2A94-03

LOWER COOK INLET PINK SALMON FORECAST FOR 1994

By

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Regional Information Report[1] No. 2A94-03

Alaska Department of Fish and Game
Division of Commercial Fisheries, Region II
333 Raspberry Road
Anchorage, Alaska 99518-1599

February 7, 1992

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ACKNOWLEDGEMENTS

Biometricians Richard Gates, Linda Brannian and Hal Geiger of the Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, helped with the Bayesian probability model. An anonymous reviewer suggested many improvements to the manuscript.

TABLE OF CONTENTS

	Page
LIST OF TABLES	iv
LIST OF FIGURES	v
LIST OF APPENDICES	vii
ABSTRACT	ix
INTRODUCTION	1
METHODS	1
Run Forecast Model	2
Database	2
Confidence Interval by Harvest Area	3
Confidence Interval for Lower Cook Inlet	4
Probability of Forecast Being Within a Range	5
RESULTS	7
DISCUSSION	8
LITERATURE CITED	9
TABLES	10
FIGURES	14
APPENDIX	25

LIST OF TABLES

Table		Page
1.	Pink salmon harvest and spawning areas for which run forecasts were made, Lower Cook Inlet, 1993.	10
2.	Linear regression statistics for models used to forecast runs of pink salmon to Lower Cook Inlet harvest areas in 1994. Statistics shown for each model were the Y-intercept (a), regression coefficient (b), coefficient of determination (r^2), F-value (F), and degrees of freedom (d.f.).	11
3.	Forecasted pink salmon runs, projected harvests[a], and potential spawning escapement shortfalls for Lower Cook Inlet pink salmon, 1994.	12
4.	Forecasted and actual runs of pink salmon to Lower Cook Inlet, 1993.	13

LIST OF FIGURES

Figure		Page
1.	Pink salmon streams in Lower Cook Inlet with formal forecasts	14
2.	Distribution of log transformed Lower Cook Inlet pink salmon runs	15
3.	Distribution of residuals from regression of log transformed Lower Cook Inlet pink salmon runs on log transformed forecasts	16
4.	Reconstructed forecasts and observed runs for Lower Cook Inlet pink salmon	17
5.	Probability of Lower Cook Inlet pink salmon runs size given 1994 forecast of 408,307	18
6.	Pink salmon escapement, return, predicted return from Ricker curve, log-log regression, and median return/spawner ratio, Humpy Creek	19
7.	Pink salmon escapement, return, predicted return from Ricker curve, log-log regression, and median return/spawner ratio, Seldovia Bay	19
8.	Pink salmon escapement, return, predicted return from Ricker curve, log-log regression, and median return/spawner ratio, Port Graham	20
9.	Pink salmon escapement, return, predicted return from Ricker curve, log-log regression, and median return/spawner ratio, Port Chatham	20
10.	Pink salmon escapement, return, predicted return from Ricker curve, log-log regression, and median return/spawner ratio, Windy Bay	21
11.	Pink salmon escapement, return, predicted return from Ricker curve, log-log regression, and median return/spawner ratio, Rocky Bay	21
12.	Pink salmon escapement, return, predicted return from Ricker curve, log-log regression, and median return/spawner ratio, Port Dick	22

LIST OF FIGURES (Continued)

Figure		Page
13.	Pink salmon escapement, return, predicted return from Ricker curve, log-log regression, and median return/spawner ratio, Nuka Bay	22
14.	Pink salmon escapement, return, predicted return from Ricker curve, log-log regression, and median return/spawner ratio, Resurrection Bay	23
15.	Pink salmon escapement, return, predicted return from Ricker curve, log-log regression, and median return/spawner ratio, Bruin Bay	23
16.	Pink salmon escapement, return, predicted return from Ricker curve, log-log regression, and median return/spawner ratio, Ursus and Rocky Coves	24

LIST OF APPENDICES

Page

APPENDIX A: BROOD YEAR TABLES 25

A.1. Spawning escapement and total return data used to forecast 1993 pink salmon run to Humpy Creek, Lower Cook Inlet 26

A.2. Spawning escapement and total return data used to forecast 1993 pink salmon run to Seldovia, Lower Cook Inlet 27

A.3. Spawning escapement and total return data used to forecast 1993 pink salmon run to Port Graham, Lower Cook Inlet 28

A.4. Spawning escapement and total return data used to forecast 1993 pink salmon run to Port Chatham, Lower Cook Inlet 29

A.5. Spawning escapement and total return data used to forecast 1993 pink salmon run to Windy Bay, Lower Cook Inlet 30

A.6. Spawning escapement and total return data used to forecast 1993 pink salmon run to Rocky Bay, Lower Cook Inlet 31

A.7. Spawning escapement and total return data used to forecast 1993 pink salmon run to Port Dick Bay, Lower Cook Inlet 32

A.8. Spawning escapement and total return data used to forecast 1993 pink salmon run to Nuka Bay, Lower Cook Inlet 33

A.9. Spawning escapement and total return data used to forecast 1993 pink salmon run to Resurrection Bay, Lower Cook Inlet 34

A.10. Spawning escapement and total return data used to forecast 1993 pink salmon run to Bruin Bay, Lower Cook Inlet 35

A.11. Spawning escapement and total return data used to forecast 1993 pink salmon run to Ursus and Rocky Cove, Lower Cook Inlet 36

LIST OF APPENDICES (Continued)

Page

APPENDIX B: FORTRAN PROGRAMS 37

B.1. FORTRAN source code for forecast program 38

B.2. FORTRAN source code for Bayesian probability program 45

ABSTRACT

Total number of pink salmon *Oncorhynchus gorbuscha* returning to 11 Lower Cook Inlet streams or drainage systems in 1994 was forecasted to be 408,000. Associated harvest was projected to be 115,000 with an potential escapement shortfall of 80,000 in six harvest areas: Port Graham, Windy Bay, Rocky Bay, Resurrection Bay, Bruin Bay, and Ursus-Rocky Coves. Lower and upper 80% confidence interval around the total run forecast were 140,000 and 1,200,000, respectively with the corresponding harvest projected to range between 54,000 and 721,000. Potential escapement shortfall may be as high as 190,000 in 10 harvest areas, if runs to all harvest areas were at the lower forecast bound. Log-log regression models of returning adults on spawning escapements as well as Ricker recruitment curve analysis were used to produce forecasts for each stream or drainage system. Cross-validation of the individual runs to the 11 harvest areas, as well as the total run to Lower Cook Inlet, were used to reconstruct historical forecasts errors. The reconstructed forecast errors were used to calculate standard deviations and 80% confidence interval. Wide confidence intervals about the total run forecast indicated the high degree of uncertainty involved in predicting the actual run. The fraction of historical runs that were within the 1993 forecast bounds and the fraction of reconstructed forecasts that were correct, i.e. within the reconstructed forecast bounds, were also calculated for each harvest area.

KEY WORDS: *Oncorhynchus gorbuscha*, pink salmon, forecast, Lower Cook Inlet

INTRODUCTION

This was the fifth year a forecast of pink salmon *Oncorhynchus gorbuscha* run size was made for Lower Cook Inlet (Figure 1). Individual forecasts of 1994 runs were made for 11 harvest areas for which historical records of commercial catches and spawning escapements were available. Pink salmon fisheries within these 11 areas have been managed to obtain spawning escapement goals in associated streams and drainages. The objective of this report was to document methods used to produce forecasts of wild pink salmon runs to Lower Cook Inlet in 1994. Forecasts of hatchery pink salmon runs (e.g. Tutka Lagoon) can be found in annual statewide salmon forecast reports (e.g. Geiger and Savikko 1993).

METHODS

Forecasts of wild pink salmon runs were prepared individually for 11 harvest areas in the Lower Cook Inlet management area. The forecast for each harvest area was the number of pink salmon expected to return in 1994 as a result of spawning escapements obtained in 1992. Harvest projections by area were obtained by subtracting the escapement goal from the forecasted run. If the forecasted run was less than the escapement goal, the projected harvest was zero. Cross-validation was used to reconstruct historical forecast errors by harvest areas. These were used to derive a standard deviation (SD) and an 80% confidence interval around individual harvest area forecasts. Projected harvest associated with the forecast bounds were calculated from the corresponding escapement ranges. Escapement ranges, however, were not available for Ursus and Rocky Cove, Resurrection Bay, and Rocky Bay, so spawning escapement goals for these systems were used instead to calculate the projected harvest associated with the upper and lower forecast bounds.

The total run forecast to Lower Cook Inlet was defined in this report as the sum of the 11 individual harvest area forecasts. Upper and lower bounds around the total run forecast, however, were derived from a cross-validation using the total runs rather than the sum of the 11 individual. harvest area confidence intervals. The aggregate escapement goal was the sum of the individual escapement goals. The total projected harvest was the total run minus the aggregated escapement goal and the total escapement shortfall.

Run Forecast Model

Pink salmon runs to individual harvest areas were forecasted using one of three methods: a Ricker recruitment curve (Ricker 1975):

$$F_{h,y}=E_{h,y-2}e^{a+bE}, \tag{1}$$

a log-log regression of total return on spawning escapement:

$$F_{h,y}=e^{a+b\ \ln\ (E_{h,y-2})}, \tag{2}$$

or median return/spawner ratios:

$$F_{h,y}=E_{h,y-2}\left(\frac{\tilde{R}}{E}\right), \tag{3}$$

where $F_{h,y}$ = forecasted total return (i.e. the sum of catch_y and escapement_y) in harvest area h during year y; E = escapement; $\tilde{R}$ = median observed total return; a = regression intercept; b = regression coefficient (slope); e = 2.1783; and the function *ln* was the natural logarithm. An F-test of analysis of variance results was used to examine the null hypothesis that the Ricker-curve and log-log regression coefficients were equal to zero. The null hypothesis was not rejected unless $P < 0.25$. If the Ricker model and the log-log regression were both found to be statistically significant, we selected the model with the greater F value. If neither of these models were significant, median return/spawner ratios were used instead.

Database

Total return and spawning escapement data for the 1960 to 1991 brood years were obtained from the most recent annual management report (Bucher and Hammarstrom 1993). While long-term records of pink salmon commercial harvests were available for at least 15 areas in Lower Cook Inlet, corresponding estimates of spawning escapement were available for only 12. Forecasts, however, were prepared for only 11 harvest areas, representing 23 spawning systems (Table 1). While data were available to prepare a forecast for Dogfish Lagoon, no forecast was made since

this area did not have a pink salmon spawning escapement goal. Return was defined as catch plus escapement. Returns estimated from the catch only were not used.

Confidence Interval by Harvest Area

To do cross-validations for each harvest area (a) spawner and return data were removed from the data file one brood year at a time; (b) a run forecast model was built using the remaining data; (c) the run was forecast for the excluded brood year; and (d) historical forecast errors or residuals r were reconstructed as either

$$r_{h,y}=\ln(\textit{cross validated } F_{h,y})-\ln(R_{h,y}), \tag{4}$$

whenever a Ricker recruitment curve or a log-log regression model was used, or as

$$r_{h,y}=\textit{cross validated } F_{h,y}-R_{h,y}, \tag{5}$$

whenever median return/spawner ratios were used. The excluded brood year was returned to the data set and this process was repeated for all brood years. The sum of the square of the reconstructed historical forecast errors was then used to estimate the cross-validation SD:

$$SD_h=\sqrt{\frac{\sum_{i=1}^{n} r_{h,i}^2}{n-1}}, \tag{6}$$

where n = number of brood years in cross-validation data set. The 80% confidence interval was estimated as either

$$e^{\ln(F_{h,y})-t_{0.1}SD_h} \le F_{h,y} \le e^{\ln(F_{h,y})+t_{0.1}SD_h}, \tag{7}$$

whenever a Ricker-curve or a log-log regression model was used, or

$$F_{h,y}-t_{0.1}SD_h \leq F_{h,y} \leq F_{h,y}+t_{0.1}SD_h, \tag{8}$$

whenever a median return/spawner ratio was used, where $t_{0.1}$ is the (1-0.2/2) quantile of the Student's t distribution for n-1 degrees of freedom.

Confidence Interval for Lower Cook Inlet

The Lower Cook Inlet forecast, an aggregate of 11 harvest areas, was calculated as

$$F_{LCI,y}=\sum_{h=1}^{H} F_{h,y}. \tag{9}$$

Its 80% confidence interval was based on the forecast errors from a simultaneous cross-validation of all harvest areas where

$$r_{LCI,y}=\ln\left(\sum_{h=1}^{H} cross\ validated\ F_{h,y}\right)-\ln\left(\sum_{h=1}^{H} catch_{h,y}+escapement_{h,y}\right), \tag{10}$$

and

$$SE_{LCI}=\sqrt{\frac{\sum_{i=1}^{n} r_{LCI,i}^2}{n-1}}. \tag{11}$$

H varied among years because brood year data from some harvest areas were excluded from the data set.

Probability of Forecast Being Within a Range

The probability of the run being within a forecast range was also estimated using Bayes theorem:

$$p(R_{LCI}|F_{Lci}) = \frac{p(R_{LCI})\, l(R_{LCI}|F_{LCI})}{\int_0^\infty p(R_{LCI})\, l(R_{LCI}|F_{LCI})}. \tag{12}$$

Since logarithms of historical run sizes were normally distributed (Figure 2), the prior probability of run size could be modeled as,

$$p(R_{LCI}) = \frac{1}{R_{LCI}\sigma_R\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\ln(R_{LCI})-\ln(\overline{R}_{LCI})}{\sigma_R}\right)^2}, \tag{13}$$

where $\overline{R}_{LCI}$ = mean run historical size and

$$\sigma_R = \sqrt{\frac{\sum_1^n [\ln(R_{LCI}) - \ln(\overline{R}_{LCI})]}{n-1}}. \tag{14}$$

The residuals from a regression of historical runs on reconstructed forecasts,

$$\ln\hat{R}_{LCI} = a + b \ln F_{LCI}, \tag{15}$$

were also normally distributed (Figure 3). This the likelihood function for the 1994 forecast to be modeled as

$$l(R_{LCI}|F_{LCI}) \propto \frac{e^{-\frac{1}{2}\left(\frac{\ln(R_{LCI})-\ln(\hat{R}_{LCI})}{\sigma_{\hat{R}}}\right)^2}}{R_{LCI}} \tag{16}$$

where $\hat{R}$ = forecast and

$$\sigma_{\hat{R}} = \sqrt{\frac{\sum_{y=1962}^{1993}[\ln(R_{LCI,y})-\ln(\hat{R}_{LCI,y})]^2}{n-2}\left(1+\frac{1}{n}+\frac{[\ln(\hat{R}_{LCI,1994})-\ln(\overline{R}_{LCI})]^2}{\sum_{y=1962}^{1993}[\ln(R_{LCI,y})-\ln(\overline{R}_{LCI})]^2}\right)}. \tag{17}$$

Combining the prior probability, Eq. (13), and likelihood function, Eq. (16), yielded the posterior probability (Box and Tiao 1973)

$$P(R_{LCI}|F_{LCI}) = \frac{\frac{(\sigma_R^{-2}+\sigma_{\hat{R}}^{-2})^{\frac{1}{2}}}{R_{LCI}} e^{-\frac{1}{2}(\sigma_R^{-2}+\sigma_{\hat{R}}^{-2})(R_{LCI}-\overline{\theta})^2}}{\int_0^\infty \frac{(\sigma_R^{-2}+\sigma_{\hat{R}}^{-2})^{\frac{1}{2}}}{R_{LCI}} e^{-\frac{1}{2}(\sigma_R^{-2}+\sigma_{\hat{R}}^{-2})(R_{LCI}-\overline{\theta})^2} dR_{LCI}}, \tag{18}$$

where

$$\overline{\theta} = \frac{1}{\sigma_R^{-2}+\sigma_{\hat{R}}^{-2}}\left(\sigma_R^{-2}\ln(\overline{R}_{LCI}) + \sigma_{\hat{R}}^{-2}\ln(\hat{R}_{LCI})\right). \tag{19}$$

To find the range of run sizes with an 80% probability of including the forecast,

$$p(R_{min} \le F_{LCI} \le R_{Max}) = 0.80, \tag{20}$$

we calculated posterior probabilities, using Eq. (18), for all run sizes between 0 and 9,000,000, approximately the maximum historical run size, in increments of 25,000. We then searched both tails of the probability distribution for R_{min} and R_{max} whose values of $P(R_{LCI}|F_{LCI})$ were equal,

$$p(R_{min}|F_{LCI}) = p(R_{max}|F_{LCI}), \tag{21}$$

such that

$$\int_{R_{min}}^{R_{max}} p(R_{LCI}|F_{LCI}) \leq 0.80. \tag{22}$$

RESULTS

Three harvest area forecasts were based on a Ricker recruitment curve and seven were based on a log-log regression model (Table 2). Median return/spawner ratios did not have to be used to generate a forecast for any harvest area. The sum of the forecasted runs to the 11 Lower Cook Inlet harvest areas for 1994 was 408,307 pink salmon. A run of this size was greater than 25%, but less than 50%, of the actual runs observed between 1962 and 1991 (Figure 4). The total projected catch for 1994 was 115,442 pink salmon. No harvests were projected for Port Graham, Windy Bay, Rocky Bay, Resurrection Bay, Bruin Bay, and Ursus-Rocky Coves since the forecasted run was less than the spawning escapement goal for these six areas (Table 3).

