Fishery Data Series No. 12-49

Estimates of the Historic Run and Escapement for the Chinook Salmon Stock Returning to the Kuskokwim River, 1976–2011

Final Report for Study 45082 and 45554
Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative

by

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September 2012

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

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

Total run of Chinook salmon (*Oncorhynchus tshawytscha)* to the Kuskokwim River from 1976 through 2011 was estimated using a model developed for data-limited situations. The model simultaneously combined information on subsistence harvest, commercial harvest and effort, sport harvest, test fish harvest and catch per unit of effort at Bethel, mark–recapture estimates of inriver abundance, and counts of salmon at 6 weirs and peak aerial counts from 14 drainages all spread throughout the Kuskokwim River drainage. The estimates of historic run size were then combined with available information on the age structure of the stock to reconstruct the total return by age and ultimately estimate a brood table.

Key words: Chinook salmon, *Oncorhynchus tshawytscha*, Kuskokwim River, run reconstruction, total run, escapement, subsistence salmon harvest, commercial salmon harvest.

INTRODUCTION

A time series of reliable estimates of total run, spawning escapement, and productivity is important for the successful management of sustainable salmon fisheries. This is especially true when the stocks are experiencing moderate to heavy exploitation. While data on the Chinook salmon (*Oncorhynchus tshawytscha*) stock of the Kuskokwim River have been collected since before statehood, the large geographic size and diversity of the drainage, coupled with the wide geographic range of the fishery, have precluded the collection of adequate information to make estimates of total run and spawning escapement. In this report, we document the continued development and use of a run reconstruction model that was first developed by Shotwell and Adkison (2004) and refined by Bue et al. (2008) for use in estimating the historical abundance of salmon. We utilized the updated model to make estimates of total run size and spawning escapement for the Chinook salmon stock returning to the Kuskokwim River from 1976 through 2011 and then combined the estimates with available age composition information to estimate return by age and ultimately estimate a brood table.

The run reconstruction model described here differs from most others in scientific literature because the goal is to estimate total run size. Total run size and other population attributes such as total catch and escapement are typically known in other studies, and run reconstruction is used to estimate the stock composition of the catches and ultimately stock specific harvest rates (Starr and Hilborn 1988; Templin et al 1996; Branch and Hilborn 2010). Most run reconstructions are associated with large commercial fisheries and have become increasingly complex as more stock specific information is made available and computing methods improve (Flynn et al. 2006; Chasco et al. 2007; Lessard et al. 2008; Branch and Hilborn 2010). In contrast, the Kuskokwim River Chinook salmon stock is exploited primarily by local subsistence fishermen and only a small fraction of the escapement is measured. The methods presented here are appropriate for data limited situations and make use of most of the historical information collected on Chinook salmon in the Kuskokwim River drainage to estimate total abundance and total escapement by age for the stock.

Estimates of the total Chinook salmon run to the Kuskokwim River are critical for the success of our model. Recently, Schaberg et al. (2012) combined estimates of escapement from enumeration weirs located on the Kwethluk and Tulusak rivers, with expansions for unmonitored drainage areas downstream of Kalskag, and estimates of the number of Chinook salmon migrating upstream of Kalskag obtained from large-scale mark–recapture studies (Figure 1). These estimates of total run size were made for the 2003 through 2007 returns and provide the basis for calibrating our run reconstruction model.

Our approach can be viewed as the estimation of the run size most likely to produce the observed stock abundance information. While none of the datasets dealing with Chinook salmon in the Kuskokwim River alone are sufficient to provide an estimate of historical abundance in the drainage, the aggregate of information does provide an indication of trends in abundance that can be calibrated by a series of total run estimates.

OBJECTIVES

This report documents a portion of the work performed for the completion of research Projects 45082 and 45554 *Kuskokwim Chinook Salmon Run Reconstruction* funded by the *Arctic Yukon Kuskokwim Sustainable Salmon Initiative*. The original objectives for this component of the research project were to:

1. Estimate spawning and total abundance of Chinook salmon in the Kuskokwim River from 1975 through 2007 using a statistical model for combining multiple data sources.
2. Describe the spawner-recruit relationship of Kuskokwim River Chinook salmon for the period 1975 through 2007 to assess the influence of parental escapement abundance on variations in return.

Project objective 1 was modified to encompass the 1976 through 2011 runs. It was determined early in the study that there was insufficient information to reconstruct the 1975 run while data for the 2008 through 2011 returns became available before this report was completed. The initial steps toward completion of project objective 2 involved combining the estimated spawning and total abundance estimates obtained from objective 1, with available age information to reconstruct the total run by age and estimate the brood table for the Kuskokwim River Chinook salmon stock. It became apparent at that time that a more in-depth analysis of the spawner-recruit relationship than proposed was warranted. It was decided that this report would cover objective 2 through the estimation of the brood table and that the description of the spawner-recruit relationship would be documented in a separate report.

METHODS

DATA SOURCES

Estimates of total inriver abundance presented in Schaberg et al. (2012; Appendix A1) are critical for scaling or anchoring the patterns of Chinook salmon abundance found in the Kuskokwim River dataset. In addition to the estimates of inriver abundance, counts of escapement collected at weirs (Appendix A2) and peak aerial survey counts (Appendix A3) were used. Escapement data are maintained by the Alaska Department of Fish and Game (ADF&G), Division of Commercial Fisheries, in Anchorage. Escapement counts at weirs were inclusive of all Chinook salmon counted or estimated to have passed the weir during operations. In some instances, our weir counts may be greater than those presented in other documents which typically only present counts obtained during a specified period of operation. Aerial survey data were compiled from Molyneaux and Brannian (2006) from 1976 through 2005 and the original data forms archived at the ADF&G office in Anchorage from 2006 through 2011. Aerial survey counts were inclusive of only index reaches that were considered to have been successfully surveyed (rating of good or fair) and included counts of carcasses.

Subsistence harvest data were compiled from several sources; estimates from 1976 through 1989 are found in Bavilla et al. (2010), estimates from 1989 through 2009 are found in Hamazaki (2011), and preliminary estimates for 2010 and 2011 are on file with ADF&G, Division of Commercial Fisheries, Anchorage. Commercial harvest and effort information from 1976 through 2009 were obtained from Bavilla et al. 2010 and the 2010 and 2011 data are on file with ADF&G, Division of Commercial Fisheries, Anchorage (Appendix A4). Data collected at the Bethel test fishery were provided by ADF&G Kuskokwim River research staff, Division of Commercial Fisheries. Data from the commercial fishery and Bethel test fishery were grouped into weekly intervals to facilitate the estimation of run timing. Age composition data were compiled from the Arctic Yukon Kuskokwim Salmon Database Management System maintained by the Alaska Department of Fish and Game, Division of Commercial Fisheries, Anchorage.

ESTIMATION OF RUN TIMING

Run timing for Chinook salmon in the W1 commercial fishing district for the years 1984 through 2011 was estimated using information from the Bethel test fishery. The proportion of the run present by year and week (p_{yj}) was defined by:

$$p_{yj} = \frac{CPUE_{yj}}{\sum_{j=1}^{z} CPUE_{yj}} \quad , \tag{1}$$

where $CPUE_{yj}$ is the total catch per unit effort during year (*y*), week (*j*) in the Bethel test fishery and *z* is the number of weeks that the test fishery operates. Run timing from 1976 through 1983 was estimated using the average run timing for the 1984 through 2011 runs.

RUN RECONSTRUCTION MODEL

A reconstruction model was used to estimate total run and ultimately total escapement of Chinook salmon into the Kuskokwim River. The model simultaneously combined information on subsistence harvest, commercial harvest and effort, sport harvest, test fishery harvest and indices of abundance at Bethel, mark–recapture estimates of inriver abundance, counts of salmon at 6 weirs spread throughout the drainage, and peak aerial counts from 14 drainages also spread throughout the Kuskokwim River drainage. To simplify the description of the estimation process, the methodology was divided into 4 logical components based on the type of data used in the model: (1) weir counts, (2) aerial observations, (3) commercial harvest and effort, and (4) total inriver abundance. The model simultaneously combined input from all 4 components to estimate total run to the Kuskokwim River.

Weir Counts

The weir component used total counts of Chinook salmon by year from 6 weirs (*i*) in the Kuskokwim drainage (Figure 1). For each weir the measurement of escapement (I_{iy}) by year (*y*) was assumed to be related to the total annual escapement into the Kuskokwim River drainage (E_y) by:

$$E_y = \hat{k}_i I_{iy} \quad , \tag{2}$$

and the expected weir count ($\hat{I}_{iy}$) was estimated by:

$$\hat{I}_{iy} = E_y / \hat{k}_i \quad , \tag{3}$$

where $\hat{k}_i$ is a scaling factor for weir *i*.

The Poisson distribution is often used to model uncertainty in count data and was initially considered for use with the weir and aerial survey information in our model. However, the variance of the observations from weir and aerial surveys was greater than the mean of the observations, with the difference being more pronounced as the mean increased (Figure 2). This indicated that the weir and aerial survey counts did not follow a Poisson distribution, which requires that the mean and variance be equal. The negative binomial distribution is commonly used for this situation where an additional parameter, typically called the overdispersion parameter, is estimated to account for the additional variability. The form of the negative binomial density presented in Hilborn and Mangel (1997) and Millar (2011) was used:

$$f\left(I_{iy};\hat{I}_{iy},\hat{m}_i\right) = \frac{\Gamma\left(\hat{m}_i + I_{iy}\right)}{\Gamma\left(\hat{m}_i\right) I_{iy}!}\left(\frac{\hat{I}_{iy}}{\hat{m}_i + \hat{I}_{iy}}\right)^{I_{iy}}\left(\frac{\hat{m}_i}{\hat{m}_i + \hat{I}_{iy}}\right)^{\hat{m}_i} \quad , \tag{4}$$

where $\hat{I}_{iy}$ is the mean or expected value of I_{iy} and $\hat{m}_i$ is the overdispersion parameter.

Aerial Observations

Similar relationships and assumptions were made for the peak aerial counts from 14 systems (*a*) spread throughout the drainage. The peak aerial count (I_{ay}) was assumed to be related to the total annual escapement into the Kuskokwim River drainage by:

$$E_y = \hat{k}_a I_{ay} \quad , \tag{5}$$

and the expected aerial count ($\hat{I}_{ay}$) was be estimated by:

$$\hat{I}_{ay} = E_y / \hat{k}_a \quad , \tag{6}$$

where $\hat{k}_a$ is a scaling factor for aerial counts from system *a*. As with the weir counts, the uncertainty between observed (I_{ay}) and estimated ($\hat{I}_{ay}$) aerial counts was assumed to follow a negative binomial distribution which required estimating both a scaling factor ($\hat{k}_a$) and an overdispersion parameter ($\hat{m}_a$).

Commercial Harvest and Effort

The commercial harvest component relates weekly (*j*) commercial harvest and effort data from commercial fishing district W1 (C_{yi}; Figure 1) to total estimated abundance by week ($\hat{N}_{yj}$). Commercial fishing effort was defined as the number of permits fished during a fishery opening times the length of the opening in hours. Subsistence harvest that occurred in the Bay, downstream of fishing district W1 was subtracted from the estimated total abundance ($\hat{N}_y$) to produce an estimate of Chinook salmon available to the commercial fishery ($\hat{W}_y$) which can be further partitioned to estimates of weekly abundance using the estimated run timing at the Bethel test fishery. The number of Chinook salmon present in commercial fishing district W1 by year and week ($\hat{W}_{yj}$) was estimated by:

$$\hat{W}_{yj} = \hat{W}_y p_{yj} \quad . \tag{7}$$

Catch by year and week ($\hat{C}_{yj}$) was estimated by:

$$\hat{C}_{yj} = \hat{W}_{yj}\left(1 - e^{-\hat{q}B_{yj}}\right)e^{\varepsilon_{yj}} \ , \quad \varepsilon_{yj} = N(0, \sigma_{\varepsilon}^2) \quad , \tag{8}$$

which is the Baranov catch equation where $\hat{q}$ is the estimated catchability coefficient and B_{yj} is the observed effort for year *y* and week *j*. The uncertainty between observed harvest (C_{yj}) and estimated harvest ($\hat{C}_{yj}$) was assumed to be distributed lognormally with a mean of zero and a standard deviation of σ_{ε}.

The commercial harvest component was stratified into three groups to account for changes in the fishery which have been shown to have dramatic effects on harvest and effort models (Maunder and Punt 2002). Catchability coefficients were estimated for fisheries with no restriction on gillnet stretched mesh size ($\hat{q}_{un}$), for fisheries with gill net stretched mesh size restricted to 6 inches or less for 1976 through 1984 ($\hat{q}_r$) and for fisheries with gillnet stretched mesh size restricted to 6 inches or less after 1984 ($\hat{q}_m$). While the distinction between fisheries using gillnets of any stretched mesh size (unrestricted) and fisheries where gillnets of 6 inches or less stretched mesh were allowed (restricted) were straightforward, the decision of whether to further stratify and for what time period within restricted fisheries was not. A major change in gillnet twine construction occurred in the early 1980s (Bue 1986a) and greatly increased the efficiency of gillnets in the Bristol Bay sockeye salmon fishery at that time (Bue 1986a, Bue 1986b). We assumed that fishermen in the Kuskokwim River salmon fisheries would have switched to gillnets with the new twine construction by 1985, and used that year to group the restricted gear for analysis.

Total Inriver Abundance

An intensive stock assessment program designed to estimate the total inriver run was essential for the successful completion of this modeling effort. An accurate estimate of the number of Chinook salmon migrating upstream of Kalskag, combined with accurate estimates of escapement for tributaries downstream of Kalskag, and estimates of the subsistence, commercial, sport, and test fishery harvests, allowed for a comparison of the observed total run (N_y) to the estimated total run ($\hat{N}_y$),

$$N_y = E_{(Downstream)y} + E_{(Upriver)y} + S_y + C_y + R_y + G_y \quad , \tag{9}$$

where annual subsistence, commercial, sport, and test-fish harvests are S_y, C_y, R_y and G_y, respectively, and

$$\hat{N}_y = N_y + \delta_y \quad , \quad \delta_y \sim N(0, \sigma_\delta^2) \quad . \tag{10}$$

The work described by Schaberg et al. (2012) provided estimates of both N_y and its standard deviation (σ_{N_y}) for the years 2003 through 2007 which were incorporated into the model as a penalized negative log likelihood similar to that described in Branch and Hilborn (2010) and Flynn et al. (2006),

$$-\ln L = \sum_y \frac{\left(N_y - \hat{N}_y\right)^2}{2\sigma_{N_y}^2} \quad . \tag{11}$$

Because the σ_{N_y} values were considered fixed and not estimated by the reconstruction model, the constant term (ln σ_{N_y}) typically included in the negative log likelihood form of the normal model was omitted.

The estimated annual escapement into the Kuskokwim River drainage ($\hat{E}_y$) was calculated as:

$$\hat{E}_y = \left(\hat{N}_y - S_y - C_y - R_y - G_y\right) \quad , \tag{12}$$

Likelihood Model

The weir, aerial, catch, and total inriver components were combined into a single likelihood model that simultaneously estimated the total run to the Kuskokwim drainage for each year,

$$L\left(\theta \middle| data\right) = \begin{array}{l} \prod_y \prod_i \frac{\Gamma\left(\hat{m}_i + I_{iy}\right)}{\Gamma\left(\hat{m}_i\right) I_{iy}!} \left(\frac{\hat{I}_{iy}}{\hat{m}_i + \hat{I}_{iy}}\right)^{I_{iy}} \left(\frac{\hat{m}_i}{\hat{m}_i + \hat{I}_{iy}}\right)^{\hat{m}_i} \\ \prod_y \prod_a \frac{\Gamma\left(\hat{m}_a + I_{ay}\right)}{\Gamma\left(\hat{m}_a\right) I_{ay}!} \left(\frac{\hat{I}_{ay}}{\hat{m}_a + \hat{I}_{ay}}\right)^{I_{ay}} \left(\frac{\hat{m}_a}{\hat{m}_a + \hat{I}_{ay}}\right)^{\hat{m}_a} \\ \prod_y \prod_j \frac{1}{\sigma_\varepsilon \sqrt{2\pi}} \exp^{\frac{-\left(\ln C_{yj} - \ln \hat{C}_{yj}\right)^2}{2\sigma_\varepsilon^2}} \\ \prod_y \exp^{\frac{-\left(N_y - \hat{N}_y\right)^2}{2\sigma_{N_y}^2}} \end{array} \tag{13}$$

The negative log likelihood form of the model was minimized (Hilborn and Mangel 1997) to arrive at the best estimates of the model parameters ($\hat{k}_i$, $\hat{k}_a$, $\hat{q}_{un}$, $\hat{q}_r$, $\hat{q}_m$, $\hat{m}_i$, $\hat{m}_a$ and $\hat{N}_y$) with the optimizer constrained to (1) values of estimated total run ($\hat{N}_y$) greater than the number of fish already accounted for in the catch and escapement and (2) values for the escapement scaling factors ($\hat{k}_i$ and $\hat{k}_a$) of 1.0 or greater. Both of these constraints reflect the assumption that there were more fish in the river system than were counted by catch and escapement programs. The optimizer was also constrained when estimating the catchability coefficients ($\hat{q}_{un}, \hat{q}_r, \hat{q}_m$) to values less than 1×10^{-4} and greater than or equal to 5×10^{-7} to protect against obtaining nonsensical negative log likelihood values. An *ad hoc* sensitivity analysis which examined model convergence for a wide range of possible starting values was performed. In addition, the negative log likelihood profile for each model parameter was examined for localized minima which could affect model convergence and the resulting estimates.

