Fisheries and Oceans Canada | Pêches et Océans Canada

Canadian Stock Assessment Secretariat
Research Document 99/129

Secrétariat canadien pour l'évaluation des stocks
Document de recherche 99/129

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Run size forecasts for Fraser River sockeye and pink salmon in 1999

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ISSN 1480-4883
Ottawa, 1999

Canada

Abstract

Run size forecasts for 1999 Fraser River sockeye and pink returns presented here are based on methods previously approved by PSARC. Forecasts are made for 18 individual sockeye stocks and four migratory timing / management groups. Forecasts of pink salmon are made for all Fraser pink populations combined. Forecasts are based on a variety of explanatory variables. For most stocks, forecasts are based on regression models that use spawning escapement to predict adult abundance. Additional explanatory variables are available for some stocks and include fry and smolt abundance estimates. Environmental indices are also used to help explain variation in ocean survival of Chilko sockeye and pink salmon. Methods that incorporate attributes of escapement-based and juvenile-based models are explored that pool results from individual sockeye forecast models (i.e. Baysian approach) where time series of different life stages are available. Sibling models were not considered suitable candidate models for forecasting 1999 returns because estimates of age-3 jack returns in 1998 are considered to be particularly unreliable and because of the poor performance of sibling models in recent years compared to other forecast models.

The total 1998 Fraser sockeye run size forecast is 8.2 million sockeye at the 50% probability level (the chance the run will exceed the forecast) and 4.8 million at the 75% probability level. Forecasts by management group are 318,000 (50%) and 197,000 (75%) for Early Stuart, 477,000 (50%) and 244,000 (75%) for Early summer stocks, 5.3 million (50%) and 3.3 million (75%) for summer run stocks and 2.1 million (50%) and 1.1 million (75%) for late run stocks. The 1999 forecast of Fraser pink is 8.1 million at the 50% probability level and 6.4 million at the 75% level (Table 1). A particular cautious note is warranted for 1999 sockeye returns. Sockeye smolts that return as adults in 1999 entered the ocean during the intense 1997 El Nino. Sockeye returns in 1995 that went to sea during the less intense 1993 El had very low survival rates for all major stocks. If the intense El Nino in 1997 resulted in low sockeye survival then forecasts presented here significantly over-estimate returns of Fraser sockeye in 1999.

Résumé

Les prévisions des remontées des saumons rouge et rose du Fraser en 1999 présentées ici sont fondées sur des méthodes antérieurement autorisées par PSARC. Des prévisions sont faites pour 18 stocks individuels de saumon rouge et quatre moments de migration ou groupes de gestion. Les prévisions de saumon rose portent sur l'ensemble des populations du Fraser. Elles reposent sur diverses variables explicatives. Pour la plupart des stocks, elles font appel à des modèles de régression où les échappées de géniteurs servent à la prévision de l'abondance des adultes. D'autres variables explicatives peuvent être utilisées pour certains stocks, notamment des estimations de l'abondance des alevins et des saumoneaux. Des indices environnementaux servent aussi à expliquer la variation de la survie en mer du saumon rouge Chilko et du saumon rose. Des méthodes faisant appel aux attributs de modèles fondés sur l'échappée et sur les juvéniles sont examinés. Ils regroupent les résultats de modèles individuels de prévision du saumon rouge (e.g. : approche Bayesienne) pour lesquelles des séries chronologiques pour les diverses étapes du cycle vital sont disponbles. Les modèles fondés sur les espèces jumelles n'ont pas été jugés appropriés pour la prévision des remontées de 1999 car les estimations des remontées des mâles de trois ans de 1998 ont été jugées particulièrement douteuses et ces modèles ont donné des résultats de beaucoup inférieurs à ceux des autres modèles de prévision au cours des dernières années.

La valeur prévue de la remontée des saumons rouges du Fraser en 1998 est 8,2 millions de saumons rouges au niveau de probabilité de 50 % (probabilité que la remontée soit supérieure à la prévision) et de 4,8 millions au niveau de probabilité de 75 %. Par groupes de gestion, les prévisions sont de 318 000 (50%) et de 197 000 (75%) pour la remontée hâtive de la Stuart, de 477 000 (50%) et 244 000 (75%) pour les stocks du début de l'été, de 5,3 millions (50%) et 3,3 millions (75%) pour les stocks d'été, et de 2,1 millions (50%) et 1,1 million (75%) pour les stocks tardifs. Les prévisions pour les saumons roses du Fraser en 1999 sont de 8,1 millions au niveau de probabilité de 50 % et de 6,4 millions au niveau de 75 % (Tableau 1). Des conditions particulières s'appliquent cependant aux remontées de saumons rouges de 1999. Les saumoneaux qui reviennent sous forme d'adultes en 1999 sont arrivés en mer pendant l'intense El Nino de 1997. Les remontées de saumons rouges de 1995 étaient constituées de poissons qui avaient atteint la mer en 1993 lorsque le El Nino était moins prononcé et le taux de survie de la plupart des stocks importants très faible. Si le El Nino prononcé de 1997 donne lieu à une faible survie du saumon rouge, les prévisions présentées ci-dessus pourraient alors être très supérieures aux remontées réelles de ce saumon rouge dans le Fraser en 1999.

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1 Introduction

Run size forecasts for 1999 Fraser River sockeye and pink returns presented here are based on methods previously approved by PSARC (Cass 1998, Cass 1997; Cass and Blackbourn 1996; Cass et al. 1995; Welch et al. 1994). Forecasts are made for 18 individual sockeye stocks and four migratory timing / management groups. The spawning escapement for these stocks accounted for 96% of the estimated total Fraser River escapement in 1995 (1999 brood year of age-4 returns). The remaining escapement was from small populations without sufficient time series of data to produce quantitative forecasts. Based on escapements in the brood year, the major stocks anticipated in 1999 are Chilko, subdominant Late Shuswap and Quesnel first off-cycle line sockeye. Forecasts are presented for age-4 and age-5 sockeye. The historical mean contribution of age-5 sockeye returns by year class is only 5%, however, the contribution of age-5s has been increasing in recent years. Age-5s can occur in much higher proportions of the returns by return year for highly cyclic stocks in off-cycle years with low age-4 abundance (i.e. 1998). Forecasts of pink salmon are made for all Fraser pink populations combined.

Forecasts of adult returns of sockeye and pink are based on a variety of explanatory variables. For most stocks, forecasts are based on regression models that use spawning escapement to predict adult abundance. Additional explanatory variables are available for some stocks and include fry and smolt abundance estimates. Environmental indices are also used to help explain variation in ocean survival of Chilko sockeye and pink salmon. Methods that incorporate attributes of escapement-based and juvenile-based models are explored that pooling results from individual sockeye forecast models (i.e. Baysian approach) where time series of different life stages are available.

Sibling models were not considered suitable candidate models for forecasting 1999 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 1999 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 1998. The discrepancy is presently about 40% or more than 3 million sockeye. Without reliable estimates of age-3 jacks and age-4 adult returns in 1998 to predict sibling returns in 1999, sibling models are not useful for predicting 1999 age-4 and age-5 sockeye returns.

A particular cautious note is warranted for 1999 sockeye returns. Sockeye smolts that return as adults in 1999 entered the ocean during the intense 1997 El Nino. Sockeye returns in 1995 that went to sea during the less intense 1993 El had very low survival rates for all major stocks. If the intense El Nino in 1997 resulted in low sockeye survival then forecasts presented here significantly over-estimate returns of Fraser sockeye in 1999.

2 Data Sources

2.1 Spawning Escapements and Run Size

Estimates of annual spawning escapements (brood years 1948-94) and returns (brood years 1952-97) for 18 Fraser River sockeye stocks are used in this analysis. 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). Methods to estimate the stock composition of the catch are described by Gable and Cox-Rogers (1993). Chilko sockeye data include data for sockeye that spawn at the south-end of the lake, reported by the PSC to migrate through coastal fisheries earlier than other Chilko populations, north-end Chilko Lake spawners and Chilko River spawners.

Two sub-stocks of Early Stuart sockeye were analysed separately. These are the Driftwood River population, a highly cyclic stock with negligible historical importance on the 1999 cycle line, and the combined populations of Takla and Trembleur Lakes (non-Driftwood). The historical annual catch for Early Stuart sockeye was apportioned by sub-stock by weighting catch by the corresponding escapement. The data used to forecast each sub-stock of early Stuart sockeye consists of total adult escapements (1959-94) and adult returns (1963-96). Early Stuart returns data for 1997 were not used because of problems partitioning returns between sub-stocks. Preliminary escapement estimates for Early Stuart sockeye in 1997 indicate they were exposed to very high and apparently disproportionate in-river mortality among sub-stocks. Estimates of escapements for Driftwood sockeye in 1997 were very low compared to non-Driftwood sockeye despite the fact that 1997 is a dominant year for Driftwood sockeye. The effect of this when partitioning catch based on the proportion of escapement in each sub-stock is to assign a very large and unrealistic component of the total Early Stuart catch (sub-stock specific catch is not estimated independent of escapement) to the non-Driftwood component.

2.2 Shuswap Lake fall fry data

Time series of hydro-acoustic abundance estimates of in-lake fry are available for a limited number of years for Shuswap Lake (10 years in dominant and subdominant brood years 1974-95). Hume et al. (1996) describes details of data collection and analytical methods for estimating fry. The fry data used here are those collected in the fall following about one year of lake residency. These are termed fall fry to distinguish them from newly emergent fry from spawning channels measured at the Nadina, Gates and Weaver sites.

The degree of reliability in the acoustic estimates of fall fry data for forecasting is not known. In a review of hydro-acoustic methods for estimating Quesnel Lake sockeye fry abundance, PSARC was concerned about the reliability of sampling methodology (Rice et al. 1997, p:107). PSARC questioned whether the survey design was sufficient to account for spatial heterogeneity in fry densities within the lake.

2.3 Chilko Lake smolts and environmental data

Estimates of smolt abundance have been made as smolts pass through a weir on the Chilko River. The estimation method has been briefly described in Goodlad et al. (1974) but no detailed account has been published. Estimates of smolt age (age-1 and age-2) were based on scale age determinations made by the PSC.

Precipitation rates were shown to explain part of the variation in age-4 Chilko returns in previous forecasts (Cass, 1998). Included in this report is an evaluation of forecast performance of precipitation and salinity variables. 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.

2.4 Early Stuart sockeye fry data

Fry estimates (brood years 1990-97) are based on trap sampling in three non-Driftwood spawning areas (Forfar, Gluske and Kynoch). These data are collected by DFO but methods and estimation procedures remain undocumented (Tracy Cone, Stock Assess Div. personal communication). Fry estimates are not used to forecast adult returns because of the short time series of data. Only three years of age-4 return data for non-Driftwood sockeye are available since brood year 1990. The relationship between escapement and fry abundance estimates is useful for evaluating whether 1999 brood year freshwater survival deviated significantly from the mean.

2.5 Birkenhead River discharge data

Birkenhead sockeye returns are subject to a greater amount of periodic coastal flooding compared to interior spawning systems. One particular cause of variation in Birkenhead sockeye has been attributed to effects of river discharge on egg-to-fry survival (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 R. 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. Commercial Services Division, Monitoring and Systems Branch, Environment Canada provides discharge rates on CD-ROM format for years to 1990. Environment Canada provided additional data. We used the maximum daily discharge recorded between 25-Sep (long term mean peak spawning date) and 28-Feb as a measure of river flow effects on survival.

2.6 Weaver, Gates and Nadina fry data

Spawning channels were constructed at Weaver Creek (1965), Gates Creek (1968) and Nadina Creek (1973) to supplement wild spawning. Habitat and Enforcement Branch, provided annual fry estimates from spawning channel facilities at Weaver Creek, Gates Creek and Nadina River. Fry estimation programs of wild sockeye spawning in these sites were recently discontinued so the forecasts of wild plus channel adult returns are based only on channel fry estimates. In the last few years of wild fry enumeration the wild component was negligible compared to channel fry abundance.

2.7 Fraser pink fry and salinity data

A detailed summary of data sources is given in a previous PSARC document (Blackbourn 1992). Annual estimates of pink fry abundance were based on trap sampling at Mission (about 70 km from the river mouth) during the downstream migration period. Current estimation procedures are consistent with procedures developed in 1962 (Vernon 1966). The salinity data is the average of data from July through September of the fry year measured at Amphitrite Point near Barkley Sound and at Race Rocks in eastern Juan de Fuca Strait.

3 Methods

All years in the available time series of data were used in the analysis for each stock. Run size and escapement data are approximately log-normally distributed (Cass and Blackbourn 1996) and for all models a log-normal error structure was assumed. The simplest forecasting models used are all-year mean and the cycle line mean returns. Historical means serve as benchmarks to judge the information content of models that incorporate explanatory variables. The next level of model includes time series of adult spawning escapements to forecast future generations of adult returns. The third levels are models that use abundance estimates measured at different ages of the same generation. Included in this category are estimates of sockeye fry (Nadina, Gates and Weaver sockeye), fall fry (Shuswap), smolts (Chilko) and pink fry in addition to environmental variables used to explain ocean survival effects on run size of Chilko sockeye and Fraser River pink salmon.

3.1 Forecast models

Apart from forecasts derived from the simple geometric mean, 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):

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

estimated using the linear regression :

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

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:

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

estimated by:

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

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

$$R_{i,t} = S_t\left[\frac{GM(R_{i,1}\ldots R_{i,t-1})}{GM(S_1\ldots S_{t-1})}\right] \quad (3)$$

4) Juvenile model:

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

$$\ln(R_{i,t}) = \beta_0 + \beta_1 \ln(Sm_t) + \sigma\varepsilon_t \quad (4)$$

was fit to adult returns at age i and juvenile data Sm 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 and Fraser pink salmon additional environmental variables were also included as follows:

$$\ln(R_{i,t}) = \beta_0 + \beta_1 \ln(Sm_t) + \beta_2 E_t + \sigma\varepsilon_t . \quad (5)$$

Variable E represents environmental indices.

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):

$$\ln(F) = \sum_{m=1}^{n}[\ln(F_m)/V_m]/\sum_{m=1}^{n}1/V_{\ell_m}, \quad (7)$$

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:

$$V_p = 1/\sum_{m=1}^{n}1/V_m. \quad (8)$$

3.3 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 (1997), 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 1980-93.

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. In the few cases where long-term mean returns resulted in better forecast performance, the forecast model based on explanatory variables, such as brood year escapement, with the lowest RMSE was selected as the 'best' model.

For each stock and regression model (eqs. 1,2,5), the variance of the prediction was computed using standard methods (Snedecor and Cochran 1967; eq. 6.12.1). Prediction intervals for forecast based on means (eqs. 3 and cycle line and yearly means) were computed using a leave-one-out cross-validation technique (Efron and Tibshirani 1993; eq.17.6). 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) wherein:

$$V_c = \sum_{i=1}^{k} w_i v_i$$

Here, V_c is the combined variance for k ages, v_i is the variance for age i and weights w_i for forecast F_i are:

$$w_i = F_i / \sum_{i=1}^{k} F_i$$

4 Results

Forecasts by model, stock and age along with the forecast prediction variance and the RMSE are listed in Table 1. The 'best' forecast by stock and timing group at various probability levels are presented in Table 2. For the major stocks, trends in production and the historical relationships between explanatory variables and returns are provided. Plots that compare annual retrospective forecasts to observed age-4 returns are also included for diagnostic purposes for each of the major stocks discussed below.

For all but four stocks (Pitt, Seymour, Late Stuart and Late Shuswap), forecasts of age-4 sockeye based on annual or cycle means had higher RMSEs compared to forecasts based on models using explanatory variables. For all models, the uncertainty associated with stock-specific forecasts of age-4 sockeye are large (Table 1 and 2) and reliable only within an order of magnitude. Age-5 forecasts are associated with even larger uncertainty compared to age-4 sockeye. The mean variance ($\log_e$ of the forecast) of age-5 forecasts is 2.7 times the mean variance for age-4 sockeye.

