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Pre-season run size forecasts for Fraser River sockeye and pink salmon in 2003

Prévisions pré-saison des remontes de saumon rouge et de saumon rose du Fraser en 2003

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Abstract

Sockeye production from the 2003 cycle line has been dominated by returns to Chilko Lake and Lower Adams River (Shuswap Lake). Average sockeye returns for all stocks on the cycle were 6.3 million sockeye/yr compared to an all-year average of 10.3 million fish/yr (1980-2000). At nearly equal proportions, Chilko and Late Shuswap sockeye together accounted for 61% of the total sockeye returns on the cycle since 1980. Forecasts are made for each of 18 individual sockeye stocks and four run timing groups (Table 1). Together the 18 sockeye stocks accounted for 96% of the estimated escapement to the Fraser River in brood year 1999. Escapement estimates for the remaining 4% are extrapolated based on mean recruits-per-spawner for combined stocks with escapement and recruitment data to forecast total returns for all spawning populations.

Fraser pink salmon forecasts for all spawning populations combined are also provided. Pink returns in brood year 2001 were near record levels at 21 million fish. Average pink returns in odd-numbered year was 14 million (1981-2001). Pink escapement in 2001 was well beyond recent historical levels.

Forecasts of returns are made using a variety of explanatory variables. For most stocks, forecasts are based on regression models that use spawning escapement to predict returning age-4 and age-5 sockeye in 2003. Additional explanatory variables are available for some stocks and include smolt and fry data. Model performance was evaluated in a retrospective analysis by comparing forecasts to estimated (observed) run sizes for years that estimates are available. The root-mean-square error criteria was used to select the best model from several candidate models.

Forecasts are provided at various probability levels of achieving specified run sizes by stock and run-timing group. The forecast of sockeye at the 50% level for all stocks combined is 5.5 million fish (89,000 Early Stuart, 412,000 Early Summer, 3.4 million Summer and 1.6 million Late run). The Summer Run forecast accounts for 61% of the total forecast with Quesnel and Chilko stocks in nearly equal proportion at 1.1 and 1.3 million sockeye respectively. The remainder is almost entirely Late run sockeye with the Late Shuswap forecast of 1 million sockeye accounting for 60% of the Late run component. The Fraser pink salmon forecast at the 50% level is 17 million fish.

Forecasts are associated with high uncertainty. Although forecasts are presented as probability distributions, they are based on models that for most stocks assume average survival conditions. Improvements to pre-season abundance forecasts are unlikely without a better understanding of environmental factors affecting survival. Reliability of forecasts ultimately depend on understanding processes that affect survival in both freshwater and the marine environment. Migratory conditions in the Fraser River in 1999 were poor for many sockeye stocks as a result of high river discharge. The effect of stress on survival of the progeny from sockeye that spawned in 1999 is not known. Indicators of sockeye freshwater survival throughout the watershed for the brood were variable. Low egg-to-fry survival was evident for Early Stuart sockeye at one of three sites sampled as well as for Nadina sockeye. Lower than average freshwater survival to the smolt stage is evident in the two sockeye populations where

smolts are enumerated (Chilko and Cultus). Cultus sockeye have experienced long-term declines exasperated by the recent high pre-spawning mortality of Late-timed runs generally.

Oceanographic and meteorological conditions in the northeast Pacific and coastal British Columbia in 2000 and 2001 reflect moderate La Niña conditions. These years are the main ocean entry years for age-5 and age-4 sockeye returning in 2003. Ocean survival conditions were favourable for some sockeye stocks and pink returns respectively in 2002 and 2001. Correlations of survival and specific oceanographic variables, however, have not been demonstrated.

Résumé

La production de saumon rouge pour le cycle de 2003 est dominée par les remontes au lac Chilko et à la basse rivière Adams (lac Shuswap). La remonte moyenne de tous les stocks de saumon rouge du cycle se chiffre à 6,3 millions par année, alors que la moyenne pour la période 1980-2000 était de 10,3 millions par année. En proportions presque égales, le saumon rouge du lac Chilko et le saumon rouge à remonte tardive du lac Shuswap ont constitué 61 % de la remonte totale du cycle depuis 1980. Nous faisons des prévisions pour 18 stocks de saumon rouge et quatre groupes de montaison à différentes périodes de l’année (tableau 1). Les 18 stocks représentent 96 % de l’échappée estimée dans le Fraser pour l’année de génération 1999. Les estimations d’échappées pour les autres 4 % sont extrapolées en fonction du nombre moyen de recrues par géniteur pour les stocks combinés, avec des données d’échappée et de recrutement pour prévoir la remonte totale pour toutes les populations de géniteurs.

Nous présentons également les prévisions pour l’ensemble des populations de saumons roses géniteurs du Fraser. La remonte de saumons roses en 2001 a atteint 21 millions de poisson, ce qui s’approche du niveau record. Pour les années impaires de 1981 à 2001, la remonte moyenne des saumons rouges s’est chiffrée à 14 millions. En 2001, l’échappée des saumons rouges a largement dépassé les valeurs récentes.

Les prévisions des remontes sont fondées sur diverses variables explicatives. Pour la plupart des stocks, les prévisions sont calculées au moyen de modèles de régression qui utilisent l’échappée pour prédire la remonte des saumons rouges de 4 et de 5 ans en 2003. D’autres variables explicatives, notamment des données sur les alevins et les saumoneaux, sont disponibles pour certains stocks. Nous avons évalué la performance du modèle par analyse rétrospective en comparant les remontes prévues aux remontes estimées (observées) pour les années où ces dernières sont disponibles. Nous avons utilisé le critère d’erreur quadratique moyenne pour choisir le meilleur modèle parmi plusieurs modèles candidats.

Nous présentons les prévisions à divers niveaux de probabilité d’atteinte des remontes déterminées pour chaque stock ou groupe de montaison. Selon les prévisions à un niveau de probabilité de 50 %, la remonte de saumons rouges, tous stocks confondus, se chiffrera à 5,5 millions d'individus (89 000 de montaison hâtive dans la rivière Stuart, 412 000 au début de l'été, 3,4 millions en été et 1,6 million de montaison tardive). La prévision de la remonte d’été représente 61 % de la prévision totale, les stocks Quesnel et Chilko y étant représentés en proportions semblables, soit respectivement 1,1 et 1,3 million de saumons rouges. Le reste de la

prévision totale comprend presque entièrement des saumons rouges à remonte tardive, dont 60 % est constitué par la prévision de 1 million de saumons à remonte tardive du lac Shuswap. La prévision, au niveau de probabilité de 50 %, de la remonte de saumons roses dans le Fraser atteint 17 millions.

Les prévisions comportent une incertitude élevée. Bien qu'elles soient présentées comme des distributions de probabilités, les prévisions sont fondées sur des modèles reposant sur l'hypothèse de conditions de survie moyennes pour la plupart des stocks. Nous ne pourrons sans doute pas améliorer les prévisions de l'abondance pré-saison sans accroître notre compréhension des déterminants environnementaux de la survie. La fiabilité des prévisions dépend de notre compréhension des processus qui influent sur la survie tant en eau douce que dans le milieu marin. En 1999, le débit élevé du fleuve Fraser a nui à la migration de nombreux stocks de saumon rouge. On ignore l'effet que le stress a pu avoir sur la survie de la progéniture des saumons rouges qui ont frayé cette année-là. Les indicateurs de la survie en eau douce des saumons de cette cohorte sont variables dans l'ensemble du réseau fluvial. À un des trois sites d'échantillonnage, le saumon rouge à montaison hâtive de la Stuart a présenté un faible taux de survie des œufs jusqu'au stade d'alevin, tout comme le stock de la Nadina. Les deux populations de saumons rouges dont on a dénombré les saumoneaux (Chilko et Cultus) avaient un taux de survie jusqu'au stade de saumoneau (en eau douce) inférieur à la moyenne. Le saumon rouge de la Cultus connaît un déclin à long terme qui est exacerbé par une mortalité pré-fraie des individus à montaison tardive qui est généralement forte récemment.

En 2000 et en 2001, les conditions océanographiques et météorologiques dans le Pacifique nord-est et sur la côte de la Colombie-Britannique correspondaient à des conditions La Nina modérées. Ces années sont les principales années d'entrée en mer des saumons rouges de 4 et de 5 ans qui seront en montaison en 2003. Les conditions de survie en mer étaient favorables pour les remontes de saumons roses en 2001 et pour certains stocks de saumons rouges en 2002. Toutefois, nous n'avons pu établir de corrélations entre la survie et des variables océanographiques précises.

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1. Introduction

Sockeye production on the 2003 cycle line has been dominated by returns to Chilko Lake and Lower Adams River (Shuswap Lake). Average Fraser River returns on the cycle were 6.3 million sockeye/yr compared to an all-year average of 10.3 million/yr (1980-2000). At nearly equal proportions, Chilko and Late Shuswap sockeye together accounted for 61% of the total sockeye returns on the cycle since 1980. The 2003 cycle line is the first off-cycle year for highly cyclic Early Stuart, Late Stuart and Quesnel sockeye. Forecasts are made for each of 18 individual sockeye stocks and four timing groups. Together the 18 sockeye stocks accounted for 96% of the estimated escapement to the Fraser River in 1999. Forecasts for the remaining stocks in each timing group for which long-term data are not available are also provided.

