**Regional Information Report No. 3A22-02**

# 2021 Kuskokwim River Chinook Salmon Run Reconstruction and 2022 Forecast

**by**

**Sean Larson**

**April 2022**

**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, $\chi^2$, 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 |

*REGIONAL INFORMATION REPORT NO. 3A22-02*

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# ABSTRACT

A maximum likelihood model was used to estimate the 2021 drainagewide run size and escapement of Kuskokwim River Chinook salmon (*Oncorhynchus tshawytscha*). The total run was estimated to be 129,751 (95% CI: 94,489–178,171) fish and escapement was estimated to be 101,000 (95% CI: 65,738–149,420) fish. Model estimates were informed by direct observations of the 2021 escapement at 3 weirs and 2021 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 2021 run and escapement. The 2021 total run of Chinook salmon was below the 1976–2020 average of 214,475 fish. The drainagewide sustainable escapement goal of 65,000–120,000 was met in 2021. The 2022 Kuskokwim River Chinook salmon forecast is for a range of 99,000–161,000 fish.



Key words: 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 2021. 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, and it was determined that the existing goal range was appropriate for this stock (Liller and Savereide 2018). 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 also 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 2021 3-system abundance estimate was provided to the NPFMC on September 22, 2021 (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 are 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 2021.

# 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 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.

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 simplify the description of the estimation process and was based on the type of data used in the model: (1)

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

escapement, (2) commercial catch and effort, and (3) direct estimates of total run size for model scaling.

## ESCAPEMENT COUNTS

Assuming 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:

$$\hat{e}_{ijy}=E_y/k_{ij}, \tag{2}$$

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:

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

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:

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

The proportion of Chinook salmon available for harvest each week and observed at 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 1984–2020.

## 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 in Liller et al. (2018).

## LIKELIHOOD MODEL

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

$$
L(\theta|data) = \begin{aligned}
&\text{Escapement Counts} \\
&+\sum_{y}\sum_{i}\sum_{j}\left( ln(\sigma_j) + 0.5\left(\frac{ln(\hat{e}_{ijy}) - ln(e_{ijy})}{\sigma_j}\right)^2\right) \\
&\text{Adjusted Commercial CPUE} \\
&+\sum_{y}\sum_{k}\left( ln(\sigma_k) + 0.5\left(\frac{ln(\widehat{CPUE}_{ky}) - ln(CPUE_{ky})}{\sigma_k}\right)^2\right) \\
&\text{Drainagewide Run} \\
&+\sum_{y}\left( 0.5\left(\frac{ln(\hat{N}_y) - ln(N_y)}{\sigma_y}\right)^2\right),
\end{aligned} \tag{5}
$$

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 2021. Model estimates in 2021 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 1979–2021 (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 1984–2021 and harvest and effort, by week, for Kuskokwim River District W-1 from 1976–2021 (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 2021.

The subsistence harvest estimate used to produce the preliminary run reconstruction estimate in September 2021 has changed. The preliminary run estimate relied on a "best guess" of 27,416 Chinook salmon harvested for subsistence purposes. Since that time, postseason subsistence harvest surveys have been completed, and the harvest was estimated to be 28,365 (95% CI 25,933–30,797; 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 run reconstruction model was informed by 6 weirs and 14 aerial survey index locations (Table 1). In 2021, 3 of 6 weirs operated and 0 of 14 aerial surveys were successfully flown. Weirs located on the George, Kogrukluk, and Takotna rivers operated. The Kwethluk River weir did not operate due to logistical challenges and weirs located on the Tuluksak and Tatlawiksuk rivers have not operated in recent years due to funding limitations. No aerial surveys were flown in 2021 due to persistent inclement weather when flights were scheduled, i.e., during peak spawning. This was the first year no aerial surveys were flown since at least 1976.

Harvest data came from subsistence and test fishery catches. The preliminary subsistence harvest of 28,365 (95% CI 25,933–30,797) Chinook salmon in 2021 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 386 Chinook salmon were caught in the Bethel test fishery. No commercial or sport fish harvest of Kuskokwim River Chinook salmon occurred during the 2021 season.

Escapement estimates and observations during 2021 indicated that the Chinook salmon escapement throughout the Kuskokwim River was generally less than prior years. In 2021, all projects reported lower escapements than the 2016–2020 averages and 1 out of 3 escapement projects reported lower escapement than the 2011–2020 averages. Escapement at all 3 projects was lower than the long-term 1976–2020 averages (Table 1).

There were 9 tributaries with established escapement goals in 2021 (Liller and Savereide 2018). Of those, only the escapement goals on the George and Kogrukluk rivers were assessed, and both were met. The escapement goal on the Kwethluk River was not assessed because the weir did not operate and the remaining tributary escapement goals were not assessed because no aerial surveys were flown in 2021.

## MODEL RESULTS

The 2021 Kuskokwim River Chinook salmon drainagewide run was an estimated 129,751 (95% CI: 94,489–178,171) fish (Table 2; Figure 2). Based on the 2021 model run, the total run in 2021 was 40% less than the 1976–2020 average of 214,475 Chinook salmon. CV for the 2021 total run was estimated to be 16%, which was larger than the 1976–2020 average of 10% (range: 5–25%; 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 2021 Kuskokwim River Chinook salmon drainagewide escapement was an estimated 101,000 (95% CI: 65,738–149,420) fish (Table 2). Based on the 2021 model run, the total escapement in 2021 was 23% less than the 1976–2020 average of 131,184 Chinook salmon. The total escapement in 2021 was greater than 17 of 45 (38%) prior years. Acknowledging that uncertainty in the drainagewide escapement was relatively high, the 95% confidence range of 65,738–149,420 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 2021 model run represents the most informed historical time series of total run and escapement and supersedes previous estimates. Estimates of total annual abundance from 1976–2020, generated by the 2021 model run, were compared against the estimates reported by Larson 2021 (Table 2). The difference between total annual run and escapement estimates changed by an average of 0.24% and 0.41%, respectively, across all years (1976–2020). The absolute difference between pairs of annual total run estimates ranged between 0–18,484[2] fish (average = 738). The long-term (1976–2020) averages for both total run and escapement differed by 636 fish between the 2021 and 2020 model runs.

## UNCERTAINTY IN 2021 MODEL ESTIMATES

There was relatively high level of uncertainty associated with the 2021 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 2021 (3 total projects) was at the 45$^{th}$ percentile (median 11; range: 2–20) over the 45 years (1976–2020) of available data, which would suggest a limited amount of information to update the model and a relatively high level of uncertainty. However, each project provided a similar 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 2021, estimates of drainagewide Chinook salmon escapements derived from individual weir projects were 96,000–105,000 fish (Table 3; Figure 5).

The sensitivity of the 2021 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 maximum observed difference between annual run estimates was less than 3 fish. Results for all parameter starting values confirmed the 2021 model run was not sensitive to starting values and the total run estimates presented represent the best fit model.

The full sensitivity of model results to the limited 2021 escapement data was explored using a "leave one-out approach (Figure 6). Specifically, the model was run with the removal of a single escapement project at a time. Running the model without the Takotna River weir served the purpose of investigating model sensitivity to headwaters projects. Early season management actions to close or heavily restrict Chinook salmon harvest during the early portion of the run (commonly referred to as the "front-end closure") have been implemented annually since 2014 (codified in regulation in 2016 5 AAC 07.365 *Kuskokwim River Salmon Management Plan*). These annual front-end-closures have resulted in disproportionately large escapements to the headwaters, compared to other areas in the drainage, and concern that the model may be overestimating total escapement when headwaters escapement data are included. All point estimates fell within the 95% confidence interval of the base model. Confidence intervals overlapped in all scenarios. When the Takotna River weir (headwaters data) was removed from the model, the total run estimate of about 127,000 fish was similar to the estimate produced using all available data. No aerial surveys were flown in 2021 so their effect could not be evaluated. These comparisons are not meant to lend more or less credibility to specific escapement data sources but rather show the importance of having a comprehensive assessment program to inform the run reconstruction model.

## 2021 RUN RECONSTRUCTION MODEL CONCLUSIONS

- The total run of Kuskokwim River Chinook salmon was estimated to be 129,751 (95% CI: 94,489–178,171) fish.

[2] In preparation for the 2021 model run, historical data were reviewed. The 1996 Takotna River weir estimates was determined to be of insufficient quality to inform the run reconstruction and was removed. This correction to the historical model input dataset resulted in relatively large change (18,484 or 5.7% difference) in the 1996 total run estimate.

