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Run size forecasts for Fraser River sockeye salmon in 1998

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Abstract

Forecasts are made for 19 individual sockeye stocks and four migratory timing/management groups. 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. Additional explanatory variables are available for some stocks and include fry, smolt, sibling adults and an index of ocean survival. For all models the uncertainty associated with stock-specific forecasts are large and reliable only within an order of magnitude. The major impediment to improvements in accuracy of pre-season run size forecasts are related to our inability to model variations in survival. The total 1998 Fraser sockeye run size forecast is 11.2 million sockeye at the 50% probability level and 6.8 million at the 75% probability level. Forecasts by management group are 175,000 (50%) and 97,000 (75%) for Early Stuart, 640,000 (50%) and 300,000 (75%) for Early summer stocks, 6.6 million (50%) and 3.9 million (75%) for summer run stocks and 3.8 million (50%) and 2.6 million (75%) for late run stocks.

Résumé

Des prévisions sont présentées pour 19 stocks de saumon rouge et quatre groupes de gestion à période de migration différente. Les prévisions du nombre d'adultes revenant aux frayères reposent sur des variables explicatives. Les prévisions de la plupart de stocks sont fondées sur des modèles de régression servant à prévoir l'abondance des adultes à partir de l'échappée de géniteurs. D'autres variables explicatives sont présentées pour certains stocks; elles portent sur les alevins, les saumoneaux, les adultes frères ainsi que sur un indice de la survie en océan. Pour tous les modèles, l'incertitude connexe aux prévisions de stocks particuliers est élevée et la fiabilité limitée à un ordre de grandeur. Les principaux obstacles à l'accroissement de l'exactitude des prévisions de la taille de la remontée d'avant-saison ont trait à notre incapacité à modéliser les variations de la survie. La prévision de la remontée totale de saumon rouge du Fraser de 1998 est de 11,2 millions de poissons, à un niveau de probabilité de 50 %, et de 6,8 millions de poissons à un niveau de probabilité de 75 %. Les prévisions par groupes de gestion sont de 175 000 (50 %) et 97 000 poissons (75 %) pour la remontée hâtive de la Stuart, de 640 000 (50 %) et 300 000 poissons (75 %) pour les stocks hâtifs d'été, de 6,6 millions (50 %) et 3,9 millions poissons (75 %) pour la remonté d'été et de 3,8 millions (50 %) et 2,6 millions poissons (75 %) pour les remontées tardives.

1 Introduction

Run size forecasts for 1998 Fraser River sockeye returns presented here are based on methods previously approved by PSARC (Cass 1997; Cass and Blackbourn 1996; Cass et al. 1995; Welch et al. 1994). Forecasts are made for 19 individual sockeye stocks and four migratory timing / management groups. The spawning escapement for these stocks accounted for 93% of the estimated total Fraser River escapement in 1994 (1998 brood year of age-4 returns) (Schubert, 1998). 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 1998 are the Late Shuswap (Adams River), Quesnel, and Chilko runs. The 1998 cycle year is noted for the dominant Adams River run that has historically been the single most important sockeye run on the 1998 cycle line. As reflected in the present forecast the importance of the sub-dominant Quesnel Lake run now rivals the Late Shuswap run. The sub-dominant Quesnel run has increased exponentially since the mid-1970s. Together the Late Shuswap and Quesnel runs accounted for 59% of the spawning escapement in 1994. Forecasts are presented for age-4 and age-5 sockeye but primarily focus on age-4 returns. Except for Birkenhead sockeye, age-4 returns have accounted for 95% of the returns of the major Fraser River stocks.

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

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 19 Fraser River sockeye stocks are used in this analysis. Except for sub-stocks of early Stuart sockeye, escapements are the number 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 Drftwood River population, a highly cyclic stock with negligible historical importance on the 1998 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 and Quesnel 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 (10 years in dominant and subdominant brood years 1974-94) and Quesnel Lakes (9 years mainly in dominant and subdominant brood years 1976-94). Hume et al. 1996 describe 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 tem 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 hydroacoustic methods for estimating Quesnel Lake sockeye fry abundance, PSARC was concerned about the reliability of sampling methodology (PSARC Advisory Doc 96-1996). 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 by expanding smolt counts from photographs taken at regular time intervals 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.

As reported in Cass et al. (1995), an environmental variable derived from rainfall measured in the "smolt" year was shown to explain variation in adult run size. Rainfall data is taken as the average of total monthly precipitation in two months (September and October) from three stations: Langara Island, in north-western British Columbia, and Annette Island and Ketchikan, both 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 and Ketchikan 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.

2.4 Birkenhead River discharge data

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 (daily) recorded between 25-Sep (long term mean peak spawning date) and 28-Feb as a measure of river flow effects on survival.

2.5 Weaver, Gates and Nadina fry data

Habitat and Enforcement Branch (C. Cross, personal communication), provided Weaver Creek (1965-94), Gates Creek (1968-93) and Nadina River (1973-93) fry data.

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. These include sibling models that use adult returns to explain older returns from the same cohort. Also, included in this category are estimates of fry (Nadina, Gates and Weaver sockeye), fall fry (Quesnel and Shuswap) and smolts (Chilko sockeye) as well as the significantly correlated precipitation/environmental index used to explain ocean survival effects on run size of Chilko sockeye.

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):

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

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 :

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

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:

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

4) Juvenile model:

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

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

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 the additional environmental variable was added as follows:

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

Variable E is the environmental rainfall index (see sec 2.4).

5) Sibling model:

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

$$\ln(R_{i+1,t+1}) = \beta_0 + \beta_1 \ln(R_{i,t}) + \sigma\varepsilon_t \tag{6}$$

For reasons discussed below, sibling models that use age-3 jacks to forecast 1998 age-4 returns are not considered reliable. For stocks with sufficient data, age-4 females standard length was added as a second explanatory variable to eq. 6 for forecasting age-5 sockeye.

A method that combines forecasts from models with independent biological explanatory variables (i.e. escapement and fry), hereafter termed the pooled model, was also considered in this analysis. Methods for combining forecasts are based on weighting schemes that weight using some measure of forecast error (McLeod et al. 1987; Noakes 1989; 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):

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

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

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

3.3 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. For stocks with >40 years of data retrospective comparisons were made for years 1970-94. Forecast data for most major sockeye stocks are sufficient to assess performance during that period. Stocks with fewer years of data (subsets of early Stuart, Scotch and Fennell sockeye) and other stocks recently supplemented by hatcheries (Late Nadina, Gates and Weaver) were only evaluated for the 1980-1994 period.

The time series of fall fry data for Quesnel and Shuswap lakes are short ($n \leq 10$) and of insufficient length to compare their performance in the retrospective analysis described above. Instead, a leave-one-out cross validation method that retrospectively forecasts every year in the time series was used to compare forecast performance among models.

Forecast errors were quantified using the root mean square error (RMSE) criteria. The model with the lowest RMSE was judged to be the 'best' forecast. If the RMSE criteria failed to differentiate among competing models then the model with the smallest variance was selected.

For each stock 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. Plots that compare annual retrospective forecasts to observed age-4 returns are 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. Spawning escapements for most stocks in 1994 were low compared to previous recent escapements and below target to the extent that prompted the 1994 Fraser River public review (Anon. 1995). Because of the low escapements in 1994 forecasts of 1998 returns based on historical means are not considered reliable and were not considered viable candidate models in the present analysis.

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 of the forecast) of age-5 forecasts is 2.7 times the variances for age-4 sockeye. Because of the relative unimportance of age-5 sockeye, the stock-specific forecasts discussed below focus primarily on age-4 forecasts.

Sibling models that use jacks to forecast age-4 returns are unlikely candidates for reliable prediction of age-4 returns in 1998 (jack returns in 1997). The proportion of jacks in many stocks underwent a long-term decline since the 1960s (Fig. 1) as somatic growth rates declined. In an attempt to correct for trends in jacking rates, the standard length of jacks was compared to jacking rates (Fig. 2). The effect of jack standard length in regressions of length and jack abundance versus age-4 returns was not significant (P>0.05) for any stock and except for Stellako sockeye does not improve age-4 sockeye forecast reliability (Table 1). Furthermore, anomalous migratory behaviour in 1997 resulted in high rates of straying of Fraser bound sockeye to non-Fraser systems and non-natal Fraser systems at unprecedented levels. Although still being investigated, the high rate of straying appears to be negatively correlated to body size (Skip McKinnell, DFO, personal communication). If smaller fish were more likely to stray in 1997 then spawning ground estimates of jacks are likely biased low. The number of jacks estimated to have returned to Fraser River spawning locations in 1997 (1998 brood) dropped dramatically compared to returns in 1993 (1994 brood). For example, the estimated return of Late Shuswap jacks was 19,000 in 1993 compared to 600 in 1994. Except for Chilko and Birkenhead sockeye, jack returns in 1997 were in the 100s of fish. Most runs in 1997 were comprised of < 1% jacks. Based on preliminary 1997 estimates, the only stocks with escapements >1% jacks were Birkenhead (4%), Gates (20%), Shuswap (42%) and Chilko (1.4%). At jacking rates experienced by most stocks in 1997, the effects of measurement error alone are likely to render jack-based sibling models unreliable. For these reasons, jack-based forecasts are not considered in this analysis. To accept the alternative hypothesis whereby the jacks in 1997 are representative of age-4 sibling abundance in 1998 is to assume unprecedented and catastrophic low survival of the 1994 brood.

The total 1998 Fraser sockeye run size forecast based on the 19 stocks considered in this report at the 50% probability level is 11.2 million sockeye. Forecasts by management group are 175,000 Early Stuart, 640,000 Early summer stocks, 6.6 million summer run stocks and 3.8 million late run stocks. 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 1998 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. 3). 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, 1998 forecast variance and the retrospective residual pattern for the Ricker model is similar to the power model (Table 1; Fig. 4). The total Early Stuart forecast (Driftwood and non-Driftwood) for 1998 at the 50% probability level is 175,000 age-4 and age-5 sockeye (Table 2).

4.2 Early summer run

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 1998 cycle line and show persistent population cycles. Scotch Creek returns on the 1998 cycle line increased from 100,000 sockeye in 1986 to 400,000 sockeye in 1994 (Fig. 5). Escapement increased from 11,000 effective females in 1986 to 34,000 in 1990. Escapement dropped to 27,000 effective females in 1994 (1998 brood). The 1998 forecast for Scotch Creek at the 50% probability level is 370,000 sockeye (Table 2). The return-per-spawner model was the best predictor of Scotch Creek age-4 returns. All of the models under-forecast the recent high returns of Scotch Creek sockeye (1986-90) (Fig. 6). Returns of Seymour River sockeye on the 1998 cycle increased from 500,000 sockeye in 1986 to 800,000 in 1990 and declined to 300,000 sockeye in 1994 (Fig. 7). Escapement to Seymour River in 1994 (1998 brood) dropped to 15,000 sockeye and was the lowest on this cycle since 1970. The 1998 forecast of 116,000 Seymour River sockeye at the 50% probability level is lower than estimated returns since 1970. All three escapement-based models resulted in similar retrospective residual patterns (Fig. 8). Forecasts of other early summer sockeye range from 9,000 (Raft River) to 47,000 (Upper Pitt River) in 1998 (Table 2).

4.3 Summer run

4.3.1 Quesnel Lake

Returns on the 1998 cycle line to Quesnel Lake have increased steadily from 19,000 in 1978 to 2.9 million in 1994 (Fig. 9). Escapements also increased during the same period. The escapement in brood year 1994 (1998 return year) was the highest on record for the 1998 cycle line at 355,000 effective females and represents a 37% increase from the preceding brood year. The multiple regression that includes fall fry and escapement results in the lowest RMSE (Table 1). This model uses only years that fry data are available (n=9 years) and results in a forecast at the 50% probability level of 4.26 million. The power model results in the lowest RMSE compared to other escapement-based models fit to all years of data and a 1998 forecast return of 4.04 million age-4 sockeye. The forecast from the age-4 return – fry regression model of 1.56 million age-4 sockeye is considerably less than forecasts from escapement-based models and has a very large variance compared to other models except for forecasts based on historical mean returns.

The fry variable in multiple regression model that includes fry and escapement does very little to improve the fit of the model (little change in the residual square error when fry are dropped from the model). There is also little basis for choosing from among models based on residual patterns from the retrospective analysis (Fig. 10). Nevertheless, the multiple regression model is the best model based on the RMSE criteria and results in a 6% increase in the forecasts compared to the escapement-based power model (4.26 versus 4.04 million).

The large variance associated with the fry-based forecast and the uncertainty in the sockeye/kokanee fry proportions in Quesnel Lake indicates the sockeye fry estimates are subject to large measurement errors and may be badly biased. The effect of not accounting for kokanee will negatively bias forecasts of subdominant line sockeye assuming that the proportion of kokanee fry is larger on low (subdominant) sockeye years compared to dominant cycle line years. For a discussion of effects of kokanee on Shuswap sockeye forecasts see sec. 4.4.2. Insufficient contrast in average fall fry body weight over the range of annual fry abundance estimates precludes the use of fry size to corroborate the low fry-based forecast.

The age-4 and age-5 forecast at the 50% probability level is 4.30 million sockeye. This is based on the sum of age-4 and age-5 sockeye forecasts. Age-4 sockeye are from the fall fry and escapement multiple regression model. The age-5 recruit-per-spawner model results in the lowest RMSE. The age-4 recruits/spawner rate in 1997 was low, deviating from the forecast based on age-4 recruits-per-spawner, therefore, the age-5 recruits/spawner ratio is likely also low resulting in a positively biased 1998 forecast of age-5 sockeye. For this reason the age-5 sibling model (eq. 6) was selected as the best age-5 forecast for 1998 (next lowest RMSE).

4.3.2 Chilko Lake

Annual returns of Chilko sockeye (1952-97) have been highly variable but without persistent four-year population cycles (Fig. 11). Average returns were 1.3 million sockeye/yr. Returns on the 1998 line increased steadily between 1974 and 1990 from 67,000 to 4.5 million sockeye. Returns declined in 1994 to 2.5 million sockeye. Escapement (effective females) on this cycle also increased from 71,000 in 1974 to 500,000 in 1990 but declined to 250,000 in 1994. The model with the best retrospective performance for forecasting age-4 returns is the multiple regression model that includes age-1 smolts and escapements (Table 1). The difference in forecast and RMSE between that model and the smolt-return regression is negligible. The respective forecasts are 1.28 million and 1.29 million sockeye. The addition of the environmental variable (Sep-Oct precipitation from coastal stations in B.C. and Alaska) results in a higher RMSE even though it explains a significant portion of the variation in smolt-return survival ($P<0.05$). This is because the precipitation variable was less able to account for the outlier resulting from low survival of returns in 1995 (Fig 12). The RMSE for the pooled model that included age-4 forecasts and variances from the Ricker model (lowest RMSE for escapement-based models) and smolt model was larger than for the model based solely on smolts. Chilko age-5 sockeye are comprised of significant numbers of sockeye that spend three winters in freshwater before smolting (age-2 smolts) as well as the typical age-5 sockeye that spend two winters in the ocean before maturing. Forecasts of the former are based on the sibling age-

4 - age-5 regression model (lowest RMSE). Forecast of age-5 sockeye that smolt at age-1 is based on a recruits-per-spawner model (lowest RMSE).

The total 1998 Chilko sockeye forecast at the 50% probability level is 1.4 million sockeye (Table 2).

4.3.3 Stellako and Late Stuart

Returns of Stellako have fluctuated without persistent four-year population cycles averaging 480,000 age-4 and age-5 sockeye/yr since 1952 (Fig 13). Average returns on the 1998 cycle were 550,000 sockeye (700,000 in 1994). Average escapement (effective females) on the cycle was 50,000 sockeye/yr (64,000 in 1994). The forecast at the 50% probability level is 545,000 sockeye based on the Ricker model. The Ricker model resulted in the lowest RMSE but performed only marginally better than other models including the long-term mean return (Table 1; Fig. 14).

Late Stuart sockeye populations show persistent cycles and are dominant on the 1997 cycle line (Fig. 15). Mean returns on the 1998 cycle line averaged 160,000 sockeye/yr but have increased from a mean of 70,000 in 1952-86 to 760,000 in 1990. Returns dropped to 380,000 in 1994. Late Stuart escapements on the 1998 cycle line showed little trend before 1990 and averaged 8,000 effective females/yr. Escapements increased to 112,000 in 1990 but declined to 39,000 effective females in 1994. All forecasts have a very large variance compared to other major Fraser stocks (Table 1; Fig. 16) and the cycle mean return had the lowest RMSE. Given the large increase in escapement and returns on this cycle since 1986 the cycle mean forecast is not considered reliable. Of the escapement-based forecast models, the power model resulted in the lowest RMSE and variance for age-4 sockeye. The 1998 forecast of age-4 and age 5 Late Stuart sockeye at the 50% probability level is 393,000 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.17 and Fig. 18). Returns recently declined from a peak of 1.6 million in 1986 to 120,000 in 1996. Escapement also peaked in 1986 at 200,000 effective females and was 150,000 in 1993 (age-5 returns in 1998) and 22,000 in 1994 (age-4 returns in 1998).

