**Fishery Data Series No. 15-18**

# Estimates of the Historic Run and Escapement for the Coho Salmon Stock Returning to the Kuskokwim River, 2000–2012

**Final Report for Study 45349, 45565, and 45716**

**Arctic–Yukon–Kuskokwim Sustainable Salmon Initiative**

**by**

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

# Symbols and Abbreviations

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**Weights and measures (metric)**

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

**Weights and measures (English)**

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

**Time and temperature**

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

**Physics and chemistry**

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

**General**

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

**Mathematics, statistics**

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

# *FISHERY DATA SERIES NO. 15-18*

# ESTIMATES OF THE HISTORIC RUN AND ESCAPEMENT FOR THE COHO SALMON STOCK RETURNING TO THE KUSKOKWIM RIVER, 2000–2012

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# ABSTRACT

Coho salmon (*Oncorhynchus kisutch*) are the most heavily exploited salmon species in the Kuskokwim River. Information on total annual run size and subsequent returns are insufficient to model stock productivity, determine optimal harvest rates, and establish escapement goals that will provide for sustained yields. Total run of coho salmon to the Kuskokwim River from 2000 through 2012 was estimated using a maximum likelihood model developed for data-limited situations. The model simultaneously combined information on subsistence harvest, commercial harvest and effort, sport harvest, Bethel test fishery harvest and catch per unit of effort, mark–recapture estimates of inriver abundance, and counts of salmon at 6 weirs spread throughout the Kuskokwim River drainage. The model was used to estimate 26 parameters using 432 observations. The total estimated run of coho salmon in the Kuskokwim River from 2000 to 2012 ranged from 500,000 to 2,700,000. 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 develop a brood table. This report provides foundational data required to estimate productivity of Kuskokwim River coho salmon and evaluate harvest strategies for maximizing sustained yields.

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

# INTRODUCTION

A continuous time series of reliable estimates of total run, spawning escapement, and productivity is important for the successful management of Kuskokwim River coho salmon (*Oncorhynchus kistuch*) fisheries. This is especially true because coho salmon are the most heavily exploited salmon species returning to the Kuskokwim River (Brazil et al. 2013). Total utilization of coho salmon averages 326,373 fish (2002–2011), which is twice as large as Kuskokwim River chum salmon (*O. keta*) and more than three times that of Chinook (*O. tshawytscha*) and sockeye salmon (*O. nerka*). Nearly 90% of the annual harvest of coho salmon occurs in the commercial fishery that is executed annually from late July through August. Commercial harvest of coho salmon averages 292,439 (2002–2011) fish, but annual harvest has been as high as 937,299 fish in 1996 (Brazil et al. 2013). For most years, exploitation is not known because estimates of total run size are not available. Total run estimates were recently published for 6 discontinuous years between 2001 and 2009 (Liller et al. 2014), and during that time harvest exploitation ranged between 20% and 32%. The available time series of total run estimates is inadequate to model stock productivity, determine optimal harvest rates, and establish escapement goals that will provide for sustained yields.

Data on the Kuskokwim River coho salmon stock have been collected since before statehood; however, the large geographic size and complexity of the drainage have precluded the collection of adequate information to make estimates of total run and spawning escapement on an annual basis. Reliable commercial catch and effort data are available annually back to the early 1960s (Brazil et al. 2013). Estimates of total subsistence harvest of coho salmon are available annually back to 1989 (Carroll and Hamazaki 2012). Inseason salmon run strength has been indexed annually since 1984 by a drift gillnet test fishery operated near Bethel (Bue and Brazil 2012). Efforts to monitor coho salmon escapement within the Kuskokwim River began in 1981 using a weir on the Kogrukluk River, a headwater tributary of the Holitna River (Hansen and Blain 2013). Beginning in the late 1990s, the Kuskokwim River salmon escapement monitoring program was expanded considerably. During that time, weirs were installed on the Kwethluk, Tuluksak, George, Tatlawiksuk, and Takotna rivers (Figure 1). Since initiation, escapement counts have been attempted annually at each location, but the monitored escapement represents only a fraction of the total. Although a considerable amount of effort is expended annually to monitor Kuskokwim River coho salmon, the information is inadequate for estimating total run and escapement, and the utility for management is limited. The result is a qualitative assessment of run dynamics based on the available suite of index projects. Preseason management of the coho salmon fisheries is therefore based upon harvest outlooks from informal projections of run strength. Inseason, managers make decisions based on indices of run abundance from test fishery and commercial harvest statistics, supplemented with informal subsistence reports. Tributary escapement counts are used postseason to index the adequacy of escapement at broad geographic scales. However, only the Kogrukluk and Kwethluk rivers have a formal escapement goal for coho salmon (Conitz et al. 2012; Munro and Volk 2013).

While none of the datasets dealing with coho 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. Maximum likelihood models have been developed (Shotwell and Adkison 2004) and refined (Bue et al. 2008 and 2012) specifically for conducting quantitative assessments of salmon populations in data-limited situations. The approach combines multiple data sources from harvest and escapement monitoring projects to create an index of annual abundance that can be scaled based on a few years of total run abundance. The approach can be viewed as the estimation of the run size most likely to produce the observed stock abundance information.

The run reconstruction models that have been used with some success in the Kuskokwim (e.g., Bue et al. 2008 and 2012) differ 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 salmon stocks are exploited heavily by local subsistence fishermen and only a small fraction of the escapement is measured. The methods used for reconstructing Kuskokwim River salmon runs are appropriate for data-limited situations and make use of most of the historical information collected to estimate total abundance and total escapement by age for the stock.

We used maximum likelihood methods to reconstruct a historical time series of Kuskokwim River coho salmon total run from 2000 to 2012. In this approach, we used commercial harvest and effort data, subsistence harvest estimates, and tributary weir counts. Independent estimates of the total coho salmon run to the Kuskokwim River were used to scale the run reconstruction model. These independent estimates were available for the 2001 through 2004, 2008, and 2009 runs (Liller et al. 2014). The estimates are from large-scale mark–recapture studies conducted upriver of Kalskag (rkm 270), combined with enumeration weirs located on the Kwethluk and Tuluksak rivers, and expansions for unmonitored drainage areas downstream of Kalskag.

# OBJECTIVES

This report documents a portion of the work performed for the completion of research projects 45349, 45565, and 45716 *Kuskokwim River Coho Salmon Investigations* funded by the *Arctic Yukon Kuskokwim Sustainable Salmon Initiative*. The original goal for this component of the research project was to estimate annual run abundance and develop a brood table for Kuskokwim River coho salmon for years 1981–2009. Early in this project, we determined that the historical escapement data were not adequate to achieve our goal. Consequently, the project objectives were modified as follows:

1. Develop a statistical model to estimate total annual abundance of Kuskokwim River coho salmon for years 2000–2012; and
2. Develop a brood table for coho salmon for years 2000–2012.

# METHODS

## MODEL OVERVIEW

The simplest approach to reconstructing total annual run abundance ($N_y$) requires adding total escapement ($E_y$) and total harvest ($H_y$) information:

$$N_y = E_y + H_y \, . \tag{1}$$

Each part of Equation 1 is known to different degrees. Estimates of total abundance are available for 6 years (Liller et al. 2014). Total annual escapement is indexed by count data from weirs located throughout the lower, middle, and upper portions of the Kuskokwim River. Total harvest is known with a high degree of confidence from commercial fish tickets, subsistence surveys, and sport fish harvest reports.

A maximum likelihood model was used to estimate total run and ultimately total escapement of coho salmon into the Kuskokwim River for years 2000–2012. 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 harvest and effort, and (3) total inriver abundance.

### Data Sources

The model utilizes 6 types of information to estimate total abundance:

#### *Independent estimates of inriver abundance*

Estimates of total inriver abundance of Kuskokwim River coho salmon were available for years 2001–2004 and 2008–2009 (Appendix A1; Liller et al. 2014). Those independent estimates were used in our model for scaling the patterns of coho salmon abundance.

#### *Salmon escapement counts from 6 weirs located throughout the drainage*

We assumed that weir counts adequately represented the relative scale of escapement to the Kuskokwim River. Therefore, we evaluated the relationship between escapement indices and total escapement in select years and used those relationships to estimate total escapement for years without total run estimates.

Counts of escapement collected at weirs are maintained by the Alaska Department of Fish and Game (ADF&G), Division of Commercial Fisheries, in Anchorage (Appendix A2). Only weir projects with at least 10 years of escapement information were included in the model. Kwethluk (rkm 131) and Tuluksak (rkm 248) river weirs are operated by U.S. Fish and Wildlife Service in cooperation with local organizations and are assumed to index the escapement to the lower portion of the Kuskokwim River. The George (rkm 453) and Tatlawiksuk (rkm 568) river weirs are operated by ADF&G and Kuskokwim Native Association and are used as an index of escapement for the central portion of the Kuskokwim River. The Kogrukluk River weir (rkm 710) is located in the Holitna River drainage and is operated by ADF&G as an index of escapement to the Holitna River. The Takotna River weir (rkm 835) is operated by ADF&G in cooperation with Takotna Tribal Council and Takotna Community Association, and is used as an index of escapement for the headwater systems of the Kuskokwim River.

#### *Harvest*

Commercial harvest and effort data were used to index abundance of coho salmon in the commercial fishing area over time. The commercial fishery is conducted in the lower section of the Kuskokwim River, and there is very little harvest below this section (Figure 1). Estimates of coho salmon abundance available in the commercial fishery area are therefore assumed to be a close approximation of total run. Commercial harvest and effort information were obtained from Brazil et al. 2013, and the 2011 and 2012 data were compiled from actual fish tickets on file with ADF&G, Division of Commercial Fisheries, Anchorage (Appendix A3).

Additional sources of coho salmon harvest were necessary for a complete accounting of fish. Subsistence harvest data were compiled from Carroll and Hamazaki (2012), and preliminary estimates for 2011 and 2012 are on file with ADF&G, Division of Commercial Fisheries, Anchorage. Sport fishery harvest information was from Chythlook (2012), or through personal communication with the Kuskokwim Area Sport Fishery Manager in Fairbanks.

#### *Test fishery indices of run timing at Bethel*

Estimation of total run size based on commercial catch and effort information requires knowledge of the proportion of the total run that that was available to the commercial fishery. Run timing of Kuskokwim River coho salmon through the commercial fishing district is indexed by a drift gillnet test fishery operated near Bethel (rkm 106). Data collected at the Bethel test fishery were provided by ADF&G Kuskokwim River research staff, Division of Commercial Fisheries.

#### *Age composition*

Coho salmon age data are collected annually from harvest and escapement monitoring projects operated throughout the Kuskokwim River. 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 (Appendix A4).