- Total run abundance was below the 1976–2020 average of 214,475 fish and below 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.
- Total escapement of Kuskokwim River Chinook salmon was estimated to be 101,000 (95% CI: 65,738–149,420) fish, and the drainagewide sustainable escapement goal of 65,000–120,000 was met.

## 2022 CHINOOK SALMON RUN FORECAST

The 2022 Kuskokwim River Chinook salmon forecast is for a range of 99,000–161,000 fish. The forecast range is equal to ±24% of the 2021 total run, as presented in this report. Uncertainty in the forecast (i.e., ±24%) is based on the 2015–2021 (7-year) average percent error between forecasted and actual run estimates. Interestingly, when using data from 1976–2021, the average percent error between forecasted and actual run estimates (23%) is nearly identical to the 7-year average percent error. Despite several years of similar run sizes since 2015, the 2019 run was well above forecast, and the 2020 run was well below forecast, both of which contributed to increased uncertainty in the 2022 forecast.

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[3] 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 2022 forecast produced by ADF&G and can be used to make explicit predictions about the 2022 run before the availability of inseason assessment data. The ADF&G 2022 forecast (based on the 7-year average percent error) represents approximately the central 60% of probable run size predictions identified through the *P*-star model. There is a 20% chance the 2021 run size will return

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

smaller than 97,000 and a 20% chance the run will return larger than 159,000 (Table 5). The *P*-star model indicated that there is a 95% chance the 2022 run size will be less than 202,000, which is less than the average run size (1976–2020 average run size is 214,475). Stated more simply, there is a high probability that the 2022 run will be smaller than average. However, the *P*-star model provides considerable evidence that the 2022 run size will be large enough to meet the drainagewide escapement goal and allow some harvest. There is a 99% chance the 2022 run size will be equal to or exceed 63,000, which is a run size just below the lower bound of the escapement goal. There is a 55% 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[4] (Table 5).

Preseason expectations of Chinook salmon harvestable surplus in 2022 are highly uncertain. Simple subtraction of the drainagewide escapement goal (65,000–120,000) from the ADF&G forecast (94,000–155,000) would suggest a harvest outlook anywhere between 0–96,000 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 2022. 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 2022 Chinook salmon run will be large enough to meet escapement needs and provide for some harvest. The dominant brood years contributing to the 2022 run will be 2016–2018. These brood years will return fish that are age-4 (2018 brood), age-5 (2017 brood), and age-6 (2016 brood). The actual number of each age class that will return in 2022 is not known with certainty, but the drainagewide escapement goal was achieved in each of the contributing brood years. Drainagewide escapement was estimated to be 99,460 fish in 2016, 114,973 fish in 2017, and 112,980 fish in 2018 (Table 6). The drainagewide escapement goal on the Kuskokwim River was designed to maximize the probability that future run sizes are large enough to meet escapement and harvest needs.

Stock productivity trends should be considered when using this forecast to plan preseason management of the 2022 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 have produced on average 3 recruits per spawner (Table 6; Figure 7).

## FUTURE MODEL CONSIDERATIONS

Improvements to the Chinook salmon run reconstruction model are being explored. 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 led to lower exploitation and higher escapements for headwater stocks than were observed before 2014. As a result, the observed

[4] Percentages presented in this text are rounded.

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. Also, the Kuskokwim River sonar is an assessment tool that has been fully operational since 2018. The sonar provides valuable salmon passage data at a site approximately 20 km upriver from Bethel. The appropriateness of using sonar data as an additional model input will continue to be explored. ADF&G will engage and report out to stakeholders and ensure an appropriate level of review if any changes to the current model are adopted.

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# REFERENCES CITED

Bue, B. G., K. L. Schaberg, Z. W. Liller, and D. B. Molyneaux. 2012. Estimates of the historic run and escapement for the Chinook salmon stock returning to the Kuskokwim River, 1976–2011. Alaska Department of Fish and Game, Fishery Data Series No. 12-49, Anchorage.

Clark, J. N., and N. J. Smith. 2019. 2017 inriver abundance and run timing of Kuskokwim River Chinook salmon. Alaska Department of Fish and Game, Fishery Data Series No. 19-21, Anchorage.

Fournier, D. A., H. J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M. N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optimization Methods and Software 27:233–249.

Hamazaki, T., M. J. Evenson, S. J. Fleischman, and K. L. Schaberg. 2012. Escapement goal recommendation for Chinook salmon in the Kuskokwim River Drainage. Alaska Department of Fish and Game, Fishery Manuscript No. 12-08, Anchorage.

Larson, S. 2021. 2020 Kuskokwim River Chinook salmon run reconstruction and 2021 forecast. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 3A21-02, Anchorage.

Liller, Z. W., T. Hamazaki, G. Decossas, W. Bechtol, M. Catalano, and N. J. Smith. 2018. Kuskokwim River Chinook salmon run reconstruction model revision – executive summary. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 3A18-04, Anchorage.

Liller, Z. W., and J. W. Savereide. 2018. Escapement goal recommendations for select Arctic-Yukon-Kuskokwim Region salmon stocks, 2019. Alaska Department of Fish and Game, Fishery Manuscript No. 18-08, Anchorage.

R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Schindler, D. E., T. E. Walsworth, M. D. Adkison, R. M. Peterman, and A. E. Punt. 2019. Kuskokwim River Chinook salmon run-reconstruction and stock recruitment models: a review by an independent expert panel. Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative, Anchorage.

Smith, N. J. 2019. 2018 Kuskokwim River Chinook salmon run reconstruction and 2019 forecast. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 3A19-02, Anchorage.

# REFERENCES CITED (Continued)

Smith, N. J., and Z. W. Liller. 2018. 2017 Kuskokwim River Chinook salmon run reconstruction and 2018 forecast. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 3A18-02, Anchorage.

Shelden, C. A., T. Hamazaki, M. Horne-Brine, and G. Roczicka. 2016. Subsistence salmon harvests in the Kuskokwim area, 2015. Alaska Department of Fish and Game, Fishery Data Series No. 16-55, Anchorage.

Shotwell, S. K., and M. D. Adkison. 2004. Estimating indices of abundance and escapement of Pacific salmon for data-limited situations. Transactions of the American Fisheries Society 133:538-558.

Staton, B. A., and M. J. Catalano. 2019. Bayesian information updating procedures for Pacific salmon run size indicators: Evaluation in the presence and absence of auxiliary migration timing information. Canadian Journal of Fisheries and Aquatic Sciences 76(10):1719-1727.

# 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 (1976–2021) | Historical average (1976–2020) | 10-yr average (2011–2020) | 5-yr average (2016–2020) | 2020 | 2021 |
|---|---|---|---|---|---|---|---|
| Weir | Kwethluk | 15 | 9,432 | 6,224 | 7,856 | – | – |
| | Tuluksak | 21 | 985 | 519 | 779 | – | – |
| | George | 23 | 3,505 | 2,598 | 3,091 | 2,418 | 2,920 |
| | Kogrukluk | 35 | 9,702 | 6,443 | 7,417 | 5,645 | 6,969 |
| | Tatlawiksuk | 18 | 1,692 | 1,663 | 2,420 | – | – |
| | Takotna | 21 | 406 | 275 | 359 | 357 | 323 |
| Aerial survey | Kwethluk | 12 | 2,061 | 943 | – | 721 | – |
| | Kisaralik | 27 | 1,082 | 642 | 655 | 350 | – |
| | Tuluksak | 11 | 421 | – | – | – | – |
| | Salmon (Aniak) | 34 | 784 | 408 | 521 | 269 | – |
| | Kipchuk | 28 | 1,018 | 768 | 995 | 723 | – |
| | Aniak | 25 | 2,576 | 1,773 | 1,691 | 1,264 | – |
| | Holokuk | 19 | 333 | 164 | 244 | 99 | – |
| | Oskawalik | 24 | 285 | 163 | 248 | 169 | – |
| | Holitna | 24 | 1,483 | 891 | 1,009 | 854 | – |
| | Cheeneetnuk | 27 | 689 | 462 | 641 | 419 | – |
| | Gagaryah | 27 | 486 | 312 | 447 | – | – |
| | Pitka | 15 | 242 | 256 | 299 | 160 | – |
| | Bear | 21 | 262 | 385 | 497 | 321 | – |
| | Salmon (Pitka) | 34 | 1,065 | 1,252 | 1,346 | 1,150 | – |
| Harvest | Subsistence | 46 | 64,384 | 30,251 | 28,625 | 35,846 | 28,365 |
| | Commercial | 46 | 17,885 | 159 | 0 | 0 | 0 |
| | Sport | 45 | 420 | 58 | 0 | 0 | 0 |
| | Test fishery | 46 | 612 | 403 | 440 | 355 | 386 |