Forecasts of returns are made using a variety of explanatory variables. For most stocks, forecasts are based on regression models that use spawning escapement to predict returning age-4 and age-5 sockeye in 2003. Additional explanatory variables are available for some stocks and include smolt and fry data. An environmental index has explained some variation in ocean survival of Chilko sockeye in the past (Cass et al. 1995) but has performed worse than biological variables in recent years and is not considered here. Methods that incorporate attributes of escapement-based and juvenile-based models were evaluated by pooling results from individual forecast models where time series of different life stages are available.

Sibling models that predict returns of age-4 and age-5 sockeye from returns of age-3 and age-4 in the previous year have performed poorly compared to escapement-based models (Cass 1998) and are not considered in the 2003 forecasts. The proportion of returns at age varies by cycle line and have undergone long-term changes that can not be explained by changes in abundance or growth rates. The proportion of age-3 jack returns have undergone dramatic long-term declines whereas the proportion of age-5 returns have increased in the last two decades.

2. Data sources and methods

Data sources and methods have been extensively reviewed by PSARC (Blackbourn 1992; Cass 2001a, Cass 2001b, Cass 2000, Cass 1999; Cass 1998; Cass 1997; Cass and Blackbourn 1996; Cass et al. 1995; Welch et al. 1994). Annual estimates of sockeye spawning escapement (1948-98) and returns (1952-2000) by stock are the primary data used to forecast Fraser sockeye. These data are in a Microsoft Access database available from the Pacific Salmon Commission. The main explanatory variable to respectively forecast age-4 and age-5 sockeye is the effective female spawning escapement in 1999 and 1998. Effective females are estimates of the number of spawning females contributing to the spawning population based on sampling for potential egg deposition. For Cultus Lake sockeye, total adult escapement was used because estimates of effective females are poorly determined. Furthermore, based on survival to the smolt stage, estimated from escapement to Cultus Lake measured at the Sweltzer Creek counting fence and smolt enumeration two years later, a 90% loss rate in reproductive potential is apparent since the mid-1990s. On the assumption this loss is due to high pre-spawning mortality between the time escapements are counted at Sweltzer Creek and until spawning, the recorded escapements for Cultus Lake since 1995 were reduced by 90%.

Estimates of Fraser pink escapements and returns are available for odd-number years (brood years 1957-2001). Spawning escapement estimates are based on mark-recapture experiments conducted by the International Pacific Salmon Fisheries Commission (1957-85) and DFO (1987-2001).

Estimates of juvenile sockeye fry from Nadina, Gates and Weaver spawning channels are available beginning respectively in 1968, 1973 and 1965 (Doug Lofthouse, Fisheries and Oceans Canada, personal communication). Egg-to-fry survival for these stocks is used to assess potential freshwater effects on recruitment in 2003. An estimate of total fry production from these systems was calculated by multiplying the ratio of total escapement (wild+channel) and channel escapement by channel fry abundance. Fry data for three spawning locations (Forfar, Gluske and Kynoch creeks) in the Early Stuart timing component are available since 1990 (Tracy Cone, Fisheries and Oceans Canada, personal communication). These data are not of sufficient duration for predicting returns based on the return-fry relationship but are used to estimate egg-to-fry survival and assess potential impact on 2003 returns. Previous forecasts of subdominant Shuswap Lake sockeye were based on acoustic estimates of in-lake juvenile abundance (Hume et al., 1996). Surveys of subdominant juveniles from the 1999 brood year were not done and cannot be considered here.

Estimates of age-1 smolts for Chilko and Cultus sockeye were also used in the analysis. Chilko smolt data is available for most years starting in brood year 1949. Cultus smolts are available from brood year 1924 but recently have been estimated intermittently since the early 1950s with 26 years of data between 1951 and 1999.

Pink fry abundance is estimated at Mission during the downstream migration period. Current estimation procedures are consistent with procedures developed in 1962 (Vernon, 1966). An environment variable based on salinity has been shown to improve pink forecasts. Two salinity data series (SST) in the fry year were assessed: 1) the average SST July-August measured at Amphitrite Point and at Race Rocks and 2) the average SST from July- September at the same locations.

3. Forecast models

For the 18 sockeye stocks with sufficient data to do stock-specific forecasts and for Fraser pinks, recruitment forecasts are made from brood-year predictor variables using several candidate models. The forecast of age 4 and age 5 sockeye returns in 2003 was computed by multiplying the recruitment forecast derived from 1999 and 1998 brood year predictors by the corresponding cycle-year average proportion of age-4 and age-5 sockeye. Several spawning populations within the Early Summer and Late run timing groups are not associated with recruitment data. For those populations, the effective female escapement estimates for the brood years were multiplied by the mean (1980-1996) recruits per effective female for Fraser sockeye stocks with recruitment data. The latter calculation excludes Birkenhead River and Upper Pitt River stocks that have anomolously high proportions of age 5 sockeye. Effective female spawning escapement for 1998 (age-5 brood) and 1999 (age-4 brood) for populations without recruitment data were combined and reported in Table 1 as “miscellaneous” stocks. For the miscellaneous Late run, the forecast for Late Shuswap and non-Late Shuswap stocks are reported separately.

Models used in the present analysis to forecast recruits for the 18 sockeye stocks and Fraser pinks are as follows:

1) Ricker function with log-normal errors (fit to the mode of recruits):

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

estimated using the linear regression :

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

Here the recruits R_t 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:

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

estimated by:

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

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

$$R_t = S_t \left[\frac{GM(R_1 \ldots R_{t-1})}{GM(S_1 \ldots S_{t-1})} \right] \qquad (3)$$

4) Juvenile models:

For Chilko, Cultus, Nadina, Gates, Weaver sockeye and Fraser pink salmon a non-linear power model of the form:

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

was fit to adult recruits and juvenile data N at generation t.

In addition, forecast performance of additional predictor variables in a multiple regression was also assessed. Specifically, where juvenile data is used, the effect of escapement (log transformed) and salinity, in the case of pinks, on forecast performance was evaluated.

The variance of the forecast in the $\log_e$ domain was computed using standard methods for prediction (Snedecor and Cochran 1967; eq. 6.12.1). The probability of achieving the forecast at the 25%, 50%, 75%, 80% and 90% levels was computed from the student's t-distribution with n-m degrees of freedom where n is the length of the time-series and m is the number of terms in the regression model. Miscellaneous stock forecasts at the specified probability levels were computed by multiplying corresponding percentiles of the 1980-96 frequency distribution of recruits per effective female for combined stocks with paired stock and recruitment data by the brood year effective females for miscellaneous stocks.

5) Pooled models:

A method that combines forecasts from models with independent biological explanatory variables described by Fried and Yuen (1987), 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 (i.e. escapement and fry). Weights were assigned using the inverse of the forecast prediction variance:

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

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

$$V_p = 1/\sum_{m=1}^{n} 1/V_m \,. \tag{6}$$

4. Model performance

Model performance was evaluated in a retrospective analysis by comparing forecasts to estimated (observed) returns for years that estimates are available. Starting with the most recent year that returns are available, a retrospective forecast for that year was made from the time series of explanatory variables. The process is continued back in time by hindcasting returns for part of the time series based on an historical baseline. In this way, retrospective forecasts for each year are based only on the time series available prior to the year being forecast. Retrospective comparisons were made for return years 1984-2000 (brood years 1980-1996) for sockeye and odd numbered years 1979-1999 (brood years 1977-2001) for pinks. Because of the shorter time series of Cultus Lake smolt data, the retrospective analysis was done using the last 12 years of smolt data (1969-1998).

The retrospective comparison of forecasting models for Early Stuart, Chilko, Quesnel and Late Shuswap sockeye and Fraser pink salmon are shown in Figures 1-5. Note that the scale is in the log domain and so the true uncertainty, to a large extent, is masked. Uncertainty in the retrospective comparisons for these stocks is depicted by the 90% prediction intervals of the forecasts in relationship to the 1:1 line. In many years the confidence intervals do not overlap the 1:1 line. In other words, the models are poor representations of the natural processes that control survival particularly in years of no overlap of the confidence intervals with the 1:1 line. The relationships between the forecast and observed returns reveal similar patterns irrespective of the forecast model.

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

$$RMSE_i = \sqrt{\frac{1}{n}\sum_{t=1}^{n}(R_t - F_t)^2}\ , \tag{7}$$

where R_t is observed and F_t is the forecast in year *t*. The RMSE criterion is appropriate for minimizing extreme high or low forecast errors. 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.

5. 2003 forecasts

Annual differences between estimated (observed) sockeye returns and forecast returns (50% level) during 1990-2002 for each run timing group are shown in Figure 6. The average absolute percent error for 1990-2002 was 38% for Early Stuart, 53% for Early Summers, 60% for Summers and 85% for Late runs. Based on final pre-season estimates of 2002 sockeye returns, the 2002 forecast over-estimated Early Stuart and Summer run returns respectively by 41% and 24% and underestimated the Early Summer and Late runs respectively by 82% and 126%. Fraser River pink salmon returns in 2001 exceed the 50% forecast by nearly 4-fold. Data trends and relationships between variables used in forecasts for major stocks are shown in Figures 7 – 11.

