Fisheries and Oceans Science
Pêches et Océans Sciences

C S A S

Canadian Stock Assessment Secretariat

S C É S

Secrétariat canadien pour l'évaluation des stocks

Research Document 2000/107

Not to be cited without
permission of the authors [1]

Document de recherche 2000/107

Ne pas citer sans
autorisation des auteurs [1]

Pre-season run size forecasts for Fraser River sockeye in 2000

A. Cass

Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, B.C. V9R 5K6

ISSN 1480-4883
Ottawa, 2000

Abstract

Adult returns of sockeye to the Fraser River on the 2000 cycle line are the lowest of the four cycle lines averaging 4.5 million sockeye compared to an all-year mean of 9.4 million during 1970-99. The major stocks expected in 2000 based on brood year escapement estimates for 1996 are Chilko, Stellako, Early Stuart, Late Stuart, Birkenhead, and Weaver sockeye. Forecasts are made for each of four migratory timing groups and 19 individual stocks. Forecasting methods are unchanged from previous PSARC reviews and are based on a variety of explanatory variables and forecast models. The 2000 forecast, all stocks combined, at the 50% probability level (point estimate) is 4.1 million sockeye or near the long-term mean (1970-1996). At the 75% probability level the forecast is 2.3 million fish. The summer run group accounts for 65% of the forecast. Within that timing group, Chilko and Stellako sockeye respectively account for 33% and 16% of the forecast at the 50% probability level. A cautionary prognosis for 2000 returns is warranted. Estimates of jack returns in 1999 (2000 age-4 returns) to several of the major stocks on the cycle line were very low compared to brood year escapements and compared to jack returns on the previous year in this cycle. Temperatures in the north Pacific Ocean in the spring of 1998 were above average during the transition from intense El Nino conditions in 1997 to cooler La Nina conditions in the latter half of 1998. Ocean survival of sockeye that went to sea in 1997 was very low. The carry-over effect of above average temperatures in the spring of 1998 on juvenile sockeye survival for the 1996 brood (2000 age-4 returns) is unknown. Qualitative information reported in this document indicate that run sizes may be less than the 50% probability level.

Résumé

Les remontées des saumons rouges adultes dans le fleuve Fraser pendant le cycle de 2000 sont les plus faibles des quatre années du cycle, s'établissant en moyenne à 4,5 millions de saumons rouges comparativement à une moyenne combinée de 9,4 millions durant 1970-1999. D'après les estimations de l'échappée de la progéniture de 1996, les principaux stocks prévus en 2000 sont constitués de Chilko, Stellako, Late Stuart, Early Stuart, Birkenhead et de Weaver. Des prévisions sont faites pour chacun des groupes pendant quatre moments de migration et pour 19 stocks individuels. Les méthodes pour établir les prévisions sont les mêmes que dans les examens antérieurs du Comité d'examen de l'évaluation des stocks du Pacifique et sont basées sur une diversité de variables explicatives et de modèles de prévision. Les prévisions de 2000, tous stocks confondus, à un niveau de probabilité de 50 % (estimation ponctuelle) sont de 4,1 millions de saumons rouges ou près de la moyenne à long terme (1970-1996). Au niveau de probabilité de 75 %, les prévisions sont de 2,3 millions de poissons. La remontée estivale compte pour 65 % des prévisions. Dans ce groupe, les saumons rouges de la Chilko et de la Stellako représentent respectivement 33 et 16 % des prévisions au niveau de probabilité de 50 %. Un pronostic prudent pour les retours de 2000 est justifié. Les estimations des retours des jeunes mâles matures en 1999 (retours des saumons de 4 ans en 2000) vers plusieurs des principaux stocks du cycle étaient très faibles comparativement à l'échappée de la progéniture et aux retours des saumons mâles matures l'année précédente du cycle. Les températures dans l'océan Pacifique nord au printemps de 1998 étaient supérieures à la moyenne pendant la transition des conditions intenses dues à El Nino en 1997 aux conditions plus fraîches de La Nina dans la dernière moitié de 1998. Très peu de saumons rouges qui sont allés à la mer en 1997 ont survécu dans l'océan. L'effet de report des températures supérieures à la moyenne au printemps de 1998 sur la survie des saumons rouges juvéniles de la ponte de 1996 (retours des saumons de 4 ans en 2000) n'est pas connu. D'après l'information qualitative contenue dans ce document, l'effectif de la remontée peut être inférieur au niveau de probabilité de 50 %.

Table of Contents

1.0 Introduction........ 4
2.0 Methods 4
2.1 Forecast models........ 5
3.0 Model Performance........ 7
4.0 Forecasts and uncertainty 8
5.0 Conclusion........ 9
6.0 References........ 10

1.0 Introduction

Adult returns of sockeye to the Fraser River on the 2000 cycle line are the lowest of the four cycle lines averaging 4.5 million sockeye compared to an all-year mean of 9.4 million during 1970-99. The major stocks expected in 2000 based on brood year escapement estimates for 1996 are Chilko (974,000 spawners), Stellako (333, 000 spawners), Early Stuart (88,000 spawners), Late Stuart (63,000 spawners), Birkenhead (56,000), and Weaver sockeye (54,000 spawners).

Forecasts are made for each of four migratory timing groups and 19 individual sockeye stocks. The spawning escapement for these stocks accounted for 96% of the estimated total Fraser River escapement in 1996. Forecasts are not provided for a number of small stocks for which data quality is poor. These include Tesako, Momich/Cayenne, Nahatlatch, Harrison and Widgeon Slough sockeye.

Forecasts of adult returns are made using a variety of explanatory variables. For most stocks, forecasts are based on regression models that use spawning escapement to predict adult abundance of age-4 and age-5 sockeye. Additional explanatory variables are available for some stocks and include fry, smolt and sibling adult run size estimates. An environmental index has explained some variation in ocean survival of Chilko sockeye (Cass et al. 1995). I also evaluated methods that incorporate attributes of escapement-based and juvenile-based models by pooling results from individual forecast models where time series of different life stages are available.