## Escapement

The monitored component of the annual escapement was based on total counts of coho salmon 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 linearly related ($\hat{k}_i$) to the total annual escapement into the Kuskokwim River drainage ($E_y$):

$$E_y = \hat{k}_i I_{iy} \quad . \qquad (2)$$

The expected weir count ($\hat{I}_{iy}$) for an estimated escapement ($\hat{E}_y$) was then estimated by:

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

The form of the negative binomial density presented in Hilborn and Mangel (1997) and Millar (2011) was used to model uncertainty in the count data. An additional parameter, typically called the overdispersion parameter ($\hat{m}_i$), was estimated to account for the additional variability due to differences between the mean and variance among weir projects (Figure 2).

$$L(I \mid \hat{I}, \hat{m}, \hat{k}) = \prod_y \prod_i \frac{\Gamma(\hat{m}_i + I_{iy})}{\Gamma(\hat{m}_i)\, I_{iy}!} \left( \frac{\hat{I}_{iy}}{\hat{m}_i + \hat{I}_{iy}} \right)^{I_{iy}} \left( \frac{\hat{m}_i}{\hat{m}_i + \hat{I}_{iy}} \right)^{\hat{m}_i} \quad . \tag{4}$$

## Commercial Harvest and Effort

Commercial harvest information was used to estimate the total number of fish available to the commercial fishery ($\hat{W}_y$) in district W1. The number of fish in the commercial area was combined with the harvest below the commercial district ($H_{y,downstream}$), and an estimate of total abundance ($\hat{N}_y$) was calculated as:

$$\hat{N}_y = \hat{W}_y + H_{y,downstream} \quad . \tag{5}$$

Fish available to the commercial fishery in W1 ($\hat{W}_{yj}$) by year ($y$) and week ($j$) was estimated using the proportion of the run present by year and week ($p_{yj}$) as:

$$\hat{W}_{yj} = \hat{W}_y p_{yj} \quad . \tag{6}$$

The proportion of the run present ($p_{yj}$) was estimated using test fishery catch per unit effort results, independently of the model, and the estimates were assumed to be measured without error.

Observed harvest ($C_{yj}$) was obtained from commercial receipts. Using the relationship from the Baranov catch equation (Quinn and Deriso 1999), fish available to the commercial fishery in W1 ($\hat{W}_{yj}$) was estimated with:

$$\hat{W}_{yj} = \frac{C_{yj}}{\left(1 - \exp^{-qD_{yj}}\right) \exp^{\varepsilon_{yj}}} \quad . \tag{7}$$

The expected effort ($\hat{D}_{iy}$) required to obtain the observed harvest ($C_{iy}$) from the estimated number of fish available to be caught ($\hat{W}_{yj}$) and estimated catchability ($\hat{q}$) was then estimated by:

$$\hat{D}_{yj} = \frac{\log(1 - C_{yj} / \hat{W}_{yj})}{-\hat{q}} \exp^{\varepsilon_{yj}} \quad . \tag{8}$$

The likelihood of the observed fishing effort ($D$) given the estimated parameters is:

$$L(D \mid \hat{D}, \hat{q}) = \prod_y \prod_j \frac{1}{\sigma_\varepsilon \sqrt{2\pi}} \exp^{\frac{-\left(\ln D_{yj} - \ln \hat{D}_{yj}\right)^2}{2\sigma_\varepsilon^2}} \quad . \tag{9}$$

## Total Inriver Abundance

Uncertainty about the total inriver run abundances ($N$) used to scale the model (Liller et al. 2014; Appendix A1) was estimated using bootstrap methods and was incorporated into the reconstruction model as a penalized negative log likelihood (Branch and Hilborn 2010; Flynn et al. 2006). Bootstrap distributions were generally unimodal and skewed towards the smaller values (Figure 3). Bootstrap estimates were log transformed to account for skewness, and the variance of the distributions ($\sigma^2_{\log N_y}$) were used to estimate the uncertainty about the model derived estimates of total inriver abundance ($\hat{N}$) for the likelihood

$$L(N \mid \hat{N}) = \prod_y \exp^{\frac{-\left(\log N_y - \log \hat{N}_y\right)^2}{2\sigma^2_{\log N_y}}} \quad . \tag{10}$$

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

## Likelihood Model

The escapement, commercial harvest, and total inriver components were combined into a single likelihood model that simultaneously estimated the total run to the Kuskokwim drainage for each year as

$$L_{Total} = L(I \mid \hat{I}, \hat{m}, \hat{k})\, L(D \mid \hat{D}, \hat{q})\, L(N \mid \hat{N}) . \tag{11}$$

The negative log likelihood form of the model was minimized (Hilborn and Mangel 1997) to arrive at the best estimates of the model parameters ($\hat{N}_y, \hat{k}_i$, $\hat{q}$, and $\hat{m}_i$) 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 ($\hat{k}_i$) 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 coefficient ($\hat{q}$) to values less than 0.5 and greater than or equal to $5\text{x}10^{-10}$ to protect against obtaining nonsensical negative log likelihood values. An *ad hoc* sensitivity analysis that 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 that 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 $\hat{N}_y$ in 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 ($\mathrm{L}(N)$) for a total run of abundance *N* by

$$2\left[\mathrm{L}(N) - \mathrm{L}(N)_{\min}\right] \ , \tag{12}$$

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

The estimated annual escapement into the Kuskokwim River drainage ($\hat{E}_y$) is simply the total estimated abundance ($\hat{N}_y$) minus the harvest from all sources (Subsistence [$S_y$]; Commercial [$C_y$]; Sport [$R_y$]; Test Fishery [$G_y$]), and was calculated as:

$$\hat{E}_y = \left(\hat{N}_y - S_y - C_y - R_y - G_y\right) \ . \tag{13}$$

## BROOD TABLE ESTIMATION

Estimates of the number of coho salmon in the harvest and escapement obtained from the run reconstruction model were combined with available age information (Appendix A4) to reconstruct the total run by year and age for the 2000 through 2012 runs, and finally estimate a brood table. Both the commercial and subsistence fisheries use gillnets to harvest coho 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, whereas only age information from the escapement would be used to estimate the age structure of the escapement.

Commercial harvest is the only portion of the total harvest that is sampled for age composition. Thus, it was assumed that the age composition of the commercial harvest was the same as the age composition of the remaining harvest components. Age data were not collected from the harvest in 2003. The age composition for 2003 was estimated as the average of the 5 years immediately before and after 2003.

The number of fish by age in the escapement segment was estimated using age information obtained from all of the operational escapement projects. 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 ($g_{yi}$):

$$\hat{P}_{ya} = \frac{\hat{h}_{yai} g_{yi}}{\sum_{y} g_{yi}} \quad . \tag{14}$$

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:

$$\hat{n}_{ya} = \hat{E}_y \hat{P}_{ya} \quad . \tag{15}$$

The harvests and escapements by age and year were summed to estimate the total run by year. A brood table was estimated using the estimates of total run by age.

# RESULTS

## RUN RECONSTRUCTION MODELING

The run reconstruction model was used to estimate 26 parameters: 13 total runs ($\hat{N}_y$; 2000 through 2012), 6 scaling factors ($\hat{k}_i$) and 6 overdispersion parameters ($\hat{m}_i$) for the escapement monitored by weirs, and a catchability coefficient ($\hat{q}$ ; Table 1). A total of 432 observations were used to fit the model (Appendices A1, A2, and A3).

Run timing of coho salmon in commercial fishing district W1 was generally unimodal, peaking during the week of August 3 through August 9 (Week 4), although a wide range of entry patterns and run timings were observed (Figure 4).

The model produced reasonable estimates of weir escapement and commercial harvest effort. On average 12.7% of the total escapement was counted at weir projects. The reconstructed counts for the weirs located upriver of Kalskag compared well with the observed counts, although there was an indication that the reconstruction model underestimated the larger escapements for the Kwethluk and Tuluksak weirs (Figure 5). Estimates of effort obtained from the catchability model were generally in agreement with the observed efforts for 3 of the 4 weeks in the model (Figure 6).

The largest estimate of the total coho salmon run was for 2004 (2,699,102) and the lowest was for 2010 (499,951) (Table 2; Figure 7). Coefficients of variation for total run estimates ranged from 6.7% to 33.8%. Escapement estimates ranged from a low of 407,065 in 2010 to a high of 2,375,943 in 2003 (Table 2; Figure 8). Coefficients of variation for annual escapement estimates ranged from 8.2% to 41.6%.

## BROOD TABLE CONSTRUCTION

Sufficient information was available to reconstruct the age composition of the total run for years 2000 to 2012 (Table 3). Age-2.1 coho salmon accounted for an average of 86% of the harvest and 88% of the escapement across all years. The number of fish returning for every spawning fish in the parent population (recruits per spawner) decreased from a high of 3.09 in brood year 2000 to a low of 0.40 in brood year 2003 and then increased through the 2007 brood year (Figure 9; Table 4). Although the data series is limited, there is some indication that recruits per spawner trends with level of escapement, with higher production occurring for lower levels of escapement and lower production being observed for higher levels of escapements (Figure 9).

# DISCUSSION

Our estimates may not represent the entire run of coho salmon during years with late run timing. Commercial fishing and the Bethel test fishery generally cease by August 24. In addition, weir operations generally cease by the end of September due to high water and icing conditions. However, during years of late run timing, coho salmon have been observed passing the weirs into early October and have been caught by subsistence fishermen under the ice in November. As a result, the model may underestimate abundance of coho salmon in years with late run timing. Although we do not know the proportion of the total run that is unaccounted for in late run timing years, our estimates are suitable to represent the abundance of coho salmon vulnerable to harvest in commercial and subsistence fisheries.

Parameters estimated in the model were reasonable when considering the number of fish monitored at each weir and the annual variability. Tributaries with a larger number of fish received a smaller scaling factor ($\hat{k}_i$), meaning the count represents a larger component of the total escapement. The overdispersion parameters ($\hat{m}_i$) are also logical because they account for the escapement monitored and the variability in these counts. Systems with low abundance and high variability receive the smallest overdispersion parameter, meaning they have less power to drive the total estimates. This can be thought of as a weighting scheme that compromises between the escapement monitored (scaling parameter) and the variability of that escapement year to year (CV).

The overall accuracy of the model results depends on the quality, quantity, and temporal distribution of the independent estimates of total run that were used to scale the model. We feel that we had adequate information to scale the model. Of the 13 annual coho salmon runs that were estimated with the model, 6 had corresponding scalars and those scalars included small and large run sizes (603,000 to 2,024,000). In addition, the independent estimates were spaced throughout the 13 years of modeled total run estimates (Appendix A1).

The model results seem reasonable given the uncertainty of estimating total coho salmon abundance in a large dynamic watershed. All model parameters displayed pronounced "U-shaped" profiles across a wide range of possible values (Figure 10). 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 reconstructed counts for the weirs located upriver of Kalskag compared well with the observed counts, whereas there was an indication that the reconstruction model underestimated the larger escapements for the Kwethluk and Tuluksak weirs (Figure 5). Estimates of effort obtained from the catchability model were generally in agreement with the observed efforts for 3 of the 4 weeks in the model (Figure 6). Total run estimates provided by the reconstruction model generally agreed with the estimates used as scalars (Liller et al. 2014; Figure 7).

