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LOWER COOK INLET PINK SALMON FORECAST FOR 1993

By

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ABSTRACT

The total number of pink salmon *Oncorhynchus gorbuscha* returning to 11 Lower Cook Inlet streams or drainage systems in 1993 was forecasted to be 798,804. Associated harvest was projected to be 451,400 with an potential escapement shortfall of 25,096 in Rocky Bay. Lower and upper 80% confidence limits around the total run forecast were 338,658 and 2,707,186, respectively with corresponding harvest projected to range between 233,469 and 2,237,186. Potential escapement shortfall may be as high as 127,388 in nine harvest areas if runs to all harvest areas were at the lower forecast bound.

Either a Ricker curve or a log-log regression of returning adults on spawning escapements were used to produce forecasts for each stream or drainage system depending on the model's *F* ratios. 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 SD and 80% confidence limits.

Wide confidence intervals about the 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 presented for each harvest areas.

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

INTRODUCTION

This was the fourth year a forecast of pink salmon *Oncorhynchus gorbuscha* run size was made for Lower Cook Inlet (Figure 1). Individual forecasts of 1993 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 1993. Forecasts of hatchery pink salmon runs (e.g. Tutka Lagoon), prepared by staff within the Division of Fisheries Rehabilitation, Enhancement and Development, will be included in the annual statewide salmon forecast report (e.g. Geiger and Savikko 1992).

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 1993 as a result of spawning escapements obtained in 1991. 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 SD and an 80% confidence limit around the 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, defined in this report as the aggregate of the 11 harvest areas only, was the sum of the individual harvest area forecast. The upper and lower bounds around the total run forecast, however, were derived from a cross-validation of the total runs. The aggregate escapement goal was the sum of the individual escapement goals. The total projected harvest was total run minus aggregated escapement goal minus total escapement shortfall.

Run Forecast Model

Pink salmon runs to individual harvest areas were forecasted from either an overcompensatory or Ricker type curve (Ricker 1975)

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

or 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 $F_{h,y}$ = forecast total return (i.e. $catch_y$ + $escapement_y$) in harvest area h and year y; E = escapement; R = 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 test 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 ratio. If neither were significant, we used the median return/spawner rates instead.

Data Base

Total return and spawning escapement data for the 1960 to 1988 brood years were obtained from the most recent annual management reports (Schroeder and Morrison 1990). Data for brood years 1989 and 1990 were obtained from end of season summary reports. 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. We did not use returns estimated from the catch only.

Confidence Interval by Harvest Area

In a cross-validation by 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

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

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

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

whenever 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 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

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

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 on n-1 degrees of freedom;

Confidence Interval for Lower Cook Inlet

The Lower Cook Inlet forecast, i.e. aggregate of 11 harvest areas, was

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

Its 80% confidence limit 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 (Table 2).

Historical Perspective

Cross-validation was also used to reconstruct historical forecast ranges. The fraction of observed runs that were within the reconstructed 80% confidence limits were used as a measure of forecast performance.

RESULTS

The forecast models selected by harvest areas are presented in Table 2. We did not resort to median return/spawner ratios.

The sum of the forecasted runs to 11 Lower Cook Inlet harvest areas for 1993 was 798,804 pink salmon. Total projected catch was 451,400 pink salmon. No harvest was projected for Rocky Bay since the forecasted run was less than the spawning escapement goal for this area (Table 3).

Forecast ranges as 80% confidence intervals for each harvest area are presented in Table 3. The sum of the lower or upper bounds derived from a cross-validation of the individual harvest areas will not match that for the Lower Cook Inlet total. The latter, a lower and upper bound of 338,658 and 2,707,186, is presented in Table 3.

While we expect some of the 11 individual runs to be either at the upper or lower end of their forecast range, we do expect all 11 to be at the upper or lower end of the range. However, if all 11 runs were to be at the lower forecast range, the projected catch would be 233,469. Similar projection at the upper bound was 2,237,186.

DISCUSSION

The forecast and total projected catch in this report will not match the 957,502 forecast and 610,090 projected catch presented to the Board of Fisheries. The numbers presented to the Board were preliminary estimates where we excluded outliers, i.e. brood years with >999% cross-validated forecast errors, and used log-log models exclusively for all harvest areas, regardless of the statistical significance of its slope.

The level of pink salmon spawning escapements in 1991, the parental year for 1993 runs, throughout Lower Cook Inlet was mixed (Table 3). The 1991 spawning escapements in Port Dick, Port Graham, Seldovia and Windy Bays were within desired spawning ranges. Escapements in Humpy Creek, Resurrection and Rocky Bays were below while those in Bruin Bay, Port Chatham, Nuka Bay, and Ursus-Rocky Coves were above the desired spawning escapement range. Nevertheless, harvestable surplus are projected from all runs in 1993 except Rocky Bay.

Wide 80% confidence intervals show the large degree of uncertainty associated with the 1993 pink salmon forecast (Table 3). To put the 1993 forecast in perspective, the fraction of the historical runs that were comparable to the 1993 forecast, i.e. within the 1993 forecast range, is presented in Table 4. For most harvest areas, the 1993 forecasts were for run sizes

that have been observed at least half of the time between 1962 and 1992. The 1993 Windy Bay forecast, however, is for a relatively large run. Its lower forecast bound was greater than 15 of the 31 historical runs in our data set.

Our forecast models tend to underforecast very large runs (Figure 2). Therefore, the fraction of reconstructed historical forecasts that were both (1) comparable to that 1993 forecast and (2) correct, i.e. within the reconstructed historical 80% confidence interval, are also presented in Table 4. The reconstructed historical forecast performance suggest that the 1993 forecast for all harvest areas appear to have a good chance of being correct.

There were an unusually large number of individual harvest areas whose runs were less than the forecasts in 1992, even with the wide confidence intervals. The composite forecast was 483% greater than the actual pink salmon run (Table 5). Similar overforecast errors were reported for hatchery stocks. Only five of the individual 1992 harvest area forecasts were within forecast 80% confidence intervals. The pattern of overforecasting has occurred for two years (Figure 2).

The Lower Cook Inlet pink salmon dominant year pattern has changed over the years. Runs were greater during the even numbered years between 1962 and 1970 and during the odd numbered years between 1971 and 1982. They became greater during the odd number years again between 1987 and 1992 after a period between 1983 and 1986 when no dominant year pattern was exhibited. If the forecast is realized, the pattern of greater run size during the odd numbered years would be maintained. A run of the size being forecast would be between the historical run 50 and 75 percentile, that is, greater than half the runs observed between 1962 and 1991 but not great enough to exceed 75% of the historical runs (Figure 2).

Ricker and log-log curves plus median return/spawner and replacement lines for each harvest area are presented in Figures 3-12. Only one variable, number of spawners, has been used to forecast pink salmon runs. Only two of the 11 harvest areas (Windy Bay and Rocky Bay) had more than 50% of the variability in past run size explained by spawning escapement. Obviously, factors other than number of spawners greatly influence pink salmon production. While causes of lower than expected pink salmon production from the 1991 brood year spawning escapements have not be identified, it is possible that production from 1991 spawning escapements could also be depressed.

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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 1993. 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	1.22290	-0.00001	0.149	5.07	1,29
Seldovia	log-log	5.35521	0.53093	0.114	3.73	1,29
Port Graham	Ricker	1.29096	-0.00004	0.217	8.04	1,29
Port Chatham	log-log	4.35791	0.57590	0.157	3.92	1,21
Windy Bay	log-log	0.69074	0.97117	0.565	37.73	1,29
Rocky Bay	log-log	2.23807	0.77532	0.547	35.06	1,29
Port Dick Bay	log-log	4.52794	0.68610	0.179	6.33	1,29
Nuka Bay	log-log	4.78343	0.58470	0.193	5.98	1,25
Resurrection Bay	Ricker	1.66924	-0.00004	0.264	5.73	1,16
Bruin Bay	Ricker	1.29362	0.00000	0.429	13.53	1,18
Ursus and Rocky Cove	log-log	4.59792	0.55839	0.298	10.19	1,24

Table 3. Forecasted pink salmon runs, projected harvests[a], and potential spawning escapement shortfalls for Lower Cook Inlet pink salmon, 1993.

Location	1991 Escapement	Forecast			Forecast Range[b]						Potential Escapement Goal Shortfall		
					Lower Bound			Upper Bound					
		Run	Escapement	Harvest	Run	Escapement	Harvest	Run	Escapement	Harvest	Forecast	Lower	Upper
Humpy Creek	17,406	48,794	37,500	11,294	9,612	25,000	0	247,694	50,000	197,694	0	15,388	0
Seldovia Bay	29,950	50,397	30,000	20,397	13,917	25,000	0	182,498	35,000	147,498	0	11,083	0
Port Graham	28,966	33,774	30,000	3,774	10,095	20,000	0	112,991	40,000	72,991	0	9,905	0
Port Chatham	23,776	25,872	12,500	13,372	3,225	10,000	0	207,573	15,000	192,573	0	6,775	0
Windy Bay	55,279	80,508	50,000	30,508	15,411	40,000	0	420,573	60,000	360,573	0	24,589	0
Rocky Bay	26,100	24,904	50,000	0	5,517	50,000	0	112,431	50,000	62,431	25,096	44,484	0
Port Dick	78,637	211,512	60,000	151,512	29,898	20,000	9,898	1,496,320	100,000	1,396,320	0	0	0
Nuka Bay	24,384	43,909	15,000	28,909	4,630	10,000	0	416,414	20,000	396,414	0	5,370	0
Resurrection Bay	19,120	51,636	30,000	21,636	7,623	30,000	0	349,764	30,000	319,764	0	22,377	0
Bruin Bay	74,910	191,887	37,500	154,387	20,119	25,000	0	1,830,176	50,000	1,780,176	0	4,882	0
Ursus & Rocky Cove	37,600	35,610	20,000	15,610	5,040	20,000	0	251,603	20,000	231,603	0	14,960	0
Lower Cook Inlet[c]	416,128	798,804	372,500	451,400	338,658	275,000	233,469	2,707,186	470,000	2,237,186	25,096	159,811	0

[a] Projected harvest = forecast - escapement goal (range) + escapement shortfall

[b] Upper and lower forecast bounds based on 80% confidence interval of the forecast for the run.