Sibling models were not considered suitable candidate models for forecasting 2000 returns. Sibling models that use age-3 jacks to forecast age-4 returns have recently performed poorly compared to other models. The proportion of age-3 jack returns have undergone dramatic long-term declines that can not be explained by changes in abundance or growth rates (Cass 1998). The use of sibling models to forecast 2000 returns is particularly suspect because of the discrepancy between in-season Mission acoustic estimates and preliminary estimates based on escapement plus catch up-river of Mission in 1999. Fraser River discharge during the adult spawning migration reach record levels in 1999. The effect of this on jack mortality is unknown but potentially has resulted in a negatively biased estimate of jack returns. Without reliable estimates of age-3 jacks, sibling models are not useful for predicting 2000 age-4 sockeye returns.

2.0 Methods

Data sources and methods have been extensively reviewed by PSARC (Cass 1999; Cass 1998; Cass 1997; Cass and Blackbourn 1996; Cass et al. 1995; Welch et al. 1994). The data used to forecast Chilko sockeye are listed in Appendix Table 1. Methods used to forecast 2000 returns are unchanged from Cass (1999). Estimates of returns in 1997-99 are very preliminary. Adult sockeye were exposed to high river discharge levels in both 1997 and 1999 during in-river migration. Large, positive differences in returns estimated at Mission in the lower river and the estimates from spawning grounds plus up-river catch occurred in those years. Large positive differences also occurred in 1998, particularly in the Early Stuart run, when temperature was abnormally high. We may never know how much of the difference was due to adverse conditions or to estimation error. For present purposes, the returns in 1997-99 assume the “missing” fish existed and, therefore, the return data include the “missing” fraction of fish.

Except for sub-stocks of early Stuart sockeye, escapements are estimates of "effective females". Effective females are estimates of the number of spawning females contributing to the spawning population each year weighted by egg deposition. The stock-specific catch component of run size (run size = catch + escapement) is estimated by the Pacific Salmon Commission (PSC). A sub-stock of Early Stuart sockeye was analysed separately that excludes the highly cyclic Driftwood River population. The abundance of sockeye that spawn in the Driftwood system is negligible on the 2000 cycle line. Data for the non-Driftwood component were estimated by apportioning the total Early Stuart catch estimates according to the corresponding escapement for the non-Driftwood and Driftwood systems. The data used to forecast the non-Driftwood component Early Stuart sockeye consists of total adult escapements (1959-96) and adult returns (1963-99).

2.1 Forecast models

Forecast models used in the present analysis are as follows:

1) Ricker function with log-normal errors and uncorrected for bias (fit to the mode not the mean returns):

$$R_{it} = \alpha S_{t-1} e^{-\beta S_{t-1}} * e^{\sigma \varepsilon_t} \qquad (1)$$

estimated using the linear regression :

$$\ln(R_{it}/S_{t-1}) = \ln(\alpha) - \beta S_{t-1} + \sigma\varepsilon_t .$$

Here the returns ($R_{i,t}$) at age i in generation t is related to the spawning escapement in generation t-1. Parameters α and β are the density independent and dependent parameters, σ is the standard deviation of the residuals and ε_t is a standard normal deviate for generation t.

2) Non-linear (power) model :

$$R_{it} = \beta_0 S_{t-1}{}^{\beta_1} * e^{\sigma\varepsilon_t} \qquad (2)$$

estimated by:

$$\ln(R_{it}) = \beta_0 + \beta_1 \ln(S_{t-1}) + \sigma\varepsilon_t .$$

3) Geometric mean (GM) return-per-spawner model:

$$R_{it} = S_t \left[\frac{GM(R_{i1} \ldots R_{it-1})}{GM(S_1 \ldots S_{t-1})} \right] \qquad (3)$$

4) Juvenile model:

For Chilko, Quesnel, Shuswap, Nadina, Gates and Weaver sockeye a non-linear power model of the form:

$$\ln(R_{it} = \boldsymbol{b}_0 + \boldsymbol{b}_1 \ln(N_t) + \boldsymbol{se}_t , \qquad (4)$$

was fit to adult returns at age i and juvenile data N at generation t. In addition, the forecast performance of escapement (log transformed) when added as a second explanatory variable in a multiple regression was also assessed. For Chilko sockeye additional environmental variables were added to represent precipitation rates and ocean salinity in the smolt year that were shown to explain part of the variation in age-4 Chilko returns in previous forecasts (Cass, 1998). The precipitation data is the average total monthly precipitation in two months (September and October) of the ocean-entry year from two stations: Langara Island, in north-western British Columbia, and Annette Island in southern southeast Alaska. Langara Island precipitation data is published in monthly climate summaries published by the Atmospheric Environment Service of Environment Canada. Precipitation data from Annette are obtained from “Annual Summaries of Climatological Data for the State of Alaska” published by the U.S. National Environmental Satellite, Data and Information Service and obtained from the National Climatic Data Center (NCDC), Asheville, North Carolina. The salinity data are the mean May-June estimates measured at Entrance Island in the ocean-entry year.

5) Sibling model:

Sibling regressions for forecasting age-5 returns from sibling age-4 returns are of the forms:

$$\ln(R_{i+1,t+1}) = \boldsymbol{b}_0 + \boldsymbol{b}_1 \ln(R_{it}) + \boldsymbol{se}_t . \qquad (6)$$

For reasons discussed, sibling models that use age-3 jacks to forecast 2000 age-4 returns are not considered reliable. For stocks with sufficient data, age-4 females standard length was added as a second explanatory variable to eq. 6 for forecasting age-5 sockeye.