Forecasts are provided at various probability levels of achieving specified run sizes by stock and run-timing group (Table 1). Forecasts for age-4 and age-5 sockeye at the 50% probability level are listed in Table 2. The forecast of sockeye at the 50% level for all stocks combined is 5.5 million fish (89,000 Early Stuart, 412,000 Early Summer, 3.4 million Summer and 1.6 million Late run). This forecast compares to an average return on the 2003 cycle of 6.3 million sockeye/yr (1980-2000). The Summer Run forecast accounts for 61% of the total forecast with Quesnel and Chilko stocks in nearly equal proportion at 1.1 and 1.3 million sockeye respectively. The remainder is almost entirely Late run sockeye with the Late Shuswap forecast of 1 million sockeye accounting for 61% of the Late run component. The Fraser pink salmon forecast at the 50% level is 17 million fish and compares to an average return of 14 million pinks/yr in odd-numbered years (1981-2001).

5.1 Early Stuart sockeye

The 2003 cycle line is the first off cycle following the dominant (2001) and subdominant line (2002) returns. The spawning escapement in brood year 1999 was impacted by high Fraser River discharges during the in-river spawning migration. The final in-season estimates of Early Stuart sockeye at Mission was 80% greater than the upstream sum of the spawning escapement and catch estimates (Anon 2001). Escapement estimates were low compared to recent escapements for the cycle (Fig. 7). A disproportionately low number of females (39%) reached the spawning sites compared to males. Females suffered an estimated 15% pre-spawning mortality. The power model had the lowest RMSE and resulted in a 50% forecast (89,000) that is 41% lower than the cycle line mean (1980-1999) of 216,000 sockeye/yr (Table 1). The forecast return at the 75% probability level is 57,000 sockeye.

Egg-to-fry survival rates (Fig. 12) have been estimated annually since 1990 at three sites (Forfar, Kynoch and Gluske Creeks). Survival rates of the 2003 brood were near the 1990-99 mean at two locations (Forfar and Gluske Creeks) and 55% less than the mean at the other site (Kynoch Creek). The ultimate impact of fry survival measured at three of about 30 spawning locations on overall adult Early Stuart recruitment is difficult to assess. The effect of stresses due to unfavourable spawning migration conditions, particularly evident for Early Stuart sockeye in 1999, is unknown. Recruitment rates are ultimately affected by survival factors throughout the life cycle. Forecasts are unlikely to improve without knowing the sum of the individual survival rates incurred both in freshwater and the ocean.

5.2 Early Summer run sockeye

The Early summer run mainly consists of several small stocks (Fennell, Bowron, Raft, Gates, Nadina, Pitt, Seymour and Scotch) (Table 1). In-season Mission estimates of escapement to the Fraser River in 1999 were 54% greater than upstream spawning escapement plus catch but pre-spawning mortality was low (~5%). The total forecast for the Early Summer group is 412,000 sockeye at the 50% level and 225,000 fish at the

75% level. These forecast levels compare to a 1980-2000 cycle mean return of 440,000 sockeye/yr.

Forecasts based on fry output from the Nadina spawning channel and weighted to account for the total fry production from both wild and channel spawning sites had a lower RMSE compared to escapement-based forecasts. The forecast based on Gates Creek fry performed poorly compared to a simple recruits-per-spawner model (lowest RMSE). The egg-to-fry survival estimate for the 1999 brood at the Gates Creek spawning channel was above the long-term mean whereas fry survival for the Nadina channel was below the long-term mean (Fig. 13).

5.3 Summer run sockeye

Of the four Summer run stocks, Chilko and Quesnel sockeye account for 74% of total Summer run forecast (Table 1). Chilko escapement in 1999 were the fourth highest on record but survival to the smolt stage was lower than average (Fig. 8). The best forecast for Chilko sockeye is based on a multiple regression that includes smolts and spawning escapement as predictors. The Chilko forecast return of 1.3 million sockeye (75% forecast = 849,000) is below the all-year and cycle-line mean returns respectively by 35% and 32%. Quesnel escapement on the 2003 cycle line has increased steadily from 2,000 adult spawners in 1983 to 214,000 adults in 1995. Escapement to Quesnel Lake declined to 187,000 adults in 1999 (Fig. 9). The best performing forecast (power model) results in a forecast of 1.2 million sockeye (75% forecast = 624,000). The high rate of return for Quesnel Lake is due in part to the high proportion of effective females compared to male spawners in 1999 and a forecast of age-5 sockeye from the subdominant cycle line (1998) that is low in proportion but high in absolute numbers.

Late Stuart escapement on the 2003 cycle line has also increased from less than 10,000 spawners/yr prior to the 1970s to an average of 60,000 spawners in the 1990s. The escapement of the Late Stuart sockeye in brood year 1999 was 62,000 adults and is the second highest on record for the cycle (Table 1). The Late Stuart forecast of 274,000 sockeye at the 50% level and 120,000 at the 75% level compares to a 1980-2000 mean return of 122,000 sockeye for the 2003 cycle. The 2003 forecast return of 595,000 Stellako sockeye at the 50% level (75% forecast = 395,000) is near the all-year and cycle line mean return/yr (Table 1).

5.4 Late Run sockeye

The forecasts at the 50% probability level for individual Late run stocks are all below the 1980-2000 cycle line mean (Table 1). The 2003 forecasts of Cultus Lake and Late Shuswap sockeye are particularly low. The Late run Shuswap forecast is 991,000 sockeye at the 50% level and 527,000 at the 75% level. This compares to a cycle line mean of 1.9 million sockeye/yr. The low Late Shuswap forecast is due to a low brood year escapement compared to the cycle mean. Spawning escapement to the Late Shuswap run on the 2003 subdominant line has declined from a high of 1.3 million sockeye in 1991 to 287,000 spawners in 1999 (Fig. 10). High in-river mortality, based on differences between Mission acoustic estimates and estimates of spawning escapement plus catches up-river of Mission, has been implicated as the cause of the decline in escapement to the Late Shuswap stock and other Late run stocks in 1999.

Cultus Lake sockeye returns and escapement have undergone a pronounced decline since the 1960s. The best performing forecast model for Cultus Lake sockeye is the smolt-based model. The 50% level is 9,000 sockeye or well below the 1980-2000 cycle line mean of 28,000 sockeye/yr (Table 1).

Both the Weaver Creek and Birkenhead River sockeye forecasts of 322,000 and 191,000 sockeye are below the 20-yr cycle line mean (Table 1). Weaver channel fry survival was above average (Fig. 13). The Portage Creek forecast at the 50% probability level of 41,000 sockeye is near the 20-yr mean of 47,000 sockeye.

5.5 2003 pink forecasts

The estimate of pink salmon returns in 2001 of 21 million fish is near the recent recorded high of 22 million in 1991 (Fig. 11). In the absence of significant pink salmon fisheries in 2001, the escapement was estimated to be 20 million fish. This is almost double the estimated escapement in any year since 1961 when quantitative escapement estimation began. Fry-to-adult survival rates indicate the large returns in 2001 were due to high ocean survival.

The forecast model with the best RMSE performance is a multiple regression that includes fry abundance estimates and mean salinity measured at Amphitrite Point and Race Rocks in the ocean entry year. The estimated 681 million pink fry from the large 2001 escapement is near the record high at 697 million fry from an escapement of 13 million in 1991 and a return of 17 million adults in 1993. The 2003 forecast is 17 million pinks at the 50% probability level and 12 million at the 75% probability level (Table 1).

6. Conclusion

Forecasts are associated with high uncertainty as indicated in Figures 1-6. Although forecasts are presented as probability distributions, for most stocks they are based on models that assume average survival conditions. Improved forecast accuracy is unlikely without a better understanding of environmental factors affecting survival. Reliability of forecasts ultimately depend on understanding processes that affect survival in both freshwater and the marine environment. Migratory conditions in the Fraser River in brood year 1999 were poor for some sockeye stocks as a result of high river discharge. The effect of stress on survival of the progeny from sockeye that spawned in 1999 is not known. Low egg-to-fry survival was evident for Early Stuart sockeye at one of three sites sampled as well as for Nadina sockeye. Lower than average freshwater survival to the smolt stage is evident in the two sockeye populations where smolts are enumerated (Chilko and Cultus). Cultus sockeye have experienced long-term declines exasperated by the recent high pre-spawning mortality of Late-timed runs generally.

Intense El Niño conditions were associated with poor marine survival of Fraser sockeye in ocean entry years 1993 and 1997 and over-forecasts in return years 1995 and 1999. Oceanographic and meteorological conditions in the northeast Pacific and coastal British Columbia in 2000 and 2001 reflect moderate La Niña conditions (Anon. 2002). These years are the main ocean entry years for age-5 and age-4 sockeye returning in 2003. Ocean survival conditions were favourable for sockeye and pink returns respectively in 2002 and 2001, however, correlations between oceanographic variables and Fraser River sockeye has not been demonstrated.

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Table 1. Pre-season sockeye and pink salmon forecasts for 2003 by stock/timing group and probability level.