The total 1999 Fraser sockeye run size forecast based on the 18 stocks is 8.2 million sockeye at the 50% probability level. As a result of statistical uncertainty, there is a 75% probability that the returns in 1999 will exceed 5 million sockeye and a 25% probability that returns will exceed 15 million (Table 2). Forecasts by management group are 318,000 Early Stuart, 477,000 Early summer stocks, 5.3 million summer run stocks and 2.1 million late run stocks at the 50% probability level. Forecasts for individual stocks within each management group are discussed below.

4.1 Early Stuart sockeye

Forecasts of Early Stuart sockeye are the sum of forecasts for two sub-stocks (Driftwood River and non-Driftwood) (Table 1). The Driftwood run is highly cyclic and has been negligible on the 1999 cycle line. Forecast variance for Driftwood River sockeye is very large compared to non-Driftwood sockeye (Table 1). Age-4 returns of non-Driftwood sockeye have been highly variable ranging from 10,000 to 770,000 sockeye/yr (1963-96) with little long-term trend (Fig. 1). The average age-4 return was 204,000 sockeye/yr. Age-5 returns were low and averaged 10,000 sockeye/yr.

For age-4 non-Driftwood sockeye, the Ricker model results in the lowest RMSE. The RMSE, 1999 forecast variance and the retrospective residual pattern for the Ricker model is similar to the power model (Table 1; Fig. 2). The egg-fry relationships at the non-Driftwood sites sampled for fry do not indicate the egg-to-fry survival for the 1999 brood year was anomalous

(Fig. 3). The total Early Stuart forecast (Driftwood and non-Driftwood) for 1998 at the 50% probability level is 318,000 age-4 and age-5 sockeye (Table 2).

4.2 Early summer run sockeye

The early summer run mainly consists of several small stocks (Fennell, Bowron, Raft, Gates, Nadina, Pitt, Seymour and Scotch). Scotch Creek and Seymour River stocks are the largest early summer stocks on the 1999 cycle line. The return-per-spawner model (eq. 3) was the best predictor of Scotch Creek age-4 returns and resulted in a forecast of 102,000 sockeye at the 50% probability level (Table 2). Of the models based on explanatory variables, the power model has the lowest RMSE for age-4 Seymour River sockeye and a combined forecast for age-4 and age-5 sockeye of 146,000 sockeye at the 50% probability level. All three escapement-based models, however, resulted in similar retrospective residual patterns (Fig. 4). Forecasts for other early summer sockeye range from 6,000 (Raft River) to 69,000 (Bowron) (Table 2).

4.3 Summer run

4.3.1 Chilko Lake

Annual returns of Chilko sockeye (1952-97) have been highly variable but without persistent four-year population cycles (Fig. 5). Average returns were 1.3 million sockeye/yr. Returns on the 1999 peaked at 4.3 million in 1991. Escapement (effective females) on this cycle was highest in 1991 at 600,000 sockeye. Spawning escapement (effective females) was 290,000 sockeye in 1995; the 1999 brood year. Estimated smolt output was at record highs in 1995 at 39 million sockeye. Of the escapement-based models, the Ricker forecast model resulted in the lowest RMSE (Table 1). The forecast model based on age-1 smolts and the two environmental variables (see section 2.3) resulted in the lowest RMSE. Both environmental variables explained a significant amount of variation in age-4 returns (F-test; $P<0.01$). When results of that model were incorporated in a pooled model (eq. 7) along with the Ricker forecast model the RMSE declined slightly and the variance was reduced considerably (Table 1). The pooled model therefore qualified as the ‘best’ forecast model for age-4 sockeye. The ‘best’ age-5 forecast model was the return-per-spawner model (eq. 3). The resulting 1999 forecast of 2.9 million age-4 and age-5 Chilko sockeye at the 50% probability level is the largest of the 18 stocks in 1999. The retrospective plots (Fig. 6) show little difference in the residual pattern among forecast models that use explanatory variables. All models tended to under-forecast returns at the upper range of observed returns. Also notable in the retrospective plots is the over-forecast of the 1995 return (El Nino smolt-entry year 1993) that returned at unexpectedly low levels in all major stocks.

4.3.1 Quesnel Lake

Escapement estimates of Quesnel sockeye on the 1999 cycle line have increased steadily from 200 in 1979 to 120,000 (age-4 and age-5) in 1995 (Fig. 7). Returns of age-4 sockeye increased during the same period to 111,000 sockeye in 1995. Age-5 sockeye from sub-dominant broods have contributed significantly to returns on the 1999 cycle in recently years accounting for 77% of the return in 1995 and 58% in 1991. Without reliable estimates of sibling age-4 returns in 1998, forecasts of age-5 returns based on the proportion of age-5s in recent years is not possible at this time.

Of the escapement-based models, there is little distinction among the models based on the residual patterns of the retrospective analysis (Fig 8). The Ricker model had the lowest RMSE with a 1999 forecast of 1.6 million age-4 and age-5 sockeye. This is nearly two order of magnitude greater than the estimated return in 1995.

4.3.3 Stellako and Late Stuart

Returns of Stellako sockeye have fluctuated without persistent four-year population cycles averaging 400,000 sockeye/yr since 1952 (Fig. 9). Average returns on the 1999 cycle were 650,000 sockeye. Returns declined to a record low of 288,000 in 1995. Average escapement (effective females) on the cycle was 45,000 sockeye/yr (54,000 in 1995). The 1999 forecast at the 50% probability level is 532,000 age-4 and age-5 sockeye . The Ricker model resulted in the lowest RMSE for age-4 Stellako sockeye but performed only marginally better than other models including the long-term mean return (Table 1; Fig. 10).

Late Stuart sockeye populations show persistent cycles and are dominant on the 1997 cycle line (Fig. 11). Returns on the 1999 cycle line averaged 70,000 sockeye/yr and have varied from 6,000 sockeye to 290,000 sockeye/yr (75,000 in 1995). Late Stuart escapements (effective females) on the 1999 cycle peaked in 1991 at 40,000 but declined to 17,000 in 1995. All escapement-based forecasts have a very large variance compared to other major Fraser stocks (Table 1) and there is little difference in residual pattern or RMSE (Table 1, Fig. 12). Of the escapement-based forecast models, the power model resulted in the lowest RMSE for age-4 sockeye. The 1999 forecast of age-4 and age 5 late Stuart sockeye at the 50% probability level is 254,000 sockeye (Table 2).

4.4 Late runs

4.4.1 Birkenhead River

Birkenhead River sockeye are the only major run of sockeye with significant numbers of age-5 sockeye. Adult returns (age-4 and age-5) were highly variable since the 1950s averaging 380,000 sockeye/yr (Fig.13 and Fig. 14). Returns recently declined from a peak of 1.6 million in 1986 to 120,000 in 1996. Age-4 returns increased slightly in 1997 to 180,000 sockeye. Escapement also peaked in 1986 at 200,000 effective females and was 22,000 in 1994 (age-4 returns in 1999) and 17,000 in 1995 (age-5 returns in 1999).

High daily maximum discharge rates for the Lillooet R (1950-95) are often associated with low Birkenhead sockeye recruitment rates but show no consistent relationship to residuals from either the best fit Ricker or power models (Fig. 15). Maximum daily discharges affecting

1999 returns were not at extreme levels, therefore, low egg-to-fry survival due to high discharges is not likely.

Forecasts of age-4 sockeye from the power model resulted in the lowest RMSE and a forecast at the 50% level of 186,000 age-4 sockeye (Table 1). The age-4 residual pattern from the retrospective analysis shows little difference between the Ricker and power models (Fig. 16). The return-per-spawner model (eq. 3) resulted in the lowest RMSE for age-5 Birkenhead sockeye and a forecast return of 43,000 fish in 1999. Both the high variance and residual pattern reveal that forecasts of age-5 Birkenhead sockeye are extremely uncertain (Table 1; Fig. 17). The combined age-4 and age-5 forecast is 229,000 sockeye at the 50% probability level (Table 2).

4.4.2 Shuswap Lake

Data for late Shuswap Lake sockeye includes Lower Adams River and Shuswap River sockeye. Both of these systems exhibit pronounced four-year population cycles that vary approximately by an order of magnitude among cycle lines. The 1999 cycle line is the subdominant cycle. Returns on the 1999 cycle line peaked at 4 million age-4 sockeye in 1991 but declined to 800,000 in 1995 (Fig. 18). Escapement in 1995 was 200,000 sockeye or less than half the escapement in the preceding cycle year (1991). The range in forecasts among candidate escapement-based models (Ricker, power, recruits-per-spawner) is only 1.4 – 1.6 million sockeye. The Ricker model resulted in the lowest RMSE and a forecast at the 50% probability level of 1.6 million age-4 sockeye.

The fall fry-based model resulted in a forecast of just 0.7 million age-4 sockeye that theoretically accounts for both early timed runs (Scotch and Seymour) and late runs (Adams and Lower Shuswap rivers) since fry from all Shuswap tributaries are assumed to be equally vulnerable to acoustic sampling. The fall fry estimate for the 1999 brood is the lowest recorded for years that routine acoustic sampling has been performed on Shuswap Lake. Shuswap acoustic estimates of fall fry cannot differentiate age-0 sockeye fry from age-0 kokanee fry. Age-0 kokanee abundance in Shuswap Lake is estimated to be roughly 10% of the total fry on the subdominant cycle line in years of average sockeye fry abundance (Chris Wood, DFO Stock Assessment Div., personal communication). Because total fry abundance estimate for the 1999 brood is low relative to other subdominant cycle years, the contribute of sockeye fry compared to kokanee fry is much more uncertain than in years of high sockeye abundance. For years that fry data are available and excluding results of the 'pooled' model that includes output from both the fry-based and Ricker-based model, the Ricker model resulted in the lowest RMSE and a forecast of 1.8 million sockeye (early and late runs combined). The pooled model that uses information from the fry and Ricker-based models results in the lowest overall RMSE and a forecast of 1.1 million sockeye (Table 1). The residual pattern for models that use explanatory variable show that there is little to chose from among competing models (Fig.19).

I recommend the fry data not be consider in the 1999 forecast of late Shuswap Lake sockeye for the following reasons: 1) the effect of incorrectly estimating the contribution of sockeye to the total fry estimate is more uncertain in subdominant years and highly uncertain in years of low fry abundance; 2) the uncertainty resulting from subtracting the early timed component (Scotch and Seymour) from the total Shuswap forecast to estimate the late run forecasts is potentially very large in low fry years. Forecasts of Scotch Creek and Seymour River sockeye are themselves very uncertain.

Accepting the Ricker model as the 'best' model for age-4 sockeye and the returns-per-spawner model as the 'best' age-5 forecast model, the forecast for late Shuswap sockeye is 1.6 million sockeye at the 50% probability. The statistical uncertainty in the late Shuswap forecast is large. There is only a 50% chance that the returns will be between 800,000 and 3 million sockeye (Table 2).

4.4.3 Weaver Creek

Weaver Creek sockeye production has been supplemented by spawning channel production starting in 1965. Data used in Weaver forecasts do not include wild sockeye production prior to brood year 1965. Returns averaged 350,000 sockeye/yr (1969-97). Returns peaked in 1986 at 1.4 million and dropped to 60,000 sockeye in 1990 (Fig. 20). The RMSE for the returns-per-spawner model was the lowest but was very similar to the power, recruits-per-spawner (RS), fry-based models and pooled model that includes information from the fry and RS models (Table 1; Fig. 21). Based on the models with the lowest RMSE the total (age-4 and age-5) Weaver Creek forecast is 171,000 sockeye at the 50% probability level (Table 2).

4.4.4 Cultus Lake and Portage Creek

Cultus and Portage sockeye are minor contributors to the late timed run with forecasts at the 50% level of 31,000 and 75,000 age-4 and age-5 sockeye (Table 2).

4.5 Pinks

Fraser pink salmon escapement and returns in odd-numbered years have increased since the late 1950s. Returns peaked in 1993 at 18 million. Estimates of returns have since declined to 13 and 8 million in 1995 and 1997 (Fig. 22). Preliminary estimates of spawning escapement in 1997 (1999 brood) was the lowest since 1987. All forecasting models with explanatory variables resulted in very similar forecasts at the 50% probability level that range from 7.7 to 8.6 million returns in 1999 (Table 1). The model with the lowest RMSE included salinity and fry in a multiple regression (eg. 5). Both the salinity and fry variables are statistically significant (F-test; $P<0.01$). Retrospective plots from the forecast models show little relationship between observed and forecast returns (Fig. 23). The 1999 forecast of Fraser pink is 8.1 million at the 50% probability level with a 50% probability range of 6.4-10.3 million.

5 Conclusion

Results presented here concur with previous analyses (Welch et al. 1994; Cass et al. 1995; and Cass and Blackbourn 1996, 1997; Noakes et al. 1990) that forecast models of Fraser sockeye, including the time series analysis by Welch et al. (1994) perform poorly. No single method has performed consistently better than any other. For many of the major sockeye stocks, particularly non-cyclic stocks with less contrast in ranges of escapements and returns compared to highly cyclic stocks, the forecast returns in the retrospective analysis shows little correlation with estimated returns. This is revealed in the retrospective plots for Stellako (Fig. 9), Birkenhead (Fig. 15 and 16) and Weaver sockeye (Fig. 20). For the highly cyclic stocks, such as Quesnel (Fig. 7), late Stuart (Fig.11) and Shuswap sockeye (Fig. 18) the range in escapement and returns vary by three orders of magnitude. With that range of contrast in the data, there is a positive correlation between forecasts and returns. Despite the positive relationship between observed returns and forecast returns since 1980, the variation within cycle lines of the highly cyclic stocks is very large. Even for highly cyclic stocks, forecast returns have large deviations from the observed returns and variances so large (>0.5) that there is insufficient information content in the forecasts for in- season management. The most important stocks in 1999 based on forecasts presented here are the Chilko at 3 million, the Quesnel at 1.6 million and Shuswap (late run) at 1.6 million sockeye (50% chance the run will be higher or lower). Table 2 shows the uncertainty in forecasts. For Chilko sockeye there is a 50% chance the run will be within 2 million and 4 million sockeye. For Quesnel and late Shuswap sockeye the forecast uncertainty is larger ranging from 700,000 to 3 million for Quesnel sockeye and 800,000 to 3 million sockeye for late Shuswap sockeye. These are large ranges for only a 50% chance of the run occurring within these levels.

The major impediment to improvements in accuracy of pre-season run size forecasts are related to our inability to model variations in survival. Much of the information on survival predictions from ocean climate studies is qualitative in content and difficult to consider in the statistical framework of forecasting models. The environmental indexes used to explain variation in Chilko sockeye and Fraser pink returns, while statistically valid, are likely to fail unless they are linked causally to ocean survival.

It is important to note that the forecasts are only reliable if survival rates in 1999 are near the long-term mean. The effect of the intense El Nino in 1997 on ocean survival of the 1990 return is unknown. We do know that survival rates of sockeye that entered the ocean during the less intense El Nino in 1993 were very low. Management plans should acknowledge the possibility that survival may be significantly less than the long-term mean.

The forecasts in this report are based on stocks with sufficient time series of data to conduct quantitative forecast analysis. Based on escapements in 1995 (1999 brood) these stocks accounted for 96% of the total brood year escapements estimated for Fraser River sockeye. The remaining stocks consist of numerous small stocks with limited data reliability. Escapements and catch for these stocks are estimated using far less rigorous methods than for larger runs. For that reason the value of accounting for these small runs in the 1999 forecast is questionable and not considered in this report. Clearly any attempt to forecast returns of these small stocks would result in forecasts that are very uncertain and well within the statistical confidence limits for the combined runs evaluated in this report.

6 Recommendations

1. Fraser sockeye and pink forecasts at various probabilities (25%, 50%, 75%, 80% and 90%) are listed in Table 2. The total 1998 Fraser sockeye run size forecast is 8.2 million sockeye at the 50% probability level (the chance the run will exceed the forecast) and 4.8 million at the 75% probability level. Forecasts by management group are 318,000 (50%) and 197,000 (75%) for Early Stuart, 477,000 (50%) and 244,000 (75%) for Early summer stocks, 5.3 million (50%) and 3.3 million (75%) for summer run stocks and 2.1 million (50%) and 1.1 million (75%) for late run stocks. The 1999 forecast of Fraser pink is 8.1 million at the 50% probability level and 6.4 million at the 75% level.

2. Preseason plans should accommodate the large uncertainties in the forecasts and acknowledge that survival rates may be well below the long-term mean.