High daily maximum discharge rates for the Lillooet R (1950-94) are often associated with low Birkenhead sockeye recruitment rates (Fig. 19). Maximum daily discharges affecting 1998 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 but are similar to other escapement-based regression models at 200,000 sockeye (Table 1). The age-4 residual pattern from the retrospective analysis shows little difference between the Ricker and power models (Fig. 20). The 1998 forecast of age-5 sockeye is based on the sibling regression that includes age-4 female standard length and is 103,000 sockeye. That particular model resulted in the lowest RMSE and variance (Table 1) as well as the most evenly distributed residual pattern about the 1:1 line in the comparison of observed versus retrospective forecasts (Fig. 21). The age-4 and age-5 forecast at the 50% level is 303,000 sockeye (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 1998 cycle line is the dominant cycle. Returns on the 1998 cycle increased during the 1960s, 1970s and 1980s and peaked at 7.5 million age-4 sockeye in 1990 (Fig. 22). Sockeye returns in 1994 were 7.3 million. Escapements also increased during the same period and peaked at 1.7 million effective females in 1990. Escapement in 1994 declined to 670,000 sockeye and was the lowest since the 1960s. The Ricker model resulted in the lowest RMSE and a forecast at the 50% probability level of 4.0 million age-4 sockeye. The range in the forecasts among candidate escapement-based models (Ricker, power, recruits-per-spawner) was only 4.0 - 4.5 million. The fall fry-based model resulted in a forecast of 3.2 million age-4 sockeye that theoretically accounts for both early timed runs (Scotch and Seymour) and late runs (fry from all Shuswap tributaries are assumed to be equally vulnerable to acoustic sampling). Subtracting the early runs from the total fry-based Shuswap forecast results in a late run forecast of 2.7 million sockeye. The RMSE for the fry model is very similar to the RMSE for escapement- based models when only the data for years with fry data are included (Table 1; Fig. 23). Pooling the Ricker and the fall fry-based forecast models (eq. 7) results in an age-4 and age-5 forecast at the 50% probability level of 3.0 million late run Shuswap sockeye (Table 2). A return of this magnitude is consistent with the recruits-per-spawner rate of the dominant line in the 1960s when escapements were in the 600,000 - 700,000 effective female range.

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). To test the effect of this magnitude of kokanee abundance on sockeye forecasts, 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 (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 fry in this way increases the fry-based forecast of age-4 returns to 3.31million sockeye in 1998 (early and late runs) or an increase of only 4.4% from the forecast based on the nominal fall fry estimate. Significant forecast bias on dominant years as a result of kokanee fry is unlikely given the level of age-0 kokanee abundance estimated for dominant years.

The forecast of late run Shuswap sockeye considered the most appropriate given the available data is from the pooled forecast that combines attributes of the escapement-based Ricker model and the nominal fall fry model. Combined with age-5 sockeye forecast (negligible in 1998) results is a total 1998 forecast of 3.0 sockeye at the 50% probability level.

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. 25). The RMSE for the pooled model (inputs from the fry and recruits-per-spawner model) was the lowest but was very similar to the power, recruits-per-spawner and fry-based models (Table 1; Fig. 26). Corresponding age-4 forecasts are 340,000 (pooled), 274,000 (power), 410,000 (recruit-per-spawner) and 303,000 sockeye (fry). Based on the age-4 pooled model and the age-5 sibling model that includes age-4 female standard length the total (age-4 and age-5) Weaver Creek forecast is 400,000 sockeye at the 50% probability level.

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 18,000 and 45,000 age-4 and age-5 sockeye.

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, including sibling models that theoretically account for most of the natural mortality incurred by a cohort, has performed consistently better than any other.

The most important stocks in 1998 based on forecasts presented here are Quesnel (summer run) at 4.3 million and Shuswap (late run) at 3.0 million sockeye (50% chance the run will be higher or lower). Forecasts for Quesnel and late Shuswap sockeye will form the basis for the early season management strategies of sockeye fisheries in 1998. Table 2 shows the uncertainty in forecasts. For Quesnel sockeye there is only a 50% chance the run will be within 2.5 million and 7.5 million sockeye. For the late Shuswap run the range in narrower at 2.0-4.0 million 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 index used to explain variation in Chilko ocean survival has worked to some extent, whether spurious or not, and is the only variable examined (to my knowledge) that is correlated to smolt survival.

Low-frequency climatic changes that are implicated in turn to cause autocorrelated recruitment patterns in fish population (low and high survival regimes) are not evident in the time series of Chilko smolt (ocean) survival data (Fig. 27). Chilko ocean survival based on age-1 smolts to adult age-4 survival have ranged from 1.2% in brood year 1957 to 23% in 1986 and above average in 1992 and 1993 at 13% (long-term mean = 9.2%). The trend in smolt survival reveals little discernible recruitment pattern and the autocorrelation is insignificant at a lag of 1 year (r=0.18). The low correlation in inter-annual recruitment for at least Chilko sockeye (the only stock with smolt-return data) suggests that ocean survival in 1998 cannot be reliably predicted from recent survival or climatic trends. There is certainly no evidence based on the most recent two years of data to indicate sockeye are in a regime of low ocean survival. However, it is important to note that ocean temperatures in 1997 were extremely high. The impact of high temperatures on sockeye returning in 1998 is not known but managers should acknowledge the possibility that survival may be affected and opt for a conservative management approach until in-season run size estimates become reliable.

The forecasts in this report are based on stocks with sufficient time series of data to conduct quantitative forecast analysis. Based on escapements in 1994 (1998 brood) these stocks accounted for 93% 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 1998 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 forecasts at various probabilities (25%, 50%, 75%, 80% and 90%) are listed in Table 2. The total 1998 Fraser sockeye run size forecast is 11.2 million sockeye at the 50% probability level (the chance the run will exceed the forecast) and 6.8 million at the 75% probability level. Forecasts by management group are 175,000 (50%) and 97,000 (75%) for Early Stuart, 640,000 (50%) and 300,000 (75%) for Early summer stocks, 6.6 million (50%) and 3.9 million (75%) for summer run stocks and 3.8 million (50%) and 2.6 million (75%) for late run stocks.

2. Preseason plans should accommodate the large uncertainties in the forecasts. Run size estimates should rely on more informative in-season estimates of actual returns. In-season indications of small fish size and low fecundity should be considered to temper target escapement projections.

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Table 1. Forecast of Fraser River sockeye stocks (millions) for 1998 with associated variance of the $\log_e$ 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_2

MODEL[a]	FORECAST	VARIANCE	RMSE
Ymean	0.1253	1.2488	0.1631
Cmean	0.0881	0.3998	0.1556
Ricker	0.1371	0.4537	0.1075
Power	0.1120	0.4275	0.1104
R/S	0.1059	0.6255	0.2568

AGE-5_2

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0066	1.1473	0.0159
Cmean	0.0067	1.8399	0.0160
Ricker	0.0093	1.4599	0.0155
Power	0.0098	1.0782	0.0150
R/S	0.0253	1.8227	0.0095

EARLY STUART (Driftwood R. systems)

AGE-4_2

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0055	10.3919	0.4070
Cmean	0.0024	4.1385	0.2984
Ricker	0.0151	2.8431	0.2891
Power	0.0124	2.4926	0.2184
R/S	0.0137	2.7442	0.2433

AGE-5_2

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0003	6.5919	0.0188
Cmean	0.0003	3.0405	0.0181
Ricker	0.0000	45.2775	0.0189
Power	0.0002	6.7611	0.0189
R/S	0.0236	15.7913	0.0192

FENNELL

AGE-4_2

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0064	4.1654	0.0351
Cmean	0.0015	6.9970	0.0324
Ricker	0.0441	0.7674	0.0260
Power	0.0259	0.7335	0.0185
R/S	0.0504	1.6412	0.0908

AGE-5_2

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0011	4.4607	0.0065
Cmean	0.0009	12.4229	0.0066
Ricker	0.0044	1.5867	0.0052
Power	0.0034	1.4588	0.0053
R/S	0.0054	1.9412	0.0063
A5~A4	0.0063	1.8488	0.0052

Table 1. (cont'd)

BOWRON

AGE-4_2

MODEL	**FORECAST**	**VARIANCE**	**RMSE**
Ymean	0.0277	0.9460	0.0376
Cmean	0.0198	0.8371	0.0353
Ricker	0.0200	0.6508	0.0318
Power	0.0199	0.5853	0.0311
R/S	0.0160	0.7323	0.0342

AGE-5_2

MODEL	**FORECAST**	**VARIANCE**	**RMSE**
Ymean	0.00270	1.2506	0.00441
Cmean	0.00380	0.7993	0.00476
Ricker	0.00100	1.4561	0.00459
Power	0.00210	1.3776	0.00450
R/S	0.00050	1.8799	0.00452
A5~A4	0.00280	1.2860	0.00516
A5~A4+A4fsl	0.00270	1.3941	0.00508

RAFT

AGE-4_2

MODEL	**FORECAST**	**VARIANCE**	**RMSE**
Ymean	0.0136	1.5483	0.0197
Cmean	0.0109	1.4083	0.0150
Ricker	0.0058	0.8103	0.0146
Power	0.0060	0.8037	0.0143
R/S	0.0055	0.7790	0.0146

AGE-5_2

MODEL	**FORECAST**	**VARIANCE**	**RMSE**
Ymean	0.0022	1.1346	0.0034
Cmean	0.0039	0.4059	0.0031
Ricker	0.0031	1.1732	0.0035
Power	0.0025	1.0114	0.0031
R/S	0.0032	1.3340	0.0024
A5~A4	0.0040	0.8009	0.0031
A5~A4+A4fsl	0.0052	0.7974	0.0034

GATES

AGE-4_2

MODEL	**FORECAST**	**VARIANCE**	**RMSE**
Ymean	0.0198	3.3307	0.1109
Cmean	0.0023	4.3666	0.0814
Ricker	0.0229	0.6000	0.0844
Power	0.0209	0.5710	0.0645
R/S	0.0211	0.5954	0.0593
A4~Fry	0.0204	0.5175	0.0811
A4~Fry + esc	0.0205	0.5365	0.0839
Pooled	0.0207	0.2769	0.0708

AGE-5_2

MODEL	**FORECAST**	**VARIANCE**	**RMSE**
Ymean	0.0016	2.3083	0.0081
Cmean	0.0023	4.1658	0.0080
Ricker	0.004	1.5596	0.0075
Power	0.0037	1.5189	0.0075
R/S	0.0054	1.5549	0.0069
A5~A4	0.0026	1.7312	0.0077
A5~A4+A4fsl	0.0226	1.3897	0.0094
A5~Fry	0.0037	1.4489	0.0074

Table 1. (cont'd)

NADINA **AGE-4_2**

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0387	1.2172	0.0534
Cmean	0.0136	0.4561	0.0968
Ricker	0.0113	0.4468	0.0712
Power	0.0112	0.5805	0.0741
R/S	0.0086	0.5336	0.0671
A4~Fry	0.0164	0.4311	0.0357
A4~Fry+esc	0.0142	0.4779	0.0444
Pooled	0.0122	0.2385	0.0444

AGE-5_2

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0051	1.3485	0.0159
Cmean	0.0093	1.3478	0.0167
Ricker	0.0056	1.5250	0.0161
Power	0.0048	1.3229	0.0160
R/S	0.0044	1.7214	0.0167
A5~A4	0.0058	1.3278	0.0156
A5~Fry	0.0028	1.1783	0.0159

PITT **AGE-4_2**

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0154	1.1672	0.0217
Cmean	0.0155	1.2727	0.0219
Ricker	0.0083	1.2828	0.0230
Power	0.0150	1.3361	0.0227
R/S	0.0040	1.4929	0.0290

AGE-5_2

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0330	0.6608	0.0285
Cmean	0.0477	0.3429	0.0275
Ricker	0.0384	0.6768	0.0293
Power	0.0344	0.6456	0.0290
R/S	0.0379	0.8033	0.0367
A5~A4	0.0314	0.5071	0.0241

SEYMOUR **AGE-4_2**

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0660	1.6055	0.2229
Cmean	0.2608	0.3312	0.1600
Ricker	0.1390	0.8034	0.1710
Power	0.1152	0.8067	0.1671
R/S	0.1399	0.8830	0.2233

AGE-5_2

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0023	2.7074	0.0156
Cmean	0.0008	4.1905	0.0155
Ricker	0.0013	2.5563	0.0154
Power	0.0015	2.3681	0.0151
R/S	0.0010	2.5978	0.0139
A5~A4	0.0008	2.5194	0.0149

Table 1. (cont'd)

SCOTCH **AGE-4_2**

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0062	5.8554	0.1275
Cmean	0.0098	10.1423	0.1225
Ricker	0.2501	2.7160	0.1045
Power	0.1540	1.7214	0.0730
R/S	0.3699	1.8276	0.0588

AGE-5_2

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0012	3.8778	0.0088
Cmean	0.0005	3.1997	0.0086
Ricker	0.0035	5.7545	0.0088
Power	0.0018	3.6592	0.0086
R/S	0.0029	5.7417	0.0150
A5~A4	0.0013	3.5871	0.0084

CHILKO **AGE-4_2**

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.8678	1.1160	1.4347
Cmean	0.8295	0.8952	1.3676
Ricker	1.7747	0.5251	1.0915
Power	1.7404	0.5620	1.2031
R/S	2.2896	0.6292	1.5021
A4~Sm (age-1)	1.2944	0.3861	0.9928
A4~Sm (age-1)+esc	1.2809	0.4094	0.9916
A4~Sm+Rn			1.2959
Pooled	1.4790	0.2220	0.9940

AGE-5_2

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0200	2.1087	0.1292
Cmean	0.0280	2.1390	0.1282
Ricker	0.0458	1.7740	0.1264
Power	0.0451	1.7292	0.1238
R/S	0.0706	1.7801	0.1161
A5~Sm (age-1)	0.0479	1.4201	0.1236
A5~Sm+Rn	0.0664	1.3512	0.1266
A5~A4	0.0698	1.3821	0.1209
A5~A4+A4fsl	0.1083	1.3203	0.1180

CHILKO **AGE-5_3**

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0319	1.5813	0.0755
Cmean	0.0535	1.2540	0.0740
Ricker	0.0570	1.2321	0.0724
Power	0.0579	1.1934	0.0718
R/S	0.1104	1.6223	0.0791
A5~Sm (age-2)	0.0369	1.1350	0.0599
A5~A4	0.0599	1.1389	0.0573
A5~Sm+Rn	0.0430	1.3844	0.0603

Table 1. (cont'd)

QUESNEL

AGE-4_2

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0298	12.1829	4.4235
Cmean	0.0424	7.5067	3.7075
Ricker	4.6367	0.8732	5.5727
Power	4.0416	0.8822	2.6009
R/S	5.1456	0.8516	3.3192
Ricker[b]	4.6367	0.9344	7.4090
Power[b]	4.0416	0.9392	4.4669
R/S[b]	5.1456	0.8516	5.2828
A4~Fall Fry[b]	1.5550	2.0821	3.2423
A4~Fall Fry + esc[b]	4.2566	0.6059	2.3238
Pooled	3.0416	0.6197	4.3843

AGE-5_2

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0079	8.6788	0.1726
Cmean	0.0074	10.7636	0.1729
Ricker	0.3684	19.7497	0.1551
Power	0.0848	7.9400	0.1667
R/S	0.3798	7.4494	0.1294
A5~A4[d]	0.0416	6.8670	0.1658
A5~Fry[a]	0.1504	0.9990	0.1847
A5~A4	0.0416	2.6205	0.2178

STELLAKO

AGE-4_2

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.3138	0.6373	0.3977
Cmean	0.4455	0.3067	0.3584
Ricker	0.5201	0.4176	0.3514
Power	0.4897	0.4365	0.3893
R/S	0.5996	0.4639	0.4902

AGE-5_2

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0314	1.2443	0.0940
Cmean	0.0178	1.0612	0.0925
Ricker	0.0402	0.9763	0.0839
Power	0.0382	0.9640	0.0835
R/S	0.0402	0.9586	0.0784
A5~A4	0.0061	0.9379	0.0825
A5~A4+A4fsl	0.0253	0.8651	0.0759

