Regional Information Report 3A19-02

2018 Kuskokwim River Chinook Salmon Run Reconstruction and 2019 Forecast

by

Nicholas J. Smith

April 2019

Alaska Department of Fish and Game **Division of Commercial Fisheries**

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

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ABSTRACT

A maximum likelihood model was used to estimate the 2018 drainagewide run size and escapement of Kuskokwim River Chinook salmon (*Oncorhynchus tshawytscha*). Total run and escapement were estimated to be 132,312 (95% CI: 104,858–166,954) and 109,583 (95% CI: 82,129–144,225) fish, respectively. Model estimates were informed by direct observations of the 2018 escapement at 14 locations (3 weirs and 11 aerial surveys) and harvest, combined with historical observations of escapement (up to 6 weirs and 14 aerial surveys), harvest, and mark–recapture data dating back to 1976. Model results are adequate to draw broad conclusions about the 2018 run and escapement. The 2018 total run of Chinook salmon was the third largest since 2009 but was considerably less than the 1976–2017 average of 216,694 fish. The drainagewide sustainable escapement goal of 65,000–120,000 was met or exceeded in 2018. The 2019 Kuskokwim River Chinook salmon forecast is for a range of 115,000–150,000 fish.

Key words: Chinook salmon *Oncorhynchus tshawytscha*, run reconstruction model, total run, total escapement, 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 2018. Because it is not possible 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 requires regular review and, when necessary, updates to ensure unbiased estimation of total run and escapement. Internal and external reviews have been conducted since model inception in 2012. Catalano et al. (2016) provided a detailed 5-chapter document that highlights important investigations related to the run reconstruction model and subsequent stock recruitment analyses. The Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative (AYKSSI) completed an independent peer review of the Kuskokwim River Chinook Salmon run reconstruction model and input data (Schindler et al. 2019). Additionally, the Alaska Department of Fish and Game (ADF&G) convened a collaborative Kuskokwim River Interagency Model Development Team (KRIMDT) to consider options for incorporating new abundance data and improving the model. Recommendations from all previous reviews were used by the KRIMDT to produce an updated run reconstruction model that was released to the public in the spring of 2018 (Liller et al. 2018). Main changes to the model included adding 4 more years of total run estimates used to scale the model, revising estimates of escapements to unmonitored lower-river tributaries, changing the software used to run the model, and treating all data sources as lognormally distributed. All model updates and revisions are presented in Liller et al. (2018). In summary, the revised model resulted in generally smaller estimates of total run and escapement since 1976 compared to previous run reconstruction reports (Bue et al. 2012; Hamazaki and Liller 2015; Liller and Hamazaki 2016; Liller 2017: Smith and Liller 2018).

The tendency for the revised model (Liller et al. 2018) to produce smaller estimates of total run cannot be attributed to any single model revision or data addition. The revisions presented in Liller et al. (2018) can be grouped into 3 basic categories: 1) statistical revisions to the model; 2) corrections to the 2003–2007 model scalars to address bias; and 3) inclusion of additional model scalars (2014–2017) during years of low run abundance. Each category contributed to generally smaller estimates of total run from 1976–2017 to varying degrees (Figure 2). With respect to recent years of low run abundance (2010–2017), each category change resulted in a similar and smaller estimate of total run size when compared to the old model last used by Smith and Liller (2018). However, the combination of all 3 major changes were necessary to improve overall model performance, correct bias throughout the entire time series, and optimize future model performance.

The previous version of the run reconstruction model was known to be sensitive to parameter starting values (Hamazaki and Liller 2015; Smith and Liller 2018; Schindler et al. 2019), which could result in different estimates of total run and escapement due to the presence of local minima, which prevented the model from arriving at the global minimum. Eliminating sensitivity to starting values was one of the main objectives of the review process, and changes were incorporated to improve model performance (Liller et al. 2018) based on independent recommendations (Schindler et al. 2019). Moving forward, a standardized sensitivity analysis will be conducted annually to ensure the model has properly converged and identified a single maximum likelihood estimate based on the available data.

The run reconstruction model has become an important tool to guide sustainable management of the Kuskokwim River Chinook salmon fishery. Model results from Bue et al. (2012) contributed to a spawner-recruit analysis that was 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 to consider the revised model, 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 with uncertainty calculated as the 7-year average percent error between forecasted and actual run sizes. The rationale for this forecast approach was based on the observation of strong serial correlation between successive years of total run size.

The current run reconstruction model has implications beyond management of Kuskokwim River Chinook salmon fisheries. Since 2016, 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 that is used by NPFMC to guide Chinook salmon bycatch thresholds in the Bering Sea pollock trawl fishery. The updated run reconstruction model was presented to the NPFMC for review in the summer of 2018. The NPFMC determined that the model changes were an improvement and approved ADF&G to use the updated model to estimate Kuskokwim River Chinook salmon run sizes within the context of the 3-system index. The preliminary 2018 3-system abundance estimate was provided to the NPFMC on September 13, 2017 (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. As such, the final total run estimate was expected to change slightly from what was provided to NPFMC.

OBJECTIVE

Estimate the total run size and escapement of Kuskokwim River Chinook salmon in 2018.

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),

$$E_y = N_y - C_y, \quad (1)$$

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

ESCAPEMENT COUNTS

Assuming 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 (j) observed by method (i; weir or aerial) is:

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

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

COMMERCIAL CATCH AND EFFORT

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

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

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:

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

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).

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 for the 1984–2018 runs.

MODEL SCALING

Direct estimates of total run size ($\widehat{N}_y$) from the years 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 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 as presented in Liller et al. (2018).

LIKELIHOOD MODEL

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

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

where $\sigma_j^2=ln(CV_j^2+1)$, $\sigma_k^2=ln(CV_k^2+1)$, and $\sigma_y^2=ln(CV_y^2+1)$.

where

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 (Appendix B; Fournier et al. 2012).

MODEL INPUTS

All model input data have been reviewed and finalized since the release of the preliminary run reconstruction estimate to NPFMC in late September 2018. In addition to using fully vetted data for the final 2018 model run, 1 correction was made to historical aerial survey data as part of a regular data review process. The correction addressed a transcription error (Appendix C). Subsistence harvest data between 1990 and 2010 were also updated to the most recent estimates presented by Shelden et al. 2016 (Appendix C).

Large amounts of data were available to inform the model and estimate total run and escapement in 2018. Model estimates in 2018 were informed by direct observations of harvest and escapement at 14 locations (3 weirs and 11 aerial surveys) and combined with historical estimates of escapement and harvest data since 1976 (Appendix C). The model was scaled using 9 years of total run estimates from 2003–2007 and 2014–2017, which corresponds to years of relatively high and low run abundance, respectively.

