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Inriver Abundance of Kuskokwim River Chinook Salmon, 2014

by

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May 2017

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

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

FISHERY DATA SERIES NO. 17-23

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ABSTRACT

We conducted a 2-sample mark–recapture experiment using radiotelemetry methods to estimate the abundance of adult Chinook salmon in the middle and upper Kuskokwim River in 2014. Fish were captured using drift gillnets and fish wheels in the mainstem Kuskokwim River at river kilometer (rkm) 270 near the community of Kalskag. Chinook salmon were marked with radio and T-bar anchor tags. Tagged fish were tracked throughout the study area using stationary and aerial telemetry methods. Four weirs located upriver from the tag site were used to recapture tagged Chinook salmon. The abundance of Chinook salmon upriver of rkm 294 was 61,255 (95% CI: 49,021–80,985).

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

INTRODUCTION

Fisheries managers require accurate estimates of Chinook salmon *Oncorhynchus tshawytscha* abundance to manage subsistence and commercial fisheries within the Kuskokwim River. 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 *O.keta* and sockeye *O. nerka* 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. 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; Liller and Hamazaki 2016). Accurate abundance estimates require that the run reconstruction model is scaled appropriately. The run reconstruction model is currently scaled using estimates of total abundance from 2003 to 2007, a period of average and record high returns (Bue et al. 2012; Liller and Hamazaki 2016). Since 2010, annual Chinook salmon run sizes have 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 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.

Estimating the total run size of Chinook salmon to the Kuskokwim River is difficult due to the large size of the drainage and numerous salmon producing tributaries. Prior estimates used a combination of methods because a drainagewide mark–recapture estimate was not considered feasible at the time. First, mark–recapture techniques were used to estimate the total abundance of Chinook salmon passing upriver of river kilometer (rkm) 294 (Schaberg et al. 2012). Escapement downriver from the tagging site was estimated using weirs located on Kwethluk (Webber et al. 2016a) and Tuluksak (Webber et al. 2016b) rivers, and then applying weir-based escapement estimates to unmonitored tributaries after adjusting for differences in productivity using a habitat model (Parken et al. 2006; Schaberg et al. 2012). Finally, estimates of total harvest that occurred in the lower portion of the Kuskokwim River were obtained from commercial fish tickets and subsistence harvest surveys. Total run abundance was estimated by combining all 3 sources of abundance information: upriver mark–recapture, lower river escapement, and lower river harvest (Schaberg et al. 2012).

Based on the recommendations of the Chinook Salmon Research Team, we initiated a 3 year effort (2014–2016) to estimate the total run size of Kuskokwim River Chinook salmon. We used standard 2-sample mark–recapture methods to estimate the total number of Chinook salmon returning to the middle and upper portion of the Kuskokwim River. Similar to past studies, we planned to reconstruct the total run size by combining the mark–recapture estimate with lower river escapement and harvest. However, we felt that the habitat-based expansion methods used for estimating escapement into unmonitored lower river tributaries (Schaberg et al. 2012) should be verified with direct observations of escapement before they can be used with confidence. As such, we initiated a separate 3-year study (2014–2016) to assess the validity of the habitat-expansion method. This report presents only Chinook salmon abundance estimates for the middle and upper Kuskokwim River in 2014. Results presented in this report could be combined with lower river harvest and escapement to produce a total run estimate, once lower river escapement estimation methods are refined.

OBJECTIVE

Estimate the abundance of adult Chinook salmon in the Kuskokwim River for all waters upriver of river kilometer 294, such that the bounds of the 95% confidence interval are within ±25% of the estimated abundance.

METHODS

STUDY AREA

Estimates of abundance are germane to all waters upriver of Birch Tree Crossing (rkm 294; Figure 1). Due to the migratory nature of Chinook salmon, sampling and tracking efforts encompassed the entire watershed upriver of Birch Tree Crossing and the mainstem portion of the Kuskokwim River downriver to rkm 233. A total of 13 telemetry towers were used to monitor movement of radiotagged fish (Figure 1). One telemetry tower located at rkm 294 (hereafter referred to as T01) was used to identify radiotagged fish that successfully migrated upriver from the tagging location. A distance of 24 rkm separated the tagging location and T01 to allow radiotagged fish adequate time to recover from capture and tag stress. Another telemetry station (T00) located at rkm 233 was used to detect fish that moved downriver after tagging. An additional 6 telemetry stations were located along the mainstem Kuskokwim River from the communities of Chuathbaluk (rkm 323) to McGrath (rkm 573). A telemetry station was also located at each of the 4 weir recovery sites.

Initial capture and tagging of Chinook salmon occurred at rkm 270 near the community of Kalskag (Figure 1). This site was chosen because it is upriver from where all commercial and nearly 90% of subsistence harvest of Chinook salmon occurs. It is also downriver from the majority of Chinook salmon spawning tributaries. Informal surveys conducted near the tag site indicate a relatively shallow and uniform bottom profile, with average depth of about 4.5 m and maximum depth of about 10.5 m at a moderate river stage.

Recapture of tagged Chinook salmon occurred at 4 weirs located on important spawning tributaries within the middle portion of the Kuskokwim River (Figure 1). A weir located on the Salmon River (rkm 404) was used to index escapement and tag returns to the Aniak River. Weirs located on the George River (rkm 453) and Tatlawiksuk River (rkm 568) were used to index escapement and tag returns to medium sized tributaries draining directly in to the Kuskokwim River. The George River drains the north side of the Kuskokwim River and the Tatlawiksuk River drains the south side. A weir on the Kogrukluk River (rkm 710) was used to index escapement and tag returns to the Holitna River, which is the largest tributary draining into the Middle Kuskokwim River.

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 from rkm 294.

First Event Sampling Methods

Efforts were made to ensure that all components of the Chinook salmon run had a non-zero probability of capture during the first event. Drift gillnets and fish wheels were used to capture adult Chinook salmon as they migrated upriver past the tag site. Fishing was conducted 6 days per week throughout the entire Chinook salmon run beginning June 5 and continuing until July 17. Onset of drift gillnet fishing was delayed until June 7 in order to establish safe drift sites. Fish wheel operations were suspended due to low catches on July 12 and July 13 to focus more effort on use of drift gillnets. Fishing effort was conducted during daylight hours as follows: 0600–1100; 1200–1600; and 1800–2300. Additional fishing effort was added from 1600–1700 when extra crew time was available. Shifts were intended to distribute fishing effort throughout the day during hours of peak Chinook salmon abundance (Liller 2013). Fish wheels operated continuously during each shift and shut down between shifts for a total of 14 hours of fishing time each day. Drift gillnets were fished for an average of 2.4 hr of soak time per shift, and total daily gillnet effort averaged 6.6 hr of soak time. Crews alternated between capture gears, checking fish wheels each hour and drift gillnetting between fish wheel checks.

One fish wheel was mounted along each bank of the river at sites that provided the most ideal conditions for fish wheel operations (Liller 2013). Fish wheels were used to target small Chinook salmon that tend to migrate in shallow waters (Hughes 2004). Consistent sampling effort was maintained by adjusting the distance from shore, vertical position of the baskets, and location (Liller 2013).

Drift gillnets were used to target medium to large size Chinook salmon that tend to migrate in offshore areas not accessible using a fish wheel. Gillnets were 12 fathoms long, 29 meshes deep, constructed of multi-fiber monofilament, and hung at a 2:1 ratio. Drift gillnets had stretched mesh sizes of 7.5 and 8.0 inches. Both mesh sizes were fished daily. Mesh size was rotated among the 3 daily shifts, such that over the 6 day work week, both mesh sizes were used with equal effort. At the start of the season, 1 drift site was established along each bank of the river, but further offshore compared to the fish wheel locations. Subsequent exploration of the area resulted in the development of 11 drift sites distributed along both banks and mid channel of the river (Figure 2). At the start of each sampling period, effort was distributed among drift sites until it was determined where fish capture was most successful. Increased sampling effort was allocated to more productive sites throughout the remainder of the shift.

