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A SYNOPSIS AND CRITIQUE OF FORECASTS OF SOCKEYE SALMON RETURNING TO BRISTOL BAY IN 1996

By

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ABSTRACT

The total number of sockeye salmon *Oncorhynchus nerka* forecasted to return to Bristol Bay in 1996 is 46,495,000 (80% confidence interval: 33,939,000 - 59,051,000). Runs are expected to exceed spawning escapement goals for all systems. Total projected sockeye salmon harvest is expected to be 37,710,000. Most of this harvest will be taken within Bristol Bay inshore fishing districts (34,581,000), but some have been allocated to June fisheries occurring in the vicinity of the Shumagin Islands and South Unimak under an existing management plan (8.3% of total Bristol Bay projected harvest = 3,130,000). The 1996 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. However for the 1996 forecast, estimates from spawner-return regressions were not used for Egegik or Ugashik Rivers because evaluations of past performance indicated that their forecasts were more accurate and less biased if only sibling and smolt information were used. Also, based on performance evaluations of the ADF&G method, data prior to the 1978 return year were omitted from calculations for all rivers. To further correct under-forecasting errors, predictions for eastside rivers (Kvichak, Branch, Naknek, Egegik and Ugashik) were adjusted by the 1984-95 average percent forecast error of the corresponding systems. Similar to last year, out of range data were used in calculations for the 1996 forecast. The number of spawners in 1991 were greater than previously recorded for the Naknek River. Because these data are greater than those included in the regression models, I have less confidence in the accuracy of the prediction for Naknek River. The outlook for 1996-99, based only on the spawner-recruit component of the forecast and not adjusted for average historic forecast errors, is for the total sockeye salmon run to Bristol Bay to be highest in 1996 and lowest in 1998. 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; Appendix A.1). ADF&G biologists use forecasts to (1) estimate commercial harvests, (2) set quotas for the Shumagin Islands-South Unimak June fishery (ADF&G 1992), and (3) determine which stocks may need protection against possible overharvesting. Seafood buyers and processors use forecasts to (1) estimate the supply of raw fish available for various uses, (2) determine staff and equipment needed for production of fresh, frozen, and canned products, and (3) 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.

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 1961-82 (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, 1987). However, these forecasts did not prove to be 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 19 of the last 20 years (Fried et al. 1988; Appendix A.1).

Methods used to calculate run size predictions were modified again in 1988 in an attempt to remedy these problems (Fried et al. 1988; Fried and Cross 1988, 1990). The omission of data prior to the 1978 return year from all calculations was the most important change in forecast methods. It was felt that models based on 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 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 (10 out of the last 12 years). Since 1991 Cross et al. (1992, 1993, 1994) and Cross (1994, 1995) adjusted the forecast to correct the continuing bias of under-forecasting. Several bias correction factors were evaluated in search of the most accurate forecast (Cross et al. 1993). The goal was an unbiased forecast without any tendency to over- or under-forecast. In 1996 I continued to analyze bias correction factors, and methods used were similar to those for the 1992-95 forecasts.

The purpose of this report is to provide a final preseason forecast of sockeye salmon returning to Bristol Bay, Alaska, in 1996 with an outlook of abundance fluctuations through 1999. Specific objectives are to (1) document changes in methods used to forecast Bristol Bay sockeye salmon runs in 1996, (2) evaluate the relative accuracy of different forecasting methods, (3) forecast annual runs for all

major river systems through 1999, and (4) 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 saltwater are indicated to the left and right of a decimal point. Historically, four age classes account for about 99% of total returns: 23% were age 1.2, 43% were age 2.2, 21% were age 1.3, and 12% were age 2.3. 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, Nushagak, 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. Estimates of numbers of spawners and recruits by age for brood years 1956-95 are documented in the 1995 Bristol Bay annual management report (ADF&G 1996). Estimates of numbers of smolt by year are taken from Crawford and Cross 1996.

Predictions for the Nushagak River drainage have only been made since 1992. Prior to 1992, forecasts were made for Nuyakuk River, a major tributary of the Nushagak River. A sonar project to count adult salmon entering the Nushagak River mainstem has operated since 1979. The 1996 forecast for Nushagak River was calculated from spawner-recruit and sibling models built from 1982-95 escapement-return 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 averaged for the forecast (Fried and Yuen 1986, 1987).

Forecasts for 1996 were calculated using only data from the 1978 return year onward (referred to as the Recent Data 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):

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

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: $\beta = 0$, $\rho > 0.25$; Snedecor and Cochran 1969), a linear regression model based on natural logarithm transformed data was used:

$$\ln(R_{a,r,y}) = \alpha + \beta \ln(E_{r,y}) + \varepsilon. \qquad 2$$

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):

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

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 four of the nine forecasted river systems. Smolt enumeration programs using sonar equipment were begun in 1971 for Kvichak (Russell 1972), 1982 for Egegik (Bue 1984), and 1983 for Ugashik (Fried et al. 1987) River systems. A smolt sonar project operated on the Naknek River from 1982-86 and 1993-94 (Crawford and Cross 1995).

Results from models were excluded from final forecast calculations if the model was not significant at the 25% level ($\rho > 0.25$). If a model was not significant for a river system age class, the 1978-95 mean return of that age class to that river system was used as the prediction. In past years, results from models were also excluded if the input variable ($E_{r,y}$ or $S_{j,r,y}$) was outside the range of data used to build the model. However, results from regression models in which the input data were out-of-range were used in 1996.

Because spawners are the most removed in time from returns, I decided to investigate whether predictions would be more accurate by not including spawner-return predictions for rivers in which I had sibling and smolt information (Kvichak, Egegik, and Ugashik). The accuracies of hindcasts for 1984-95 which averaged estimates from spawner-return, sibling-return, and smolt-return models were compared to those which only included estimates from sibling-return and smolt-return models.

Evaluation of Forecast Performance

Comparison of Recent and All Data Forecasts

Since the Recent Data 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 past performance for several years. Due to the limited amount of data available (all data prior to the 1978 return year were omitted from analyses), Recent Data method hindcasts could be calculated for only 12 years, 1984-95. Hindcasts prior to 1984 could not be calculated because models were not significant at the 25% level ($\rho > 0.25$).

Recent Data method hindcasts for 1984-95 were compared with All Data method hindcasts for the 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:

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

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:

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

where:

N = number of years.

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

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

Modeling Historic Forecast Errors

In an effort to reduce the tendency to under-forecast Bristol Bay runs, I looked at ways to model historic forecast errors and develop bias adjustment factors for the 1991-95 predictions (Cross et al. 1992, 1993, 1994, and Cross 1994, 1995). Based on results from these investigations I limited my analysis for the 1996 forecast to looking at trends in forecast errors for predictions based on Recent Data. Adjustment factors for the 1996 individual river predictions were estimated by taking the mean percent error from 1984-95. I decided to adjust each individual river's forecast by its own average forecast error because the errors have varied considerably among rivers. I was concerned that using one adjustment for the entire eastside or westside of Bristol Bay would result in overforecasting some systems (Kvichak River) while under forecasting other systems (Egegik River).

I also compared the performance of adjusting Kvichak River's predictions by the 1984-95 mean forecast error versus adjusting it by the mean error for peak-cycle (1984, 1985, 1989, 1990, 1994, 1995) and off-cycle (1986, 1987, 1988, 1991, 1992, 1993) years.

Confidence Intervals

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

$$80\%CI = F \pm t_{0.2} S_F \qquad 7$$

where:

F = forecasted total run of sockeye salmon to all of Bristol Bay (total of river system predictions) in 1996,

S_F = standard error of the forecasted total run of sockeye salmon to Bristol Bay in 1996, and

$t_{0.2}$ = Student's t value with a probability of type I error of 0.20, and N-1 df.

Estimation of (S_F) was based on the mean squared error (MSE) calculated from 1984-95 total run predictions using the same techniques as 1996:

$$S_F = \sqrt{MSE}, \qquad 8$$

$$MSE = \frac{\sum_{i=1}^{N} (F_i - A_i)^2}{N - 1} \qquad 9$$

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 (1984-95).

Outlook to 1999

Forecasts were made for 1997, 1998, and 1999 using only spawner-recruit data (Equation 1 or 2). These forecasts were not adjusted for historic forecast errors.

RESULTS

Forecast Data Base

Kvichak River's forecasts which included spawner-recruit estimates had better accuracies and precision than those which excluded the data, while Egegik and Ugashik Rivers' forecasts had worse or similar accuracies and precision. The 1984-95 MPE and MAPE for Kvichak predictions which included spawner-recruit estimates were 0.9 and 52.5, compared to 1.3 and 57.1 for predictions with no spawner-recruit estimates (Table 1). Egegik predictions which excluded spawner-recruit data were more accurate (MAPE = 23.8) and precise (MPE = -27.4) than predictions which included the information (MAPE = 38.8, MPE = -38.8). Ugashik River predictions which included spawner-recruit data had a 1984-95 MPE and MAPE of -14.1 and 34.2 compared to a MPE of -22.0 and a MAPE of 27.7 for predictions which excluded the data. Additionally, the number of spawners in Egegik River in 1990 and 1991, parent years for the five-year and six-year-old returns, were greater than previously recorded. Ugashik River spawners in 1991 and 1992, parent years for the four-year and five-year-old returns, were the second and third highest on record. Because the relationship of increasing spawners to returns has not been well described, and results from hindcasting indicated that spawner-recruit information did not improve Egegik and Ugashik River's forecast performance, I decided not to include spawner-recruit estimates in the 1996 Egegik and Ugashik Rivers predictions. I did include spawner-recruit estimates for the 1996 Kvichak prediction based on the fact that forecast performance had been enhanced in the past by its inclusion and parent year spawners were within historic ranges.

Performance of Recent and All Data Forecasts

Justification for use of the Recent Data method was based on the observation that the number of returning adults produced per spawner has increased dramatically 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 under-forecasting bias of annual runs. If results for 1984-95 are representative of future performance, then forecasts of total sockeye salmon returns to Bristol Bay based on the Recent Data method should be less biased (MPE = -24.6) and more accurate

(MAPE = 29.1) than forecasts based on the All Data method (MPE = -46.0; MAPE = 46.0; Appendix B.1).

Unfortunately, the All Data method was more accurate than the Recent Data method for Wood, Igushik, Nuyakuk/Nushagak, and Togiak Rivers based on the 1984-95 average errors (Appendix B.1). However, the All Data method performed better than the Recent Data method for westside systems only during the earlier years (1984-86); while Recent Data forecasts were more accurate and less biased during 1987-95. The 1987-95 MPE and MAPE for combined westside systems was 4.2 and 24.2 for the Recent Data method and -31.4 and 31.4 for the All Data method. Because the Recent Data method performed better for the more recent years, I decided to use only Recent Data in our 1996 projections for all Bristol Bay rivers.

Out-Of-Range Data

Branch and Naknek Rivers were the only systems which had input variables (siblings and parent escapement) which were outside the data ranges used to build the model. The number of age-2.2 returns to Branch River in 1995 which are the siblings to the age-2.3 returns in 1996 were greater than previously recorded. The 1991 Naknek escapement or parent year for 1996 age-1.3 and age-2.2 returns was also greater than previously recorded. Although there is a high degree of uncertainty when a model is used to predict an outcome outside its existing values, I felt that using the out-of-range input variables in the regression models was preferable to excluding the information.

Unadjusted River System Forecasts

Kvichak River

Spawner-recruit, sibling, and smolt data bases were available for estimating Kvichak River run sizes in 1996.

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 was not made because no age-1.1 sockeye salmon were present in samples collected from the Kvichak River in 1995. The spawner-recruit estimate of 3,025,000 was 12% greater than the smolt estimate of 2,705,000. The average of the two estimates was 2,865,000 sockeye salmon.

Age 2.2. The age-2.2 forecast was based upon spawner-recruit, sibling, and smolt data (Appendix C.1). The spawner-recruit estimate of 4,295,000 was 46% greater than the smolt estimate of 2,944,000 which was 384% greater than the sibling estimate of 608,000. The average of the three estimates was 2,616,000 sockeye salmon.

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 1,807,000 was 33% greater than the sibling estimate of 1,349,000 and 79% greater than the smolt estimate of 1,007,000. The average of the three estimates was 1,388,000 sockeye salmon.