The model and independent scalars both indicated that the total coho salmon run size in 2003 and 2004 was very large; however, the relative magnitude of the estimates did not agree. The model estimated the 2003 run significantly larger than 2004. Conversely, the 2004 scalar estimate was larger than 2003, but the 2 estimates were not statistically different. We believe that the difference was due in part to the ability of each estimation method to account for annual variation in the distribution of coho salmon. The model estimates abundance based on the average relationship between each index project and total abundance. This approach assumes the distribution of coho salmon and the proportion of the total escapement monitored at each weir is constant. As a result, the model output is fairly logical in that years like 2003 with very large weir counts will return an estimate that is very large, compared to years like 2004 with more average weir counts. The scalar estimates are largely based on results from mark–recapture studies, which do not require that the distribution of coho salmon be consistent, only that fish are tagged in proportion to abundance. Weirs used to recapture tagged fish counted record-high numbers of coho salmon in 2003 and considerably less in 2004. However, the ratio of tagged to untagged fish was much higher in 2003, suggesting that the weirs represented a larger proportion of the total escapement in 2003 compared to 2004. The 95% confidence bounds for the model and scalar estimates overlapped in both years, providing little evidence that the estimates were significantly different from each other (Figure 7). Regardless of which estimate is considered most accurate, the interpretation of the coho salmon population productivity would probably remain unchanged.

It is important with this type of model to periodically update and evaluate the model with new independent estimates of total run. 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. Although coho salmon have a much simpler life history than sockeye salmon, if this pattern is also true for the coho 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 the further in time from the independent estimates. We recommend evaluating the model with 3 consecutive independent estimates of total run on a 5- or 10-year interval.

This study provides new information for the formulation of fisheries management strategies for Kuskokwim River coho salmon and hopefully leads to development of future population assessment projects. This data set is adequate to assess spawner recruit dynamics, acknowledging the latest fraction of the run is not monitored or included year to year. The result of a spawner recruit assessment could be used to develop an escapement goal for the Kuskokwim River. In a more immediate nature, the development of the brood table in this study will allow for forecasting future returns, allowing for management strategies to be formulated prior to each season.

# ACKNOWLEDGEMENTS

We would like to thank all the people involved with the project design, data collection, and reporting for projects in the Kuskokwim River drainage over the years. Specifically, we would like to thank Doug Molyneaux, who spearheaded this endeavor before his retirement, and Brian Bue, who contributed substantially to the model development. Staff from many organizations worked cooperatively to collect this information, including the Kuskokwim Native Association; Association of Village Council Presidents; Orutsararmiut Native Council; the U.S. Fish and Wildlife Service Yukon Delta National Wildlife Refuge, Office of Subsistence Management, and

Kenai Fisheries Resource Office; and the Alaska Department of Fish and Game Divisions of Commercial Fisheries, Sport Fish, and Subsistence. This work was funded through grants by the Arctic–Yukon–Kuskokwim Sustainable Salmon Initiative (Projects 45349, 45565, and 45716) and contributions by Coastal Villages Region Fund.

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# TABLES AND FIGURES

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

| | Scaling parameter ( $\hat{k}_i$ ) | 95% Bound | | CV | Overdispersion parameter ( $\hat{m}_i$ ) |
|---|---|---|---|---|---|
| | | Lower | Upper | | |
| Weir projects | | | | | |
| Kwethluk weir | 29.1 | 25.9 | 32.3 | 5.6% | 19.0 |
| Tuluksak weir | 83.4 | 66.0 | 101.3 | 10.8% | 2.3 |
| George weir | 53.9 | 46.3 | 61.8 | 7.3% | 5.8 |
| Kogrukluk weir | 37.0 | 33.0 | 40.9 | 5.5% | 21.3 |
| Tatlawiksuk weir | 87.6 | 77.9 | 97.2 | 5.6% | 14.6 |
| Takotna weir | 251.0 | 218.8 | 284.9 | 6.7% | 8.1 |
| Catchability ( $\hat{q}$ ) | 1.1E-04 | 9.3E-05 | 1.3E-04 | 9.3% | |

*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 coho salmon, 2000–2012.

| Year | Estimated total run | 95% Confidence bounds | | CV | Estimated escapement | 95% Confidence bounds | | CV |
|---|---|---|---|---|---|---|---|---|
| | | Lower | Upper | | | Lower | Upper | |
| 2000 | 875,447 | 639,612 | 1,127,362 | 14.2% | 567,210 | 331,375 | 819,125 | 21.9% |
| 2001 | 742,976 | 638,353 | 852,148 | 7.3% | 515,962 | 411,339 | 625,134 | 10.6% |
| 2002 | 631,145 | 534,541 | 739,341 | 8.3% | 500,566 | 403,962 | 608,762 | 10.4% |
| 2003 | 2,699,102 | 2,335,550 | 3,095,705 | 7.2% | 2,375,943 | 2,012,391 | 2,772,546 | 8.2% |
| 2004 | 1,679,812 | 1,474,121 | 1,916,357 | 6.7% | 1,191,700 | 986,009 | 1,428,245 | 9.5% |
| 2005 | 819,739 | 491,844 | 1,167,710 | 21.0% | 639,004 | 311,109 | 986,975 | 27.0% |
| 2006 | 694,283 | 456,243 | 932,323 | 17.5% | 464,617 | 226,577 | 702,657 | 26.1% |
| 2007 | 777,552 | 544,286 | 1,018,752 | 15.6% | 597,110 | 363,844 | 838,310 | 20.3% |
| 2008 | 1,130,279 | 950,357 | 1,324,042 | 8.4% | 931,753 | 751,831 | 1,125,516 | 10.2% |
| 2009 | 723,807 | 604,158 | 861,183 | 9.1% | 583,283 | 463,634 | 720,659 | 11.2% |
| 2010 | 499,951 | 171,412 | 834,612 | 33.8% | 407,065 | 78,526 | 741,726 | 41.6% |
| 2011 | 1,170,785 | 802,824 | 1,591,312 | 17.2% | 1,064,277 | 696,316 | 1,484,804 | 18.9% |
| 2012 | 559,219 | 335,531 | 787,471 | 20.6% | 443,296 | 219,608 | 671,548 | 26.0% |

*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.–Reconstructed run by year, harvest and escapement, and age for coho salmon returning to the Kuskokwim River, Alaska, 2000–2012.

| Run year | | Age class | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | | 1.1 | 1.2 | 2.1 | 2.2 | 3.1 | 3.2 | 4.1 | |
| 2000 | Total harvest | 10,788 | 0 | 290,976 | 0 | 6,473 | 0 | 0 | 308,237 |
| | Total escapement | 15,716 | 0 | 543,996 | 0 | 7,498 | 0 | 0 | 567,210 |
| | Total | 26,504 | 0 | 834,971 | 0 | 13,971 | 0 | 0 | 875,447 |
| 2001 | Total harvest | 15,210 | 0 | 187,514 | 0 | 24,518 | 0 | 0 | 227,241 |
| | Total escapement | 18,952 | 0 | 446,207 | 0 | 50,803 | 0 | 0 | 515,962 |
| | Total | 34,162 | 0 | 633,721 | 0 | 75,320 | 0 | 0 | 743,203 |
| 2002 | Total harvest | 1,306 | 0 | 121,700 | 0 | 7,574 | 0 | 0 | 130,579 |
| | Total escapement | 3,945 | 0 | 448,080 | 0 | 48,461 | 0 | 0 | 500,485 |
| | Total | 5,250 | 0 | 569,779 | 0 | 56,035 | 0 | 0 | 631,064 |
| 2003 | Total harvest | 17,386 | 0 | 280,793 | 0 | 24,980 | 0 | 0 | 323,159 |
| | Total escapement | 123,488 | 0 | 2,057,882 | 0 | 192,629 | 0 | 0 | 2,373,999 |
| | Total | 140,874 | 0 | 2,338,675 | 0 | 217,610 | 0 | 0 | 2,697,158 |
| 2004 | Total harvest | 5,369 | 0 | 434,908 | 0 | 47,835 | 0 | 0 | 488,112 |
| | Total escapement | 38,406 | 0 | 1,096,465 | 0 | 56,606 | 0 | 0 | 1,191,477 |
| | Total | 43,776 | 0 | 1,531,373 | 0 | 104,441 | 0 | 0 | 1,679,589 |
| 2005 | Total harvest | 13,194 | 0 | 150,914 | 0 | 16,628 | 0 | 0 | 180,735 |
| | Total escapement | 25,713 | 0 | 549,218 | 0 | 64,048 | 0 | 0 | 638,978 |
| | Total | 38,906 | 0 | 700,131 | 0 | 80,675 | 0 | 0 | 819,713 |
| 2006 | Total harvest | 32,383 | 0 | 188,785 | 0 | 8,727 | 0 | 0 | 229,896 |
| | Total escapement | 45,782 | 0 | 401,267 | 0 | 16,371 | 0 | 0 | 463,420 |
| | Total | 78,165 | 0 | 590,053 | 0 | 25,098 | 0 | 0 | 693,316 |
| 2007 | Total harvest | 9,022 | 0 | 163,300 | 0 | 8,120 | 0 | 0 | 180,442 |
| | Total escapement | 28,379 | 0 | 544,630 | 0 | 24,033 | 0 | 0 | 597,042 |
| | Total | 37,402 | 0 | 707,930 | 0 | 32,153 | 0 | 0 | 777,484 |
| 2008 | Total harvest | 11,117 | 0 | 155,446 | 0 | 31,764 | 0 | 0 | 198,327 |
| | Total escapement | 31,480 | 0 | 770,353 | 0 | 129,997 | 0 | 0 | 931,829 |
| | Total | 42,598 | 0 | 925,798 | 0 | 161,761 | 0 | 0 | 1,130,157 |
| 2009 | Total harvest | 7,026 | 0 | 122,818 | 0 | 10,539 | 0 | 0 | 140,383 |
| | Total escapement | 18,299 | 0 | 524,804 | 0 | 40,041 | 0 | 0 | 583,144 |
| | Total | 25,325 | 0 | 647,622 | 0 | 50,580 | 0 | 0 | 723,528 |

-continued-

Table 3.–Page 2 of 2.

