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2023 Kuskokwim River Chinook Salmon Run Reconstruction and 2024 Forecast

by

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Alaska Department of Fish and Game Division of Commercial Fisheries

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

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ABSTRACT

A maximum likelihood model was used to estimate the 2023 drainagewide run size and escapement of Kuskokwim River Chinook salmon (*Oncorhynchus tshawytscha*). The total run was estimated to be 134,007 (95% CI: 106,870–168,036) fish, and escapement was estimated to be 96,630 (95% CI: 69,493–130,659) fish. Model estimates were informed by direct observations of the 2023 escapement (2 weirs and 8 aerial surveys) and harvest, combined with historical observations of escapement (up to 6 weirs and 14 aerial surveys), harvest, test fishery, and mark–recapture data dating back to 1976. Model results are adequate to draw broad conclusions about the 2023 run and escapement. The 2023 total run of Chinook salmon was below the 1976–2022 average of 210,011 fish. The drainagewide sustainable escapement goal of 65,000–120,000 was met in 2023. The 2024 Kuskokwim River Chinook salmon forecast is for a range of 108,000–160,000 fish.

Keywords: Chinook salmon *Oncorhynchus tshawytscha*, run reconstruction model, total run, total escapement, forecast, Kuskokwim River

INTRODUCTION

This report describes methods used to estimate the drainagewide run size and escapement of Chinook salmon (*Oncorhynchus tshawytscha*) that returned to the Kuskokwim River in 2023. Because it is impossible to count all Chinook salmon that return to the Kuskokwim River, estimates of annual abundance and escapement were made using a maximum likelihood model. The model (Bue et al. 2012), with subsequent revisions (Liller et al. 2018), is an extension of the approach presented by Shotwell and Adkison (2004) and was specifically developed for use in data-limited situations. The model combines information about subsistence harvest, commercial catch and effort, sport harvest, test fishery harvest and catch per unit effort (CPUE) at Bethel, estimates of total inriver abundance, counts of salmon at 6 weirs, and peak aerial survey counts from 14 tributaries spread throughout the Kuskokwim River drainage (Figure 1). Each of these data sources provides an index of total abundance, and some data are more informative than others. The model provides an approach to combine and weight available information about Kuskokwim River Chinook salmon abundance to arrive at a scientifically defensible estimate of total run size and escapement. Estimates produced by the model represent the most likely run size given the observed data.

The run reconstruction model has become an important tool to guide the sustainable management of the Kuskokwim River Chinook salmon fishery. Model results from Bue et al. (2012) contributed to a spawner-recruit analysis used to establish a drainagewide escapement goal of 65,000–120,000 Kuskokwim River Chinook salmon (Hamazaki et al. 2012). The established escapement goal was reviewed in 2018 (Liller and Savereide 2018) and again in 2021 (Liller and Savereide 2022), and it was determined that the existing goal range was appropriate for this stock. The run reconstruction model has been used annually since 2013 as a postseason tool to determine if the drainagewide escapement goal was achieved. Model results have been used since 2012 to inform preseason management strategies to achieve escapement goals. Since 2014, a preseason forecast range has been developed based on the prior year’s run size, as determined from the run reconstruction model.

The run reconstruction model has implications beyond the management of Kuskokwim River Chinook salmon fisheries. Since 2016, the Alaska Department of Fish and Game (ADF&G) has been required to provide the North Pacific Fishery Management Council (NPFMC) with a preliminary total run estimate of Kuskokwim River Chinook salmon abundance no later than October 1 of each year. The preliminary run abundance estimate is 1 component of a 3-system index (Upper Yukon, Unalakleet, and Kuskokwim Rivers) of Western Alaska Chinook salmon abundance used by NPFMC to guide Chinook salmon bycatch thresholds in the Bering Sea pollock trawl fishery. The preliminary 2023 3-system abundance estimate was provided to the NPFMC on September 11, 2023 (Appendix A), before final escapement and subsistence harvest estimates were available. The preliminary Kuskokwim River abundance estimate was based on model output from the run reconstruction model using preliminary escapement estimates and a prediction of total subsistence harvest. The final total run estimate was expected to change slightly from what was provided to NPFMC.

Given the significance of the run reconstruction model, it is important that the model is reviewed regularly and any changes communicated in a timely and transparent manner. The model underwent a multi-year interagency peer review. The details of that review process and a description of the model changes that resulted from that review are documented in Liller et al. (2018) and Schindler et al. (2019). ADF&G adopted the revised model in 2018 (Smith 2019), and NPFMC also approved its use in the 3-system index[1]. There have been no changes to the run reconstruction model since that review.

OBJECTIVE

The project objective was to estimate the total run size and escapement of Kuskokwim River Chinook salmon in 2023.

METHODS

MODEL OVERVIEW

Drainagewide escapement (E_y) of Kuskokwim River Chinook salmon for year (y) is equal to the drainagewide run size (N_y) minus harvest (C_y),

$$E_y = N_y - C_y, \tag{1}$$

where C_y is the sum of harvest by subsistence, commercial, sport, and test fisheries. Each part of Equation 1 was known to different degrees. Total annual escapement was indexed by count data from weirs and aerial surveys of tributaries located throughout the lower, middle, and upper portions of the Kuskokwim River (Figure 1). Estimates of total abundance for scaling the model were derived from mark–recapture, escapement, and harvest data. Total abundance estimates were available for the years 2003–2007 and 2014–2017 (Liller et al. 2018). Total annual harvests from commercial fish tickets and test fisheries were known to a high degree of confidence. Subsistence harvest was estimated from extensive postseason surveys, and the estimates were incorporated into the model without error (Shelden et al. 2016; Dave Koster, Research Analyst, Division of Subsistence, ADF&G, Anchorage; personal communication). Estimates of sport fish harvest were less precise, but the effect of a lower level of precision was assumed to be negligible because of the small annual sport harvest.

The total run and escapement of Kuskokwim River Chinook salmon were estimated using a maximum likelihood model (Appendix B) developed for data-limited situations, with subsequent revisions to the model configuration (summarized in Liller et al. 2018). The model simultaneously combined abundance data from multiple sources to estimate a time series of the most likely estimates of total annual run abundance. The methodology was divided into 3 components to

[1] NORTH PACIFIC FISHERY MANAGEMENT COUNCIL - File #: ID 18-064 (legistar.com)

simplify the description of the estimation process and was based on the type of data used in the model: (1) escapement, (2) commercial catch and effort, and (3) direct estimates of total run size for model scaling.

ESCAPEMENT COUNTS

Assuming the annual escapement of Chinook salmon returning to each tributary and observed by a weir or aerial survey is a constant fraction of drainagewide escapement (E_y), the expected escapement ($\hat{e}$) in year (y) to tributary (i) observed by method (j: weir or aerial) is:

$$\hat{e}_{ijy}=E_y/k_{ij}, \quad (2)$$

where k_{ij} is a scaling parameter estimated by the model. The assumption of constant proportionality is tenuous and not supported by the tributary escapement data, but the revised model performance has been shown to be robust to violations of this assumption (Schindler et al. 2018).

COMMERCIAL CATCH AND EFFORT

Assuming commercial CPUE each week is proportional to the drainagewide run migrating during that week, the expected commercial catch CPUE ($\widehat{CPUE}_{wky}$) in week (w) with net configuration (k) is:

$$\widehat{CPUE}_{wky}=c_{wky}/f_{wky} = q_k\left(p_{wy}N_y\right), \quad (3)$$

where $\widehat{CPUE}_{wky}$ is the expected commercial catch CPUE at week (w) of net configuration (k), c_{wky} is the commercial catch at week (w) of net configuration (k), f_{wky} is the commercial efforts at week (w) of net configuration (k), p_{wy} is the proportion of Chinook salmon available at week (w) observed at Bethel test fishery, and q_k is the catchability coefficient of net configurations (k) (i.e., unrestricted, restricted).

Summing for all weeks and adjusting by the proportion of fish migrating through the harvest area during the weeks when fisheries occurred, the expected annual cumulative CPUE ($\widehat{CPUE}_{ky}$) is:

$$\widehat{CPUE}_{ky}=\frac{\sum_w(c_{wky}/f_{wky})}{\sum_w p_{wy}} = q_k N_y. \quad (4)$$

The proportion of Chinook salmon available for harvest each week and observed at the Bethel test fishery included weeks 3–10. Data from weeks 8–10 were combined. Commercial catch and effort by week and net configuration included weeks 3–9. Data from weeks 8 and 9 were combined. Run timing from 1976–1983 was estimated using the average run timing from 1984–2023.

MODEL SCALING

Direct estimates of total run size ($\widehat{N}_y$) from 2003–2007 and 2014–2017 were derived using a combination of mark–recapture data, escapement estimates, extrapolation of escapement values to unmonitored areas, and harvests. Those estimates of the total run and associated uncertainties were used to scale the run reconstruction model. Measurement error associated with the model scalars was represented using the estimates of variance presented by Liller et al. (2018).

LIKELIHOOD MODEL

Assuming all observations follow lognormal distributions, negative log-likelihoods with omissions of constants were constructed as:

$$L(\theta|data) = \begin{array}{l} \text{Escapement Counts} \\ +\sum_y \sum_i \sum_j \left(ln(\sigma_j) + 0.5 \left(\frac{ln(\hat{e}_{ijy}) - ln(e_{ijy})}{\sigma_j} \right)^2 \right) \\ \text{Adjusted Commercial CPUE} \\ +\sum_y \sum_k \left(ln(\sigma_k) + 0.5 \left(\frac{ln(\widehat{CPUE}_{ky}) - ln(CPUE_{ky})}{\sigma_k} \right)^2 \right) \\ \text{Drainagewide Run} \\ +\sum_y \left(0.5 \left(\frac{ln(\hat{N}_y) - ln(N_y)}{\sigma_y} \right)^2 \right), \end{array} \tag{5}$$

where $\sigma_j^2 = ln(CV_j^2+1)$, $\sigma_k^2 = ln(CV_k^2+1)$, and $\sigma_y^2 = ln(CV_y^2+1)$, CV_j and CV_k were estimated from the model, and CV_y was the observed CV of drainagewide run sizes of 2003–2007 and 2014–2017.

The model was written in AD Model Builder and run using the computing environment R (Appendix B; Fournier et al. 2012; R Core Team 2019).

MODEL INPUTS

Numerous data sources were available to inform the model and estimate the total run and escapement in 2023. Model estimates in 2023 were informed by independent scalers using total run estimates from 2003–2007 and 2014–2017, which corresponded to years of relatively high and low run abundance (Appendix C). The model was also informed by commercial, subsistence, sport, and test fishery harvest and escapement at 6 weirs and 14 aerial surveys from 1979–2023 (Appendix C). Finally, the model was informed by the proportion of total annual Chinook salmon run in District W-1 by week, as estimated using data collected from the Bethel test fishery from 1984–2023 and harvest and effort, by week, for Kuskokwim River District W-1 from 1976–2023 (Appendix C). All model inputs were the best available data at the time of reporting and have been reviewed and finalized since the release of the preliminary run reconstruction estimate to NPFMC in September 2023.

The subsistence harvest estimate used to produce the preliminary run reconstruction estimate in September 2023 has changed. The preliminary run estimate relied on a best guess of 26,562 Chinook salmon harvested for subsistence purposes. Since that time, postseason subsistence harvest surveys have been completed, and the harvest was estimated to be 37,091 (95% CI 32,667–41,514; Dave Koster, Division of Subsistence, ADF&G; personal communication). The revised subsistence harvest estimate was used in this final run reconstruction analysis.

RESULTS AND DISCUSSION

The historical run reconstruction model was informed by 6 weirs and 14 aerial survey index locations (Table 1). Weirs located on the Tuluksak and Tatlawiksuk rivers have not operated since

2017. In 2023, 4 of 6 weirs operated and 8 of 14 aerial surveys were successfully flown. In 2023, weirs were operated on the Kwethluk, George, Kogrukluk, and Takotna rivers; however, total passage was not estimated at the Kwethluk and Kogrukluk river weirs due to extended periods of missed passage. Of the 6 aerial surveys that were unsuccessful in 2023, 4 were not flown due to inclement weather and 2 were flown but received poor survey ratings and were not included in the analysis. Of the 8 successful aerial surveys, 6 (75%) had good ratings and 2 (25%) had fair ratings.

Harvest data came from subsistence and test fishery catches. The 2023 preliminary subsistence harvest of 37,091 (95% CI 32,667–41,514) Chinook salmon is unlikely to change substantially and was below the amounts reasonably necessary for subsistence uses (ANS: 67,200–109,800) as defined by the Alaska Board of Fisheries (5 AAC 01.286). A total of 286 Chinook salmon were caught in the Bethel test fishery. No commercial or sport fish harvest of Kuskokwim River Chinook salmon occurred during the 2023 season.

Escapement estimates and observations during 2023 indicated that the Chinook salmon escapement throughout the Kuskokwim River was generally less than in prior years. In 2023, 7 out of 10 projects reported lower escapements than the 1976–2022 averages (Table 1). There were 4 tributaries with established escapement goals in 2023 (Liller and Savereide 2022). Of those, only the escapement goals on the George and Salmon (Pitka Fork) rivers were assessed, and both were met. The tributary escapement goals on the Kwethluk and Kogrukluk rivers were not assessed because of too much missed passage during the 2023 season.

MODEL RESULTS

The 2023 Kuskokwim River Chinook salmon drainagewide run was an estimated 134,007 (95% CI: 106,870–168,036) fish (Table 2; Figure 2). Based on the 2023 model run, the total run in 2023 was 36% less than the 1976–2022 average of 210,011 Chinook salmon. CV for the 2023 total run was estimated to be 12%, which was larger than the 1976–2022 average of 10% (range: 5–24%; Figure 3). The root mean square error was smaller for weirs compared to aerial surveys, which indicated the model fit weir data better than aerial survey data (Figure 4).

The 2023 Kuskokwim River Chinook salmon drainagewide escapement was an estimated 96,630 (95% CI: 69,493–130,659) fish (Table 2). Based on the 2023 model run, the total escapement in 2023 was 25% less than the 1976–2022 average of 128,918 Chinook salmon. The total escapement in 2023 was greater than 17 of 47 (36%) prior years. Acknowledging that uncertainty in the drainagewide escapement was relatively high, the 95% confidence range of 69,493–130,659 fish provided evidence that the drainagewide escapement goal of 65,000–120,000 fish was met (Table 2; Figure 2).