RESULTS AND DISCUSSION

Quality of the 2018 assessment information used to inform the 2018 total run and escapement estimate was generally good (Table 1). Weir-based tributary escapements were successfully estimated at the George, Kogrukluk, and Takotna Rivers in 2018. An escapement estimate was not produced for the Kwethluk River weir due to operational challenges that resulted in too much missed passage occurring throughout the target operation period in 2018. Peak spawning aerial survey counts in 2018 were flown during a 1-week period in the early portion of the standardized survey period. A total of 12 aerial surveys were flown in 2018, of which, 11 were used to inform the run reconstruction model. Of the 12 aerial surveys, 8 (75%) had a good rating, 2 (17%) had fair ratings, and 1 (8%) had a poor rating. The single survey with a poor rating (i.e., Oskawalik River) was not used in the run reconstruction model. No commercial harvest of Kuskokwim River Chinook salmon occurred during the 2018 season. The preliminary subsistence harvest of 22,264 (95% CI: 20,505–24,023) Chinook salmon in 2018 is unlikely to change substantially and was well below the amounts reasonably necessary for subsistence uses (ANS: 67,200–109,800) as defined by the Alaska Board of Fisheries (5 AAC 01.2086).

Escapement estimates and observations during 2018 indicated that the Chinook salmon escapement throughout the Kuskokwim River was generally consistent with prior years when run sizes were below average and harvest restrictions were implemented. A total of 8 (57%) out of 14 escapement projects reported higher escapements in 2018 compared to the 2013–2017 average, 9 (64%) projects exceeded the 2008–2017 average, and 4 (29%) projects exceeded the 1976–2017 average (Table 1). There were 10 tributaries with established escapement goals in 2018 (Conitz et al. 2015), of which 9 were assessed. Of those, 8 were within the goal range, and 1 exceeded the upper bound of the goal.

MODEL RESULTS

The 2018 Kuskokwim River Chinook salmon drainagewide run was estimated to be 132,312 (95% CI: 104,858–166,954) fish (Table 2; Figure 3). CV for the 2018 total run was estimated to be 12% which was near the 1976–2017 average of 10% (range: 5%–25%; Figure 4). 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 5).

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 2018 model run represents the most informed historical time-series of total run and escapement and supersedes previous estimates. Estimates of total annual abundance from 1976–2017, generated by the 2018 model run, were an average 0.01% (234 fish) smaller than estimates reported by Liller et al. 2018 using the revised model (Table 2).

The 2018 Kuskokwim River Chinook salmon drainagewide escapement was estimated to be 109,583 (95% CI: 82,129–144,225) fish (Table 2). Based on the 2018 model run, total escapement in 2018 was 16% less than the 1976–2017 average of 129,774 Chinook salmon. Total escapement in 2018 was greater than 22 of 42 (52%) prior years. Acknowledging that uncertainty in the drainagewide escapement was relatively high, the 95% confidence range of 82,129–144,225 fish provided considerable evidence the drainagewide escapement goal of 65,000–120,000 fish was met or exceeded (Table 2; Figure 3).

UNCERTAINTY IN 2018 MODEL ESTIMATES

Model uncertainty in 2018 was the highest observed since 2000 (Figure 4). 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 the total run provided by each project. The number of index projects operated in 2018 (14 total projects) was at the 71 percentile (median 11; range: 2–20) over the 42 years (1976–2017) of available data, which would suggest a large amount of information to update the model and a relatively low level of uncertainty. However, some index projects indicated the 2018 total escapement was very small, whereas others indicated the escapement was very large. The model is specifically designed to accommodate "conflicting" data from a range of index projects; however, greater differences among projects results in greater uncertainty about the actual size of the total run and escapement. To illustrate this, the entire drainagewide escapement was estimated with data from 1 escapement project at a time (Figure 6). In 2018, estimates of drainagewide Chinook salmon escapements derived from individual weir projects ranged from 64,000–120,000 fish whereas estimates derived from individual aerial surveys ranged from 85,000–329,000 fish (Table 3; Figure 6).

Sensitivity of the 2018 model results to parameter starting values was evaluated. Run estimates were simulated across a range of 100 starting values for all model parameters independently (Table 4). Across all simulations, the maximum observed difference between annual run estimates was less than 1 fish. Simulation tests for all parameter starting values confirmed the 2018 model run was not sensitive to starting values and the total run estimates presented represent the best fit model.

Sensitivity of model results to 2018 escapement data was explored (Figure 7). Specifically, the model was run using only weir data, only aerial survey data, with headwaters projects removed (i.e., Takotna River weir, Salmon (Pitka) Fork aerial, Upper Pitka Fork aerial, and Bear Creek aerial), and with removal a single escapement project at a time. Point estimates in all cases fell within the 95% confidence interval of the base model and confidence intervals overlapped. However, there was a clear difference between estimates of total run when the model was informed with only weir escapement data or only aerial escapement data (Figure 7). In aggregate, weir data suggests a total run of 105,000 fish and aerial data suggests a total run of 161,000 fish. The influence of relatively large escapements to headwater tributaries (monitored with aerial surveys) on model results continues to be of interest and presumably explains some of the disparity observed between weir only and aerial only model results. When headwaters data (1 weir; 3 aerial surveys) was removed from the model the total run estimate was near the estimate produced using all available data. These results are not meant to discredit any data source, but rather show the importance of having a comprehensive assessment program to inform the run reconstruction model.

2018 Run Reconstruction Model Conclusions

- The total run of Kuskokwim River Chinook salmon was estimated to be 132,312 (95% CI: 104,858–166,954) fish.
- Total run abundance was below the 1976–2017 average, but within a range of run sizes that could likely have supported subsistence harvest at levels near the lower bound of amounts necessary for subsistence (67,200–109,800) as defined by the Alaska Board of Fisheries (5 AAC 01.2086).
- Total escapement of Kuskokwim River Chinook salmon was estimated to be 109,583 (95% CI: 82,129–144,225) fish and the drainagewide sustainable escapement goal of 65,000–120,000 was met or exceeded (Table 2).
- Total escapement was near average (Table 2).

2019 CHINOOK SALMON RUN FORECAST

The 2019 Kuskokwim River Chinook salmon forecast is for a range of 115,000–150,000 fish. The forecast range is equal to ±13% of the 2018 total run as presented in this report. Uncertainty in the forecast (i.e., ±13%) is based on the 2012–2018 (i.e., recent 7-year) average percent error between forecasted and actual run estimates. The forecast is not based on probability and alone provides no insight into the most likely run size within the forecasted range. Therefore, additional information, such as recent year abundance trends, stock productivity, age-class relationships, and other available information should be considered when using this forecast to plan preseason management of the 2019 Chinook salmon run.