| Run year | | Age class 1.1 | 1.2 | 2.1 | 2.2 | 3.1 | 3.2 | 4.1 | Total |
|---|---|---|---|---|---|---|---|---|---|
| 2010 | Total harvest | 7,152 | 0 | 82,761 | 0 | 2,972 | 0 | 0 | 92,886 |
| | Total escapement | 15,961 | 0 | 351,775 | 0 | 25,447 | 0 | 0 | 393,183 |
| | Total | 23,113 | 0 | 434,536 | 0 | 28,419 | 0 | 0 | 486,069 |
| 2011 | Total harvest | 16,083 | 0 | 84,461 | 0 | 5,858 | 0 | 0 | 106,401 |
| | Total escapement | 62,219 | 0 | 932,769 | 0 | 67,638 | 422 | 0 | 1,063,047 |
| | Total | 78,301 | 0 | 1,017,230 | 0 | 73,496 | 422 | 0 | 1,169,449 |
| 2012 | Total harvest | 18,316 | 0 | 91,347 | 0 | 6,260 | 0 | 0 | 115,923 |
| | Total escapement | 47,476 | 0 | 356,260 | 0 | 39,482 | 0 | 185 | 443,403 |
| | Total | 65,791 | 0 | 447,607 | 0 | 45,742 | 0 | 185 | 559,326 |

Table 4.–Estimated brood table for coho salmon returning to the Kuskokwim River, Alaska.

| Brood year | Escapement | Age class 1.1 | 1.2 | 2.1 | 2.2 | 3.1 | 3.2 | 4.1 | Recruits | Recruits per spawner |
|---|---|---|---|---|---|---|---|---|---|---|
| 1994 | | | | | | | 0 | 0 | | |
| 1995 | | | | | 0 | 13,971 | 0 | 0 | | |
| 1996 | | | 0 | 834,971 | 0 | 75,320 | 0 | 0 | | |
| 1997 | | 26,504 | 0 | 633,721 | 0 | 56,035 | 0 | 0 | 716,260 | |
| 1998 | | 34,162 | 0 | 569,779 | 0 | 217,610 | 0 | 0 | 821,551 | |
| 1999 | | 5,250 | 0 | 2,338,675 | 0 | 104,441 | 0 | 0 | 2,448,366 | |
| 2000 | 567,210 | 140,874 | 0 | 1,531,373 | 0 | 80,675 | 0 | 0 | 1,752,922 | 3.09 |
| 2001 | 515,962 | 43,776 | 0 | 700,131 | 0 | 25,098 | 0 | 0 | 769,005 | 1.49 |
| 2002 | 500,566 | 38,906 | 0 | 590,053 | 0 | 32,153 | 0 | 0 | 661,112 | 1.32 |
| 2003 | 2,375,943 | 78,165 | 0 | 707,930 | 0 | 161,761 | 0 | 0 | 947,855 | 0.40 |
| 2004 | 1,191,700 | 37,402 | 0 | 925,798 | 0 | 50,580 | 0 | 0 | 1,013,780 | 0.85 |
| 2005 | 639,004 | 42,598 | 0 | 647,622 | 0 | 28,419 | 422 | 0 | 719,061 | 1.13 |
| 2006 | 464,617 | 25,325 | 0 | 448,409 | 0 | 73,496 | 0 | 185 | 547,416 | 1.18 |
| 2007 | 597,110 | 23,113 | 0 | 1,018,522 | 0 | 45,742 | 0 [a] | 0 [a] | 1,087,377 | 1.82 |
| 2008 | 931,753 | 78,301 | 0 | 447606.9 | | | | | | |
| 2009 | 583,283 | 65,791 | | | | | | | | |
| 2010 | 407,065 | | | | | | | | | |
| 2011 | 1,064,277 | | | | | | | | | |
| 2012 | 443,296 | | | | | | | | | |

[a] Data incomplete for this age class and return was estimated to be zero.

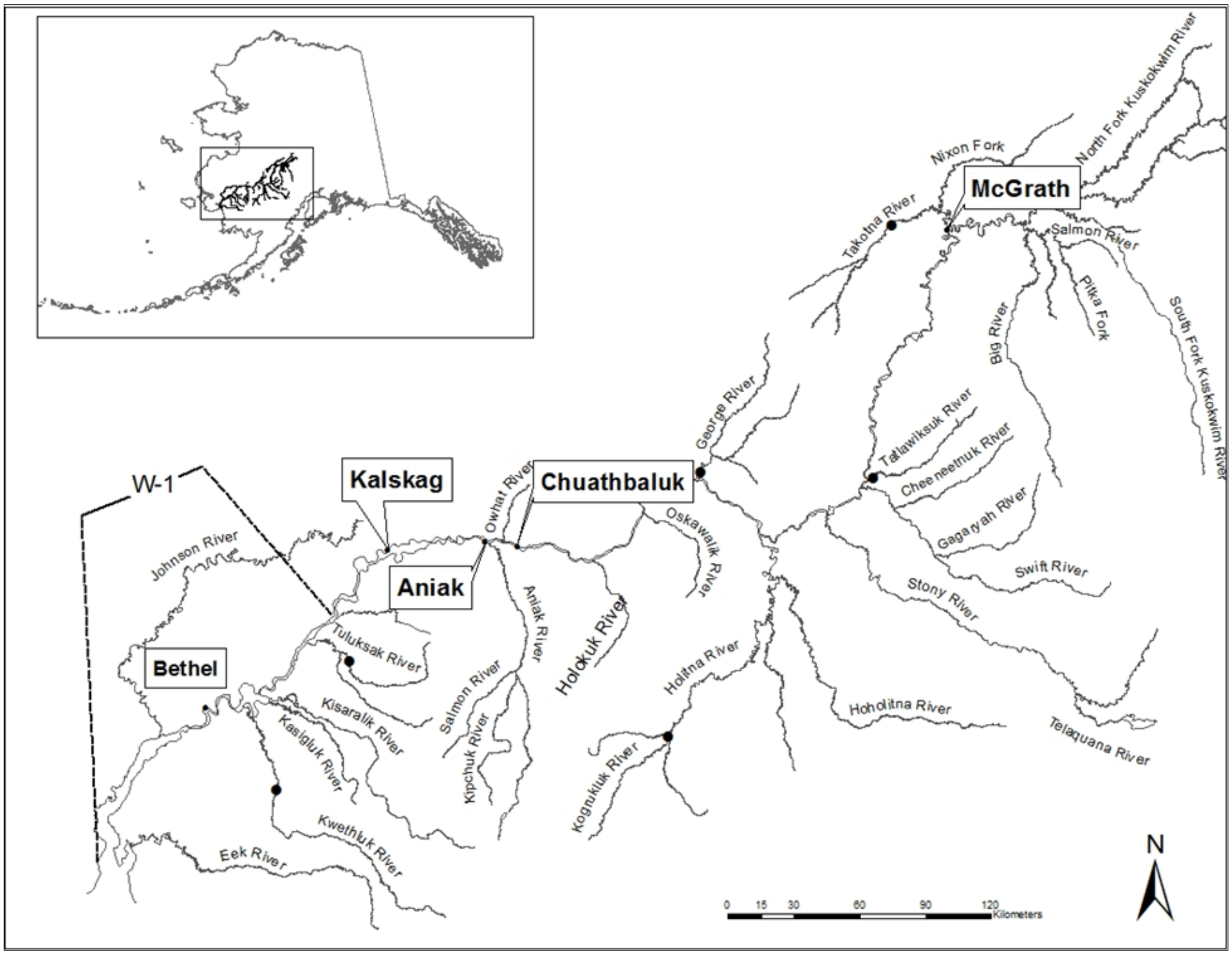


Figure 1.–Map of the study area from which data were obtained for the Kuskokwim River coho salmon run reconstruction project.

*Note*: Black dots show the location of the enumeration weirs; the bracket indicates the location of the W1 commercial fishing district.

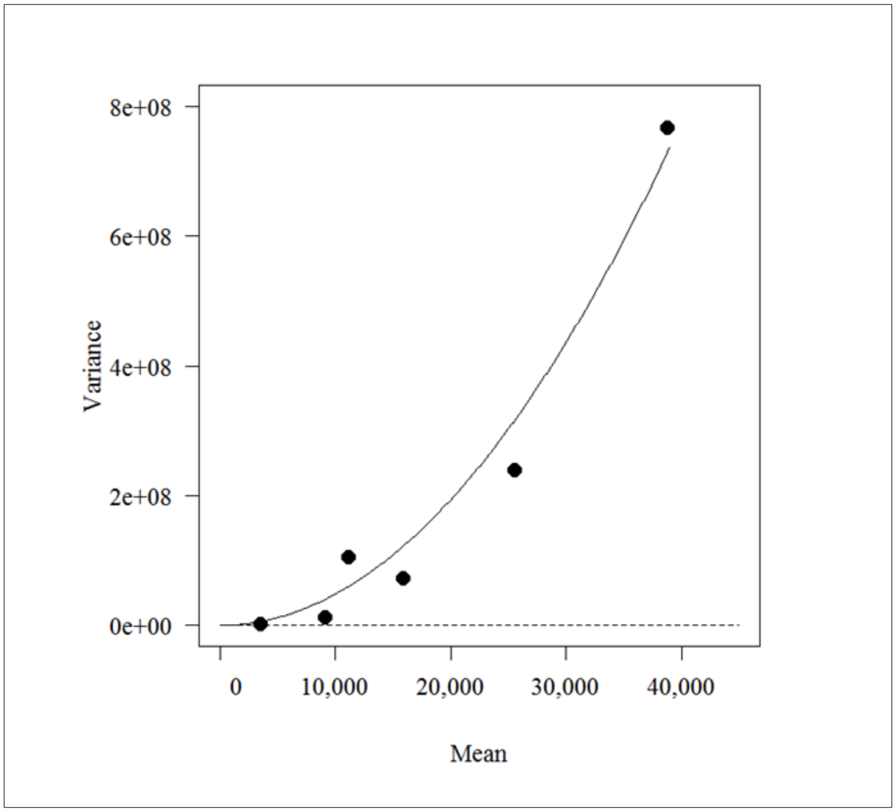


Figure 2.–Comparision of the mean and variance estimates for weir projects in the Kuskokwim River drainage.

*Note*: The dashed line shows where the mean and variances(var{Y}) are equal for these projects. The solid line is the least square of var $\{Y\}=\mu+0.48\mu^2$.