Age 2.3. The age-2.3 forecast was based upon spawner-recruit, sibling, and smolt data (Appendix C.1). The sibling estimate of 1,464,000 was about 14% greater than the smolt estimate of 1,279,000, and 32% greater than the spawner-recruit estimate of 1,113,000. The average of the three estimates was 1,285,000 sockeye salmon.

Branch River

Spawner-recruit and sibling data bases were available for estimating Branch River run sizes in 1996. There has never been a smolt project on the Branch River.

Age 1.2. The age-1.2 forecast was based upon spawner-recruit and sibling data (Appendix C.2). The spawner-recruit estimate of 215,000 was similar to the sibling estimate of 200,000. The average of the two estimates was 208,000 sockeye salmon.

Age 2.2. The age-2.2 forecast was based on the 1978-95 mean return of age-2.2 sockeye salmon (Appendix C.2). Predictions based on spawner-recruit and sibling data were not used because the regression models were not significant at the 25% level ($\rho > 0.25$). The mean return estimate was 90,000 sockeye salmon.

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 because the model was not significant at the 25% level ($P > 0.25$). The spawner-recruit estimate was 119,000 sockeye salmon.

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 because the model was not significant at the 25% level ($\rho > 0.25$). The sibling estimate was 33,000 sockeye salmon.

Naknek River

Spawner-recruit, sibling, and smolt data bases were available for estimating Naknek River run sizes in 1996. The smolt project on the Naknek River operated from 1982-86 and again in 1993-94.

Age 1.2. The age-1.2 forecast was based only on spawner-recruit data (Appendix C.3). A prediction based on sibling data was not made because no age-1.1 sockeye salmon were present in samples collected from the Naknek River in 1995. A prediction based on smolt data was not used because the

model was not significant at the 25% level. The spawner-recruit estimates was 522,000 sockeye salmon.

Age 2.2. The age-2.2 forecast was based only upon spawner-recruit data (Appendix C.3). Predictions based on sibling and smolt data were not used because models were not significant at the 25% level ($\rho > 0.25$). The spawner-recruit estimate was 1,416,000 sockeye salmon.

Age 1.3. The age-1.3 forecast was based on spawner-recruit, sibling, and smolt data (Appendix C.3). The spawner-recruit estimate of 3,234,000 was 112% greater than the sibling estimate of 1,529,000, and 203% greater than the smolt estimate of 1,066,000. The average of the three estimates was 1,943,000 sockeye salmon.

Age 2.3. The age-2.3 forecast was based on spawner-recruit, sibling, and smolt data (Appendix C.3). The spawner-recruit estimate of 1,267,000 was similar to the sibling estimate of 1,196,000, and 75% greater than the smolt estimate of 724,000. The average of the three estimates was 1,062,000 sockeye salmon.

Egegik River

Spawner-recruit, sibling, and smolt data bases were available for estimating 1996 Egegik River run sizes. However, spawner-recruit information was not used for the final 1996 Egegik prediction. Evaluation of past forecast performance indicated that Egegik predictions were more accurate and less bias if spawner-recruit data were not incorporated.

Age 1.2. The age-1.2 forecast was based only smolt data (Appendix C.4). A prediction based on sibling data was not made because no age-1.1 sockeye salmon were present in samples collected from the Egegik River in 1995. The smolt estimates was 1,255,000 sockeye salmon.

Age 2.2. The age-2.2 forecast was based upon sibling and smolt data (Appendix C.4). The smolt estimate of 6,197,000 was 62% greater than the sibling estimate of 3,817,000. The average of the two estimates was 5,007,000 sockeye salmon.

Age 1.3. The age-1.3 forecast was based upon sibling and smolt data (Appendix C.4). The sibling estimate of 2,910,000 was 52% greater than the smolt estimate of 1,919,000. The average of the two estimates was 2,415,000 sockeye salmon.

Age 2.3. The age-2.3 forecast for this system was based upon sibling and smolt data (Appendix C.4). The sibling estimate of 4,345,000 was 13% greater than the smolt estimate of 3,834,000. The average of the two estimates was 4,090,000 sockeye salmon.

Ugashik River

Spawner-recruit, sibling, and smolt data bases were available for estimating 1996 Ugashik River run sizes. However, spawner-recruit information was not used for the final 1996 Ugashik prediction. Evaluation of past forecast performance indicated that Ugashik predictions which omitted spawner-recruit information had similar average performances compared to those which included spawner-recruit data. In addition, Ugashik spawners in 1990 and 1991 were the second and third highest on record.

Age 1.2. The age-1.2 forecast was based only upon data (Appendix C.5). The prediction based on smolt data was not used because the model was not significant at the 25% level ($\rho > 0.25$). The sibling estimate was 996,000 sockeye salmon.

Age 2.2. The age-2.2 forecast was based only upon sibling data (Appendix C.5). The prediction based on smolt data was not used because the model was not significant at the 25% level ($P > 0.25$). The sibling estimate 1,020,000 sockeye salmon.

Age 1.3. The age-1.3 forecast was based upon sibling and smolt data (Appendix C.5). The sibling estimate of 1,961,000 was 78% greater than the smolt estimate of 1,100,000. The average of the two estimates was 1,531,000 sockeye salmon.

Age 2.3. The age-2.3 forecast was based only upon sibling data (Appendix C.5). The prediction based on smolt data was not used because the model was not significant at the 25% level ($\rho > 0.25$). The sibling estimates was 893,000 sockeye salmon.

Wood River

Spawner-recruit and sibling data bases were available for estimating Wood River run sizes in 1996. Smolt emigrating from the Wood River were last counted in 1990.

Age 1.2. The age-1.2 forecast was based upon spawner-recruit and sibling data (Appendix C.6). The spawner-recruit estimate of 1,424,000 was 15% greater than the sibling estimate of 1,243,000. The average of the two estimates was 1,334,000 sockeye salmon.

Age 2.2. The age-2.2 forecast was based on the 1978-95 mean return of age-2.2 sockeye salmon to Wood River (Appendix C.6). The prediction based on spawner-recruit data was not used because the model was not significant at the 25% level ($\rho > 0.25$). A prediction based on sibling information was not made because no age-2.1 sockeye salmon were present in samples taken from Wood River in 1995. The mean return estimate was 179,000 sockeye salmon.

Age 1.3. The age-1.3 forecast was based upon spawner-recruit and sibling data (Appendix C.6). The sibling estimate of 1,761,000 was 13% greater than the spawner-recruit estimate of 1,556,000. The average of the two estimates was 1,659,000 sockeye salmon.

Age 2.3. The age-2.3 forecast was based only upon sibling data (Appendix C.6). The prediction based on spawner-recruit data was not used because the model was not significant at the 25% level ($\rho > 0.25$). The sibling estimate was 106,000 sockeye salmon.

Igushik River

Spawner-recruit and sibling data bases were available for estimating Igushik River run sizes in 1996. 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 because no age-1.1 sockeye salmon were present in samples collected from Igushik River in 1995. The spawner-recruit estimate was 267,000 sockeye salmon.

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 present in samples collected from Igushik River in 1995. The spawner-recruit estimate was 49,000 sockeye salmon.

Age 1.3. The age-1.3 forecast was based upon spawner-recruit and sibling data (Appendix C.7). The spawner-recruit estimate of 919,000 was similar to the sibling estimate of 997,000. The average of the two estimates was 958,000 sockeye salmon.

Age 2.3. The age-2.3 forecast was based upon spawner-recruit and sibling data (Appendix C.7). The sibling estimate of 80,000 was 67% greater than the spawner-recruit estimate of 48,000. The average of the two estimates was 64,000 sockeye salmon.

Nushagak River

Reliable age information for sockeye salmon returning to Nushagak River was available from 1982-95 return years. Spawner-recruit and sibling data bases from 1982-95 return years were used to predict Nushagak River run sizes in 1996.

Age 0.2. The age-0.2 forecast was based only upon spawner-recruit data (Appendix C.8). A prediction based on sibling data could not be made because no age-0.1 sockeye salmon were present in samples collected from Nushagak River in 1995. The spawner-recruit estimate was 46,000 sockeye salmon.

Age 1.2. The age-1.2 forecast was based only upon results from spawner-recruit data (Appendix C.8). A prediction based on sibling data was not made because no age-1.1 sockeye salmon were present in samples collected from Nushagak River in 1995. The spawner-recruit estimate was 125,000 sockeye salmon.

Age 2.2. The age-2.2 forecast was based only upon results from spawner-recruit data (Appendix C.8). A prediction based on sibling data was not made because no age-2.1 sockeye salmon were present in samples collected from Nushagak River in 1995. The spawner-recruit estimate was 5,000 sockeye salmon.

Age 0.3. The age-0.3 forecast was based on spawner-recruit and sibling data bases (Appendix C.8). The sibling estimate of 681,000 was 38% greater than the spawner-recruit estimate of 495,000. The average of the two estimates was 588,000 sockeye salmon.

Age 1.3. The age-1.3 forecast was based upon spawner-recruit and sibling data (Appendix C.8). The sibling estimate of 849,000 was 17% greater than the spawner-recruit estimate of 726,000. The average of the two estimates was 788,000 sockeye salmon.

Age 2.3. The age-2.3 forecast was based upon spawner-recruit and sibling data (Appendix C.8). The spawner-recruit estimate of 16,000 was the same as the sibling estimate, therefore the average of the two estimates was 16,000 sockeye salmon.

Age 0.4. The age-0.4 forecast was based on spawner-recruit and sibling data bases (Appendix C.8). The spawner-recruit estimate of 59,000 was 247% greater than the sibling estimate of 17,000. The average of the two estimates was 38,000 sockeye salmon.

Togiak River

Spawner-recruit and sibling data bases were available for estimating Togiak River run sizes in 1996. A smolt project was operated on Togiak River only in 1988.

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 because no age-1.1 sockeye salmon were present in samples collected from Togiak River in 1995. The spawner-recruit estimate was 131,000 sockeye salmon.

Age 2.2. The age-2.2 forecast was based only on spawner-recruit data (Appendix C.9). A prediction based on sibling data was not made because no age-2.1 sockeye salmon were present in 1995 Togiak River samples. The spawner-recruit estimate was 26,000 sockeye salmon.

Age 1.3. The age-1.3 forecast was based on spawner-recruit and sibling data (Appendix C.9). The sibling estimate of 482,000 was 21% greater than the spawner-recruit estimate of 397,000. The average of the two estimates was 440,000 sockeye salmon.

Age 2.3. The age-2.3 forecast for this system was based on spawner-recruit and sibling data (Appendix C.9). The sibling estimate of 67,000 was 76% greater than the spawner-recruit estimate of 38,000. The average of the two estimates was 53,000 sockeye salmon.

1996 Individual Rivers' Forecast Adjustments

Kvichak River

Errors in Kvichak River forecasts based on Recent Data varied considerably from 1984-95 (Figure 2). Predictions for pre-peak and peak cycle years (1984-85, 1989-90, 1994, 1995) generally under-forecasted the actual run more than predictions for off-cycle years (1986-87, 1991-93). I compared adjustments based on the 1984-95 average error to an adjustment based on cycle year errors (average pre-peak and peak year error and an average off-cycle error). Predictions adjusted by the 1984-95 error had an 1990-95 average error of -9% and an average absolute error of 22%, while predictions adjusted by cycle years errors had a 1990-95 average error of -9% and an average absolute error of 12%. The average precision were the same between the cycle year adjusted forecasts and the average error adjusted forecasts. However, the accuracy was higher for the cycle year adjusted forecasts compared to the average error adjusted forecasts. I decided to use the cycle error adjustment because the accuracy was 10% higher.

The 1996 unadjusted prediction for Kvichak River was 8.1 million. The estimated error for the 1996 prediction based on cycle year errors was -1.1 million fish (Table 2). Using cycle year errors to adjust Kvichak River forecasts improved the forecast performance for all years tested (1990-95) except during 1993 (Figure 2). The 1990-95 average error for Kvichak River forecasts was reduced from -44% to -9% by adjusting for previous cycle years average error.