A method that combines forecasts from models with independent biological explanatory variables (i.e. escapement and fry), hereafter termed the pooled model, was also considered in this analysis. Methods for combining forecasts are based on weighting schemes that weight using some measure of forecast error (McLeod et al. 1987; Noakes et al. 1990). I assume that forecasts from models that use different life stages are independent. Weights were assigned using the inverse of the forecast prediction variance (Fried and Yuen 1987):

$$\ln(F) = \sum_{m=1}^{n} \left[\ln(F_m)/V_m\right] / \sum_{m=1}^{n} 1/V_m \ , \tag{7}$$

where F is the weighted mean forecast for n separate forecasts, F_m is the model-specific forecast and V_m is the model-specific variance ($\log_e$ of the forecast). For independent explanatory variables the pooled variance V_p is valid where:

$$V_p = 1/\sum_{m=1}^{n} 1/V_m \ . \tag{8}$$

3.0 Model Performance

Model performance was evaluated in a retrospective analysis by comparing run size forecasts to estimated (observed) run sizes for years that estimates are available. Starting with the most recent year that estimated returns are available (1999), a retrospective forecast for that year was made from the time series of explanatory variables by leaving out the most recent return data. In this way, retrospective forecasts for each year are based only on the time series available prior to the year being forecast. Retrospective comparisons were made for brood years 1980-95. The retrospective comparison for age-4 Chilko sockeye by model, including the historical performance of the age-4 versus age-3 (jack) sibling model is shown in Figure 1. Note that the scale in Figure 1 is in the log domain so that the true uncertainty, to a large extent, is masked. Model results depicted in Figure 1 show that the 90% confidence intervals of the forecasts in many years do not overlap the 1:1 line. In other words, the models are poor representations of the natural processes that control survival particularly in years of no overlap of the confidence intervals with the 1:1 line.

Forecast errors were quantified using the root mean square error (RMSE) criteria. The model with the lowest RMSE was judged to be the ‘best’ forecast. If the RMSE criteria failed to differentiate among competing models then the model with the smallest variance was selected. For each stock, the variance of the prediction was computed using standard methods (Snedecor and Cochran 1967; eq. 6.12.1). The combined variances for age-4 plus age-5 sockeye by stock were computed as the sum of the weighted variances (weighted by the age-specific forecasts).

A retrospective analysis was not possible for the Upper Adams stock. Only one forecast model was considered for sockeye returning to the Upper Adams spawning area. Estimates of spawners to the Upper Adams were 25,000 in 1996. This exceeds recent historical estimates by eight fold as a result of stock recovery on this cycle. Because the escapement in 1996 are well beyond levels record for this stock, a simple recruit-per-spawner model was applied that used the mean recruits-per-spawner for all Fraser stocks to forecast a point estimate of returns to the Upper Adams in 2000.

4.0 Forecasts and uncertainty

Annual differences between estimated returns and forecast returns (point estimate) during 1990-99 were large (Fig. 2). The mean absolute deviation was ± 58% for all timing groups combined. The error for individual timing groups was of similar magnitude: ±49% for Early Stuart, ±48% for Early Summers, ±72% for Summer and ±60% for late runs. Forecast errors in 1999 were particularly large and difficult to evaluate because of the "missing" fish issue (Table 1). When missing fish are included in the comparison for 1999, the forecast was 85% more than the estimated run for Early Stuart, 36% more for Early Summer, 197% more for Summers, 134% more for Lates and 134% for all stocks combined. The deviation for 6 of the 18 stock comparisons were outside the 90% confidence intervals for the "best" forecast model in 1999. When missing fish are excluded from the analysis the forecast error is larger for each timing group and the estimated return in 1999 was outside the 90% confidence intervals in 13 of the 18 stock comparisons.

Forecasts for 2000 are provided as probability distributions by stock and run-timing group (Table 2). The probability distributions of the 2000 forecasts are large compared to the observed historical returns (Fig. 3) and again attests to large statistical uncertainty in the forecast. The 2000 forecast, all stocks combined, at the 50% probability level (point estimate) is 4.1 million sockeye or slightly less than the long-term mean (1970-1996). At the 75% probability level the forecast is 2.3 million fish. The abundance of highly cyclic stocks (Early Stuart, Late Stuart, Quesnel and Shuswap) that return on the 2000 cycle line are low compared to the dominant and sub-dominant years and together account for 23% of the forecast. The summer run group accounts for 65% of the forecast. Within that timing group, Chilko and Stellako sockeye respectively account for 33% and 16% of the forecast at the 50% probability level.

A cautionary prognosis for 2000 returns is warranted. Jack returns in 1999 (2000 age-4 returns) to several of the major stocks on the cycle line were estimates to be very low relative to brood year escapements. Sibling forecast models that incorporate jacks perform poorly because the proportion of sockeye that return as jacks has declined independent of age-4 returns from the brood. Nevertheless, the jack returns in 1999 were estimated to be low even when the decline in jack return rates is considered. The quality of the 1999 jack data, however, is suspect and may be biased low due to disproportionate mortality from high discharge rates. If in-river jack mortality was high then the presumption of low survival of the age-4 return in 2000 based on jacks is not justified.

Temperatures in the North Pacific Ocean in the spring of 1998 were above average during the transition from intense El Nino conditions in 1997 to cooler La Nina conditions in the latter half of 1998. Ocean survival of sockeye that went to sea in 1997 was very low. The carry-over effect of above average temperatures in the spring of 1998 on juvenile sockeye survival for the 1996 brood (2000 age-4 returns) is unknown. Survival of south coast stocks of pink and coho in ocean-entry-year 1998 for which ocean survival rates are estimated were very low. Age-4 sockeye returns in 2000 also entered the ocean in 1998. There is no evidence for correlated ocean survival trends among Fraser sockeye and other south coast salmon species. However, the trend in salmon production seen so far from ocean-entry-year 1998 in south coast regions is consistent with the hypothesis of generally unfavourable ocean conditions in 1998. Offshore indices of ocean productivity measured by nitrate concentrations were also low in 1998 (personal communication, Frank Witney, Institute of Ocean Sciences, Sidney, BC). The latter can only be viewed as qualitative since the nitrate data is not of sufficient quality to link directly to time series of sockeye survival data.

For Chilko sockeye, the low survival in return years 1995 and 1999 is associated with intense El Nino events but overall there is no longer-term trend in survival patterns (Fig. 4). In isolation from other information, these low survival years do not necessarily imply continued low survival of returns in 2000. It is difficult to quantify the effects of low sibling jack returns, low survival trends for other south coast salmon species, and low nitrate levels. They do, however, argue for precautionary management in 2000. If these indexes signal low sockeye survival then returns will likely be lower than the 50% probability level (Table 2).

