed in 2016 were consistent with what was observed in 2015. In both years, the Tatlawiksuk River and tributaries upriver from McGrath had earlier migration timing compared to fish returning to spawn in less distant tributaries. In both 2015 and 2016, tagged fish tended to travel a similar and nearly consistent rate, regardless of the tributary of return. Similar migration rates were observed in both years through discrete reaches. In both years, the relatively slow migration rate between the tag site and Bethel is probably 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).

Although not the focus of this study, radiotelemetry results provided insight into Chinook salmon spawning distribution. In 2016, 12% of radiotagged Chinook salmon migrated upriver from the community of McGrath. The proportion of upriver fish observed in 2016 was smaller than what was observed in 2014 (21%; Head et al. 2017) and 2015 (23%; Smith and Liller 2017), but notably larger compared to the average observed from 2002 to 2007 (5%; Schaberg et al. 2012). Salmon spawning distribution is known to vary naturally (Schindler et al. 2010), however; changes in harvest timing are the most likely explanation for the recent proportional increase in escapement to upriver tributaries. Much of the Kuskokwim River subsistence harvest of Chinook salmon has historically occurred during the early portion of the run (Hamazaki 2008), and there is substantial evidence that Chinook salmon bound for upriver tributaries are the most abundant stock in the river during the first few weeks of season (Head et al. 2017; Smith and Liller 2017). Beginning in 2014, early season fishery closures were implemented as a conservative management strategy in response to low run abundances. As a result, the exploitation of early migrating (upriver) Chinook salmon probably declined since 2014 compared to the 2002–2007 studies.

CHINOOK SALMON RUN RECONSTRUCTION MODEL REVIEW

The primary motivation for conducting mark–recapture studies in 2014–2016 was to evaluate the Chinook salmon run reconstruction model. The mark–recapture estimates provided in this report, Head et al. (2017), and Smith and Liller (2017) can be used to reconstruct total run size by adding harvest and escapement downriver from the tag site. Direct comparisons between mark–recapture based total run estimates and estimates produced by the run reconstruction model indicate that the model may have overestimated true run size and escapement in 2014, 2015, and 2016 (Liller 2017). Liller (2017) provides an overview of model review plans and timelines.

ACKNOWLEDGEMENTS

Without the support and cooperation of many individuals and organizations this project would not have been possible. Commercial Fisheries tagging and telemetry staff members Jordan Head, Josh Clark, Carlton Hautala, Mattias Hautala, Elizabeth Lindley, Brian Mielke, Anguyaluk Pavilla-Anderson, Joseph Spencer, Michael McNulty, and Morgan MacConell were an invaluable part of this project. Commercial Fisheries weir staff, especially Tracy Hansen and Rob Stewart, was vital to the success of this project. We thank XinXian Zhang, Charles Brazil, and an anonymous peer reviewer for their critical reviews that improved the final document. USFWS biologists (Ken Harper and Aaron Webber) and technicians made it possible to incorporate the Kwethluk and Tuluksak weirs into the study design and they provided a vast amount of radiotelemetry tracking support. Lastly, we would like to thank all the Kuskokwim River residents that contributed to this study through their support and participation in volunteer tag recovery program.

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TABLES AND FIGURES

Table 1.–Summary of 2016 aerial telemetry tracking surveys used to locate radiotagged Chinook salmon in the Kuskokwim River.

		Mainstem[a]		
Date	Agency	Start	End	Tributary
6/1	USFWS	Fowler Island	Tuluksak	–
6/6	USFWS	Fowler Island	Tuluksak	–
6/9	USFWS	Fowler Island	Aniak	–
6/12	USFWS	Eek Island	Aniak	–
6/13	USFWS	Bethel	Kwethluk	Kwethluk R., Kisaralik R.
6/15	ADF&G	Aniak	Sleetmute	Holitna R. (to Hoholitna R.)
6/16	USFWS	Eek Island	Aniak	–
6/20	USFWS	–	–	Kwethluk R. (to weir)
6/22	ADF&G	Aniak	Sleetmute	Holitna R. (to Hoholitna R.)
6/22	USFWS	Eek Island	Aniak	Kwethluk R., Kisaralik R., Tuluksak R.
6/28	USFWS	Fowler Island	Tuluksak	Kwethluk R., Kisaralik R., Tuluksak R.
6/29	ADF&G	Aniak	Sleetmute	Holitna R. (to Hoholitna R.), Aniak R. up to Buckstock R. confluence.
7/1	USFWS	Fowler Island	Tuluksak	Kwethluk R., Kisaralik R., Tuluksak R.
7/6	ADF&G	Aniak	Sleetmute	Holitna R. (to Hoholitna R.), Aniak R. up to Buckstock R. confluence, Buckstock R., and Holokuk R..
7/6	USFWS	Fowler Island	Tuluksak	Kwethluk R., Kasigluk R, Kisaralik R., Tuluksak R.
7/8	USFWS	Fowler Island	Tuluksak	Kwethluk R., Kasigluk R, Kisaralik R., Tuluksak R.
7/12	USFWS	Fowler Island	Tuluksak	Kwethluk R., Kasigluk R, Kisaralik R., Tuluksak R.
7/15	USFWS	Fowler Island	Tuluksak	Kwethluk R.(to weir), Kasigluk R, Kisaralik R., Tuluksak R.
7/18	ADF&G	–	–	Hoholitna R., Blackwater Cr., Middle Fork, Big River
7/18	USFWS	Fowler Island	Tuluksak	Kisaralik R., Tuluksak R.
7/26	USFWS	Fowler Island	Tuluksak	Kwethluk R.(above weir), Kasigluk R, Kisaralik R., Tuluksak R.
8/2	USFWS	–	–	Kwethluk R.(above weir), Kasigluk R, Kisaralik R.
8/9	USFWS	–	–	Kwethluk R., Crooked Cr.
8/17	ADF&G	Fowler Island	Aniak	Kasigluk R., Kisaralik R.
8/18	ADF&G	–	–	Aniak R., Buckstock R., Salmon R., Kipchuk R.
8/22	ADF&G	Sleetmute	McGrath	Takotna R., 4th of July Cr., Nixon Fork, Pitka Fork, Salmon R., Little Tonzona R., Moose Cr.
8/23	ADF&G	Aniak	Sleetmute	George R., Holitna R., Hoholitna R., Chukowan R., Gemuk R., Shotgun Cr., Kogrukluk R., Taylor Cr.

