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A SYNOPSIS AND CRITIQUE OF FORECASTS OF SOCKEYE SALMON RETURNING TO BRISTOL BAY, ALASKA, IN 1991

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ABSTRACT

The total number of sockeye salmon (*Oncorhynchus nerka*) forecasted to return to Bristol Bay in 1991 is 31,866,000 (80% confidence interval: 2,168,000 - 61,564,000). Runs are expected to exceed spawning escapement goals for all systems. Total projected sockeye salmon harvest is expected to be 23,131,000. Most of this harvest will be taken within Bristol Bay inshore fishing districts (21,211,000), but some has been allocated to fisheries occurring in June in the vicinity of the Shumagin Islands and South Unimak under an existing management plan (8.3% of total Bristol Bay projected harvest: 1,920,000). The 1991 forecast was based on the ADF&G method which averaged results from three linear regression models based on the relationship between returns and either spawner, sibling, or smolt data. Based on performance evaluations of the ADF&G method, all available data was used to forecast 1991 runs to Nushagak and Togiak Districts, but data prior to the 1978 return year were omitted from calculations for Naknek-Kvichak, Egegik and Ugashik Districts. To further correct under-forecasting errors, predictions for east-side Bristol Bay systems (Kvichak, Branch, Naknek, Egegik, and Ugashik Rivers) were adjusted by the 1984-90 average percent forecast error (30.38%). Although out of range data were not used in calculations, their occurrence suggested that age-1.2 predictions for Egegik River and age-1.3 predictions for Egegik and Ugashik Rivers could be too low. The outlook for 1991-1994, based only on the spawner-recruit component of the ADF&G method which was not adjusted for the average historic forecast error, is for the total sockeye salmon run to Bristol Bay to be greatest in 1994 and least in 1991, mostly due to variations in the Kvichak River run. For all years examined, runs to all river systems are expected to exceed spawning goal requirements.

KEY WORDS: Salmon forecast, sockeye salmon, *Oncorhynchus nerka*, Bristol Bay, spawner-recruit, environmental indicators

INTRODUCTION

Preseason forecasts of sockeye salmon (*Oncorhynchus nerka*) runs to Bristol Bay, Alaska, have been made by the Alaska Department of Fish and Game (ADF&G) since 1961 (ADF&G 1961). ADF&G biologists use forecasts to estimate commercial harvests; to set quotas for the Shumagin Islands-South Unimak June fishery; and to determine which stocks might be in low abundance and need protection against possible overharvesting. Seafood buyers and processors use forecasts to estimate the supply of raw fish which will be available for various uses; to determine staff and equipment needed for production of fresh, frozen, and canned products; and to plan deployment of tenders and processing vessels. Commercial fishermen use forecasts to decide which areas might provide them with the best fishing opportunities and to assist in decisions involving future investments for equipment and gear.

Until 1983, annual preseason forecasts made by ADF&G were usually calculated as the mean of estimates obtained from models using either spawner-recruit, sibling, or smolt data. Forecasts from this method, referred to as the ADF&G method, had a mean absolute percent error (MAPE) of 37.0 for 1961-1982 (MAPE range: 2.7 - 78.0) (Fried and Yuen 1987; Fried et al. 1988). Beginning in 1983 attempts were made to improve forecast accuracy by combining results from the ADF&G method with those from other methods (Eggers et al. 1983a, 1983b; Fried and Yuen 1985, 1986, and 1987). However, these forecasts did not prove to be any more accurate than forecasts based solely on the ADF&G method and did not correct the tendency of published forecasts to under-estimate total run size for 15 of the last 17 years (Fried et al. 1988) (Appendix A.1).

In an attempt to remedy these problems, the methods used to calculate run size predictions were again modified in 1988 (Fried et al. 1988; Fried and Cross 1988, 1990). The most important change was the omission of data prior to the 1978 return year from all calculations. We felt that models based on more recent data would more accurately reflect current trends in sockeye salmon production. Most Bristol Bay river systems have shown a dramatic increase in the number of returning sockeye salmon adults produced by each spawner since 1978, coincident with: (1) decreased interception of maturing sockeye salmon on the high seas, (2) the onset of more favorable climatic conditions, and (3) improvements in ADF&G's ability to determine and attain spawning escapement goals for most major Bristol Bay systems (Eggers et al. 1984).

Although forecasts based on only recent data decreased under-forecasting errors for river systems on the east side of Bristol Bay, there was still a tendency to under-forecast the run (five out of the last seven years). In 1991 we sought to further adjust the forecast to correct this continuing bias of under-forecasting. Several bias correction factors were evaluated in search of the most accurate forecast. Our goal was an unbiased forecast resulting in no tendency to over- or under-forecast.

The purpose of this report is to provide a final preseason forecast of sockeye salmon returning to Bristol Bay, Alaska, in 1991 with an outlook of abundance fluctuations through 1994. Specific objectives are: 1) to document changes in the methods used to forecast sockeye salmon runs to Bristol Bay in 1991, 2) to judge the relative accuracy of different forecasting methods, 3) to forecast annual runs for all major river systems through 1994, and (4) to indicate where actual runs are most likely to depart from preseason expectations.

METHODS

Age Designation

Sockeye salmon ages were expressed according to European system designations (Koo 1962), wherein the number of annuli formed in fresh and salt water are indicated to the left and right of a decimal point. Four age classes account for about 98% of total returns: age-1.2 (28%), -2.2 (31%), -1.3 (28%), and -2.3 (11%). These four age classes are equivalent to the following Gilbert and Rich (1927) designations: 4_2, 5_3, 5_2, and 6_3, which are dated from the time of egg deposition and show both total age (first digit) as well as the year of life in which seaward migration occurred (subscript).

Smolt ages were expressed as either age 1. or 2., corresponding to sockeye salmon that migrated seaward in either their second or third year of life.

Forecast Data Base and Techniques

The ADF&G method forecast has been used to predict the number of sockeye salmon, by major age class, returning to nine river systems that account for about 98% of Bristol Bay sockeye salmon production, these are: Kvichak, Branch, Naknek, Egegik, Ugashik, Wood, Igushik, Nuyakuk, and Togiak Rivers (Figure 1). Forecasts for each system and age class have been calculated by averaging results of several models which used either (1) spawner-recruit, (2) sibling, or (3) smolt data. Prior to 1986, predictions for each data component were calculated by averaging results from two or more models (e.g. linear regression, ratio estimator, mean proportion) (Eggers et al. 1983a, 1983b). Beginning in 1986 only results from a single model per component (spawner-recruit, sibling, or smolt) were calculated and then averaged for the forecast (Fried and Yuen 1986 and 1987).

Forecasts for 1991 were first calculated using all available data (referred to as the All Data ADF&G method) and then recalculated with all data prior to the 1978 return year excluded from calculations (referred to as the Recent Data ADF&G method).

Predicted returns from spawner-recruit data were based on a linear form of the Ricker (1954) curve constructed for age-specific returns (Brannian et al. 1982):

$$\ln\left(\frac{R_{a,r,y}}{E_{r,y}}\right) = \ln(\alpha) + \beta E_{r,y} + \epsilon \quad (1)$$

where:

$R_{a,r,y}$ = number of age-*a* sockeye salmon returning to river system *r* from brood year *y*,

$E_{r,y}$ = total number of spawners in river system *r* during brood year *y*,

α, β = regression coefficients estimated by least square methods; and

ϵ = random error with mean, 0, and variance s^2.

In cases where the Ricker relationship was not significant at the 25% level (F-test, Ho: ß = 0, P>0.25; Snedecor and Cochran 1969), a linear regression model based on natural logarithm transformed data was used:

$$\ln(R_{a,r,y}) = \alpha + \beta \ln(E_{r,y}) + \epsilon \quad (2)$$

Predicted returns from sibling (younger age classes from the same brood year) and smolt data were also based upon linear regression models using natural logarithm transformed data, as suggested by Peterman (1982a, 1982b):

$$\ln(R_{a,r,y}) = \alpha + \beta \ln(S_{j,r,y}) + \epsilon \quad (3)$$

where:

$S_{j,r,y}$ = either the number of age-*j* smolt (where j = age 1. or 2.) migrating from river system *r* which were progeny of brood year *y*, or the number of age-*j* adults (where j =[a-1]) returning to river system *r* from spawning in brood year *y*.

Smolt data were available for five of the nine river systems for which forecasts were made. Smolt enumeration programs using sonar equipment were begun in 1971 for Kvichak (Russell 1972), 1975 for Wood (Krasnowski 1976), 1982 for Egegik (Bue 1984), and 1983 for Ugashik (Fried et al. 1987) and Nuyakuk (Minard and Frederickson 1987) River systems.

Results from models were excluded from final forecast calculations if the fit of the model was not significant at the 25% level (P>0.25) or the value of the input variable ($E_{r,y}$ or $S_{j,r,y}$) was outside the range of data used to build the model. If results from spawner-recruit, sibling or smolt models did not meet these criteria for a river system age class, the mean return of that age class to that river system was used as the prediction. For All Data ADF&G method forecasts, mean returns for all past years (1956-1990) were used. For Recent Data ADF&G method forecasts, mean returns for the past 13 years, 1978-1990, were used.

Evaluation of Forecast Performance

Comparison of Recent and All Data Forecasts

Since the Recent Data ADF&G method was first used for the 1988 forecast, a hindcasting procedure, in which only data prior to the year of interest were used to build models, was used to simulate its past performance for several past years. Due to the limited amount of data available (i.e. all data prior to the 1978 return year were omitted from analyses), Recent Data ADF&G method hindcasts could be calculated for only seven years, 1984-1990. Hindcasts prior to 1984 could not be calculated because most models were not significant at the 25% level ($P>0.25$) and many of the input data were out of range of values used for models.

Recent Data ADF&G method hindcasts for 1984-1990 were compared with All Data ADF&G method hindcasts for this same period to determine which method could be expected to produce less biased and more accurate forecasts. Three statistics were used for comparisons: percent error (PE), mean percent error (MPE), and mean absolute percent error (MAPE). PE is a measure of annual performance:

$$PE = 100\left(\frac{F_{i,r} - A_{i,r}}{A_{i,r}}\right) \tag{4}$$

where:

$F_{i,r}$ = forecasted total return of sockeye salmon for year i and river system r; and

$A_{i,r}$ = actual total return of sockeye salmon for year i and river system r.

MPE is a measure of bias:

$$MPE = \frac{\sum_{i=1}^{N} 100\left(\frac{F_{i,r} - A_{i,r}}{A_{i,r}}\right)}{N} \tag{5}$$

MAPE is measure of overall accuracy which treats under- and over-forecasting errors similarly:

$$MAPE = \frac{\sum_{i=1}^{N} 100\left(\frac{|F_{i,r} - A_{i,r}|}{A_{i,r}}\right)}{N} \tag{6}$$

Modeling Historic Forecast Errors

In an effort to reduce the tendency to under-forecast runs to Bristol Bay, we looked at ways to model historic forecast errors and develop a bias adjustment factor for the 1991 forecast. We investigated the trends in forecast errors for predictions based on All Data and Recent Data. We compared baywide forecast errors, east side versus west side forecast errors, and individual river system forecast errors.

Predictions based on All Data were hindcasted for the years 1965-90 using the same methods described above for the 1991 forecast. Errors in numbers of fish for the 1965-90 All Data forecasts were modeled using a linear regression model:

$$Y_i = \alpha + \beta i + \epsilon \tag{7}$$

and second-order polynomial regression model:

$$Y_i = \alpha + \beta_1 i + \beta_2 i^2 + \epsilon \tag{8}$$

where:

Y_i = predicted run - actual run for year i,

α,β = regression coefficients estimated by least square methods; and

ϵ = random error with mean, 0, and variance s^2.

Errors for All Data forecasts were also modeled using Box-Jenkins forecasting procedures (Chatfield 1984). Autoregressive integrated moving average (ARIMA) models were fitted to forecast errors in numbers of fish or percent error (PE). The most appropriate model for the data was an AR(1) model and forecast errors were predicted as:

$$PE_i = \alpha + \beta PE_{i-1} \tag{9}$$

where model coefficients (α,β) were estimated using STATGRAPHICS (Statistical Graphics Systems, 1988) computer software.

Predictions based on Recent Data were hindcasted only for the years 1984-90 because of the limited data base (Recent Data include years 1978 through 1990). With only seven years of Recent Data forecast errors available, regression and time series modeling techniques could not be used. Therefore, an adjustment factor for the 1991 forecast was estimated by taking the mean percent error from 1984-90 Recent Data forecasts.

Although forecast errors by river system were analyzed individually, we decided to base the 1991 adjustment factor on models which described forecasts errors for east side systems combined and west side systems combined. Consequently, adjustment factors for the total east side forecast and total west side forecast were estimated. The 1991 final adjustment factor was apportioned to individual river forecasts based on each river's contributions to the total combined forecast.