5.0 Conclusion

Forecasts are associated with high uncertainty as shown in Table 2 and Figures 1-3. Although forecasts are presented as probability distributions, they are based on models that assume average survival conditions. Improvements to pre-season abundance forecasts are unlikely without a better understanding of environmental factors affecting survival. The large differences between forecasts and observed returns in 1995 and 1999 coincide with intense El Ninos in sea entry years 1993 and 1997. At least during the recent period of intense El Nino events, the discrepancies between forecasts and run size is related to poor Fraser sockeye ocean survival (Fig 4). The influence of the very intense 1997-98 El Nino on returns of age-4 sockeye in 2000 is unknown. Age-5 fish that went to sea in 1997 and return in 2000 are likely to be lower than expected based on ocean survival estimates. The high ocean temperature associated with the most recent El Nino dissipated in the spring of 1998. The effects on ocean survival of age-4 sockeye returning in 2000 is unknown but qualitative information reported in this document indicates that run sizes may be less than the 50% probability level.

6.0 References

Cass, A. 1999. Run size forecasts for Fraser River sockeye and pink salmon in 1999. Canadian Stock Assessment Secretariat Research Doc. 99/129.

Cass, A. 1998. Run size forecasts for Fraser River sockeye salmon in 1998. Canadian Stock Assessment Secretariat Research Doc. 98/44.

Cass, A. 1997. Updated Fraser River sockeye forecasts for 1997. Pacific Stock Assessment Review Committee Working Paper X97-1.

Cass, A. and D. Blackbourn. 1996. Forecasts of Fraser River sockeye salmon for return year 1996. Pacific Stock Assessment Review Committee Working Paper S96-1.

Cass, A.J., D. Blackbourn, and Hume J. 1995. Forecasts of Fraser River sockeye and pink salmon for return year 1995 and preliminary sockeye forecasts for 1996. Pacific Stock Assessment Review Committee Working Paper S94-20.

Fried, S.M. and H.J. Yuen. 1987. Forecasting sockeye salmon (*Oncorhynchus nerka*) returning to Bristol Bay, Alaska: a review and critique of methods. Canadian Special Publication of Fisheries and Aquatic Sciences 45:850-855.

McLeod, A. I, D.J. Noakes, K.W. Hipel; and R.M. Thompstone. 1987. Combining hydrologic forecasts. J. Water Resources Planning and Management. 113: 29-40.

Noakes, D. J., D. W. Welch, M. Henderson and E. Mansfield. 1990. A comparison of pre-season forecasting methods for returns of two British Columbia sockeye salmon stocks. N. Amer. J. Fish. Man. 10: 46-57.

Snedecor, G. W. and W. G. Cochran. 1967. Statistical methods 6th Edition. The Iowa State University Press, Ames, Iowa, U.S.A.

Welch D. W., H. M. C. Kelly and W. Saito. 1994. An assessment of recruitment forecast methods for Fraser River sockeye salmon with forecasts for 1994, 1995 and 1996. Pacific Stock Assessment Review Committee Working Paper S94-16

Table 1. Comparison of pre-season forecasts and observed stock sizes in 1999. Deviations outside the 90% confidence intervals are highlighted. Timing groups are shown in bold font. Run sizes and forecasts are in thousands of fish.

Stock/ Timing group	Method[d]	50% forecast	Run Size observed[a]		Forecast error[b]		Percent error		Probability of greater error[c]	
			IMF	EMF	IMF	EMF	IMF	EMF	IMF	EMF
Early Stuart	**Ricker**	**318**	**172**	**33**	**-146**	**-285**	**-84.9%**	**-863.6%**	**18.4%**	**<1%**
Early Summer		**477**	**350**	**130**	**-127**	**-347**	**-36.3%**	**-266.9%**	**31.1%**	**8.4%**
Fennell	Power	33	24	11	-9	-22	-37.5%	-200.0%	36.6%	11.9%
Bowron	Power	69	34	15	-35	-54	-102.9%	-360.0%	21.2%	4.2%
Raft	Power	6	49	19	43	13	87.8%	68.4%	98.4%	88.2%
Gates	Power	47	34	13	-13	-34	-38.2%	-261.5%	32.9%	4.0%
Nadina	Pooled	34	73	29	39	-5	53.4%	-17.2%	81.4%	42.6%
Pitt[e]	Power	40	41	0	-1	40	-2.4%		50.9%	
Seymour	Power	146	78	35	-68	-111	-87.2%	-317.1%	25.4%	6.6%
Scotch	RS	102	17	8	-85	-94	-500.0%	-1175.0%	4.1%	1.0%
Summers		**5328**	**1792**	**1690**	**-3536**	**-3638**	**-197.3%**	**-215.3%**	**8.8%**	**7.7%**
Chilko	Pooled	2949	1135	1078	-1814	-1871	-159.8%	-173.6%	7.7%	6.7%
Quesnel	Power	1593	336	346	-1257	-1247	-374.1%	-360.4%	5.9%	6.2%
Stellako	Ricker	532	221	183	-311	-349	-140.7%	-190.7%	7.7%	4.2%
Late Stuart	Ricker	254	100	83	-154	-171	-154.0%	-206.0%	23.0%	18.8%
Lates		**2125**	**1210**	**534**	**-915**	**-1591**	**-75.6%**	**-297.9%**	**25.2%**	**5.0%**
Birkenhead	Power	229	164	66	-65	-163	-39.6%	-247.0%	34.6%	89.6%
Late Shuswap	Ricker	1619	736	375	-883	-1244	-120.0%	-331.7%	21.1%	6.9%
Cultus	Power	31	40	16	9	-15	22.5%	-93.8%	60.6%	24.2%
Portage	RS	75	39	11	-36	-64	-92.3%	-581.8%	26.4%	3.2%
Weaver	RS	171	231	66	60	-105	26.0%	-159.1%	62.6%	16.4%
TOTAL		**8248**	**3524**	**2387**	**-4724**	**-5861**	**-134.1%**	**-245.5%**		

[a] preliminary values that include missing fish (IMF) and exclude missing fish (EMF) where the estimate of "missing fish" is the difference between the PSC's gross escapement estimate at Steveston (PSC's gross escapement estimate at Mission plus the First Nations catch below Mission)

[b] observed sun size - 50% forecast

[c] probability of a greater absolute deviation from the 50% forecast under forecast probability distribution

[d] based on best forecast model for age-4 sockeye. Ricker and power models are for log-normal error and RS is based on the geometric mean recruits per spawner

[e] estimates of discrepenies for Pitt R sockeye are not available. They spawn below Mission.