The run reconstruction model produces updated total run and escapement estimates for all years since 1976 each time the model is updated with new information. Results from prior year model runs represented the best available estimates based on information available at that time. The 2023 model run represents the most informed historical time series of total run and escapement and supersedes previous estimates. Estimates of total annual abundance from 1976–2022, generated by the 2023 model run, were compared against the 2022 model run estimates reported by Larson 2023 (Table 2). The difference between total annual run and escapement estimates changed by an average of 0.18% and 0.35%, respectively, across all years (1976–2022). The long-term (1976–2022) differences for both total run and escapement differed by an average of 390 fish between the 2023 and 2022 model runs. The absolute difference between pairs of annual total run estimates ranged between 0–3,348 fish (average = 686 fish).

UNCERTAINTY IN 2023 MODEL ESTIMATES

There was a relatively high level of uncertainty associated with the 2023 model run (Figure 3). Uncertainty about any individual year model estimate is generally related to the number of index projects that operated in that year and the similarity in the information about each project's total run. The number of index projects operated in 2023 (10 total projects) was at the forty-third percentile (median 11; range: 2–20) over the 47 years (1976–2022) of available data, which would suggest a moderate amount of information to update the model. However, each project provided a different picture of the total run. The model is specifically designed to accommodate "conflicting" data from a range of index projects; however, smaller differences among projects result in less uncertainty about the actual size of the total run and escapement. To illustrate this, the entire drainagewide escapement was estimated using data from 1 escapement project at a time (Figure 5). In 2023, estimates of drainagewide Chinook salmon escapements derived from individual weir projects were 77,000–98,000 fish, whereas estimates derived from individual aerial surveys were 19,000–340,000 fish (Table 3; Figure 5).

The sensitivity of the 2023 model results to parameter starting values was evaluated. Run estimates were compared across a range of 100 starting values for all model parameters independently (Table 4). The average observed difference between annual run estimates was less than 1 fish. Results for all parameter starting values confirmed the 2023 model run was not sensitive to starting values, and the total run estimates presented represent the best-fit model.

The sensitivity of model results to 2023 escapement data was explored (Figure 6). Specifically, the model was run using only weir data, only aerial survey data, with headwaters projects removed (i.e., Takotna River weir, Salmon (Pitka) Fork aerial, Upper Pitka Fork aerial, and Bear Creek aerial), and with removal of a single escapement project at a time. All point estimates fell within the 95% confidence interval of the base model. Confidence intervals overlapped in all scenarios. However, there was a difference between estimates of total run when the model was informed using only weir escapement data, only aerial escapement data, and escapement data with headwaters projects removed (Figure 6). In aggregate, weir data suggests a total run of about 124,000 fish, aerial data suggests a total run of about 144,000 fish. When headwaters data (1 weir; 3 aerial surveys) were removed from the model, the total run estimate was about 162,000 fish. These comparisons are not meant to lend more or less credibility to the specific escapement data source, but rather show the importance of having a comprehensive assessment program to inform the run reconstruction model.

2023 RUN RECONSTRUCTION MODEL CONCLUSIONS

- The total run of Kuskokwim River Chinook salmon was estimated to be 134,007 (95% CI: 106,870–168,036) fish.
- Total run abundance was below the 1976–2022 average of 210,011 fish. The midpoint estimate suggests the 2023 total run size was within the range of run sizes necessary to meet at least the lower bound of the drainagewide escapement goal (65,000–120,000) and support at least the lower bound of ANS (67,200–109,800) as defined by the Alaska Board of Fisheries (5 AAC 01.2086). For example, a run of at least 132,200 fish would be needed to meet the lower bounds of the drainagewide escapement goal and ANS.
- The total escapement of Kuskokwim River Chinook salmon was estimated to be 96,630 (95% CI: 69,493–130,659) fish and suggests the drainagewide sustainable escapement goal of 65,000–120,000 was met or exceeded.

2024 CHINOOK SALMON RUN FORECAST

The 2024 Kuskokwim River Chinook salmon forecast is for a range of 108,000–160,000 fish. The forecast range is equal to ±19% of the 2023 total run, as presented in this report. Uncertainty in the forecast (i.e., ±19%) is based on the 2017–2023 (7-year) average percent error between forecasted and actual run estimates. Interestingly, when using data from 1976–2023, the average percent error between forecasted and actual run estimates (22%) is similar to the 7-year average percent error.

The forecast range is not based on probability and provides no insight into the most probable run size within the forecasted range. The value of the forecast is in preseason planning. For example, managers and stakeholders may choose to put equal effort into planning for all run-size scenarios within the forecast range or focus their planning on a subset of the forecast. This forecast can be used alongside probability-based forecasts to identify run sizes with the highest probability to guide preseason planning.

Probability-based forecast methods like the *P*-star model[2] developed by Staton and Catalano (2019) have been explored for Kuskokwim River Chinook salmon. That model uses the same prior year method for defining the mean of the forecast range but uses the entire time series to describe forecast uncertainty. That model assumes uncertainty around the forecast expectation is lognormally distributed. A bias-corrected lognormal distribution is used to ensure the mean of the distribution is the same as the previous year's run size. Forecast uncertainty is quantified by calculating the errors the previous-year method would have made, as though they were lognormal random variables, and calculating their standard deviation. The method described by Staton and Catalano (2019) produces forecast ranges based on any statistical confidence interval that is desired and can be used to describe the probability of different run sizes occurring. Probability-based forecasts necessitate proper interpretation and context to be useful for focusing preseason management planning discussions.

Probability-based methods like the *P*-star model can provide context to understand better the 2024 forecast produced by ADF&G and can be used to make explicit predictions about the 2024 run before the availability of inseason assessment data. The ADF&G 2024 forecast (based on the 7-year average percent error) represents approximately the central 50% of probable run size predictions identified through the *P*-star model. There is a 25% chance the 2023 run size will return smaller than 107,000 and a 25% chance the run will return larger than 156,000 (Table 5). The *P*-star model indicated that there is a 90% chance the 2023 run size will be less than 184,000, which is less than the average run size (1976–2022 average run size is 210,011 fish). Stated more simply, there is a high probability that the 2024 run will be smaller than average. However, the *P*-star model provides considerable evidence that the 2024 run size will be large enough to meet the drainagewide escapement goal and allow some harvest. There is a 99% chance the 2024 run size will exceed 67,000, which is a run size just above the lower bound (65,000) of the escapement goal. There is a 60% chance that the run will return larger than 120,000, which is a run size at the upper bound (120,000) of the drainagewide escapement goal[3] (Table 5).

Preseason expectations of Chinook salmon harvestable surplus in 2024 are highly uncertain. Simple subtraction of the drainagewide escapement goal (65,000–120,000) from the ADF&G

[2] https://bstaton.shinyapps.io/BayesTool

[3] Percentages presented in this text are rounded.

forecast (108,000–160,000) would suggest a harvest outlook anywhere between 0–95,000 fish. However, run size probabilities from the *P*-star model provide considerable evidence that large run sizes suitable for supporting large harvests have a low chance of occurring in 2024. Actual harvest opportunities will be determined inseason based on run size assessments and expectations of achieving the drainagewide escapement goal range (65,000–120,000) and tributary escapement goals.

Successive years of achieving the drainagewide escapement goal provide some support for the notion that the 2024 Chinook salmon run will be large enough to meet escapement needs and provide for some harvest. The dominant brood years contributing to the 2024 run will be 2018–2020. These brood years will return fish that are age-4 (2020 brood), age-5 (2019 brood), and age-6 (2018 brood). The actual number of each age class that will return in 2024 is not known with certainty, but the drainagewide escapement goal was met or exceeded in each of the contributing brood years. Drainagewide escapement was estimated to be 109,632 fish in 2018, 181,267 fish in 2019, and 88,648 fish in 2020 (Table 6). While the drainagewide escapement goal was designed to maximize the probability that future run sizes are large enough to meet escapement and harvest needs, shifts in stock productivity have occurred.

Stock productivity trends should be considered when using this forecast to plan preseason management of the 2024 Chinook salmon run. Kuskokwim River Chinook salmon productivity, measured as recruits per spawner, has fluctuated through time (Figure 7). Relatively high productivity occurred during brood years 1982–1991 and again during brood years 1999–2001. Brood years 2004–2009 experienced low productivity (<1 recruit per spawner). Since that time, productivity has increased, and the 2011–2013 brood years produced, on average, 3 recruits per spawner. However, the most recent complete brood year (2016) produced about 1 recruit per spawner (Table 6; Figure 7). As such, the number of fish returning from escapements within the escapement goal range is less than the original goal analysis predicted.

FUTURE MODEL CONSIDERATIONS

ADMB will not be supported after 2024 and a new platform will be required to update the run reconstruction model in future years. Anticipating a shutdown of the ADMB Foundation, transition of the model software from ADMB to Template Model Builder (TMB) (Kristensen et al. 2016) has been initiated (Appendix D). To determine the impact of changes to the coding platform, ADF&G ran the 2023 model using both ADMB and TMB. TMB model estimates were identical with ADMB (Appendices D1 and D2). Given this finding, the model will be run using TMB as early as 2024.

Improvements to the Chinook salmon run reconstruction model are being explored. Since implementation of the model, a sonar and two additional weirs (Salmon (Aniak) and Salmon (Pitka Fork) river weirs) were installed. The sonar has provided total salmon passage data at a site approximately 20 km upriver from Bethel since 2018. The run reconstruction model would benefit from including those additional 3 datasets.

Further, the model may benefit from time-varying scaling parameters that accommodate changes in management or spatial shifts in production that could affect the proportion of the total escapement observed at individual assessment locations. For example, headwaters stocks tend to have earlier run timing than middle river stocks (Clark and Smith 2019). Managers have heavily restricted fishing during the early portion of the Chinook salmon run since 2014, which has generally led to lower exploitation and higher escapements for headwater stocks than were observed before 2014. As a result, the observed escapement at headwater assessment projects has tended to be higher than what the run reconstruction model predicted. This may be addressed by incorporating a time-variant scaler into the model.

ADF&G will consider options to implement the above model changes as early as 2024.

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TABLES AND FIGURES

Table 1.–Historical and recent year observations of Kuskokwim River Chinook salmon abundance used to inform the run reconstruction model.

Method	Location	Number of years of data (1976–2023)	Historical average (1976–2022)	10-yr average (2013–2022)	5-yr average (2018–2022)	2022	2023
Weir	Kwethluk	16	9,268	6,775	7,657	6,808	–
	Tuluksak	21	985	558	–	–	–
	George	25	3,515	2,925	3,361	4,318	2,834
	Kogrukluk	36	9,519	6,387	7,009	5,837	–
	Tatlawiksuk	18	1,692	1,903	–	–	–
	Takotna	22	402	310	360	–	233
Aerial survey	Kwethluk	12	2,061	943	721	–	–
	Kisaralik	27	1,082	650	666	–	–
	Tuluksak	11	421	83	–	–	–
	Salmon (Aniak)	34	784	506	554	–	–
	Kipchuk	28	1,018	922	1,063	–	–
	Aniak	26	2,576	1,773	1,986	–	628
	Holokuk	20	333	197	327	–	660
	Oskawalik	25	285	205	404	–	373
	Holitna	24	1,483	891	1,070	–	–
	Cheeneetnuk	28	689	526	776	–	645
	Gagaryah	28	486	370	599	–	449
	Pitka	16	242	299	320	–	28
	Bear	22	262	425	471	–	326
	Salmon (Pitka)	35	1,065	1,385	1,489	–	671
Harvest	Subsistence	48	62,974	28,010	31,710	34,134	37,091
	Commercial	48	17,124	22	0	0	0
	Sport	47	402	0	0	0	0
	Test fishery	48	602	414	430	381	286

Note: Not all projects operated in all years. En dash represents the project did not operate or a historical average could not be calculated due to insufficient data.

Table 2.–Annual drainagewide run and escapement of Kuskokwim River Chinook salmon from the 2023 run reconstruction model.

	2023 model run				2023 model run			
Year	Total run estimate	Lower 95% CI	Upper 95% CI	Previously published total run estimate[a]	Total esc. estimate	Lower 95% CI	Upper 95% CI	Previously published total esc. estimate[a]
1976	200,895	157,411	256,392	202,841	110,348	66,864	165,845	112,294
1977	324,350	229,213	458,977	325,406	230,643	135,506	365,270	231,699
1978	239,407	190,937	300,182	239,077	155,935	107,465	216,710	155,605
1979	241,342	176,590	329,837	239,666	145,040	80,288	233,535	143,364
1980	364,019	222,558	595,394	364,437	267,051	125,590	498,426	267,469
1981	315,401	231,953	428,870	313,173	205,002	121,554	318,471	202,774
1982	143,390	125,438	163,910	143,417	36,389	18,437	56,909	36,416
1983	148,677	121,765	181,537	148,079	66,532	39,620	99,392	65,934
1984	172,646	136,952	217,643	173,487	83,470	47,776	128,467	84,311
1985	145,134	118,856	177,221	144,881	63,207	36,929	95,294	62,954
1986	124,809	93,509	166,586	123,608	54,197	22,897	95,974	52,996
1987	181,983	145,424	227,734	182,484	77,740	41,181	123,491	78,241
1988	209,991	181,504	242,949	208,937	82,228	53,741	115,186	81,174
1989	214,877	176,922	260,973	214,002	88,724	50,769	134,820	87,849
1990	271,151	232,843	315,761	270,020	106,965	68,657	151,575	105,834
1991	216,726	184,058	255,193	215,900	103,578	70,910	142,045	102,752
1992	261,231	227,085	300,511	261,053	130,131	95,985	169,411	129,953
1993	278,934	229,674	338,759	277,856	179,267	130,007	239,092	178,189
1994	409,446	314,538	532,990	406,098	287,342	192,434	410,886	283,994
1995	374,291	303,058	462,269	373,831	239,562	168,329	327,540	239,102
1996	307,097	245,124	384,739	306,070	201,522	139,549	279,164	200,495
1997	300,800	247,096	366,175	298,489	209,466	155,762	274,841	207,155
1998	190,779	146,262	248,845	189,600	90,807	46,290	148,873	89,628
1999	161,746	132,585	197,320	161,598	83,153	53,992	118,727	83,005
2000	129,683	114,977	146,271	128,739	61,474	46,768	78,062	60,530
2001	207,416	176,707	243,461	206,792	128,776	98,067	164,821	128,152
2002	224,296	194,783	258,280	224,504	142,448	112,935	176,432	142,656
2003	232,759	208,736	259,548	232,722	164,054	140,031	190,843	164,017
2004	364,230	322,818	410,954	364,208	263,589	222,177	310,313	263,567
2005	326,068	294,224	361,357	326,453	234,292	202,448	269,581	234,677
2006	320,091	285,119	359,352	320,091	225,706	190,734	264,967	225,706
2007	245,306	222,602	270,324	244,891	148,446	125,742	173,464	148,031
2008	213,587	189,574	240,642	213,331	114,682	90,669	141,737	114,426
2009	188,981	166,499	214,498	189,192	101,047	78,565	126,564	101,258

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Table 2.–Page 2 of 2.