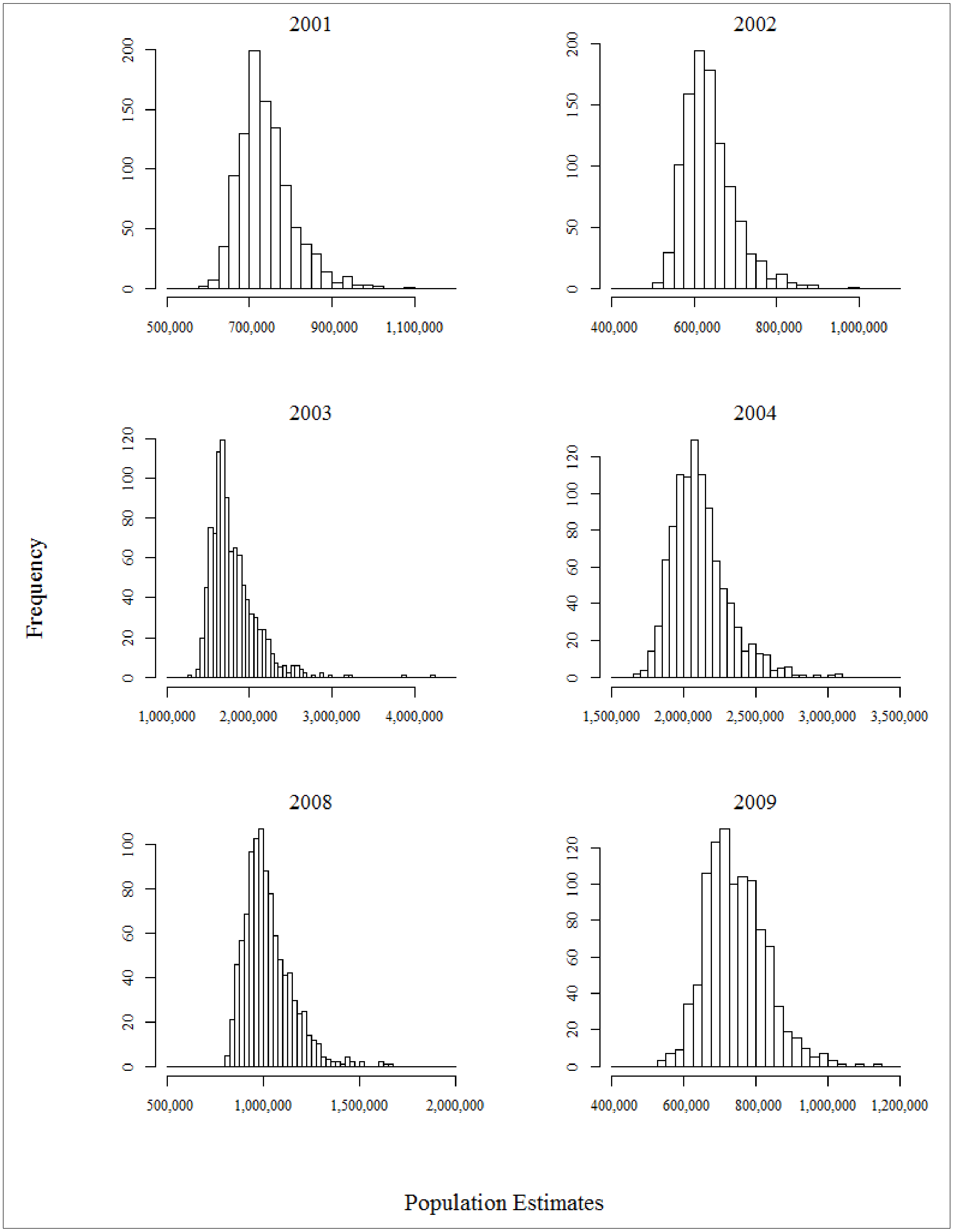


Figure 3.–Frequency distribution of bootstrap estimates of the total inriver population of coho salmon returning to the Kuskokwim River.

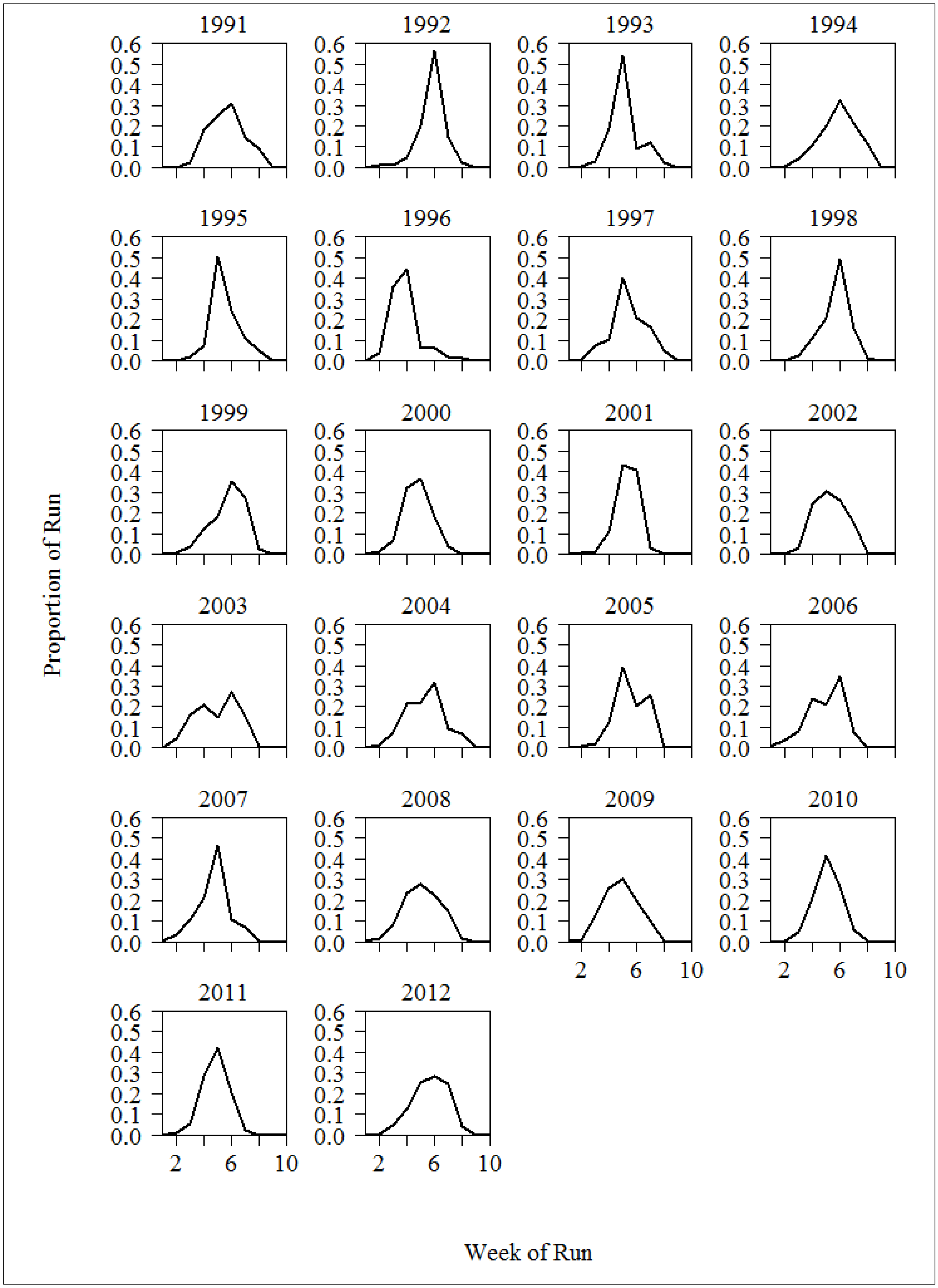


Figure 4.–Run timing of coho salmon in the W1 commercial fishing district of the Kuskokwim River, Alaska, as estimated by the Bethel test fishery from 1991 through 2012.

*Note*: Week 1 begins July 17 of each year.

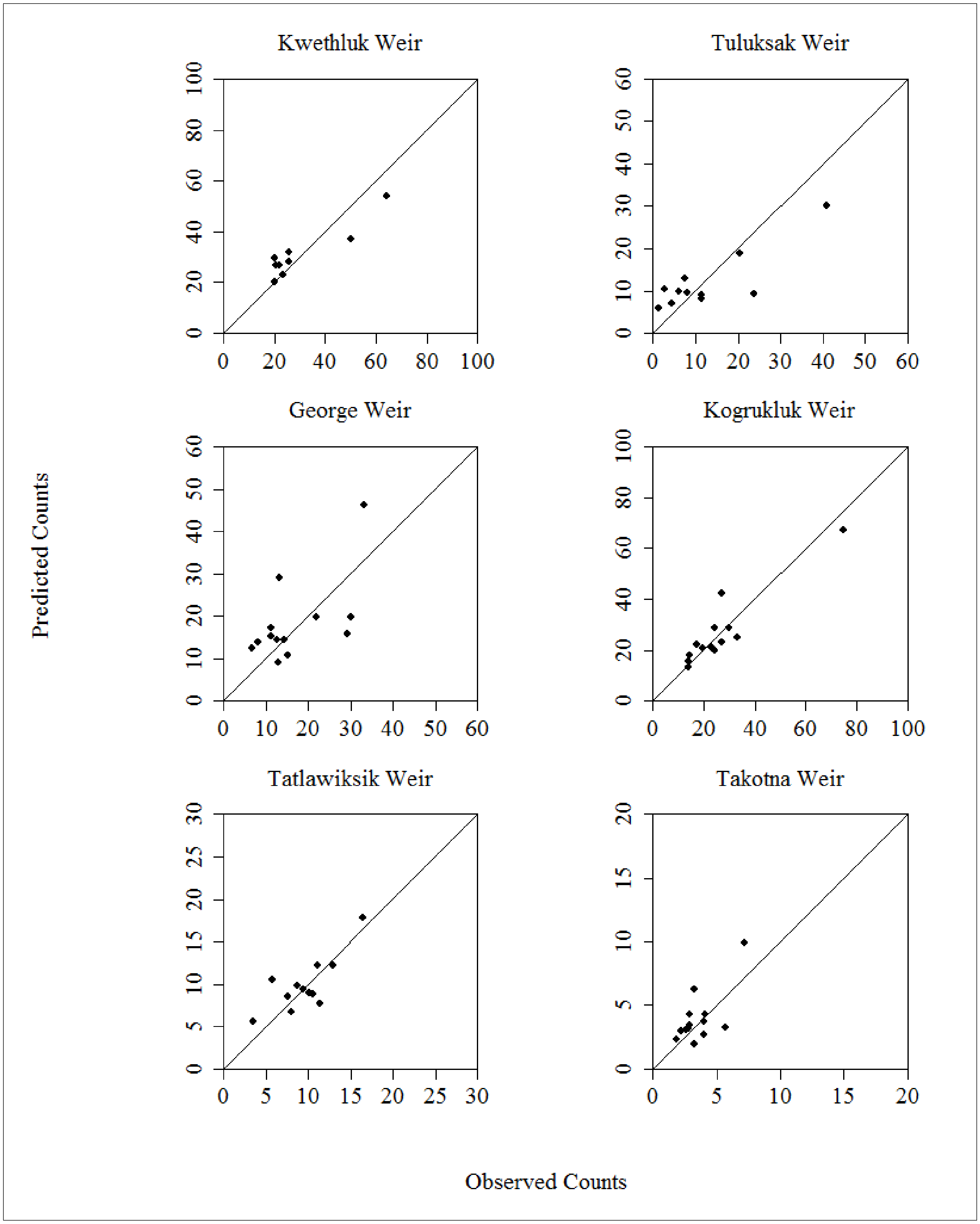


Figure 5.–Comparison of the estimated weir count obtained from the run reconstruction model to actual weir counts obtained from the individual weir projects for coho salmon returning to the Kuskokwim River.

