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# Pre-season run size forecasts for Fraser River sockeye and pink salmon in 2001

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**Abstract**

Forecasts are made for each of 18 individual sockeye stocks and four timing groups and for Fraser River pink salmon, all spawning populations combined. Adult returns of sockeye to the Fraser River on the 2001 cycle line are the highest of the four cycle lines averaging 15.9 million/ year (1980-97) compared to 9.3 million/year for the same period on the other three cycle lines combined. 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 12.9 million fish (420,000 Early Stuart, 202,000 Early Summer, 11.7 million Summer and 528,000 Late run). The total forecast at the 50% probability level is nearly two times the forecast at the 75% level (6.8 million). Quesnel, Late Stuart and Chilko sockeye are the three largest stocks anticipated in 2001. The 2001 pink forecast at the 50% probability level is 5.5 million fish or about half of the long-term odd-year return mean of 10.5 million/yr. Migratory conditions in the Fraser River for the early-timed sockeye runs (i.e. Early Stuart and Early Summer sockeye) in brood-year 1997 were poor as a result of high river discharge rates. The effect of stress on survival of the progeny from those fish that spawned in 1997 is not known. Except for low egg-to-fry survival of Early Stuart sockeye at one of two sites sampled, there is no evidence of anomalous freshwater conditions that signal low freshwater survival in the egg-to-fry stages where data exist (Early Stuart and Quesnel). There is, however, inadequate sampling throughout the watershed to reliably predict freshwater survival. The recent intense El Ninos were associated with poor marine survival of Fraser sockeye in ocean entry years 1993 and 1997 and over-forecasts in return years 1995 and 1997. Oceanographic and meteorological conditions in the northeast Pacific returned to near normal values in 1999 (2001 age-4 ocean entry year) and there is little evidence based on oceanographic conditions that adverse marine sockeye survival conditions prevailed in ocean-entry-year 1999 of age-4 sockeye returning in 2001. Fraser River pinks returning to spawn in 2001 entered the ocean as fry in 2000. Based on preliminary information on oceanographic condition that prevailed in 2000, there is no evidence to indicate adverse survival conditions.

## Résumé

Des prévisions sont faites au sujet de chacun de 18 stocks de saumon rouge, de quatre groupes de géniteurs à montaison en année impaire et du saumon rose du Fraser, toutes populations de géniteurs confondues. Les remontes dans le Fraser de saumons rouges adultes du cycle de 2001 sont les plus fortes des quatre cycles, se chiffrant en moyenne à 15,9 millions d'individus par année (1980-1997) en comparaison de 9,3 millions par année pour le total des trois cycles pendant la même période. Les prévisions sont présentées à divers niveaux de probabilité d'atteinte des remontes déterminées selon le stock et le groupe de géniteurs à montaison en 2001. Selon les prévisions à un niveau de probabilité de 50 %, la remonte de saumon rouge, tous stocks confondus, se chiffrera à 12,9 millions d'individus (420 000 de montaison hâtive dans la rivière Stuart, 202 000 au début de l'été, 11,7 millions en été et 528 000 de montaison tardive). La prévision globale au niveau de probabilité de 50 % est presque deux fois la prévision au niveau de 75 % (6,8 millions de saumons). Les stocks de saumon rouge de la Quesnel, de la Chilko et à montaison tardive dans la Stuart sont les trois plus abondants stocks anticipés en 2001. La prévision, au niveau de probabilité de 50 %, de la remonte de saumon rose en 2001 la chiffre à 5,5 millions d'individus, soit environ la moitié de la moyenne à long terme de la remonte en années impaires de 10,5 millions d'individus par année. Les conditions dans le Fraser pour les saumons rouges à montaison hâtive (c.-à-d., à montaison hâtive dans la Stuart et à montaison au début de l'été) nés en 1997 étaient mauvaises en raison des débits élevés. L'effet du stress sur la survie de la progéniture des saumons qui ont frayé cette année-là est inconnu. Sauf pour un faible taux de survie des œufs jusqu'au stade de l'alevin chez le saumon rouge à montaison hâtive dans la Stuart à l'un des deux endroits échantillonnés, rien n'indique l'existence de conditions anormales en eau douce qui pourraient expliquer ce faible taux de survie dans les eaux douces pour lesquelles des données sont disponibles (saumon à montaison hâtive dans la Stuart et saumon de la Quesnel). L'échantillonnage à l'échelle du bassin versant étant inadéquat, il est impossible de prédire avec fiabilité le taux de survie en eau douce. Les récents El Niño, de très forte intensité, sont à l'origine d'un faible taux de survie en mer du saumon rouge du Fraser arrivé dans le milieu marin en 1993 et en 1997 et des prévisions trop optimistes des remontes en 1995 et en 1997. Les conditions océanographiques et météorologiques dans le Pacifique nord-est étant revenues à des valeurs presque normales en 1999, il n'y a pas lieu de croire que les conditions océanographiques ont nui à la survie en mer du saumon rouge qui y est arrivé en 1999 et qui est remonté en eau douce en 2001 à l'âge de 4 ans. Le saumon rose du Fraser revenant frayer en 2001 est descendu en mer en 2000 au stade d'alevin. D'après des données préliminaires sur les conditions océanographiques qui régnaient en 2000, il n'y a pas lieu de croire que les conditions en mer ont nui à sa survie.

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# 1. Introduction

Adult returns of sockeye to the Fraser River on the 2001 cycle line are the highest of the four cycle lines averaging 15.9 million/ year (1980-97) compared to 9.3 million for the same period on the other three cycle lines combined. Historically, the most abundant sockeye stocks on the 2001 cycle are Quesnel, Late Stuart and Chilko sockeye. Estimates of spawning escapement in brood year 1997 were 1.8 million Quesnel, 0.89 Chilko and 0.91 million Late Stuart sockeye.

Forecasts are made for each of 18 individual sockeye stocks and four timing groups and for Fraser River pink salmon, all spawning populations combined. Together the 18 sockeye stocks accounted for 93% of the estimated escapement to the Fraser River in 1997. Forecasts are not provided for a number of small stocks for which estimates of escapement are made but, for which return estimates are unavailable. These include Tesako, Momich/Cayenne, Nahatlatch, Harrison and Widgeon Slough sockeye. The escapement estimates for these stocks are based on visual counts and, therefore, are subject to relatively high measurement errors.

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. Estimates of age-3 jack or age-4 adult returns by stock in 2000 were not available at the time of this analysis to entertain sibling models. Regardless, sibling models are not considered suitable candidate models for forecasting 2001 returns and have recently performed poorly compared to other models. The proportion of age-3 jack returns have undergone dramatic long-term declines that can not be explained by changes in abundance or growth rates (Cass 1998).

# 2. Data sources and methods

Data sources and methods have been extensively reviewed by PSARC (Cass 2000, Cass 1999; Cass 1998; Cass 1997; Cass and Blackbourn 1996; Cass et al. 1995; Welch et al. 1994). Methods used to forecast 2001 returns are unchanged from previous reviews. Annual estimates of sockeye spawning escapement (1948-97) and returns by age class (1952-1999) by stock are the primary data used to forecast Fraser sockeye. These data are in a Microsoft Access database available from the Pacific Salmon Commission. The main explanatory variable used to forecast the return of age-4 sockeye in 2001 is the spawning escapement (effective females) in 1997. The escapement in 1996 is the main explanator of age-5 returns in 2001. Effective females are estimates of the number of spawning females contributing to the spawning population based on sampling for potential by egg deposition. The stock-specific catch component of run size (run size = catch + escapement) is estimated by the Pacific Salmon Commission (PSC). Other data include Quesnel Lake fry estimates, Chilko age-1 smolts, spawning channel fry data for Nadina, Gates and Weaver sockeye, downstream fry data for three spawning locations (Forfar, Gluske and Kynoch creeks), of Early Stuart sockeye.

For Quesnel Lake sockeye, in-lake juvenile abundance and size data based on estimates made for a 10-year period (1977-97 brood years) of dominant and sub-dominant cycle line data (Jeremy Hume, Fisheries and Oceans Canada, personal communication) was used to evaluate the utility of juvenile-return relationships for forecasting returns in 2001. Fry abundance estimates are made each year from surveys in the summer (late summer or August) and fall (October- early November). Details on data collection and analytical methods are in Hume et al. (1996).

The Early Stuart fry data are collected by DFO but methods and estimation procedures remain undocumented (Tracy Cone, Fisheries and Oceans Canada, personal communication). The relationship between Early Stuart escapement and fry abundance (1990-99 brood years) are evaluated to assess egg-to-fry survival and the potential impact on 2001 recruitment.

In previous forecasts of Early Stuart sockeye, two components (Driftwood River and non-Driftwood River) were analysed separately based on escapement – return relationships in addition to all substocks combined. Driftwood River sockeye are highly cyclic with highest returns on the 2001 cycle. The abundance of Driftwood River sockeye on the other three cycle lines is negligible. Non-Driftwood sockeye spawn in numerous small spawning tributaries of Takla and Trembluer Lakes and do not exhibit pronounced cyclic behaviour. The returns to the Driftwood and non-Driftwood systems are not estimated directly in-season because catch composition of the two groups are not estimated separately. For purposes of this analysis, the total returns were estimated by apportioning the total Early Stuart returns according to the corresponding annual escapement estimates for the non-Driftwood and Driftwood systems. This method assumes the catch is proportional to the escapements of the two sub-systems. Sockeye escapements for Driftwood and non-Driftwood components are those compiled by Fisheries and Oceans Canada in an Access database (Tracy Cone, Fisheries and Oceans Canada, personal communication). The effect of separating Early Stuart sockeye into two components on forecast performance is compared to the performance based on Early Stuart forecasts with all substocks combined.

In recent years, anomalous Fraser River flow conditions have been associated with large discrepancies between estimated returns at Mission and the estimated up-river catch plus spawning escapement for some run timing groups. In 1994 and 1997 the discrepancies were particularly large for Early Stuart sockeye with 63% and 41% more sockeye respectively estimated at Mission that reported up-river (Anon. 1997; 1999). The discrepancies for other timing groups were much less. Up-river estimates of Early Summer and Summer run sockeye in 1994, were respectively 11% and 7% less than the corresponding Mission estimates. The only timing group with reported discrepancies in 1997 other than Early Stuart sockeye is the Early Summer run with 12% more sockeye reported at Mission (Anon. 1999). Since 1995, high in-river pre-spawning mortality of Late run sockeye are inferred from apparent discrepancies between inseason estimates, abnormal migratory timing and the unusual presence of carcasses of Late run sockeye. The amount of pre-spawning mortality of Late run sockeye is highly uncertain but estimates, such as they are, have increased each year. The data used in the forecasts presented here include the “missing” fraction of fish. The effect of excluding the “missing” fish from the Early Stuart data are discussed in section 5.1. The effect of excluding “missing” fish on forecasts of individual Early Summer and Late run stocks is not assessed. For Early Summer stocks the overall discrepancies are low. For individual Early Summer and Late run stocks the discrepancies are difficult to estimate.

For Chilko sockeye additional environmental variables were added to represent precipitation rates and ocean salinity in the smolt year that were shown to explain part of the variation in age-4 Chilko returns in previous forecasts (Cass, 2000). The precipitation data is the average total monthly precipitation in two months (September and October) of the ocean-entry year from two stations: Langara Island, in north-western British Columbia, and Annette Island in southern southeast Alaska. Langara Island precipitation data is published in monthly climate summaries published by the Atmospheric Environment Service of Environment Canada. Precipitation data from Annette are obtained from "Annual Summaries of Climatological Data for the State of Alaska" published by the U.S. National Environmental Satellite, Data and Information Service and obtained from the National Climatic Data Center (NCDC), Asheville, North Carolina. The salinity data are the mean May-June estimates measured at Entrance Island in the ocean-entry year.

The Birkenhead River is a coastal system subject to high flow rates. High river discharge during egg-to-fry development has been associated with low recruits-per-spawner of Birkenhead River sockeye. 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 and at the Nahatlatch River. 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. Data for the Nahatlatch R., located in an adjacent watershed, are available for 1973 to the present. Discharge rates are provided on CD-ROM format for years to 1990 by Commercial Services Division, Monitoring and Systems Branch, Environment Canada. Additional data were provided by Environment Canada and the Pacific Salmon Commission (PSC). I used the maximum discharge (daily) recorded between 25-Sep (long term mean peak spawning date) and 28-Feb as a measure of river flow effects on survival.

Estimates of Fraser pink escapements and returns are available for odd-number years (brood years 1957-97). Spawning escapement estimates are based on mark-recapture experiments conducted by the International Pacific Salmon Fisheries Commission (1957-85) and DFO (1987-99) (see Cass and Whitehouse 1993; Cass et al. 1995). Pink fry abundance estimated at Mission during the downstream migration period combined with salinity data have been the best predictors of Fraser River pink salmon. Current methods for estimating fry abundance are consistent with procedures developed in 1962 (Vernon, 1966). The salinity data is the average of data from i) July through August and ii) July through September of the fry year measured at Amphitrite Point near Barkley Sound and at Race Rocks in eastern Juan de Fuca Strait.

## 3. Forecast models

Forecast models used in the present analysis are as follows:

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

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

estimated using the linear regression :

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

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

*2) Non-linear (power) model:*

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

estimated by:

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

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

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

*4) Juvenile models:*

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

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

was fit to adult returns at age i and juvenile data $N$ at generation t.

In addition, the forecast performance of escapement (log transformed) when added as a second explanatory variable in a multiple regression was also assessed.

*5) Pooled models:*

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

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

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:

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

## 4. Model performance

Model performance was evaluated in a retrospective analysis by comparing run size forecasts to estimated (observed) run sizes for years that estimates are available. Starting with the most recent year that estimated returns are available (1999), a retrospective forecast for that year was made from the time series of explanatory variables by leaving out the most recent return data. In this way, retrospective forecasts for each year are based only on the time series available prior to the year being forecast. Retrospective comparisons were made for return years 1984-1999 (brood years 1980-1995). To retrospectively compare the Early Stuart forecast performance based on separate forecasts for Driftwood River and non-Driftwood sub-stocks with the performance based on the total Early Stuart stock, all systems combined, the annual forecasts for the Driftwood and non-Driftwood sub-stocks were summed before performing the retrospective analysis.

The retrospective comparison of forecasting models for age-4 Early Stuart, Late Stuart, Quesnel, Chilko sockeye and Fraser River pinks 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% confidence 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.

Except for the forecasts based on the mean annual returns or the cycle line mean returns, which retrospectively performed very poorly, the relationships between the forecast and observed age-4 returns reveal similar patterns irrespective of the forecast model.

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

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

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

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

Retrospective performance could not be evaluated for Early Stuart or Quesnel fry data because the time series is too short. Theoretically, juvenile data should improve forecasts because they eliminate uncertainty in predictions caused by variable egg-to-fry survival. Unfortunately, in addition to the short time series of juvenile data, it is unclear how representative the Early Stuart fry experiments conducted at two of approximately 30 spawning systems are of the entire Early Stuart stock. Results of analysis of juvenile data for these stocks are discussed in the following section.

## 5. 2001 Forecasts

Data trends and forecast relationships for sockeye are compared in Figures 6 - 23 for each stock that forecasts are produced. Forecasts are provided at various probability levels of achieving specified run sizes by stock and run-timing group (Table 1). The forecast of sockeye at the 50% level for all stocks combined is 12.9 million fish (420,000 Early Stuart, 207,000 Early Summer, 11.7 million Summer and 530,000 Late run). This forecast compares to an average return on the 2001 cycle of 15.9 million sockeye/yr (1980-97). The Summer Run forecast accounts for 91% of the total sockeye forecast. The total forecast at the 50% probability level is nearly two fold times the forecast at the 75% level (6.8 million). For Quesnel and Late Stuart, the two largest stocks anticipated in 2001, the 50% forecast is 1.9 times the 75% level for Quesnel sockeye (7.8 versus 4.1 million) and 2.3 times for Late Stuart sockeye (1.9 million versus 800,000).