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TABLES AND FIGURES

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

Method	Location	Number of years of data (1976–2018)	Historical average (1976–2017)	10-yr average (2008–2017)	5-yr average (2013–2017)	2017	2018
Weir	Kwethluk	14	9,782	5,263	6,240	7,345	–
	Tuluksak	21	985	488	559	645	–
	George	20	3,439	2,339	2,383	3,685	3,306
	Kogrukluk	33	10,134	6,945	6,136	9,992	5,770
	Tatlawiksuk	18	1,660	1,395	1,831	2,156	–
	Takotna [a]	18	410	238	–	301	191
Aerial Survey	Kwethluk [b]	11	2,183	826	–	–	–
	Kisaralik	25	1,134	636	638	–	584
	Tuluksak [b]	12	392	83	–	–	–
	Salmon (Aniak)	32	802	372	471	423	442
	Kipchuk	26	1,013	694	837	889	1,123
	Aniak	23	2,656	1,935	1,614	1,781	1,534
	Holokuk	17	335	190	99	140	162
	Oskawalik	21	284	136	105	136	–
	Holitna	22	1,542	723	757	676	980
	Cheeneetnuk	25	719	306	339	660	565
	Gagaryah	24	481	204	255	453	438
	Pitka [c]	13	222	163	–	234	471
	Bear	19	227	259	379	492	550
	Salmon (Pitka)	32	1,024	985	1,323	687	1,399
Harvest	Subsistence	43	66,695	44,255	24,309	16,380	22,264
	Commercial	43	19,162	1,985	43	0	0
	Sport	42	451	255	0	0	0
	Test Fishery	43	623	383	397	290	465

Note: Not all projects were operated in all years.

[a] Weir operated 1995–2013; 2017–2018.

[b] Aerial surveys not flown since 2013 because the system is monitored by a weir.

[c] 2017 aerial survey was the first since 2011.

Table 2.–Annual drainagewide run and escapement of Kuskokwim River Chinook salmon from the 2018 run reconstruction model.

	2018 Model run				2018 Model run			
Year	2018 Total run estimate	Lower 95% CI	Upper 95% CI	Previously published total run estimate[a]	2018 Total esc. estimate	Lower 95% CI	Upper 95% CI	Previously published total esc. estimate[a]
1976	187,910	144,509	244,346	187,584	97,363	53,962	153,799	97,037
1977	347,576	243,426	496,288	348,824	253,869	149,719	402,581	255,117
1978	241,159	190,768	304,860	241,781	157,687	107,296	221,388	158,309
1979	233,989	168,576	324,785	233,787	137,687	72,274	228,483	137,485
1980	358,448	219,595	585,101	357,950	261,480	122,627	488,133	260,982
1981	307,931	223,396	424,455	308,660	197,532	112,997	314,056	198,261
1982	172,512	145,789	204,133	173,072	65,511	38,788	97,132	66,071
1983	148,236	121,304	181,148	148,278	66,091	39,159	99,003	66,133
1984	172,329	134,935	220,085	171,853	83,153	45,759	130,909	82,677
1985	143,784	118,431	174,565	143,568	61,857	36,504	92,638	61,641
1986	123,767	92,796	165,076	123,452	53,155	22,184	94,464	52,840
1987	185,652	143,609	240,004	186,184	81,409	39,366	135,761	81,941
1988	205,050	177,362	237,060	204,824	77,287	49,599	109,297	77,061
1989	214,030	176,180	260,011	214,081	87,877	50,027	133,858	87,928
1990	266,729	228,651	311,149	266,353	102,543	64,465	146,963	102,167
1991	210,919	178,457	249,287	210,525	97,771	65,309	136,139	97,377
1992	259,043	223,854	299,764	259,154	127,943	92,754	168,664	127,881
1993	274,699	224,772	335,715	274,830	175,032	125,105	236,048	175,319
1994	403,431	307,678	528,982	411,724	281,327	185,574	406,878	289,094
1995	371,257	299,155	460,737	371,079	236,528	164,426	326,008	236,161
1996	309,632	242,502	395,344	307,072	204,057	136,927	289,769	201,561
1997	296,105	241,052	363,732	295,259	204,771	149,718	272,398	203,878
1998	184,341	142,352	238,715	184,356	84,369	42,380	138,743	84,140
1999	159,861	129,526	197,301	158,770	81,268	50,933	118,708	80,940
2000	129,109	113,351	147,057	129,138	60,900	45,142	78,848	60,905
2001	205,477	173,332	243,584	205,152	126,837	94,692	164,944	126,677
2002	226,323	194,871	262,852	226,106	144,475	113,023	181,004	144,445
2003	232,559	208,152	259,829	232,282	163,854	139,447	191,124	164,180
2004	366,840	323,992	415,353	366,725	266,199	223,351	314,712	266,084
2005	327,299	294,792	363,391	326,904	235,523	203,016	271,615	235,901
2006	326,544	289,979	367,720	326,067	232,159	195,594	273,335	232,409
2007	244,114	221,009	269,634	244,754	147,254	124,149	172,774	146,637
2008	210,784	186,113	238,725	219,709	111,879	87,208	139,820	111,613
2009	190,966	166,669	218,804	189,370	103,032	78,735	130,870	103,101

-continued-

Table 2.–Page 2 of 2.

Year	2018 Model run: 2018 Total run estimate	2018 Model run: Lower 95% CI	2018 Model run: Upper 95% CI	Previously published total run estimate[a]	2018 Model run: 2018 Total esc. estimate	2018 Model run: Lower 95% CI	2018 Model run: Upper 95% CI	Previously published total esc. estimate[a]
2010	114,146	103,656	125,696	112,975	43,482	32,992	55,032	43,541
2011	113,548	101,926	126,495	113,749	49,519	37,897	62,466	49,718
2012	79,210	64,952	96,598	79,238	55,718	41,460	73,106	55,746
2013	84,430	75,866	93,961	84,311	36,942	28,378	46,473	36,823
2014	84,444	72,562	98,271	84,326	72,678	60,796	86,505	72,560
2015	125,106	110,360	141,824	125,058	108,502	93,756	125,220	108,454
2016	128,696	111,957	147,938	128,855	97,478	80,739	116,720	97,640
2017	133,178	114,013	155,563	133,267	116,508	97,343	138,893	116,597
2018	132,312	104,858	166,954		109,583	82,129	144,225	
Average (1976-2017)	216,694			216,929	129,774			129,882

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 Liller et al. (2018). Based on the prior year model run, the 1976–2017 average total run and escapement was larger than the 2018 model run average by 234 fish (0.1%) and 108 (0.01%), respectively.

Table 3.–Parameter estimates derived from the 2018 run reconstruction model.