[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 that fall within each of the subareas used to classify the final location of radiotagged Chinook salmon in the Kuskokwim River, 2016.

Subarea	Monitored tributaries	Unmonitored tributaries
1	–	–
2	Kwethluk, Tuluksak	Kisaralik, Kasigluk, Fog
3	–	–
4	Salmon of Aniak	Aniak (Minus Salmon), Owhat
5	George	Kolmakof, Holokuk, Veahna, Oskawalik, Crooked
6	Kogrukluk of Holitna	Holitna, Vreeland
7	–	Stony
8	Tatlawiksuk	Swift, Nunsatuk, Selatna
9	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 that radiotagged Kuskokwim River Chinook salmon were separated into for variance estimation, 2016.

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, 2016.

Number marked (M')[a]	Number examined (C)	Number recovered	Adjusted recovered (R')[b]	Marked fraction	Abundance estimate	L 95% CI	U 95% CI
527	21,590	91	94	0.44%	120,000	99,304	147,502

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

[b] Based on estimate of radio tag loss.

Table 5.–Captured and radiotagged Kuskokwim River Chinook salmon by day at the rkm 67 tagging site, 2016.

Day	Captured	Tagged	Day	Captured	Tagged
5/26[a]	6	2	6/25	46	20
5/27[a]	8	3	6/26	60	19
5/28[a]	2	2	6/27	44	24
5/29[a]	6	3	6/28[a]	51	24
5/30	16	4	6/29	44	18
5/31	25	3	6/30	33	16
6/1	21	4	7/1	25	12
6/2	25	3	7/2[a]	16	8
6/3	34	4	7/3	33	9
6/4[a]	26	5	7/4	33	10
6/5	29	7	7/5	28	12
6/6	28	8	7/6[a]	6	5
6/7	44	8	7/7	14	8
6/8	32	13	7/8	13	6
6/9	23	14	7/9[a]	20	5
6/10[a]	34	14	7/10	15	5
6/11	41	18	7/11	19	4
6/12	22	17	7/12	20	4
6/13	58	21	7/13[a]	16	3
6/14	31	21	7/14	20	4
6/15[a]	57	23	7/15	8	2
6/16	70	24	7/16[a]	5	2
6/17	38	23	7/17	7	2
6/18	38	23	7/18	7	2
6/19[a]	15	15	7/19	5	4
6/20	53	24	7/20	2	2
6/21	51	23	7/21	8	2
6/22	47	24	7/22	0	0
6/23[a]	14	14	7/23	1	1
6/24	39	21	Total	1,532	621

[a] Days when only 1 crew fished.

Table 6.–Fates assigned to radiotagged Chinook salmon in the Kuskokwim River, 2016.

Fate	Fate description	Count
	Radio tags that did not enter experiment	
1	Failed to migrate above rkm 67 tag site.	87
2	Harvested downstream of rkm 67 tag site.	7
	Total	94
	Radio tags that entered experiment	
3	Harvested between tag site (rkm 67) and tower T01 (rkm 112).	58
4	Harvested upriver from tower T01 (rkm 112).	46
5	Moved upstream of monitoring weir while in operation.	91
6	Moved upstream of weir while out of operation.	33
7	Entered non-monitored tributaries	275
8	Did not enter a tributary (mainstem final location)	24
	Total	527

Table 7.–Voluntary tag returns of radiotagged Kuskokwim River Chinook salmon captured in subsistence harvest by nearest community, 2016.

Nearest community	rkm	Total
Tuntutuliak[a]	32	7
Napakiak	87	21
Oscarville	97	13
Bethel	106	27
Kwethluk	131	8
Akiachak	143	18
Akiak	161	4
Tuluksak	193	2
Lower Kalskag	259	0
Kalskag	263	4
Aniak	307	3
Chuathbaluk	323	1
Napaimute	359	0
Crooked Creek	417	0
Sleetmute	488	1
McGrath	765	1
Nikolai	941	1
Total		111

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

Table 8.–Number of radiotagged Kuskokwim River Chinook salmon considered part of marked (M') population for abundance estimation, 2016.

Total radio tags (n_r)[a]	Radio tags (n_{rup})[b]	Marked proportion (p_{up})[c]
621	527	0.85

[a] Number of radio tags deployed at the rkm 67 tagging site.