Sockeye				**Probability of Achieving Specified Run Sizes[a]**				
stock/timing group	**forecast model[b]**	**mean run size[c]** all cycles	**mean run size[c]** 2003 cycle	**0.25**	**0.5**	**0.75**	**0.8**	**0.9**
Early Stuart	Power	**383,000**	**216,000**	**139,000**	**89,000**	**57,000**	**51,000**	**38,000**
Early Summer		**489,000**	**440,000**	**748,000**	**412,000**	**225,000**	**196,000**	**133,000**
Fennell	Power	27,000	31,000	87,000	46,000	25,000	21,000	14,000
Bowron	Power	23,000	29,000	52,000	31,000	18,000	16,000	11,000
Raft	Power	21,000	13,000	46,000	27,000	16,000	14,000	10,000
Gates	R/S	65,000	25,000	42,000	25,000	16,000	14,000	10,000
Nadina	Fry	78,000	107,000	66,000	37,000	21,000	18,000	13,000
Pitt	Power	46,000	29,000	138,000	82,000	49,000	43,000	30,000
Seymour	Power	168,000	190,000	113,000	61,000	32,000	28,000	18,000
Scotch	R/S	61,000	16,000	37,000	16,000	6,000	5,000	3,000
Misc[d]	R/S	-	-	167,000	87,000	42,000	37,000	24,000
Summer		**6,017,000**	**2,801,000**	**5,775,000**	**3,360,000**	**1,988,000**	**1,749,000**	**1,246,000**
Chilko	Smolt/esc[e]	1,982,000	1,896,000	2,063,000	1,323,000	849,000	760,000	566,000
Quesnel	Power	2,547,000	241,000	2,188,000	1,168,000	624,000	534,000	352,000
Stellako	Ricker	546,000	542,000	897,000	595,000	395,000	357,000	272,000
Late Stuart	Power	942,000	122,000	627,000	274,000	120,000	98,000	56,000
Late		**3,369,000**	**2,803,000**	**3,082,000**	**1,641,000**	**871,000**	**746,000**	**491,000**
Birkenhead	Power	536,000	528,000	575,000	322,000	180,000	156,000	106,000
Late Shuswap	Ricker	2,286,000	1,909,000	1,863,000	991,000	527,000	451,000	297,000
Cultus	Power	28,000	68,000	18,000	9,000	5,000	4,000	3,000
Portage	R/S	68,000	47,000	90,000	41,000	19,000	15,000	9,000
Weaver	R/S	451,000	251,000	370,000	191,000	98,000	83,000	53,000
Misc Shuswap[f]	R/S	-	-	100,000	52,000	25,000	22,000	14,000
Misc. non-Shuswap[f]	R/S	-	-	66,000	35,000	17,000	15,000	9,000
TOTAL		**10,258,000**	**6,260,000**	**9,744,000**	**5,502,000**	**3,141,000**	**2,742,000**	**1,908,000**
Pink	Fry+salinity[g]	**-**	**14,303,000**	**25,504,000**	**17,273,000**	**11,698,000**	**10,605,000**	**8,144,000**

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

[b] see text for model descriptions

[c] 1980-2000 mean

[d] unforecasted miscellaneous Early Summer stocks

[e] based on multiple regression using smolts and escapement as the independent variables

[f] unforecasted miscellaneous Late stocks

[g] based multiple regression using fry and salinity (July - September) (see text)

Table 2. Forecast at the 50% probability level by stock/stock group and age class.

Stock/timing group	**age-5**	**age-4**	**total**
Early Stuart	**3,000**	**86,000**	**89,000**
Early Summer	**90,000**	**235,000**	**325,000**
Fennell	11,000	36,000	47,000
Bowron	4,000	26,000	30,000
Raft	6,000	21,000	27,000
Gates	4,000	22,000	26,000
Nadina	5,000	32,000	37,000
Pitt	58,000	24,000	82,000
Seymour	1,000	59,000	60,000
Scotch	1,000	15,000	16,000
Summer	**335,000**	**3,025,000**	**3,360,000**
Chilko	29,000	1,294,000	1,323,000
Quesnel	223,000	945,000	1,168,000
Late Stuart	24,000	250,000	274,000
Stellako	59,000	536,000	595,000
Late	**187,000**	**1,367,000**	**1,554,000**
Birkenhead	125,000	197,000	322,000
Portage	4,000	37,000	41,000
Cultus	0	9,000	9,000
Late Shuswap	27,000	964,000	991,000
Weaver	31,000	160,000	191,000

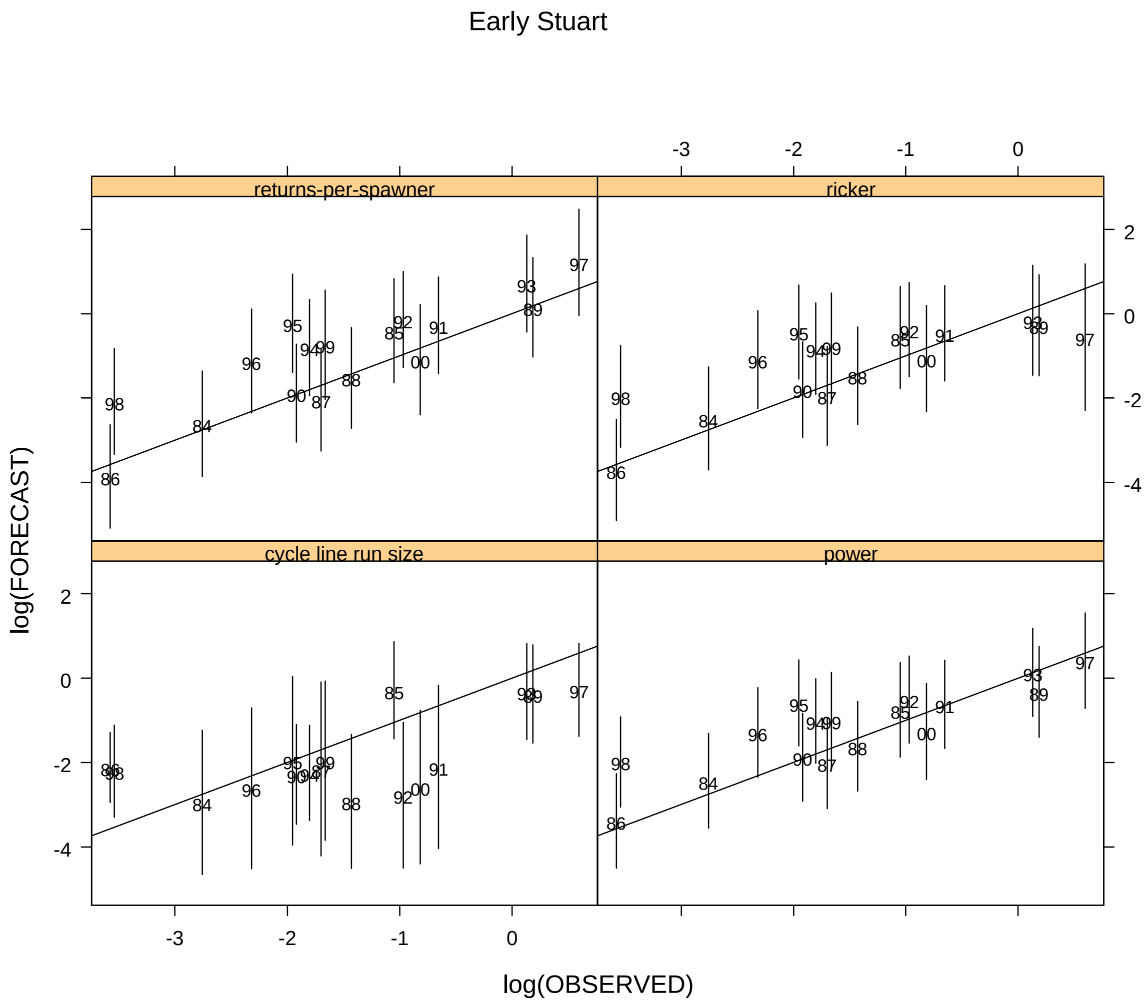

Figure 1. Comparison of estimated (observed) returns and retrospective forecast returns (millions ($\log_e$ scale)) of Early Stuart sockeye for candidate models. Data points are median (50%) forecasts and are denoted by return year. Diagonal lines are 1:1 lines not regression lines. Error bars are 90%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