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Table 1. Forecasts of Fraser River sockeye stocks (milions) for 1999 with associated variance of the log of the forecast and root-mean-square error (RMSE). The 'best' forecast according to the selection criteria (see text) is underlined[a].

Early Stuart (excluding Driftwood R. systems)

Age-4

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.125	1.249	0.163
Cmean	0.150	1.295	0.156
<u>Ricker</u>	<u>0.294</u>	<u>0.465</u>	<u>0.108</u>
Power	0.303	0.439	0.110
RS	0.472	0.625	0.257

Age-5

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.007	1.147	0.016
Cmean	0.004	1.534	0.016
Ricker	0.008	1.386	0.015
Power	0.006	1.041	0.015
<u>RS</u>	<u>0.005</u>	<u>1.823</u>	<u>0.010</u>

Early Stuart (Driftwood R. systems)

Age-4

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.006	10.392	0.407
Cmean	0.001	4.460	0.298
Ricker	0.025	2.840	0.289
<u>Power</u>	<u>0.019</u>	<u>2.500</u>	<u>0.218</u>
RS	0.023	2.744	0.243

Age-5

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0003	6.592	0.0188
Cmean	0.0000	7.642	0.0181
Ricker	0.0003	14.524	0.0189
<u>Power</u>	<u>0.0002</u>	<u>5.947</u>	<u>0.0189</u>
RS	0.0001	15.791	0.0192

Fennell

Age-4

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.006	3.973	0.029
Cmean	0.009	3.928	0.026
Ricker	0.037	0.757	0.023
<u>Power</u>	<u>0.031</u>	<u>0.716</u>	<u>0.016</u>
RS	0.078	1.726	0.094

Age-5

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0011	4.3094	0.0053
Cmean	0.0009	5.8443	0.0053
Ricker	0.0038	1.5496	0.0040
<u>Power</u>	<u>0.0025</u>	<u>1.3740</u>	<u>0.0040</u>
RS	0.0037	1.9138	0.0054

Bowron

Age-4

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.026	1.059	0.017
Cmean	0.067	1.030	0.030
Ricker	0.066	0.737	0.020
<u>Power</u>	<u>0.067</u>	<u>0.665</u>	<u>0.018</u>
RS	0.112	0.751	0.022

Age-5

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0025	1.2829	0.0035
Cmean	0.0018	1.9304	0.0037
<u>Ricker</u>	<u>0.0022</u>	<u>1.4628</u>	<u>0.0034</u>
Power	0.0022	1.3038	0.0035
RS	0.0014	1.8728	0.0037

Table 1 (cont'd)

Raft

Age-4

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.013	1.521	0.019
Cmean	0.006	2.182	0.010
Ricker	0.005	0.756	0.013
Power	0.005	0.753	0.013
RS	0.005	0.723	0.015

Age-5

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0021	1.1525	0.0039
Cmean	0.0015	2.0853	0.0036
Ricker	0.0014	1.2493	0.0041
Power	0.0015	1.0695	0.0036
RS	0.0009	1.4138	0.0026

Gates

Age-4

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.020	3.292	0.099
Cmean	0.017	0.260	0.068
Ricker	0.060	0.923	0.078
Power	0.046	0.718	0.060
RS	0.061	0.961	0.063
A4~fry			0.067
Pooled			0.065

Age-5

MODEL	FORECAST	VARIANCE	RMSE
Cmean	0.0007	1.1227	0.0080
Ricker	0.0013	1.5220	0.0073
Power	0.0012	1.4282	0.0073
RS	0.0011	1.4929	0.0066
A4~fry	0.0012	1.4305	0.0073
pooled	0.0012	0.7374	0.0073

Nadina

Age-4

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.038	1.253	0.053
Cmean	0.122	0.728	0.042
Ricker	0.065	0.457	0.073
Power	0.061	0.554	0.075
RS	0.067	0.551	0.066
A4~fry	0.010	0.444	0.035
Pooled	0.031	0.247	0.034

Age-5

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0051	1.3476	0.0154
Cmean	0.0020	0.8104	0.0146
Ricker	0.0016	1.5727	0.0157
Power	0.0031	1.5290	0.0156
RS	0.0010	1.7294	0.0164
A4~fry	0.0029	1.3103	0.0155
pooled	0.0022	0.7148	0.0156

Pitt

Age-4

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.015	1.163	0.013
Cmean	0.021	2.041	0.016
Ricker	0.009	1.236	0.014
Power	0.014	1.328	0.013
RS	0.004	1.409	0.017

Age-5

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.033	0.665	0.021
Cmean	0.023	0.986	0.021
Ricker	0.024	0.657	0.020
Power	0.026	0.652	0.020
RS	0.017	0.733	0.021

Table 1 (cont'd)

Seymour

Age-4

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.062	1.720	0.263
Cmean	0.160	0.398	0.191
Ricker	0.170	0.899	0.206
Power	0.143	0.907	0.198
RS	0.187	0.964	0.266

Age-5

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0021	2.4389	0.0100
Cmean	0.0030	1.8304	0.0097
Ricker	0.0035	2.3024	0.0096
Power	0.0026	2.1205	0.0093
RS	0.0033	2.4261	0.0086

Scotch

Age-4

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.006	5.682	0.127
Cmean	0.005	3.669	0.126
Ricker	0.092	2.044	0.110
Power	0.052	1.711	0.079
RS	0.100	1.951	0.053

Age-5

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0010	3.3413	0.0049
Cmean	0.0016	8.0525	0.0050
Ricker	0.0045	7.7788	0.0047
Power	0.0027	3.6487	0.0047
RS	0.0194	5.6269	0.0117

Chilko

Age-4

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.877	1.152	1.940
Cmean	1.318	0.333	1.830
Ricker	1.822	1.822	1.528
Power	1.931	0.613	1.688
RS	2.669	0.681	2.051
A4~smolt	2.763	0.423	1.449
A4~smolt+esc	2.764	0.435	1.459
A4~smolt+E1+E2	3.669	0.295	1.408
Pooled	2.893	0.195	1.403

Age-5

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.021	2.271	0.195
Cmean	0.020	3.457	0.194
Ricker	0.041	1.945	0.192
Power	0.038	1.930	0.189
RS	0.056	2.027	0.180
A4~smolt	0.032	1.522	0.192
A4~smolt+esc	0.022	1.530	0.194
A4~smolt+E1+E2	0.041	1.525	0.186
pooled	0.041	0.855	0.192

Table 1 (cont'd)

Quesnel

Age-4

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.030	12.119	5.319
Cmean	0.002	6.167	4.457
Ricker	1.805	0.769	5.835
Power	1.492	0.787	3.730
RS	1.825	0.777	4.976

Age-5

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.008	8.834	0.219
Cmean	0.006	14.532	0.219
Ricker	0.096	8.418	0.198
Power	0.036	7.508	0.212
RS	0.100	7.716	0.161

Stellako

Age-4

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.313	0.609	0.327
Cmean	0.565	0.290	0.304
Ricker	0.470	0.399	0.267
Power	0.435	0.422	0.329
RS	0.516	0.461	0.492

Age-5

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.032	1.337	0.153
Cmean	0.030	0.997	0.152
Ricker	0.062	1.030	0.135
Power	0.056	1.033	0.134
RS	0.062	0.999	0.122

Late Stuart

Age-4

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.086	5.328	2.033
Cmean	0.032	2.108	1.417
Ricker	0.231	1.787	1.418
Power	0.177	1.533	1.355
RS	0.213	1.804	1.783

Age-5

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.005	3.754	0.076
Cmean	0.004	2.201	0.074
Ricker	0.026	3.499	0.075
Power	0.010	2.814	0.072
RS	0.023	4.452	0.049

Birkenhead

Age-4

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.214	0.665	0.465
Cmean	0.233	0.537	0.464
Ricker	0.192	0.590	0.452
Power	0.186	0.589	0.429
RS	0.140	0.927	0.708

Age-5

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.049	1.321	0.220
Cmean	0.053	1.776	0.222
Ricker	0.048	1.051	0.199
Power	0.045	1.027	0.193
RS	0.043	1.095	0.190

Table 1 (cont'd)

Total Shuswap (includes Seymour + Scotch)

Age-4

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.351	5.316	4.482
Cmean	1.435	0.554	1.909
Ricker	1.760	0.644	1.912
Power	1.585	0.668	2.172
RS	1.712	0.659	2.626
Ricker[b]	1.760	0.644	2.920
Power[b]	1.585	0.668	3.317
RS[b]	1.712	0.659	4.011
A4~fry[b]	0.703	0.569	3.150
Pooled	1.081	0.302	2.586

Age-5

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0059	3.8467	0.0848
Cmean	0.0249	2.4353	0.0789
Ricker	0.0341	2.5317	0.0779
Power	0.0206	2.1083	0.0762
RS	0.0478	2.8304	0.0525
A4~fry	0.0374	0.7571	0.0665
Pooled	0.0366	0.5828	0.0858

Late Shuswap

Age-4

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.188	8.010	4.175
Cmean	1.230	0.667	1.661
Ricker	1.595	0.897	1.681
Power	1.351	0.917	1.899
RS	1.534	0.916	2.426

Age-5

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0035	6.3976	0.0784
Cmean	0.0230	2.3736	0.0718
Ricker	0.0212	3.0124	0.0704
Power	0.0150	2.7539	0.0704
RS	0.0238	2.9898	0.0622

Cultus

Age-4

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.028	2.640	0.032
Cmean	0.106	0.724	0.043
Ricker	0.033	0.852	0.024
Power	0.030	0.833	0.023
RS	0.030	0.863	0.027

Age-5

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0011	1.9431	0.0016
Cmean	0.0013	1.6424	0.0019
Ricker	0.0009	1.5062	0.0016
Power	0.0007	1.3508	0.0016
RS	0.0005	1.6760	0.0017

Table 1 (cont'd)

Portage

Age-4

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.012	4.676	0.086
Cmean	0.012	3.002	0.080
Ricker	0.060	1.158	0.066
Power	0.048	1.072	0.055
RS	0.074	1.384	0.052

Age-5

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0006	3.9298	0.0081
Cmean	0.0006	5.6203	0.0080
Ricker	0.0009	4.3290	0.0081
Power	0.0006	4.1122	0.0081
RS	0.0008	4.4756	0.0080

Weaver

Age-4

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.233	0.770	0.352
Cmean	0.127	0.247	0.339
Ricker	0.171	1.009	0.405
Power	0.198	0.739	0.314
RS	0.135	1.075	0.298
A4~fry	0.235	0.657	0.316
Pooled	0.176	0.348	0.322

Age-5

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0181	1.8368	0.0800
Cmean	0.0171	4.0754	0.0789
Ricker	0.0354	1.3224	0.0577
Power	0.0318	1.3262	0.0686
RS	0.0345	1.2666	0.0633
A4~fry	0.0332	1.4204	0.0751
Pooled	0.0343	0.6848	0.0726

PINK

Ymean	8.877	0.517	9.402
Ricker	9.965	0.350	8.548
Power	8.864	0.366	8.664
RS	8.852	0.489	13.578
Return~fry	7.677	0.267	6.616
Return~fry+Esc	7.908	0.281	8.151
Return~fry+salinity	8.148	0.120	4.548
Pooled	8.595	0.151	6.595

a: Ymean = all year mean; Cmean = cycle-year mean
Ricker = Ricker stock-recruit
Power = power stock-recruit
RS = geometric mean recruit per spawner
A4~Fry (or Fall Fry) = regression of age-4 vs fry
A4~Fry (or Fall Fry) +esc = regression of age-4 vs fry + esc
A4~Smolt = regression of age-4 vs smolts
A4~Smolt+E1+E2 = regression of age-4 vs smolts+rain +salinity variables
A4~Sm+esc = regression of age-4 vs smolts + escapement
A5~Fry = regression of age-5 vs fry
A5~A4 = regression of age-5 vs age-4
Pooled = combined forecast based on different life stages = sum of forecasts weighted by Inverse of respective variances (see text).

Table 2. Fraser River run size forecasts of age-4 and age-5 sockeye by stock and timing group (bold) and Fraser River pink salmon for 1999.

Probability of Achieving Specified Run Sizes[a]

STOCK/TIMING	25%	50%	75%	80%	90%
Early Stuart	**512,000**	**318,000**	**197,000**	**175,000**	**127,000**
Early Summer	**954,000**	**477,000**	**244,000**	**209,000**	**135,000**
Fennell	60,000	33,000	18,000	16,000	10,000
Bowron	122,000	69,000	39,000	34,000	24,000
Raft	11,000	6,000	3,000	3,000	2,000
Gates	85,000	47,000	26,000	23,000	15,000
Nadina	50,000	34,000	23,000	20,000	15,000
Pitt	75,000	40,000	21,000	18,000	12,000
Seymour	282,000	146,000	75,000	64,000	41,000
Scotch	269,000	102,000	39,000	31,000	16,000
Mid Summers	**9,024,000**	**5,328,000**	**3,299,000**	**2,946,000**	**2,199,000**
Chilko	4,086,000	2,949,000	2,128,000	1,962,000	1,580,000
Quesnel	3,422,000	1,593,000	741,000	611,000	361,000
Stellako	847,000	532,000	334,000	297,000	218,000
Late Stuart	669,000	254,000	96,000	76,000	40,000
Late Summer	**4,097,000**	**2,125,000**	**1,103,000**	**937,000**	**606,000**
Birkenhead	402,000	229,000	130,000	113,000	77,000
Late Shuswap	3,118,000	1,619,000	841,000	714,000	462,000
Cultus	57,000	31,000	16,000	14,000	9,000
Portage	167,000	75,000	33,000	27,000	16,000
Weaver	353,000	171,000	83,000	69,000	42,000
TOTAL	**14,587,000**	**8,248,000**	**4,843,000**	**4,267,000**	**3,067,000**
PINKS	**10,348,000**	**8,148,000**	**6,415,000**	**6,039,000**	**5,128,000**

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

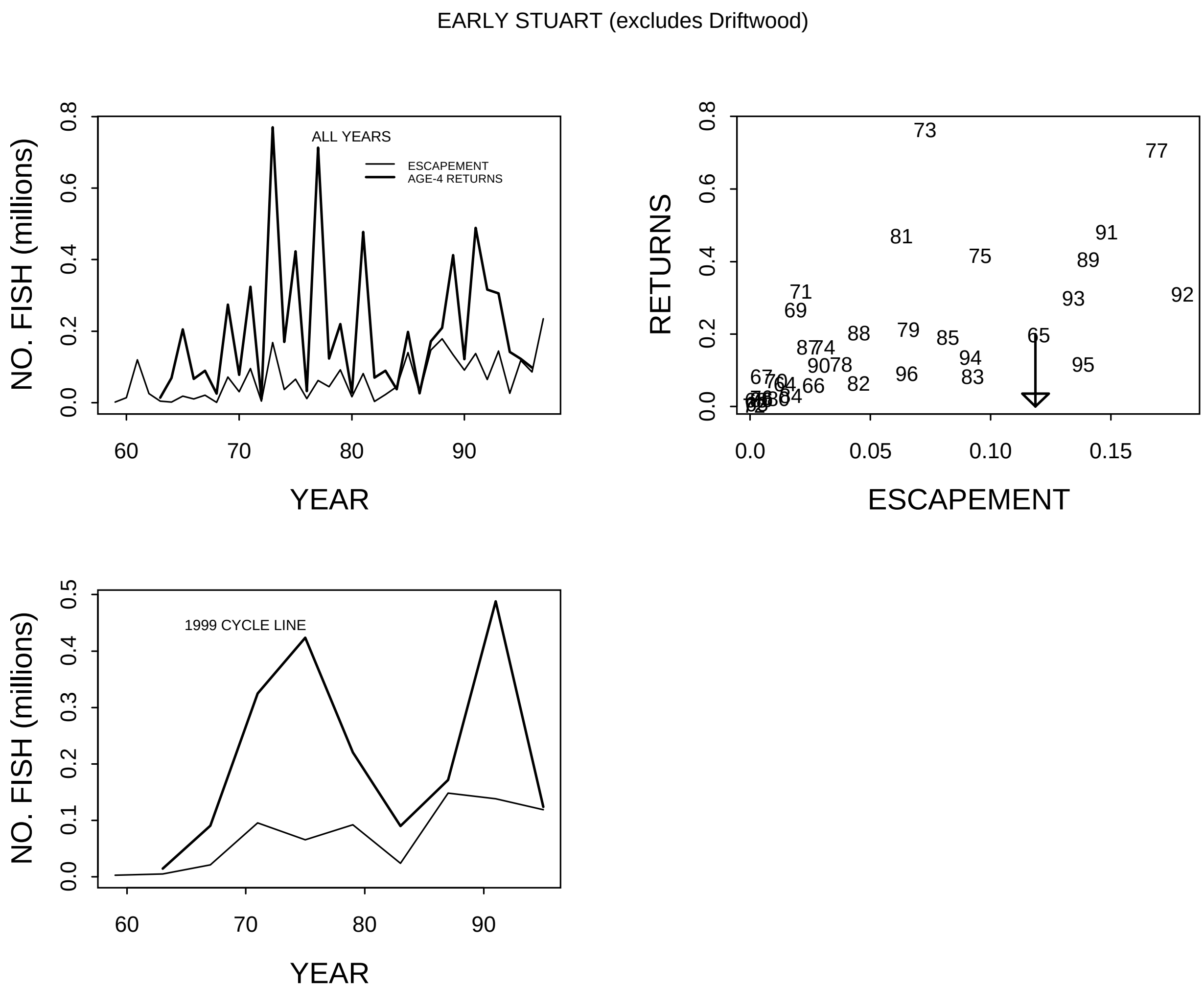

Figure 1. Trends in escapement and age-4 returns (millions) and the relationship between adult escapement and age-4 returns for Early Stuart sockeye (non-Driftwood). Data labels are return years. The arrow represents the 1995 escapement.