Confidence Intervals

The 80% confidence interval (80% CI) for the total run forecast was calculated as:

$$80\%\ CI = F \pm t_{0.2} s_f \qquad (10)$$

where:

F = forecasted total run of sockeye salmon to all of Bristol Bay (total of river system predictions) in 1991,

s_f = standard error of the forecasted total run of sockeye salmon to Bristol Bay in 1991; and

$t_{0.2}$ = Student's t value with a probability of type I error of 0.20.

Estimation of (s_f) was based on the mean squared error (MSE) calculated from total run predictions using the same techniques as 1991 made for 1984-1990:

$$s_f = \sqrt{MSE}\ , \qquad (11)$$

$$MSE = \frac{\sum_{i=1}^{N} (F_i - A_i)^2}{N - 2} \qquad (12)$$

where:

F_i = forecasted total return of sockeye salmon for year *i*,
A_i = actual total return of sockeye salmon for year *i*; and
N = number of years (1984-1990).

Outlook to 1994

Using only spawner-recruit data (equation 1 or 2), forecasts were also made for the years 1992, 1993, and 1994. These forecasts were not adjusted for historic forecast errors as was the final 1991 forecast. Sockeye salmon production and mean June Cold Bay air temperatures were also examined to determine whether the positive correlation between these factors noted in previous studies (Eggers et al. 1984) was being maintained.

A total Bristol Bay return per spawner (RPS) value for each return year (*y*) was calculated from the weighted sum of total escapements four ($E_{(y-4)}$), five ($E_{(y-5)}$), and six ($E_{(y-6)}$) years prior to each total return:

$$RPS_y = \frac{R_y}{P_{1.2}E_{y-4} + (P_{1.3} + P_{2.2})E_{y-5} + P_{2.3}E_{y-6}} \qquad (13)$$

where $P_{1.2}$, $P_{1.3}$, $P_{2.2}$, and $P_{2.3}$ are mean proportions of age-1.2, age-1.3, age-2.2, and age-2.3 sockeye salmon, respectively, returning to Bristol Bay each year.

The air temperature index (ATI) for each return year *y* was calculated from the weighted sum of mean June air temperatures recorded at Cold Bay, Alaska, one ($T_{(y-1)}$), two ($T_{(y-2)}$), and three ($T_{(y-3)}$) years prior to each total return:

$$ATI_y = \frac{(P_{1.3} + P_{2.3})T_{y-3} + T_{y-2} + T_{y-1}}{(P_{1.3} + P_{2.3}) + 2} \qquad (14)$$

Deviations (D) from the mean were then calculated for actual (1965-1990) and forecasted (1991-1994) RPS value:

$$D_{RPS,y} = \left(RPS_y - \overline{RPS}\right) \qquad (15)$$

and for ATI values associated with each actual (1965-1990) RPS value:

$$D_{ATI,y} = \left(ATI_y - \overline{ATI}\right) \qquad (16)$$

Finally, a plot was made of all deviations that could be calculated for the period 1965-1990, and the correlation coefficient (Snedecor and Cochran 1969) between $D_{RPS,y}$ and $D_{ATI,y}$ was calculated for 1965-1990.

RESULTS

Performance of Recent and All Data Forecasts

Justification for use of the Recent Data ADF&G method was based on the observation that the number of returning adults produced per spawner has shown a dramatic increase since 1978 (Fried et al. 1988). It was hoped that use of only recent data would provide a more accurate estimate of total sockeye salmon returns and would help correct the past bias of under-forecasting annual runs. If results for 1984-1990 are representative of future performance, then forecasts of total sockeye salmon returns to Bristol Bay based on the Recent Data ADF&G method should be less biased (MPE = -8.1) and more accurate (MAPE=20.4) than forecasts based on the All Data ADF&G method (MPE = -38.9; MAPE=38.9) (Appendix B.1).

Unfortunately, results for individual river systems strongly suggested that the All Data ADF&G method was more accurate and less biased for Kvichak, Wood, Igushik, Nuyakuk, and Togiak than the Recent Data method (Appendix B.1). Results for Nushagak and Togiak District systems based on the Recent Data ADF&G method showed a three- to five-fold decrease in accuracy as well as a large bias towards over-forecasting when compared to results based on the All Data ADF&G method.

We tried to balance gains and losses in total Bristol Bay and individual river system forecast bias and accuracy by using results of the Recent Data ADF&G method for some systems and the All Data ADF&G method for the remaining systems. For the 1991 forecast, we used Recent Data for east side river systems (Kvichak, Branch, Naknek, Egegik, and Ugashik) and All Data for west side river systems (Wood, Igushik, Nushagak, and Togiak). This method is similar to that used for the 1989 and 1990 forecasts and is referred to as the Mixed Data ADF&G method (Appendix B.2). We felt it would provide the least biased and most accurate forecast of total returns to Bristol Bay and would also furnish reasonable individual river system forecasts.

Unadjusted River System Forecasts

Results from models were excluded from final river system forecast calculations if the fit of the model was not significant at the 25% level (P>0.25) or the value of the input variable ($E_{r,y}$ or $S_{i,r,y}$) was outside the range of data used to build the model. If results from spawner-recruit, sibling and smolt models did not meet these criteria for a river system age class, the mean return for 1978-90 was used for east side rivers (Recent Data) and the mean return for 1956-1990 (All Data) was used for west side rivers.

Kvichak River

Spawner-recruit, sibling, and smolt data bases were available for estimating Kvichak River run sizes in 1991.

Age-1.2. The age-1.2 forecast for this system was based upon spawner-recruit and smolt data (Appendix C.1). A prediction based on sibling data could not be made since the regression model was not significant at the 25% level (P>0.25). The spawner-recruit estimate of 3,197,000 was about 32% less than the smolt estimate of 4,672,000. The average of the two estimates was 3,935,000.

Age-2.2. The age-2.2 forecast was also based upon spawner-recruit and smolt data (Appendix C.1). A prediction based on sibling data could not be made because no age-2.1 siblings were obtained in samples from the Kvichak River in 1990. The spawner-recruit estimate of 851,000 was 50% greater than the smolt estimate of 566,000. The average of the two estimates was 709,000.

Age-1.3. The age-1.3 forecast was based upon spawner-recruit, sibling, and smolt data (Appendix C.1). The spawner-recruit estimate of 711,000 was 17% greater than the sibling estimate of 608,000 and only 3% less than the smolt estimate of 734,000. The average of the three estimates was 684,000.

Age-2.3. The age-2.3 forecast was based upon spawner-recruit, sibling, and smolt data (Appendix C.1). The spawner-recruit estimate of 994,000 was only about 1% greater than the sibling estimate of 987,000, but 34% greater than the smolt estimate of 743,000. The average of the three estimates was 908,000.

Branch River

Spawner-recruit and sibling data bases were available for estimating Branch River run sizes in 1991. There has never been a smolt project on the Branch River.

Age-1.2. The age-1.2 forecast was based only upon spawner-recruit data (Appendix C.2). A prediction based on sibling data could not be made because no age-1.1

siblings were obtained in samples from the Branch River in 1990. The spawner-recruit estimate was 209,000.

Age-2.2. The age-2.2 forecast was based only upon spawner-recruit data (Appendix C.2). A prediction based on sibling data could not be made because no age-2.1 siblings were obtained in samples from the Branch River in 1990. The spawner-recruit estimate was 26,000.

Age-1.3. The age-1.3 forecast was based only upon spawner-recruit data (Appendix C.2). The prediction based on sibling data was not used since the model was not significant at the 25% level (P>0.25). The spawner-recruit estimate was 140,000.

Age-2.3. The age-2.3 forecast was based only upon sibling data (Appendix C.2). The prediction based on spawner-recruit data was not used since the model was not significant at the 25% level (P>0.25). The sibling estimate was 20,000.

Naknek River

Spawner-recruit and sibling data bases were available for estimating Naknek River run sizes in 1991. The smolt project on the Naknek River has not operated since 1986.

Age-1.2. The age-1.2 forecast was based on the mean return of this age class for 1978-1990 (Appendix C.3). The prediction based on spawner-recruit data was not used since the model was not significant at the 25% level (P>0.25). A prediction based on sibling data could not be made because no age-1.1 sockeye salmon were obtained in samples from the Naknek River in 1990. The mean return estimate was 779,000.

Age-2.2. The age-2.2 forecast was also based on the mean return of this age class for 1978-1990 (Appendix C.3). Predictions based on spawner-recruit and sibling data were not used since neither model was significant at the 25% level (P>0.25). The mean return estimate was 785,000.

Age-1.3. The age-1.3 forecast was based on spawner-recruit and sibling data (Appendix C.3). The spawner-recruit estimate of 1,811,000 was 37% less than the sibling estimate of 2,861,000. The average of the two estimates was 2,336,000.

Age-2.3. The age-2.3 forecast was based upon spawner-recruit and sibling data (Appendix C.3). The spawner-recruit estimate of 966,000 was 6% less than the sibling estimate of 1,032,000. The average of the two estimates was 999,000.

Egegik River

Spawner-recruit, sibling, and smolt data bases were available for estimating Egegik River run sizes in 1991.

Age-1.2. The age-1.2 forecast was based only upon spawner-recruit data (Appendix C.4). A prediction based on sibling data was not made because no age-1.1 siblings were obtained from samples from the Egegik River in 1990. A prediction based on smolt data was not used because age-1. smolt production in 1989 was greater than past values used to build the model. The spawner-recruit estimate was 406,000.

Age-2.2. The age-2.2 forecast was based upon spawner-recruit, sibling, and smolt data (Appendix C.4). The spawner-recruit estimate of 3,681,000 was 42% greater than the sibling estimate of 2,582,000, but 9% less than the smolt estimate of 4,029,000. The average of the three estimates was 3,431,000.

Age-1.3. The age-1.3 forecast was based upon spawner-recruit and smolt data (Appendix C.4). A prediction based on sibling data was not used because the age-1.2 sibling return in 1990 was greater than past values used to build the model. The spawner-recruit estimate of 700,000 was about 66% less than the smolt estimate of 2,049,000. The average of the two estimates was 1,375,000.

Age-2.3. The age-2.3 forecast for this system was based upon spawner-recruit, sibling, and smolt data (Appendix C.4). The spawner-recruit estimate of 1,408,000 was 18% less than the sibling estimate of 1,711,000, but was 9% greater than the smolt estimate of 1,286,000. The average of the three estimates was 1,468,000.

Ugashik River

Spawner-recruit, sibling, and smolt data bases were available for estimating Ugashik River run sizes in 1991.

Age-1.2. The age-1.2 forecast was based upon spawner-recruit and sibling data (Appendix C.5). The prediction based on smolt data was not made since the model was not significant at the 25% level (P>0.25). The spawner-recruit estimate of 628,000 was only 5% less than the sibling estimate of 659,000. The average of the two estimates was 644,000.

Age-2.2. The age-2.2 forecast was based upon spawner-recruit and sibling data (Appendix C.5). The prediction based on smolt data was not used since the model was not significant at the 25% level (P>0.25). The spawner-recruit estimate of 1,374,000 was 109% greater than the sibling estimate of 658,000. The average of the two estimates was 1,016,000.

Age-1.3. The age-1.3 forecast was based upon spawner-recruit and sibling data (Appendix C.5). The prediction based on smolt data was not used since the model was not significant at the 25% level (P>0.25), and age-1. smolt production (182,719,000) was much greater than past values used to build the model. The spawner-recruit estimate of 906,000 was 64% greater than the sibling estimate of 554,000. The average of the two estimates was 730,000.

Age-2.3. The age-2.3 forecast was based upon spawner-recruit and sibling data (Appendix C.5). The prediction based on smolt data was not used since the model was not significant at the 25% level (P>0.25). The spawner-recruit estimate of 528,000 was 33% greater than the sibling estimate of 396,000. The average of the two estimates was 462,000.

Wood River

Spawner-recruit, sibling, and smolt data bases were available for estimating Wood River run sizes in 1991.

Age-1.2. The age-1.2 forecast was based upon spawner-recruit and smolt data (Appendix C.6). A prediction based on sibling data could not be made because no age-1.1 sockeye salmon were obtained in samples from Wood River in 1990. The spawner-recruit estimate of 1,069,000 was only 7% greater than the smolt estimate of 998,000. The average of the two estimates was 1,034,000.

Age-2.2. The age-2.2 forecast was based upon spawner-recruit and smolt data (Appendix C.6). A prediction based on sibling data could not be made because no age-2.1 sockeye salmon were in samples from Wood River in 1990. The spawner-recruit estimate of 75,000 was similar to the smolt estimate of 79,000. The average of the two estimates was 77,000.