[c] Lower Cook Inlet forecast bounds were derived from cross-validations SD and will not equal the sum of the individual forecast ranges.

Table 4. The 1993 forecast in historical perspective.

Harvest Area	1993 forecast lower bound	1993 forecast upper bound	Fraction of historical runs that were similar in size to 1993 forecast[a]	Fraction of historical forecast similar in size to 1993 forecast that were correct[b]	n[c]
Humpy Creek	9,612	247,694	0.871	0.852	31
Seldovia Bay	13,917	182,498	0.806	0.960	31
Port Graham	10,095	112,991	0.710	0.955	31
Port Chatham	3,227	207,573	0.870	0.800	23
Windy Bay	15,411	420,573	0.484	0.933	31
Rocky Bay	5,517	112,431	0.581	0.889	31
Port Dick	29,898	1,496,320	0.806	0.960	31
Nuka Bay	4,630	416,414	0.856	0.913	27
Resurrection Bay	7,623	349,764	0.889	1.000	18
Bruin Bay	20,119	1,830,176	0.650	0.923	20
Ursus and Rocky Coves	5,040	251,603	0.769	0.850	26

[a] Within 1993 forecast bounds.
[b] Within reconstructed 80% confidence interval.
[c] Total number of historical years that were analyzed

Table 5. Forecasted and actual runs of pink salmon to Lower Cook Inlet, 1992.

	Forecast	Lower Bound	Upper Bound	Actual Run	% Error[a]	Run compared to Forecast
Humpy Creek	81,885	23,531	284,948	14,583	462	R < F
Seldovia	49,960	13,812	180,719	16,596	201	R within F
Port Graham	30,080	9,542	94,826	5,450	452	R < F
Port Chatham	31,733	9,106	110,579	4,304	637	R < F
Windy Bay	26,085	6,546	103,951	12,059	116	R within F
Rocky Bay	18,629	4,015	86,425	26,077	-29	R within F
Port Dick Bay	329,490	107,026	1,014,369	17,024	1835	R < F
Nuka Bay	61,408	14,318	263,360	7,177	756	R < F
Resurrection Bay	26,687	3,096	230,067	7,986	234	R within F
Bruin Bay	65,244	11,351	375,007	6,554	895	R < F
Ursus and Rocky Coves	12,468	2,511	61,906	8,266	51	R within F
Total	734,504	269,292	2,003,389	126,076	483	R < F

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

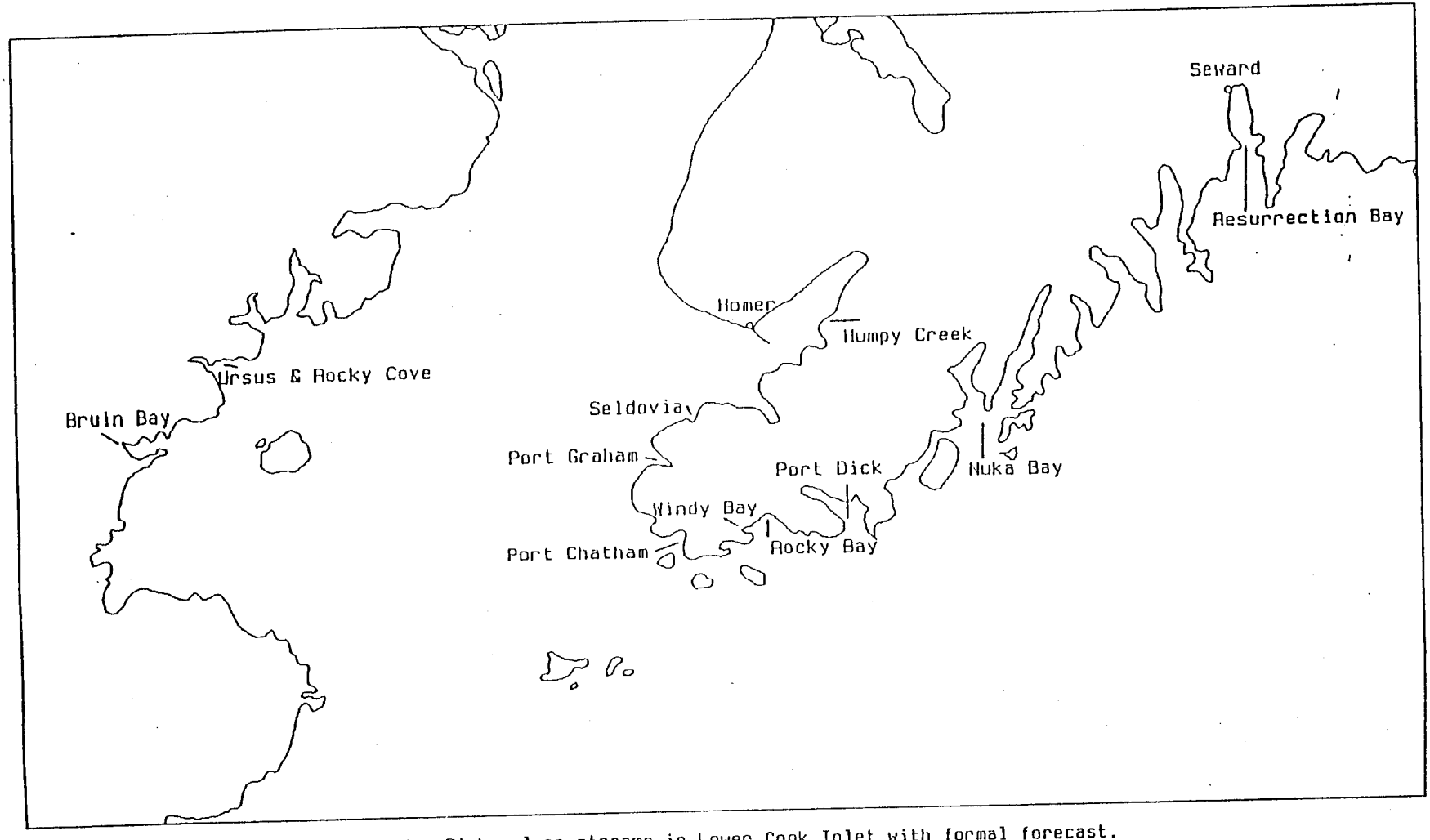

Figure 1. Pink salmon streams in Lower Cook Inlet with formal forecast.