The 80% confidence interval for the total Lower Cook Inlet pink salmon run was 139,932 to 1,191,393 (Table 3). The 80% confidence intervals for total run and individual harvest area forecasts were calculated independently using a cross-validation technique (see Methods). Therefore, it was not surprising that sum of the lower and upper bounds of the 11 individual harvest area forecasts did not match the upper and lower bounds of the 80% confidence interval for total Lower Cook Inlet forecast. If all 11 runs were at their lower forecast bound, the total projected catch would be 54,961 pink salmon. I f all 11 runs were at their upper forecast bound, the total projected catch could be 721,393 pink salmon. However, there is no reason to expect that all 11 will be at the upper or lower end of their ranges.

Based on Bayesian theory, a forecast of 408,307 pink salmon would have an 80% chance of falling between 250,000 and 925,000 in 1994 (Figure 5).

All methods examined to forecast Lower Cook Inlet pink salmon runs relied solely on the number of spawners (Figures 6-15). However, the number of spawners explained more than 50% of the variability in run size for only two of the 11 harvest areas examined, Windy and Rocky Bays.

DISCUSSION

Pink salmon spawning escapements in 1992, the parental year for 1994 runs, were below the lower range of escapement goals throughout Lower Cook Inlet (Table 3). Consequently, the low forecasted run for 1994 is not surprising.

The Lower Cook Inlet pink salmon dominant year run pattern has changed over the years. Runs were greater during even than during odd years between 1962 and 1970, but were greater during odd than during even years between 1971 and 1982. No dominant year pattern was evident between 1983 and 1986, but runs became greater during odd than during even years between 1987 and 1992. If the forecast is accurate, the pattern of lesser run size during even years would be maintained.

Wide 80% confidence intervals show the large degree of uncertainty associated with the 1994 pink salmon forecast (Table 3). Our models tend to underforecast larger runs but appear to be good indicators of smaller runs, such as that forecast for 1994 (Figure 4). Since only two of the 11 harvest areas examined had more than 50% of the variability in past run size explained by spawning escapement, it is obvious that factors other than spawning escapement greatly influence pink salmon production. Until these factors are identified and incorporated into predictive models, it is unlikely that the accuracy of Lower Cook Inlet pink salmon forecasts will improve.

The 1994 forecast is for a run smaller than that observed in 1993. The preliminary estimate of the 1993 run was 687,171 pink salmon, less than the 1993 forecast of 798,804. Individual runs in all harvest areas during 1993 were within their, albeit wide, confidence intervals. The 1993 run was similar to the historical median run size (Figure 4).

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Table 1. Pink salmon harvest and spawning areas for which run forecasts were made, Lower Cook Inlet, 1993.

Harvest Area	Corresponding Spawning Area(s)
Humpy Creek	Humpy Creek
Seldovia Bay	Seldovia River
Port Graham Bay	Port Graham River
Port Chatham	Port Chatham Creeks
Windy Bay	Windy Left and Windy Right Creeks
Rocky Bay	Rocky River
Port Dick Bay	Port Dick and Island Creeks
Nuka Bay	South Nuka, Desire Lake Creek, James Lagoon
Resurrection Bay	Bear, Salmon, Mayor, Clear, Thumb, Humpy and Tonsina Creeks
Bruin Bay	Bruin Bay River and Amakdedori Creek
Rocky and Ursus Coves	Sunday and Brown's Peak Creek

Table 2. Linear regression statistics for models used to forecast runs of pink salmon to Lower Cook Inlet harvest areas in 1994. Statistics shown for each model were the Y-intercept (a), regression coefficient (b), coefficient of determination (r^2), F-value (F), and degrees of freedom (d.f.).

	Model	a	b	r^2	F	d.f.
Humpy Creek	Ricker	1.33941	-0.00001	0.199	7.20	1,23
Seldovia Bay	log-log	5.35603	0.53063	0.114	3.86	1,30
Port Graham	Ricker	1.29513	-0.00004	0.231	9.01	1,30
Port Chatham	Ricker	2.02429	-0.00009	0.392	12.27	1,19
Windy Bay	log-log	0.59859	0.99458	0.691	64.72	1,29
Rocky Bay	log-log	2.13489	0.79031	0.552	37.03	1,30
Port Dick	log-log	4.78692	0.69980	0.340	12.86	1,25
Nuka Bay	Ricker	2.44258	-0.00005	0.433	16.83	1,22
Resurrection Bay	log-log	4.50738	0.63227	0.441	12.63	1,16
Bruin Bay	log-log	4.95621	0.60755	0.474	16.25	1,18
Ursus & Rocky Cove	log-log	5.09551	0.53024	0.394	16.25	1,25

Table 3. Forecasted pink salmon runs, projected harvests*, and potential spawning escapement shortfalls for Lower Cook Inlet pink salmon, 1994.

		Forecast			Forecast Range: Lower Bound			Forecast Range: Upper Bound			Potential Escapement Goal Shortfall		
Location	1992 Escapement	Forecast Run	Escapement Goal	Projected Harvest	Forecast Run	Escapement Goal	Projected Harvest	Forecast Run	Escapement Goal	Projected Harvest	Point Forecast	Lower Bound	Upper Bound
Humpy Creek	14,583	46,716	37,500	9,216	9,971	25,000	0	218,877	50,000	168,877	0	15,029	0
Seldovia Bay	14,682	34,444	30,000	4,444	9,532	25,000	0	124,465	35,000	89,465	0	15,468	0
Port Graham	5,450	15,991	30,000	0	4,515	20,000	0	56,635	40,000	16,635	14,010	15,485	0
Port Chatham	4,304	21,859	12,500	9,359	4,846	10,000	0	98,611	15,000	83,611	0	5,155	0
Windy Bay	12,059	20,853	50,000	0	5,339	40,000	0	81,452	60,000	21,452	29,147	34,661	0
Rocky Bay	26,077	26,146	50,000	0	5,681	50,000	0	120,333	50,000	70,333	23,854	44,319	0
Port Dick	17,024	109,606	60,000	49,606	27,579	20,000	7,579	435,606	100,000	335,606	0	0	0
Nuka Bay	7,177	57,815	15,000	42,815	13,019	10,000	3,019	256,753	20,000	236,753	0	0	0
Resurrection Bay	7,986	26,599	30,000	0	6,198	30,000	0	114,145	30,000	84,145	3,401	23,802	0
Bruin Bay	6,400	29,168	37,500	0	4,664	25,000	0	182,427	50,000	132,427	8,332	20,336	0
Ursus & Rocky Cove	7,955	19,109	20,000	0	4,226	20,000	0	86,414	20,000	66,414	891	15,774	0
Lower Cook Inlet	123,697	408,307	372,500	115,442	139,932	275,000	54,961	1,191,393	470,000	721,393	79,635	190,029	0

NOTE: LCI total forecast based on crossvalidation, does not equal to sum of individual forecasts
do not add up harvest, instead forecast-escapement+escapement shortfall=harvest

Table 4. Forecasted and actual runs of pink salmon to Lower Cook Inlet, 1993.

	1993 Forecast	Lower Bound	Upper Bound	1993 Run	% Error[a]	
Humpy Creek	48,794	9,612	247,694	36,196	35	Run within Forecast Range
Seldovia	50,397	13,917	182,498	46,848	8	Run within Forecast Range
Port Graham	33,774	10,095	112,991	24,819	36	Run within Forecast Range
Port Chatham	25,872	3,225	207,573	36,893	-30	Run within Forecast Range
Windy Bay	80,508	15,411	420,573	84,866	-5	Run within Forecast Range
Rocky Bay	24,904	5,517	112,431	74,848	-67	Run within Forecast Range
Port Dick Bay	211,512	29,898	1,496,320	78,485	169	Run within Forecast Range
Nuka Bay	43,909	4,630	416,414	98,426	-55	Run within Forecast Range
Resurrection Bay	51,636	7,623	349,764	20,007	158	Run within Forecast Range
Bruin Bay	191,887	20,119	1,830,176	86,467	122	Run within Forecast Range
Ursus and Rocky Coves	35,610	5,040	251,603	99,316	-64	Run within Forecast Range
Total	798,804	125,087	5,628,038	687,171	16	Run within Forecast Range

[a] Percent error is ((Forecasted Run - Actual Run) / Actual Run) x 100.

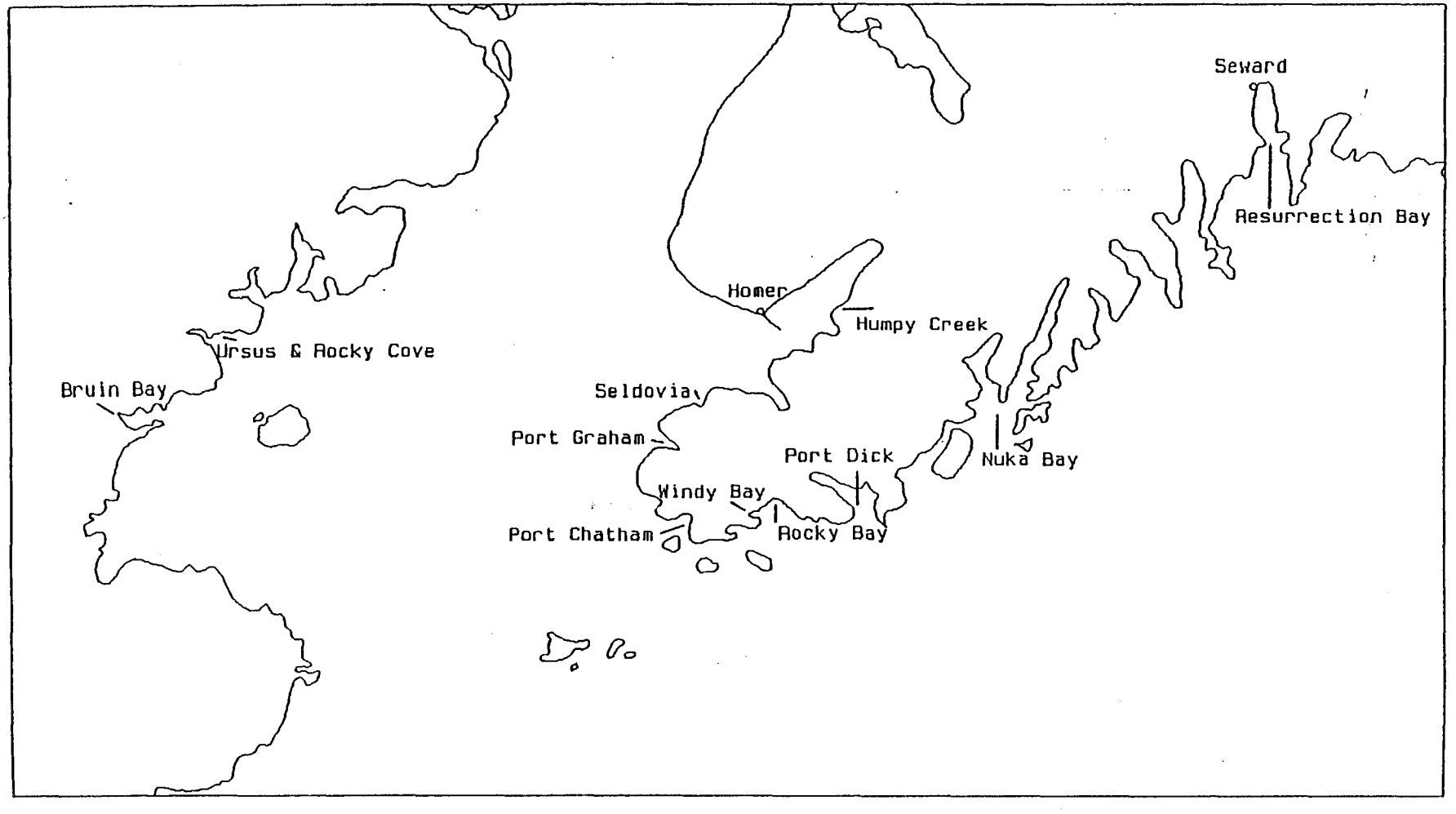

Figure 1. Pink salmon streams in Lower Cook Inlet with formal forecast.

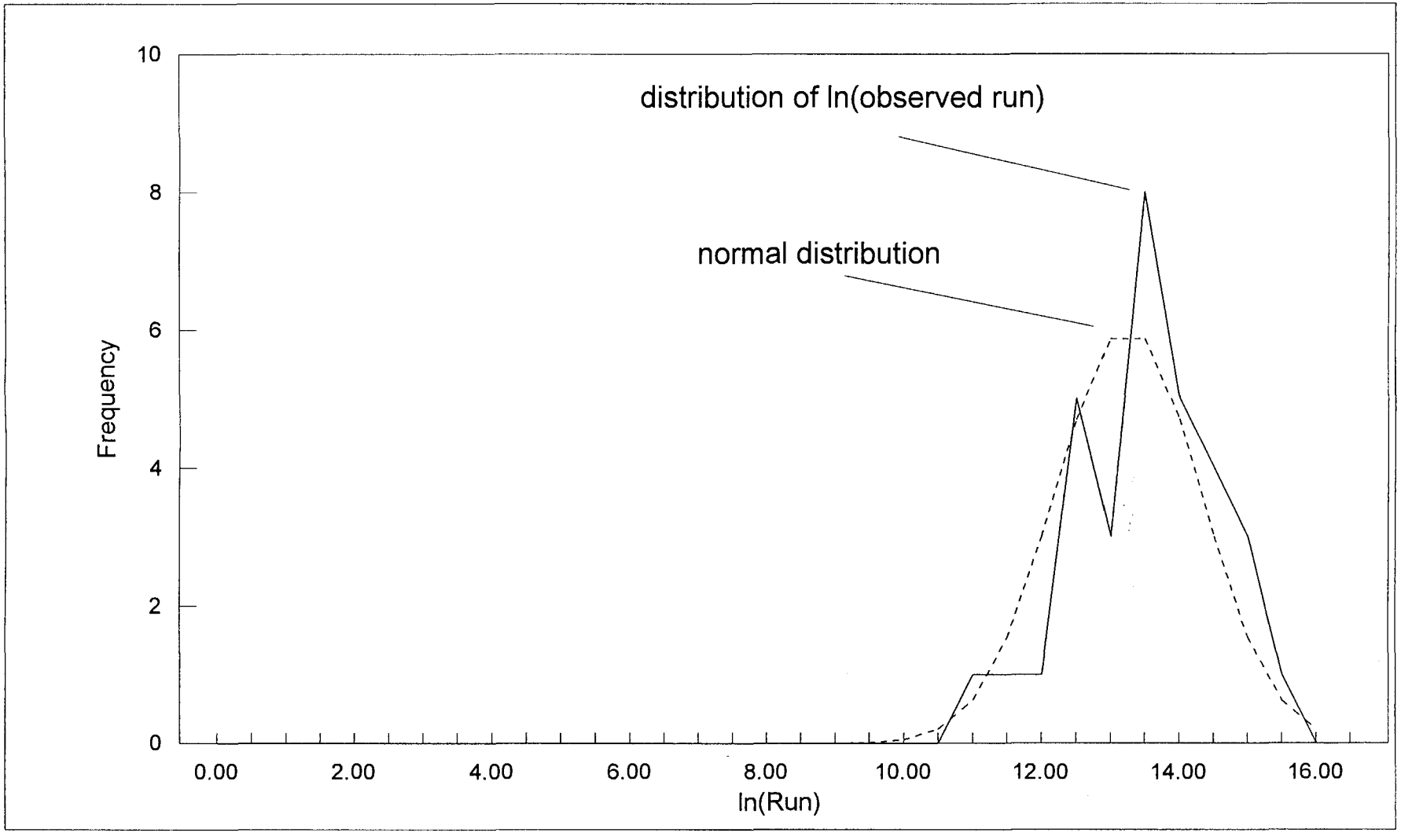

Figure 2. Distribution of log-transformed Lower Cook Inlet pink salmon runs.