Strict handling, tagging, and release methods were used to minimize fish stress (Liller 2013). When it was suspected that a Chinook salmon was captured in a drift gillnet, the net was immediately retrieved to the boat. Chinook salmon that were captured with fish wheels were held for no longer than 1 hour in a livebox before they were sampled and released (Liller et al. 2011). All tagging procedures occurred in a tote containing fresh circulated river water and fish were immobilized in a cradle. A physical examination was performed on all captured fish. 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 received a rank of 1 or 2 were tagged. Chinook salmon were released immediately following tagging.

All Chinook salmon ≥450 mm METF (mid eye to tail fork) length that passed the physical examination were given a primary mark consisting of an Advanced Telemetry Systems (ATS)[1] esophageal radio tag. Two sizes of radio tag were used to ensure that tags did not exceed 2% of the fish's body weight (Cooke 2012). Fish from 450 to 550 mm MEF length were implanted with a model F1840B (20 grams total weight) tag whereas fish greater than 550 mm MEF length received a model F1845B (24 grams total weight) tag. Each radio tag was distinguishable by a unique frequency and encoded pulse pattern. A total of 10 frequencies separated by 20 kHZ in the 149 Mhz range with 70 encoded pulse patterns per frequency were used, for a total of 700 uniquely identifiable tags. In addition to a radio tag, all radiotagged Chinook salmon were given a secondary mark consisting of a T-bar anchor tag (Floy Model FD-68BC; Floy Tag and Manufacturing, Inc.). Tag insertion was completed using Avery Dennison pistol-grip tagging gun equipped with a 1.125-inch stainless steel needle. The needle was inserted into the dorsal musculature of the fish near the preferred area approximately 1 cm ventral to the posterior insertion of the dorsal fin between the third and fourth fin rays. The tag was then inserted and securely attached between the pterygiopores. Placement of the secondary mark was intended to be visible to staff conducting recapture sampling and provided an opportunity to estimate the proportion of fish that retained the radio tag.

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

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

Radiotagged Chinook salmon that failed to migrate and remain upstream of the tag site were accounted for by means of a telemetry tracking tower placed at rkm 294. The number of radiotagged fish that moved and remained upstream of the tagging site (n_{rup}) out of the total number of radiotagged fish released at the tag site (n_{rm}) formed the estimated proportion of tagged fish that were available for recapture, $p_{up} = n_{rup}/n_{rm}$. Then, the number of fish that successfully entered the marked population past tower T01 (M') was estimated as $n_{rm} \cdot p_{up}$.

We used tower T01 to monitor for the occurrence of Chinook salmon radiotagged in a separate study conducted downriver near the mouth of the Kuskokwim River (Clark et al. 2014). That study deployed radio tags in adult Chinook salmon using similar methods to those described in this report. The number of Chinook salmon tagged in the downriver study that passed upriver of T01 was added to the marked population for the purpose of abundance estimation.

To evaluate harvest mortality of tagged fish, a volunteer tag lottery was conducted to encourage reporting of tagged fish harvested in the subsistence fishery. 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 prizes ranging from $200 to $500.

Second Event Sampling Methods

Telemetry Tracking

Radiotagged Chinook salmon were tracked as they migrated up the Kuskokwim River using a network of 13 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.

One aerial tracking survey was performed along the mainstem Kuskokwim River on August 27 and 28 to assist with determining final fate of radiotagged fish. The flight focused on the mainstem Kuskokwim River between the communities of Tuluksak (rkm 192) and McGrath (rkm 753). The survey was conducted by a pilot and 2 biologists in a Cessna 182 aircraft. During the flight, each biologist controlled an ATS receiver attached to either the 2 wing mounted H-antennas or the downward facing C-antenna on the belly of the plane. The H-type antenna provided directional detection of fish (i.e., left or right side of plane). The C-type antenna was used to increase detection of tagged fish directly below the plane.

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 8 subareas upriver from rkm 294 using the network of towers along the mainstem to identify the broad-scale distribution and assess delayed mortality of radiotagged fish (Table 1; 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 later detected in the mainstem during the aerial tracking survey. An aerial survey was flown throughout the Holitna and Aniak drainages to test this assumption.

Recapture Sampling

Recapture sampling occurred at 4 tributary escapement monitoring weirs located upstream of the tag site (Figure 1). A single tracking tower was located at each of these weirs to determine the number of radiotagged Chinook salmon that passed upriver.

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). Total captures at each location (C'_i) consisted of all Chinook salmon that were estimated passing upstream of the weir i (i = 1,…, 4). The total estimated passage of Chinook salmon at all weir sites ($\sum C'_i$) comprised the capture sample (C'). 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. The proportion of fish that retained the radio tag (p_{rt}) was estimated using the total number of T-bar anchor tags observed by weir staff (n_o), and the subset of those tagged fish that were also detected by the telemetry tower located at the weir site (n_{rt}), where $p_{rt} = n_{rt}/n_o$. That proportion was used to expand the number of telemetry-detected 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 $\sum R_i/p_{rt}$.

Data Analysis

Chapman's modification of the Petersen estimator (Chapman 1951; Seber 1982) was used to estimate total abundance ($\hat{N}$) of Chinook salmon upstream of rkm 294:

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

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

The proportion of tagged fish that entered the marked population (p_i), was separated into 5 classes (i = 0,…, 4) as follows:

1) entered marked population but did not pass through a weir or was harvested (p_0);

2) moved upstream of Salmon River weir (p_1);

3) moved upstream of George River weir (p_2);

4) moved upstream of Kogrukluk River weir (p_3); and

5) moved upstream of Tatlawiksuk River weir (p_4).

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:

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

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:

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

We used data modeling and hypothesis testing to determine whether this study met the critical assumptions of the estimator (Chapman 1951; Seber 1982). The requirement for a closed population was addressed by conducting tagging and recapturing operations throughout most of the Chinook salmon run and including only the number of tagged fish that successfully resumed upriver migration. Limited 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, second sample, or that tagged fish mixed completely with untagged fish was evaluated following recommendations outlined in Seber (1982). A chi-square test of independence was used to evaluate equal probability of capture and recapture. All statistical tests were considered significant at $\alpha = 0.05$.

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. However, tests involving fish examined during the second event (C') were modified to account for the fact that sex and length composition of the fish in the second event samples (i.e., the escapement past each weir) was estimated (Liller et al. 2016). In other words, the sex and length composition was derived from a sample of fish measured at each weir, 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,…, 4) 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 (ECDF) for the second sampling event was modeled.

The count (l) of samples collected at each discrete length m (m = 330…,1003) 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:

$$F_m = \sum \left(\frac{l_{mi}}{\sum l_{mi}} * C'_i \right) . \tag{4}$$

The estimated count of fish by length in the recapture sample was converted to a cumulative distribution and compared to the cumulative length distribution of the marked sample using a Kolmogorov-Smirnov goodness-of-fit test (Appendix A2).

RESULTS

The estimated abundance of Chinook salmon upstream of rkm 294 was 61,255 (95% CI: 49,021–80,985; Table 2). The bounds of the 95% confidence interval are within (±) 26% of the estimated abundance, which was slightly larger than our stated criteria.

