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Pre-season run size forecasts for Fraser River Sockeye salmon (*Oncorhynchus nerka*) in 2010

Prévisions présaison des remontes de saumon rouge du fleuve Fraser (*Oncorhynchus nerka*) en 2010

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ABSTRACT

- Pre-season forecasts of salmon abundance are generally highly uncertain due the combination of historical variability in annual survival rates (stochastic uncertainty) and uncertainty regarding future survival rates. Fraser River Sockeye Salmon (Fraser Sockeye) forecasts in 2010 are especially uncertain given the decreasing trends in productivity for most stocks in recent years and, in particular, the unexpectedly poor returns in 2009.
- Uncertainty that is attributed to stochastic (random) variability in annual Fraser Sockeye survival is communicated in the 2010 forecast paper through a series of forecasted values that correspond to standardized cumulative probabilities (10%, 25%, 50%, 75%, 90%) (Figure 10). For example, there would be a one in four chance at the 25% probability level that the actual number of returning Sockeye will be at or below the forecasted value given the assumptions about future survival.
- Uncertainty about future Fraser Sockeye survival is communicated in this paper through the presentation of three alternative cases (forecast tables) to characterize stock productivity for the 2010 returns:
  - **Case 1.** "Long Term Average Productivity" assumes that average stock productivity (across entire stock-recruitment time series) will persist through to 2010 (Table 2). Methods and model ranks were identical to the 2009 forecast (DFO 2009).
  - **Case 2.** "Recent Productivity" assumes that recent productivity trends will persist through to 2010 (Table 3). To forecast age-4 recruits, this case includes the addition of three new models that consider recent productivity. Model performance was evaluated in recent years only (brood years 1997-2004). Age-5 recruits were forecast using preliminary productivity for the 2005 brood year (2009 returns).
  - **Case 3.** "Productivity Equivalent to the 2005 Brood Year (2009 Returns)" assumes this low productivity will re-occur in 2010 (Table 5). Age-4 and age-5 recruits were forecast using preliminary productivity for the 2005 brood year (2009 returns),
  - At the time of this paper, the 2005 brood year productivity data used to forecast age-5 recruits in the Case 2 forecast and age-4 and age-5 recruits in the Case 3 forecast were preliminary and also do not include the age-5 recruits that will return in 2010.
- The forecast with the greatest degree of belief (as recommended by the March 9, 2010 Canadian Science Advisory Secretariat (CSAS) Regional Advisory Process (RAP)) was Case 2 ("Recent Productivity"). For this case, the number of returning Fraser Sockeye in 2010 will range from 7.0 million-18.3 million at the 25% to 75% probability levels. The same probability range each of the four run timing groups are as follows: Early Stuart Run: 26,000-66,000; Early Summer Run: 374,000-1.6 million; Summer Run: 1.6 million-4.3 million; and Late Run: 5.0 million-12.3 million (Figure 11 and Table 3).
- For Case 1 ("Long-Term Average Productivity"), the forecast range is from 8.4 million to 23.5 million at the 25% to 75% probability levels (Figure 11 and Table 2).
- For Case 3 ("Productivity Equivalent to the 2005 Brood Year (2009 Return)), the forecast range is from 1.6 million to 7.9 million at the 25% to 75% probability levels (Figure 11 and Table 5).

RÉSUMÉ

- Les prévisions présaison de l'abondance du saumon sont généralement très incertaines en raison de la combinaison de la variabilité historique des taux de survie annuels (incertitude stochastique) et de la variabilité relative aux taux de survie futurs. Les prévisions de 2010 touchant le saumon rouge du Fraser sont particulièrement incertaines compte tenu de la tendance à la baisse de la productivité de la plupart des stocks au cours des dernières années et en particulier des remontes qui, contre toute attente, se sont révélées médiocres en 2009.
- L'incertitude attribuée à la variabilité stochastique (aléatoire) de la survie annuelle du saumon rouge est exposée dans le document de prévision de 2010 par l'entremise d'une série de valeurs prévues correspondant à des probabilités cumulatives normalisées (10 %, 25 %, 50 %, 75 %, 90 %) (figure 10). Au niveau de probabilité de 25 % par exemple, il y aurait une chance sur quatre que le nombre réel de remontés de saumons rouges soit égal ou inférieur à la valeur prévue, compte tenu des hypothèses sur leur survie future.
- Dans le présent document, l'incertitude concernant la survie future du saumon rouge du Fraser est exposée dans le cadre de trois cas (tableaux de prévision) destinés à préciser la productivité des stocks pour les remontes de 2010.
    - **Cas 1.** La « productivité moyenne à long terme » suppose que la productivité moyenne des stocks (sur l'ensemble des séries chronologiques entre les stocks et le recrutement) persistera tout au long de 2010 (tableau 2). Les méthodes et les mesures de rendement du modèle sont identiques à la prévision de 2009 (MPO 2009).
    - **Cas 2.** La « productivité récente » suppose que les tendances récentes de la productivité persisteront tout au long de 2010 (tableau 3). Pour prévoir les recrues d'âge 4, ce cas inclut l'ajout de trois nouveaux modèles qui examinent la productivité récente. Le rendement du modèle n'a été évalué que pour les années récentes (années d'éclosion 1997-2004). Pour prévoir les recrues d'âge 5, on s'est servi de la productivité préliminaire pour l'année d'éclosion 2005 (remontes de 2009).
    - **Cas 3.** La « productivité équivalente à l'année d'éclosion 2005 (remontes de 2009) » suppose que cette faible productivité se reproduira en 2010 (tableau 5). Pour prévoir les recrues d'âges 4 et 5, on s'est servi de la productivité préliminaire pour l'année d'éclosion 2005 (remontes de 2009).
    - Au moment de la publication du présent document, les données sur la productivité pour l'année d'éclosion 2005 utilisées pour prévoir les recrues d'âge 5 dans le cas 2 et les recrues d'âges 4 et 5 dans le cas 3 étaient préliminaires et n'incluaient pas les recrues d'âge 5 qui seront en montaison en 2010.
- Le cas 2 (« productivité récente ») était la prévision la plus crédible (selon la recommandation d'avis scientifique régional du Secrétariat canadien de consultation scientifique (SCCS) tenu le 9 mars 2010. Pour ce cas, le nombre de saumons rouges en montaison en 2010 variera entre 7,0 millions et 18,3 millions aux niveaux de probabilité de 25 % à 75 %. Voici les quatre groupes de montaison pour la même fourchette de probabilité : montaison hâtive de la Stuart - 26 000 à 66 000; montaison hâtive d'été - 374 000 à 1,6 million; montaison d'été - 1,6 million à 4,3 millions et montaison tardive - 5,0 millions à 12,3 millions (figure 11 et tableau 3).
- Pour le cas 1 (« productivité moyenne à long terme »), la fourchette de prévision va de 8,4 millions à 23, 5 millions aux niveaux de probabilité de 25 % à 75 % (figure 11 et tableau 2). Pour le cas 3 (« productivité équivalente à l'année d'éclosion 2005 (remontes de 2009 »), la fourchette de prévision va de 1,6 million à 7,9 millions aux niveaux de probabilité de 25 % à 75 % (figure 11 et tableau 5)