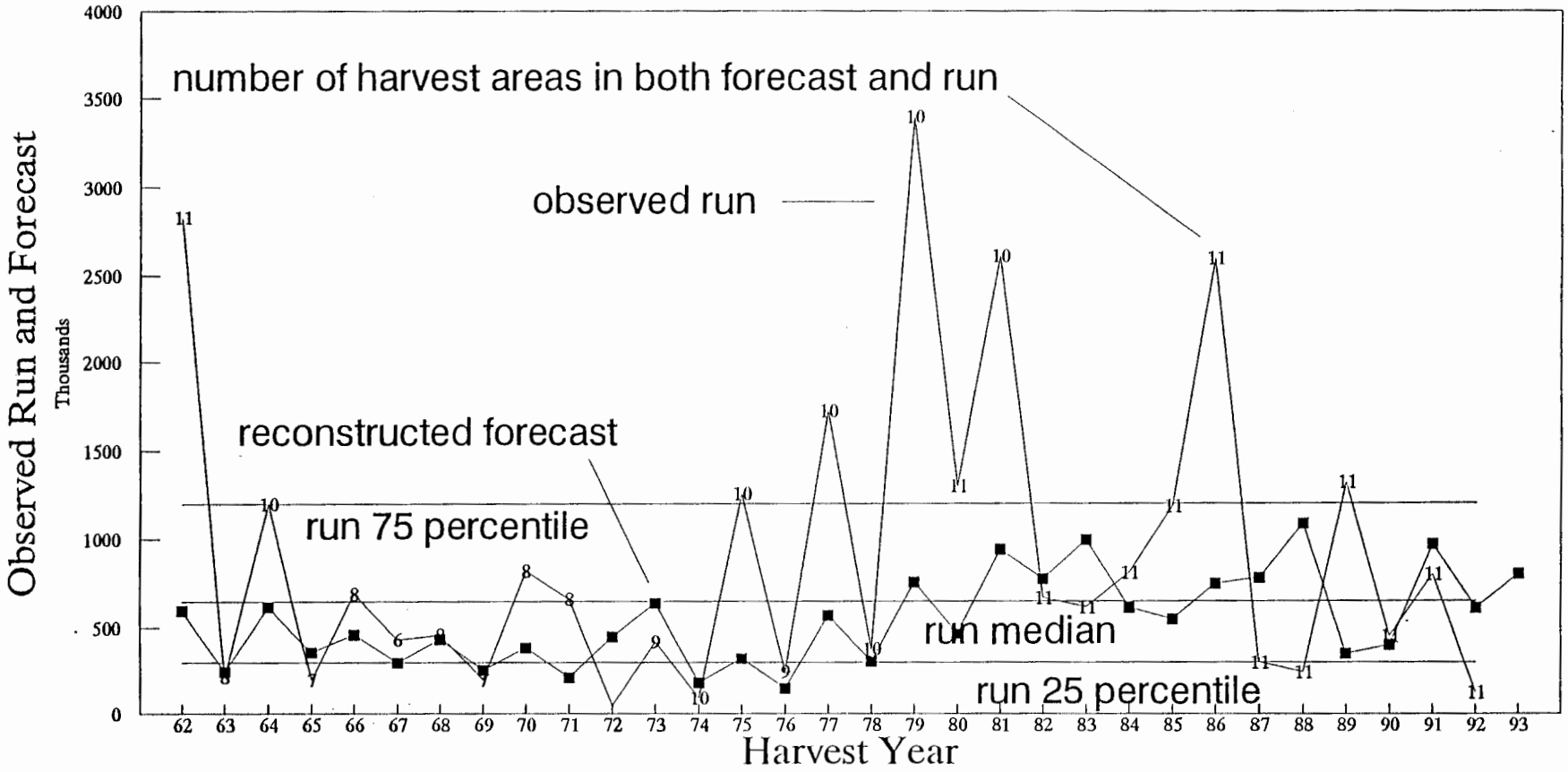

Figure 2. Reconstructed forecasts and observed runs for Lower Cook Inlet pink salmon.

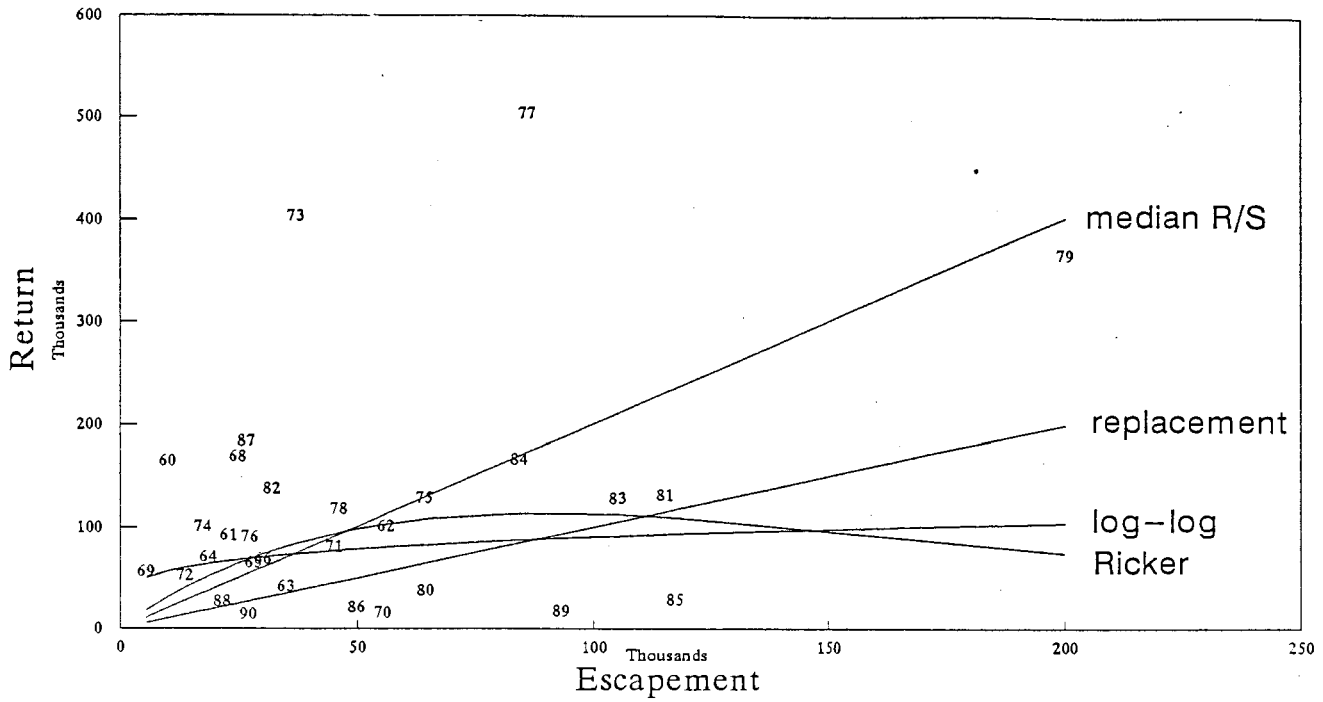

Figure 3. Pink salmon escapement, return, predicted return from Ricker curve, log–log regression and median return/spawner ratio, Humpy Creek.

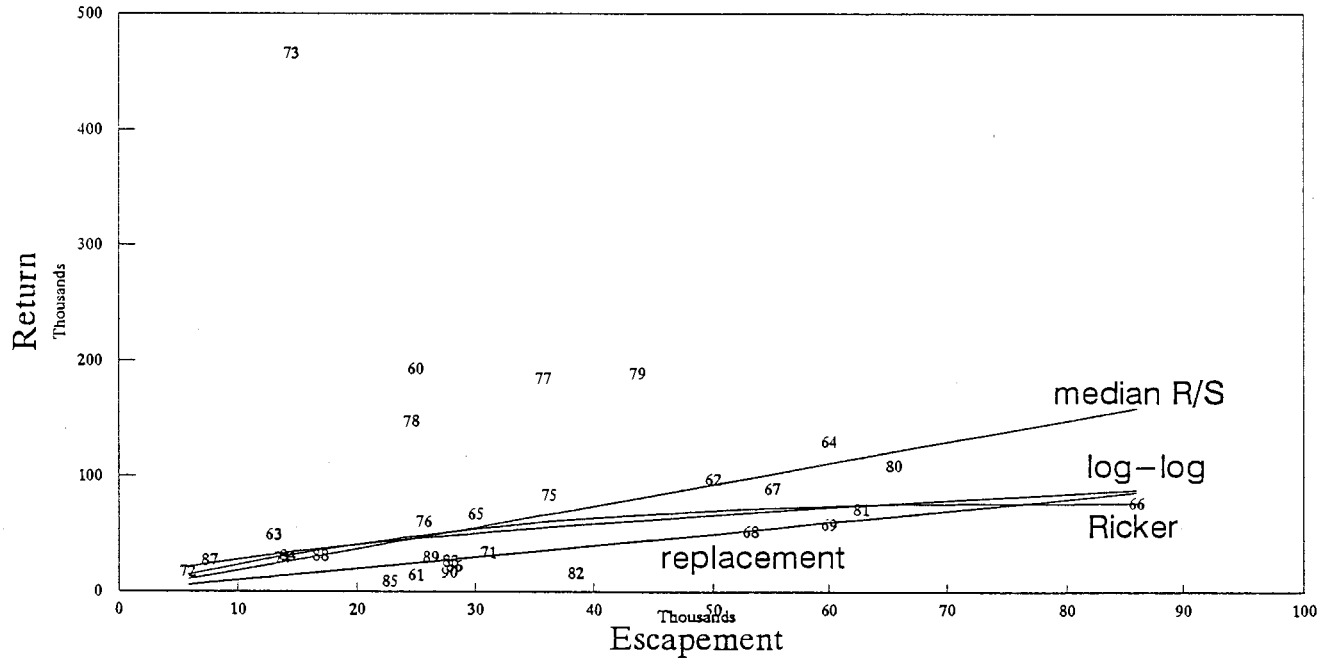

Figure 4. Pink salmon escapement, return, predicted return from Ricker curve, log–log regression and median return/spawner ratio, Seldovia.

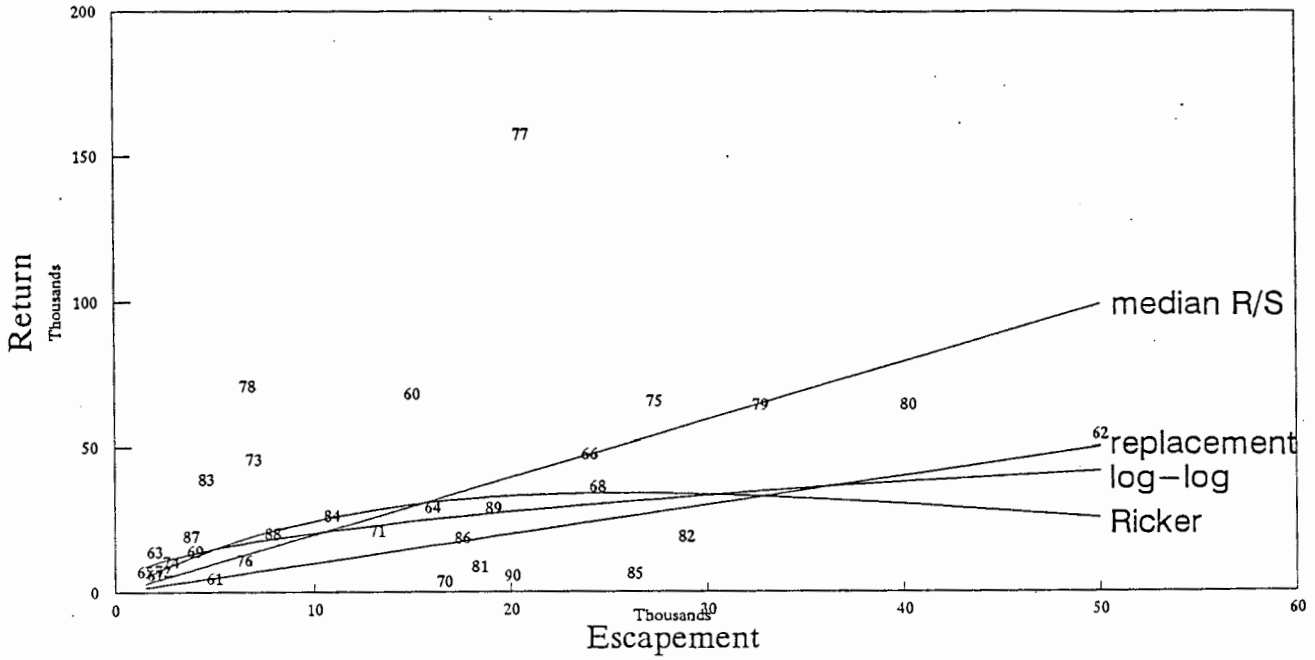

Figure 5. Pink salmon escapement, return, predicted return from Ricker curve, log−log regression and median return/spawner ratio, Port Graham.