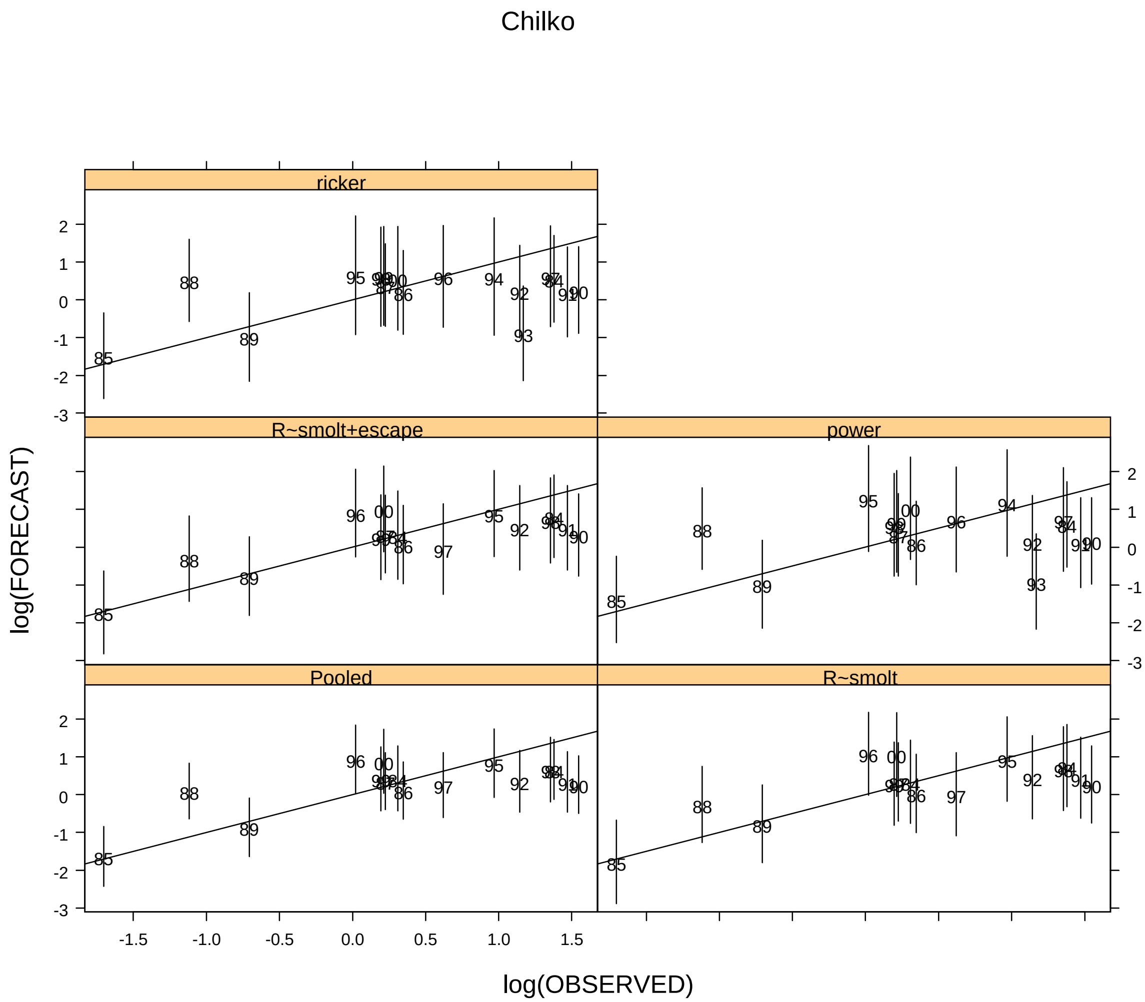

Figure 2. Comparison of estimated (observed) returns and retrospective forecast returns (millions ($\log_e$ scale)) of Chilko sockeye for candidate models. Data points are median (50%) forecasts and are denoted by return year. Diagonal lines are 1:1 lines not regression lines. Error bars are 90% confidence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

Quesnel

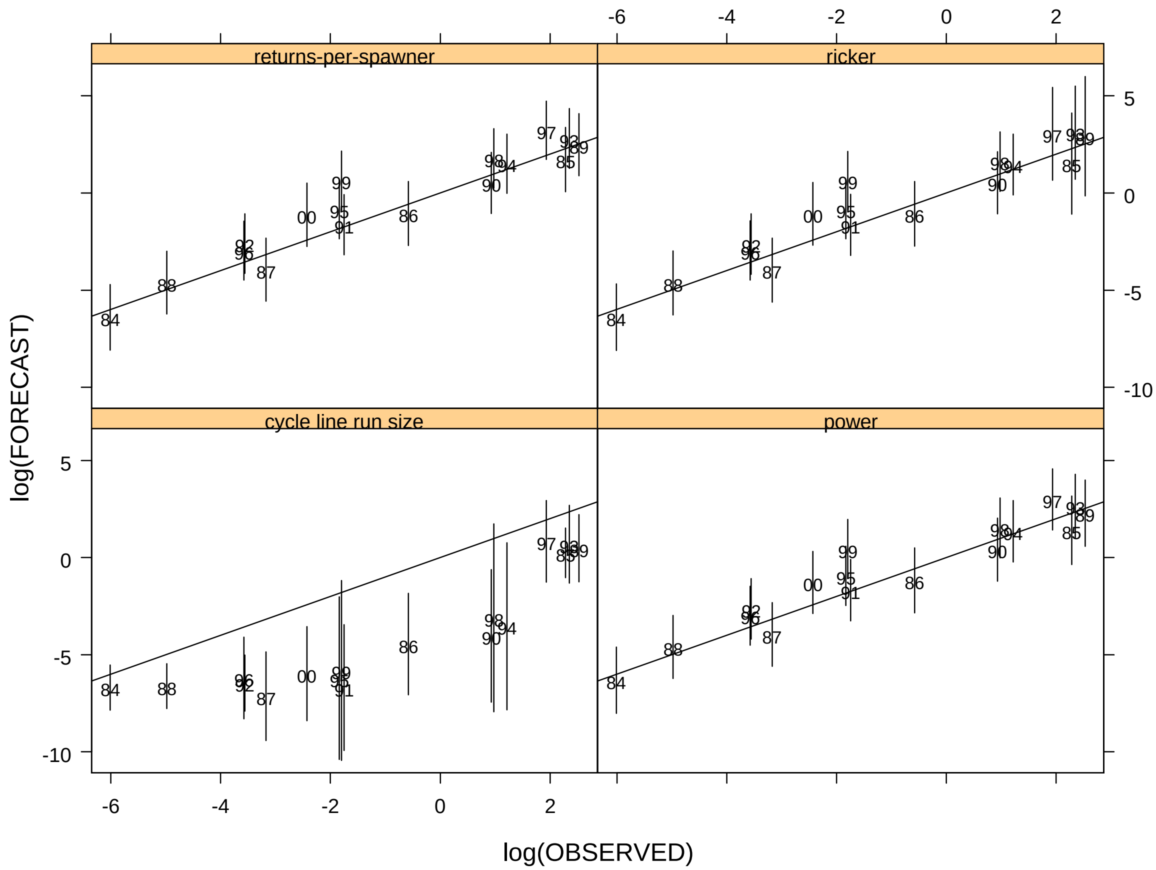

Figure 3. Comparison of estimated (observed) returns and retrospective forecast returns (millions (log_e scale)) of Quesnel sockeye for candidate models. Data points are median (50%) forecasts and are denoted by return year. Diagonal lines are 1:1 lines not regression lines. Error bars are 90% confidence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

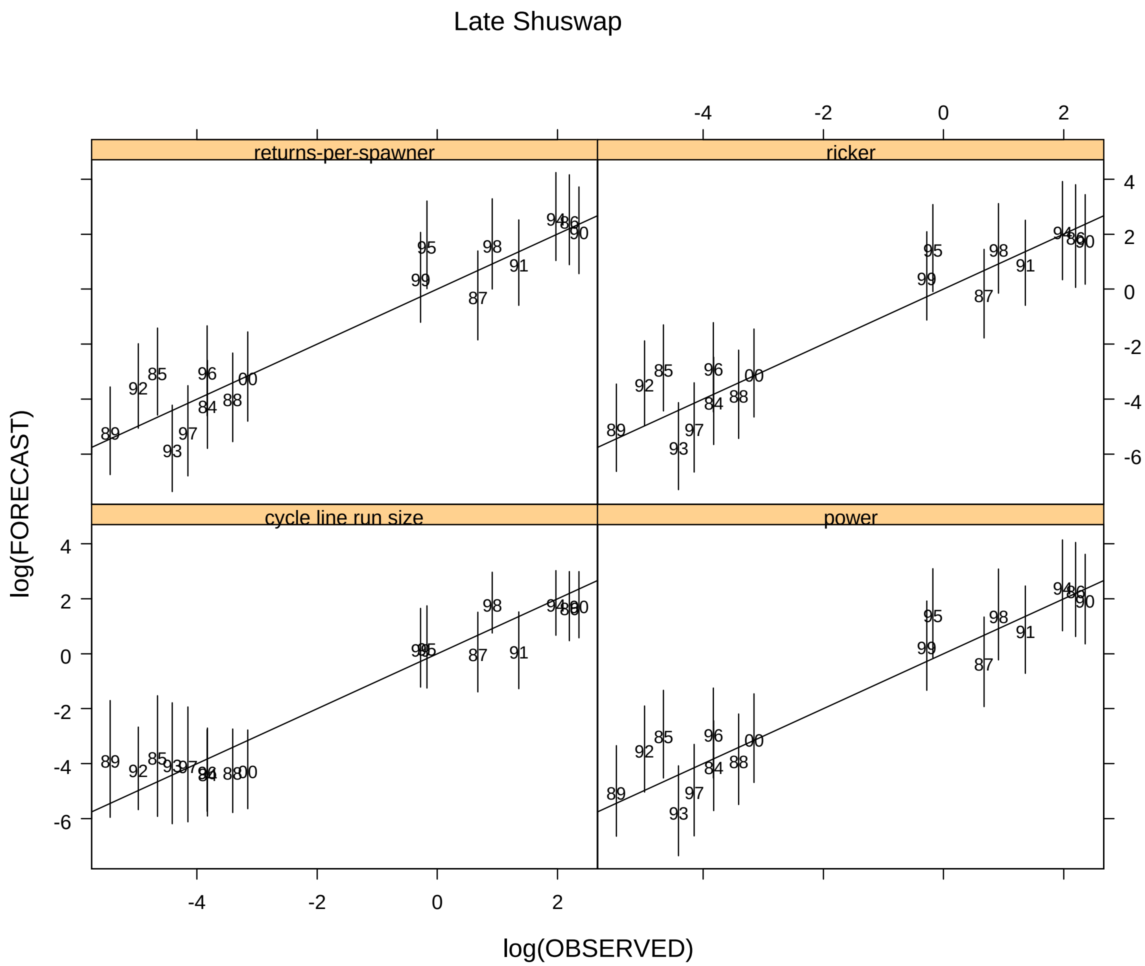

Figure 4. Comparison of estimated (observed) returns and retrospective forecast returns (millions ($\log_e$ scale)) of Late Shuswap sockeye for candidate models. Data points are median (50%) forecasts and are denoted by return year. Diagonal lines are 1:1 lines not regression lines. Error bars are 90%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