*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 2021 run reconstruction model.

| | 2021 Model run | | | | 2021 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 | 206,497 | 159,586 | 267,197 | 206,588 | 115,950 | 69,039 | 176,650 | 116,041 |
| 1977 | 326,456 | 232,630 | 458,124 | 326,025 | 232,749 | 138,923 | 364,417 | 232,318 |
| 1978 | 238,287 | 189,742 | 299,252 | 237,858 | 154,815 | 106,270 | 215,780 | 154,386 |
| 1979 | 237,200 | 170,555 | 329,888 | 236,265 | 140,898 | 74,253 | 233,586 | 139,963 |
| 1980 | 364,886 | 225,891 | 589,408 | 364,915 | 267,918 | 128,923 | 492,440 | 267,947 |
| 1981 | 311,648 | 226,301 | 429,183 | 310,624 | 201,249 | 115,902 | 318,784 | 200,225 |
| 1982 | 143,792 | 126,113 | 163,948 | 143,849 | 36,791 | 19,112 | 56,947 | 36,848 |
| 1983 | 148,623 | 122,379 | 180,496 | 148,494 | 66,478 | 40,234 | 98,351 | 66,349 |
| 1984 | 175,387 | 137,056 | 224,439 | 175,454 | 86,211 | 47,880 | 135,263 | 86,278 |
| 1985 | 145,221 | 117,927 | 178,832 | 145,166 | 63,294 | 36,000 | 96,905 | 63,239 |
| 1986 | 124,380 | 94,000 | 164,579 | 124,134 | 53,768 | 23,388 | 93,967 | 53,522 |
| 1987 | 183,056 | 146,919 | 228,082 | 182,733 | 78,813 | 42,676 | 123,839 | 78,490 |
| 1988 | 207,428 | 179,423 | 239,805 | 207,057 | 79,665 | 51,660 | 112,042 | 79,294 |
| 1989 | 215,158 | 178,011 | 260,059 | 215,249 | 89,005 | 51,858 | 133,906 | 89,096 |
| 1990 | 268,544 | 230,482 | 312,891 | 268,125 | 104,358 | 66,296 | 148,705 | 103,939 |
| 1991 | 216,118 | 182,272 | 256,249 | 215,904 | 102,970 | 69,124 | 143,101 | 102,756 |
| 1992 | 261,317 | 225,801 | 302,419 | 260,912 | 130,217 | 94,701 | 171,319 | 129,812 |
| 1993 | 273,777 | 224,788 | 333,443 | 272,597 | 174,110 | 125,121 | 233,776 | 172,930 |
| 1994 | 399,365 | 306,403 | 520,530 | 397,965 | 277,261 | 184,299 | 398,426 | 275,861 |
| 1995 | 372,332 | 301,288 | 460,128 | 371,818 | 237,603 | 166,559 | 325,399 | 237,089 |
| 1996 | 341,902 | 254,049 | 460,137 | 323,418 | 236,327 | 148,474 | 354,562 | 217,843 |
| 1997 | 262,761 | 217,339 | 317,676 | 262,514 | 171,427 | 126,005 | 226,342 | 171,180 |
| 1998 | 255,174 | 195,431 | 333,179 | 254,394 | 155,202 | 95,459 | 233,207 | 154,422 |
| 1999 | 160,752 | 130,069 | 198,673 | 160,317 | 82,159 | 51,476 | 120,080 | 81,724 |
| 2000 | 122,487 | 107,873 | 139,080 | 122,173 | 54,278 | 39,664 | 70,871 | 53,964 |
| 2001 | 192,752 | 163,867 | 226,728 | 192,403 | 114,112 | 85,227 | 148,088 | 113,763 |
| 2002 | 238,306 | 204,482 | 277,725 | 238,306 | 156,458 | 122,634 | 195,877 | 156,458 |
| 2003 | 231,909 | 207,667 | 258,980 | 231,941 | 163,204 | 138,962 | 190,275 | 163,236 |
| 2004 | 365,032 | 322,554 | 413,104 | 365,280 | 264,391 | 221,913 | 312,463 | 264,639 |
| 2005 | 327,044 | 294,649 | 363,001 | 327,123 | 235,268 | 202,873 | 271,225 | 235,347 |
| 2006 | 323,372 | 287,230 | 364,063 | 323,790 | 228,987 | 192,845 | 269,678 | 229,405 |
| 2007 | 248,471 | 224,993 | 274,398 | 248,548 | 151,611 | 128,133 | 177,538 | 151,688 |
| 2008 | 214,922 | 189,492 | 243,765 | 214,918 | 116,017 | 90,587 | 144,860 | 116,013 |
| 2009 | 194,718 | 169,598 | 223,559 | 194,763 | 106,784 | 81,664 | 135,625 | 106,829 |

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Table 2.–Page 2 of 2.

| | 2021 Model run | | | | 2021 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] |
| 2010 | 116,026 | 105,082 | 128,110 | 115,951 | 45,362 | 34,418 | 57,446 | 45,287 |
| 2011 | 115,858 | 103,939 | 129,144 | 114,453 | 51,829 | 39,910 | 65,115 | 50,424 |
| 2012 | 75,242 | 62,158 | 91,082 | 74,992 | 51,750 | 38,666 | 67,590 | 51,500 |
| 2013 | 88,498 | 79,099 | 99,012 | 88,496 | 41,010 | 31,611 | 51,524 | 41,008 |
| 2014 | 82,133 | 70,833 | 95,237 | 82,216 | 70,367 | 59,067 | 83,471 | 70,450 |
| 2015 | 125,767 | 110,941 | 142,576 | 125,677 | 109,163 | 94,337 | 125,972 | 109,073 |
| 2016 | 130,678 | 113,679 | 150,218 | 130,443 | 99,460 | 82,461 | 119,000 | 99,225 |
| 2017 | 131,643 | 112,759 | 153,690 | 131,530 | 114,973 | 96,089 | 137,020 | 114,860 |
| 2018 | 135,711 | 107,775 | 170,887 | 136,076 | 112,980 | 85,044 | 148,156 | 113,345 |
| 2019 | 226,224 | 182,779 | 279,995 | 226,835 | 187,720 | 144,275 | 241,491 | 188,331 |
| 2020 | 124,540 | 102,781 | 150,904 | 124,486 | 88,339 | 66,580 | 114,703 | 88,285 |
| 2021 | 129,751 | 94,489 | 178,171 | | 101,000 | 65,738 | 149,420 | |
| Average (1976–2020) | 214,475 | | | 213,839 | 131,184 | | | 130,549 |

*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 (2021). Based on the prior year model run, the 1976–2020 average total run and escapement was larger than the 2020 model run average by 636 fish (0.24%) and 81 fish (0.41%), respectively.

Table 3.–Parameter estimates derived from the 2021 run reconstruction model.

| | Parameter | 95% Bound | | Observed | Total |
|---|---|---|---|---|---|
| | estimate (*k*) | Lower | Upper | escapement | escapement[a] |
| Weir projects (*k*) | | | | | |
| Kwethluk weir | 2.74 | 2.54 | 2.94 | – | – |
| Tuluksak weir | 5.05 | 4.87 | 5.22 | – | – |
| George weir | 3.55 | 3.38 | 3.73 | 2,920 | 101,945 |
| Kogrukluk weir | 2.63 | 2.47 | 2.78 | 6,969 | 96,306 |
| Tatlawiksuk weir | 4.19 | 4.01 | 4.38 | – | – |
| Takotna weir | 5.78 | 5.60 | 5.96 | 323 | 104,941 |
| | | | | | |
| Aerial survey (*k*) | | | | | |
| Kwethluk River | 4.44 | 4.10 | 4.79 | – | – |
| Kisaralik River | 5.14 | 4.91 | 5.38 | – | – |
| Tuluksak River | 6.12 | 5.76 | 6.48 | – | – |
| Salmon (Aniak River) | 5.36 | 5.14 | 5.58 | – | – |
| Kipchuk River | 5.01 | 4.77 | 5.24 | – | – |
| Aniak River | 4.05 | 3.81 | 4.30 | – | – |
| Holokuk River | 6.31 | 6.04 | 6.58 | – | – |
| Oskawalik River | 6.49 | 6.24 | 6.74 | – | – |
| Holitna River | 4.54 | 4.28 | 4.79 | – | – |
| Cheeneetnuk River | 5.41 | 5.17 | 5.64 | – | – |
| Gagaryah River | 5.84 | 5.60 | 6.08 | – | – |
| Pitka Fork | 6.41 | 6.10 | 6.71 | – | – |
| Bear River | 6.27 | 6.01 | 6.54 | – | – |
| Salmon(Pitka Fork) | 4.80 | 4.58 | 5.02 | – | – |
| | | | | | |
| Catchability (*q*) | | | | | |
| Unrestricted | -9.51 | -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 2021 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 | 0.008 | 0.03 |
| Weir escapement scaling ($k_{ij}$) | 0.01–10 | 0.121 | 0.963 |
| Aerial escapement scaling ($k_{ij}$) | 0.01–10 | 0.003 | 0.018 |
| Catchability ($q_k$) | -20–1 | 0.015 | 0.096 |
| Weir coefficient of variation[c] | -20–20 | 0.229 | 2.846 |
| Aerial coefficient of variation[c] | -20–20 | 0.229 | 2.846 |
| Catchability coefficient of variation[c] | -20–20 | 0.229 | 2.846 |

[a] Average difference in numbers of fish among all 1976–2021 total run estimates across a range of 100 different starting values for each parameter.