[b] Number of radiotagged fish that continued upriver based on tracking and recapture data.

[c] Proportion of radiotagged fish that continued upriver.

Table 9.–Number of Chinook salmon observed at each upriver recapture site and considered part of capture (C) and recapture (R') populations for abundance estimation, 2016.

			Tag loss			
Recapture location	Weir passage (C)	Radio tag[a]	Inspected[b]	Counted[c]	Tag retention (P_{rt})[d]	Corrected recaptures (R')[e]
Kwethluk River	3,428	19	18	18		
Tuluksak River	909	7	5	5		
Salmon River (Aniak)	503	3	1	1		
George River	1,499	3	2	2		
Tatlawiksuk River	1,888	7	6	6		
Kogrukluk River	7,037	25	21	21		
Salmon River (Pitka Fork)	6,326	27	20	18		
Total	21,590	91	73	71	97%	94

[a] Number of radiotagged Chinook salmon detected passing weir by tracking station during operational periods.

[b] Number of spaghetti tags that were observed passing the weir by the weir crews.

[c] Number of tagged Chinook salmon inspected that retained the radio tag.

[d] Percentage of inspected fish that retained the radio tag. Estimated from radio tag and weir recovery data.

[e] Number of radio tags recaptured at weirs expanded by estimated tag loss percentage.

Table 10.–Radiotagged Kuskokwim River Chinook salmon recovery ratios by recovery site, 2016.

					Chi square		
Recapture location	Distance (rkm)[a]	Total recaptures[b]	Total untagged	Ratio[c]	X^2	*df*	*p*-value[d]
Kwethluk River	216	19	3,409	0.0056	1.4397		
Tuluksak River	171	7	902	0.0078	2.6317		
Salmon (Aniak) River	327	3	500	0.0060	[e]		
George River	376	3	1,496	0.0020	0.7075		
Tatlawiksuk River	491	7	1,881	0.0037	0.1158		
Kogrukluk River	633	25	7,012	0.0036	0.7354		
Salmon (Pitka Fork) River	847	27	6,299	0.0043	0.0043		
Total		91	21,499	0.0042	5.63425	5	0.3435

[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] *P*-value criteria is based on an alpha of 0.05.

[e] Data from Salmon (Aniak) River and George River weirs were pooled due to small sample sizes.

Table 11.–Radio tag recovery ratios of Kuskokwim River Chinook salmon by weekly temporal strata, 2016.

Temporal strata[a]	Not recovered	Recovered	Ratio	Chi square X^2	Chi square *df*	Chi square *p*-value[b]
5/26–6/5	32	8	0.25	0.91		
6/6–6/12	80	12	0.15	0.19		
6/13–6/19	125	25	0.20	0.49		
6/20–6/26	126	19	0.15	0.28		
6/27–7/3	98	13	0.13	0.77		
7/4–7/23	69	14	0.20	0.33[c]		
Total	530	91	0.17	2.963	5	0.706

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

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

[c] Last 3 weeks were pooled due to low expected tag recoveries.

Table 12.–Number of Kuskokwim River Chinook salmon sex and length samples from each Kuskokwim River recapture location used to test for selective sampling bias, 2016.

Recapture location	Weir passage	Available samples	Percent sampled
Kwethluk River	3,428	69	2%
Tuluksak River	909	278	31%
Salmon (Aniak) River	503	0	0%
George River	1,499	45	3%
Tatlawiksuk River	1,888	64	3%
Kogrukluk River	7,037	232	3%
Salmon (Pitka Fork) River	6,326	288	5%
Total	21,590	976	5%

Note: The length samples from each weir recapture location was 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), 2016.

							Test for selective sampling					
Sample sizes			Length (mm, METF)				M vs. R		C vs. R		M vs. C	
M	C	R		M	R	C[a]	D	*p*-value[b]	D	*p*-value[b]	D	*p*-value[b]
			Min	511	551	362						
			Max	927	925	1030						
621	91	629	Mean	726	739	706	0.106	0.34	0.9314	<0.005	0.9314	<0.005

Note: METF is mideye to tail of fork.

[a] Minimum and maximum 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.

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

Table 14.–Median radio tag deployment date at rkm 67 for Kuskokwim River Chinook salmon migrating to known subareas, 2016.

River area	Subarea	Total	Median deployment
Lower river	1	–	–
	2	80	6/26
Middle river	3	–	–
	4	94	6/26
	5	14	6/23
	6	99	6/24
	7	24	6/25
	8	39	6/20
	Subtotal	270	6/25
Upper river	9	48	6/15
	Total	398	6/24

Table 15.–Temporal pattern of entry timing past the rkm 67 tag site for radiotagged Kuskokwim River Chinook salmon with known final fate, 2016.

Date	Operational week	Radio tags	Lower tributaries[a]	Middle tributaries[b]	Upper tributaries[c]
5/26–6/5	1	22	5%	45%	50%
6/6–6/12	2	30	13%	60%	27%
6/13–6/19	3	81	17%	65%	17%
6/20–6/26	4	111	22%	72%	6%
6/27–7/3	5	85	24%	69%	7%
7/4–7/10	6	42	24%	76%	0%
7/11–7/17	7	18	22%	67%	11%
7/18–7/23	8	9	33%	67%	0%

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

[a] Radiotagged Chinook salmon that migrated to tributaries is Subarea 2.

