Fisheries and Oceans Science | Pêches et Océans Sciences

C S A S | **S C C S**

Canadian Science Advisory Secretariat | **Secrétariat canadien de consultation scientifique**

Research Document 2001/147 | **Document de recherche 2001/147**

Not to be cited without permission of the authors *

Ne pas citer sans autorisation des auteurs *

Pre-season run size forecasts for Fraser River sockeye in 2002

Al Cass

Fisheries and Oceans, Canada
Pacific Biological Station
Nanaimo, BC
V9T 6N7

* This series documents the scientific basis for the evaluation of fisheries resources in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

* La présente série documente les bases scientifiques des évaluations des ressources halieutiques du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

Research documents are produced in the official language in which they are provided to the Secretariat.

Les documents de recherche sont publiés dans la langue officielle utilisée dans le manuscrit envoyé au Secrétariat.

This document is available on the Internet at:

Ce document est disponible sur l'Internet à:

http://www.dfo-mpo.gc.ca/csas/

ISSN 1480-4883
Ottawa, 2001

Abstract

The 2002 cycle line is noted for the historically dominant Lower Adams River (Shuswap Lake) sockeye returns. This cycle line was once the highest of the four cycle lines averaging 15.5 million/year since 1980 compared to 8.9 million/year for the other three cycles. Together, Adams River sockeye and other late run Shuswap Lake stocks accounted for about 50% of the total returns on the 2002 cycle. The sub-dominant Quesnel run has rebuilt within the last two decades and escapements in the 1998 brood year were equal to the dominant Late Shuswap escapement at 1.2 million sockeye.

Forecasts for 2002 are provided at various probability levels of achieving specified run sizes by stock and run-timing group. The forecast of sockeye at the 50% level for all stocks combined is 12.9 million fish (105,000 Early Stuart, 493,000 Early Summer, 9.0 million Summer and 3.3 million Late run). This forecast compares to an average return on the 2002 cycle of 15.5 million sockeye/year (1980-2000). The reason for the disparity between the forecast and mean return since 1980 is due primarily to a decline in returns of Late run stocks. The Summer Run forecast in 2002 accounts for 70% of the total forecast. Quesnel (6.5 million) and Late Shuswap (2.3 million) sockeye together account for 70% of the total forecast.

Migratory conditions in the Fraser River in 1998 were poor for many stocks as a result of high water temperatures. The effect of stress on survival of the progeny from those fish that spawned in 1998 is not known. Indicators of freshwater survival throughout the watershed for the brood were variable. Low freshwater survival was evident for Early Stuart sockeye at two of three site as well as for Chilko and Shuswap lakes. Channel fry survival rates, however, showed no indication of poor egg-to-fry conditions.

Oceanographic and meteorological conditions in the northeast Pacific returned to near normal values in 1999 (2002 age-5 ocean entry year) (Anon. 2000b). Moderate La Nina conditions occurred in 2000 and ocean temperatures were normal to slightly below normal and salinity was near normal in the north Pacific region in 2000 (2002 age-4 ocean entry year).

Résumé

Les remontes de saumon rouge dans le cours inférieur de la rivière Adams (lac Shuswap), qui ont toujours été les plus importantes par le passé, marquent le cycle de 2002. Elles ont déjà été les plus fortes des quatre cycles, s'établissant en moyenne à 15,5 millions de saumons rouges par année depuis 1980 comparativement à 8,9 millions par année pour le total des trois cycles pendant la même période. Les stocks de saumon rouge de la rivière Adams conjugués à ceux à montaison tardive dans le lac Shuswap représentent environ 50 % de l'ensemble des retours du cycle de 2002. La remonte de la Quesnel, la seconde en importance, s'est reconstituée au cours des deux dernières décennies, et l'échappée de la progéniture de 1998 était égale à l'échappée tardive dominante de 1,2 million de saumons rouges du lac Shuswap.

Les prévisions pour 2002 sont présentées à divers niveaux de probabilité d'atteinte des remontes déterminées selon le stock et le moment de migration. La prévision pour le saumon rouge à un niveau de probabilité de 50 %, tous stocks confondus, est de 12,9 millions de poissons (105 000 de montaison hâtive dans la Stuart, 493 000 au début de l'été, 9,0 millions en été et 3,3 millions de montaison tardive). Cette prévision se compare au retour moyen pour le cycle de 2002 de 15,5 millions de saumons rouges par année (1980-2000). L'écart entre la prévision et le retour moyen depuis 1980 s'explique principalement par le fléchissement des retours des stocks à montaison tardive. La prévision de la montaison estivale en 2002 compte pour 70 % de la prévision totale. Les stocks de saumon rouge de la Quesnel (6,5 millions) et ceux à montaison tardive dans le lac Shuswap (2,3 millions) comptent pour 70 % de la prévision totale.

Les conditions migratoires dans le Fraser en 1998 ont été mauvaises pour de nombreux stocks en raison des températures élevées de l'eau. L'effet du stress sur la survie de la progéniture des poissons qui ont frayé en 1998 est inconnu. Les indicateurs de la survie en eau douce de la progéniture dans l'ensemble du bassin hydrographique ont été variables. Le faible taux de survie des œufs jusqu'au stade de l'alevin du saumon rouge à montaison hâtive dans la Stuart était manifeste à deux des trois endroits échantillonnés, de même que pour les stocks des lacs Chilko et Shuswap. Les taux de survie des alevins dans le chenal ne semblent toutefois pas indiquer que les conditions étaient mauvaises de la ponte à l'alevinage.
Les conditions océanographiques et météorologiques dans le Pacifique Nord-Est sont revenues à des valeurs presque normales en 1999 (arrivée en mer à l'âge de 5 ans en 2002) (Anon. 2000b). Les conditions de La Nina ont été modérées en 2000, et les températures de l'océan étaient normales à légèrement inférieures à la normale, tandis que la salinité était près de la normale dans le Pacifique Nord en 2000 (arrivée en mer à l'âge de 4 ans en 2002).

Table of Contents

1. Introduction

The 2002 cycle line is noted for the historically dominant Lower Adams River (Shuswap Lake) sockeye returns. This cycle line was once the highest of the four cycle lines averaging 15.5 million/year since 1980 compared to 8.9 million/year for the other three cycles. Together, Adams River sockeye and other late run Shuswap Lake stocks accounted for about 50% of the total returns on the 2002 cycle. The sub-dominant Quesnel run has rebuilt within the last two decades and escapements in the 1998 brood year were equal to the dominant Late Shuswap escapement at 1.2 million sockeye. The total spawning escapement to the Fraser River in 1998 of 4.4 million sockeye was near the 1980-2000 cycle mean.

Forecasts are made for each of 18 individual sockeye stocks and four timing groups. Together the 18 sockeye stocks accounted for 93% of the estimated escapement to the Fraser River in 1998. Forecasts are not provided for a number of small stocks for which estimates of escapement are made but, for which return estimates are unavailable. 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 smolt and sibling adult run size estimates. An environmental index has explained some variation in ocean survival of Chilko sockeye in the past (Cass et al. 1995) but has performed worse than biological variables in recent years and is not considered here. Methods that incorporate attributes of escapement-based and juvenile-based models were evaluated by pooling results from individual forecast models where time series of different life stages are available.

Sibling models that predict returns of age-4 and age-5 sockeye from returns of age-3 and age-4 in the previous year have performed poorly compared to escapement-based models (Cass 1998). The proportion of returns at age have undergone dramatic long-term changes that can not be explained by changes in abundance or growth rates. The proportion of age-3 jack returns have undergone dramatic long-term declines whereas the proportion of age-5 returns have increased in the last two decades. Estimates of age-5 sockeye on the 2002 cycle, in particular, have increased significantly. In 1998, the proportion of age-5 sockeye was 28% for the 18 stocks in this assessment. The proportion of age-5s for Early and Late Stuart sockeye was estimated to be 85%. This represents a large increase respectively from 22% and 29% age-5s in 1994. Estimates of age-4 returns in 2001 were made available for most stocks in January 2002. The utility of sibling models was completed at that time but still performed poorly compared to other models. A variety of independent variable including age-4 female standard length and categorical variables to account for cycle line effects were considered. No further discussion of sibling models is presented in this report.

2. Data sources and methods

Data sources and methods have been extensively reviewed by PSARC (Blackbourn 1992; Cass 2001, Cass 2000, Cass 1999; Cass 1998; Cass 1997; Cass and Blackbourn 1996; Cass et al. 1995; Welch et al. 1994). Methods used to forecast 2002 returns are unchanged from previous reviews. Annual estimates of sockeye spawning escapement (1948-98) and returns by age class (1952-2000) by stock are the primary data used to forecast Fraser sockeye. These data are in a Microsoft Access database available from the Pacific Salmon Commission. The main explanatory variable used to forecast the return of age-4 sockeye in 2002 is the spawning escapement (effective females) in 1998. The escapement in 1997 is the main explanator of age-5 returns. Effective females are estimates of the number of spawning females contributing to the spawning population based on sampling for potential by egg deposition. The stock-specific catch component of run size (run size = catch + escapement) is estimated by the Pacific Salmon Commission (PSC).

Estimates of juvenile sockeye fry from Nadina, Gates and Weaver spawning channels are available beginning respectively in 1968, 1973 and 1965 (Doug Lofthouse, Fisheries and Oceans Canada, personal communication). Egg-to-fry survival for these stocks is used to assess potential freshwater effects on recruitment in 2002. An estimate of total fry production from these systems was calculated by multiplying the ratio of total escapement (wild+channel) and channel escapement by channel fry abundance. The performance of fry-based forecasts based on these data is compared to escapement-based forecasts. Downstream fry data for three spawning locations (Forfar, Gluske and Kynoch creeks) in the Early Stuart timing component are available since 1990 (Tracy Cone, Fisheries and Oceans Canada, personal communication). These data are not of sufficient duration for predicting returns based on the return-fry relationship, but are used to estimate egg-to-fry survival and assess potential impact on 2002 returns.

In-lake juvenile abundance and fish size data are available for Quesnel and Shuswap sockeye based on hydro-acoustic estimation techniques (Hume et al. 1996). A 10-year data set (1977-98 dominant and subdominant brood years) is now available for Quesnel Lake (Jeremy Hume, Fisheries and Oceans Canada, personal communication). A 14-year data set is available for Shuswap Lake. These data were used to evaluate the utility of juvenile-return relationships for forecasting returns in 2002. Fry abundance estimates are made each year from surveys in the summer (late summer or August) and fall (October- early November). Only the fall fry data were assessed. Fall fry abundance is assumed to represent most of the freshwater survival effects and theoretically are better predictors of adult recruitment compared to summer fry estimates.

Separate forecasts for the two principal components of Early Stuart sockeye (Driftwood River and non-Driftwood River) are also evaluated. Driftwood River sockeye are highly cyclic with highest returns on the 2001 cycle. The abundance of Driftwood River sockeye on the other three cycle lines is low to negligible. Non-Driftwood sockeye spawn in numerous small spawning tributaries of Takla and Trembluer Lakes and do not exhibit pronounced cyclic behaviour. The returns to the Driftwood and non-Driftwood systems are not estimated directly in-season because catch composition of the two groups is not estimated. For purposes of forecasting, the total returns were reconstructed by apportioning the total Early Stuart returns according to the corresponding annual effective female escapement estimates for the non-Driftwood and

Driftwood systems. This method assumes the catch is proportional to the escapements of the two substocks. Sockeye escapements for Driftwood and non-Driftwood components are those compiled by Fisheries and Oceans Canada in an Access database (Tracy Cone, Fisheries and Oceans Canada, personal communication). The effect of separating Early Stuart sockeye into two components on forecast performance is compared to the performance based on Early Stuart forecasts with all substocks combined.

In recent years, there have been large discrepancies between estimated returns at the Mission hydro-acoustic facility and the estimated catch plus spawning escapement up-river for some run timing groups. In 1994 and 1997 the discrepancies were particularly large for Early Stuart sockeye with 63% and 41% respectively more sockeye estimated at Mission than reported up-river (Anon. 1997; 1999). The Discrepancies for other timing groups were much less. Up-river estimates of Early Summer and Summer run sockeye in 1994 respectively were 11% and 7% less than the corresponding Mission estimates. The only timing group with reported discrepancies in 1997 other than Early Stuart sockeye was the Early Summer run with 12% more sockeye reported at Mission (Anon. 1997). The cause(s) of the discrepencies in the Early Stuart, Early Summer and Summer timing groups has not been definitively identified. Explanations centre on environmentally induced mortality from anomalous river discharge rates and high water temperature in the Fraser River.

Beginning in 1995, anomalous early entry of late runs (i.e. Weaver, Cultus, Portage, Late Shuswap) has been associated with large discrepencies between Mission and up-river estimates. This discrepancy has been attributed to high in-river mortality prior to spawning (Anon 2001a). Estimates of mortality have ranged from 60-90% depending on the year and stock. The forecasts presented here are for sockeye return data that include the positive discrepancies measured at Mission. Therefore, the return data fit to the forecast models includes estimates of “missing” fish. The effect of excluding the “missing” fish from the Early Stuart and Late Shuswap sockeye data are assessed in Section 6.

The Birkenhead River is a coastal system subject to high flow rates. High river discharge during egg-to-fry development has been associated with low recruits-per-spawner of Birkenhead River sockeye and considered a potential cause of high survival variation (Jim Woodey, Pacific Salmon Commission, personal communication). The effect of river flow during the fall-winter period of egg development of Birkenhead River sockeye was assessed using the available time series of Lillooet River flow rates measured near Pemberton, B.C. Discharge records for the Birkenhead River are only available for the period 1948-71. The Lillooet River is located in the upper watershed of the Birkenhead system and data exist for 1950 to the present. Discharge rates are provided on CD-ROM format for years to 1990 by Commercial Services Division, Monitoring and Systems Branch, Environment Canada. Additional data were provided by Environment Canada (Lynne Campo; personal communication) and the PSC. The maximum daily discharge recorded between 25-September (long term mean peak spawning date) and 28-February as a measure of river flow effects on survival.

3. Forecast models

Forecast models used in the present analysis are as follows:

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

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

estimated using the linear regression :

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

Here the returns (R_{it}) 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:

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

estimated by:

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

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

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

4) Juvenile models:

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

$$\ln(R_{it} = \beta_0 + \beta_1 \ln(N_t) + \sigma \varepsilon_t , \tag{4}$$

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.

5) Pooled models:

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):

$$\ln(F) = \sum_{m=1}^{n}\left[\ln(F_m)/V_m\right] / \sum_{m=1}^{n} 1/V_m \ , \qquad (5)$$

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:

$$V_p = 1/\sum_{m=1}^{n} 1/V_m \ . \qquad (6)$$

4. 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 (2000), 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 return years 1984-2000 (brood years 1980-1996) for escapement-based models. Because the time series of Quesnel fall fry and associated age-4 return data are short (n=8 years) the retrospective analysis was for 1986-98. The retrospective comparison of forecasting models for four main stocks contributing to the 2002 forecast (Early Stuart, Chilko, Quesnel and Late Shuswap) are shown in Figures 1-4. Note that the scale is in the log domain and so the true uncertainty, to a large extent, is masked. Uncertainty in the retrospective comparisons for these stocks is depicted by the 90% prediction intervals of the forecasts in relationship to the 1:1 line. In many years the confidence intervals 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. The relationships between the forecast and observed age-4 returns reveal similar patterns irrespective of the forecast model.