LATE STUART

AGE-4_2

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0848	5.2794	1.5211
Cmean	0.0877	1.0109	1.0417
Ricker	0.4979	1.7412	1.0866
Power	0.3206	1.5084	1.0800
R/S	0.4739	1.7966	2.5213

AGE-5_2

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0048	3.6781	0.0632
Cmean	0.0165	3.1609	0.0610
Ricker	0	21.3163	0.0619
Power	0.0395	3.0761	0.0603
R/S	0.6522	4.4468	0.0448
A5~A4	0.0274	2.6180	0.0575
A5~A4+A4fsl	0.0722	1.6216	0.0447

Table 1. (cont'd)

BIRKENHEAD **AGE-4$_2$**

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.2127	0.6363	0.3697
Cmean	0.2876	1.1406	0.3690
Ricker	0.2256	0.5545	0.3500
Power	0.1997	0.5401	0.3183
R/S	0.1792	0.8508	0.5187

AGE-5$_2$

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0494	1.2926	0.1565
Cmean	0.0414	1.9774	0.1582
Ricker	0.1307	1.1980	0.1406
Power	0.1570	1.0916	0.1373
R/S	0.2922	1.0662	0.1368
A5~A4	0.0726	0.8476	0.1329
A5~A4+A4fsl	0.1032	0.7103	0.1249

LATE SHUSWAP **AGE-4$_2$**

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.1645	8.6335	3.4489
Cmean	5.7832	0.3584	1.0767
Ricker	3.9657	0.9859	1.1905
Power	4.1712	1.0071	1.5814
R/S	4.5408	0.9682	1.6469
Ricker[b]	3.9657	0.6261	2.7690
Power[b]	4.1712	0.6587	2.8080
R/S[b]	4.5408	0.6137	3.0790
A4~Fry[b]	2.7048	0.3619	2.7393
A4~Fall Fry+esc[b]	3.0148	0.4191	2.8662
Pooled	2.9937	0.2293	2.3271

AGE-5$_2$

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0030	6.4609	0.0596
Cmean	0.0000	0.0000	0.0536
Ricker	0.0000	1.6476	0.0532
Power	0.0001	1.6401	0.0530
R/S	0.0000	2.5988	0.0454
A5~A4	0.0001	1.6369	0.0542
A5~A4+A4fsl	0.0002	1.7059	0.0549

CULTUS **AGE-4$_2$**

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0270	2.8002	0.0386
Cmean	0.0496	1.0795	0.0505
Ricker	0.0193	0.8601	0.0240
Power	0.0181	0.8437	0.0240
R/S	0.0173	0.8519	0.0267

AGE-5$_2$

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0011	2.1610	0.0017
Cmean	0.0005	1.9148	0.0020
Ricker	0.0001	2.2827	0.0015
Power	0.0001	2.3503	0.0015
R/S	0.0001	2.0960	0.0015
A5~A4	0.0001	2.1329	0.0017

Table 1. (cont'd)

PORTAGE **AGE-4_2**

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0117	4.6216	0.0640
Cmean	0.0535	0.4203	0.0560
Ricker	0.0569	1.1315	0.0450
Power	0.0433	1.0524	0.0383
R/S	0.0656	1.3797	0.0429

AGE-5_2

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0006	4.6917	0.0085
Cmean	0.0009	1.1295	0.0083
Ricker	0.0009	5.3570	0.0085
Power	0.0008	5.0065	0.0085
R/S	0.0019	5.0538	0.0085
A5~A4	0.0015	4.4798	0.0084
A5~A4+A4fsl	0.0040	6.0460	0.0093

WEAVER **AGE-4_2**

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.2300	0.7422	0.3364
Cmean	0.2917	2.0035	0.3235
Ricker	0.3588	0.9648	0.3897
Power	0.2742	0.7081	0.2937
R/S	0.4106	1.0395	0.2778
A4~Fry	0.3027	0.6482	0.3010
A4~Fry+esc	0.3029	0.6603	0.3212
Pooled	0.3403	0.3992	0.2620

AGE-5_2

MODEL	FORECAST	VARIANCE	RMSE
Ymean	0.0168	1.6339	0.0654
Cmean	0.0252	0.2618	0.0648
Ricker	0.0319	1.0676	0.0358
Power	0.0283	1.0655	0.0514
R/S	0.0312	1.0929	0.0435
A5~Fry	0.0286	1.1855	0.0594
A5~A4	0.0177	0.9646	0.0397
A5~A4+A4fsl	0.0542	0.8733	0.0340

a: Cmean = cycle-year mean
Ricker = Ricker stock-recruit
Power = power stock-recruit
R/S = 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~Sm = regression of age-4 vs smolts
A4~Sm+Rn = regression of age-4 vs smolts+rain index
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
A5~A4+A4fsl = regression of age-5 vs age-4 + age-4 female standard length
Pooled = combined forecast based on different life stages = sum of forecasts weighted by inverse of respective variances (see text).
b: RMSE are based on years that dominant and subdominant fall fry data are available.
c: escapement-based model not considered due to significant decline in age-4 sibling recruits/spawner in 1997

Table 2. Fraser River run size forecasts of age-4 and age-5 sockeye by stock and timing group (bolded) for 1998.

	Probability of Achieving Specified Run Sizes[a]				
STOCK/TIMING	**25%**	**50%**	**75%**	**80%**	**90%**
Early Stuart	**321000**	**175000**	**97000**	**84000**	**58000**
Driftwood	38000	13000	4000	3000	2000
non-Driftwood	283000	162000	93000	81000	56000
Early Summer	**1436000**	**642000**	**296000**	**245000**	**150000**
Fennell	57000	30000	16000	14000	9000
Bowron	38000	22000	13000	11000	8000
Raft	18000	9000	5000	4000	3000
Gates	49000	26000	14000	12000	8000
Nadina	39000	22000	13000	11000	8000
Pitt	84000	46000	25000	22000	15000
Seymour	215000	116000	63000	54000	36000
Scotch	936000	371000	147000	117000	63000
Mid Summer	**11525000**	**6647000**	**3862000**	**3376000**	**2364000**
Chilko	2269000	1411000	878000	780000	569000
Quesnel	7489000	4298000	2467000	2148000	1486000
Stellako	856000	545000	348000	311000	230000
LateStuart	911000	393000	169000	137000	79000
Late Summer	**5519000**	**3754000**	**2567000**	**2335000**	**1819000**
Birkenhead	513000	303000	179000	157000	111000
Late Shuswap	4250000	2994000	2109000	1932000	1531000
Cultus	34000	18000	10000	8000	5000
Portage	93000	45000	21000	18000	11000
Weaver	629000	394000	248000	220000	161000
TOTAL	**18801000**	**11218000**	**6822000**	**6040000**	**4391000**

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

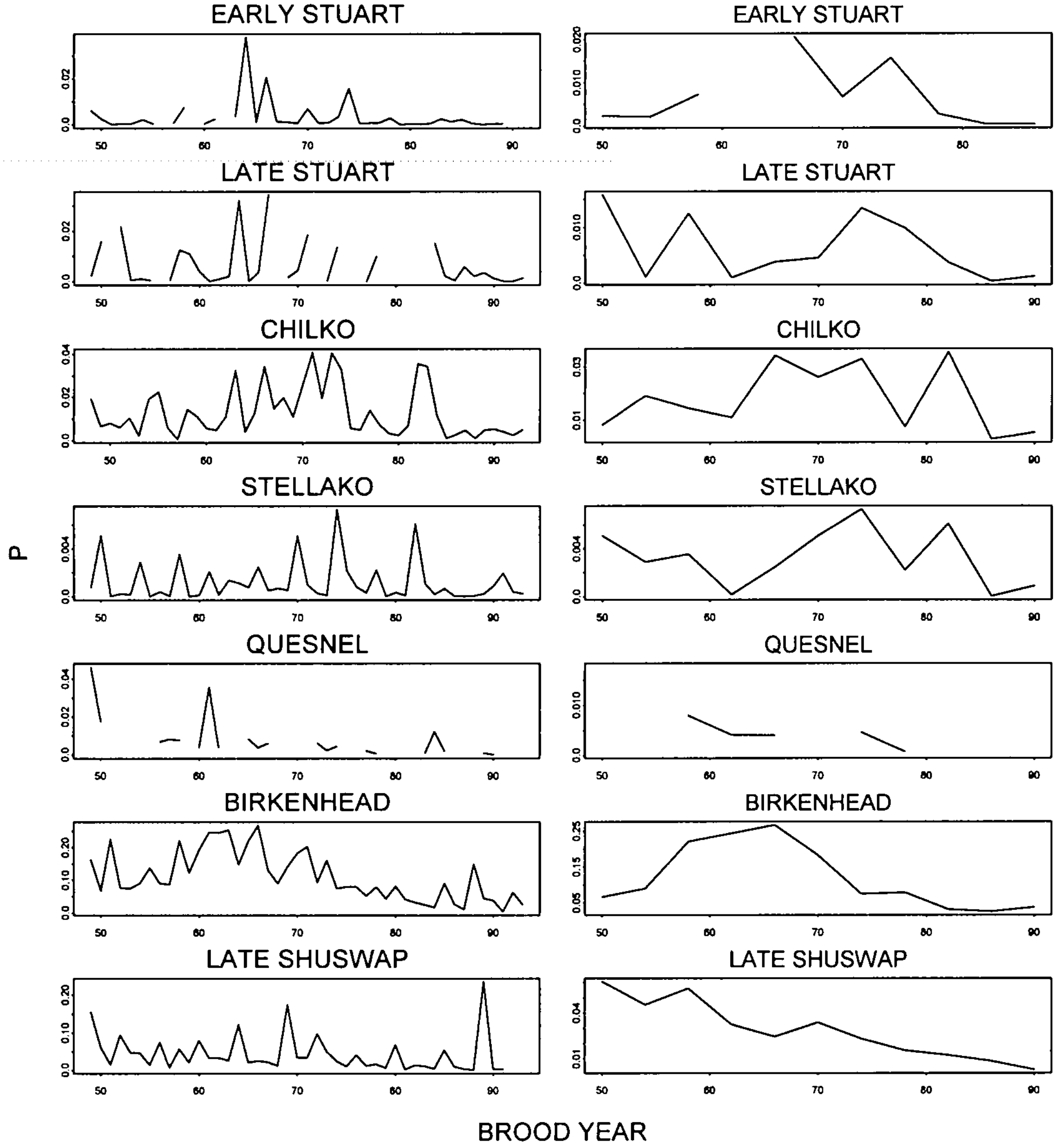

Fig. 1. Proportion (P) of age-3 jack returns (P=jacks/(jacks+age-4 returns) for major stocks of Fraser sockeye. (left panel = all years; right panel = 1998 cycle line years)

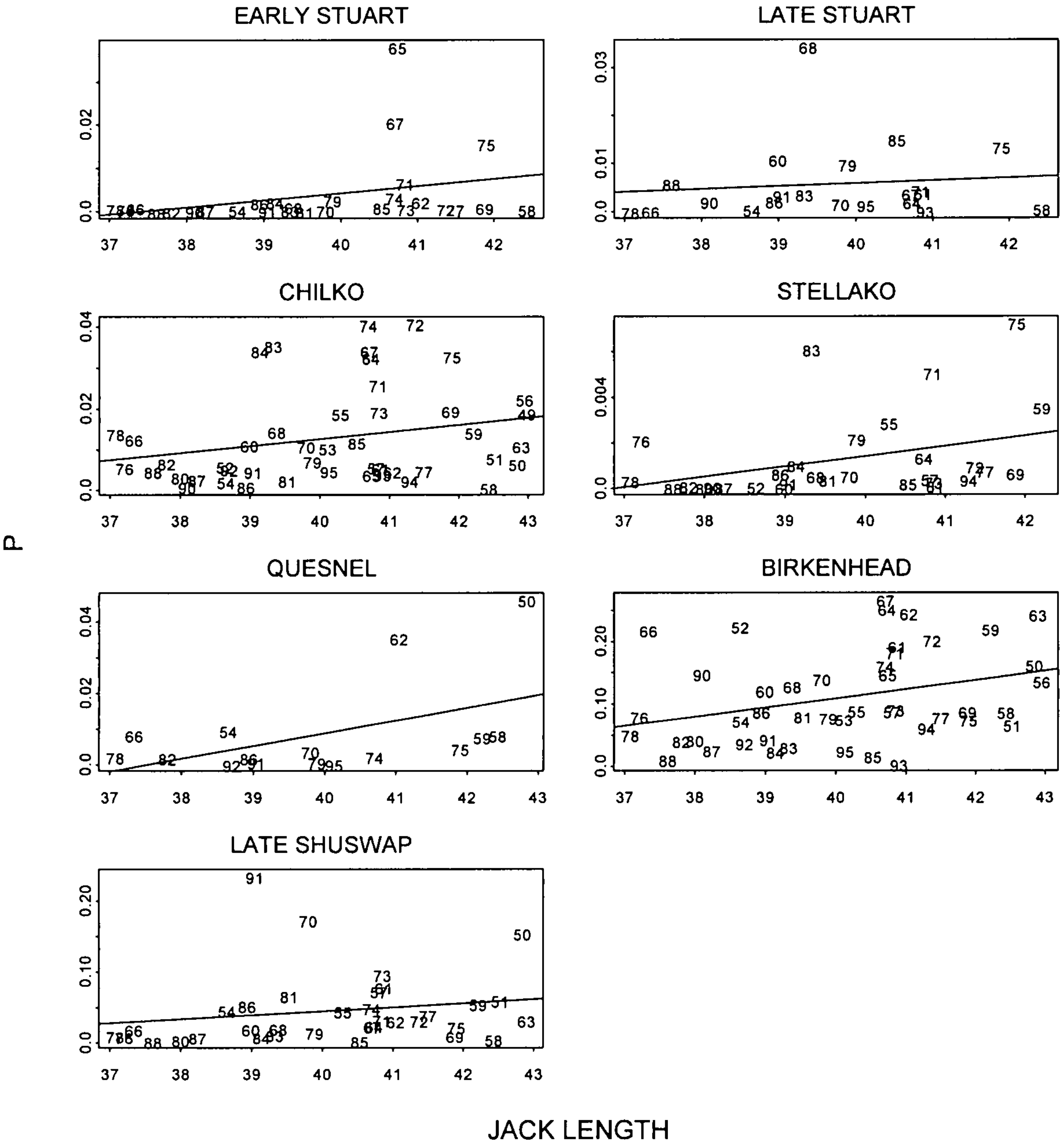

Fig. 2. Proportion (P) of age-3 jack returns (P=jacks/(jacks+age-4 returns) versus jack standard length for major stocks of Fraser sockeye. Data labels are brood years.