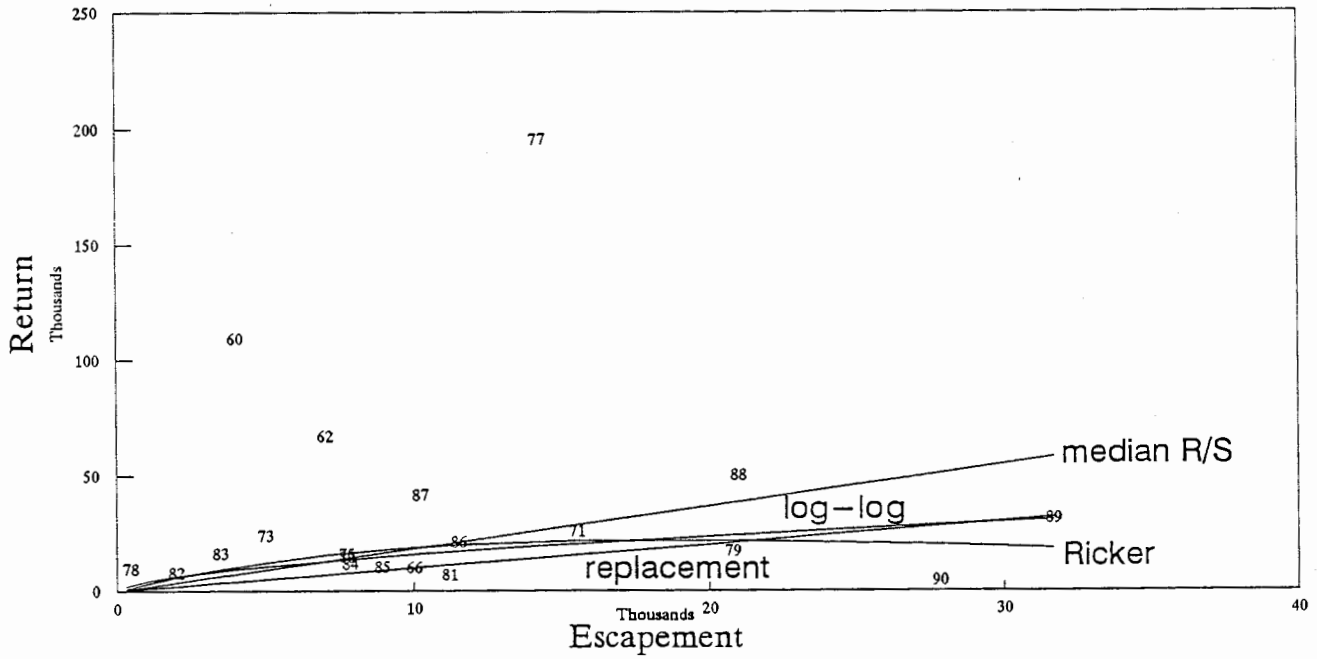

Figure 6. Pink salmon escapement, return, predicted return from Ricker curve, log−log regression and median return/spawner ratio, Port Chatham.

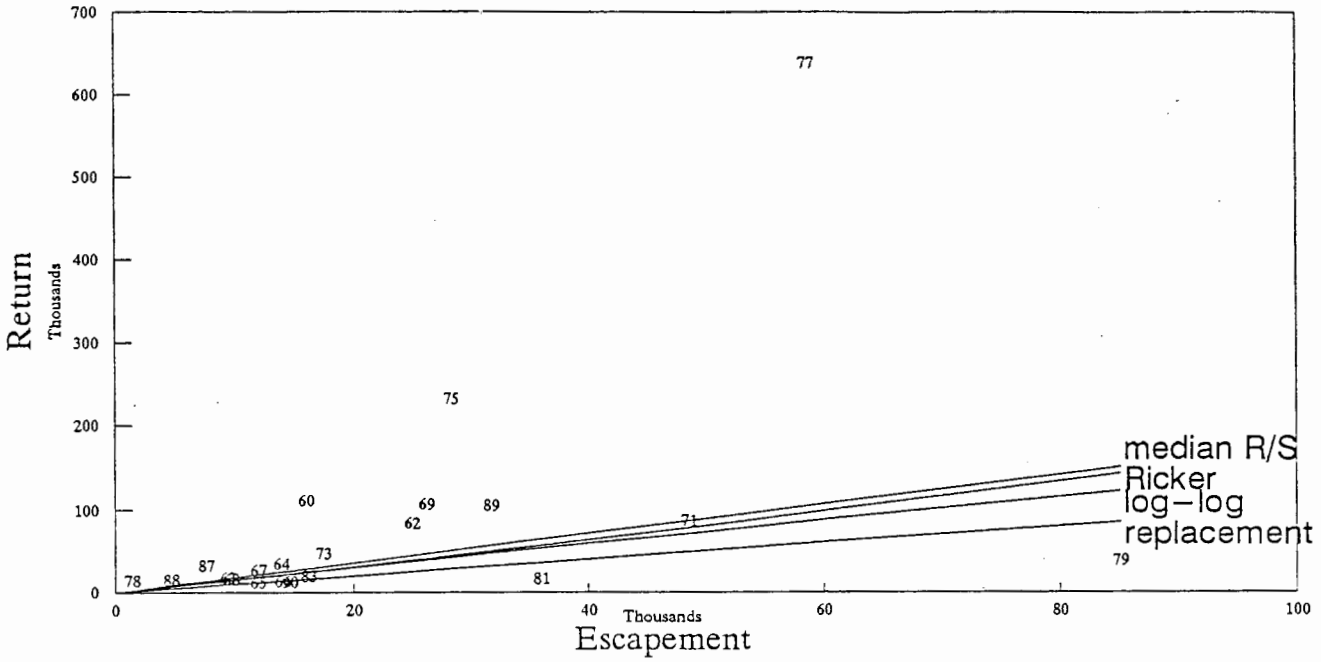

Figure 7. Pink salmon escapement, return, predicted return from Ricker curve, log–log regression and median return/spawner ratio, Windy Bay.

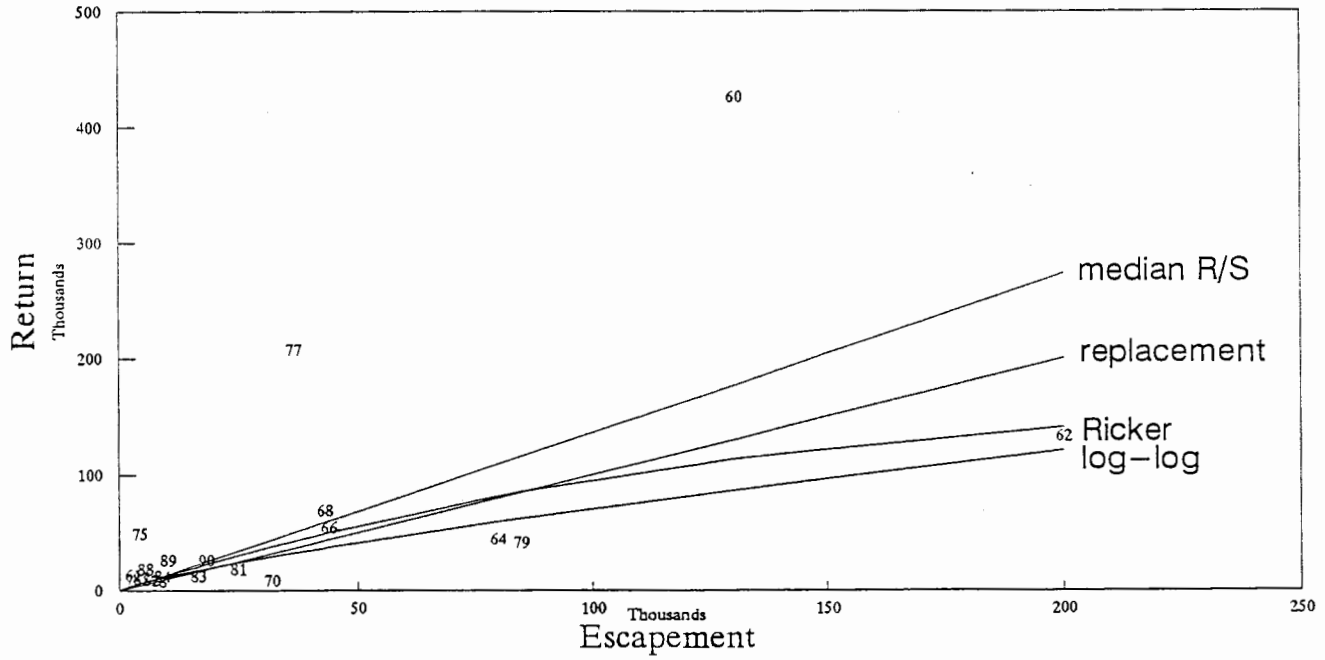

Figure 8. Pink salmon escapement, return, predicted return from Ricker curve, log–log regression and median return/spawner ratio, Rocky Bay.