Age-1.3. The age-1.3 forecast was based upon spawner-recruit, sibling, and smolt data (Appendix C.6). The spawner-recruit estimate of 871,000 was similar to the sibling estimate of 865,000 but about 37% less than the smolt estimate of 1,380,000. The average of the three estimates was 1,039,000.

Age-2.3. The age-2.3 forecast was based on spawner-recruit and sibling data (Appendix C.6). A prediction based on smolt data was not made since the model was not significant at the 25% level (P>0.25). The spawner-recruit estimate of 60,000 was about 76% greater than the sibling estimate of 34,000. The average of the two estimates was 46,000.

Igushik River

Spawner-recruit and sibling data bases were available for estimating Igushik River run sizes in 1991. There has never been a smolt project on the Igushik River.

Age-1.2. The age-1.2 forecast was based only upon results from spawner-recruit data (Appendix C.7). A prediction based on sibling data was not made since the regression model was not significant at the 25% level (P>0.25) and no age-1.1 sockeye salmon were obtained in samples collected from Igushik River in 1990. The spawner-recruit estimate was 83,000.

Age-2.2. The age-2.2 forecast was based only on spawner-recruit data (Appendix C.7). A prediction based on sibling data was not made because no age-2.1 sockeye salmon were obtained in samples collected from the Igushik River in 1990. The spawner-recruit estimate was 41,000.

Age-1.3. The age-1.3 forecast was based upon spawner-recruit and sibling data (Appendix C.7). The spawner-recruit estimate of 474,000 was 12% greater than the sibling estimate of 422,000. The average of the two estimates was 448,000.

Age-2.3. The age-2.3 forecast was based upon spawner-recruit and sibling data (Appendix C.7). The spawner-recruit estimate of 34,000 was 33% less than the sibling estimate of 51,000. The average of the two estimates was 43,000.

Nuyakuk

Spawner-recruit and smolt data bases were available for estimating Nuyakuk River run sizes in 1991. Predictions were not made from sibling data because the counting tower on the Nuyakuk River ceased operation in 1988, consequently sibling information from 1990 was not available.

Age-1.2. The age-1.2 forecast was based only upon spawner-recruit data (Appendix C.8). The prediction based on smolt data was not used since the model was not significant at the 25% level (P>0.25). The spawner-recruit estimate was 55,000.

Age-2.2. The age-2.2 forecast was based only upon spawner-recruit data (Appendix C.8). The prediction based on smolt data was not used since the model was not significant at the 25% level (P>0.25). The spawner-recruit estimate was 26,000.

Age-1.3. The age-1.3 forecast was based only upon spawner-recruit data (Appendix C.8). The prediction based on smolt data was not used since the model was not significant at the 25% level (P>0.25). The spawner-recruit estimate was 1,102,000.

Age-2.3. The age-2.3 forecast was based only upon spawner-recruit data (Appendix C.8). The prediction based on smolt data was not used since the model was not significant at the 25% level (P>0.25). The spawner-recruit estimate was 20,000.

Togiak River

Spawner-recruit and sibling data bases were available for estimating Togiak River run sizes in 1991. Smolt projects did not operate on the Togiak River in 1988 or 1989.

Age-1.2. The age-1.2 forecast was based only on spawner-recruit data (Appendix C.9). A prediction based on sibling data was not made since the regression model was not significant at the 25% level (P>0.25) and no age 1.1 sockeye salmon were obtained in samples collected from the Togiak River in 1990. The spawner-recruit estimate was 92,000.

Age-2.2. The age-2.2 forecast was based only on spawner-recruit data (Appendix C.9). The prediction based on sibling data was not used since the regression model was not significant at the 25% level (P>0.25) and no age-2.1 sockeye salmon were obtained in samples collected from the Togiak River in 1990. The spawner-recruit estimate was 25,000.

Age-1.3. The age-1.3 forecast was based on spawner-recruit and sibling data (Appendix C.9). The spawner-recruit estimate of 287,000 was 32% greater than the sibling estimate of 217,000. The average of the two estimates was 252,000.

Age-2.3. The age-2.3 forecast for this system was based on spawner-recruit and sibling data (Appendix C.9). The spawner-recruit estimate of 26,000 was the same as the sibling estimate of 26,000.

Historic Forecast Errors and 1991 Forecast Adjustment

All Data Forecast Errors

Forecast errors for the east side river systems based on All Data showed an increasing trend from 1966-90 (Figure 2). Linear and polynomial regression models of the relationship between forecast year and east side forecast error were significant ($P<0.01$; Figures 3 and 4). The 1991 prediction for combined east side systems based on All Data was 15.1 million sockeye salmon. The estimated error for the 1991 prediction based on the linear and polynomial regression models were -18.2 million and -20.4 million, respectively (Table 1). A Box-Jenkins time series AR(1) model was estimated for the relationship between forecast year and east side relative forecast errors (percent error; Figure 5). The time series model estimated an error for the 1991 east side All Data prediction at -95.1% (-14.4 million fish; Table 1). Therefore, estimated error adjustments for an east side All Data prediction were greater than or similar to the original prediction (Table 1).

The performance of using All Data to predict east side systems and correcting the prediction by an adjustment factor based on a linear regression or time series models was reviewed by hindcasting runs with these techniques. Correcting All Data predictions by errors estimated from linear regression models resulted in over forecasts for 1984-88 and under forecasts for 1989-90 (Figure 6). The MPE of All Data predictions corrected by linear regression models was +8.2% for 1984-90 compared to -61.5% for unadjusted predictions. Correcting All Data predictions by errors estimated from time series models resulted in over forecasts for 1986-88 and under forecasts for 1989-90 (Figure 7). The MPE of All Data predictions corrected by time series models was -7.0% for 1986-90 compared to -63.7% for unadjusted predictions.

Errors of west side forecasts based on All Data showed no trend through time (Figure 8). Linear and polynomial regression models of the relationship between year and west side forecast error were not significant ($P>0.25$).

Recent Data Forecast Errors

Errors of east side forecasts based on Recent Data were generally negative (forecasted run less than actual run), but showed no trend through time for the years 1984-90 (Figure 9). Because errors of Recent Data east side forecasts were not correlated with time, the 1984-90 average error (-30.38%) was used as an estimate of the 1991 prediction error. The 1991 prediction for combined east side systems based on Recent Data was 21.1 million fish. The estimated error for the 1991 east side prediction based on average errors was -6.4 million fish (Table 1). Using the average error to adjust Recent Data forecasts resulted in under forecasts in 1987, 1989-90 and an over forecast for 1988 (Figure 10). The

1987-90 MPE for Recent Data east side forecasts was reduced from -38.2% to -16.3% by adjusting for previous years average error.

1991 Forecast Adjustment

Errors in All Data forecasts increased from 1966-1990, however they were clustered in two groups. Prior to 1978 forecasts were greater or equal to actual runs and after 1978 forecasts were less than actual runs (Figure 2). Because the errors appeared to be clustered in time, we felt that regression analysis was not appropriate. Regression and time series models estimated adjustment factors for the 1991 east side All Data forecast which were similar or larger than the original forecast. We decided that using Recent Data to forecast the east side systems and adjusting by a smaller number of fish was preferable to using the entire data base (All Data) and adjusting by a very large number. Therefore, we decided to use the Recent Data forecast for the east side systems and increased it by the 1984-90 average error (30.38%, or 6.4 million fish). Because forecast errors for the west side did not show a trend through time, we did not adjust forecasts for west side rivers.

Adjusted Total Bristol Bay Forecast

Based on results of the Mixed Data ADF&G method adjusted by the 1984-90 average percent error, a total of 31,866,000 sockeye salmon (80% CI: 2,168,000 - 61,564,000) are expected to return to Bristol Bay in 1991 (Table 2). This level of production would be about 10% (2,833,000 sockeye salmon) greater than the 20-year (1971-1990) mean return of 29,033,000 (range: 3,517,000 to 66,293,000), and about 12% (4,395,000) less than the most recent 10-year (1981-1990) mean return of 36,261,000 (range: 23,996,000 - 48,971,000).

Total projected sockeye salmon harvest is 23,131,000 (80% CI: 0 - 47,600,000) (Table 2). Most (21,211,000) of this harvest will be taken within Bristol Bay inshore fishing districts (Table 3). The remainder of the sockeye harvest (8.3% of total Bristol Bay harvest = 1,920,000) has been allocated to fisheries occurring in June in the vicinity of Shumagin Islands and South Unimak under an existing management plan (regulation 5AAC 09.365, ADF&G 1990). No estimate is available of the number of Bristol Bay sockeye salmon expected to be harvested by foreign or domestic high seas fisheries.

The total number of sockeye salmon expected to return to Bristol Bay, after the Shumagin Islands and South Unimak fisheries have occurred is 29,946,000 (Table 3). Runs should exceed spawning escapement goals for all river systems. The projected Bristol Bay combined fishing district harvest of 21,211,000 would be 33% (5,268,000) greater than the 20-year (1971-1990) mean harvest of 15,943,000 (range: 761,000 - 37,372,000), but 9% (2,211,000) less than the 10-year (1981-1990) mean harvest of 23,422,000 (range: 14,006,000 - 37,372,000).

Adjusted River System Forecasts

The combined prediction for east side river systems (Kvichak, Branch, Naknek, Egegik, and Ugashik) was increased by the 1984-90 average forecast error (30.38%). Forecasts for individual east side rivers were increased proportionally based on their contribution to the combined east side prediction. Predictions for west side rivers (Wood, Igushik, Nuyakuk, and Togiak) were not adjusted for historic forecast errors.

Kvichak River

A total of 8,130,000 sockeye salmon was forecasted to return to this system (Table 3). Sockeye salmon production within the Kvichak River system has followed a five-year abundance cycle (Mathisen and Poe 1981). A return of 8,130,000 sockeye salmon to the Kvichak River system in 1991, a year following the peak year, would be about 12% greater than the mean return of sockeye salmon (range: 2,025,000 - 14,279,000) observed during past "post-peak" years (1961, 1966, 1971, 1976, 1981, 1986). Age-1.2 sockeye salmon comprised the majority (63%) of the forecasted Kvichak River return in 1991.

Branch River

A total of 515,000 sockeye salmon was forecasted to return to this system (Table 3). A total run of this size would be about 8% greater than the mean return of 479,000 for 1981-1990 (range: 283,000 - 861,000), and about 27% greater than the mean return of 404,000 for 1971-1990 (range: 55,000 - 861,000). Age-1.2 and age-1.3 comprised 53% and 36%, respectively, of the Branch River forecast.

Naknek River

A total of 6,386,000 sockeye salmon was forecasted to return to this system (Table 3). A total run of this size would be 41% greater than the mean return of 4,516,000 for 1981-1990 (range: 1,796,000 - 8,644,000) and 79% more than the mean return of 3,558,000 for 1971-1990 (range: 724,000 - 8,644,000).

Egegik River

A total of 8,708,000 sockeye salmon was forecasted to return to this system (Table 3). A total run of this size would be about 11% greater than the mean return of 7,811,000 for 1981-1990 (range: 3,918,000 - 12,611,000), but about 72% greater than the mean return of 5,062,000 for 1971-1990 (range: 790,000 - 12,611,000). The actual run to this system could be greater than forecasted. Age-1.2 and age-1.3 returns could be greater than forecasted based on smolt and sibling data, respectively, which had greater values than past years included in the models (Appendix C.4). The forecast for Egegik river was comprised of a high (51%) percentage of age-2.2 sockeye salmon.

Ugashik River

A total of 3,718,000 sockeye salmon was forecasted to return to this system (Table 3). A total run of this size would be about 12% less than the mean return of 4,227,000 for 1981-1990 (range: 2,256,000 - 7,875,000) but about 42% greater than the mean return of 2,621,000 for 1971-1990 (range: 60,000 - 7,875,000). All four major age classes were well represented in the 1991 Ugashik River forecast.

Wood River

A total of 2,196,000 sockeye salmon was forecasted to return to this system (Table 3). A total run of this size would be about 24% less than the mean return of 2,893,000 for 1981-1990 (range: 1,694,000 - 4,925,000) and about 15% less than the mean return of 2,595,000 for 1971-1990 (range: 716,000 - 4,925,000). The 1991 Wood River forecast was comprised of equal (47%) percentages of age-1.2 and age-1.3 sockeye salmon.

Igushik River

A total of 615,000 sockeye salmon was forecasted to return to this system (Table 3). A total run of this size would be about 43% less than the mean return of 1,077,000 for 1981-1990 (range: 415,000 - 2,409,000) and about 36% less than the mean return of 966,000 for 1971-1990 (range: 133,000 - 3,276,000). Approximately 73% of the 1991 Igushik River forecast was comprised of age-1.3 sockeye salmon.