Year	2023 model run Total run estimate	Lower 95% CI	Upper 95% CI	Previously published total run estimate[a]	2023 model run Total esc. estimate	Lower 95% CI	Upper 95% CI	Previously published total esc. estimate[a]
2010	113,487	103,763	124,121	113,266	42,823	33,099	53,457	42,602
2011	116,143	104,791	128,726	115,713	52,114	40,762	64,697	51,684
2012	81,368	67,303	98,374	80,837	57,876	43,811	74,882	57,345
2013	84,341	76,200	93,352	84,404	36,853	28,712	45,864	36,916
2014	84,695	73,071	98,168	85,035	72,929	61,305	86,402	73,269
2015	125,759	111,185	142,242	125,745	109,155	94,581	125,638	109,141
2016	131,638	114,833	150,902	131,446	100,420	83,615	119,684	100,228
2017	131,634	113,247	153,006	131,358	114,964	96,577	136,336	114,688
2018	132,363	105,973	165,324	132,532	109,632	83,242	142,593	109,801
2019	219,771	179,142	269,614	220,554	181,267	140,638	231,110	182,050
2020	124,849	103,606	150,448	124,322	88,648	67,405	114,247	88,121
2021	130,195	97,814	173,296	129,556	101,444	69,063	144,545	100,805
2022	142,740	108,064	188,543	142,495	108,225	73,549	154,028	107,980
2023	134,007	106,870	168,036		96,630	69,493	130,659	
Average (1976–2022)	210,011			209,621	128,918			128,529

Note: The run reconstruction model produces estimates for all years every time the model is updated with new information. Previously published estimates of total run and escapement associated with prior year model runs are shown for reference.

[a] Prior year model run from Larson (2023). Based on the prior year model run, the 1976–2022 average total run and escapement was larger than the 2022 model run average by 390 fish, a difference of 0.18% for total run and 0.35% for escapement.

Table 3.–Parameter estimates derived from the 2023 run reconstruction model.

	Parameter estimate (*k*)	95% Bound Lower	Upper	Observed escapement	Total escapement[a]
Weir projects (*k*)					
Kwethluk weir	2.73	2.55	2.91	–	–
Tuluksak weir	5.05	4.88	5.21	–	–
George weir	3.54	3.38	3.70	2,834	97,641
Kogrukluk weir	2.63	2.49	2.78	–	–
Tatlawiksuk weir	4.20	4.03	4.37	–	–
Takotna weir	5.80	5.64	5.97	233	77,051
Aerial survey (*k*)					
Kwethluk River	4.43	4.07	4.78	–	–
Kisaralik River	5.12	4.88	5.36	–	–
Tuluksak River	6.11	5.74	6.48	–	–
Salmon (Aniak River)	5.36	5.13	5.58	–	–
Kipchuk River	5.00	4.76	5.24	–	–
Aniak River	4.08	3.83	4.33	628	37,225
Holokuk River	6.24	5.97	6.52	660	339,786
Oskawalik River	6.46	6.21	6.71	373	238,365
Holitna River	4.54	4.28	4.80	–	–
Cheeneetnuk River	5.39	5.15	5.63	645	141,730
Gagaryah River	5.83	5.59	6.06	449	152,104
Pitka Fork	6.50	6.20	6.80	28	18,664
Bear River	6.23	5.97	6.50	326	165,734
Salmon(Pitka Fork)	4.81	4.59	5.03	671	82,187
Catchability (*q*)					
Unrestricted	-9.50	-9.79	-9.22	–	–
Restricted	-10.05	-10.21	-9.88	–	–

Note: Parameter values (*k*) are presented as natural logarithms (ln). En dash means not applicable.

[a] The expected drainagewide total escapement equals the observed escapement*EXP(*k*).

Table 4.–Starting values used for the 2023 run reconstruction model sensitivity analysis and associated results.

Parameter	Starting values range	Average difference[a]	Max difference[b]
Total run (N_y)	100,000–400,000	0.143	1.017
Weir escapement scaling (k_{ij})	0.01–10	0.054	0.187
Aerial escapement scaling (k_{ij})	0.01–10	0.000	0.004
Catchability (q_k)	-20–1	0.002	0.008
Weir coefficient of variation[c]	-20–20	0.002	0.011
Aerial coefficient of variation[c]	-20–20	0.002	0.011
Catchability coefficient of variation[c]	-20–20	0.002	0.011

[a] Average difference in numbers of fish among all 1976–2023 total run estimates across a range of 100 different starting values for each parameter.

[b] Maximum difference in numbers of fish among all 1976–2023 total run estimates across a range of 100 different starting values for each parameter.

[c] Weir, aerial, and catchability coefficient of variation starting values were evaluated simultaneously.

Table 5.–Kuskokwim River Chinook salmon forecast produced using the *P*-star model, 2024.

Run size	Percent chance of being below run size	Percent chance of being above run size
67,000	1%	99%
81,000	5%	95%
90,000	10%	90%
96,000	15%	85%
102,000	20%	80%
107,000	25%	75%
111,000	30%	70%
116,000	35%	65%
120,000	40%	60%
124,000	45%	55%
129,000	50%	50%
133,000	55%	45%
138,000	60%	40%
144,000	65%	35%
149,000	70%	30%
156,000	75%	25%
163,000	80%	20%
172,000	85%	15%
184,000	90%	10%
204,000	95%	5%
247,000	99%	1%

Note: The model assumes the probability of outcomes between any 2 intervals is not uniform; that is, values closer to the mean (134,007 fish) have higher probabilities of being the correct run size than values farther from the mean. Statistical methodology is described in Staton and Catalano (2019), and the *P*-star model can be accessed at https://bstaton.shinyapps.io/BayesTool. Model code can be accessed at https://github.com/bstaton1/kusko-bayes-tool.

Table 6.–Brood table for Kuskokwim River Chinook salmon.

Brood year	Escapement	Return by age class (0.2)	(1.1)	(0.3)	(1.2)	(2.1)	(0.4)	(1.3)	(2.2)	(1.4)	(2.3)	(1.5)	(2.4)	(1.6)	(2.5)	Return	R/S
1976	110,348	0	64	6	65,641	6	0	107,155	34	82,151	85	6,105	260	89	0	261,595	2.37
1977	230,643	0	66	6	24,077	6	0	44,155	32	77,488	70	7,386	515	67	0	153,868	0.67
1978	155,935	0	683	5	11,425	5	0	39,462	26	60,578	498	4,832	52	5	0	117,572	0.75
1979	145,040	0	209	4	24,479	4	32	75,588	159	61,051	64	6,476	60	6	0	168,133	1.16
1980	267,051	0	693	5	27,491	5	0	51,877	176	46,452	74	3,471	80	7	0	130,331	0.49
1981	205,002	0	369	4	27,010	4	0	59,568	28	82,638	99	12,299	85	7	0	182,111	0.89
1982	36,389	0	48	5	11,367	5	0	52,819	37	70,084	104	6,578	1,062	10	0	142,118	3.91
1983	66,532	0	701	6	42,765	6	0	97,423	39	103,138	733	5,720	130	33	303	250,997	3.77
1984	83,470	0	74	7	29,923	7	0	67,092	1,579	73,062	161	5,287	843	8	0	178,042	2.13
1985	63,207	0	78	7	34,428	7	0	132,210	60	108,102	1,279	5,049	219	8	90	281,538	4.45
1986	54,197	0	90	10	56,846	10	0	72,517	1,934	91,664	236	10,546	735	10	0	234,598	4.33
1987	77,740	0	3,008	7	26,273	7	0	87,211	621	101,558	786	6,194	1,690	9	0	227,365	2.92
1988	82,228	76	82	8	69,754	8	0	84,680	215	133,580	2,046	4,124	362	16	0	294,951	3.59
1989	88,724	0	6,204	8	79,815	8	187	218,324	1,461	195,797	390	33,593	116	7	0	535,910	6.04
1990	106,965	0	431	10	44,287	10	0	108,499	56	108,662	674	3,238	95	7	0	265,968	2.49
1991	103,578	93	758	9	65,103	9	0	131,678	336	142,611	117	4,277	97	7	0	345,096	3.33
1992	130,131	0	144	9	31,786	9	0	70,817	44	67,740	120	3,114	87	6	0	173,876	1.34
1993	179,267	0	130	7	83,613	7	0	92,291	45	96,232	107	4,198	81	0	0	276,711	1.54
1994	287,342	0	88	7	25,540	7	0	48,129	168	58,637	99	8,303	81	0	0	141,060	0.49
1995	239,562	0	284	7	13,641	7	0	49,989	37	108,112	0	7,789	0	0	0	179,864	0.75
1996	201,522	0	232	6	16,502	6	0	68,879	0	90,215	0	9,763	0	0	0	185,604	0.92
1997	209,466	0	104	0	21,817	0	0	79,674	56	76,158	0	4,619	0	0	0	182,428	0.87
1998	90,807	0	0	0	46,287	0	0	102,675	0	106,324	0	4,398	172	0	0	259,857	2.86
1999	83,153	0	186	0	43,617	0	0	111,005	426	109,866	547	14,613	91	0	0	280,350	3.37
2000	61,474	0	382	0	140,756	0	0	152,185	10	124,885	182	5,151	1,091	0	0	424,642	6.91
2001	128,776	0	1,202	0	58,570	0	0	96,978	91	89,530	466	4,741	180	0	0	251,758	1.96

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Table 6.–Page 2 of 2.

Brood year	Escapement	Return by age class (0.2)	(1.1)	(0.3)	(1.2)	(2.1)	(0.4)	(1.3)	(2.2)	(1.4)	(2.3)	(1.5)	(2.4)	(1.6)	(2.5)	Return	R/S
2002	142,448	0	483	0	82,063	0	0	80,582	0	61,154	1,247	2,106	300	0	0	227,936	1.60
2003	164,054	0	1,070	0	68,146	0	0	104,309	65	81,853	263	3,144	39	64	0	258,954	1.58
2004	263,589	0	190	0	41,409	0	0	69,764	736	39,388	0	1,662	55	0	0	153,204	0.58
2005	234,292	0	445	0	33,876	0	0	48,211	78	37,784	277	911	1	0	0	121,583	0.52
2006	225,706	0	81	68	22,330	68	0	46,429	110	25,039	497	804	95	0	0	95,520	0.42
2007	148,446	0	194	0	29,460	0	0	44,418	0	45,304	236	844	0	0	0	120,457	0.81
2008	114,682	0	264	0	10,444	0	0	25,775	67	31,130	366	446	1	0	0	68,492	0.60
2009	101,047	51	0	0	11,829	67	0	33,937	496	24,056	360	5	1	0	77	70,878	0.70
2010	42,823	0	95	0	14,900	0	122	44,274	766	17,065	359	17	99	0	0	77,698	1.81
2011	52,114	0	2,868	0	54,828	2	0	75,255	234	28,673	205	108	0	0	0	162,174	3.11
2012	57,876	65	805	0	36,782	0	0	59,943	165	21,781	51	77	454	0	0	120,122	2.08
2013	36,853	0	1,936	0	41,317	0	120	57,672	120	29,210	1,573	866	112	0	0	132,926	3.61
2014	72,929	0	1,056	0	49,370	0	226	71,792	2,228	28,266	4	642	137	0	0	153,721	2.11
2015	109,155	0	3,100	239	102,048	88	0	51,966	54	26,729	58	207	0	0	0	184,489	1.69
2016	100,420	30	11,982	0	42,329	0	1	49,198	80	10,619	76	355	0	0	0	114,670	1.14
2017	114,964	0	1,223	119	51,641	100	2	54,040	205	14,264	1	0	0	0	0	121,594	–
2018	109,632	0	1,672	180	75,443	47	1	73,983	0	0	0	0	0	0	0	151,326	–
2019	181,267	0	1,902	70	44,715	37	0	0	0	0	0	0	0	0	0	46,723	–
2020	88,648	1	619	0	0	0	0	0	0	0	0	0	0	0	0	620	–
2021	101,444	0	0	0	0	0	0	0	0	0	0	0	0	0	0	–	–
2022	108,225	0	0	0	0	0	0	0	0	0	0	0	0	0	0	–	–
2023	96,630	0	0	0	0	0	0	0	0	0	0	0	0	0	0	–	–

Note: The number of recruits returning from brood year escapement are shown as R/S. Brood years 2017–2023 are incomplete. En dash means no component of the return has been realized, or the R/S cannot be calculated at this time.

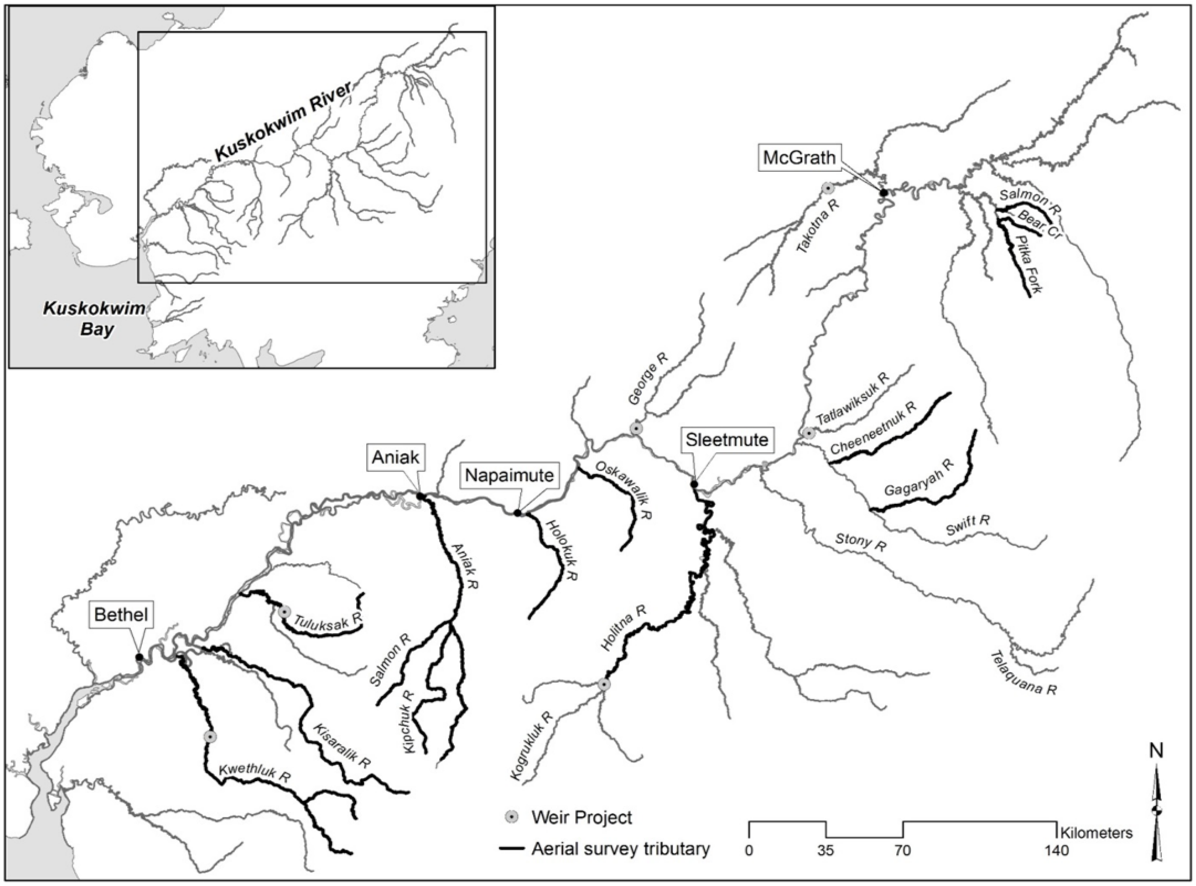

Figure 1.–Kuskokwim River Chinook salmon escapement monitoring projects used to inform the run reconstruction model.