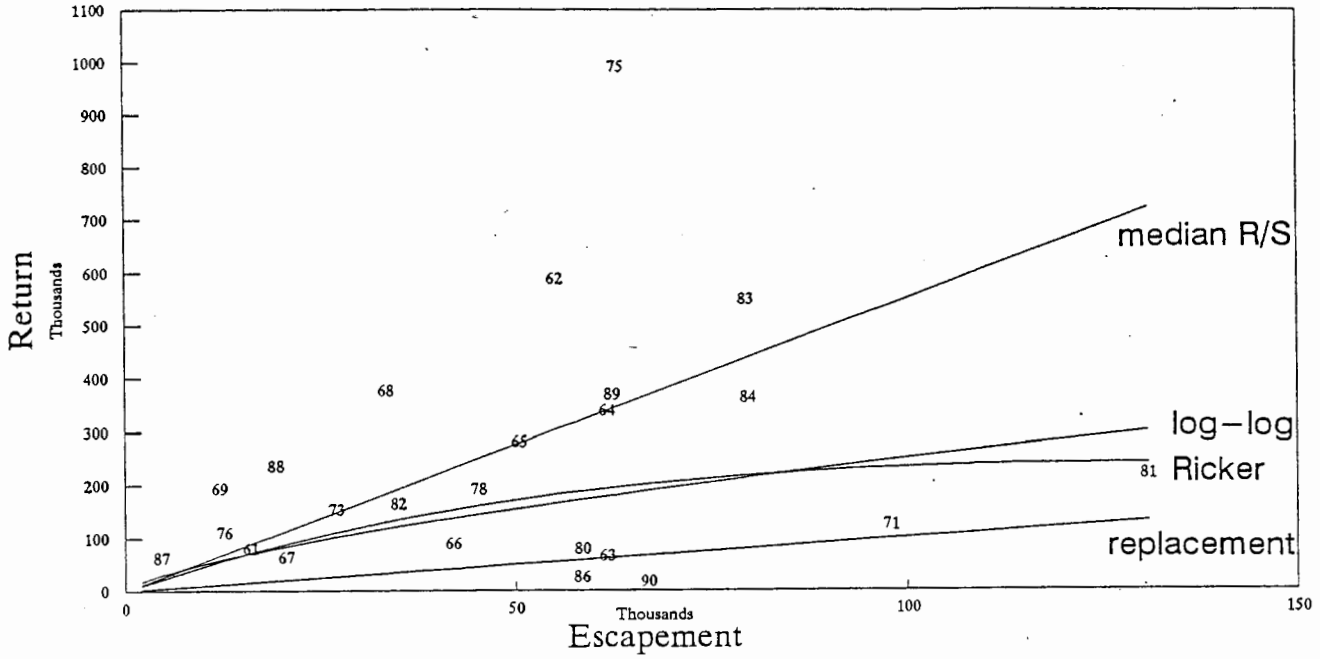

Figure 9. Pink salmon escapement, return, predicted return from Ricker curve, log−log regression and median return/spawner ratio, Port Dick Bay.

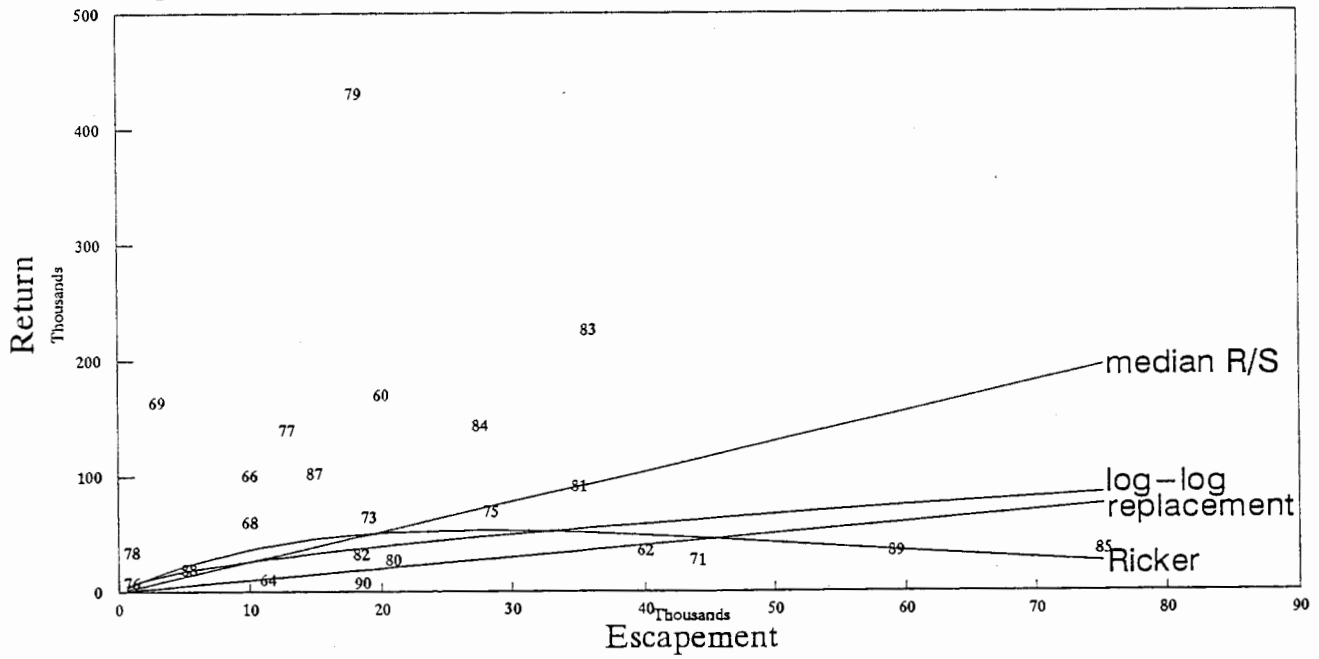

Figure 10. Pink salmon escapement, return, predicted return from Ricker curve, log−log regression and median return/spawner ratio, Nuka Bay.

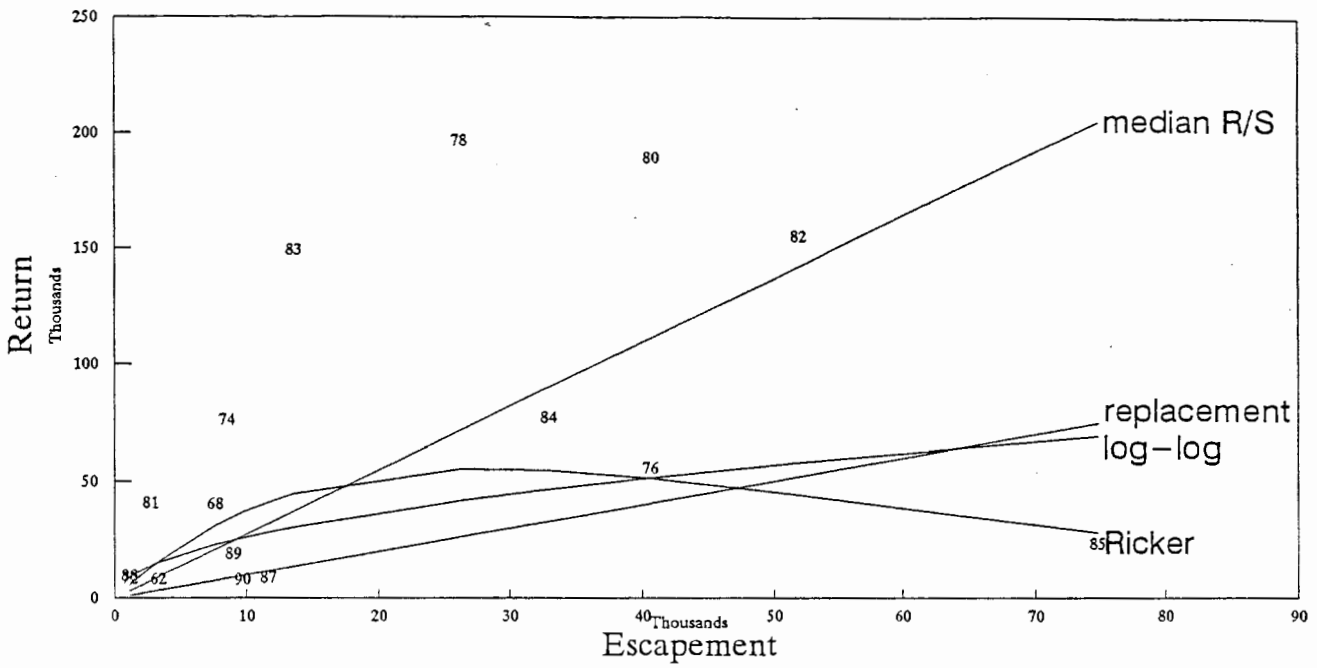

Figure 11. Pink salmon escapement, return, predicted return from Ricker curve, log–log regression and median return/spawner ratio, Resurrection Bay.