	Parameter	95% Bound	
	estimate (*k*)	Lower	Upper
Weir projects (*k*)			
Kwethluk Weir	2.67904	2.48	2.88
Tuluksak Weir	5.0343	4.86	5.21
George Weir	3.57398	3.40	3.75
Kogrukluk Weir	2.56429	2.40	2.72
Tatlawiksuk Weir	4.20949	4.03	4.39
Takotna Weir	5.82367	5.64	6.01
Aerial survey (*k*)			
Kwethluk River	4.39365	4.02	4.76
Kisaralik River	5.13923	4.89	5.39
Tuluksak River	6.11176	5.75	6.47
Salmon (Aniak River)	5.35846	5.12	5.59
Kipchuk River	4.99474	4.75	5.24
Aniak River	4.0171	3.75	4.28
Holokuk River	6.32205	6.03	6.62
Oskawalik River	6.51993	6.25	6.79
Holitna River	4.53971	4.27	4.81
Cheeneetnuk River	5.40605	5.15	5.66
Gagaryah River	5.88148	5.63	6.14
Pitka Fork	6.40559	6.07	6.74
Bear River	6.3356	6.05	6.62
Salmon(Pitka Fork)	4.83753	4.61	5.07
Catchability (*q*)			
Unrestricted	-9.5288	-9.82	-9.24
Restricted	-10.03345	-10.20	-9.87

Table 4.–Starting values used for sensitivity analysis and results for 2018 run reconstruction model.

Parameter	Starting values range	Average difference[a]	Max difference[b]
Total run (N_y)	100,000–400,000	0.003	0.012
Weir escapement scaling (k_{ij})	0.01–10	0.010	0.036
Aerial escapement scaling (k_{ij})	0.01–10	0.003	0.016
Catchability (q_k)	-20–1	0.007	0.027
Weir coefficient of variation	-20–20	0.008	0.035
Aerial coefficient of variation[c]	-20–20	0.008	0.035
Catchability coefficient of variation[c]	-20–20	0.008	0.035

[a] Average difference in numbers of fish among all 1976-2018 total run estimates across a range of 100 different starting values for each parameter.

[b] Maximum difference in numbers of fish among all 1976-2018 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.

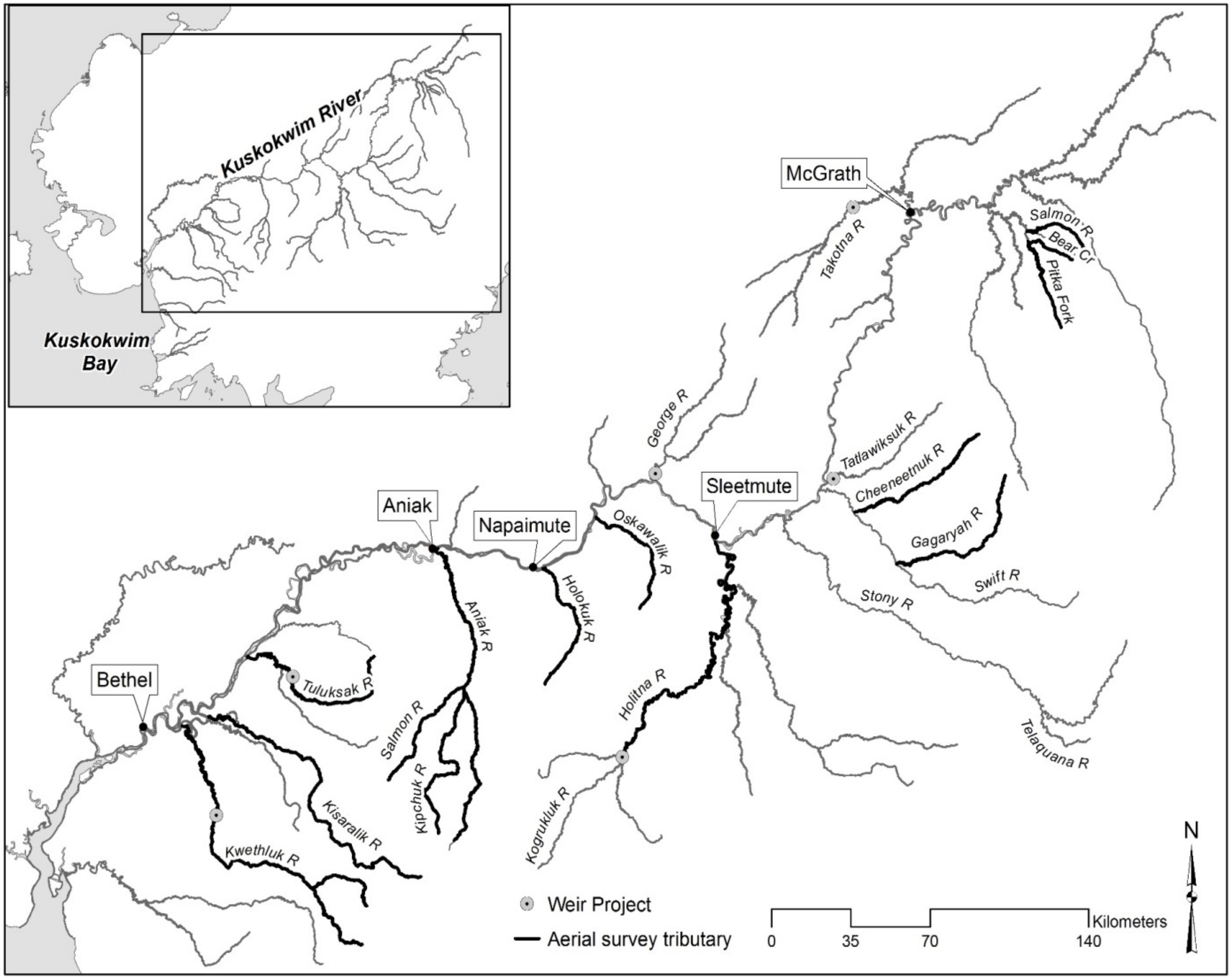

Figure 1.–Kuskokwim River Chinook salmon escapement monitoring projects used to inform the run reconstruction model.