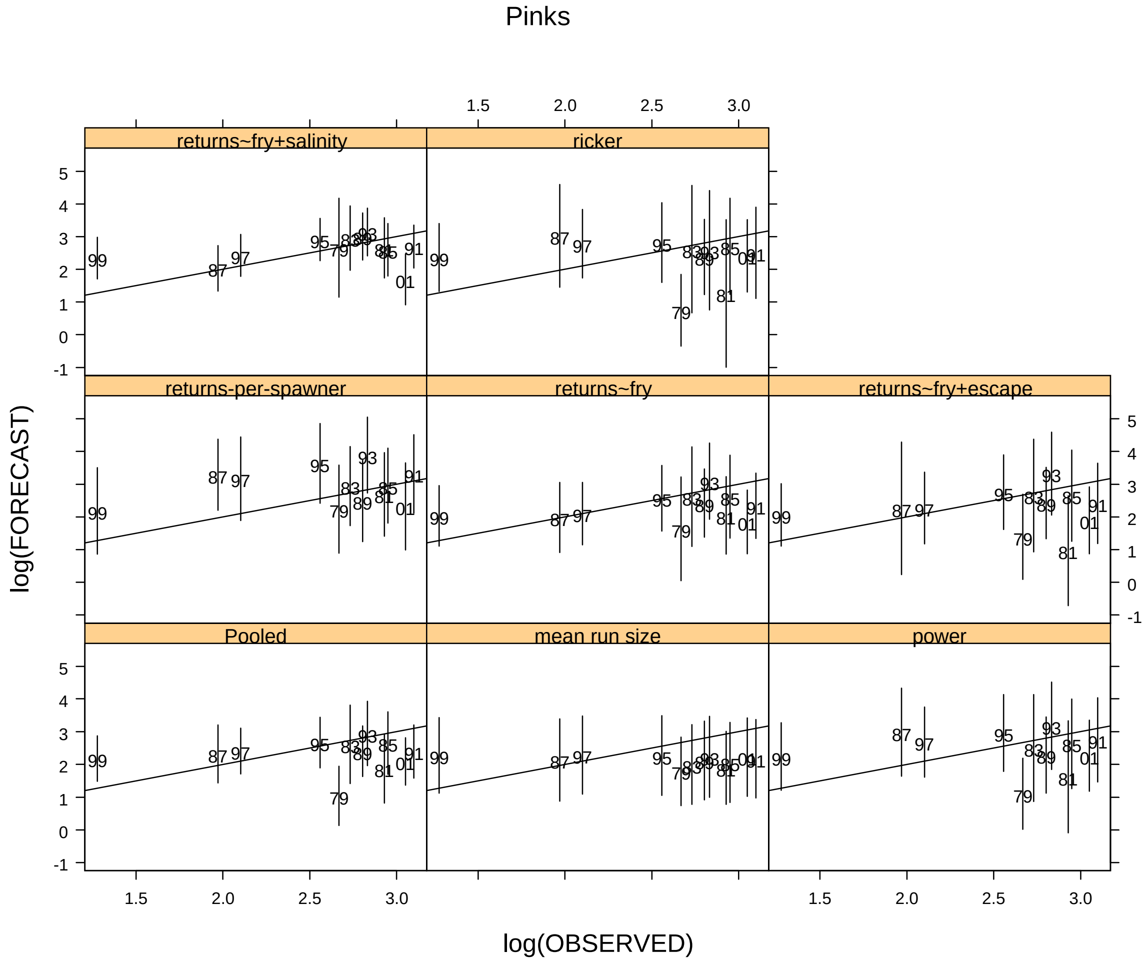

Figure 5. Comparison of estimated (observed) returns and retrospective forecast returns (millions ($\log_e$ scale)) of odd-year pink salmon for candidate models. Data points are median (50%) forecasts and are denoted by return year. Diagonal lines are 1:1 lines not regression lines. Error bars are 90% confidence intervals.

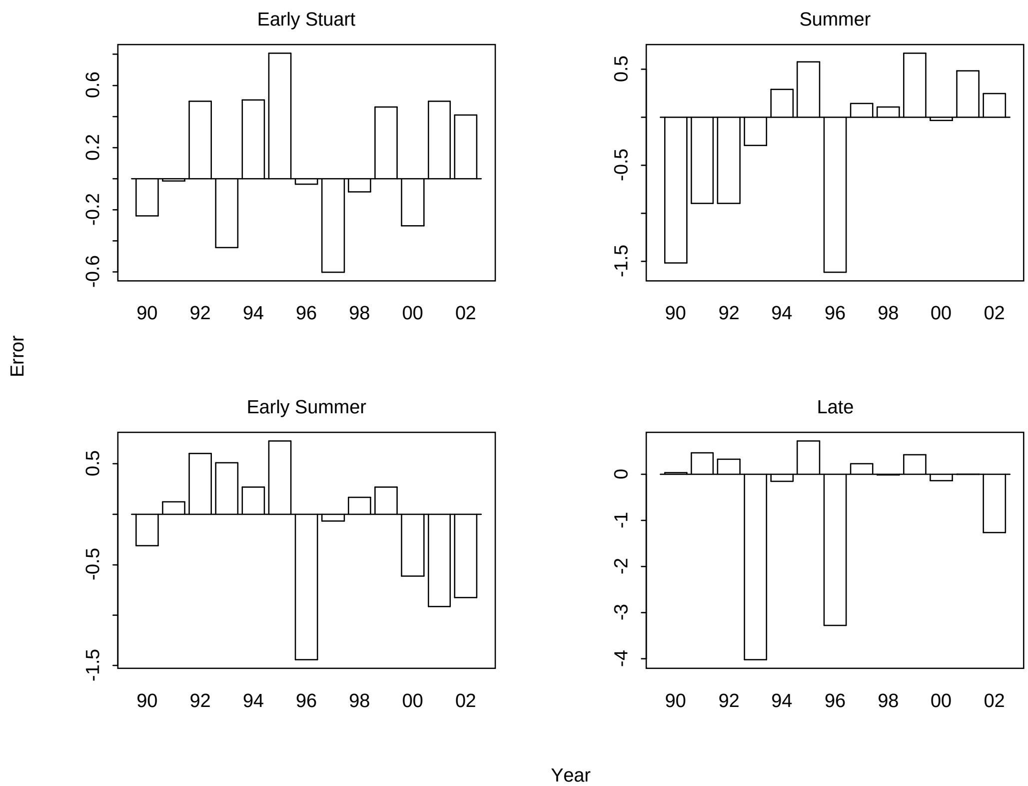

Figure 6. Proportional deviation of forecasts from observed run size by run-timing group for Fraser River sockeye (1990-2001). Deviations in 1990-2000 are based on post-season estimates of run size. Deviations in 2001 are based on final in-season estimates and are therefore very preliminary.

Early Stuart

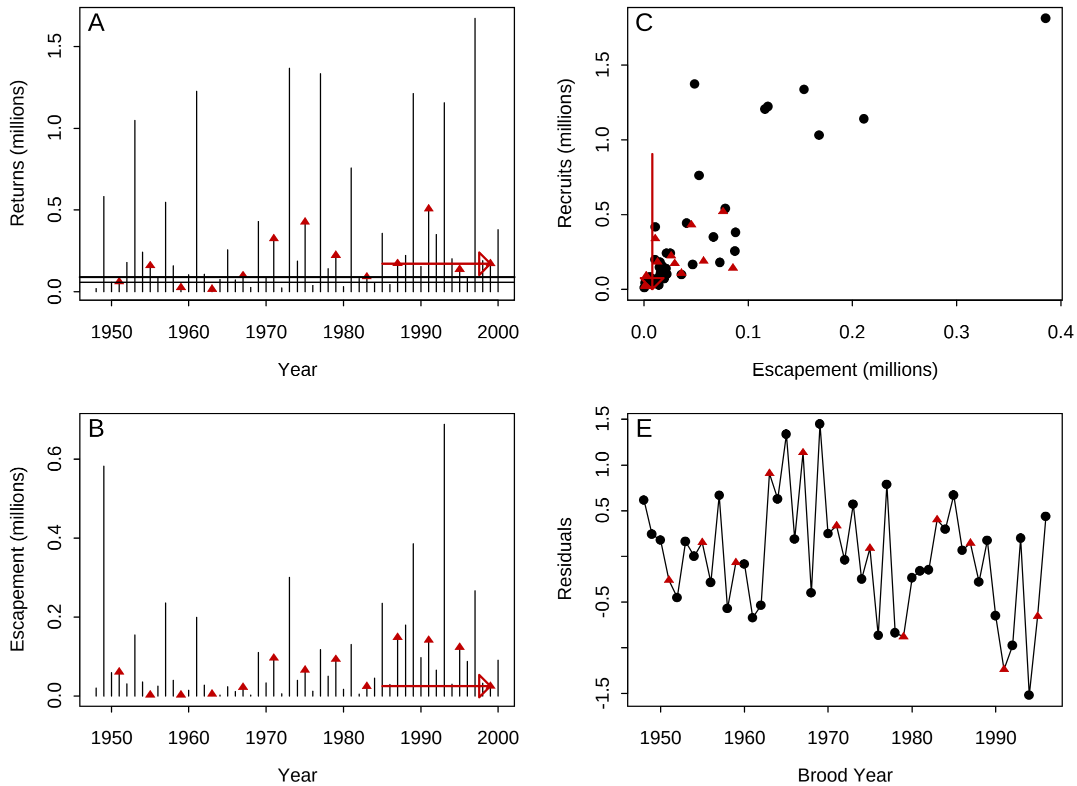

Figure 7. A) Trend in Early Stuart sockeye adult returns. Horizontal lines show the 2003 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, C) recruit-effective female escapement relationship and D) residual trend ($\log_e$ scale) from the fit of the power model to the relationship in C. Arrows depict 1999 data. Triangles (red) depict the 2003 cycle line data points.