Annual differences between estimated returns and forecast returns (point estimate) during 1990-99 were large (Fig. 25). The mean absolute deviation was ± 58% for all timing groups combined. The error for individual timing groups was of similar magnitude: ±49% for Early Stuart, ±48% for Early Summers, ±72% for Summer and ±60% for late runs. Forecast errors in

1999 were particularly large and difficult to evaluate because of the "missing" fish issue. When missing fish are included in the comparison for 1999, the forecast was 85% more than the estimated run for Early Stuart, 36% more for Early Summer, 197% more for Summers, 134% more for Lates and 134% for all stocks combined. The deviation for 6 of the 18 stock comparisons were outside the 90% confidence intervals for the "best" forecast model in 1999. When missing fish are excluded from the analysis the forecast error is larger for each timing group and the estimated return in 1999 was outside the 90% confidence intervals in 13 of the 18 stock comparisons.

Data trends and forecast relationships for pink salmon is shown in Figure 24.

### 5.1 Early Stuart sockeye

The Early Stuart forecast of 420,000 at the 50% level is low relative to historical returns on this cycle (1955-1997 cycle mean = 920,000) as a result of low spawning escapement for the 1997 brood year. Escapement to the Driftwood River in 1997 was low compared to recent cycle line escapements. Escapements to the Driftwood River on the 2001 cycle line increased from 47,000 sockeye in 1981 to 408,000 in 1993 but dropped to 20,000 in 1997. The 50% forecast is also lower than anticipated based on the total number of spawners to the Early Stuart system in 1997. This is because the female escapement was only 33% of the male plus female escapement. The effective female escapement was 81% of the total escapement or 27% of the male plus females escapement.

Fraser River discharge in 1997 was the second highest on record and is associated with large negative discrepancies between estimates of spawning escapement and escapements at Mission after accounting for in-river catch. High in-river mortality of Early Stuart sockeye is hypothesized as the reason for the large discrepancy between Mission and up-river estimates. The impact of potential stresses on egg survival caused by adverse in-river migratory conditions is unknown. Estimates of egg-to-fry survival measured at Forfar and Gluske Creeks are inconclusive (Fig. 26). The survival estimates for Forfar was 8.5% in 1997 compared to the 1990-99 mean of 25.0%. The survival at Gluske was near normal at 13.7% compared to a mean of 14.5%.

The forecast regressions used in the forecasts of Early Stuart sockeye include estimates of missing fish reported in 1994 and 1997. Because it is not possible to partition measurement errors and en-route mortality losses, the question of whether to include or exclude the "missing" fish in the forecast regressions cannot be answered. If the discrepancy between Mission and up-river estimates is assumed to be entirely measurement error, then the 1994 and 1997 "missing" fish should be excluded from the data. A forecast that excludes the missing fish reduces the 50% forecasts by 8%, which is low given the overall uncertainty in the forecast.

The sum of forecasts for Driftwood and non-Driftwood components of Early Stuart returns of 427,000 sockeye at the 50% probability was very near the forecast of 420,000 sockeye based on the forecast without separating components of the Early Stuart stock. This is not surprising because the escapement to the Driftwood River in 1997 was anomolously low compared to the non-Driftwood component. The forecast performance of the two methods was also very similar. For these reasons, and the potential errors incurred by separating returns proportionally based on escapements, the recommended forecast is the forecast based on data that is not separated by substock.

### 5.2 Early Summer Run sockeye

The forecast of Early Summer run sockeye at the 50% probability level is 207,000 sockeye or 36% below the long-term mean return for the 2001 cycle line (Table 1). Except for North Thompson River sockeye (Raft River and Fennell Creek), the 50% forecasts are all below the long-term cycle line mean mainly as a result of low spawning escapements in 1997. Nadina River and Seymour River sockeye forecasts are particularly low compared to the cycle line mean. The 59% forecast for the Nadina River, including the Nadina channel, is 12,000 sockeye compared to the cycle line mean of 82,000 sockeye. The best performing forecast model for Nadina sockeye is the spawning channel fry- total return relationship. The estimate of channel fry in brood year 1997 was a record low (1973-97). Seymour River forecasts of 14,000 sockeye is nearly half of the long-term cycle line mean.

### 5.3 Summer Run sockeye

Forecasts at the 50% probability level of summer run stocks are all above the long-term cycle line mean (Table 1). The highly cyclic Quesnel and Late Stuart stocks have rebuild on the 2001 dominant cycle particularly since the 1980s. Returns of Chilko sockeye have increased on all cycle lines over the same period. Stellako sockeye returns have remained relatively stable.

The 2001 forecast of Quesnel sockeye at the 50% level of 7.8 million sockeye accounts for 67% of the Summer Run forecast at the 50% probability level. The 50% forecast of Late Stuart and Chilko sockeye is 1.9 and 1.6 million fish respectively or 16% and 14% of the Summer run forecast. The forecast of Stellako sockeye is 420,000 sockeye or 3.6% of the Summer run.

As mentioned, the forecasts of Quesnel and Lake Stuart sockeye, the stocks with the largest 2001 forecast, are particularly uncertain. The adult return - fall fry acoustic estimates is consistent with the return – escapement relationship for Quesnel Lake sockeye (Fig. 27). The predicted return in 2001 based on the return – fry relationship is 7.3 million sockeye compared to the 7.8 million sockeye forecast based on the return – escapement relationship.

### 5.4 Late Run sockeye

Except for Portage Creek sockeye, the forecasts at the 50% probability level are below the long-term cycle line mean (Table 1). The 2001 forecasts of Late Shuswap and Cultus Lake sockeye are particularly low and reflect low spawning escapements in brood year 1997. Late Shuswap returns on the 2001 cycle line are on average the lowest of the four cycle lines. The forecast of Late Shuswap sockeye at the 50% level is 6,000 fish compared to a cycle line mean of 29,000 sockeye/yr. The lower than average anticipated return in 2001 of Late Shuswap sockeye is important when considering management action of late run sockeye. The late run has experienced anomolously high in-river pre-spawning mortality associated with the unexplained early entry of the Late run into the Fraser River each year beginning in 1995. Cultus Lake sockeye returns and escapement have undergone a pronounced decline since the 1960s. The forecast of Cultus Lake sockeye at the 50% level is 800 sockeye or well below the long-term cycle line mean of 27,000 sockeye/yr.

Maximum daily discharge rates for the Lillooet River in 1997 were at high levels during the egg-to-fry stage (Fig. 28). Although discharge rates since 1948 are often associated with low negative residuals for Birkenhead River sockeye based on power and recruits-per-spawner models, the relationship is not particularly revealing. A large number of years with low discharge levels are also associated with negative residuals, therefore, the premise that river discharge explains variation in the survival of Birkenhead sockeye is not supported by the data explored in this analysis.

### 5.5 Pink salmon

The forecast model with the best RMSE performance is the multiple regression that includes fry abundance estimates and mean salinity measured at Amphitrite Point and Race Rocks in the ocean-entry-year as the explanatory variables. The 2001 pink forecast at the 50% probability level is 5.5 million fish or about half of the long-term odd-year return of 10.5 million/yr (Table 1). Annual return estimates of Fraser River pink salmon have declined from a peak of 23 million fish in 1991 to 3.6 million in 1999. Spawning escapement estimates declined from 12 million to 3.4 million fish over the same period.

## 6. Conclusion

Forecasts are associated with high uncertainty (Table 1; Fig 1-5; Fig. 25). Although forecasts are presented as probability distributions, they are based on models that assume average survival conditions. Improvements to pre-season abundance forecasts are unlikely without a better understanding of environmental factors affecting survival. Except for Chilko sockeye, where environmental variables have partially reduced forecast error in years prior to1995, the inclusion of environmental variable has not been useful explanators of sockeye run size (Blackbourn 1992). Reliability of forecasts ultimately depend on survival conditions that prevail in both freshwater and the marine environment. Migratory conditions in the Fraser River for the early-timed sockeye runs in 1997 (i.e. Early Stuart and Early Summer sockeye) were poor as a result of high river discharge rates. The effect of stress on survival of the progeny from those fish that spawned in 1997 is not known. Except for low egg-to-fry survival of Early Stuart sockeye at one site (Forfar Creek), there is no evidence of anomalous freshwater conditions that signal low freshwater survival in the egg-to-fry stages where data exist (Early Stuart and Quesnel). There is, however, inadequate sampling throughout the watershed to reliably predict freshwater survival effects from the adverse conditions in the Fraser River in 1997.

The recent intense El Ninos were associated with poor marine survival of Fraser sockeye in ocean entry years 1993 and 1997 and over-forecasts in return years 1995 and 1997. Oceanographic and meteorological conditions in the northeast Pacific returned to near normal values in 1999 (2001 age-4 ocean entry year) (Anon. 2000). Off Vancouver Island, water temperatures were normal to slightly below normal and salinity was near normal or slightly above normal. Normal upwelling condition prevailed in coastal areas in the summer of 1999. Concentrations of all major zooplankton in 1999 shifted to taxa representative of northern species compared to the period prior to 1998 associated with above average ocean temperatures and southern zooplankton species. There is little evidence based on oceanographic conditions in 1999 that adverse sockeye survival conditions prevailed during the spring out-migration of Fraser River sockeye smolts.

Fraser River pinks returning to spawn in 2001 entered the ocean as fry in 2000. Based on preliminary information on oceanographic conditions that prevailed in 2000, there is no evidence to indicate adverse survival conditions.

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Table 1. Pre-season sockeye and pink salmon run size forecasts for 2001 by stock/timing group and probability level.

| stock/timing group | mean run size[b] all cycles | mean run size[b] 2001 cycle | forecast model[c] | Probability of Achieving Specified Run Sizes[a] 25% | 50% | 75% | 80% | 90% |
|---|---|---|---|---|---|---|---|---|
| **Early Stuart** | **341,000** | **918,000** | Power | **682,000** | **420,000** | **258,000** | **229,000** | **167,000** |
| **Early Summer** | **410,000** | **322,000** | | **392,000** | **202,000** | **107,000** | **89,500** | **61,000** |
| Fennell | 20,000 | 14,000 | Power | 50,000 | 26,000 | 14,000 | 12,000 | 8,000 |
| Bowron | 44,000 | 28,000 | Power | 39,000 | 22,000 | 13,000 | 11,000 | 8,000 |
| Raft | 25,000 | 19,000 | Power | 42,000 | 21,000 | 11,000 | 9,000 | 6,000 |
| Gates | 44,000 | 40,000 | Power | 62,000 | 32,000 | 17,000 | 14,000 | 10,000 |
| Nadina | 45,000 | 82,000 | Fry | 23,000 | 12,000 | 6,000 | 5,000 | 3,000 |
| Pitt | 67,000 | 89,000 | Power | 113,000 | 62,000 | 34,000 | 29,000 | 20,000 |
| Seymour | 128,000 | 27,000 | R/S | 16,000 | 9,000 | 5,000 | 4,500 | 3,000 |
| Scotch | 37,000 | 23,000 | R/S | 47,000 | 18,000 | 7,000 | 5,000 | 3,000 |
| **Mid Summers** | **3,653,000** | **6,885,000** | | **22,560,000** | **11,714,000** | **6,159,000** | **5,262,000** | **3,489,000** |
| Chilko | 1,418,000 | 861,000 | smolt | 2,465,000 | 1,578,000 | 1,010,000 | 904,000 | 676,000 |
| Quesnel | 1,219,000 | 3,908,000 | Power | 14,974,000 | 7,839,000 | 4,104,000 | 3,496,000 | 2,292,000 |
| Stellako | 454,000 | 245,000 | Ricker | 733,000 | 424,000 | 245,000 | 214,000 | 150,000 |
| Late Stuart | 562,000 | 1,871,000 | Ricker | 4,388,000 | 1,874,000 | 800,000 | 648,000 | 372,000 |
| **Late Summer** | **2,852,000** | **943,000** | | **1,026,000** | **528,000** | **273,000** | **232,000** | **152,000** |
| Birkenhead | 375,000 | 324,000 | Power | 444,000 | 247,000 | 138,000 | 119,000 | 81,000 |
| Late Shuswap | 2,061,000 | 29,000 | Ricker | 11,000 | 6,000 | 3,000 | 2,000 | 2,000 |
| Cultus | 64,000 | 27,000 | Power | 2,000 | 800 | 400 | 300 | 200 |
| Portage | 40,000 | 43,000 | R/S | 189,000 | 86,000 | 40,000 | 33,000 | 20,000 |
| Weaver | 312,000 | 520,000 | R/S | 382,000 | 188,000 | 93,000 | 78,000 | 49,000 |
| **TOTAL** | **7,256,000** | **9,068,000** | | **24,660,000** | **12,864,000** | **6,797,000** | **5,812,500** | **3,869,000** |
| **PINKS** | **-** | **10,467,000** | fry-salinity | **7,384,000** | **5,468,000** | **4,049,000** | **3,759,000** | **3,090,000** |

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

[b] mean run sizes are computed over the range of the time series except for stocks with spawning channel supplemention. Channel startup years were Nadina (1968), Gates (1973) and Weaver (1965).

[c] see text for model descriptions.

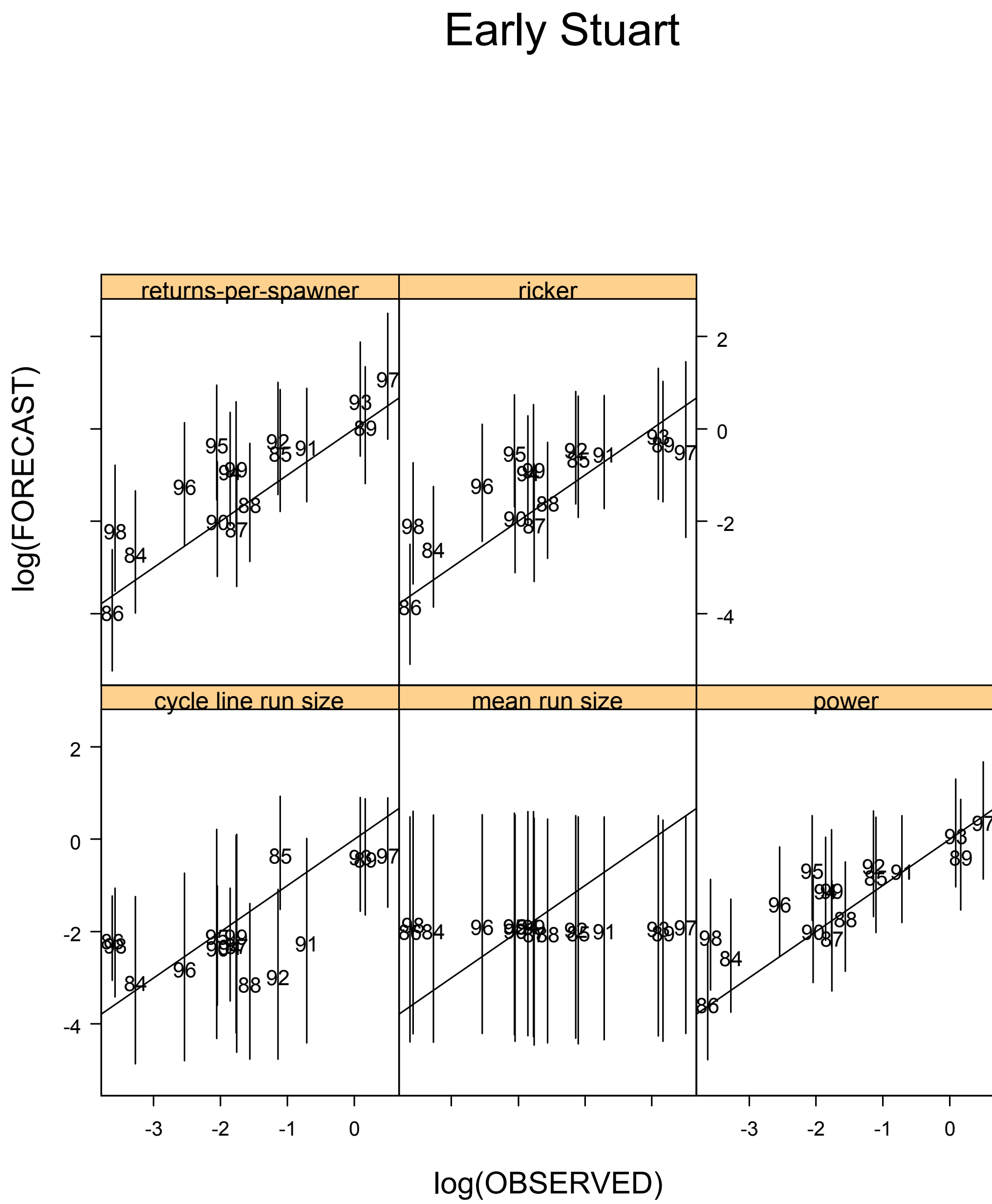


Figure 1. Comparison of estimated (observed) returns and retrospective run size forecasts (millions ($\log_e$ scale)) of age-4 Early Stuart sockeye by model. Data points are median (50%) forecasts and are denoted by return year. Diagonal lines are 1:1 lines not regression lines. Error bars are 90% confidence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

