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A SYNOPSIS AND CRITIQUE OF FORECASTS OF SOCKEYE SALMON RETURNING TO BRISTOL BAY IN 1998

By

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ABSTRACT

The total number of sockeye salmon *Oncorhynchus nerka* forecasted to return to Bristol Bay in 1998 is 32,110,000 (80% confidence interval: 10,759,000 - 53,461,000). Runs are expected to exceed spawning escapement goals for all systems. Total projected sockeye salmon harvest is expected to be 22,475,000. Most of this harvest will be taken within Bristol Bay inshore fishing districts (20,609,000), 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 = 1,865,000). The 1998 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, data prior to the 1978 return year were omitted from calculations for all rivers. Similar to past years, out of range sibling and smolt data were used in calculations for the 1998 forecast. The outlook for 1999-2001, based only on the spawner-recruit component of the forecast, is for the total sockeye salmon run to Bristol Bay to be highest in 1999 and lowest in 2001. 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, sibling information, smolt.

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 (Figure 1; 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 1998), 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 23 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, there was still a tendency to under-forecast the run. Beginning in 1991 Cross et al. (1992, 1993, 1994) and Cross (1994, 1995, 1996) 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. We did not adjust the 1998 forecast by historic forecast errors because the trend of over forecasting experienced in 1989-1995 was no longer evident in 1996 and 1997. Adjusted predictions for 1996 and 1997 were greater than the actual runs by 23% and 75%.

The purpose of this report is to provide a final preseason forecast of sockeye salmon returning to Bristol Bay, Alaska, in 1998 with an outlook of abundance fluctuations through 2001. Specific objectives are to (1) document changes in methods used to forecast Bristol Bay sockeye salmon runs in 1998, (2) evaluate

the relative accuracy of different forecasting methods, (3) forecast annual runs for all major river systems through 2001, 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 was 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 2). 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 1956-97 are documented by Gray (1998). Estimates of numbers of smolt by year are taken from Crawford and Cross (1998).

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).

We evaluated using a weighted average of the results from each model (spawner-recruit, sibling, smolt) rather than a simple average. The squared error of each model for Kvichak, Naknek, Egegik and Ugashik was calculated by age group for the years 1990-1997. The 1990-1997 mean squared error for each model and age group was used to estimate a weight to apply to the 1998 results.

Forecasts for all rivers except Nushagak River for 1998 were calculated using only data from the 1978 return year onward. The 1998 forecast for Nushagak River was calculated from spawner-recruit and sibling models built from 1982-97 escapement-return data. 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.

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 three 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

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 1978-97 mean return of that age class to that river system was used as the prediction. Prior to 1991, 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 predictions for 1991-1998.

Confidence Intervals

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

$$80\%CI = F \pm t_{0.2} S_F \qquad 4$$

where:

F = forecasted total run of sockeye salmon to all of Bristol Bay (total of river system predictions) in 1998,

S_F = standard error of the forecasted total run of sockeye salmon to Bristol Bay in 1998, 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 1984-97 total run predictions using the same techniques as 1998:

$$S_F = \sqrt{MSE}, \qquad 5$$

$$MSE = \frac{\sum_{i=1}^{N} (F_i - A_i)^2}{N - 1} \qquad 6$$

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 (1984-97).

Outlook to 2001

Forecasts were made for 1999, 2000, and 2001 using only spawner-recruit data (Equation 1 or 2). These forecasts were not adjusted for historic forecast errors.

RESULTS

Out-Of-Range Data

Systems which had input variables (spawners, siblings or smolt) which were outside the data ranges used to build the model included Kvichak, Branch, and Egegik Rivers. The number of age-1. smolt migrating from the Kvichak River in 1996 that will produce the 1998 age-1.2 run was greater than previously recorded. The 1993 Branch River escapement or parent year for 1998 age-1.2 returns was greater than previously recorded. The age-1.1 returns to Egegik River in 1997 which are siblings to the 1998 age-1.2 returns were greater than previously recorded; while the age-2. smolt migrating from Egegik River in 1996 that will produce the 1998 age-2.2 run was the lowest recorded. Although there is a high degree of uncertainty when a model is used to predict an outcome outside its existing values, we felt that using the out-of-range input variables in the regression models was preferable to excluding the information.

Comparison Of Weighted Averages To Simple Averages

Weighting factors estimated from the mean squared errors of the various models were different among rivers and age groups (Table 1). Sibling models were given more weight for the Kvichak River, while for Egegik River smolt models were generally weighted higher. Sibling models were also given higher weights for Ugashik River, while weights for spawner-recruit and sibling models were similar for Naknek River. Overall the weighted averages were not that different from the predictions estimated from simple averages. The difference between the two averaging procedures was 616 thousand (2%) fish out of 26 million fish for the total eastside Bristol Bay prediction. We decided to continue using a simple average to combine results from the various models because the weighting procedure had such a small effect. Also, we found the weights were sensitive to what years were included in the analysis.