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

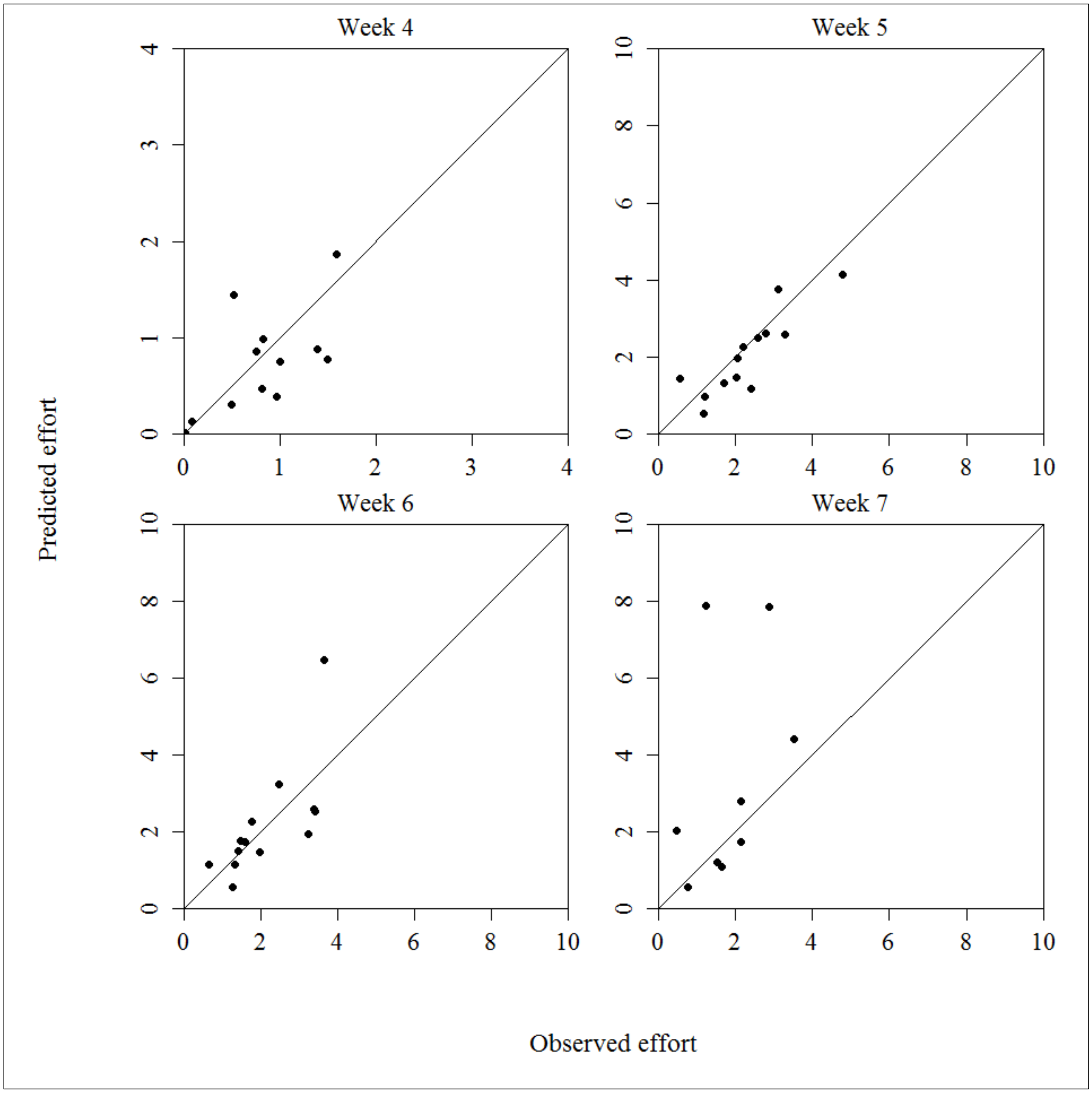


Figure 6.–Comparison of the estimates of fishing effort obtained from the run reconstruction model to the observed fishing effort used to harvest coho salmon in District W1 of the Kuskokwim River.

*Note*: The solid lines are where estimated counts are the same as actual counts. Week 4 begins on August 3 each year.

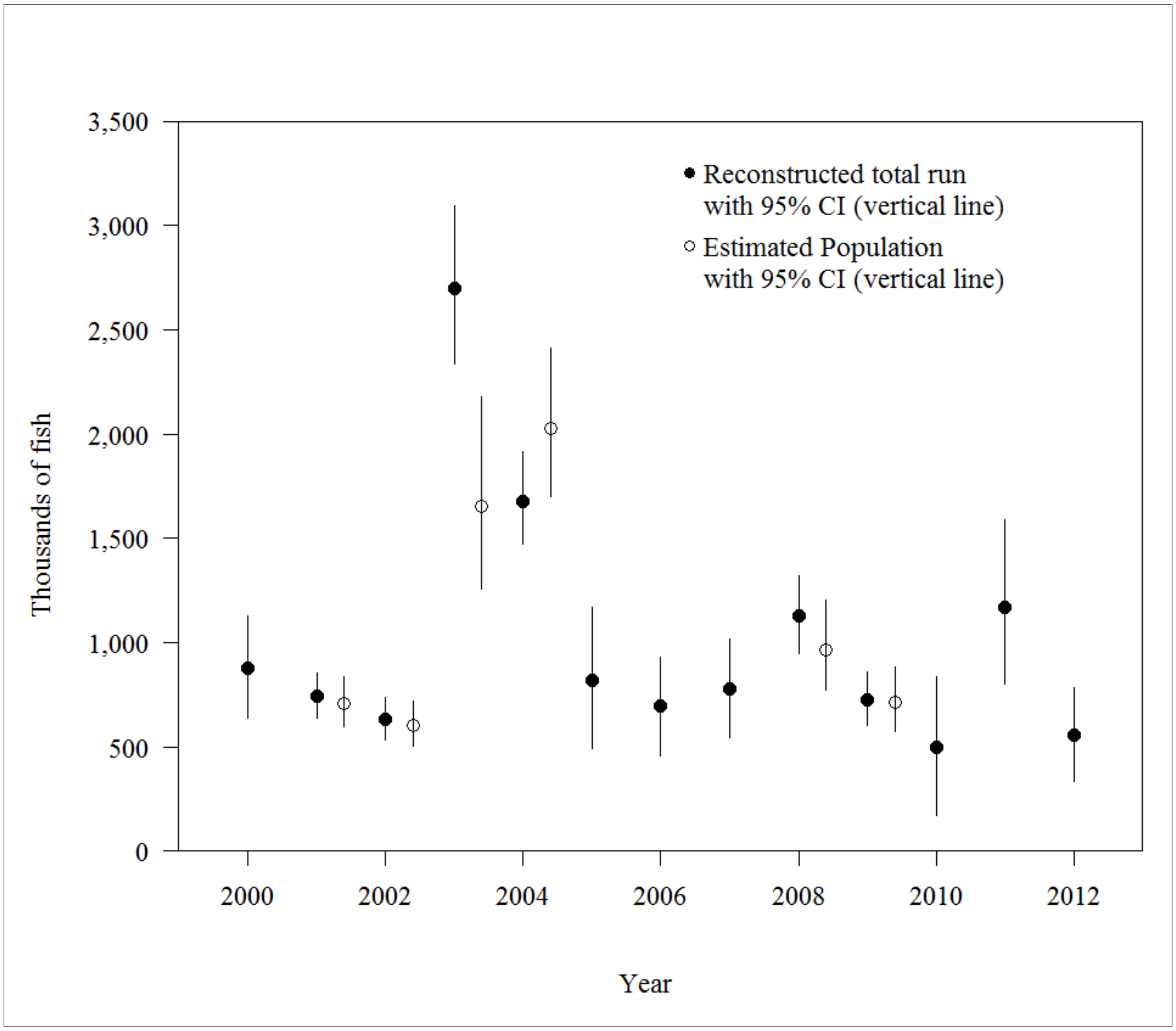


Figure 7.–Estimates of the total run of coho salmon returning to the Kuskokwim River, Alaska, obtained from the run reconstruction model (black dots) and the estimates of total run from Liller et al. (2014; hollow dots).

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

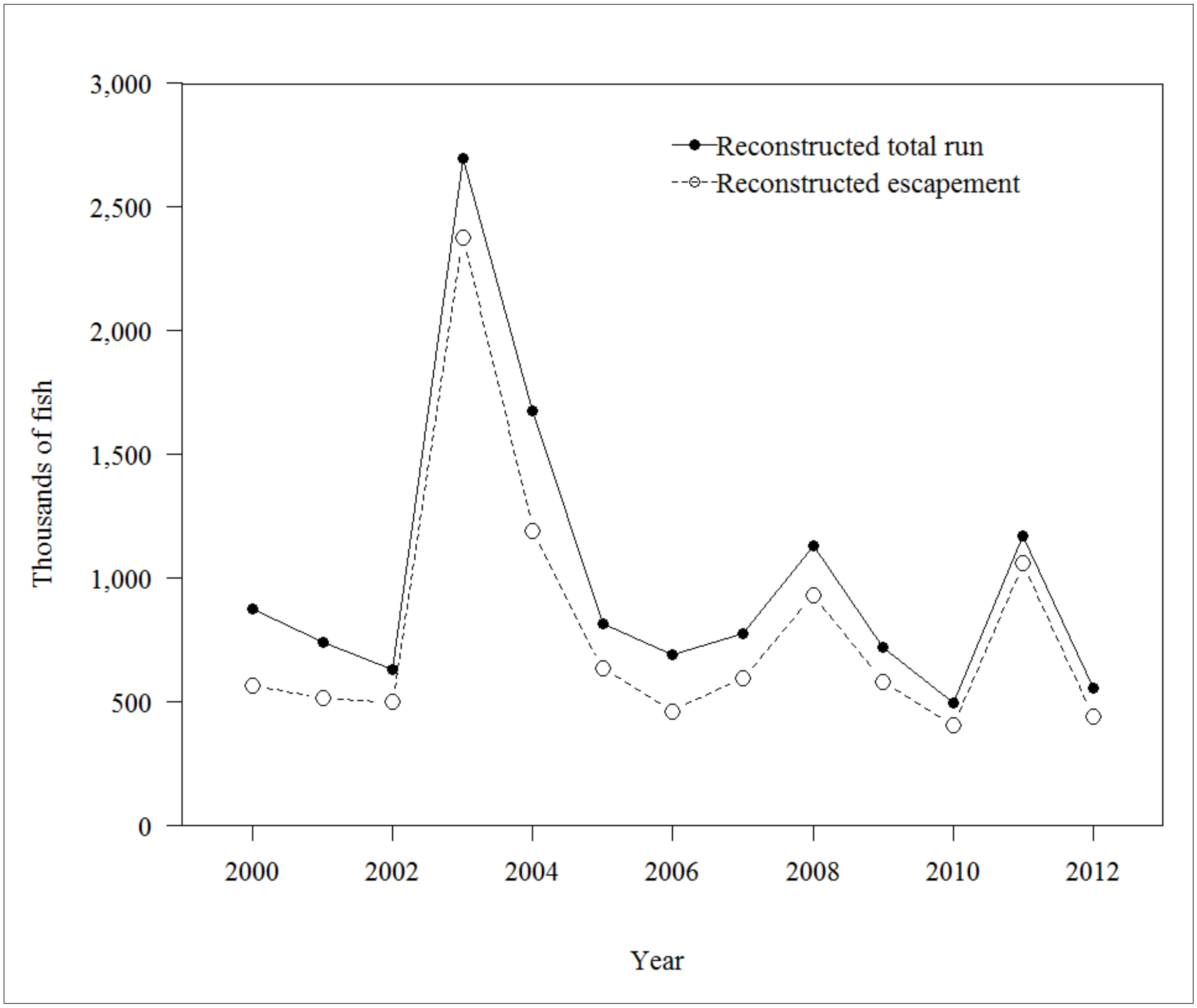


Figure 8.–Estimates of the total run and escapement of coho salmon returning to the Kuskokwim River, Alaska, from 2000 through 2012, obtained from the run reconstruction model.