Late Stuart

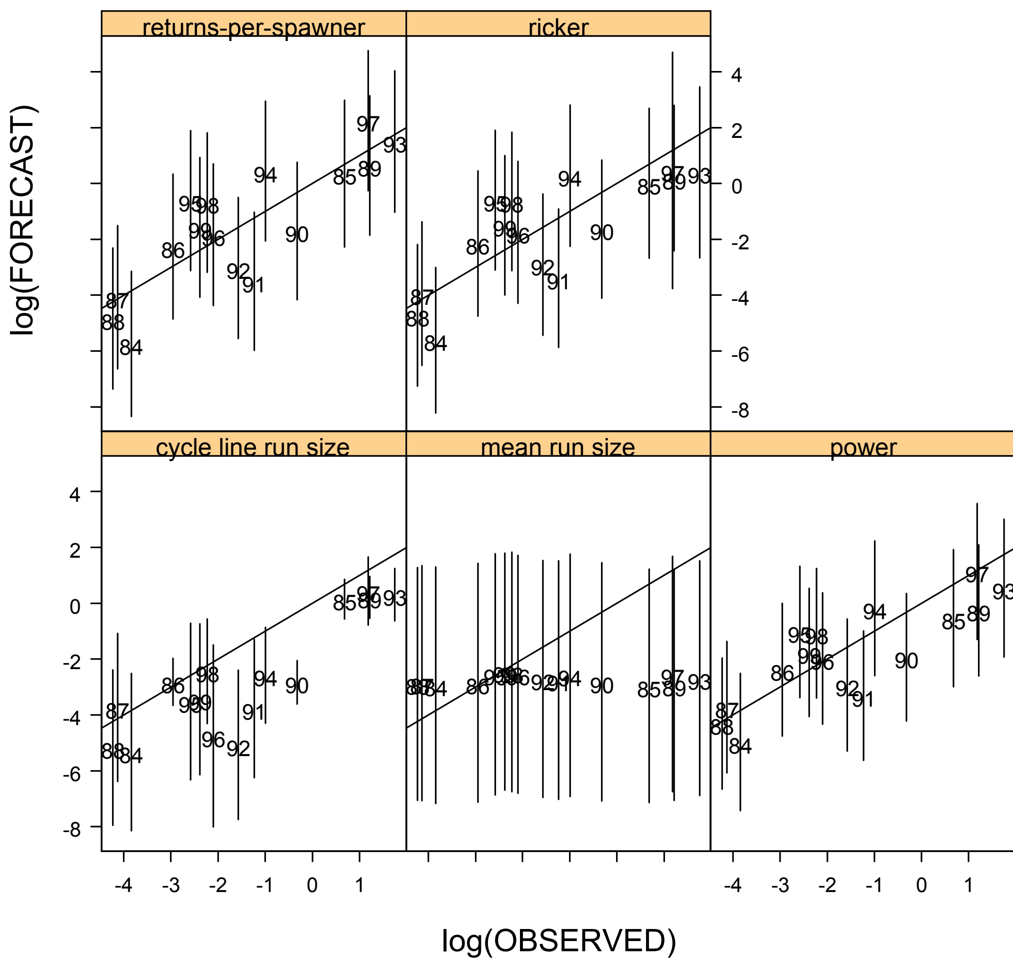


Figure 2. Comparison of estimated (observed) returns and retrospective run size forecasts (millions ($\log_e$ scale)) of age-4 Late Stuart sockeye by model. Data points are median (50%) forecasts and are denoted by return year. Diagonal lines are 1:1 lines not regression lines. Error bars are 90% confidence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

Quesnel

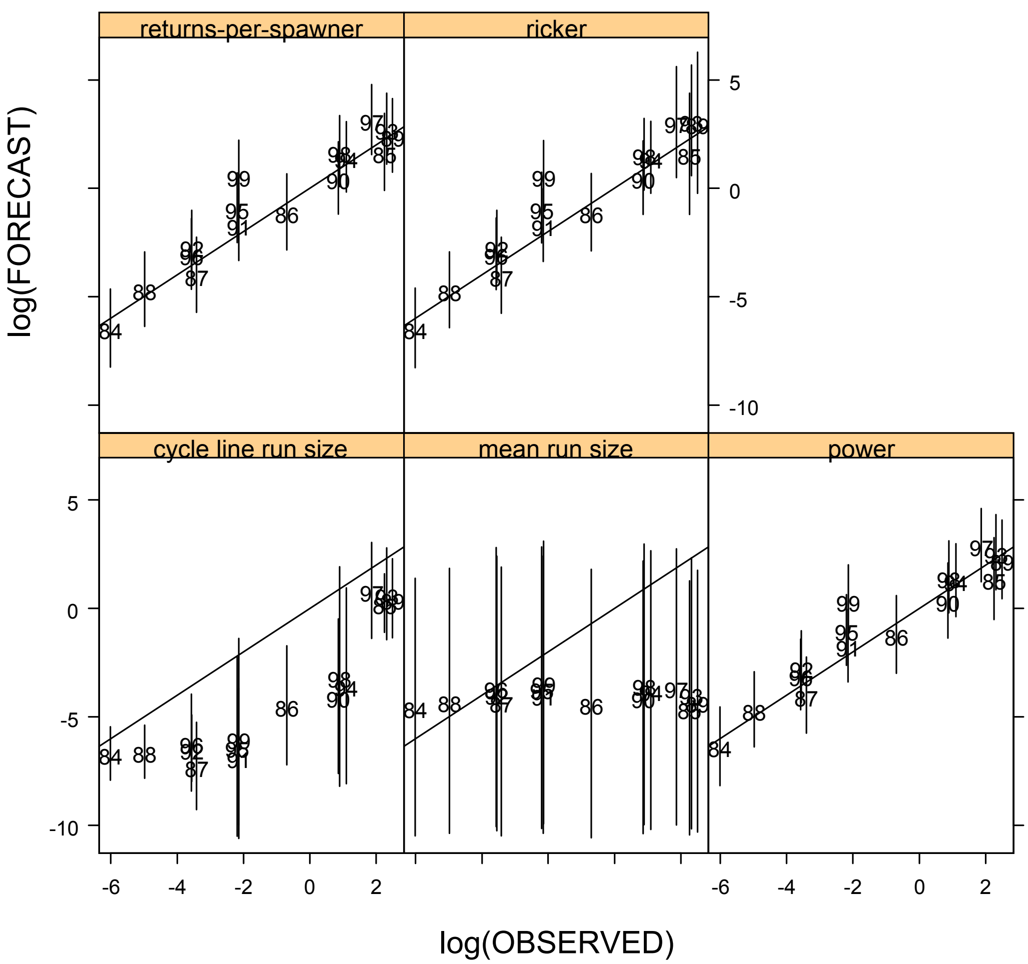


Figure 3. Comparison of estimated (observed) returns and retrospective run size forecasts (millions ($\log_e$ scale)) of age-4 Quesnel sockeye by model. Data points are median (50%) forecasts and are denoted by return year. Diagonal lines are 1:1 lines not regression lines. Error bars are 90% confidence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

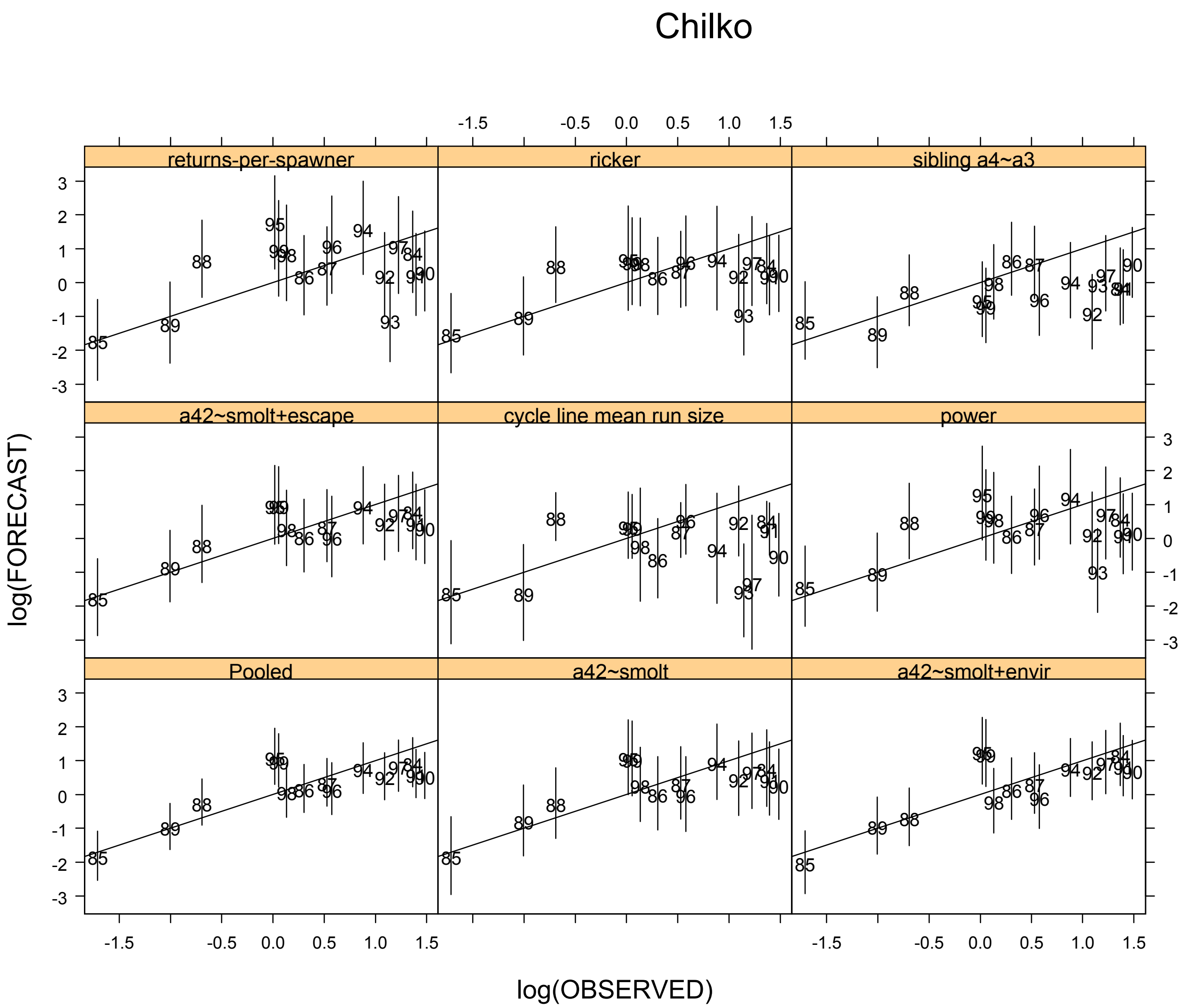


Figure 4. Comparison of estimated (observed) returns and retrospective run size forecasts (millions ($\log_e$ scale)) of age-4 Chilko sockeye by model. Data points are median (50%) forecasts and are denoted by return year. Diagonal lines are 1:1 lines not regression lines. Error bars are 90% confidence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

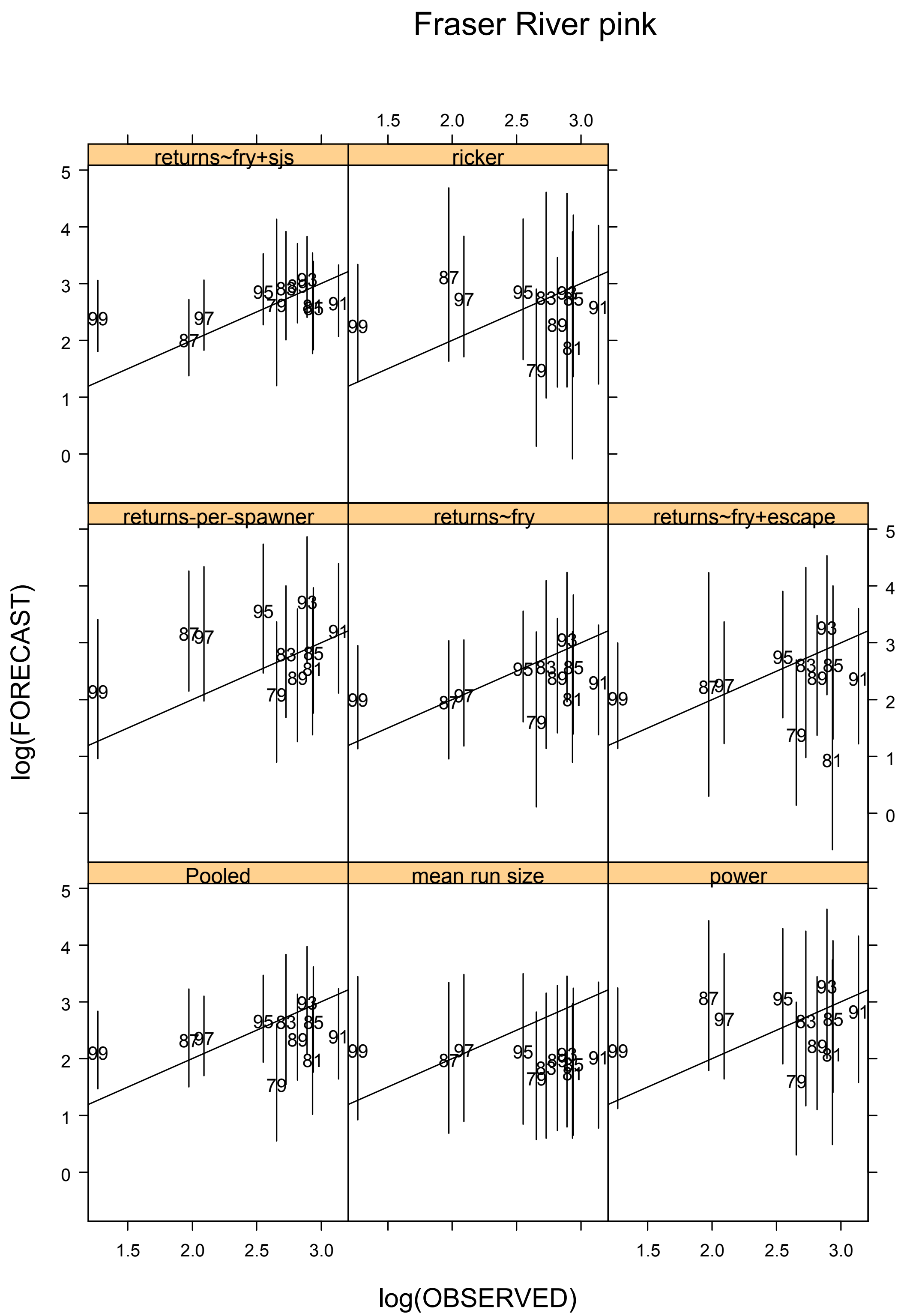


Figure 5. Comparison of estimated (observed) returns and retrospective run size forecasts (millions ($\log_e$ scale)) of pink salmon by model. Data points are median (50%) forecasts and are denoted by return year. Diagonal lines are 1:1 lines not regression lines. Error bars are 90% confidence intervals.