River System Forecasts By Age

Kvichak River

Spawner-recruit, sibling, and smolt data bases were available for estimating Kvichak River run sizes in 1998.

Age 1.2. The age-1.2 forecast for this system was based upon spawner-recruit and smolt data (Appendix B.1). A prediction based on sibling data was not used because the regression model was not significant at the 25% level ($\rho > 0.25$). The smolt estimate of 3,996,000 was 31% greater than the spawner-recruit estimate of 3,042,000. The average of the two estimates was 3,519,000 sockeye salmon.

Age 2.2. The age-2.2 forecast was based upon spawner-recruit, sibling, and smolt data (Appendix B.1). The three different data bases predicted significantly different age-2.2 returns. We had no information that one data base was a better indicator of the 1998 age-2.2 run. The smolt estimate of 8,363,000 was 152% greater than the spawner-recruit estimate of 3,309,000 and 1,730% greater than the sibling estimate of 457,000. The average of the three estimates was 4,043,000 sockeye salmon.

Age 1.3. The age-1.3 forecast was based upon spawner-recruit, sibling, and smolt data (Appendix B.1). The smolt estimate of 1,873,000 was 22% greater than the spawner-recruit estimate of 1,537,00 and 176% greater than the sibling estimate of 678,000. The average of the three estimates was 1,363,000 sockeye salmon.

Age 2.3. The age-2.3 forecast was based upon spawner-recruit, sibling, and smolt data (Appendix B.1). The spawner-recruit estimate of 871,000 was about 130% greater than the smolt estimate of 379,000, and 239% greater than the sibling estimate of 257,000. The average of the three estimates was 502,000 sockeye salmon.

Branch River

Spawner-recruit and sibling data bases were available for estimating Branch River run sizes in 1998. 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 B.2). The spawner-recruit estimate of 192,000 was 18% greater than the sibling estimate of 162,000. The average of the two estimates was 177,000 sockeye salmon.

Age 2.2. The age-2.2 forecast was based on the 1978-97 mean return of age-2.2 sockeye salmon (Appendix B.2). A prediction based on spawner-recruit data was not used because the regression model was not significant at the 25% level ($\rho > 0.25$). An estimate based on a sibling model was not made because no age-2.1 salmon returned to Branch River in 1997. The mean return estimate was 93,000 sockeye salmon.

Age 1.3. The age-1.3 forecast was based only upon spawner-recruit data (Appendix B.2). The prediction based on sibling data was not used because the model was not significant at the 25% level ($\rho > 0.25$). The spawner-recruit estimate was 87,000 sockeye salmon.

Age 2.3. The age-2.3 forecast was based only upon sibling data (Appendix B.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 15,000 sockeye salmon.

Naknek River

Spawner-recruit, and sibling data bases were available for estimating Naknek River run sizes in 1998. Smolt information was not available for any age groups of fish returning in 1998. The smolt project on the Naknek River operated from 1982-86 and again in 1993-94 (Crawford and Cross 1995).

Age 1.2. The age-1.2 forecast was based only on sibling data (Appendix B.3). A prediction based on spawner-recruit data was not used because the model was not significant at the 25% level. The sibling estimate was 782,000 sockeye salmon.

Age 2.2. The age-2.2 forecast was based on spawner-recruit and sibling data (Appendix B.3). The sibling estimate was 968,000 sockeye salmon which was 33% greater than the spawner-recruit estimate of 730,000 salmon. The average of the two estimates was 849,000 sockeye salmon.

Age 1.3. The age-1.3 forecast was based on spawner-recruit and sibling data (Appendix B.3). The spawner-recruit estimate of 1,554,000 was 62% greater than the sibling estimate of 960,000 sockeye salmon. The average of the two estimates was 1,257,000 sockeye salmon.

Age 2.3. The age-2.3 forecast was based on spawner-recruit and sibling data (Appendix B.3). The spawner-recruit estimate of 972,000 was % greater than the sibling estimate of 486,000 sockeye salmon. The average of the two estimates was 729,000 sockeye salmon.

Egegik River

Spawner-recruit, sibling, and smolt data bases were available for estimating 1998 Egegik River run sizes.

Age 1.2. The age-1.2 forecast was based on spawner-recruit and smolt data (Appendix B.4). The smolt estimate of 790,000 sockeye salmon was 38% greater than the spawner-recruit estimate of 574,000. The average of the two estimates was 682,000 sockeye salmon.

Age 2.2. The age-2.2 forecast was based upon spawner-recruit, sibling and smolt data (Appendix B.4). The spawner-recruit estimate of 4,873,000 was similar to the sibling estimate of 4,414,000, but 105% greater than the smolt estimate of 2,371,00 sockeye salmon. The average of the three estimates was 3,886,000 sockeye salmon.

Age 1.3. The age-1.3 forecast was based upon spawner-recruit, sibling and smolt data (Appendix B.4). The smolt estimate of 1,232,00 was similar to the spawner-recruit estimate of 1,210,000, but 53% greater than the sibling estimate of 803,000 sockeye salmon. The average of the three estimates was 1,082,000 sockeye salmon.