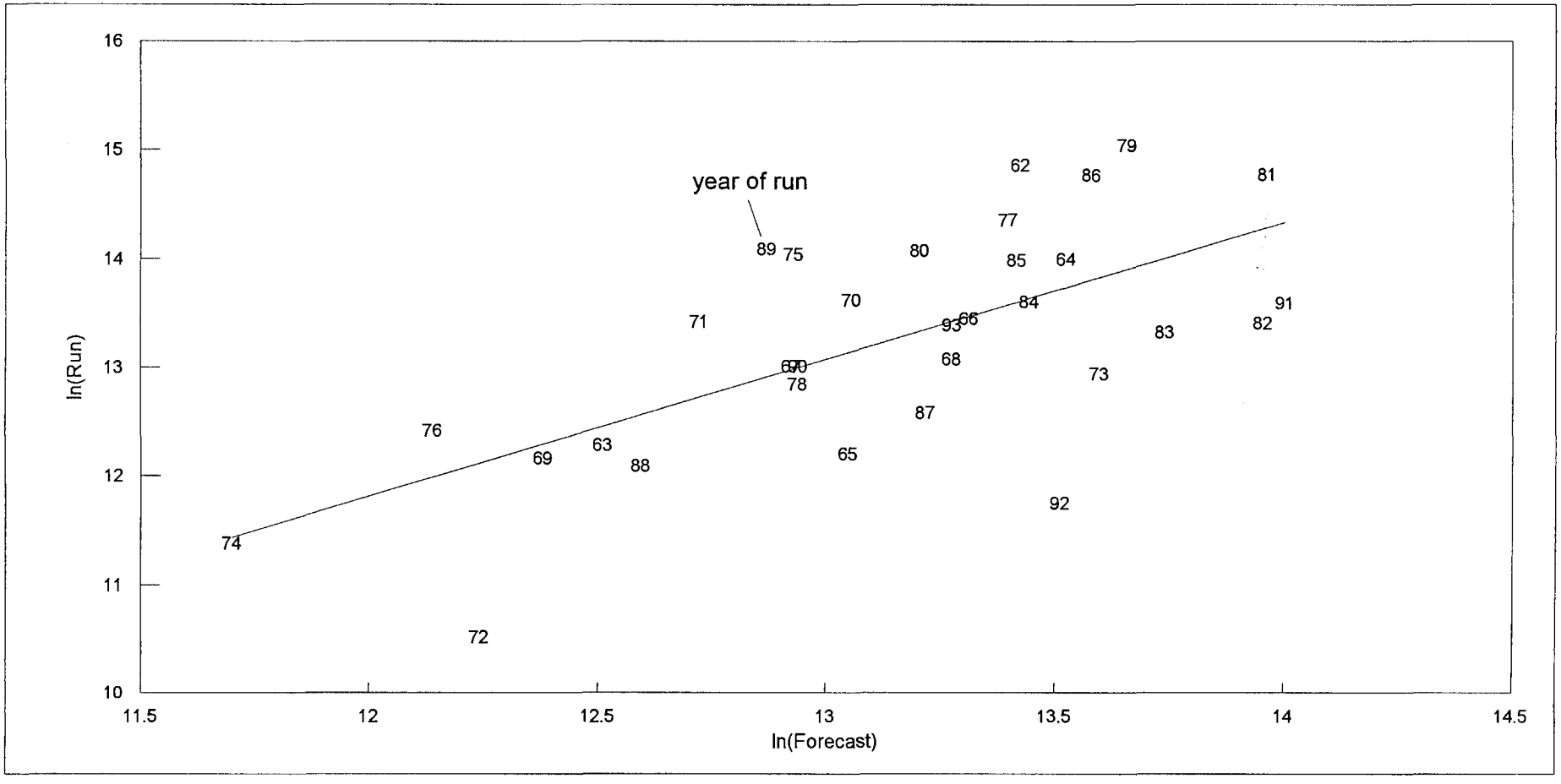

Figure 3. Distribution of residuals from regression of log-transformed Lower Cook Inlet pink salmon runs on log-transformed forecast.

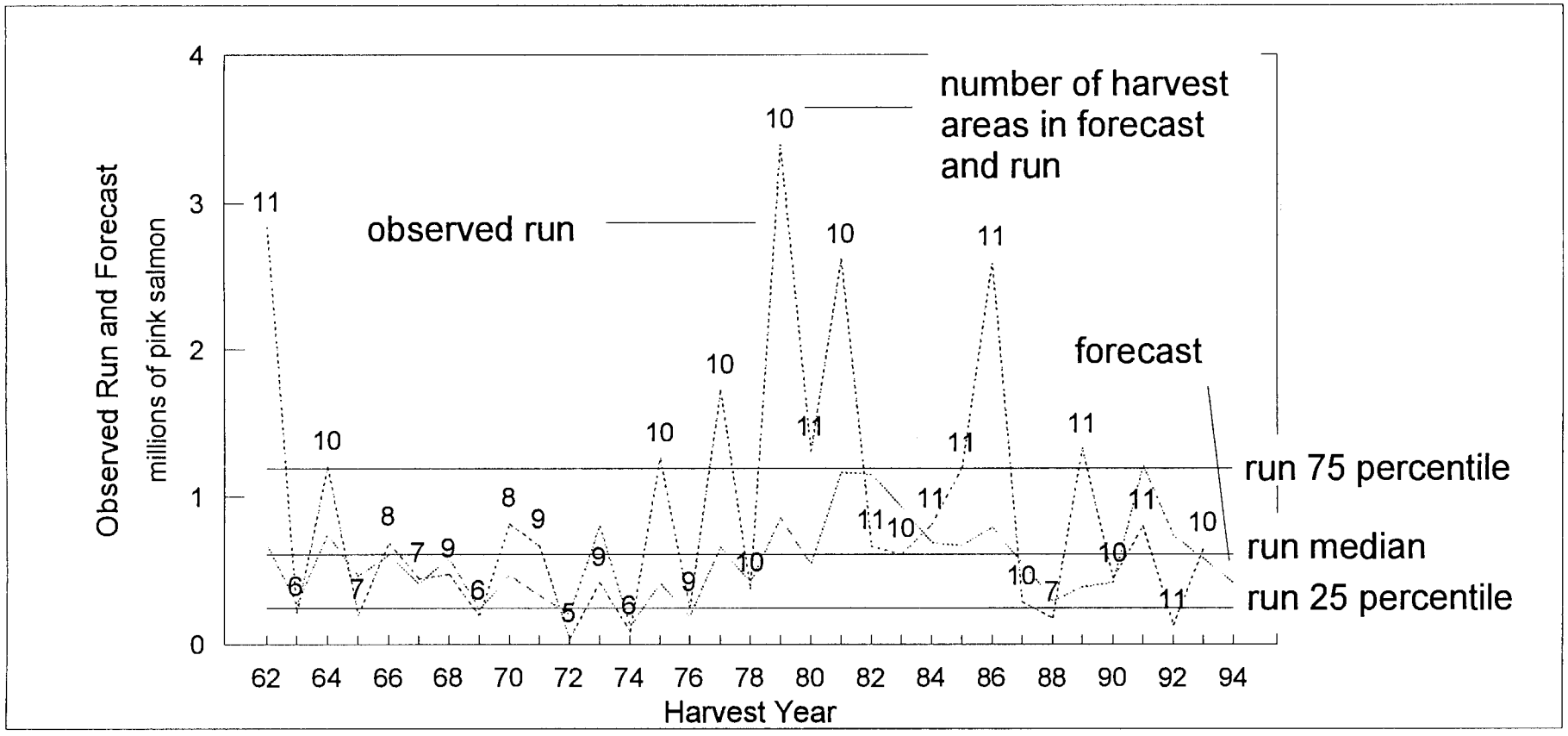

Figure 4. Reconstructed forecasts and observed runs for Lower Cook Inlet pink salmon.

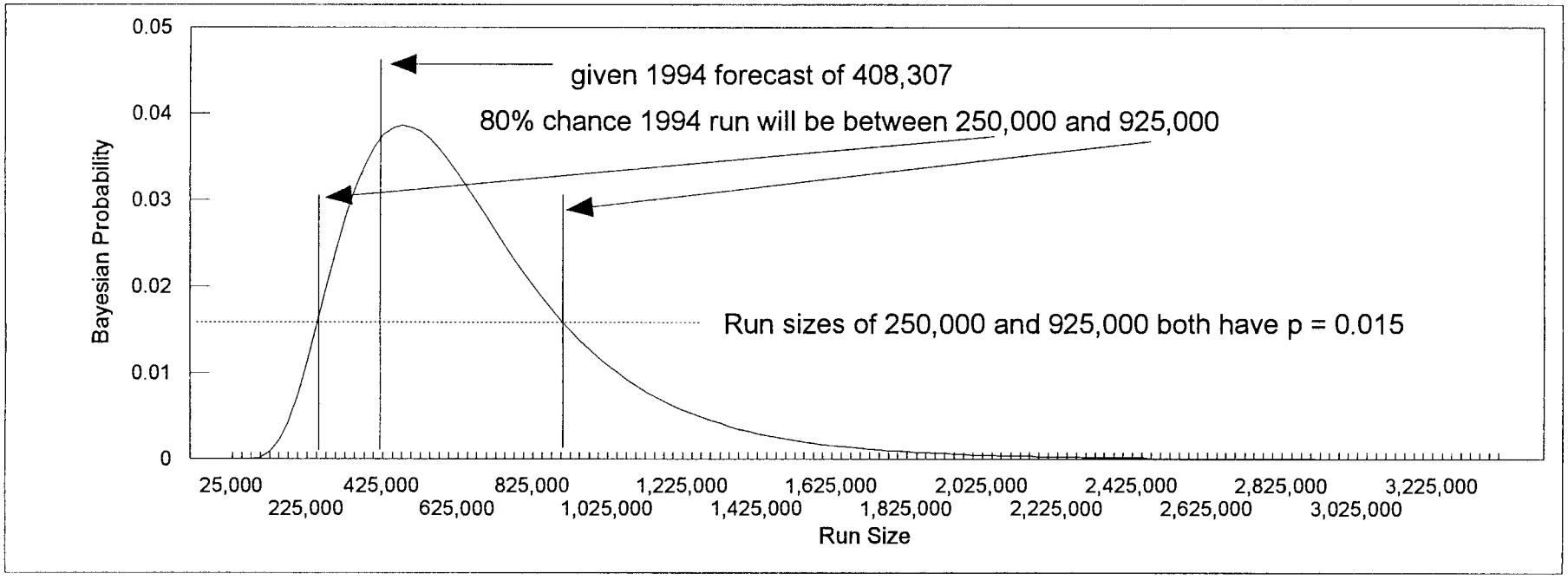

Figure 5. Probability of Lower Cook Inlet pink salmon run size given 1994 forecast of 408,307.

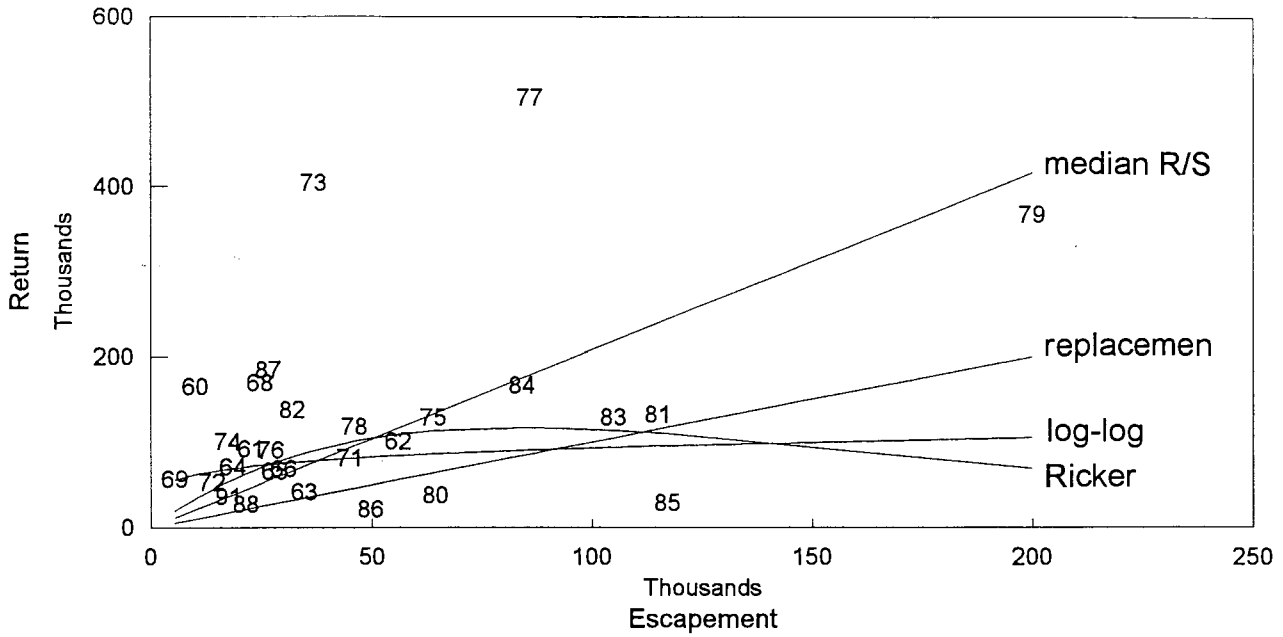

Figure 6. Pink salmon escapement, return, predicted return from Ricker curve, log-log regression and median return/spawner ratio, Humpy Creek.

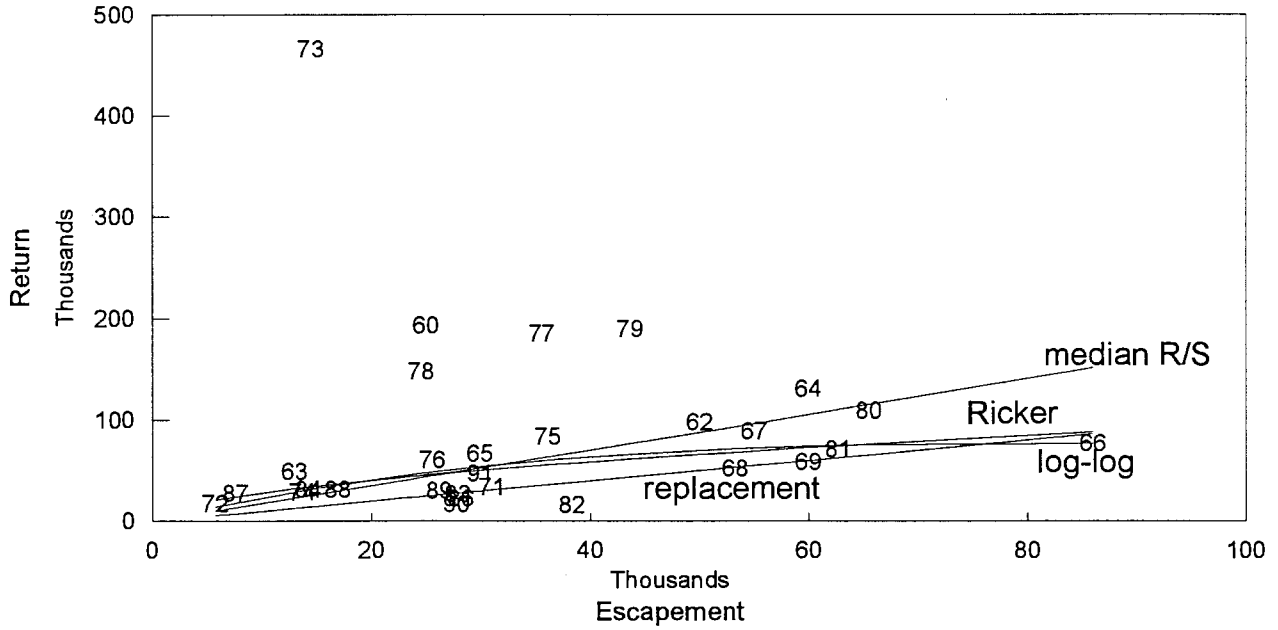

Figure 7. Pink salmon escapement, return, predicted return from Ricker curve, log-log regression and median return/spawner ratio, Seldovia.