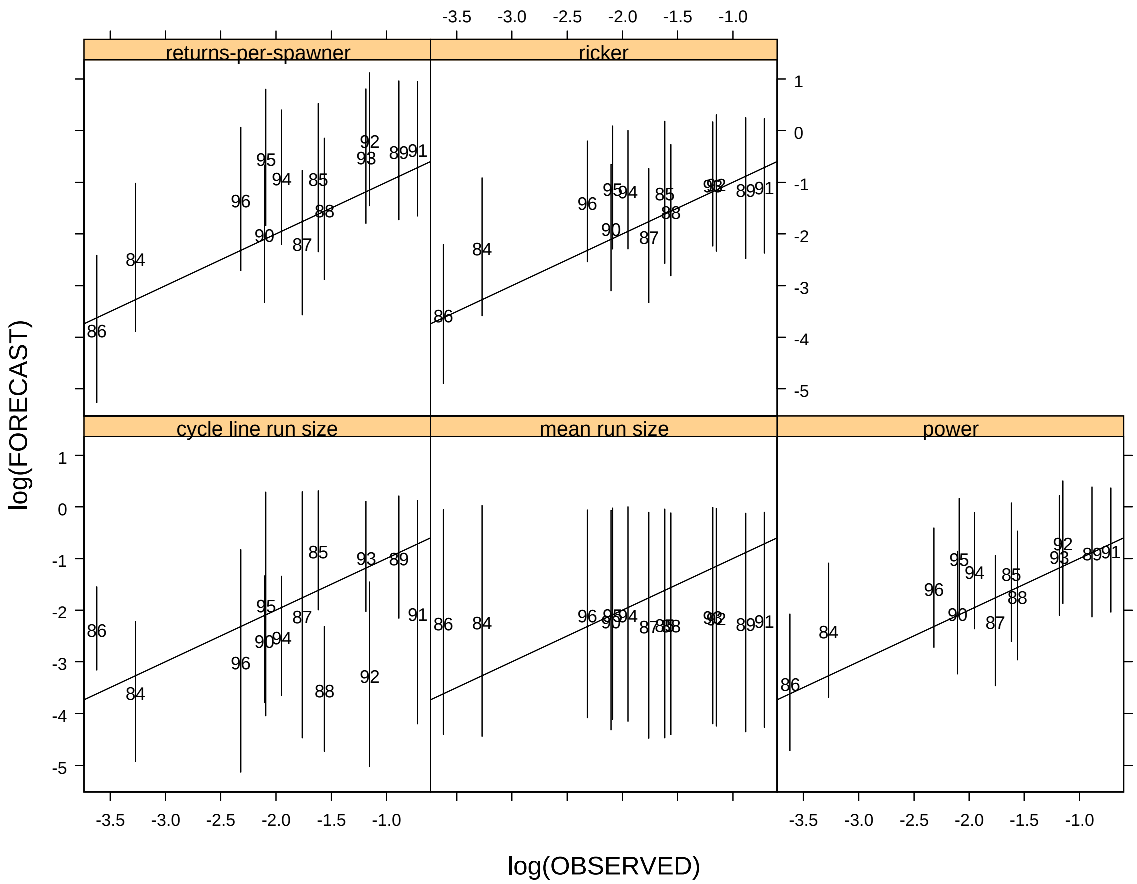

Figure 2. Comparison of estimated (observed) returns and retrospective run size forecasts (millions (log_e scale)) of age-4 Early Stuart sockeye (excluding Driftwood River) by model. Data points are modes of distributions and denoted by return year. Diagonal lines are 1:1 line not regression lines. Error bars are 90% confidence intervals.

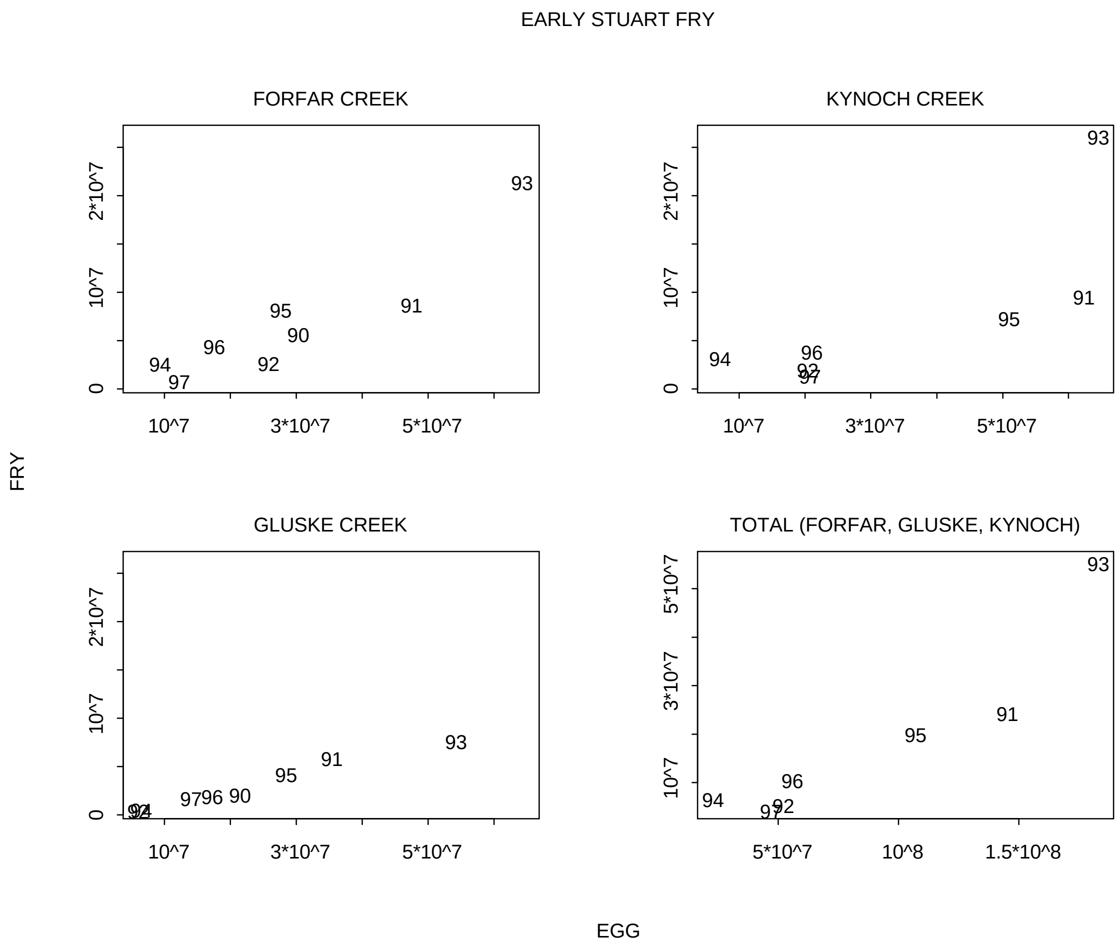

Figure 3. Relationship between potential egg deposition based of female spawners and estimates of fry by individual spawning location and for all three sites combined. Data points are denoted by brood year.

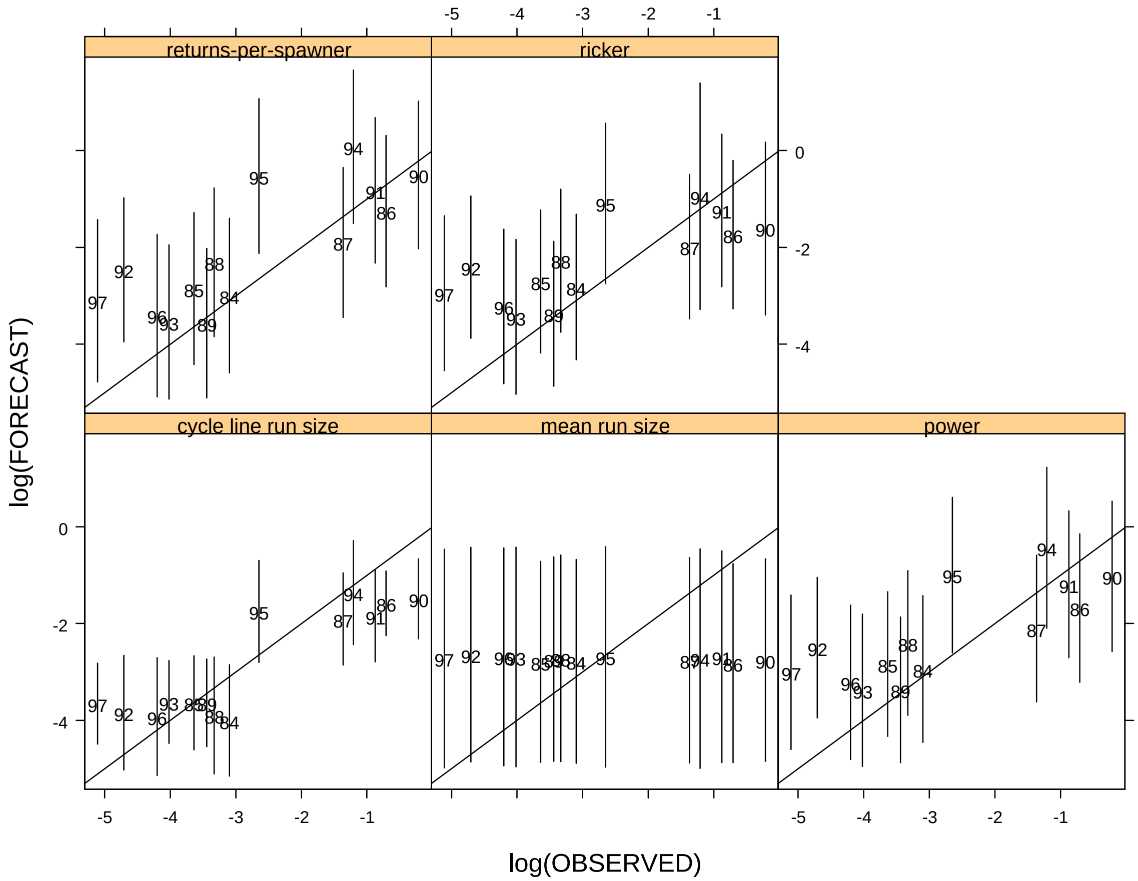

Figure 4. Comparison of estimated (observed) returns and retrospective run size forecasts (millions (log_e scale)) of age-4 Seymour River sockeye (excluding Driftwood River) by model. Data points are modes of distributions and denoted by return year. Diagonal lines are 1:1 line not regression lines. Error bars are 90% confidence intervals.

CHILKO

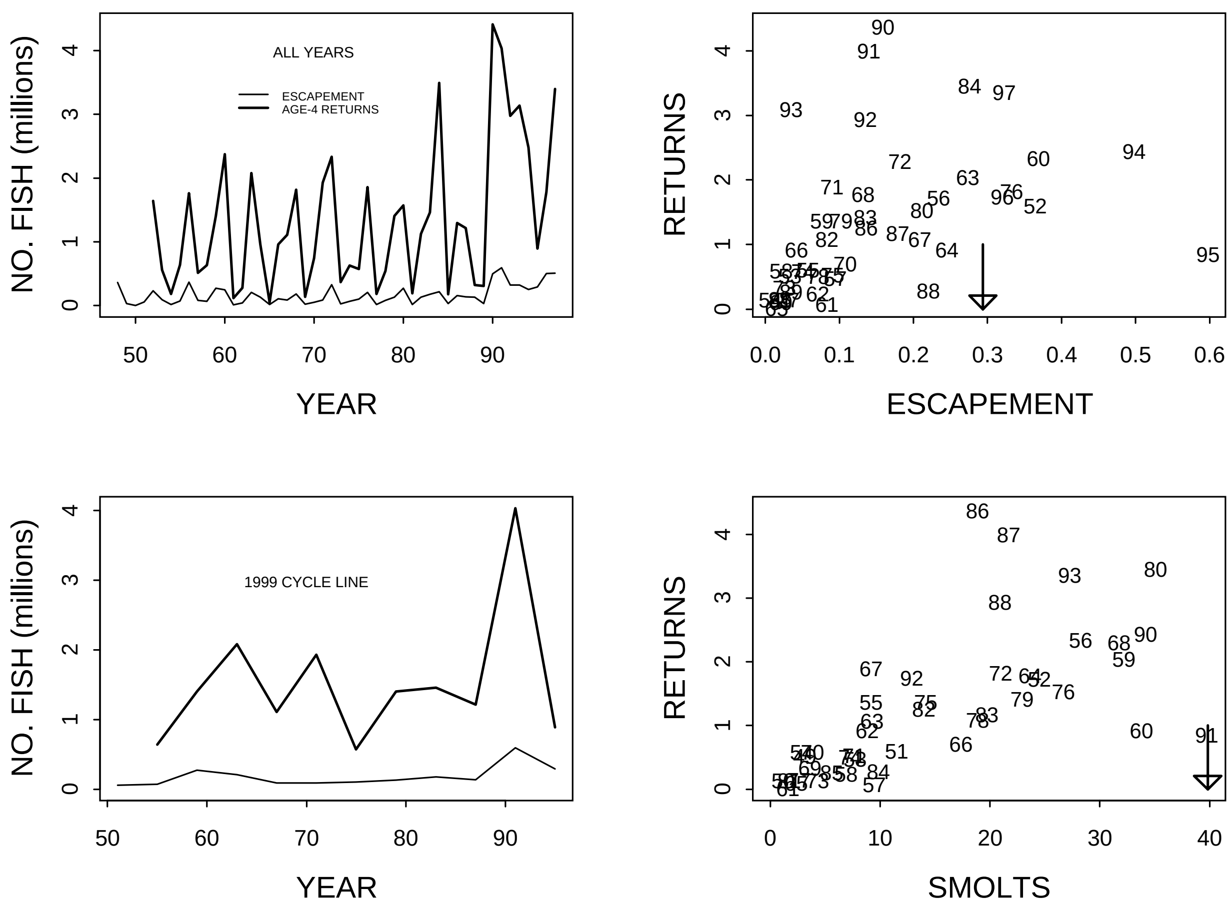

Figure 5. Trends in escapement and age-4 returns (millions) and the relationship between adult escapement, smolts and age-4 returns for Chilko Lake sockeye. Data labels are return years. The arrow represents the 1995 escapement and smolt output.