The confidence regions about the estimates of total run were calculated using the negative log-likelihood profiles for $\hat{N}_y$ for each year. For this method, the negative log-likelihood profile for an estimate of total abundance for a selected year was estimated by calculating the negative log-likelihood for individual levels of possible run size within a wide range of possible run abundances while searching over all possible values of the other parameters in the model. The confidence bounds for $\hat{N}_y$ were then estimated using the negative log-likelihood ($\mathbf{L}(N)$) for a total run of abundance N by,

$$2\left[\mathbf{L}(N) - \mathbf{L}(N)_{\min}\right] \ , \tag{14}$$

which is chi-square distributed with 1 df (Venzon and Moolgavkar 1988; Hilborn and Mangel 1997).

BROOD TABLE ESTIMATION

Estimates of the number of Chinook salmon in the harvest and escapement obtained from the run reconstruction model were combined with available age information to reconstruct the total run by year and age, and the resulting information was then used to estimate a brood table. Whenever possible, estimates of age composition were combined with the corresponding segment of the total run estimate. For example, the estimated age composition of the 2009 commercial harvest was applied to the estimated number of fish caught in the commercial fishery in 2009 to estimate the number of fish by age in that segment of the run. For many years, however, age composition information was missing for one or more of the segments, which required some form of data pooling to estimate the number of salmon by age. Commercial and subsistence fisheries both use gillnets to harvest Chinook salmon. This gear has been shown to be selective for size and age, which makes it highly unlikely that the harvest and escapement would have the same age composition. Because of the selective nature of the fisheries, it was decided that only age information from the harvest segment would be used to estimate the age composition of the harvest, while only age information from the escapement would be used to estimate the age structure of the escapement.

The harvest segment was composed of harvest from the commercial, subsistence, sport, and test fishery, with the commercial and subsistence fisheries comprising by far most of the harvest. In addition, age composition information for the subsistence harvests was available only from 2001 through 2011. Since subsistence harvest was greater than commercial harvest for all years except 1978 (Appendix A2), it was important to include an estimate of age composition for that segment. The subsistence fishery has historically used large mesh gillnets and the age composition of the harvest from 2001 through 2011 has been relatively consistent, which suggested that the average age composition from 2001 through 2011 could be used for the previous years (1976–2000). In contrast, the commercial fishery for Chinook salmon occurs at the same time as the fishery for chum salmon and the stretched mesh size of the gillnets allowed in the commercial fishery was often restricted to 6 inches or less (smaller gear), which suggested that age information from the commercial and subsistence harvest were not interchangeable. No estimate of the number of fish by age in the harvest was made when the commercial harvest was greater than 1,000 fish and corresponding age information was not available. When the commercial harvest was less than 1,000 fish and corresponding age composition information was not available, the number of fish by age was estimated by summing the commercial and subsistence harvests and then applying the subsistence age information. Because the magnitude of sport and test fishery harvests were always quite small relative to the overall harvest, harvests from these fisheries were pooled with commercial and subsistence information whenever age information for the sport and test fisheries were unavailable.

The number of fish by age in the escapement segment was estimated using age information obtained from all of the operational escapement projects. Age composition information came solely from the Kogrukluk River weir from 1976 through 1990 after which additional escapement projects became operational and more age information became available. A weighted estimate of the proportion ($\hat{P}_{ya}$) of each age group (*a*) was obtained for each year (*y*) by weighting the age composition estimates ($\hat{h}_{yai}$) from each weir (*i*) by the number of fish enumerated at the project for which age information was collected at (g_{yi}),

$$\hat{P}_{ya} = \frac{\hat{h}_{yai} g_{yi}}{\sum_{y} g_{yi}} \quad . \tag{15}$$

The number of fish of age *a* from year *y* ($\hat{n}_{ya}$) was estimated by multiplying the estimated escapement from the reconstruction model ($\hat{E}_y$) by the estimated proportion of age *a* fish,

$$\hat{n}_{ya} = \hat{E}_y \hat{P}_{ya} \quad . \tag{16}$$

No estimate of the age composition of the escapement was made, if age information from the escapement was unavailable.

The harvests and escapements by age and year were summed to estimate the total run by year for all years where both harvest and escapement by age were estimated. No estimate of total run by age was made if either the harvest or escapement component was not estimated.

A brood table was estimated using the estimates of total run by age. An evaluation of the sibling relationships for the major age classes (age 1.2, 1.3, 1.4, and 1.5; Peterman 1982) was performed for years with complete age data to determine whether the appropriate sibling relationship could be used to estimate the number of fish by age for years with incomplete age data. If the sibling relationships were unreliable for that purpose, then the average return by age was used.

RESULTS

ESTIMATION OF RUN TIMING

Run timing of Chinook salmon in commercial fishing district W1 was generally unimodal, peaking during week 4 of the season (June 17 through June 23); although a wide range of entry patterns and run timings have been observed (Figure 3).

RUN RECONSTRUCTION MODELING

Seventy-nine parameters were estimated for the run reconstruction model: 36 total runs ($\hat{N}_y$; 1976 through 2011), 6 scaling factors ($\hat{k}_i$) and 6 overdispersion parameters ($\hat{m}_i$) for the escapement monitored by weirs, 14 scaling factors ($\hat{k}_a$) and 14 overdispersion parameters ($\hat{m}_a$) for the systems monitored by aerial survey, and 3 catchability coefficients ($\hat{q}_{un}$, $\hat{q}_r$ and $\hat{q}_m$; Table 1). While the number of parameters is high, 432 observations were used to fit the model (Appendices A2, A3, and A4). Constraints placed on the estimation of catchability did not adversely influence parameter estimation since the value of catchability that minimized the negative log likelihood was between 8.0x10^{-5} and 1.0x10^{-5} for the 3 catchability models. The *ad hoc* examination of model stability showed that the model converged to approximately the same values for nearly all scenarios. The exception to this occurred when a starting catchability value was less than the constrained range.

All model parameters associated with the escapement components displayed pronounced "U-shaped" profiles across a wide range of possible values (Figures 4 and 5). This pattern in the negative log likelihoods indicated that there was a unique solution for the model within the range of parameter values examined. The point where the profile was minimized was the parameter value which provided the most likely solution for the run reconstruction model. In addition, the negative log likelihood scales for Figures 4–6 have been adjusted such that the minimum value was zero and each unit increase in the negative log likelihood was one unit increase in the scale. This adjustment not only simplified the scale but also provided an easy way to approximate the 95% confidence range about the parameter estimates. Two times the difference between the negative log likelihood for a parameter value and the minimum negative log likelihood was chi-square distributed with 1 degree of freedom (Equation 14). The chi-square value for 95.45% and 1 degree of freedom is 4.0; thus an approximate 95% confidence range for a parameter was found at the points where the likelihood profile crossed the value of 2.0 on the adjusted axis. An examination of the negative log likelihood profiles for the catchability parameters also indicated good model convergence (Figure 6) as well as evidence that the model stratification was appropriate and showed little overlap of the parameter profiles at adjusted values less than 2.0.

The reconstructed counts for the weirs located above Kalskag compared well with the observed counts while there was an indication that the reconstruction model estimated higher escapements for the lower weir counts and lower escapements for the high weir counts observed at the Kwethluk and Tuluksak River weirs; more so for the Kwethluk than the Tuluksak (Figure 7). The mouths of both of these systems are in the lower Kuskokwim River where the majority of subsistence and commercial harvests occur, and it is possible that fishery management decisions influenced the exploitation rates on these populations differently from other weir populations. There was some suggestion that large aerial counts did not always result in large reconstructed counts (Figure 8; Kwethluk, Kisaralik, Aniak, and Oskawalik for example). The inconsistencies with the aerial information is not surprising since salmon entry and mortality in these systems can be very dynamic and variable from year to year, and abundance data are obtained from a single aerial survey made during the same time period each year often using different observers. Some researchers recommend against the use of peak aerial surveys for estimating abundance (Parsons and Skalski 2010) while others have demonstrated that escapement estimates based on multiple observations distributed throughout the run are imprecise (Bue et al. 1998; Hilborn et al. 1999; Holt and Cox 2008). We felt that the inclusion of the aerial survey information in the reconstruction was justified since it provided abundance information from throughout the Kuskokwim drainage and any uncertainty in the model fit was reflected in the likelihoods. Estimates of harvest obtained from the catchability model were generally in agreement with the observed harvests (Figure 9).

Total run estimates provided by the model were a good fit to the total runs estimated by Schaberg et al. (2012; Figure 10). The greatest difference between a reconstructed estimate and a total run estimated by Schaberg et al. (2012) occurred for 2006. However, the 95% confidence bounds for the two estimates overlapped, providing little evidence that the two estimates were significantly different from each other (Figure 11).

The largest estimates of total run occurred in 1981, 1994, 1995, 2004, and 2005 with the lowest occurring in 1986, 2000, 2010, and 2011 (range 118,507 to 389,791; Table 2, Figure 12). Coefficients of variation for the annual escapement estimates ranged from 8% to 16%. The time series of Chinook salmon escapement estimates ranged from lows in 1986, 2000, and 2010, to highs in 1981, 2004, and 2005 (range 49,073 to 287,178; Table 2, Figure 12). Coefficients of variation for the annual escapement estimates ranged from 12% to 33%.

BROOD TABLE CONSTRUCTION

Sufficient age information was available to reconstruct the age composition of the total run for 30 of the 36 years estimated by the run reconstruction model (Appendix A6). Fortunately, the years for which information was lacking occurred early in the time series and in close proximity to each other temporally, which minimized the effect of missing age data upon the estimation of the brood table. Estimates for 1976 and 1979 were not made due to the lack of age information from the commercial harvest, while estimates for 1977, 1980, 1983 and 1987 were omitted due to the lack of age information from the escapements (Table 3; Appendix A6). Estimates of the age composition of the harvest were made for 2000 through 2003 and 2007 even though no age information was collected from the commercial harvest (Table 3; Appendix A6). Commercial harvest for those years was low relative to the subsistence harvest (less than 500 fish or 0.5% of the subsistence harvest for all years; Appendix A6). Estimates of age composition were available from the subsistence harvest for 2001 through 2003 and 2007, and were used to estimate the number of fish by age in both the commercial and subsistence harvest for their respective years while average age composition from the subsistence fishery for 2001 through 2011 was used to estimate the 2000 harvest.

The estimates of total run by age and year were rearranged by brood year so the number of fish produced for a particular escapement could be estimated (Table 4). Nine brood years, 1976 through 1984 (Table 4), were affected by the lack of age information for the 1976, 1977, 1979, 1980, 1983, and 1987 returns. Examination of the sibling relationships for the major age classes indicated that the number of age 1.3 (r^2=0.47, p<0.001) and age 1.4 (r^2=0.59, p<0.001) fish could be estimated using sibling models. However, the relationship for age 1.2 fish was not statistically significant (r^2=0.0, p>0.34; Figure 13), and the relationship for age 1.5 fish (r^2=0.22, p<0.02) was driven by one data point (Figure 13), and was thought to be unreliable. Thus, sibling relationships were used to estimate missing returns for age 1.3 and 1.4 fish, while the average return by age class was used to estimate missing returns for the other age classes.

The estimated number of fish in the escapement for the period 1976 through 2011 ranged from a low of 49,073 in 2010 to a high of 287,178 in 2004 (Table 4). The number of fish returning for every spawning fish (return per spawner) ranged from lows of 0.57, 0.58, and 0.50 (1994, 2004 and 2005 brood years, respectively) to a high of 6.90 (2000 brood year). The return per spawner tended to cycle from periods of low production to periods of higher production (Figure 14A; Table 4). There also was a suggestion that return per spawner trended with level of escapement, with higher production occurring for lower levels of escapement and lower production being observed for higher levels of escapements (Figure 14B).

DISCUSSION

We believe our methodology did an acceptable job of describing the true pattern of abundance and provided reasonable estimates of the time series of total run size and escapement. The overall confidence in our time series of abundance estimates depends on the number and accuracy of the independent estimates of total run, as well as the range of abundance levels encompassed by the independent estimates. Generally, our confidence in the run reconstruction estimates increases as the range and number of independent estimates of total run increases. Schaberg et al. (2012) provided 5 independent estimates of total run, spanning almost a two-fold range of run sizes (241,617 to 422,657).

Reliance upon a relatively small number of independent estimates of run size from a narrow window of time may result in a degradation of model accuracy over time. Hilborn et al. (2003) and Schindler et al. (2010) demonstrated for Bristol Bay sockeye salmon that distinct geographic and life history components of a stock contribute differently to the stock's abundance through time, with some populations being minor producers under one climatic regime but dominating during the next. If this pattern is also true for the Chinook salmon stock returning to the Kuskokwim River drainage, our reconstruction model will perform well for the years closer to the time period for which the independent estimates of run size were made, with accuracy decreasing for earlier and later years. Because of this it will be important to periodically update the model with new independent estimates of total run size.

Estimates of uncertainty about the age composition estimates and estimates of return by brood year were not made. Sample size information was available for all cases where age composition estimates were made, but there was the potential for unknown sampling bias. The subsistence fishery was not sampled sufficiently until 2001 and the average estimated age composition of the 2001 through 2011 subsistence harvests was used to estimate the 1976 through 2000 harvest. While the commercial harvests and weir projects were sampled for most years using adequate sample sizes and stratified designs to account for differences in population structure through time, less than 14% of the total escapement was counted past the weirs prior to 1996, with the percentage increasing as more weir projects became operational (Table 5). More than 75% of the escapement was never in the population of fish available for age sampling, and if age structure varies between tributaries, the true age structure of the escapement may be different than that estimated by the weir populations.

We do not feel these weakness decreases the value of our estimates of the historical time series, age composition by return year, and estimates of brood year returns. This study provides new information for the formulation of fisheries management strategies and hopefully helps with the development of future population assessment projects.

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REFERENCES CITED

Bavilla, J., D. Bue, H. Carroll, T. Elison, D. Taylor, J. Estensen and C. Brazil. 2010. 2009 Kuskokwim area management report. Alaska Department of Fish and Game, Fishery Management Report No. 10-56, Anchorage.

Branch, T. A., and R. Hilborn. 2010. A general model for reconstructing salmon runs. Canadian Journal of Fisheries and Aquatic Sciences 67:886-904.

Bue, B. G., D. B. Molyneaux and K. L. Schaberg. 2008. Kuskokwim River chum salmon run reconstruction. Alaska Department of Fish and Game, Fishery Data Series No. 08-64, Anchorage.

Bue, B. G. 1986a. Effects of gill net selectivity on sockeye salmon in the Egegik and Naknek-Kvichak Districts, Bristol Bay, Alaska. University of Alaska, Fairbanks.

Bue, B. G. 1986b. Comparison of cable lay and center core gill net catches from the Port Moller offshore test fishery, 1985. Alaska Department of Fish and Game, Division of Commercial Fisheries, Bristol Bay Data Report No. 86-4, Anchorage.

Bue, B. G., S. M. Fried, S. Sharr, D. G. Sharp, J. A. Wilcock, and H. J. Geiger. 1998. Estimating salmon escapement using area-under-the-curve, aerial observer efficiency, and stream-life estimates: the Prince William Sound example. North Pacific Anadromous Fish Commission Bulletin 1:240-250.

Chasco, B., R. Hilborn and A. E. Punt. 2007. Run reconstruction of mixed-stock salmon fisheries using age-composition data. Canadian Journal of Fisheries and Aquatic Sciences 64:1479-1490.

Flynn, L., A. E. Punt, R. Hilborn. 2006. A hierarchical model for salmon run reconstruction and application to the Bristol Bay sockeye salmon (*Oncorhynchus nerka*) fishery. Canadian Journal of Fisheries and Aquatic Sciences 63:1564-1577.

Hamazaki, T.. 2011. Reconstruction of subsistence salmon harvests in the Kuskokwim River drainage, 1990-2009. Alaska Department of Fish and Game, Fishery Manuscript Series No. 11-09, Anchorage.

Hilborn, R., T. P. Quinn, D. E. Schindler and D. E. Rogers. 2003. Biocomplexity and fisheries sustainability. Proceedings of the National Academy of Sciences of the United States of America 100(11): 6564-6568.

Hilborn, R., B. G. Bue, and S. Sharr. 1999. Estimating spawning escapements from periodic counts: a comparison of methods. Canadian Journal of Fisheries and Aquatic Sciences 56:888-896.

Hilborn, R., and M. Mangel. 1997. The ecological detective: confronting models with data. Princeton University Press, Princeton, New Jersey.