Chinook salmon were captured on the first day of operation (Table 3). Catches were less than 5 Chinook salmon per day until June 14. Peak catches of 20–30 fish per day occurred from June 17–26 (Table 3) and then decreased abruptly as of June 28 following the first subsistence fishing opportunity in the vicinity of the tag site (on June 27). The daily catch of Chinook salmon decreased over the last 3 weeks of the season. Daily catches averaged less than 2 fish per day during the final week of operation, July12–July 17 (Table 3).

A total of 330 Chinook salmon were captured at the Kalskag tag site, of which 304 (92%) were tagged. Of all captured fish, 78% were ranked 1 (good condition), 20% were ranked 2 (minor injuries), and less than 2% were given a rank of 3 or 4 (major injuries or deceased). Of the 304 fish that received tags, 28% were captured in fish wheels and 72% were captured in drift gillnets. An additional 45 Chinook salmon radiotagged as part of a separate feasibility study also passed upriver from the tag site, resulting in a total of 349 radiotagged fish.

Final fate was determined for all 349 radiotagged fish (Table 4). Only 20 (6%) tagged fish failed to migrate and remain upriver from T01. Of those, 2 fish were harvested, 10 were located near the tag site, and 8 passed downriver and were last detected on T00. A total of 329 (94%) tagged fish were detected upstream of T01, indicating that majority of fish survived tagging and continued their upriver migration. The probability that a tagged fish migrated and remained upriver from T01 (p_{up}) was estimated to be 0.94 (Table 5).

Final fate was determined for each fish that migrated upriver from T01 (Table 6). Only 6 tagged fish were harvested in the subsistence fishery, including 2 fish harvested near the community of Aniak (Section 1), 1 fish harvested near each of the communities of Sleetmute (Section 4) and Lime Village (Section 5), and 2 fish harvested on the Salmon River of the Pitka Fork (Section 8). A total of 13 tagged fish were located in the mainstem between T01 and T08. A total of 310 (94%) fish were assigned to tributaries. The surveys flown to validate final fate assignments focused only on the major tributaries of the Holitna and Aniak rivers and provided a conservative estimate of the accuracy of our fate assignments. Final fate assignment was confirmed for a minimum of 87% of fish in Subarea 1 and 95% of fish in Subarea 4 (Table 6).

A total of 53 tagged Chinook salmon passed telemetry tracking stations located at the 4 recapture weirs. In total, 34 external tags were physically observed by weir crews, of which 33 had a radio tag. Therefore, radio tag retention was estimated to be 97% and total tag recoveries (R') was adjusted to 55 tags (Table 7). Total estimated escapement from all 4 recapture weirs was 10,394 fish (Hansen et al. 2015). Tagged Chinook salmon represented 0.53% of the monitored escapement past the recapture weirs (Table 2).

Conditions for an unbiased estimate of abundance were achieved. The marked fraction of Chinook salmon at each weir was not significantly different, which provides support that all sub-stocks passing upriver of the tag site had an equal probability of capture (Table 8; $\chi^2 = 1.93595$; $p = 0.58581$). This result satisfied the criteria for using Chapman's modification of the Petersen estimator. Recapture ratios were significantly different over time (Table 9; $\chi^2 = 9.22059$; $p < 0.01$), which indicates that equal probability of recapture was not met. Tag recapture ratios increased throughout the recapture period, which indicates that fish tagged early in the season had disproportionately low recapture rates. Large sample sizes were available for detecting length biases (Table 10). There was evidence that the first sampling event disproportionately selected larger fish; however, there was no length selectivity during the second event (Table 11; Figure 4). Sex assignment at the tag site was unreliable based on postseason validation. Comparisons between the sex assignment of fish at the tag and recapture sites revealed a 25% error rate at the tag site. As a result, tests for sex-selective sampling are not presented.

The occurrence of individual sub-stocks passing the tag site changed over the course of the run. Fish bound for upriver tributaries (i.e., final destinations upriver from the Tatlawiksuk River) made up an average of 51.0% during the first 2 weeks of sampling (57.0% and 45.0% respectively; Table 12). Upriver tributary fish made up 9.6% of the catch during the third week of sampling and decreased to 0.0% by the end of tagging operations. Average capture date of upriver fish was June 17. Fish that migrated to tributaries below Tatlawiksuk River had an average capture date of June 23 (Table 13).

DISCUSSION

Tagging operations were conducted throughout the majority of the Chinook salmon run. Based on information from the Bethel Test Fishery (rkm 106), up to 5% of the total run may have passed before tagging operations began (Lipka and Poetter 2016; AYKDBMS[2]). During previous study years (2002–2007), the total number of Chinook salmon captured at the tag site prior to June 5 was negligible (<1% of the season total; Schaberg et al. 2012). This information was used as justification for the start date of June 5. We believe that Chinook salmon conservation measures in 2014, which included salmon fishing closures during much of the run (Lipka et al. 2016), allowed more early running upriver spawners to migrate through the fishery than usual, thus increasing early season catches. However, daily catches were less than 1% of season total for the first 8 days of operations, indicating the early portion of the run was probably well represented. Tagging operations continued until catches were less than 1% for 12 consecutive days.

Throughout the 2014 season, we experienced substantial challenges capturing adequate numbers of Chinook salmon using drift gillnets and fish wheels. Drift gillnet sampling was difficult due to the prevalence of large woody debris along the river bottom that caused nets to snag. This was a particular issue early in the season, which resulted in the need to delay the start of drift

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

gillnetting by 2 days. Throughout the season, snags were encountered several times each day, which resulted in operational delays, net damage, and the need to deviate from the net rotation schedule. The time required to repair nets was unexpected and interfered with time reserved for conducting routine fish wheel maintenance and adjustments to accommodate changes in river level and water velocity. As a result, fish wheel performance was less than optimal. Additionally, water levels were low and unusually clear during much of the season. Under these conditions, fish could see the fish wheels and simply swim around them, resulting in reduced catches. We evaluated options for increasing catches by switching to night shifts, but the potential benefit was determined to be small. Despite these challenges, catches were comparable to 2002–2007 project years which averaged 438 tags when run sizes were 2–4 times larger (Schaberg et al. 2012).

Recapture weirs and telemetry tracking stations were effective and no operational challenges were identified. The weirs experienced only minor instances of missed passage, and on average over 96% of the total escapement past each weir were observed (Hansen et al. 2015). Furthermore, estimates of missed passage were small and the uncertainty associated with these estimates was considered negligible. Therefore, this source of uncertainty was not considered in the mark–recapture variance estimate. On-site test radio tags confirmed that all telemetry towers operated continuously throughout the season. As a result, it is unlikely that any radiotagged fish migrated undetected past the telemetry towers. Telemetry data associated with each radiotagged fish was adequate to confidently determine date, time, and direction of travel past each tower.

We are confident that all tagged Chinook salmon in the second event were identifiable and accurately reported. Radiotelemetry towers located at the weirs presumably detected all marked fish that retained their radio tag. Radio tag retention was estimated to be 97% between the tagging and recapture sites. The sample size for investigating tag loss was relatively small ($n = 35$); however, the power to detect tag loss was probably adequate given that 64% of all recaptured fish were evaluated.

Recapture rates changed as the season progressed, indicating that tagged fish did not have an equal probability of recapture at the weirs. We believe this was due to the lack of a recapture site in the headwaters. During operational Weeks 1 and 2, the percentage of fish tagged that migrated to the headwaters was 57% and 45%, respectively, but corresponding recapture rates at the weirs during those weeks were low. The recapture rate increased throughout the season as the percentage of the weekly catch migrating to the headwaters decreased. Although there were temporal differences in recapture rates, the use of a Petersen estimator was still appropriate because there is no evidence that sub-stocks were not tagged in proportion to their abundance.