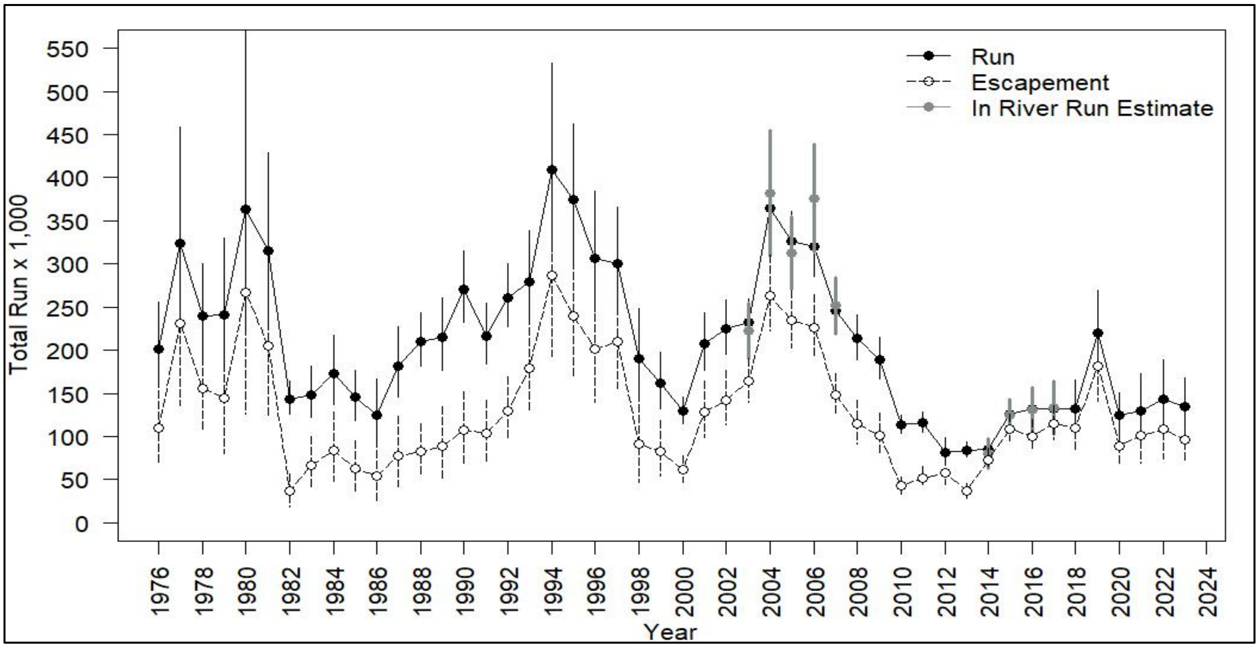

Figure 2.–Annual run (black) and escapement (white) estimates and 95% confidence intervals estimated from the 2023 run reconstruction model.

Note: Grey dots are drainagewide run size and 95% confidence intervals for years 2003–2007 and 2014–2017 used to scale the model. Model scalars are direct estimates of total run derived from a combination of mark–recapture data, escapement estimates, extrapolation of escapement values to unmonitored areas, and harvests (Liller et al. 2018).

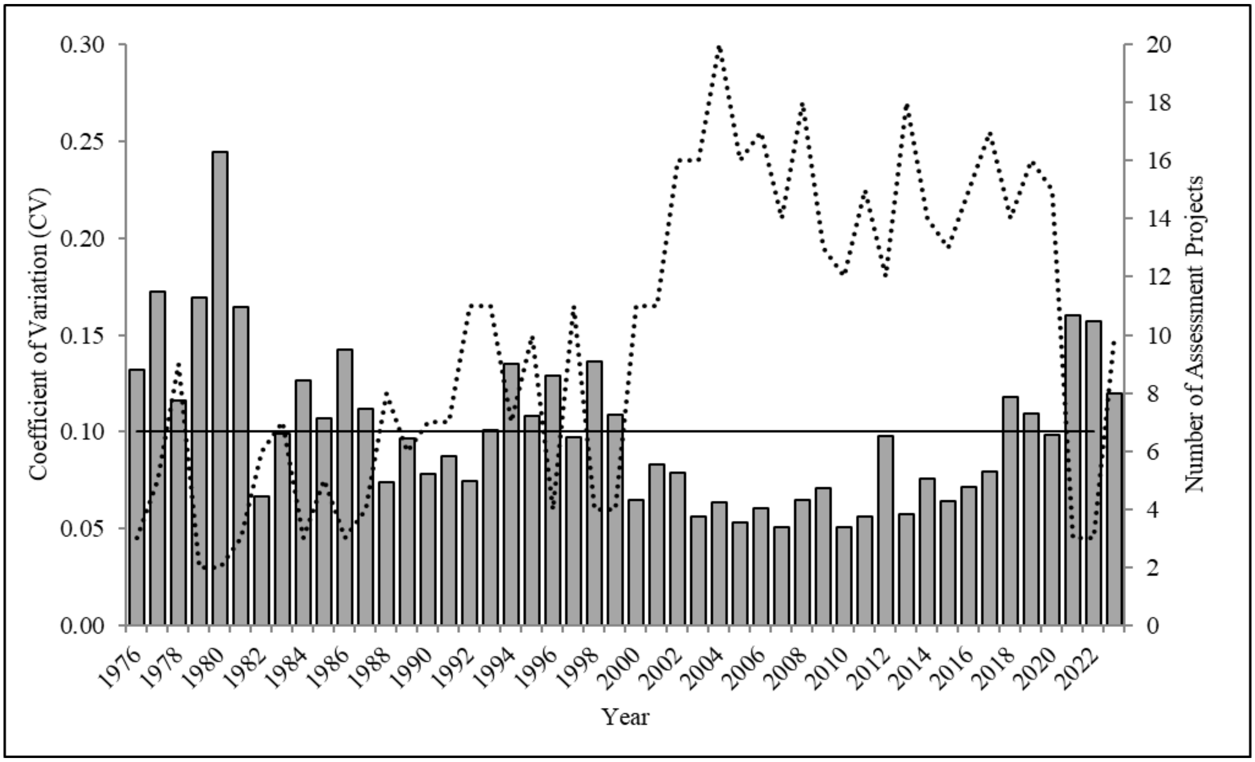

Figure 3.–Annual uncertainty (coefficient of variation; grey bars) of the run reconstruction model estimate of total run size and the number of assessment projects (dotted black line) used to inform the model in each year.

Note: The solid black line is the average coefficient of variation (10%) across years 1976–2022.

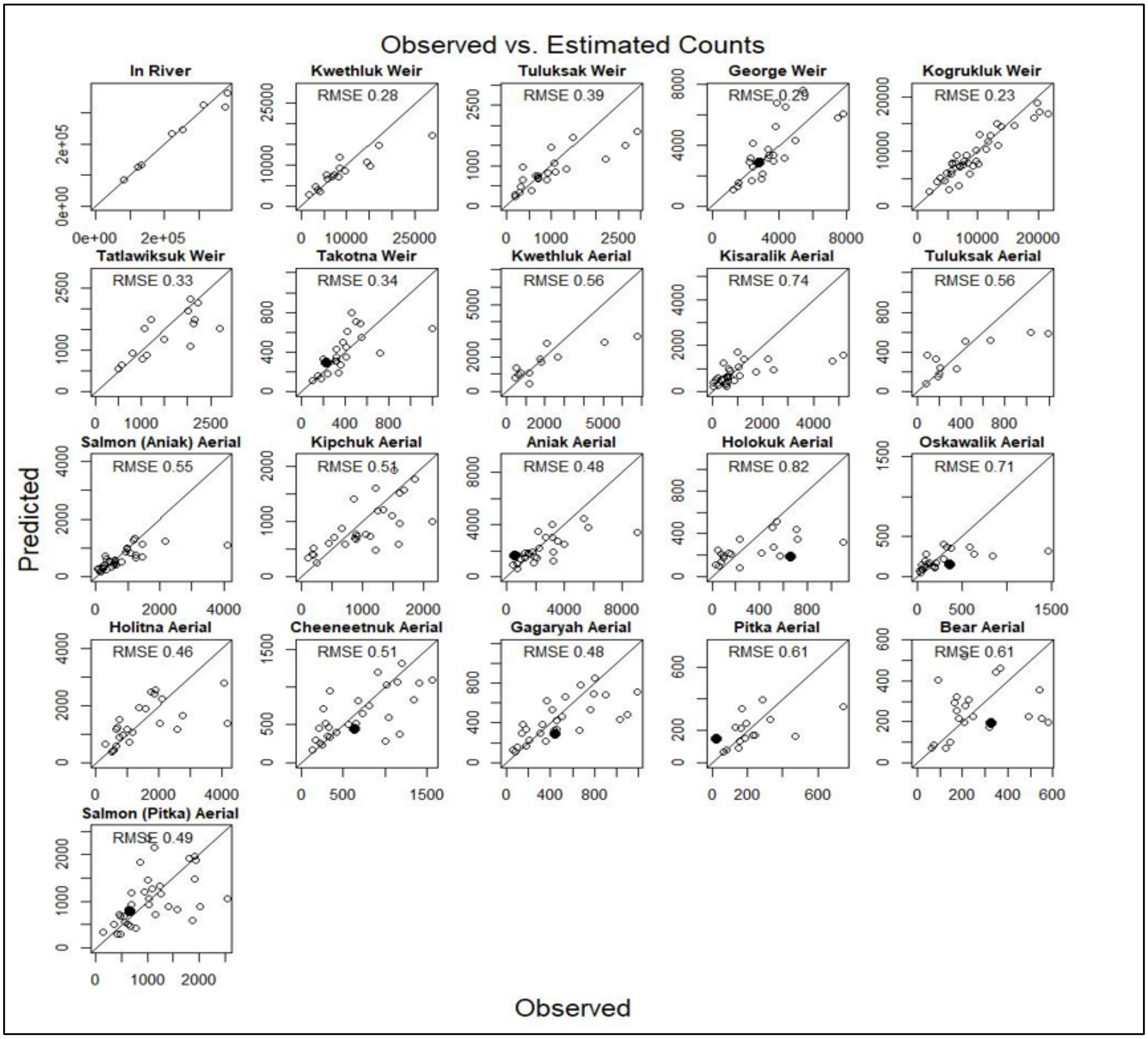

Figure 4.–Observed versus model estimated escapement counts.

Note: The diagonal line within each subplot represents the 1:1 line, which is the point at which observed and estimated escapements are equal. Hollow dots are the prior year observations and solid dots are the 2023 observations. Dots that fall below the 1:1 line indicate that the observed counts are higher than the model estimates, and the opposite is also true. The top left subplot titled "Inriver" is the 2003–2007 and 2014–2017 total run estimates used to scale the model.

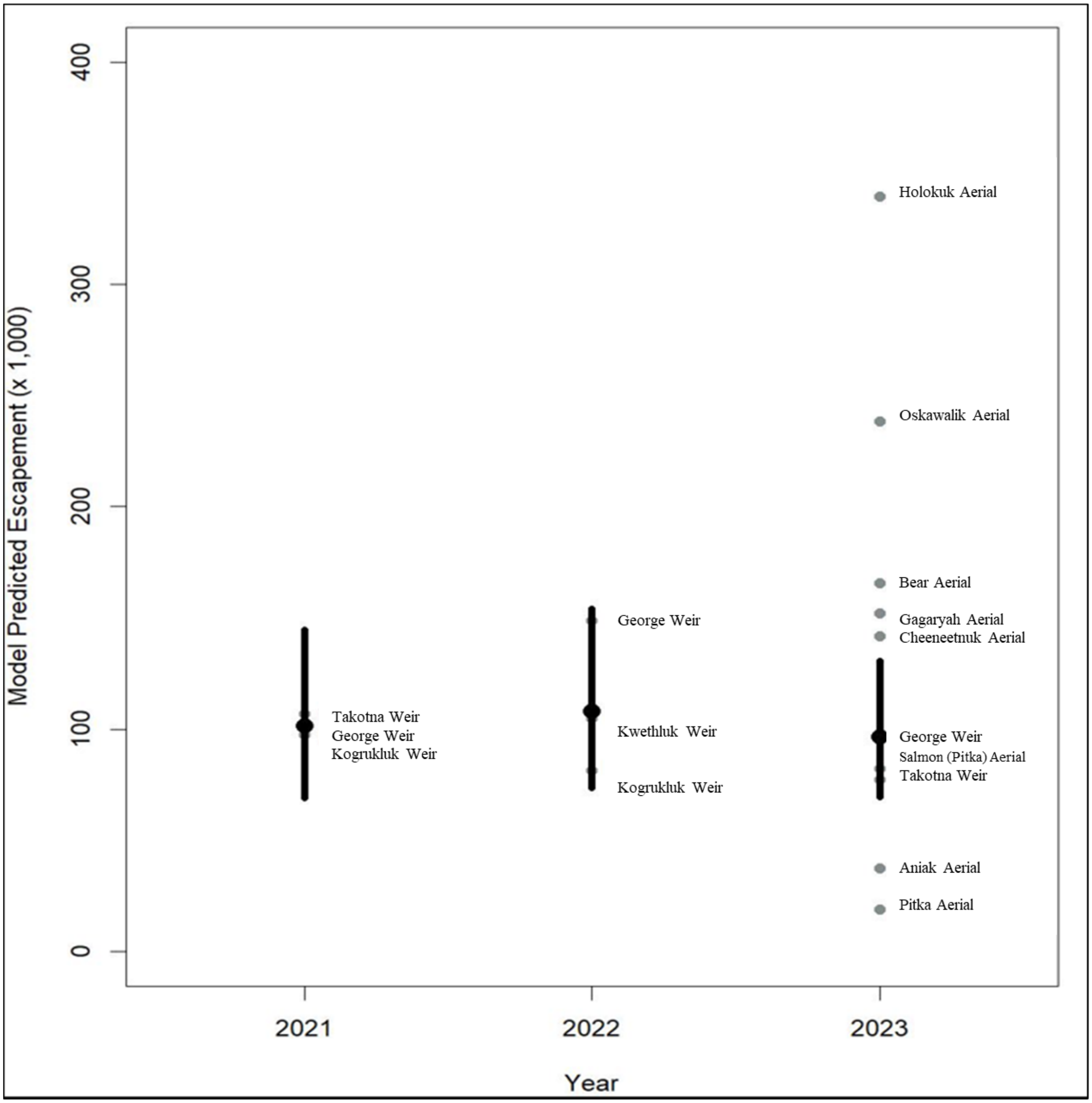

Figure 5.–Range of drainagewide escapement estimates produced by the model based on each escapement project.