[b] Maximum difference in numbers of fish among all 1976–2021 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, 2022.

| Run size | Percent chance of being below run size | Percent chance of being above run size |
|---|---|---|
| 63,000 | 1% | 99% |
| 77,000 | 5% | 95% |
| 85,000 | 10% | 90% |
| 92,000 | 15% | 85% |
| 97,000 | 20% | 80% |
| 102,000 | 25% | 75% |
| 107,000 | 30% | 70% |
| 111,000 | 35% | 65% |
| 116,000 | 40% | 60% |
| 120,000 | 45% | 55% |
| 125,000 | 50% | 50% |
| 129,000 | 55% | 45% |
| 134,000 | 60% | 40% |
| 139,000 | 65% | 35% |
| 145,000 | 70% | 30% |
| 152,000 | 75% | 25% |
| 159,000 | 80% | 20% |
| 169,000 | 85% | 15% |
| 181,000 | 90% | 10% |
| 202,000 | 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 (129,800 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 | | Return by age class | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| year | Escapement | (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 | 115,950 | 0 | 64 | 6 | 65,825 | 6 | 0 | 106,018 | 34 | 82,418 | 85 | 6,103 | 260 | 91 | 0 | 260,908 | 2.25 |
| 1977 | 232,749 | 0 | 66 | 6 | 23,800 | 6 | 0 | 44,254 | 32 | 77,458 | 70 | 7,482 | 515 | 67 | 0 | 153,755 | 0.66 |
| 1978 | 154,815 | 0 | 672 | 5 | 11,441 | 5 | 0 | 39,452 | 26 | 61,301 | 498 | 4,835 | 52 | 5 | 0 | 118,293 | 0.76 |
| 1979 | 140,898 | 0 | 209 | 4 | 24,468 | 4 | 32 | 76,890 | 159 | 61,090 | 64 | 6,445 | 60 | 6 | 0 | 169,433 | 1.20 |
| 1980 | 267,918 | 0 | 693 | 5 | 28,107 | 5 | 0 | 51,908 | 176 | 46,312 | 74 | 3,481 | 80 | 7 | 0 | 130,848 | 0.49 |
| 1981 | 201,249 | 0 | 372 | 4 | 27,024 | 4 | 0 | 59,350 | 28 | 83,160 | 99 | 12,094 | 85 | 7 | 0 | 182,227 | 0.91 |
| 1982 | 36,791 | 0 | 48 | 5 | 11,330 | 5 | 0 | 53,085 | 37 | 69,279 | 104 | 6,583 | 1,062 | 10 | 0 | 141,547 | 3.85 |
| 1983 | 66,478 | 0 | 699 | 6 | 43,040 | 6 | 0 | 96,072 | 39 | 103,302 | 733 | 5,714 | 130 | 33 | 302 | 250,077 | 3.76 |
| 1984 | 86,211 | 0 | 74 | 7 | 29,718 | 7 | 0 | 67,163 | 1,579 | 72,770 | 161 | 5,277 | 842 | 8 | 0 | 177,605 | 2.06 |
| 1985 | 63,294 | 0 | 78 | 7 | 34,469 | 7 | 0 | 130,586 | 60 | 107,737 | 1,276 | 5,050 | 219 | 8 | 90 | 279,589 | 4.42 |
| 1986 | 53,768 | 0 | 90 | 10 | 56,228 | 10 | 0 | 72,341 | 1,927 | 91,691 | 236 | 10,330 | 720 | 10 | 0 | 233,592 | 4.34 |
| 1987 | 78,813 | 0 | 2,938 | 7 | 26,229 | 7 | 0 | 87,237 | 621 | 99,883 | 780 | 6,109 | 1,641 | 9 | 0 | 225,463 | 2.86 |
| 1988 | 79,665 | 76 | 82 | 8 | 69,782 | 8 | 0 | 83,370 | 211 | 130,779 | 1,985 | 4,120 | 360 | 16 | 0 | 290,795 | 3.65 |
| 1989 | 89,005 | 0 | 6,208 | 8 | 77,896 | 8 | 180 | 212,476 | 1,423 | 194,717 | 388 | 38,716 | 116 | 7 | 0 | 532,145 | 5.98 |
| 1990 | 104,358 | 0 | 421 | 10 | 43,143 | 10 | 0 | 107,999 | 56 | 119,236 | 764 | 3,142 | 95 | 7 | 0 | 274,884 | 2.63 |
| 1991 | 102,970 | 90 | 738 | 9 | 64,728 | 9 | 0 | 146,919 | 385 | 124,163 | 117 | 5,118 | 97 | 7 | 0 | 342,382 | 3.33 |
| 1992 | 130,217 | 0 | 144 | 9 | 35,500 | 9 | 0 | 64,293 | 44 | 86,684 | 120 | 3,106 | 87 | 6 | 0 | 190,002 | 1.46 |
| 1993 | 174,110 | 0 | 130 | 7 | 70,667 | 7 | 0 | 126,403 | 45 | 95,521 | 107 | 3,968 | 81 | 0 | 0 | 296,936 | 1.71 |
| 1994 | 277,261 | 0 | 88 | 7 | 35,796 | 7 | 0 | 47,930 | 166 | 55,514 | 99 | 7,742 | 81 | 0 | 0 | 147,431 | 0.53 |
| 1995 | 237,603 | 0 | 284 | 7 | 13,568 | 7 | 0 | 47,413 | 37 | 101,219 | 0 | 8,138 | 0 | 0 | 0 | 170,672 | 0.72 |
| 1996 | 236,327 | 0 | 230 | 6 | 15,237 | 6 | 0 | 63,736 | 0 | 94,760 | 0 | 9,736 | 0 | 0 | 0 | 183,713 | 0.78 |
| 1997 | 171,427 | 0 | 100 | 0 | 19,756 | 0 | 0 | 84,856 | 61 | 75,913 | 0 | 4,625 | 0 | 0 | 0 | 185,311 | 1.08 |
| 1998 | 155,202 | 0 | 0 | 0 | 50,205 | 0 | 0 | 102,299 | 0 | 106,510 | 0 | 4,410 | 172 | 0 | 0 | 263,597 | 1.70 |
| 1999 | 82,159 | 0 | 204 | 0 | 43,415 | 0 | 0 | 111,233 | 426 | 110,167 | 548 | 14,770 | 91 | 0 | 0 | 280,856 | 3.42 |
| 2000 | 54,278 | 0 | 381 | 0 | 141,134 | 0 | 0 | 152,629 | 10 | 125,987 | 182 | 5,207 | 1,100 | 0 | 0 | 426,631 | 7.86 |
| 2001 | 114,112 | 0 | 1,206 | 0 | 58,786 | 0 | 0 | 97,901 | 91 | 90,353 | 470 | 4,767 | 180 | 0 | 0 | 253,754 | 2.22 |

-continued-

Table 6.–Page 2 of 2.