Branch River

Errors in Branch River forecasts based on Recent Data showed a trend of being increasingly negative from 1984-95 (Figure 3). The 1996 unadjusted prediction for Branch River was 0.4 million. The estimated error for the 1996 prediction based on average errors was -0.3 million fish (Table 2). The 1987-95 mean error for Branch River forecasts was similar for unadjusted (-38%) and adjusted (-34%) forecasts (Figure 3). Although the 1987-95 average error was similar for adjusted forecasts, errors for all years except 1989 and 1990 were reduced.

Naknek River

Errors in Naknek River forecasts based on Recent Data showed no trend from 1984-95 (Figure 4). The 1996 unadjusted prediction for Naknek River was 4.9 million. The estimated error for the 1996 prediction based on average errors was -0.9 million fish (Table 2). The 1987-95 average error for Naknek River forecasts increased slightly from -30% to -31% by adjusting for previous years average error (Figure 4). I decided not to adjust the 1996 Naknek River forecast because the overall accuracy and precision did not improve, especially during the past two years.

Egegik River

Egegik River forecasts based on Recent Data and no spawner-recruit data were less than observed runs for all years except 1986 and 1994 (Figure 5). The 1996 unadjusted prediction for Egegik River was 12.8 million. The estimated error for the 1996 prediction based on average errors was -5.3 million fish (Table 2). Using average errors to adjust forecasts for Egegik River resulted in over-forecasts in 1987, 1988, 1991 and 1994 and under-forecasts in 1989, 1990, 1992, 1993, and 1995 (Figure 5). The 1987-95 average error for Egegik River forecasts was reduced from -47% to -13% by adjusting for previous years average error.

Ugashik River

Ugashik River forecasts based on Recent Data were generally less than actual runs from 1984-95 (Figure 6). The 1996 unadjusted prediction for Ugashik River was 4.4 million. The estimated error for the 1996 prediction based on average errors was -2.2 million fish (Table 2). The 1987-95 average error for Ugashik River forecasts was reduced from -40% to 7% by adjusting for previous years average error (Figure 6).

Wood River

Errors in Wood River forecasts based on Recent Data were positive from 1984-86, however the magnitude of the errors has been reduced in recent years (Figure 7). The 1996 unadjusted prediction for Wood River was 3.3 million. The estimated error for the 1996 prediction based on average errors was 0.3 million fish (Table 2). I did not adjust the 1996 Wood River forecast because the 1987-95 average error of the Recent Data forecasts was only -6%, while errors for adjusted forecasts averaged -52% (Figure 7).

Igushik River

Igushik River forecast errors based on Recent Data were positive from 1984-88, however in recent years errors have been either negative or slightly positive (Figure 8). The 1996 unadjusted prediction for Igushik River was 1.3 million. The estimated error for the 1996 prediction based on average errors was 0.1 million fish (Table 2). I did not adjust the 1996 Igushik River forecast because the 1987-95 average error of the Recent Data forecasts was only -14%, while errors for adjusted forecasts averaged -84% (Figure 8).

Nushagak River

Errors in Nushagak River forecasts based on spawner-recruit data from 1982-95 showed no clear trend from 1990-95 (Figure 9). The 1996 unadjusted prediction for Nushagak River was 1.6 million. The estimated error for the 1996 prediction based on average errors was -0.2 million (Table 2). I did not adjust the 1996 Nushagak River forecast because the 1993-95 average error of the unadjusted predictions was only -5% while the average error of the adjusted predictions was 17% (Figure 9).

Togiak River

Errors in Togiak River forecasts based on Recent Data showed no clear trend from 1984-95 (Figure 10). The 1996 unadjusted prediction for Togiak River was 0.6 million. The estimated error for the 1996 prediction based on average errors was 15 thousand fish (Table 2). I did not adjust the 1996 Togiak River forecast because the 1987-95 average error of the unadjusted forecasts was only -10%, while errors for adjusted forecasts averaged -40% (Figure 10).

1996 Forecast Adjustments

I used only Recent Data (1978-95) to forecast all Bristol Bay systems. I also adjusted individual eastside rivers forecasts by their average forecast errors, but did not adjust forecasts for Naknek River or westside systems. The 1996 forecasts by eastside river were increased by: 13.4% for Kvichak, 52% for Branch, 41.8% for Egegik, and 49.7% for Ugashik River.

Adjusted Total Bristol Bay Forecast

Based on results of the Recent Data method adjusted by individual rivers 1984-95 average percent error, a total of 46,495,000 sockeye salmon (80% CI: 33,939,000 - 59,051,000) are expected to return to Bristol Bay in 1996 (Table 3). A run of this size would be the ninth highest run since 1956, the first year of total run information. The 1996 prediction is 20% (7,687,000 sockeye salmon) greater than the

20-year (1976-95) mean return of 38,808,,000 (range: 10,671,000 - 66,293,000), and about 7% (3,156,000) greater than the most recent 10-year (1986-95) mean return of 43,339,000 (range: 23,996,000 - 62,825,000).

Total projected sockeye salmon harvest is 37,710,000 (80% CI: 25,154,000 - 50,266,000; Table 3). Most (34,581,000) of this harvest will be taken within Bristol Bay inshore fishing districts (Table 4). The remainder of the sockeye harvest (8.3% of total Bristol Bay harvest = 3,130,000) 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 1995). 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 43,365,000 (Table 4). Runs should exceed spawning escapement goals for all river systems. The projected Bristol Bay combined fishing district harvest of 34,581,000 would be 45% (10,680,000) greater than the 20-year (1976-95) mean harvest of 23,901,000 (range: 4,878,000 - 44,427,000), and 21% (5,990,000) greater than the 10-year (1986-95) mean harvest of 28,591,000 (range: 13,990,000 - 44,427,000).

Adjusted River System Forecasts

Kvichak River

A total of 9,248,000 sockeye salmon were forecasted to return to this system (Table 4). Sockeye salmon production within Kvichak River has followed a five-year abundance cycle (Mathisen and Poe 1981). A return of 9,248,000 sockeye salmon to the Kvichak River system in 1996, a year following the peak year, would be 25% greater than the mean return of 7,426,000 sockeye salmon (range: 2,025,000 -14,279,000) observed during past "post-peak" years (1961, 1966, 1971, 1976, 1981, 1986, 1991). Age-1.2 and age-2.2 sockeye salmon comprised 35% and 32% of the forecasted Kvichak River return (Table 3).

Branch River

A total of 684,000 sockeye salmon were forecasted to return to this system (Table 4). A total run of this size would be 24% greater than the mean return of 550,000 for 1986-1995 (range: 308,000 - 862,000), and about 35% greater than the mean return of 506,000 for 1976-1995 (range: 152,000 - 862,000). Age-1.2 and age-1.3 comprised 46% and 26% of the Branch River forecast (Table 3).

Naknek River

A total of 4,943,000 sockeye salmon were forecasted to return to this system (Table 4). A total run of this size would be similar to the mean return of 4,770,000 for 1986-95 (range: 1,796,000 - 10,353,000) and 13% greater than the mean return of 4,363,000 for 1976-95 (range: 1,796,000 - 10,353,000). Age-1.3 and age-2.2 comprised 39% and 29% of the Naknek River forecast (Table 3).

Egegik River

A total of 18,106,000 sockeye salmon were forecasted to return to this system (Table 4). A total run of this size would be about 42% greater than the mean return of 12,760,000 for 1986-95 (range: 6,175,000 - 24,687,000), but about 107% greater than the mean return of 8,749,000 for 1976-95 (range: 2,031,000 - 24,687,000). The 1996 Egegik River forecast was 53% age-2.2 and 28% age-2.3 sockeye salmon (Table 3).

Ugashik River

A total of 6,645,000 sockeye salmon were forecasted to return to this system (Table 4). A total run of this size would be about 36% greater than the mean return of 4,867,000 for 1986-95 (range: 2,256,000 - 6,020,000) and about 68% greater than the mean return of 3,958,000 for 1976-95 (range: 95,000 - 7,875,000). Age-2.2 and age-1.3 sockeye salmon comprised 36% and 30% of the 1996 Ugashik River forecast (Table 3).

Wood River

A total of 3,277,000 sockeye salmon were forecasted to return to this system (Table 4). A total run of this size would be 12% greater than the mean return of 2,935,000 for 1986-95 (range: 1,793,000 - 4,180,000) and similar to the mean return of 3,088,000 for 1976-95 (range: 929,000 - 4,925,000). The 1996 Wood River forecast was comprised of 41% age-1.2 and 51% age-1.3 sockeye salmon (Table 3).

Igushik River

A total of 1,338,000 sockeye salmon were forecasted to return to this system (Table 4). A total run of this size would be similar to the mean return of 1,300,000 for 1986-95 (range: 415,000 - 2,573,000) and also similar to the mean return of 1,306,000 for 1976-95 (range: 164,000 - 3,276,000). Approximately 72% of the 1996 Igushik River forecast was comprised of age-1.3 sockeye salmon (Table 3).

Nushagak River

A total of 1,605 ,000 sockeye salmon were forecasted to return to this system (Table 4). A total run of this size would be similar to the mean return of 1,680,000 for 1986-95 (range: 800,000 - 2,362,000). The 1996 Nushagak River forecast was comprised of 49% age-1.3 and 42% zero freshwater aged sockeye salmon (Table 3).

Togiak River

A total of 649,000 sockeye salmon were forecasted to return to this system (Table 4). A total run of this size would be 5% greater than the mean return of 621,000 for 1986-95 (range: 179,000 - 1,002,000), and similar to the mean return of 658,000 for 1976-95 (range: 179,000 - 1,173,000). About 68% of the sockeye salmon forecasted to return to Togiak River in 1996 were age 1.3 (Table 3).

Expected Forecast Performance

Our best estimate of 1996 sockeye run size was based on the Recent Data method, and subsequently, forecasts for individual eastside river systems were increased by their 1984-95 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 would be most likely to occur in three areas:

River System	Most Probable Deviation from Forecasted Return	Reason for Probable Deviation
Kvichak	greater than expected return of age-2.2 sockeye salmon	Spawner-return, and smolt forecasts indicated higher returns of age-2.2 fish than sibling forecasts.
Egegik	greater than expected return of all ages of sockeye salmon.	The spawner-return relationships were not used in 1996, but they predicted greater runs than either sibling or smolt forecasts.

River System	Most Probable Deviation from Forecasted Return	Reason for Probable Deviation
Ugashik	greater than expected runs of age-12., age-2.2, and age-1.3 sockeye salmon.	The spawner-return relationships were not used in 1996, but they predicted greater runs than either sibling or smolt forecasts.

This is the sixth year ADF&G adjusted the forecast based on historic forecast errors. If the 1996 run is similar to runs occurring in the past 12 years, the forecast should be close to the actual run. If the 1996 run is below average, similar to 1986 and 1988 runs, the 1996 forecast will be too high. Other indicators that can be used to assess preseason forecast accuracy will not be available until June 1996 when the Shumagin Islands-South Unimak commercial fishery and the Port Moller offshore test fishery (operated by Fisheries Research Institute, University of Washington) take place. Catch, effort, and age composition data collected from these fisheries have been used in past years with varying degrees of success to modify preseason expectations (Eggers and Shaul 1987; Fried and Hilborn 1988; Yuen and Fried 1985).

Outlook to 1999

Comparisons of 1996-99 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 highest in 1996 and lowest in 1998 (Table 5). Runs to all river systems are not only expected to exceed escapement goals, but also produce high catches similar to the past five years. The reader is cautioned that these long-term predictions are based only on spawner-recruit data and will undoubtedly change as smolt and sibling information become available.

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Table 1. Annual percent errors, mean percent errors (MPE), and mean absolute percent errors (MAPE) for hindcasts of sockeye salmon based on Recent Data which include and exclude spawner-recruit estimates, Kvichak, Egegik and Ugashik Rivers, 1984-95.