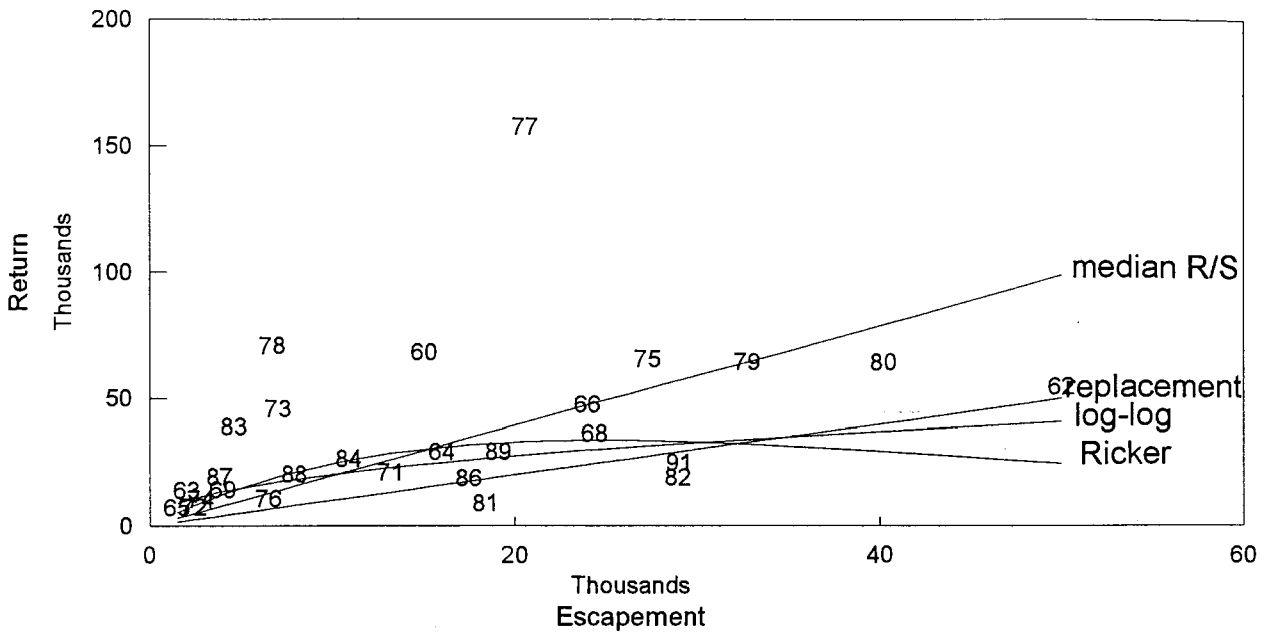

Figure 8. Pink salmon escapement, return, predicted return from Ricker curve, log-log regression and median return/spawner ratio, Port Graham.

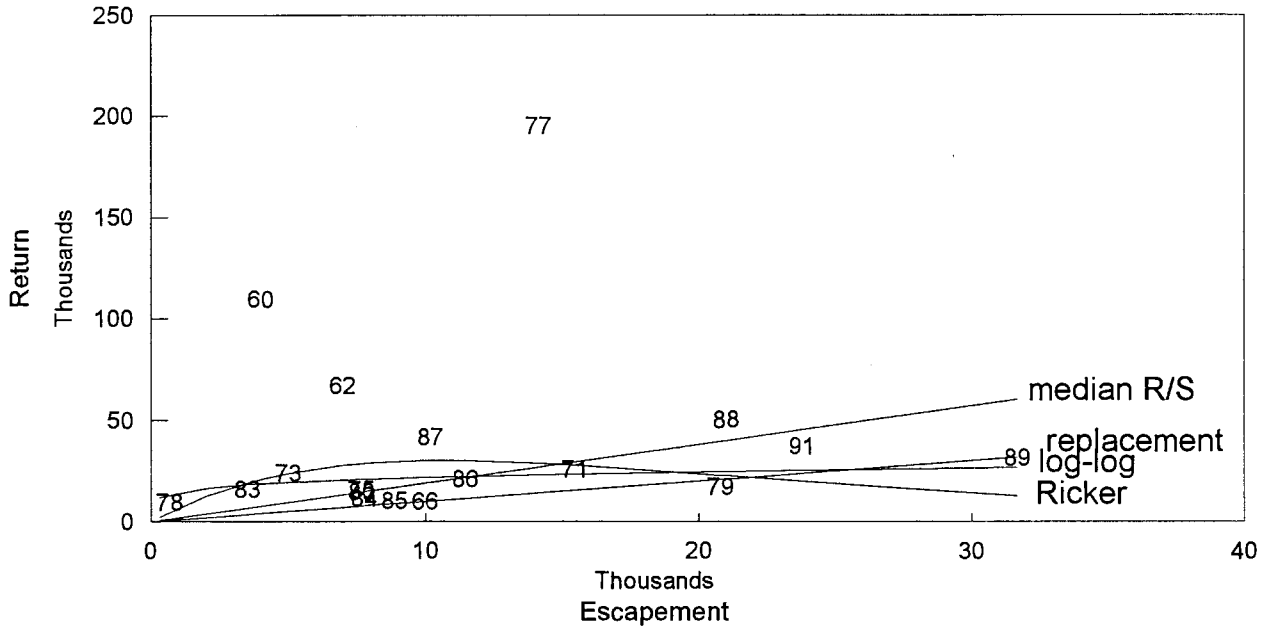

Figure 9. Pink salmon escapement, return, predicted return from Ricker curve, log-log regression and median return/spawner ratio, Port Chatham.

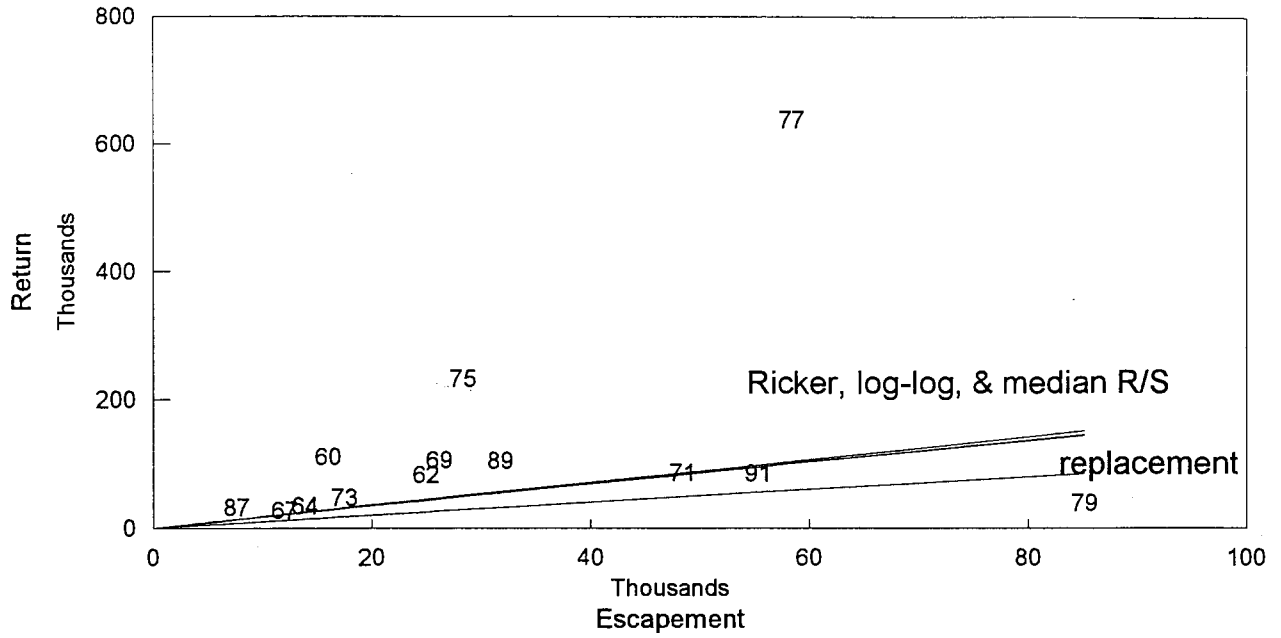

Figure 10. Pink salmon escapement, return, predicted return from Ricker curve, log-log regression and median return/spawner ratio, Windy Bay.

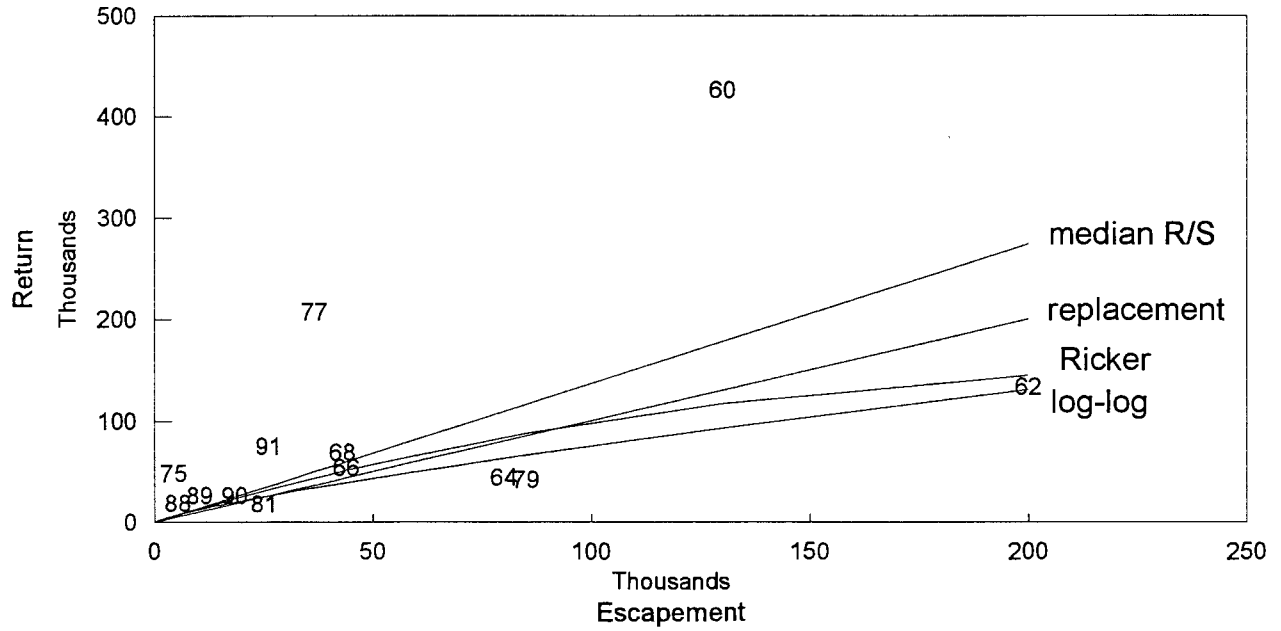

Figure 11. Pink salmon escapement, return, predicted return from Ricker curve, log-log regression and median return/spawner ratio, Rocky Bay.

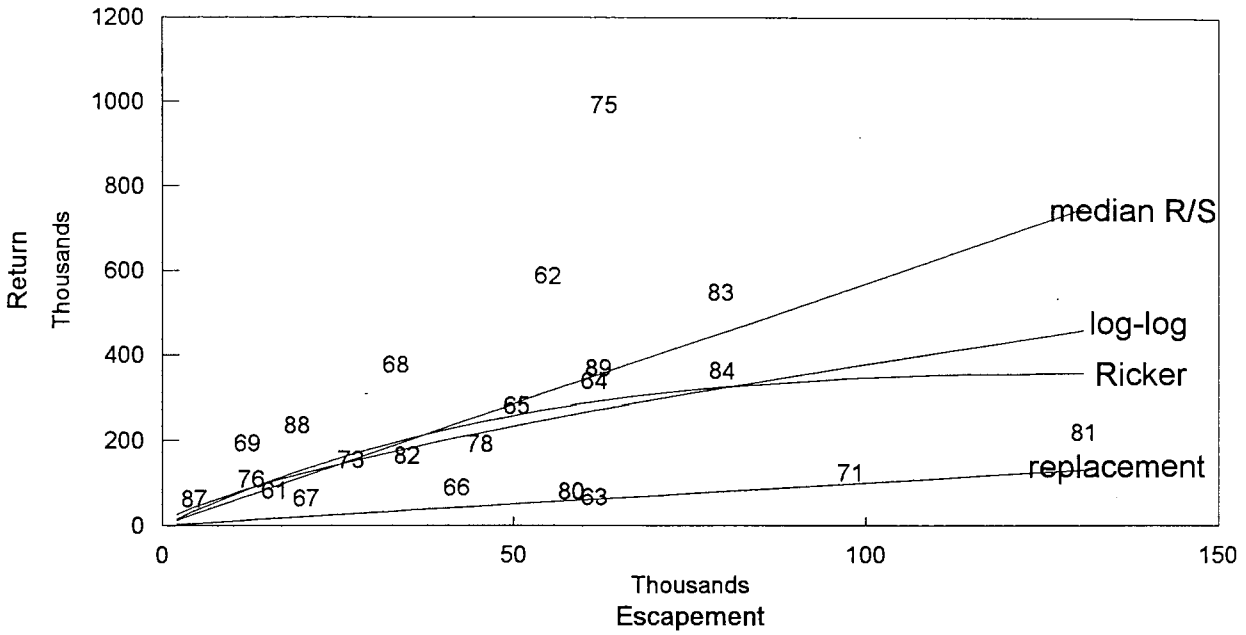

Figure 12. Pink salmon escapement, return, predicted return from Ricker curve, log-log regression and median return/spawner ratio, Port Dick Bay.

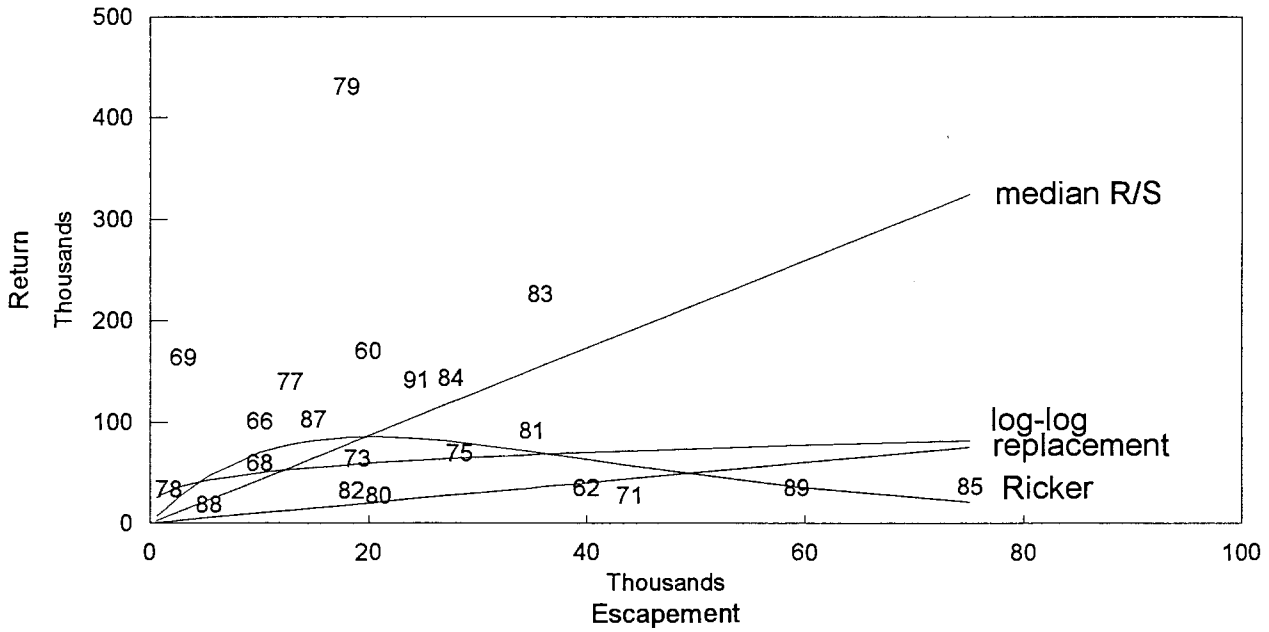

Figure 13. Pink salmon escapement, return, predicted return from Ricker curve, log-log regression and median return/spawner ratio, Nuka Bay.