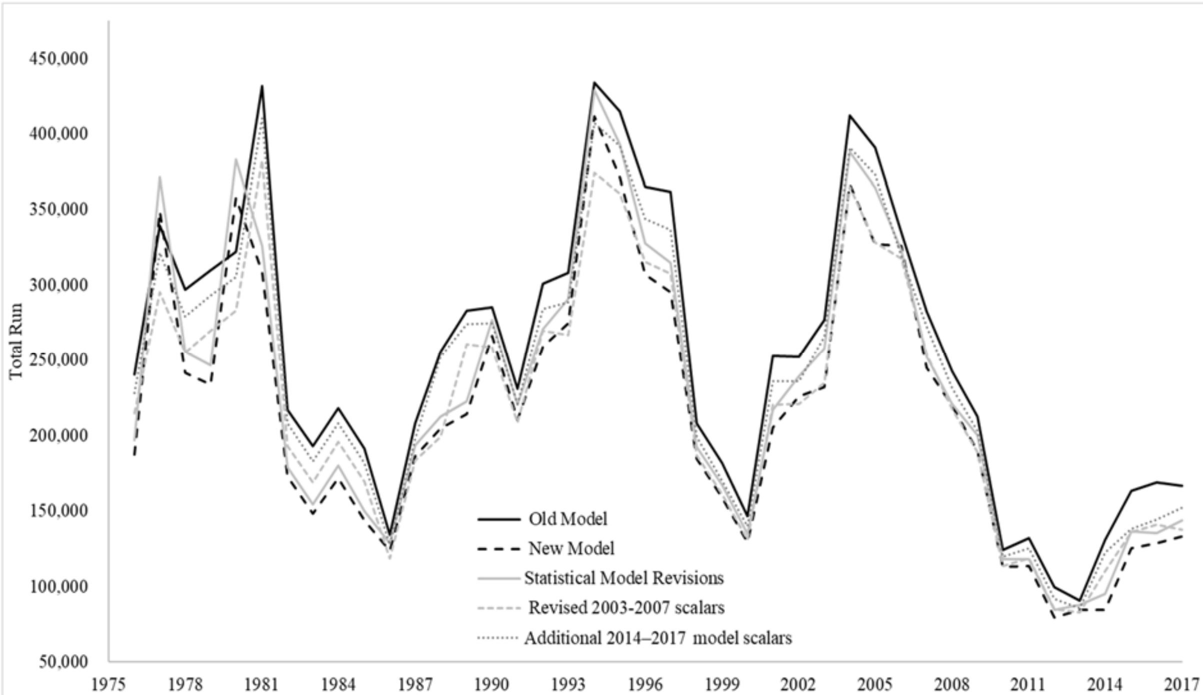

Figure 2.–Comparison of total run estimates from 1976–2017 based on the old model (black line; Smith and Liller 2018) and new model (dashed black line; Liller et al. 2018) and the effects of model changes related to statistical revisions only (solid grey line), revisions to the 2003–2007 model scalers only (dashed grey line), and addition of 2014–2017 model scalers only (dotted grey line).

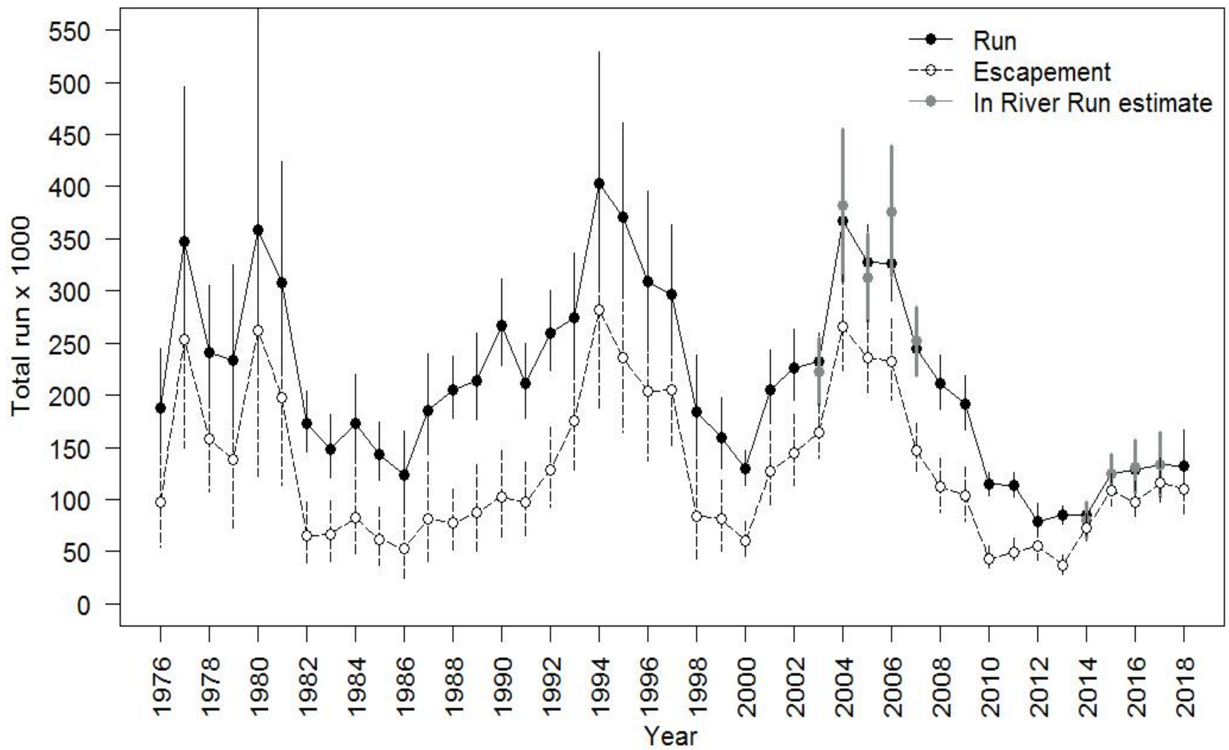

Figure 3.–Annual run (black) and escapement (white) estimates with 95% confidence intervals estimated from the 2018 run reconstruction model. Gray dots are drainagewide run size and 95% confidence intervals for years 2003–2007 and 2014–2017 used to scale the model.

Note: 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).

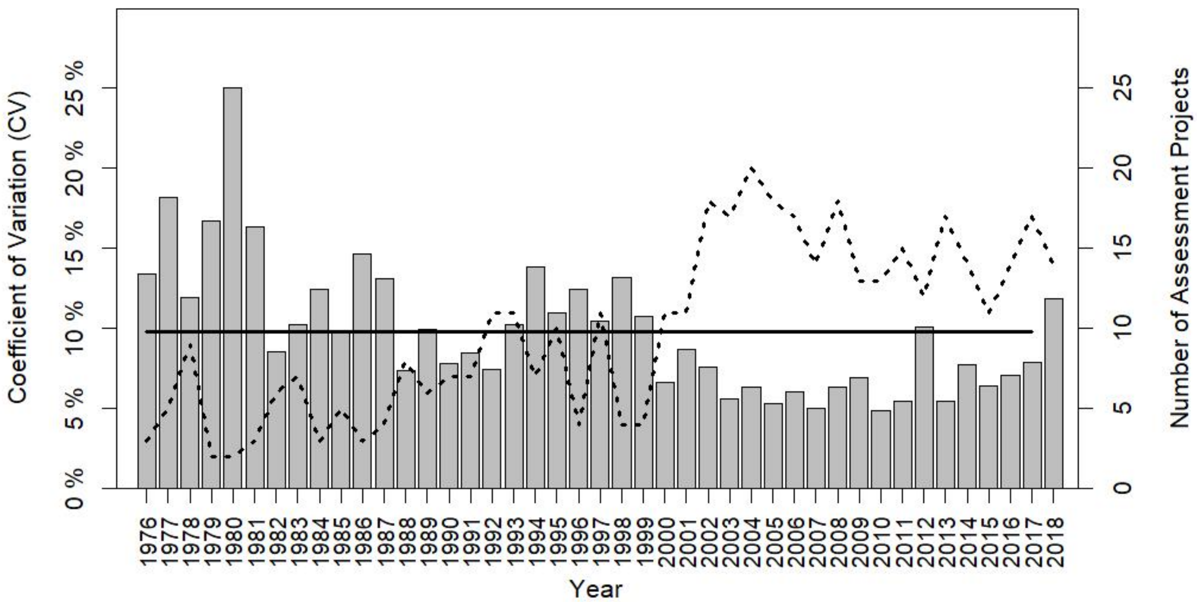

Figure 4.–Annual uncertainty (coefficient of variation; gray bars) of the run reconstruction model estimate of total run size and the number of assessment projects (dotted black line) used to inform the model in each year. The solid black line is the average coefficient of variation (10%) across years 1976–2017.