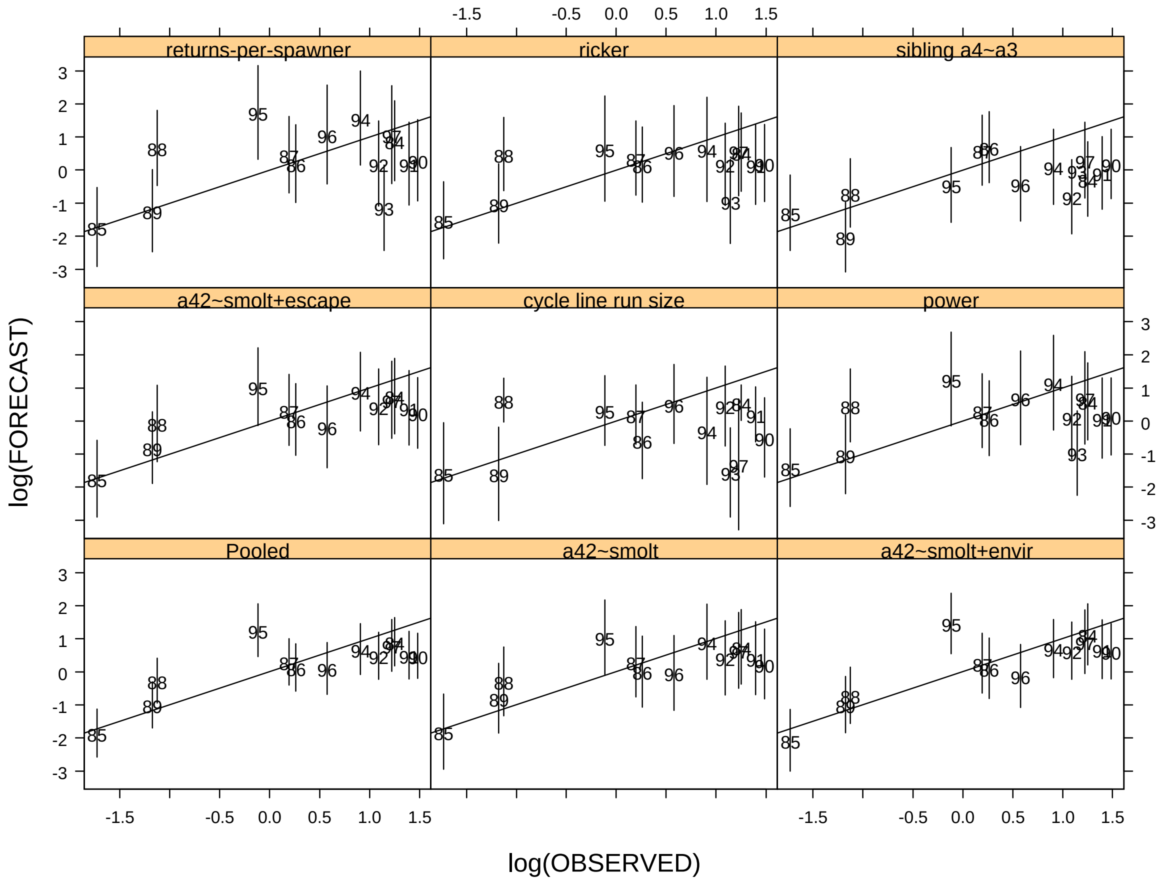

Figure 6. Comparison of estimated (observed) returns and retrospective run size forecasts (millions (log_e scale)) of age-4 Chilko Lake sockeye by model. Data points are modes of distributions and denoted by return year. Diagonal lines are 1:1 line not regression lines. Error bars are 90% confidence intervals.

QUESNEL

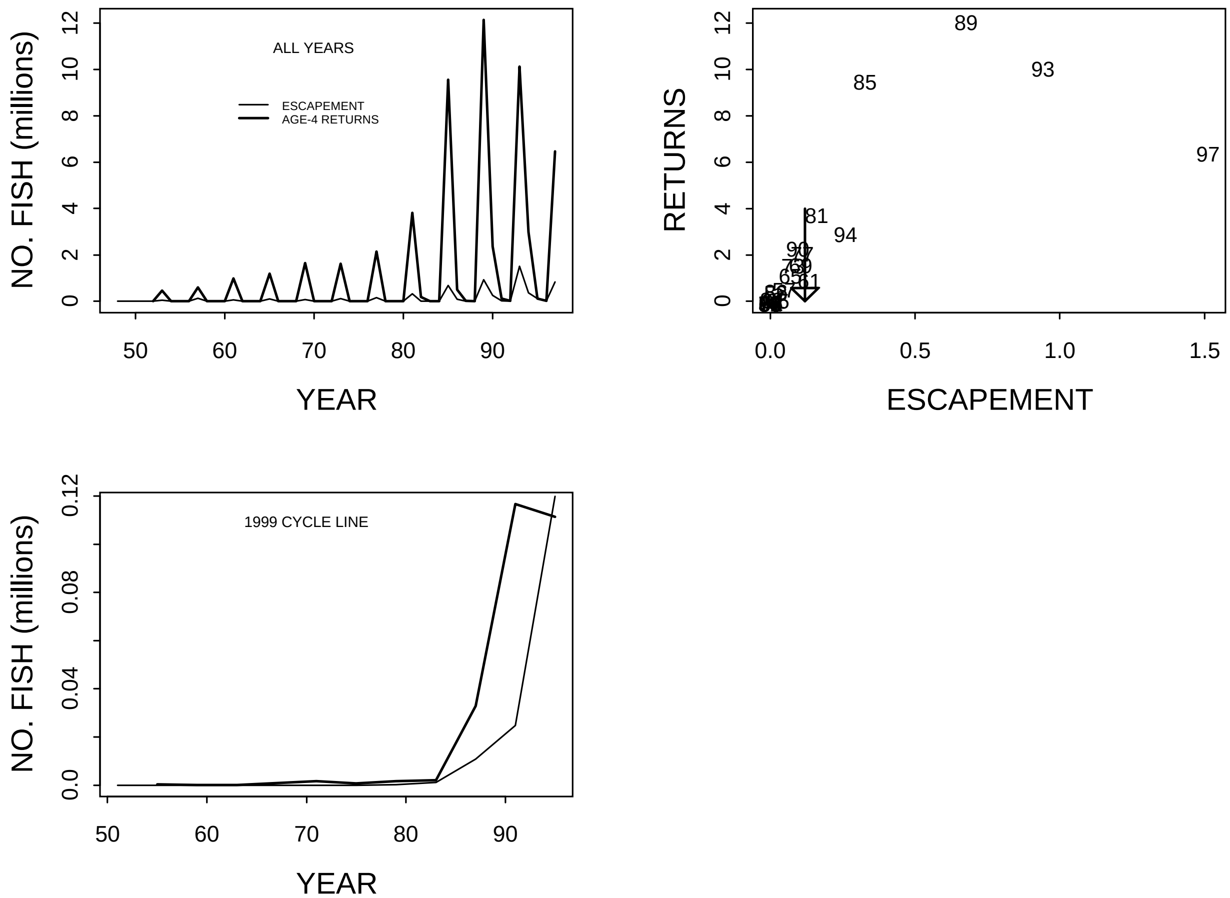

Figure 7. Trends in escapement and age-4 returns (millions) and the relationship between adult escapement, smolts and age-4 returns for Quesnel Lake sockeye. Data labels are return years. The arrow represents the 1995 escapement and smolt output.

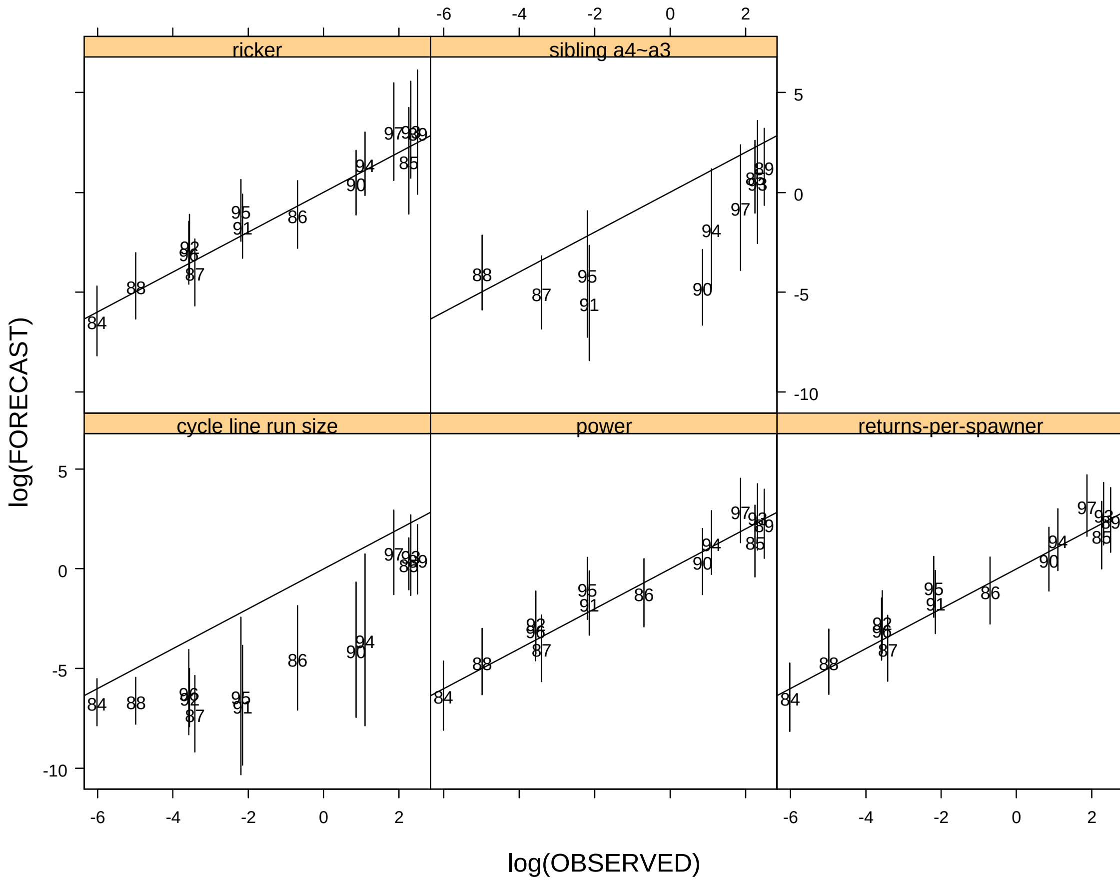

Figure 8. Comparison of estimated (observed) returns and retrospective run size forecasts (millions (log_e scale)) of age-4 Quesnel Lake sockeye by model. Data points are modes of distributions and denoted by return year. Diagonal lines are 1:1 line not regression lines. Error bars are 90% confidence intervals.

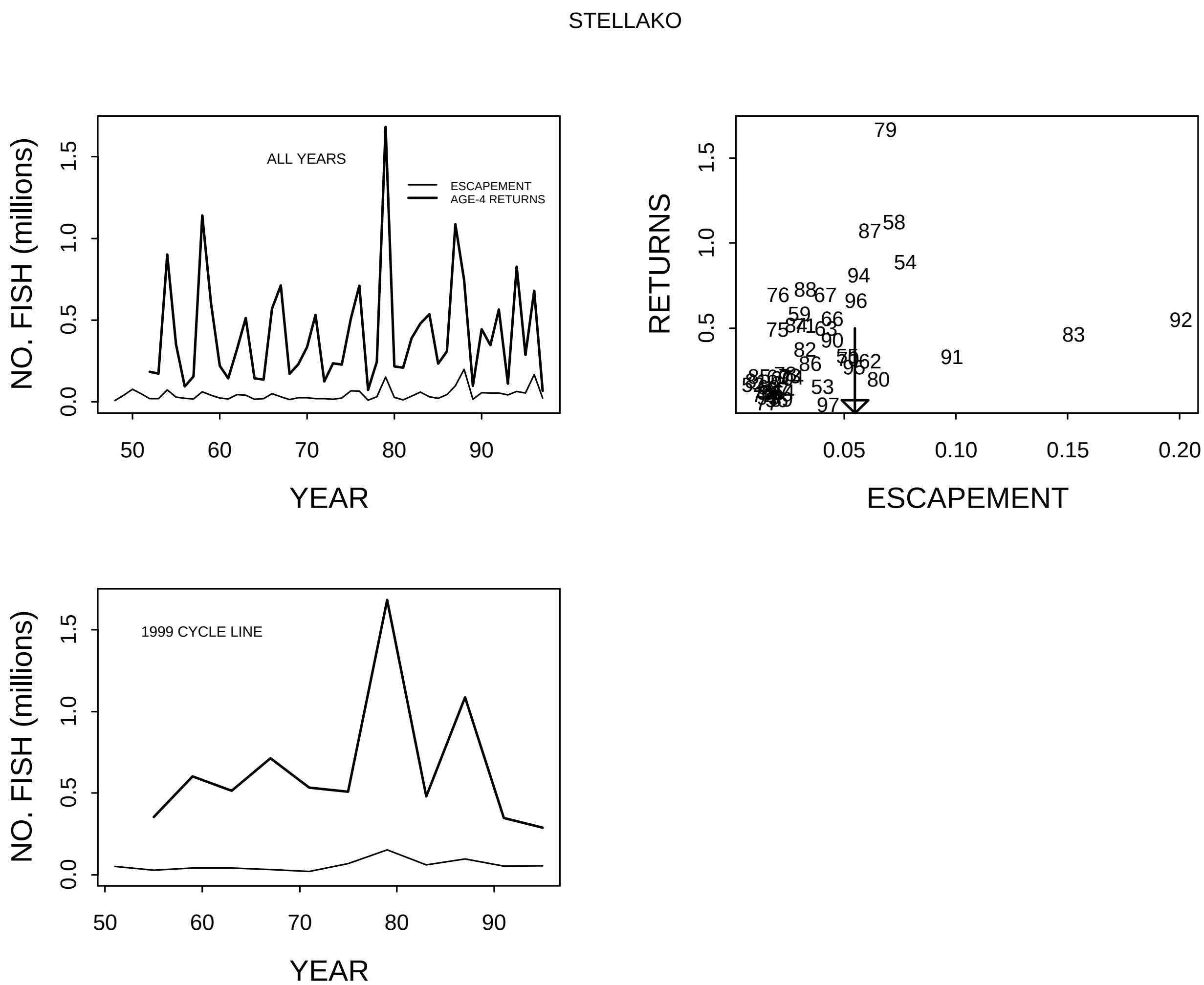

Figure 9. Trends in escapement and age-4 returns (millions) and the relationship between adult escapement and age-4 returns for Stellako River sockeye. Data labels are return years. The arrow represents the 1995 escapement and smolt output.