[b] Radiotagged Chinook salmon that migrated to tributaries in Subareas 4 through 8.

[c] Radiotagged Chinook salmon that migrated to tributaries in Subarea 9.

Table 16.–Median travel time (days; IQR) and migration rate (km/day; IQR) of Kuskokwim River Chinook salmon between each successive mainstem telemetry towers, 2016.

	Mainstem section	Distance (rkm)[a]	Subarea 2	4	5	6	7	8	9	Median
Travel time										
	Tag site - T01	45	5 (3.1-6.7)	4.6 (3.6-6.1)	4.3 (2.7-5)	4.5 (2.9-5.3)	4.4 (3.4-7)	3.7 (2.7-7.2)	3 (2.1-5.2)	4.40
	T01-T02	12	0.3 (0.3-0.9)	0.4 (0.3-0.5)	0.3 (0.3-0.4)	0.4 (0.3-0.5)	0.4 (0.3-0.4)	0.3 (0.3-0.5)	0.3 (0.3-0.5)	0.30
	T02-T03	106		3.1 (2.7-3.5)	3.2 (2.9-3.4)	2.9 (2.6-3.4)	3 (2.5-3.7)	2.9 (2.6-3.5)	3.1 (2.9-3.7)	3.05
	T03-T04	68		2.2 (2-2.6)	1.9 (1.8-2.1)	1.9 (1.7-2.1)	2 (1.8-2.5)	1.9 (1.7-2.4)	2 (1.8-2.2)	1.95
	T04-T05	54			1.4 (1.3-1.7)	1.4 (1.3-1.6)	1.5 (1.4-1.8)	1.5 (1.3-1.8)	1.6 (1.4-1.8)	1.50
	T05-T06	127				3.1 (2.9-3.4)	3.4 (2.9-3.7)	3.1 (2.7-3.5)	3.3 (3.1-3.8)	3.20
	T06-T07	35					1.1 (0.9-1.2)	0.9 (0.8-1.1)	1 (0.9-1.1)	1.00
	T07-T08	47						1.5 (1.2-1.9)	1.4 (1.2-1.6)	1.45
	T08-T09	205							5 (4.6-5.7)	-
Migration rate			2	4	5	6	7	8	9	Median
	Tag site - T01	45	9 (7-14)	10 (7-12)	10 (9-16)	10 (8-15)	10 (6-13)	12 (6-17)	15 (9-21)	10
	T01-T02	12	35 (13-42)	33 (27-43)	38 (29-44)	34 (25-41)	33 (27-37)	39 (25-47)	39 (26-45)	35
	T02-T03	106		35 (31-39)	33 (31-36)	37 (31-41)	35 (29-43)	36 (30-40)	34 (29-37)	35
	T03-T04	68		31 (26-34)	35 (33-37)	36 (32-40)	34 (27-39)	36 (29-40)	34 (31-37)	35
	T04-T05	54			37 (32-42)	38 (33-42)	36 (30-38)	37 (29-42)	35 (29-38)	37
	T05-T06	127				41 (37-44)	38 (34-44)	41 (36-47)	38 (34-41)	40
	T06-T07	35					31 (29-40)	37 (33-41)	35 (32-38)	35
	T07-T08	47						31 (24-38)	33 (29-38)	32
	T08-T09	205							41 (36-45)	-
		Median[b]	-	33	36	37	35	37	35	36