Note: Grey dots are individual project estimates of the total run based on the model estimated scaling factor. Black dots and lines show the model derived drainagewide escapement and 95% confidence interval after simultaneously combining the information from all escapement monitoring projects. Estimates for years 2021 and 2022 are shown to provide context for 2023 results.

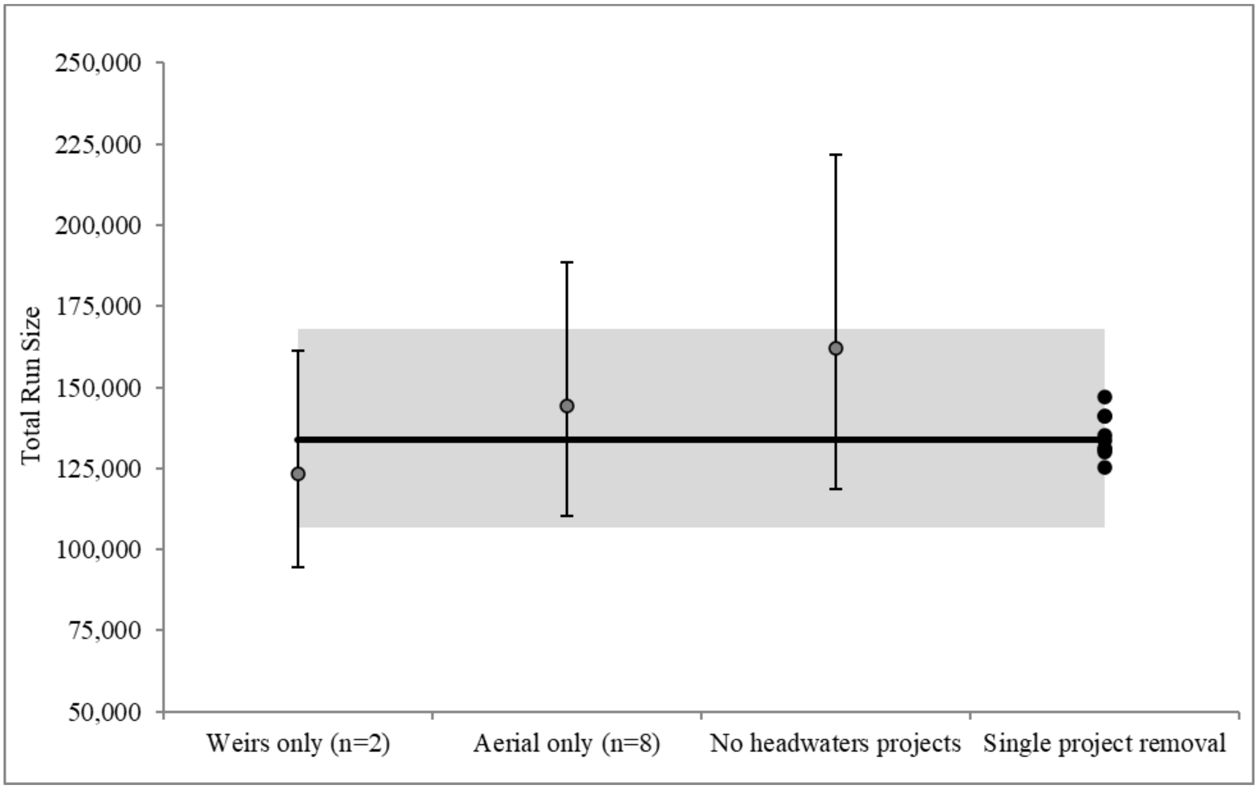

Figure 6.–Sensitivity of 2023 Chinook salmon total run size estimates using all available data (base data) and removal of single escapement monitoring projects (dots).

Note: The solid black line is the point estimate of the ADF&G base model, and the grey shaded area is the 95% confidence interval. Alternative estimates (dots) and 95% confidence intervals are shown for comparison. The amount of overlap with the grey shaded area indicates the degree of similarity between estimates.

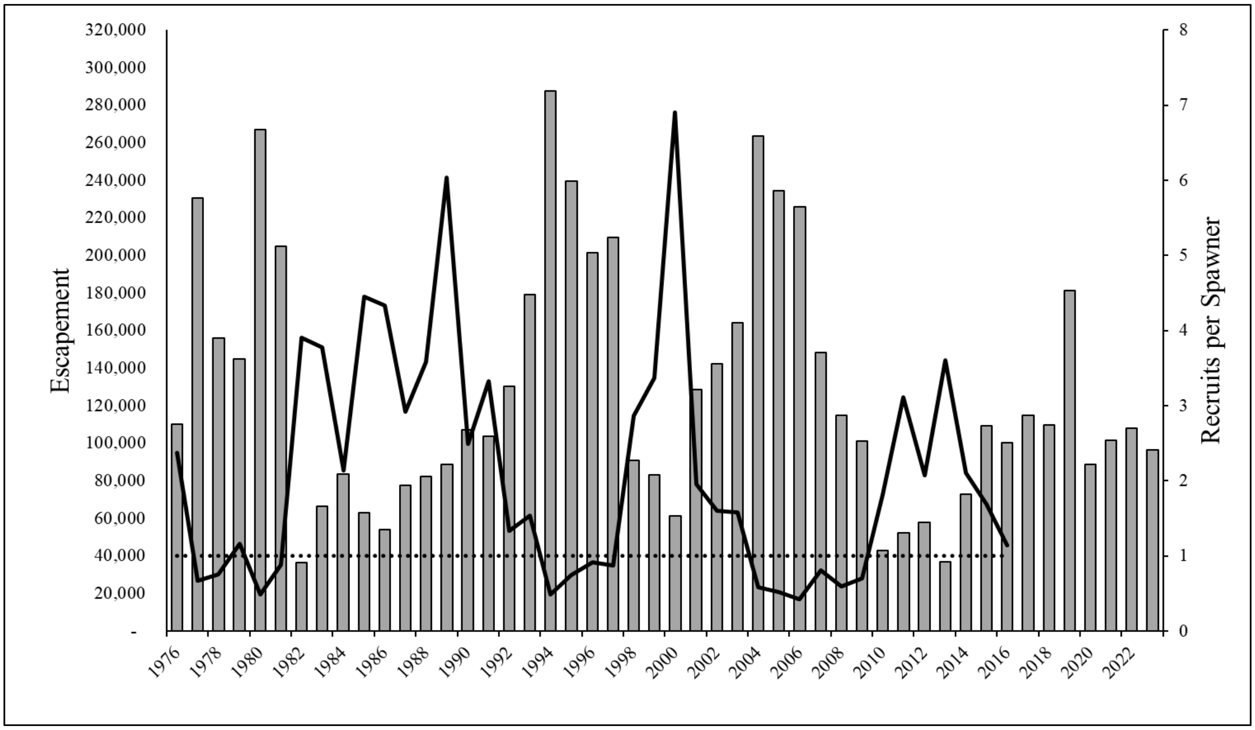

Figure 7.–Escapement (bars), recruits per spawner (solid line), and the 1:1 replacement line for recruits per spawner (dotted line) for Kuskokwim River Chinook salmon, 1976–2023.

APPENDIX A: 2023 NPFMC 3-SYSTEM INDEX LETTER

Appendix A1.–2023 North Pacific Fishery Management Council (NPFRMC) 3-system index letter.

THE STATE of ALASKA
GOVERNOR MIKE DUNLEAVY

Department of Fish and Game
Division of Commercial Fisheries
Headquarters Office
1255 West 8th Street
P.O. Box 115526
Juneau, Alaska 99811-5526
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September 11, 2023

Jon Kurland, Administrator
NOAA Fisheries, Alaska Region
PO Box 21668
Juneau, Alaska 99802-1668

Dear Mr. Kurland,

In April 2015, the North Pacific Fishery Management Council (Council) adopted an action that lowers Chinook salmon bycatch caps in the Bering Sea walleye pollock fishery when Chinook salmon abundance in Western Alaska is at historically low levels.[1] The Council's action identifies historically low Western Alaskan Chinook salmon abundance using a three-system index of inriver adult Chinook salmon run sizes from the Unalakleet, Upper Yukon, and Kuskokwim rivers combined at or below the threshold level of 250,000 fish. The Council's action also specified a process by which the Alaska Department of Fish and Game (department) would provide postseason abundance estimates to the National Marine Fisheries Service (NMFS) by October 1, following the salmon season each year. If the threshold is not met, the low performance standard and hard cap applicable to the Bering Sea walleye pollock fishery is in effect the following year.

Methods and analyses used by the department to estimate the postseason run size for each of the three systems have been approved by the Council, and there were no changes to those methods in 2023. The methods used for the Unalakleet and Upper Yukon rivers are consistent with what is outlined in the Council's public review analysis.[2] Methods used for the Kuskokwim River were approved by the Council in June 2018[3].

The 2023 three-system index of inriver adult Chinook salmon run sizes from the Unalakleet, Upper Yukon, and Kuskokwim rivers is 148,443 and is below the threshold level of 250,000.

The following details the preliminary total run estimates for each system:

Unalakleet River

An extremely low run size of Unalakleet River Chinook salmon returned in 2023 and was about half the run size observed in 2022. The preliminary 2023 postseason run size estimate of Unalakleet River Chinook salmon is **802**, based on the sum of reported commercial harvest, expected subsistence harvest, and estimated total escapement. A total of 11 Chinook salmon were commercially harvested in Norton Sound Subdistrict 6 (Unalakleet Subdistrict), and the total catch was assumed to be bound for the Unalakleet River. The department estimates approximately 100 Unalakleet River Chinook salmon were harvested for subsistence uses in 2023. Subsistence harvest in 2023 is expected to be smaller than the 2022 harvest (465 fish) due to reduced fishing opportunities in response to overlapping poor Chinook and chum salmon runs and concerns for not meeting the established Chinook salmon escapement goal on the North River. The North River Tower operated successfully throughout the Chinook salmon run, and standardized methods were used to estimate minor missed passage. The Unalakleet River weir was out of operation for nine days corresponding to the normal peak passage of Chinook salmon, and only 40 Chinook salmon were counted while the weir was

[1] https://npfmc.legistar.com/LegislationDetail.aspx?ID=2237783&GUID=89E4DA9C-19B8-4BDE-8643-B19D68DD9EE3
[2] Public Review draft Environmental Assessment/ Regulatory Impact Review/ Initial Regulatory Flexibility Analysis for Proposed Amendment to the Fishery Management Plan for Bering Sea Aleutian Islands Groundfish Bering Sea Chinook and Chum salmon bycatch management measures, March 2015.
[3] https://npfmc.legistar.com/LegislationDetail.aspx?ID=3486558&GUID=81056FD0-C9E8-4376-BD59-C2F6084C82E9&Options=ID|Text|&Search=Kuskokwim

-continued-

operational. Available methods to estimate missed passage at the Unalakleet River weir or expand North River Tower counts to the entire Unalakleet River drainage were considered unreliable. Aerial peak spawning surveys upriver from the Unalakleet River weir counted 70 Chinook salmon, which is considered a minimum escapement to the Unalakleet River. The sum of the North River Tower count and the Unalakleet River aerial survey count was used as a conservative estimate of total escapement to the Unalakleet River drainage. The preliminary total escapement of Chinook salmon to the Unalakleet River drainage was estimated to be 691 and is highly uncertain. The North River escapement was one of the smallest on record since the project began in 1972. While uncertain, the escapement upstream of the Unalakleet River weir was likely less than the 2022 run which was the smallest on record since the project began in 2010.

Upper Yukon River

An extremely low run size of Upper Yukon River Chinook salmon returned in 2023 with the run only slightly larger than the record low observed in 2022. The preliminary postseason run size estimate of Upper Yukon River Chinook salmon is **16,804**, based on the preliminary assessment of total passage into Canada and expectations of the total harvest in Alaska. Chinook salmon passage into Canada was based on a sonar project operated near the U.S./Canada border, downriver from Eagle, Alaska. The preliminary sonar count is 15,304 (90% CI: 15,081–15,527). The total harvest of Upper Yukon River Chinook salmon in Alaska is expected to be about 1,500. The potential for a very small Chinook salmon and summer chum salmon runs were forecasted preseason, and inseason assessment indicated the Chinook salmon run was very weak. As such, conservation actions were implemented to protect both Chinook salmon and chum salmon which co-migrate throughout much of the Yukon River. There were no commercial salmon fisheries opened in the Yukon River drainage in 2023, relevant sport fisheries were closed, subsistence fishing was closed for all salmon beginning June 2 in the lower portion of the river, and subsistence closures were applied in upriver districts commensurate with salmon run timing. Selective gear openings for subsistence harvest of summer chum were allowed starting June 26 in the lower river once a majority of Chinook had passed and inseason run projections for summer chum indicated we would be above the lower end of the escapement goal. All Chinook salmon were required to be released alive from selective gear. Limited harvest of Upper Yukon River Chinook salmon occurred in test fisheries operated by the department and cooperative partners and in small-mesh gillnet opportunities directed at non-salmon species. The 2023 preliminary harvest of 1,500 is a maximum expectation and was informed by the 2021 and 2022 harvest of Canadian-origin Chinook salmon, which resulted from full subsistence salmon fishing closures like those imposed in 2023, except for some late season subsistence opportunity with selective gear for summer chum salmon. The preliminary total run size of Upper Yukon River Chinook salmon was below the lower end of the preseason run forecast (80% CI: 26,000–43,000), and about half of the inseason run size estimate (i.e., 28,000) based on independent sonar and genetic stock identification programs operated in the lower portion of the Yukon River.