Table 2. Pre-season Fraser River sockeye run size forecasts by stock and timing group for 2000.

		Probability of Achieving Specified Run Sizes[a]				
STOCK/TIMING	**MODEL**	**25%**	**50%**	**75%**	**80%**	**90%**
Early Stuart	**power**	**540,000**	**291,000**	**157,000**	**134,000**	**89,000**
Early Summer		**1,046,000**	**547,000**	**289,000**	**248,000**	**161,000**
Fennell	power	87,000	47,000	25,000	22,000	14,000
Bowron	power	58,000	33,000	18,000	16,000	11,000
Raft	power	217,000	115,000	61,000	52,000	34,000
Gates	fry	96,000	43,000	19,000	16,000	9,000
Nadina	power	74,000	41,000	22,000	19,000	13,000
Pitt	power	63,000	29,000	14,000	11,000	7,000
Seymour	power	154,000	82,000	44,000	38,000	25,000
Scotch	RS	77,000	29,000	11,000	8,000	4,000
Upper Adams[b]	RS	220,000	128,000	75,000	66,000	44,000
Mid Summers		**4,680,000**	**2,668,000**	**1,564,000**	**1,373,000**	**977,000**
Chilko	smolt	2,240,000	1,444,000	931,000	834,000	623,000
Quesnel	power	735,000	311,000	132,000	106,000	59,000
Stellako	Ricker	1,078,000	645,000	386,000	340,000	242,000
Late Stuart	power	627,000	268,000	115,000	93,000	53,000
Late Summer		**1,171,000**	**577,000**	**286,000**	**241,000**	**153,000**
Birkenhead	power	427,000	240,000	134,000	116,000	79,000
Late Shuswap	Ricker	98,000	51,000	26,000	22,000	14,000
Cultus	power	9,000	5,000	2,000	2,000	1,000
Portage	RS	68,000	31,000	14,000	11,000	7,000
Weaver	fry	569,000	250,000	110,000	90,000	52,000
TOTAL		**7,437,000**	**4,083,000**	**2,296,000**	**1,996,000**	**1,380,000**

[a] probability that the actual run size will exceed the specified forecast

[b] the Upper Adams forecast is based on recruits-per-spawner data for all stocks combined.

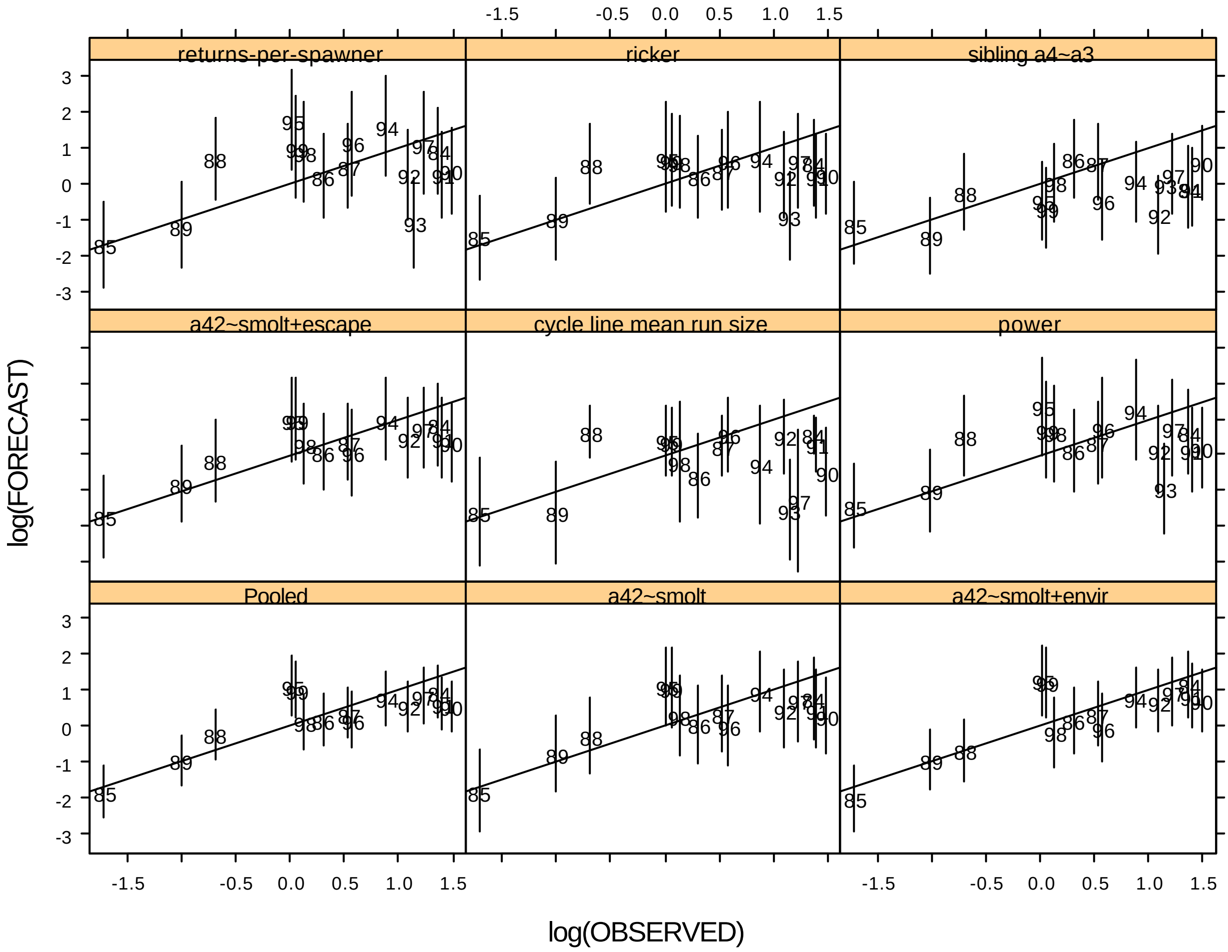

Figure 1. Comparison of estimated (observed) returns and retrospective run size forecasts (millions ($\log_e$ scale)) of age-4 Chilko sockeye by model. Data points are median (50%) forecasts and are denoted by return year. Diagonal lines are 1:1 lines not regression lines. Error bars are 90% confidence intervals.