Forecast errors were quantified using the root mean square error (RMSE) criteria:

$$RMSE_i = \sqrt{\frac{1}{n}\sum_{t=1}^{n}(R_{it} - F_{it})^2} \,,$$

where R_{it} is the estimated post-season return and F_{it} is the corresponding pre-season forecast in year *t* for stock *i*.

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).

5. 2002 Forecasts

Annual differences between estimated returns and forecast returns (point estimate) during 1990-2001 were large (Fig. 5). The mean absolute deviation was 74% for all timing groups combined. The error for individual timing groups was of similar magnitude: 76% for Early Stuart, 67% for Early Summers, 65% for Summer and 87% for late runs. Data trends and relationships between variables used in forecasts are shown in Figures 6 – 22 for each stock. Forecasts are provided at various probability levels of achieving specified run sizes by stock and run-timing group (Table 1). Forecasts for age-4 and age-5 sockeye at the 50% probability level are listed in Table 2.

The forecast of sockeye at the 50% level for all stocks combined is 12.9 million fish (105,000 Early Stuart, 493,000 Early Summer, 9.0 million Summer and 3.3 million Late run). This forecast compares to an average return on the 2002 cycle of 15.5 million sockeye/year (1980-2000). The reason for the disparity between the forecast and mean return since 1980 is due primarily to a decline in returns of Late run stocks. The Summer Run forecast in 2002 accounts for 70% of the total forecast. Quesnel (6.7 million) and Late Shuswap (2.3 million) sockeye together account for 70% of the total forecast.

5.1 Early Stuart sockeye

The 2002 cycle line is the first off cycle following the dominant line return in 2001 (Fig 5). The spawning escapement in brood year 1998 was impacted by high Fraser River water temperatures and escape levels were well below the target. The final in-season estimates of Early Stuart sockeye at Mission was 75% greater that upstream sum of the spawning escapement and catch estimates. Female sockeye that reached the spawning sites suffered an estimated 44% pre-spawning mortality (Anon. 1998). A forecast based on the sum of individual forecasts (age-4 and age-5) for the Driftwood River and non-Driftwood substocks is 133,000 sockeye at the 50% probability level and 60,000 at the 75% level. The power model had the lowest RMSE for both stock components. The non-Driftwood component accounts for 89% of the total Early Stuart forecast. Age-4 sockeye comprise 89% of the forecast return. The point estimate is near the 2002 cycle line mean (1980-2000) of 134,000 sockeye/year. Again based on the power model, the "best" forecast from the combined Early Stuart data set that does not distinguish between the two stocks components is 105,000 sockeye (83% age-4) at the 50% level and 59,000 at the 75% level. The point estimate is 22% below the cycle line mean return (Table 1).

The basis for choosing between the two forecasts, either based on the sum of the two substocks or for all data combined, relies on identifying the forecast with the lowest RMSE. The RMSE calculated for the sum of the two substock forecasts is 0.241 compared to 0.191 for the forecast based on the combined data, therefore, the forecast of 105,000 sockeye at the 50% level is proposed (Table 1).

Egg-to-fry survival rates have been estimated annually since 1990 at three sites (Forfar, Kynoch and Gluske Creeks). Survival rates of the 2002 brood were significantly below the 1990-1999 mean at two locations (Forfar and Kynoch Creeks) and slightly greater than the long-term mean at the other site (Gluske Creek). The ultimate impact of fry survival measured at three of about 30 spawning locations on overall adult Early Stuart recruitment is difficult to assess. The effect of stresses due to unfavourable spawning migration conditions, particularly evident for Early Stuart sockeye in 1998, is unknown but may be a contributing factor to poor fry survival. If the low freshwater survival rates measured at Forfar and Kynoch Creeks are representative of the Early Stuart system then the forecast may be optimistic. Recruitment rates are ultimately affected by survival factors throughout the life cycle. Forecasts are unlikely to improve without knowing the sum of the individual survival rates incurred both in freshwater and the ocean.

5.2 Early Summer Run sockeye

The early summer run mainly consists of several small stocks (Fennell, Bowron, Raft, Gates, Nadina, Pitt, Seymour and Scotch). The Seymour River and Scotch Creek stocks are the largest early summer stocks on the 2002 cycle line. Returns for these two stocks are historically dominant on 2002 cycle (Fig. 13 and 14). In-season Mission estimates of escapement to the Fraser River in 1998 were 49% greater than upstream spawning escapement plus catch but pre-spawning mortality estimates were variable depending on the stock. The total forecast for the Early Summer group is 493,000 at the 50% level and 237,000 at the 75% level. These forecast levels compare to a 1980-2000 cycle mean return of 735,000 sockeye. Scotch and Seymour sockeye account for 59% of the forecast, respectively at 102,000 and 189,000 sockeye at the 50% level (Table 1). For Seymour sockeye this represents a 75% decline from the cycle line mean return of 411,000 sockeye (Table 1). Forecasts for other stocks in the group are greater than the cycle line mean return.

Forecasts based on fry output from the Nadina spawning channel and weighted to account for the total fry production from both wild and channel spawning sites had a lower RMSE compared to escapement-based forecasts. The forecast based on Gates Creek fry performed poorly compared to a simple recruits-per-spawner model (lowest RMSE). The Upper Pitt River sockeye forecast is particularly uncertain. The brood year escapement for age-4 returns in 2002 was estimated to be the highest on record and therefore results in a forecast based on data beyond the historical range. Age-4 sockeye account for 50% of the 2002 forecast to the Upper Pitt.

Fry survival estimates for the brood year at Nadina and Gates Creek spawning channels (Fig. 25) are above the long-term mean.

5.3 Summer Run sockeye

Except for Chilko Lake sockeye, the best performing forecasts for 2002 are larger than the 1980-2000 cycle line mean returns (Table 1). Returns on the 2002 subdominant cycle line to Quesnel Lake have increased steadily from 19,000 in 1978 to 3.3 million in 1994 (Fig. 16). The return in 1998 was 2.9 million sockeye. Escapements of Quesnel sockeye also increased during the same period. The brood year escapement of 1.2 million fish is the highest on record for the subdominant cycle line. The RMSE for the three models that include fry as a predictor are all less than models that only include escapement as a predictor. The multiple regression model that includes fall fry and escapement results in the lowest RMSE. This model uses only years that fall fry data are available (n=8 years) and results in a forecast of 6.7 million at the 50% probability level and 4.0 million at the 75% level. There is, however, little basis for choosing from among the three models that use fry as a predictor based on residual patterns from the retrospective analysis (Fig. 3). The inability to separate sockeye from kokanee fry in the data potentially biases sockeye fry estimates. The effect of accounting for kokanee would decrease the slope in the return – fry relationship because sockeye fry in low years are assumed to be positively biased to a greater degree than in high fry years. A decrease in the slope would result in a larger forecast (see further discussion regarding kokanee in Shuswap Lake in Sec. 5.4). The "best" forecast model based solely on escapement is the power model with a 50% forecast of 4.8 million or nearly 50% less than the fry-based model. Accounting for the direction of the bias induced by kokanee would increase the fry-based forecasts beyond the proposed 6.5 million at the 50% level. There is no evidence based on fall fry fish size data that capacity limits in Quesnel Lake affected in-lake growth. The mean fall fry size for the 2002 brood of 3.5 g is only slightly less than the mean of 3.6 g for dominant and subdominant years.

Late Stuart sockeye have also increased on the subdominant cycle line. The escapement to the Late Stuart system in the brood year was the second highest on record for the 2002 cycle. The RMSE for the power model was the lowest for a forecast of 724,000 sockeye at the 50% level and 254,000 at the 75% level. This compares to a 1980-2000 mean return of 444,000 sockeye for the 2002 cycle. A decline in freshwater survival in Chilko Lake has resulted in a forecast that is less than the 1980-2000 mean return (Fig. 15). The best forecast for Chilko sockeye is based on a multiple regression that includes smolts and spawning escapement as predictors. The cause of low freshwater survival of Chilko sockeye is unknown but density effects cannot be ruled out. If the high escapement for the years during which Chilko Lake was fertilized are excluded, Chilko escapement in the brood year was near the largest recorded. The forecast for Chilko sockeye is 946,000 fish at the 50% level and 535,000 at the 75% level compared to a cycle line mean of 2.3 million fish. The 2002 forecast of 615,000 Stellako sockeye (50% estimate) is near the cycle line mean of 609,000 sockeye/year.

5.4 Late Run sockeye

Except for Portage Creek sockeye, the forecasts at the 50% probability level are all below the 1980-2000 cycle line mean (Table 1). The 2002 forecasts of Cultus Lake and Late Shuswap sockeye are particularly low. The low Late Shuswap forecast is due to a low brood year escapement compared to the cycle mean as well as an apparent decline in freshwater survival. The lower than average anticipated return in 2002 of Late Shuswap sockeye is important when considering management action of late run sockeye. The late run has experienced anomalously high in-river pre-spawning mortality associated with the unexplained early entry of the Late run into the Fraser River each year beginning in 1995. Cultus Lake sockeye returns and escapement have undergone a pronounced decline since the 1960s (Fig. 21). The forecast of Cultus Lake sockeye at the 50% level is 7,000 sockeye or well below the 1980-2000 cycle line mean of 26,000 sockeye/year.

Data for late Shuswap Lake sockeye includes Lower Adams River and Shuswap River sockeye. Both of these systems exhibit persistent four-year population cycles. Returns on the dominant 2002 cycle line increased since the 1960s and peaked at 10.3 million sockeye in 1990 (Fig. 20). Since then returns declined to 2.5 million in 1998. Escapement of Late Shuswap sockeye followed a similar trend and declined from 3.6 million in 1990 to 1.2 million in 1998; the lowest on the cycle since 1974. The best performing model for Shuswap sockeye is based on a pooled model (eq. 5) that combines the fall fry – return power model and the escapement based Ricker model. Because fry estimates include all sockeye that rear in Shuswap Lake, the forecast theoretically also includes the early-timed Scotch and Seymour stocks. The forecast for Late Shuswap sockeye shown in Table 1 was computed by subtracting the forecasts for Scotch and Seymour sockeye from the total Shuswap Lake forecast. The forecast is 2.3 million sockeye at the 50% level and 1.7 million at the 75% level. The forecast at the 50% level is considerably less than the forecast of 4.0 million based solely on the Ricker model and implies that freshwater survival to the fall fry stage was lower than average as indicated in Figure 20. Perhaps countering the effects of low fall fry estimates on returns in 2002 is the large mean body weight of the fry observed for the 2002 brood. The mean weight for the brood was 3.5 g compared to a weight of 2.5 g for years that dominant and subdominant fry data have been collected.

Shuswap fall fry estimates are comprised of age-0 sockeye and age-0 kokanee. Age-0 kokanee abundance in Shuswap Lake is estimated to be roughly 1% of the total fry on the dominant cycle line (10% of the subdominant line) (Chris Wood, DFO Stock Assessment Div., personal communication). An assessment presented in the 1998 PSARC forecast document (Cass, 1998) examined the potential effects that kokanee have on sockeye forecasts based on fry. At that time a rough estimate of age-0 sockeye for each dominant and subdominant year that fall fry estimates were made was computed by subtracting 10% of the mean annual nominal subdominant fall fry estimate. The result is a new fry-return relationship with a reduced slope (Cass 1998; Fig. 24). The slope declines because of the disproportionate shift in sockeye fry estimates between dominant and subdominant years. Evidence indicates kokanee populations in Shuswap Lake do not cycle in synchrony with sockeye populations (Levy and Wood 1992), therefore, the nominal subdominant fall fry estimate will always be more positively biased than dominant year estimates. The effect of accounting for kokanee in this resulted in a small (<5%) increase in a forecasts based on a return – fry power model given the nominal fry estimate for brood year

1994. The bias in a forecast generated from nominal fry for brood year 2002 was of a similar magnitude and small compared to overall forecast uncertainty.

Maximum daily discharge rates for the Lillooet River affecting age-4 Birkenhead returns were low. Discharge levels affecting age-5 returns were high (Fig. 26). Based on age-specific forecasts for returning Birkenhead sockeye in 2002, the bulk of the returns (90%) are anticipated to be age-4 based on the relative escapements in 1997 and 1998. It is important to note that although discharge rates since 1950 have often been associated with low negative residuals for Birkenhead River sockeye based on power and recruits-per-spawner models, the relationship is not particularly revealing. A large number of years with low discharge levels are also associated with negative residuals, therefore, the premise that river discharge explains variation in the survival of Birkenhead sockeye is not supported by the data. Both the Weaver Creek and Birkenhead River sockeye forecasts respectively of 380,000 and 420,000 fish are well below the 20-yr (Table 1). Weaver channel fry survival was above average (Fig. 25).

6. Effect of data discrepencies on forecasts

At the PSARC review of Fraser sockeye forecasts for 2001, concern was raised regarding the effect of data discrepencies in recent years on forecasts. Speculation about the causes of the differences in estimates based on in-season estimation in the lower Fraser River at Mission, B.C. and upstream estimates of spawning escapement plus catch have centred on data measurement error and in-river mortality. The sockeye return data used in the forecasts presented in this report and provided by the PSC include estimates of the so-called “missing” fish that make up the discrepancies. In this section the alternative assumption that the discrepancies are not real but reflect a positive measurement error at Mission or a negative measurement error upriver is tested. Forecasts of Early Stuart and Shuswap age-4 sockeye were made by excluding the missing fish in years of significant differences between estimates. To account for the discrepancies, the return data used in the forecasting models were adjusted by subtracting the following list of estimated discrepancies by stock:

Year	Early Stuart	Late Shuswap
1994	120,000	
1997	90,000	
1998	140,000	190,000
1999	140,000	370,000
2000	90,000	20,000

The values presented here were rounded up to the nearest 10,000 fish from those reported in PSC Annual Reports. In the Early Stuart case the 2002 forecast with the re-adjusted data were on average 6% less at the 50% level and 5% for the escapement based power model with the lowest RMSE. In the Late Shuswap case the forecasts were on average 7% lower for candidate models and 10% for the “best” (pooled) model. The choice of whether to include or exclude data discrepancies has a small effect on the forecasts relative to other sources of forecast uncertainty (i.e. mis-specified models and undetected and unpredictable sources of survival factors).

7. Conclusion

Forecasts are associated with high uncertainty. 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. Reliability of forecasts ultimately depend on understanding processes that affect survival in both freshwater and the marine environment. Migratory conditions in the Fraser River in 1998 were poor for many stocks as a result of high water temperatures. The effect of stress on survival of the progeny from those fish that spawned in 1998 is not known. Indicators of freshwater survival throughout the watershed for the brood were variable. Low freshwater survival was evident for Early Stuart sockeye at two of three site as well as for Chilko and Shuswap lakes. Channel fry survival rates, however, showed no indication of poor egg-to-fry conditions.

Intense El Nino conditions were associated with poor marine survival of Fraser sockeye in ocean entry years 1993 and 1997 and over-forecasts in return years 1995 and 1997. Oceanographic and meteorological conditions in the northeast Pacific returned to near normal values in 1999 (2002 age-5 ocean entry year) (Anon. 2000). Moderate La Nina conditions occurred in 2000 and ocean temperatures were normal to slightly below normal and salinity was near normal in the north Pacific region in 2000 (2002 age-4 ocean entry year) (Anon. 2001b). A trend for higher proportions of age-5 sockeye in many stocks has been apparent over the last two decades (Fig. 27). Future forecasts should consider methods to account for this change should it persist. As noted previously, sibling models that predict age-5 sockeye from age-4 returns for the same cohort perform poorly compared to escapement-based models.