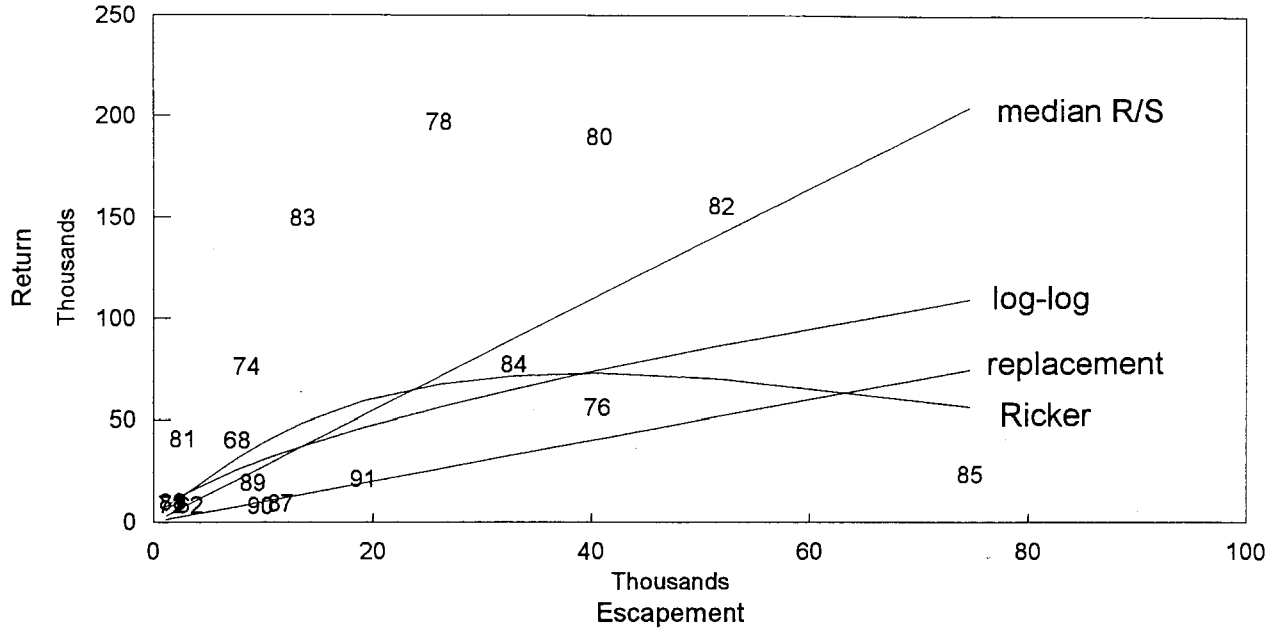

Figure 14. Pink salmon escapement, return, predicted return from Ricker curve, log-log regression and median return/spawner ratio, Resurrection Bay.

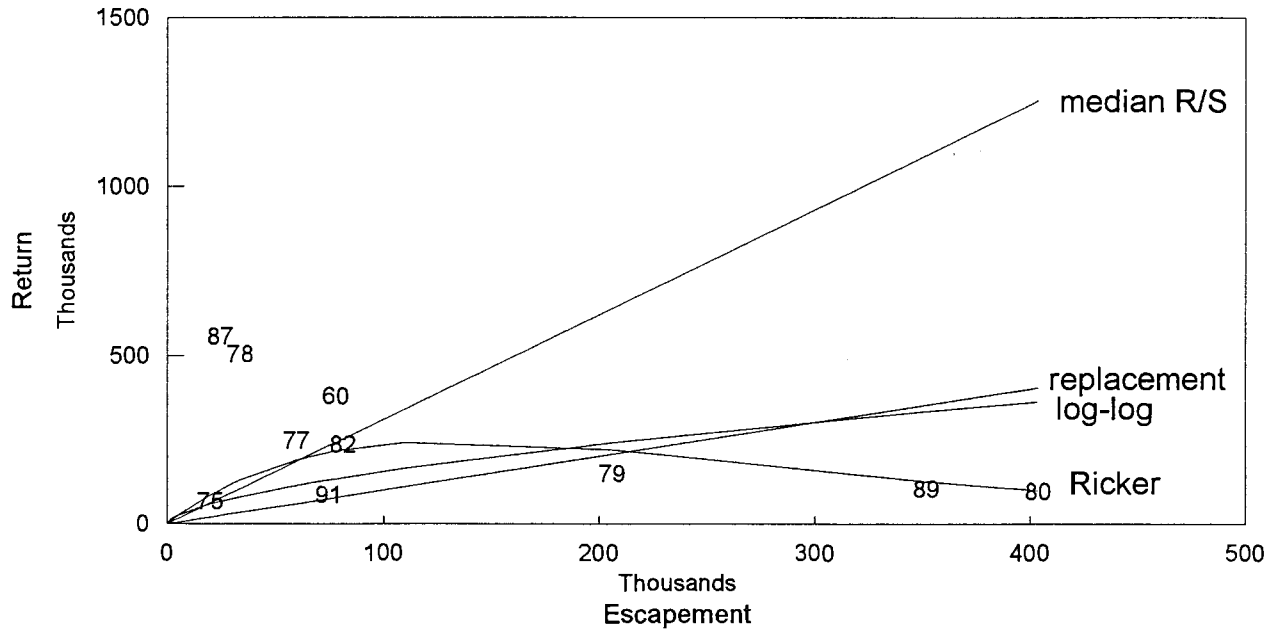

Figure 15. Pink salmon escapement, return, predicted return from Ricker curve, log-log regression and median return/spawner ratio, Bruin Bay.

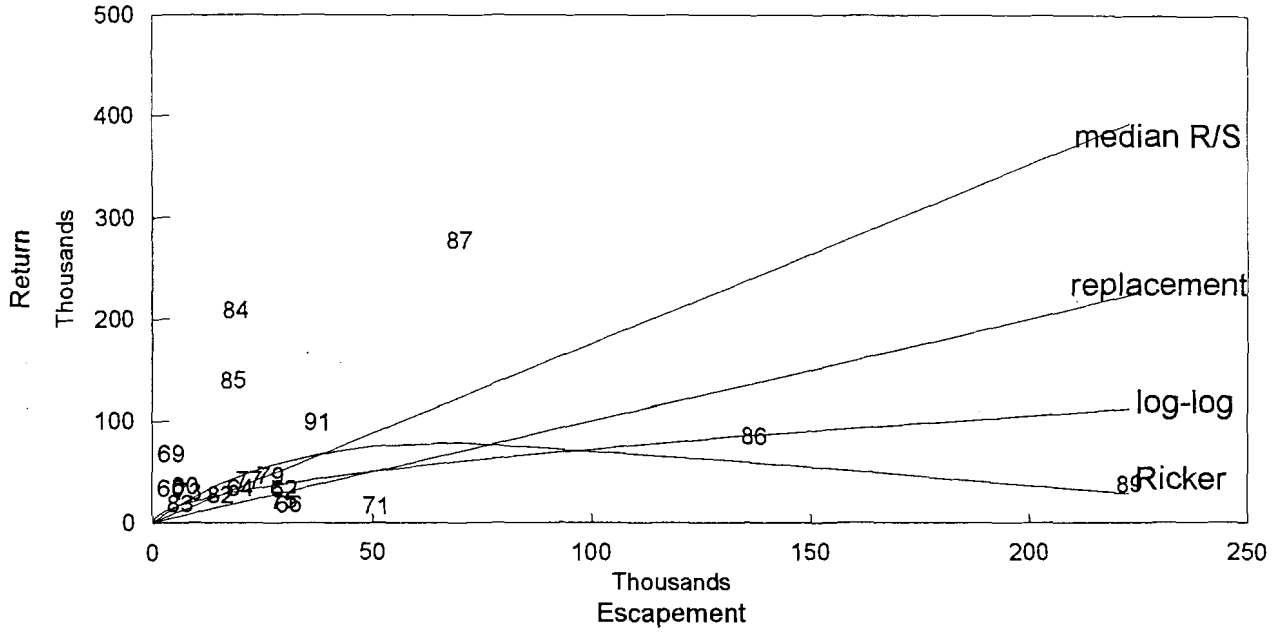

Figure 16. Pink salmon escapement, return, predicted return from Ricker curve, log-log regression and median return/spawner ratio, Ursus and Rocky Coves.

APPENDIX A: BROOD YEAR TABLES

Appendix A.1. Spawning escapement and total return data used to forecast 1993 pink salmon run to Humpy Creek, Lower Cook Inlet.

Brood Year	Spawning Escapement	Total Return
1960	10,000	164,800
1961	22,600	92,100
1962	56,000	100,900
1963	34,700	41,800
1964	18,500	70,700
1965	28,000	65,400
1966	30,000	68,600
1967	25,000	6,000
1968	24,700	169,300
1969	5,400	56,400
1970	55,200	15,900
1971	45,000	81,200
1972	13,800	52,800
1973	36,900	403,300
1974	17,400	100,300
1975	64,000	128,700
1976	27,200	90,100
1977	86,000	504,000
1978	46,100	117,700
1979	200,000	365,900
1980	64,400	37,900
1981	115,000	131,700
1982	31,900	137,700
1983	104,800	128,400
1984	84,200	166,400
1985	117,000	28,600
1986	49,700	21,400
1987	26,600	184,400
1988	21,400	27,000
1989	93,000	17,406
1990	27,000	14,583
1991	17,406	36,196
1992	14,583	

Appendix A.2. Spawning escapement and total return data used to forecast 1993 pink salmon run to Seldovia, Lower Cook Inlet.

Brood Year	Spawning Escapement	Total Return
1960	25,000	192,800
1961	25,000	14,600
1962	50,000	97,400
1963	13,000	49,200
1964	60,000	130,100
1965	30,000	66,700
1966	86,000	76,800
1967	55,000	88,800
1968	53,200	52,000
1969	60,000	58,400
1970	23,000	6,000
1971	31,100	33,900
1972	5,800	17,200
1973	14,500	465,800
1974	13,700	28,600
1975	36,200	83,300
1976	25,600	60,400
1977	35,700	184,500
1978	24,600	147,200
1979	43,700	189,100
1980	65,500	108,700
1981	62,700	71,200
1982	38,400	16,400
1983	27,900	26,600
1984	14,200	31,000
1985	22,800	8,800
1986	28,200	22,400
1987	7,600	27,300
1988	16,900	31,292
1989	26,200	26,365
1990	27,782	16,596
1991	29,950	46,848
1992	14,682	

Appendix A.3. Spawning escapement and total return data used to forecast 1993 pink salmon run to Port Graham, Lower Cook Inlet.

Brood Year	Spawning Escapement	Total Return
1960	15,000	68,100
1961	5,000	4,700
1962	50,000	54,400
1963	2,000	13,900
1964	16,000	29,100
1965	1,500	7,100
1966	24,000	47,400
1967	2,000	6,000
1968	24,400	36,200
1969	4,000	14,200
1970	16,600	3,500
1971	13,200	20,900
1972	2,400	7,300
1973	7,000	45,600
1974	2,800	10,400
1975	27,300	65,400
1976	6,500	10,700
1977	20,600	157,400
1978	6,700	70,700
1979	32,700	64,300
1980	40,200	64,300
1981	18,400	8,700
1982	28,900	18,900
1983	4,600	38,800
1984	10,900	26,300
1985	26,300	6,100
1986	17,500	18,600
1987	3,800	19,100
1988	7,900	20,053
1989	19,100	28,966
1990	20,053	5,450
1991	28,966	24,819
1992	5,450	

Appendix A.4. Spawning escapement and total return data used to forecast 1993 pink salmon run to Port Chatham, Lower Cook Inlet.

Brood Year[a]	Spawning Escapement	Total Return
1960	4,000	109,200
1961	7,000	800
1962	7,000	67,100
1966	10,000	10,000
1970	3,000	1,000
1971	15,500	25,600
1972	1,000	200
1973	5,000	23,700
1975	7,700	15,600
1977	14,200	195,200
1978	300	9,500
1979	20,800	17,000
1980	7,700	14,600
1981	11,200	6,800
1982	2,000	7,800
1983	3,500	15,900
1984	7,800	11,500
1985	8,900	10,200
1986	11,500	21,000
1987	10,200	41,400
1988	21,000	49,925
1989	31,700	31,239
1990	27,822	4,304
1991	23,776	36,893
1992	4,304	

[a] only years with both catch and escapement data

Appendix A.5. Spawning escapement and total return data used to forecast 1993 pink salmon run to Windy Bay, Lower Cook Inlet.

Brood Year	Spawning Escapement	Total Return
1960	16,000	110,500
1961	15,000	9,400
1962	25,000	82,500
1963	9,400	17,400
1964	13,900	34,100
1965	12,000	12,000
1966	14,000	13,100
1967	12,000	26,200
1968	9,700	15,900
1969	26,200	105,700
1970	9,700	15,900
1971	48,400	86,000
1972	500	200
1973	17,500	46,500
1974	200	400
1975	28,400	231,600
1976	400	1,400
1977	58,400	637,900
1978	1,400	14,200
1979	85,200	38,900
1980	14,200	9,100
1981	36,000	16,200
1982	9,100	5,900
1983	16,200	19,100
1984	5,900	4,700
1985	14,300	7,600
1986	4,700	4,700
1987	7,600	31,800
1988	4,700	14,618
1989	31,800	104,410
1990	14,618	12,059
1991	55,279	84,866
1992	12,059	

Appendix A.6. Spawning escapement and total return data used to forecast 1993 pink salmon run to Rocky Bay, Lower Cook Inlet.

Brood Year	Spawning Escapement	Total Return
1960	130,000	425,900
1961	2,000	13,400
1962	200,000	133,200
1963	12,000	400
1964	80,000	44,000
1965	300	1,000
1966	44,000	53,900
1967	1,000	1,000
1968	43,100	68,800
1969	1,000	1,700
1970	32,000	8,200
1971	1,600	2,200
1972	8,200	1,500
1973	2,000	4,400
1974	1,500	2,700
1975	4,400	48,300
1976	2,700	8,200
1977	36,700	207,200
1978	8,200	7,800
1979	85,000	41,500
1980	6,400	6,600
1981	25,000	17,900
1982	6,600	9,000
1983	16,600	12,100
1984	9,000	12,000
1985	12,100	4,500
1986	12,000	5,400
1987	4,500	10,300
1988	5,400	18,250
1989	10,300	26,100
1990	18,250	26,077
1991	26,100	74,848
1992	26,077	

Appendix A.7. Spawning escapement and total return data used to forecast 1993 pink salmon run to Port Dick Bay, Lower Cook Inlet.

Brood Year	Spawning Escapement	Total Return
1960	58,200	1,173,300
1961	16,000	80,500
1962	55,000	587,800
1963	61,500	65,800
1964	61,500	338,800
1965	50,500	280,400
1966	42,000	88,300
1967	20,500	63,600
1968	33,300	376,500
1969	12,100	192,500
1970	40,000	11,700
1971	97,900	123,500
1972	11,700	2,600
1973	26,900	153,200
1974	2,000	12,700
1975	62,900	991,600
1976	12,700	108,900
1977	109,900	1,081,400
1978	45,300	191,600
1979	116,600	1,271,900
1980	58,300	78,900
1981	131,000	219,400
1982	34,900	164,200
1983	79,400	548,800
1984	79,600	362,200
1985	93,200	7,600
1986	27,600	143,400
1987	4,600	62,100
1988	19,200	235,762
1989	62,100	359,625
1990	66,706	17,024
1991	78,637	43,935
1992	17,024	

Appendix A.8. Spawning escapement and total return data used to forecast 1993 pink salmon run to Nuka Bay, Lower Cook Inlet.

Brood Year[a]	Spawning Escapement	Total Return
1960	20,000	169,800
1961	2,000	400
1962	40,000	35,100
1964	11,300	10,000
1966	10,000	100,200
1968	10,000	59,400
1969	3,000	163,700
1971	44,000	27,100
1973	19,000	63,800
1975	28,400	69,100
1976	600	7,300
1977	12,800	139,700
1978	1,000	33,700
1979	18,000	430,100
1980	20,900	27,100
1981	35,000	90,800
1982	18,400	32,000
1983	35,800	225,900
1984	27,600	143,400
1985	75,100	35,800
1987	14,900	102,200
1988	5,400	18,647
1989	59,200	34,970
1990	18,486	7,177
1991	24,384	141,614
1992	7,177	

[a] only years with both catch and escapement data

Appendix A.9. Spawning escapement and total return data used to forecast 1993 pink salmon run to Resurrection Bay, Lower Cook Inlet.