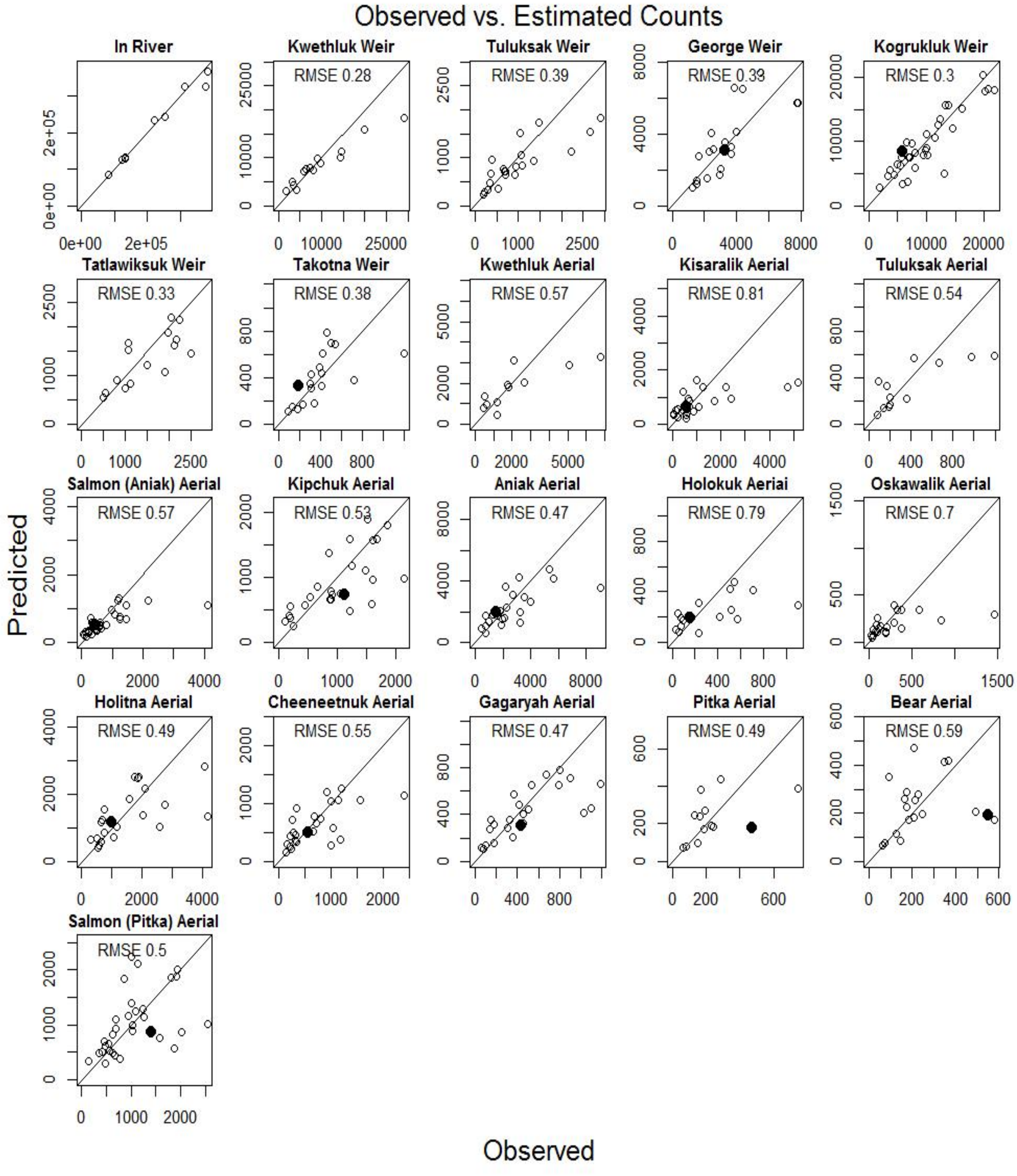

Figure 5.–Observed versus model estimated escapement counts.

Note: The diagonal line within each subplot represent 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 2018 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 "In River" is the 2003–2007 and 2014–2017 total run estimates used to scale the model.