	Percent Errors[a]					
	Kvichak		Egegik		Ugashik	
Year	Include S/R[b]	Omit S/R	Include S/R	Omit S/R	Include S/R	Omit S/R
1984	-21.7	-33.8	-34.0	-20.9	-27.7	-27.7
1985	-29.6	-8.0	-44.0	-39.7	-49.1	-57.9
1986	287.6	335.6	-36.1	19.9	-15.7	-37.5
1987	-55.9	-67.7	-27.4	-12.7	59.2	20.2
1988	33.1	14.9	-28.5	-15.7	51.9	5.4
1989	-37.6	-54.8	-44.0	-30.0	-24.3	-32.4
1990	-47.5	-51.0	-53.4	-45.7	9.6	-16.0
1991	-25.6	-19.1	-33.2	-7.9	-50.2	-60.4
1992	-12.1	-17.6	-54.8	-47.1	-41.8	-32.7
1993	-4.5	-10.7	-67.3	-52.1	-33.2	-24.5
1994	-35.6	-38.4	-3.8	3.3	-20.0	-28.0
1995	-39.5	-33.6	-29.6	-38.7	-27.4	-29.8
84-95 MPE	0.9	1.3	-38.8	-27.4	-14.1	-22.0
84-95 MAPE	52.5	57.1	38.8	23.8	34.2	27.7

[a] Percent error calculated as:
(forecast - actual return) / actual return x 100

[b] S/R stands for spawner-recruit estimates.

Table 2. Comparison of 1996 preliminary forecasts, estimated forecast errors, and adjusted forecasts based on Recent Data for individual Bristol Bay rivers.

Data Base	Method of Modeling	Millions of Sockeye Salmon		
		Original 1996 Forecast	Estimated Error 1996[a]	Adjusted 1996 Forecast
Recent Data	84-95 Avg Error			
Kvichak		8.1	-1.1	9.2
Branch		0.4	-0.3	0.7
Naknek		4.9	-0.9	Did Not Adjust
Egegik		12.8	-5.3	18.1
Ugashik		4.4	-2.2	6.6
Wood		3.3	+0.3	Did Not Adjust
Igushik		1.3	+0.1	Did Not Adjust
Nushagak		1.6	-0.2	Did Not Adjust
Togiak		0.6	+0.0	Did Not Adjust

[a] Error = (predicted - actual).

Table 3. Forecasted production, spawning escapement goals, and total projected harvests of major age classes of sockeye salmon returning to Bristol Bay river systems in 1996 based on results of the Recent Data method adjusted by individual rivers 1984-95 average percent error.

	Thousands of Sockeye Salmon							
	Forecasted Production by Age Class							
District: River	1.2	2.2	1.3	2.3	Other[a]	Total	Spawning Goal	Total Harvest
NAKNEK-KVICHAK:								
Kvichak	3,249	2,967	1,574	1,458		9,248	4,000	5,248
Branch	316	137	181	50		684	185	499
Naknek	522	1,416	1,943	1,062		4,943	1,000	3,943
Total	4,087	4,520	3,698	2,570		14,875	5,185	9,690
EGEGIK	1,147	9,689	2,234	5,036		18,106	1,000	17,106
UGASHIK	1,381	2,406	2,000	858		6,645	700	5,945
NUSHAGAK:[b]								
Wood	1,334	179	1,658	106		3,277	1,000	2,277
Igushik	267	49	958	64		1,338	200	1,138
Nushagak	125	5	787	16	672	1,605	550	1,055
Total	1,726	233	3,403	186	672	6,220	1,750	4,470
TOGIAK[c]	131	26	439	53		649	150	499
BRISTOL BAY	8,472	16,874	11,774	8,703	672	46,495	8,785	37,710

[a] Other includes zero freshwater ages (0.2, 0.3, 0.4) which are only forecasted for Nushagak River.

[b] Forecast for Snake River system was not included (1971-1991 average escapement was 18,000).

[c] Forecasts for Kulukak, Kanik, Osviak, and Matogak River systems were not included. These systems may contribute an additional 76,000 (1986-1995 mean catch) to Togiak District harvest.

Table 4. Projected commercial harvests of sockeye salmon returning to Bristol Bay river systems in 1996 based on results of the Recent Data method adjusted by individual rivers 1984-95 average percent error.

	Thousands of Sockeye Salmon				
		Shumagin	Bristol Bay		
District: River	Forecasted Total Production	Islands-S. Unimak Harvest[a]	Total Run	Spawning Goal	Harvest
NAKNEK-KVICHAK:					
Kvichak	9,248	622	8,626	4,000	4,626
Branch	684	46	638	185	453
Naknek	4,943	333	4,610	1,000	3,610
Total	14,875	1,001	13,874	5,185	8,689
EGEGIK	18,106	1,216	16,887	1,000	15,887
UGASHIK	6,645	447	6,198	700	5,498
NUSHAGAK:					
Wood	3,277	221	3,056	1,000	2,056
Igushik	1,338	90	1,248	200	1,048
Nushagak	1,605	108	1,497	550	947
Total	6,220	419	5,801	1,750	4,051
TOGIAK	649	44	605	150	455
BRISTOL BAY	46,495	3,130	43,365	8,785	34,581

[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 5. Preliminary forecasts of sockeye salmon returns to Bristol Bay, 1996-1999, based on spawner-recruit data only, and not adjusted for historic forecast errors.

DISTRICT: River	Thousands of Sockeye Salmon 1996	1997	1998	1999
NAKNEK-KVICHAK:				
Kvichak	10,240	10,435	10,711	16,743
Branch	397	446	477	469
Naknek	6,439	4,820	3,890	3,195
Total	17,076	15,701	15,078	20,407
EGEGIK	19,702	15,745	11,627	12,912
UGASHIK	7,295	7,170	5,448	4,594
NUSHAGAK:				
Wood	3,131	3,230	3,241	3,157
Igushik	1,283	1,443	1,495	1,497
Nushagak-Mulchatna	1,471	1,602	1,499	1,216
Total	5,885	6,275	6,235	5,870
TOGIAK	592	609	611	603
BRISTOL BAY	50,550	45,500	38,999	44,386

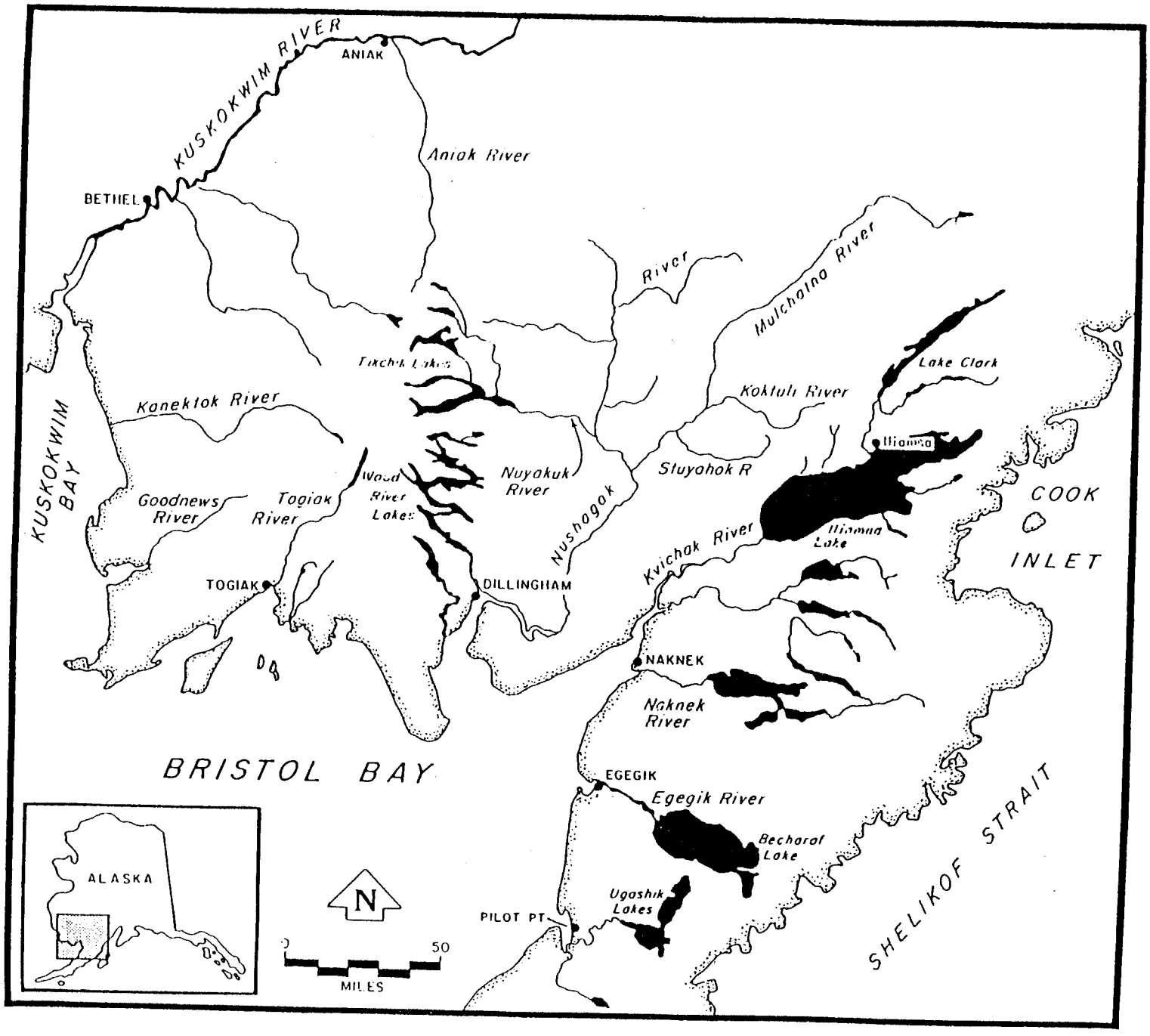


Figure 1. Map of Bristol Bay, Alaska showing major rivers.