Holt, K. R., and S. P. Cox. 2008. Evaluation of visual methods for monitoring Pacific salmon (*Oncorhynchus* spp.) escapement in relation to conservation guidelines. Canadian Journal of Fisheries and Aquatic Sciences 65:212-226.

Lessard, R. B., R. Hilborn and B. E. Chasco. 2008. Escapement goal analysis and stock reconstruction of sockeye salmon populations (*Oncorhynchus nerka*) using life-history models. Canadian Journal of Fisheries and Aquatic Sciences 65:2269-2278.

Maunder, M. N., and A. E. Punt. 2002. Standardizing catch and effort data: a review of recent approaches. Fisheries Research 70:141-159.

Millar, R. B. 2011. Maximum likelihood estimation and inference: with examples in R, SAS, and ADMB. John Wiley and Sons, Ltd.

Molyneaux, D. B., and L. K. Brannian. 2006. Review of escapement and abundance information for Kuskokwim area salmon stocks. Alaska Department of Fish and Game, Fishery Manuscript No. 06-08, Anchorage.

Molyneaux, D. B., A. R. Brodersen, and C. A. Shelden. 2010. Salmon age, sex, and length catalog for the Kuskokwim Area, 2009. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 3A10-05, Anchorage.

Parsons, A. L., and J. R. Skalski. 2010. Quantitative assessment of salmonid escapement techniques. Reviews in Fisheries Science 18(4):302-314.

REFERENCES CITED (Continued)

Peterman, R. M. 1982. Model of salmon age structure and its use in preseason forecasting and studies of marine survival. Canadian Journal of Fisheries and Aquatic Sciences 39:1444-1452.

Schaberg, K. L., Z. W. Liller, D. B. Molyneaux, B. G. Bue, and L. Stuby. 2012. Kuskokwim River Chinook salmon run estimates, 2002 to 2007. Alaska Department of Fish and Game, Fishery Data Series No. 12-36, Anchorage.

Schindler, D. E., R. Hilborn, B. Chasco, C. P. Boatright, T. P. Quinn, L. A. Rodgers, and M. S. Webster. 2010. Population diversity and the portfolio effect in an exploited species. Nature 465:609-612.

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.

Starr, P., and R. Hilborn. 1988. Reconstruction of harvest rates and stock contribution in Gauntlet salmon fisheries: application to British Columbia and Washington sockeye (*Oncorhynchus nerka*). Candian Journal of Fisheries and Aquatic Sciences 45:2216-2229

Templin, W. D., J. S. Collie and T. J. Quinn II. 1996. Run reconstruction of the wild pink salmon fishery in Prince William Sound, 1990-1991. American Fisheries Society Symposium 18:499-508.

Venzon, D. J., and S. H. Moolgavkar. 1988. A method for computing profile-likelihood based confidence intervals. Applied Statistics 37:87-94.

TABLES AND FIGURES

Table 1.–Estimates of the parameter values for the reconstruction of the historical total runs of Chinook salmon to the Kuskokwim River.

		Parameter Estimate	95% Bound Lower	95% Bound Upper	CV	Overdispersion Parameter
Weir Projects						
Kwethluk Weir	$\hat{k}_i$	16.8	12.5	22.0	14%	10.5
Tuluksak Weir		153.0	110.0	205.0	16%	4.8
George Weir		37.4	28.0	48.0	14%	9.3
Kogrukluk Weir		13.3	10.5	17.0	12%	10.7
Tatlawiksuk Weir		89.4	70.0	112.5	12%	28.4
Takotna Weir		335.2	240.0	450.0	16%	6.0
Aerial Survey Streams	$\hat{k}_a$					
Kwethluk River		94.5	65.0	135.0	19%	3.8
Kisaralik River		144.1	90.0	215.0	22%	1.5
Tuluksak River		410.4	280.0	600.0	20%	3.6
Salmon (Aniak River)		185.2	135.0	245.0	15%	4.3
Kipchuk River		159.7	115.0	210.0	15%	4.6
Aniak River		57.1	42.0	74.0	14%	7.9
Holokuk River		883.2	600.0	1,250.0	19%	1.9
Oskawalik River		520.2	330.0	770.0	22%	2.0
Holitna River		95.6	70.0	125.0	15%	9.0
Cheeneetnuk River		198.3	140.0	280.0	18%	3.4
Gagaryah River		331.3	240.0	440.0	15%	4.2
Pitka Fork		703.5	500.0	960.0	17%	6.3
Bear River		728.4	550.0	925.0	13%	14.9
Salmon(Pitka Fork)		152.6	115.0	195.0	13%	7.3
Catchability						
Unrestricted gear	$\hat{q}_{un}$	0.0000791	0.000060	0.000100	13%	
Restricted 1976-1984	$\hat{q}_r$	0.0000141	0.000010	0.000020	18%	
Restricted 1985-2011	$\hat{q}_m$	0.0000545	0.000044	0.000068	11%	

Note: The upper and lower bound represent the 95% confidence interval as estimated from the negative log likelihood profiles for each parameter; CV is estimated as the standard deviation divided by the estimate where standard deviation is estimated by dividing the width of the 95% confidence interval by 2 x 1.96.

Table 2.–Estimated total run and escapement for Kuskokwim River Chinook salmon, 1976 through 2011.

Year	Estimated Total Run	95% Confidence Bounds Lower	Upper	CV	Estimated Escapement	95% Confidence Bounds Lower	Upper	CV
1976	233,967	185,000	300,000	13%	143,420	94,453	209,453	20%
1977	295,559	230,000	385,000	13%	201,852	136,293	291,293	20%
1978	264,325	210,000	330,000	12%	180,853	126,528	246,528	17%
1979	253,970	190,000	350,000	16%	157,668	93,698	253,698	26%
1980	300,573	230,000	410,000	15%	203,605	133,032	313,032	23%
1981	389,791	300,000	515,000	14%	279,392	189,601	404,601	20%
1982	187,354	160,000	225,000	9%	80,353	52,999	117,999	21%
1983	166,333	135,000	210,000	12%	84,188	52,855	127,855	23%
1984	188,238	150,000	250,000	14%	99,062	60,824	160,824	26%
1985	176,292	140,000	235,000	14%	94,365	58,073	153,073	26%
1986	129,168	105,000	160,000	11%	58,556	34,388	89,388	24%
1987	193,465	155,000	270,000	15%	89,222	50,757	165,757	33%
1988	207,818	180,000	250,000	9%	80,055	52,237	122,237	22%
1989	241,857	205,000	295,000	9%	115,704	78,847	168,847	20%
1990	264,802	230,000	320,000	9%	100,614	65,812	155,812	23%
1991	218,705	185,000	270,000	10%	105,589	71,884	156,884	21%
1992	284,846	240,000	350,000	10%	153,573	108,727	218,727	18%
1993	269,305	220,000	340,000	11%	169,816	120,511	240,511	18%
1994	365,246	285,000	485,000	14%	242,616	162,370	362,370	21%
1995	360,513	295,000	450,000	11%	225,595	160,082	315,082	18%
1996	302,603	235,000	405,000	14%	197,092	129,489	299,489	22%
1997	303,189	240,000	395,000	13%	211,247	148,058	303,058	19%
1998	213,873	170,000	275,000	13%	113,627	69,754	174,754	24%
1999	189,939	150,000	240,000	12%	112,082	72,143	162,143	20%
2000	136,618	115,000	165,000	9%	65,180	43,562	93,562	20%
2001	223,707	180,000	280,000	11%	145,232	101,525	201,525	18%
2002	246,296	200,000	300,000	10%	164,635	118,339	218,339	15%
2003	248,789	205,000	295,000	9%	180,687	136,898	226,898	13%
2004	388,136	320,000	465,000	10%	287,178	219,042	364,042	13%
2005	366,601	305,000	435,000	9%	275,598	213,997	343,997	12%
2006	307,662	255,000	375,000	10%	214,004	161,342	281,342	14%
2007	273,060	230,000	320,000	8%	174,943	131,883	221,883	13%
2008	237,074	200,000	285,000	9%	128,978	91,904	176,904	17%
2009	204,747	170,000	250,000	10%	118,478	83,731	163,731	17%
2010	118,507	105,000	140,000	8%	49,073	35,566	70,566	18%
2011	133,059	110,000	160,000	10%	72,097	49,037	99,037	18%

Note: The upper and lower bound represent the 95% confidence interval as estimated from the negative log likelihood profiles for each parameter; CV is estimated as the standard deviation divided by the estimate where standard deviation is estimated by dividing the width of the 95% confidence interval by 2 x 1.96.

Table 3.–Sources of the age information used to estimate the total run by age of Chinook salmon returning to the Kuskokwim River, Alaska, 1976 through 2011.

	Harvest				Escapement					
Year	Commercial	Subsistence	Sport	Test fish	Kwethluk	Tuluksak	George	Kogrukluk	Tatlawiksuk	Takotna
1976		x [a]						x		
1977	x	x [a]								
1978	x	x [a]						x		
1979		x [a]						x		
1980	x	x [a]								
1981	x	x [a]						x		
1982	x	x [a]						x		
1983	x	x [a]								
1984	x	x [a]						x		
1985	x	x [a]						x		
1986	x	x [a]						x		
1987	x	x [a]								
1988	x	x [a]						x		
1989	x	x [a]						x		
1990	x	x [a]						x		
1991	x	x [a]				x		x		
1992	x	x [a]			x	x		x [b]		
1993	x	x [a]				x		x [b]		
1994	x	x [a]				x		x [b]		
1995	x	x [a]						x		
1996	x	x [a]					x	x		
1997	x	x [a]					x	x		
1998	x	x [a]						x		
1999	x	x [a]					x [b]	x		
2000		x [a]			x			x		x
2001		x		x			x	x		
2002		x		x	x	x	x	x	x	x
2003		x		x	x	x		x		x [c]
2004	x	x		x	x	x	x	x	x	x [d]
2005	x	x		x		x	x	x	x	
2006	x	x			x	x	x	x	x	x
2007		x			x	x	x [b]	x	x	x
2008	x	x			x	x	x	x	x	x
2009	x	x			x	x	x	x	x	x
2010	x	x			x	x	x	x	x	
2011	x	x			x		x	x	x	x

[a] Estimated using the average age composition from the 2001 to 2011 subsistence harvests.

[b] Estimated using information from 2 of the 3 sampling strata for the year.

[c] Age composition estimated using 61 ASL samples collected from a weir passage of 378 fish.

[d] Age composition estimated using 69 ASL samples collected from a weir passage of 462 fish.

Table 4.–Estimated brood table for Chinook salmon returning to the Kuskokwim River, Alaska, 1976 through 2011.

Brood Year	Escapement	Return by Age Class 0.2	1.1	1.2	2.1	1.3	2.2	1.4	2.3	1.5	2.4	1.6	2.5	Return	Return per Spawner
1976	143,420	5 [a]	685 [a]	45,301 [a]	7 [a]	129,032	26	113,427	78	7,813 [a]	270 [a]	80	0	296,724	2.07
1977	201,852	5 [a]	685 [a]	29,297	0	53,519	24	67,261 [b]	350 [a]	8,145	503	101	0	159,889	0.79
1978	180,853	0	913	11,960	0	59,692 [b]	313 [a]	65,360	491	6,014	43	5	0	144,790	0.80
1979	157,668	0	139	45,301 [a]	7 [a]	82,411	152	75,392	58	7,029	50	13 [a]	12 [a]	210,564	1.34
1980	203,605	5 [a]	685 [a]	30,686	32	62,372	170	48,479	68	7,813 [a]	270 [a]	7	0	150,587	0.74
1981	279,392	0	367	31,815	0	61,253	21	72,840 [b]	350 [a]	11,546	70	7	0	178,270	0.64
1982	80,353	0	318	11,508	0	59,307 [b]	313 [a]	69,437	95	7,410	1,045	10	0	149,444	1.86
1983	84,188	0	747	45,301 [a]	7 [a]	97,996	30	119,935	723	6,245	108	37	281	271,408	3.22
1984	99,062	5 [a]	685 [a]	28,540	0	73,040	1,568	73,672	146	5,617	841	8	0	184,122	1.86
1985	94,365	0	86	38,015	0	126,302	46	110,193	1,253	5,788	449	8	90	282,231	2.99
1986	58,556	0	99	55,236	0	72,342	1,939	100,040	253	10,399	745	10	0	241,062	4.12
1987	89,222	0	3016	26,034	0	94,115	942	99,770	768	5,912	1,432	9	0	231,998	2.60
1988	80,055	65	90	76,148	0	80,801	186	119,483	1,744	4,517	251	10	0	283,295	3.54
1989	115,704	0	7088	76,113	0	194,963	1,603	189,281	293	33,004	103	7	0	502,456	4.34
1990	100,614	0	409	39,167	170	103,957	43	110,564	615	3,623	79	8	0	258,635	2.57
1991	105,589	73	670	61,980	0	128,496	324	144,684	108	6,060	81	7	0	342,483	3.24
1992	153,573	0	163	29,341	0	70,580	34	85,749	110	3,787	72	6	0	189,842	1.24
1993	169,816	0	127	83,961	0	105,460	34	117,186	97	5,193	70	0	0	312,128	1.84
1994	242,616	0	97	16,062	0	53,331	236	55,960	95	11,520	2	0	0	137,304	0.57
1995	225,595	0	293	14,894	0	55,957	30	120,178	0	8,318	0	0	0	199,669	0.89
1996	197,092	0	317	19,163	0	67,457	0	97,481	0	9,395	0	0	0	193,813	0.98
1997	211,247	0	131	24,550	0	88,004	63	80,879	0	4,899	0	0	0	198,527	0.94
1998	113,627	0	0	52,214	0	107,444	0	112,376	0	4,917	172	0	0	277,124	2.44
1999	112,082	0	215	50,637	0	118,418	439	122,425	618	14,411	107	0	0	307,272	2.74
2000	65,180	0	434	150,604	0	170,004	10	121,781	161	6,204	814	0	0	450,011	6.90
2001	145,232	0	1398	67,655	0	92,751	54	97,738	294	5,190	198	0	0	265,278	1.83
2002	164,635	0	801	77,048	0	90,865	0	67,652 [a]	1,354	2,330	329	0	0	240,378	1.46
2003	180,687	0	996	76,950	0	115,515	70	86,835	300	3,268	43	61	0	284,036	1.57
2004	287,178	0	196	46,546	0	76,442	842	40,712	0	1,768	43	13 [a]	12 [a]	166,576	0.58
2005	275,598	0	542	37,652	0	49,730	67	42,194	340	7,813 [a]	270 [a]	13 [a]	12 [a]	138,634	0.50
2006	214,004	0	169	24,509	0	51,306	116								
2007	174,943	0	178	36,998	0										
2008	128,978	0	157												
2009	118,478														
2010	49,073														
2011	72,097														

[a] Interpolated as the average return for that age. Information prior to the 1976 brood year not included in the average.

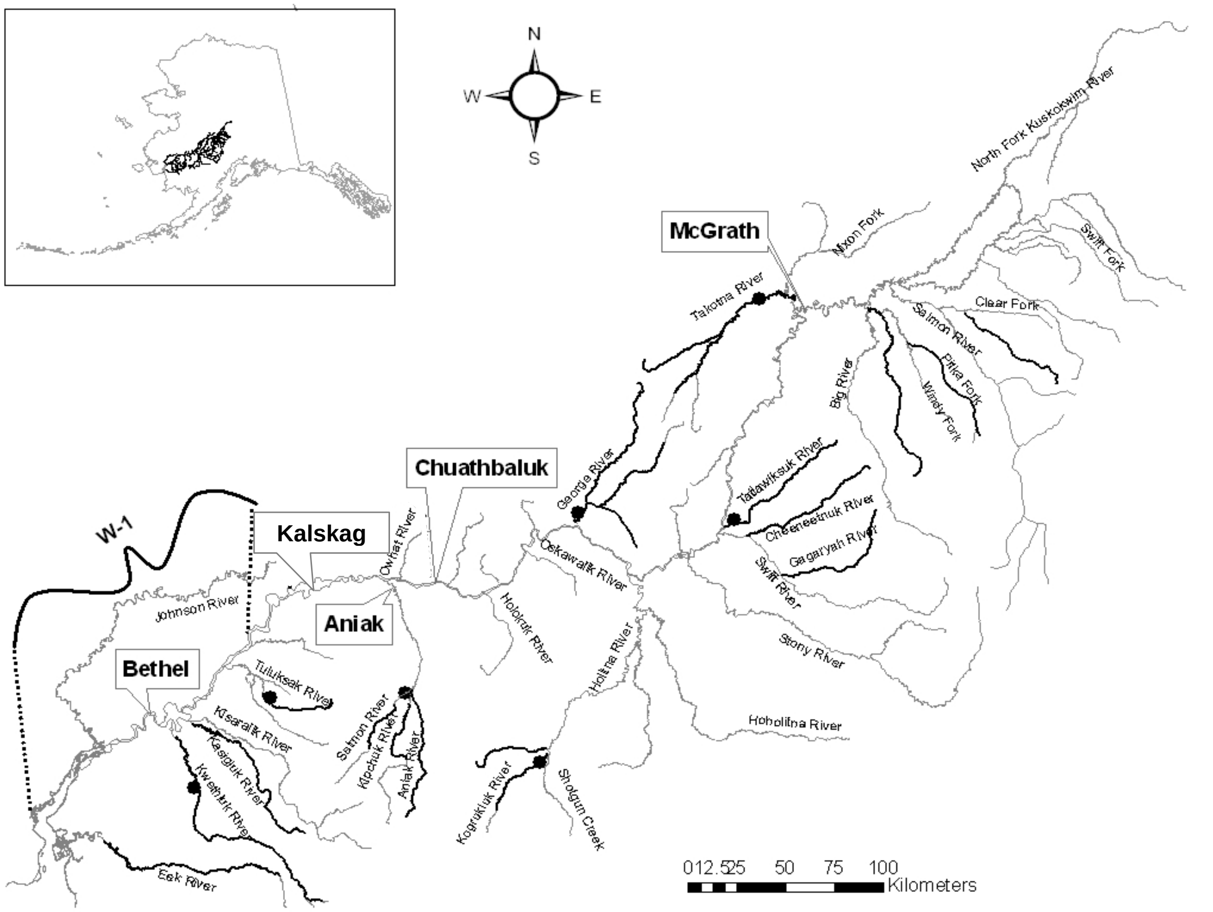
[b] Interpolated using sibling relationships.