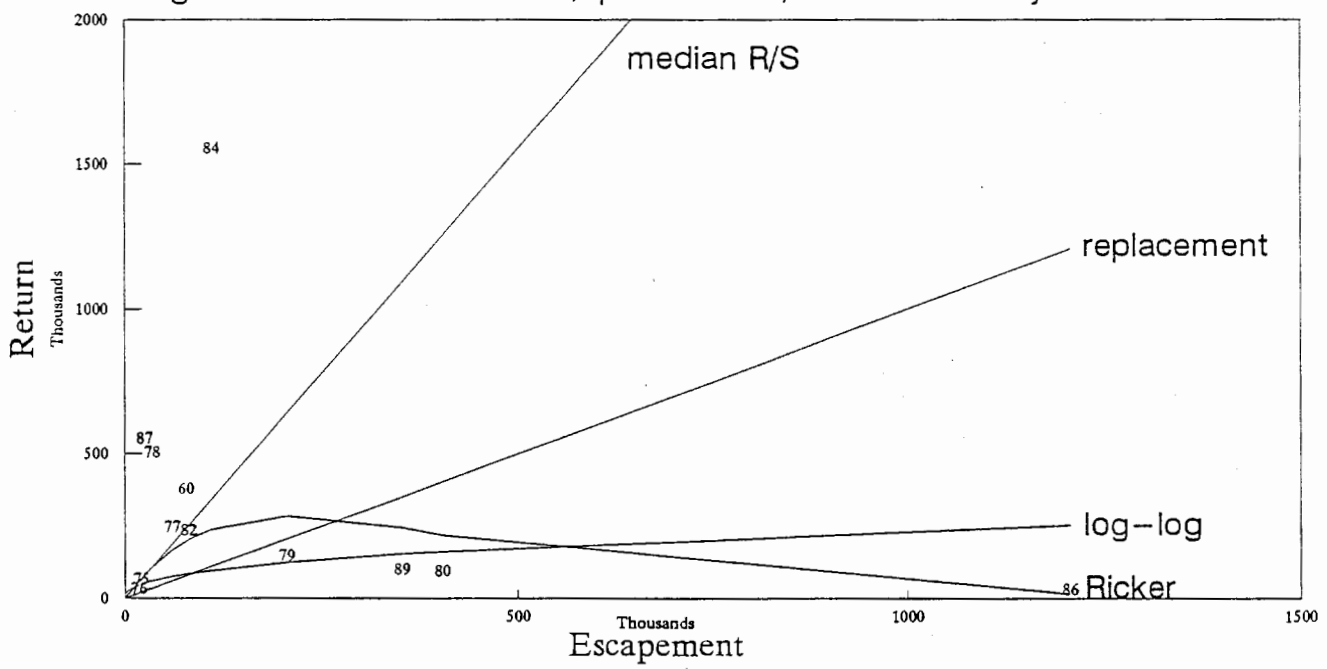

Figure 12. Pink salmon escapement, return, predicted return from Ricker curve, log–log regression and median return/spawner ratio, Bruin Bay.

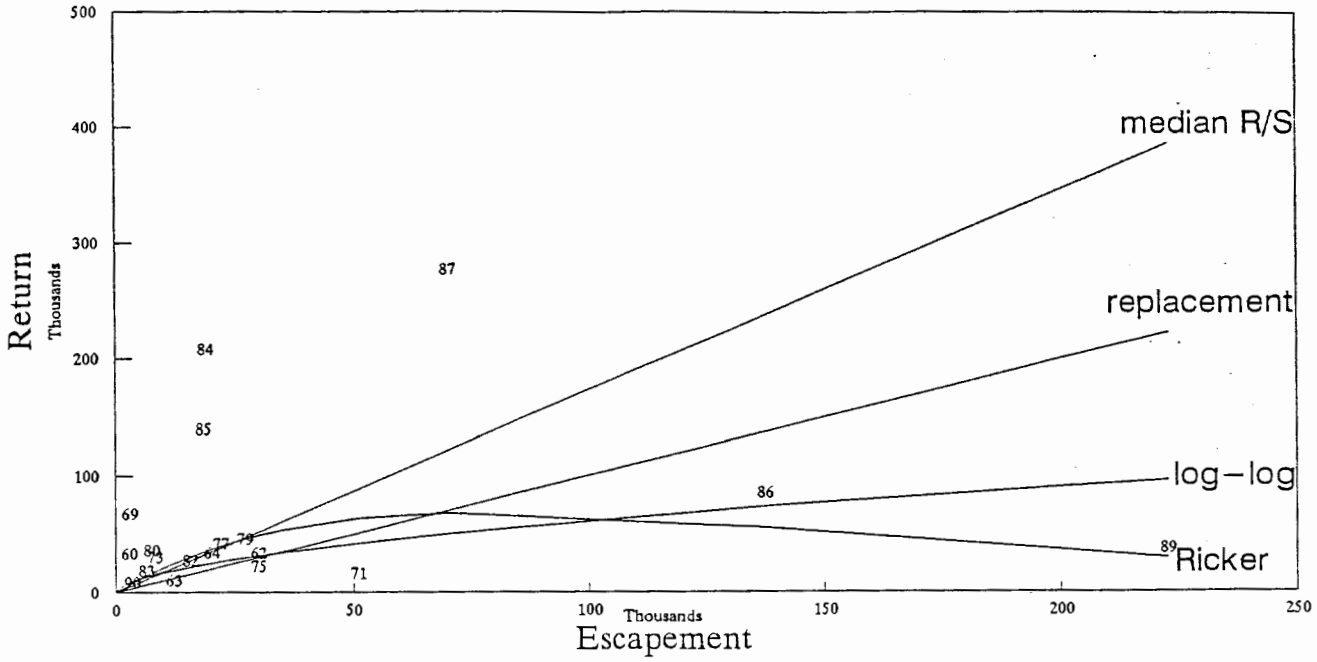

Figure 13. Pink salmon escapement, return, predicted return from Ricker curve, log−log regression and median return/spawner ratio, Ursus and Rocky Coves.