8. References

Anon. 2001a. Report of the Fraser River Panel to the Pacific Salmon Commission on the 2000 Fraser River sockeye salmon fishing season. Pacific Salmon Commission. Vancouver, B.C (in press).

Anon. 2001b. 2000 Pacific region state of the ocean. Ocean Status Report 2001/01.

Anon. 2000. 1999 Pacific region state of the ocean. Ocean Status Report 2000/01.

Anon. 1998. Report of the Fraser River Panel to the Pacific Salmon Commission on the 1998 Fraser River sockeye salmon fishing season. Pacific Salmon Commission. 64 p. Vancouver, B.C.

Anon. 1999. Report of the Fraser River Panel to the Pacific Salmon Commission on the 1997 Fraser River sockeye salmon fishing season. Pacific Salmon Commission. 38 p. Vancouver, B.C.

Anon. 1997. Report of the Fraser River Panel to the Pacific Salmon Commission on the 1994 Fraser River sockeye salmon fishing season. Pacific Salmon Commission. 38 p. Vancouver, B.C.

Blackbourn, D.J. 1992. Two examples of methods used in forecasting stock abundance and adult migration behaviour in some stocks of southern pink chum and sockeye salmon. Pacific Stock Assessment Review Committee, Working Paper S92-12.

Cass, A. 2001. Cass, A. 2001. Pre-season run size forecasts for Fraser River sockeye and pink salmon in 2001. Canadian Stock Assessment Secretariat. Research Doc 2001/063.

Cass, A. 2000. Run size forecasts for Fraser River sockeye in 2000. Canadian Stock Assessment Secretariat. Research Doc 99/129.

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.

Hume, J.M.B., K.S. Shortreed, and K. F. Morton. 1996. Juvenile sockeye rearing capacity of three lakes in the Fraser River system. Can. J. Fish. Aquat. Sci. 53: 719-733.

Levy, D.A. and C.C. Wood. 1992. Review of proposed mechanisms for sockeye salmon population cycles in the Fraser River. Bull. Math. Biol. 54: 241-261.

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.

Vernon, E.H. 1966. Enummeration of migrant pink salmon fry in the Fraser River estuary. Internat. Pacific Salmon. Fish. Comm. Bull. XIX, 83.p.

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. Pre-season sockeye and pink salmon run size forecasts for 2002 by stock/timing group and probability level.

stock/timing group	forecast model[b]	mean run size[c] all cycles	mean run size[c] 2002 cycle	Probability of Achieving Specified Run Sizes[a] 25%	50%	75%	80%	90%
Early Stuart	Power	**392000**	**134,000**	**184,000**	**104,600**	**59,400**	**51,600**	**35,500**
Early Summer		**489,000**	**735,000**	**1,059,000**	**493,100**	**237,100**	**198,100**	**124,100**
Fennell	Power	27,000	21,000	52,200	27,300	14,300	12,100	7,900
Bowron	Power	23,000	23,000	46,100	25,900	14,600	12,600	8,600
Raft	Power	21,000	9,000	48,900	26,700	14,600	12,600	8,400
Gates	R/S	65,000	21,000	51,500	30,200	17,800	15,500	10,900
Nadina	Fry	78,000	20,000	52,900	29,900	16,900	14,600	9,900
Pitt	Power	46,000	40,000	118,100	62,600	33,200	28,300	18,600
Seymour	Power	168,000	411,000	191,600	101,800	54,100	46,200	30,400
Scotch	R/S	61,000	190,000	497,700	188,700	71,600	56,200	29,400
Mid Summers		**6,166,000**	**5,283,000**	**15,931,400**	**9,005,600**	**5,203,800**	**4,549,400**	**3,194,800**
Chilko	Smolt/esc[d]	1,976,000	2,252,000	1,671,300	945,700	535,100	464,200	318,200
Quesnel	pooled[e]	2,671,000	1,978,000	11,223,000	6,720,600	4,024,400	3,541,200	2,520,900
Stellako	Ricker	540,000	609,000	967,600	614,900	390,700	348,900	258,400
Late Stuart	Power	979,000	444,000	2,069,500	724,400	253,600	195,100	97,300
Late Summer		**3,498,000**	**9,340,000**	**5,134,100**	**3,312,600**	**2,194,100**	**1,981,100**	**1,504,800**
Birkenhead	Power	547,000	824,000	779,400	421,000	227,400	195,000	129,500
Late Shuswap	pooled[e]	2,399,000	7,615,000	3,138,900	2,300,400	1,678,500	1,545,200	1,225,900
Cultus	Power	29,000	26,000	13,000	6,700	3,400	2,900	1,900
Portage	R/S	70,000	113,000	457,900	208,100	94,600	77,700	46,000
Weaver	R/S	453,000	762,000	744,900	376,400	190,200	160,300	101,500
TOTAL		**10,545,000**	**15,492,000**	**22,308,500**	**12,915,900**	**7,694,400**	**6,780,200**	**4,859,200**

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

[b] see text for model descriptions

[c] 1980-2000 mean

[d] based on multiple regression using juveniles and escapement as the independent variables

[e] pooling based on combining smolt and power (return - escapement) forecasts weighted by inverse of variance

Table 2. Forecast at the 50% probability level by stock/stock group and age class with corresponding standard deviation (SD) of the $\log_e$ of the forecast.

stock/timing group	**Age-4**	**SD Log(Age-4)**	**Age-5**	**SD Log(Age-5)**	**Total**
Early Stuart	**86,700**	0.672	**17,900**	**1.360**	**104,600**
Early Summer	**436,300**	**1.152**	**56,900**	**0.927**	**493,100**
Fennell	23,000	0.902	4,300	1.184	27,300
Bowron	23,300	0.799	2,600	1.188	25,900
Raft	24,200	0.864	2,500	1.096	26,700
Gates	29,000	0.748	1,200	1.308	30,200
Nadina	26,900	0.785	3,000	1.176	29,900
Pitt	20,600	1.162	42,000	0.797	62,600
Seymour	101,600	0.930	200	1.499	101,800
Scotch	187,600	1.421	1,100	1.609	188,700
Mid Summers	**8,382,100**	**0.611**	**623,500**	**2.321**	**9,005,600**
Chilko	825,500	0.717	120,200	1.411	945,700
Quesnel	6,478,300	0.515	242,300	2.949	6,720,600
Stellako	590,600	0.650	24,300	1.001	614,900
Late Stuart	487,700	1.232	236,700	2.042	724,400
Late Summer	**3,255,100**	**0.892**	**57,400**	**1.013**	**3,312,601**
Birkenhead	376,300	0.892	44,700	1.013	421,001
Late Shuswap	2,300,400	0.459	0	-	2,300,400
Cultus	6,700	0.977	0	-	6,700
Portage	207,000	1.153	1,100	1.995	208,100
Weaver	364,800	0.993	11,600	1.184	376,400
TOTAL	**12,160,200**		**755,700**		**12,915,901**

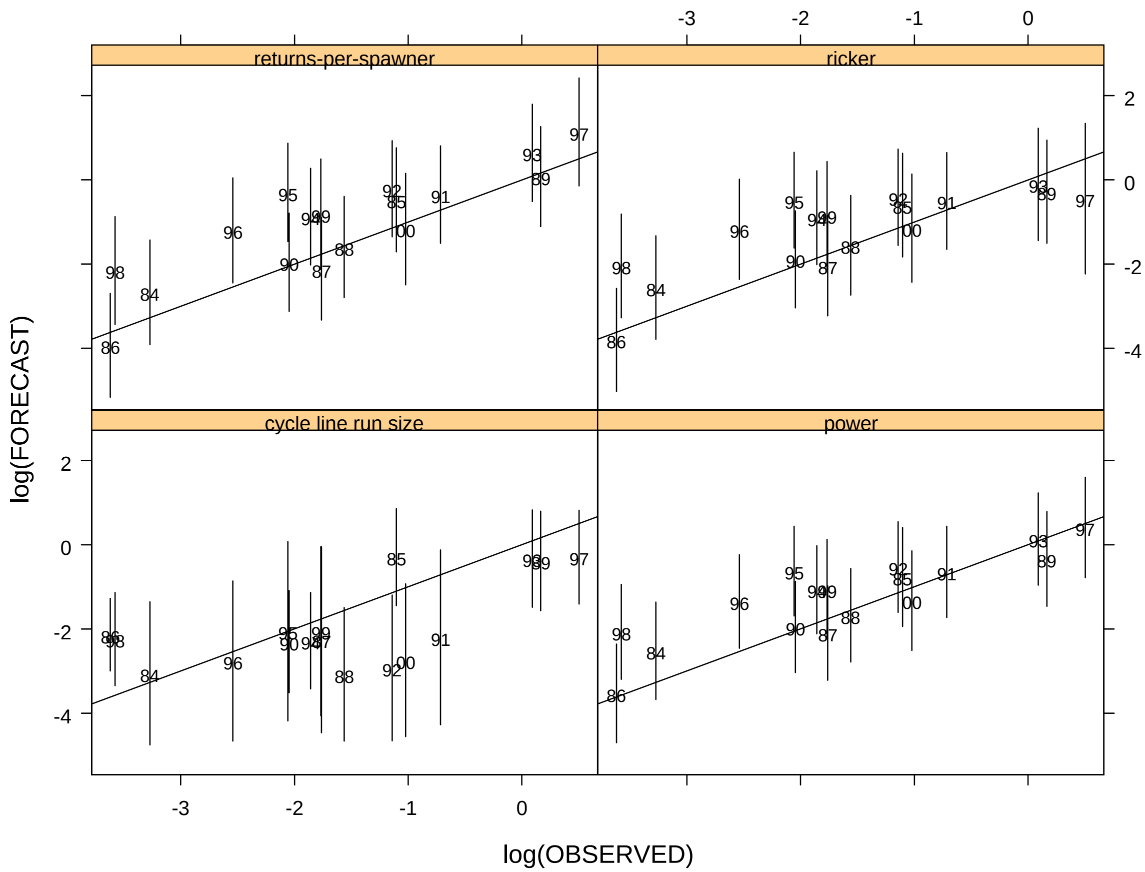

Figure 1. Comparison of estimated (observed) returns and retrospective run size forecasts (millions ($\log_e$ scale)) of age-4 Early Stuart sockeye for candidate models. Data points are median (50%) forecasts and are denoted by return year. Diagonal lines are 1:1 lines not regression lines. Error bars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

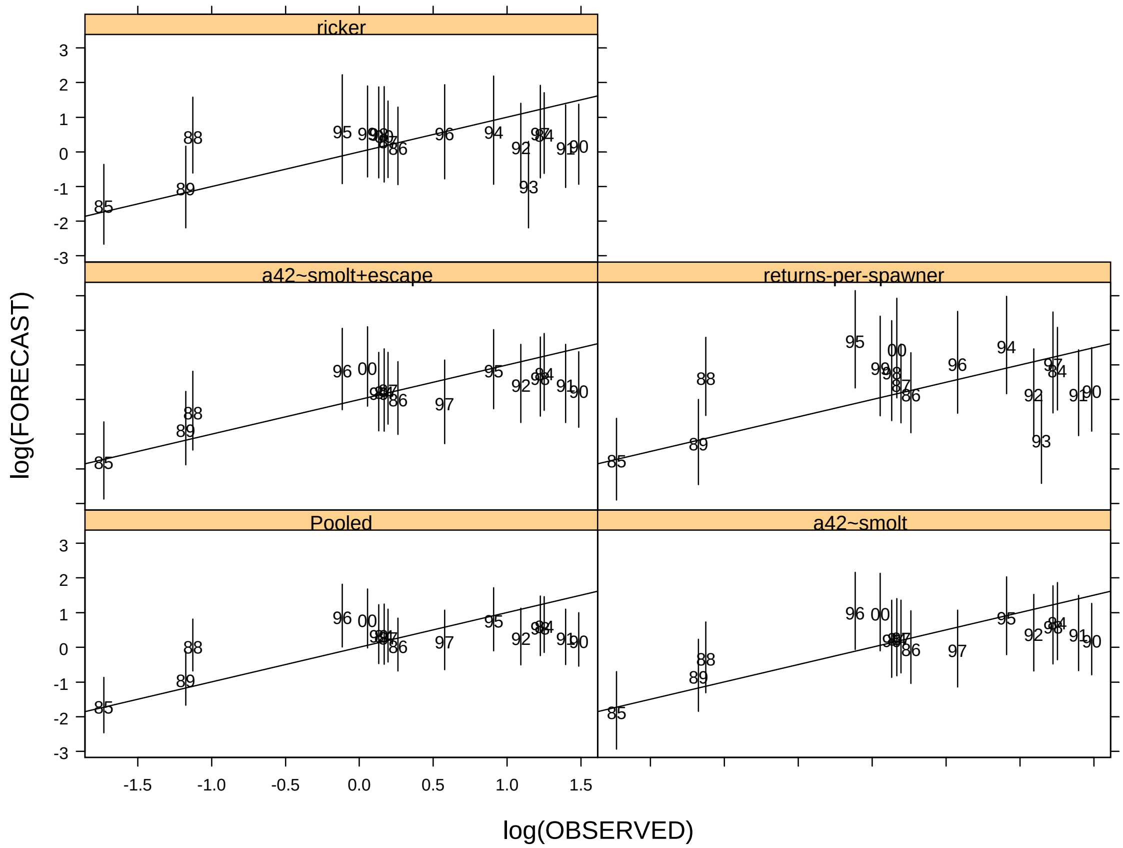

Figure 2. Comparison of estimated (observed) returns and retrospective run size forecasts (millions ($\log_e$ scale)) of age-4 Chilko sockeye for candidate models. Data points are median (50%) forecasts and are denoted by return year. Diagonal lines are 1:1 lines not regression lines. Error bars are 90% confidence intervals.

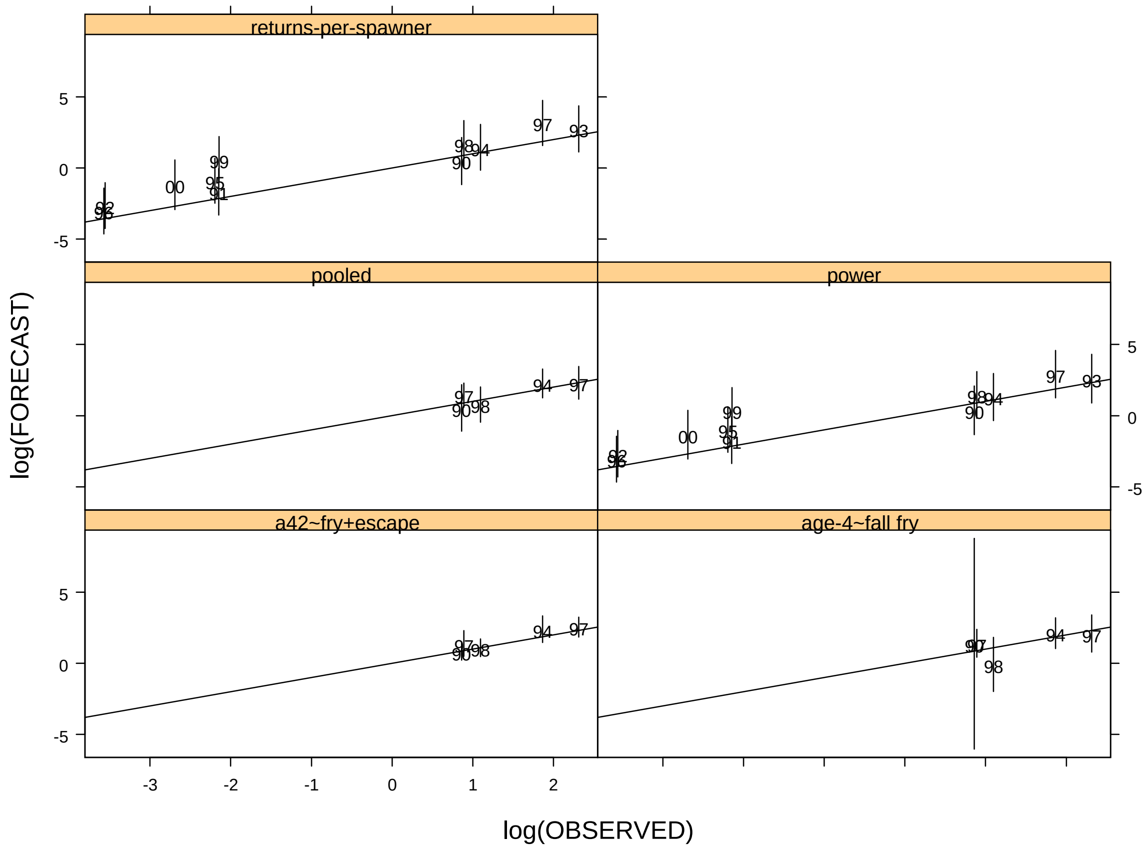

Figure 3. Comparison of estimated (observed) returns and retrospective run size forecasts (millions ($\log_e$ scale)) of age-4 Quesnel sockeye for candidate models. Data points are median (50%) forecasts and are denoted by return year. Diagonal lines are 1:1 lines not regression lines. Error bars are 90% confidence intervals.