Age 2.3. The age-2.3 forecast for this system was based upon spawner-recruit, sibling and smolt data (Appendix B.4). The smolt estimate of 4,753,000 was 42% greater than the spawner-recruit estimate of 3,344,000 and 97% greater than the sibling estimate of 2,410,000 sockeye salmon. The average of the three estimates was 3,502,000 sockeye salmon.

Ugashik River

Spawner-recruit, sibling, and smolt data bases were available for estimating 1998 Ugashik River run sizes

Age 1.2. The age-1.2 forecast was based only upon spawner-recruit and sibling data (Appendix B.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 of 1,108,000 sockeye salmon was 63% greater than the spawner-recruit estimate of 680,000. The average of the two estimates was 894,000 sockeye salmon.

Age 2.2. The age-2.2 forecast was based upon spawner-recruit and sibling data (Appendix B.5). The prediction based on smolt data was not used because the model was not significant at the 25% level ($\rho > 0.25$). The spawner-recruit estimate of 1,641,000 sockeye salmon was 22% greater than the sibling estimate was 1,349,000. The average of the two estimates was 1,119,000 sockeye salmon.

Age 1.3. The age-1.3 forecast was based upon spawner-recruit, sibling, and smolt data (Appendix B.5). The spawner-recruit estimate of 1,191,000 was 163% greater than the smolt estimate of 453,000 and 226% greater than the sibling estimate of 365,000. The average of the three estimates was 670,000 sockeye salmon.

Age 2.3. The age-2.3 forecast was based upon spawner-recruit, sibling, and smolt data (Appendix B.5). The prediction based on spawner-recruit data was 1,091,000 which was 58% greater than the smolt estimate of 689,000, and 130% greater than the sibling estimate of 474,000. The average of the three estimates was 751,000 sockeye salmon.

Wood River

Spawner-recruit and sibling data bases were available for estimating Wood River run sizes in 1998. Smolt emigrating from the Wood River were last counted in 1990.

Age 1.2. The age-1.2 forecast was based only upon spawner-recruit data (Appendix B.6). A sibling model was not used because it was not significant at the 23% level ($\rho > 0.25$). The spawner-recruit estimate was 1,449,000 sockeye salmon.

Age 2.2. The age-2.2 forecast was based on the 1978-97 mean return of age-2.2 sockeye salmon to Wood River (Appendix B.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 1997. The mean return estimate was 167,000 sockeye salmon.

Age 1.3. The age-1.3 forecast was based upon spawner-recruit and sibling data (Appendix B.6). The spawner-recruit estimate of 1,587,000 was similar to the sibling estimate of 1,551,000. The average of the two estimates was 1,569,000 sockeye salmon.

Age 2.3. The age-2.3 forecast was based only upon sibling data (Appendix B.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 60,000 sockeye salmon.

Igushik River

Spawner-recruit and sibling data bases were available for estimating Igushik River run sizes in 1998. 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 B.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 1997. The spawner-recruit estimate was 236,000 sockeye salmon.

Age 2.2. The age-2.2 forecast was based only on spawner-recruit data (Appendix B.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 1997. The spawner-recruit estimate was 40,000 sockeye salmon.

Age 1.3. The age-1.3 forecast was based upon spawner-recruit and sibling data (Appendix B.7). The spawner-recruit estimate of 1,030,000 was 73% greater than the sibling estimate of 596,000. The average of the two estimates was 813,000 sockeye salmon.

Age 2.3. The age-2.3 forecast was based upon spawner-recruit and sibling data (Appendix B.7). The spawner-recruit estimate of 45,000 was 165% greater than the sibling estimate of 17,000. The average of the two estimates was 31,000 sockeye salmon.

Nushagak River

Spawner-recruit and sibling data bases from 1982-97 return years were used to predict Nushagak River run sizes in 1998.

Age 0.2. The age-0.2 forecast was based only upon spawner-recruit data (Appendix B.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 1997. The spawner-recruit estimate was 28,000 sockeye salmon.

Age 1.2. The age-1.2 forecast was based only upon results from spawner-recruit data (Appendix B.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 1997. The spawner-recruit estimate was 105,000 sockeye salmon.

Age 2.2. The age-2.2 forecast was based only upon results from spawner-recruit data (Appendix B.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 1997. The spawner-recruit estimate was 8,000 sockeye salmon.

Age 0.3. The age-0.3 forecast was based only upon results from spawner-recruit data (Appendix B.8). A prediction based on sibling data was not made because no age-0.2 sockeye salmon were present in samples collected from Nushagak River in 1997. The spawner-recruit estimate was 354,000 sockeye salmon.

Age 1.3. The age-1.3 forecast was based upon spawner-recruit and sibling data (Appendix B.8). The spawner-recruit estimate of 856,000 was 63% greater than the sibling estimate of 525,000. The average of the two estimates was 691,000 sockeye salmon.