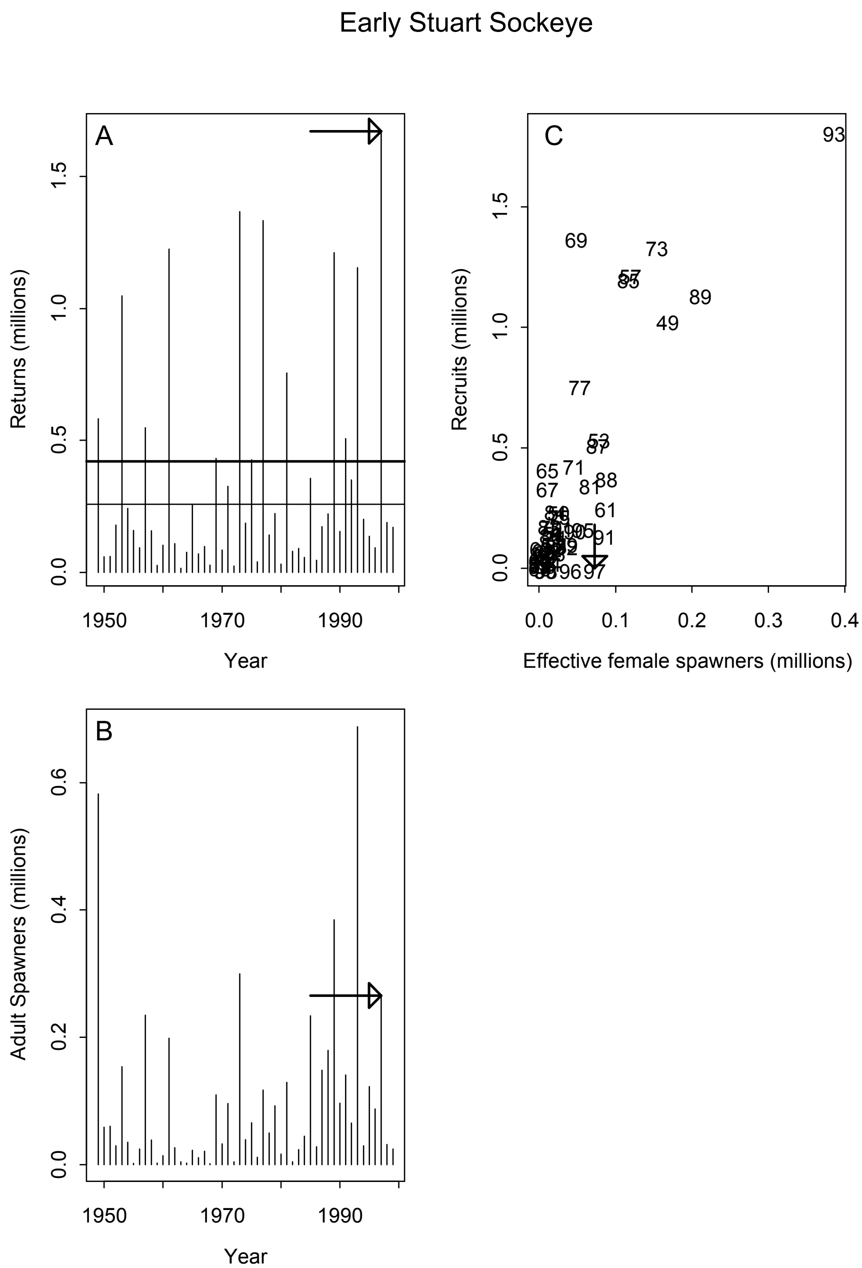


Figure. 6. A) Trend in Early Stuart sockeye adult returns. Horizontal lines shows 2001 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, and C) effective female – recruit relationship. Arrows depict 1997 data.

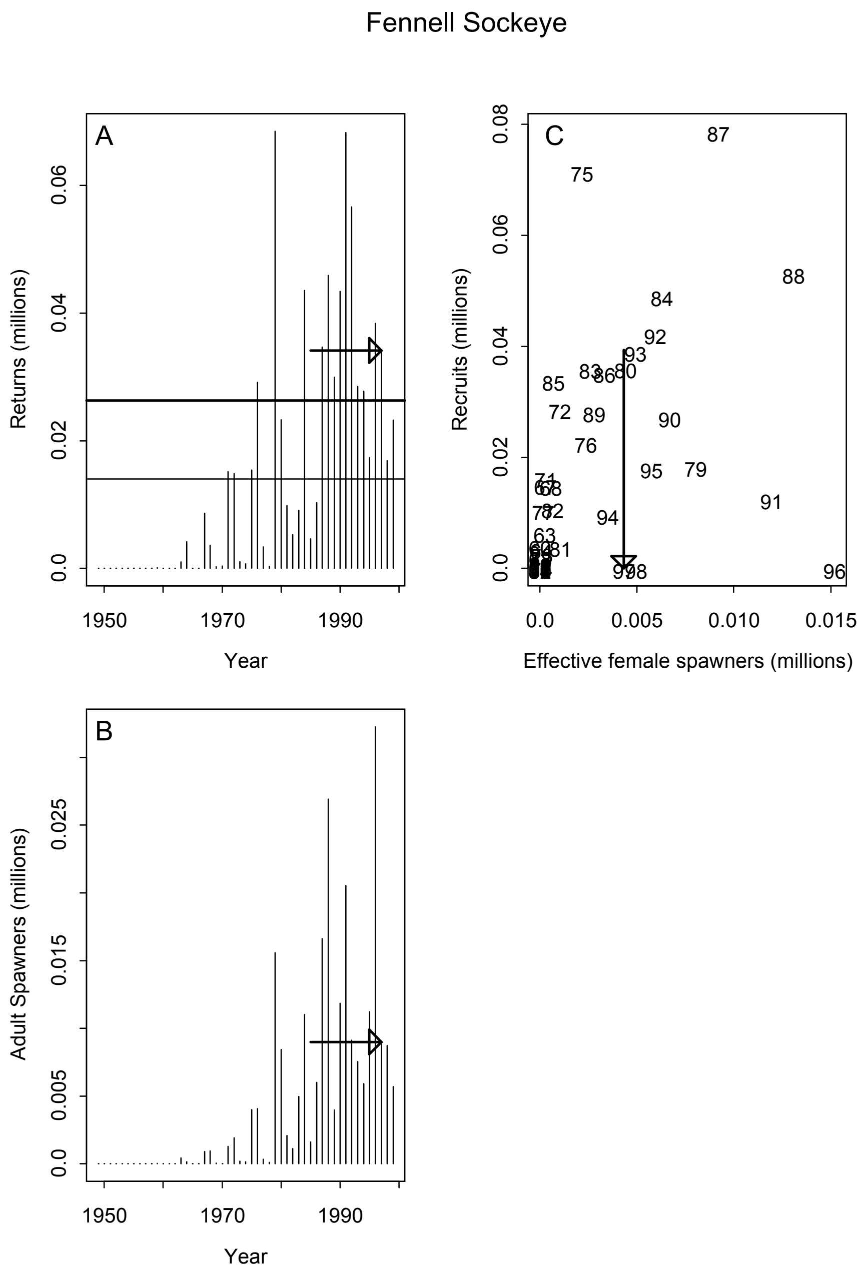


Figure. 7. A) Trend in Fennell Creek sockeye adult returns. Horizontal lines shows 2001 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, and C) effective female – recruit relationship. Arrows depict 1997 data.

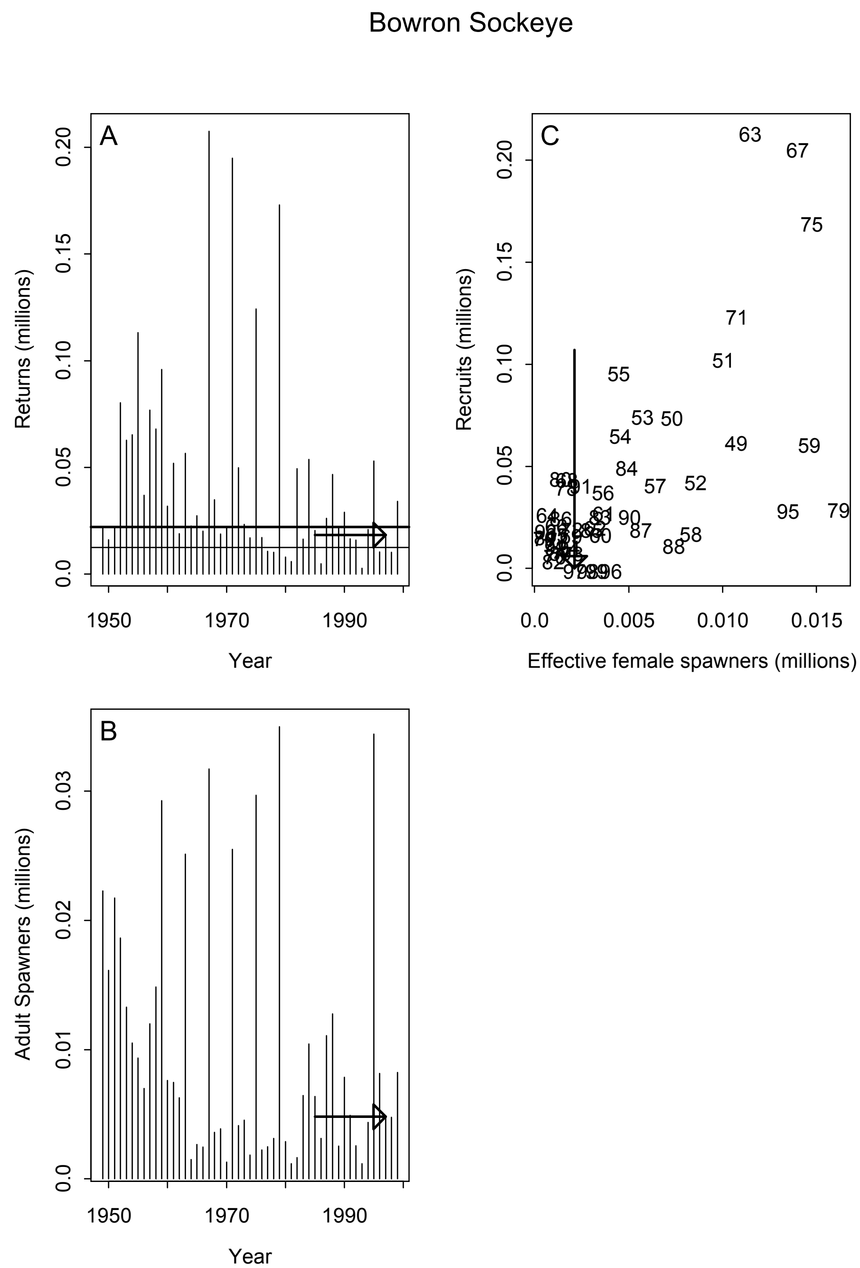


Figure. 8. A) Trend in Bowron River sockeye adult returns. Horizontal lines shows 2001 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, and C) effective female – recruit relationship. Arrows depict 1997 data.

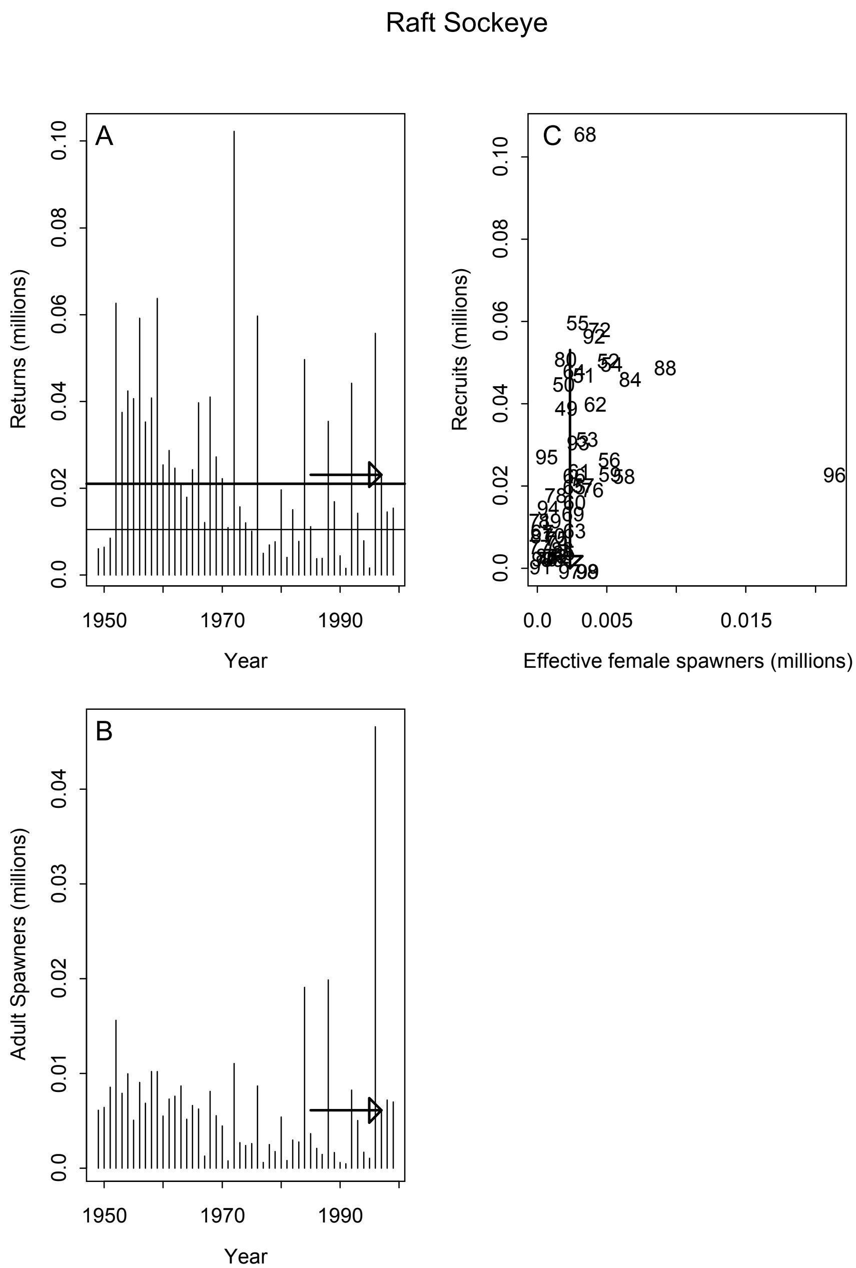


Figure. 9. A) Trend in Raft River sockeye adult returns. Horizontal lines shows 2001 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, and C) effective female – recruit relationship. Arrows depict 1997 data.

Gates Sockeye

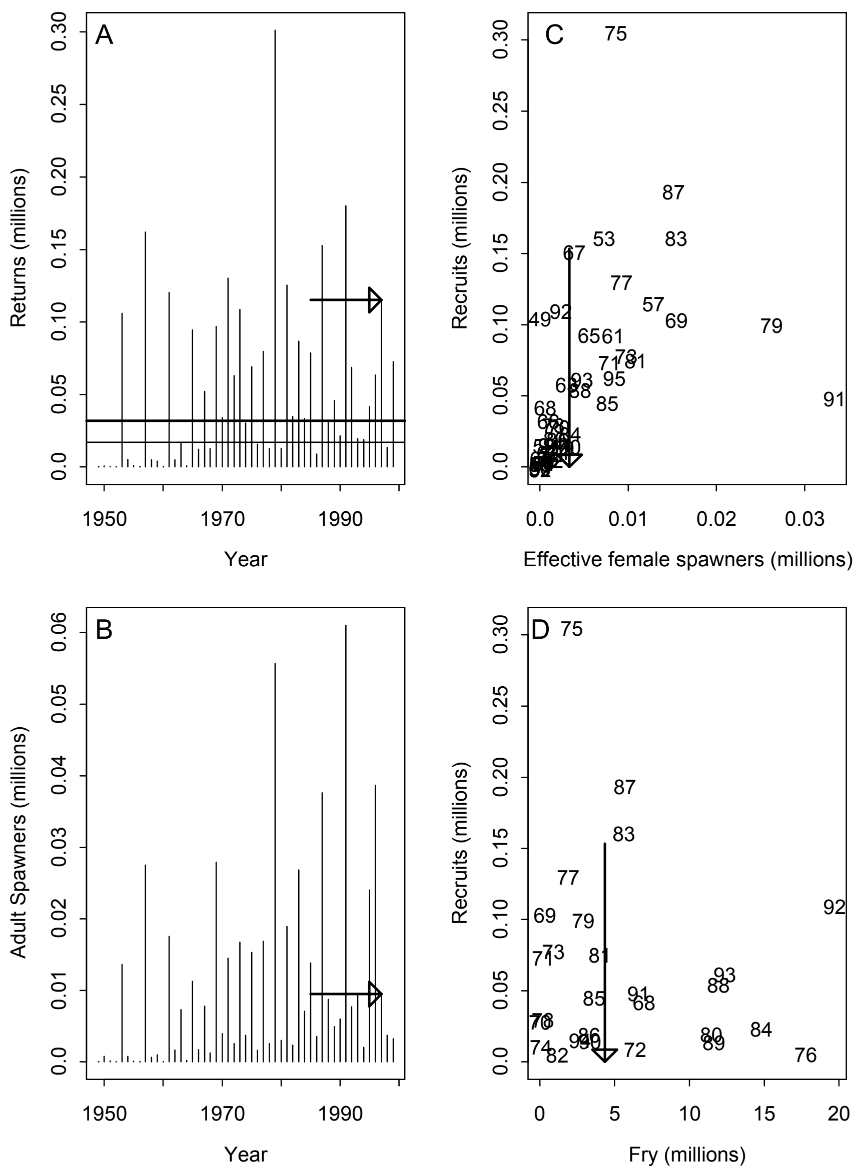


Figure. 10. A) Trend in Gates Creek sockeye adult returns. Horizontal lines shows 2001 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, and C) effective female – recruit relationship. D) Spawning channel fry – recruits relationship. Arrows depict 1997 data.