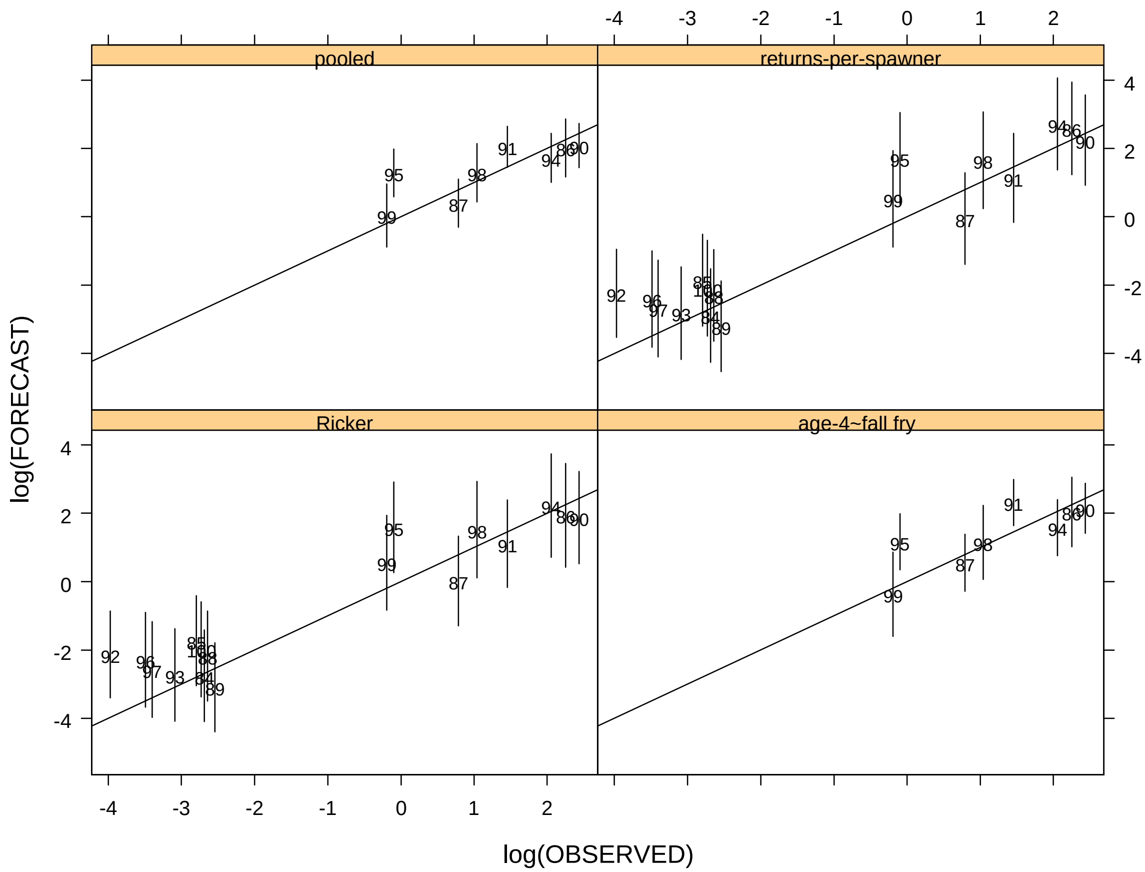

Figure 4. Comparison of estimated (observed) returns and retrospective run size forecasts (millions ($\log_e$ scale)) of age-4 Late Shuswap sockeye for candidate models. Data points are median (50%) forecasts and are denoted by return year. Diagonal lines are 1:1 lines not regression lines. Error bars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

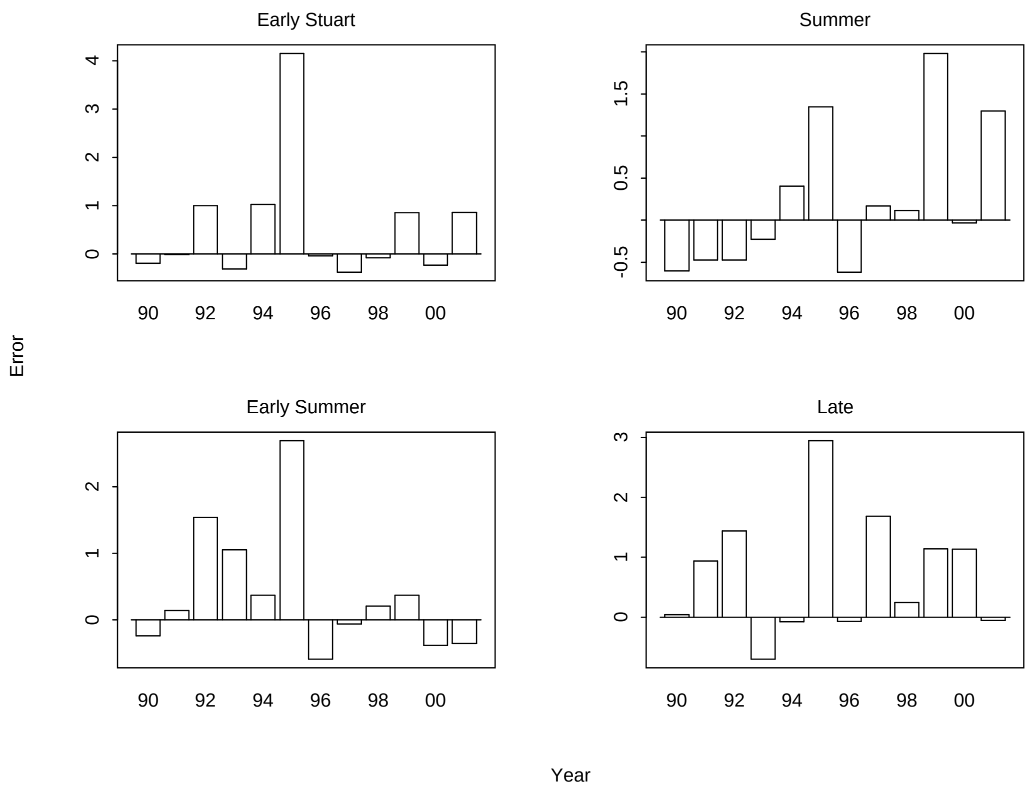

Figure 5. Proportional deviation of forecasts from observed run size by run-timing group for Fraser River sockeye (1990-2001). Deviations in 1990-2000 are based on post-season estimates of run size. Deviations in 2001 are based on final in-season estimates and are therefore very preliminary.

Early Stuart

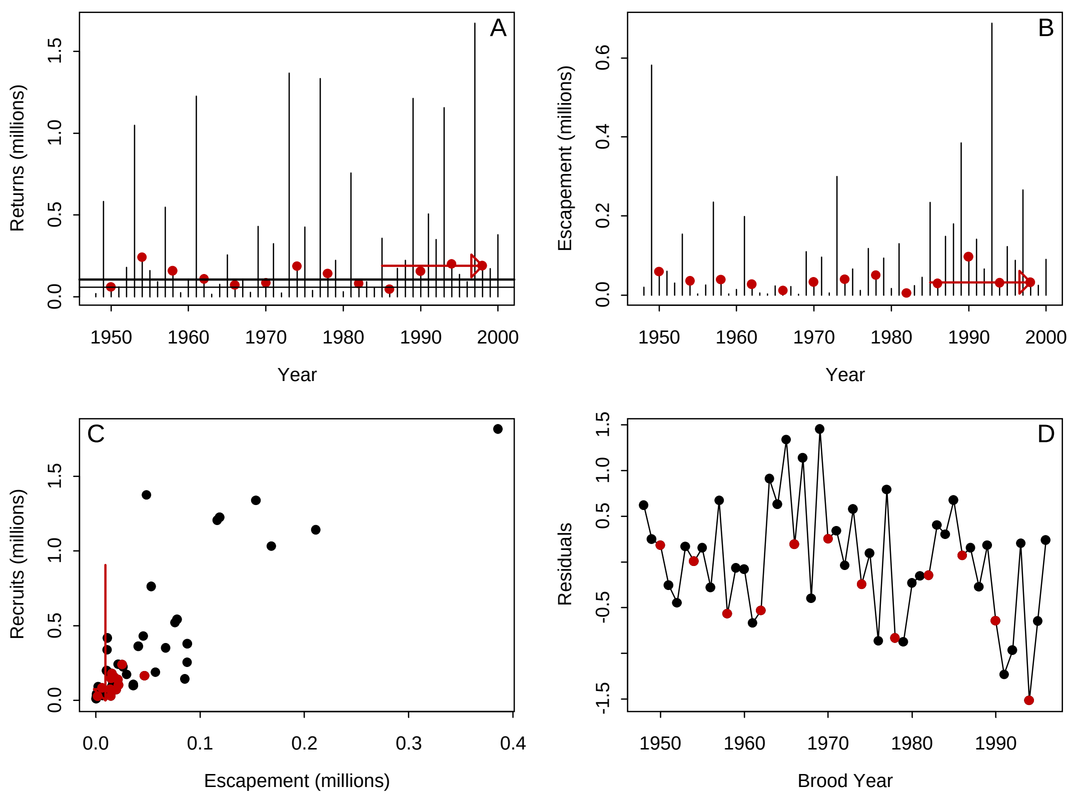

Figure. 6. A) Trend in Early Stuart sockeye adult returns. Horizontal lines show the 2002 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, C) recruit-effective female escapement relationship and D) residual trend ($\log_e$ scale) from the fit of the Power model to the relationship in C. Arrows depict 1998 data. Red data points depict the 2002 cycle line.

Fennell

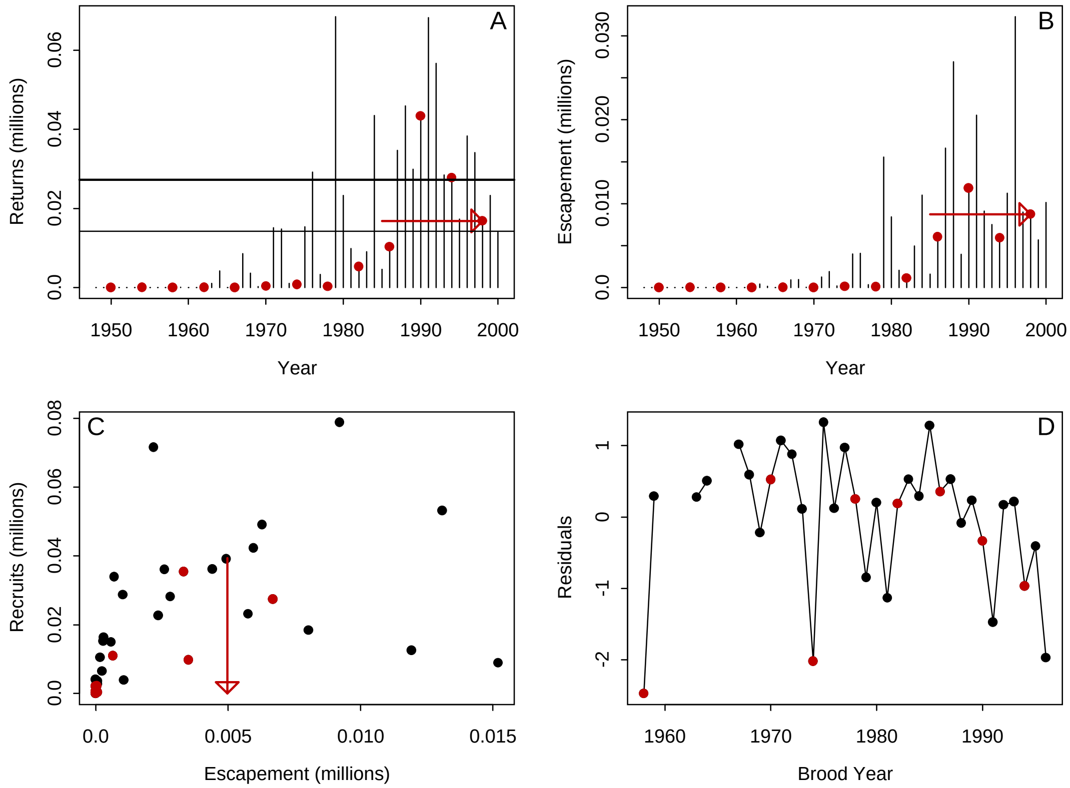

Figure. 7. A) Trend in Fennell Creek sockeye adult returns. Horizontal lines show the 2002 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, C) recruit-effective female escapement relationship and D) residual trend ($\log_e$ scale) from the fit of the Power model to the relationship in C. Arrows depict 1998 data. Red data points depict the 2002 cycle line.