Nuyakuk River

A total of 1,203,000 sockeye salmon was forecasted to return to this system (Table 3). A total run of this size would be about 21% less than the mean return of 1,519,000 for 1981-1988 (range: 616,000 - 3,587,000) and about 5% less than the mean return of 1,272,000 for 1971-1988 (range: 92,000 - 5,052,000). Sibling data were not available since the adult enumeration project for this system was discontinued in 1989. Beginning in 1992, a forecast for the entire Nushagak River (Nushagak, Mulchatna, and Nuyakuk Rivers) will be made based on spawner-recruit and sibling data obtained from a hydroacoustic project conducted on the main stem of the Nushagak River near Portage Creek. The majority (92%) of the 1991 Nuyakuk River forecast was comprised of age-1.3 sockeye salmon.

Togiak River

A total of 395,000 sockeye salmon was forecasted to return to this system (Table 3). A total run of this size would be about 34% less than the mean return of 599,000 for 1981-1990 (range: 179,000 - 1,002,000), and about 29% less than the mean return of 554,000 for 1971-1990 (range: 177,000 - 1,173,000). Most (64%) of the sockeye salmon forecasted to return to the Togiak River in 1991 were age-1.3.

Expected Forecast Performance

Our best estimate of sockeye salmon run size for 1991 was based on the Mixed Data method. Subsequently forecasts for east side systems (Kvichak, Branch, Naknek, Egegik, and Ugashik) were adjusted upwards to correct for the 1984-90 average percent error. Although this forecast is our best estimate of returning run size, differences among the various forecasting components and methods suggested that deviations from our forecast would be most likely to occur in five areas:

River System	Most Probable Deviation from Forecasted Return	Reasons for Probable Deviation
Egegik	greater than expected return of age-1.2 sockeye salmon	The number of age-1. smolt that migrated in 1989 (72.4 million) was greater than any of those previously recorded.
	greater than expected return of age-1.3 sockeye salmon	The number of age-1.2 siblings in 1990 (1.8 million) was greater than any of those previously recorded.
Ugashik	greater than expected return of age-1.3 sockeye salmon	The number of age-1. smolt that migrated in 1988 (183.0 million) was much greater than any of those previously recorded. However, the age-1.2 return in 1990 which was also from the 1988 smolt migration was not large.
Nuyakuk	less than expected return of age-1.2 sockeye salmon	The number of age-1. smolt that migrated in 1989 (5.6 million) was less than any of those previously recorded. two years have been far above
West Side Systems	greater than expected return of age-1.2 and age-1.3 sockeye salmon return	West side forecast was not corrected for past forecast errors. All Data method has under forecasted west side systems by 16% from 1984-90.

This is the first year ADF&G has adjusted the forecast based on historic forecast errors. If the 1991 run is similar to runs occurring in the past ten years, the forecast should be close to the actual run. However, if the 1991 run is more similar to the runs which occurred during the last two years, the forecast will again be conservative. Conversely, if the 1991 run is below average as were the 1986 and 1988 runs, the 1991 forecast could be too high. Other indicators that can be used to assess preseason forecast accuracy will not be available until June 1991 when the Shumagin Islands-South Unimak commercial fishery and the Port Moller offshore test fishery (operated by the University of Washington with funding from the fishing industry) take place. Catch, effort, and age composition data collected from these fisheries have been used with varying degrees of success in past years to modify preseason expectations (Eggers and Shaul 1987; Fried and Hilborn 1988; Yuen and Fried 1985).

Outlook to 1994

Comparisons of 1991-94 forecasts based only on spawner-recruit data not adjusted for historic errors suggested that the total number of sockeye salmon returning to Bristol Bay would be lowest in 1991 (Table 4). The low forecast in 1991 was due to the predicted low run to Kvichak River. Kvichak River runs were predicted to be lowest in 1991, similar in 1992-93, and highest in 1994. Predicted runs to Egegik River were similar for 1991-94. Runs to Ugashik River were predicted to be lowest in 1992 and highest in 1994. Rivers in Nushagak District had fairly high predictions in 1991 and 1994, but lower predictions for 1992-93. Runs to Togiak River were predicted to be highest in 1993 and lowest in 1994. Annual returns to all river systems were predicted to be greater than desired spawning goals for all years examined.

Fried and Yuen (1987) and Fried et al. (1988) suggested that sockeye salmon returns after 1986 might be adversely affected by what appeared to be the onset of less favorable environmental conditions: cooler than average June air temperatures during the three years each brood year spent at sea (Figure 10). Although mean production was not expected to fall to the levels observed prior to 1978 (mean RPS, 1965-1977: 2.0; range: 0.5-3.6), when large numbers of sockeye salmon were captured on the high seas by foreign vessels, production was also not anticipated to attain the extremely high levels observed during 1978-1983 (mean RPS: 4.6; range: 3.8-5.7). Based on results of the analyses presented in this paper, we feel that sockeye salmon production from brood years contributing to returns in 1991-1994 (mean predicted RPS: 2.8; range: 2.4-3.5) will be similar to the long-term, 1965-1990, average (mean RPS: 2.8); but slightly lower than the previous five year, 1986-1990, average (mean RPS: 3.1; range: 2.2-4.1).

However, as we cautioned in our last report (Fried and Cross 1990), while a strong positive correlation ($r=0.622$, significant at the 99% level, $P>0.01$) was present between RPS and ATI deviations for all available years, 1965-1990, there have been departures from the expected relationship in six out of the seven most recent years (Figure 11). RPS values for the 1984, 1985, and 1986 return years were below average when corresponding ATI values were above average; RPS values for the 1987 and 1989 return years were above average when the corresponding ATI values were either below average or average. These occurrences suggest that the formerly strong relationship between RPS and ATI deviations appears to be deteriorating. It may be that either very large deviations in ATI (in excess of 1.5 F^{o} or 2 F^{o} as were observed during the period 1973-1982) must occur before sockeye salmon production is affected, or that the correlation between ATI and RPS was spurious.

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Table 1. Comparison of preliminary forecasts, estimated forecast errors, and adjusted forecasts for 1991 combined east side Bristol Bay rivers.

	Millions of Sockeye Salmon			
Data Base	Original 1991 Forecast	Method of Modeling	Estimated Error 1991[a]	Adjusted 1991 Forecast
All Data	15.1	Linear Regression	-18.2	33.3
All Data	15.1	Polynomial Regression	-20.4	35.5
All Data	15.1	Time Series AR(1)	-14.4	29.5
Recent Data	21.1	Average Error	-6.4	27.5

[a] Error = (predicted - actual).

Table 2. Forecasted production, spawning escapement goals, and total projected harvests of major age classes of sockeye salmon returning to L.istol Bay, Alaska, river systems in 1991, based on results of the Mixed Data ADF&G method adjusted by the 1984-90 average percent error.

	Numbers of sockeye salmon (thousands)						
	Forecasted Production by Age Class						
District: System	1.2	2.2	1.3	2.3	Total	Spawning Goal	Total Harvest
NAKNEK-KVICHAK:							
Kvichak	5,130	924	892	1,184	8,130	4,000	4,130
Branch	272	34	183	26	515	185	330
Naknek	1,016	1,023	3,045	1,302	6,386	1,000	5,386
Total	6,418	1,981	4,120	2,512	15,031	5,185	9,846
EGEGIK	529	4,473	1,792	1,914	8,708	1,000	7,708
UGASHIK	839	1,325	952	602	3,718	700	3,018
NUSHAGAK:[a]							
Wood	1,034	77	1,039	46	2,196	1,000	1,196
Igushik	83	41	448	43	615	200	415
Nuyakuk	55	26	1,102	20	1,203	500	703
Total	1,172	144	2,589	109	4,014	1,700	2,314
TOGIAK[b]	92	25	252	26	395	150	245
TOTAL BRISTOL BAY	9,050	7,948	9,705	5,163	31,866	8,735	23,131

[a] Forecasts for Nushagak-Mulchatna and Snake River systems were not included. However, since Nushagak District catches have not been allocated to either of these systems in past years, additional returns would only be seen as spawning escapements (mean total escapement based on aerial surveys, 1956-1988, 98 thousand).

[b] Forecasts for Kulukak, Kanik, Osviak, and Matogak River systems were not included. These systems may contribute an additional 102 thousand (mean total return, 1978-1990) sockeye salmon to the total Togiak District return.

Table 3. Projected commercial harvests of sockeye salmon returning to Bristol Bay, Alaska, river systems in 1991, based on results of the Mixed Data ADF&G method adjusted by the 1984-90 average percent error.

District: System	Numbers of sockeye salmon (thousands)				
	Forecasted Total Production	Shumagin Islands-S. Unimak Harvest[a]	Bristol Bay		
			Total Run	Spawning Goal	Harvest
NAKNEK-KVICHAK:					
Kvichak	8,130	490	7,640	4,000	3,640
Branch	515	31	484	185	299
Naknek	6,386	385	6,001	1,000	5,001
Total	15,031	906	14,125	5,185	8,940
EGEGIK	8,708	525	8,183	1,000	7,183
UGASHIK	3,718	224	3,494	700	2,794
NUSHAGAK:					
Wood	2,196	132	2,064	1,000	1,064
Igushik	615	37	578	200	378
Nuyakuk	1,203	72	1,131	500	631
Total	4,014	241	3,773	1,700	2,073
TOGIAK	395	24	371	150	221
TOTAL BRISTOL BAY	31,866	1,920	29,946	8,735	21,211

[a] Guideline harvest calculated as 8.3% of projected Bristol Bay harvest. Numbers were apportioned among river systems based on proportions in the forecast of total production.

Table 4. Preliminary forecasts of sockeye salmon returns to Bristol Bay, Alaska, 1991-1994, based only on spawner-recruit data not adjusted for historic forecast errors.

DISTRICT: River System	Number of Sockeye Salmon (thousands)			
	1991	1992	1993	1994
NAKNEK-KVICHAK:				
Kvichak	5,753	10,550	10,093	14,574
Branch	397	448	427	423
Naknek	4,977	3,818	3,533	3,619
Total	11,127	14,816	14,053	18,616
EGEGIK	6,195	6,934	6,458	6,655
UGASHIK	3,436	2,796	3,260	4,522
NUSHAGAK:				
Wood	2,075	1,910	2,003	2,029
Igushik	632	500	519	707
Nuyakuk	1,203	447	780	1,621
Total	3,910	2,857	3,302	4,357
TOGIAK	430	459	499	326
TOTAL BRISTOL BAY	25,098	27,862	27,572	34,476

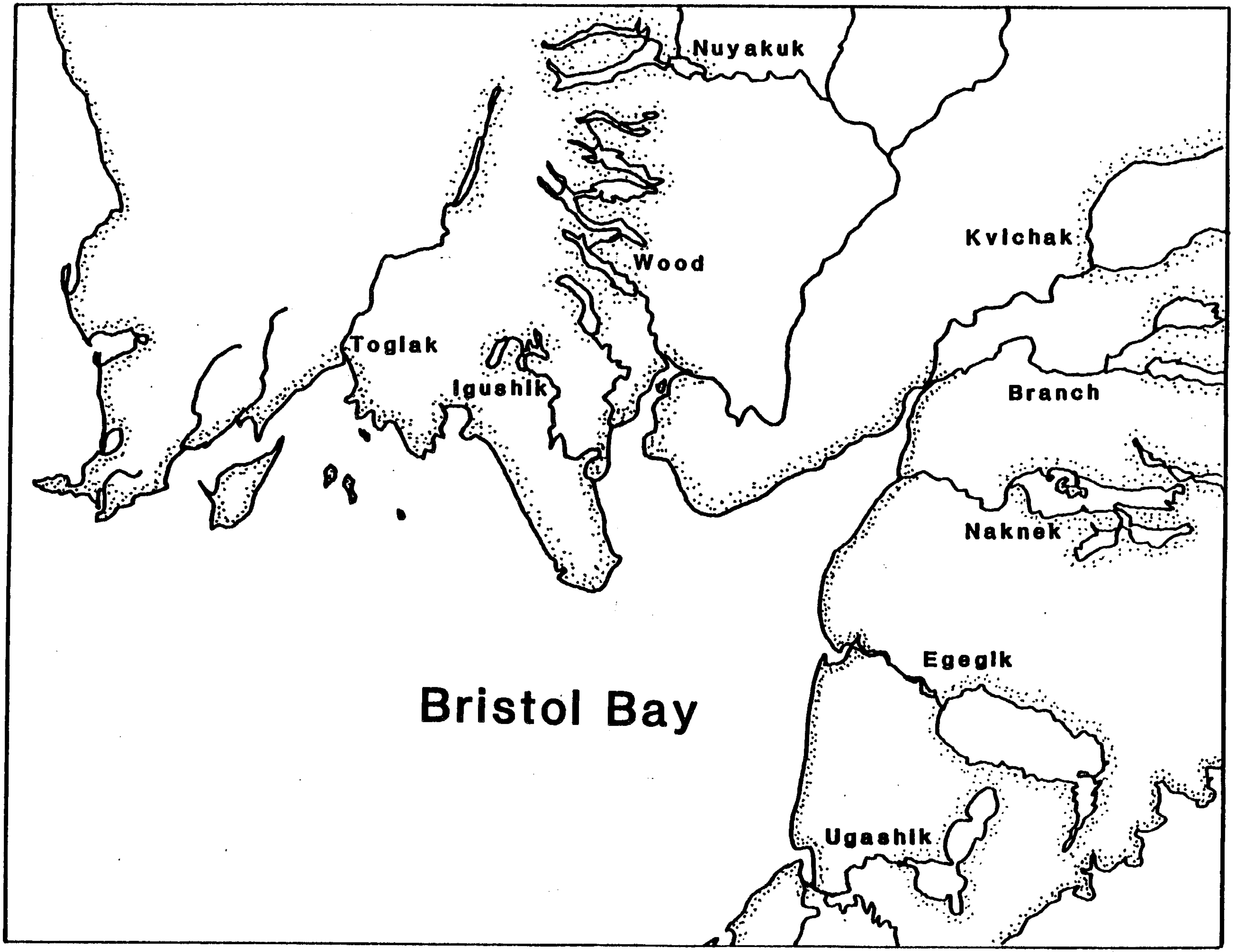

Figure 1. Map of Bristol Bay, Alaska showing fishing districts and major rivers.