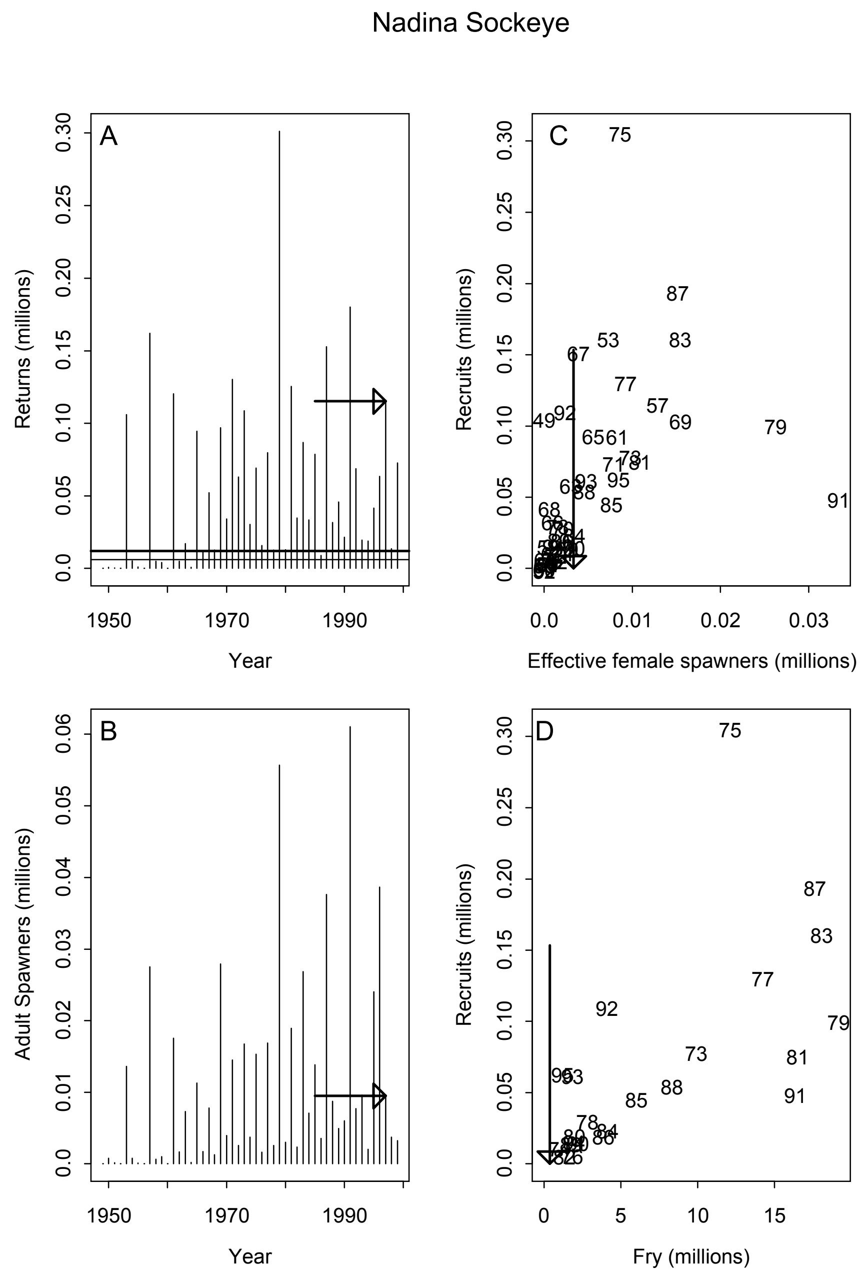


Figure. 11. A) Trend in Nadina sockeye adult returns. Horizontal lines shows 2001 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, and C) effective female – recruit relationship. D) Spawning channel fry – recruits relationship. Arrows depict 1997 data.

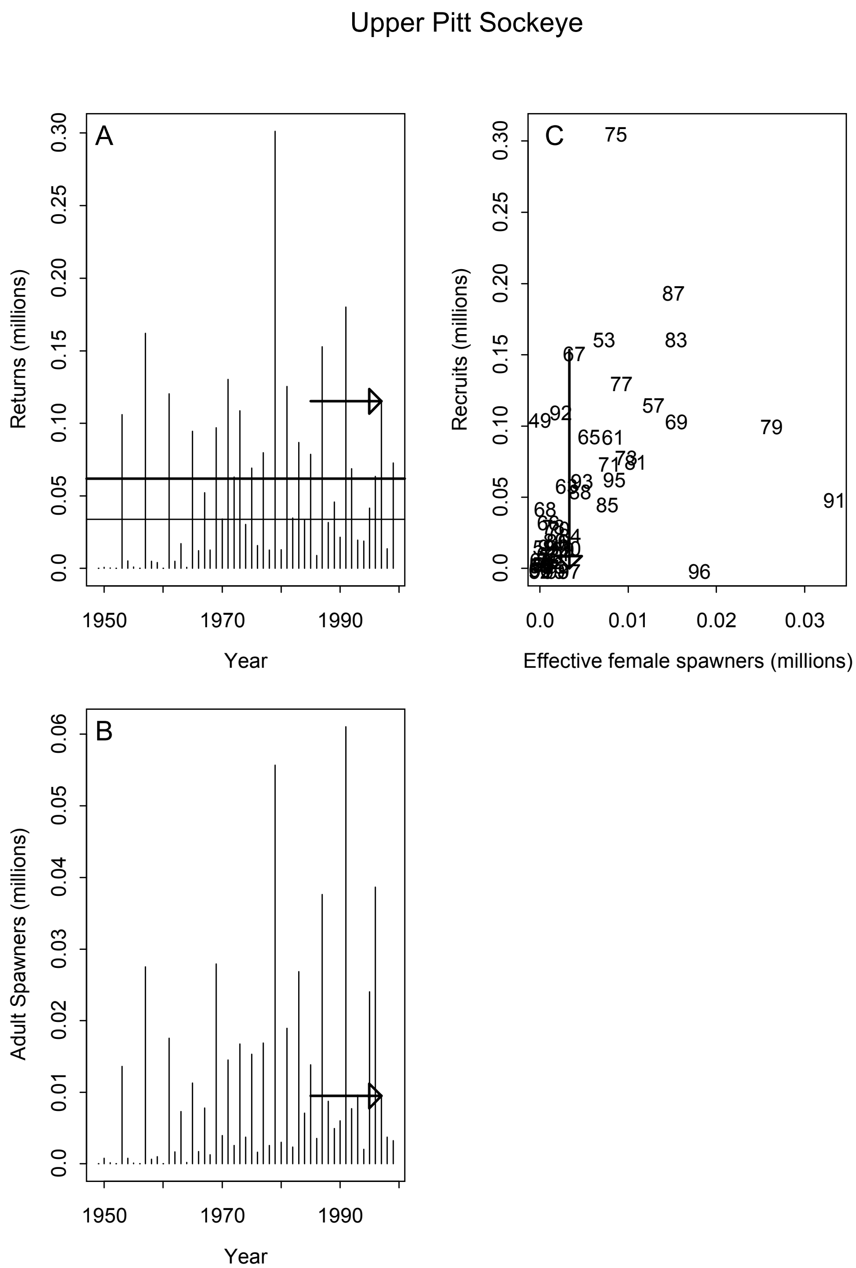


Figure. 12. A) Trend in Upper Pitt sockeye adult returns. Horizontal lines shows 2001 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, and C) effective female – recruit relationship. Arrows depict 1997 data.

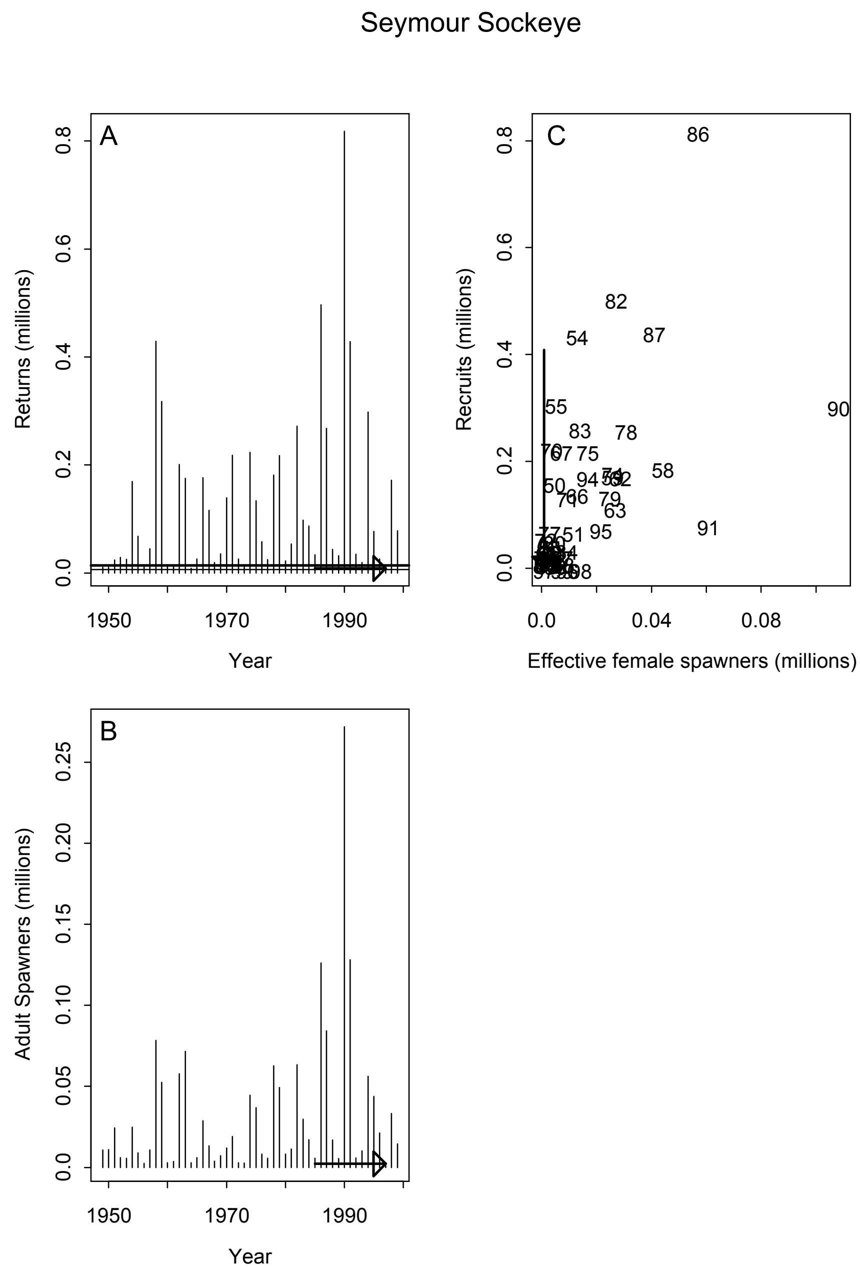


Figure. 13. A) Trend in Seymour River sockeye adult returns. Horizontal lines shows 2001 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, and C) effective female – recruit relationship. Arrows depict 1997 data.

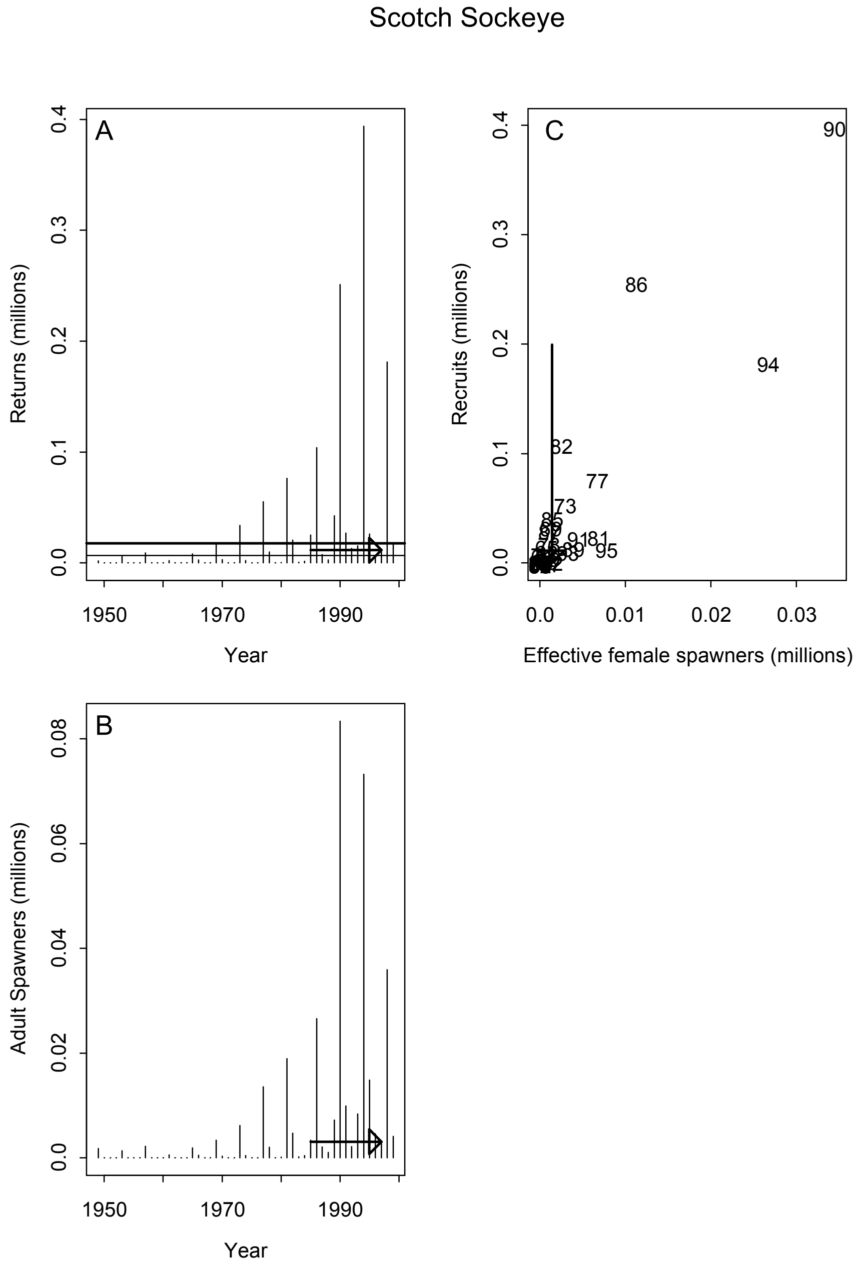


Figure. 14. A) Trend in Scotch Creek sockeye adult returns. Horizontal lines shows 2001 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, and C) effective female – recruit relationship. Arrows depict 1997 data.