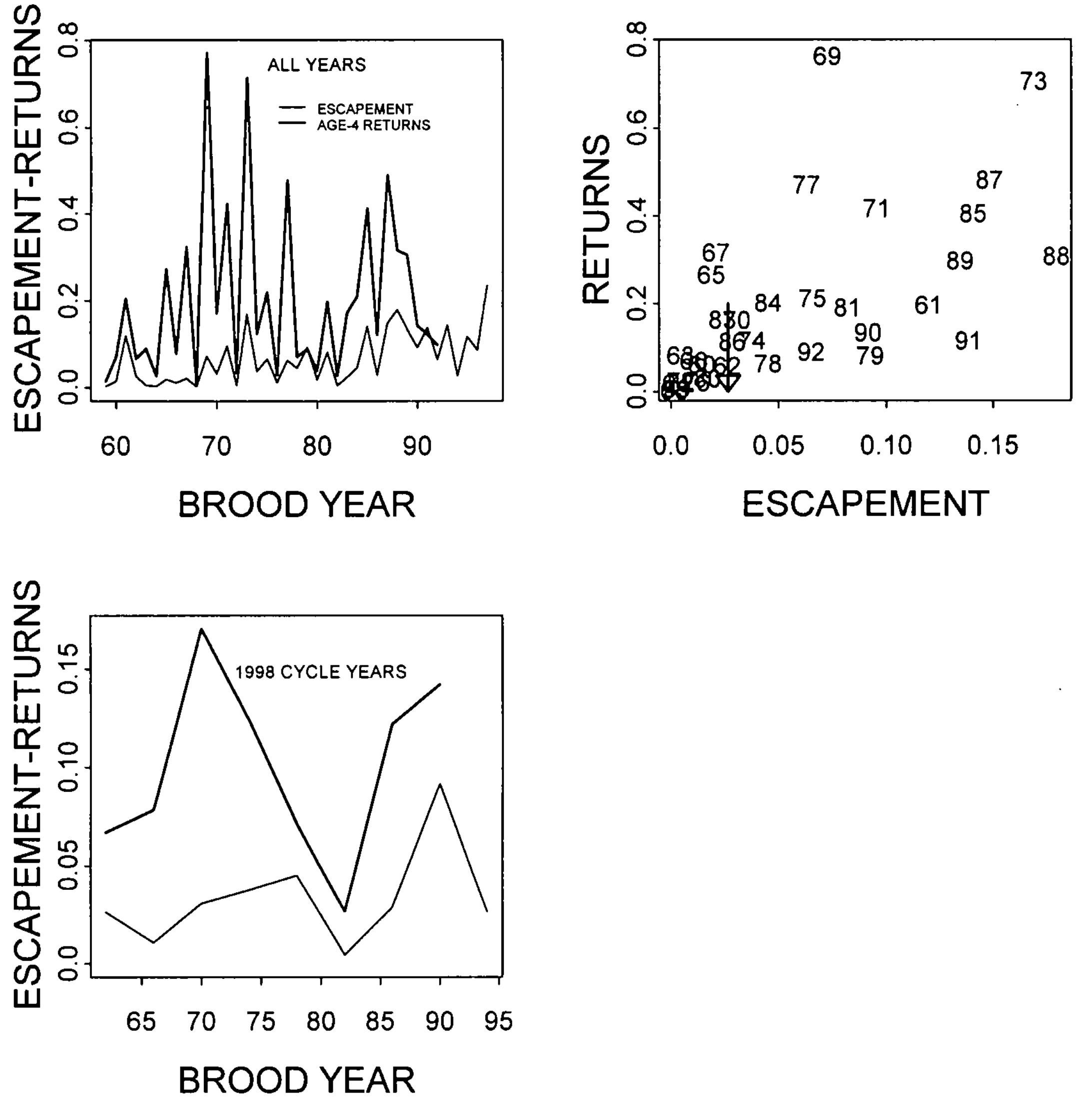

Fig. 3. Trends in escapement and age-4 returns (millions) and the relationship between adult escapement and age-4 returns for Early Stuart sockeye (non-Driftwood). Data labels are brood years. The arrow represents the 1994 escapement.

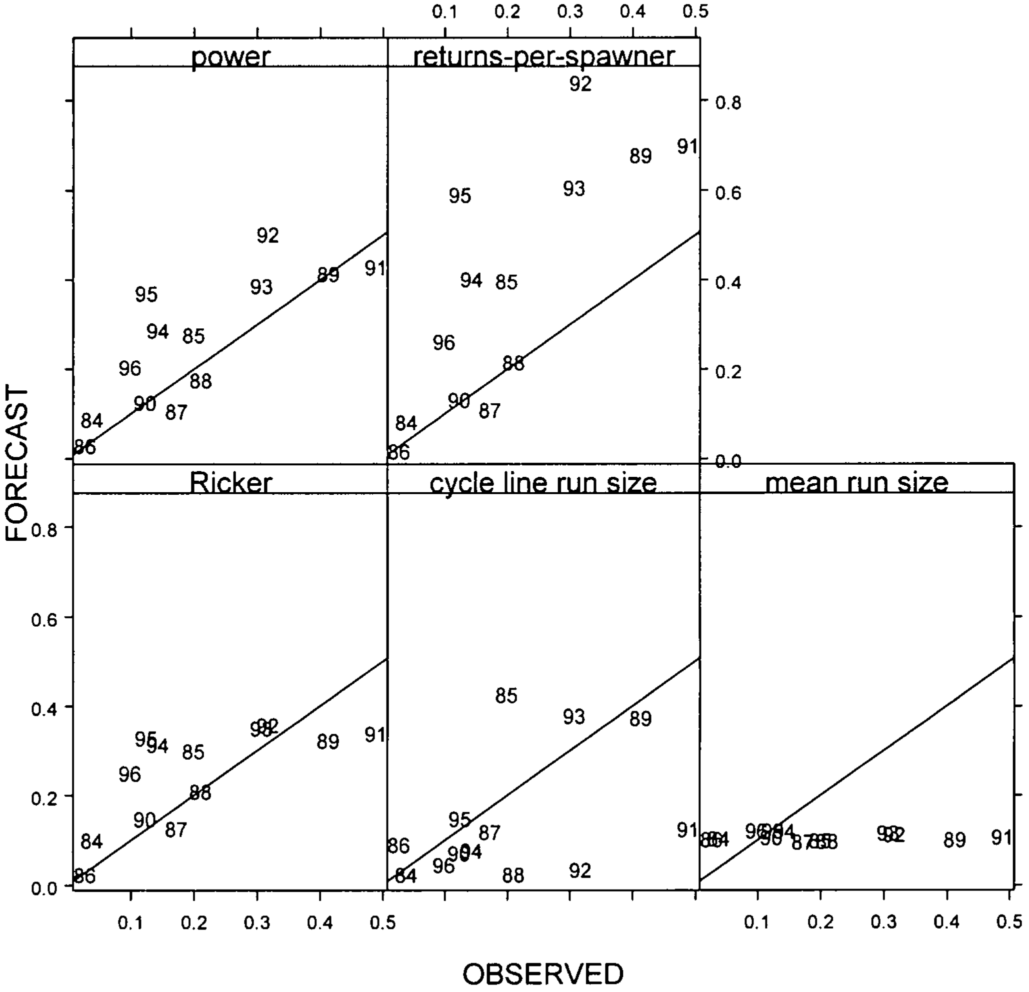

Fig. 4. Comparison of estimated (observed) returns and retrospective run size forecasts (millions) of age-4 Early Stuart sockeye (excluding Driftwood River) by model. Data points are modes of distributions and denoted by return year. Diagonal lines are 1:1 line not regression lines.

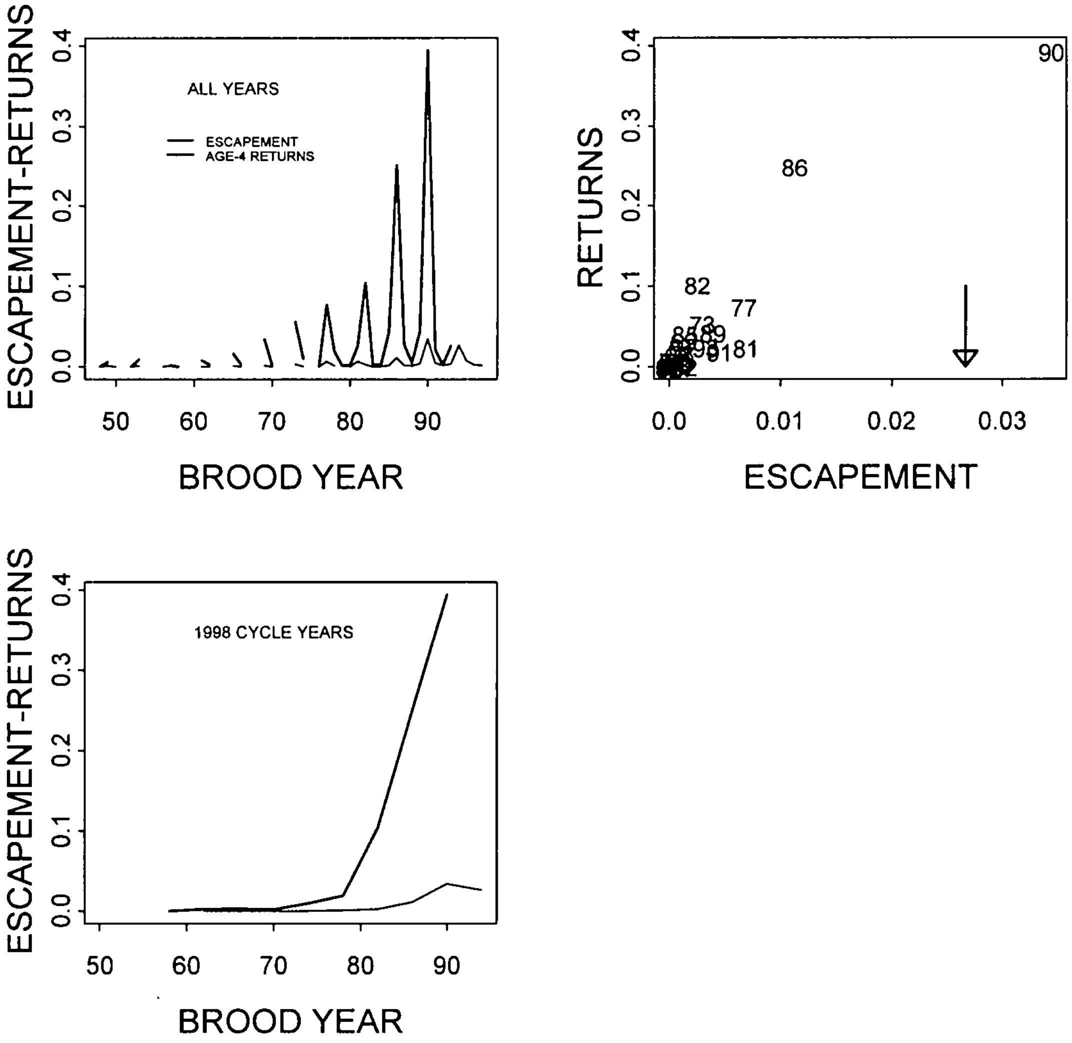

Fig. 5. Trends in escapement and age-4 returns (millions) and relationship between escapement and age-4 returns (millions) for Scotch Creek sockeye. Data labels are brood years. The arrow represents the 1994 escapement.

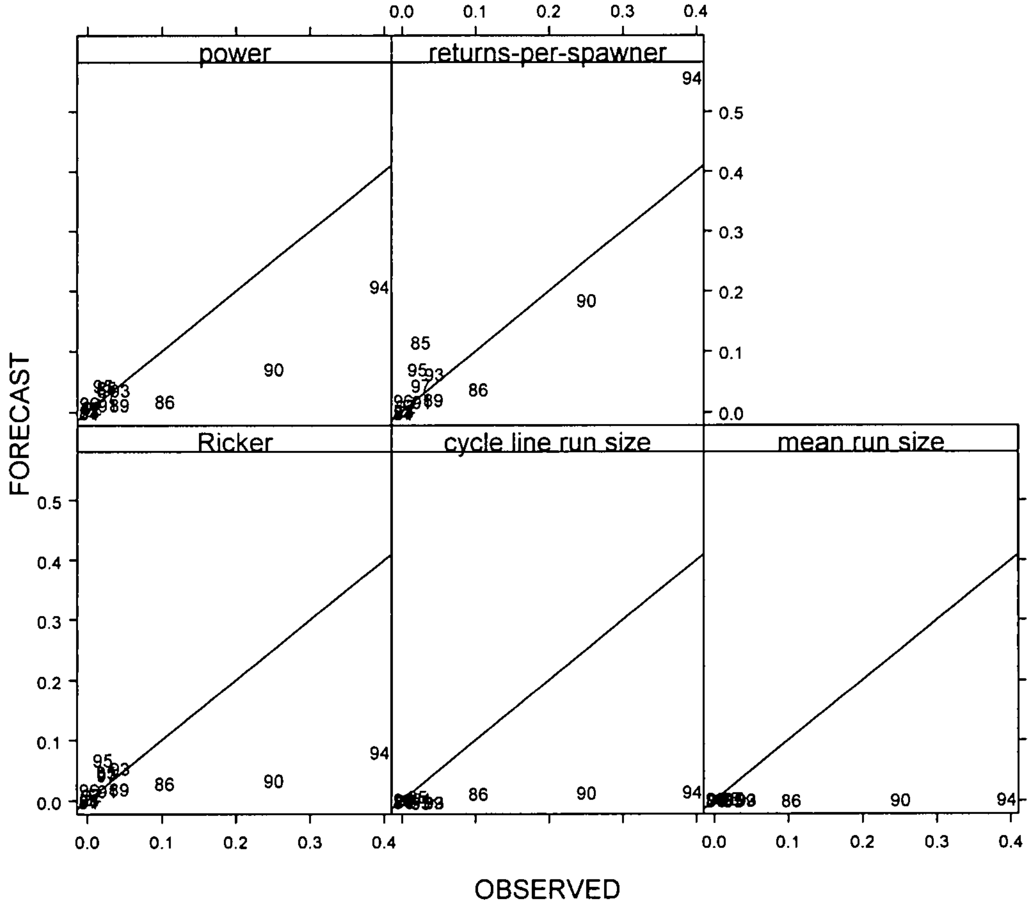

Fig. 6. Comparison of estimated (observed) returns and retrospective run size forecasts (millions) of age-4 Scotch Creek sockeye. Data points are mode of distributions and are denoted return year. Diagonal lines are 1:1 line not regression lines.

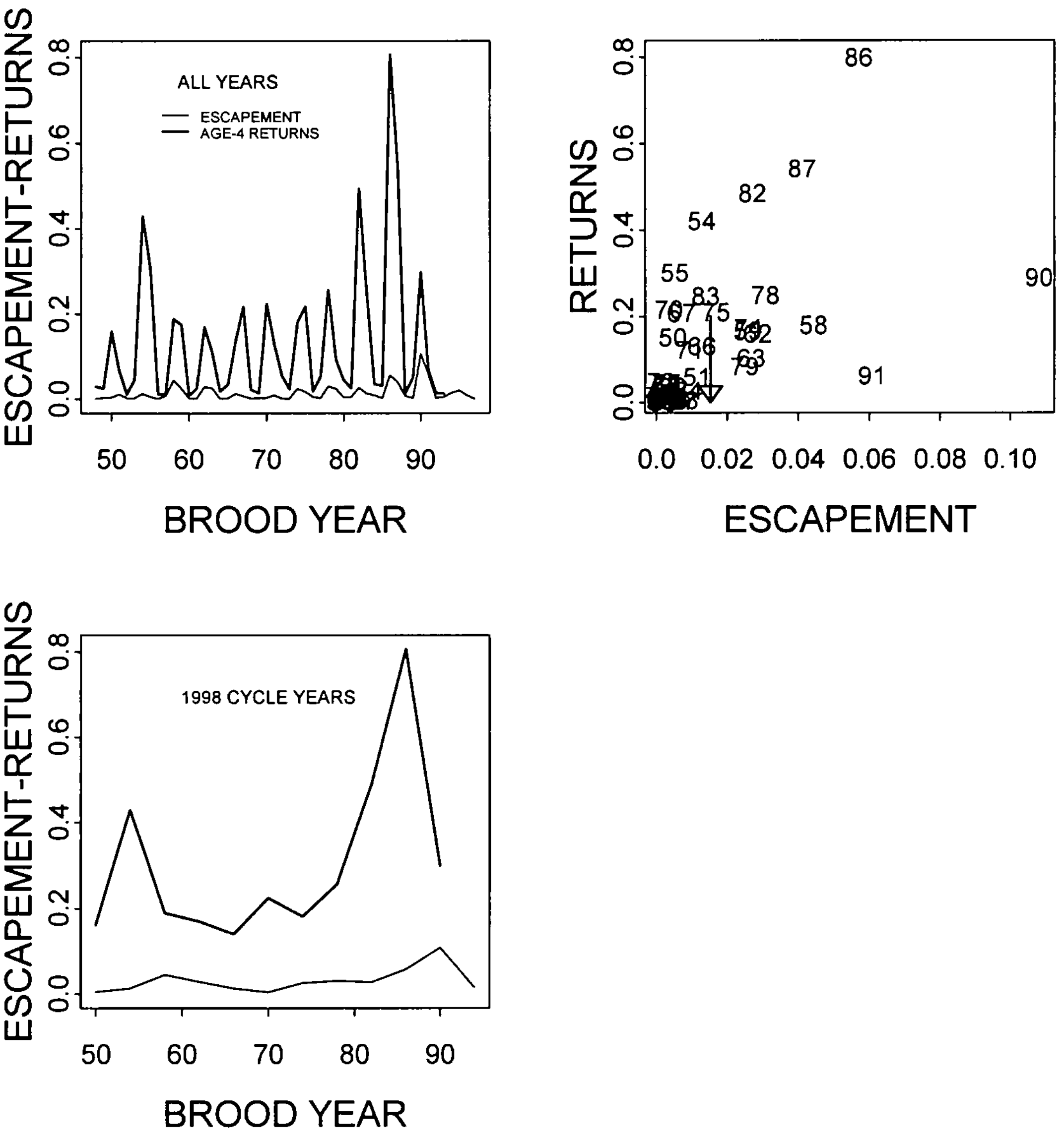

Fig. 7. Trends in escapement and age-4 returns (millions) and relationship between escapement and age-4 returns (millions) for Seymour River sockeye. Data labels are brood years. The arrow represents the 1994 escapement.