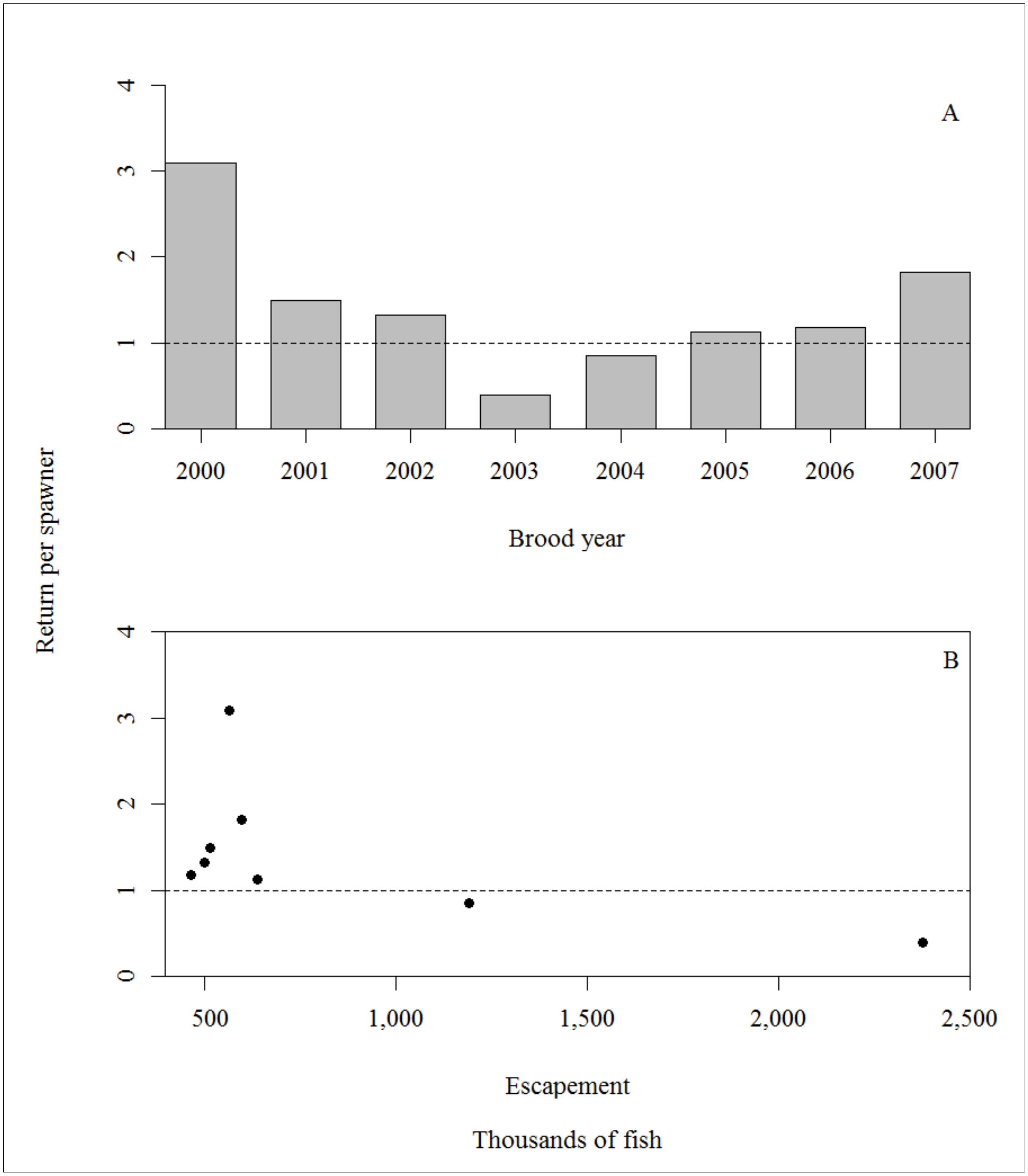


Figure 9.–Return per spawner by year (A) and level of escapement (B) for the coho salmon population returning to the Kuskokwim River, Alaska.

*Note*: The horizontal dashed line is 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.

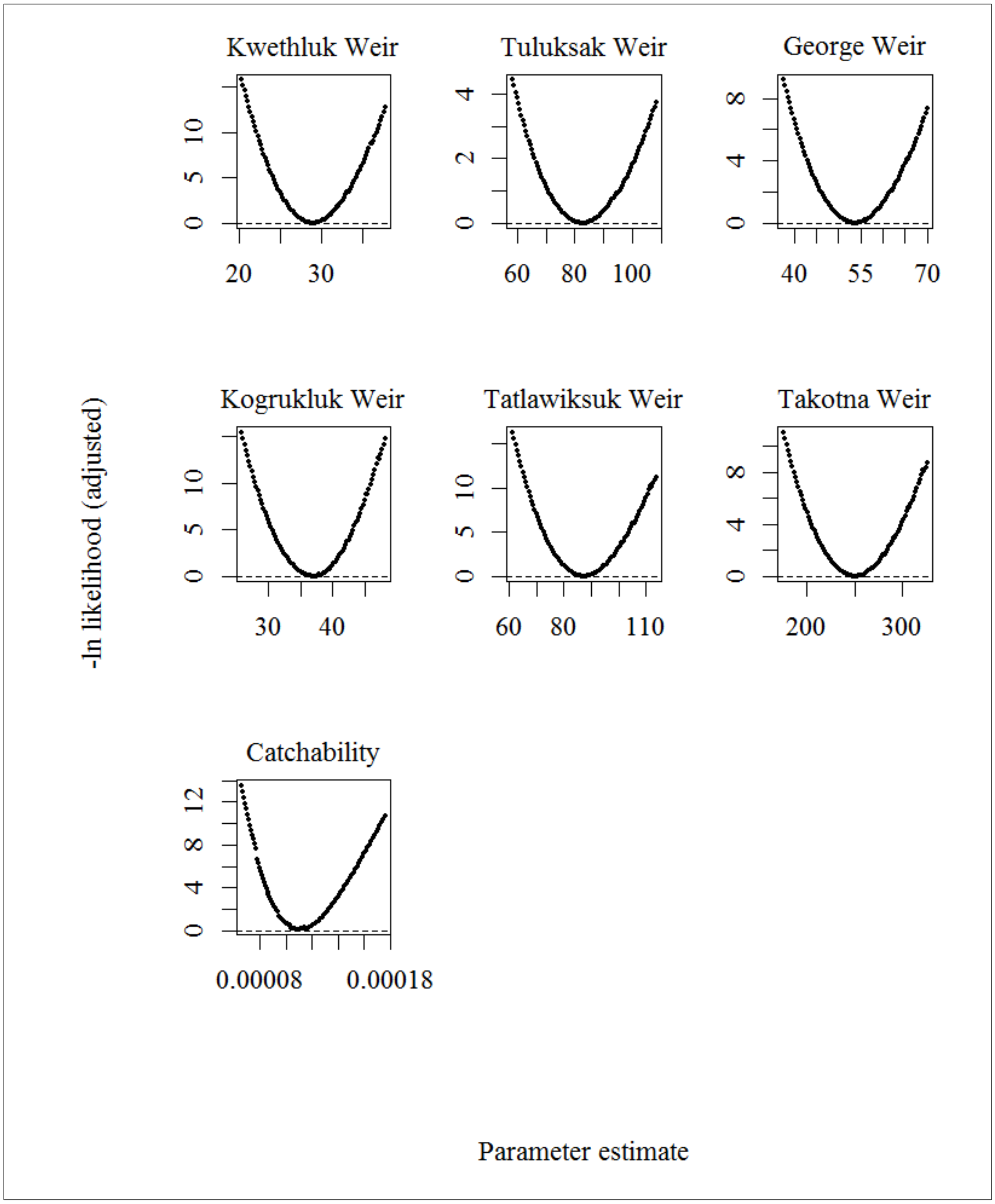


Figure 10.–Negative log likelihood profiles for the escapement scaling factors ($\hat{k}_i$) and the catchability coefficient ($\hat{q}$) used to expand total weir counts and catch effort data.

*Note*: The negative log likelihood scale was adjusted such that the minimum value was zero. 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° of freedom. The chi-square value for 95.45% and 1° 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.

# APPENDIX A: MODEL INPUT AND SOURCE DATA

Appendix A1.–Total inriver abundance of coho salmon in the Kuskokwim River 2001–2005, 2008, and 2009.

| | Year | | | | | | |
|---|---|---|---|---|---|---|---|
| Component | 2001 | 2002 | 2003 | 2004 | 2005 | 2008 | 2009 |
| Abundance upstream of Birch Tree Crossing | 344,146 | 354,049 | 758,092 | 1,207,446 | 462,273 | 532,769 | 464,388 |
| Escapement downstream of Birch Tree Crossing | 140,871 | 128,464 | 576,883 | 331,848 | – | 241,805 | 115,582 |
| Lower Kuskokwim River harvest | | | | | | | |
| Subsistence [a] | 25,354 | 32,924 | 29,298 | 42,616 | 27,432 | 38,746 | 24,046 |
| Commercial [b] | 192,998 | 83,463 | 284,064 | 435,407 | 142,319 | 142,862 | 104,546 |
| Bethel test fish [c] | 1,723 | 2,484 | 2,377 | 2,259 | 1,499 | 2,984 | 2,394 |
| Sport [d] | 1,204 | 2,030 | 3,459 | 4,996 | 3,539 | 3,893 | 3,526 |
| Total harvest | 221,279 | 120,901 | 319,198 | 485,278 | 174,789 | 188,485 | 134,512 |
| Total Inriver abundance | 706,296 | 603,414 | 1,654,173 | 2,024,571 | – | 963,058 | 714,481 |
| Lower 95% CI | 642,493 | 546,298 | 1,449,026 | 1,811,785 | – | 848,856 | 605,985 |
| Upper 95% CI | 896,892 | 785,349 | 2,500,529 | 2,581,274 | – | 1,299,578 | 927,998 |
| CV% | 9% | 10% | 17% | 10% | – | 13% | 12% |

*Note*: Abundance was estimated by combining harvest estimates and estimates derived from mark–recapture and habitat model techniques. From Liller et al. 2014

[a] Subsistence harvest includes all villages from Kalskag downstream to the mouth of the Kuskokwim River, plus north Kuskokwim Bay village of Kongiganak. Data from Hamazaki 2011.