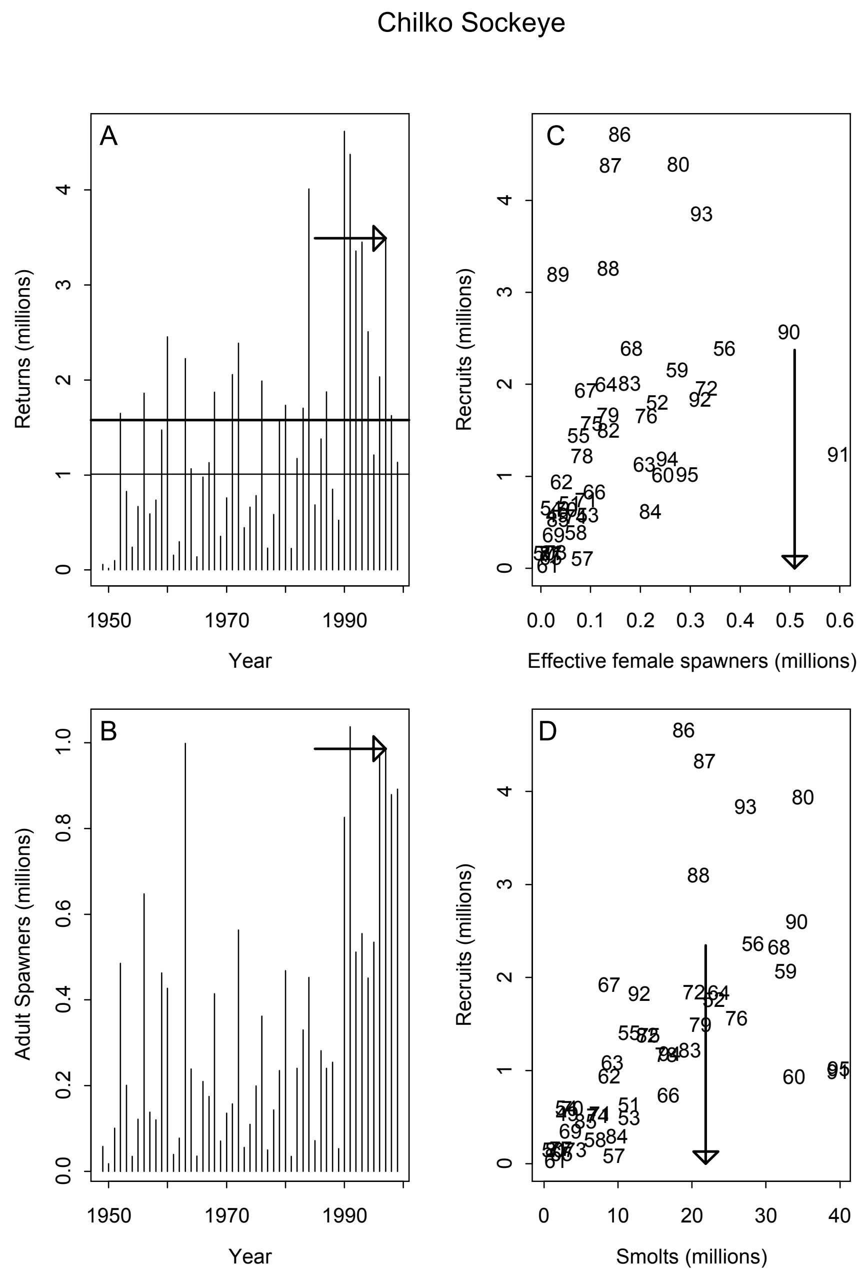


Figure. 15. A) Trend in Chilko sockeye adult returns. Horizontal lines shows 2001 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, and C) effective female – recruit relationship. D) Smolt – recruit relationship. Arrows depict 1997 data.

Quesnel Sockeye

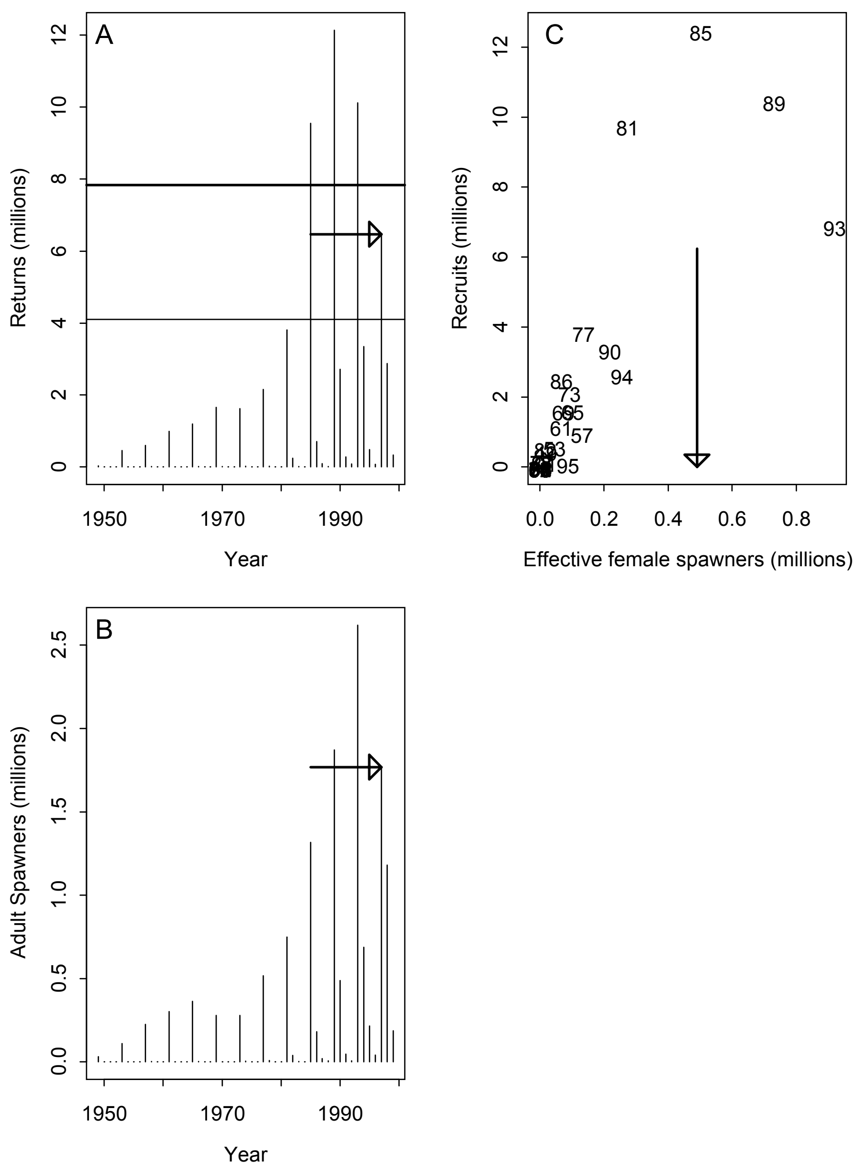


Figure. 16. A) Trend in Quesnel sockeye adult returns. Horizontal lines shows 2001 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, and C) effective female – recruit relationship. Arrows depict 1997 data.

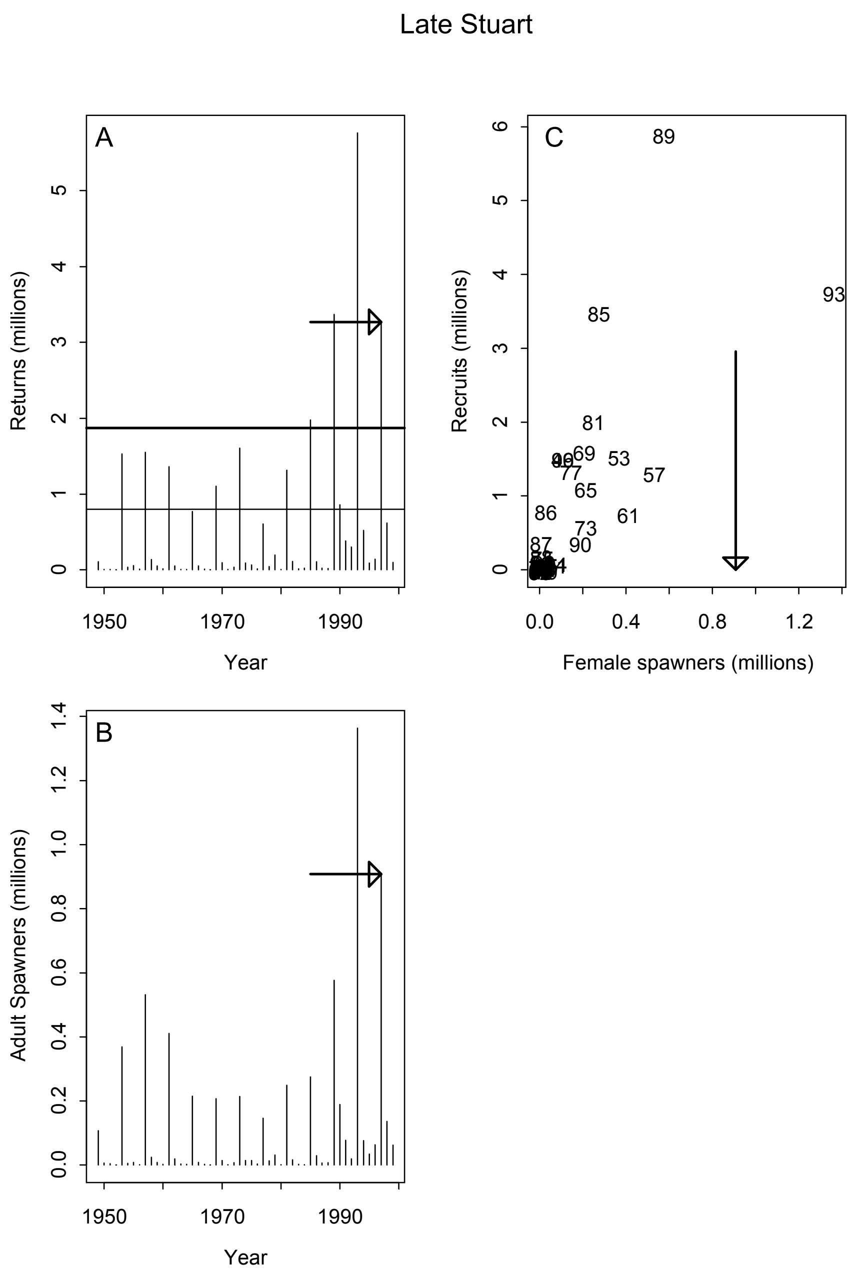


Figure. 17. A) Trend in Late Stuart sockeye adult returns. Horizontal lines shows 2001 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, and C) effective female – recruit relationship. Arrows depict 1997 data.

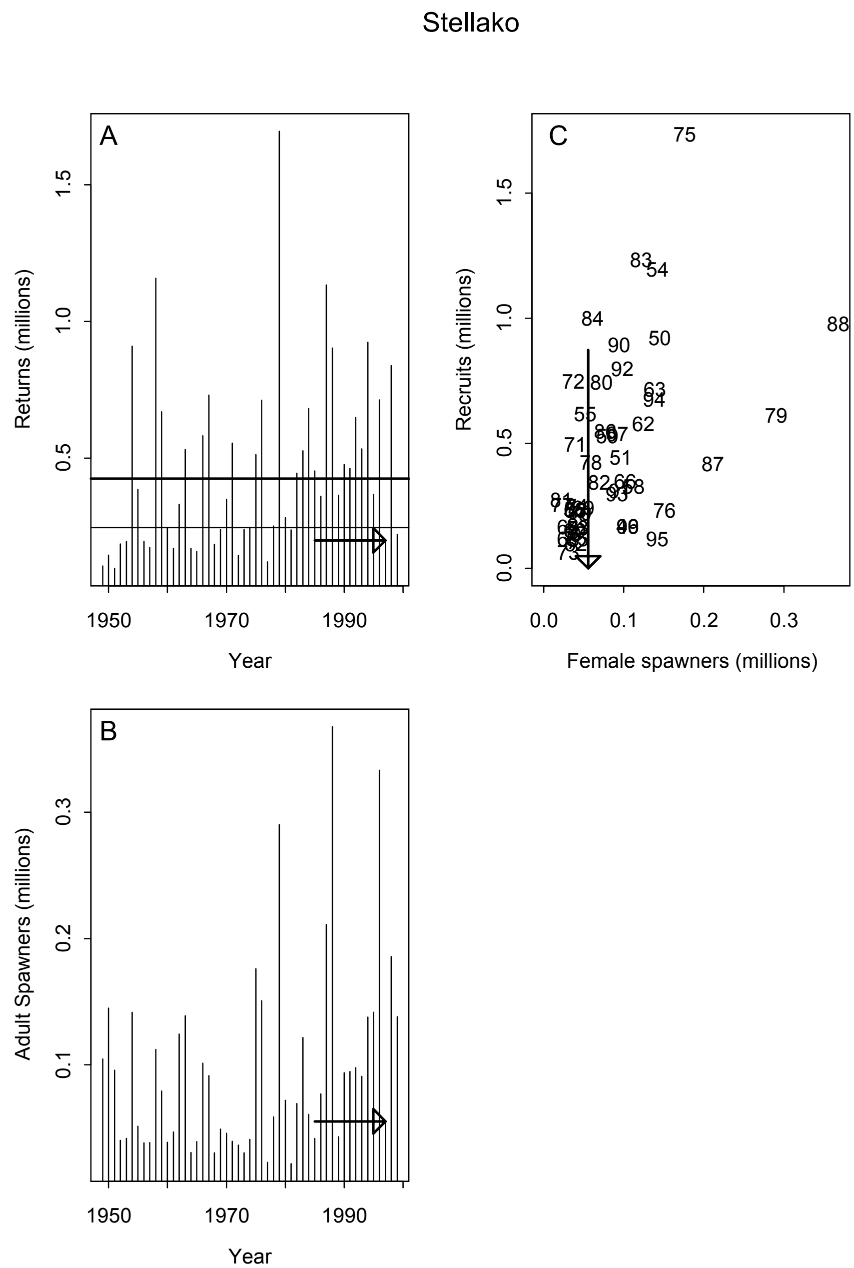


Figure. 18. A) Trend in Stellako sockeye adult returns. Horizontal lines shows 2001 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, and C) effective female – recruit relationship. Arrows depict 1997 data.

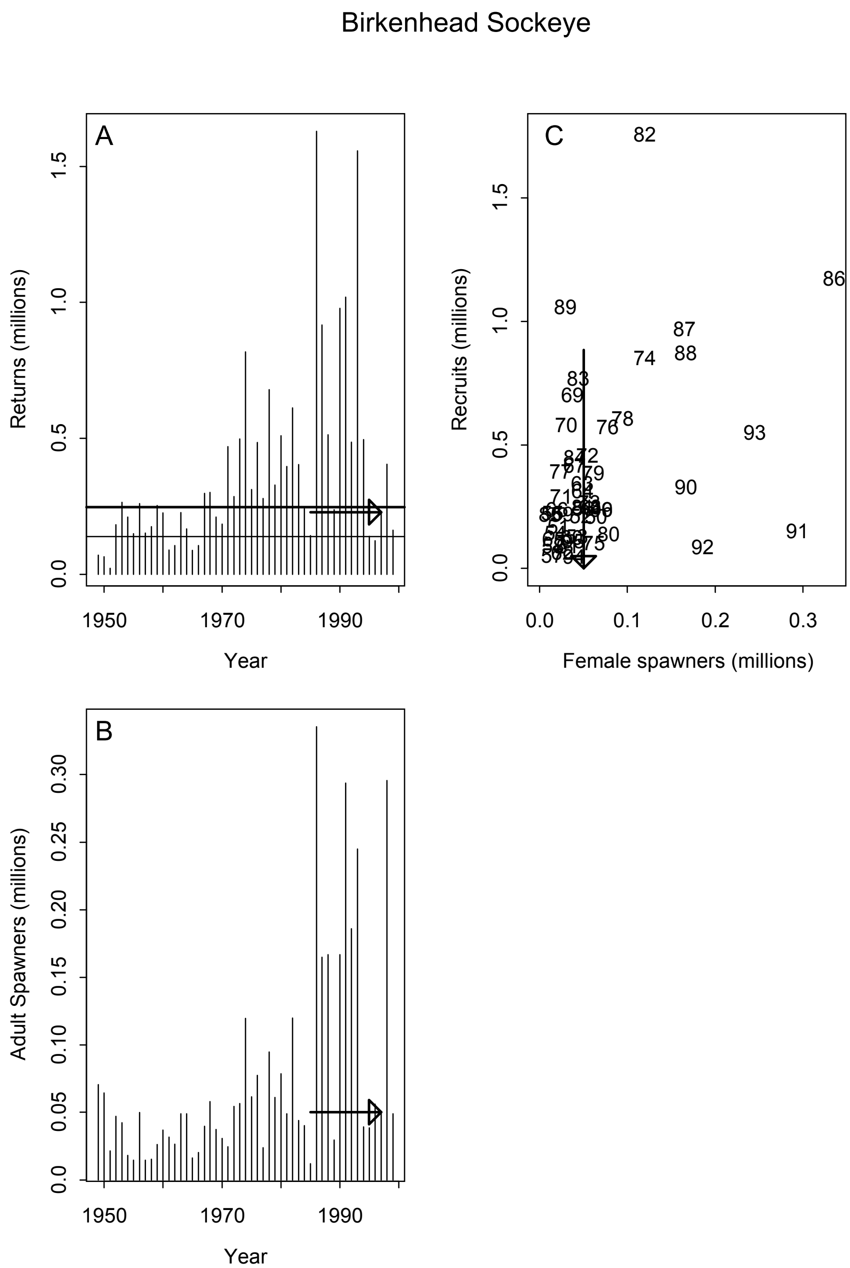


Figure. 19. A) Trend in Birkenhead River sockeye adult returns. Horizontal lines shows 2001 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, and C) effective female – recruit relationship. Arrows depict 1997 data.