Our decision to not operate a recapture site in the headwaters, upriver from McGrath was based on prior telemetry studies but, unfortunately, turned out to be a substantial weakness in our study design. Previous mark–recapture study results (2002–2007) indicated on average only 5% of tagged fish that were successfully tracked to spawning areas passed upriver from McGrath (Schaberg et al. 2012). However, a total of 21% of the 2014 season catch was tracked to areas upriver from McGrath, with 75% of headwaters fish captured during the first 2 weeks of operations. As a result, we did not have the opportunity to evaluate mark-to-unmarked ratio for the relatively large number of tagged fish that traveled to the headwaters. Although the potential for bias exists, the number of tagged fish tracked to the headwaters seems reasonable given the lack of subsistence harvest during times when those fish were available for capture at the tag site.

We believe that the notable increase in tags tracked to the headwaters compared to prior years was a result of Chinook salmon conservation measures during the 2014 season (Lipka et al. 2016). Historically, there have been no restrictions on the timing of subsistence salmon fishery, and much of the fishing effort was concentrated on the early portion of the run (Hamazaki 2008) when fish migrating to the headwaters are most abundant (Stuby 2007; Schaberg et al. 2012). In 2014, subsistence fishing was closed to salmon fishing beginning May 20 (Lipka et al. 2016). The intended management effect was to reduce exploitation on all Chinook salmon sub-stocks. The unintended effect on the mark–recapture study was an increased catch of headwater Chinook salmon due to a substantial delay to the start of subsistence fishing and a reduced exploitation on upriver sub-stocks in particular.

We were unable to determine why 13 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 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 end route mortality for tagged fish. As such, we must acknowledge the possibility that some of these 13 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.

The estimated Chinook salmon abundance upriver from rkm 294 is probably unbiased and the precision is realistic given the challenges associated with operating a mark–recapture study of this scale. The spatial distribution of telemetry and recapture efforts resulted in adequate data to test critical mark–recapture assumptions and test for bias in the estimate. Data supported the decision to use a pooled Petersen estimator. However, the 95% confidence bounds were slightly wider than our stated objective of ±25%. Achieving the desired precision required that we tag and recapture adequate numbers of Chinook salmon given the true population abundance (Robson and Reiger 1964). During the operational planning stages, we anticipated a population abundance ranging between 50,000 and 150,000 (Liller 2013) based on preseason run forecasts. We expected to tag at least 400 Chinook salmon, regardless of run size, based on the tagging success of prior studies conducted at this location. We expected weir passage to increase with run size, which would provide the additional power to achieve the desired precision level at larger run sizes. The relatively wide confidence interval was primarily due to difficulty capturing Chinook salmon at the tag site which resulted in fewer (n = 329) than planned tagged fish available for recapture. The strength of our study design was established in the recapture sampling event. Nearly 17% of the total estimated abundance passed through the 4 weirs resulting in a large number of fish evaluated for tags.

RECOMMENDATIONS

The greatest improvement that could be made to this study would be to develop a means of establishing a marked-to-unmarked ratio of Chinook salmon in the headwaters. Having a recapture site in the headwaters would allow recapture efforts to occur in all geographic components of the drainage. In 2014, of all tagged fish traveling to the headwaters (n = 70), 69% migrated to the Pitka Fork complex, which is a series of small spawning tributaries in the headwaters. Within the Pitka Fork complex, the Salmon River tributary had the single largest concentration of tagged fish, representing 26% of all tagged fish upriver of McGrath (Table 14). Aerial telemetry data from previous Chinook salmon telemetry studies (2002–2007) confirm the Salmon River is an important headwater spawning tributary (Stuby 2007; Table 14). Based on 7 years of telemetry data, we funded a weir on the Salmon Pitka Fork (Figure 5) beginning in 2015 (Blain et al. 2016) which was used as a tag recapture site for Chinook salmon mark–recapture studies conducted in 2015 and 2016.

Study results demonstrated that it is necessary to use both fish wheels and drift gillnets to capture the full range of Chinook salmon sizes. As a passive gear, fish wheels captured 28% of the tagged fish in this study. Although gillnets required greater effort, they were necessary in order to achieve adequate catches of Chinook salmon to meet the precision and accuracy levels of this study. Fish wheels are required to increase the overall size range of captured Chinook salmon. For example, the drift gillnets captured fish ranging from 536–975 mm and when fish wheel catches are included, the range of captured fish is 308–975 mm. Even with the use of both gear types, we were unable to capture a representative sample of fish lengths, and data from tagged fish should not be used to estimate the length distribution of Kuskokwim River Chinook salmon. However, recapture efforts were shown to be unbiased with respect to fish size.

To increase efficiency of future tagging studies that target adult Chinook salmon, the number of gillnet mesh sizes should be reduced to 1 mesh size. There was no difference in length composition of catches between 7.5 (μ = 760 mm; range: 536–960 mm) and 8.0 inch (μ = 789 mm; range: 555–975 mm) mesh gillnets (K–S Test; D = 0.142; p = 0.197). Additionally, the logistical difficulties of switching between mesh sizes, difficulties with net repairs that were encountered, and the inability to follow the mesh schedule reduced the overall productivity of first event sampling in this study. Based on these findings, only 7.5 inch mesh gillnets were used in Chinook salmon tagging studies conducted in 2015 and 2016.

Our efforts to validate our methods to determine final fate of tagged fish indicated that future studies can reduce the amount of aerial tracking surveys conducted. This study did not require determining the exact location of all radiotagged fish. Therefore, costly aerial surveys across all mainstem and tributary locations would have increased the project budget, but would not have yielded any further benefits to study objectives. This study has continued to demonstrate that a single end-of-season aerial survey of the mainstem Kuskokwim River, coupled with stationary telemetry tower data, yields accurate and cost-effective final fate determination (Liller et al. 2011). As a result, future mark–recapture studies utilizing telemetry methods should only use a single end-of-season survey along the mainstem Kuskokwim River, unless detailed spawning distribution is an explicit study objective.

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TABLES AND FIGURES

Table 1.–Monitored and unmonitored tributaries within each of the 8 subareas used to monitor migration and distribution of tagged Chinook salmon in 2014.

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

Table 2.–Chinook salmon abundance estimate worksheet, 2014.

Number marked (M′)[a]	Number examined (C′)[b]	Number recovered[c]	Adjusted recovered (R′)[d]	Marked fraction[e]	Abundance estimate	Lower 95% CI	Upper 95% CI
329	10,394	53	55	0.53%	61,255	49,021	80,985

[a] Includes radiotagged fish that passed upriver of rkm 294 from both the rkm 77 and rkm 270 tag sites.

[b] Examined at 4 weirs located on the Salmon (Aniak), George, Tatlawiksuk, and Kogrukluk (Holitna) Rivers. Includes estimates of missed passage for periods when weirs were inoperable.

[c] Detected by telemetry towers located at recapture weir locations.

[d] Based on estimate of radio tag loss rate.

[e] Percent of Chinook salmon that passed upriver weirs that were tagged.

Table 3.–Tagged and untagged Chinook salmon caught by day at the Kalskag tagging site with both fish wheels (FW) and drift gill nets (DGN), 2014.