Kuskokwim River

The preliminary postseason run size estimate of Kuskokwim River Chinook salmon is **130,837** fish (95% CI: 98,692–173,452), based on preliminary results of a maximum likelihood model. The total run estimate was informed by direct observations of escapement and an expectation of drainagewide harvest. The preliminary escapement estimate (103,989) is uncertain (95% CI: 71,844–146,604) because the model was informed by only one weir project and eight aerial surveys. Poor weather conditions prevented the department from flying a subset of aerial surveys during the 2023 season. Additionally, extended periods of missed passage resulted in the inability to produce escapement estimates at three out of four weirs that are used to inform the model. The total harvest of Kuskokwim River Chinook salmon is expected to be 26,848. No commercial harvest of Kuskokwim River Chinook salmon occurred during the 2023 season. Nearly all harvest occurred in the subsistence fishery, and minimal harvest occurred in test fisheries operated by the department and collaborators. Subsistence fishing restrictions were implemented throughout the Chinook salmon run in 2023. U.S. Fish and Wildlife Service (USFWS) estimated that approximately 21,062 Chinook salmon were harvested within a portion of the Yukon Delta National Wildlife refuge during subsistence fishing openings announced by Federal Special Actions. A preliminary estimate of drainagewide subsistence harvest was generated using a seven-year relationship between partial harvest estimates developed inseason by USFWS and drainagewide estimates developed postseason by the department. The preliminary total run size of Kuskokwim River Chinook salmon was within the preseason run forecast of 115,000–170,000 fish but larger

-continued-

Jon Kurland- 3 - September 11, 2023

than an independent total run estimate of approximately 97,000 Chinook salmon, based on a sonar project operated near Bethel, Alaska plus harvest downriver.

Sincerely,

Sam Rabung
Director, Division of Commercial Fisheries

cc: Doug Vincent-Lang, Commissioner
Rachel Baker, Deputy Commissioner
David Witherell, NPFMC

APPENDIX B: 2023 ADMB-CODE WITH ANNOTATIONS

Appendix B1.–2023 ADMB-code with annotations.

```
//=============================================================================
//DATA SECTION
//=============================================================================
DATA_SECTION
  init_int nyear; // number of years with datae
  init_int nweek; // number of weeks for harvest data
  init_int nweir; // number of weir sites
  init_int nair;  // number of aerial survey sites
  init_matrix testf(1,nyear,1,nweek); //Estimates of run proportion by week
  init_matrix ceff(1,nyear,1,nweek);  // Weekly effort commercial fishery
  init_matrix ccat(1,nyear,1,nweek);  // Weekly catch commercial fishery
  init_matrix creg(1,nyear,1,nweek);  // Weekly indicator of fishery regulation
  init_vector inriv(1,nyear);         // Annual in-river run estimate
  init_vector inriv_sd(1,nyear);      // SD of annual in-river run estimate
  init_vector tcatch(1,nyear);          // Total harvest across all fishery sectors
  init_matrix esc_w(1,nyear,1,nweir);   // Weir escapement indices
  init_matrix esc_a(1,nyear,1,nair);    // Aerial escapement indices
  init_vector minesc(1,nyear);           // Minimum annual escapement
  init_vector minrun(1,nyear);           // Minimum annual run size
  init_vector ubrun(1,nyear);           // Upper bounds for annual run size estimation

//=====================================================
// Parameter Section
//=====================================================
PARAMETER_SECTION
// log drainage-wide run
  init_bounded_number_vector log_trun(1,nyear,minrun,ubrun,1);
  init_bounded_vector log_wesc(1,nweir,0,7,1);   // log slope for weir counts
  init_bounded_vector log_aesc(1,nair,0,7,1);    // log slope for aerial counts
// log Catchability for different fishery sectors
  init_bounded_vector log_q(1,2,-12,-9,1);
  init_bounded_number log_cvw(-10,1,1);    // log cv for weir counts
  init_bounded_number log_cva(-10,1,1);     // log cv for aerial counts
  init_bounded_number log_cvq(-10,1,1);     // log cv for commercial cpue
  vector t_run(1,nyear);   // storage for untransformed total runs
  vector wesc(1,nweir);    // storage for untransformed weir escapement slopes
  vector aesc(1,nair);     // storage for untransformed aerial escapement slopes
  vector q(1,2);           // storage for untransformed catchabilities
  number cvw;              // storage for untransformed weir cv parameters
  number cva;              // storage for untransformed aerial cv parameters
  number cvq;             // storage for untransformed fishery cv parameters
// storage matrix for the estimated number of fish available for harvest each week
  matrix wk_est(1,nyear,1,nweek);
  number tfw;             // likelihood for weir counts
  number tfa;             // likelihood for aerial counts
  vector tfc(1,3);        // likelihood for commercial CPUE
  number tft;             // likelihood for in-river run estimates
  vector esc(1,nyear);    // vector of total escapement estimates
  number var1;            // storage for Weir Escapement variance parameter
  number var2;            // storage for Aerial Escapement variance parameter
  number var3;            // storage for CPUE variance parameter
  matrix cpue(1,3,1,nyear);      // storage matrix for annual CPUE by fishery
matrix testp(1,3,1,nyear);  // testfish weekly run proportion
```

```
objective_function_value objf

INITIALIZATION_SECTION
  log_trun  12.5;
  log_wesc  5.0;
  log_aesc  4.0;
  log_q  -11.0;
  log_cvw  1.0;
  log_cva  1.0;
  log_cvq  1.0;
//=======================================================
// Calculate Annual run adjusted CPUE
//=======================================================
PRELIMINARY_CALCS_SECTION
   int i,j,k;
  for (i=1;i<=nyear;i++)
  {
  for (j=1;j<=nweek;j++)
        {
// Unrestricted mesh catch
    if(creg(i,j)==1)
            {
                cpue(1,i) += ccat(i,j)/ceff(i,j);
                testp(1,i) += testf(i,j);
            }
// Restricted mesh catch
    if(creg(i,j)==2)
            {
                cpue(2,i) += ccat(i,j)/ceff(i,j);
                testp(2,i) += testf(i,j);
                }
// Mono-filament mesh catch
    if(creg(i,j)==3 or creg(i,j)==5)
            {
                cpue(3,i) += ccat(i,j)/ceff(i,j);
                testp(3,i) += testf(i,j);
                    }
        }
  }
//==========================================================
// Procedure Section
//=========================================================
PROCEDURE_SECTION
  objf = 0.0;
  convert_parameters_into_rates();
  evaluate_obj_func();

RUNTIME_SECTION
  maximum_function_evaluations 200000000
  convergence_criteria 1.e-30  //was 1.e-20 //low converge was .000001

//==========================================================
// Function convert_parameters_into_rates
//==========================================================
FUNCTION convert_parameters_into_rates
```

```
   t_run=exp(log_trun);
   wesc=exp(log_wesc);
   aesc=exp(log_aesc);
   q=exp(log_q);
   cvw=exp(log_cvw);
   cva=exp(log_cva);
   cvq=exp(log_cvq);
   var1 = log(square(cvw)+1);
   var2 = log(square(cva)+1);
   var3 = log(square(cvq)+1);

//==========================================================
// Function evaluate_obj_func
//==========================================================
FUNCTION evaluate_obj_func
   int i,j,k,l,ctr1,ctr2,ctr3;
   tfw= 0.0;
   tfa= 0.0;
   tft= 0.0;
   tfc=0.0;

     for (i=1;i<=nyear;i++)
   {
    esc(i)=t_run(i)-tcatch(i);

    if(inriv(i)>0)
    {
    tft+=0.5*square(log(inriv(i))-log(t_run(i)))/log(square(inriv_sd(i)/inriv(i))+1);
    // In-River run estimate likelihood
    }
 // Weir likelihoods
    for(j=1;j<=nweir;j++)
    {
       if(esc_w(i,j)>0)
       {
         tfw += log(sqrt(var1))+0.5*square(log(esc_w(i,j))-log(esc(i)/wesc(j)))/var1;
       }
    }
// Aerial likelihoods
    for(k=1;k<=nair;k++)
    {
     if(esc_a(i,k)>0)
     {
      tfa += log(sqrt(var2))+0.5*square(log(esc_a(i,k))-log(esc(i)/aesc(k)))/var2;
     }
    }
//===  Calculate annual run adjusted CPUE ==================================
      if(cpue(1,i)>0)
      {
tfc(1)+=log(sqrt(var3))+0.5*square(log(cpue(1,i)/testp(1,i))-
log(q(1)*t_run(i)))/var3;
      }
// Remove CPUE during the Restricted Period
//    if(cpue(2,i)>0)
//    {
```

```
//     tfc(2) += log(sqrt(var3))+0.5*square(log(cpue(2,i)/testp(2,i))-
       log(q(2)*t_run(i)))/var3;
//     }
       if(cpue(3,i)>0)
       {
       tfc(3) += log(sqrt(var3))+0.5*square(log(cpue(3,i)/testp(3,i))-
       log(q(2)*t_run(i)))/var3;
       }
   }
   objf+= tft+tfw+tfa+sum(tfc);
//==================================================================================
// Report Section
//==================================================================================
REPORT_SECTION
   report<<"Total Run"<< endl << t_run << endl;
   report<<"ObjFunc"<< endl << objf << endl;
   report<<"tfc"<<endl<< tfc <<endl;
   report<<"tft"<<endl<< tft <<endl;
   report<<"tfa"<<endl<< tfa <<endl;
   report<<"tfw"<<endl<< tfw <<endl;
   report<<"cvw"<<endl<< cvw << endl;
   report<<"cva"<<endl<< cva << endl;
   report<< "q" << endl << q << endl;
   report<< "wesc" <<endl<< wesc << endl;
   report<< "aesc" <<endl<< aesc << endl;
   report<<"tcatch"<<endl<< tcatch<<endl;
   report<<"TotalEscapement"<<endl<< esc << endl;
//===================================================================================
// Globals Section
//===================================================================================
GLOBALS_SECTION
  #include <df1b2fun.h>
  #include <math.h>
  #include <time.h>
  #include <statsLib.h>
  #include <adrndeff.h>
  #include <admodel.h>
  time_t start,finish;
  long hour,minute,second;
  double elapsed_time;

TOP_OF_MAIN_SECTION
  arrmblsize = 100000000;
  gradient_structure::set_MAX_NVAR_OFFSET(30000000);
  gradient_structure::set_GRADSTACK_BUFFER_SIZE(3000000);
  gradient_structure::set_CMPDIF_BUFFER_SIZE(100000000);
  time(&start);

FINAL_SECTION
 // Output summary stuff
  time(&finish);
  elapsed_time = difftime(finish,start);
  hour = long(elapsed_time)/3600;
  minute = long(elapsed_time)%3600/60;
  second = (long(elapsed_time)%3600)%60;
```

```
  cout << endl << endl << "Starting time: " << ctime(&start);
  cout << "Finishing time: " << ctime(&finish);
  cout << "This run took: " << hour << " hours, " << minute << " minutes, " << second
<< " seconds." <<   endl << endl;
```

APPENDIX C: MODEL INPUT DATA

Appendix C1.–Independent estimates of Kuskokwim River Chinook salmon abundance, used to scale the run reconstruction model.

Conventional name:	Year	Total run	Standard error
	2003	222,145	16,055
	2004	381,958	36,322
	2005	312,353	21,083
	2006	376,291	31,094
	2007	251,781	16,315
	2014	80,399	8,605
	2015	124,421	9,362
	2016	131,090	12,632
	2017	133,292	15,702

Appendix C2.–Harvest of Kuskokwim River Chinook salmon.

Var name:	Year	H.Com	H.Sub	H.Sports	H.Test
Conventional name:	Year	Commercial	Subsistence	Sport	Testfish
	1976	30,735	58,606	–	1,206
	1977	35,830	56,580	33	1,264
	1978	45,641	36,270	116	1,445
	1979	38,966	56,283	74	979
	1980	35,881	59,892	162	1,033
	1981	47,663	61,329	189	1,218
	1982	48,234	58,018	207	542
	1983	33,174	47,412	420	1,139
	1984	31,742	56,930	273	231
	1985	37,889	43,874	85	79
	1986	19,414	51,019	49	130
	1987	36,179	67,325	355	384
	1988	55,716	70,943	528	576
	1989	43,217	81,175	1,218	543
	1990	53,502	109,778	394	512
	1991	37,778	74,820	401	149
	1992	46,872	82,481	367	1,380
	1993	8,735	87,830	587	2,515
	1994	16,211	102,817	1,139	1,937
	1995	30,846	101,921	541	1,421
	1996	7,419	96,477	1,432	247
	1997	10,441	79,334	1,227	332
	1998	17,359	80,969	1,434	210
	1999	4,705	73,538	252	98
	2000	444	67,596	105	64
	2001	90	78,174	290	86
	2002	72	81,169	319	288
	2003	158	67,737	401	409
	2004	2,305	96,788	857	691
	2005	4,784	85,863	572	557
	2006	2,777	90,812	444	352
	2007	179	94,898	1,478	305
	2008	8,865	88,912	708	420
	2009	6,664	79,896	904	470
	2010	2,732	67,286	354	292
	2011	747	62,366	579	337
	2012	627	22,544	0	321
	2013	174	47,113	0	201
	2014	35	11,234	0	497
	2015	8	16,124	0	472
	2016	0	30,693	0	525
	2017	0	16,380	0	290
	2018	0	22,266	0	465
	2019	0	37,941	0	563
	2020	0	35,846	0	355
	2021	0	28,365	0	386
	2022	0	34,134	0	381
	2023	0	37,091	0	286

Appendix C3.–Weir escapement counts of Kuskokwim River Chinook salmon.