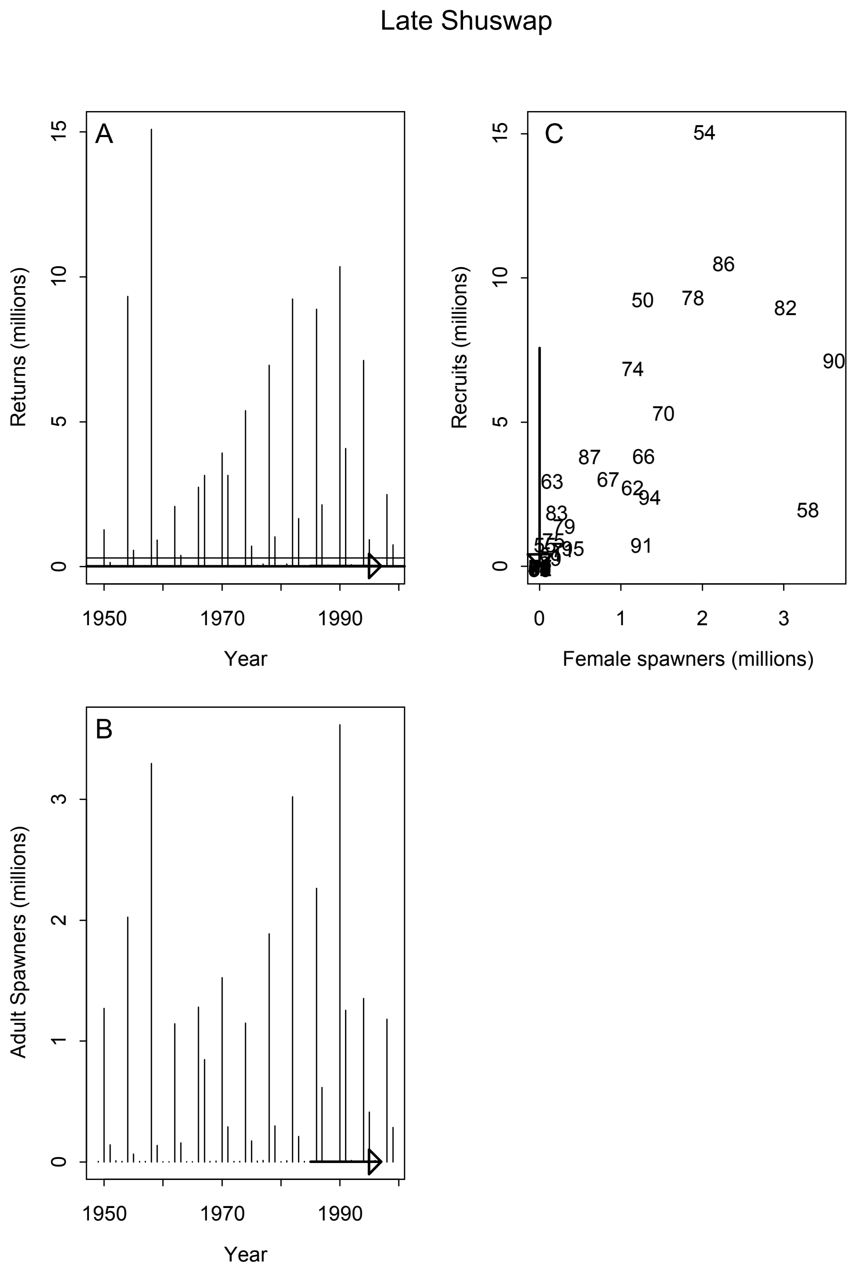


Figure. 20. A) Trend in Late Shuswap sockeye adult returns. Horizontal lines shows 2001 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, and C) effective female – recruit relationship. Arrows depict 1997 data.

Cultus

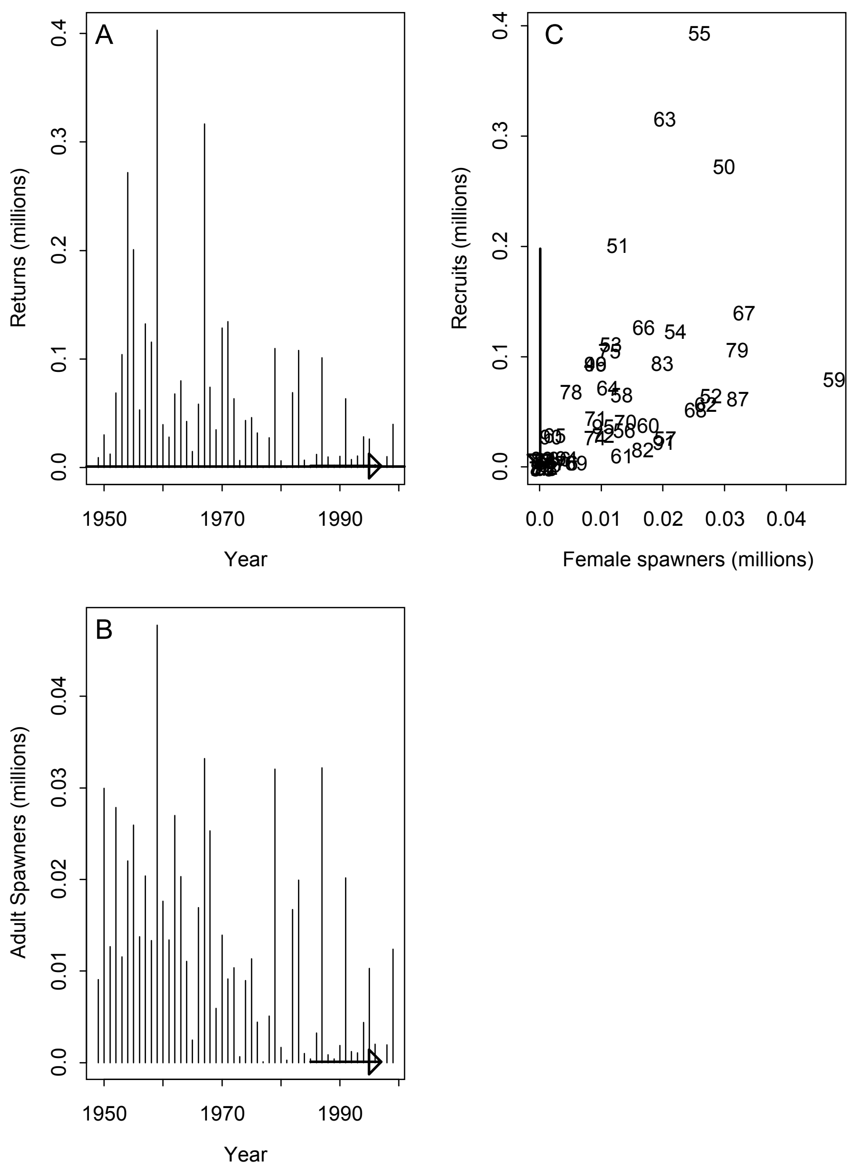


Figure. 21. A) Trend in Cultus Lake sockeye adult returns. Horizontal lines shows 2001 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, and C) effective female – recruit relationship. Arrows depict 1997 data.

Weaver

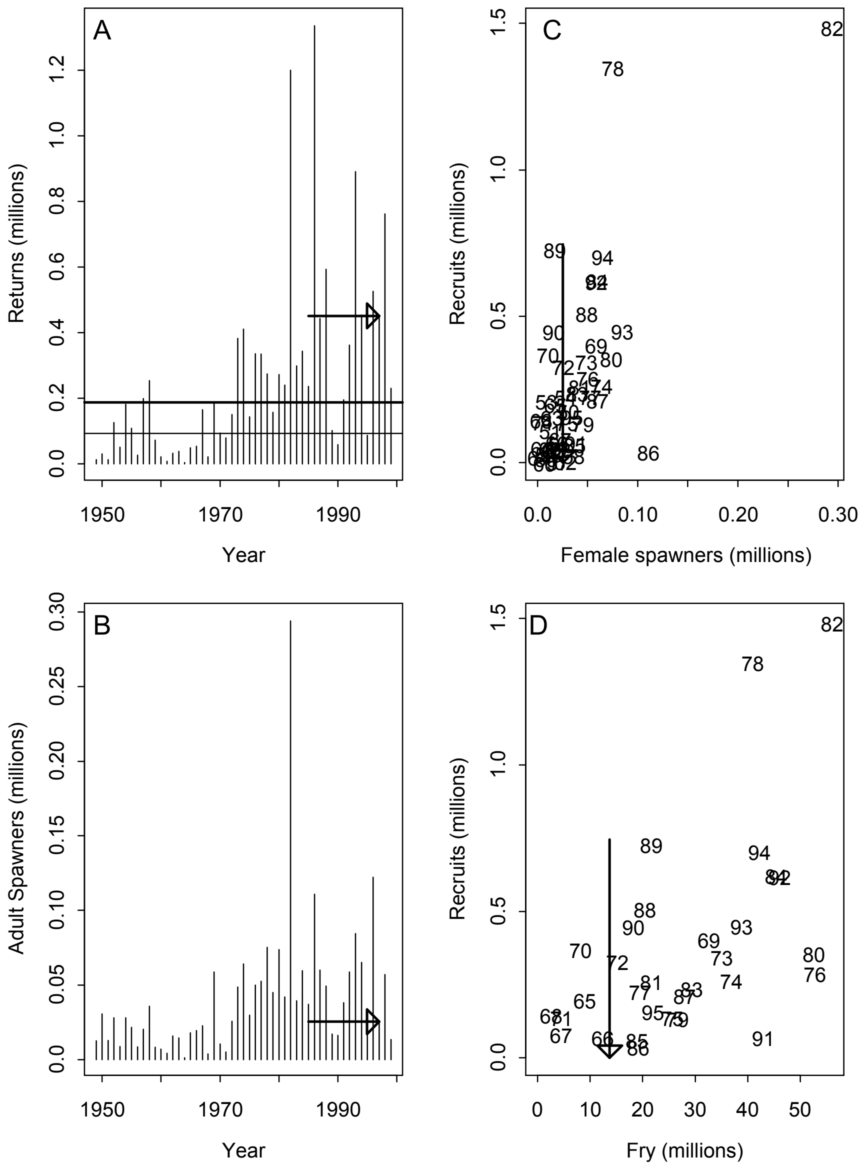


Figure. 22. A) Trend in Weaver sockeye adult returns. Horizontal lines shows 2001 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, and C) effective female – recruit relationship. D) Spawning channel fry – recruits relationship. Arrows depict 1997 data.

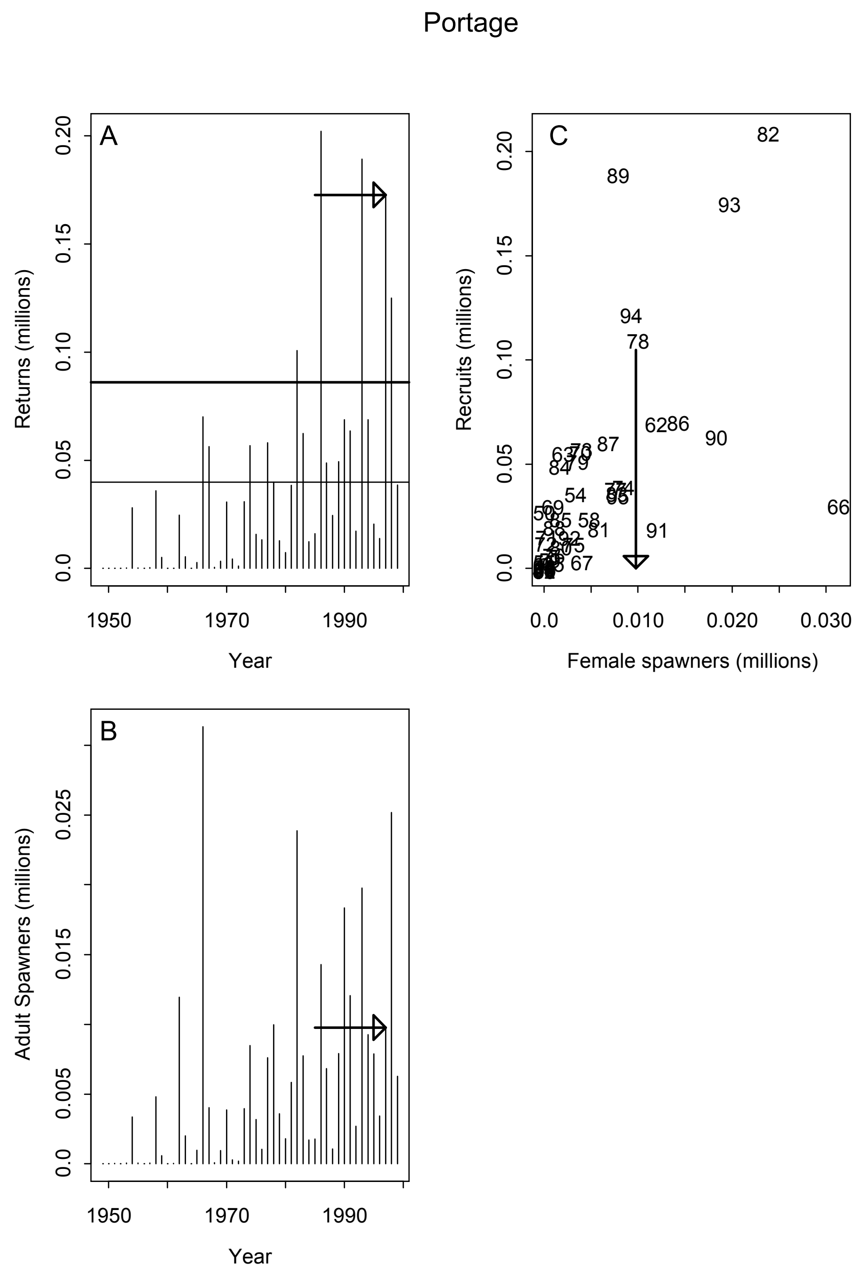


Figure. 23. A) Trend in Portage sockeye adult returns. Horizontal lines shows 2001 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, and C) effective female – recruit relationship. Arrows depict 1997 data.