Table 5.–Total estimated Chinook salmon escapement obtained from the run reconstruction, monitored escapement counted past weirs, and the percent of the total estimated escapement that was monitored, Kuskokwim River, Alaska.

	Escapement		Percent		Escapement		Percent
Year	Estimated [a]	Monitored [b]	Monitored	Year	Estimated [a]	Monitored [b]	Monitored
1976	143,420	5,600	3.9%	1994	242,616	18,144	7.5%
1977	201,852			1995	225,595	20,651	9.2%
1978	180,853	13,667	7.6%	1996	197,092	29,752	15.1%
1979	157,668	11,338	7.2%	1997	211,247	32,717	15.5%
1980	203,605			1998	113,627	12,107	10.7%
1981	279,392	16,809	6.0%	1999	112,082	10,608	9.5%
1982	80,353	10,993	13.7%	2000	65,180	10,972	16.8%
1983	84,188	3,025	3.6%	2001	145,232	16,336	11.2%
1984	99,062	4,928	5.0%	2002	164,635	24,949	15.2%
1985	94,365	4,625	4.9%	2003	180,687	34,063	18.9%
1986	58,556	5,038	8.6%	2004	287,178	58,232	20.3%
1987	89,222			2005	275,598	31,924	11.6%
1988	80,055	8,520	10.6%	2006	214,004	44,672	20.9%
1989	115,704	11,940	10.3%	2007	174,943	33,693	19.3%
1990	100,614	10,214	10.2%	2008	128,978	19,888	15.4%
1991	105,589	8,547	8.1%	2009	118,478	20,854	17.6%
1992	153,573	17,513	11.4%	2010	49,073	9,805	20.0%
1993	169,816	14,551	8.6%	2011	72,097	13973	19.4%

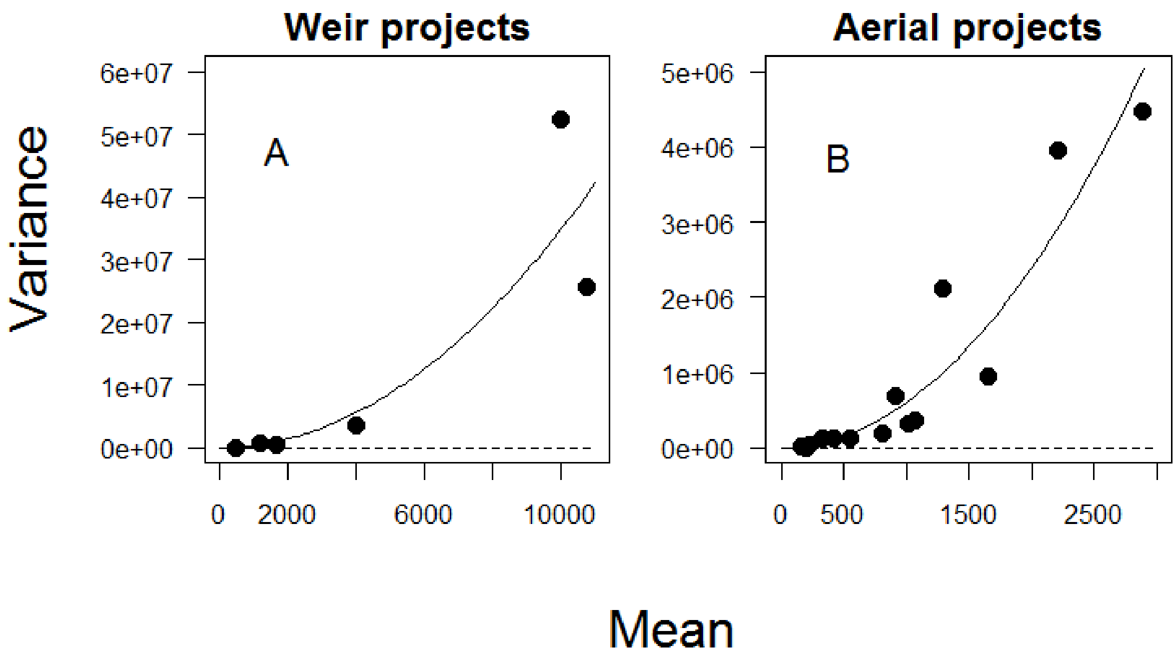
[a] Estimated escapement obtained from the run reconstruction.

[b] Total number of fish counted past the weirs operating for that year.



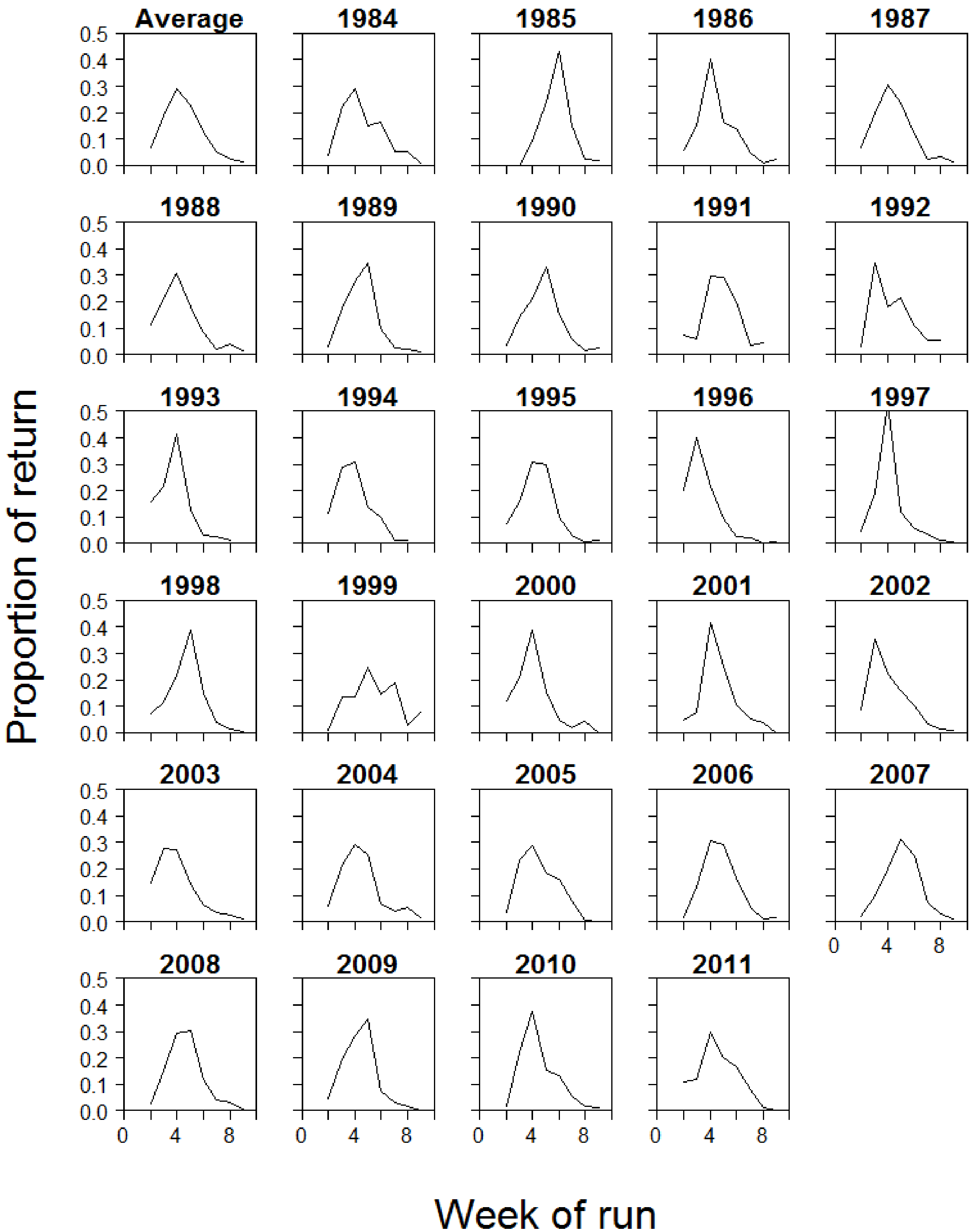
Note: Black dots show the location of the enumeration weirs, bold river segments represent systems monitored by aerial surveys, the bracket indicates the location of the W-1 fishing district, and some major communities are shown in text boxes.

Figure 1.–Map of the study area from which data were obtained for the Kuskokwim River Chinook salmon run reconstruction project.



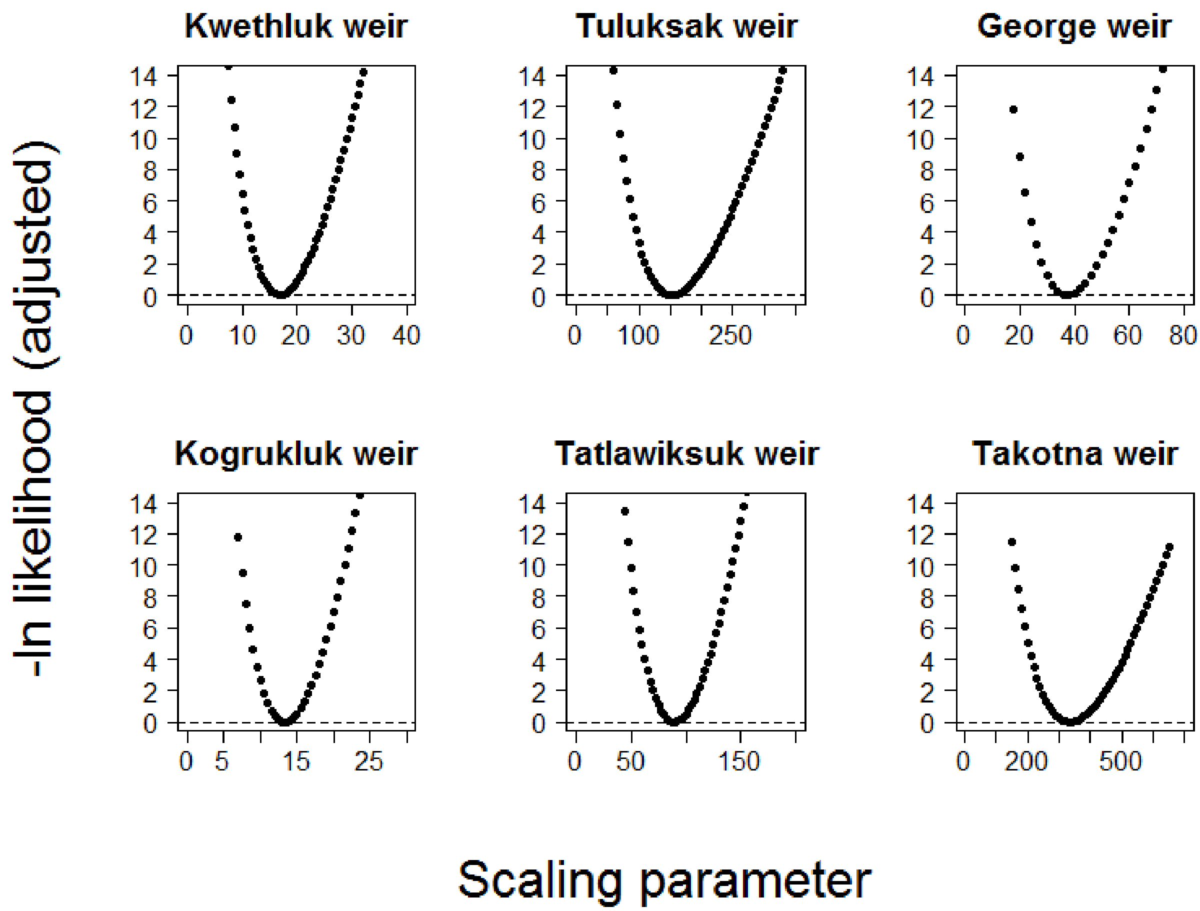
Note: Dashed lines show where the means (μ) and variances (var{Y}) are equal for these projects. Solid lines are the least squares fit of var{Y} = μ+0.349μ2 for weir projects (A) and var{Y} = μ+0.599μ2 for aerial projects (B).

Figure 2.–Comparison of mean and variance estimates for weir (A) and aerial (B) projects.



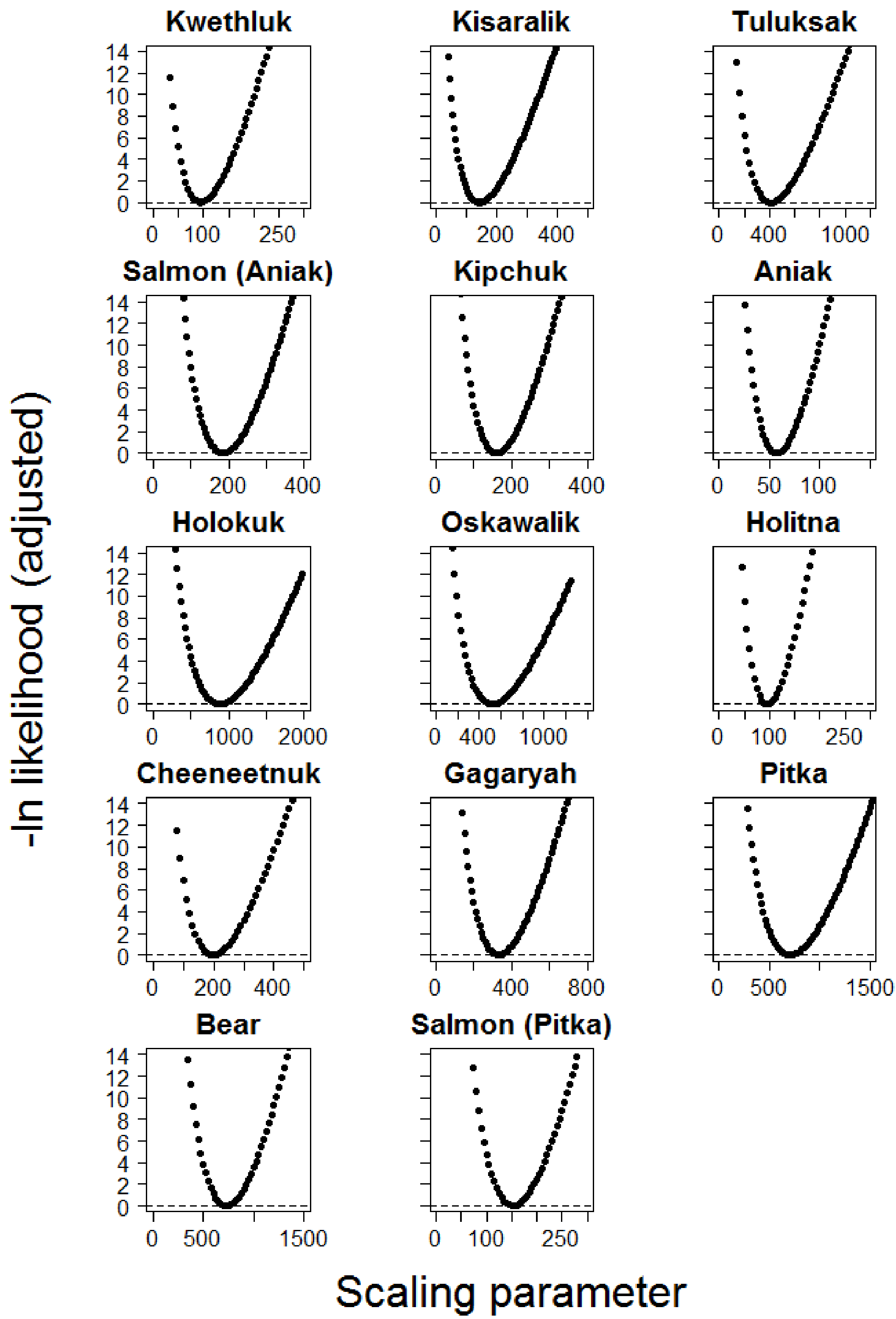
Note: Week of Run is described in Appendix A5 with Week 4 beginning on June 17 each year.