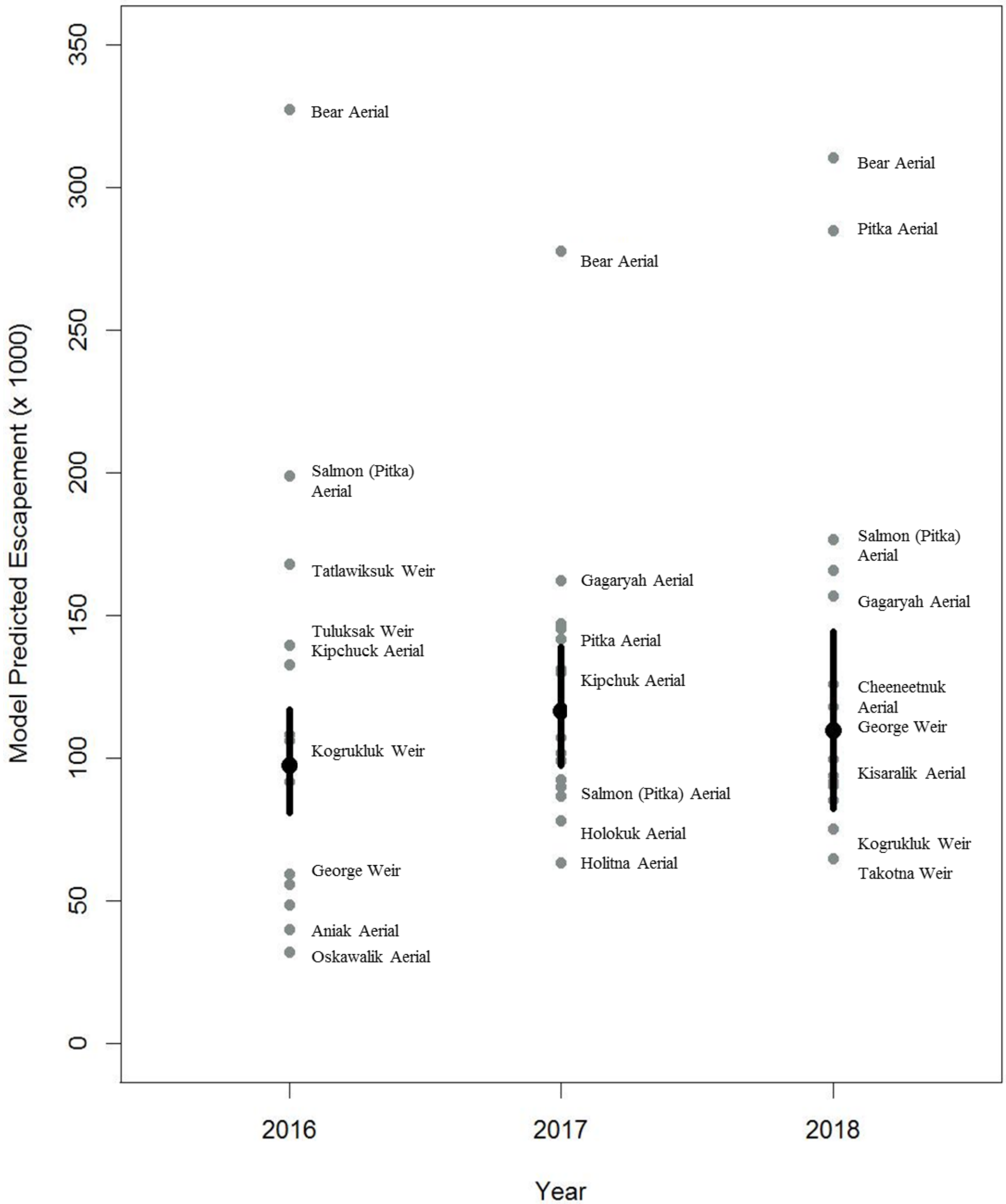

Figure 6.–Range of drainagewide escapement estimates produced by the model based on each individual escapement project.

Note: Gray dots are individual project estimates of 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 between 2016 and 2018 are shown to provide context.

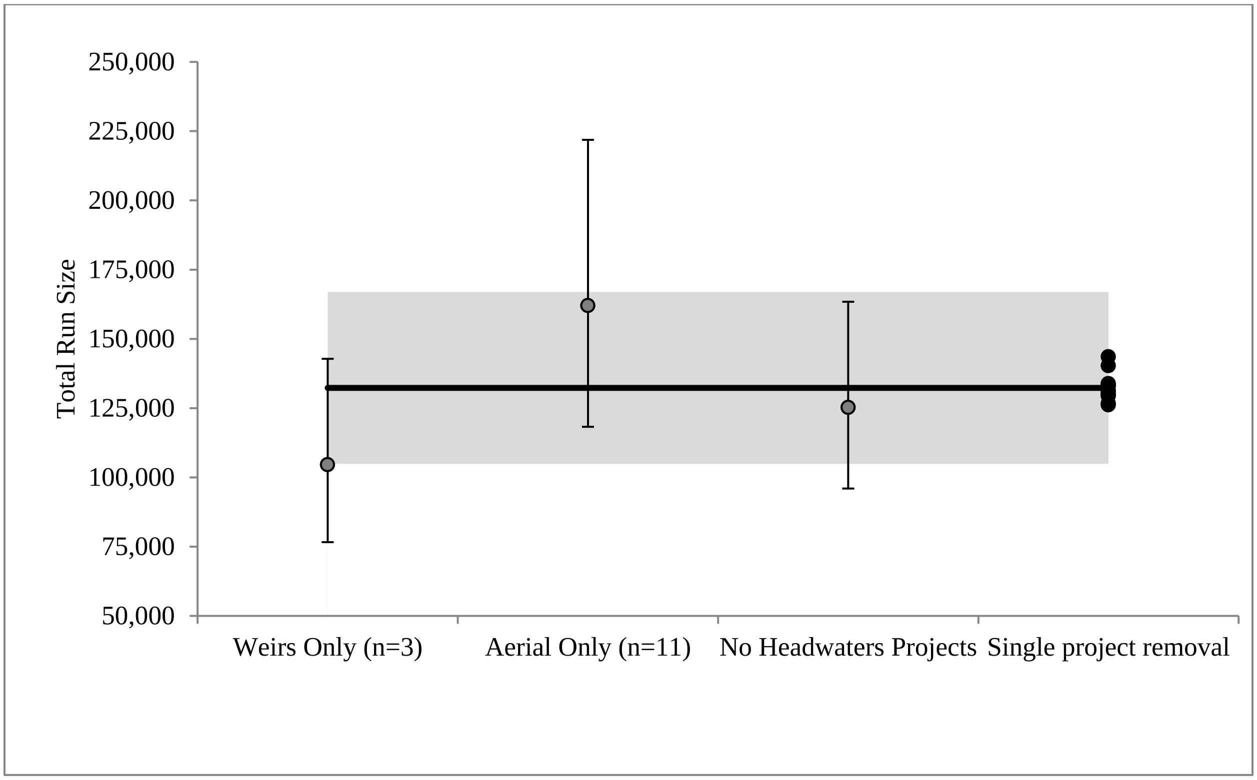

Figure 7.–Sensitivity of 2018 Chinook salmon total run size estimates using weir data only, aerial survey data only, exclusion of headwaters project data, and removal of single escapement monitoring projects (black dots).

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 (grey 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.

APPENDIX A: 2018 NPFMC 3-SYSTEM INDEX LETTER

Appendix A1.–2018 NPFRMC 3-system index letter.

THE STATE of ALASKA

GOVERNOR BILL WALKER

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 13, 2018

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] This action identifies historically low Western Alaskan Chinook salmon abundance using a 3-system index of in-river adult Chinook salmon run sizes from the Unalakleet, Upper Yukon, and Kuskokwim rivers combined at or below the threshold level of 250,000 fish. It 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, to determine if the combined adult Chinook salmon abundance in the indexed systems falls at or below the threshold level of 250,000 fish. The performance standard and hard cap applicable to the Bering Sea pollock fishery would be lowered in the year following the year in which the index was ≤250,000 Chinook salmon.

Methods and analyses used by the department to estimate the 2018 postseason run size for each of the three systems have been approved by the Council. The methods used for the Unalakleet and Upper Yukon rivers have not changed and are consistent with what is outlined in the Council's public review analysis.[2] The department revised the model used to estimate total run size of Kuskokwim River Chinook salmon after a multi-year process which included interagency collaboration and independent expert review. The department presented the revised Kuskokwim model to the Council and the Council's Scientific and Statistical Committee in June 2018. The Council approved the revised model for use in the 3-river index.[3] As required by NMFS, the department will notify the Council of any future improvements to methods used in the assessment of the 3-system index so that they may be evaluated and approved through the Council process.

[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

2018 Postseason Chinook Salmon Run Size Estimates

The 3-system index of in-river adult Chinook salmon run sizes from the Unalakleet, Upper Yukon, and Kuskokwim rivers is 225,908. The following details the preliminary total run estimates for each system.