Brood Year[a]	Spawning Escapement	Total Return
1960	1,400	3,400
1962	3,300	8,200
1968	7,600	40,200
1972	1,100	8,500
1974	8,500	76,000
1976	40,600	55,800
1978	26,100	196,500
1980	40,700	189,300
1981	2,700	40,700
1982	51,900	155,200
1983	13,600	149,300
1984	32,900	77,200
1985	74,700	23,400
1987	11,600	9,000
1988	1,100	9,706
1989	9,000	339
1990	9,706	7,986
1991	19,120	20,930
1992	7,986	

[a] only years with both catch and escapement data

Appendix A.10. Spawning escapement and total return data used to forecast 1993 pink salmon run to Bruin Bay, Lower Cook Inlet.

Brood Year[a]	Spawning Escapement	Total Return
1960	78,000	380,000
1967	500	5,000
1969	5,000	11,700
1973	2,000	20,000
1974	600	13,500
1975	20,000	66,200
1976	13,500	33,900
1977	60,000	246,300
1978	33,900	504,400
1979	206,000	148,400
1980	403,800	94,600
1982	81,300	235,200
1983	4,200	4,500
1984	110,000	1,555,700
1985	4,500	25,600
1987	24,400	554,800
1988	30,000	19,847
1989	352,000	102,388
1990	19,050	6,554
1991	74,910	86,467
1992	6,400	

[a] only years with both catch and escapement data

Appendix A.11. Spawning escapement and total return data used to forecast 1993 pink salmon run to Ursus and Rocky Cove, Lower Cook Inlet.

Brood Year[a]	Spawning Escapement	Total Return
1960	1,500	33,200
1962	30,000	33,500
1963	12,000	10,000
1964	20,000	33,900
1969	3,000	67,400
1970	2,000	3,200
1971	51,000	16,100
1972	3,200	200
1973	8,200	30,000
1974	200	1,500
1975	30,000	22,000
1976	1,500	1,200
1977	22,000	41,400
1978	1,100	7,500
1979	27,000	46,000
1980	7,500	35,700
1981	31,900	6,400
1982	15,500	27,300
1983	6,400	18,400
1984	18,800	208,100
1985	18,400	139,300
1986	137,000	84,900
1987	69,900	276,800
1988	35,000	37,600
1989	223,000	17,200
1990	3,380	8,266
1991	37,600	99,316
1992	7,955	