	FW				DGN		Total	
	RB		LB					
Day	Tagged	Untagged	Tagged	Untagged	Tagged	Untagged	Tagged	Untagged
6/5/2014[a]	2	0	2	0	–	–	4	0
6/6/2014[a]	1	0	0	0	–	–	1	0
6/7/2014	0	0	0	0	4	0	4	0
6/8/2014	0	0	0	0	1	0	1	0
6/9/2014	0	0	0	0	3	0	3	0
6/10/2014	0	0	0	0	3	0	3	0
6/11/2014	0	0	0	0	2	1	2	1
6/12/2014	0	0	0	0	4	0	4	0
6/13/2014[b]	–	–	–	–	–	–	–	–
6/14/2014	0	0	0	0	3	0	3	0
6/15/2014	1	0	0	0	5	0	6	0
6/16/2014	3	0	0	0	12	0	15	0
6/17/2014	3	0	2	0	22	1	27	1
6/18/2014	4	1	1	0	13	1	18	2
6/19/2014	6	0	2	0	14	0	22	0
6/20/2014[b]	–	–	–	–	–	–	–	–
6/21/2014	1	0	0	1	18	0	19	1
6/22/2014	3	0	0	0	21	0	24	0
6/23/2014	7	0	2	1	17	0	26	1
6/24/2014	8	0	7	1	15	1	30	2
6/25/2014	3	1	4	0	7	0	14	1
6/26/2014	2	2	8	1	9	0	19	3
6/27/2014[b]	–	–	–	–	–	–	–	–
6/28/2014	1	1	5	3	5	0	11	4
6/29/2014	1	2	0	1	3	0	4	3
6/30/2014	0	0	0	0	2	0	2	0
7/1/2014	2	0	0	1	6	0	8	1
7/2/2014	2	1	0	2	4	0	6	3
7/3/2014	0	0	1	1	3	0	4	1
7/4/2014[b]	–	–	–	–	–	–	–	–
7/5/2014	0	0	1	0	5	0	6	0
7/6/2014	0	0	0	0	2	0	2	0
7/7/2014	0	0	0	0	1	0	1	0
7/8/2014	0	0	0	0	1	0	1	0
7/9/2014	0	0	0	0	3	0	3	0
7/10/2014	0	1	0	0	2	0	2	1
7/11/2014[b]	–	–	–	–	–	–	–	–
7/12/2014[c]	–	–	–	–	2	0	2	0
7/13/2014[c]	–	–	–	–	0	0	0	0
7/14/2014	0	0	1	0	0	0	1	0
7/15/2014	0	0	0	0	2	0	2	0
7/16/2014	0	0	0	0	3	1	3	1
7/17/2014	0	0	0	0	1	0	1	0
Total	50	9	36	12	218	5	304	26

[a] Days when drift gillnets (DGN) were not operational.
[b] Days off, when no fishing occurred.
[c] Days when fish wheels were not operational.

Table 4.–Fates assigned to Chinook salmon radiotagged in the Kuskokwim River, 2014.

Fate	Description	Count	Percentage
	Tagged fish used for abundance estimation [a]		
1	Migrated upstream of rkm 294, and located in the mainstem	13	4%
2	Migrated upstream of rkm 294, and located in an unmonitored tributary	257	74%
3	Moved upstream of Salmon River weir.	6	2%
4	Moved upstream of George River weir.	17	5%
5	Moved upstream of Kogrukluk River weir.	22	6%
6	Moved upstream of Tatlawiksuk River weir.	8	2%
7	Harvested upstream of rkm 270 tag site.	6	2%
	Subtotal	329	94%
	Tagged fish culled from experiment [b]		
8	Failed to migrate and remain above rkm 294.	18	5%
9	Harvested downstream of rkm 294.	2	1%
	Subtotal	20	6%
	Grand total	349	100%

[a] Includes 285 Chinook salmon tagged at the Kalskag site (rkm 270) plus an additional 44 Chinook salmon tagged downriver from Bethel (rkm 77) as part of a separate tagging study.

[b] Chinook salmon that were tagged at the Kalskag site, but not included as part of the marked population for abundance estimation.

Table 5.–Summary of radiotagged Chinook salmon used for abundance estimation, 2014.

Tag site	Number of Chinook salmon
Kalskag (rkm 270)	
Total tagged	304
Continued upriver past T01, (M′)	285
p_{up} [a]	0.94
LKRT (rkm 77) [b]	
Total tagged	45
Continued upriver past T01	44
p_{up} [a]	0.98
Combined	
Total tagged	349
Continued upriver past T01	329
p_{up} [a]	0.94

[a] The proportion radiotagged fish that passed and remained upstream of T01 located at Birch Tree Crossing (rkm 297).

[b] Occurrence of Chinook salmon radiotagged were monitored in a separate study conducted downriver near the mouth of the Kuskokwim River (Clark et al. 2014). The number of Chinook salmon from that study detected on T01 is presented and were evaluated for inclusion in the marked population for the purpose of abundance estimation.

Table 6.–Final fates of radiotagged Chinook salmon that migrated and remained upriver from rkm 294 and were used for abundance estimation, 2014.

Subarea	Total fish	Tributaries[a]	Harvested[b]	Mainstem[c]	Percent confirmed[d]
1	38	33	2	3	87.2%
2	11	9	0	2	–
3	24	21	0	3	–
4	114	113	1	0	94.7%
5	35	31	1	3	–
6	34	33	0	1	–
7	3	2	0	1	–
8	70	68	2	0	–
Total	329	310	6	13	

[a] 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.

[b] Harvested Chinook salmon were reported in the volunteer tag lottery.

[c] Chinook salmon were assigned a fate of mainstem if they were detected in the mainstem during the aerial tracking survey.

[d] A basic aerial survey was flown through the mainstem and major tributaries of the Holitna and Aniak in order to confirm the assumption that Chinook salmon in a subarea that were not found in the mainstem, a weir, or harvested should be assigned to a tributary.

Table 7.–Number of Chinook salmon observed at each upriver recapture site and considered part of capture (C′) and recapture (R′) populations for abundance estimation, 2014.

			Tag Loss			
Recapture location	Weir passage (C′)	Radio tag[a]	Inspected[b]	Counted[c]	Tag retention (p_{rt})[d]	Corrected recaptures (R′)[e]
Salmon River	1,757	6	3	3		
George River	2,993	17	11	10		
Tatlawiksuk River	1,904	8	5	5		
Kogrukluk River	3,740	22	16	16		
Total	10,394	53	35	34	97%	55

[a] Number of radiotagged Chinook salmon detected by tracking station.

[b] Number of T-bar anchor 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 8.–Chinook salmon tag recovery ratios by recovery site, 2014.

Recapture location	Distance (rkm)[a]	Total recaptures[b]	Total untagged	Ratio[c]	Chi-square X^2	df	*p*-value[d]
Salmon River	134	6	1,751	0.0034	0.98238		
George River	183	17	2,976	0.0057	0.19903		
Tatlawiksuk River	298	8	1,896	0.0042	0.30226		
Kogrukluk River	440	22	3,718	0.0059	0.45228		
Total		53	10,341	0.0051	1.93595	3	0.58581

[a] Distance from rkm 270 tagging site.
[b] Total number of tags past weirs.
[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.

Table 9.–Chinook salmon tag recovery ratios by weekly temporal strata, 2014.

Temporal strata[a]	Not recovered	Recovered	Ratio	Chi-square X^2	df	*p*-value [b]
6/5–6/19[c]	102	11	0.0973	2.56309		
6/21–6/26	113	19	0.1439	0.05593		
6/28–7/17[d]	43	16	0.2712	6.60157		
Total	258	46	0.1513	9.22059	2	0.00995

[a] Based on operational week, generally 6 days, Saturday to Thursday.
[b] The *p*-value criteria is based on an alpha of 0.05.
[c] Weeks 1 and 2 were pooled due to low expected tag recoveries.
[d] Weeks 4, 5, and 6 were pooled due to low expected tag recoveries.