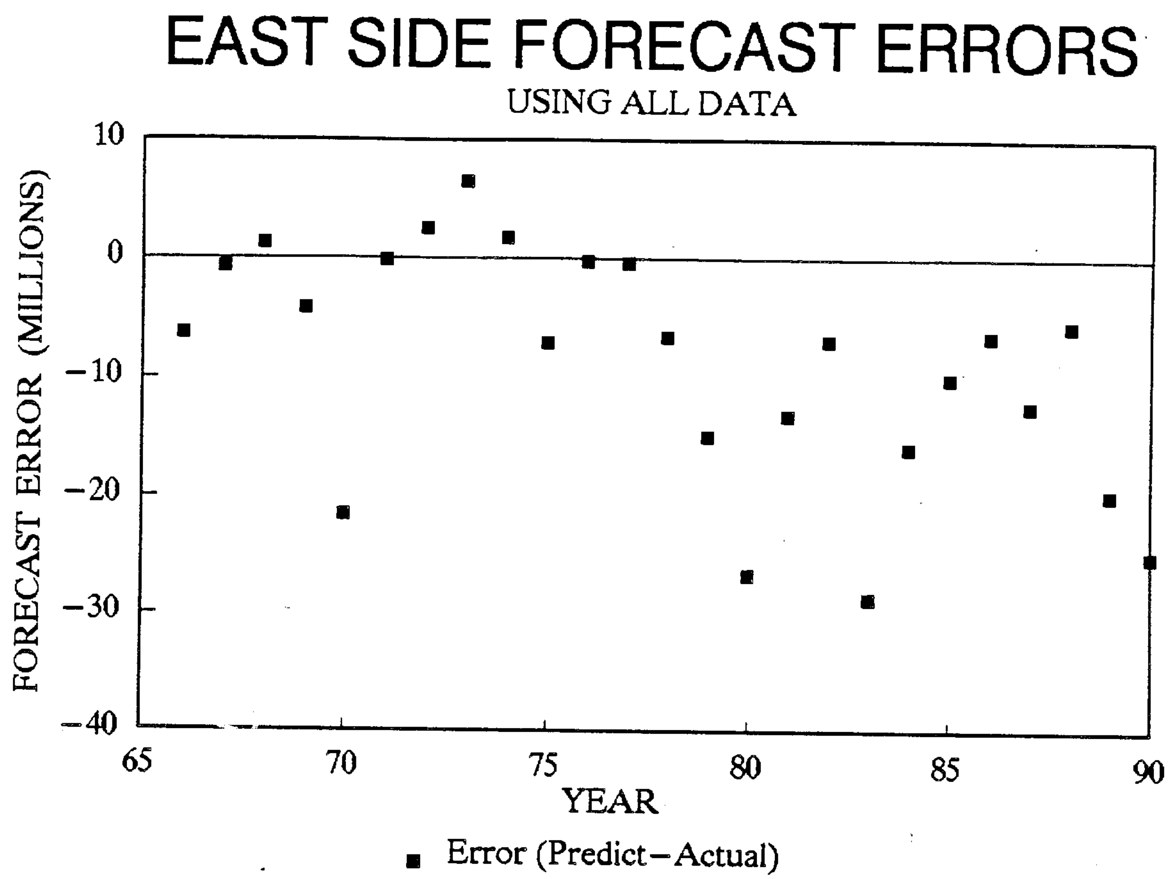

Figure 2. Errors (predicted run - actual run) of combined east side Bristol Bay forecasts made with All Data for 1965-1990.

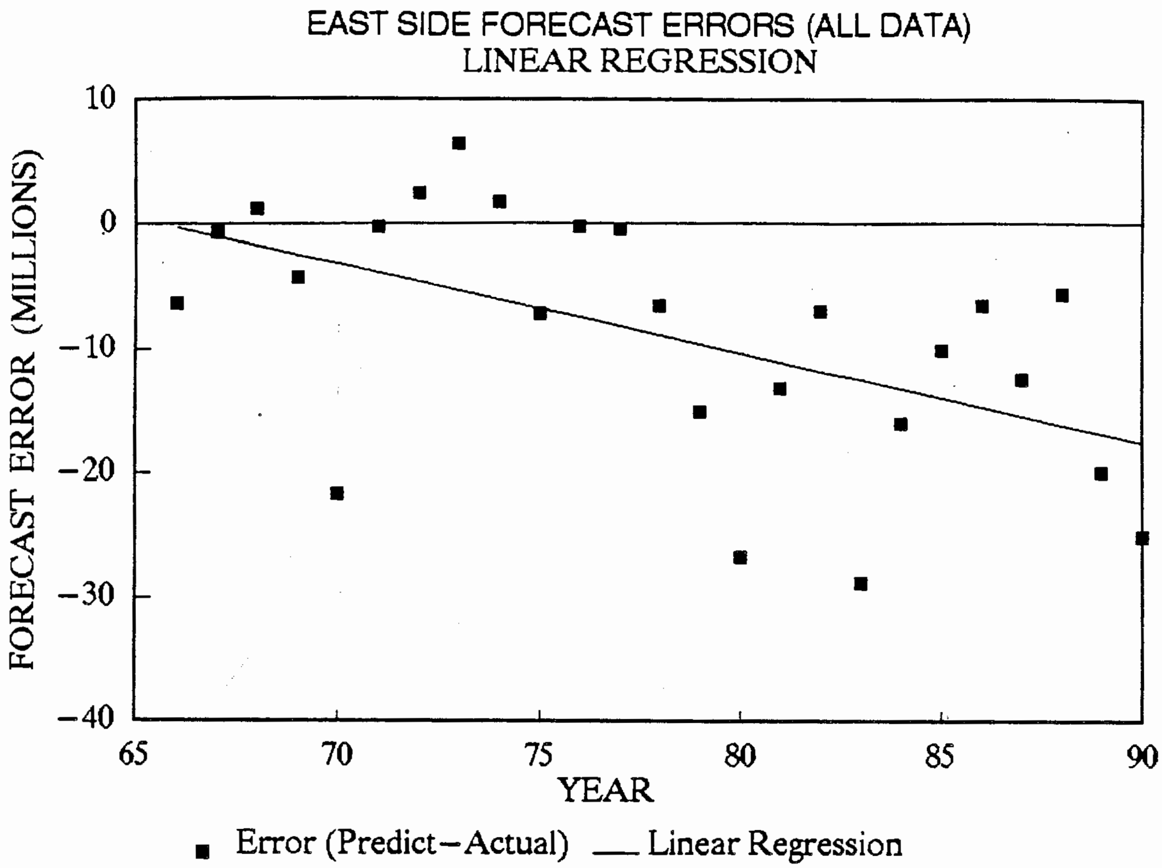

Figure 3. Linear regression model of errors (predicted run - actual run) of combined east side Bristol Bay forecasts made with All Data for 1965-1990.

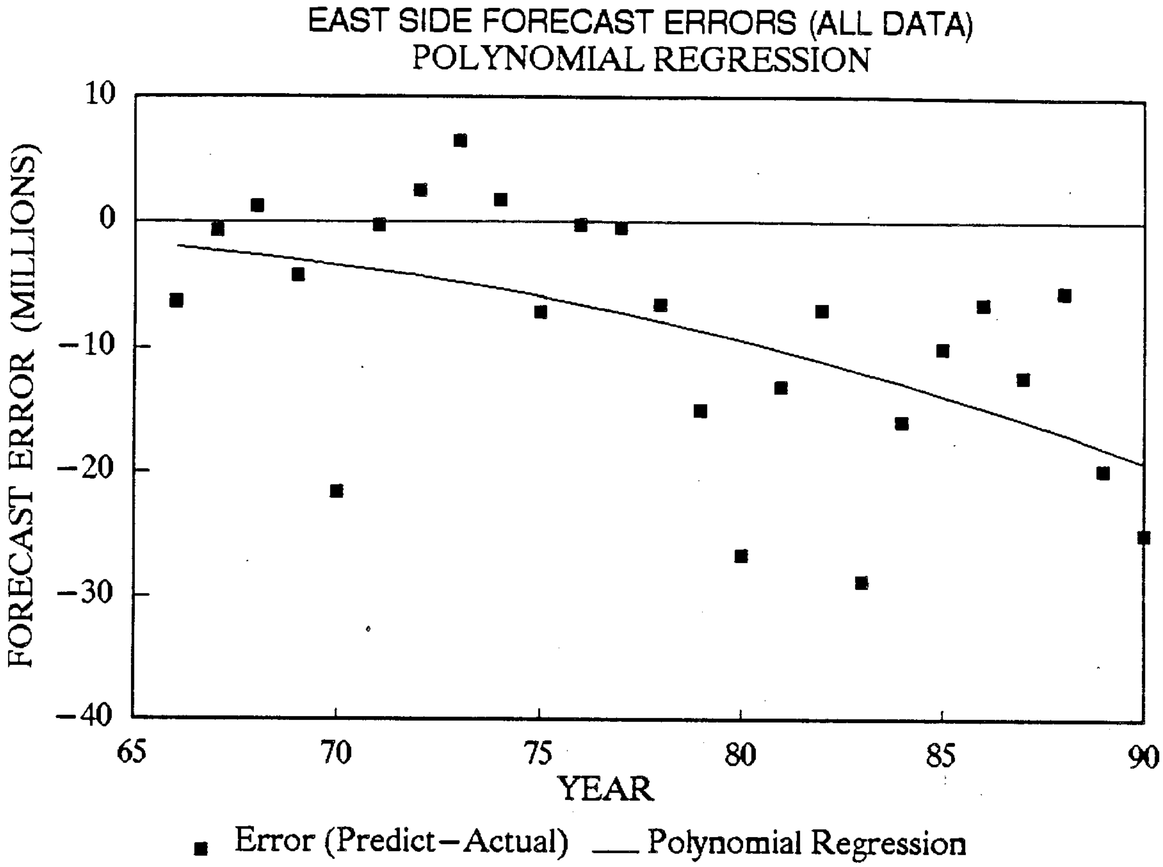

Figure 4. Polynomial regression model of errors (predicted run - actual run) of combined east side Bristol Bay forecasts made with All Data for 1965-1990.