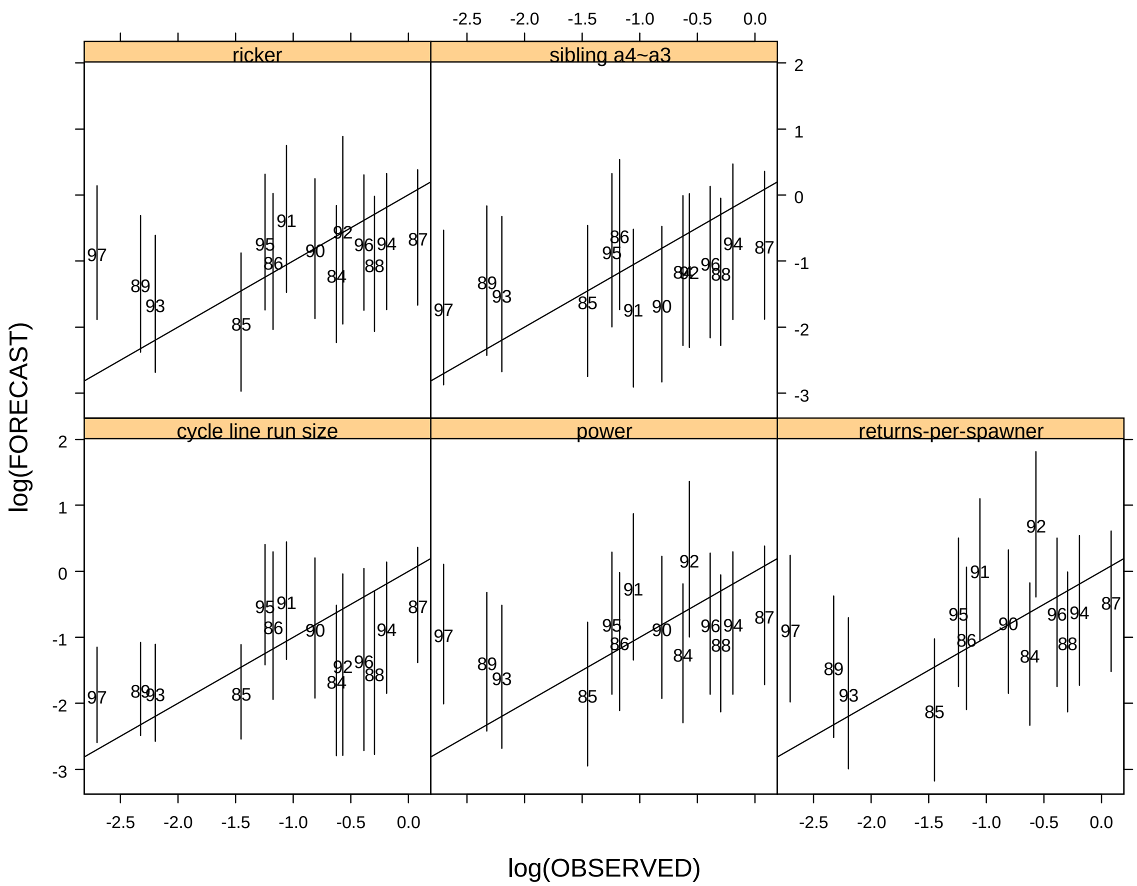

Figure 10. Comparison of estimated (observed) returns and retrospective run size forecasts (millions ($\log_e$ scale)) of age-4 Stellako River sockeye by model. Data points are modes of distributions and denoted by return year. Diagonal lines are 1:1 line not regression lines. Error bars are 90% confidence intervals.

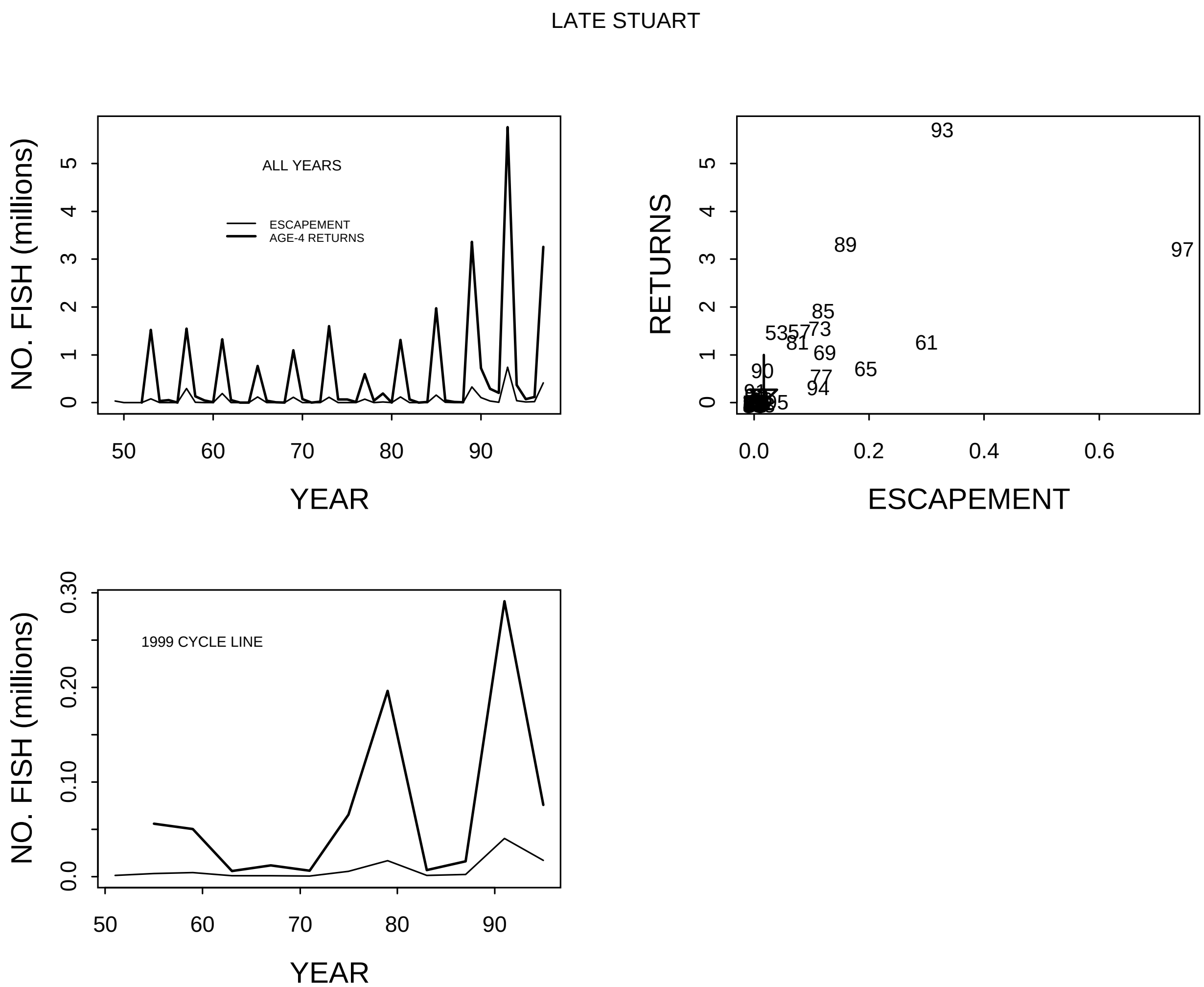

Figure 11. Trends in escapement and age-4 returns (millions) and the relationship between adult escapement and age-4 returns for Late Stuart sockeye. Data labels are return years. The arrow represents the 1995 escapement and smolt output.

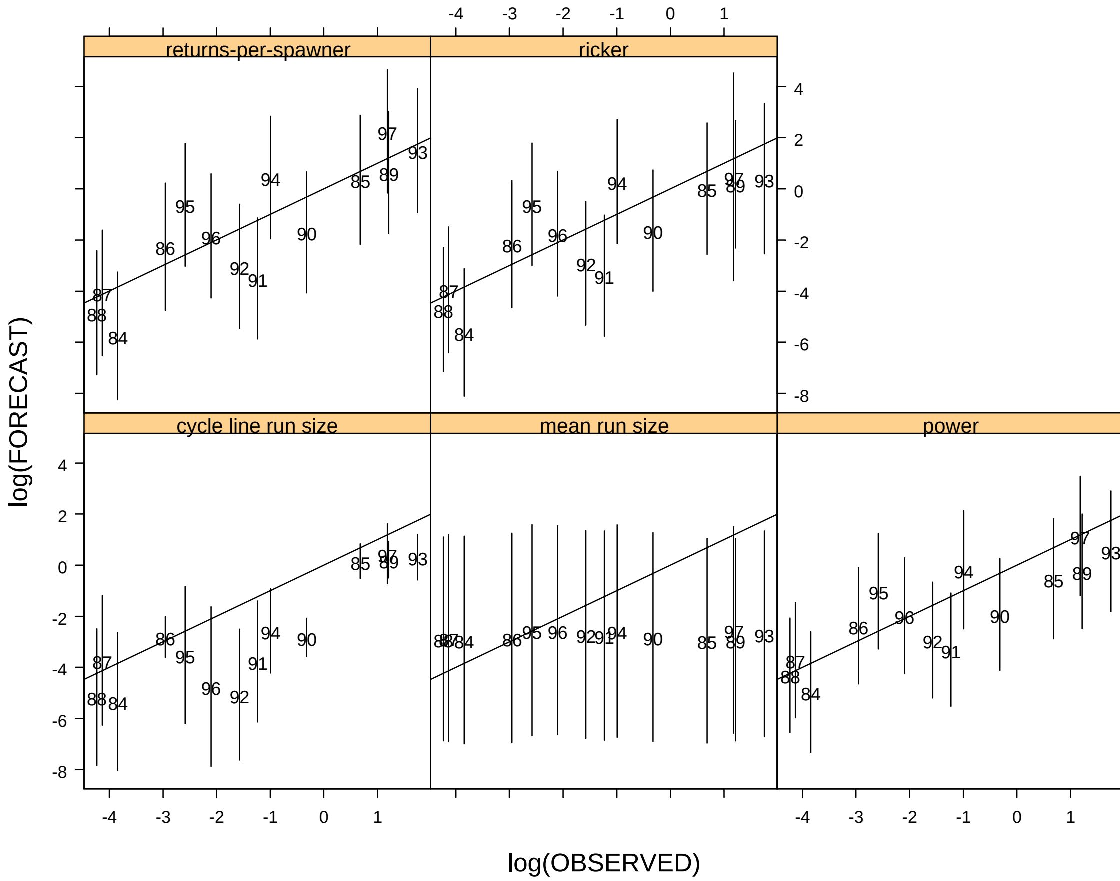

Figure 12. Comparison of estimated (observed) returns and retrospective run size forecasts (millions (log_e scale)) of age-4 Late Stuart sockeye by model. Data points are modes of distributions and denoted by return year. Diagonal lines are 1:1 line not regression lines. Error bars are 90% confidence intervals.

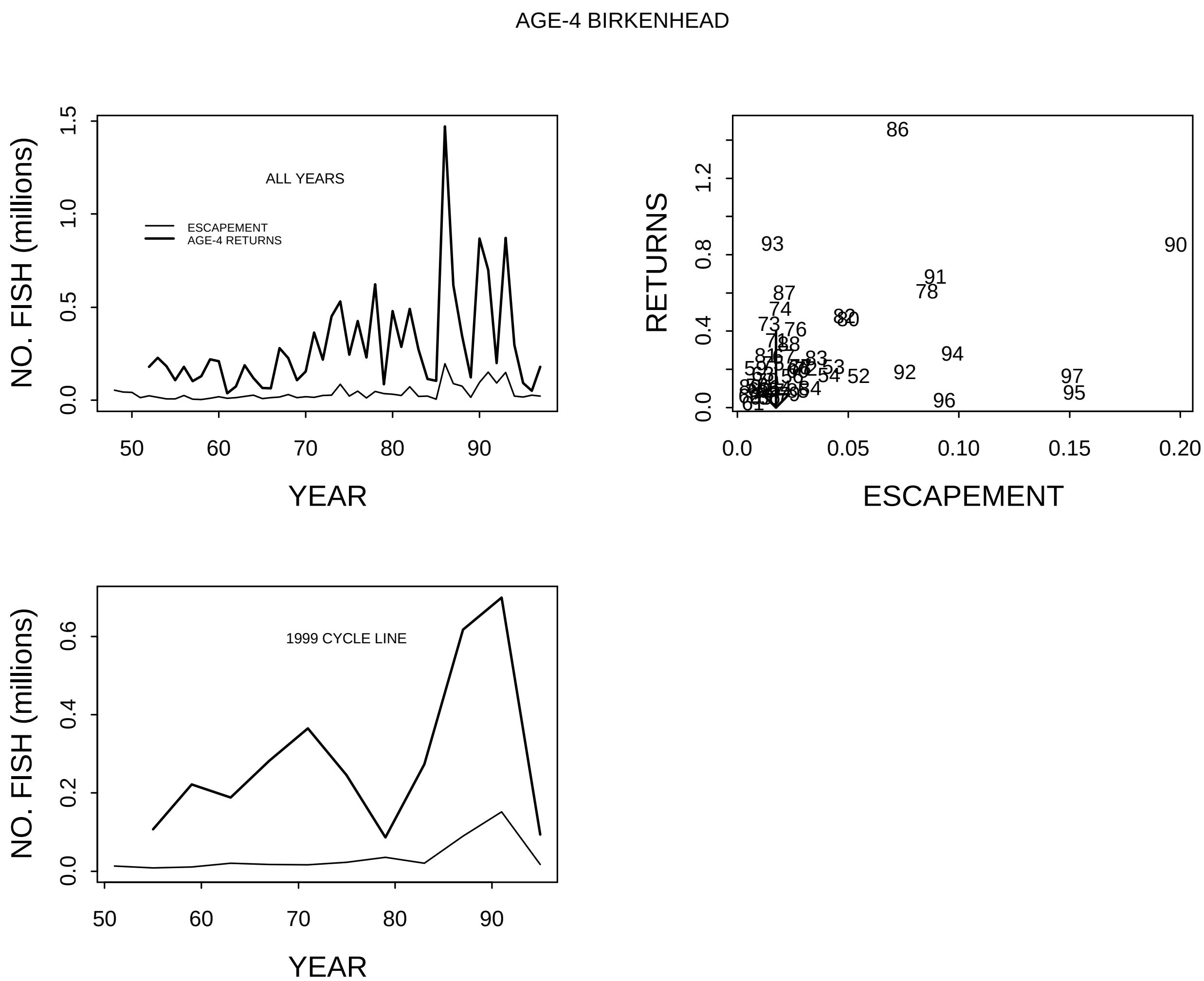

Figure 13. Trends in escapement and age-4 returns (millions) and the relationship between adult escapement and age-4 returns for Birkenhead sockeye. Data labels are return years. The arrow represents the 1995 escapement.

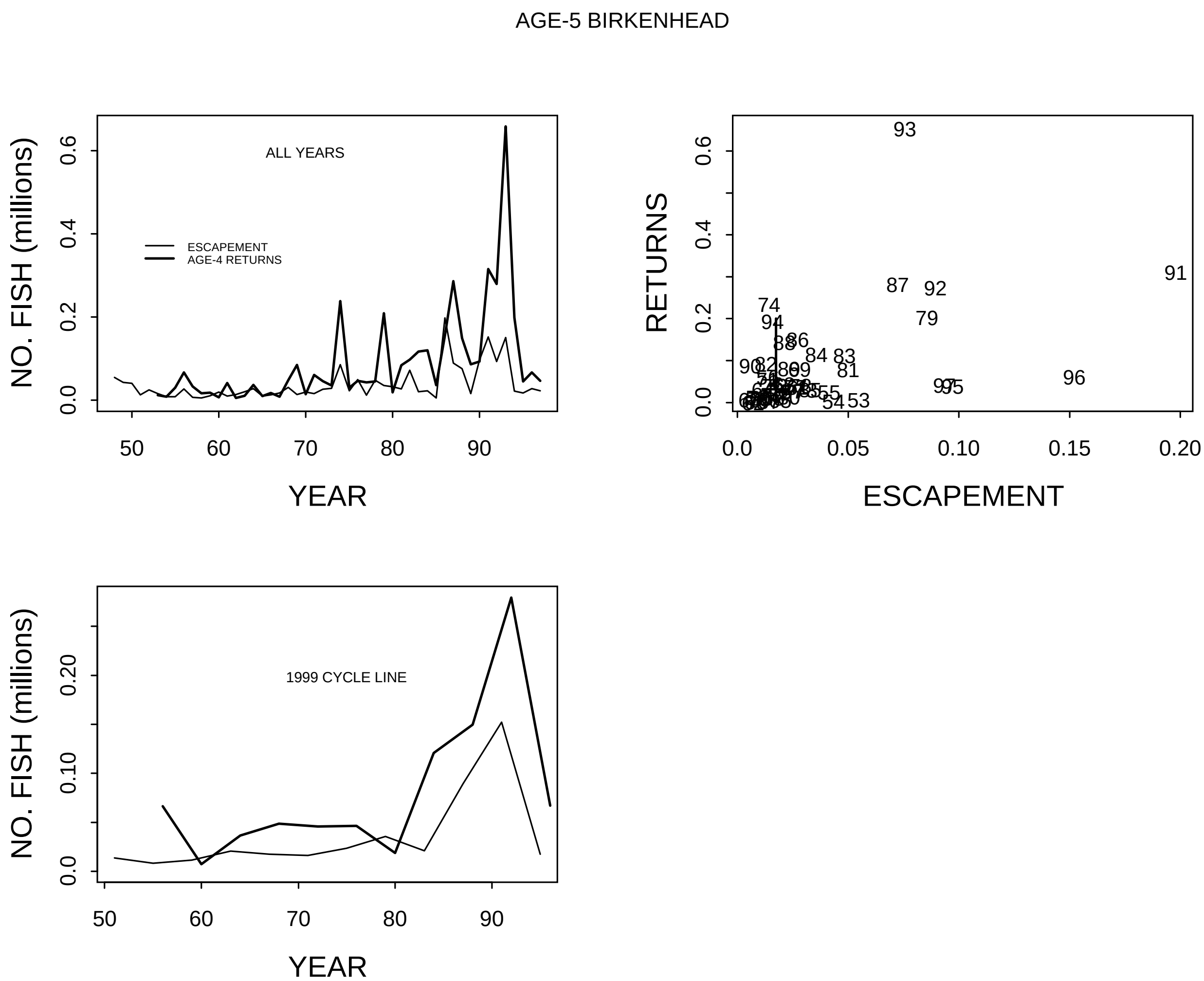

Figure 14. Trends in escapement and age-5 returns (millions) and the relationship between adult escapement and age-5 returns for Birkenhead sockeye. Data labels are return years. The arrow represents the 1994 escapement.