Figure 3.–Average and year specific run timing of Chinook salmon in the W1 commercial fishing district of the Kuskokwim River, Alaska, as estimated by the Bethel test fishery from 1984 through 2011.



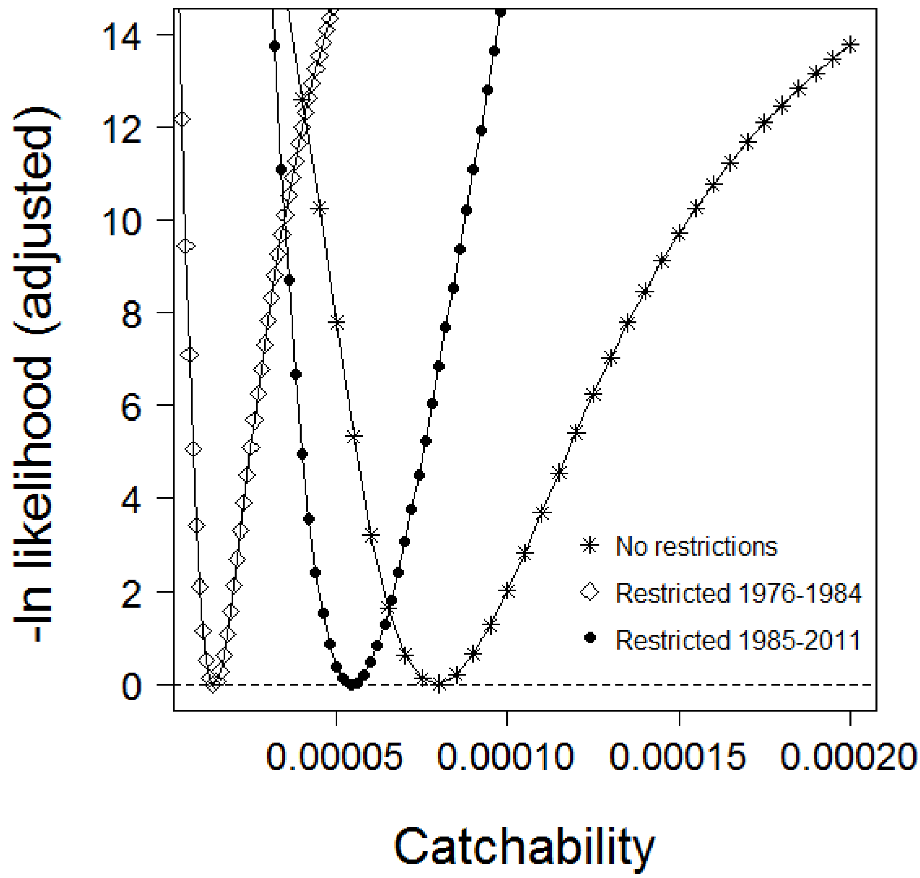
Note: The negative log likelihood scale was adjusted such that the minimum value was zero.

Figure 4.–Negative log likelihood profiles for the escapement scaling factor ($\hat{k}_i$) used to expand total weir counts of Chinook salmon in the Kuskokwim River drainage.



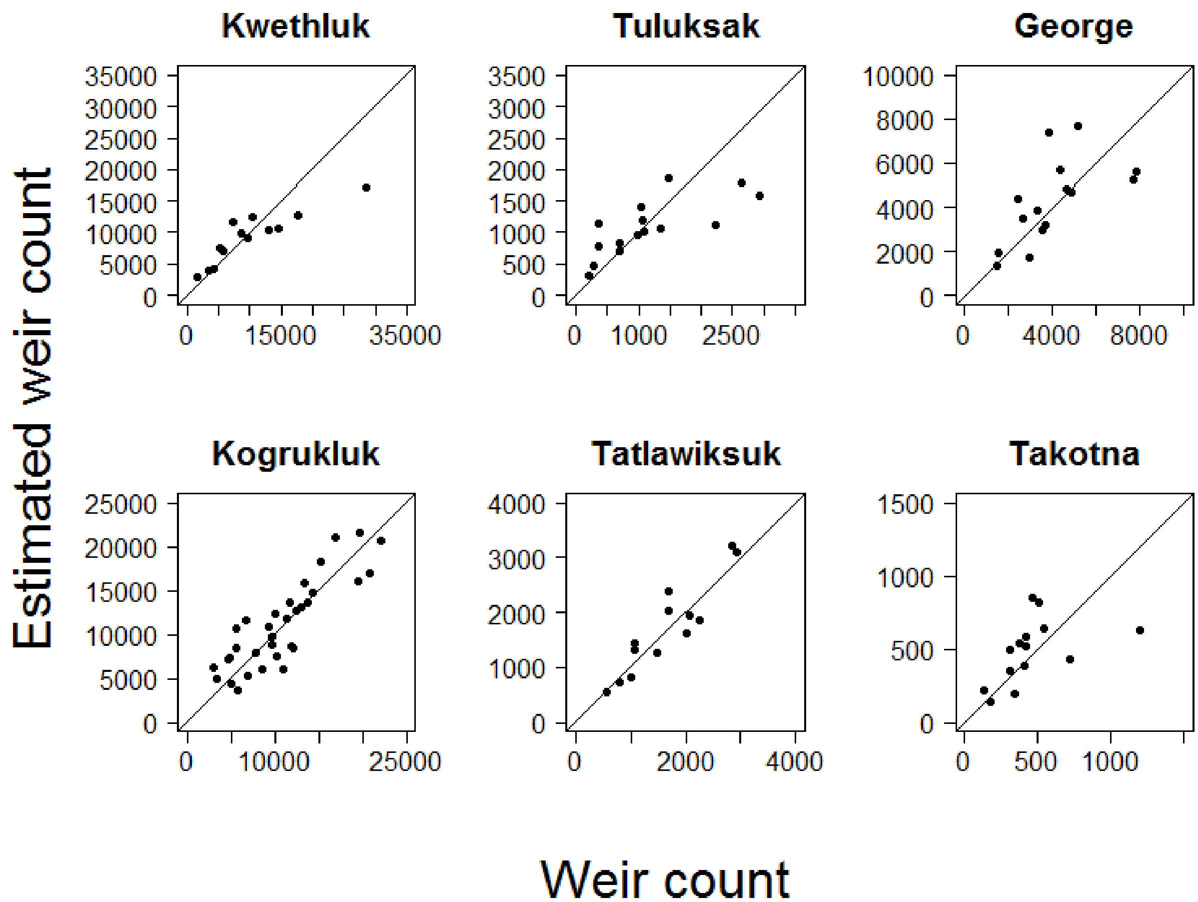
Note: The negative log likelihood scale was adjusted such that the minimum value was zero.

Figure 5.–Negative log likelihood profiles of the escapement scaling factors ($\hat{k}_a$) used to expand aerial counts of Chinook salmon in the Kuskokwim River.



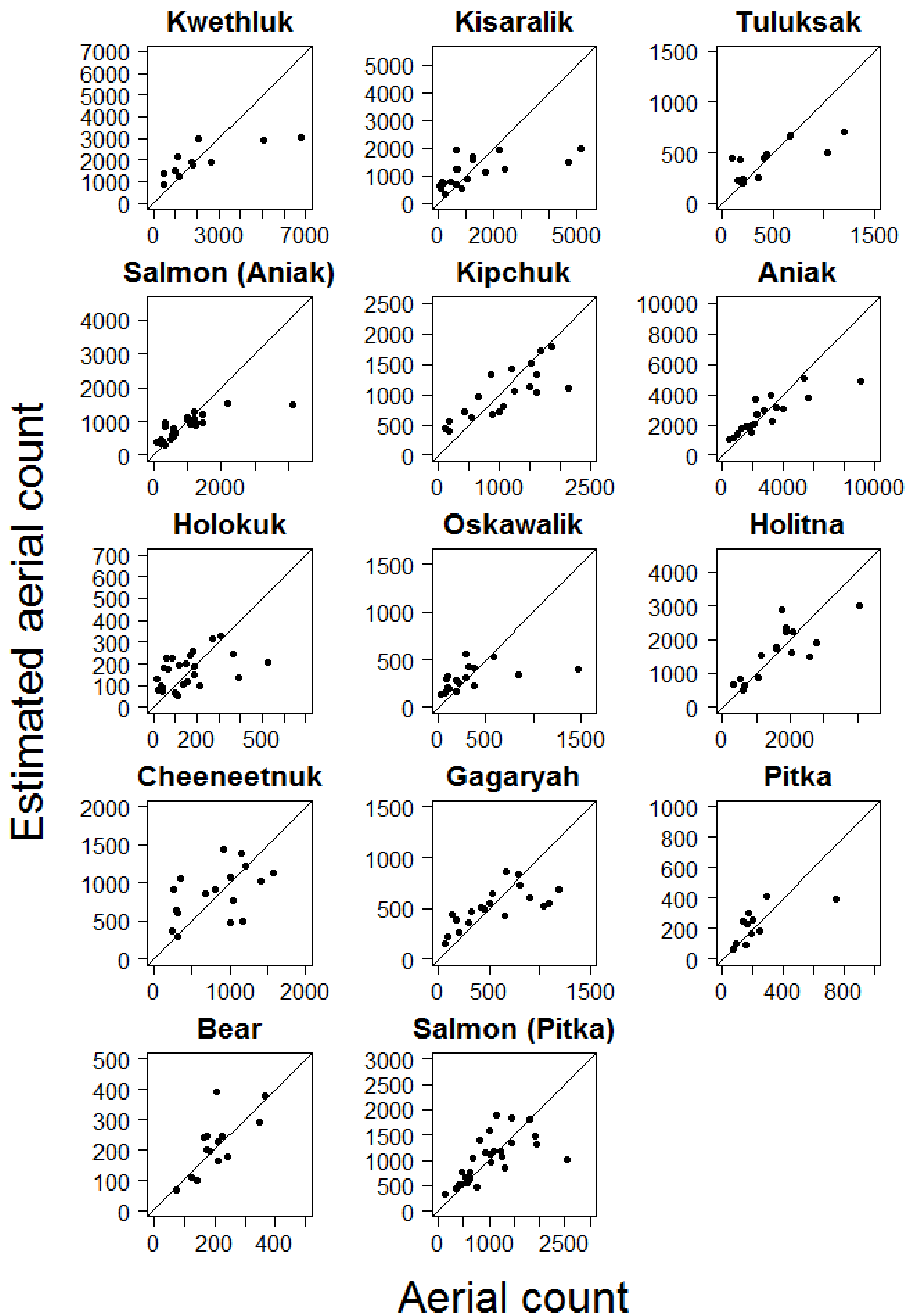
Note: The negative log likelihood scale was adjusted such that the minimum value was zero.

Figure 6.–Negative log likelihood profiles of the catchability parameters estimated for each of the three strata of the commercial harvest component of the model to reconstruct the Chinook salmon run to the Kuskokwim River.



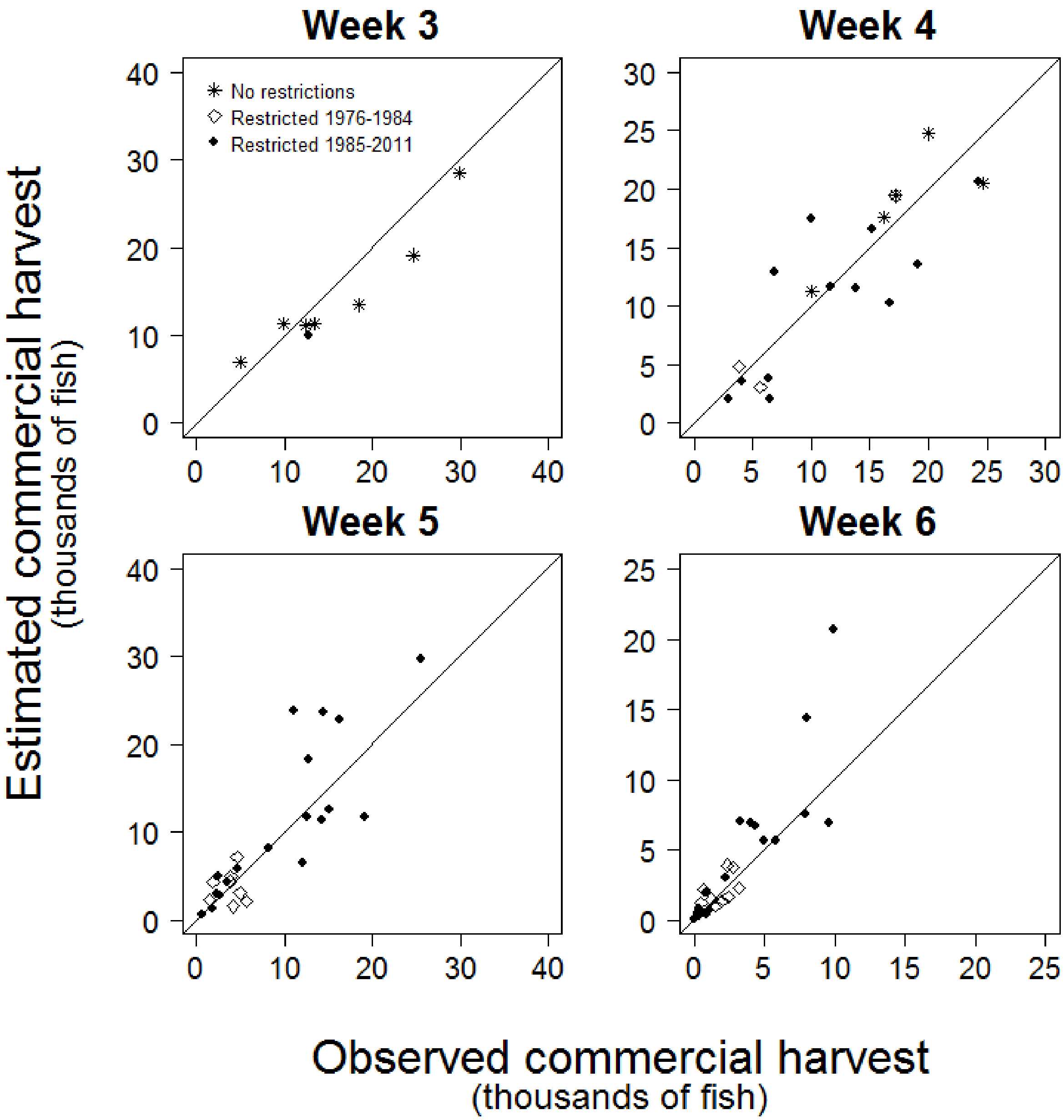
Note: The solid lines are where estimated counts are the same as actual counts.

Figure 7.–Comparison of the estimated weir count obtained from the run reconstruction model to actual weir counts obtained from the individual weir projects for Chinook salmon returning to the Kuskokwim River.



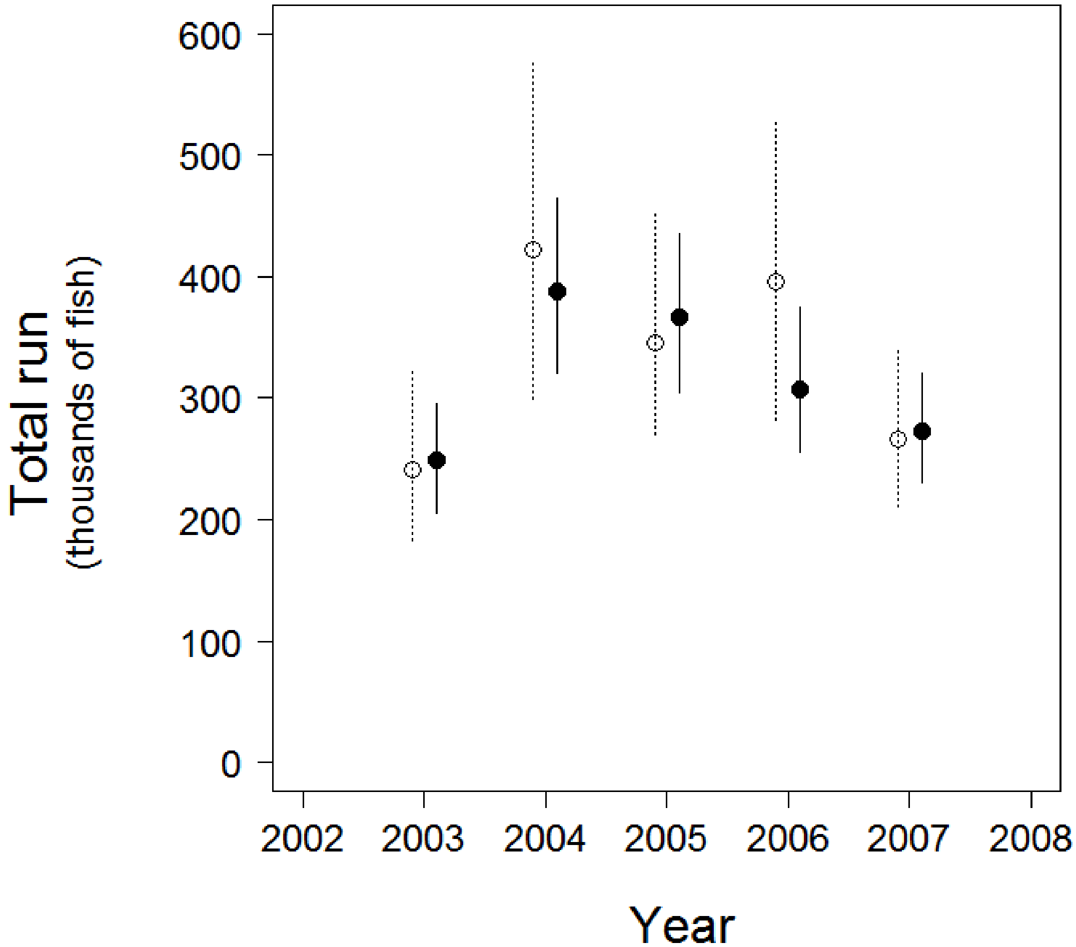
Note: The solid lines are where estimated counts are the same as actual counts.