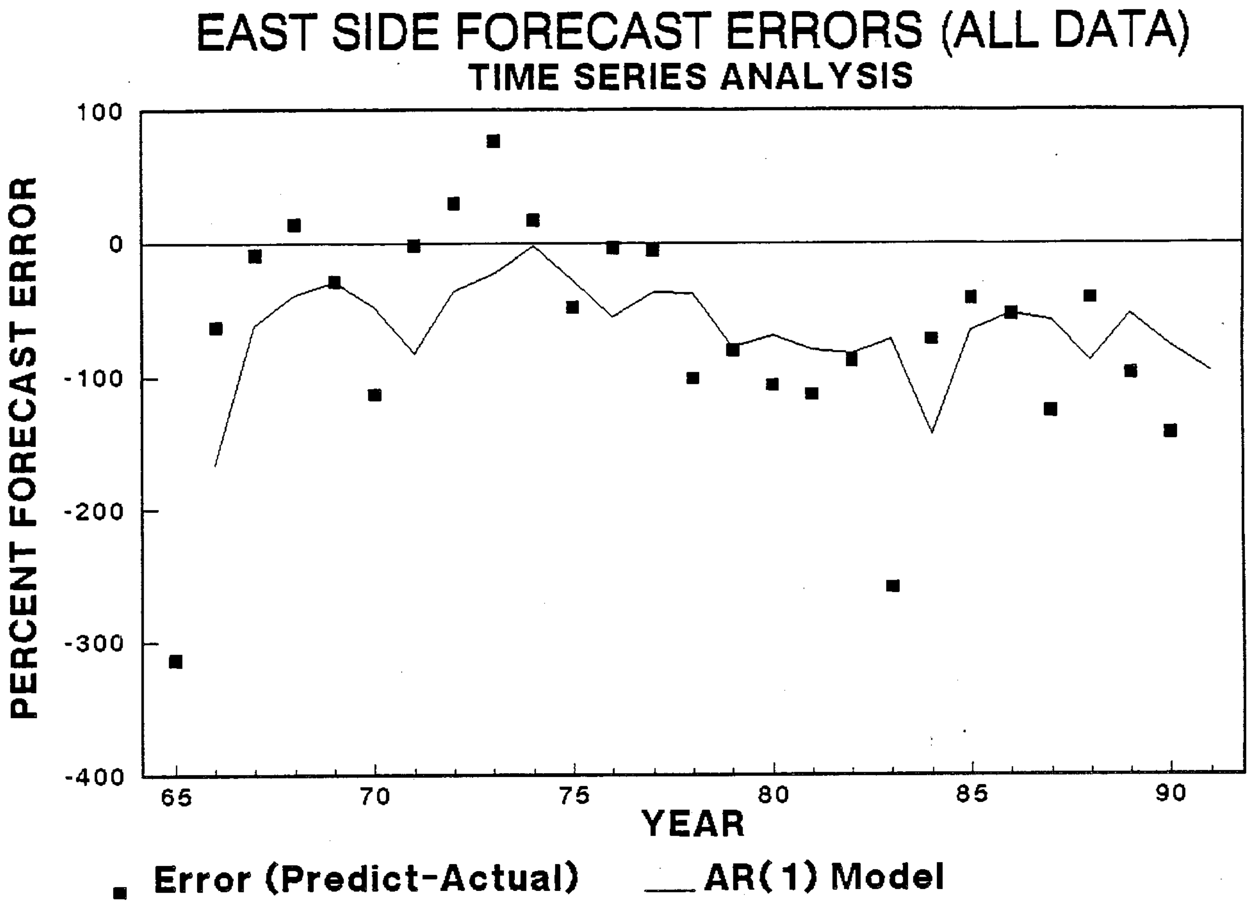

Figure 5. Time series model of errors (predicted run - actual run) of combined east side Bristol Bay forecasts made with All Data for 1965-1990.

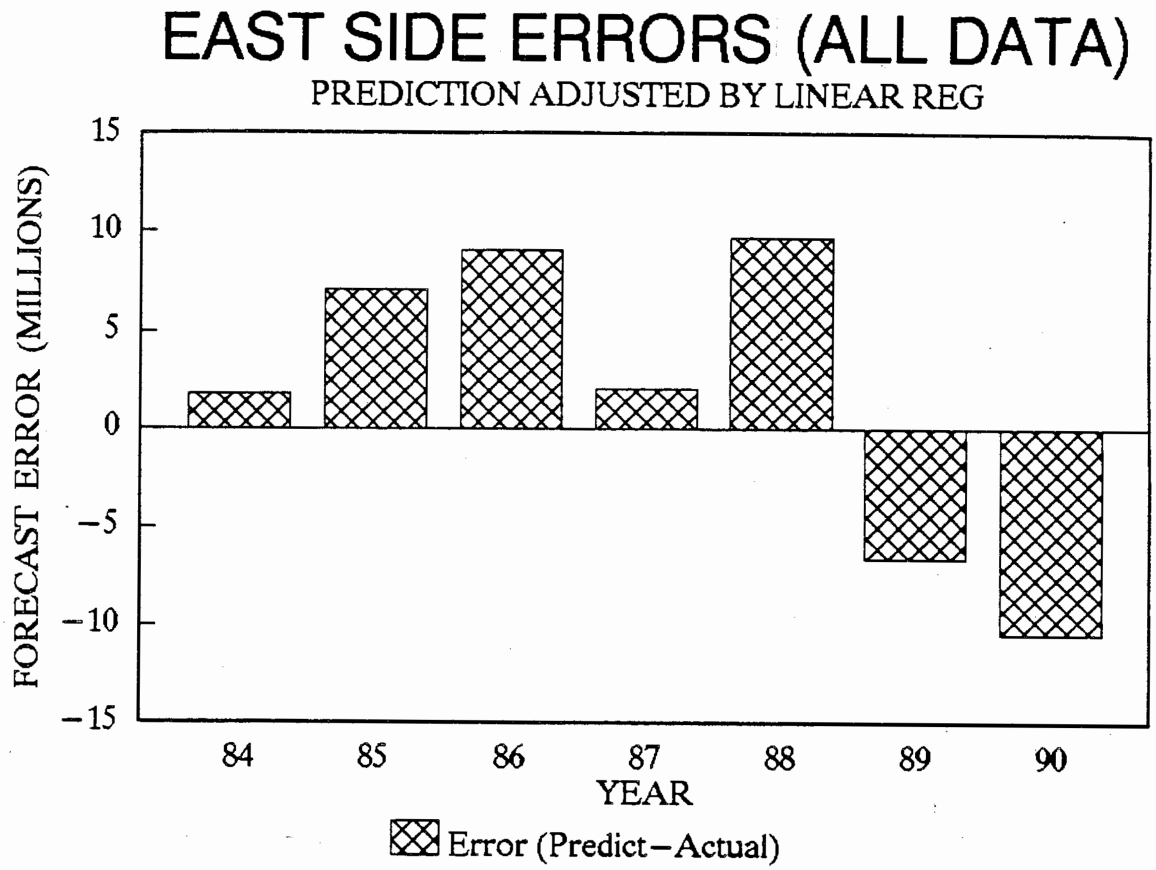

Figure 6. Errors (predicted run - actual run) of combined east side Bristol Bay forecasts made with All Data and adjusted with an estimate of error from linear regression model, 1984-1990.

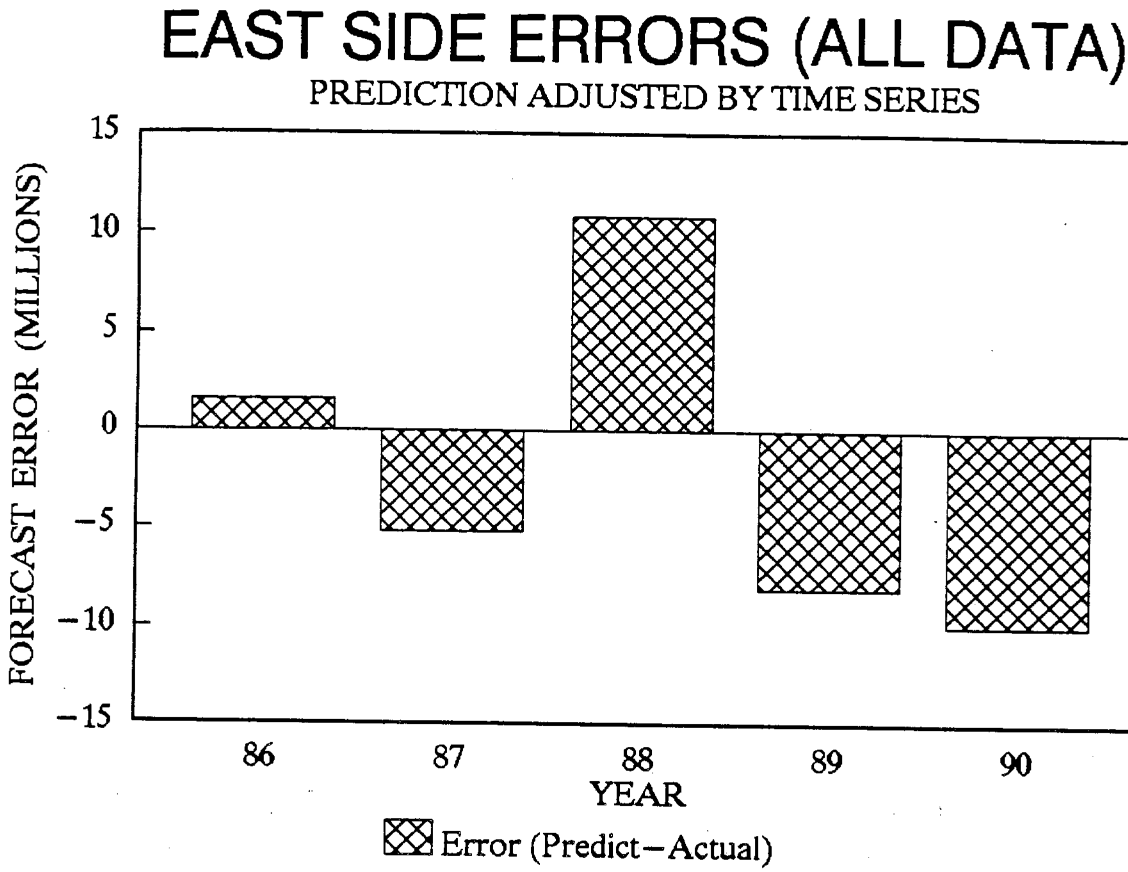

Figure 7. Errors (predicted run - actual run) of combined east side Bristol Bay forecasts made with All Data and adjusted with an estimate of error from time series model, 1986-1990.

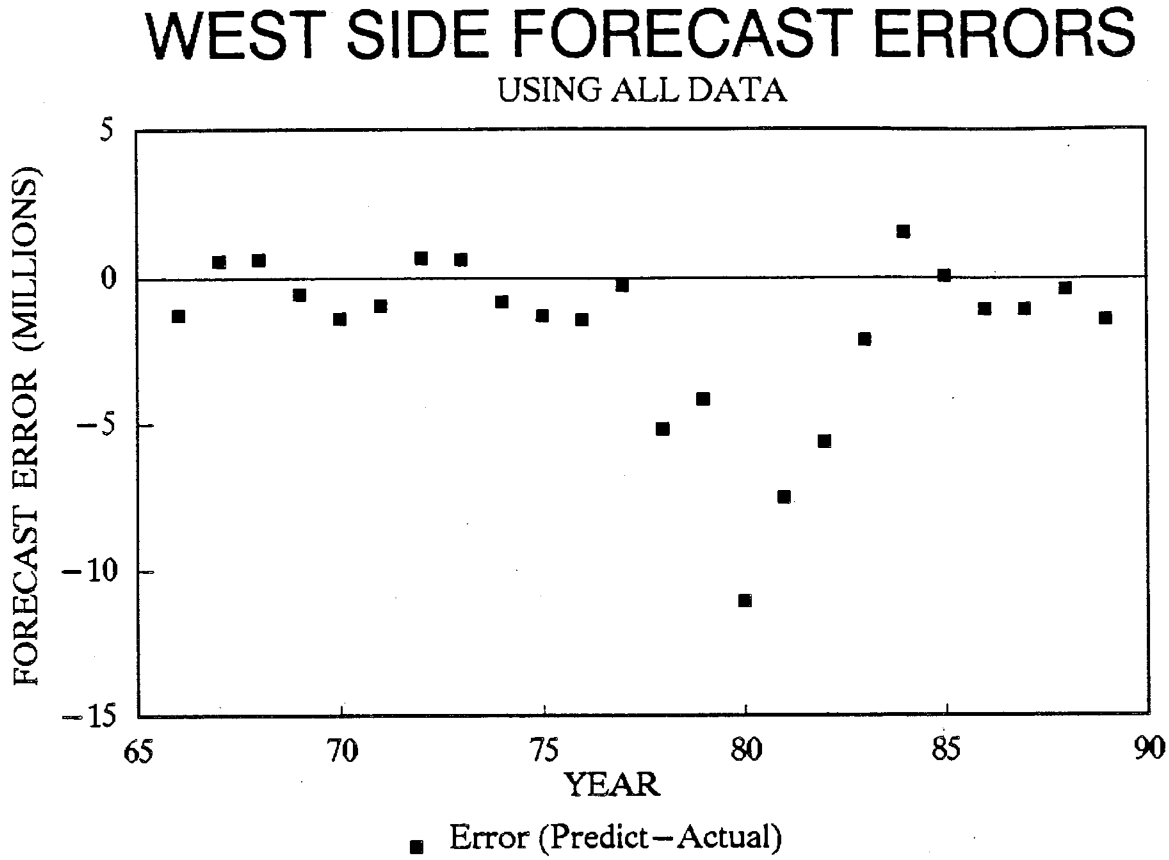

Figure 8. Errors (predicted run - actual run) of combined west side Bristol Bay forecasts made with All Data for 1965-1990.