| Brood year | Escapement | Return by age class | | | | | | | | | | | | | | Return | R/S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (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) | | |
| 2002 | 156,458 | 0 | 485 | 0 | 83,147 | 0 | 0 | 81,535 | 0 | 61,496 | 1,254 | 2,162 | 312 | 0 | 0 | 230,391 | 1.47 |
| 2003 | 163,204 | 0 | 1,083 | 0 | 69,463 | 0 | 0 | 104,911 | 66 | 83,930 | 273 | 3,210 | 41 | 64 | 0 | 263,040 | 1.61 |
| 2004 | 264,391 | 0 | 194 | 0 | 41,763 | 0 | 0 | 72,011 | 771 | 40,084 | 0 | 1,659 | 55 | 0 | 0 | 156,537 | 0.59 |
| 2005 | 235,268 | 0 | 448 | 0 | 35,178 | 0 | 0 | 49,026 | 79 | 37,705 | 276 | 873 | 1 | 0 | 0 | 123,585 | 0.53 |
| 2006 | 228,987 | 0 | 81 | 68 | 23,282 | 68 | 0 | 46,342 | 109 | 23,188 | 452 | 830 | 95 | 0 | 0 | 94,514 | 0.41 |
| 2007 | 151,611 | 0 | 202 | 0 | 29,346 | 0 | 0 | 41,021 | 0 | 47,094 | 236 | 814 | 0 | 0 | 0 | 118,714 | 0.78 |
| 2008 | 116,017 | 0 | 264 | 0 | 9,654 | 0 | 0 | 27,058 | 75 | 30,098 | 353 | 446 | 1 | 0 | 0 | 67,948 | 0.59 |
| 2009 | 106,784 | 45 | 0 | 0 | 12,858 | 75 | 0 | 32,858 | 483 | 24,057 | 360 | 5 | 1 | 0 | 77 | 70,818 | 0.66 |
| 2010 | 45,362 | 0 | 95 | 0 | 14,514 | 0 | 122 | 44,277 | 766 | 16,925 | 358 | 17 | 99 | 0 | 0 | 77,173 | 1.70 |
| 2011 | 51,829 | 0 | 2,861 | 0 | 54,832 | 2 | 0 | 74,680 | 233 | 28,676 | 205 | 111 | 0 | 0 | 0 | 161,601 | 3.12 |
| 2012 | 51,750 | 65 | 805 | 0 | 36,557 | 0 | 0 | 59,947 | 165 | 22,342 | 52 | 77 | 468 | 0 | 0 | 120,478 | 2.33 |
| 2013 | 41,010 | 0 | 1,919 | 0 | 41,320 | 0 | 124 | 59,192 | 124 | 30,136 | 1,629 | 863 | 111 | 0 | 0 | 135,418 | 3.30 |
| 2014 | 70,367 | 0 | 1,057 | 0 | 50,538 | 0 | 234 | 73,854 | 2,306 | 28,188 | 4 | 648 | 163 | 0 | 0 | 156,991 | 2.23 |
| 2015 | 109,163 | 0 | 3,186 | 239 | 104,936 | 88 | 0 | 51,840 | 54 | 27,124 | 58 | 0 | 0 | 0 | 0 | 187,526 | – |
| 2016 | 99,460 | 30 | 12,404 | 0 | 42,230 | 0 | 1 | 48,638 | 107 | 0 | 0 | 0 | 0 | 0 | 0 | 103,410 | – |
| 2017 | 114,973 | 0 | 1,219 | 119 | 50,883 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 52,320 | – |
| 2018 | 112,980 | 0 | 2,107 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2,107 | – |
| 2019 | 187,720 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | – | – |
| 2020 | 88,339 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | – | – |
| 2021 | 101,000 | 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 2015–2021 are incomplete. En dash means no component of the return has been realized or the R/S cannot be calculated at this time.

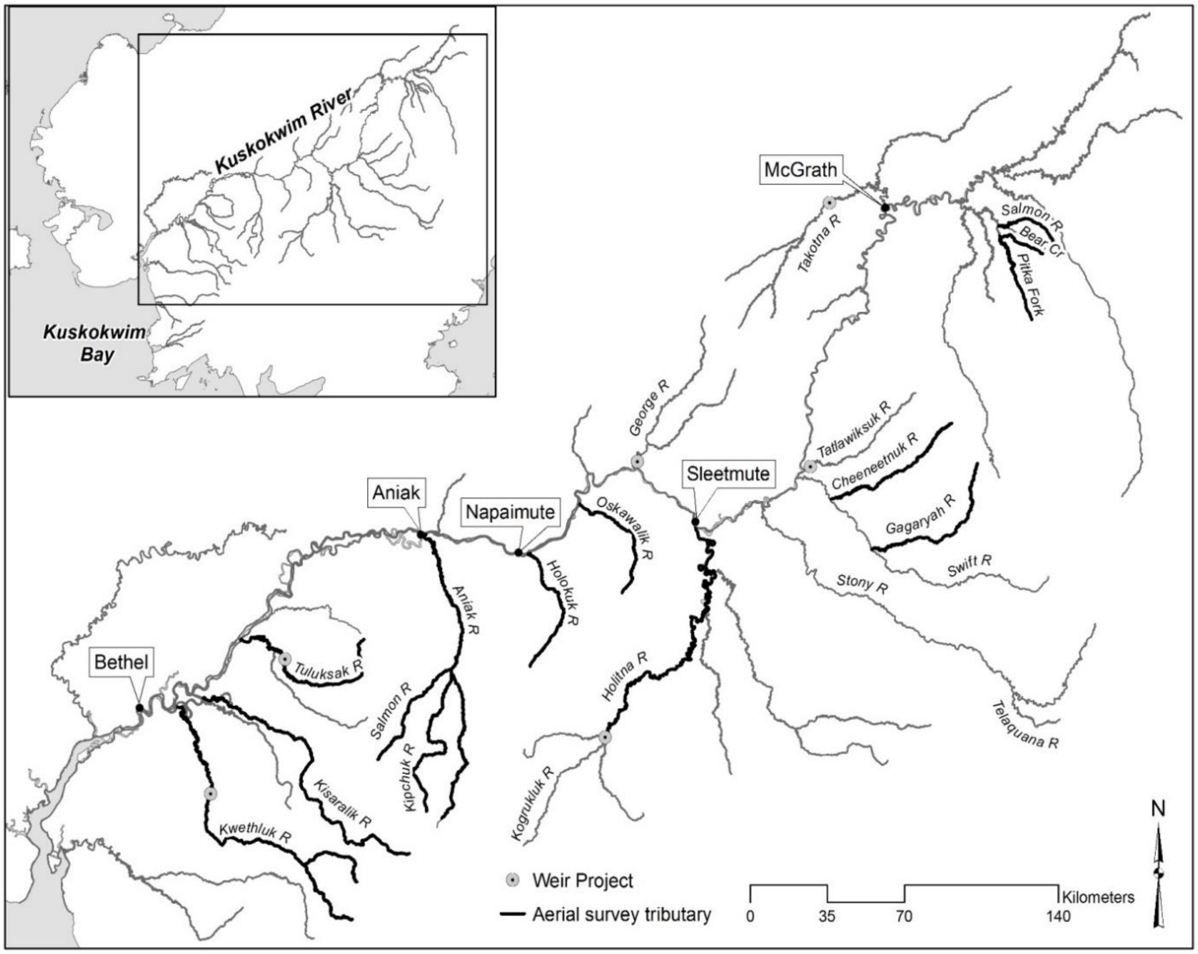


Figure 1.–Kuskokwim River Chinook salmon escapement monitoring projects used to inform the run reconstruction model.