[a] only years with both catch and escapement data

Appendix B.1. FORTRAN source code for forecast program.

```
$DEBUG
c.....forecast lci pink salmon runs with 80% confidence interval
c.....for both future and historical reconstruction
c
c.....use cross-validation to
c.....reconstruct historical forecast, forecast errors, & forecast bounds
c
c.....cross-validation is defined as
c.....leave one year out of data, build model, forecast missing year
c.....calculate the forecast error, repeat for all years of data
c
c.....the reconstructed forecast errors are used to
c.....calculate std. dev. for 80% confidence interval
c.....which in turn is used to calculate forecast bounds
c.....the sd, 89% cl, and forecast bound can be historical reconstruction
c.....or for the future
c
c.....we perform 2 historical reconstruction simultaneously
c.....for each historical year:
c.....(1) reconstruct by harvest area
c.....    in order to calculate the forecast bounds by harvest area
c.....    we need to leave out year being reconstructed
c.....    and loop remaining years thru cross validation.
c.....    when loop is completed, use all 'remaining' years to forecast
c.....    year being reconstructed.
c.....(2) reconstruct lower cook inlet total
c.....    accumulate the reconstructed harvest area forecast by year
c.....    to obtain the lci total run forecast.
c
c.....when all the above is completed, we forecast the future
c.....from all available data
c.....we use the reconstructed forecast errors to calculate sd
c.....and confidence limits for the future forecast bound
c
c.....given the reconstructed forecast bounds, we can calculate the fraction
c.....of runs within the future forecast bounds (i.e. probability or run)
c.....and the fraction of
c.....reconstructed forecast bounds that sucessfully encompassed its
c.....corresponding observed run (i.e. likelihood of run given forecast)
c
c.....find probability of run from frequency distribution
c
c.....use bayes theorum to estimate probability of run given forecast
c.....alternate hypothesis are run = < 80 % cl, within 80% cl, > 80% cl
c
c.....the following options is also present but 'turned off'
c.....(to turn 'on' remove comment code in column 1)
c
c.....(1) forecast pink returns from fry index
c
c.....(2) include climate in model (need to be completed and debugged)
c.....where climate is from 1st year at sea for a specific month only
c
c.....this program does not use brood years with missing run or escapement
c.....this program assumes earliest brood year is 1960

      IMPLICIT DOUBLE PRECISION (A-H)
      IMPLICIT DOUBLE PRECISION (O-Z)
      CHARACTER*30 FNAME
      CHARACTER*6 NAME(11)
      CHARACTER*21 LNAME(11)
C     CHARACTER*1 CLIMATE
C     DIMENSION TEM(12),TEMP(40)
C.....REGRESSION COEFFICIENT, Student's T
      DIMENSION B(2),T(40)
      DIMENSION ESCLCI(40),RTNLCI(40),FCSTLCI(40)
```



```
      INTEGER LCISAMP(40)
      COMMON /C/RTN(40),S(40),FCST(40),FLO(40),HI(40),N,IYR(40)
      COMMON /F/FVAL(50)
      COMMON /R/A,B,R2,IDF,SE,F,NVR
C.....T-DISTRIBUTION FOR 80% C.L.
      DATA T/3.078,1.886,1.638,1.533,1.476,1.440,1.415,1.397,1.383,1.372
     &      ,1.363,1.356,1.350,1.345,1.341,1.337,1.333,1.330,1.328,1.325
     &      ,1.323,1.321,1.319,1.318,1.316,1.315,1.314,1.313,1.311,1.310
     &      ,1.309,1.308,1.308,1.307,1.306,1.305,1.305,1.304,1.304,1.303
     &/
      DATA NAME/'HMP.ER'
     &,'SEL.ER'
     &,'GRA.ER'
     &,'CHA.ER'
     &,'WDY.ER'
     &,'RKY.ER'
     &,'PDK.ER'
     &,'NKA.ER'
     &,'RES.ER'
     &,'BRU.ER'
     &,'URS.ER'/
      DATA LNAME/'Humpy Creek,
     &,'Seldovia Bay         ,
     &,'Port Graham Bay      ,
     &,'Port Chatham         ,
     &,'Windy Bay            ,
     &,'Rocky Bay            ,
     &,'Port Dick Bay        ,
     &,'Nuka Bay             ,
     &,'Ressurection Bay     ,
     &,'Bruin Bay            ,
     &,'Rocky and Ursus Coves'/

   10 WRITE(*,1005)
 1005 FORMAT(1H0,'READ F DISTRIBUTION FILE')
      WRITE(*,'(A\)')' FILE NAME?
      READ(*,'(A)') FNAME
      OPEN(1,FILE=FNAME,STATUS='OLD',ERR=20)
      GO TO 25
   20 WRITE(*,2358)
      GOTO 10
   25 READ(1,1007)
      DO 30 I=1,50
      READ(1,1007) N,FVAL(N)
 1007 FORMAT(I2,1X,F9.2)
   30 CONTINUE

      WRITE(*,1220)
 1220 FORMAT(/,' FORECAST FOR WHICH YEAR? (e.g. 92)  ',\)
      READ(*,2200) KYR2
C.....CALCULATE ESCAPEMENT YEAR FOR RETURN YEAR
      KYR=KYR2-2

      WRITE(*,1300)
 1300 FORMAT(/,' USE (1) FRY OR (2) ESCAPEMENT DATA?   ',\)
      READ(*,2200) ISPAWN

      WRITE(*,1500)
 1500 FORMAT(/,' (1) use all data except those marked as outliers',/
     &,' (2) skip data when return < escapement',/
     &,'     and when marked as an outlier?    ',\)
      READ(*,2200) ISKIP

      WRITE(*,1550)KYR2
 1550 FORMAT(/,' (1) reconstruct ALL historical forecast ranges',/
     &,' (2) forecast range only for 19',I2,'    ',\)
```

```
      READ(*,2200) IRG

C     WRITE(*,1500)
C1500 FORMAT(/,' INCLUDE CLIMATE IN REGRESSION?   ',\)
C     READ(*,1600) CLIMATE
C1600 FORMAT(A1)
C     IF(CLIMATE.EQ.'y') CLIMATE='Y'
C     IF(CLIMATE.NE.'Y') GO TO 40
C     WRITE(*,1800)
C1800 FORMAT(/,' READ CLIMATE DATA FILE')
C     WRITE(*,'(A\)')' FILENAME?   '
C     READ(*,'(A)') FNAME
C     OPEN(1,FILE=FNAME,STATUS='OLD')
C     READ(1,2400)
C     WRITE(*,2000)
C2000 FORMAT(/,' MONTH (e.g. 4 = April)?   ',\)
C     READ(*,2200) IMON
 2200 FORMAT(I2)

      WRITE(*,2325)
 2325 FORMAT(/,' WRITE OUTPUT')
      WRITE(*,'(A\)')' FILENAME?   '
      READ(*,'(A)') FNAME
      CLOSE(2)
      OPEN(2,FILE=FNAME)

      WRITE(*,2326)
 2326 FORMAT(/,' WRITE PRN FILE')
      WRITE(*,'(A\)')' FILENAME?   '
      READ(*,'(A)') FNAME
      CLOSE(5)
      OPEN(5,FILE=FNAME)

      FCSTL=0.
      DO 40 K=1,40
      ESCLCI(K)=0.
      RTNLCI(K)=0.
      FCSTLCI(K)=0.
      LCISAMP(K)=0
   40 CONTINUE
      DO 900 L=1,11
      CLOSE(4)
      OPEN(4,FILE=NAME(L),STATUS='OLD',ERR=50)
      WRITE(2,2356) NAME(L),LNAME(L)
 2356 FORMAT(A30,1X,A21)
      WRITE(*,2357) NAME(L),LNAME(L)
 2357 FORMAT(' ',A30,1X,A21/)
C.....SKIP HEADER RECORD
      READ(4,2400)
      GO TO 55
   50 WRITE(*,2358)FNAME
 2358 FORMAT(/' ',A6,' not in current directory, try again')
      STOP

C.....READ SPAWNER & RETURN DATA
   55 N=0
   60 N=N+1
   70 READ(4,2400,END=120)LCODE,IYR(N),ESC,CAT,RTN(N),IOUT,FI
 2400 FORMAT(I4,1X,I2,3F9.0,I9,F9.0)
C.....DON'T USE RETURN DATA FROM YEAR BEING FORECAST AND LATER
      IF(IYR(N).GE.KYR) RTN(N)=0
      IF(IOUT.EQ.1) GO TO 70
C.....CHOOSE EITHER FRY OR ESCAPEMENT DATA
      IF(ISPAWN.EQ.1) S(N)=FI
      IF(ISPAWN.EQ.2) S(N)=ESC
C.....SAVE FORECAST YEAR AND SPAWNER DATA
```



```
      IF(IYR(N).EQ.KYR) ESAV=ESC
      IF(IYR(N).EQ.KYR) YSAV=IYR(N)
C.....SKIP YEARS WHERE RETURN LESS THAN ESCAPEMENT
      IF(ISKIP.EQ.2.AND.ISPAWN.EQ.2.AND.RTN(N).LT.ESC) GO TO 70
C.....SKIP YEARS WITHOUT FRY/ESCAPEMENT DATA
      IF(S(N).EQ.0) GO TO 70
C.....SKIP YEARS WITHOUT RETURN DATA
      IF(RTN(N).EQ.0) GO TO 70
C     IF(CLIMATE.EQ.'Y') GO TO 80
      GO TO 60

C.....FIND MATCHING YEAR FOR CLIMATE
C  80 NY=IYR(N)+1
C  90 READ(1,2600,END=120) JYR,(TEM(MM),MM=1,12)
C2600 FORMAT(7X,I2,12F9.1)
C     TEMP(N)=TEM(IMON)
C     IF(IYR(N).EQ.KYR) TSAV=TEMP(N)
C     IF(JYR.EQ.NY) GO TO 110
C     GO TO 90
C 110 IF(TEMP(N).EQ.0) GO TO 70
C     WRITE(2,2500)IYR(N),S(N),RTN(N),TEMP(N)
C     GO TO 60

  120 CALL FIT(KYR,MODEL)

      IF(MODEL.EQ.1) WRITE(2,2640)
 2640 FORMAT(/,' HISTORICAL RECONSTRUCTION FROM CROSS-VALIDATION'
     &,' (REGRESSION W/ LOG-LOG TRANSFORMATION)')
      IF(MODEL.EQ.2) WRITE(2,2660)
 2660 FORMAT(/,' HISTORICAL RECONSTRUCTION FROM CROSS-VALIDATION'
     &,' (RICKER CURVE)')

      WRITE(2,2700)
 2700 FORMAT(/' YR  intercept  reg coef  SE(pred)   r2      F',
     & '    Spawn    Return Forecast   % ERR',
     & ' lo range hi range SD(cv)')

C.....CLEAR ARRAYS AND STORAGE
      N1=N
      N=N-1
      ASUM=0
      SUM=0
      S(N1)=ESAV
      IYR(N1)=YSAV
      RTN(N1)=0

C.....FOR YEARS K=1 THRU N RECONSTRUCT HISTORICAL FORECAST AND ERRORS
C.....E.G. 1962-PRESENT (HISTORICAL)
C.....FOR YEAR K=N1 FORECAST FUTURE
C.....E.G. 1993 (THE FUTURE)
      DO 400 K=1,N1

C.....IN THE FIRST CROSS-VALIDATION
C.....RECONSTRUCT THE FORECAST RANGE
C.....E.G. TO RECONSTRUCT 1962 FORECAST RANGE,
C.....CROSS-VALIDATED 1963-PRESENT AND FIND SUM OF FORECAST ERRORS SQUARED
C.....USE SUM OF FORECAST ERRORS SQUARED TO ESTIMATE STD DEV
C.....WHICH IN TURN IS USED TO RECONSTRUCT FORECAST RANGE (CONFIDENCE INTERVAL)
      SS=0
      SD=0
      IF(IRG.EQ.2.AND.K.EQ.N1) GO TO 300
      IF(IRG.EQ.1) GO TO 300
      GO TO 310
  300 CALL CV(MODEL,IYR(K),1,ISKIP,SS,SKIP,SE)
C.....-1 FOR YEAR BEING FORECAST, -1 FOR UNBIASED SAMPLE
      COUNT=N-1-1
```

```
      SD=SQRT(SS/COUNT)

C.....IN THE SECOND CROSS-VALIDATION
C.....FUTURE FORECAST ONLY (E.G. 1993), NO STD DEV
  310 CALL CV(MODEL,IYR(K),2,K,SKIP,PRED,SE)
      FCST(K)=PRED
C.....USE SD FROM FIRST CROSS-VALIDATION FOR 80% CONFIDENCE LIMITS (BY HARVEST AR
EA)
      JDF=IDF+1
      FLO(K)=0
      HI(K)=0
      IF(IRG.EQ.2.AND.K.LT.N1)GO TO 340
C.....SOKAL AND ROHLF P 384
      FLO(K)=EXP(LOG(FCST(K))-T(JDF)*SD)
      HI(K)= EXP(LOG(FCST(K))+T(JDF)*SD)
C.....WRITE OUTPUT
  340 IYR2=IYR(K)+2
      IF(K.EQ.N1) GO TO 350
      PCTERR=(FCST(K)-RTN(K))/RTN(K)
      IF(RTN(K).GE.FLO(K).AND.RTN(K).LE.HI(K))
     &WRITE(2,5700)IYR2,A,B(1),SE,R2,F,S(K),
     &RTN(K),FCST(K),PCTERR,FLO(K),HI(K),SD
 5700 FORMAT(' ',I3,2F10.5,F10.3,F5.3,F7.2,
     &F9.1,F10.1,F9.1,F10.3,F9.1,F10.1,F11.3,' R within F')
      IF(RTN(K).LT.FLO(K))
     &WRITE(2,5710)IYR2,A,B(1),SE,R2,F,S(K),
     &RTN(K),FCST(K),PCTERR,FLO(K),HI(K),SD
 5710 FORMAT(' ',I3,2F10.5,F10.3,F5.3,F7.2,
     &F9.1,F10.1,F9.1,F10.3,F9.1,F10.1,F11.3,' R < F')
      IF(RTN(K).GT.HI(K).AND.HI(K).NE.0)
     &WRITE(2,5720)IYR2,A,B(1),SE,R2,F,S(K),
     &RTN(K),FCST(K),PCTERR,FLO(K),HI(K),SD
 5720 FORMAT(' ',I3,2F10.5,F10.3,F5.3,F7.2,
     &F9.1,F10.1,F9.1,F10.3,F9.1,F10.1,F11.3,' R > F')
      IF(FLO(K).EQ.0.AND.HI(K).EQ.0)
     &WRITE(2,5725)IYR2,A,B(1),SE,R2,F,S(K),
     &RTN(K),FCST(K),PCTERR
 5725 FORMAT(' ',I3,2F10.5,F10.3,F5.3,F7.2,
     &F9.1,F10.1,F9.1,F10.3)
      SUM=SUM+PCTERR
      ASUM=ASUM+ABS(PCTERR)
      GO TO 390
  350 WRITE(2,5730)
 5730 FORMAT(/,'FUTURE FORECAST')
      WRITE(2,5800)IYR2,A,B(1),SE,R2,F,ESAV,FCST(K)
     &,FLO(K),HI(K),SD
 5800 FORMAT(/' ',I3,2F10.5,F10.3,F5.3,F7.2,F9.1,10X,F9.1
     &,10X,F9.1,F10.1,F11.3)
      WRITE(5,5805)IYR2,A,B(1),SE,R2,F,ESAV,FCST(K)
     &,FLO(K),HI(K),SD
 5805 FORMAT(I3,2F10.5,F10.3,F5.3,F7.2,F9.1,10X,F9.1
     &,10X,F9.1,F10.1,F11.3)

C.....ACCUMULATE FUTURE FORECAST FOR LOWER COOK INLET TOTAL
      FCSTL=FCSTL+FCST(K)

C.....ASSIGN INDEX, ASSUME FIRST BROOD YEAR IS 1960
C.....don't use K as year index because skipped brood year will not index
C.....properly for Lower Cook Inlet annual totals
  390 KK=IYR(K)-59
C.....ACCUM RECONSTRUCTED RUN AND FORECAST (BY YEAR) FOR LOWER COOK INLET TOTAL
      ESCLCI(KK)=ESCLCI(KK)+S(K)
      RTNLCI(KK)=RTNLCI(KK)+RTN(K)
      FCSTLCI(KK)=FCSTLCI(KK)+PRED
      LCISAMP(KK)=LCISAMP(KK)+1
```



```
  400 CONTINUE

C.....SUMMARIZE % ERRORS AND STATISTICS FOR CROSS VALIDATION STD DEV
      COUNT=N
      AAVG=ASUM/COUNT
      AVG=SUM/COUNT
      WRITE(2,5750) AVG,AAVG,NVR,IDF,T(JDF),JDF
 5750 FORMAT(/
     &' CROSS VALIDATION: mean % error =',F12.2,/,
     &'                   mean abs % error =',F12.2,/,
     &'                   d.f. (for regression F statistic) =',I3,',',I3
     &,/,'                   t(0.2) (for confidence interval) =',F6.3,/,
     &'                   std. dev. d.f. (for t(0.2))=',I3)

  900 CONTINUE
C.....LOWER COOK INLET TOTAL
C.....FIND ANNUAL LCI TOTAL FORECAST ERROR SQUARED

C.....WRITE DATA FOR BAYESIAN PROBABILITY MODEL
      OPEN(3,FILE='BAYES.DAT')
      WRITE(3,7420)IYR2
      SS=0
      N=0
      WRITE(2,7410)
 7410 FORMAT(//'LOWER COOK INLET TOTAL'/
     &'year  escapement      return    forecast      error  n  lo range'
     &,'   hi range        SD')
      DO 920 K=1,40
      IF(RTNLCI(K).EQ.0) GOTO 920
      ERR=FCSTLCI(K)-RTNLCI(K)
      SS=SS+(LOG(FCSTLCI(K))-LOG(RTNLCI(K)))**2
      IY=K+61
      WRITE(2,7420) IY,ESCLCI(K),RTNLCI(K),FCSTLCI(K),ERR,LCISAMP(K)
      WRITE(3,7420) IY,ESCLCI(K),RTNLCI(K),FCSTLCI(K)
 7420 FORMAT(I4,4F12.0,I3)
      N=N+1
  920 CONTINUE
      DF=N-1
      SD=SQRT(SS/DF)
      LDF=DF
C.....FIND 80% CONFINDENCE INTERVAL
      FLO(40)=EXP(LOG(FCSTL)-T(LDF)*SD)
      HI(40)= EXP(LOG(FCSTL)+T(LDF)*SD)
      WRITE(2,5730)
      WRITE(2,7430)IYR2,FCSTL,FLO(40),HI(40),SD
 7430 FORMAT(/,I4,24X,F12.0,15X,3F10.0)
      WRITE(3,7440)IYR2,FCSTL
 7440 FORMAT(I4,24X,F12.0)
      STOP
      END
C.....MULTIPLE LINEAR REGRESSION SUBROUTINE
C.....NVR = NUMBER OF X VARIABLES
C.....NOBS = NUMBER OF OBSERVATIONS
C.....SNEDECOR AND COCHRAN CHAPTER 13 (USING INVERSE MATRIX METHOD)
C.....HANKE AND GREITSCH CHAPTER 5
      SUBROUTINE SUBMR(NOBS,X,Y,Z,IMESS,SYHAT)
      IMPLICIT DOUBLE PRECISION (A-H)
      IMPLICIT DOUBLE PRECISION (O-Z)
      DIMENSION SUMX(2),SX2(2,2),C(2,2),B(2),SXY(2)
      DIMENSION LABEL(2),SUMXX(2,2),SUMXY(2)
      DIMENSION Y(40),X(40,2)
      REAL MSREG,MSDEV
      COMMON /F/FVAL(50)
      COMMON /R/A,B,R2,IDF,SE,F,NVR

      IF(NOBS.LE.3) RETURN
```

```
C.....ZERO ARRAYS
      DO 20 I=1,NVR
      SUMXY(I)=0.0
      SUMX(I)=0.0
      B(I)=0.0
   20 CONTINUE
      SUMY=0.0
      SUMYY=0.0

C.....FIND SUMS
      DO 30 I=1,NOBS
      SUMY=SUMY+Y(I)
      SUMYY=SUMYY+Y(I)*Y(I)
      DO 30 K=1,NVR
      SUMXY(K)=SUMXY(K)+X(I,K)*Y(I)
   30 SUMX(K)=SUMX(K)+X(I,K)
      DO 50 I=1,NVR
      DO 45 J=1,NVR
      SUMXX(I,J)=0.0
      DO 40 K=1,NOBS
   40 SUMXX(I,J)=SUMXX(I,J)+X(K,I)*X(K,J)
   45 CONTINUE
   50 CONTINUE
C.....FORM MATRIX OF SUMS OF SQAURES AND PRODUCTS (P 389)
      SUMN=NOBS
      DO 72 I=1,NVR
      DO 72 J=1,NVR
      SX2(I,J)=SUMXX(I,J)-(SUMX(I)*SUMX(J))/SUMN
      C(I,J)=SX2(I,J)
   72 CONTINUE
C.....GAUSS MULTIPLIERS = INVERSE OF MATRIX = sums of squares/D (P 390)
      I=NVR
      CALL MTINV(C,I,I,I,LABEL)
      DO 110 I=1,NVR
      SXY(I)=SUMXY(I)-(SUMX(I)*SUMY)/SUMN
  110 CONTINUE

      SSREG=0.0
      A=SUMY/SUMN
C.....b = PRODUCT OF GAUSS MULTIPIERS AND CROSS PRODUCTS (P 390)

      DO 140 I=1,NVR
      DO 130 J=1,NVR
      B(I)=B(I)+C(I,J)*SXY(J)
  130 CONTINUE
C.....REGRESSION SS (P 386)
      SSREG=SSREG+B(I)*SXY(I)
C.....CONSTANT (P 382)
      A=A-B(I)*(SUMX(I)/SUMN)
  140 CONTINUE

C     WRITE(2,2500) A
C2500 FORMAT(/,'          a =',F14.5)
C.....TOTAL SS
      SY2=SUMYY-((SUMY*SUMY)/SUMN)
C.....DEVIATION SS (TOTAL - REGRESSION SS)
      SSDEV=SY2-SSREG
      DF=NOBS-NVR-1
      IDF=DF
      MSDEV=SSDEV/DF
C.....REGRESSION COEFFICIENT STD ERROR (P 138, 391)
      S=SQRT(MSDEV)

      DO 200 I=1,NVR
      SREG=S*SQRT(C(I,I))
C     WRITE(2,2900)I,B(I),SREG
```



```
C2900 FORMAT('       b(',I1,') =',F14.5,' SE(b coef) = ',F14.5)
  200 CONTINUE

C.....STANDARD ERROR OF THE PREDICTION (P155-156)
C.....FOR ONE X VARIABLE, SEE PAGE 392 AND MODIFY THIS SECTION
C.....IF MORE THAN ONE X VARIABLE
      XBAR=SUMX(1)/SUMN
      ERR=Z-XBAR
      SYHAT=S*SQRT(1+(1/SUMN)+((ERR**2)/SX2(1,1)) )

C.....CORRELATION COEFFICIENT (RESIDUAL SS/TOTAL SS, P 402)
      R2=SSREG/SY2
C     WRITE(2,2600)R2
C2600 FORMAT('  R Squared =',F14.5)

C.....DEGREES OF FREEDOM AND F STATISTIC (P 387)
      DF=NVR
      MSREG=SSREG/(DF)
      F=MSREG/MSDEV
C     WRITE(2,4000) F,NVR,IDF
C4000 FORMAT(1H ,'          F =',F8.2,' d.f. =',I3,',',I3)
      IF(F.GE.FVAL(IDF))GO TO 290
      IF(IMESS.EQ.1)WRITE(2,4050)
 4050 FORMAT(' regression not significant')
  290 IF(NVR.EQ.1) GO TO 900
      DO 300 I=1,NVR
      AFTER=SSREG-((SXY(I)*SXY(I))/SX2(I,I))
      F=AFTER/MSDEV
      WRITE(2,4100) I
 4100 FORMAT(/,' effect of removing variable ',I1)
      WRITE(2,4200) F,IDF
 4200 FORMAT(1H ,'          F =',F8.2,' d.f. =  1',',',I3)
      IF(F.GE.FVAL(IDF))GO TO 300
C     WRITE(2,4050)
  300 CONTINUE
  900 RETURN
      END
      SUBROUTINE MTINV(A,NRARG,NCARG,IDIM,LABEL)
C..... *************MATRIX INVERSION*************************
      IMPLICIT DOUBLE PRECISION (A-H)
      IMPLICIT DOUBLE PRECISION (O-Z)
      DIMENSION A(IDIM,NCARG),LABEL(NRARG)
    1 NR=NRARG
      NC=NCARG
      DO 21 J1=1,NR
   21 LABEL(J1)=J1
      DO 291 J1=1,NR
C..... **************FIND REMAINING ROW CONTAINING LARGEST***
C..... **************ABSOLUTE VALUE IN PIVOTAL COLUMN********
  101 TEMP=0.0
      DO 121 J2=J1,NR
      IF(ABS(A(J2,J1)).LT.TEMP) GO TO 121
      TEMP=ABS(A(J2,J1))
      IBIG=J2
  121 CONTINUE
      IF(IBIG.EQ.J1)GO TO 201
C..... **************REARRANGE ROWS TO PLACE LARGEST ABSOLUTE
C..... **************VALUE IN PIVOT POSITION*****************
      DO 141 J2=1,NC
      TEMP=A(J1,J2)
      A(J1,J2)=A(IBIG,J2)
  141 A(IBIG,J2)=TEMP
      I=LABEL(J1)
      LABEL(J1)=LABEL(IBIG)
      LABEL(IBIG)=I
C.....::::COMPUTE COEFFICIENTS IN PIVOTAL ROW::::
```

```
  201 TEMP=A(J1,J1)
      A(J1,J1)=1.0
      DO 221 J2=1,NC
  221 A(J1,J2)=A(J1,J2)/TEMP
C.....  **************COMPUTE COEFFICIENTS IN OTHER ROWS******
      DO 281 J2=1,NR
      IF(J2.EQ.J1) GO TO 281
      TEMP=A(J2,J1)
      A(J2,J1)=0.0
      DO 241 J3=1,NC
  241 A(J2,J3)=A(J2,J3)-TEMP*A(J1,J3)
  281 CONTINUE
  291 CONTINUE
C.....  **************INTERCHANGE COLUMNS ACCORDING TO********
C.....  **************INTERCHANGES OF ROWS OF ORIGINAL MATRIX*
  301 N1=NR-1
      DO 391 J1=1,N1
      DO 321 J2=J1,NR
      IF(LABEL(J2).NE.J1) GO TO 321
      IF(J2.EQ.J1) GO TO 391
      GO TO 341
  321 CONTINUE
  341 DO 361 J3=1,NR
      TEMP=A(J3,J1)
      A(J3,J1)=A(J3,J2)
  361 A(J3,J2)=TEMP
      LABEL(J2)=LABEL(J1)
  391 CONTINUE
 5001 RETURN
      END
      SUBROUTINE CV(MODEL,IFY,ISW,LCODE,SS,PRED,SYHAT)
c.....cross validation subroutine

c.....find standard error only when isw=1

c.....forecast for withheld year when isw=2

c.....ify=year excluded from data set
c.....lcode is index for year being forecast
c.....ss=sum of prediction errors squared
c.....pred =prediction
c.....of remaining years drop one from data set and build model
      IMPLICIT DOUBLE PRECISION (A-H)
      IMPLICIT DOUBLE PRECISION (O-Z)
      DIMENSION B(2),X(40,2),Y(40)
      COMMON /C/RTN(40),S(40),FCST(40),FLO(40),HI(40),N,IYR(40)
      COMMON /R/A,B,R2,IDF,SE,F,NVR

C.....LOOP TO CROSS VALIDATE ALL YEARS
      IF(ISW.EQ.1) LBEG=1
      IF(ISW.EQ.1) LEND=N
      IF(ISW.EQ.2) LBEG=LCODE
      IF(ISW.EQ.2) LEND=LCODE
      DO 225 L=LBEG,LEND
C.....EXCLUDE YEAR BEING FORECAST WHEN CALCULATING STD DEV
      IF(ISW.EQ.1.AND.IYR(L).EQ.IFY) GO TO 225

C.....LOOP TO ASSIGN DATA TO X AND Y ARRAYS
      NOBS=0
      DO 200 J=1,N
C.....ALWAYS EXCLUDE YEAR BEING FORECAST FROM OATA SET
      IF(IYR(J).EQ.IFY) GO TO 200
C.....EXCLUDE YEAR BEING BEING DROPPED OUT IN CROSS VALIDATION
C.....L is the same as the year being forecast when isw=2
      IF(J.EQ.L) GO TO 150
      NOBS=NOBS+1
```



```
      IF(MODEL.EQ.1)Y(NOBS)=LOG(RTN(J))
      IF(MODEL.EQ.1)X(NOBS,1)=LOG(S(J))
      IF(MODEL.EQ.2)Y(NOBS)=LOG(RTN(J)/S(J))
      IF(MODEL.EQ.2)X(NOBS,1)=S(J)
C     IF(CLIMATE.EQ.'Y')X(NOBS,2)=TEMP(J)
      WRITE(*,1000)IFY,IYR(L),IYR(J)
 1000 FORMAT('+',
     &' forecast:',I3,' hindcasting:',I3,' crossvalidating:',I3)
      GO TO 200
  150 IF(MODEL.EQ.2)Z=S(L)
      IF(MODEL.EQ.1)Z=LOG(S(L))
  200 CONTINUE

C.....FIT REGRESSION MODEL

      NVR=1
C     IF(CLIMATE.EQ.'Y')NVR=2
      CALL SUBMR(NOBS,X,Y,Z,O,SYHAT)

C.....FORECAST FOR YEAR WITH DATA REMOVED
C     IF(CLIMATE.NE.'Y') GO TO 210
C     IF(MODEL.EQ.1)PRED=EXP(A+B(1)*LOG(S(L))+B(2)*TEMP(L))
C     IF(MODEL.EQ.2)PRED=EXP(A+B(1)*S(L)+B(2)*TSAV)*S(L)
C     GO TO 220
  210 IF(MODEL.EQ.1)PRED=EXP(A+B(1)*LOG(S(L)))
      IF(MODEL.EQ.2)PRED=EXP(A+B(1)*S(L))*S(L)

C.....DON'T COMPUTE ERROR FOR YEAR ULTIMATELY BEING FORECAST
      IF(ISW.EQ.2)GO TO 225
C.....COMPUTE ERROR FOR CROSS VALIDATED YEARS
      ERR=LOG(PRED)-LOG(RTN(L))
C.....ACCUM FORECAST ERRORS FOR CROSS VALIDATED STD. OEV.
  220 SS=SS+ERR**2
  225 CONTINUE

      RETURN
      END
      SUBROUTINE FIT(IFY,MODEL)
c.....fit log-log regression, and Ricker curve
c.....find which has greater F-ratio
      IMPLICIT DOUBLE PRECISION (A-H)
      IMPLICIT DOUBLE PRECISION (O-Z)
      DIMENSION B(2),X(40,2),Y(40),SAVE(2)
      COMMON /C/RTN(40),S(40),FCST(40),FLO(40),HI(40),N,IYR(40)
      COMMON /R/A,B,R2,IDF,SE,F,NVR

C.....FIT LOG-LOG REGRESSION AND RICKER CURVE
      DO 300 ISW=1,2
C.....LOOP TO ASSIGN DATA TO X AND Y ARRAYS
      NOBS=0
      DO 200 J=1,N
C.....ALWAYS EXCLUDE YEAR BEING FORECAST FROM DATA SET
      IF(IYR(J).EQ.IFY) GO TO 200
      IF(RTN(J).LE.0) GOT O 200
      NOBS=NOBS+1
      IF(ISW.EQ.1)Y(NOBS)=LOG(RTN(J))
      IF(ISW.EQ.1)X(NOBS,1)=LOG(S(J))
      IF(ISW.EQ.2)Y(NOBS)=LOG(RTN(J)/S(J))
      IF(ISW.EQ.2)X(NOBS,1)=S(J)
C     IF(CLIMATE.EQ.'Y')X(NOBS,2)=TEMP(J)
      GO TO 200
      Z=S(J)
      IF(ISW.EQ.1)Z=LOG(S(J))
  200 CONTINUE

C.....FIT REGRESSION MODEL
```

```
      NVR=1
C     IF(CLIMATE.EQ.'Y')NVR=2
      CALL SUBMR(NOBS,X,Y,Z,1,SYHAT)
      SAVE(ISW)=F
      IF(ISW.EQ.1)WRITE(2,1000) F
 1000 FORMAT(' Log-log regression model F ratio = ',F12.6)
      IF(ISW.EQ.2)WRITE(2,1100) F
 1100 FORMAT(' Ricker Curve F ratio = ',F12.6)
  300 CONTINUE

      MODEL=1
      IF(SAVE(2).GT.SAVE(1)) MODEL=2
      RETURN
      END
```