Age 2.3. The age-2.3 forecast was based upon spawner-recruit and sibling data (Appendix B.8). The spawner-recruit estimate of 8,000 was similar to the sibling estimate of 11,000 sockeye salmon. The average of the two estimates was 10,000 sockeye salmon.

Age 0.4. The age-0.4 forecast was based on spawner-recruit and sibling data bases (Appendix B.8). The spawner-recruit estimate of 56,000 was 2,700% greater than the sibling estimate of 2,000. The average of the two estimates was 29,000 sockeye salmon.

Togiak River

Spawner-recruit and sibling data bases were available for estimating Togiak River run sizes in 1998. 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 B.9). A prediction based on sibling data was not used because the model was not significant at the 25% level ($\rho > 0.25$). The spawner-recruit estimate was 120,000 sockeye salmon.

Age 2.2. The age-2.2 forecast was based only on spawner-recruit data (Appendix B.9). A prediction based on sibling data was not made because no age-2.1 sockeye salmon were present in 1997 Togiak River samples. The spawner-recruit estimate was 28,000 sockeye salmon.

Age 1.3. The age-1.3 forecast was based on spawner-recruit and sibling data (Appendix B.9). The spawner-recruit estimate of 382,000 was 60% greater than the sibling estimate of 238,000. The average of the two estimates was 310,000 sockeye salmon.

Age 2.3. The age-2.3 forecast for this system was based on spawner-recruit and sibling data (Appendix B.9). The spawner-recruit and sibling estimate were both 37,000 sockeye salmon.

Final 1998 Total Bristol Bay Forecast

A total of 32,110,000 sockeye salmon (80% confidence interval: 10,759,000 - 53,461,000) are expected to return to Bristol Bay in 1998 (Table 2). A run of this size would be the eighteenth highest run since 1956, the first year of total run information. The 1998 prediction is 20% (8,360,000 sockeye salmon) less than the 20-year (1978-97) mean return of 40,470,000 (range: 20,527,000 - 66,293,000), and about 27% (11,636,000) less than the most recent 10-year (1988-97) mean return of 43,746,000 (range: 20,527,000 - 62,825,000).

Total projected sockeye salmon harvest is 22,475,000 (80% CI: 1,124,000 - 43,826,000; Table 2). Most (20,609,000) 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 = 1,865,000) 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 1998). 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 30,244,000 (Table 3). Runs should exceed spawning escapement goals for all river systems. The projected Bristol Bay combined fishing district harvest of 20,609,000 would be 19% (4,791,000) less than the 20-year (1978-97) mean harvest of 25,400,000 (range: 9,898,000 - 44,427,000), and 30% (8,905,000) less than the 10-year (1988-97) mean harvest of 29,514,000 (range: 12,256,000 - 44,427,000).

Final 1998 River System Forecasts

Kvichak River

A total of 9,427,000 sockeye salmon were forecasted to return to this system (Table 3). Sockeye salmon production within Kvichak River has followed a five-year abundance cycle (Mathisen and Poe 1981). A return of 9,427,000 sockeye salmon to the Kvichak River system in 1998, an off-cycle year, would be 59% greater than the mean return of 5,915,000 sockeye salmon (range: 337,000-20,983,000) observed during past off-cycle years (1962-63, 1967-68, 1972-73, 1977-78, 1982-83, 1987-88, 1992-93. 1996-97). Age-2.2 and age-1.2 sockeye salmon comprised 43% and 37% of the forecasted Kvichak River return (Table 2).

Branch River

A total of 372,000 sockeye salmon were forecasted to return to this system (Table 3). A total run of this size would be 36% less than the mean return of 578,000 for 1988-1997 (range:267,000 - 868,000), and about 31% less than the mean return of 539,000 for 1978-1997 (range: 267,000 - 868,000). Age-1.2 fish comprised 48% of the Branch River forecast (Table 2).

Naknek River

A total of 3,617,000 sockeye salmon were forecasted to return to this system (Table 3). A total run of this size would be 27% less than the mean return of 4,974,468 for 1988-97 (range: 1,531,000 - 10,353,000) and 20% less than the mean return of 4,524,463 for 1978-97 (range: 1,531,000 - 10,353,000). Age-1.3 sockeye salmon comprised 35% of the Naknek River forecast while age-2.2 and age-1.2 comprised 23% and 22% (Table 2).

Egegik River

A total of 9,152,000 sockeye salmon were forecasted to return to this system (Table 3). A total run of this size would be 33% less than the mean return of 13,619,000 for 1988-97 (range: 6,885,000 - 24,687,000), and similar to the mean return of 9,594,000 for 1978-97 (range: 2,229,000 - 24,687,000). The 1998 Egegik River forecast was 42% age-2.2 and 38% age-2.3 sockeye salmon (Table 2).

Ugashik River

A total of 3,434,000 sockeye salmon were forecasted to return to this system (Table 3). A total run of this size would be about 26% less than the mean return of 4,675,000 for 1988-97 (range: 2,256,000 - 6,040,000) and 20% less than the mean return of 4,273,000 for 1978-97 (range: 95,000 - 7,875,000). Age-2.2 and age-1.2 sockeye salmon comprised 32% and 26% of the 1998 Ugashik River forecast (Table 2).