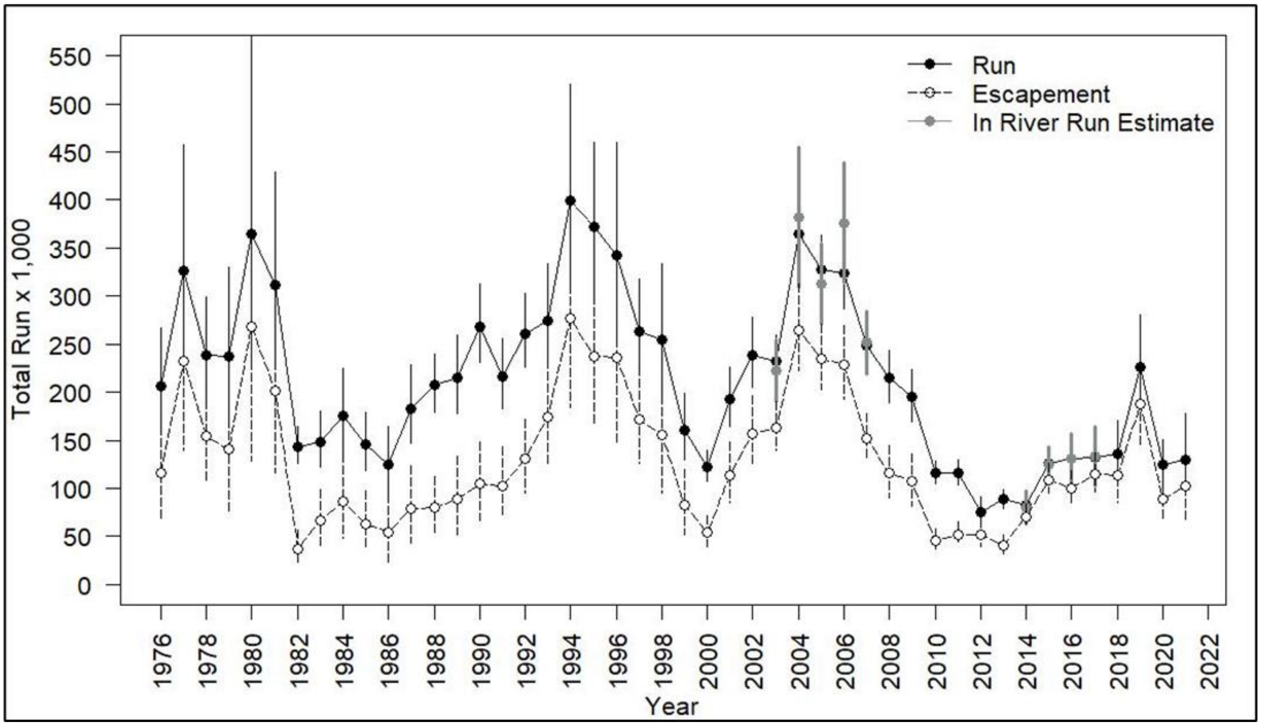


Figure 2.–Annual run (black) and escapement (white) estimates with 95% confidence intervals estimated from the 2021 run reconstruction model.

*Note*: Gray 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).

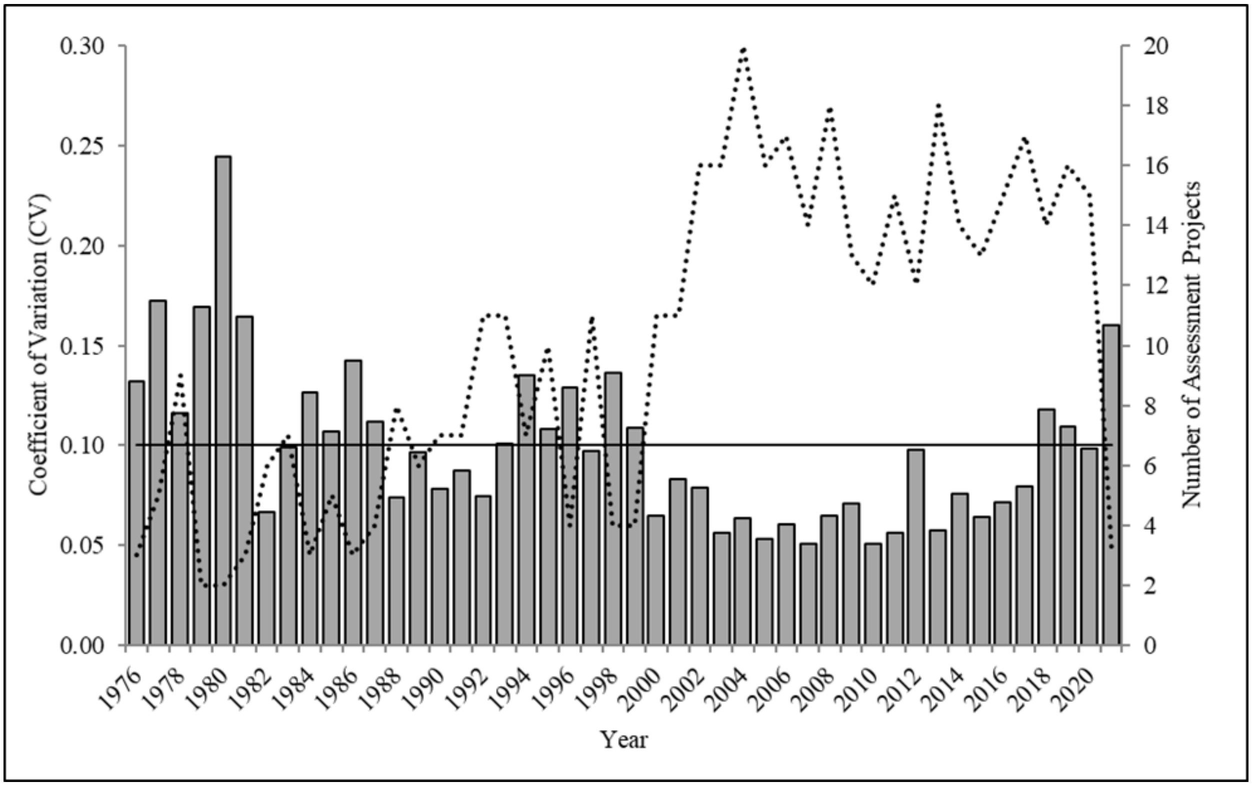


Figure 3.–Annual uncertainty (coefficient of variation; grey bars) of the run reconstruction model estimate of total run size and the number of assessment projects (dotted black line) used to inform the model in each year.

*Note*: The solid black line is the average coefficient of variation (10%) across years 1976–2020.

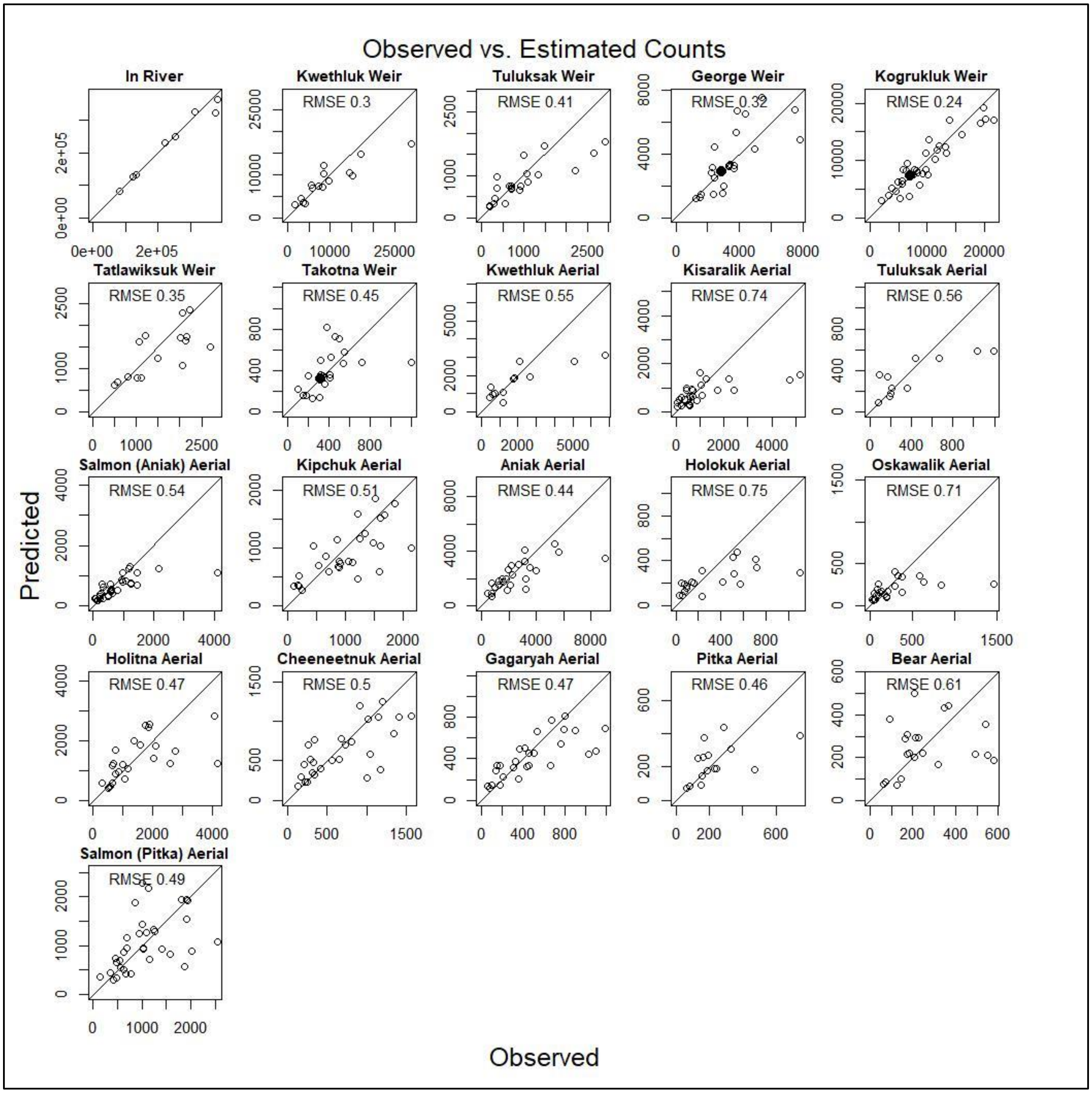


Figure 4.–Observed versus model estimated escapement counts.