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

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

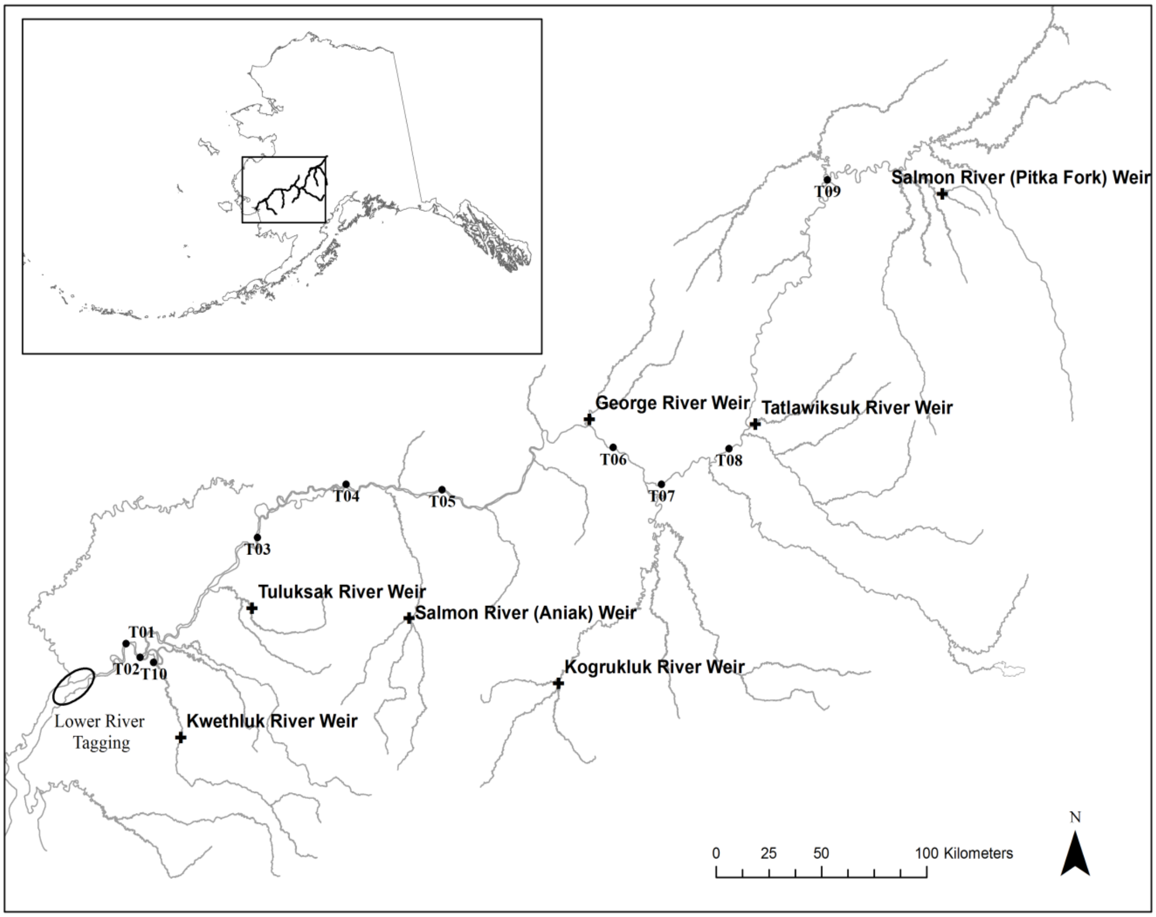

Figure 1.–Location of the tagging site, telemetry towers (black crosses), and escapement monitoring weirs (black dots) used to tag, track, and recapture Kuskokwim River Chinook salmon, 2016.

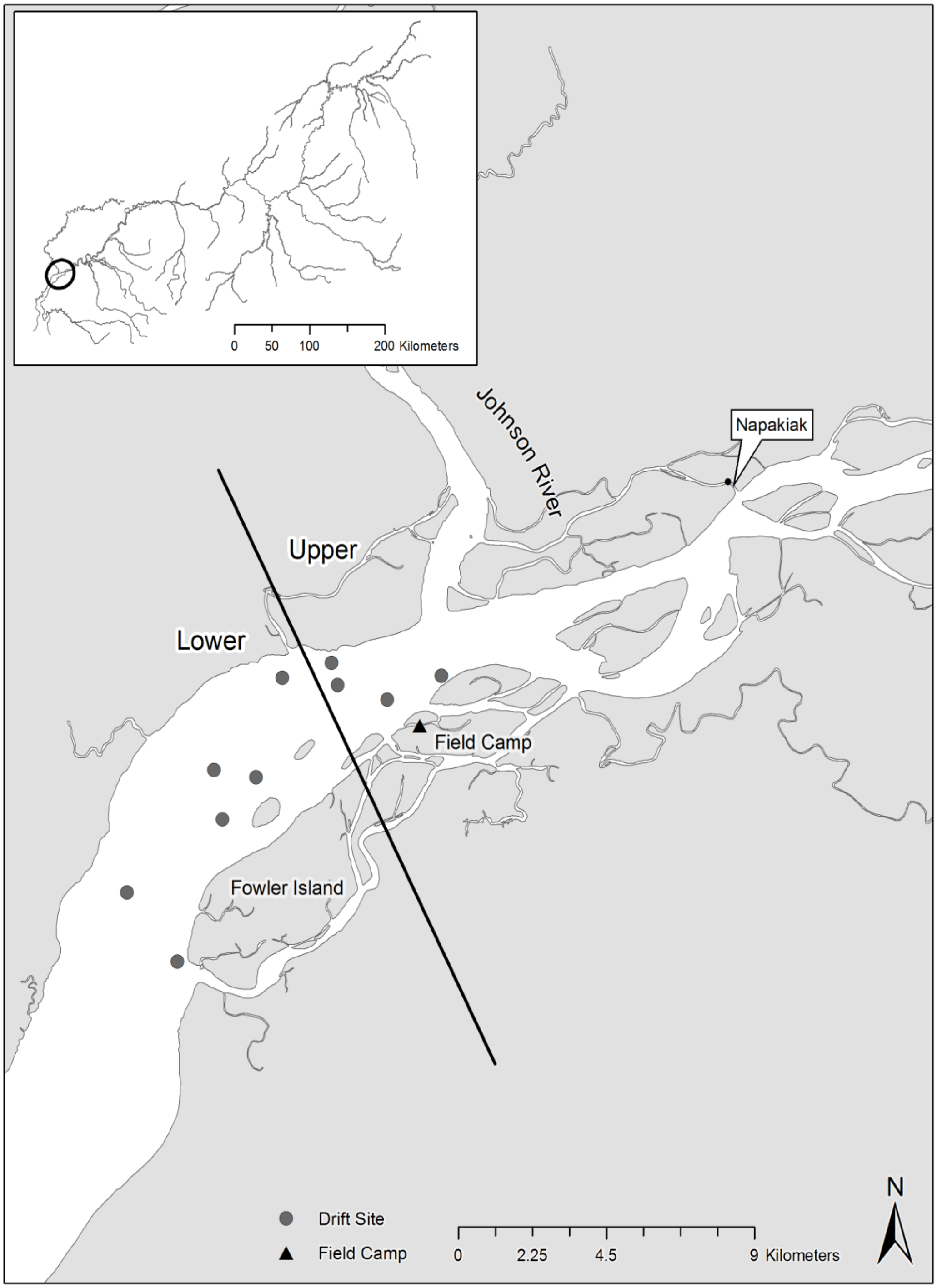

Figure 2.–Location of Kuskokwim River Chinook salmon tagging sites (upper and lower), drift zones (circles), and field camp (triangle), 2016.