Chilko

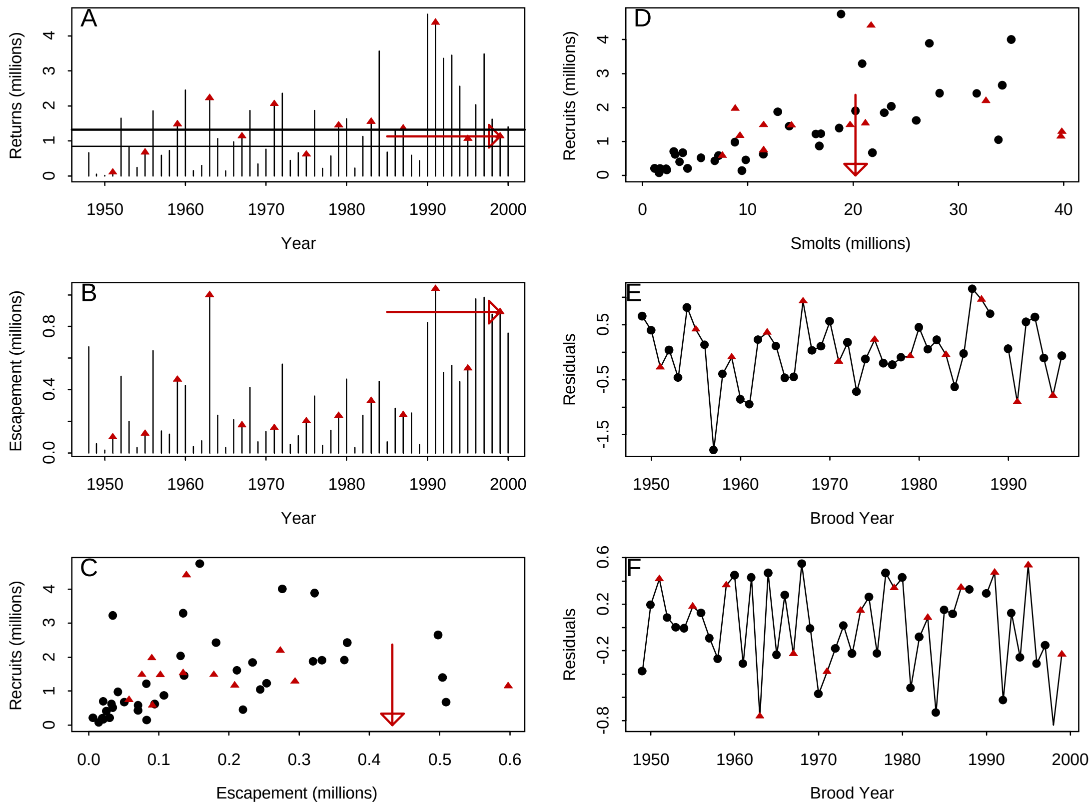

Figure 8. A) Trend in Chilko sockeye adult returns. Horizontal lines show the 2003 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, C) recruitment-effective female escapement relationship, D) recruitment - smolt relationship and E) residual trend (log_e scale) from the fit of power model to the relationship in D. Arrows depict 1999 data. Triangles (red) depict the 2003 cycle line data points.

Quesnel

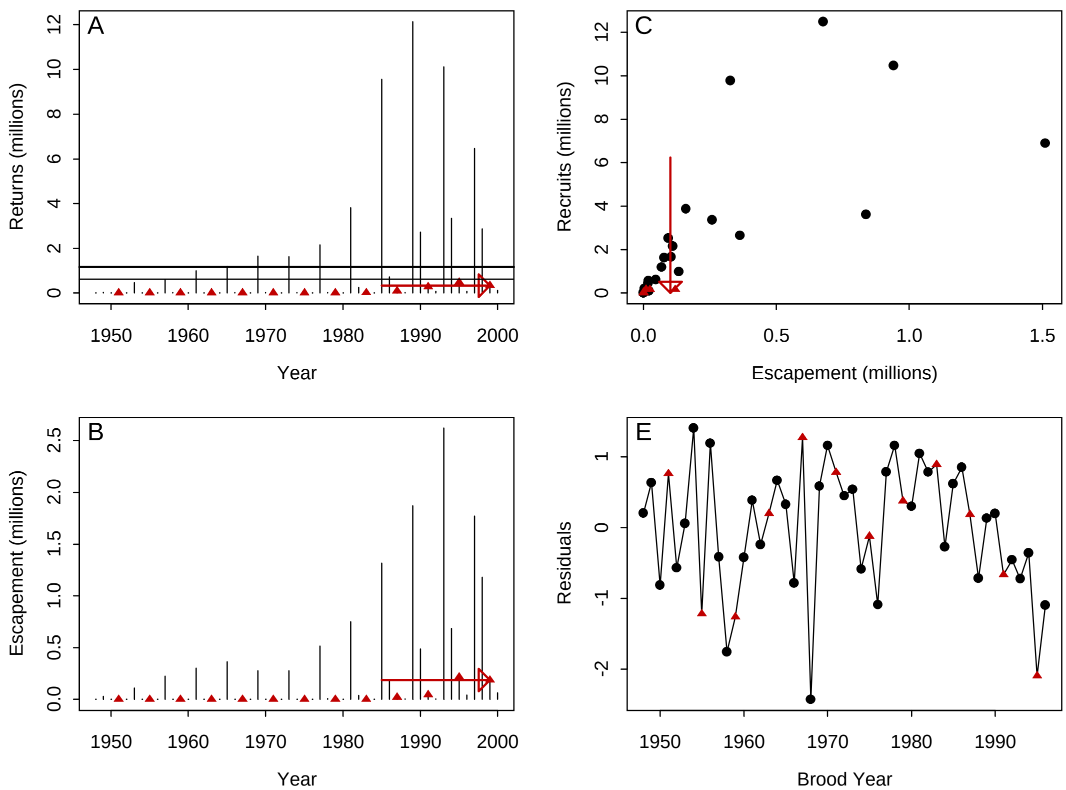

Figure 9. A) Trend in Quesnel sockeye adult returns. Horizontal lines show the 2003 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, C) recruit-effective female escapement relationship and D) residual trend ($\log_e$ scale) from the fit of the power model to the relationship in C. Arrows depict 1999 data. Triangles (red) depict the 2003 cycle line data points.

Late Shuswap

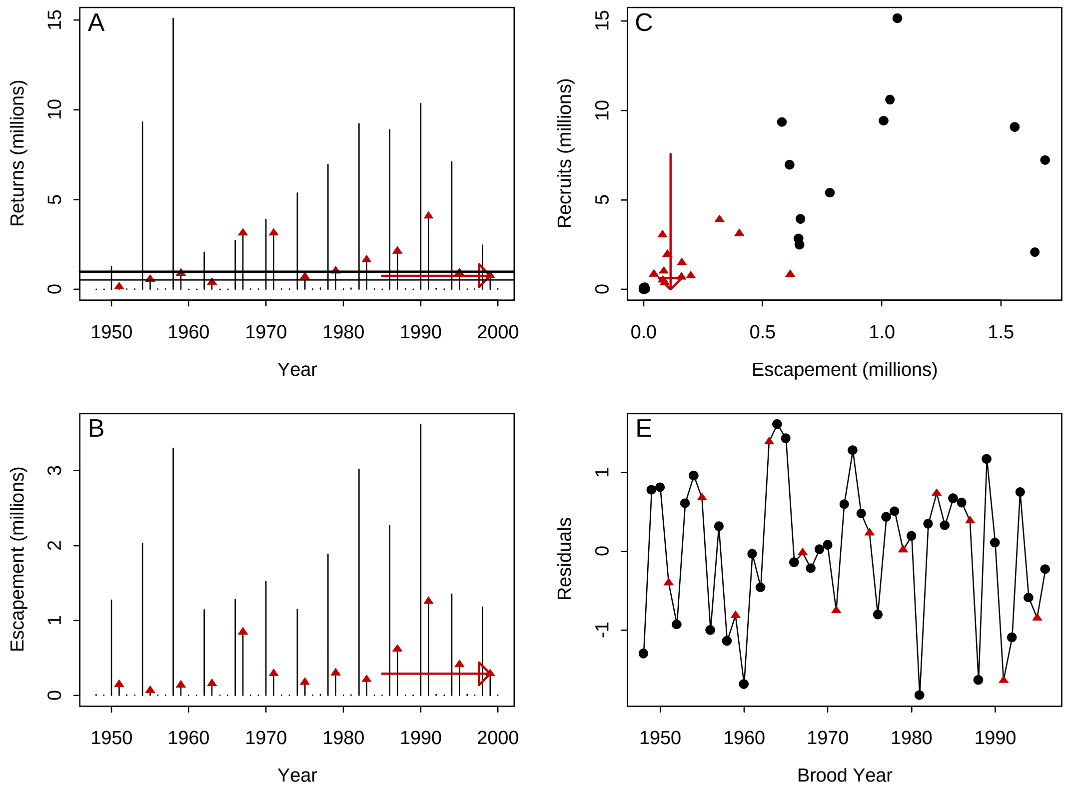

Figure 10. A) Trend in Late Shuswap sockeye adult returns. Horizontal lines show the 2003 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, C) recruit-effective female escapement relationship and D) residual trend ($\log_e$ scale) from the fit of the power model to the relationship in C. Arrows depict 1999 data. Triangles (red) depict the 2003 cycle line data points.