Unalakleet River

The postseason run size estimate of Unalakleet River Chinook salmon is **7,058** based on preliminary assessment of total escapement, commercial harvest, and expectations of subsistence harvest. Preliminary Chinook salmon escapement in the Unalakleet River was 5,886 fish, measured by escapement projects on the North River tributary (2,577 fish) and mainstem Unalakleet River (3,309 fish). Both escapement projects experienced operational delays at the beginning of the season prior to the arrival of large numbers of Chinook salmon. The North River escapement counting project was impaired by high water after the Chinook salmon run had passed. The combined escapement is considered a reliable measure of the total Chinook salmon escapement. Harvest of Unalakleet River Chinook salmon included 647 commercially caught fish and approximately 525 subsistence caught fish. The subsistence harvest was expected to be slightly larger than what was estimated in 2017, because similar fishing restrictions were enacted and subsistence users indicated that more Chinook salmon were caught this season.

Upper Yukon River

The postseason run size estimate of Upper Yukon River Chinook salmon is **77,959**, based on preliminary assessment of total escapement into Canada and expectations of subsistence harvest in Alaska. The escapement of the Upper Yukon, or Canadian-origin, stock group into Canada is assessed by a sonar project at Eagle, AK. The 2018 preliminary sonar estimate is 57,959 Chinook salmon. There were no commercial sales of Chinook salmon harvested incidentally during the 2018 season, and all incidentally caught Chinook salmon were retained for personal use. Subsistence harvest of Upper Yukon River Chinook salmon is expected to be about 20,000 fish. Subsistence harvest was restricted based on inseason run projections which indicated the Upper Yukon stock group may be below average and near the lower bound of the preseason forecast. In most districts, subsistence fishing periods were reduced to half the usual regulatory schedule and gillnet mesh size was restricted to 6" or smaller to reduce harvest. Subsistence harvest of Upper Yukon River Chinook salmon in Alaska has averaged approximately 30,000 in years with no restrictions, based on rigorous subsistence harvest surveys conducted annually in the fall/winter. The 2018 expectation of a subsistence harvest near 20,000 is based on 1) management actions intended to reduce harvest compared to years with unrestricted fishing, 2) inseason run assessment, and 3) consultation with subsistence users during inseason management meetings. This postseason Upper Yukon run size estimate is corroborated by a preseason forecast that predicted 71,000–103,000 fish would return in 2018 and by inseason run projections that indicated approximately 74,000 Upper Yukon Chinook salmon passed the lower Yukon River sonar site located near Pilot Station, which is upriver from where some harvest occurred.

Kuskokwim River

The postseason run size estimate of Kuskokwim River Chinook salmon is **140,891** fish. Total run in the Kuskokwim River is estimated using a maximum likelihood model which was originally published in 2012 and subsequently revised, and approved by the Council in 2018 (see public review analysis and referenced documents). The revised model resulted in more accurate estimates of total run and increased model stability. The total run estimate for 2018 was informed by direct observations of escapement at 14 locations combined with historical observations of escapement, harvest, and commercial fishing effort since 1976. The model was scaled using nine years of independent estimates of total run size representing a range of run abundance including record high and record low run sizes. No commercial harvest of Kuskokwim River Chinook salmon occurred during the 2018 season and the sport fishery was closed. Subsistence restrictions were again necessary in 2018 to ensure that escapement goals were met, and included regulatory early season closures, mesh size and gillnet length restrictions, and time/area closures. Due to projected low run sizes and anticipated subsistence restrictions, the U.S. Fish and Wildlife Service (USFWS) issued a Federal Special Action and assumed management of the Chinook salmon fishery within the boundaries of the Yukon Delta National Wildlife Refuge. USFWS estimated that between 17,600 and 24,600 Chinook salmon were harvested during the limited subsistence fishing opportunities they provided within a portion of the mainstem Kuskokwim River. The department expects that the total subsistence harvest will be about 30,000 Chinook salmon based on available inseason harvest data provided from USFWS, historical harvest patterns, post hoc survey responses from subsistence users, and input from fisheries managers and assessment biologists. Total preliminary harvest of Kuskokwim River Chinook salmon is expected to be about 30,465 and includes 465 Chinook salmon harvest in the test fishery operated by ADF&G near Bethel. This preliminary total run estimate is corroborated by a preseason forecast that predicted a run size between 116,000–150,000.

Sincerely,

Scott Kelley
Commercial Fisheries Division Director

cc: Glenn Merrill, NMFS AKR

APPENDIX B: 2018 ADMB-CODE WITH ANNOTATIONS

Appendix B1.–2018 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	22,264	0	465

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				5,638		
	1977						
	1978				14,533		
	1979				11,393		
	1980						
	1981				16,089		
	1982				13,126		
	1983						
	1984				4,922		
	1985				4,442		
	1986						
	1987						
	1988				8,028		
	1989						
	1990				10,093		
	1991		697		6,835		
	1992	9,675	1,083		6,563		
	1993		2,218		12,377		
	1994		2,916				
	1995				20,662		
	1996			7,770	13,771		423
	1997			7,810	13,190		1,197
	1998						
	1999				5,543	1,484	
	2000	3,547		2,959	3,242	807	345
	2001		954	3,277	7,475	1,978	718
	2002	8,963	1,346	2,443	10,025	2,237	316
	2003	14,474	1,064		12,008		390
	2004	29,111	1,475	5,488	19,819	2,833	461
	2005		2,653	3,845	21,819	2,864	499
	2006	19,899	1,033	4,355	20,205	1,700	541
	2007	14,438	377	4,011		2,032	412
	2008	6,300	683	2,563	9,750	1,075	413
	2009	5,828	362	3,663	9,528	1,071	311
	2010	1,772	207	1,498	5,812	546	181
	2011	4,217	287	1,547	6,731	992	136
	2012		542	2,201		1,116	228
	2013		194	1,292	1,819	495	97
	2014	3,213	338	2,993	3,732	1,904	
	2015	8,163	711	2,282	8,081	2,104	
	2016		909	1,663	7,056	2,494	
	2017	7,345	645	3,685	9,992	2,156	301
	2018			3,306	5,770		191

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				182	
	1977	2,075		424							2,407	897			1,930
	1978	1,722	2,417		289					2,766	268	504		227	1,100
	1979														682
	1980			975	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	142							1,002				620
	1986				336		424			650					
	1987				516	193			193		317				
	1988	622	869	195	244		954		80						474
	1989	1,157	152		631	1,598	2,109								452
	1990		631	200	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[a]		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		425	443	1,930								
	1999								98	741					
	2000				238	182	714			301			151		362
	2001				598			52		4,156		143		175	1,033
	2002	1,795	1,727		1,236	1,615		513	295	733	730	452	165	211	1,255

-continued-

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Var name:	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				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	1123	1534	162		980	565	438	471	550	1399

Note: 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] Data correction made to database in 2018.

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

Appendix C6.–Chinook salmon catch and effort (permit-hours) by week 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

-continued-

		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

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