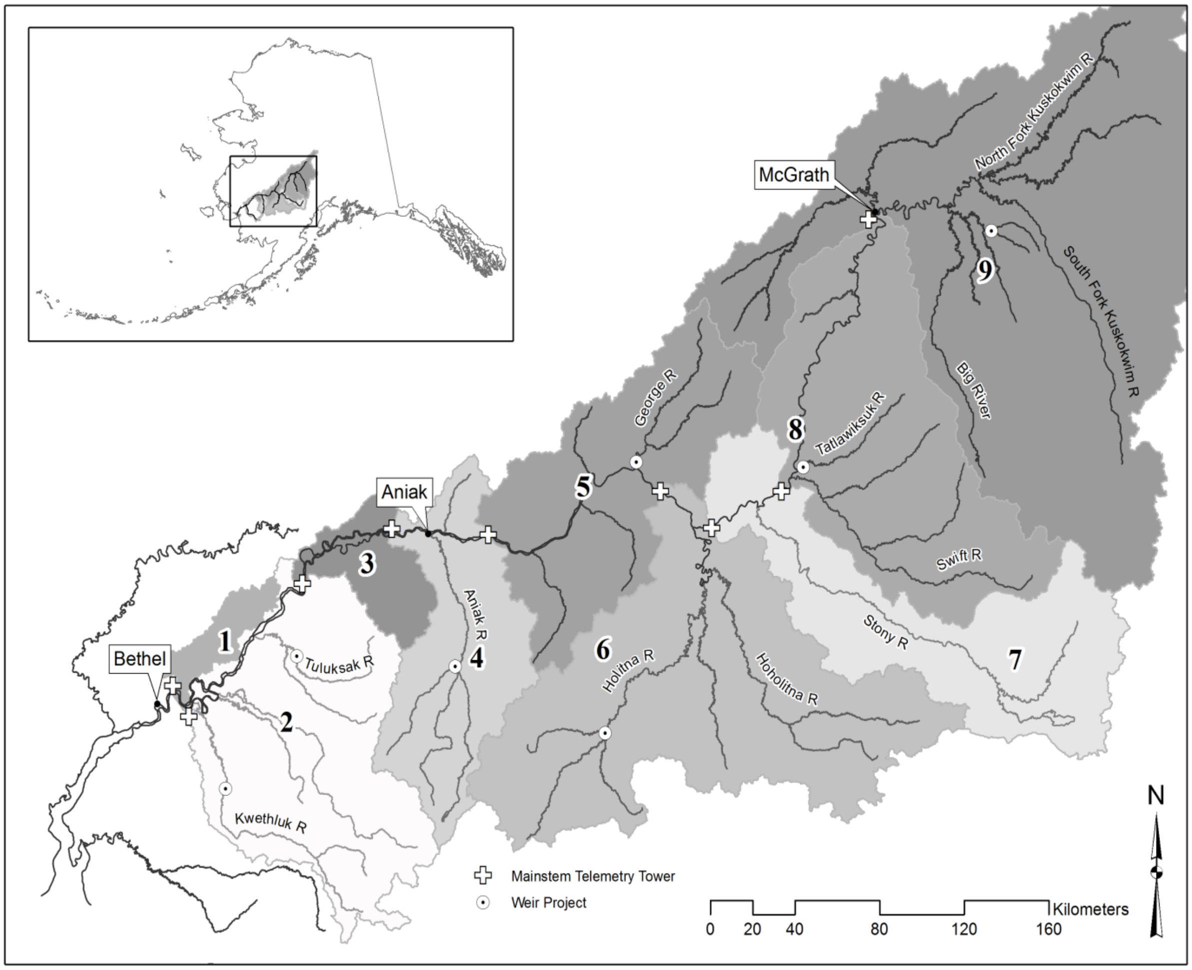

Figure 3.–Subareas used to classify the final location of radiotagged Chinook salmon in the Kuskokwim River, 2016.