Bowron

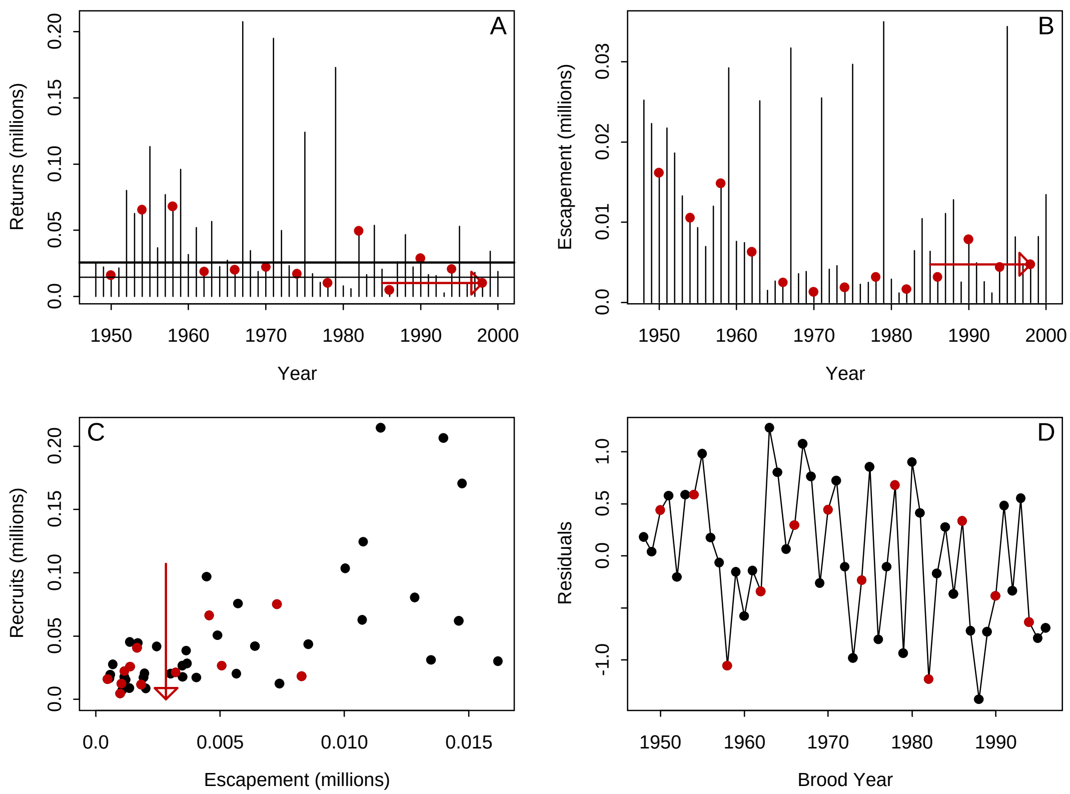

Figure. 8. A) Trend in Bowron River sockeye adult returns. Horizontal lines show the 2002 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, C) recruit-effective female escapement relationship and D) residual trend ($\log_e$ scale) from the fit of the Power model to the relationship in C. Arrows depict 1998 data. Red data points depict the 2002 cycle line.

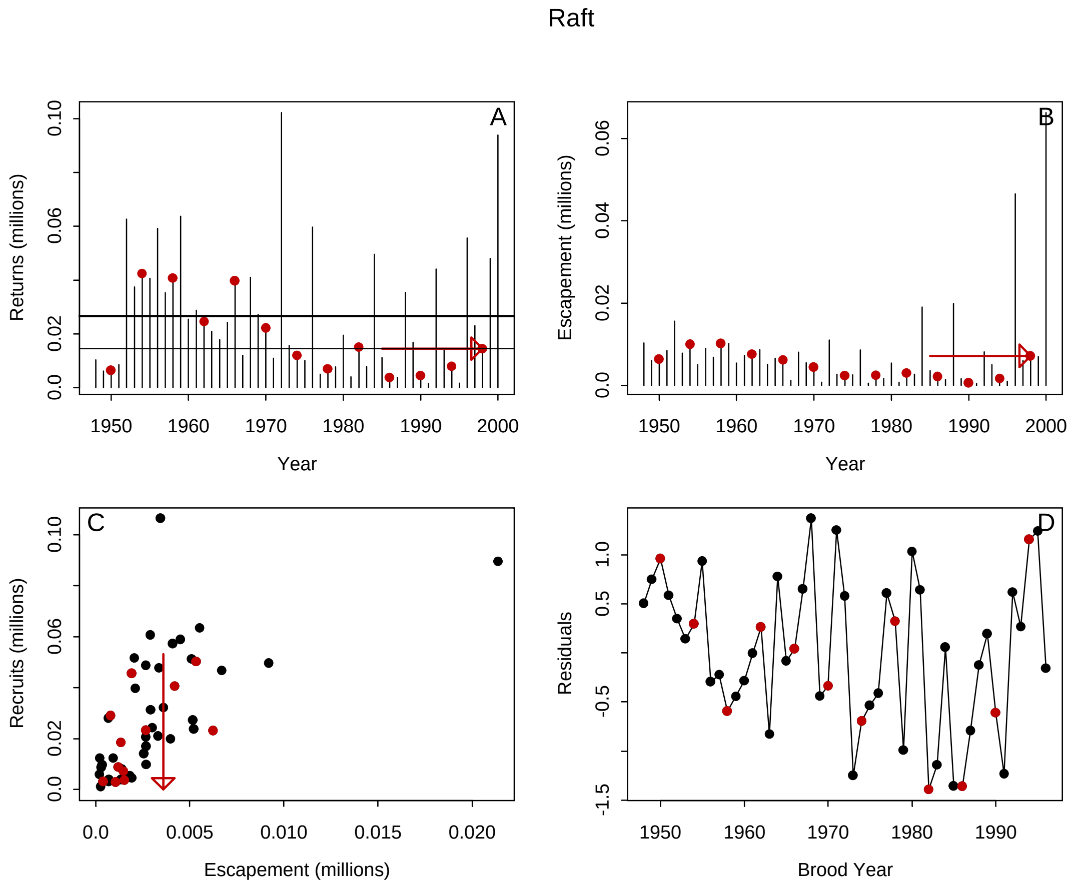

Figure.9. A) Trend in Raft River sockeye adult returns. Horizontal lines show the 2002 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, C) recruit-effective female escapement relationship and D) residual trend ($\log_e$ scale) from the fit of the Power model to the relationship in C. Arrows depict 1998 data. Red data points depict the 2002 cycle line.

Gates

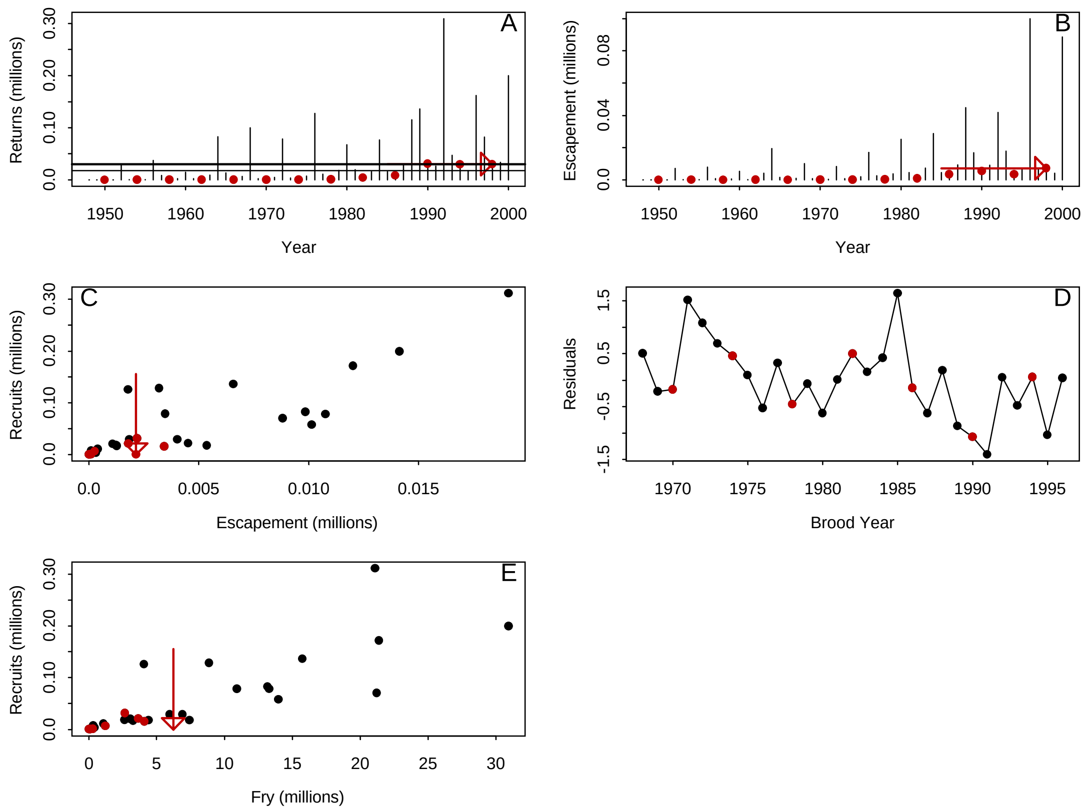

Figure. 10. A) Trend in Gates Creek sockeye adult returns. Horizontal lines show the 2002 forecast at the 50% (upper) and 75% (lower) probability level. B) Trend in adult spawners, C) recruit-effective female relationship, D) residual trend ($\log_e$ scale) from a recruits-per-spawner model and E) recruit-fry relationship. Plots C-E exclude years prior to spawning channel production. Arrows depict 1998 data. Red data points depict the 2002 cycle line.

Nadina

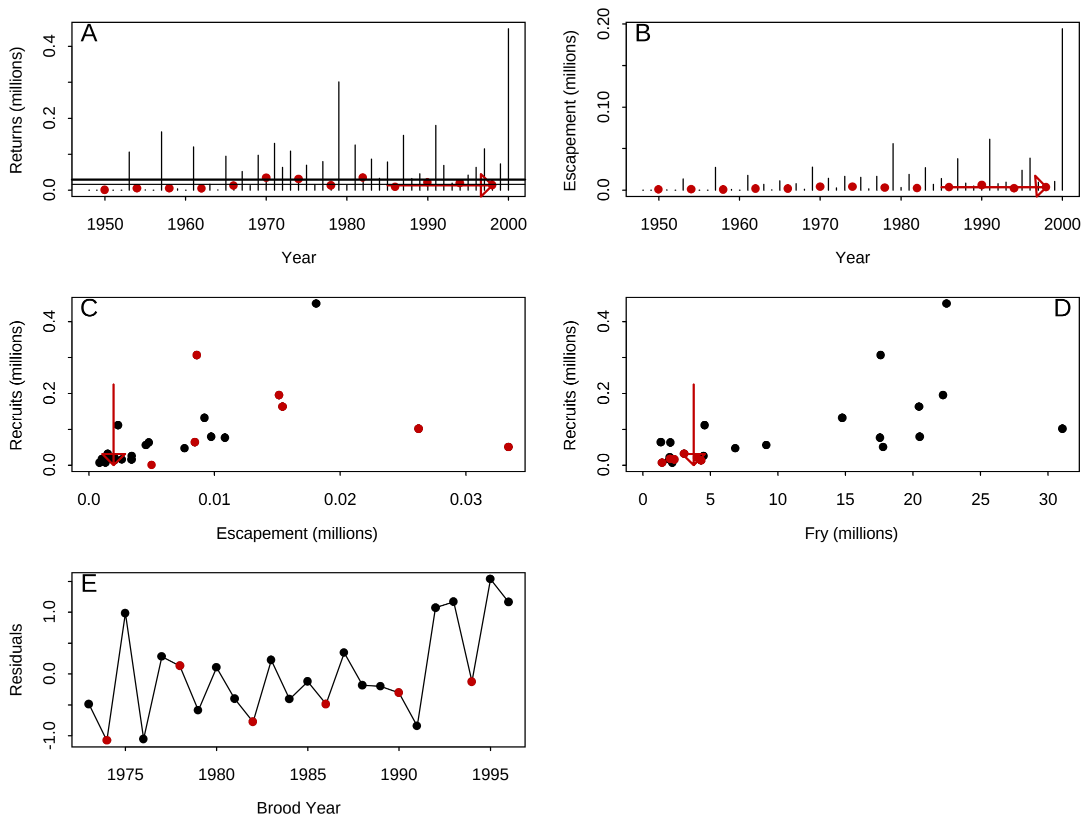

Figure. 11. A) Trend in Nadina River sockeye adult returns. Horizontal lines show the 2002 forecast at the 50% (upper) and 75% (lower) probability level. B) Trend in adult spawners, C) recruit-effective female relationship, D) recruit-fry relationship and E) residual trend ($\log_e$ scale) from the fit of the power model to the relationship in D. Plots C-E exclude years prior to spawning channel production. Arrows depict 1998 data. Red data points depict the 2002 cycle line.

Upper Pitt

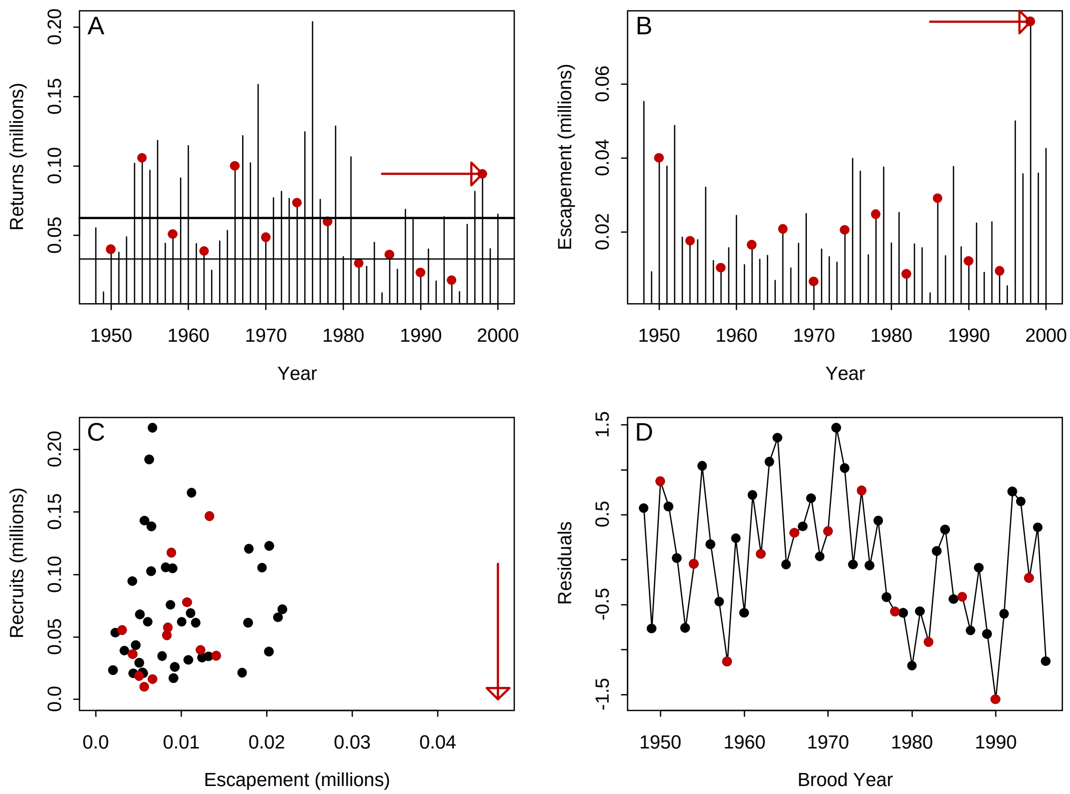

Figure. 12. A) Trend in Upper Pitt sockeye adult returns. Horizontal lines show the 2002 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, C) recruit-effective female escapement relationship and D) residual trend ($\log_e$ scale) from the fit of the Power model to the relationship in C. Arrows depict 1998 data. Red data points depict the 2002 cycle line.