APPENDIX

Appendix A. 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	

Appendix B. 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	

Appendix C. 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	

Appendix D. 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	

[a] only years with both catch and escapement data

Appendix E. 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	

Appendix F. 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	

Appendix G. 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	

Appendix H. 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	

[a] only years with both catch and escapement data

Appendix I. 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	

[a] only years with both catch and escapement data

Appendix J. 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	

[a] only years with both catch and escapement data

Appendix K. 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	

[a] only years with both catch and escapement data

Appendix L. Lower Cook Inlet pink salmon forecast FORTRAN source code.

```
$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) LIKELIHOOD FUNCTION BASED ON REGRESSION OF RUN ON FORECAST
C.....L(R|F)= exp-(ERROR SQUARED)/2 SIGMA SQUARED
C.....FROM FRIED AND HILBORN (NEED TO BE TESTED AND DEBUGGED)
C
C.....(2) FORECAST PINK RETURNS FROM FRY INDEX
C
C.....(3) 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),TYPE(3)
      CHARACTER*21 LNAME(11)
      CHARACTER*10 REMARK(3)
```



```
C     CHARACTER*1 CLIMATE
C     DIMENSION TEM(12),TEMP(40)
      DIMENSION FREQ(10),ACCUM(10),BEG(10),END(10)
      DIMENSION POST(3),PRIOR(3),TALLY(3)
C.....REGRESSION COEFFICIENT, Student's T
      DIMENSION B(2),T(40)
      INTEGER LCISAMP(40)
      REAL LCIFCST(40),LCIESC(40),LCIRTN(40),LFCST
      COMMON /R/A,B,R2,IDF,SE,F,NVR
      COMMON /C/RTN(40),S(40),FCST(40),FLO(40),HI(40),N,IYR(40)
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'/
      DATA REMARK /'R within F','R < F    ','R > F    '/
      DATA TYPE/'Ricker','ln-ln ','median'/

      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',/
     &,' (3) use all data regardless    ',\)
      READ(*,2200) ISKIP

      WRITE(*,1550)KYR2
 1550 FORMAT(/,' (1) reconstruct historical forecast ranges ',
     &'(est run time:  2hr)',
     &/,' (2) forecast range only for 19',I2,
     &' (est run time:  5 min)    ',\)
      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)

      LFCST=0
      DO 40 K=1,40
      LCIESC(K)=0
      LCIRTN(K)=0
      LCIFCST(K)=0
      LCISAMP(K)=0
   40 CONTINUE
      DO 900 L=1,11
      CLOSE(4)
      OPEN(4,FILE=NAME(L),STATUS='OLD',ERR=50)
      WRITE(*,2356) NAME(L),LNAME(L)
 2356 FORMAT(A30,1X,A21/)
      WRITE(2,2357) NAME(L),LNAME(L)
 2357 FORMAT(//' ',A6,1X,A21,73('-')/)
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
C.....SKIP OUTLIER IF REQUESTED (OPTION 1,2)
      IF(ISKIP.LE.2.AND.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 REQUESTED (OPTION 2)
      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 WRITE(2,2620)
 2620 FORMAT(/,' Historical reconstruction from cross-validation',
     &' Ricker curve, log-log regression, or median return/spawner')

      WRITE(2,2700)
 2700 FORMAT(/' YR   model  intercept  reg coef   r2      F       R/S',
     & '     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. 1962-1992 (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 1963-1992 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
      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,AVG)
      COUNT=N-1
      SD=SQRT(SS/COUNT)

C.....IN THE SECOND CROSS-VALIDATION
C.....RECONSTRUCT FORECAST (E.G. 1962) AS WELL AS FUTURE FORECAST (E.G. 1993)
C.....THIS TIME, THE FORECAST ERROR IS FOR PRINTOUT ONLY
C.....IN THE SECOND CROSS-VALIDATION, IT IS NOT USED FOR STD. DEV
  310 CALL CV(MODEL,IYR(K),2,K,SKIP,PRED,SE,AVG)
      FCST(K)=PRED
C.....USE SD FROM FIRST CROSS-VALIDATION FOR 80% CONFIDENCE LIMITS (BY HARVEST AR
EA)
      JDF=IDF+1
      IF(MODEL.EQ.3) GOTO 335
      IF(MODEL.EQ.2) GOTO 330
      IF(MODEL.EQ.1) GOTO 328
      STOP
C.....RICKER MODEL
```

```
  328 RS=FCST(K)/S(K)
      FLO(K)=EXP(LOG(RS)-T(JDF)*SD)*S(K)
      HI(K)= EXP(LOG(RS)+T(JDF)*SD)*S(K)
      GO TO 340
C.....LOG-LOG   (SOKAL AND ROHLF P 384)
  330 FLO(K)=EXP(LOG(FCST(K))-T(JDF)*SD)
      HI(K)= EXP(LOG(FCST(K))+T(JDF)*SD)
      GO TO 340
C.....MEDIAN
  335 FLO(K)=FCST(K)-T(JDF)*SD
      HI(K)=FCST(K)+T(JDF)*SD

  340 IF(RTN(K).GE.FLO(K).AND.RTN(K).LE.HI(K))IFR=1
      IF(RTN(K).LT.FLO(K))IFR=2
      IF(RTN(K).GT.HI(K))IFR=3
C.....WRITE OUTPUT
  345 IYR2=IYR(K)+2
      IF(K.EQ.N1) GO TO 350
      PCTERR=((FCST(K)-RTN(K))/RTN(K))*100

C.....PRINTOUT WHEN REGRESSION MODEL USED
      IF(MODEL.NE.3.AND.IRG.EQ.1)WRITE(2,5700)IYR2,TYPE(MODEL)
     &,A,B(1),R2,F,
     &S(K),RTN(K),FCST(K),PCTERR,FLO(K),HI(K),SD,REMARK(IFR)
 5700 FORMAT(' ',I3,1X,A6,1X,2F10.5,F5.3,F7.2,10X,
     &F9.1,F10.1,F9.1,F10.3,F9.1,F10.1,F7.3,1X,A10)
      IF(MODEL.NE.3.AND.IRG.EQ.2)WRITE(2,5700)IYR2,TYPE(MODEL)
     &,A,B(1),R2,F,S(K),RTN(K),FCST(K),PCTERR

C.....PRINTOUT WHEN MEDIAN RETURN/SPAWNER USED
      IF(MODEL.EQ.3.AND.IRG.EQ.1)WRITE(2,5710)IYR2,TYPE(MODEL),AVG,
     &S(K),RTN(K),FCST(K),PCTERR,FLO(K),HI(K),SD,REMARK(IFR)
 5710 FORMAT(' ',I3,1X,A6,1X,32X,F10.3,
     &F9.1,F10.1,F9.1,F10.3,F9.1,F10.1,F7.3,1X,A10)
      IF(MODEL.EQ.3.AND.IRG.EQ.2)WRITE(2,5710)IYR2,TYPE(MODEL),AVG,
     &S(K),RTN(K),FCST(K),PCTERR

      SUM=SUM+PCTERR
      ASUM=ASUM+ABS(PCTERR)
      GO TO 390
  350 WRITE(2,5730)
 5730 FORMAT(/,'FUTURE FORECAST')
C.....SUMMARIZE % ERRORS AND STATISTICS FOR CROSS VALIDATION STD DEV
      COUNT=N
      AAVG=ASUM/COUNT
      AVER=SUM/COUNT
      WRITE(2,5750) AVER,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)

C.....PRINTOUT WHEN REGRESSION MODEL USED
      IF(MODEL.NE.3)WRITE(2,5800)IYR2,TYPE(MODEL),A,B(1),R2,F,ESAV,
     &FCST(K),FLO(K),HI(K),SD
 5800 FORMAT(/' ',I3,1X,A6,1X,2F10.5,F5.3,F7.2,10X,F9.1,10X,F9.1
     &,10X,F9.1,F10.1,F7.3)

C.....PRINTOUT WHEN MEDIAN RETURN/SPAWNER USED
      IF(MODEL.EQ.3)WRITE(2,5850)IYR2,TYPE(MODEL),AVG,
     &S(K),FCST(K),FLO(K),HI(K),SD
 5850 FORMAT(' ',I3,1X,A6,1X,32X,F10.3,
     &F9.1,10X,F9.1,10X,F9.1,F10.1,F7.3)
```



```
C.....ACCUMULATE FUTURE FORECAST FOR LOWER COOK INLET TOTAL
      LFCST=LFCST+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
      LCIESC(KK)=LCIESC(KK)+S(K)
      LCIRTN(KK)=LCIRTN(KK)+RTN(K)
      LCIFCST(KK)=LCIFCST(KK)+PRED
      LCISAMP(KK)=LCISAMP(KK)+1

  400 CONTINUE

C.....DEFINE INTERVALS FOR HYPOTHESIS
C.....J=1: BELOW FORECAST RANGE
C.....J=2: WITHIN FORECAST RANGE
C.....J=3: ABOVE FORECAST RANGE
      BEG(1)=0
      END(1)=FLO(N1)
      BEG(2)=FLO(N1)
      END(2)=HI(N1)
      BEG(3)=HI(N1)
      END(3)=99999999

      DO 512 J=1,3
      FREQ(J)=0
      ACCUM(J)=0
      PRIOR(J)=0
  512 CONTINUE

C.....FIND FREQUENCY DISTRIBUTION OF RUNS
C.....J=1: BELOW FORECAST RANGE
C.....J=2: WITHIN FORECAST RANGE
C.....J=3: ABOVE FORECAST RANGE
      DO 515 I=1,N
C.....SORT RETURNS
      DO 514 J=1,3
      IF(RTN(I).GE.BEG(J).AND.RTN(I).LT.END(J)) GO TO 513
      GO TO 514
C.....ACCUMULATE FOR PRIOR PROBABILITY ACCORDING TO RUN SIZE
  513 PRIOR(J)=PRIOR(J)+1
  514 CONTINUE
  515 CONTINUE
      SUM=N
      DO 516 J=1,3
      PRIOR(J)=PRIOR(J)/SUM
  516 CONTINUE

C.....FIND SAMPLE FRACTION OR RUNS WITHIN FORECAST RANGE
C.....J=1: BELOW FORECAST RANGE
C.....J=2: WITHIN FORECAST RANGE
C.....J=3: ABOVE FORECAST RANGE
      DO 615 J=1,3