Appendix B.2. FORTRAN source code for Bayesian probability program.

```
$DEBUG
C.....BAYESIAN POSTERIOR PROBABILITY GIVEN LOG-NORMAL
C.....LIKELIHOOD AND PRIOR PROBABILITY
      IMPLICIT DOUBLE PRECISION (A-H)
      IMPLICIT DOUBLE PRECISION (O-Z)
      DIMENSION POSTP(200),RUN(200)
      COMMON /S/S,XBAR,SUMN,SUMX2

      OPEN(2,FILE='BAYES.OUT')

      WRITE(*,1000)
 1000 FORMAT(' PROBABILITY ? (e.g. .80)   '\)
      READ(*,1100) PROB
 1100 FORMAT(F4.3)

      CALL REGRESS(PRED)

C.....STD DEV ASSOCIATED W/ PRIOR PROBABILITY OF RUN SIZE
C.....I.E. DISTRIBUTION OF HISTORICAL LN(RUN)
      SPRIOR=SQRT(SUMX2/(SUMN-1))
C.....RECIPRICAL OF STD DEV SQUARED
      SP2=SPRIOR**(-2)

C.....FIND DEMONIMATOR OF THE POSTERIOR PROBABILITY
      MAX=3400000
      POSTD=0
      DO 100 J=25000,MAX,25000
      RR=LOG(J)
      ERR=RR-XBAR
C.....STD DEV ASSOCIATED W/ LIKELIHOOD OF FORECAST GIVEN RUN
C.....DERIVED FROM REGRESSION OF LN(FORECAST) ON LN(RUN)
      SLIKELI=S*SQRT(1+(1/SUMN)+((ERR**2)/SUMX2) )
C.....RECIPRICAL OF STD DEV SQUARED
      SL2=SLIKELI**(-2)
      A=(1/(SL2+SP2))*(XBAR*SP2+PRED*SL2)
C.....2*PI = 2*3.14159 = 6.28319
      C=SQRT(SL2+SP2)/SQRT(6.28319)
      POSTD=POSTD+(C*(EXP(-0.5*(SL2+SP2)*(RR-A)**2)/RR))
  100 CONTINUE

C.....FIND NUMERATOR OF POSTERIOR PROBABILITY
      K=1
      DO 200 I=25000,MAX,25000
      POSTP(K)=0.
      RUN(K)=0
      R=LOG(I)
      ERR=R-XBAR
C.....STD DEV ASSOCIATED W/ LIKELIHOOD OF FORECAST GIVEN RUN
C.....DERIVED FROM REGRESSION OF LN(FORECAST) ON LN(RUN)
      SLIKELI=S*SQRT(1+(1/SUMN)+((ERR**2)/SUMX2) )
C.....RECIPRICAL OF STD DEV SQUARED
      SL2=SLIKELI**(-2)

      A=(1/(SL2+SP2))*(XBAR*SP2+PRED*SL2)
C.....2*PI = 2*3.14159 = 6.28319
      C=SQRT(SL2+SP2)/SQRT(6.28319)
      POSTN=C*EXP(-0.5*(SL2+SP2)*(R-A)**2)/R
      POSTP(K)=POSTN/POSTD
      RUN(K)=I
      WRITE(2,2000)I,POSTP(K)
 2000 FORMAT(' ',I10,12F8.4)
      K=K+1
  200 CONTINUE

      WRITE(2,2100)
 2100 FORMAT(' RUN, POSTERIOR PROBABILITY')
```



```
      IEND=200
      DO 700 I=1,200
      IBEG=I
C.....CHECK POSITIVE VALUES ONLY
      IF(POSTP(I).LT.0.00005) GO TO 700
      DO 600 J=IEND,IBEG,-1
      IF(POSTP(J).LT.POSTP(I)) GO TO 550
      SUM=0
      DO 500 K=IBEG,IEND
      SUM=SUM+POSTP(K)
  500 CONTINUE
      IF(SUM.LE.PROB) THEN
      WRITE(2,5000) SUM,RUN(IBEG),RUN(IEND)
 5000 FORMAT(F5.2,' CHANCE RUN WILL BE BETWEEN ',F8.0,' & ',F8.0)
      STOP
      ENDIF
      GOTO 700
  550 IEND=J
  600 CONTINUE

  700 CONTINUE

      STOP
      END

      SUBROUTINE REGRESS(PRED)
c.....read output from pinkfcst.for:
c.....combined lci pink salmon returns and reconstructed forecasts
      IMPLICIT DOUBLE PRECISION (A-H)
      IMPLICIT DOUBLE PRECISION (O-Z)
      DIMENSION Y(40),X(40,2),B(2)
      COMMON /F/FVAL(50)
      COMMON /R/A,B,R2,IDF,SE,F,NVR
      COMMON /S/S,XBAR,SUMN,SUMX2

      OPEN(3,FILE='c:\pinkfcst\FVALUES.75')
      READ(3,1007)
      DO 30 I=1,50
      READ(3,1007,end=50) N,FVAL(N)
 1007 FORMAT(I2,1X,F9.2)
   30 CONTINUE


      OPEN(1,FILE='BAYES.DAT')
C.....FIRST LINE IS FORECAST YEAR
      READ(1,2200) KYR
 2200 FORMAT(I4)
      N=1
   50 READ(1,3000,END=100) IYR,RUN,FCST
 3000 FORMAT(I4,12X,2F12.0)
      IF(IYR.EQ.KYR) THEN
      N=N-1
      SAVE=LOG(FCST)
      GO TO 100
      ENDIF

      X(N,1)=LOG(FCST)
      Y(N)=LOG(RUN)
      N=N+1
      GO TO 50

  100 NVR=1
      CALL SUBMR(N,X,Y,Z,O,SYHAT)
      PRED=A+B(1)*SAVE
```

```
      RETURN
      END
C.....MULTIPLE LINEAR REGRESSION SUBROUTINE
C.....NVR = NUMBER OF X VARIABLES
C.....NOBS = NUMBER OF OBSERVATIONS
C.....SNEDECOR AND COCHRAN CHAPTER 13 (USING INVERSE MATRIX METHOD)
C.....HANKE AND GREITSCH CHAPTER 5
      SUBROUTINE SUBMR(NOBS,X,Y,Z,IMESS,SYHAT)
      IMPLICIT DOUBLE PRECISION (A-H)
      IMPLICIT DOUBLE PRECISION (O-Z)
      DIMENSION SUMX(2),SX2(2,2),C(2,2),B(2),SXY(2)
      DIMENSION LABEL(2),SUMXX(2,2),SUMXY(2)
      DIMENSION Y(40),X(40,2)
      REAL MSREG,MSDEV
      COMMON /F/FVAL(50)
      COMMON /R/A,B,R2,IDF,SE,F,NVR
      COMMON /S/S,XBAR,SUMN,SUMX2

      IF(NOBS.LE.3) RETURN
C.....ZERO ARRAYS
      DO 20 I=1,NVR
      SUMXY(I)=0.0
      SUMX(I)=0.0
      B(I)=0.0
   20 CONTINUE
      SUMY=0.0
      SUMYY=0.0

C.....FIND SUMS
      DO 30 I=1,NOBS
      SUMY=SUMY+Y(I)
      SUMYY=SUMYY+Y(I)*Y(I)
      DO 30 K=1,NVR
      SUMXY(K)=SUMXY(K)+X(I,K)*Y(I)
   30 SUMX(K)=SUMX(K)+X(I,K)
      DO 50 I=1,NVR
      DO 45 J=1,NVR
      SUMXX(I,J)=0.0
      DO 40 K=1,NOBS
   40 SUMXX(I,J)=SUMXX(I,J)+X(K,I)*X(K,J)
   45 CONTINUE
   50 CONTINUE
C.....FORM MATRIX OF SUMS OF SQAURES AND PRODUCTS (P 389)
      SUMN=NOBS
      DO 72 I=1,NVR
      DO 72 J=1,NVR
      SX2(I,J)=SUMXX(I,J)-(SUMX(I)*SUMX(J))/SUMN
      C(I,J)=SX2(I,J)
   72 CONTINUE
C.....GAUSS MULTIPLIERS = INVERSE OF MATRIX = sums of squares/D (P 390)
      I=NVR
      CALL MTINV(C,I,I,I,LABEL)
      DO 110 I=1,NVR
      SXY(I)=SUMXY(I)-(SUMX(I)*SUMY)/SUMN
  110 CONTINUE

      SSREG=0.0
      A=SUMY/SUMN
C.....b = PRODUCT OF GAUSS MULTIPIERS AND CROSS PRODUCTS (P 390)

      DO 140 I=1,NVR
      DO 130 J=1,NVR
      B(I)=B(I)+C(I,J)*SXY(J)
  130 CONTINUE
C.....REGRESSION SS (P 386)
```



```
      SSREG=SSREG+B(I)*SXY(I)
C.....CONSTANT (P 382)
      A=A-B(I)*(SUMX(I)/SUMN)
  140 CONTINUE

C     WRITE(*,2500) A
C2500 FORMAT(/,'          a =',F14.5)
C.....TOTAL SS
      SY2=SUMYY-((SUMY*SUMY)/SUMN)
C.....DEVIATION SS (TOTAL - REGRESSION SS)
      SSDEV=SY2-SSREG
      DF=NOBS-NVR-1
      IDF=DF
      MSDEV=SSDEV/DF
C.....REGRESSION COEFFICIENT STD ERROR (P 138, 391)
      S=SQRT(MSDEV)

      DO 200 I=1,NVR
      SREG=S*SQRT(C(I,I))
C     WRITE(*,2900)I,B(I),SREG
C2900 FORMAT('        b(',I1,') =',F14.5,' SE(b coef) = ',F14.5)
  200 CONTINUE

C.....STANDARD ERROR OF THE PREDICTION (P155-156)
C.....FOR ONE X VARIABLE, SEE PAGE 392 AND MODIFY THIS SECTION
C.....IF MORE THAN ONE X VARIABLE

      XBAR=SUMX(1)/SUMN
      ERR=Z-XBAR
      SUMX2=SX2(1,1)
      SYHAT=S*SQRT(1+(1/SUMN)+((ERR**2)/SX2(1,1)) )

C.....CORRELATION COEFFICIENT (RESIDUAL SS/TOTAL SS, P 402)
      R2=SSREG/SY2
C     WRITE(*,2600)R2
C2600 FORMAT('  R Squared =',F14.5)

C.....DEGREES OF FREEDOM AND F STATISTIC (P 387)
      DF=NVR
      MSREG=SSREG/(DF)
      F=MSREG/MSDEV
C     WRITE(2,4000) F,NVR,IDF
C4000 FORMAT(1H ,'          F =',F8.2,' d.f. =',I3,',',I3)
      IF(F.GE.FVAL(IDF))GO TO 290
      IF(IMESS.EQ.1)WRITE(2,4050)
 4050 FORMAT(' regression not significant')
  290 IF(NVR.EQ.1) GO TO 900
      DO 300 I=1,NVR
      AFTER=SSREG-((SXY(I)*SXY(I))/SX2(I,I))
      F=AFTER/MSDEV
C     WRITE(2,4100) I
C4100 FORMAT(/,' effect of removing variable ',I1)
C     WRITE(2,4200) F,IDF
C4200 FORMAT(1H ,'          F =',F8.2,' d.f. =  1',',',I3)
      IF(F.GE.FVAL(IDF))GO TO 300
C     WRITE(2,4050)
  300 CONTINUE
  900 RETURN
      END
      SUBROUTINE MTINV(A,NRARG,NCARG,IDIM,LABEL)
C.....  *************MATRIX INVERSION*************************
      IMPLICIT DOUBLE PRECISION (A-H)
      IMPLICIT DOUBLE PRECISION (O-Z)
      DIMENSION A(IDIM,NCARG),LABEL(NRARG)
    1 NR=NRARG
      NC=NCARG
```

```
      DO 21 J1=1,NR
   21 LABEL(J1)=J1
      DO 291 J1=1,NR
C..... **************FIND REMAINING ROW CONTAINING LARGEST***
C..... **************ABSOLUTE VALUE IN PIVOTAL COLUMN********
  101 TEMP=0.0
      DO 121 J2=J1,NR
      IF(ABS(A(J2,J1)).LT.TEMP) GO TO 121
      TEMP=ABS(A(J2,J1))
      IBIG=J2
  121 CONTINUE
      IF(IBIG.EQ.J1)GO TO 201
C..... **************REARRANGE ROWS TO PLACE LARGEST ABSOLUTE
C..... **************VALUE IN PIVOT POSITION*****************
      DO 141 J2=1,NC
      TEMP=A(J1,J2)
      A(J1,J2)=A(IBIG,J2)
  141 A(IBIG,J2)=TEMP
      I=LABEL(J1)
      LABEL(J1)=LABEL(IBIG)
      LABEL(IBIG)=I
C.....::::COMPUTE COEFFICIENTS IN PIVOTAL ROW::::
  201 TEMP=A(J1,J1)
      A(J1,J1)=1.0
      DO 221 J2=1,NC
  221 A(J1,J2)=A(J1,J2)/TEMP
C..... **************COMPUTE COEFFICIENTS IN OTHER ROWS******
      DO 281 J2=1,NR
      IF(J2.EQ.J1) GO TO 281
      TEMP=A(J2,J1)
      A(J2,J1)=0.0
      DO 241 J3=1,NC
  241 A(J2,J3)=A(J2,J3)-TEMP*A(J1,J3)
  281 CONTINUE
  291 CONTINUE
C..... **************INTERCHANGE COLUMNS ACCORDING TO********
C..... **************INTERCHANGES OF ROWS OF ORIGINAL MATRIX*
  301 N1=NR-1
      DO 391 J1=1,N1
      DO 321 J2=J1,NR
      IF(LABEL(J2).NE.J1) GO TO 321
      IF(J2.EQ.J1) GO TO 391
      GO TO 341
  321 CONTINUE
  341 DO 361 J3=1,NR
      TEMP=A(J3,J1)
      A(J3,J1)=A(J3,J2)
  361 A(J3,J2)=TEMP
      LABEL(J2)=LABEL(J1)
  391 CONTINUE
 5001 RETURN
      END
```