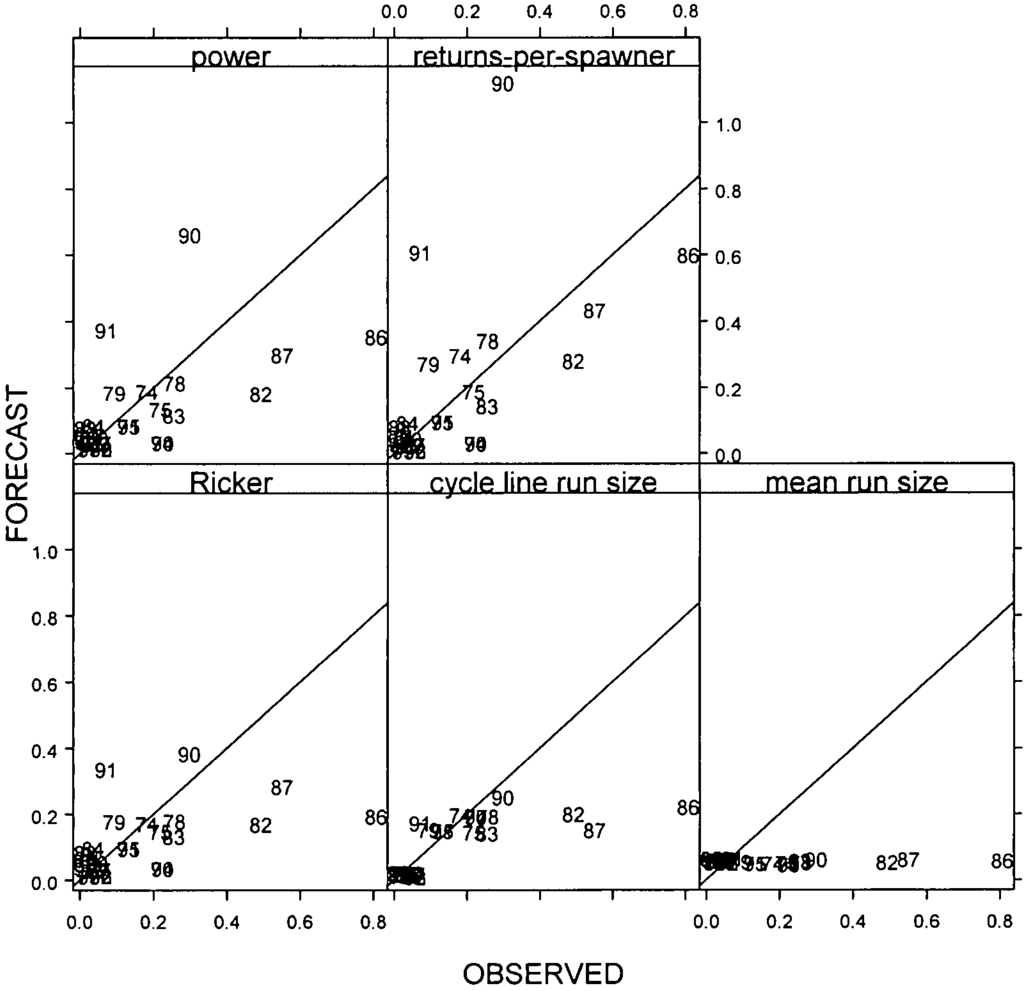

Fig. 8. Comparison of estimated (observed) returns and retrospective run size forecasts (millions) of age-4 Seymour River sockeye. Data points are mode of distributions and denoted return year. Diagonal lines are 1:1 line not regression lines.

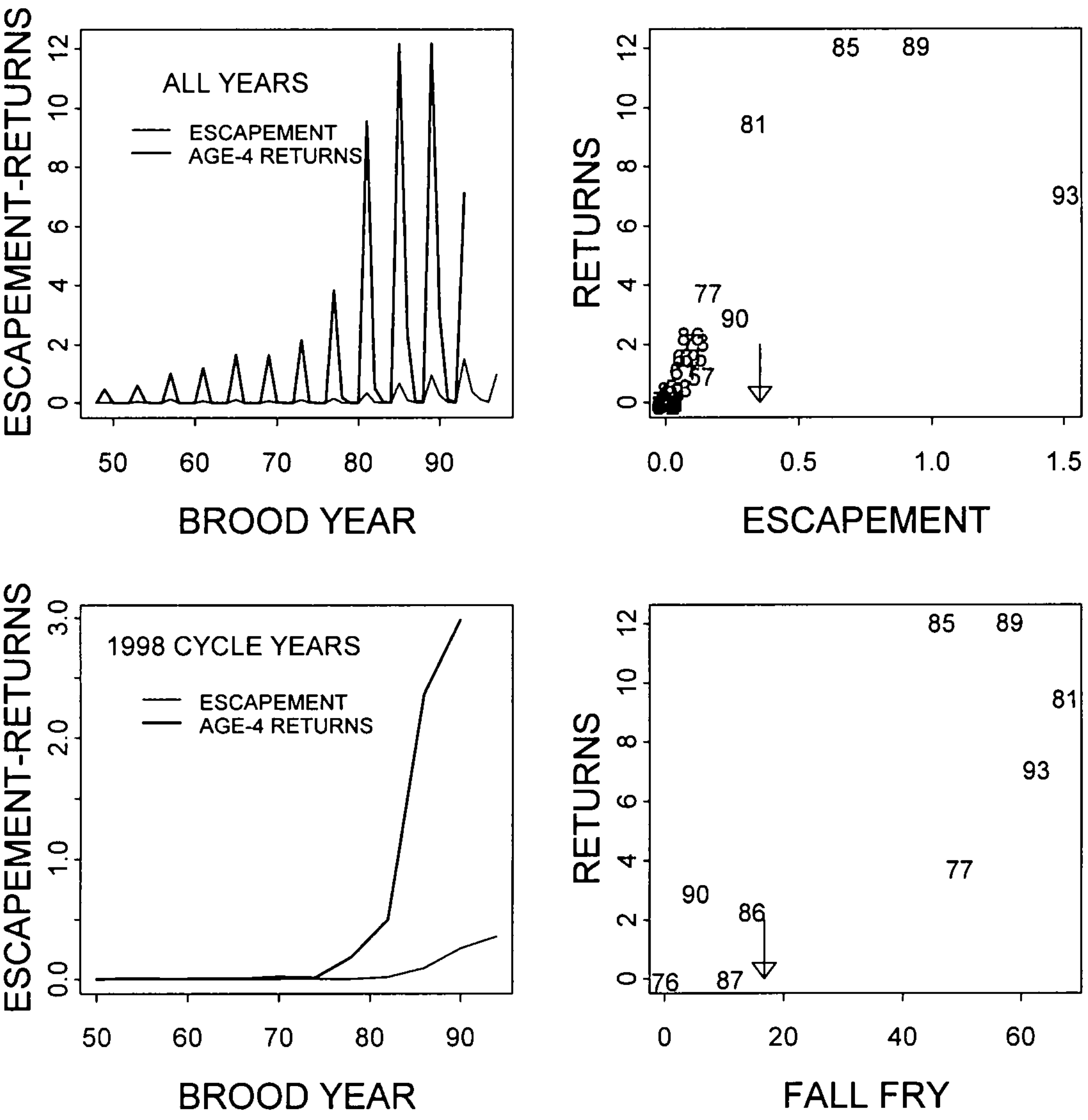

Fig. 9. Trends in escapement and age-4 returns (millions), relationship between escapement (effective females) and age-4 returns (millions) and fall fry and age-4 returns for Quesnel Lake sockeye. Data labels are brood years. The arrows represent the 1994 escapement and fall fry estimates.

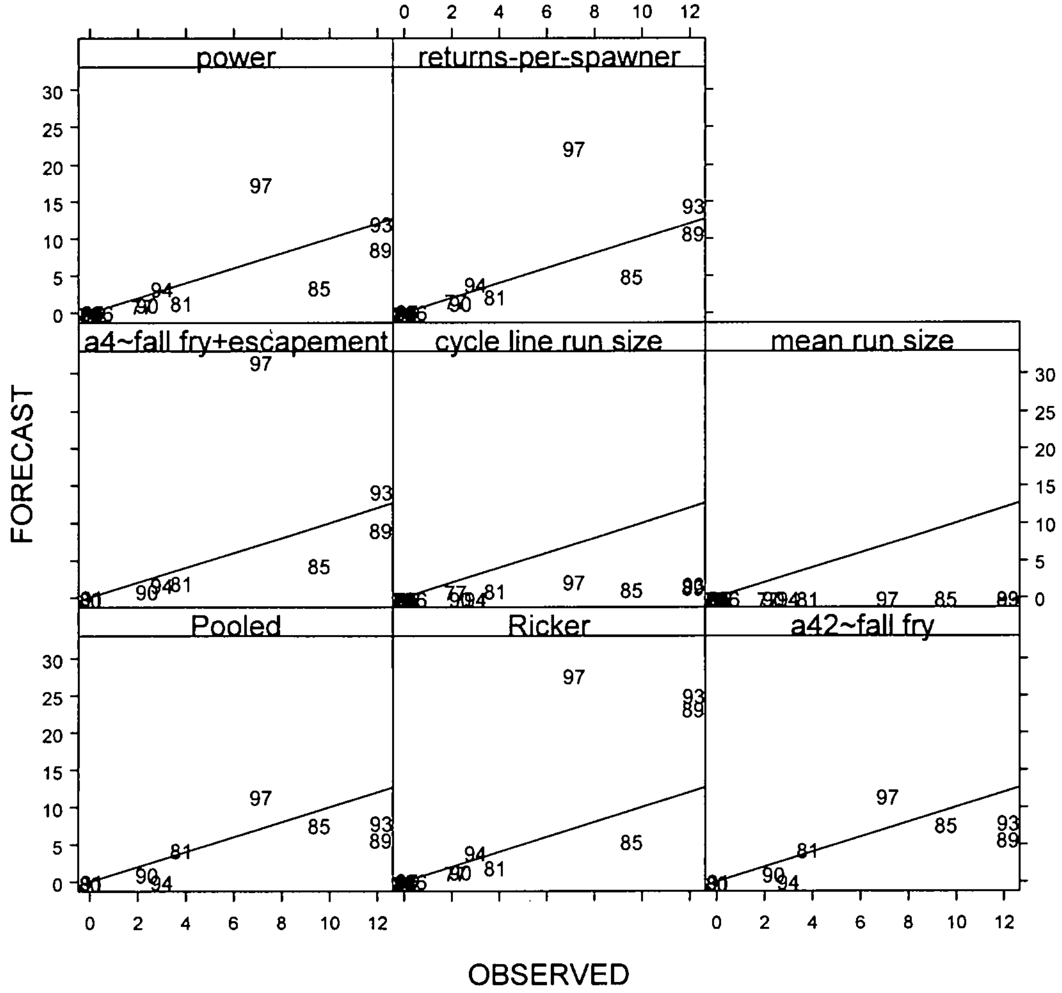

Fig. 10. Comparison of estimated (observed) returns and retrospective run size forecasts (millions) of age-4 Quesnel Lake sockeye. Data points are mode of distributions and denoted return year. Diagonal lines are 1:1 line not regression lines.

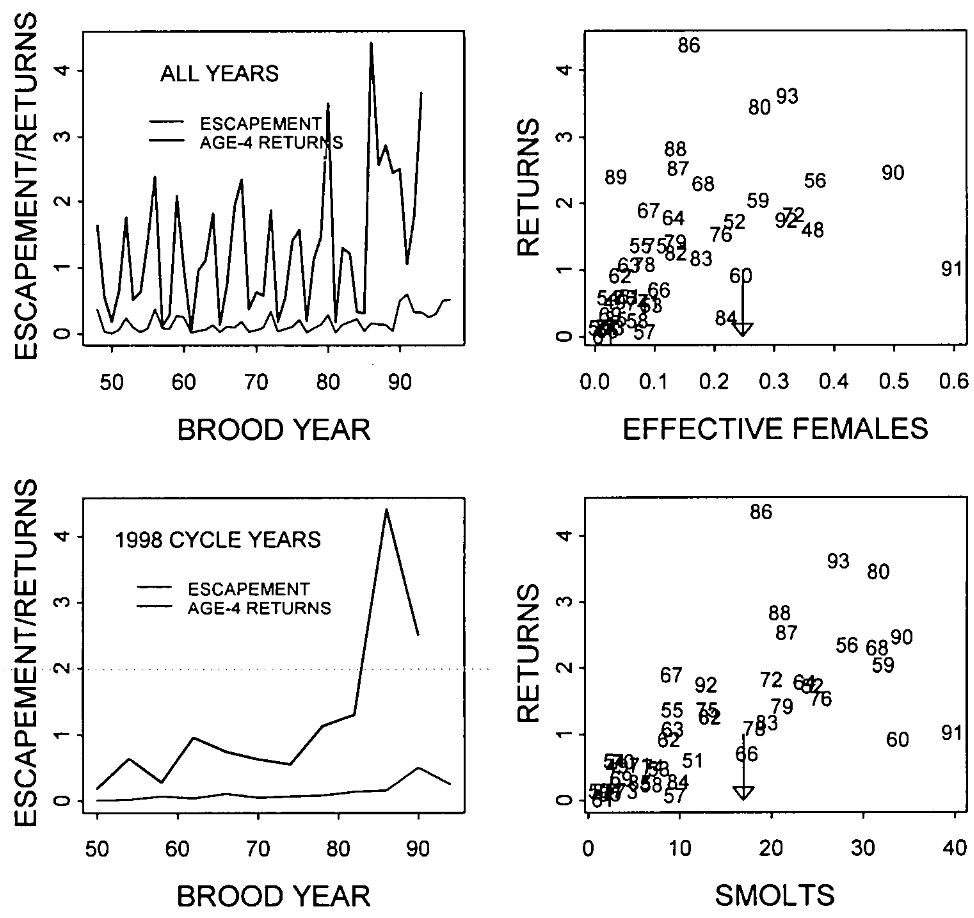

Fig. 11. Trends in escapement and age-4 returns, relationship between escapement (effective females) and age-4 returns and smolts and age-4 returns for Chilko Lake sockeye (millions of fish). Data labels are brood years. The arrows represent 1994 escapement and smolt estimates.

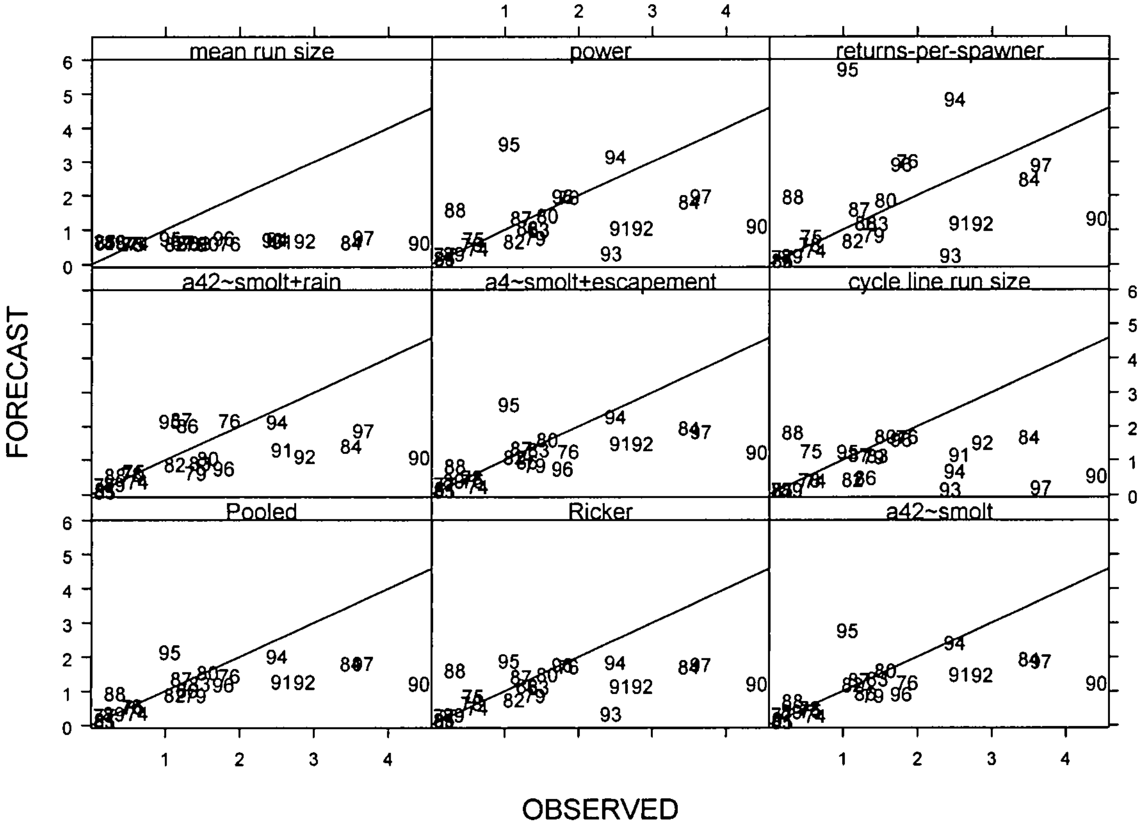

Fig. 12. Comparison of estimated (observed) returns and retrospective run size forecasts (millions) of age-4 Chilko Lake sockeye. Data points are mode of distributions and denoted return year. Diagonal lines are 1:1 line not regression lines.