Wood River

A total of 3,245,000 sockeye salmon were forecasted to return to this system (Table 3). A total run of this size would be similar to the mean return of 3,324,000 for 1988-97 (range: 1,793,000 - 5,182,000) and similar to the mean return of 3,393,000 for 1978-97 (range: 929,000 - 5,182,000). The 1998 Wood River forecast was comprised of 48% age-1.3 and 45% age-1.2 sockeye salmon (Table 2).

Igushik River

A total of 1,120,000 sockeye salmon were forecasted to return to this system (Table 3). A total run of this size would be 15% less than the mean return of 1,319,000 for 1988-97 (range: 316,000 - 2,513,000) and 18% less than the mean return of 1,365,000 for 1978-97 (range: 164,000 - 3,276,000). Approximately 73% of the 1998 Igushik River forecast was comprised of age-1.3 sockeye salmon (Table 2).

Nushagak River

A total of 1,248,000 sockeye salmon were forecasted to return to this system (Table 3). A total run of this size would be 21% less than the mean return of 1,581,000 for 1989-97 (range: 792,000 - 2,330,000). The 1998 Nushagak River forecast was comprised of 55% age-1.3 and 35% zero freshwater aged sockeye salmon (Table 2).

Togiak River

A total of 495,000 sockeye salmon were forecasted to return to this system (Table 3). A total run of this size would be 18% less than the mean return of 601,000 for 1988-97 (range: 179,000 - 1,002,000), and 24% less than the mean return of 650,000 for 1978-97 (range: 179,000 - 1,173,000). About 63% of the sockeye salmon forecasted to return to Togiak River in 1998 were age 1.3 (Table 2).

Expected Forecast Performance

Our best estimate of 1998 sockeye run size was based on linear regression models using data from 1978-97. 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	less than expected return of all ages of sockeye salmon	There is a threefold difference in predicted 1998 runs between results based on siblings, which indicate a run of 5 million, and results based on smolt which indicate a run of 15 million.
Ugashik	less than expected return of all ages of sockeye salmon	There is a twofold difference in predicted 1998 runs between results based on smolt, which indicate a run of 2.4 million, and results based on spawners, which indicate a run of 4.6 million.
Nushagak	less than expected runs of age-0.3 sockeye salmon	Although no age-0.2 sockeye salmon occurred in 1997 run samples, results based on spawners predict 0.3 million age-0.3 sockeye salmon.

Indicators that can be used to assess preseason forecast accuracy will not be available until June 1998 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 2001

Comparisons of 1998-2001 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 1999 and lowest in 2001 (Table 4). Runs to all river systems are not only expected to exceed escapement goals, but also produce 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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Table1. Weights assigned to model estimates based on 1990-1997 mean squared errors of forecasts.

River	Age	Weight			Weighted Estimate	Original Estimate	Difference
		Recruit	Sibling	Smolt			
KVICHAK	1.2	0.591		0.409	3432	3519	-87
	1.3	0.259	0.398	0.343	1310	1363	-53
	2.2	0.216	0.450	0.334	3713	4043	-330
	2.3	0.440	0.508	0.052	533	502	31
	Total				8988	9427	-439
NAKNEK	1.2	Couldn't Calculate			782	782	0
	1.3	0.482	0.518		1246	1257	-11
	2.2	Couldn't Calculate			849	849	0
	2.3	0.451	0.549		705	729	-24
	Total				3582	3617	-35
EGEGIK	1.2	0.253	0.291	0.456	928	938	-10
	1.3	0.250	0.421	0.329	1046	1082	-36
	2.2	0.157	0.378	0.465	3537	3886	-349
	2.3	0.222	0.422	0.356	3450	3502	-52
	Total				8961	9408	-447
UGASHIK	1.2	0.505	0.495		892	894	-2
	1.3	0.300	0.427	0.273	637	670	-33
	2.2	0.215	0.785		1412	1119	293
	2.3	0.525	0.475		798	751	47
	Total				3739	3434	305
EASTSIDE	Total				25270	25886	-616

Table 2. Forecasted production, spawning escapement goals, and total projected harvests of major age classes of sockeye salmon returning to Bristol Bay river systems in 1998.

District: River	Thousands of Sockeye Salmon							
	Forecasted Production by Age Class							
	1.2	2.2	1.3	2.3	Other[a]	Total	Spawning Goal	Total Harvest
NAKNEK-KVICHAK:								
Kvichak	3,519	4,043	1,363	502		9,427	4,500	4,927
Branch	177	93	87	15		372	185	187
Naknek	782	849	1,257	729		3,617	1,100	2,517
Total	4,478	4,985	2,707	1,246		13,416	5,785	7,631
EGEGIK	682	3,886	1,082	3,502		9,152	1,100	8,052
UGASHIK	894	1,119	670	751		3,434	850	2,584
NUSHAGAK:[b]								
Wood	1,449	167	1,569	60		3,245	1,000	2,245
Igushik	236	40	813	31		1,120	200	920
Nushagak	105	8	691	10	434	1,248	550	698
Total	1,790	215	3,073	101	434	5,613	1,750	3,863
TOGIAK[c]	120	28	310	37		495	150	345
BRISTOL BAY	7,964	10,233	7,842	5,637	434	32,110	9,635	22,475

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 71,000 (1988-1997 mean catch) to Togiak District harvest.