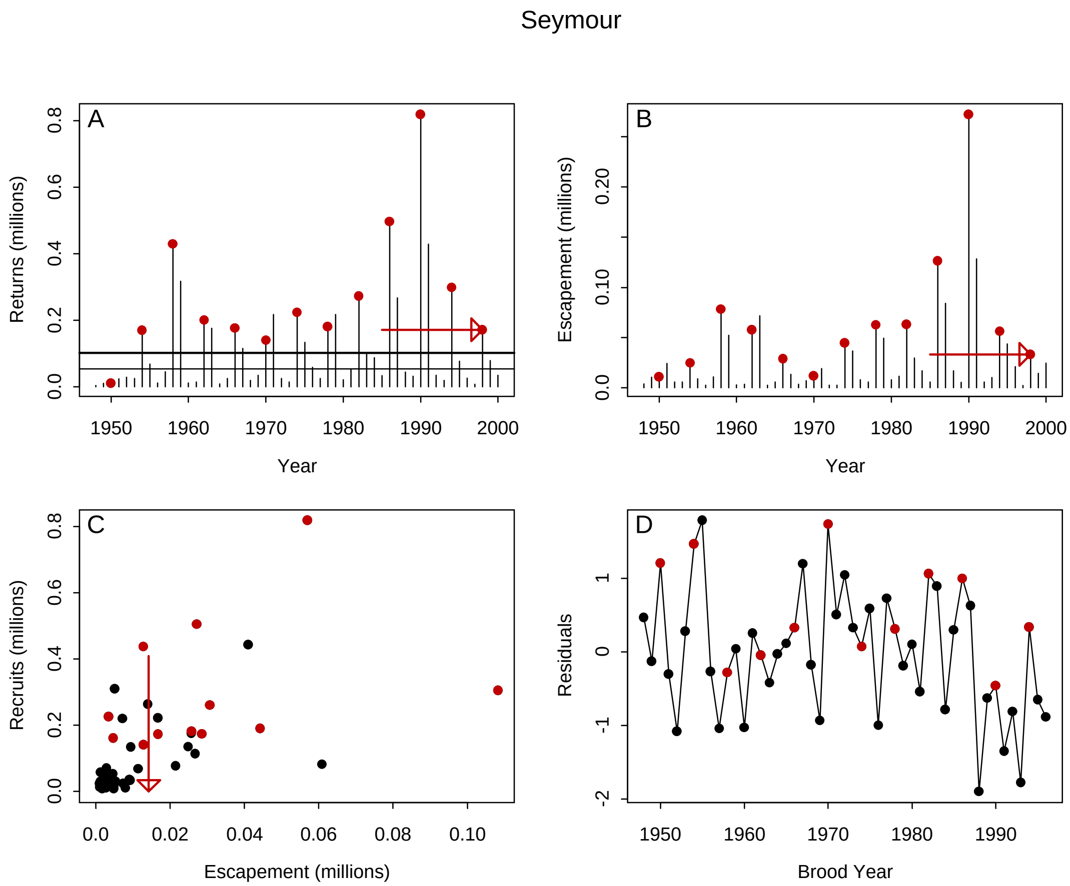

Figure. 13. A) Trend in Seymour River sockeye adult returns. Horizontal lines show the 2002 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, C) recruit-effective female escapement relationship and D) residual trend ($\log_e$ scale) from the fit of the Power model to the relationship in C. Arrows depict 1998 data. Red data points depict the 2002 cycle line.

Scotch

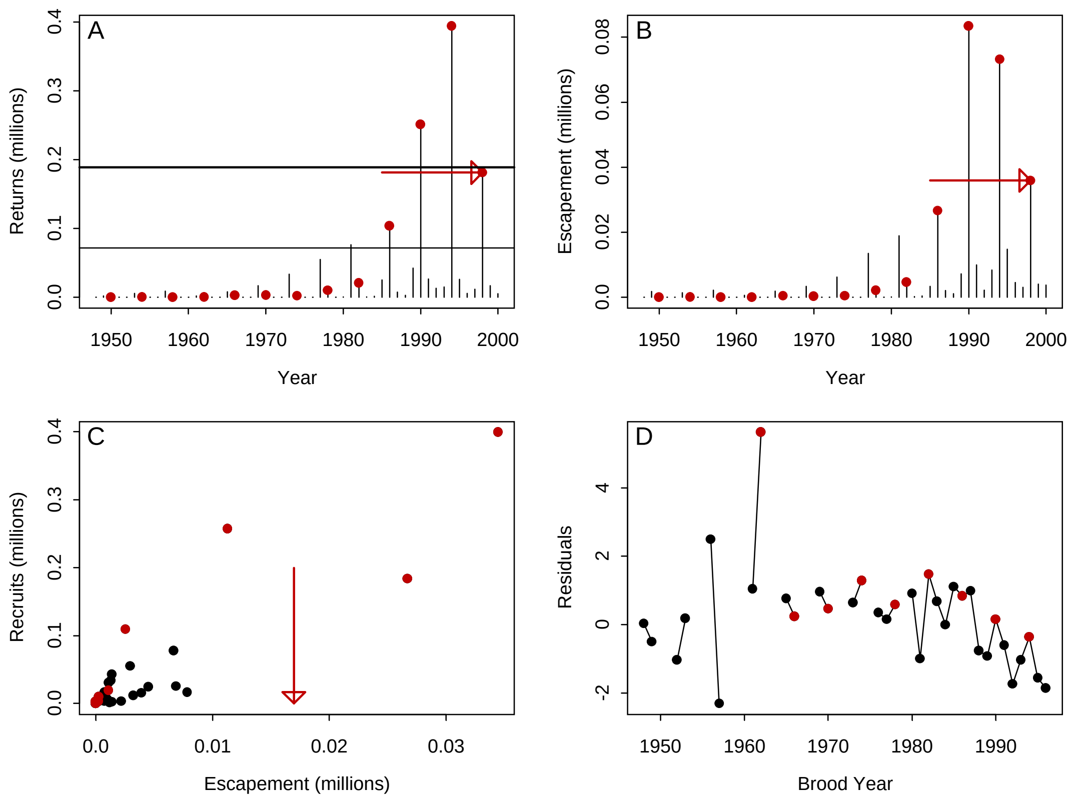

Figure. 14. A) Trend in Scotch Creek sockeye adult returns. Horizontal lines show the 2002 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, C) recruit-effective female escapement relationship and D) residual trend ($\log_e$ scale) from a recruits-per-spawner model. Arrows depict 1998 data. Red data points depict the 2002 cycle line.

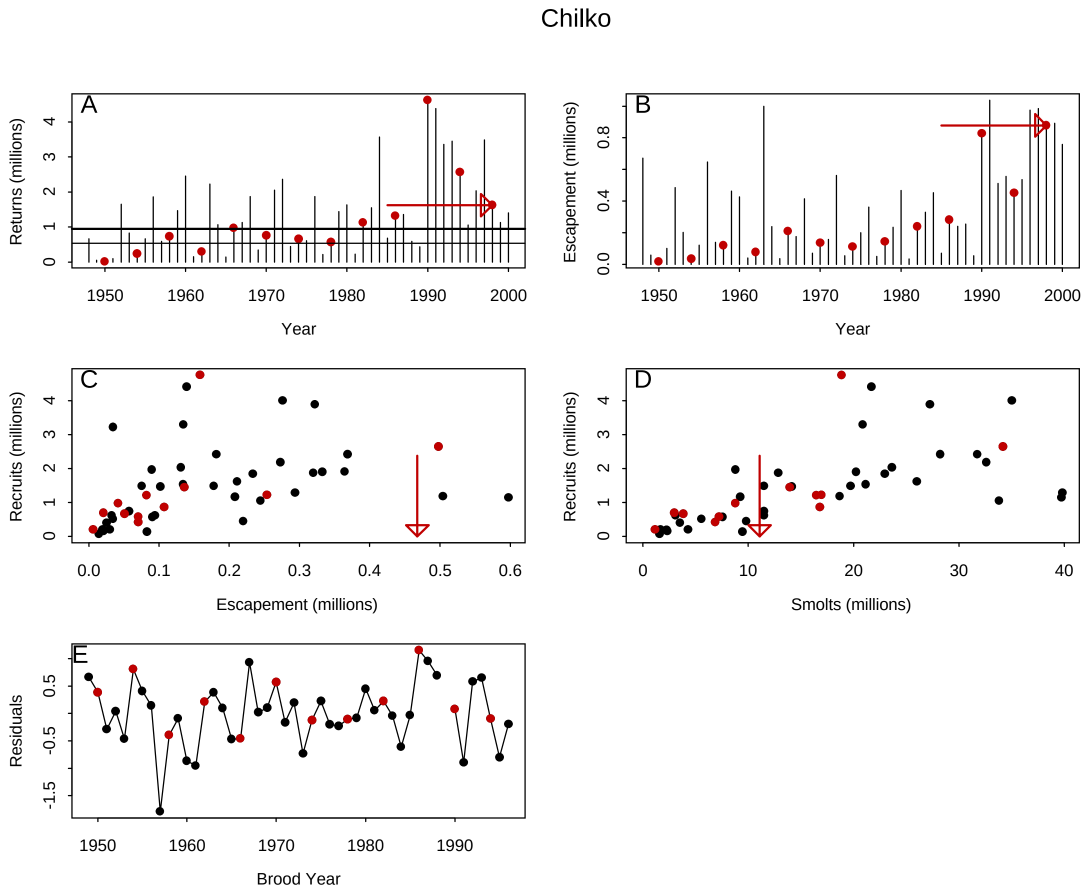

Figure. 15. A) Trend in Chilko sockeye adult returns. Horizontal lines show the 2002 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, C) recruit-effective female relationship, D) recruit-smolt relationship and E) residual trend ($\log_e$ scale) from the fit of the Power model with effective females and smolts as independent variables. Arrows depict 1998 data. Red data points depict the 2002 cycle line.

Quesnel

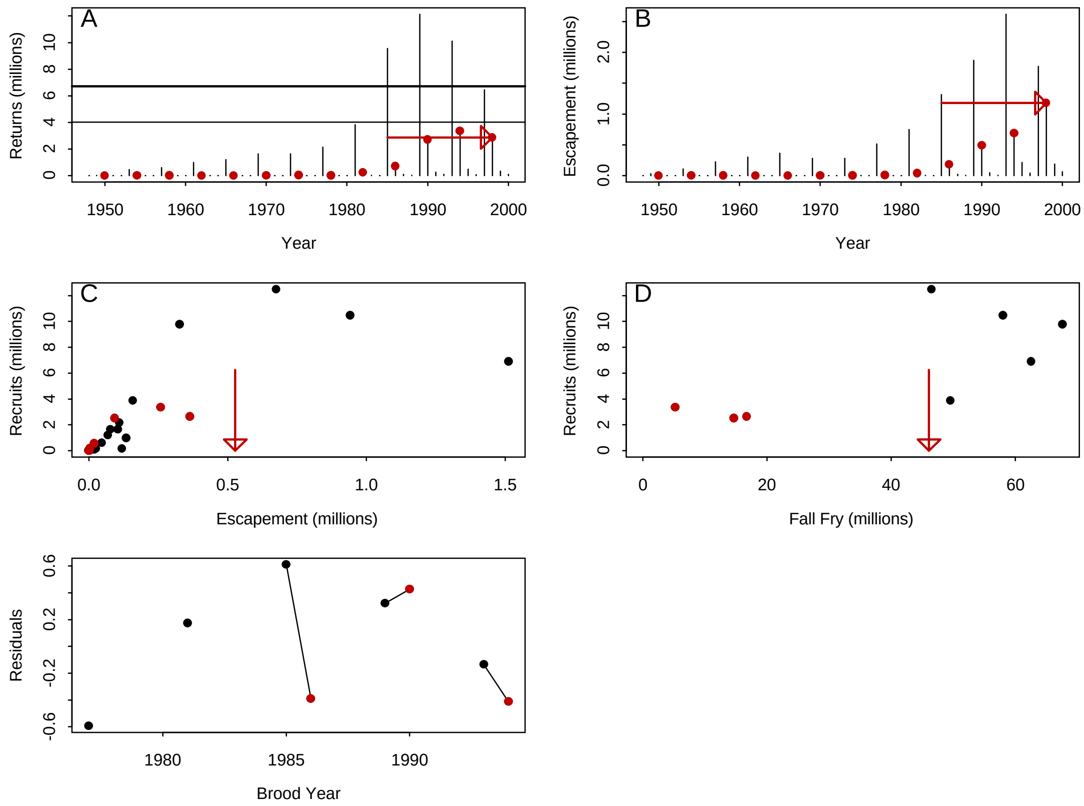

Figure. 16. A) Trend in Quesnel sockeye adult returns. Horizontal lines show the 2002 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, C) recruit-effective female relationship, D) recruit-Fall Fry relationship and E) residual trend ($\log_e$ scale) from the fit of the Power model to the relationship in D. Arrows depict 1998 data. Red data points depict the 2002 cycle line.

Late Stuart

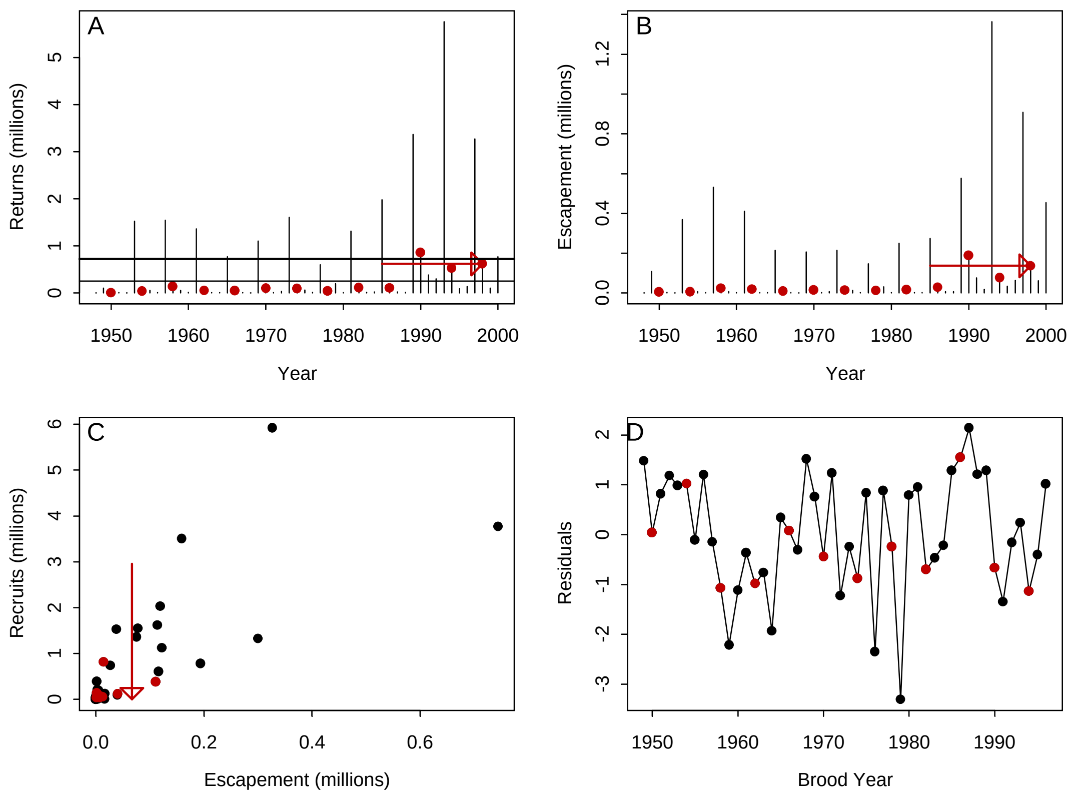

Figure. 17. A) Trend in Late Stuart sockeye adult returns. Horizontal lines show the 2002 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, C) recruit-effective female escapement relationship and D) residual trend (log_e scale) from the fit of the Power model to the relationship in C. Arrows depict 1998 data. Red data points depict the 2002 cycle line.