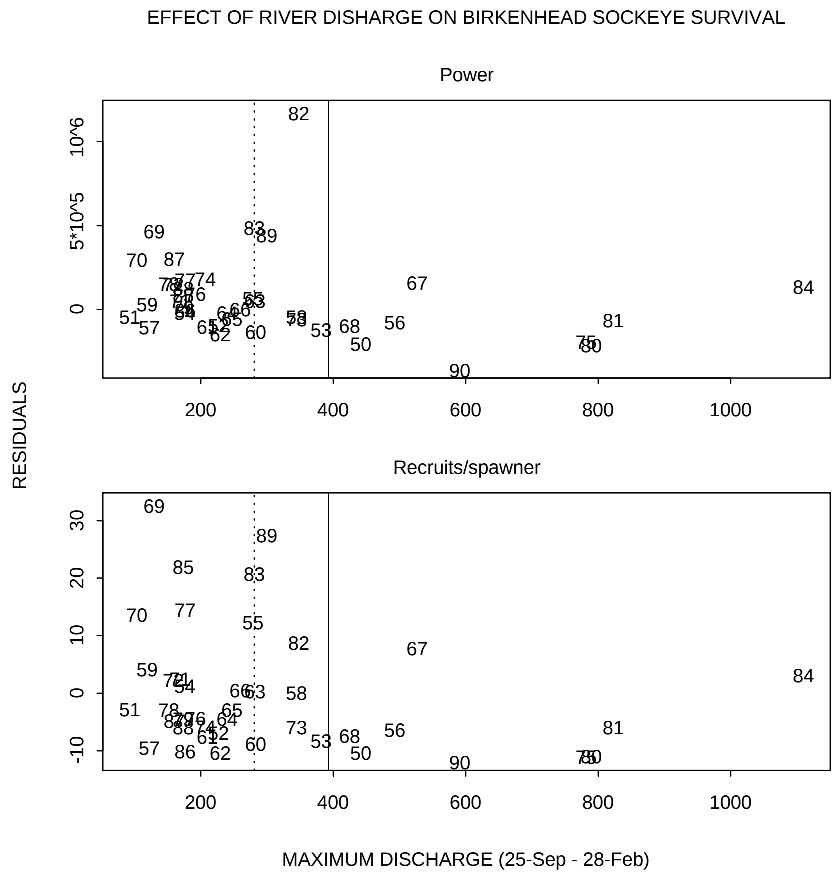

Figure 15. Residuals from relationships (power and recruits-per-spawner models) between Lillooet River discharge rate (1950-95) and returns (age-4 and age-5) for Birkenhead River sockeye. Vertical lines correspond to discharge rates affecting 1999 returns (solid line is for age-4 returns; broken lines is for age-5 returns)

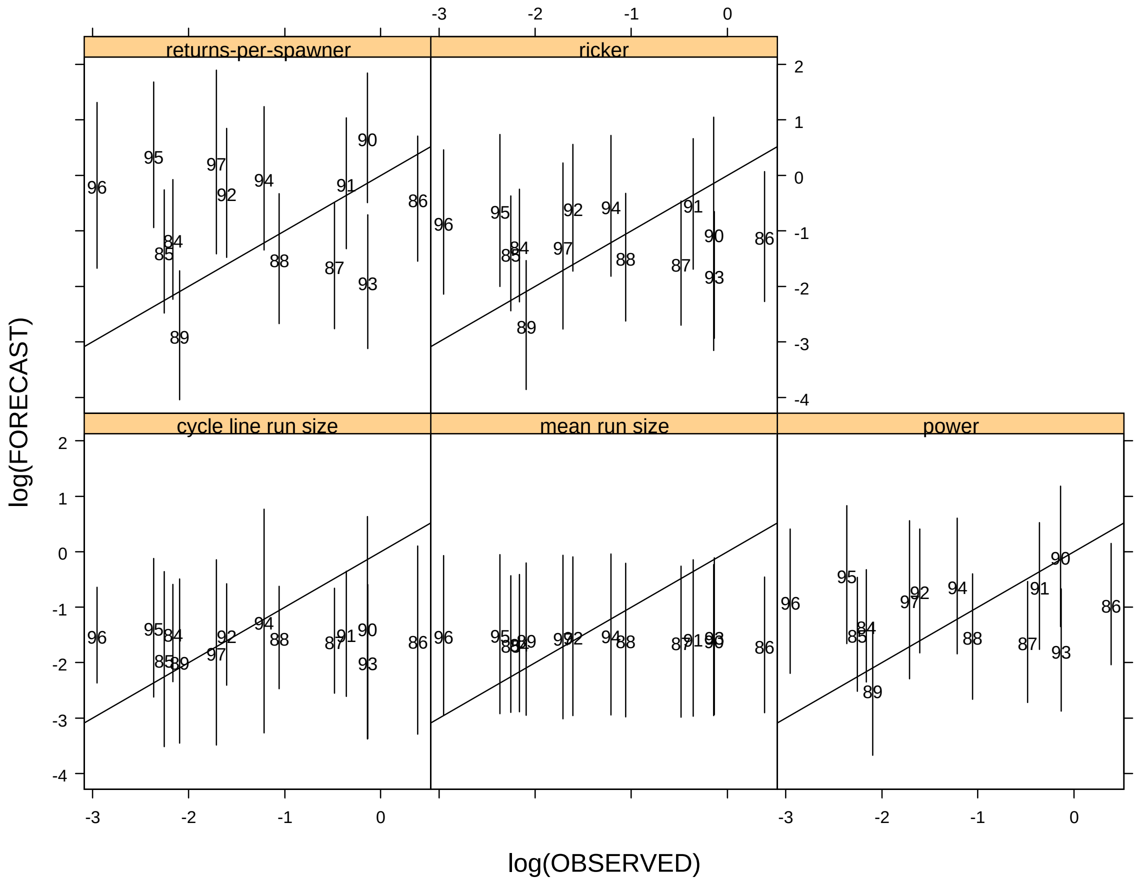

Figure 16 Comparison of estimated (observed) returns and retrospective run size forecasts (millions ($\log_e$ scale)) of age-4 Birkenhead sockeye by model. Data points are modes of distributions and denoted by return year. Diagonal lines are 1:1 line not regression lines. Error bars are 90% confidence intervals.

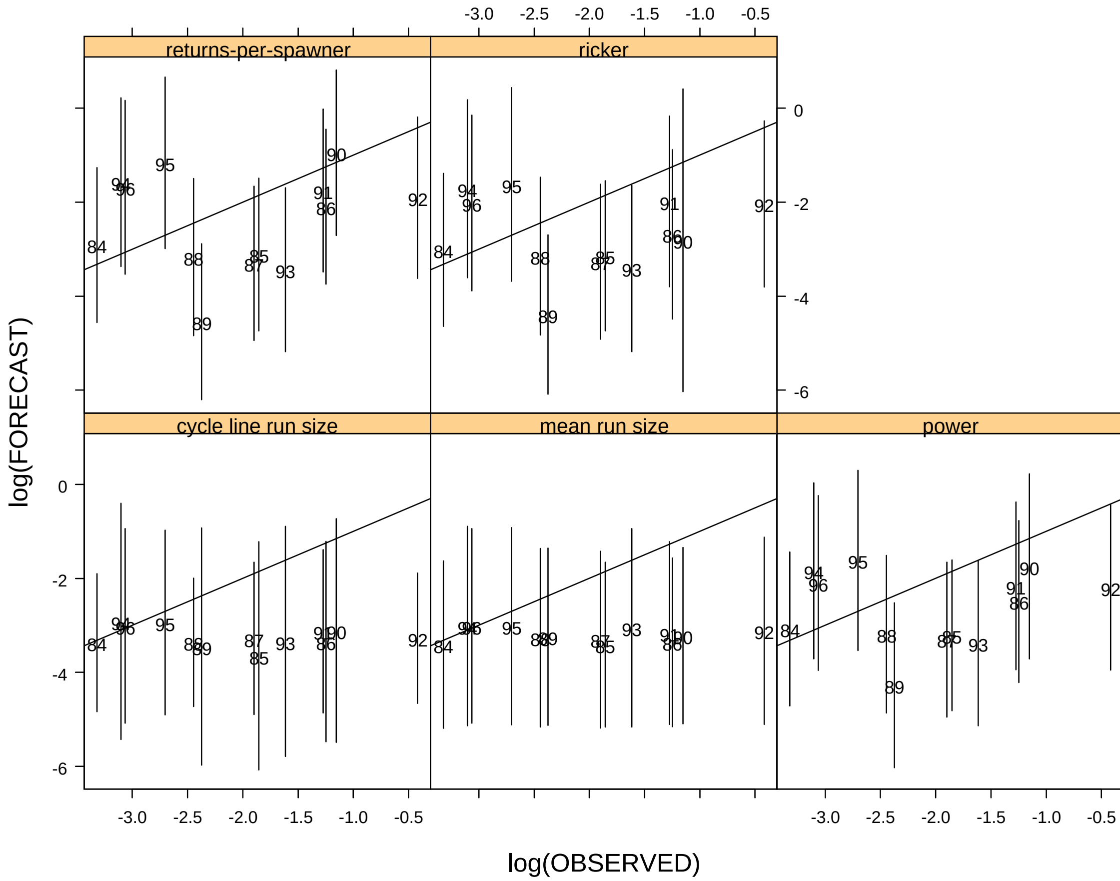

Figure 17. Comparison of estimated (observed) returns and retrospective run size forecasts (millions (log_e scale)) of age-5 Birkenhead sockeye by model. Data points are modes of distributions and denoted by return year. Diagonal lines are 1:1 line not regression lines. Error bars are 90% confidence intervals.

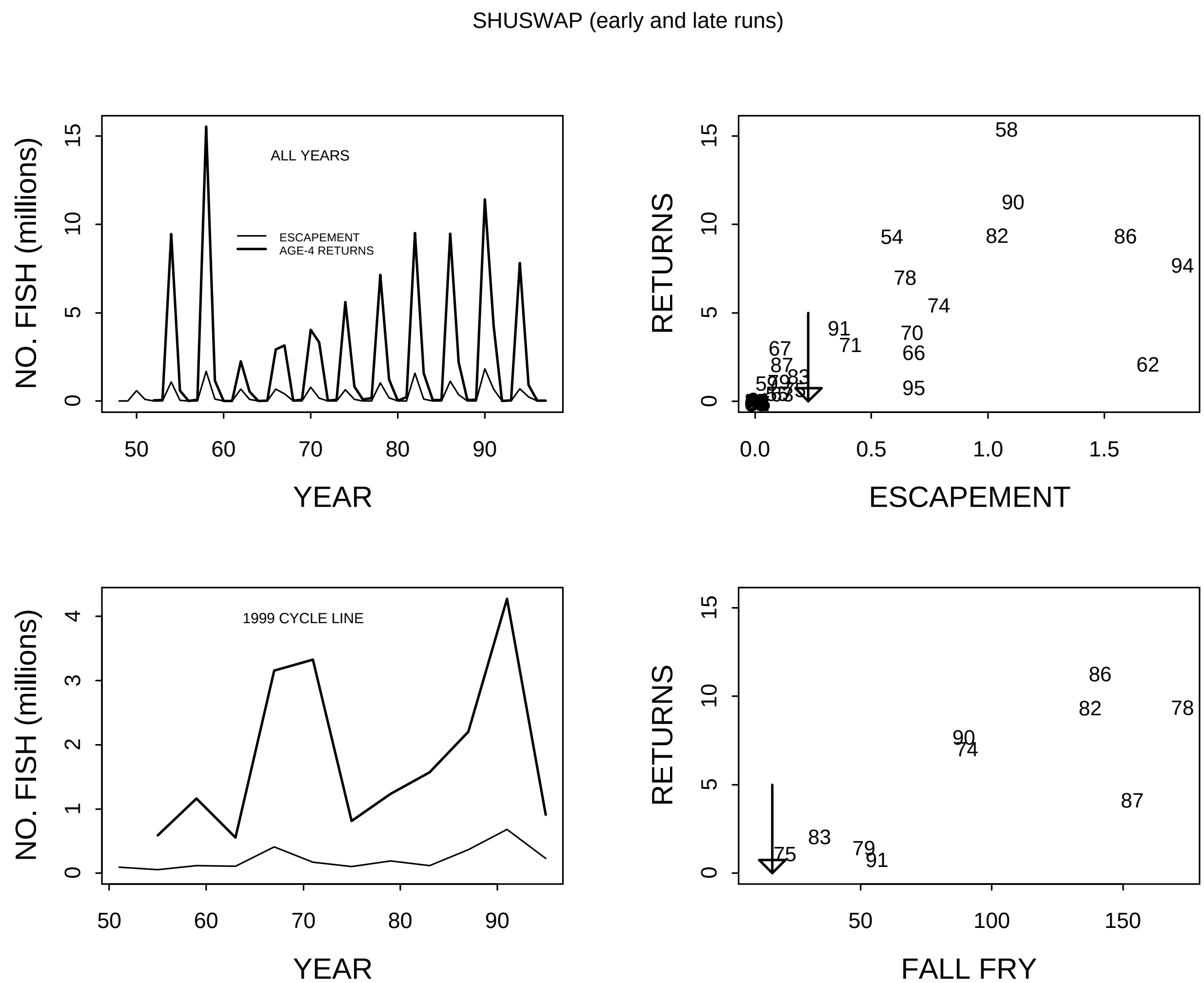

Figure 18. Trends in escapement and age-4 returns (millions) and the relationship between adult escapement and age-4 returns for Shuswap Lake sockeye. Data labels are return years. The arrow represents the 1994 escapement.

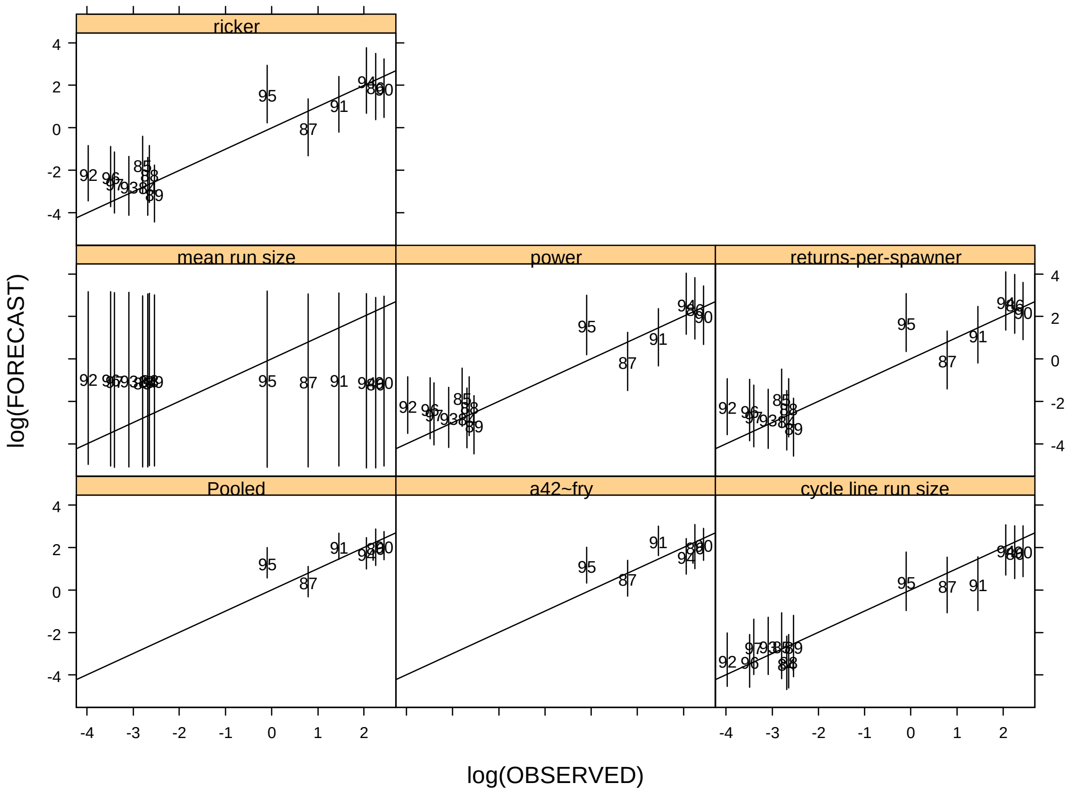

Figure 19. Comparison of estimated (observed) returns and retrospective run size forecasts (millions ($\log_e$ scale)) of age-4 Shuswap Lake sockeye by model. Data points are modes of distributions and denoted by return year. Diagonal lines are 1:1 line not regression lines. Error bars are 90% confidence intervals.