Var name:	Year	w.kwe	w.tul	w.geo	w.kog	w.tat	w.tak
Conventional name:	Year	Kwethluk	Tuluksak	George	Kogrukluk	Tatlawiksuk	Takotna
	1976	–	–	–	5,822	–	–
	1977	–	–	–	–	–	–
	1978	–	–	–	13,436	–	–
	1979	–	–	–	11,437	–	–
	1980	–	–	–	–	–	–
	1981	–	–	–	16,075	–	–
	1982	–	–	–	–	–	–
	1983	–	–	–	–	–	–
	1984	–	–	–	4,922	–	–
	1985	–	–	–	4,479	–	–
	1986	–	–	–	–	–	–
	1987	–	–	–	–	–	–
	1988	–	–	–	8,603	–	–
	1989	–	–	–	–	–	–
	1990	–	–	–	10,093	–	–
	1991	–	697	–	7,602	–	–
	1992	9,675	1,083	–	6,471	–	–
	1993	–	2,218	–	12,157	–	–
	1994	–	2,932	–	–	–	–
	1995	–	–	–	20,249	–	–
	1996	–	–	7,501	13,900	–	423
	1997	–	–	7,810	13,116	–	1,197
	1998	–	–	–	–	–	–
	1999	–	–	–	5,567	1,484	–
	2000	3,547	–	2,956	3,254	808	345
	2001	–	924	3,313	8,151	2,013	718
	2002	8,543	1,346	2,445	9,830	2,237	326
	2003	14,475	1,067	–	11,751	–	378
	2004	28,801	1,475	5,392	19,880	2,833	461
	2005	–	2,653	3,845	21,686	2,858	499
	2006	17,019	1,008	4,359	19,305	1,700	537
	2007	15,112	374	4,972	–	2,058	412
	2008	5,642	707	3,383	9,740	1,194	413
	2009	5,826	362	3,664	9,201	1,071	311
	2010	1,716	201	1,500	5,160	554	183
	2011	4,056	284	1,605	6,926	1,011	149
	2012	–	559	2,362	–	1,116	238
	2013	–	198	1,267	1,919	495	104
	2014	3,191	325	2,988	3,726	2,050	–
	2015	8,163	711	2,301	8,333	2,131	–
	2016	–	909	2,218	7,062	2,693	–
	2017	7,207	648	3,669	7,787	2,146	318
	2018	–	–	3,322	6,292	–	205
	2019	8,505	–	3,828	10,301	–	554
	2020	–	–	2,418	5,645	–	357
	2021	–	–	2,920	6,969	–	323
	2022	6,808	–	4,318	5,837	–	–
	2023	–	–	2,834	–	–	233

Note: En dash means no data.

Appendix C4.–Peak aerial survey index counts of Kuskokwim River Chinook salmon.

Var name:	Year	a.kwe	a.kis	a.tul	a.sla	a.kip	a.ank	a.hlk	a.osk	a.hlt	a.che	a.gag	a.pit	a.ber	a.slp
Conventional name:	Year	Kwethluk	Kisaralik	Tuluksak	Salmon (Aniak)	Kipchuk	Aniak	Holokuk	Oskawalik	Holitna	Cheeneetnuk	Gagaryah	Pitka	Bear	Salmon (Pitka)
	1976	–	–	–	–	–	–	–	–	2,571	–	663	–	182	–
	1977	2,075	–	439	–	–	–	–	–	–	1,407	897	–	–	1,930
	1978	1,722	2,417	–	289	–	–	–	–	2,766	268	504	–	227	1,100
	1979	–	–	–	–	–	–	–	–	–	–	–	–	–	682
	1980	–	–	1,035	1,186	–	–	–	–	–	–	–	–	–	–
	1981	–	–	–	–	–	9,074	–	–	–	–	–	–	93	–
	1982	–	81	–	126	–	–	–	–	521	–	–	–	127	413
	1983	471	–	186	231	–	1,909	–	–	1,069	173	–	–	–	572
	1984	–	–	–	–	–	–	–	–	–	1,177	–	–	–	545
	1985	–	63	–	–	–	–	–	–	–	1,002	–	–	–	620
	1986	–	–	–	336	–	424	–	–	650	–	–	–	–	–
	1987	–	–	–	516	193	–	–	193	–	317	205	–	–	–
	1988	622	869	195	244	–	954	–	80	–	–	–	–	–	474
	1989	1,157	152	–	631	1,598	2,109	–	–	–	–	–	–	–	452
	1990	–	631	205	596	537	1,255	–	113	–	–	–	–	–	–
	1991	–	217	358	583	885	1,564	–	–	–	–	–	–	–	–
	1992	–	–	–	335	670	2,284	–	91	2,022	1,050	328	–	–	2,536
	1993	–	–	–	1,082	1,248	2,687	233	103	1,573	678	419	–	–	1,010
	1994	–	1,021	–	1,218	1,520	–	–	–	–	1,206	807	–	–	1,010
	1995	–	1,243	–	1,446	1,215	3,171	–	326	1,887	1,565	1,193	–	–	1,911
	1996	–	–	–	985	–	–	–	–	–	–	–	–	–	–
	1997	–	439	–	980	855	2,187	–	1,470	2,093	345	364	–	–	–
	1998	–	457	–	557	443	1,930	–	–	–	–	–	–	–	–
	1999	–	–	–	–	–	–	–	98	741	–	–	–	–	–
	2000	–	–	–	238	182	714	–	62	301	–	–	151	–	362
	2001	–	–	–	598	–	–	52	–	4,156	–	143	–	175	1,033
	2002	1,795	1,727	–	1,236	1,615	–	513	295	733	730	452	165	211	1,255

-continued-

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Var name:	a.kwe	a.kis	a.tul	a.sla	a.kip	a.ank	a.hlk	a.osk	a.hlt	a.che	a.gag	a.pit	a.ber	a.slp
Conventional name: Year	Kwethluk	Kisaralik	Tuluksak	Salmon (Aniak)	Kipchuk	Aniak	Holokuk	Oskawalik	Holitna	Cheeneetnuk	Gagaryah	Pitka	Bear	Salmon (Pitka)
2003	2,661	654	94	1,242	1,493	3,514	1,096	844	–	810	1,095	197	176	1,242
2004	6,801	5,157	1,196	2,177	1,868	5,362	539	293	4,051	918	670	290	206	1,138
2005	5,059	2,206	672	4,097	1,679	–	510	582	1,760	1,155	788	744	367	1,801
2006	–	4,734	–	–	1,618	5,639	705	386	1,866	1,015	531	170	347	862
2007	–	692	173	1,458	2,147	3,984	–	–	–	–	1,035	131	165	943
2008	487	1,074	–	589	1,061	3,222	418	213	–	290	177	242	245	1,033
2009	–	–	–	–	–	–	565	379	–	323	303	187	209	632
2010	–	235	–	–	–	–	229	–	587	–	62	67	75	135
2011	–	534	–	79	116	–	61	26	–	249	96	85	145	767
2012	–	588	–	49	193	–	36	51	–	229	178	–	–	670
2013	1,165	599	83	154	261	754	–	38	532	138	74	–	64	469
2014	–	622	–	497	1,220	3,201	80	200	–	340	359	–	–	1,865
2015	–	709	–	810	917	–	77	–	662	–	–	–	–	2,016
2016	–	622	–	–	898	718	100	47	1,157	217	135	–	580	1,578
2017	–	–	–	423	889	1,781	140	136	676	660	453	234	492	687
2018	–	584	–	442	1,123	1,534	162	–	980	565	438	471	550	1,399
2019	–	1,063	–	950	1,344	3,160	719	638	1,377	1,345	760	330	542	1,918
2020	721	350	–	269	723	1,264	99	169	854	419	–	160	321	1,150
2021[a]	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2022[a]	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2023	–	–	–	–	–	628	660	373	–	645	449	28	326	671

Note: En dash means no data. Only surveys rated good or fair were used. Only surveys flown between July 17 and August 5, inclusive, were used. Chinook salmon live and carcass counts were combined.

[a] No aerial surveys were flown due to inclement weather.

Appendix C5.–Proportion of total annual Chinook salmon run in District W-1, by week, as estimated by Bethel test fishery.

Var name:	Year	rpw.3	rpw.4	rpw.5	rpw.6	rpw.7	rpw.8	rpw.9	rpw.10
Conventional name:	Year	6/10/–6/16	6/17–6/23	6/24–6/30	7/1–7/7	7/8–7/14	7/15–7/21	7/22–7/28	7/29–8/26
	1976	–	–	–	–	–	–	–	–
	1977	–	–	–	–	–	–	–	–
	1978	–	–	–	–	–	–	–	–
	1979	–	–	–	–	–	–	–	–
	1980	–	–	–	–	–	–	–	–
	1981	–	–	–	–	–	–	–	–
	1982	–	–	–	–	–	–	–	–
	1983	–	–	–	–	–	–	–	–
	1984	0.2243	0.2903	0.1488	0.1633	0.0509	0.0522	0.0090	0.0173
	1985	0.0000	0.0930	0.2427	0.4306	0.1504	0.0247	0.0175	0.0410
	1986	0.1503	0.4039	0.1656	0.1399	0.0488	0.0097	0.0241	0.0000
	1987	0.1988	0.3070	0.2368	0.1137	0.0210	0.0344	0.0130	0.0094
	1988	0.2080	0.3086	0.1786	0.0852	0.0218	0.0419	0.0145	0.0192
	1989	0.1769	0.2780	0.3474	0.0976	0.0258	0.0190	0.0119	0.0112
	1990	0.1434	0.2095	0.3325	0.1492	0.0609	0.0136	0.0266	0.0256
	1991	0.0593	0.2965	0.2942	0.1994	0.0337	0.0430	0.0000	0.0000
	1992	0.3466	0.1791	0.2132	0.1085	0.0542	0.0554	0.0000	0.0118
	1993	0.2148	0.4172	0.1270	0.0328	0.0273	0.0097	0.0000	0.0000
	1994	0.2883	0.3098	0.1396	0.1009	0.0138	0.0122	0.0000	0.0061
	1995	0.1566	0.3066	0.3005	0.0988	0.0300	0.0050	0.0097	0.0050
	1996	0.4007	0.2138	0.0963	0.0288	0.0214	0.0000	0.0066	0.0033
	1997	0.1913	0.5295	0.1196	0.0533	0.0357	0.0119	0.0079	0.0059
	1998	0.1166	0.2199	0.3866	0.1513	0.0378	0.0116	0.0055	0.0000
	1999	0.1360	0.1349	0.2469	0.1462	0.1903	0.0297	0.0754	0.0297
	2000	0.2089	0.3896	0.1530	0.0461	0.0205	0.0410	0.0000	0.0183
	2001	0.0791	0.4157	0.2510	0.1036	0.0528	0.0367	0.0000	0.0156
	2002	0.3547	0.2245	0.1601	0.1034	0.0337	0.0137	0.0089	0.0132
	2003	0.2764	0.2748	0.1433	0.0662	0.0351	0.0255	0.0112	0.0042
	2004	0.2130	0.2927	0.2513	0.0693	0.0406	0.0537	0.0160	0.0021
	2005	0.2335	0.2851	0.1876	0.1601	0.0768	0.0062	0.0000	0.0168
	2006	0.1299	0.3054	0.2935	0.1675	0.0535	0.0114	0.0142	0.0105
	2007	0.0996	0.2000	0.3114	0.2472	0.0754	0.0316	0.0095	0.0032

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Appendix C5.–Page 2 of 2.

Var name:	Year	rpw.3	rpw.4	rpw.5	rpw.6	rpw.7	rpw.8	rpw.9	rpw.10
Conventional name:	Year	6/10/–6/16	6/17–6/23	6/24–6/30	7/1–7/7	7/8–7/14	7/15–7/21	7/22–7/28	7/29–8/26
	2008	0.1524	0.2931	0.3057	0.1183	0.0431	0.0334	0.0083	0.0139
	2009	0.1955	0.2830	0.3460	0.0753	0.0323	0.0164	0.0000	0.0049
	2010	0.2190	0.3755	0.1517	0.1335	0.0556	0.0185	0.0113	0.0103
	2011	0.1188	0.2976	0.1996	0.1695	0.0818	0.0130	0.0000	0.0031
	2012	0.0508	0.2964	0.3308	0.2114	0.0627	0.0201	0.0088	0.0127
	2013	0.1681	0.3708	0.2654	0.0963	0.0743	0.0108	0.0000	0.0000
	2014	0.2834	0.2370	0.1217	0.0771	0.0148	0.0146	0.0000	0.0029
	2015	0.1859	0.2292	0.1520	0.1316	0.0625	0.0591	0.0338	0.0238
	2016	0.1696	0.1830	0.2085	0.1385	0.0722	0.0296	0.0197	0.0112
	2017	0.0899	0.2067	0.3202	0.1459	0.1117	0.0473	0.0266	0.0265
	2018	0.1979	0.1706	0.3085	0.174	0.0539	0.0231	0.0175	0.0108
	2019	0.1478	0.3298	0.2459	0.0473	0.0591	0.0165	0.0106	0.0000
	2020	0.1327	0.1895	0.2331	0.1599	0.1398	0.0435	0.0073	0.0124
	2021	0.1722	0.1931	0.2705	0.1270	0.1275	0.0284	0.0096	0.0000
	2022	0.1366	0.2747	0.3244	0.1117	0.0776	0.0170	0.0234	0.0000
	2023	0.0689	0.3084	0.3165	0.1326	0.0965	0.0343	0.0097	0.0061

Note: En dash means no data.

Appendix C6.–Chinook salmon catch and effort (permit-hours) for Kuskokwim River District W-1.

		Week 3 6/10–6/16			Week 4 6/17–6/23			Week 5 6/24–6/30		
Var name:	Year	chw.3	cew.3	cfw.3	chw.4	cew.4	cfw.4	chw.5	cew.5	cfw.5
Conventional name:	Year	Catch	Effort	Net	Catch	Effort	Net	Catch	Effort	Net
	1976	0	0	0	20,010	5,724	1	4,143	2,088	2
	1977	12,458	2,802	1	16,227	2,904	1	1,841	4,722	2
	1978	18,483	3,972	1	10,066	2,004	1	3,723	5,346	2
	1979	24,633	6,432	1	5,651	3,012	2	3,860	6,438	2
	1980	9,891	2,814	1	21,698	5,364	4	1,460	2,448	2
	1981	29,882	6,180	1	3,830	3,066	2	4,563	5,952	2
	1982	4,912	2,784	1	24,628	5,970	1	12,555	5,176	4
	1983	13,406	5,634	1	8,063	5,544	2	4,925	5,958	2
	1984	0	0	0	17,181	5,562	1	5,643	5,616	2
	1985	0	0	0	6,519	2,538	3	19,204	5,880	3
	1986	0	0	0	0	0	0	11,986	6,540	3
	1987	0	0	0	19,126	4,734	3	0	0	0
	1988	12,640	4,816	3	11,708	3,672	3	15,060	7,518	3
	1989	0	0	0	15,215	5,208	3	11,094	6,144	3
	1990	0	0	0	16,690	3,780	3	25,459	7,536	3
	1991	0	0	0	13,813	3,606	3	12,612	3,696	3
	1992	0	0	0	24,334	9,488	3	16,307	8,628	3
	1993	0	0	0	0	0	0	8,184	4,976	3
	1994	0	0	0	0	0	0	14,221	4,608	3
	1995	0	0	0	6,895	2,276	3	14,424	4,532	3
	1996	0	0	0	4,091	1,056	3	666	360	3
	1997	0	0	0	10,023	2,118	3	0	0	0
	1998	0	0	0	0	0	0	12,771	4,584	3
	1999	0	0	0	0	0	0	4,668	2,454	3
	2000	0	0	0	0	0	0	0	0	0
	2001	0	0	0	0	0	0	0	0	0
	2002	0	0	0	0	0	0	0	0	0
	2003	0	0	0	0	0	0	0	0	0
	2004	0	0	0	0	0	0	520	104	3
	2005	0	0	0	0	0	0	3,531	1,189	3
	2006	0	0	0	0	0	0	2,493	1,038	3
	2007	0	0	0	0	0	0	0	0	0
	2008	0	0	0	6,415	1,026	3	2,362	783	3
	2009	0	0	0	3,003	668	3	2,539	752	3
	2010	0	0	0	0	0	0	1,724	1,324	5
	2011	0	0	0	0	0	0	0	0	0
	2012	0	0	0	0	0	0	0	0	0
	2013	0	0	0	0	0	0	0	0	0
	2014	0	0	0	0	0	0	0	0	0
	2015	0	0	0	0	0	0	0	0	0
	2016	0	0	0	0	0	0	0	0	0
	2017	0	0	0	0	0	0	0	0	0
	2018	0	0	0	0	0	0	0	0	0
	2019	0	0	0	0	0	0	0	0	0
	2020	0	0	0	0	0	0	0	0	0
	2021	0	0	0	0	0	0	0	0	0
	2022	0	0	0	0	0	0	0	0	0
	2023	0	0	0	0	0	0	0	0	0