Stellako

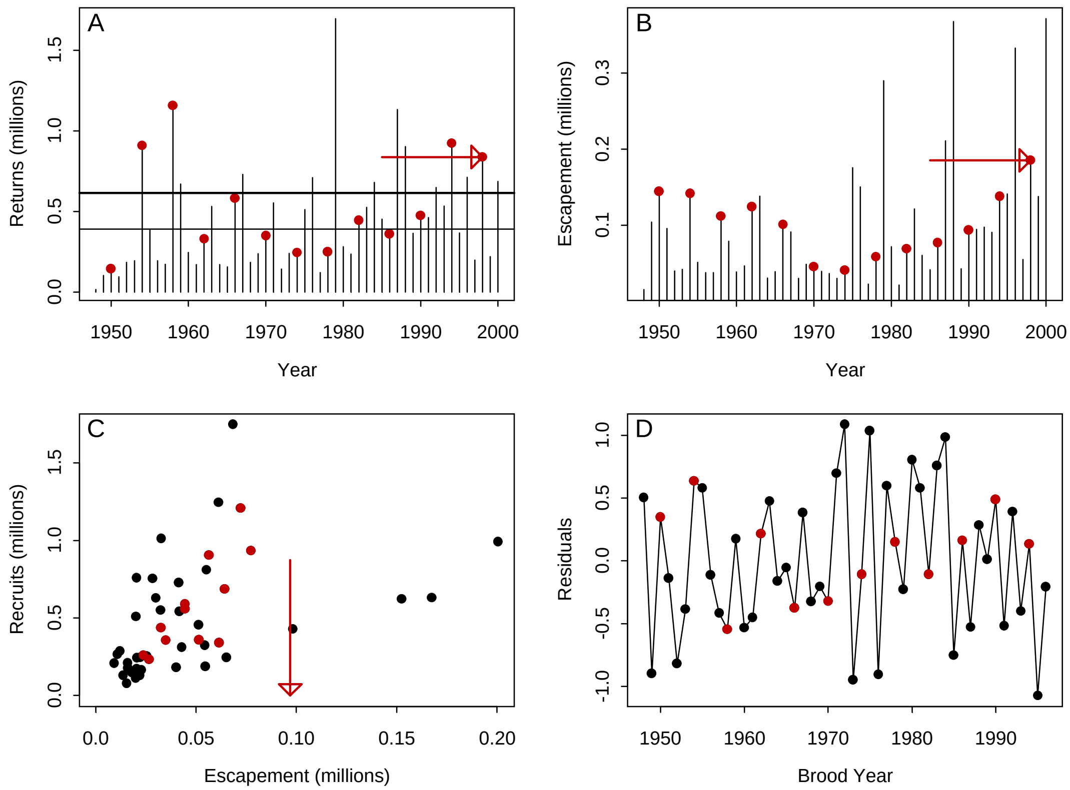

Figure. 18. A) Trend in Stellako sockeye adult returns. Horizontal lines shows the 2002 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, C) recruit-effective female escapement relationship and D) residual trend ($\log_e$ scale) from the fit of the Ricker model to the relationship in C. Arrows depict 1998 data. Red data points depict the 2002 cycle line.

Birkenhead

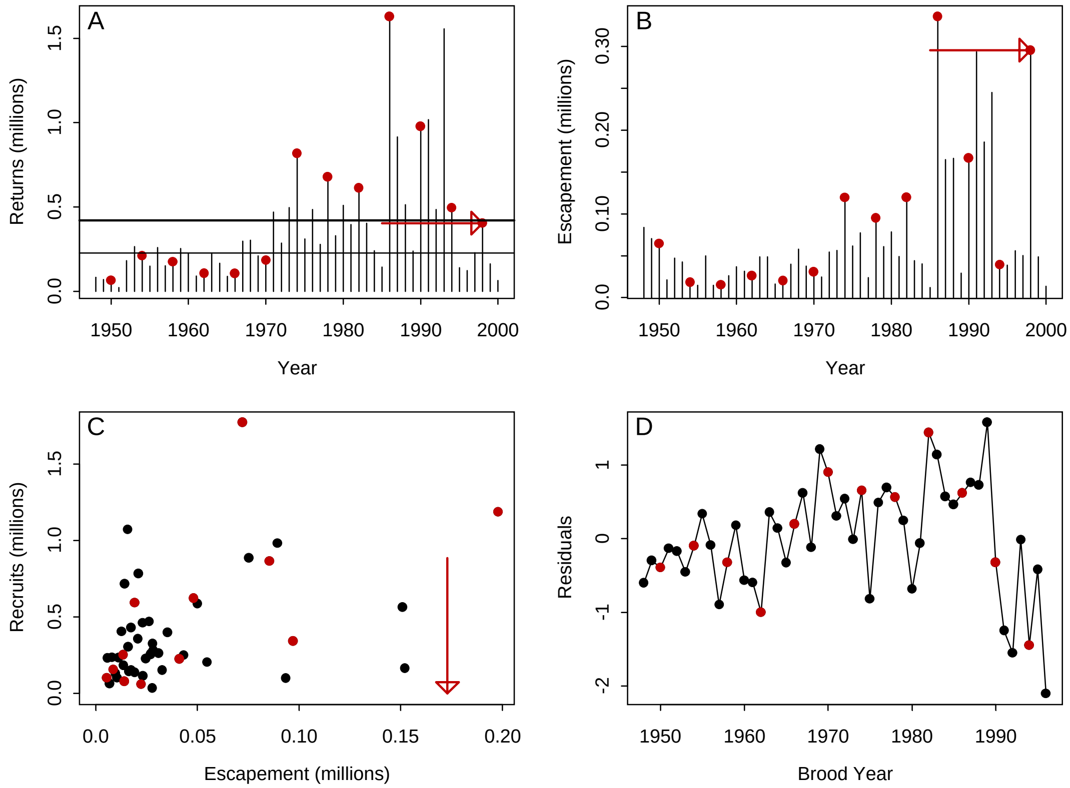

Figure. 19. A) Trend in Birkenhead River sockeye adult returns. Horizontal lines show the 2002 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, C) recruit-effective female escapement relationship and D) residual trend (log_e scale) from the fit of the Power model to the relationship in C. Arrows depict 1998 data. Red data points depict the 2002 cycle line.

Late Shuswap

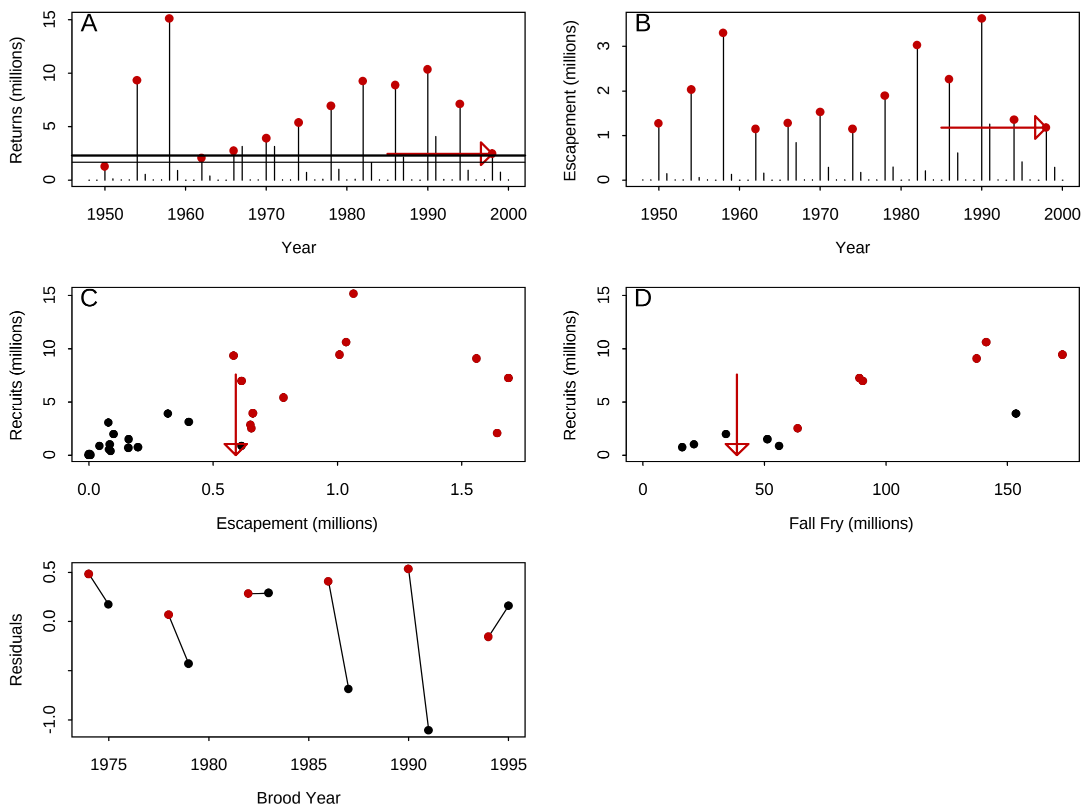

Figure. 20. A) Trend in Late Shuswap sockeye adult returns. Horizontal lines shows 2002 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, C) recruit-effective female relationship, D) recruit-Fall Fry relationship and E) residual trend ($\log_e$ scale) from the fit of the Power model to the relationship in D. Arrows depict 1998 data. Red data points depict the 2002 cycle line.

Cultus

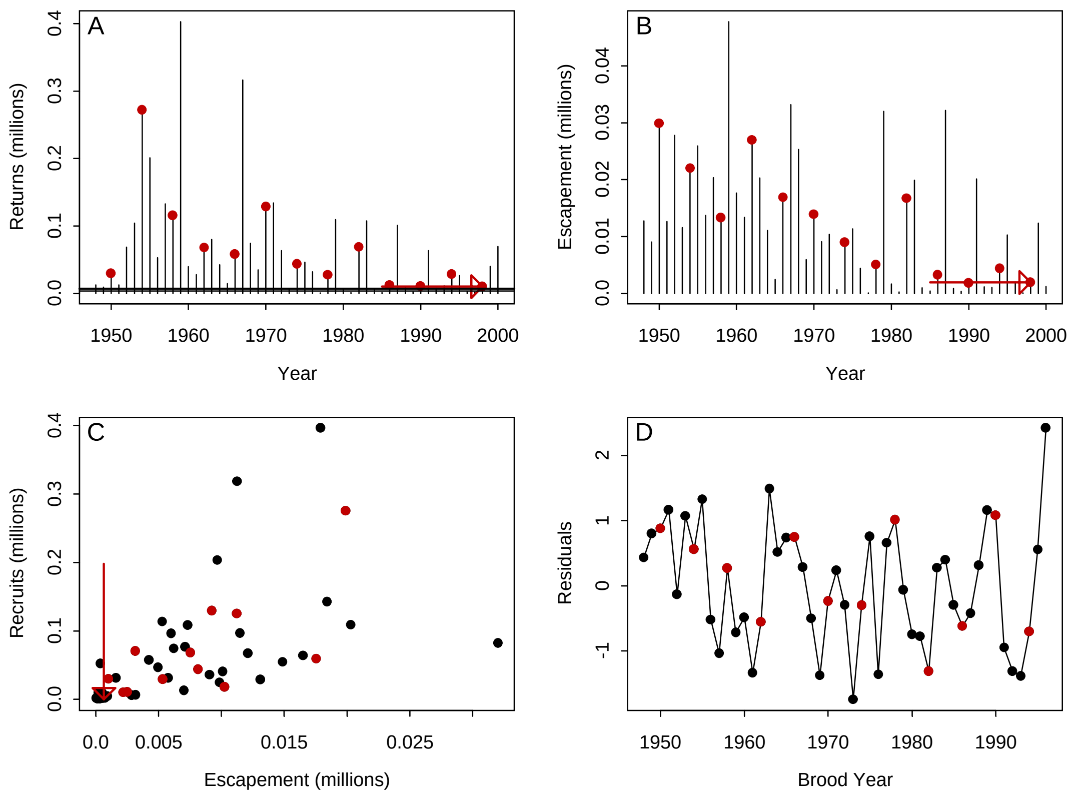

Figure. 21. A) Trend in Cultus Lake sockeye adult returns. Horizontal lines show the 2002 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, C) recruit-effective female escapement relationship and D) residual trend ($\log_e$ scale) from the fit of the Power model to the relationship in C. Arrows depict 1998 data. Red data points depict the 2002 cycle line.

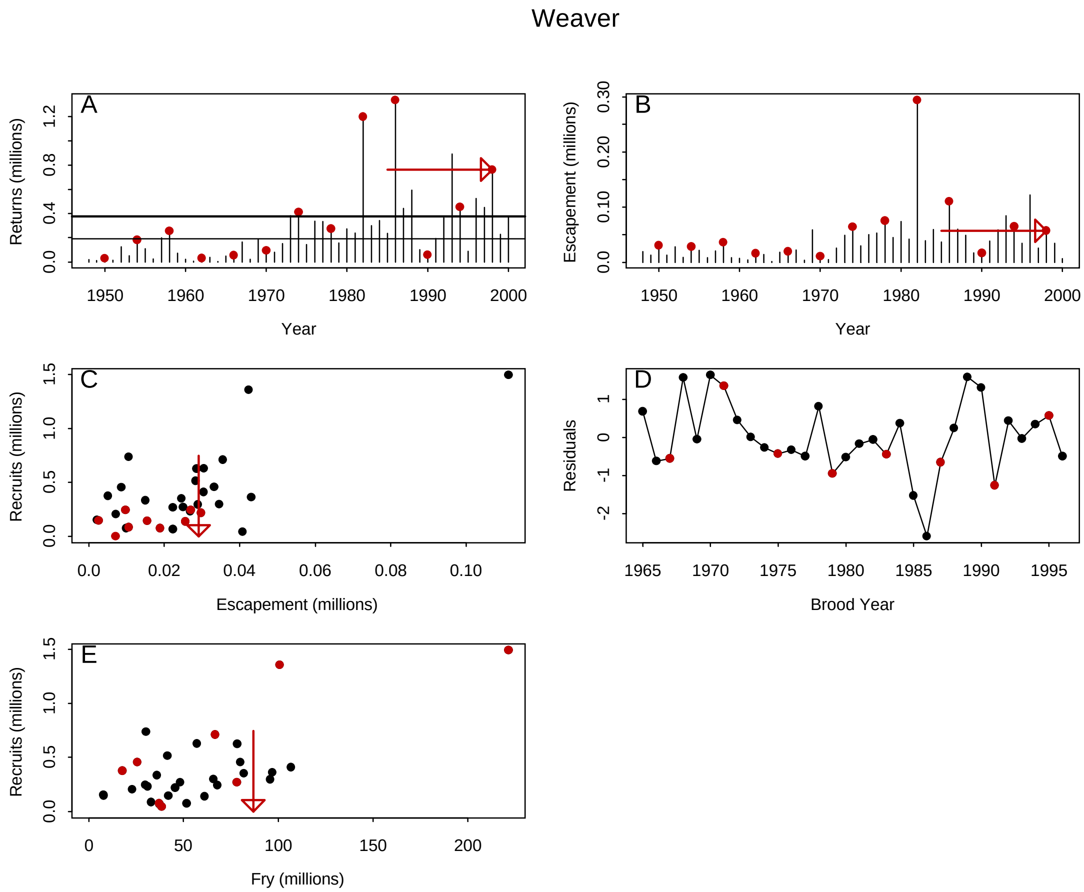

Figure. 22. A) Trend in Weaver Creek sockeye adult returns. Horizontal lines show the 2002 forecast at the 50% (upper) and 75% (lower) probability level. B) Trend in adult spawners, C) recruit-effective female relationship, D) residual trend ($\log_e$ scale) from a recruits-per-spawner model, and E) recruit-fry relationship. Plots C-E exclude years prior to spawning channel production. Arrows depict 1998 data. Red data points depict the 2002 cycle line.