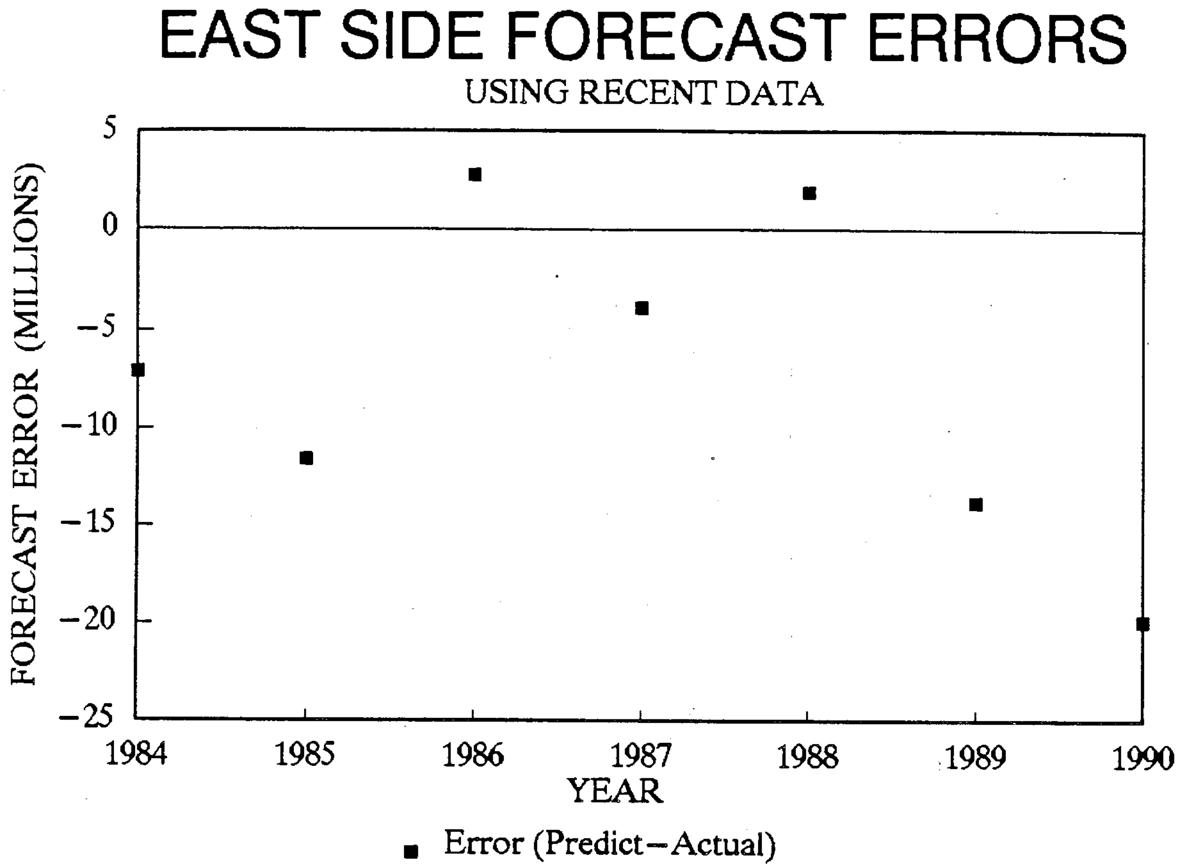

Figure 9. Errors (predicted run - actual run) of combined east side Bristol Bay forecasts made with Recent Data for 1984-1990.

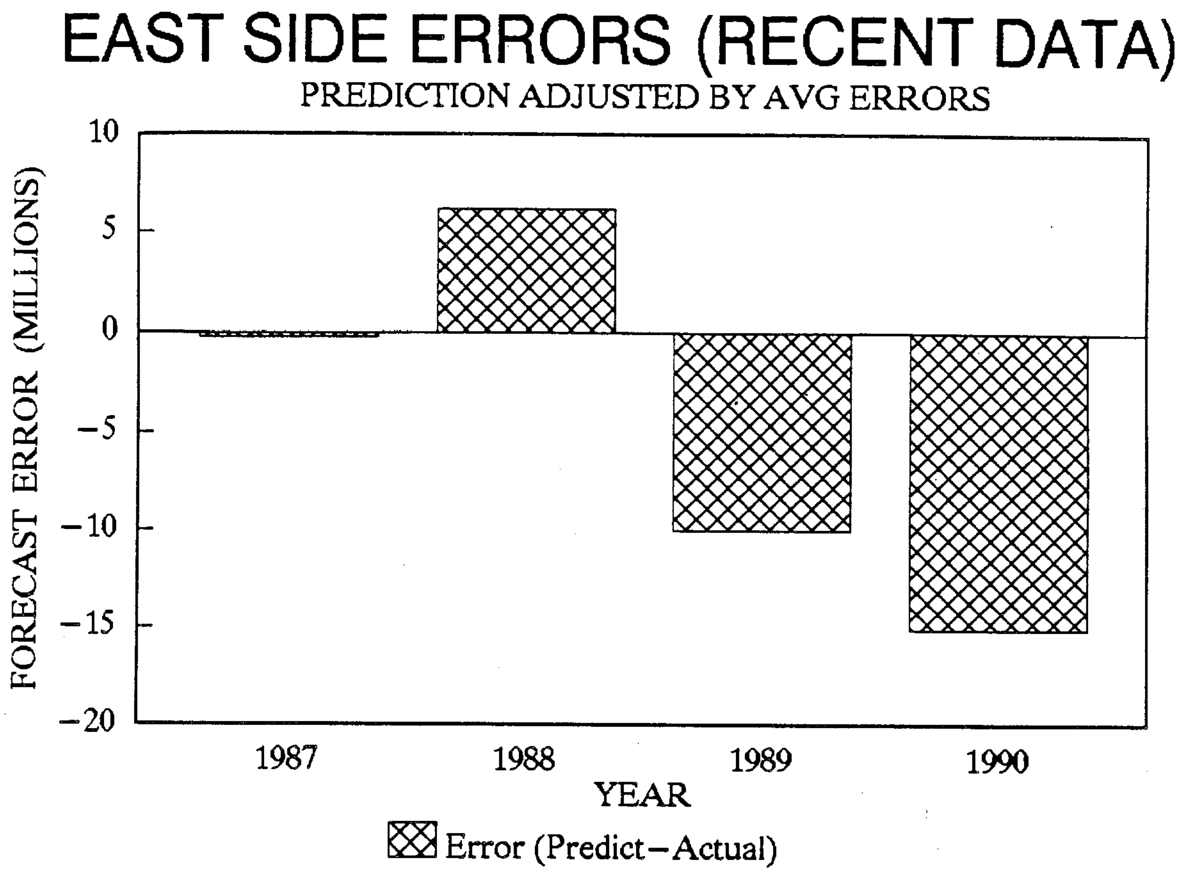

Figure 10. Errors (predicted run - actual run) of combined east side Bristol Bay forecasts made with Recent Data and adjusted with the average percent error, 1987-1990.

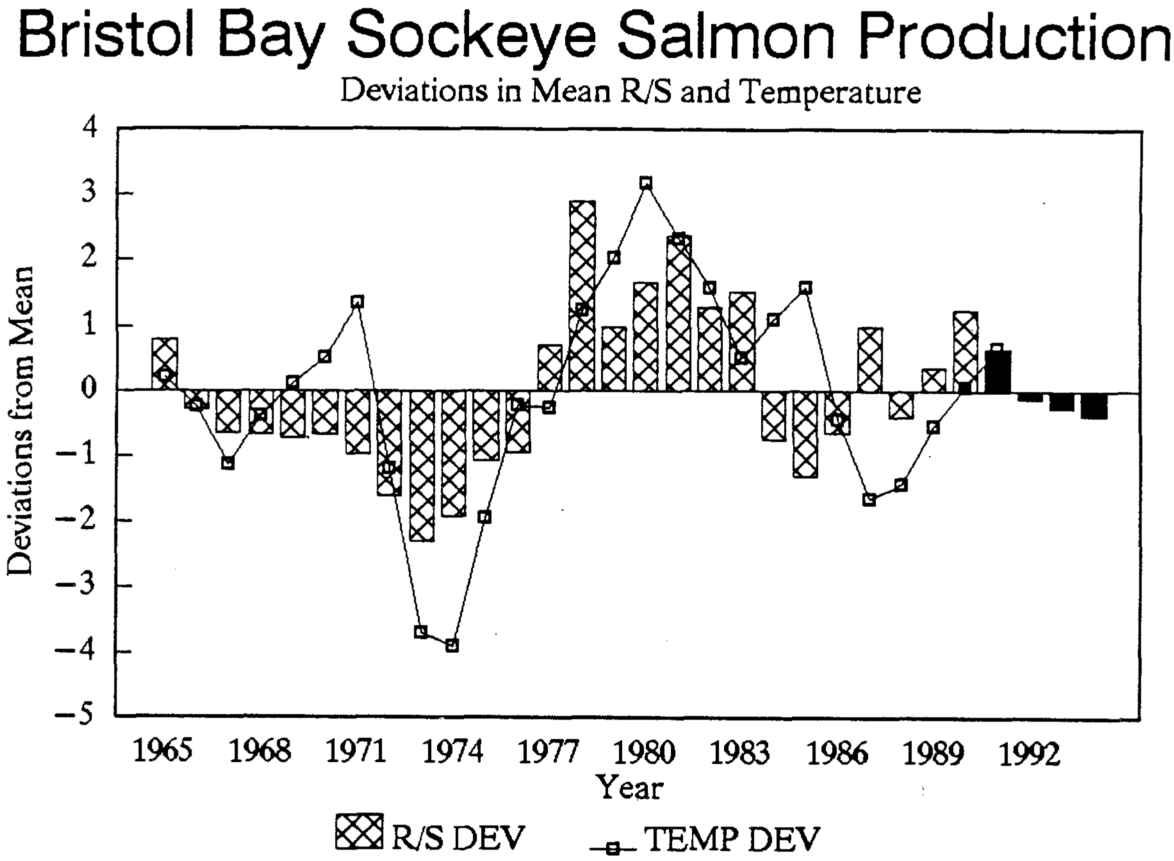

Figure 11. Annual deviations from the mean number of returning Bristol Bay, Alaska, sockeye salmon produced per spawner (bar chart) and weighted mean Cold Bay, Alaska, June air temperature (line chart), 1965-1990. Deviations from forecasted return per spawner values are shown for 1991-1994 (solid bars).

APPENDIX A

Historic Sockeye Forecasts and Returns

Appendix A.1. Preseason forecasts of sockeye salmon returns to Bristol Bay, Alaska, 1961-1990, issued by the Alaska Department of Fish and Game.

Year	Forecast (millions)	Actual Return (millions) Inshore	Actual Return (millions) Total[a]	Percent Error[b]
1961	43.6	18.1	24.5	78.0
1962	19.6	10.4	11.7	67.5
1963	8.6	6.9	8.0	7.5
1964	17.4	10.9	11.5	51.3
1965	27.8	53.1	60.8	-54.3
1966	31.3	17.5	20.0	56.5
1967	13.7	10.3	11.5	19.1
1968	10.4	8.0	9.4	10.6
1969	21.3	19.0	21.9	-2.7
1970	55.8	39.4	45.0	24.0
1971	15.2	15.8	18.3	-16.9
1972	9.7	5.4	7.2	34.7
1973	6.2	2.4	3.5	77.1
1974	5.0	10.9	11.5	-56.5
1975	12.0	24.2	25.8	-53.5
1976	12.0	11.5	12.8	-6.3
1977	8.4	9.7	10.7	-21.5
1978	11.5	19.8	20.8	-44.7
1979	22.7	39.8	40.9	-44.5
1980	54.5	62.4	66.2	-17.7
1981	26.7	34.5	37.1	-28.0
1982	34.6	22.1	24.7	40.1
1983	33.4	45.8	48.0	-30.4
1984	31.1	41.0	42.6	-27.0
1985	35.0	36.6	38.5	-9.1
1986	22.5	23.7	24.4	-7.8
1987	16.5	27.3	28.3	-41.7
1988	28.8	23.2	24.0	20.0
1989	30.4	43.9	45.7	-33.5
1990	26.7	47.6	49.0	-45.5

[a] Includes foreign high seas and domestic Shumagin Islands-South Unimak catches for 1961-1990.

[b] Percent error calculated as:
(forecast - actual total return) / actual total return.

APPENDIX B

Hindcast Errors

Appendix B.1. Annual percent errors, mean percent errors (MPE), and mean absolute percent errors (MAPE) for hindcasts of total sockeye salmon returns to Bristol Bay, Alaska, river systems, 1984-90, based on All Data (1956-90) or Recent Data (1978-90).