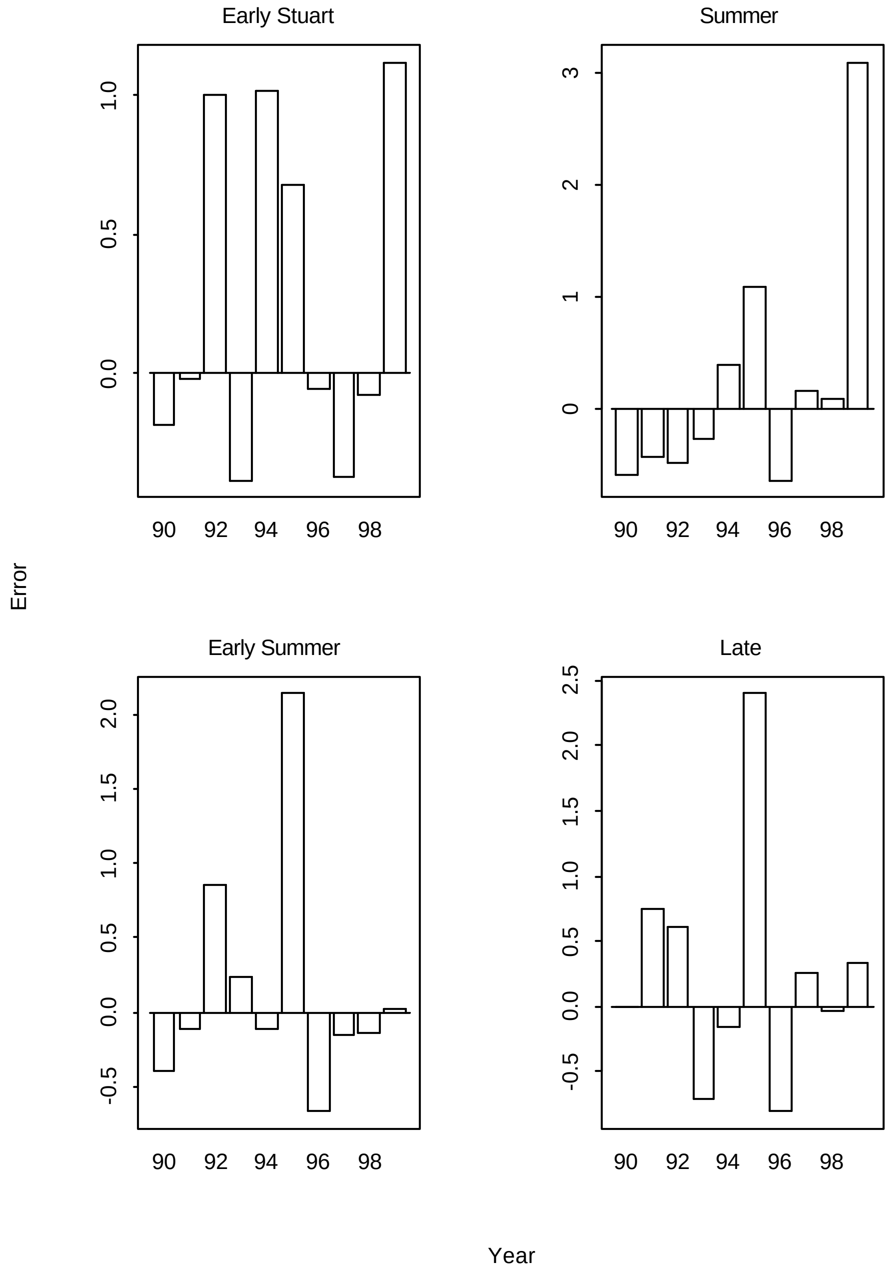

Figure 2. Proportional deviation of forecasts from observed run size by run-timing group for Fraser River sockeye (1990-99).