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

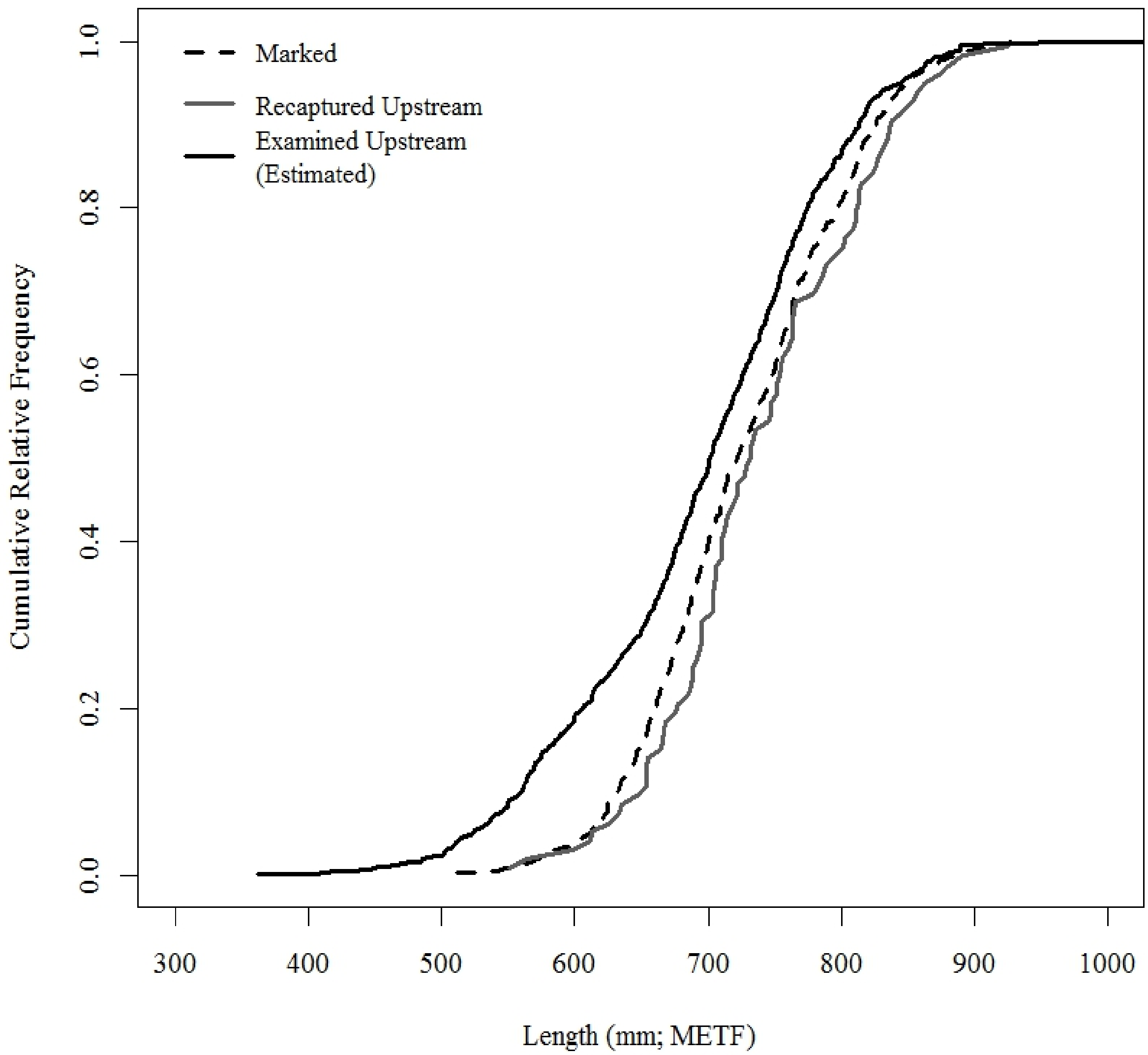

Figure 4.–Cumulative relative length frequencies of Chinook salmon tagged at rkm 67 (marked) and recovered upstream (recaptured), compared with the estimated length composition of all fish examined at upstream recovery weirs (examined), 2016.

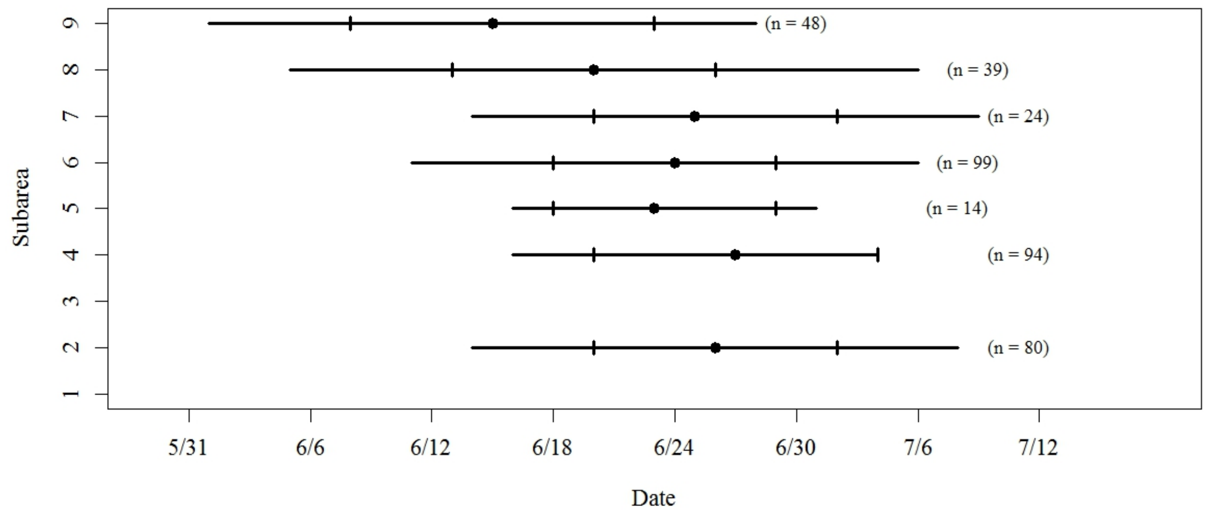

Figure 5.–Chinook salmon subarea-specific tagging dates, Kuskokwim River 2016.

Note: Median, central 50%, central 80% of tagging dates, and sample sizes (*n*) are shown. The tagging site was located at river kilometer 67.