*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 2021 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.

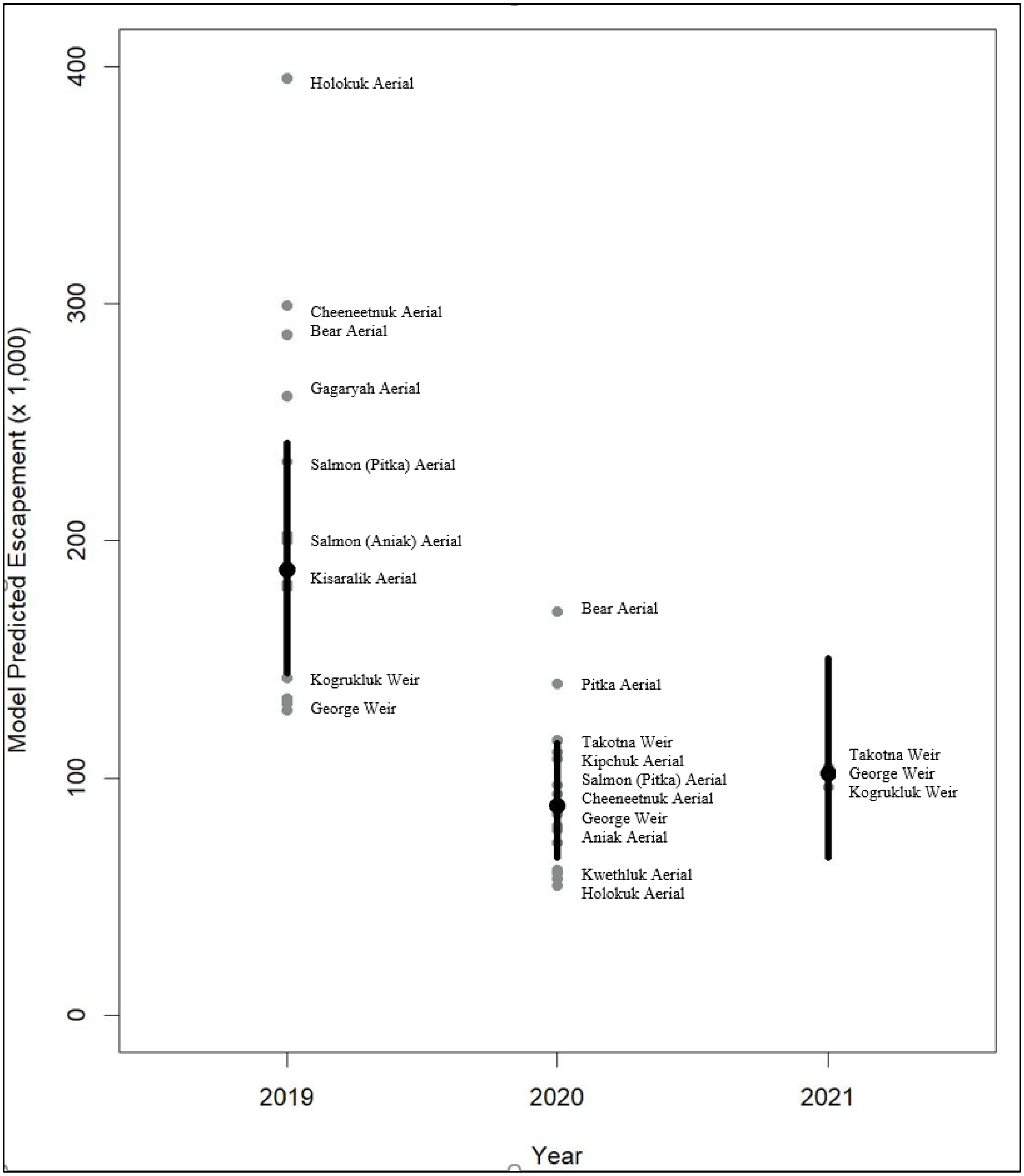


Figure 5.–Range of drainagewide escapement estimates produced by the model based on each escapement project.

*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 2019 and 2020 are shown to provide context for 2021 results.

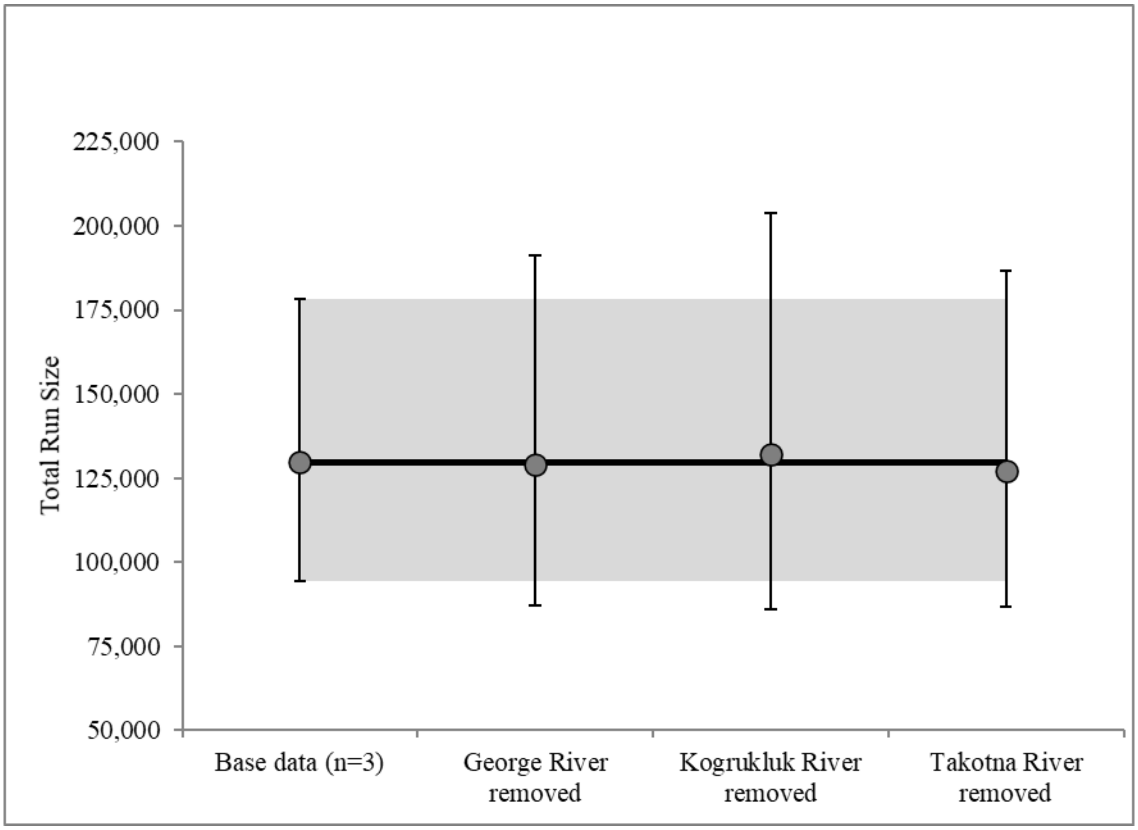


Figure 6.–Sensitivity of 2021 Chinook salmon total run size estimates using all available data (base data) and removal of single escapement monitoring projects (dots).

*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.