Portage

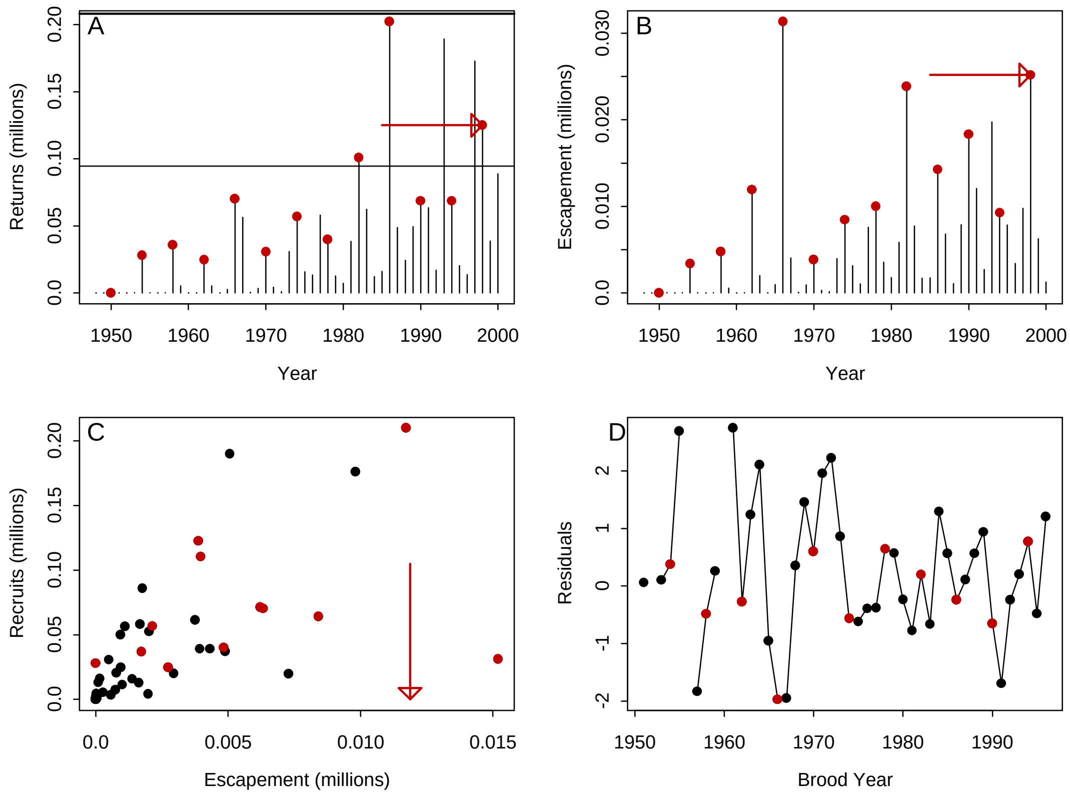

Figure. 23. A) Trend in Portage sockeye adult returns. Horizontal lines shows 2002 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, C) recruit-effective female escapement relationship and D) residual trend (log_e scale) from a fit of the recruits-per-spawner model. Arrows depict 1998 data. Red data points depict the 2002 cycle line.

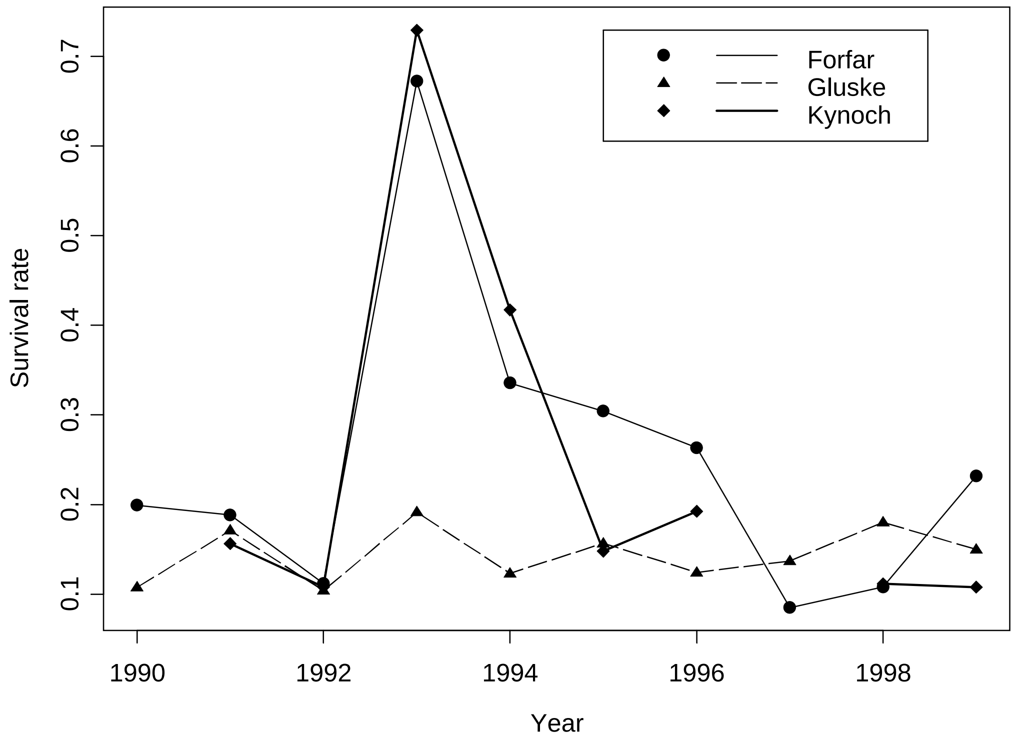

Figure. 24. Early Stuart fry survival rates by spawning site.

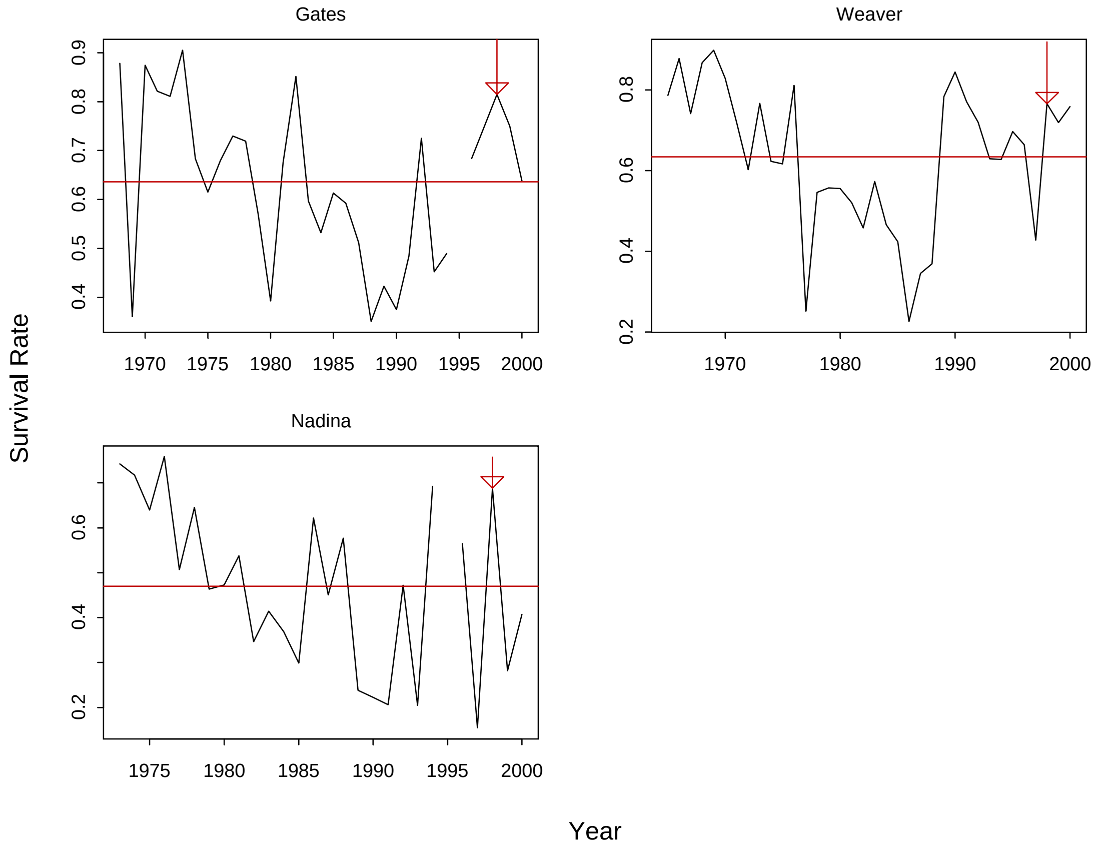

Figure 25. Sockeye Egg-to-fry survival rates at Fraser River spawning channels. The arrow shows the 1998 brood survival. The horizontal line in the long-term mean.

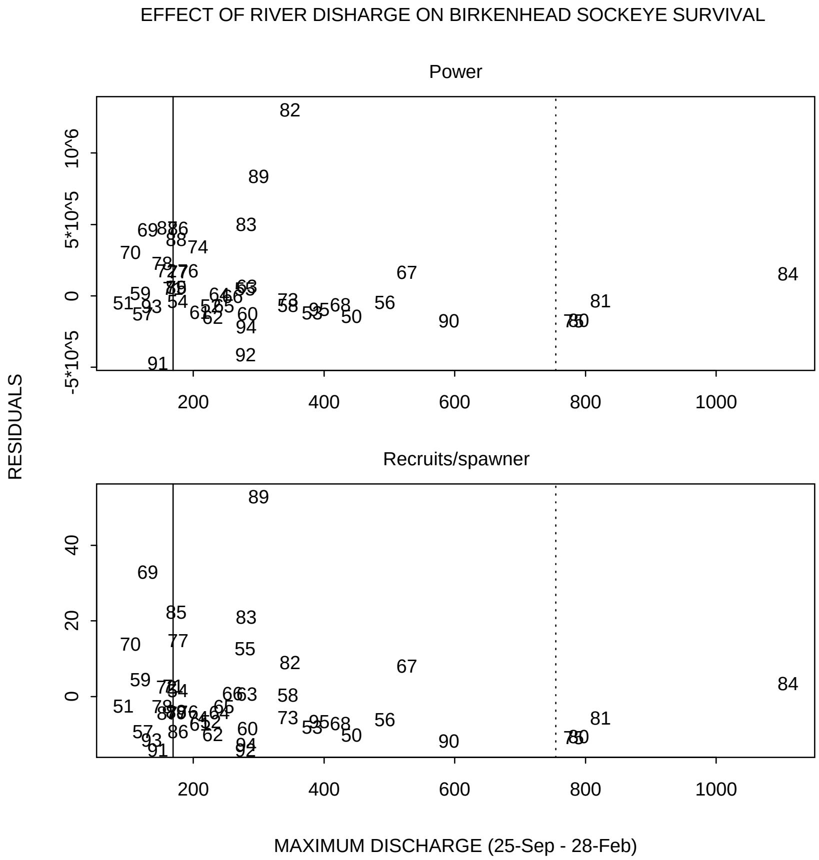

Figure. 26. Residuals from escapement - returns data fit to a power model and recruits-per-spawner model versus Lillooet River discharge rates (1950-98). Vertical lines correspond to the observed maximum daily discharge rate between September 25 and February 28. The broken line is for discharge rates affecting age-5 returns and solid line is for discharge rates affectingage-4 returns in 2002.

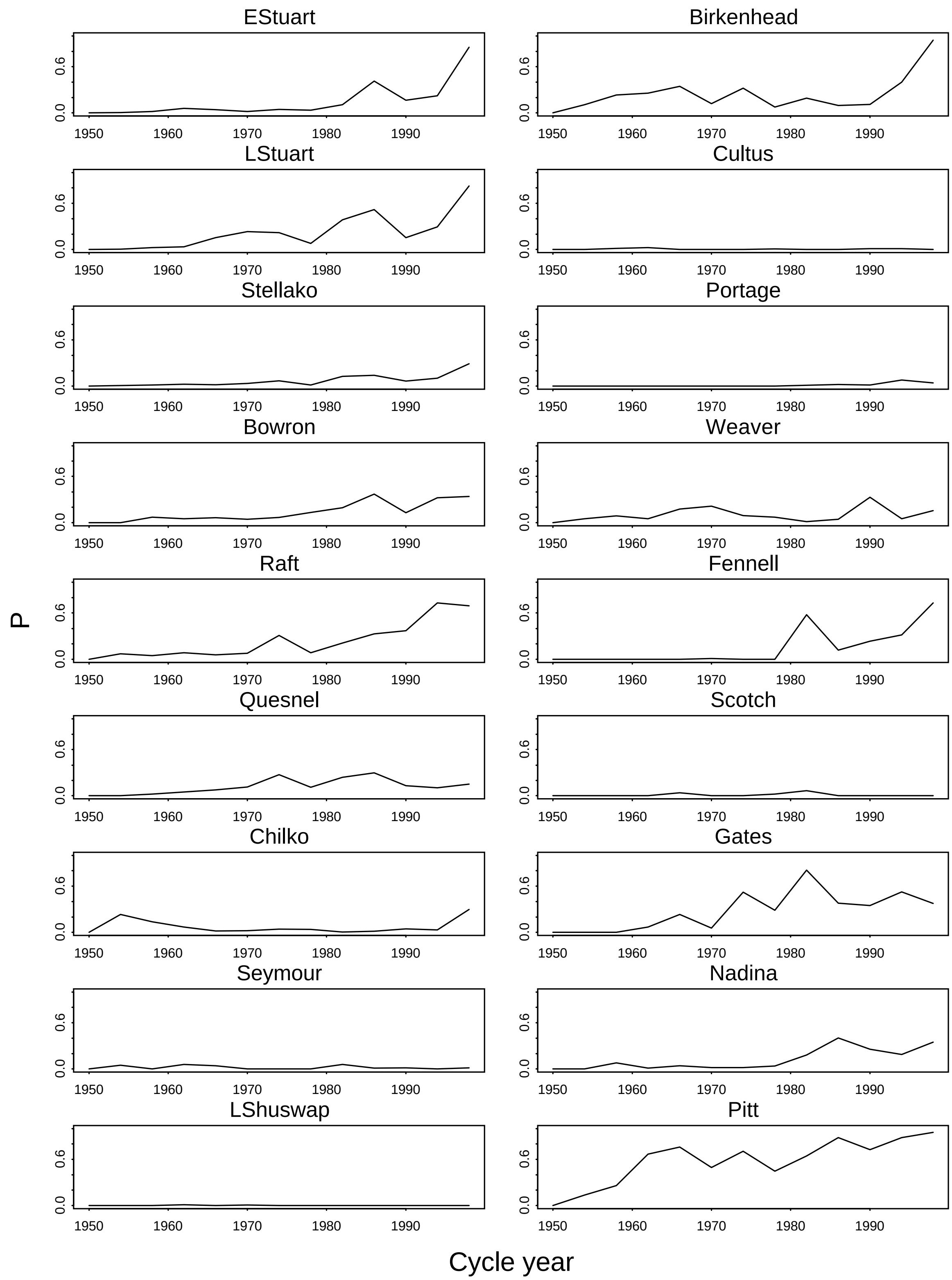

Figure 27. Proportion (P) of age-5 returns (1950-1998) on the 2002 cycle line by stock.