Pink

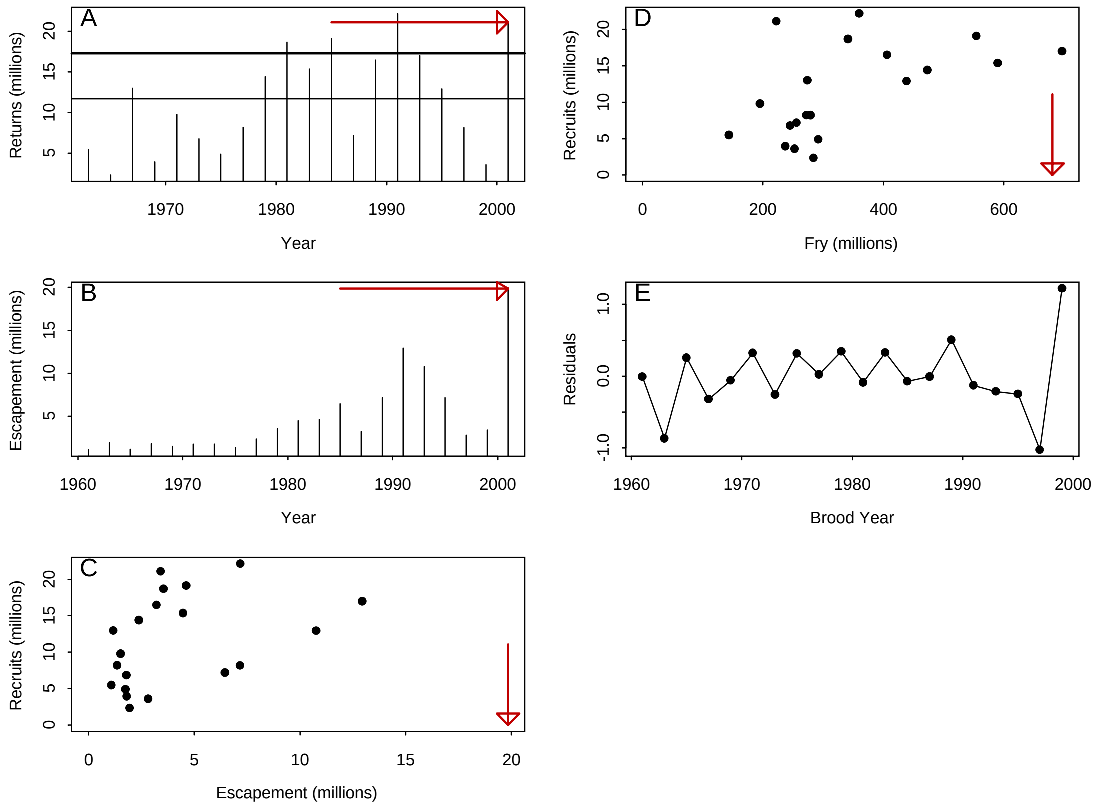

Figure 11. A) Trend in Fraser pink salmon returns. Horizontal lines show the 2003 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, C) recruit-effective female escapement relationship and D) residual trend ($\log_e$ scale) from the fit of the power model that includes salinity as a variable to explain environmental variation. Arrows depict 2001 data.

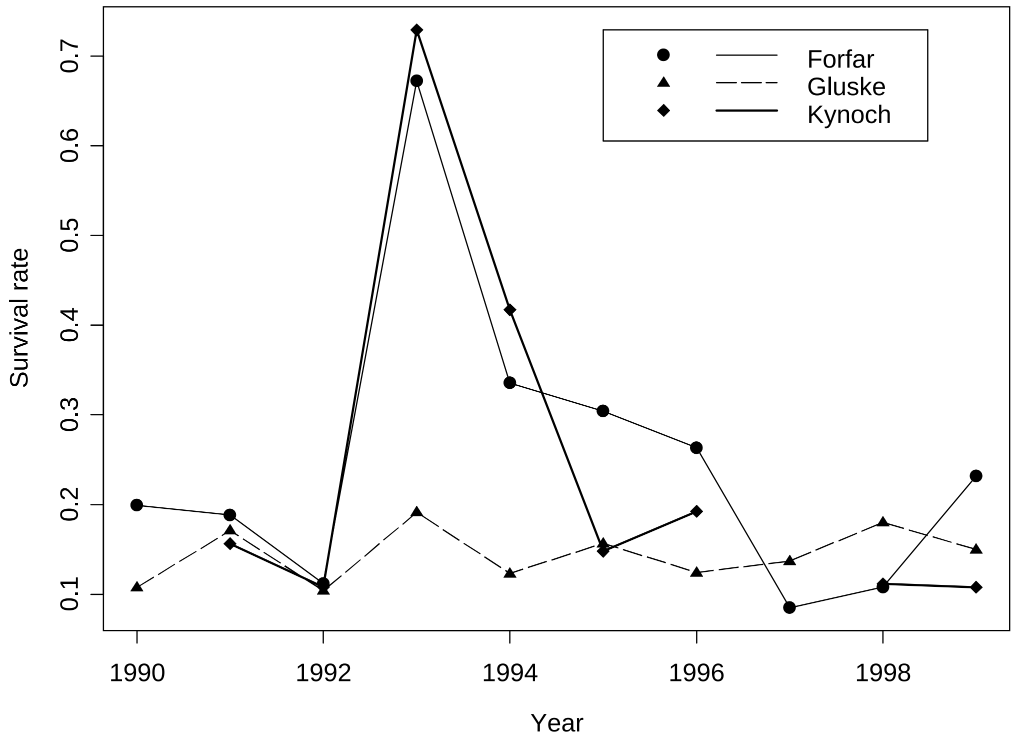

Figure. 12. Early Stuart fry survival rates by spawning site and brood year.

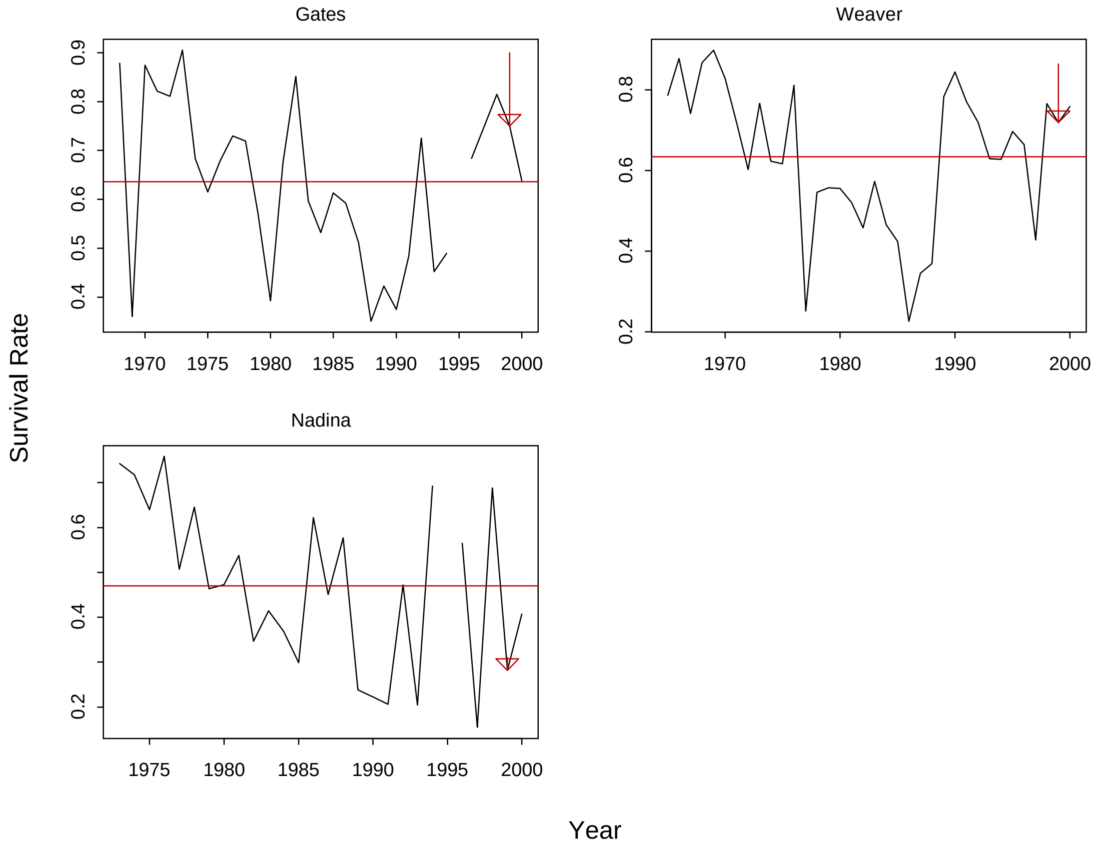

Figure 13. Sockeye egg-to-fry survival rates by brood year for Fraser River spawning channels. The arrow shows the 1999 brood survival. The horizontal line is the long-term mean.