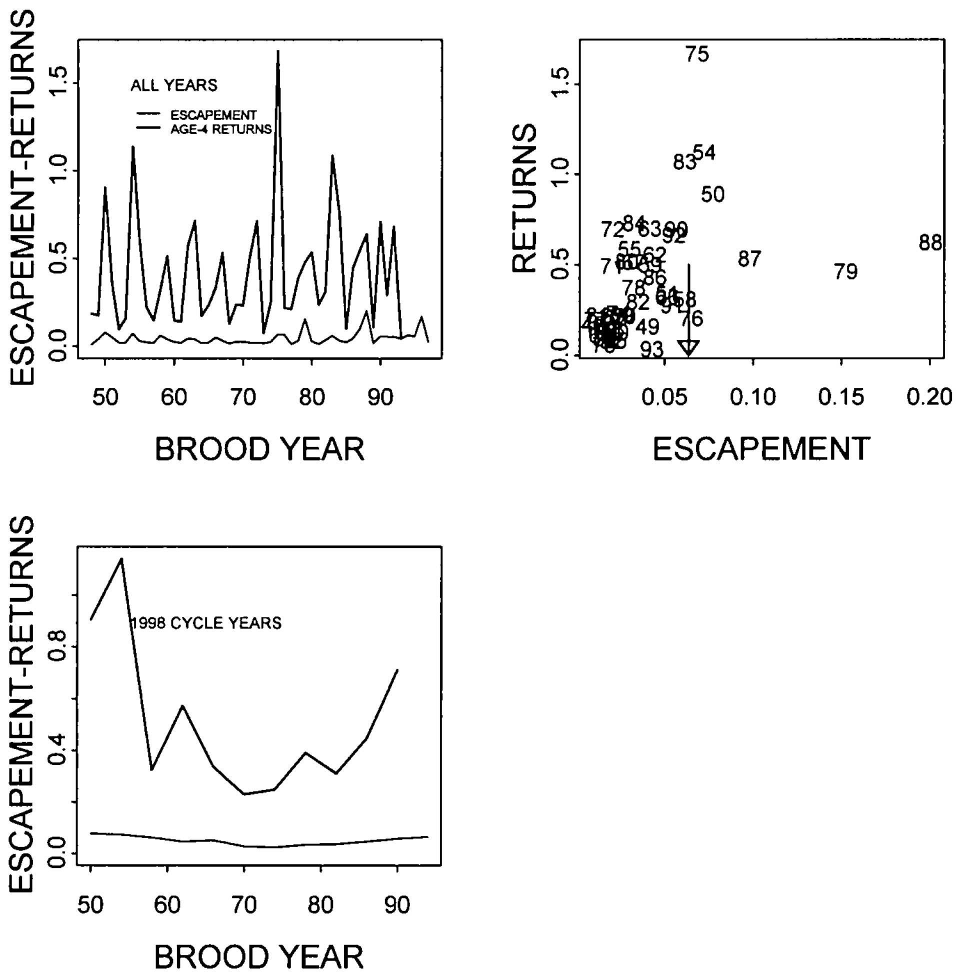

Fig. 13. Trends in escapement and age-4 returns (millions) and relationship between escapement and age-4 returns (millions) for Stellako River sockeye. Data labels are brood years. The arrow represents the 1994 escapement.

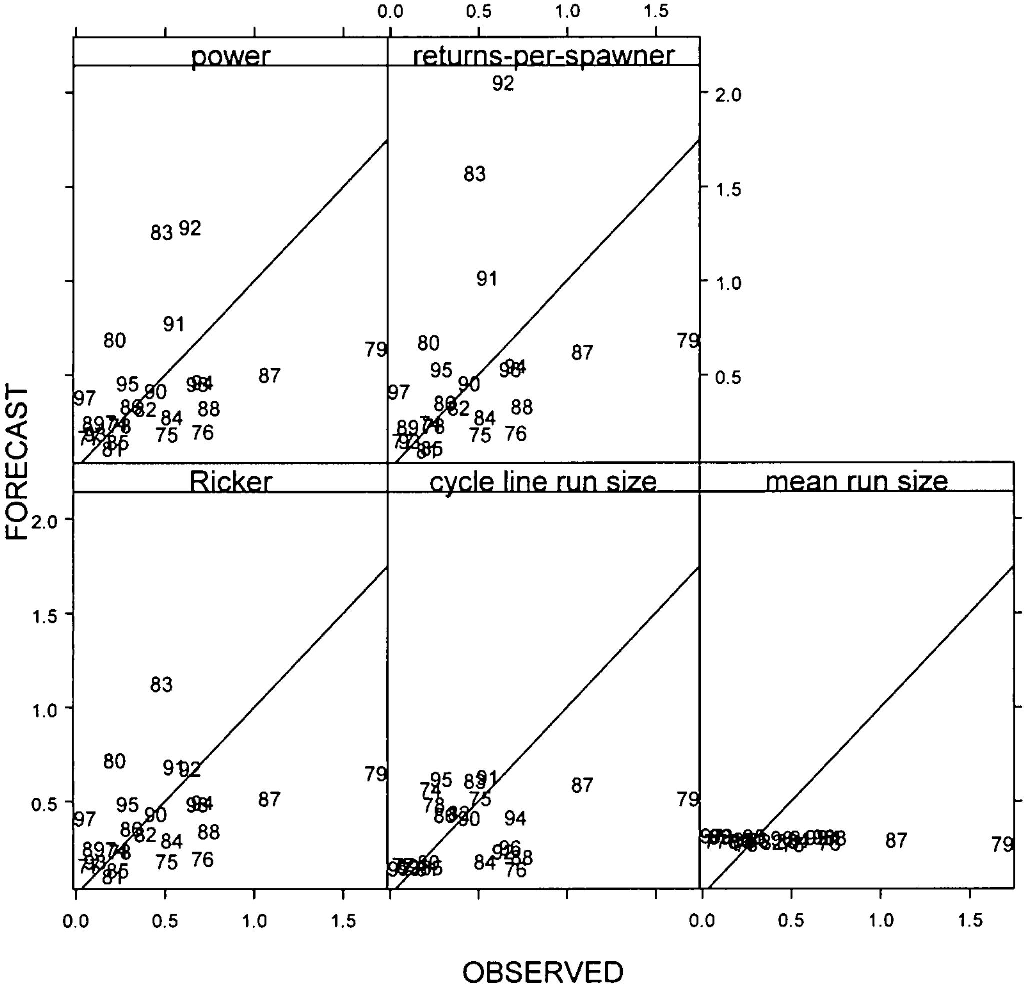

Fig. 14. Comparison of observed (estimated returns) and retrospective run size forecasts of age-4 Stellako River sockeye. Data points are mode of distributions and denoted return year. Diagonal lines are 1:1 line not regression lines.

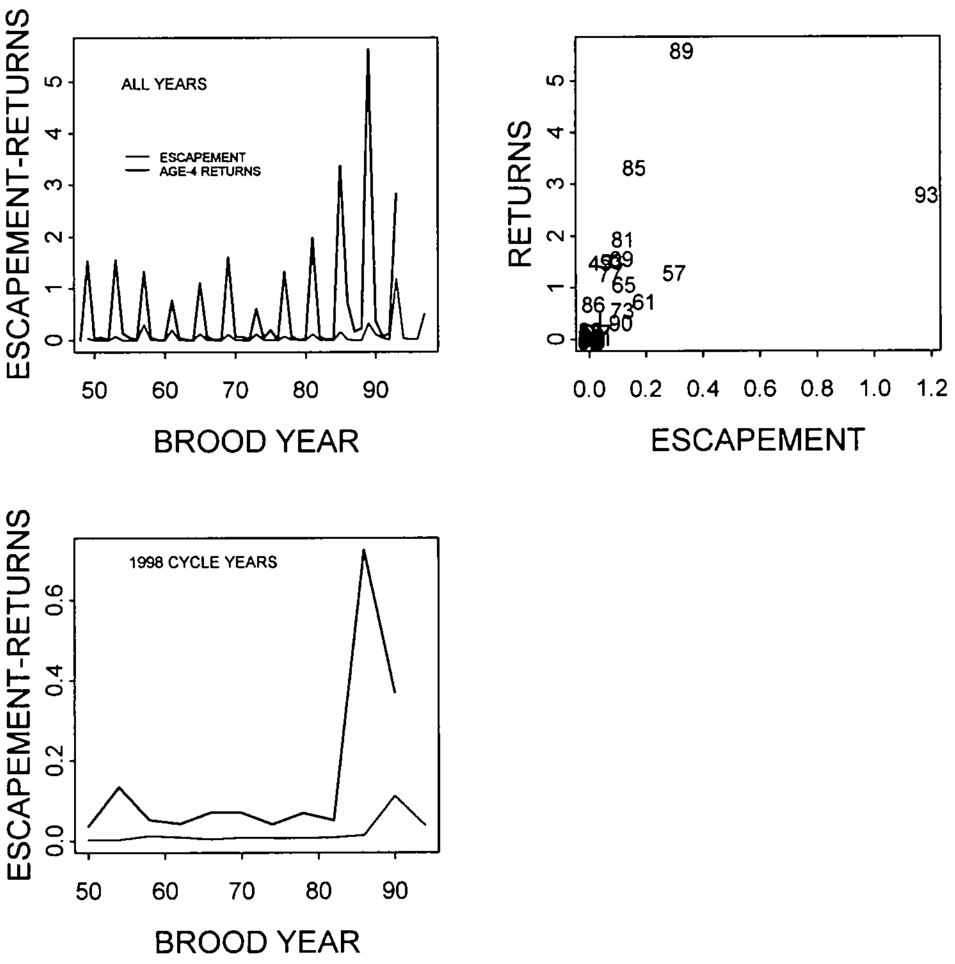

Fig. 15. Trends in escapement and age-4 returns (millions) and relationship between escapement and age-4 returns (millions) for Late Stuart sockeye. Data labels are brood years. The arrow represents the 1994 escapement.

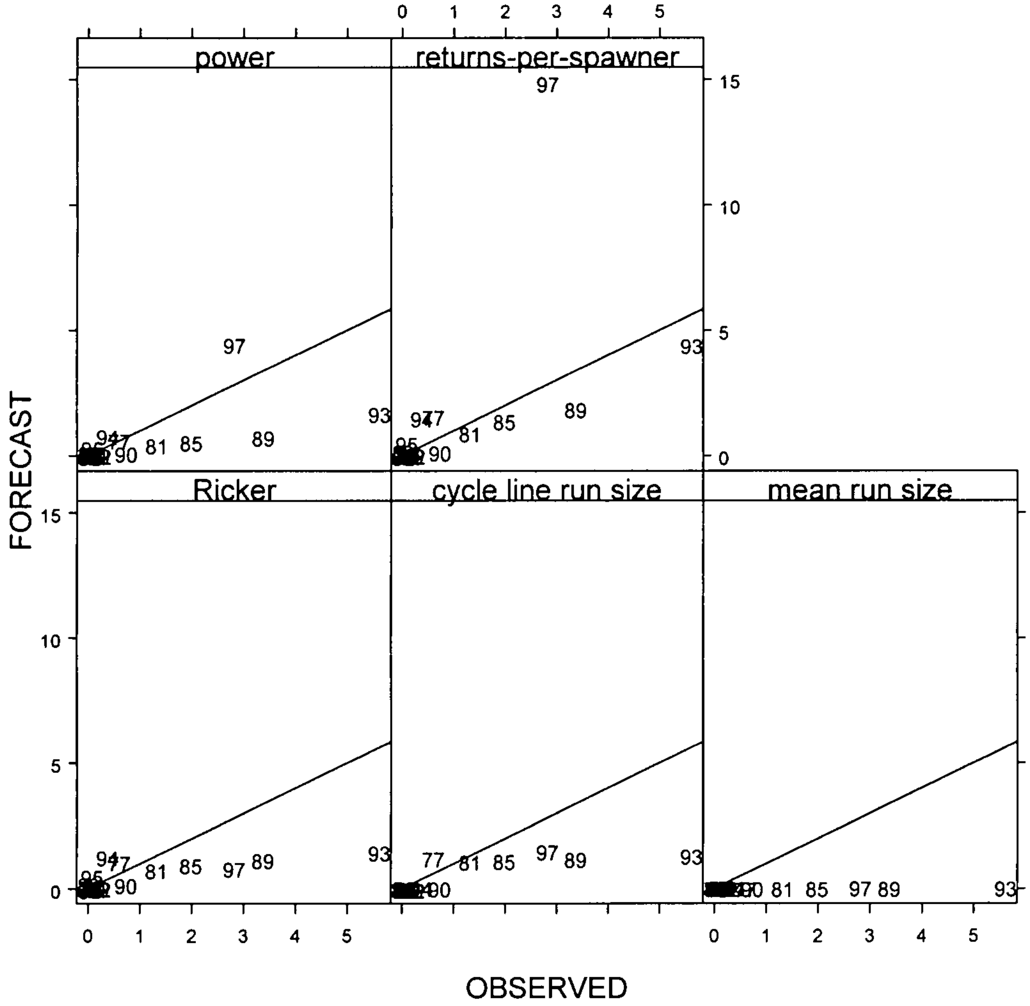

Fig. 16. Comparison of estimated (observed) returns and retrospective run size forecasts of age-4 Late Stuart sockeye. Data points are mode of distributions and denoted return year. Diagonal lines are 1:1 line not regression lines.

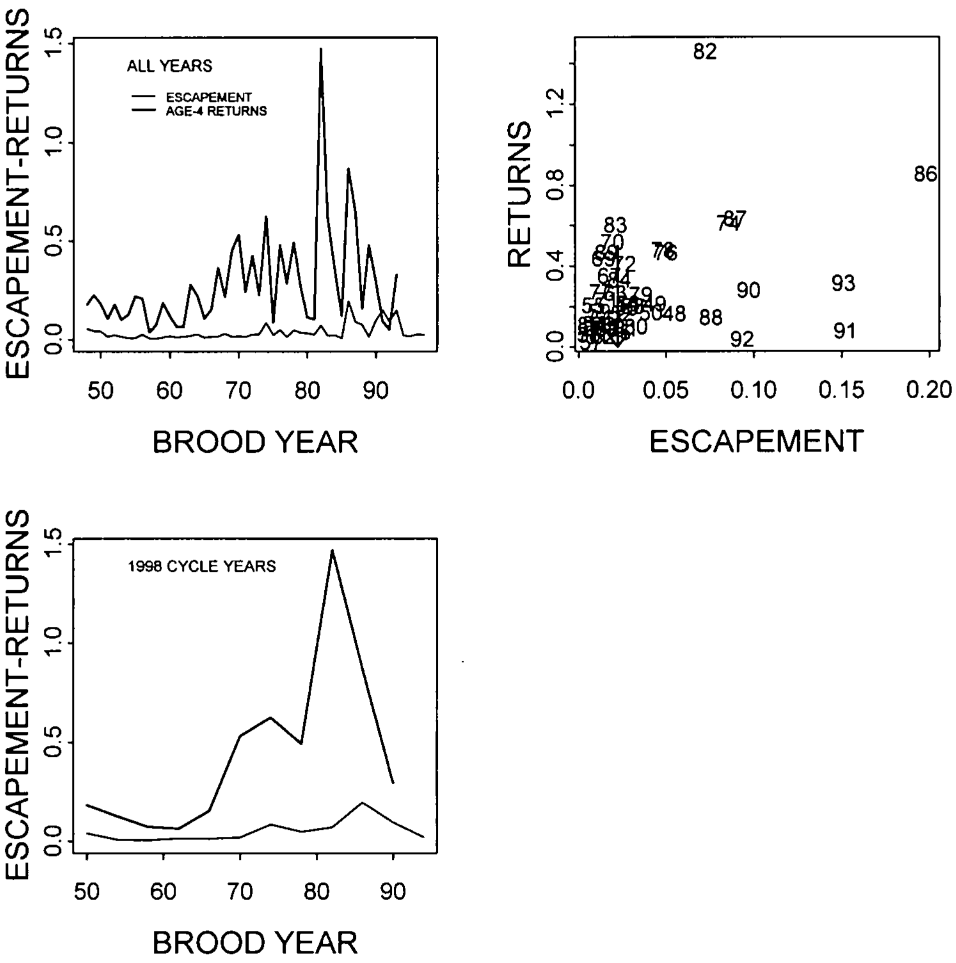

Fig. 17. Trends in escapement and age-4 returns (millions) and relationship between escapement and age-4 returns (millions) for age-4 Birkenhead sockeye. Data labels are brood years. The arrow represents the 1994 escapement.