Table 10.–Number of length samples from each recapture location used to test for size selective sampling bias, 2014.

Recapture location	Weir passage	Available samples	Percent sampled
Salmon River	1,757	143	8%
George River	2,993	231	8%
Tatlawiksuk River	1,904	187	10%
Kogrukluk River	3,740	230	6%
Total	10,394	791	8%

Note: Length samples from weir recapture locations were used to estimate length composition.

Table 11.–Results of tests for size selective sampling in the marked (M), captured (C), and recaptured (R) sample populations of 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	453	420	525						
			Max	975	1,003	950						
331	790	54	Mean	742	725	750	0.074	0.963	0.8759	<0.005	0.8734	<0.005

[a] Includes only Chinook salmon with a length measurement. Number of marked and recaptured Chinook salmon 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 Chinook salmon counted through the appropriate weir.

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

Table 12.–Percentage of radiotagged Chinook salmon that migrated to upriver tributaries, 2014.

Date	Operational week	% Upriver tributaries[a]
6/5–6/12	1	57.0%
6/14–6/19	2	45.0%
6/21–6/26	3	9.6%
6/28–7/3	4	8.5%
7/5–7/10	5	5.5%
7/10–7/17	6	0.0%

[a] Percent of weekly radio tags deployed at rkm 270 that migrated to tributaries above the Tatlawiksuk River.

Table 13.–Average capture date for Chinook salmon traveling to known subareas, 2014.

River area	Subarea	Total	Average deployment
Middle River	1	39	6/25
	2	11	6/21
	3	24	6/24
	4	114	6/24
	5	35	6/26
	6	34	6/20
	1-6		6/23
Upper River	7	3	6/16
	8	70	6/17
	7-8		6/17
	Total	330	6/21

Table 14.–Percentage of tagged Chinook salmon that traveled upstream of McGrath (rkm 753).

Year	Total above McGrath[a]	Percent to the Pitka Fork[b]	Percent to the Salmon River[c]
2003	25	56%	40%
2004	6	50%	50%
2005	16	38%	19%
2006	17	41%	29%
2007	16	38%	25%
2014	70	69%	26%

[a] Radiotagged Chinook salmon that migrated upstream of McGrath.

[b] The percent of radiotagged Chinook salmon upstream of McGrath that traveled to the Pitka Fork.

[c] The percent of radiotagged Chinook salmon upstream McGrath that traveled to the Salmon River tributary of the Pitka Fork.

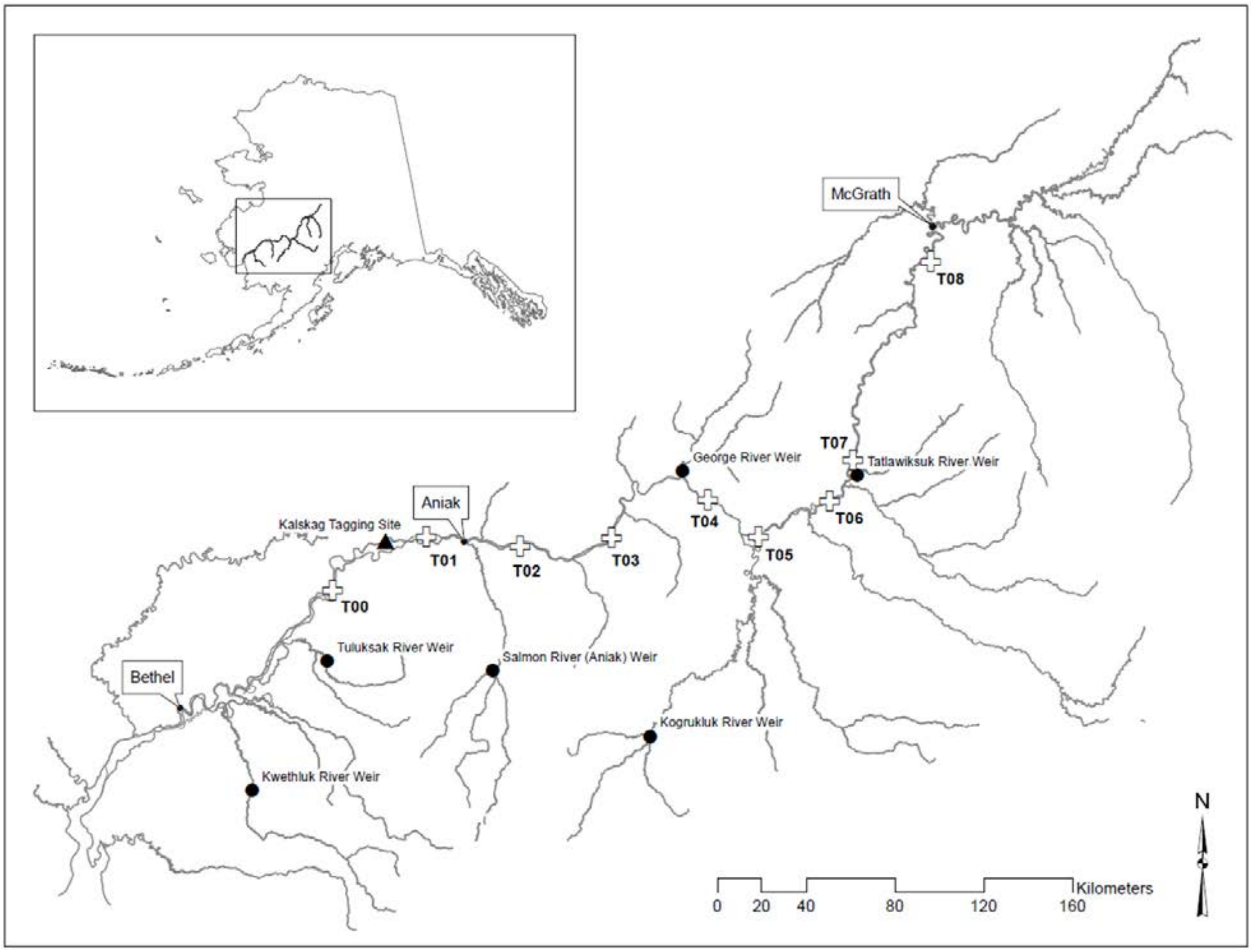


Figure 1.–Location of tagging site (black triangle), salmon escapement monitoring weirs (black dots), and telemetry tracking towers (white crosses).

Note: Salmon escapement monitoring weirs located upstream of T01 were all equipped with telemetry tracking towers and acted as recapture locations.

Figure 2.–Drift gillnet and fish wheel sites used to capture adult Chinook salmon in 2014.

Note: Gillnet site numbering does not follow any standard convention.