Figure 8.–Comparison of the estimated aerial count obtained from the run reconstruction model to actual aerial survey observations from individual streams for Chinook salmon returning to the Kuskokwim River.



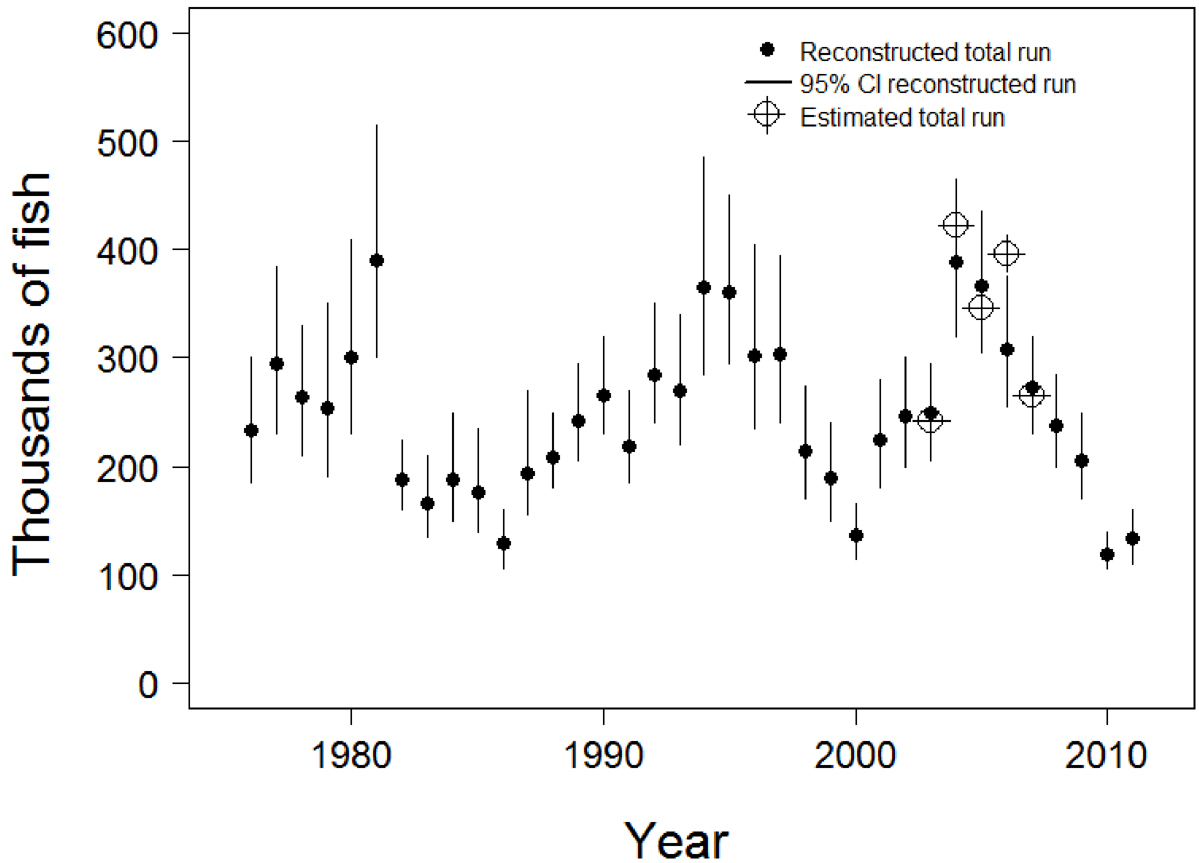
Note: The solid lines are where estimated counts are the same as actual counts. Weeks are described in Appendix A5 with Week 4 beginning on June 17 each year.

Figure 9.–Comparison of the estimates of commercial harvest obtained from the run reconstruction model to the observed commercial harvest of Chinook salmon harvested in District W1 of the Kuskokwim River.



Note: The open points and dashed lines are the Schaberg et al. (2012) estimates and corresponding 95% confidence intervals, while the solid points and lines are the run reconstruction estimates and corresponding 95% confidence intervals.

Figure 10.–Comparison of the estimates of total run obtained from the run reconstruction model to the corresponding estimates made by Schaberg et al. (2012) for Chinook salmon returning to the Kuskokwim River.



Note: Confidence bounds are presented for the reconstructed total run.

Figure 11.–Estimates of the total run of Chinook salmon returning to the Kuskokwim River, Alaska, obtained from the run reconstruction model and the estimates of total run from Schaberg et al. (2012).

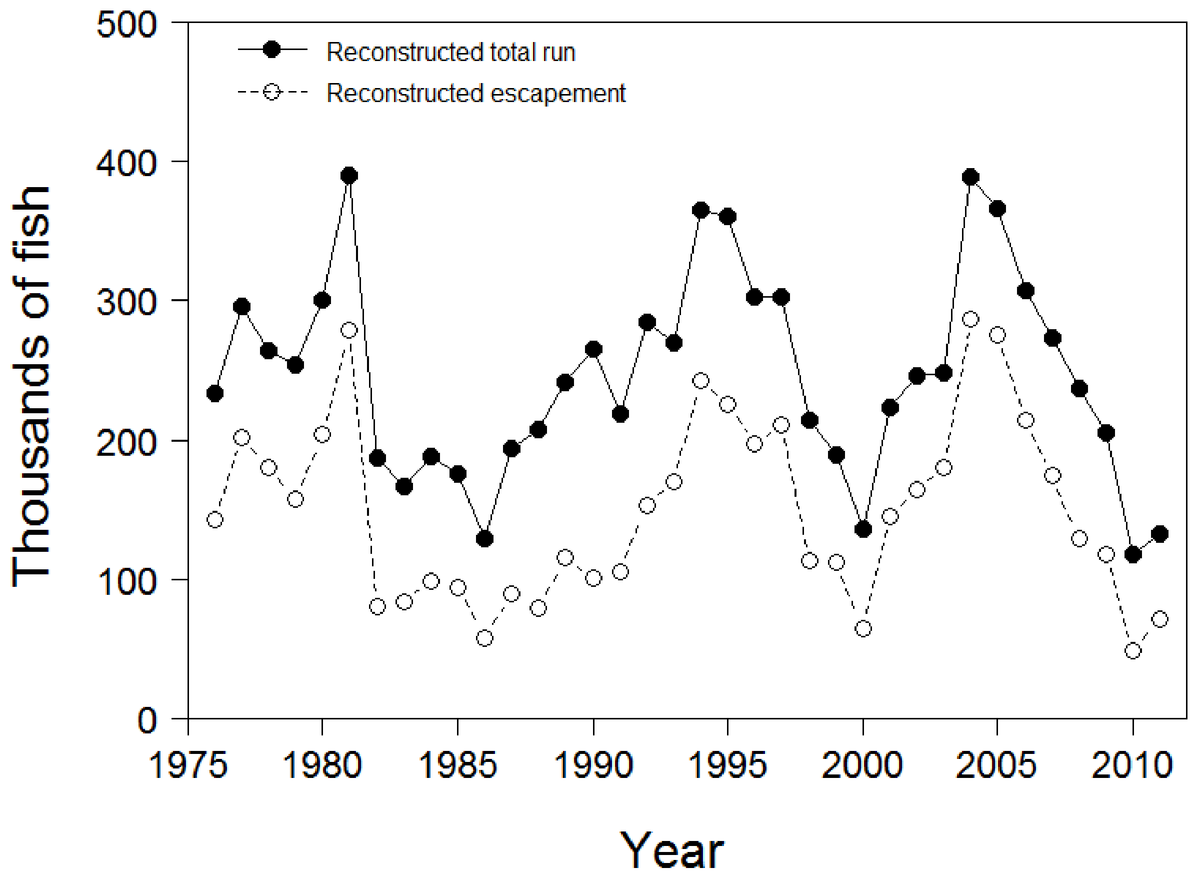


Figure 12.–Estimates of the total run and escapement of Chinook salmon returning to the Kuskokwim River, Alaska, from 1976 through 2011, obtained from the run reconstruction model.

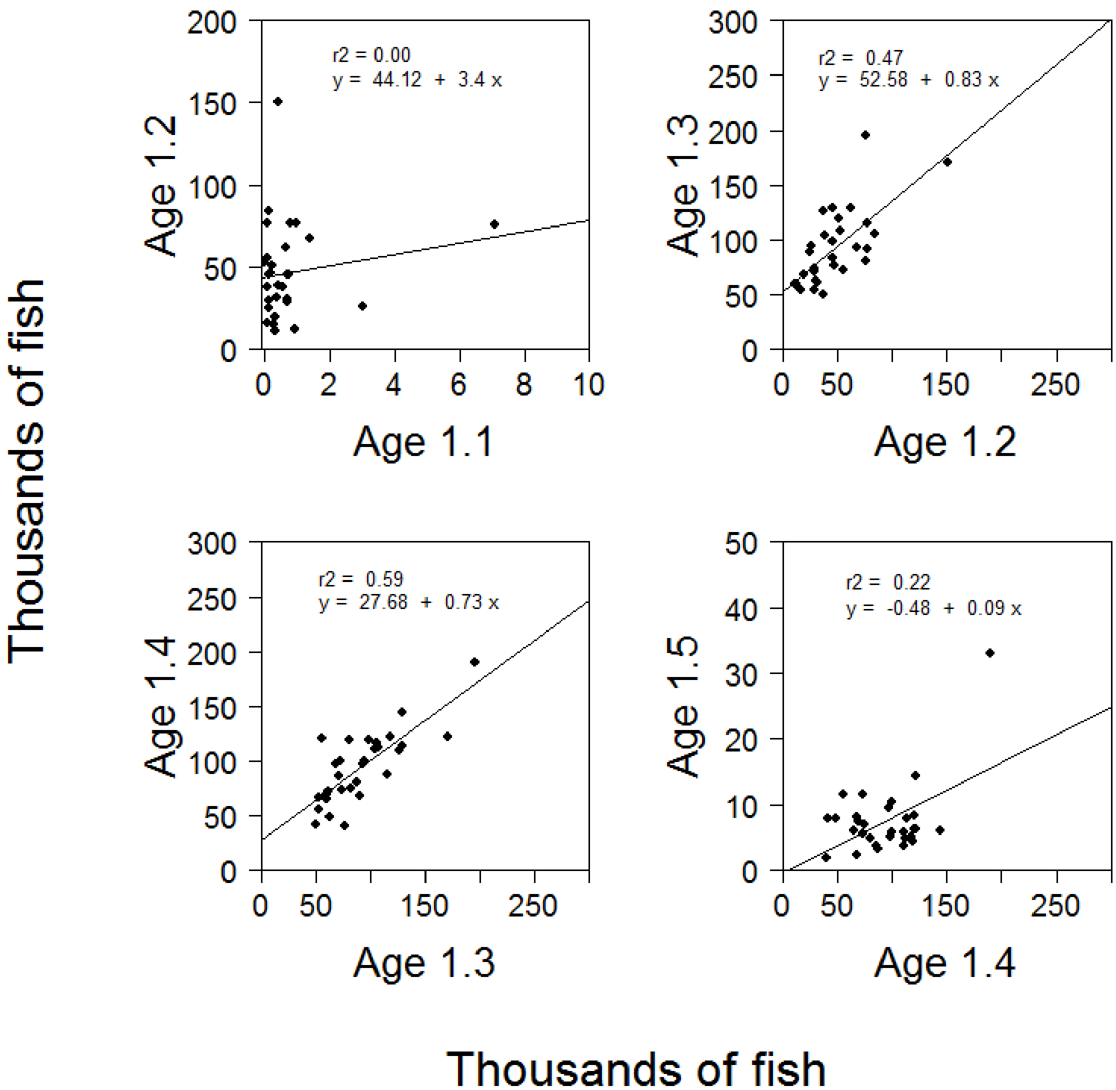
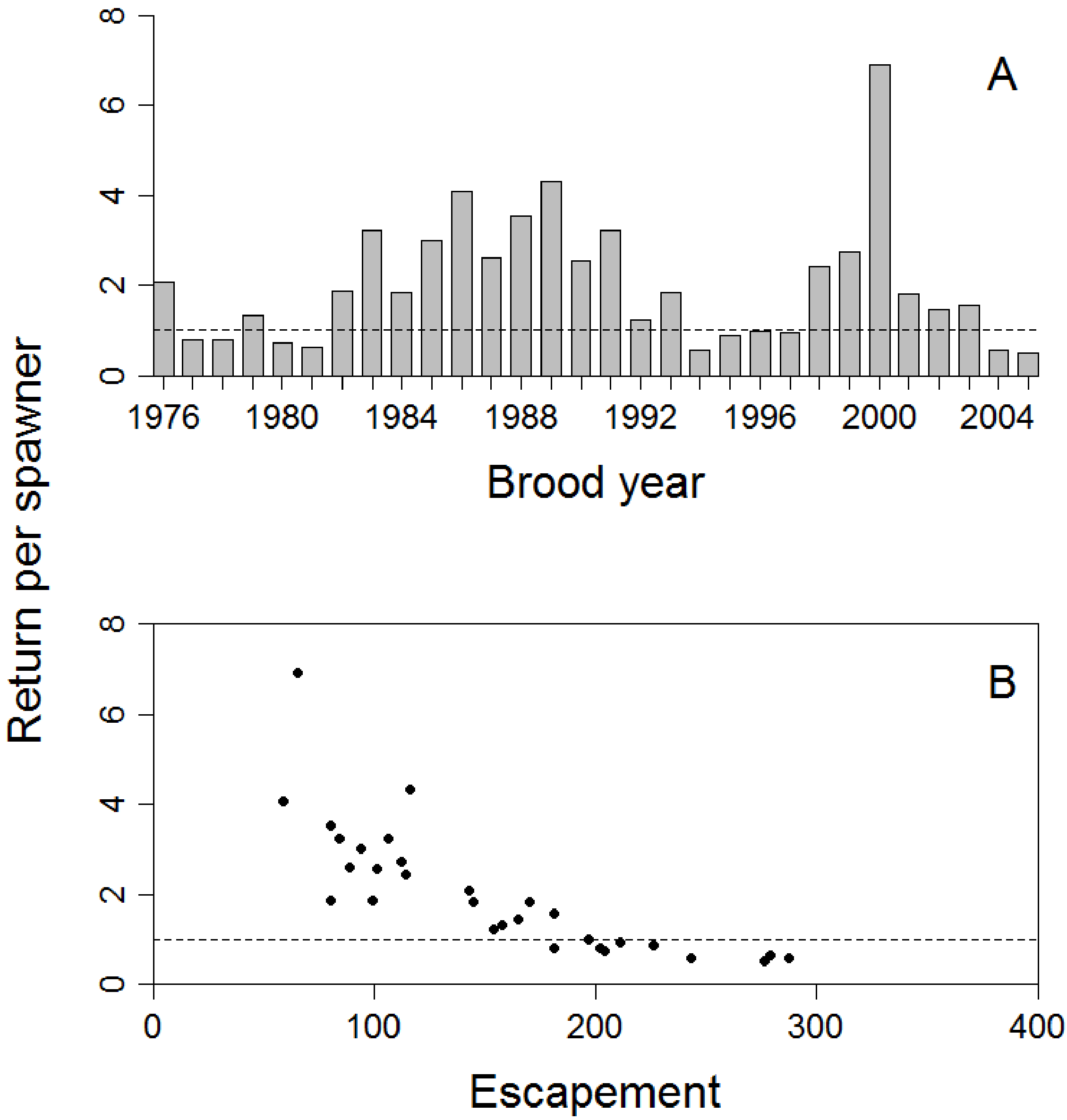


Figure 13.–Sibling relationships for Chinook salmon returning to the Kuskokwim River, Alaska.



Note: The horizontal dashed line is at a return per spawner value of 1.0, the level of return at which the number of fish that escape to spawn produce an equal number of returning fish.