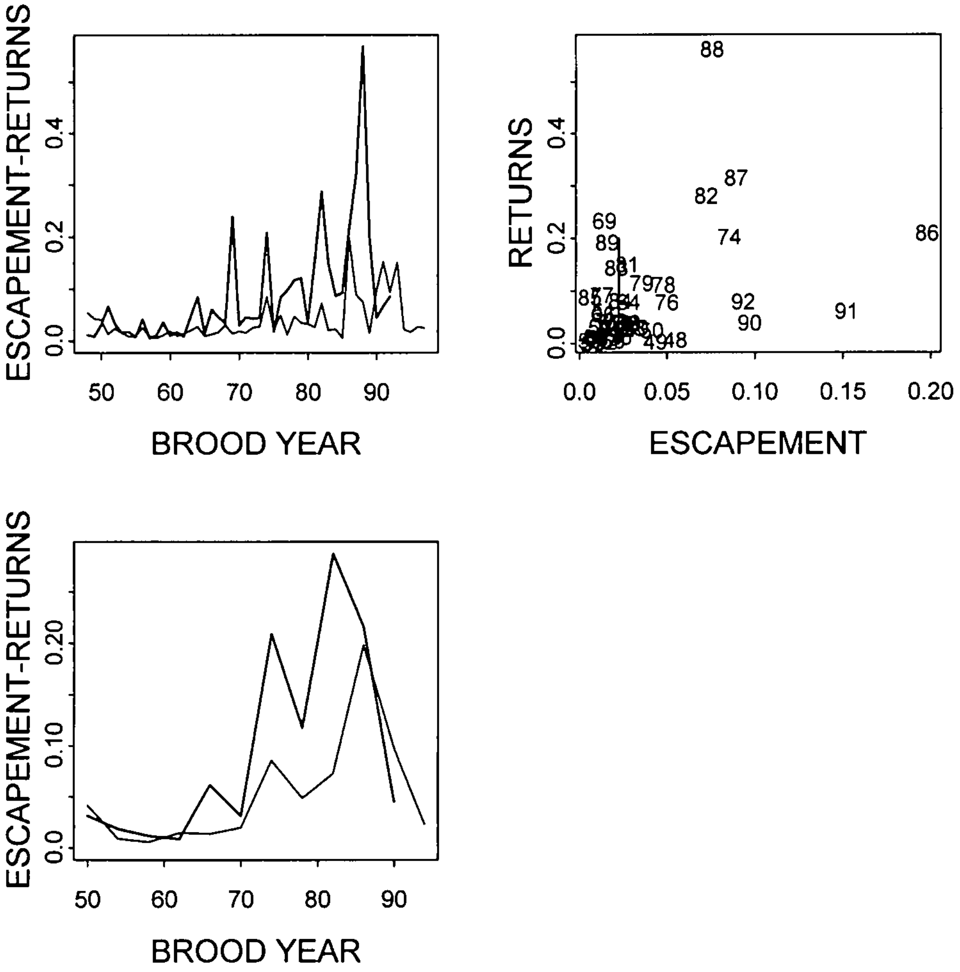

Fig. 18. Trends in escapement and age-4 returns (millions) and relationship between escapement and age-5 returns (millions) for age-4 Birkenhead sockeye. Data labels are brood years. The arrow represents the 1994 escapement.

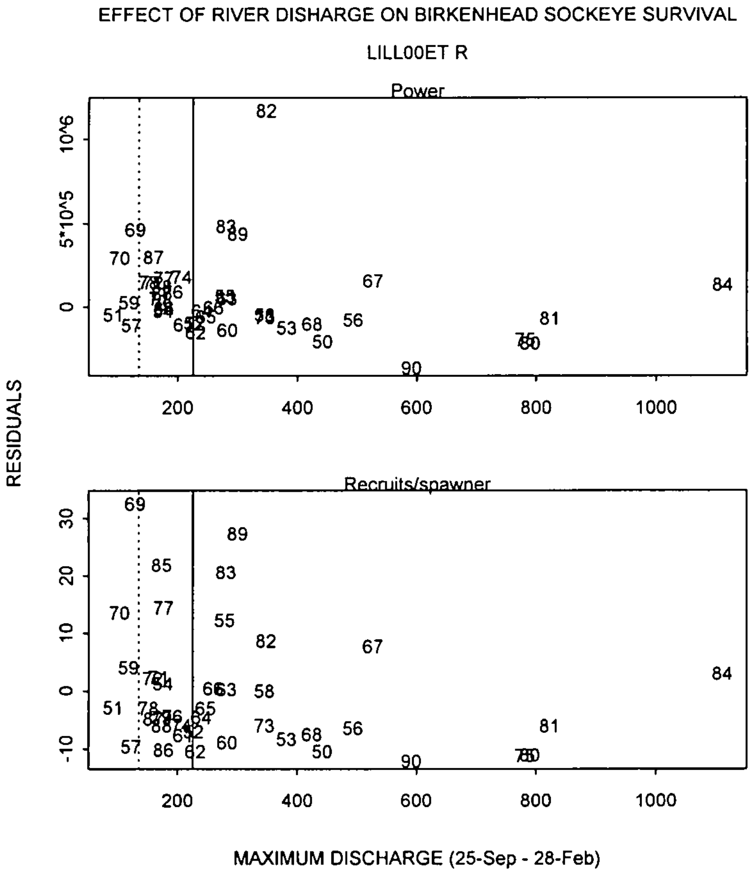

Fig. 19. Residuals from relationships (power and recruits-per-spawner models) between Lillooet River discharge rate (1950-95) and returns (age-4 and age-5) for Birkenhead River sockeye. Vertical lines correspond to discharge rates affecting 1998 returns (solid line is for age-4 returns; broken lines is for age-5 returns)

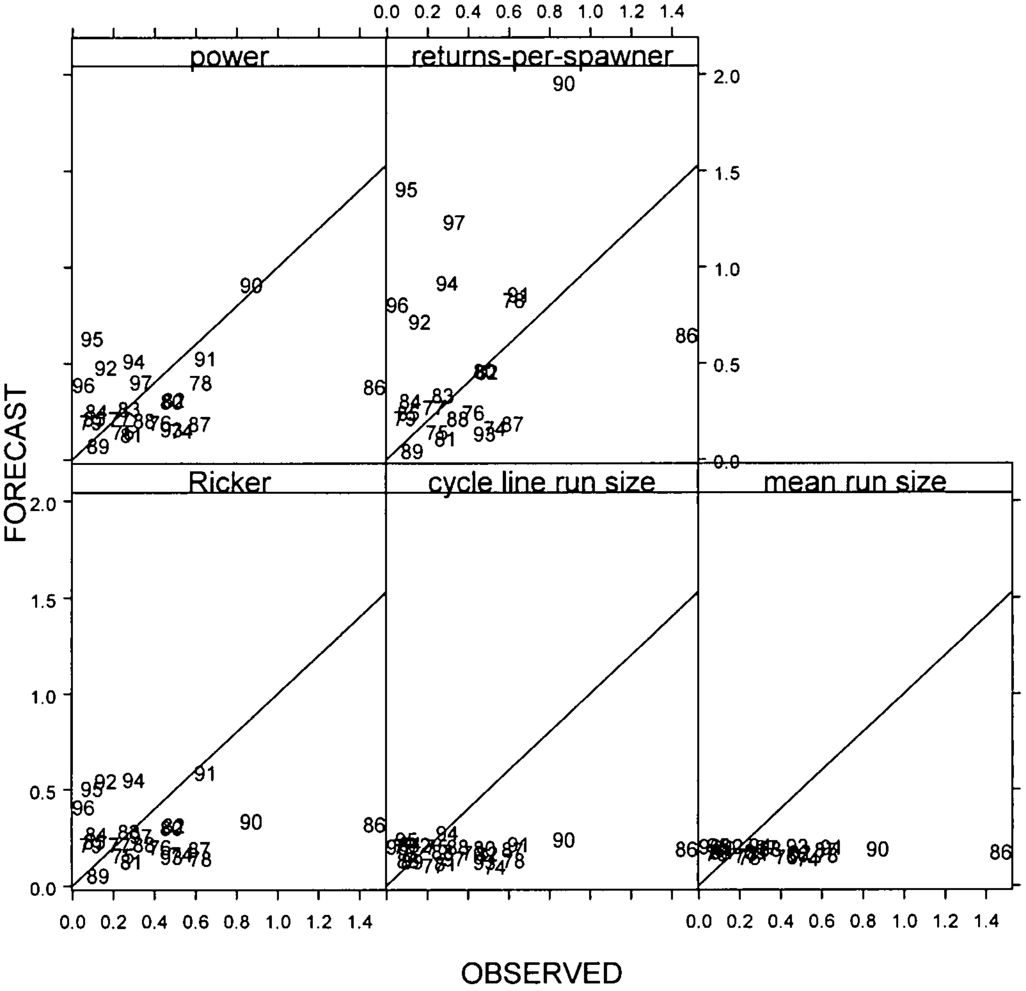

Fig. 20. Comparison of estimated returns (observed) and retrospective run size forecasts of age-4 Birkenhead sockeye. Data points are mode of distributions and denoted return year. Diagonal lines are 1:1 line not regression lines.

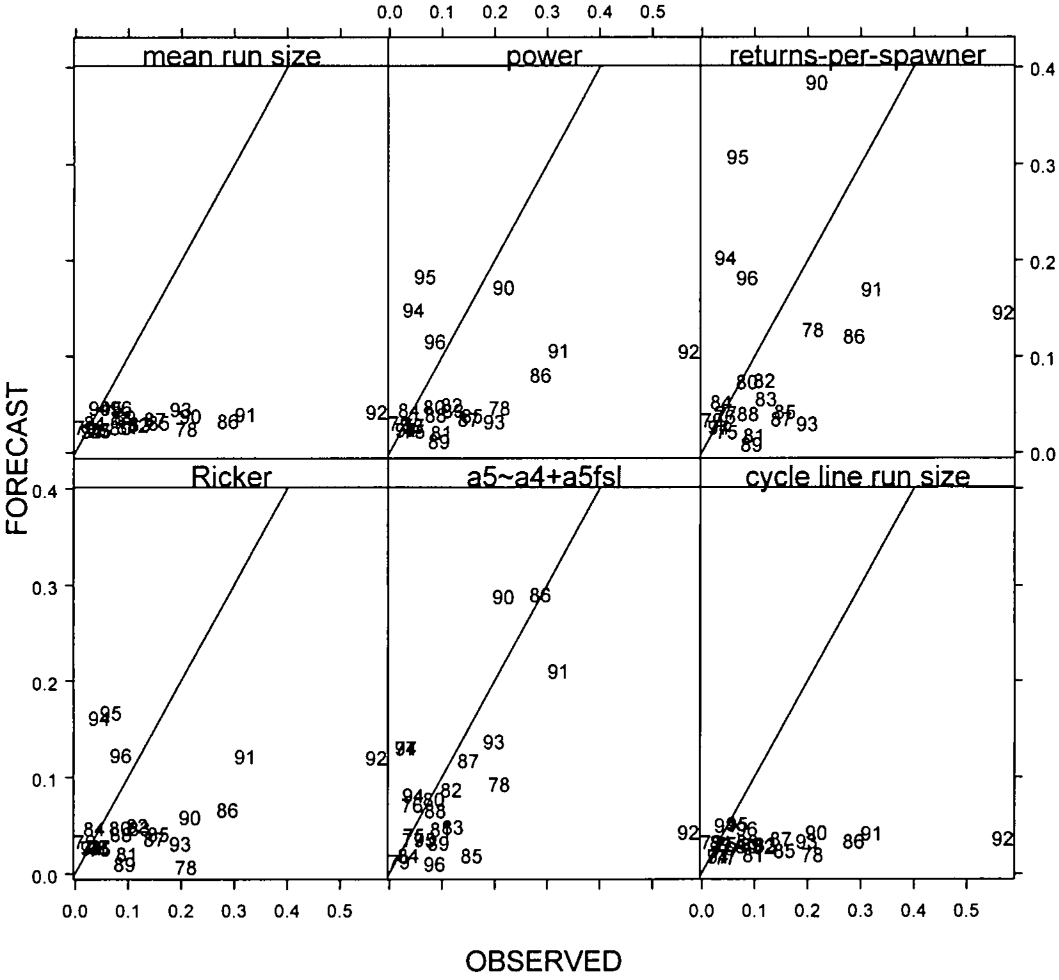

Fig. 21. Comparison of estimated (observed) returns and retrospective run size forecasts of age-5 Birkenhead sockeye. Data points are mode of distributions and denoted return year. Diagonal lines are 1:1 line not regression lines.

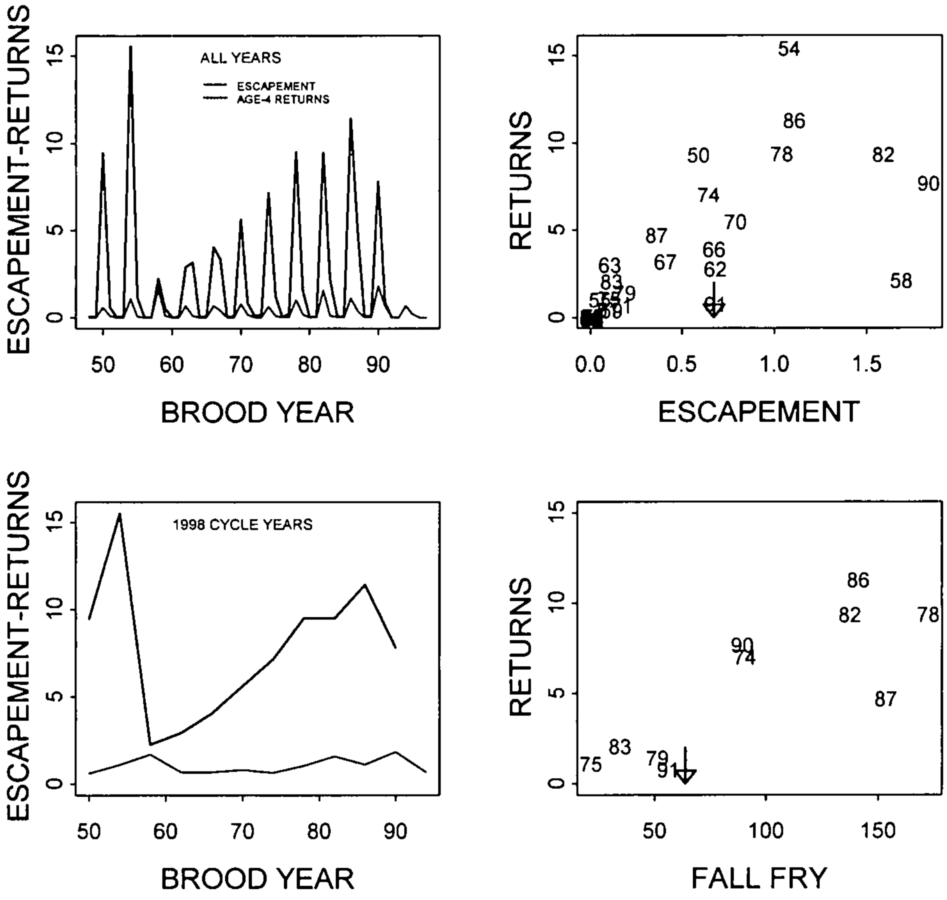

Fig. 22. Trends in escapement and age-4 returns (millions), relationship between escapement (effective females) and age-4 returns (millions) and fall fry and age-4 returns for Late Shuswap sockeye. Data labels are brood years. The arrows represent the 1994 escapement.