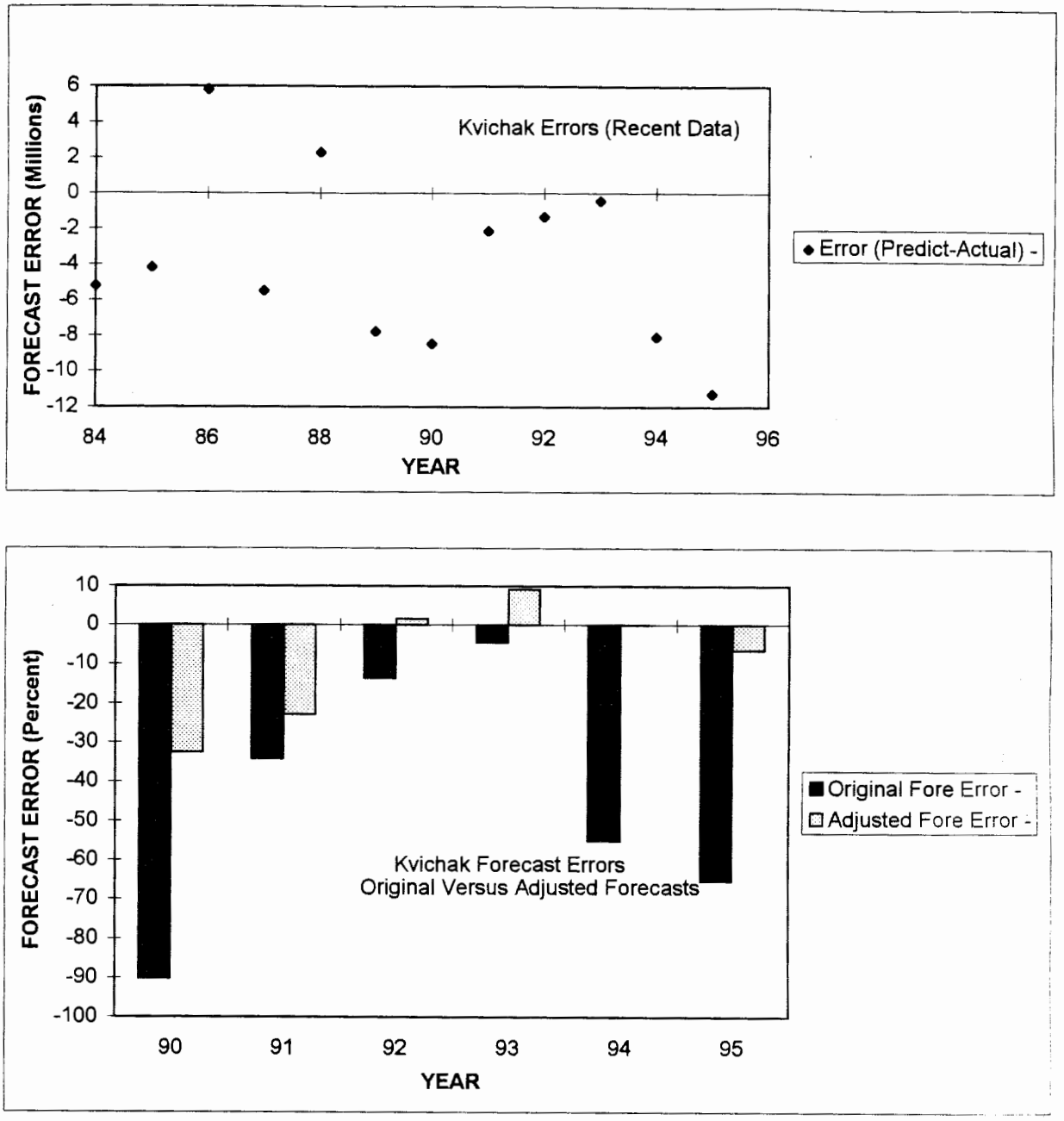
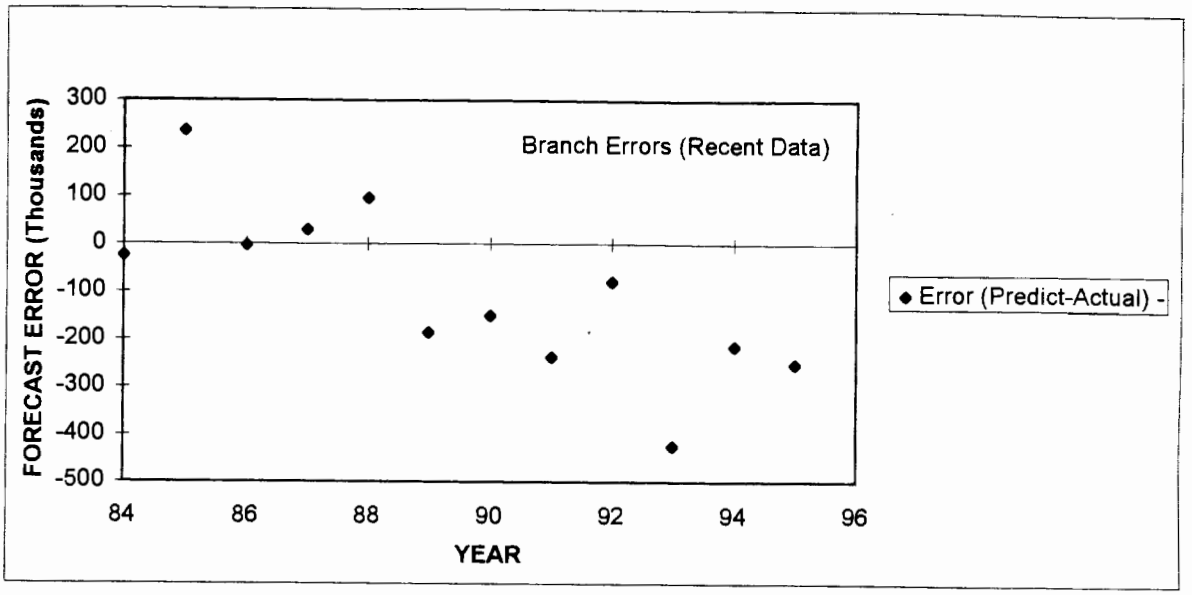


Figure 2. Errors (predicted run - actual run) of Kvichak River forecasts made with Recent Data for 1984-95 (top) and a comparison between original and adjusted forecast errors, 1990-95 (bottom).



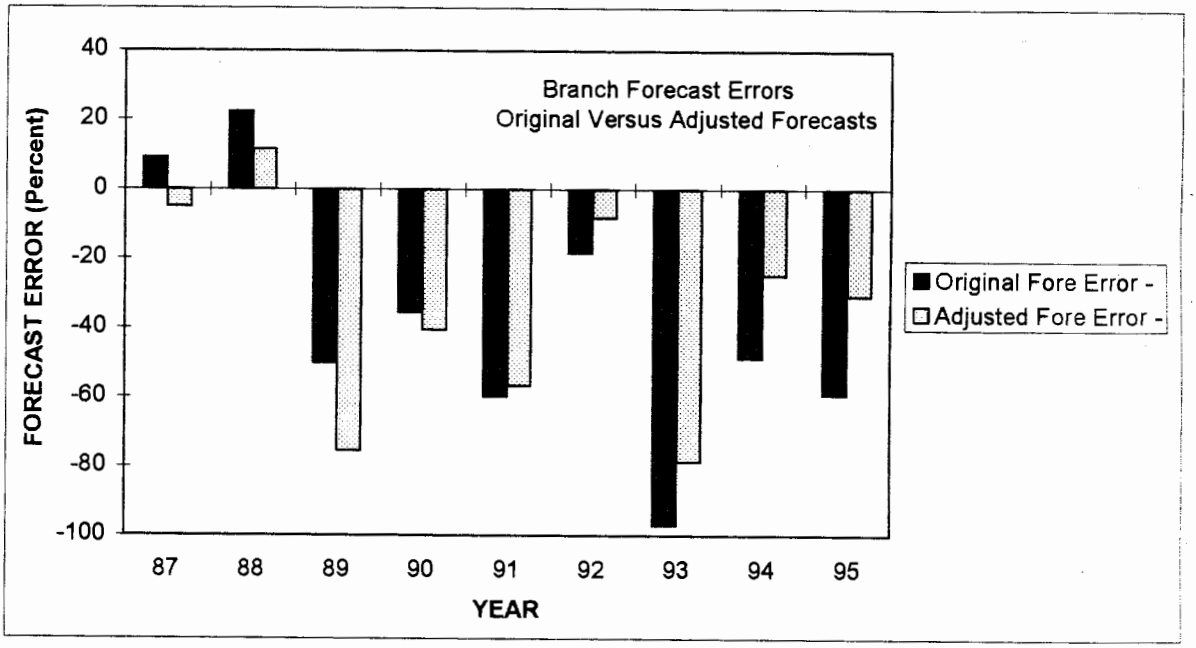


Figure 3. Errors (predicted run - actual run) of Branch River forecasts made with Recent Data for 1984-95 (top) and a comparison between original and adjusted forecast errors, 1987-95 (bottom)

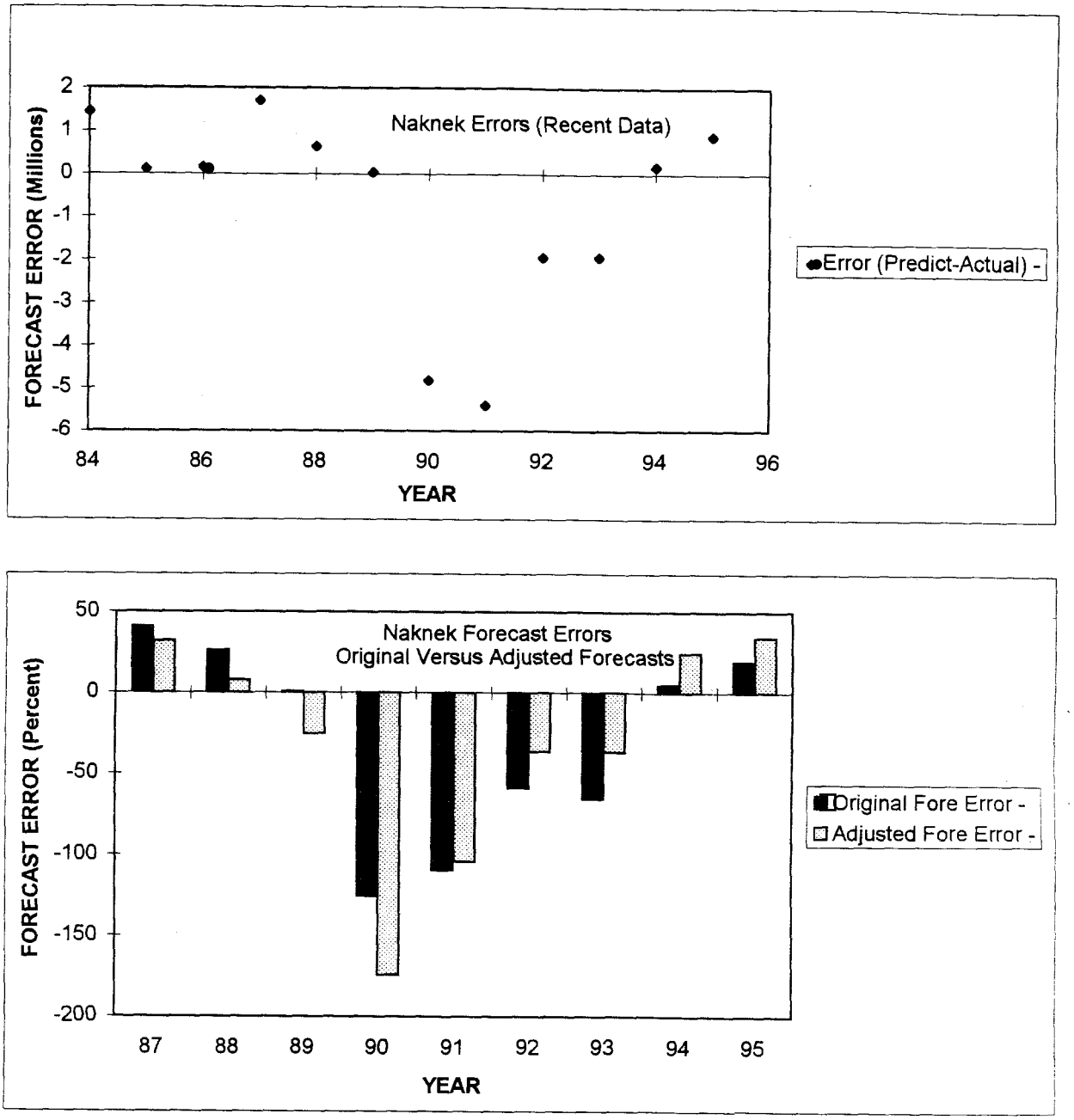


Figure 4. Errors (predicted run - actual run) of Naknek River forecasts made with Recent Data for 1984-95 (top) and a comparison between original and adjusted forecast errors, 1987-95 (bottom).