Figure 14.–Return per spawner by year (A) and level of escapement (B) for the Chinook salmon population returning to the Kuskokwim River, Alaska.

APPENDIX A: SUPPORTING INFORMATION

Appendix A1.–Total inriver abundance of Chinook salmon in the Kuskokwim River, 2003 through 2007.

Component	Year					
	2002	2003	2004	2005	2006	2007
Abundance Upstream of Birch Tree Crossing	-	125,235	224,519	174,317	245,043	130,279
Escapement Downstream of Birch Tree Crossing	33,171	53,864	105,118	87,051	65,034	46,925
Lower Kuskokwim River Harvest						
Subsistence [a]	72,932	61,550	89,172	78,533	82,598	87,053
Commercial [b]	72	158	2,300	4,784	2,777	179
Bethel Test Fishery [b]	288	409	691	557	352	305
Sport [c]	319	401	857	572	444	1,478
Total Harvest	73,611	62,518	93,020	84,446	86,171	89,015
Total Inriver Abundance	-	241,617	422,657	345,814	396,248	266,219
Lower 95% CI		182,710	298,728	270,560	281,847	211,280
Upper 95% CI		326,202	577,993	453,516	528,218	340,445

Source: Schaberg et al. 2012.

Note: Abundance was estimated by combining harvest estimates and estimates derived from mark–recapture and habitat model techniques.

[a] Subsistence harvest includes all villages from Kalskag downstream to the mouth of the Kuskokwim River, plus the north Kuskokwim Bay village of Kongiganak. Source for subsistence data is Hamazaki (2011).

[b] Source for commercial and Bethel test fishery data is Bavilla et al. (2010).

[c] Sport harvest data from a personal communication with John Chythlook, Sport Fish Biologist, ADF&G; Fairbanks.

Appendix A2.–Harvests and escapements of Chinook salmon returning to the Kuskokwim River, Alaska, 1976 to 2011.

	Harvest				Weir					
Year	Subsistence	Commercial	Sport	Test fishery	Kwethluk	Tuluksak	George	Kogrukluk	Tatlawiksuk	Takotna
1976	58,606	30,735		1,206				5,600		
1977	56,580	35,830	33	1,264						
1978	36,270	45,641	116	1,445				13,667		
1979	56,283	38,966	74	979				11,338		
1980	59,892	35,881	162	1,033						
1981	61,329	47,663	189	1,218				16,809		
1982	58,018	48,234	207	542				10,993		
1983	47,412	33,174	420	1,139				3,025		
1984	56,930	31,742	273	231				4,928		
1985	43,874	37,889	85	79				4,625		
1986	51,019	19,414	49	130				5,038		
1987	67,325	36,179	355	384						
1988	70,943	55,716	528	576				8,520		
1989	81,175	43,217	1,218	543				11,940		
1990	109,778	53,504	394	512				10,214		
1991	74,820	37,778	401	117		697		7,850		
1992	82,654	46,872	367	1,380	9,675	1,083		6,755		
1993	87,684	8,735	587	2,483		2,218		12,333		
1994	103,343	16,211	1,139	1,937		2,917		15,227		
1995	102,110	30,846	541	1,421				20,651		
1996	96,413	7,419	1,432	247	7,415		7,716	14,199		422
1997	79,381	10,441	1,788	332	10,395		7,834	13,285		1,203
1998	81,213	17,359	1,464	210				12,107		
1999	72,775	4,705	279	98			3,548	5,570	1,490	
2000	70,825	444	105	64	3,547		2,960	3,310	810	345
2001	78,009	90	290	86		998	3,309	9,298	2,010	721
2002	80,982	72	319	288	8,502	1,346	2,444	10,104	2,237	316
2003	67,134	158	401	409	14,474	1,064	4,693	11,771	1,683	378
2004	97,110	2,300	857	691	28,604	1,475	5,207	19,651	2,833	462
2005	85,090	4,784	572	557		2,653	3,845	22,000	2,920	506
2006	90,085	2,777	444	352	17,618	1,043	4,357	19,414	1,700	540
2007	96,155	179	1,478	305	12,927	374	4,883	13,029	2,061	419
2008	98,103	8,865	708	420	5,275	701	2,698	9,730	1,071	413
2009	78,231	6,664	904	470	5,744	362	3,663	9,702	1,071	312
2010	66,056	2732	354	292	1,669	201	1,500	5,690	567	178
2011	59,245	748	633	337	4,079	284	1,571	6,891	1,012	136

Appendix A3.–Peak aerial survey counts of Chinook Salmon returning to drainages of the Kuskokwim River, Alaska, 1976 to 2011.

Year	Kwethluk	Kisaralik	Tuluksak	Salmon (Aniak)	Kipchuk	Aniak	Holokuk	Oskawalik	Holitna	Cheeneetnuk	Gagaryah	Pitka	Bear	Salmon (Pitka)
1976	997								2,571		663		182	
1977	1,116		439				60			1,407	897			1,940
1978	1,722	2,417	403	322					2,766	268	504		227	1,100
1979							45							682
1980			1,035	1,186										1,450
1981	2,034	672				9,074								1,439
1982	471	81					42		521				123	413
1983			202	231		1,909	33		1,069					572
1984										1,177				545
1985		63	142				135			1,002				620
1986				336		424	100		650	317				
1987				516	193		210	193			205			
1988		869	188	244		954		80						473
1989	1,157	152		631	994	2,109								452
1990		631	200	596	537	1,255	157	113						
1991		217	358	583	885	1,564								
1992				335	670	2,284	64	91	2,022	1,050	328			2,536
1993				1,082	1,248	2,687	114	103	1,573	678	419			1,010
1994		1,243		1,218	1,520					1,206	807			1,010
1995		1,243		1,446	1,215	3,171	181	326	1,887	1,565	1,193			1,911
1996				985			85							
1997				980	855	2,187	165	1,470	2,093	345				
1998		457		557	443	1,930								
1999							18	98						
2000				238	182	714	42		301			151		362
2001				598				186	1,130		143		175	1,033
2002	1,795	1,727		1,236	1,615		186	295	1,578		452	165	211	1,255
2003	2,628	654	94	1,242	1,493	3,514	528	844		810	1,095	197	176	1,241
2004	6,801	5,157	1,196	2,177	1,868	5,362	306	293	4,051	918	670	290	206	1,138
2005	5,059	2,206	672	4,097	1,679		268	582	1,760	1,155	788	744	367	1,801
2006		4,734			1,618	5,639	365	386	1,866	1,015	531	170	347	833
2007		692	173	1,458	2,147	3,984	146				1,035	131	165	921
2008	487	1,074		589	1,061	3,222	190	213		290	177	242	245	1,305
2009							390	379		323	303	187	209	632
2010		235					108		587		62	67	75	135
2011				79	116		20	26		249	96	85	145	767

Appendix A4.–Harvest and effort data for Chinook salmon in commercial fishing district W1 by week and year, Kuskokwim River, Alaska, 1976 to 2011.

	Week 3		Week 4		Week 5		Week 6		Week 7		Week 8	
	6/10 - 6/16		6/17 - 6/23		6/24 - 6/30		7/1 - 7/7		7/8 - 7/14		7/15 - 7/21	
Year	Catch	Effort	Catch	Effort	Catch	Effort	Catch	Effort	Catch	Effort	Catch	Effort
1976	0	0	20,010	5,724 [a]	4,143	2,088 [b]	1,550	2,490 [b]	1,238	4,548 [b]	236	1,590 [b]
1977	12,458	2,802 [a]	16,227	2,904 [a]	1,841	4,722 [b]	673	4,194 [b]	153	2,310 [b]	0	0
1978	18,483	3,972 [a]	10,066	2,004 [a]	3,723	5,346 [b]	2,354	8,676 [b]	987	7,668 [b]	0	0
1979	24,633	6,432 [a]	5,651	3,012 [b]	3,860	6,438 [b]	1,233	3,252 [b]	470	3,120 [b]	0	0
1980	9,891	2,814 [a]	21,698	5,364 [d]	1,460	2,448 [b]	498	2,298 [b]	445	2,586 [b]	0	0
1981	29,882	6,180 [a]	3,830	3,066 [b]	4,563	5,952 [b]	2,795	5,520 [b]	941	2,640 [b]	0	0
1982	4,912	2,784 [a]	24,628	5,970 [a]	12,555	5,176 [d]	1,970	3,968 [b]	1,055	4,734 [b]	0	0
1983	13,406	5,634 [a]	8,063	5,544 [b]	4,925	5,958 [b]	2,415	5,634 [b]	633	2,796 [b]	0	0
1984	0	0	17,181	5,562 [a]	5,643	5,616 [b]	3,206	5,454 [b]	2,069	5,592 [b]	744	2,238 [b]
1985	0	0	6,519	2,538 [c]	19,204	5,880 [c]	9,942	5,844 [c]	0	0	0	0
1986	0	0	0	0	11,986	6,540 [c]	5,029	6,852 [c]	1,156	3,192 [c]	0	0
1987	0	0	19,126	4,734 [c]			9,606	6,948 [c]	1,910	3,582 [c]	2,758	6,720 [c]
1988	12,640	4,816 [c]	11,708	3,672 [c]	15,060	7,518 [c]	5,871	6,954 [c]	5,270	10,794 [c]	1,728	6,636 [c]
1989	0	0	15,215	5,208 [c]	11,094	6,144 [c]	7,911	7,092 [c]	6,043	10,962 [c]	868	2,622 [c]
1990	0	0	16,690	3,780 [c]	25,459	7,536 [c]	4,071	3,546 [c]	4,931	8,534 [c]	0	0
1991	0	0	13,813	3,606 [c]	12,612	3,696 [c]	8,068	7,308 [c]	904	3,426 [c]	452	3,408 [c]
1992	0	0	24,334	9,488 [c]	16,307	8,628 [c]	3,250	4,696 [c]	0	0	0	0
1993	0	0	0	0	8,184	4,976 [c]	0	0	0	0	0	0
1994	0	0	0	0	14,221	4,608 [c]	0	0	578	1,984 [c]	441	3,000 [c]
1995	0	0	6,895	2,276 [c]	14,424	4,532 [c]	4,368	3,824 [c]	1,452	3,716 [c]	568	3,488 [c]
1996	0	0	4,091	1,056 [c]	666	360 [c]	861	836 [c]	408	896 [c]	251	1,195 [c]
1997	0	0	10,023	2,118 [c]	0	0	0	0	0	0	0	0
1998	0	0	0	0	12,771	4,584 [c]	2,277	1,780 [c]	1,127	1,668 [c]	0	0
1999	0	0	0	0	4,668	2,454 [c]	0	0	0	0	0	0
2000	0	0	0	0	0	0	357	896 [c]	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	0	0	0	0	520	104 [c]	1,107	446 [c]	0	0	0	0
2005	0	0	0	0	3,531	1,189 [c]	874	604 [c]	0	0	0	0
2006	0	0	0	0	2,493	1,038 [c]	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0	0	0	0
2008	0	0	6,415	1,026 [c]	2,362	783 [c]	19	4 [c]	1	6 [c]	0	6 [c]
2009	0	0	3,003	668 [c]	2,539	752 [c]	762	519 [c]	113	436 [c]	83	672 [c]
2010	0	0	0	0	1,724	1,324 [c]	290	522 [c]	271	686 [c]	186	958 [c]
2011	0	0	0	0	0	0	361	634 [c]	227	996 [c]	129	1,226 [c]

Note: Effort is estimated as the number of permits fished times the number of hours the fishery was open; week is described in Appendix A5.

[a] Unrestricted fishery, large mesh gear allowed.

[b] Restricted fishery, gill net mesh size restricted to 6 inches or less.

[c] Restricted fishery, gill net mesh size restricted to 6 inches or less; 1985–2011.

[d] Both unrestricted and restricted openings during this week. The information was not used in the run reconstruction model.

Appendix A5.–Dates used for grouping commercial and test fishery data into weekly intervals for the estimation of run timing.

Week Number	Date Range
1	May 27 – June 2
2	June 3 – June 9
3	June 10 – June 16
4	June 17 – June 23
5	June 24 – June 30
6	July 1 – July 7
7	July 8 – July 14
8	July 15 – July 21
9	July 22 – July 28
10	July 29 – August 4
11	August 5 – August 11
12	August 12 – August 18
13	August 19 – August 25
14	August 26 – September 1

Appendix A6.–Reconstructed run by year, harvest, escapement, and age for Chinook salmon returning to the Kuskokwim River, Alaska, 1976 to 2011.

Run Year		Age Class												
		0.2	1.1	1.2	2.1	1.3	2.2	1.4	2.3	1.5	2.4	1.6	2.5	Total
1976	Commercial					Age data not available								30,735
	Subsistence	0	70	4,627	0	23,419	24	28,144	78	2,170	57	5	0	58,606
	Sport					Age data not available								
	Test fishery					Age data not available								1,206
	Total Harvest					No estimate made due to limited age information								90,547
	Total Escapement	0	0	10,900	0	58,372	0	72,857	0	574	0	0	0	143,420
	Total					No estimate made due to limited harvest age information								233,967
1977	Commercial	0	0	251	0	11,179	0	23,397	0	1,003	0	0	0	35,830
	Subsistence	0	68	4,467	0	22,610	24	27,171	75	2,095	55	5	0	56,580
	Sport					Age data not available								33
	Test fishery					Age data not available								1,264
	Total Harvest	0	69	4,784	0	34,263	24	51,278	76	3,142	56	5	0	93,707
	Total Escapement					Age data not available								201,852
	Total					No estimate made due to limited escapement age information								295,559
1978	Commercial	0	0	91	0	5,842	0	37,517	0	2,191	0	0	0	45,641
	Subsistence	0	43	2,863	0	14,494	15	17,418	48	1,343	35	3	0	36,270
	Sport					Age data not available								116
	Test fishery					Age data not available								1,445
	Total Harvest	0	44	3,011	0	20,723	15	55,982	49	3,601	36	3	0	83,472
	Total Escapement	0	362	30,745	0	18,990	0	100,916	2,532	5,426	21,883	0	0	180,853
	Total	0	406	33,756	0	39,713	15	156,898	2,581	9,027	21,919	3	0	264,325
1979	Commercial					Age data not available								38,966
	Subsistence	0	68	4,443	0	22,491	23	27,028	75	2,084	35	5	0	56,283
	Sport					Age data not available								74
	Test fishery					Age data not available								979
	Total Harvest					No estimate made due to limited age information								96,302
	Total Escapement	0	0	104,376	0	22,704	0	25,700	0	4,888	21,883	0	0	157,668
	Total					No estimate made due to limited harvest age information								253,970
1980	Commercial	0	0	3,911	0	23,359	0	7,427	0	1,148	0	0	0	35,881
	Subsistence	0	72	4,728	0	23,933	25	28,762	79	2,218	59	5	0	59,892
	Sport					Age data not available								162
	Test fishery					Age data not available								1,033
	Total Harvest	0	73	8,747	0	47,882	25	36,640	80	3,408	59	6	0	96,968
	Total Escapement					Age data not available								203,605
	Total					No estimate made due to limited escapement age information								300,573

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Appendix A6.–Page 2 of 7.