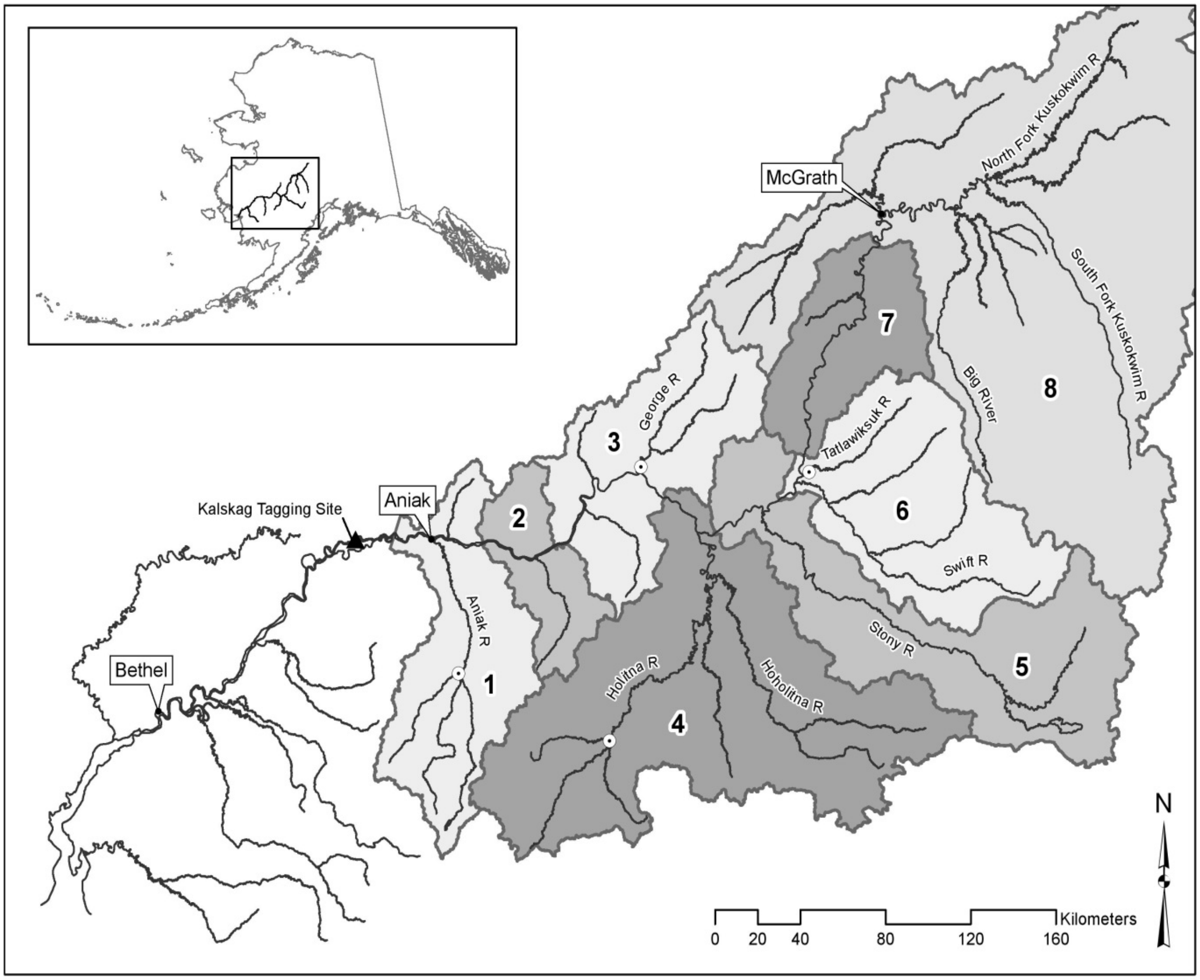


Figure 3.–Location of the 8 subareas used to monitor migration and distribution of tagged Chinook salmon in 2014.

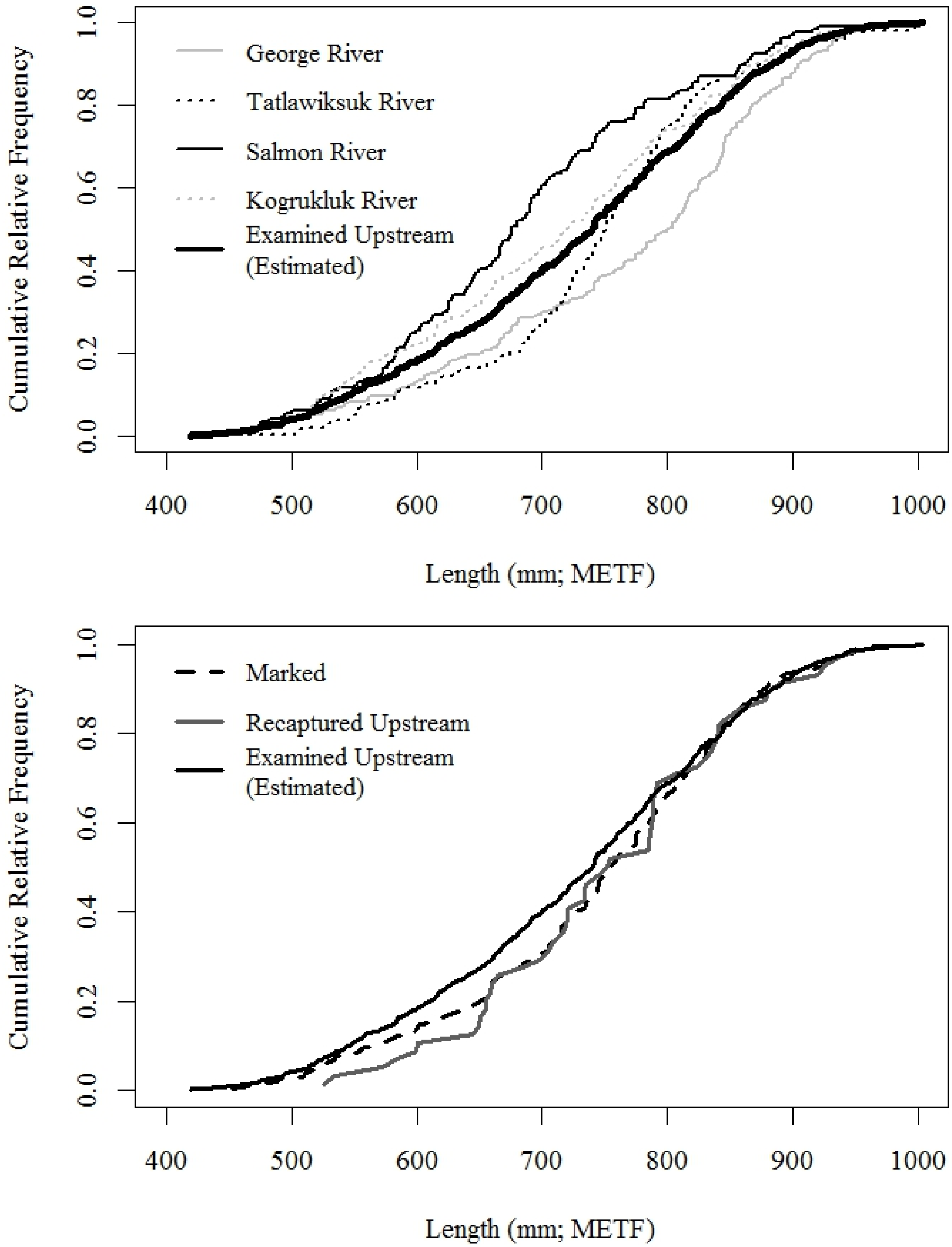


Figure 4.–Cumulative relative length frequencies of Chinook salmon sampled at upstream recovery projects (top), at the rkm 270 tag site (marked; bottom) and recovered upstream (recaptured; bottom). The estimated length composition for the second sampling event (examined upstream) is presented in both panels.