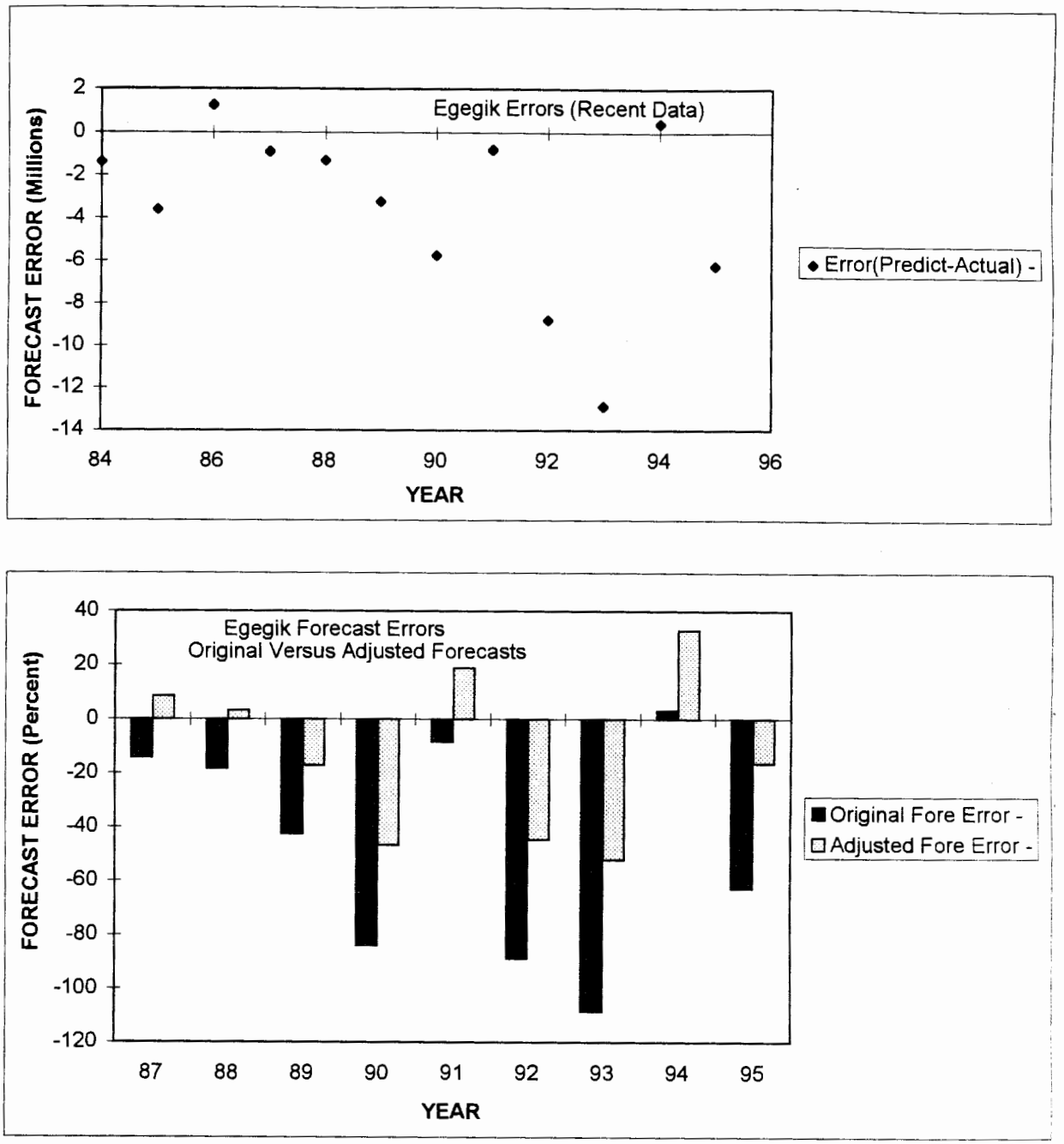


Figure 5. Errors (predicted run - actual run) of Egegik River forecasts made with Recent Data for 1984-95 (top) and a comparison between original and adjusted forecast errors, 1987-95 (bottom).

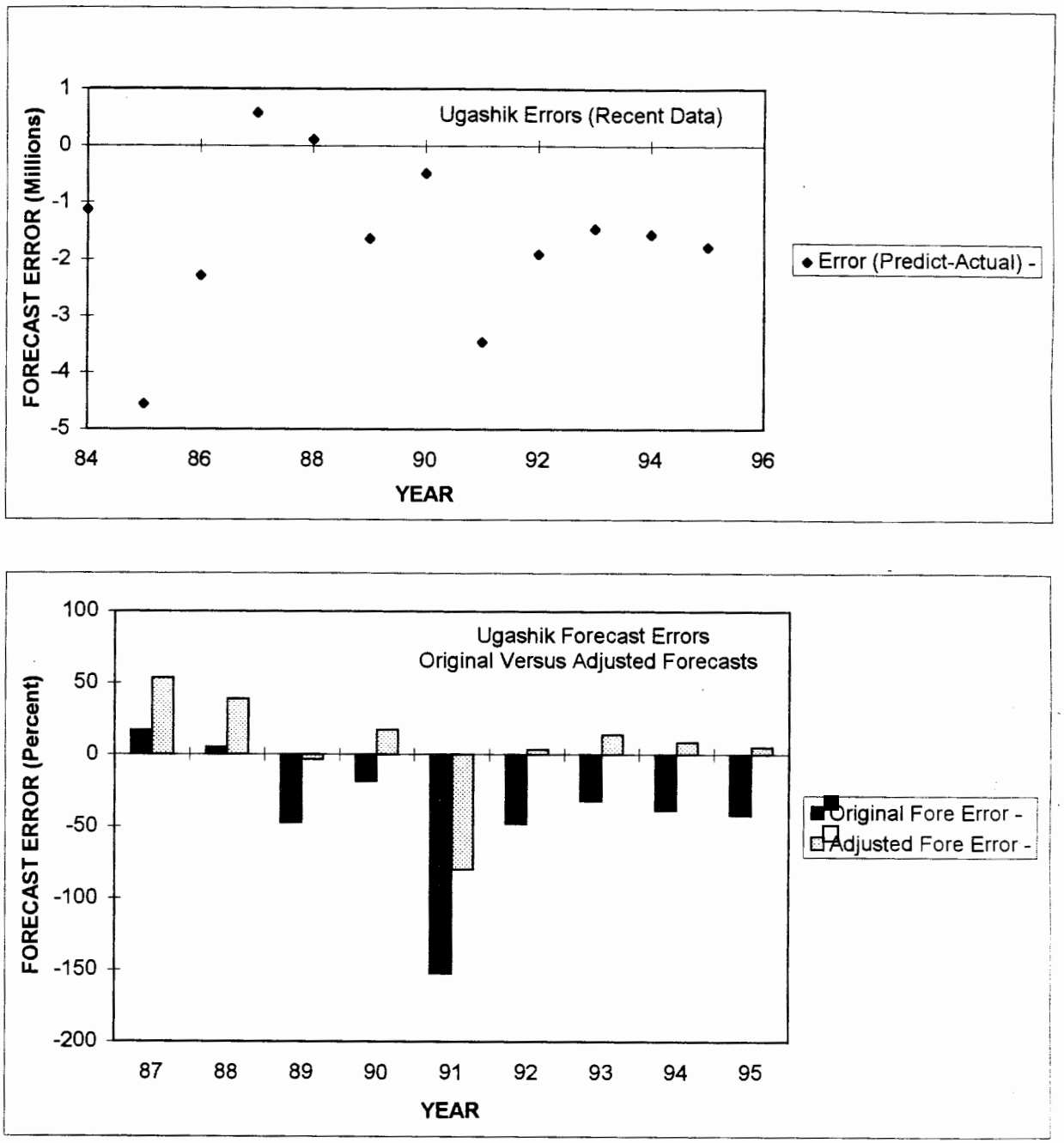
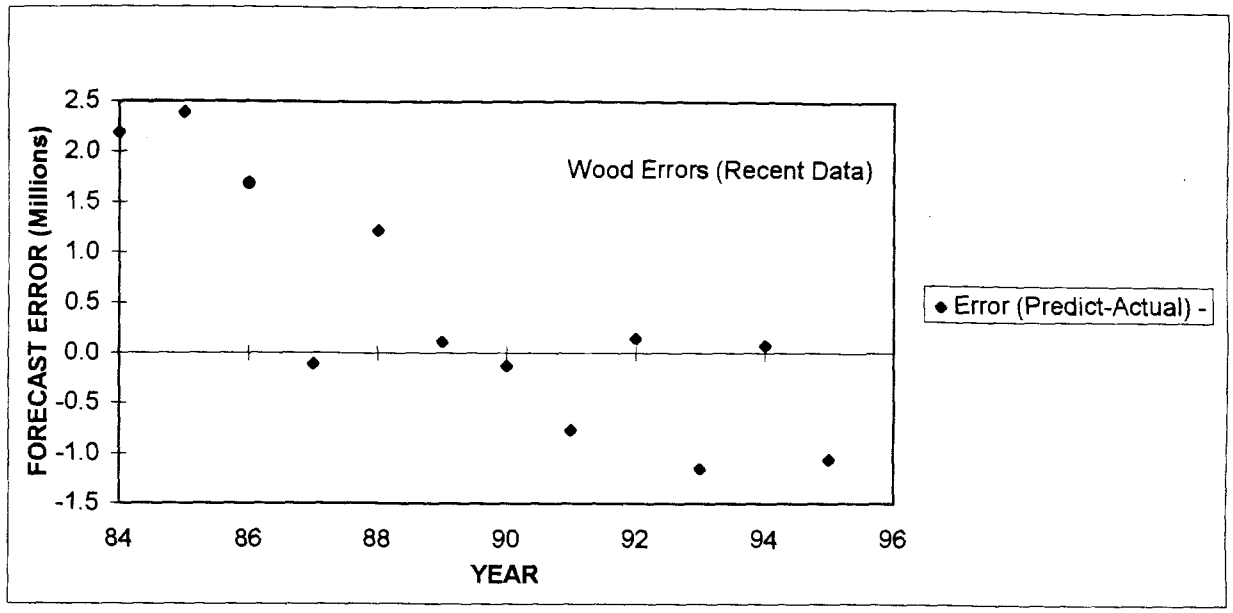


Figure 6. Errors (predicted run - actual run) of Ugashik River forecasts made with Recent Data for 1984-95 (top) and a comparison between original and adjusted forecast errors, 1987-95 (bottom).



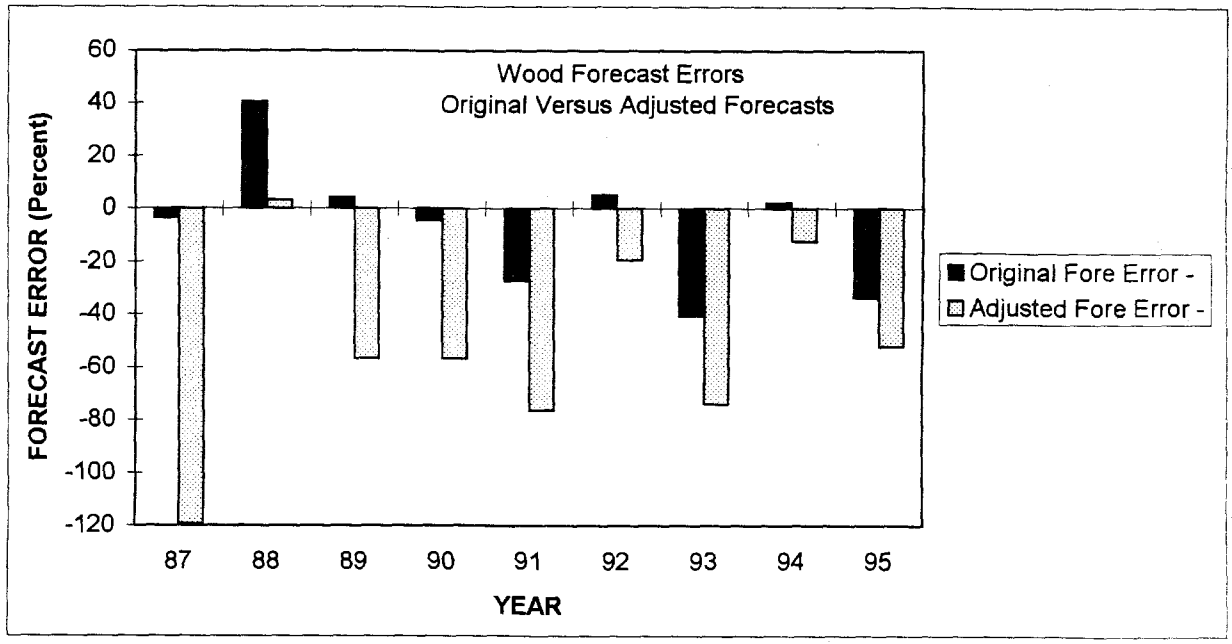


Figure 7. Errors (predicted run - actual run) of Wood River forecasts made with Recent Data for 1984-95 (top) and a comparison between original and adjusted forecast errors, 1987-95 (bottom).