Fraser River pink salmon

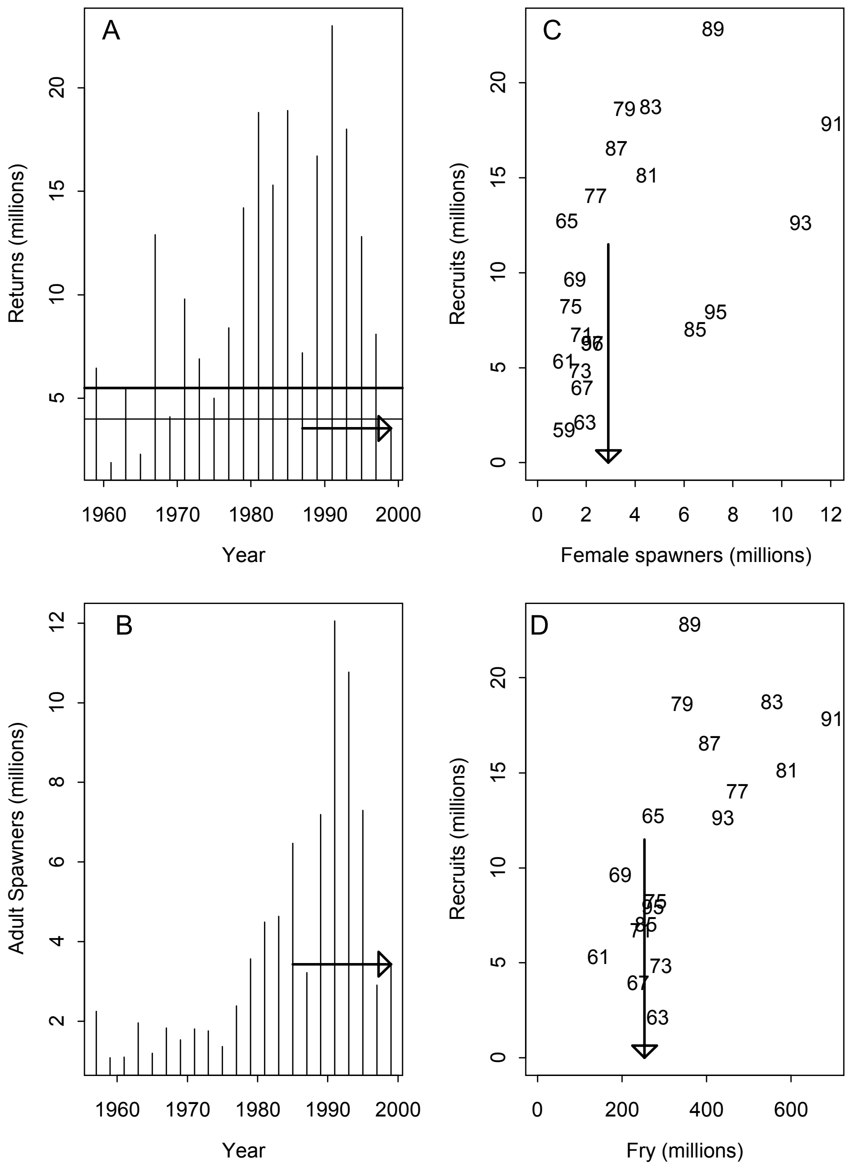


Figure 24. Production trends for Fraser River pink salmon. Horizontal lines shows 2001 forecast at the 50% (upper) and 75% (lower) probability level. B) Trends in adult spawners, and C) effective female – recruit relationship. D) Spawning channel fry – recruits relationship. Arrows depict 1999 data.

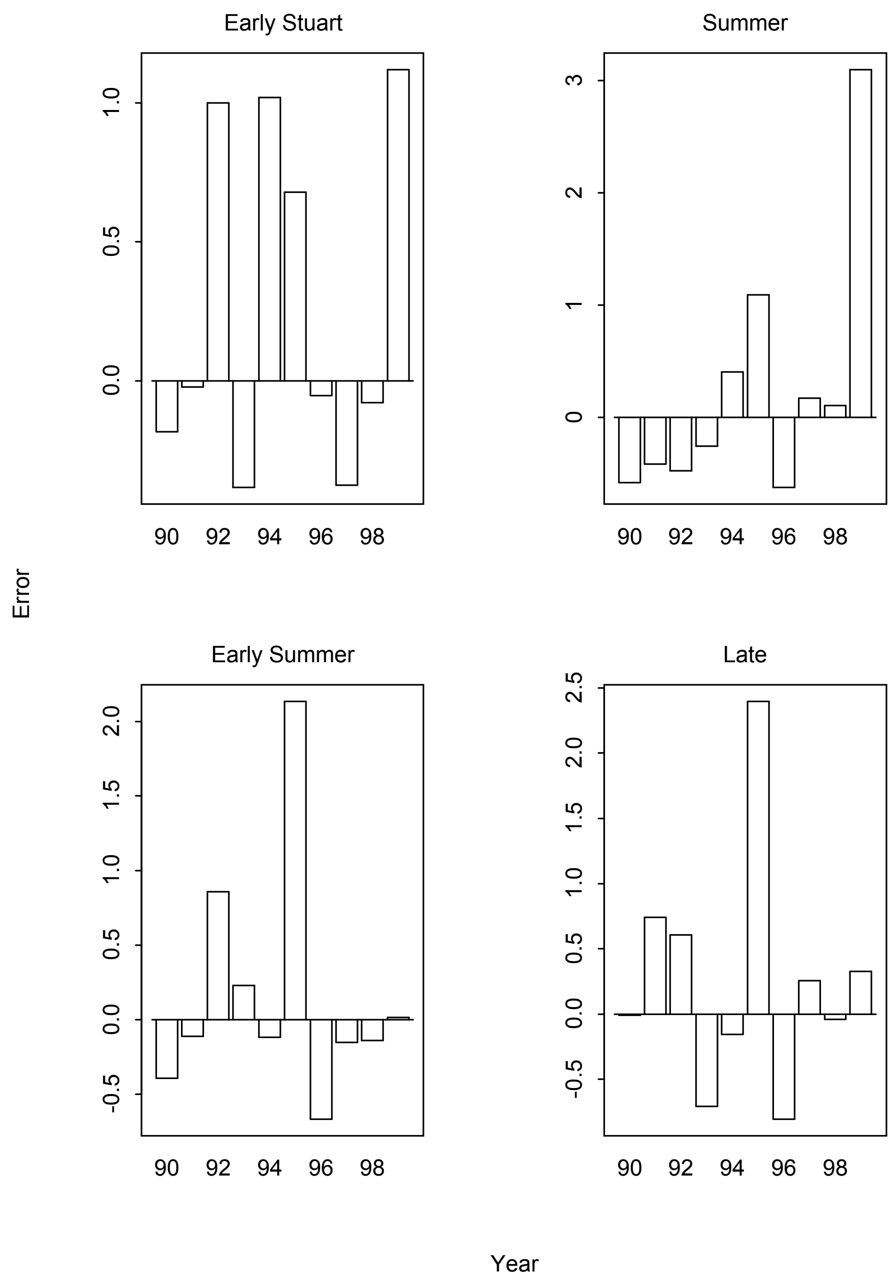


Figure 25. Proportional deviation of forecasts from observed run size by run-timing group for Fraser River sockeye (1990-99).

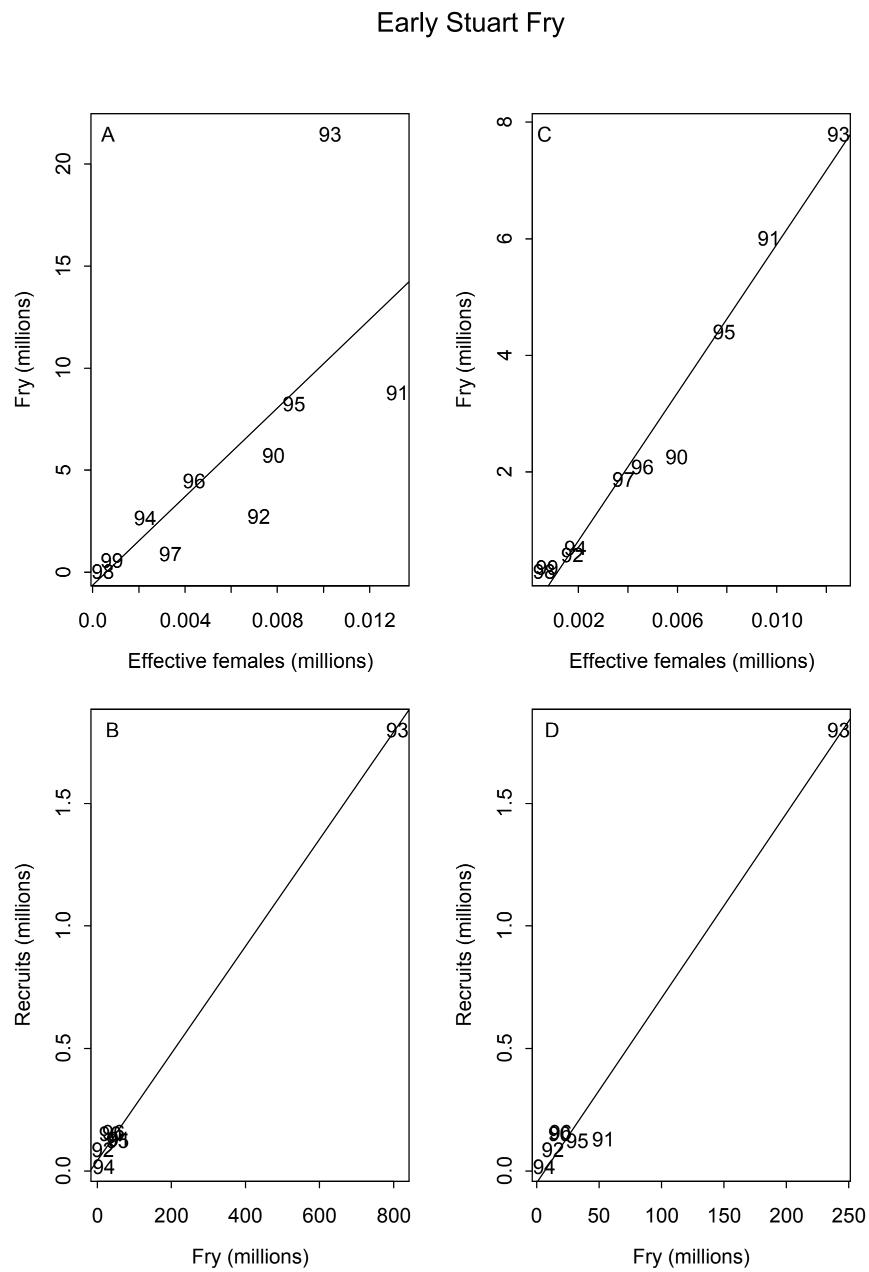


Figure. 26. A) Forfar Creek fry – effective female relationship. B) Total Early Stuart recruits – fry relationship based on extrapolating from Forfar Creek fry data, C) Gluske Creek fry – effective female relationship. D Total Early Stuart recruits – fry relationship based on extrapolating from Gluske fry data. Fry extrapolations were computed by multiplying the fry:effective female ratio for Forfar and Gluske Creeks by the total number of effective females for the Early Stuart system.

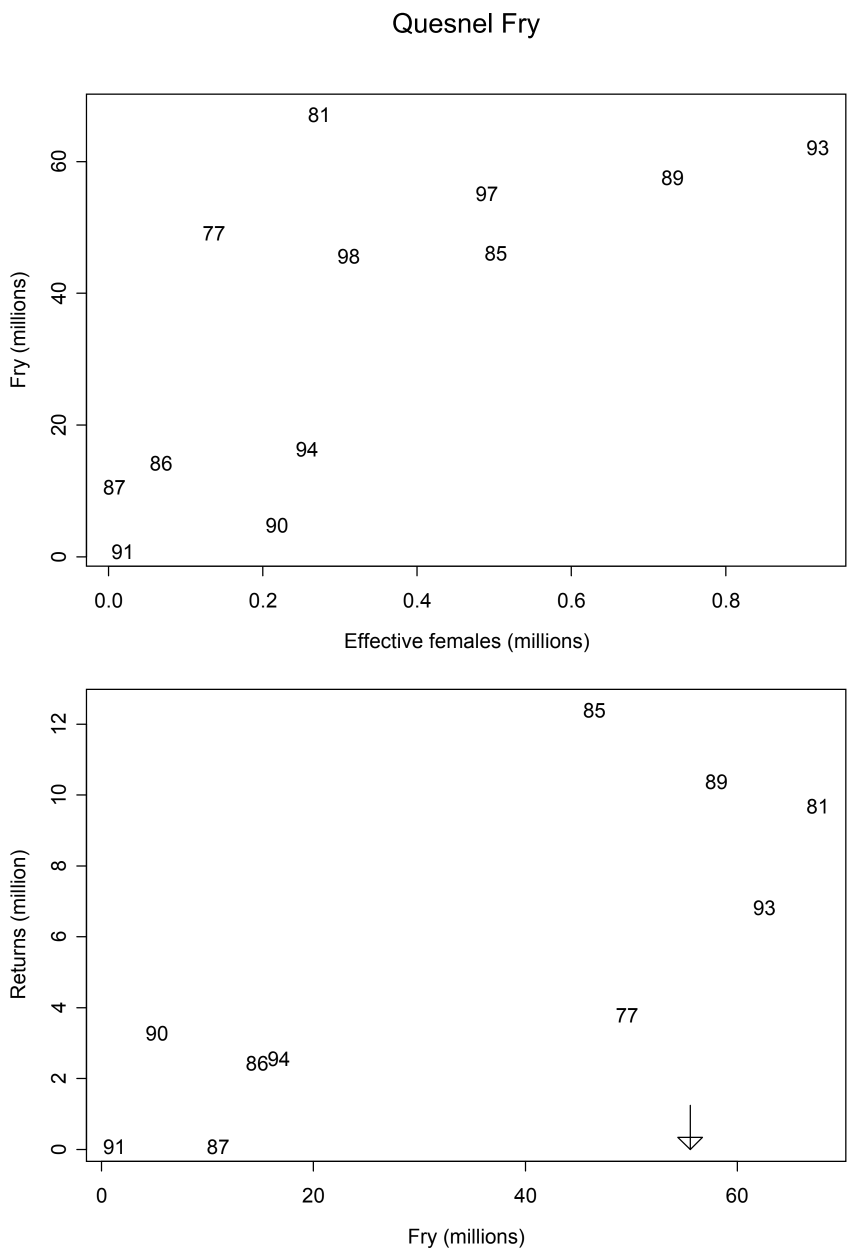


Figure. 27. Fall fry - effective female relationship (upper). Return - fall fry relationship (lower). Data labels are brood years.

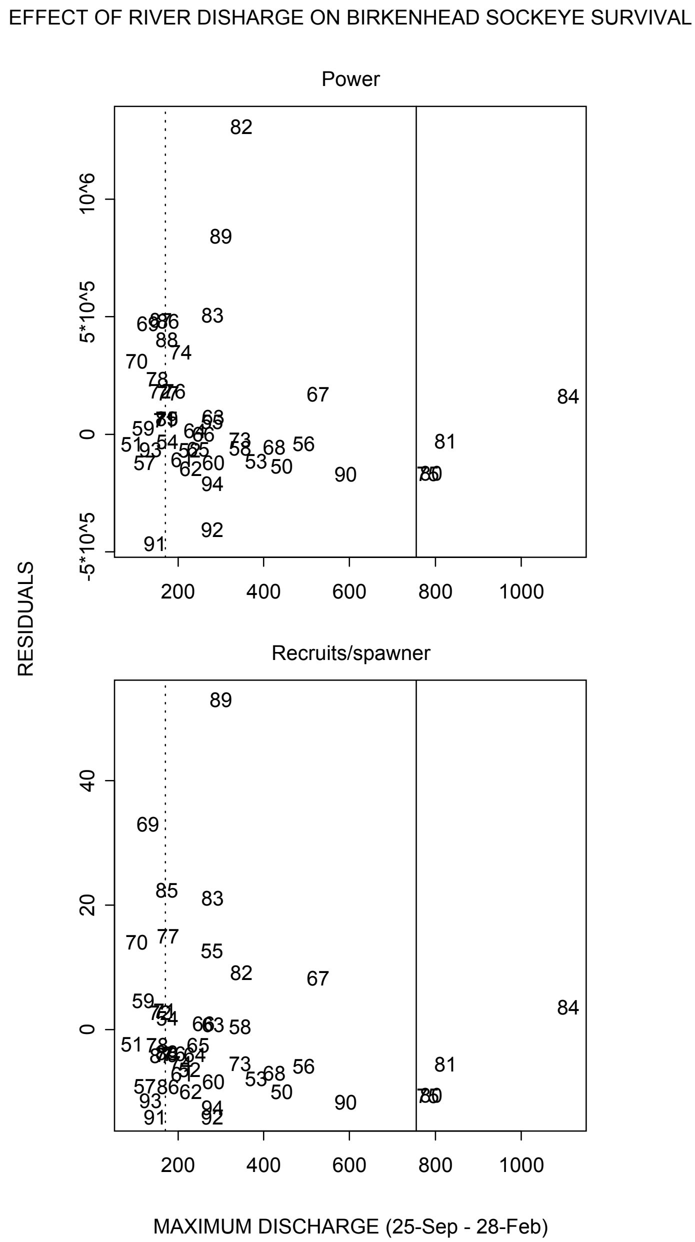


Figure. 28. Residuals from escapement - returns data fit to a power model and recruits-per-spawner model versus Lillooet River discharge rates (1950-95). Vertical lines correspond to the observed maximum daily discharge rate between September 25 and February 28. The broken line is for discharge rates affecting age-5 returns and solid line is for discharge rates affectingage-4 returns in 2001.