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		Week 6 7/1–7/7			Week 7 7/8–7/14			Week 8 7/15–7/21			Week 9 7/22–7/28		
Var name:	Year	chw.6	cew.6	cfw.6	chw.7	cew.7	cfw.7	chw.8	cew.8	cfw.8	chw.9	cew.9	cfw.9
Conventional name:	Year	Catch	Effort	Net	Catch	Effort	Net	Catch	Effort	Net	Catch	Effort	Net
	1976	1,550	2,490	2	1,238	4,548	2	236	1,590	2	0	0	0
	1977	673	4,194	2	153	2,310	2	0	0	0	0	0	0
	1978	2,354	8,676	2	153	2,310	2	0	0	0	0	0	0
	1979	1,233	3,252	2	470	3,120	2	0	0	0	0	0	0
	1980	498	2,298	2	445	2,586	2	0	0	0	0	0	0
	1981	2,795	5,520	2	941	2,640	2	0	0	0	0	0	0
	1982	1,970	3,968	2	1,055	4,734	2	0	0	0	0	0	0
	1983	2,415	5,634	2	633	2,796	2	0	0	0	0	0	0
	1984	3,206	5,454	2	2,069	5,592	2	744	2,238	2	0	0	0
	1985	9,942	5,844	3	0	0	0	0	0	0	0	0	0
	1986	5,029	6,852	3	1,156	3,192	3	0	0	0	0	0	0
	1987	9,606	6,948	3	1,910	3,582	3	2,758	6,720	3	0	0	0
	1988	5,871	6,954	3	5,270	10,794	3	1,728	6,636	3	662	6,276	3
	1989	7,911	7,092	3	6,043	10,962	3	868	2,622	3	210	3,372	3
	1990	4,071	3,546	3	4,931	8,534	3	0	0	0	0	0	0
	1991	8,068	7,308	3	904	3,426	3	452	3,408	3	419	7,522	3
	1992	3,250	4,696	3	0	0	0	0	0	0	0	0	0
	1993	0	0	0	0	0	0	0	0	0	0	0	0
	1994	0	0	0	578	1,984	3	441	3,000	3	538	6,348	3
	1995	4,368	3,824	3	1,452	3,716	3	568	3,488	3	0	0	0
	1996	861	836	3	408	896	3	251	1,195	3	307	6,398	3
	1997	0	0	0	0	0	0	0	0	0	0	0	0
	1998	2,277	1,780	3	1,127	1,668	3	0	0	0	816	4,296	3
	1999	0	0	0	0	0	0	0	0	0	0	0	0
	2000	357	896	3	0	0	0	0	0	0	0	0	0
	2001	0	0	0	0	0	0	0	0	0	0	0	0
	2002	0	0	0	0	0	0	0	0	0	0	0	0
	2003	0	0	0	0	0	0	0	0	0	0	0	0
	2004	1,107	446	3	0	0	0	0	0	0	127	360	3
	2005	874	604	3	0	0	0	0	0	0	0	0	0
	2006	0	0	0	0	0	0	0	0	0	0	0	0
	2007	0	0	0	0	0	0	0	0	0	0	0	0
	2008	19	4	3	1	6	3	0	6	0	0	12	0
	2009	762	519	3	113	436	3	83	672	3	58	752	3
	2010	290	522	3	271	686	3	186	958	3	176	1,632	3
	2011	361	634	5	227	996	5	129	1,226	5	24	1,668	5
	2012	0	0	0	45	604	5	195	1,616	5	39	1,464	5
	2013	0	0	0	0	0	0	139	2,018	5	21	1,556	5
	2014	0	0	0	14	584	5	14	2,276	5	0	0	0
	2015	0	0	0	0	0	0	0	0	0	0	0	0
	2016	0	0	0	0	0	0	0	0	0	0	0	0
	2017	0	0	0	0	0	0	0	0	0	0	0	0
	2018	0	0	0	0	0	0	0	0	0	0	0	0
	2019	0	0	0	0	0	0	0	0	0	0	0	0
	2020	0	0	0	0	0	0	0	0	0	0	0	0
	2021	0	0	0	0	0	0	0	0	0	0	0	0
	2022	0	0	0	0	0	0	0	0	0	0	0	0
	2023	0	0	0	0	0	0	0	0	0	0	0	0

Note: Key to column net:

1 = Gillnet mesh size unrestricted.
2 = Gillnets were restricted to 6" or less - old gear.
3 = Gillnets were restricted to 6" or less - new gear.
4 = Both unrestricted and restricted mesh size periods in the week.
5 = Personal use harvest was also included in the catch and effort calculation.

APPENDIX D: ADMB TMB COMPARISON

Appendix D1.–Comparisons of model Parameters between ADMB and TMB.

	ADMB		TMB	
	Estimate	SD	Estimate	SD
Weir projects (*k*)				
Kwethluk weir	2.73310	0.09107	2.73309	0.09107
Tuluksak weir	5.04545	0.08252	5.04544	0.08252
George weir	3.53961	0.07946	3.53960	0.07946
Kogrukluk weir	2.63481	0.07455	2.63480	0.07455
Tatlawiksuk weir	4.19693	0.08697	4.19693	0.08697
Takotna weir	5.80118	0.08377	5.80117	0.08377
Aerial survey (*k*)				
Kwethluk River	4.42560	0.18023	4.42560	0.18023
Kisaralik River	5.12484	0.12252	5.12483	0.12252
Tuluksak River	6.11187	0.18924	6.11185	0.18924
Salmon (Aniak River)	5.35570	0.11494	5.35569	0.11494
Kipchuk River	4.99678	0.12180	4.99677	0.12180
Aniak River	4.08219	0.12769	4.08218	0.12768
Holokuk River	6.24383	0.13869	6.24383	0.13869
Oskawalik River	6.45998	0.12802	6.45998	0.12802
Holitna River	4.54249	0.13162	4.54248	0.13162
Cheeneetnuk River	5.39243	0.12287	5.39242	0.12287
Gagaryah River	5.82530	0.12178	5.82530	0.12178
Pitka Fork	6.50215	0.15382	6.50215	0.15382
Bear River	6.23124	0.13492	6.23124	0.13492
Salmon(Pitka Fork)	4.80798	0.11191	4.80797	0.11191
Catchability (*q*)				
Unrestricted	-9.49165	0.14756	-9.49164	0.14756
Restricted	-10.04080	0.08543	-10.04080	0.08543
Additional variance				
Weir	-1.15937	0.07225	-1.15937	0.07225
Aerial	-0.45674	0.04801	-0.45674	0.04801
Catch	-0.8671	0.1360	-0.86705	0.13599

Appendix D2.–Comparisons of model total run (log scale) estimate between ADMB and TMB.

	ADMB		TMB	
Year	Estimate	SD	Estimate	SD
1976	12.211	0.124	12.211	0.124
1977	12.690	0.177	12.690	0.177
1978	12.386	0.115	12.386	0.115
1979	12.394	0.159	12.394	0.159
1980	12.805	0.251	12.805	0.251
1981	12.662	0.157	12.662	0.157
1982	11.873	0.068	11.873	0.068
1983	11.910	0.102	11.910	0.102
1984	12.059	0.118	12.059	0.118
1985	11.885	0.102	11.885	0.102
1986	11.735	0.147	11.735	0.147
1987	12.112	0.114	12.112	0.114
1988	12.255	0.074	12.255	0.074
1989	12.278	0.099	12.278	0.099
1990	12.510	0.078	12.510	0.078
1991	12.286	0.083	12.286	0.083
1992	12.473	0.071	12.473	0.071
1993	12.539	0.099	12.539	0.099
1994	12.923	0.135	12.923	0.135
1995	12.833	0.108	12.833	0.108
1996	12.635	0.115	12.635	0.115
1997	12.614	0.100	12.614	0.100
1998	12.159	0.136	12.159	0.136
1999	11.994	0.101	11.994	0.101
2000	11.773	0.061	11.773	0.061
2001	12.242	0.082	12.242	0.082
2002	12.321	0.072	12.321	0.072
2003	12.358	0.056	12.358	0.056
2004	12.806	0.062	12.806	0.062
2005	12.695	0.052	12.695	0.052
2006	12.676	0.059	12.676	0.059
2007	12.410	0.050	12.410	0.050
2008	12.272	0.061	12.272	0.061
2009	12.149	0.065	12.149	0.065
2010	11.639	0.046	11.639	0.046
2011	11.663	0.052	11.663	0.052
2012	11.307	0.097	11.307	0.097
2013	11.343	0.052	11.343	0.052
2014	11.347	0.075	11.347	0.075
2015	11.742	0.063	11.742	0.063
2016	11.788	0.070	11.788	0.070
2017	11.788	0.077	11.788	0.077
2018	11.793	0.113	11.793	0.113
2019	12.300	0.104	12.300	0.104
2020	11.735	0.095	11.735	0.095
2021	11.777	0.146	11.777	0.146
2022	11.869	0.142	11.869	0.142
2023	11.806	0.115	11.806	0.115

Appendix D3.–2023 TMB-code with annotations.

```
#include <TMB.hpp>
// square function
template<class Type>
Type square(Type x){
  return pow(x,2);
}

// sqrt function
template<class Type>
Type sqrt(Type x){
  return pow(x,0.5);
}

template<class Type>
Type objective_function<Type>::operator() ()
{
//--------------------------------------------------------------------------------
// 1.0  Data Entry
//--------------------------------------------------------------------------------
  DATA_INTEGER(nyear);  // The number of years
  DATA_INTEGER(nweir);  // The number of years
  DATA_INTEGER(naerial);  // The number of years
  DATA_VECTOR(tcatch);    // Sum of all Catches
// Read Drainage wide total run size data
  DATA_VECTOR(inriv);            // Total River MR Estimates
  DATA_VECTOR(inriv_sd);         // Total River MR SD
// Read Weir data
  DATA_MATRIX(w_esc);  // Weir Escapement
// Read Aerial data
  DATA_MATRIX(a_esc);  // Aerial  Escapement
// Read Weekly Commercial  data
  DATA_MATRIX(cpue);     // CPUE by fishery
  DATA_MATRIX(testp);   //  prop of run by fishery

//--------------------------------------------------------------------------------
// 2.0  Define parameters
//--------------------------------------------------------------------------------
  PARAMETER_VECTOR(log_trun);    //log drainage-wise run
  PARAMETER_VECTOR(log_wesc);    //log slope for weir
  PARAMETER_VECTOR(log_aesc);    //log slope for aerial
  PARAMETER(log_cvw);  //log cv for weir
  PARAMETER(log_cva);  //log cv for aerial
  PARAMETER_VECTOR(log_q);      // log catchability  model1
  PARAMETER(log_cvq);      // log sd cpue model1

//--------------------------------------------------------------------------------
//  2.1  Transformed parrameters
//--------------------------------------------------------------------------------
  vector<Type> t_run=exp(log_trun);           //Total run
  vector<Type> wesc=exp(log_wesc);     // slope for weir model
  vector<Type> aesc=exp(log_aesc);     // slope for aerial model
  vector<Type> q=exp(log_q);             // slope for catchability
```

```
  vector<Type> esc(nyear);
  Type sd2 = sqrt(log(square(exp(log_cvw))+1));
  Type sd3 = sqrt(log(square(exp(log_cva))+1));
  Type sd4 = sqrt(log(square(exp(log_cvq))+1));

//==== Likelihood Parameters ===============================================
// Set temprary vector and initialize to 0
  vector<Type>  tfw(nweir);  // Weir likelihood
  vector<Type>  tfa(naerial); // Aerial likelihood
  vector<Type>  tfc(2);  // Com catch likelihood
  Type tfr = 0.0;
  tfw.setZero();
  tfa.setZero();
  tfc.setZero();

//===============================================================================
// 3.0 Likeihood
//===============================================================================
 for (int i=0; i<nyear; i++)
   {
     esc(i)=t_run(i)-tcatch(i);
// ===  Total Run ==============================================================
// Total run
  if(inriv(i)>0)
     {
   Type sd1 = sqrt(log(square(inriv_sd(i)/inriv(i))+1));
    tfr -= dnorm(log(inriv(i)),log(t_run(i)),sd1,true);
      }
//============= Escapement =====================================================
// Weir escapement
  for(int j=0;j<nweir;j++)
   {
      if(w_esc(j,i)>0)
     {
      tfw(j) -= dnorm(log(w_esc(j,i)),log(esc(i)/wesc(j)),sd2,true);
     }
   }
  for(int j=0;j<naerial;j++)
  {
// Aerial escapement
      if(a_esc(j,i)>0)
     {
      tfa(j) -= dnorm(log(a_esc(j,i)),log(esc(i)/aesc(j)),sd3,true);
     }
   }
//===  CPUE ====================================================================
      if(cpue(0,i)>0)
      {
      tfc(0) -= dnorm(log(cpue(0,i)/testp(0,i)),log(q(0)*t_run(i)),sd4,true);
      }
      if(cpue(2,i)>0)
      {
      tfc(1) -= dnorm(log(cpue(2,i)/testp(2,i)),log(q(1)*t_run(i)),sd4,true);
      }
  }
```

```
// Sum all likelihood ===========================================================
  Type f = tfr+sum(tfw)+sum(tfa)+sum(tfc);
//-------------------------------------------------------------------------------
// 4.0   REPORT_SECTION
//-------------------------------------------------------------------------------
  ADREPORT(t_run);
  ADREPORT(esc);
  REPORT(f);
  REPORT(tfw);
  REPORT(tfa);
  REPORT(tfc);
  REPORT(tfr);
  return f;
  }
```