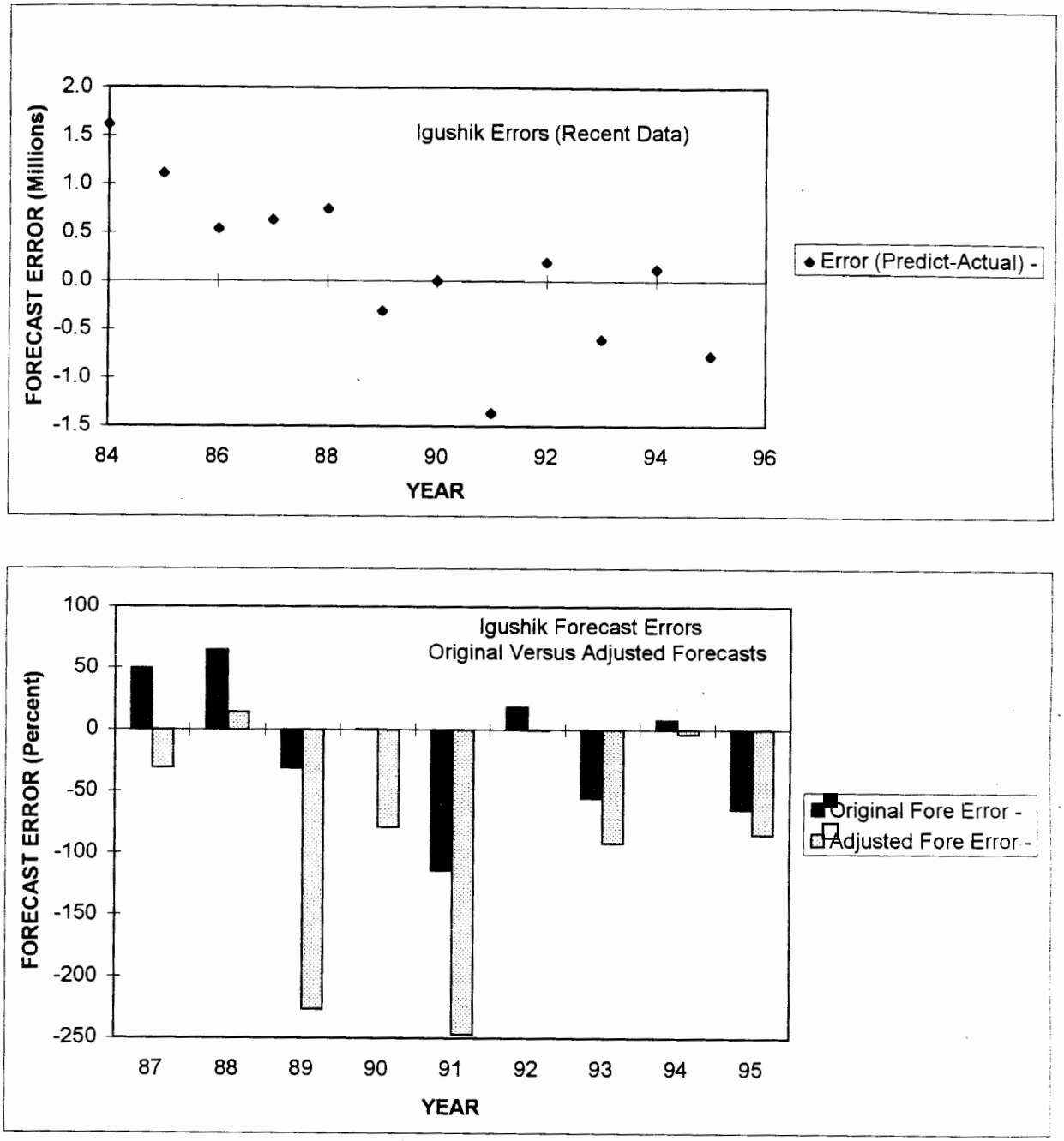
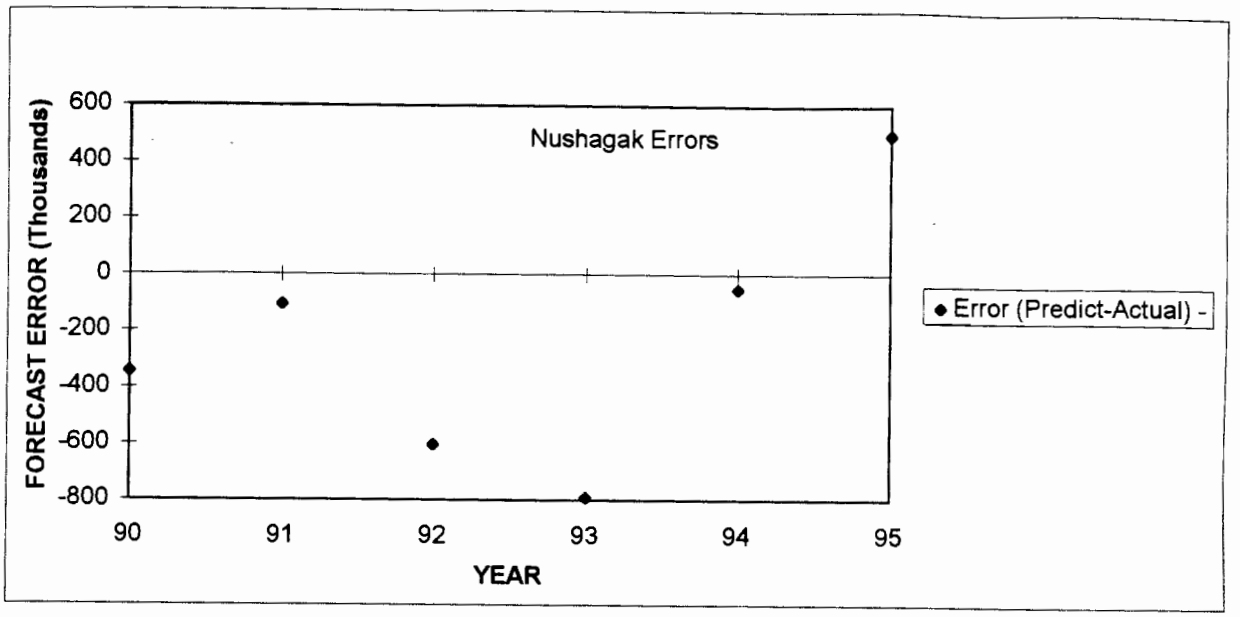


Figure 8. Errors (predicted run - actual run) of Igushik River forecasts made with Recent Data for 1984-95 (top) and a comparison between original and adjusted forecast errors, 1987-95 (bottom).



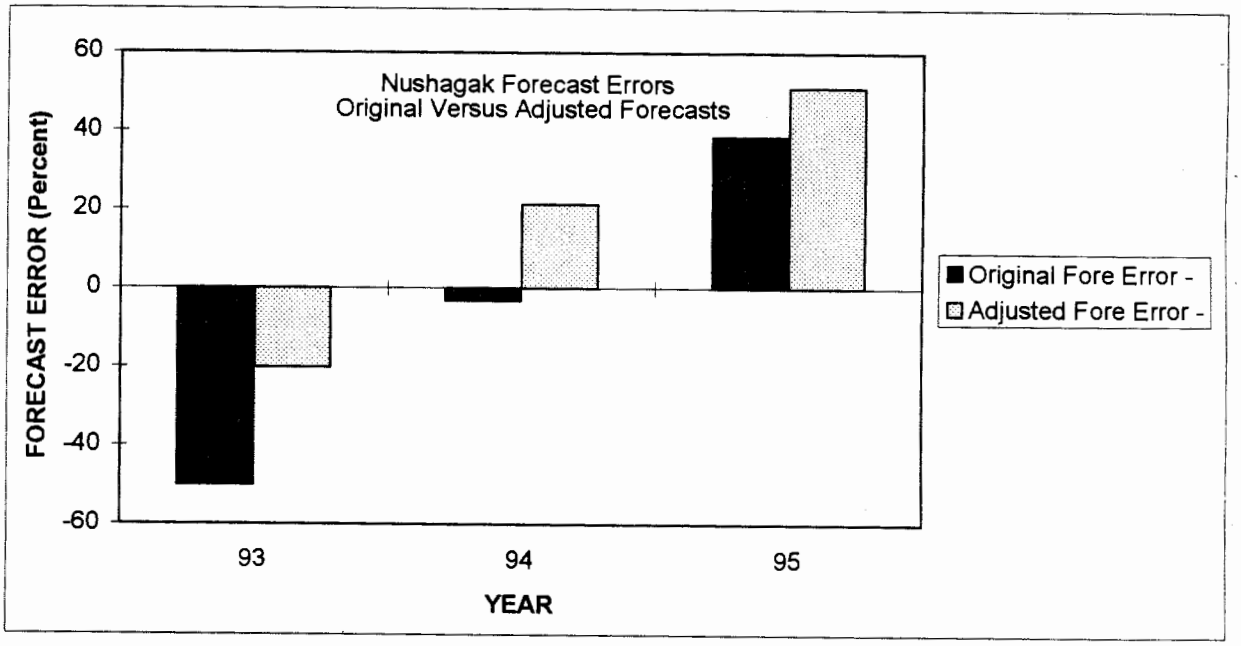
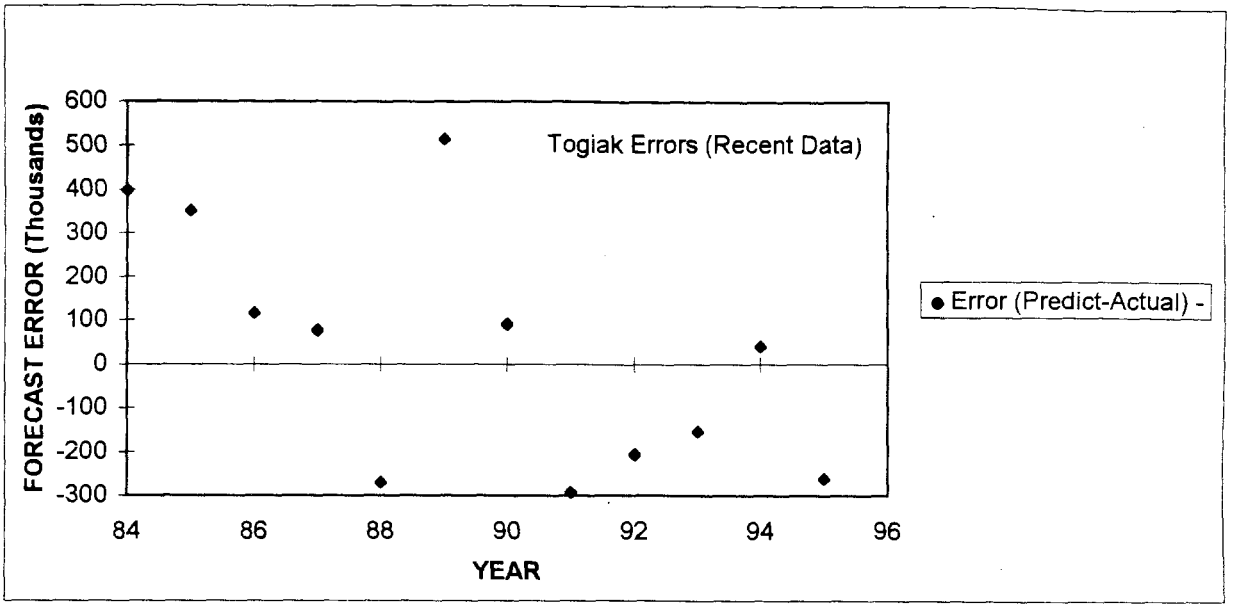


Figure 9. Errors (predicted run - actual run) of Nushagak River forecasts made with Recent Data for 1990-95 (top) and a comparison between original and adjusted forecast errors, 1993-95 (bottom),



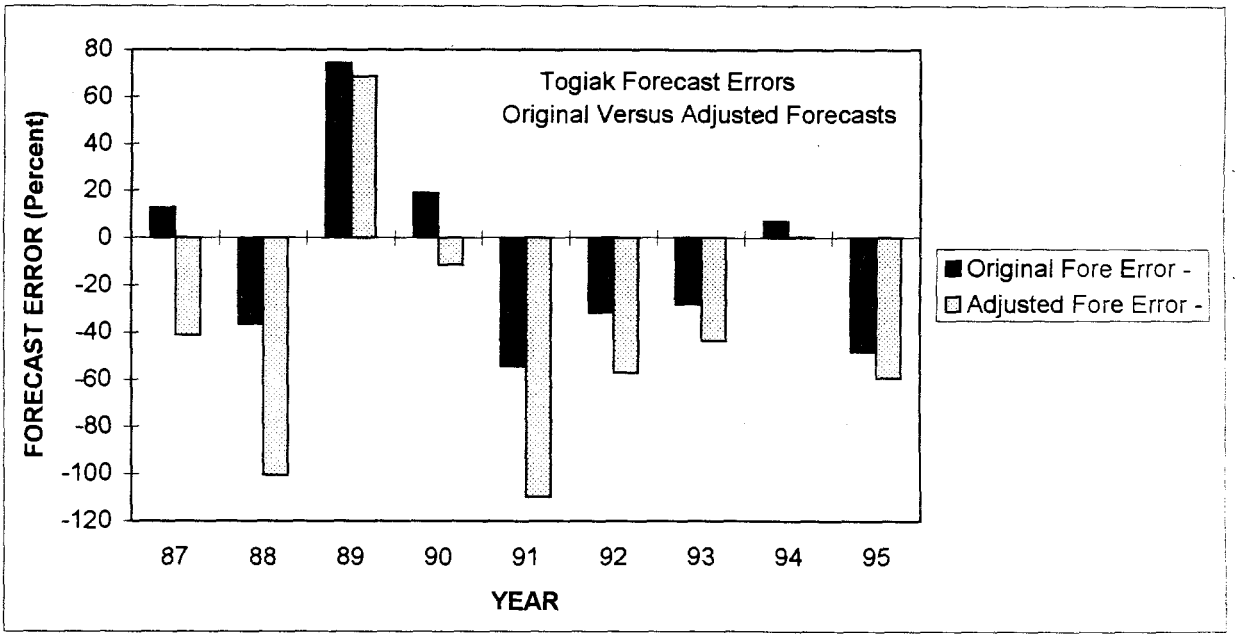


Figure 10. Errors (predicted run - actual run) of Togiak River forecasts made with Recent Data for 1984-95 (top) and a comparison between original and adjusted forecast errors, 1987-95 (bottom

APPENDIX A: HISTORIC SOCKEYE FORECASTS AND RETURNS

Appendix A.1. Preseason forecasts of sockeye salmon returns to Bristol Bay, 1961-1995 issued by the Alaska Department of Fish and Game.