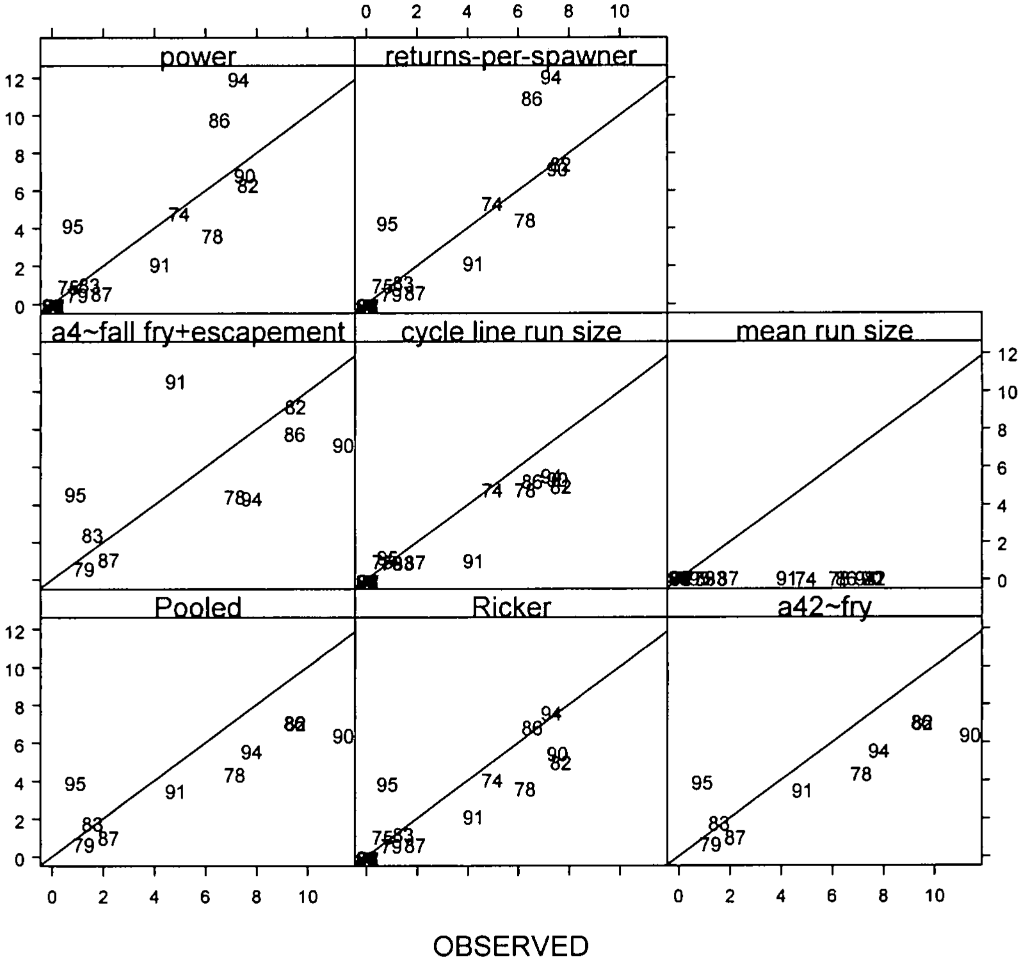

Fig. 23. Comparison of estimated (observed) returns and retrospective run size forecasts of age-4 Shuswap Lake sockeye (early and late runs). Data points are mode of distributions and denoted return year. Diagonal lines are 1:1 line not regression lines.

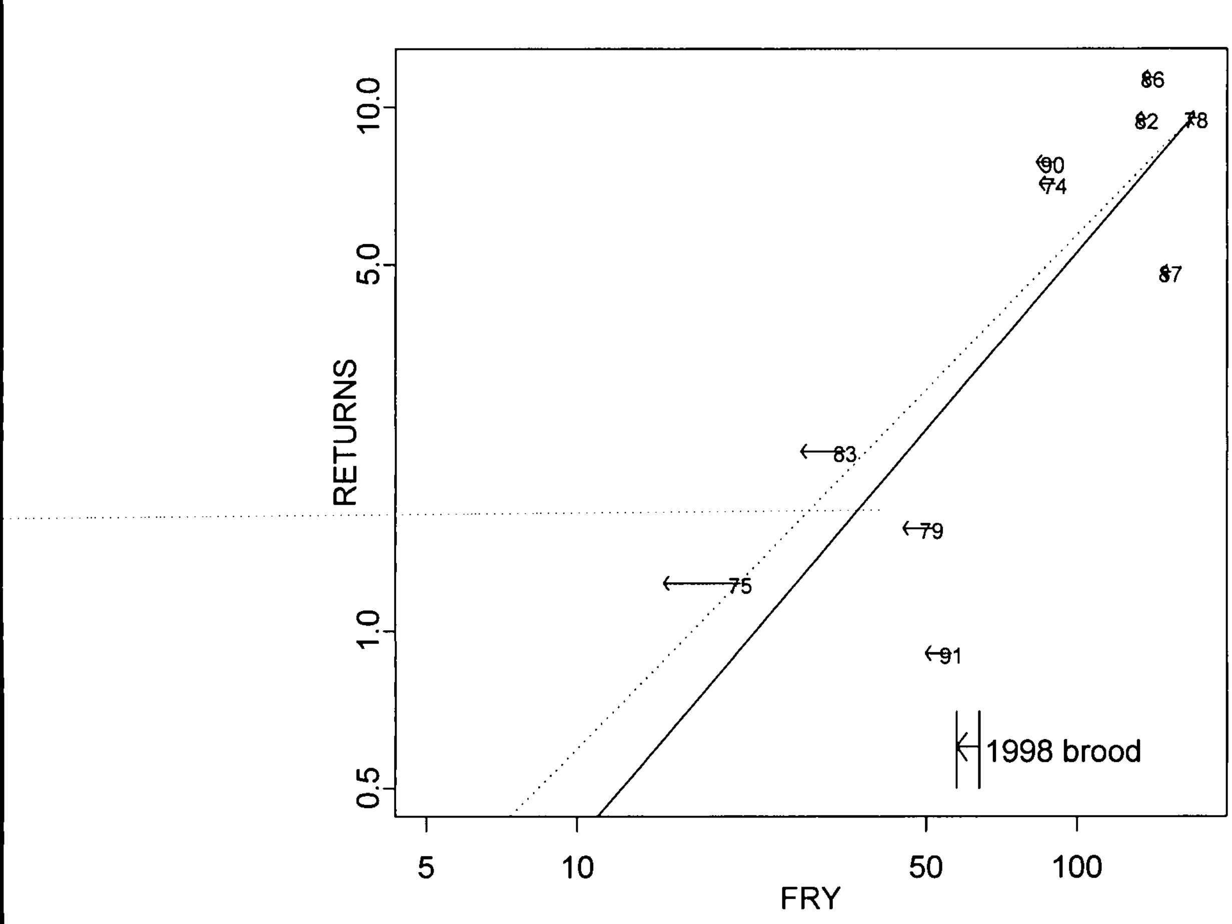

Fig. 24. Log-Log relationship between Shuswap Lake sockeye fry and age-4 returns. Solid line is fit to nominal fry data. Dashed line is fit to sockeye fry adjusted to account for kokanee fry assumed to equal 10% of the mean subdominant estimate of fry. Arrows represent the estimates of sockeye fry after adjusting for kokanee fry.

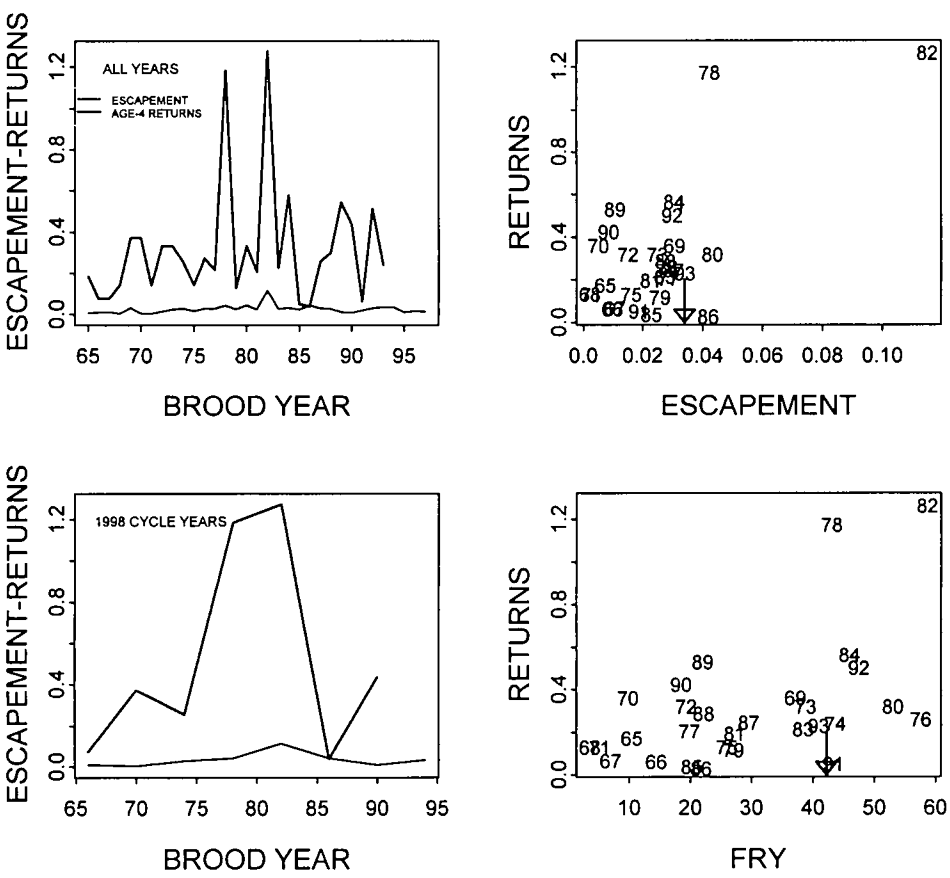

Fig. 25. Trends in escapement and age-4 returns (millions), relationship between escapement (effective females) and age-4 returns (millions) for Weaver Creek sockeye. Data labels are brood years. The arrow represents the 1994 escapement.

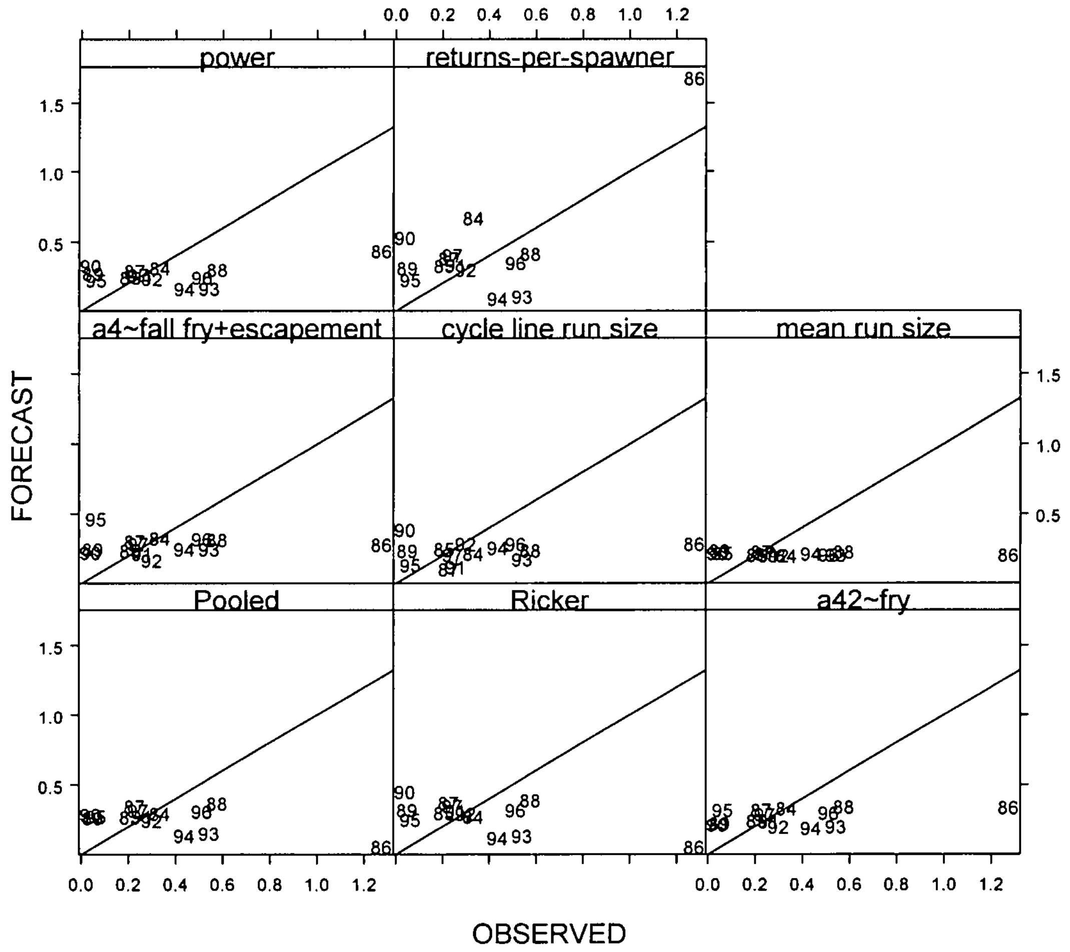

Fig. 26. Comparison of observed (estimated returns) and retrospective run size forecasts of age-4 Weaver Creek sockeye. Data points are mode of distributions and denoted return year. Diagonal lines are 1:1 line not regression lines.

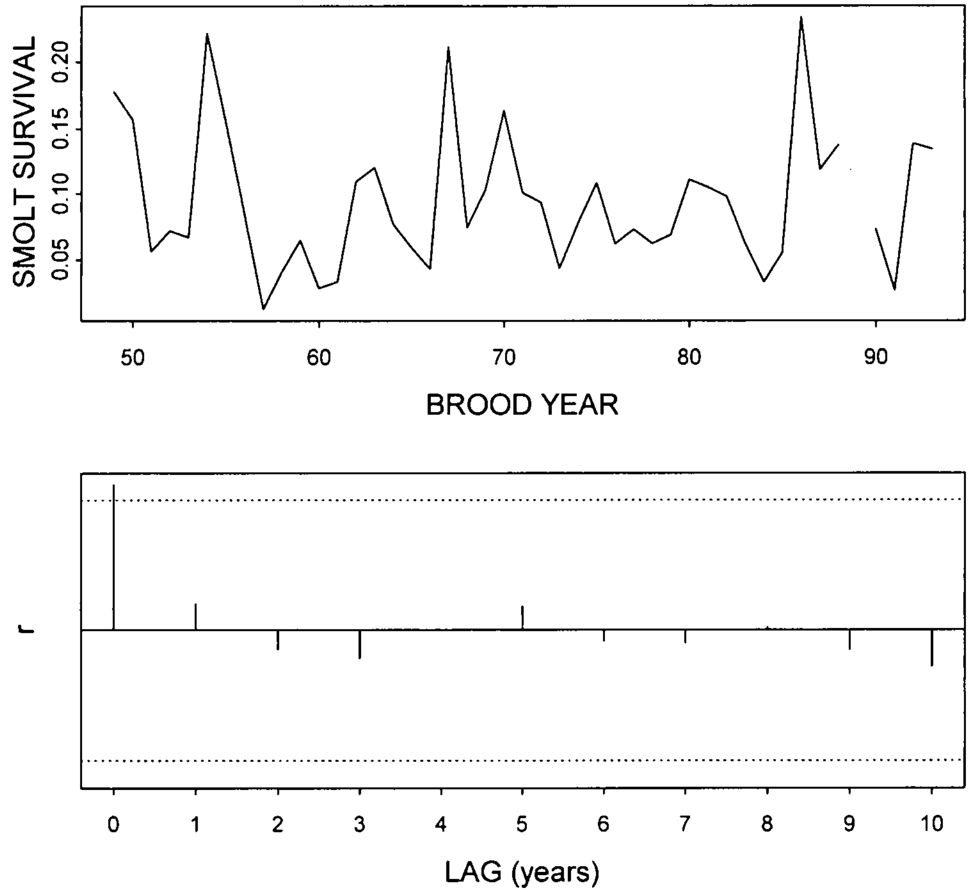

Fig. 27. Smolt (age-1) to adult return (age-4) survival of Chilko sockeye (upper) and corresponding survival autocorrelation (r) showing 95% confidence intervals (lower).