[b] Commercial and Bethel test fish harvest data from Bavilla et al. (2010).

[c] Bethel test fish harvest from annual test fish files maintained by ADF&G. Harvest numbers presented do not match Bavilla et al. (2010) for 2003, 2008, or 2009.

[d] Sport harvest from John Chythlook, Kuskokwim Area Sport Fish Manager, personal communication.

Appendix A2.–Harvests and escapements of coho salmon returning to the Kuskokwim River, Alaska, 1981 to 2012.

| | Harvest | | | | Weir | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Commercial | Subsistence | Sport | Test fish | Kwethluk | Tuluksak | George | Kogrukluk | Tatlawiksuk | Takotna |
| 1981 | 211,251 | | | | | | | 11,455 | | |
| 1982 | 447,117 | | | | | | | 37,796 | | |
| 1983 | 196,287 | | 1,375 | | | | | 8,538 | | |
| 1984 | 623,447 | | 1,442 | | | | | 27,595 | | |
| 1985 | 335,606 | | 136 | | | | | 16,441 | | |
| 1986 | 659,988 | | 1,222 | 280 | | | | 22,506 | | |
| 1987 | 399,467 | | 1,767 | 586 | | | | 22,821 | | |
| 1988 | 524,296 | | 927 | 1,206 | | | | 13,512 | | |
| 1989 | 479,856 | 52,917 | 2,459 | 1,901 | | | | | | |
| 1990 | 410,332 | 57,560 | 581 | 1,279 | | | | 6,132 | | |
| 1991 | 500,935 | 39,252 | 1,003 | 1,188 | | 4,651 | | 9,964 | | |
| 1992 | 666,170 | 52,299 | 1,692 | 10,109 | 45,605 | 7,501 | | | | |
| 1993 | 610,739 | 28,485 | 980 | 8,084 | | 8,328 | | | | |
| 1994 | 724,689 | 36,609 | 1,925 | 7,830 | | 7,952 | | 35,050 | | |
| 1995 | 471,461 | 36,823 | 1,497 | 6,620 | | | | | | |
| 1996 | 937,299 | 43,173 | 3,423 | 3,013 | | | | 50,555 | | |
| 1997 | 130,803 | 29,816 | 2,408 | 1,103 | | | 9,211 | 12,238 | | |
| 1998 | 210,481 | 24,667 | 2,419 | 607 | | | | 24,346 | | |
| 1999 | 23,593 | 27,409 | 1,998 | 343 | | | 8,930 | 12,609 | 3,449 | |
| 2000 | 261,379 | 42,341 | 1,689 | 2,828 | 25,610 | | 11,262 | 33,135 | 5,756 | 3,944 |
| 2001 | 192,998 | 31,089 | 1,204 | 1,723 | 20,725 | 23,768 | 14,415 | 19,387 | 10,540 | 2,606 |
| 2002 | 83,463 | 42,602 | 2,030 | 2,484 | 23,298 | 11,487 | 6,759 | 14,518 | 11,363 | 3,982 |
| 2003 | 284,064 | 33,259 | 3,459 | 2,377 | 109,163 | 41,071 | 33,281 | 74,605 | | 7,146 |
| 2004 | 435,407 | 45,450 | 4,996 | 2,259 | 64,216 | 20,336 | 13,248 | 27,042 | 16,410 | 3,201 |
| 2005 | 142,319 | 33,378 | 3,539 | 1,499 | | 11,324 | 8,200 | 24,115 | 7,560 | 2,209 |
| 2006 | 185,598 | 41,408 | 1,474 | 1,186 | 25,664 | 6,111 | 11,294 | 17,011 | 9,451 | 5,655 |
| 2007 | 141,049 | 35,332 | 2,504 | 1,557 | 20,256 | 2,807 | 29,317 | 27,034 | 8,686 | 2,836 |
| 2008 | 142,862 | 48,841 | 3,839 | 2,984 | 49,972 | 7,457 | 21,956 | 29,661 | 11,065 | 2,831 |
| 2009 | 104,546 | 30,058 | 3,526 | 2,394 | 21,911 | 8,137 | 12,573 | 22,981 | 10,155 | 2,727 |
| 2010 | 58,031 | 32,106 | 1,729 | 1,020 | | 1,216 | 12,961 | 13,970 | 3,521 | 3,217 |
| 2011 | 74,108 | 29,500 | 1,693 | 1,207 | | | 30,028 | 24,174 | 12,927 | 4,062 |
| 2012 | 86,389 | 25,400 | 2,879 | 1,255 | 19,960 | 4,407 | 15,272 | 13,697 | 8,070 | 1,838 |

*Note*: Escapement counts at weirs presented here may differ from other published counts because we included fish monitored outside the designated operational period at these projects. Projects only include those operated for over 10 years. The dashed line is meant to show the data set available prior to 2000 that was lacking escapement data adequate to represent the total escapement.

Appendix A3.–Harvest and effort data for coho salmon in commercial fishing District W1 by week and year, Kuskokwim River, Alaska.

| | Week 1 7/13–7/19 | | Week 2 7/20–7/26 | | Week 3 7/27–8/2 | | Week 4 8/3–8/9 | | Week 5 8/10–8/16 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Catch | Effort | Catch | Effort | Catch | Effort | Catch | Effort | Catch | Effort |
| 2000 | – | – | – | – | 25,642 | 1,488 | 129,992 | 4,776 | 54,217 | 2,478 |
| 2001 | – | – | – | – | – | – | 83,632 | 2,580 | 80,183 | 3,398 |
| 2002 | – | – | – | – | 2,492 | 80 | 47,803 | 2,206 | 33,168 | 1,470 |
| 2003 | – | – | – | – | 17,424 | 494 | 72,503 | 2,050 | 102,638 | 1,976 |
| 2004 | – | – | – | – | 31,733 | 1,386 | 118,981 | 3,108 | 99,091 | 3,228 |
| 2005 | – | – | – | – | 8,666 | 750 | 75,468 | 3,294 | 27,454 | 1,596 |
| 2006 | – | – | – | – | 10,309 | 810 | 45,847 | 2,772 | 74,269 | 3,378 |
| 2007 | – | – | – | – | 19,133 | 828 | 50,056 | 2,418 | 48,657 | 3,654 |
| 2008 | 14 | 6 | 174 | 12 | 267 | 12 | 47,039 | 2,014 | 54,795 | 1,776 |
| 2009 | 1,363 | 420 | – | – | 31,362 | 516 | 35,935 | 552 | 19,278 | 648 |
| 2010 | 114 | 416 | 5,964 | 1,868 | 8,849 | 1,004 | 21,900 | 1,188 | 21,204 | 1,424 |
| 2011 | 297 | 1,482 | 4,520 | 1,272 | 13,041 | 965 | 26,401 | 1,160 | 13,976 | 1,276 |
| 2012 | 368 | 1,592 | 3,940 | 1,532 | 14,708 | 1,588 | 21,185 | 1,688 | 20,773 | 1,332 |

| | Week 6 8/17–8/23 | | Week 7 8/24–8/30 | | Week 8 8/31–9/6 | | Week 9 9/7–9/11 | |
|---|---|---|---|---|---|---|---|---|
| Year | Catch | Effort | Catch | Effort | Catch | Effort | Catch | Effort |
| 2000 | 45,679 | 4,158 | 4,191 | 636 | – | – | – | – |
| 2001 | 24,653 | 3,342 | 4,530 | 708 | – | – | – | – |
| 2002 | – | – | – | – | – | – | – | – |
| 2003 | 44,657 | 1,655 | 36,975 | 2,286 | 9,636 | 888 | – | – |
| 2004 | 57,175 | 3,532 | 87,428 | 4,968 | 34,955 | 2,400 | 6,025 | 480 |
| 2005 | 12,049 | 768 | 13,708 | 1,254 | 4,974 | 768 | – | – |
| 2006 | 37,970 | 2,862 | 17,203 | 2,142 | – | – | – | – |
| 2007 | 16,944 | 2,136 | 6,259 | 774 | – | – | – | – |
| 2008 | 29,767 | 2,148 | 10,806 | 984 | – | – | – | – |
| 2009 | 16,608 | 480 | – | – | – | – | – | – |
| 2010 | – | – | – | – | – | – | – | – |
| 2011 | 15,873 | 1,232 | – | – | – | – | – | – |
| 2012 | 19,332 | 1,518 | 6,083 | 930 | – | – | – | – |

*Note*: Effort is estimated as the number of permits fished times the number of hours the fishery was open.

Appendix A4.–Sources of the age information used to estimate the total run by age of coho salmon returning to the Kuskokwim River, Alaska.

| | Harvest | | | | Escapement | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Commercial [a] | Subsistence | Sport | Test fish | Kwethluk | Tuluksak | George | Kogrukluk | Tatlawiksuk | Takotna |
| 2000 | X | – | – | – | X | | X | X | X | X |
| 2001 | X | – | – | – | X | X | X | X | X | X |
| 2002 | X | – | – | – | X | X | X [c] | X | X | X |
| 2003 | [b] | – | – | – | X | X | X | X | | X |
| 2004 | X | – | – | – | X | X | X | X | X | X |
| 2005 | X | – | – | – | | X | X | X | X | X |
| 2006 | X | – | – | – | X | X | X | X | X [c] | X |
| 2007 | X | – | – | – | X | X | X | X | X | X |
| 2008 | X | – | – | – | X | X | X | X | X | X |
| 2009 | X | – | – | – | X | X | X | X | X | X |
| 2010 | X | – | – | – | X [c,d] | | X | X | X | X |
| 2011 | X | – | – | – | X | | X | X | X | X |
| 2012 | X | – | – | – | X [c,d] | X | X | X [d] | X | X |

*Note*: Unless otherwise noted, age composition was estimated using a minimum of 200 samples collected throughout the annual escapement.

[a] Age data collected from commercial harvest was used to represent total harvest.

[b] Age data not collected. Age composition estimated using the average of the 5 years before and after.

[c] Age composition based on fewer than 200 samples.

[d] Weir did not operate through the coho salmon counting season.