	Percent Errors											
Year	Kvichak	Branch	Naknek	Egegik	Ugashik	Wood	Igushik	Nuyakuk	Togiak	Combined East	Combined West	Total
						ALL DATA FORECASTS						
1984	-40.0	-32.7	-29.4	-49.1	-44.4	-12.2	73.5	23.9	0.4	-41.1	7.8	-36.5
1985	1.3	-9.5	-21.0	-58.9	-56.9	5.1	-33.5	-4.6	-20.5	-29.8	-5.7	-27.7
1986	126.3	-52.6	-32.0	-54.7	-67.8	-3.5	-36.2	-26.8	-4.4	-34.7	-18.1	-31.3
1987	-78.4	-13.4	-15.5	-43.0	-47.8	-35.0	-18.9	37.7	-24.0	-55.7	-22.0	-49.8
1988	-9.5	-13.0	13.5	-54.5	-17.0	9.9	13.5	42.3	-56.0	-27.3	-1.3	-23.0
1989	-48.5	-48.0	-18.4	-61.4	-47.4	-24.6	-64.5	-37.0	81.0	-49.4	-33.5	-47.5
1990	-55.6	-47.6	-65.1	-61.5	-50.2	-29.6	-51.1	-52.2	-11.9	-58.8	-39.6	-56.3
84-90 MPE	-14.9	-31.0	-24.0	-54.7	-47.4	-12.8	-16.8	-2.4	-5.1	-42.4	-16.1	-38.9
84-90 MAPE	51.4	31.0	39.1	54.7	47.4	17.1	41.6	32.1	28.3	42.4	18.3	38.9
						RECENT DATA FORECASTS						
1984	-21.7	-4.1	47.4	-34.0	-27.7	105.7	355.7	196.4	80.2	-18.7	152.9	-2.5
1985	-29.6	83.7	2.9	-44.0	-49.1	141.0	227.6	34.8	92.4	-33.2	124.4	-19.6
1986	287.6	-0.7	3.7	-36.1	-15.7	93.1	59.1	23.5	28.5	14.3	56.0	23.0
1987	-55.9	9.8	68.9	-27.4	59.2	-3.7	98.1	248.4	14.6	-17.5	45.2	-6.6
1988	33.1	28.6	35.4	-28.5	51.9	68.4	181.0	177.0	-26.9	9.4	74.3	20.1
1989	-37.6	-33.5	0.9	-44.0	-24.3	4.4	-24.1	-2.3	287.7	-34.4	5.5	-29.7
1990	-47.5	-26.4	-55.7	-53.4	9.6	-4.6	0.5	-16.1	23.6	-46.7	-5.1	-41.3
84-90 MPE	18.3	8.2	14.8	-38.2	0.6	57.8	128.3	94.5	71.4	-18.1	64.7	-8.1
84-90 MAPE	73.3	26.7	30.7	38.2	34.0	60.2	135.2	99.8	79.1	24.9	66.2	20.4

Appendix B.2. Annual percent errors, mean percent errors (MPE), and mean absolute percent errors (MAPE) for hindcasts of total sockeye salmon returns to Bristol Bay, Alaska, river systems, 1984-1990, based on the Mixed Data ADF&G method[a].

Year	Kvichak	Branch	Naknek	Egegik	Ugashik	Wood	Igushik	Nuyakuk	Togiak	Total
	Percent Errors									
1984	-21.7	-4.1	47.4	-34.0	-27.7	-12.2	73.5	23.9	0.4	-16.2
1985	-29.6	83.7	2.9	-44.0	-49.1	5.1	-33.5	-4.6	-20.5	-30.8
1986	287.6	-0.7	3.7	-36.1	-15.7	-3.5	-36.2	-26.8	-4.4	7.6
1987	-55.9	9.8	68.9	-27.4	59.2	-35.0	-18.9	37.7	-24.0	-18.3
1988	33.1	28.6	35.4	-28.5	51.9	9.9	13.5	42.3	-56.0	7.6
1989	-37.6	-33.5	0.9	-44.0	-24.3	-24.6	-64.5	-37.0	81.0	-34.3
1990	-47.5	-26.4	-55.7	-53.4	9.6	-29.6	-51.1	-52.2	-11.9	-45.8
84-90 MPE	18.3	8.2	14.8	-38.2	0.6	-12.8	-16.8	-2.4	-5.1	-18.6
84-90 MAPE	73.3	26.7	30.7	26.7	34.0	17.1	41.6	25.2	28.3	22.9

[a] Recent Data (1978-90) used for Kvichak, Branch, Naknek, Egegik, and Ugashik River systems; All Data (1956-90) used for other river systems:

APPENDIX C

Unadjusted River System Forecasts

Appendix C.1. Forecasted returns of major age classes of sockeye salmon to the Kvichak River system, Bristol Bay, Alaska, in 1991 based on linear regression models using spawner-recruit, sibling, and smolt data.

Spawner-Recruit Data

Age Class	Spawning Escapement (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	6,065	3,197	10.0	13
2.2	1,179	851	0.1	13
1.3	1,179	711	0.1	13
2.3	7,211	994	5.0	13
	Total	5,753		

Sibling Data

Age Class	Sibling Return in 1990 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	4	4[a]	NS	7
2.2	0	[b]	0.1	10
1.3	693	608	1.0	12
2.3	13,375	987	2.5	12
	Total	1,599		

Smolt Data

Age Class	Smolt Production (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	146,603	4,672	10.0	13
2.2	6,830	566	0.1	13
1.3	13,126	734	10.0	12
2.3	87,004	743	5.0	12
	Total	6,715		

[a] Estimate not used; regression model not significant at 25% level (P>0.25).

[b] Estimate not made; zero age-2.1 sockeye salmon returned to Kvichak River in 1990.

Appendix C.2. Forecasted returns of major age classes of sockeye salmon to the Branch River system, Bristol Bay, Alaska, in 1991 based on linear regression models using spawner-recruit and sibling data.

Spawner-Recruit Data

Age Class	Spawning Escapement (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	154	209	5.0	13
2.2	230	26	10.0	12
1.3	230	140	2.5	12
2.3	118	9[a]	NS	13
	Total	384		

Sibling Data

Age Class	Sibling Return in 1990 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	0	[b]	25.0	10
2.2	0	[b]	NS	3
1.3	346	149[a]	NS	12
2.3	91	20	25.0	11
	Total	169		

[a] Estimate not used; regression model not significant at 25% level (P>0.25).

[b] Estimate not made; zero age-1.1 or age-2.1 sockeye salmon returned to Branch River in 1990.

Appendix C.3. Forecasted returns of major age classes of sockeye salmon to the Naknek River system, Bristol Bay, Alaska, in 1991 based on linear regression models using spawner-recruit and sibling data.

Spawner-Recruit Data

Age Class	Spawning Escapement (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	1,061	472[a]	NS	13
2.2	1,977	926[a]	NS	13
1.3	1,977	1,811	25.0	13
2.3	1,849	966	10.0	13
	Total	4,175		

Sibling Data

Age Class	Sibling Return in 1990 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	0	[b]	NS	11
2.2	6	937[a]	NS	10
1.3	1,995	2,861	10.0	12
2.3	1,283	1,032	2.5	12
	Total	4,830		

[a] Estimate not used; regression model not significant at 25% level (P>0.25).

[b] Estimate not made; zero age-1.1 *sockeye* salmon returned to Naknek River in 1990.

Appendix C.4. Forecasted returns of major age classes of sockeye salmon to the Egegik River system, Bristol Bay, Alaska, in 1991 based on linear regression models using spawner-recruit, sibling, and smolt data.

Spawner-Recruit Data

Age Class	Spawning Escapement (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	1,273	406	5.0	13
2.2	1,151	3,681	5.0	13
1.3	1,151	700	25.0	13
2.3	1,095	1,408	25.0	13
	Total	6,195		

Sibling Data

Age Class	Sibling Return in 1990 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	0	[a]	25.0	9
2.2	10	2,582	5.0	12
1.3	1,846	3,778[b]	0.1	12
2.3	4,262	1,711	5.0	12
	Total	8,071		

Smolt Data

Age Class	Smolt Production (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	72,458	1,486[c]	5.0	7
2.2	27,347	4,029	25.0	7
1.3	36,122	2,049	5.0	6
2.3	12,758	1,286	25.0	6
	Total	8,850		

[a] Estimate not made; zero age-1.1 sockeye salmon returned to Egegik River in 1990.

[b] Estimate not used; age-1.2 sibling return greater than past values used to build model (131 thousand - 1,756 thousand).

[c] Estimate not used; age-1. smolt production greater than past values used to build model (2,242 thousand - 54,586 thousand).

Appendix C.5. Forecasted returns of major age classes of sockeye salmon to the Ugashik River system, Bristol Bay, Alaska, in 1991 based on linear regression models using spawner-recruit, sibling, and smolt data.

Spawner-Recruit Data

Age Class	Spawning Escapement (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	669	628	2.5	13
2.2	1,001	1,374	1.0	13
1.3	1,001	906	0.5	13
2.3	998	528	0.1	13
	Total	3,436		

Sibling Data

Age Class	Sibling Return in 1990 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	<1	659	2.5	9
2.2	<1	658	10.0	11
1.3	501	554	0.1	12
2.3	968	396	0.1	12
	Total	2,267		

Smolt Data

Age Class	Smolt Production (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	88,999	574[a]	NS	6
2.2	34,657	1,524[a]	NS	6
1.3	182,719	1,083[b]	NS	5
2.3	33,238	727[a]	NS	5
	Total	3,908		

[a] Estimate not used; regression model not significant at 25% level (P>0.25).

[b] Estimate not used; age-1. smolt production greater than past values used to build model (5,462 thousand - 75,491 thousand); regression model not significant at 25% level (P>0.25).

Appendix C.6. Forecasted returns of major age classes of sockeye salmon to the Wood River system, Bristol Bay, Alaska, in 1991 based on linear regression models using spawner-recruit, sibling, and smolt data.

Spawner-Recruit Data

Age Class	Spawning Escapement (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	1,337	1,069	0.1	31
2.2	818	75	5.0	30
1.3	818	871	0.1	30
2.3	939	60	10.0	27
	Total	2,075		

Sibling Data

Age Class	Sibling Return in 1990 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	0	[a]	1.0	22
2.2	0	[a]	2.5	13
1.3	1,215	865	5.0	34
2.3	29	34	0.1	32
	Total	899		

Smolt Data

Age Class	Smolt Production (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	37,653	998	0.5	14
2.2	3,574	79	0.1	14
1.3	39,828	1,380	2.5	13
2.3	971	41[b]	NS	13
	Total	2,498		

[a] Estimate not made; zero age-1.1 or age-2.1 siblings returned to Wood River in 1990.

[b] Estimate not used; regression model not significant at 25% level (P>0.25).

Appendix C.7. Forecasted returns of major age classes of sockeye salmon to the Igushik River system, Bristol Bay, Alaska, in 1991 based on linear regression models using spawner-recruit and sibling data.

Spawner-Recruit Data

Age Class	Spawning Escapement (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	169	83	1.0	31
2.2	308	41	2.5	30
1.3	308	474	0.1	30
2.3	212	34	0.1	29
	Total	632		

Sibling Data

Age Class	Sibling Return in 1990 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	0	[a]	NS	3
2.2	0	[b]	25.0	5
1.3	238	422	2.5	34
2.3	85	51	<0.1	34
	Total	473		

[a] Estimates not made; zero age-1.1 siblings returned to Igushik River in 1990; regression model not significant at 25% level (P>0.25).

[b] Estimates not made; zero age-2.1 siblings returned to Igushik River in 1990.

Appendix C.8. Forecasted returns of major age classes of sockeye salmon to the Nuyakuk River system, Bristol Bay, Alaska, in 1991 based on linear regression models using spawner-recruit and smolt data.

Spawner-Recruit Data

Age Class	Spawning Escapement (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	163	55	0.5	29
2.2	821	26	0.1	27
1.3	821	1,102	<0.1	28
2.3	429	20	2.5	25
	Total	1,203		

Smolt Data

Age Class	Smolt Production (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	5,586	75[a]	NS	4
2.2	568	11[a]	NS	4
1.3	8,305	355[a]	NS	3
2.3	288	20[a]	NS	3
	Total	461		

[a] Estimate not used; regression model not significant at 25% level (P>0.25).

Appendix C.9. Forecasted returns of major age classes of sockeye salmon to the Togiak River system, Bristol Bay, Alaska, in 1991 based on linear regression models using spawner-recruit and sibling data.

Spawner-Recruit Data

Age Class	Spawning Escapement (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	249	92	1.0	31
2.2	203	25	1.0	30
1.3	203	287	0.5	30
2.3	145	26	<0.1	29
	Total	430		

Sibling Data

Age Class	Sibling Return in 1990 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	0	[a]	NS	12
2.2	0	[a]	NS	6
1.3	85	217	0.5	33
2.3	37	26	0.5	33
	Total	243		

[a] Estimate not made; zero age-1.1 and age-2.1 siblings returned to Togiak River in 1990; regression models not significant at 25% level (P>0.25).

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