Table 3. Projected commercial harvests of sockeye salmon returning to Bristol Bay river systems in 1998.

	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	9,427	547	8,880	4,500	4,380
Branch	372	22	350	185	165
Naknek	3,617	210	3,407	1,100	2,307
Total	13,416	779	12,637	5,785	6,852
EGEGIK	9,152	532	8,620	1,100	7,520
UGASHIK	3,434	199	3,235	850	2,385
NUSHAGAK:					
Wood	3,245	189	3,056	1,000	2,056
Igushik	1,120	65	1,055	200	855
Nushagak	1,248	73	1,175	550	625
Total	5,613	327	5,286	1,750	3,536
TOGIAK	495	29	466	150	316
BRISTOL BAY	32,110	1,866	30,244	9,635	20,609

[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, 1998-2001, based on spawner-recruit data only, and not adjusted for historic forecast errors.

DISTRICT: River	Thousands of Sockeye Salmon 1998	1999	2000	2001
NAKNEK-KVICHAK:				
Kvichak	8,759	13,836	13,600	5,438
Branch	412	474	442	430
Naknek	3,879	3,290	2,905	2,914
Total	13,050	17,600	16,947	8,782
EGEGIK	10,001	10,880	8,939	7,193
UGASHIK	4,603	3,973	3,899	2,885
NUSHAGAK:				
Wood	3,307	3,230	3,192	3,127
Igushik	1,357	1,366	1,307	1,209
Nushagak-Mulchatna	1,415	1,143	1,035	1,158
Total	6,079	5,739	5,534	5,494
TOGIAK	567	562	565	553
BRISTOL BAY	34,300	38,754	35,884	24,907

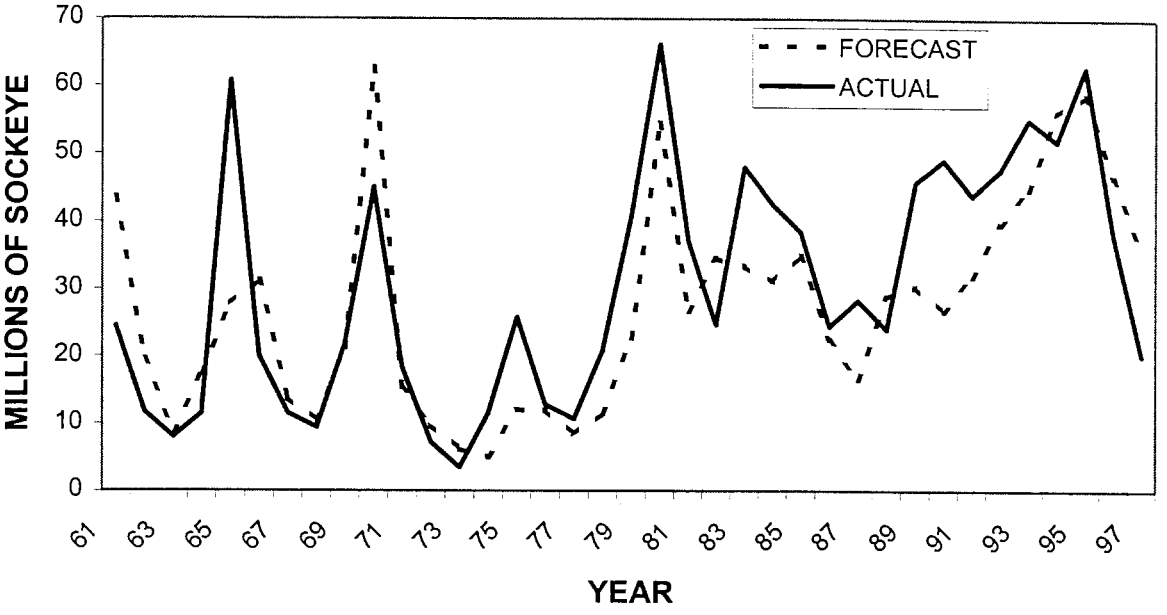

Figure 1. Sockeye salmon forecasts compared to actual runs, Bristol Bay 1961-1997.