Run Year		Age Class												Total
		0.2	1.1	1.2	2.1	1.3	2.2	1.4	2.3	1.5	2.4	1.6	2.5	
1981	Commercial	0	0	3,670	0	19,304	0	23,117	0	1,573	0	0	0	47,663
	Subsistence	0	74	4,842	0	24,507	26	29,452	81	2,271	60	6	0	61,329
	Sport	Age data not available												189
	Test fishery	Age data not available												1,218
	Total Harvest	0	75	8,622	0	44,376	26	53,247	82	3,894	61	6	0	110,388
	Total Escapement	0	838	20,675	0	84,656	0	162,327	0	10,896	0	0	0	279,392
	Total	0	913	29,297	0	129,032	26	215,574	82	14,790	61	6	0	389,780
1982	Commercial	0	68	2,189	0	11,209	0	33,146	0	1,558	63	0	0	48,234
	Subsistence	0	70	4,580	0	23,184	24	27,862	77	2,149	57	5	0	58,018
	Sport	Age data not available												207
	Test fishery	Age data not available												542
	Total Harvest	0	139	6,817	0	34,636	24	61,438	78	3,733	121	5	0	106,990
	Total Escapement	0	0	5,143	0	18,883	0	51,989	0	4,339	0	0	0	80,353
	Total	0	139	11,960	0	53,519	24	113,427	78	8,072	121	5	0	187,344
1983	Commercial	0	498	7,000	0	6,469	0	17,317	0	1,692	199	0	0	33,174
	Subsistence	0	57	3,743	0	18,946	20	22,768	63	1,756	46	4	0	47,412
	Sport	Age data not available												420
	Test fishery	Age data not available												1,139
	Total Harvest	0	565	10,950	0	25,907	20	40,861	64	3,514	250	4	0	82,145
	Total Escapement	Age data not available												84,188
	Total	No estimate made due to limited escapement age information												166,333
1984	Commercial	0	222	3,904	32	12,379	127	11,649	413	2,571	444	0	0	31,742
	Subsistence	0	68	4,494	0	22,750	24	27,339	76	2,108	56	5	0	56,930
	Sport	Age data not available												273
	Test fishery	Age data not available												231
	Total Harvest	0	292	8,446	32	35,329	152	39,210	491	4,706	503	5	0	89,166
	Total Escapement	0	75	22,240	0	47,083	0	26,150	0	3,439	0	75	0	99,062
	Total	0	367	30,686	32	82,411	152	65,360	491	8,145	503	80	0	188,228
1985	Commercial	0	265	13,072	0	11,139	152	11,897	0	1,364	0	0	0	37,889
	Subsistence	0	53	3,464	0	17,532	18	21,069	58	1,625	43	4	0	43,874
	Sport	Age data not available												85
	Test fishery	Age data not available												79
	Total Harvest	0	318	16,569	0	28,729	170	33,033	58	2,995	43	4	0	81,919
	Total Escapement	0	0	15,247	0	33,643	0	42,359	0	3,019	0	97	0	94,365
	Total	0	318	31,815	0	62,372	170	75,392	58	6,014	43	101	0	176,284

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Run Year		Age Class 0.2	1.1	1.2	2.1	1.3	2.2	1.4	2.3	1.5	2.4	1.6	2.5	Total
1986	Commercial	0	427	2,427	0	10,969	0	4,698	0	893	0	0	0	19,414
	Subsistence	0	61	4,028	0	20,387	21	24,501	68	1,889	50	5	0	51,019
	Sport	Age data not available												49
	Test fishery	Age data not available												130
	Total Harvest	0	490	6,471	0	31,436	21	29,273	68	2,789	50	5	0	70,603
	Total Escapement	0	257	5,037	0	29,817	0	19,206	0	4,239	0	0	0	58,556
	Total	0	747	11,508	0	61,253	21	48,479	68	7,029	50	5	0	129,158
1987	Commercial	0	0	17,076	0	5,680	0	12,916	0	543	0	0	0	36,179
	Subsistence	0	81	5,315	0	26,903	28	32,331	89	2,493	66	6	0	67,325
	Sport	Age data not available												355
	Test fishery	Age data not available												384
	Total Harvest	0	81	22,551	0	32,816	28	45,570	90	3,058	66	6	0	104,243
	Total Escapement	Age data not available												89,222
	Total	No estimate made due to limited escapement age information												193,465
1988	Commercial	0	0	17,216	0	24,515	0	10,642	0	3,343	0	0	0	55,716
	Subsistence	0	85	5,601	0	28,349	30	34,068	94	2,627	69	6	0	70,943
	Sport	Age data not available												528
	Test fishery	Age data not available												576
	Total Harvest	0	86	23,016	0	53,325	30	45,100	95	6,022	70	7	0	127,750
	Total Escapement	0	0	5,524	0	44,671	0	24,337	0	5,524	0	0	0	80,055
	Total	0	86	28,540	0	97,996	30	69,437	95	11,546	70	7	0	207,805
1989	Commercial	0	0	14,305	0	10,718	1,513	12,879	605	2,247	951	0	0	43,217
	Subsistence	0	97	6,408	0	32,438	34	38,982	108	3,006	79	7	0	81,175
	Sport	Age data not available												1,218
	Test fishery	Age data not available												543
	Total Harvest	0	99	21,006	0	43,767	1,568	52,595	723	5,328	1,045	7	0	126,138
	Total Escapement	0	0	17,009	0	29,273	0	67,340	0	2,083	0	0	0	115,704
	Total	0	99	38,015	0	73,040	1,568	119,935	723	7,410	1,045	7	0	241,842
1990	Commercial	0	0	22,151	0	20,197	0	9,303	0	1,854	0	0	0	53,504
	Subsistence	0	132	8,666	0	43,868	46	52,718	146	4,065	107	10	0	109,778
	Sport	Age data not available												394
	Test fishery	Age data not available												512
	Total Harvest	0	132	30,988	0	64,420	46	62,365	146	5,952	108	10	0	164,168
	Total Escapement	0	2,884	24,248	0	61,882	0	11,307	0	293	0	0	0	100,614
	Total	0	3,016	55,236	0	126,302	46	73,672	146	6,245	108	10	0	264,782

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Run Year		Age Class 0.2	1.1	1.2	2.1	1.3	2.2	1.4	2.3	1.5	2.4	1.6	2.5	Total
1991	Commercial	65	0	12,479	0	11,508	704	10,743	554	1,050	503	0	171	37,778
	Subsistence	0	90	5,907	0	29,898	31	35,930	99	2,771	73	7	0	74,820
	Sport					Age data not available								401
	Test fishery					Age data not available								117
	Total Harvest	65	90	18,471	0	41,597	739	46,888	657	3,839	579	7	171	113,102
	Total Escapement	0	0	7,563	0	30,745	1,200	63,305	596	1,778	262	30	109	105,589
	Total	65	90	26,034	0	72,342	1,939	110,193	1,253	5,617	841	37	281	218,691
1992	Commercial	0	549	21,427	0	12,987	111	11,266	0	466	66	0	0	46,872
	Subsistence	0	99	6,525	0	33,029	35	39,692	110	3,061	81	8	0	82,654
	Sport					Age data not available								367
	Test fishery					Age data not available								1,380
	Total Harvest	0	657	28,329	0	46,637	147	51,646	111	3,575	149	8	0	131,258
	Total Escapement	0	6,431	47,819	0	47,478	795	48,394	142	2,214	300	0	0	153,573
	Total	0	7,088	76,148	0	94,115	942	100,040	253	5,788	449	8	0	284,830
1993	Commercial	0	0	5,381	0	1,878	0	839	419	44	87	0	87	8,735
	Subsistence	0	105	6,922	0	35,039	37	42,108	116	3,247	86	8	0	87,684
	Sport					Age data not available								587
	Test fishery					Age data not available								2,483
	Total Harvest	0	109	12,695	0	38,092	38	44,314	553	3,396	179	8	90	99,473
	Total Escapement	0	300	63,418	0	42,709	149	55,456	215	7,003	567	0	0	169,816
	Total	0	409	76,113	0	80,801	186	99,770	768	10,399	745	8	90	269,289
1994	Commercial	0	81	2,805	0	8,154	308	4,215	162	324	162	0	0	16,211
	Subsistence	0	124	8,158	0	41,296	43	49,628	137	3,827	101	9	0	103,343
	Sport					Age data not available								1,139
	Test fishery					Age data not available								1,937
	Total Harvest	0	210	11,245	0	50,723	360	55,228	307	4,258	270	10	0	122,611
	Total Escapement	73	459	27,922	170	144,240	1,243	64,255	1,437	1,654	1,162	0	0	242,616
	Total	73	670	39,167	170	194,963	1,603	119,483	1,744	5,912	1,432	10	0	365,227
1995	Commercial	0	38	10,540	0	4,914	0	15,101	0	252	0	0	0	30,846
	Subsistence	0	122	8,061	0	40,804	43	49,036	135	3,781	100	9	0	102,110
	Sport					Age data not available								541
	Test fishery					Age data not available								1,421
	Total Harvest	0	163	18,876	0	46,393	43	65,083	137	4,093	101	9	0	134,899
	Total Escapement	0	0	43,104	0	57,564	0	124,198	156	424	150	0	0	225,595
	Total	0	163	61,980	0	103,957	43	189,281	293	4,517	251	9	0	360,495

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Run Year		0.2	1.1	1.2	2.1	1.3	2.2	1.4	2.3	1.5	2.4	1.6	2.5	Total
		Age Class												
1996	Commercial	0	19	2,058	0	3,157	0	1,473	11	694	0	8	0	7,419
	Subsistence	0	116	7,611	0	38,527	40	46,300	128	3,570	94	9	0	96,413
	Sport	Age data not available												1,432
	Test fishery	Age data not available												247
	Total Harvest	0	127	8,330	0	42,163	44	50,669	140	3,907	103	10	0	105,492
	Total Escapement	0	0	21,011	0	86,333	280	59,895	475	29,097	0	0	0	197,092
	Total	0	127	29,341	0	128,496	324	110,564	615	33,004	103	10	0	302,584
1997	Commercial	0	0	5,482	0	1,744	0	3,153	0	63	0	0	0	10,441
	Subsistence	0	95	6,267	0	31,721	33	38,121	105	2,940	78	7	0	79,381
	Sport	Age data not available												1,788
	Test fishery	Age data not available												332
	Total Harvest	0	97	12,026	0	34,255	34	42,248	108	3,073	79	7	0	91,927
	Total Escapement	0	0	71,935	0	36,326	0	102,436	0	550	0	0	0	211,247
	Total	0	97	83,961	0	70,580	34	144,684	108	3,623	79	7	0	303,174
1998	Commercial	0	191	4,131	0	10,242	0	2,413	0	382	0	0	0	17,359
	Subsistence	0	97	6,411	0	32,453	34	39,000	108	3,007	79	7	0	81,213
	Sport	Age data not available												1,464
	Test fishery	Age data not available												210
	Total Harvest	0	293	10,722	0	43,420	34	42,117	110	3,447	81	8	0	100,231
	Total Escapement	0	0	5,340	0	62,040	0	43,633	0	2,613	0	0	0	113,627
	Total	0	293	16,062	0	105,460	34	85,749	110	6,060	81	8	0	213,858
1999	Commercial	0	24	1,388	0	1,092	0	2,150	0	52	0	0	0	4,705
	Subsistence	0	87	5,745	0	29,081	30	34,948	97	2,695	71	7	0	72,775
	Sport	Age data not available												279
	Test fishery	Age data not available												98
	Total Harvest	0	111	7,168	0	30,320	31	37,279	97	2,760	72	7	0	77,844
	Total Escapement	0	205	7,726	0	23,012	205	79,907	0	1,027	0	0	0	112,082
	Total	0	317	14,894	0	53,331	236	117,186	97	3,787	72	7	0	189,926
2000	Commercial	Age data not available												444
	Subsistence	0	85	5,591	0	28,302	30	34,012	94	2,623	69	6	0	70,825
	Sport	Age data not available												105
	Test fishery	Age data not available												64
	Total Harvest	0	86	5,640	0	28,547	30	34,306	95	2,645	70	6	0	71,425
	Total Escapement	0	45	13,523	0	27,410	0	21,654	0	2,548	0	0	0	65,180
	Total	0	131	19,163	0	55,957	30	55,960	95	5,193	70	6	0	136,605

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Appendix A6.–Page 6 of 7.

Run Year		Age Class 0.2	1.1	1.2	2.1	1.3	2.2	1.4	2.3	1.5	2.4	1.6	2.5	Total
2001	Commercial					Age data not available								90
	Subsistence	0	0	3,354	0	13,574	0	54,294	0	6,787	0	0	0	78,009
	Sport					Age data not available								290
	Test fishery	0	0	26	0	23	0	29	0	6	2	0	0	86
	Total Harvest	0	0	3,397	0	13,663	0	54,587	0	6,826	2	0	0	78,475
	Total Escapement	0	0	21,153	0	53,794	0	65,590	0	4,694	0	0	0	145,232
	Total	0	0	24,550	0	67,457	0	120,178	0	11,520	2	0	0	223,707
2002	Commercial					Age data not available								72
	Subsistence	0	0	6,317	0	26,643	0	43,730	0	4,211	0	0	0	80,982
	Sport					Age data not available								319
	Test fishery	0	0	92	0	95	4	95	0	1	0	0	0	288
	Total Harvest	0	0	6,446	0	26,894	4	44,080	0	4,237	0	0	0	81,661
	Total Escapement	0	215	45,768	0	61,110	59	53,401	0	4,081	0	0	0	164,635
	Total	0	215	52,214	0	88,004	63	97,481	0	8,318	0	0	0	246,296
2003	Commercial					Age data not available								158
	Subsistence	0	134	4,565	0	29,673	0	28,263	0	4,498	0	0	0	67,134
	Sport					Age data not available								401
	Test fishery	0	1	148	0	162	0	82	0	16	0	0	0	409
	Total Harvest	0	137	4,752	0	30,082	0	28,580	0	4,551	0	0	0	68,102
	Total Escapement	0	297	45,885	0	77,362	0	52,300	0	4,843	0	0	0	180,687
	Total	0	434	50,637	0	107,444	0	80,879	0	9,395	0	0	0	248,789
2004	Commercial	0	28	1,339	0	584	0	336	0	14	0	0	0	2,300
	Subsistence	0	194	13,498	0	35,397	291	45,108	0	2,622	0	0	0	97,110
	Sport					Age data not available								857
	Test fishery	0	0	223	0	294	4	155	0	15	0	0	0	691
	Total Harvest	0	224	15,189	0	36,585	298	45,988	0	2,673	0	0	0	100,958
	Total Escapement	0	1,174	135,415	0	81,833	141	66,388	0	2,226	0	0	0	287,177
	Total	0	1,398	150,604	0	118,418	439	112,376	0	4,899	0	0	0	388,135
2005	Commercial	0	0	1,761	0	2,296	10	708	0	10	0	0	0	4,784
	Subsistence	0	35	4,558	0	42,333	0	36,361	212	1,519	71	0	0	85,090
	Sport					Age data not available								572
	Test fishery	0	0	141	0	244	0	166	0	7	0	0	0	557
	Total Harvest	0	36	6,500	0	45,157	10	37,470	213	1,545	71	0	0	91,003
	Total Escapement	0	765	61,154	0	124,847	0	84,954	405	3,371	101	0	0	275,598
	Total	0	801	67,655	0	170,004	10	122,425	618	4,917	172	0	0	366,601

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Appendix A6.–Page 7 of 7.

Run Year		Age Class 0.2	1.1	1.2	2.1	1.3	2.2	1.4	2.3	1.5	2.4	1.6	2.5	Total
2006	Commercial	0	31	1,691	0	755	0	286	0	14	0	0	0	2,777
	Subsistence	0	160	5,657	0	32,181	53	48,084	160	3,682	107	0	0	90,085
	Sport					Age data not available								444
	Test fishery	0	0	0	0	0	0	0	0	0	0	0	0	352
	Total Harvest	0	192	7,383	0	33,093	54	48,601	161	3,714	107	0	0	93,304
	Total Escapement	0	804	69,665	0	59,658	0	73,180	0	10,698	0	0	0	214,004
	Total	0	996	77,048	0	92,751	54	121,781	161	14,411	107	0	0	307,308
2007	Commercial					Age data not available								179
	Subsistence	0	0	7,036	0	35,507	0	50,235	281	2,486	610	0	0	96,155
	Sport					Age data not available								1,478
	Test fishery					Age data not available								305
	Total Harvest	0	0	7,179	0	36,231	0	51,260	287	2,537	622	0	0	98,117
	Total Escapement	0	196	69,771	0	54,634	0	46,478	7	3,667	191	0	0	174,943
	Total	0	196	76,950	0	90,865	0	97,738	294	6,204	814	0	0	273,060
2008	Commercial	0	0	3,573	0	4,131	27	887	115	133	0	0	0	8,865
	Subsistence	0	196	8,044	0	52,779	0	33,649	589	2,551	196	0	0	98,103
	Sport					Age data not available								708
	Test fishery					Age data not available								420
	Total Harvest	0	198	11,740	0	57,511	27	34,900	711	2,712	198	0	0	107,997
	Total Escapement	0	343	34,806	0	58,004	43	32,752	642	2,478	0	0	0	128,978
	Total	0	542	46,546	0	115,515	70	67,652	1,354	5,190	198	0	0	236,975
2009	Commercial	0	0	2,792	0	1,999	33	1,753	0	67	13	0	0	6,664
	Subsistence	0	78	7,823	0	27,146	78	41,932	78	1,017	78	0	0	78,231
	Sport					Age data not available								904
	Test fishery					Age data not available								470
	Total Harvest	0	79	10,787	0	29,617	113	44,391	79	1,101	93	0	0	86,269
	Total Escapement	0	90	26,865	0	46,825	729	42,443	220	1,228	236	0	0	118,478
	Total	0	169	37,652	0	76,442	842	86,835	300	2,330	329	0	0	204,747
2010	Commercial	0	0	973	0	1,058	0	680	0	9	12	0	0	2,732
	Subsistence	0	66	5,152	0	32,566	66	26,224	0	1,982	0	0	0	66,056
	Sport					Age data not available								354
	Test fishery					Age data not available								292
	Total Harvest	0	67	6,183	0	33,939	67	27,157	0	2,009	12	0	0	0
	Total Escapement	0	111	18,326	0	15,791	0	13,555	0	1,259	31	0	0	49,073
	Total	0	178	24,509	0	49,730	67	40,712	0	3,268	43	0	0	118,507
2011	Commercial					Age data not available								748
	Subsistence	0	59	7,880	0	28,438	0	21,565	118	1,126	0	59	0	59,245
	Sport					Age data not available								633
	Test fishery					Age data not available								337
	Total Harvest	0	61	8,108	0	29,262	0	22,190	122	1,158	0	61	0	60,963
	Total Escapement	0	96	28,890	0	22,044	116	20,004	219	610	43	0	0	72,097
	Total	0	157	36,998	0	51,306	116	42,194	340	1,768	43	61	0	133,059