      TALLY(J)=0
      POST(J)=0
      DO 614 I=1,N
C.....SORT RUNS ACCORDING TO HYPOTHESIS
      IF(RTN(I).GE.BEG(J).AND.RTN(I).LT.END(J)) GO TO 613
      GO TO 614
C.....SEE IF RUN WITHIN CROSS VALIDATED FORECAST RANGE
  613 TALLY(J)=TALLY(J)+1
      IF(RTN(I).GE.FLO(I).AND.RTN(I).LE.HI(I)) POST(J)=POST(J)+1
  614 CONTINUE
      IF(TALLY(J).GT.0)POST(J)=POST(J)/TALLY(J)
```

```
  615 CONTINUE

C.....SUMMARIZE OBSERVED FRACTIONS REGARDING
C.....FORECAST BEING CORRECT AND
C.....RUN SIZE OCCURING
      WRITE(2,7300)
 7300 FORMAT(/'                          fraction of            '/
     &'                     forecast that      historical runs'/
     &'-range of run sizes-     were correct    n within range')

      DO 850 J=1,3
      ICNT=TALLY(J)
      WRITE(2,7400)BEG(J),END(J),POST(J),ICNT,PRIOR(J)
 7400 FORMAT(F10.1,F11.1,F16.3,I5,F9.3,F16.3)
  850 CONTINUE

  900 CONTINUE
C.....LOWER COOK INLET TOTAL
C.....FIND ANNUAL LCI TOTAL FORECAST ERROR SQUARED
C.....methods for 80% confidence interval same for Ricker and ln-ln model
C.....ln(forecast/spawner)-ln(return/spanwer) = ln(forecast)-ln(return)
C.....because division by a constant, i.e. spawner
C.....therefore no adjustments to the following section
C.....unless median R/S is used
      SS=0
      N=0
      WRITE(2,7410)
 7410 FORMAT(//'LOWER COOK INLET TOTAL'/
     &'        escapement       return    forecast      n')
      DO 920 K=1,40
      IF(LCIRTN(K).EQ.0) GOTO 920
      SS=SS+(LOG(LCIFCST(K))-LOG(LCIRTN(K)))**2
      WRITE(2,7420) K,LCIESC(K),LCIRTN(K),LCIFCST(K),LCISAMP(K)
 7420 FORMAT('  ',I6,3F12.0,I6)
      N=N+1
  920 CONTINUE
C.....FIND CROSS VALIDATION S.D.
      DF=N-1
      SD=SQRT(SS/DF)
      LDF=DF
C.....FIND 80% CONFINDENCE INTERVAL
      IF(MODEL.EQ.3) GOTO 935
      IF(MODEL.EQ.1) GOTO 928
      IF(MODEL.EQ.2) GOTO 930
C.....RICKER
  928 RS=LOG(LFCST/LCIESC(N1))
      FLO(40)=EXP(RS-T(LDF)*SD)*LCIESC(N1)
      HI(40)= EXP(RS+T(LDF)*SD)*LCIESC(N1)
      GO TO 940
C.....LOG-LOG
  930 FLO(40)=EXP(LOG(LFCST)-T(LDF)*SD)
      HI(40)= EXP(LOG(LFCST)+T(LDF)*SD)
      GO TO 940
C.....MEDIAN
  935 FLO(40)=LFCST-T(LDF)*SD
      HI(40)=LFCST+T(LDF)*SD
  940 WRITE(2,7500)IYR2,LCIESC(N1),LFCST,FLO(40),HI(40),SD
 7500 FORMAT(/' ',I3,' Lower Cook Inlet Total        ',12X,F9.0,10X,F9.1
     &,30X,F9.0,F10.0,F7.3)
      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
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```
      SUBROUTINE SUBMR(NOBS,X,Y,Z,SYHAT,SIGNIF)
      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
C.....FVALUES (p=0.75) d.f.= 1,(1 to 50)
      DIMENSION FVAL(50)
      COMMON /R/A,B,R2,IDF,SE,F,NVR
      DATA FVAL/5.83,2.57,2.02,1.81,1.69,1.62,1.57,1.54,1.51,1.49,1.47
     &,1.46,1.45,1.44,1.43,1.42,1.42,1.41,1.41,1.40,1.40,1.40,1.39
     &,1.39,1.39,1.38,1.38,1.38,1.38,1.38,1.38,1.37,1.37,1.37,1.37
     &,1.37,1.37,1.37,1.37,1.36,1.36,1.36,1.36,1.36,1.36,1.36,1.36
     &,1.36,1.36,1.36/

      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)
      SIGNIF=0
      IF(F.GE.FVAL(IDF))GO TO 290
      SIGNIF=1
      RETURN
  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,AVG)
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
C.....START WITH RICKER MODEL, IF NOT SIGNIFICANT, THEN
C.....TRY LOG-LOG MODEL, IF NOT SIGNIFICANT, THEN USE MEDIAN R/S
      IMPLICIT DOUBLE PRECISION (A-H)
      IMPLICIT DOUBLE PRECISION (O-Z)
      DIMENSION B(2),X(40,2),Y(40)
      COMMON /R/A,B,R2,IDF,SE,F,NVR
      COMMON /C/RTN(40),S(40),FCST(40),FLO(40),HI(40),N,IYR(40)

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.....START WITH RICKER MODEL
C.....LOOP TO ASSIGN DATA TO X AND Y ARRAYS
      NOBS=0
      DO 100 J=1,N
C.....ALWAYS EXCLUDE YEAR BEING FORECAST FROM DATA SET
      IF(IYR(J).EQ.IFY) GO TO 100
C.....EXCLUDE YEAR BEING BEING DROPPED OUT IN CROSS VALIDATION
C.....THIS IS THE SAME AS THE YEAR BEING FORECAST WHEN ISW=2
      IF(J.EQ.L) GO TO 100
      NOBS=NOBS+1

      Y(NOBS)=LOG(RTN(J)/S(J))
      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)
  100 CONTINUE

C.....FIT REGRESSION MODEL FOR RICKER MODEL
      Z=S(L)
      NVR=1
C     IF(CLIMATE.EQ.'Y')NVR=2
      CALL SUBMR(NOBS,X,Y,Z,SYHAT,SIGNIF)
      SIGNIFSAV=SIGNIF
      ASAV=A
      BSAV=B(1)
      R2SAV=R2
      IDFSAV=IDF
      SESAV=SE
      FSAV=F
      NVRSAV=NVR

C.....NEXT, TRY LOG-LOG
C.....LOOP TO ASSIGN DATA TO X AND Y ARRAYS
      NOBS=0
      DO 110 J=1,N
C.....ALWAYS EXCLUDE YEAR BEING FORECAST FROM DATA SET
      IF(IYR(J).EQ.IFY) GO TO 110
C.....EXCLUDE YEAR BEING BEING DROPPED OUT IN CROSS VALIDATION
C.....THIS IS THE SAME AS THE YEAR BEING FORECAST WHEN ISW=2
      IF(J.EQ.L) GO TO 110
      NOBS=NOBS+1
      Y(NOBS)=LOG(RTN(J))
      X(NOBS,1)=LOG(S(J))
C     IF(CLIMATE.EQ.'Y')X(NOBS,2)=TEMP(J)
  110 CONTINUE

C.....FIT REGRESSION MODEL TO LN-LN MODEL
      Z=LOG(S(L))
      NVR=1
C     IF(CLIMATE.EQ.'Y')NVR=2
      CALL SUBMR(NOBS,X,Y,Z,SYHAT,SIGNIF)

C.....IF RICKER AND LN-LN BOTH NOT SIGNIFICANT
      IF(SIGNIFSAV.EQ.1.AND.SIGNIF.EQ.1) GO TO 204
C.....IF RICKER NOT SIGNIFICANT BUT LN-LN IS SIGNIFICANT
      IF(SIGNIFSAV.EQ.1.AND.SIGNIF.EQ.0) GO TO 140
```



```
C.....IF RICKER IS SIGNIFICANT BUT LN-LN NOT SIGNIFICANT
      IF(SIGNIFSAV.EQ.0.AND.SIGNIF.EQ.1) GO TO 150
C.....IF BOTH SIGNIFICANT, SELECT GREATER F RATIO
      IF(FSAV.GE.F) GOTO 150
C.....LN-LN HAS GREATER F-RATIO OR
C.....IF RICKER NOT SIGNIFICANT BUT LN-LN IS SIGNIFICANT
  140 MODEL=2
      GO TO 210
C.....RICKER HAS GREATER F-RATIO OR
C.....1F RICKER SIGNIFICANT BUT LN-LN NOT SIGNIFICANT
  150 MODEL=1
      SIGNIF=SIGNIFSAV
      A=ASAV
      B(1)=BSAV
      R2=R2SAV
      IDF=IDFSAV
      SE=SESAV
      F=FSAV
      NVR=NVRSAV
      GO TO 210

C.....USE MEDIAN R/S IF BOTH RICKER AND LN-LN NOT SIGNIFICANT
  204 MODEL=3
      NOBS=0
      DO 205 J=1,N
C.....ALWAYS EXCLUDE YEAR BEING FORECAST FROM DATA SET
      IF(IYR(J).EQ.IFY) GO TO 205
C.....EXCLUDE YEAR BEING BEING DROPPED OUT IN CROSS VALIDATION
C.....THIS IS THE SAME AS THE YEAR BEING FORECAST WHEN ISW=2
      IF(J.EQ.L) GO TO 205
      NOBS=NOBS+1
      Y(NOBS)=RTN(J)/S(J)
  205 CONTINUE
      CALL MEDIAN(Y,NOBS,AVG)

C.....REGRESSION FORECAST FOR YEAR WITH DATA REMOVED
C     IF(CLIMATE.NE.'Y') GO TO 210
C     IF(MODEL.EQ.1)PRED=A+B(1)*S(L)+B(2)*TEMP(L)
C     IF(MODEL.EQ.2)PRED=EXP(A+B(1)*LOG(S(L))+B(2)*TEMP(L))
C     IF(MODEL.EQ.3)PRED=EXP(A+B(1)*S(L)+B(2)*TSAV)*S(L)
C     GO TO 215
  210 IF(MODEL.EQ.3)PRED=S(L)*AVG
      IF(MODEL.EQ.1)PRED=EXP(A+B(1)*S(L))*S(L)
      IF(MODEL.EQ.2)PRED=EXP(A+B(1)*LOG(S(L)))

C.....COMPUTE ERROR FOR CROSS VALIDATED YEARS
C.....DON'T COMPUTE ERROR FOR YEAR ULTIMATELY BEING FORECAST
  215 IF(LCODE.GT.N) RETURN
      IF(MODEL.EQ.3)E=PRED-RTN(L)
      IF(MODEL.EQ.1)E=(A+B(1)*S(L))-LOG(RTN(L)/S(L))
      IF(MODEL.EQ.2)E=LOG(PRED)-LOG(RTN(L))
  222 IF(ISW.EQ.2)GO TO 225
C.....ACCUM FORECAST ERRORS FOR CROSS VALIDATED STD. DEV.
      SS=SS+E**2
  225 CONTINUE

      RETURN
      END
      SUBROUTINE MEDIAN(X,N,AVG)
C     CALCULATE MEDIAN VALUES
      IMPLICIT DOUBLE PRECISION (A-H)
      IMPLICIT DOUBLE PRECISION (O-Z)
      DIMENSION X(40)
C     SORT DATA
      DO 100 I=1,N-1
      DO 100 J=I+1,N
```

```
      IF(X(I).LT.X(J))GO TO 100
      TEMP=X(I)
      X(I)=X(J)
      X(J)=TEMP
  100 CONTINUE
C     FIND MEDIAN
      FN=N
      TEMP=FN/2
      ITEMP=TEMP
      FTEMP=ITEMP
      HALF=TEMP-FTEMP
      IF(HALF.EQ.0) GO TO 200
      MED=ITEMP+1
      AVG=X(MED)
      RETURN
  200 I1=ITEMP+1
      AVG=(X(ITEMP)+X(I1))/2
      RETURN
      END
```