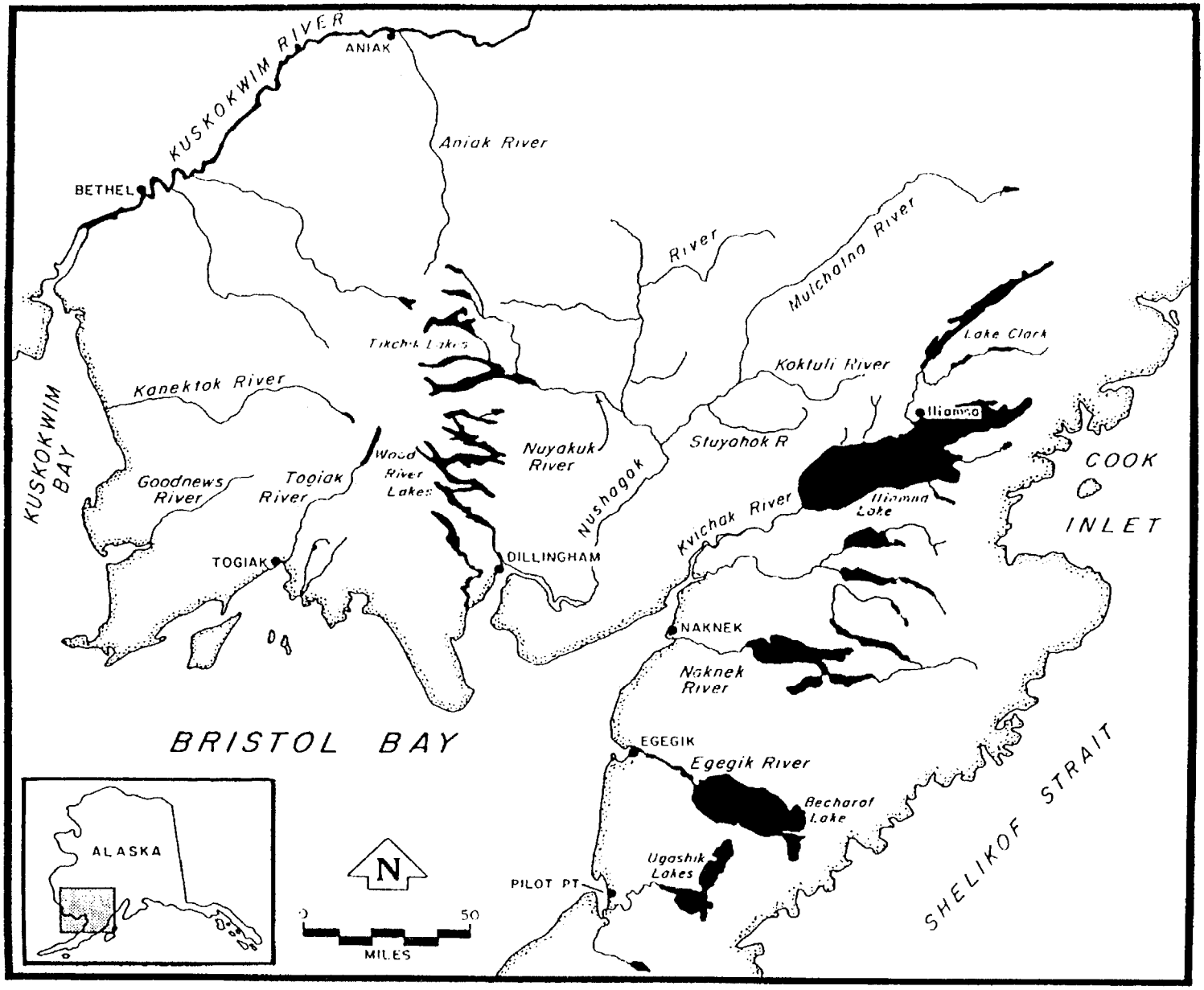

Figure 2. Map of Bristol Bay, Alaska showing major rivers.

APPENDIX A: HISTORIC SOCKEYE FORECASTS AND RETURNS

Appendix A.1. Preseason forecasts of sockeye salmon returns to Bristol Bay, 1961-1998 issued by the Alaska Department of Fish and Game.

Year	Forecast (millions)	Actual Return (millions)		Percent Error[a]
		Inshore	Total	
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	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
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
1996	46.5	36.9	37.9	22.7
1997	35.8	18.9	20.5	74.6

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

APPENDIX B: UNADJUSTED RIVER SYSTEM FORECASTS

Appendix B.1. Forecasted returns of major age classes of sockeye salmon to the Kvichak River in 1998 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	8,338	3,042	5.0	20
2.2	4,025	3,309	0.1	20
1.3	4,025	1,537	0.1	20
2.3	4,726	871	5.0	20
	Total	8,759		

Sibling Data

Age Class	Sibling Return in 1997 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	2	2,496[a]	NS	13
2.2	1	457	0.1	17
1.3	855	678	1.0	19
2.3	571	257	1.0	19
	Total	3,888		

Smolt Data

Age Class	Smolt Production (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	276,731	3,996	5.0	20
2.2	96,434	8,363	0.1	20
1.3	209,857	1,873	5.0	19
2.3	11,034	379	5.0	19
	Total	14,611		

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

Appendix B.2. Forecasted returns of major age classes of sockeye salmon to the Branch River in 1998 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	242	192	0.5	20
2.2	348	93[a]	NS	19
1.3	348	87	1.0	20
2.3	225	35[a]	NS	19
	Total	407		

Sibling Data

Age Class	Sibling Return in 1997 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	1	162	10.0	17
2.2	0	[b]		
1.3	127	197[a]	NS	19
2.3	66	15	2.5	16
	Total	374		

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

[b] Estimate not made; no age-2.1 salmon returned to Branch River in 1997.