Year	Forecast (millions)	Actual Return (millions)		Percent Error[b]
		Inshore	Total[a]	
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	62.7	39.4	45.0	39.3
1971	1.2	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
1991	31.9	42.2	43.8	-27.2
1992	39.6	45.1	47.5	-16.6
1993	44.7	52.1	55.0	-18.7
1994	56.0	50.3	51.8	8.1
1995	58.7	60.7	62.8	-6.5

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

[b] Percent error calculated as:
(forecast - actual total return) / actual total return x 100.

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 river systems, 1984-95 based on All Data (1956-95) or Recent Data (1978-95).

	Percent Errors[a]											
Year	Kvichak	Branch	Naknek	Egegik	Ugashik	Wood	Igushik	Nuyakuk/ Nushagak[b]	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
1991	-49.1	-49.2	-68.1	-41.1	-75.9	-38.0	-75.9	-34.8	-52.3	-56.8	-49.7	-55.4
1992	-27.3	-42.4	-53.5	-65.7	-62.8	-23.3	-37.8	-23.5	-45.4	-53.3	-28.4	-50.0
1993	-31.8	-61.9	-49.1	-73.2	-42.6	-44.6	-65.4	-27.9	-36.7	-57.7	-43.4	-55.4
1994	-45.8	-45.3	-19.3	-17.1	-46.3	-36.6	-41.5	-3.2	-23.6	-35.7	-28.4	-34.8
1995	-48.0	-51.0	1.7	-41.9	-43.6	-40.1	-65.8	62.5	-45.1	-42.4	-36.5	-41.7
84-95 MPE	-25.5	-38.9	-29.7	-51.8	-50.2	-22.7	-33.6	-3.6	-19.9	-45.2	-24.9	-42.4
84-95 MAPE	46.8	38.9	35.8	51.8	50.2	25.2	48.1	31.4	33.5	45.2	26.2	42.4
87-95 MPE	-43.8	-41.3	-30.4	-51.1	-48.2	-29.1	-45.3	- 4.0	-23.8	-48.6	-31.4	-46.0
87-95 MAPE	43.8	41.3	33.8	51.1	48.2	31.3	48.3	35.7	41.8	48.6	31.4	46.0
						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
1991	-25.6	-37.5	-52.4	-33.2	-50.2	-21.6	-53.4	-12.8	-35.4	-39.9	-30.3	-38.0
1992	-12.1	-15.6	-37.1	-54.8	-41.8	5.6	22.4	-23.5	-24.2	-38.9	-5.2	-34.4
1993	-4.5	-49.3	-39.7	-67.3	-33.2	-29.0	-35.8	-27.9	-22.1	-46.2	-29.4	-43.6
1994	-35.6	-32.8	5.4	-3.8	-20.0	2.4	8.6	-3.2	7.9	-21.6	2.7	-18.4
1995	-39.5	-37.2	24.1	-29.6	-27.4	-25.3	-39.3	62.5	-28.9	-31.0	-20.1	-29.7
84-95 MPE	0.9	-9.6	0.3	-38.0	-14.1	28.0	66.7	54.7	33.1	-25.4	30.9	-18.4
84-95 MAPE	52.5	29.9	31.1	38.0	34.2	42.1	92.1	69.0	56.0	29.3	45.9	25.6
87-95 MPE	-25.0	-21.5	-5.6	-38.0	-8.5	0.4	17.6	44.7	21.8	-29.6	4.2	-24.6
87-95 MAPE	32.4	30.1	35.5	38.0	35.3	18.3	51.5	63.7	52.4	31.7	24.2	29.1

[a] Percent error calculated as:
(forecast - actual total return) / actual total return x 100.

[b] Hindcasts 1984-91 were for Nuyakuk River, 1992-95 hindcasts were for total Nushagak River.

APPENDIX C: UNADJUSTED RIVER SYSTEM FORECASTS

Appendix C.1. Forecasted returns of major age classes of sockeye salmon to the Kvichak River in 1996 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	4,725	3,025	5.0	18
2.2	4,222	4,295	0.1	18
1.3	4,222	1,807	0.1	18
2.3	6,970	1,113	2.5	18
		Total 10,240		

Sibling Data

Age Class	Sibling Return in 1995 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	0	[a]		
2.2	1	608	0.1	15
1.3	2,698	1,349	1.0	17
2.3	21,262	1,464	1.0	17
		Total 3,421		

Smolt Data

Age Class	Smolt Production (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	53,638	2,705	5.0	18
2.2	30,207	2,944	0.1	18
1.3	21,781	1,007	5.0	17
2.3	204,626	1,279	5.0	17
		Total 7,935		

[a] Estimate not made; no age-1.1 sockeye salmon returned to Kvichak River in 1995

Appendix C.2. Forecasted returns of major age classes of sockeye salmon to the Branch River in 1996 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	224	215	5.0	18
2.2	277	50[a]	NS	17
1.3	277	119	1.0	18
2.3	168	13[a]	NS	18
	Total	397		

Sibling Data

Age Class	Sibling Return in 1995 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	1	200	10.0	15
2.2	3	158[a]	NS	5
1.3	200	142[a]	NS	17
2.3	332	33	5.0	16
	Total	533		

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

Appendix C.3. Forecasted returns of major age classes of sockeye salmon to the Naknek River in 1996 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	1,606	522	25.0	18
2.2	3,578	1,416	25.0	18
1.3	3,578	3,234	5.0	18
2.3	2,092	1,267	10.0	18
	Total	6,439		

Sibling Data

Age Class	Sibling Return in 1995 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	0	[a]		
2.2	1	779[b]	NS	15
1.3	547	1,529	0.5	17
2.3	1,355	1,196	5.0	17
	Total	3,504		

Smolt Data

Age Class	Smolt Production (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	32,615	438[b]	NS	6
2.2	42,322	694[b]	NS	6
1.3	24,183	1,066	5.0	5
2.3	28,838	724	5.0	5
	Total	2,484		

[a] Estimate not made; no age-1.1 salmon returned to Naknek River in 1995.

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

Appendix C.4. Forecasted returns of major age classes of sockeye salmon to the Egegik River in 1996 based on linear regression models using spawner-recruit, sibling, and smolt data.

Spawner-Recruit Data[a]

Age Class	Spawning Escapement (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	1,945	643	5.0	18
2.2	2,786	14,028	5.0	18
1.3	2,786	714[b]	NS	18
2.3	2,191	4,317	10.0	18
		Total 19,702		

Sibling Data

Age Class	Sibling Return in 1995 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	0	[c]	25.0	11
2.2	19	3,817	1.0	17
1.3	1,383	2,910	0.1	17
2.3	9,606	4,345	1.0	17
		Total 11,076		

Smolt Data

Age Class	Smolt Production (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	54,909	1,255	1.0	12
2.2	39,158	6,197	1.0	12
1.3	20,203	1,919	1.0	11
2.3	37,719	3,834	1.0	11
		Total 13,205		

[a] Spawner-recruit estimates were not used for the 1996 Egegik River projection. Results from hindcasting indicated that forecasts were more accurate and less bias using only sibling and smolt information.

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

[c] Estimate not made; no age-1.1 sockeye salmon returned to Egegik River in 1995

Appendix C.5. Forecasted returns of major age classes of sockeye salmon to the Ugashik River in 1996 based on linear regression models using spawner-recruit, sibling, and smolt data.

Spawner-Recruit Data[a]

Age Class	Spawning Escapement (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	2,194	1,401	1.0	18
2.2	2,482	3,153	0.5	18
1.3	2,482	2,145	0.5	18
2.3	749	596	0.2	18
	Total	7,295		

Sibling Data

Age Class	Sibling Return in 1995 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	2	996	5.0	14
2.2	1	1,020	10.0	16
1.3	2,011	1,961	0.1	17
2.3	2,307	893	0.1	17
	Total	4,870		

Smolt Data

Age Class	Smolt Production (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	24,305	685[b]	NS	10
2.2	5,725	1,476[b]	NS	10
1.3	58,331	1,100	10.0	9
2.3	12,415	456[b]	NS	9
	Total	3,717		

[a] Spawner-recruit estimates were not used for the 1996 Ugashik River projection. Results from hindcasting indicated that forecasts had similar accuracies and precision levels using only sibling and smolt information.

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

Appendix C.6. Forecasted returns of major age classes of sockeye salmon to the Wood River in 1996 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	1,286	1,424	0.1	18
2.2	1,159	95[a]	NS	18
1.3	1,159	1,556	0.1	18
2.3	1,069	56[a]	NS	18
	Total	3,131		

Sibling Data

Age Class	Sibling Return in 1995 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	1	1,243	25.0	13
2.2	0	[b]	5.0	5
1.3	2,637	1,761	2.5	17
2.3	286	106	5.0	17
	Total	3,110		

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

b Estimate not made; no age-2.1 salmon returned to Wood River in 1995.

Appendix C.7. Forecasted returns of major age classes of sockeye salmon to the Igushik River in 1996 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	304	267	0.1	18
2.2	756	49	2.5	18
1.3	756	919	0.1	18
2.3	365	48	2.5	18
		Total 1,283		

Sibling Data

Age Class	Sibling Return in 1995 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	0	[a]		
2.2	0	[a]		
1.3	318	997	1.0	17
2.3	183	80	5.0	17
		Total 1,077		

[a] Estimates not made; no age-1.1 or age-2.1 sockeye salmon returned to Igushik River in 1995

Appendix C.8. Forecasted returns of major age classes of sockeye salmon to the Nushagak River in 1996 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
0.2	715	46	1.5	14
1.2	695	125	1.5	14
2.2	493	5	10.0	13
0.3	695	495	1.0	14
1.3	493	726	0.1	14
2.3	680	16	3.0	14
0.4	493	59	5.0	14
		Total 1,472		

Sibling Data

Age Class	Sibling Return in 1995 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
0.2	0	[a]		
1.2	0	[a]		
2.2	0	[a]		
0.3	82	681	0.1	13
1.3	172	849	0.8	13
2.3	18	16	4.0	12
0.4	153	17	1.0	13
		Total 1,563		

[a] Estimates not made; no age-0.1, -1.1, or -2.1 sockeye salmon returned to Nushagak River in 1995.

Appendix C.9. Forecasted returns of major age classes of sockeye salmon to the Togiak River in 1996 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	215	131	1.0	18
2.2	278	26	10.0	18
1.3	278	397	0.5	18
2.3	189	38	2.5	18
	Total	592		

Sibling Data

Age Class	Sibling Return in 1995 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	0	[a]		
2.2	0	[a]		
1.3	187	482	0.1	17
2.3	74	67	0.2	17
	Total	549		

[a] Estimate not made; no age-1.1 or age-2.1 sockeye salmon returned to Togiak River in 1995

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