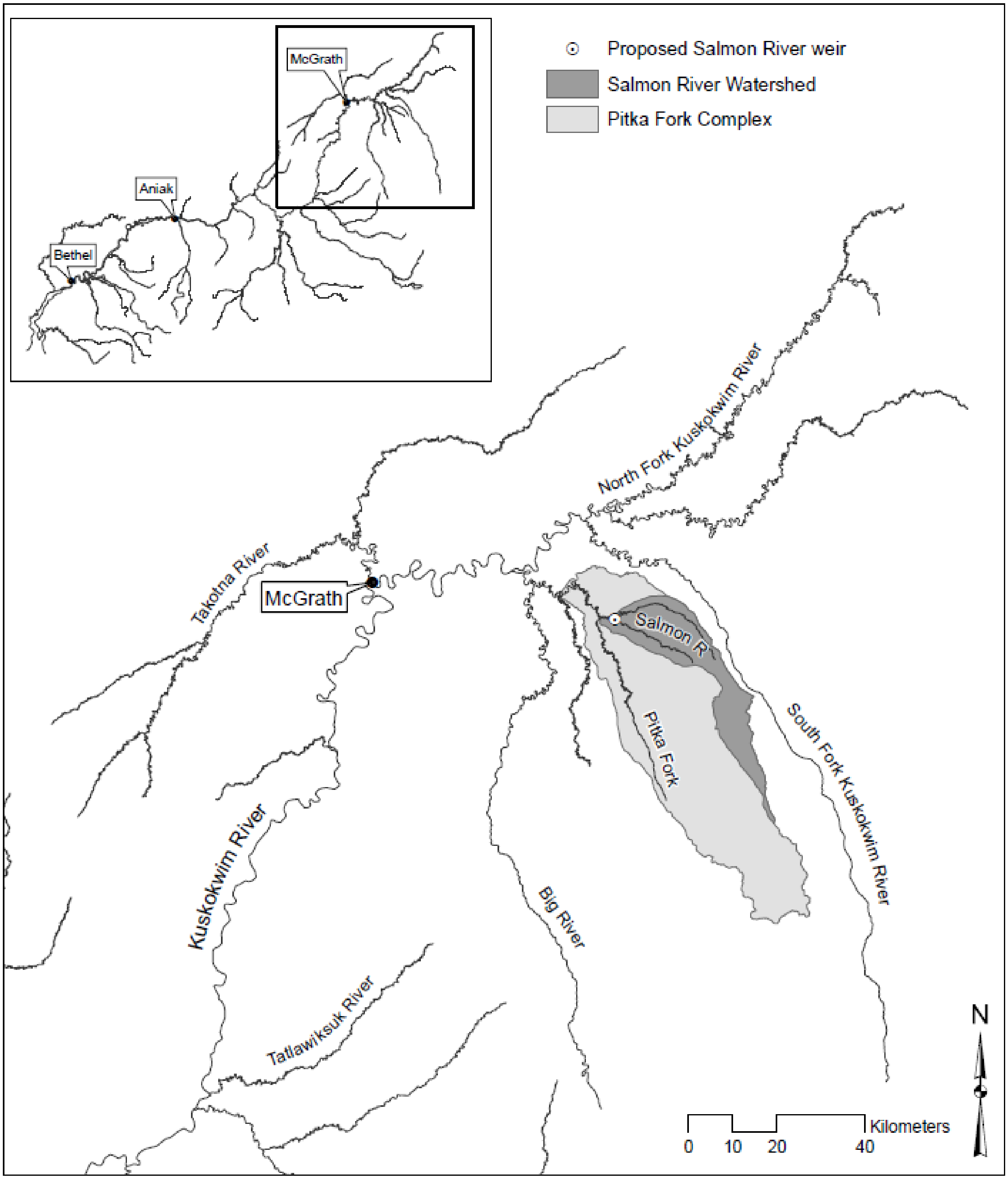


Figure 5.–Salmon Pitka Fork weir site.

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 3 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 3 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 A2.–Detection of size and/or sex selective sampling (from Stuby 2007).

Size selective sampling: The Kolmogorov-Smirnov 2 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 2 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 2 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:

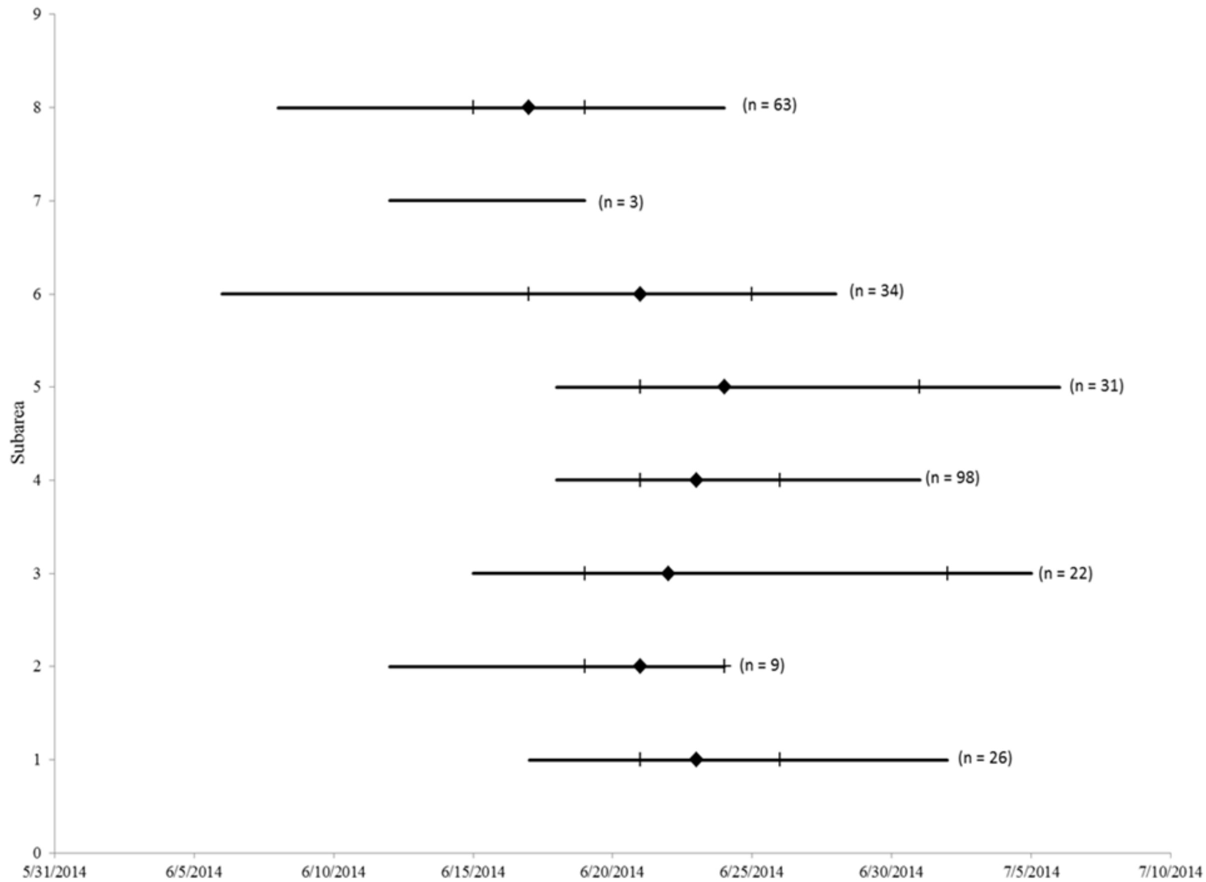
$$\hat{p}_k = \sum_{i=1}^{j} \frac{\hat{N}_i}{\hat{N}_\Sigma} \hat{p}_{ik} \text{ ; and,} \tag{1}$$

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

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.

APPENDIX B: STOCK-SPECIFIC ENTRY TIMINING



Appendix B1.–Chinook salmon subarea-specific tagging dates, Kuskokwim River, 2014.

Note: Median, interquartile range, central 80% of tagging dates, and sample sizes (*n*) are shown. The tagging site was located at river kilometer 270.