WEAVER

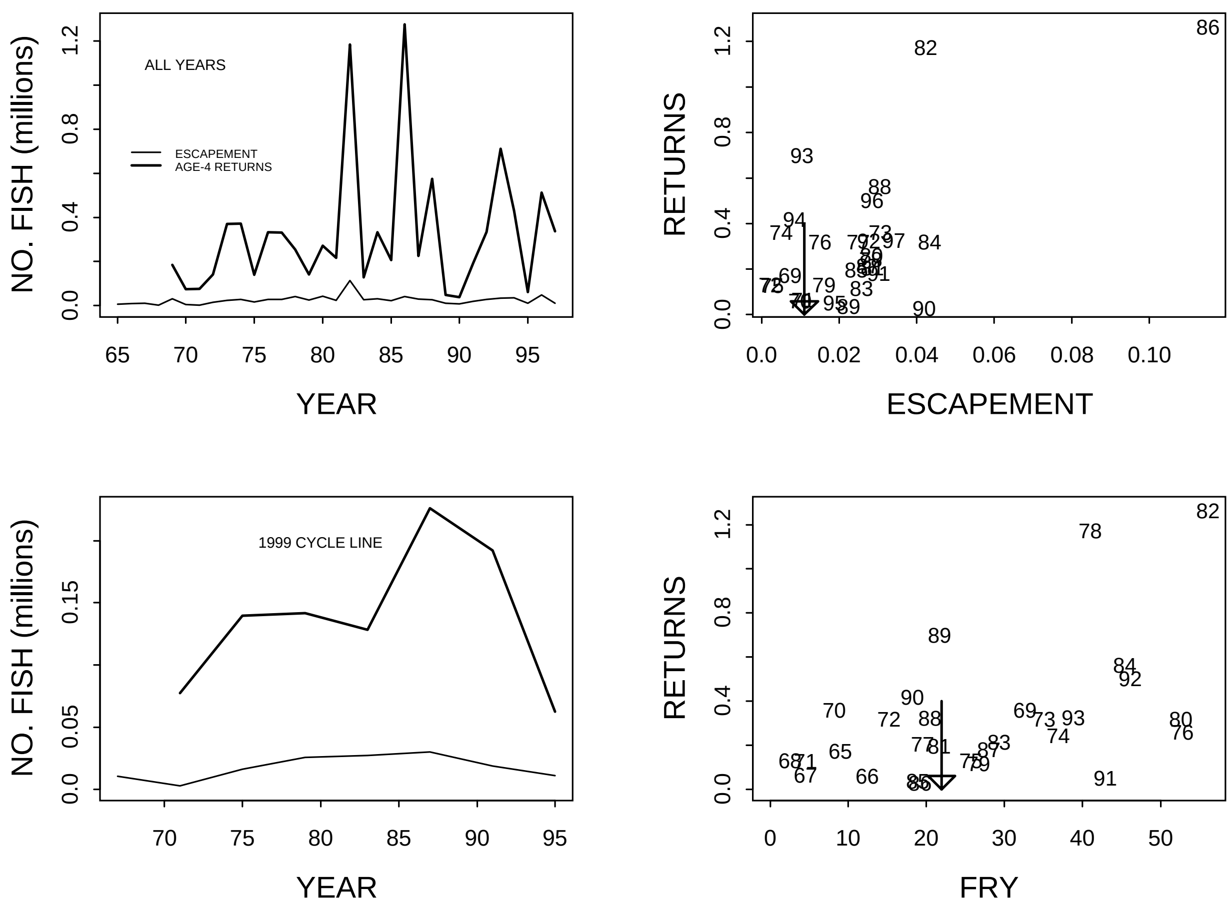

Figure 20. Trends in escapement and age-4 returns (millions) and the relationship between adult escapement and age-4 returns for Weaver sockeye. Data labels are return years. The arrow represents the 1994 escapement.

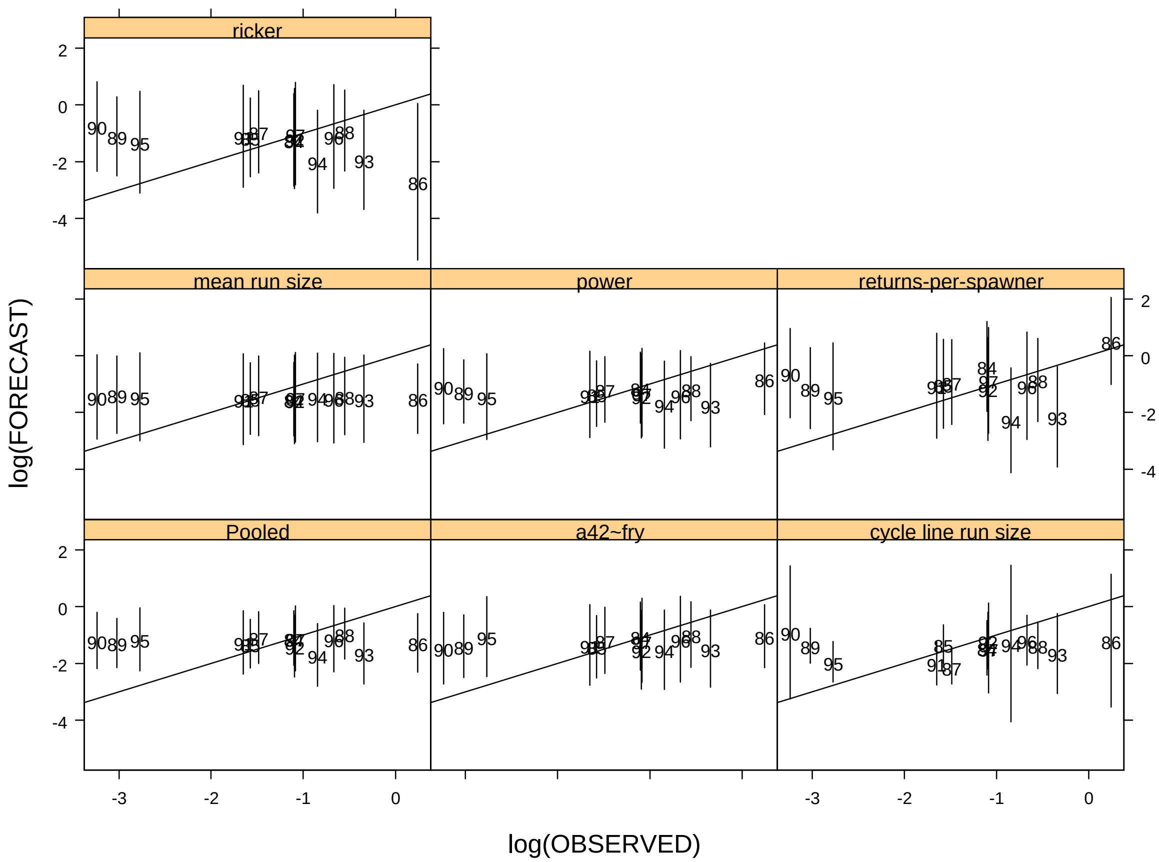

Figure 21. Comparison of estimated (observed) returns and retrospective run size forecasts (millions ($\log_e$ scale)) of age-4 Weaver sockeye by model. Data points are modes of distributions and denoted by return year. Diagonal lines are 1:1 line not regression lines. Error bars are 90% confidence intervals.

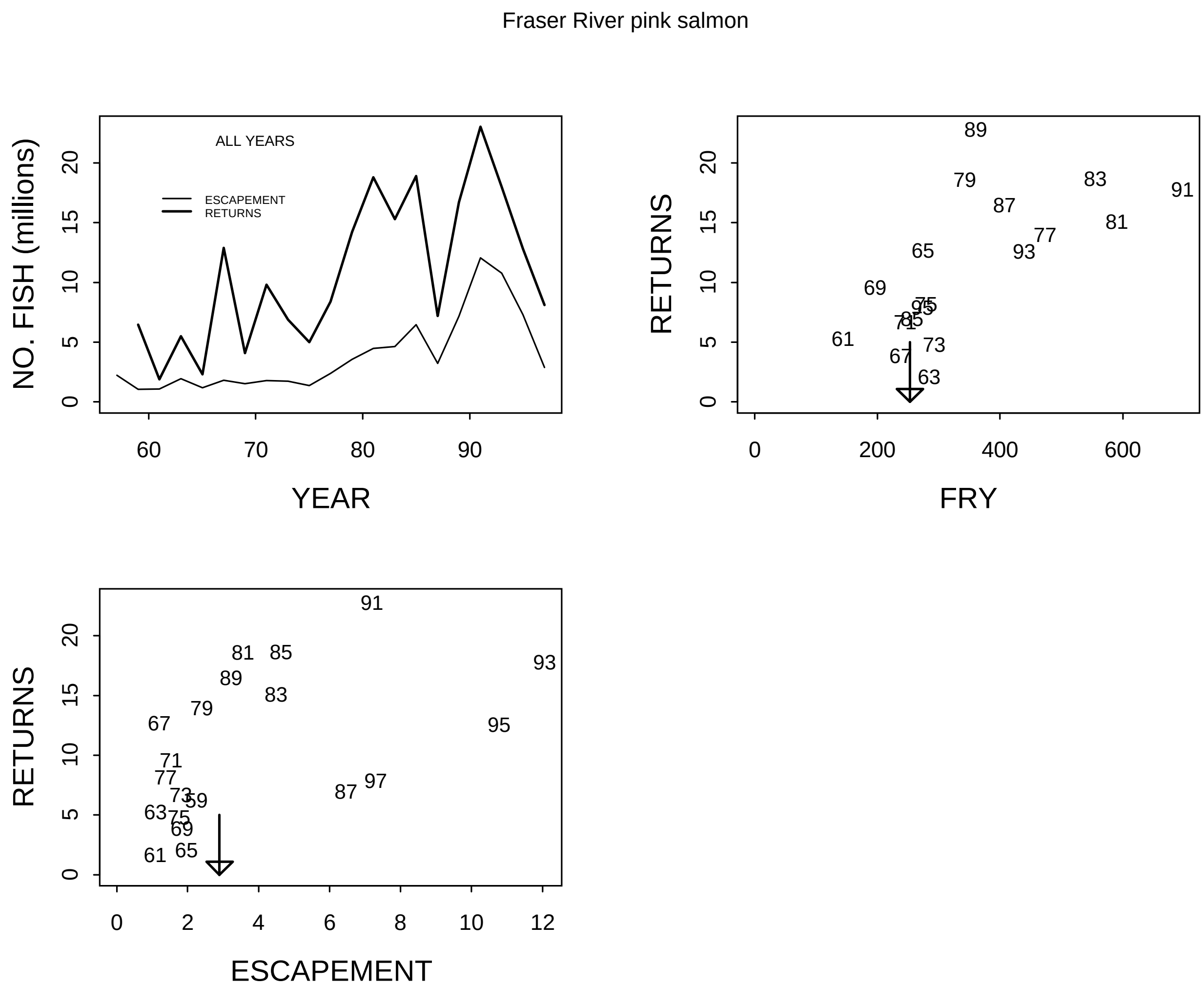

Figure 22. Trends in escapement and returns (millions) and the relationship between adult escapement and returns and fry and returns in odd-numbered years for Fraser River pink salmon. Data labels are return years. The arrow represents the estimated 1997 escapement and fry abundance.

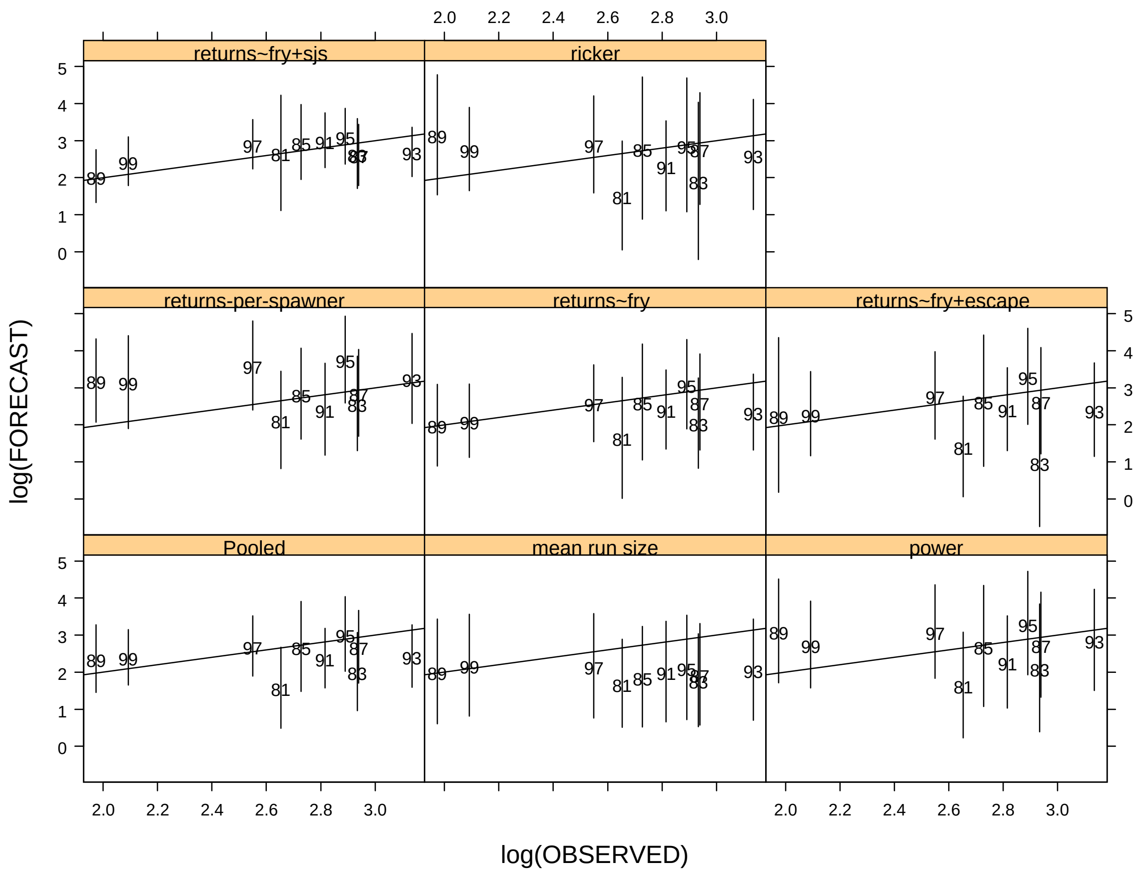

Figure 23. Comparison of estimated (observed) returns and retrospective run size forecasts (millions ($\log_e$ scale)) of Fraser River pinks by model. Data points are modes of distributions and denoted by return year. Diagonal lines are 1:1 line not regression lines. Error bars are 90% confidence intervals.