Appendix B.3. Forecasted returns of major age classes of sockeye salmon to the Naknek River in 1998 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	990	632[a]	NS	20
2.2	1,535	730	5.0	20
1.3	1,535	1,554	2.5	20
2.3	1,606	972	2.5	20
		Total 3,888		

Sibling Data

Age Class	Sibling Return in 1997 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	6	782	25.0	14
2.2	12	968	2.5	17
1.3	296	960	0.1	19
2.3	253	486	2.5	19
		Total 3,196		

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

Appendix B.4. Forecasted returns of major age classes of sockeye salmon to the Egegik River in 1998 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	1,897	574	2.5	20
2.2	1,517	4,873	0.5	20
1.3	1,517	1,210	25.0	20
2.3	1,946	3,344	2.5	20
		Total 10,001		

Sibling Data

Age Class	Sibling Return in 1997 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	8	1,451[a]	NS	13
2.2	31	4,414	0.5	19
1.3	499	803	0.1	19
2.3	5,003	2,410	0.5	19
		Total 9,078		

Smolt Data

Age Class	Smolt Production (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	22,113	790	5.0	14
2.2	8,089	2,371	1.0	14
1.3	7,412	1,232	1.0	13
2.3	49,962	4,753	1.0	13
		Total 9,146		

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

Appendix B.5. Forecasted returns of major age classes of sockeye salmon to the Ugashik River in 1998 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	1,095	680	1.0	20
2.2	1,413	1,641	0.5	20
1.3	1,413	1,191	0.5	20
2.3	2,195	1,091	0.2	20
	Total	4,603		

Sibling Data

Age Class	Sibling Return in 1997 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	11	1,108	25.0	16
2.2	6	1,349	2.5	18
1.3	258	365	0.1	19
2.3	1,002	474	0.1	19
	Total	3,296		

Smolt Data

Age Class	Smolt Production (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	1,147	867[a]	NS	12
2.2	1,429	367[a]	NS	12
1.3	6,961	453	10.0	11
2.3	15,272	689	10.0	11
	Total	2,376		

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

Appendix B.6. Forecasted returns of major age classes of sockeye salmon to the Wood River in 1998 based on linear regression models using spawner-recruit and sibling data.

Age Class	Spawning Escapement (thousands)	Spawner-Recruit Data: Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	1,471	1,449	0.5	20
2.2	1,176	167[a]	NS	20
1.3	1,176	1,587	0.1	20
2.3	1,286	106[a]	NS	20
		Total 3,309		

Age Class	Sibling Return in 1997 (thousands)	Sibling Data: Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	10	1,495[a]	NS	14
2.2	0	[b]		5
1.3	1,800	1,551	2.5	19
2.3	74	60	1.0	19
		Total 3,106		

[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 1997.

Appendix B.7. Forecasted returns of major age classes of sockeye salmon to the Igushik River in 1998 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	445	236	0.1	20
2.2	405	40	2.5	20
1.3	405	1,030	0.1	20
2.3	305	45	2.5	20
	Total	1,351		

Sibling Data

Age Class	Sibling Return in 1997 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	0	[a]		
2.2	0	[a]		
1.3	134	596	0.1	19
2.3	8	17	1.0	19
	Total	613		

[a] Estimates not made; no age-1.1 or age-2.1 sockeye salmon returned to Igushik River in 1997.

Appendix B.8. Forecasted returns of major age classes of sockeye salmon to the Nushagak River in 1998 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	281	28	1.0	15
1.2	509	105	1.0	16
2.2	715	8	5.0	15
0.3	509	354	5.0	16
1.3	715	856	0.1	16
2.3	695	8	3.0	16
0.4	715	56	12.0	16
	Total	1,415		

Sibling Data

Age Class	Sibling Return in 1997 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
0.2	0	[a]		
1.2	0	[a]		
2.2	0	[a]		
0.3	0	[a]		
1.3	64	525	0.6	15
2.3	10	11	5.0	14
0.4	43	2	0.5	15
	Total	538		

[a] Estimates not made; no age-0.1, age-1.1, age-0.2 or age-2.1 sockeye salmon returned to Nushagak River in 1997.

Appendix B.9. Forecasted returns of major age classes of sockeye salmon to the Togiak River in 1998 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	174	120	1.0	20
2.2	189	28	5.0	20
1.3	189	382	0.5	20
2.3	209	37	2.5	20
	Total	567		

Sibling Data

Age Class	Sibling Return in 1997 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	1	143[a]	NS	6
2.2	0	[b]		
1.3	57	238	0.1	19
2.3	29	37	0.5	19
	Total	418		

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

[b] Estimate not made; no age-2.1 sockeye salmon returned to Togiak River in 1997