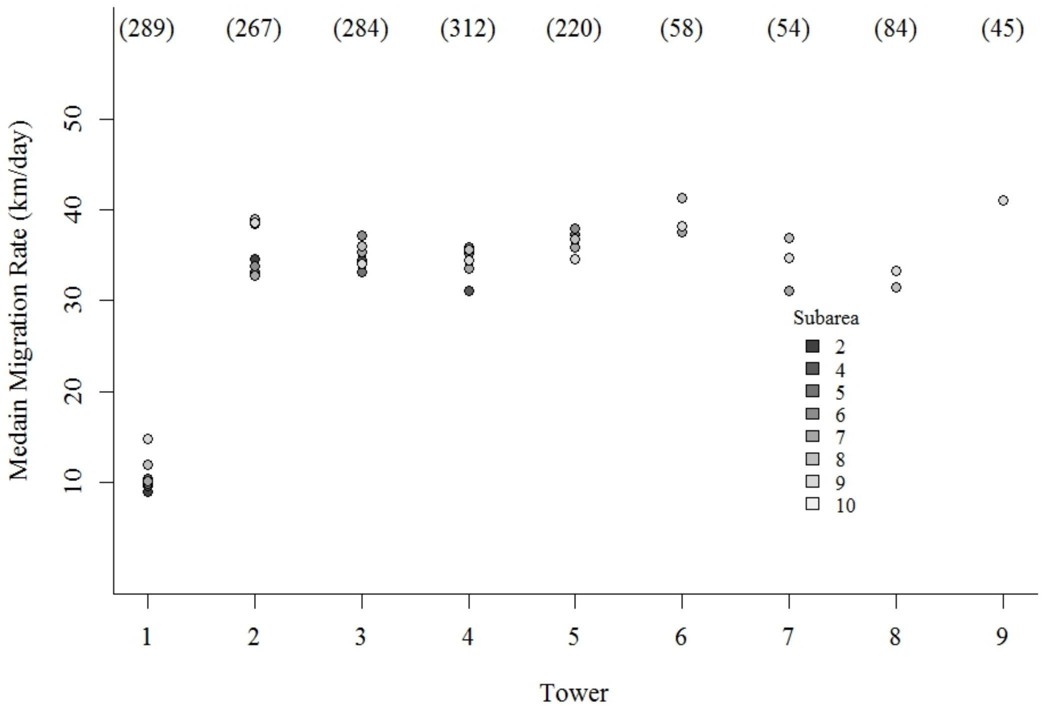

Figure 6.–Subarea specific median migration speed (km/day) among stationary mainstem telemetry towers, 2016.

APPENDIX A: SPAGHETTI TAG DATA COLLECTED IN 2016 BUT NOT USED IN ANALYSIS

Appendix A1.–Number of Kuskokwim River Chinook salmon spaghetti tagged by day at the rkm 67 tagging site, 2016.

Day	Tagged	Day	Tagged
5/26[a]	6	6/25	46
5/27[a]	8	6/26	60
5/28[a]	2	6/27	44
5/29[a]	6	6/28[a]	50
5/30	16	6/29	44
5/31	24	6/30	33
6/1	21	7/1	23
6/2	24	7/2[a]	16
6/3	33	7/3	32
6/4[a]	26	7/4	33
6/5	28	7/5	27
6/6	26	7/6[a]	5
6/7	42	7/7	14
6/8	32	7/8	13
6/9	21	7/9[a]	19
6/10[a]	34	7/10	15
6/11	41	7/11	19
6/12	22	7/12	19
6/13	58	7/13[a]	15
6/14	31	7/14	20
6/15[a]	56	7/15	8
6/16	69	7/16[a]	5
6/17	38	7/17	7
6/18	38	7/18	7
6/19[a]	15	7/19	5
6/20	51	7/20	2
6/21	51	7/21	8
6/22	47	7/22	0
6/23[a]	14	7/23	1
6/24	39	Total	1,509

[a] Days when only 1 crew fished.

Appendix A2.–Voluntary tag returns from spaghetti tagged Kuskokwim River Chinook salmon captured in subsistence harvest by nearest community, 2016.

Nearest community	rkm	Spaghetti tag
Tuntutuliak[a]	32	2
Napakiak	87	53
Oscarville	97	15
Bethel	106	18
Kwethluk	131	10
Akiachak	143	17
Akiak	161	5
Tuluksak	193	5
Lower Kalskag	259	2
Kalskag	263	1
Aniak	307	8
Chuathbaluk	323	2
Napaimute	359	1
Crooked Creek	417	3
Sleetmute	488	1
McGrath	765	0
Nikolai	941	2
Total		145

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

Appendix A3.–Number of spaghetti tagged Kuskokwim River Chinook salmon observed at each upriver recapture site, 2016.

Recapture location	Distance (rkm	Spaghetti tag[a]
Kwethluk River	216	18
Tuluksak River	171	8
Salmon River (Aniak)	327	1
George River	376	5
Tatlawiksuk River	491	5
Kogrukluk River	633	15
Salmon River (Pitka Fork)	847	26
Total		78

[a] Observed by weir staff.

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

Appendix B1.–Tests of consistency for the Petersen estimator.

As presented in Study 2007.

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-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: $\Sigma_j \theta_{ij} p_j = d$, where p_j is the probability of capturing a fish in section j during the second event, and d is a constant.

Appendix B2.–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.