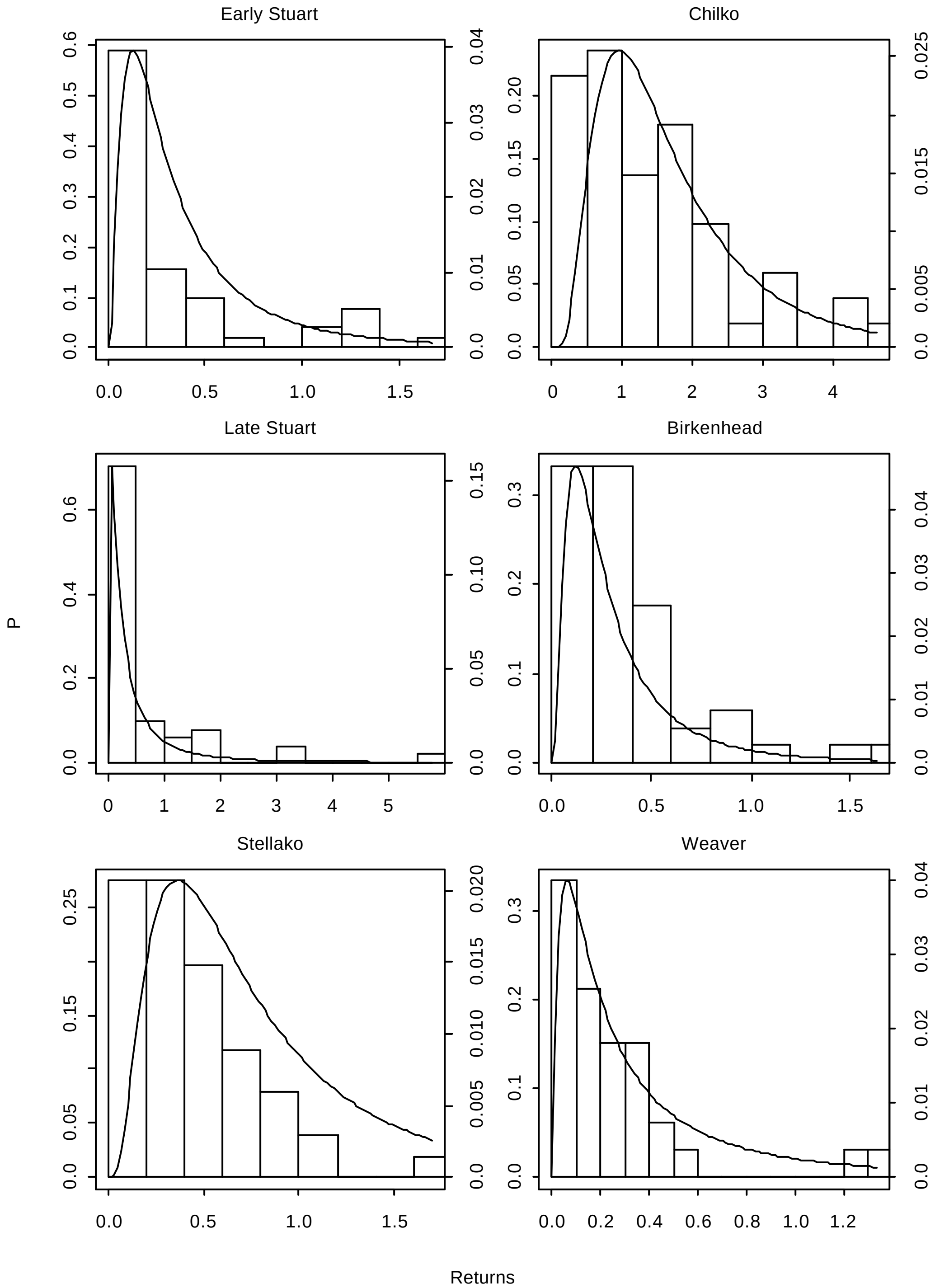

Figure 3. Histogram of historical run size (left axis) and probability distribution of the 2000 forecast (right axis) for major stocks of Fraser River sockeye on the 2000 cycle line.

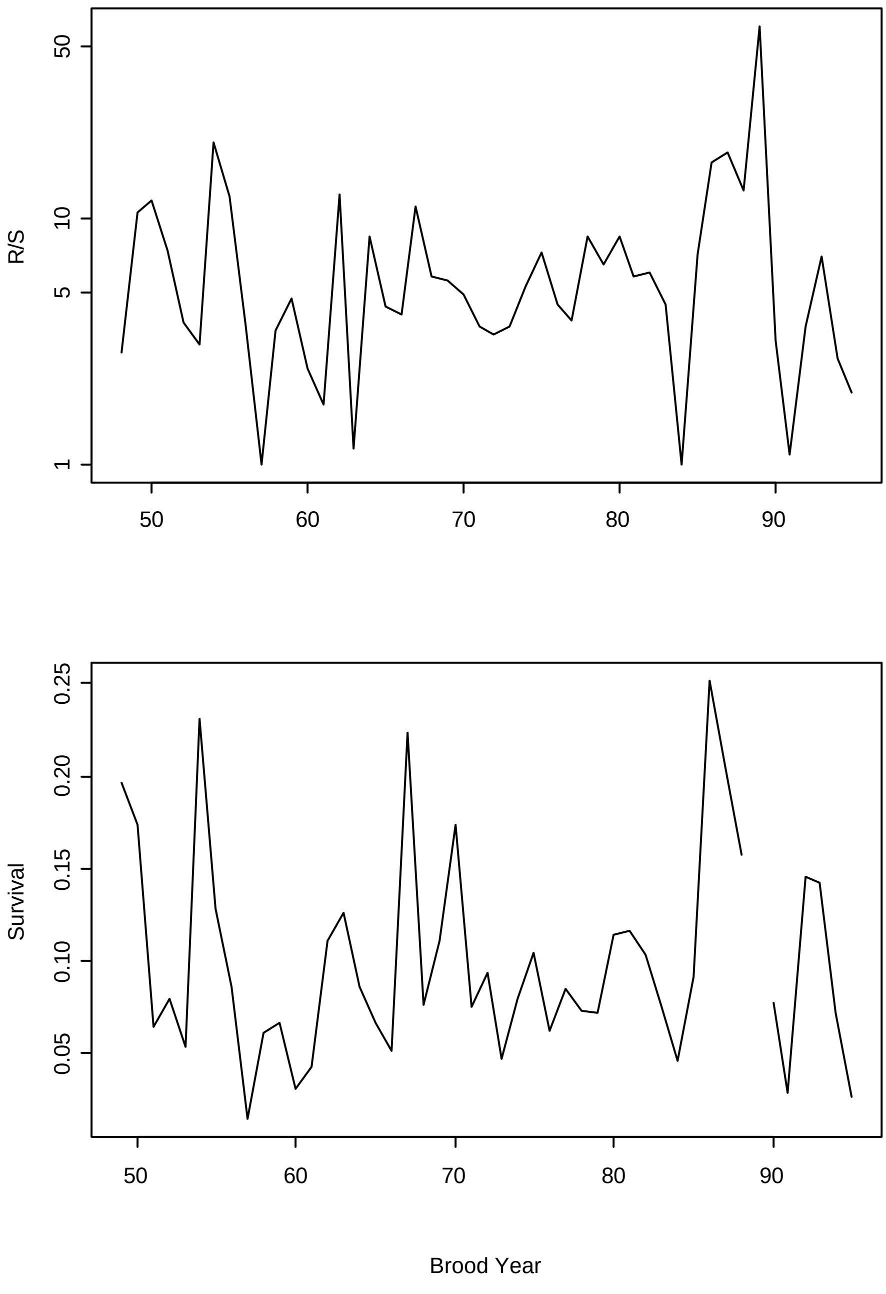

Figure 4. Recruits-per-spawner (upper) and smolt survival trends for Chilko sockeye (1949-95 brood years).

Appendix Table 1. Chilko sockeye data used to forecast 2000 returns.