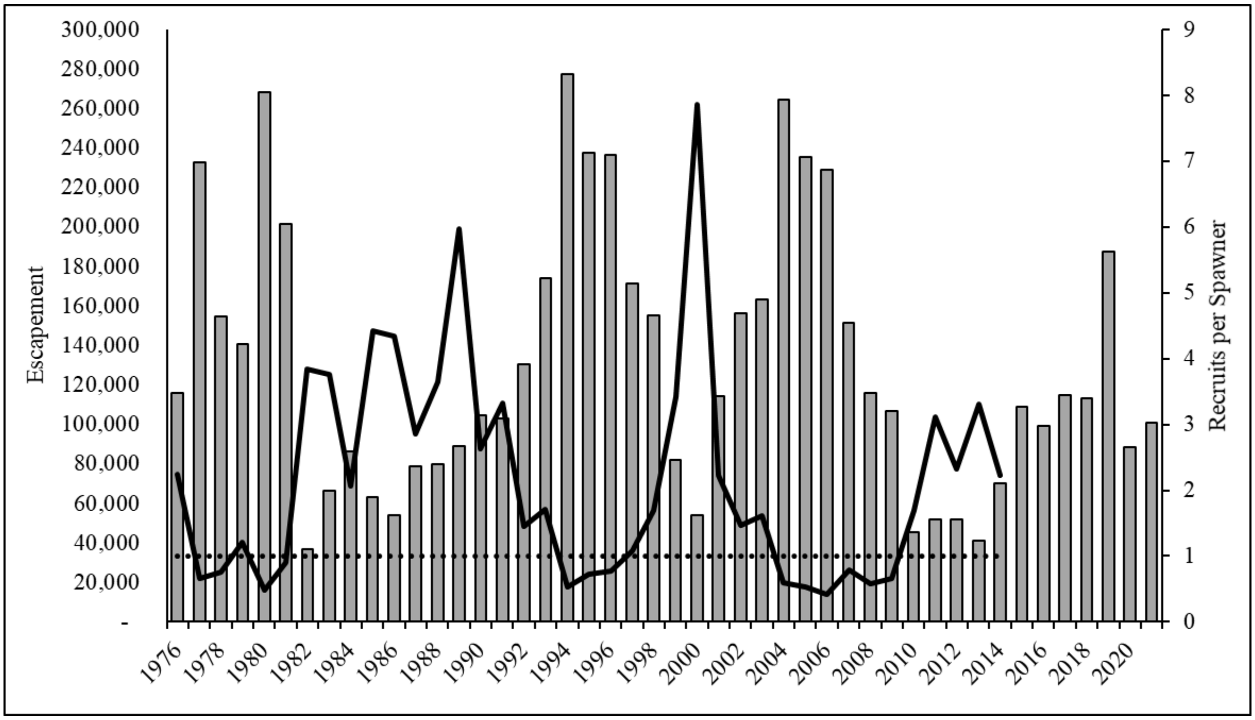


Figure 7.–Escapement (bars), recruits per spawner (solid line), and the 1:1 replacement line for recruits per spawner (dotted line) for Kuskokwim River Chinook salmon, 1976–2021.

# APPENDIX A: 2021 NPFMC 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
Main: 907.465.4210
Fax: 907.465.2604

September 22, 2021

Dr. James Balsiger, Administrator
NOAA Fisheries, Alaska Region
PO Box 21668
Juneau, Alaska 99802-1668

Dear Dr. Balsiger,

In April 2015, the North Pacific Fishery Management Council (Council) adopted an action that lowers Chinook salmon bycatch caps in the Bering Sea 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 performance standard and hard cap applicable to the Bering Sea pollock fishery would be lowered in 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 2021. 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 2021 three-system index of inriver adult Chinook salmon run sizes from the Unalakleet, Upper Yukon, and Kuskokwim rivers is 165,148 and is below the threshold level of 250,000.**

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

**Unalakleet River**

The preliminary postseason run size estimate of Unalakleet River Chinook salmon is **2,892,** based on the sum of reported commercial harvest, expected subsistence harvest, and estimated total escapement. A total of seven 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 expects approximately 1,500 Unalakleet River Chinook salmon were harvested for subsistence uses in 2021. Subsistence harvest in 2021 is expected to be comparable or slightly smaller than the 2020 harvest (i.e., 1,778) given similarities in fishing opportunities combined with adverse weather conditions. The North River Tower and Unalakleet River weir operated successfully during much of the target operational period. The preliminary total escapement of Chinook salmon to the Unalakleet River was estimated to be 1,385 and is considered reliable (95% CI[4]: 977–1,793).

[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
[4] CI: confidence interval

-continued-

**Upper Yukon River**

The preliminary postseason run size estimate of Upper Yukon River Chinook salmon is **33,251,** 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 31,631 (90% CI: 31,289–31,973). The total harvest of Upper Yukon River Chinook salmon in Alaska is expected to be about 1,620. The potential for a very small Chinook salmon run was forecasted preseason, and inseason assessment indicated both the Chinook salmon and chum salmon runs were 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 executed in the Yukon River in 2021, relevant sport fisheries were closed, and subsistence fishing was closed for all salmon beginning June 2 in the lower portion of the river. Limited harvest of Upper Yukon River Chinook salmon occurred in test fisheries operated by the department and in small-mesh gillnet opportunities directed at non-salmon species. The 2021 preliminary harvest expectation was informed by the 2014 total harvest (approximately 3,000), which resulted from heavy restrictions like those imposed in 2021, and the recent five-year average proportion of Canadian-origin Chinook salmon in Alaska fisheries (54%). The preliminary total run size of Upper Yukon River Chinook salmon was generally consistent with the lower end of the preseason run forecast (i.e., 80% CI: 42,000–77,000), but notably smaller than the lower end of the inseason run size estimate (i.e., 59,000) based on independent sonar and genetic stock identification programs.

**Kuskokwim River**

The preliminary postseason run size estimate of Kuskokwim River Chinook salmon is **129,005** fish (95% CI: 93,700–177,600), 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 (101, 203) is uncertain (95% CI: 65,900–149,800) because the model was informed by only three weir projects. Poor weather conditions prevented the department from flying aerial surveys during the 2021 season, and those indices of escapement were not available to inform the model. The total harvest of Kuskokwim River Chinook salmon is expected to be 27,802. No commercial harvest of Kuskokwim River Chinook salmon occurred during the 2021 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 2021. U.S. Fish and Wildlife Service (USFWS) estimated that approximately 21,560 Chinook salmon were harvested within a portion of the Yukon Delta National Wildlife refuge during subsistence fishing openers announced by Federal Special Actions. A preliminary estimate of drainagewide subsistence harvest was generated using a five-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 94,000–155,000 and is consistent with an independent partial run estimate of 102,525 (90% CI: 84,409–120,641) Chinook salmon, based on a sonar project operated near Bethel, Alaska.

Sincerely,

Sam Rabung
Director, Division of Commercial Fisheries

cc: Doug Vincent-Lang, Commissioner
Rachel Baker, Deputy Commissioner
Glenn Merrill, NMFS AKR
David Witherell, NPFMC

# APPENDIX B: 2021 ADMB-CODE WITH ANNOTATIONS

Appendix B1.–2021 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
 init_bounded_number_vector log_trun(1,nyear,minrun,ubrun,1);  // log drainage-wide run
 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
 init_bounded_vector log_q(1,2,-12,-9,1);       // log Catchability for different fishery sectors
 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
 matrix wk_est(1,nyear,1,nweek);     // storage matrix for the estimated number of fish available for harvest
each week
 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 |

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 | – | – |
| | 1997 | – | – | 7,810 | 13,116 | – | 423 |
| | 1998 | – | – | – | – | – | 1,197 |
| | 1999 | – | – | – | 5,567 | 1,484 | – |
| | 2000 | 3,547 | – | 2,956 | 3,254 | 808 | – |
| | 2001 | – | 924 | 3,313 | 8,151 | 2,013 | 345 |
| | 2002 | 8,543 | 1,346 | 2,445 | 9,830 | 2,237 | 718 |
| | 2003 | 14,475 | 1,067 | – | 11,751 | – | 326 |
| | 2004 | 28,801 | 1,475 | 5,392 | 19,880 | 2,833 | 378 |
| | 2005 | – | 2,653 | 3,845 | 21,686 | 2,858 | 461 |
| | 2006 | 17,019 | 1,008 | 4,359 | 19,305 | 1,700 | 499 |
| | 2007 | 15,112 | 374 | 4,972 | – | 2,058 | 537 |
| | 2008 | 5,642 | 707 | 3,383 | 9,740 | 1,194 | 412 |
| | 2009 | 5,826 | 362 | 3,664 | 9,201 | 1,071 | 413 |
| | 2010 | 1,716 | 201 | 1,500 | 5,160 | 554 | 311 |
| | 2011 | 4,056 | 284 | 1,605 | 6,926 | 1,011 | 183 |
| | 2012 | – | 559 | 2,362 | – | 1,116 | 149 |
| | 2013 | – | 198 | 1,267 | 1,919 | 495 | 238 |
| | 2014 | 3,191 | 325 | 2,988 | 3,726 | 2,050 | 104 |
| | 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 |

*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 |

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Appendix C4.–Page 2 of 2.

| 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) |
| | 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] | – | – | – | – | – | – | – | – | – | – | – | – | – | – |

*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 in 2021 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 |

*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 |

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Appendix C6.–Page 2 of 2.

| | | 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 |

*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 also included in catch and effort calculations - 6" or less new gear.