Brood	Escapement			Proportion	Smolts	returns at age[a]					
year[b]	jack	male	female	spawn	age-1	r3s2	r4s2	r5s2	r4s3	r5s3	r6s3
1948	403	277,737	392,885	0.93		32,000	1,643,062	11,182	6,131	254,316	1,282
1949	63	24,056	34,191	0.97	3,146,830	3,732	560,635	10,368	621	46,358	1,424
1950	9,139	9,815	7,493	0.87	1,170,491	1,489	183,278	4,705	954	15,449	0
1951	17,994	41,982	58,134	0.99	11,504,581	3,925	644,911	20,763	5,004	74,115	3,609
1952	4,480	224,256	261,329	0.89	24,491,079	18,732	1,763,929	35,975	114	38,833	893
1953	554	91,350	109,341	0.86	7,690,383	1,172	514,554	14,004	2,583	86,362	781
1954	3,447	12,459	21,837	0.97	2,853,403	12,234	632,132	4,415	2,844	58,891	2,233
1955	10,979	40,578	80,589	0.94	9,159,120	32,418	1,407,963	31,011	1,373	40,510	0
1956	862	260,525	386,381	0.95	28,242,157	13,905	2,379,854	16,684	75	25,152	0
1957	2,301	54,952	83,512	1.00	9,458,468	76	117,362	3,149	63	17,578	0
1958	16,977	49,600	70,504	1.00	6,894,577	4,055	278,320	13,613	1,711	130,581	5,091
1959	8,102	189,677	273,383	1.00	32,164,794	23,792	2,080,497	18,659	1,272	88,363	0
1960	61	179,209	247,337	0.99	33,780,351	5,472	958,877	5,980	1,045	81,961	0
1961	1,214	15,515	23,586	0.64	1,592,073	256	52,713	11,583	409	4,492	0
1962	14,754	28,212	49,501	0.85	8,813,395	10,657	960,609	13,582	0	696	18
1963	4,021	454,959	543,272	0.38	9,269,764	37,579	1,112,861	4,045	3,971	47,006	841
1964	329	103,777	134,495	0.98	23,664,571	7,252	1,818,921	55,810	1,343	156,756	0
1965	4,567	12,294	23,041	0.90	2,346,223	1,787	138,555	2,360	1,782	14,460	0
1966	17,083	94,921	114,698	0.94	17,354,774	26,456	744,469	27,636	1,479	89,160	0
1967	1,622	72,563	102,152	0.88	9,148,004	28,734	1,933,329	23,351	5,300	13,996	0
1968	584	173,238	240,624	0.76	31,728,000	46,952	2,349,375	21,925	1,108	55,581	1,128
1969	5,616	28,491	42,411	0.60	3,586,283	4,126	369,954	15,839	294	12,146	0
1970	9,661	63,483	71,905	0.71	3,849,000	16,775	630,046	1,084	4,296	41,128	0
1971	17,073	57,727	99,466	0.91	7,609,000	58,786	740,253	0	2,592	40,581	0
1972	1,815	225,935	336,715	0.99	20,970,000	42,709	1,947,465	12,635	902	29,880	0
1973	6,032	24,786	30,889	0.98	4,300,000	8,835	185,279	4,843	2,879	17,949	0
1974	18,568	36,569	72,994	0.97	7,246,000	20,228	560,709	4,748	2,309	30,956	0
1975	20,815	81,685	118,054	0.86	14,149,000	13,385	1,524,814	7,375	3,960	73,812	390
1976	2,559	146,424	215,328	0.98	26,686,000	9,119	1,650,944	25,168	161	14,210	0
1977	4,783	20,671	28,868	0.69	2,629,000	3,346	190,527	2,743	0	2,584	0
1978	8,433	60,269	83,133	1.00	18,884,000	8,616	1,169,034	77,743	44	9,789	0
1979	5,370	80,701	154,223	0.87	22,940,000	9,358	1,615,466	72,206	113	15,308	7,804
1980	846	169,437	298,375	0.93	35,038,000	12,504	3,920,494	473,961	414	32,179	2,375
1981	1,549	12,919	21,441	0.94	1,704,000	1,722	180,656	4,547	1,633	18,862	0
1982	2,360	99,437	140,466	0.97	13,967,000	52,424	1,355,953	115,688	0	58,923	1,412
1983	2,290	138,690	190,530	0.94	19,715,000	45,476	1,698,381	36,418	1,461	310,875	4,399
1984	350	223,925	228,693	0.96	9,843,000	9,772	500,714	2,890	316	153,895	5,802
1985	14,685	36,373	35,062	0.99	5,588,000	970	366,037	184,400	1,563	18,862	1,136
1986	28,626	112,924	168,847	0.94	18,885,000	47,835	4,413,216	282,507	335	54,505	5,033
1987	2,102	88,974	150,627	0.93	21,695,000	11,552	4,036,989	316,979	863	56,111	2,975
1988	514	115,629	139,039	0.97	20,901,000	2,697	2,979,547	157,353	797	154,472	0
1989	5,480	17,444	35,595	0.98		11,841	3,139,648	87,372	0	2,371	0
1990	7,476	316,764	509,073	0.98	34,168,000	13,265	2,413,222	168,114	3,056	24,994	0
1991	1,887	420,297	617,440	0.97	39,722,000	4,425	1,017,944	128,918	1,140	123,021	0
1992	4,396	190,554	320,713	1.00	12,866,000	4,633	1,781,463	79,236	614	9,774	0
1993	6,639	230,736	324,490	0.99	27,258,000	18,173	3,401,545	470,430	208	13,659	0
1994	1,494	188,475	262,270	0.97	16,977,000	10,606	1,142,007	73,494	184	4,593	0
1995	4,709	219,798	314,761	0.93	39,826,000	2,778	1,056,481		36		
1996	15,159	441,875	532,474	0.95	18,700,496	359					
1997	7,427	428,977	556,850	0.91	21,837,625						
1998	1,934	367,343	511,674	0.91							
1999	355	441,606	449,961	0.96							

[a] age of returns: rX year olds that went to sea in the sX year.

[b] 1994 and 1995 brood year return data are very preliminary