INTRODUCTION

OVERVIEW OF PAST ADULT RETURNS

To provide context for the 2010 Fraser River Sockeye Salmon (Fraser Sockeye) adult return forecasts, the cycle average returns are presented in Table 3 (column I). On the 2010 cycle, average annual returns (1980-2006) for all 19 forecasted stocks combined were ~15 million. Late Shuswap (Late Run) has been the main driver of the average return abundances on the 2010 cycle line, accounting for 50% of the total return. The 2010 cycle is the dominant cycle for Late Shuswap, and most adult Sockeye produced in this system are generated in the Adams River. Quesnel and Chilko (Summer Run) stocks have also contributed relatively high proportions (~15%) to the 2010 cycle average returns. Although the 2010 Quesnel cycle has not been historically a strong cycle (pre-1980 average returns: 10,000), returns on the 2010 subdominant cycle began to increase in the 1980’s to a maximum of 5 million in 2002. Quesnel returns on this cycle have subsequently declined to 700,000 in 2006. Other stocks that make up more than 1% each of the 2010 average cycle returns include the following: Early Summers: Scotch (dominant in 2010) and Seymour (dominant in 2010); Summer Run: Late Stuart and Stellako; Late Run: Weaver and Birkenhead.

ESCAPEMENT IN THE 2005 AND 2006 BROOD YEARS

The abundance of adult returns in any given year is influenced by three main factors: the abundance of their parental spawners (brood year escapement), the proportions of cohorts returning at a given age, and the survival rate of the resulting offspring. Since most Fraser Sockeye stocks are comprised of predominantly age-4 fish (Gilbert-Rich aging convention: 4_2), most Sockeye that return in 2010 are recruited from eggs spawned by adults in 2006 (brood year). For some of the stocks, data on the number of juveniles (fry or smolts) produced by the spawners are available and can be used as an alternative variable within the forecast models.

In the 2006 brood year, either the number of effective female spawners (EFS) or smolts (Chilko and Cultus) for 15 of the 19 forecasted Fraser Sockeye stocks was close to or above the time series average (1980-2005) (Table 3, column C). The four stocks with below average EFS abundance in the 2006 brood year were Bowron, Late Stuart, Quesnel, and Weaver (Table 3, column C). The greatest contributors to the 2006 brood year EFS (77% of the total) were Late Shuswap (57%), Chilko (13%), Birkenhead (7%), and several stocks (Scotch, Seymour, Quesnel, Stellako, and Harrison) that contributed ~4% each to the total. The remaining 11 forecasted stocks contributed less than 1% to the total 2006 brood year escapement.

Most Fraser Sockeye stocks also have a small age-5 (5_2) component. For most of these stocks the numbers of EFS contributing to age-5 returns in 2010 (2005 brood year) were close to average or above average (time series: 1980-2005), with the exception of Early Stuart, Bowron, Seymour, Late Stuart, Quesnel, and Birkenhead (Table 3, column D). However for Case 2 (“Recent Productivity”) and Case 3 (“Productivity Equivalent to the 2005 Brood Year”), the forecasted returns of age-5 fish from these escapements has been reduced (see Age-4 and Age-5 Recruitment Forecasts in Methods) to account for the low productivity associated with the 2005 brood year (2009 returns). These calculations are consistent with the hypothesis that the low return of age-4 fish in 2009 is due to poor survival of the 2005 brood, not a shift in age-at-maturity.

SURVIVAL RATES (PRODUCTIVITY)

Total productivity for all Fraser Sockeye stocks combined has been declining since the 1990's (Figure 1 B). This decline in productivity coincides with variable total escapement (Figure 1 A). Most Fraser Sockeye stocks have experienced lower total productivity in $\log_e$(recruits-per-effective female spawners (R/EFS)) in the past four (2000- 2003) (Table 3, column F & Table 4, column E) to eight (1996-2003) brood years (Table 3, column E & Table 4, column D) relative to a 1980-2003 reference period (Table 4, column C). In contrast, total productivity for most stocks in the early part of the time series (up to 1979) was generally greater than this reference period (Table 4, column B). This reference period was selected since it represents a consistent number of years to compare across stocks with varying lengths of stock-recruitment data depending on when the time series begins.

The $\log_e$(R/EFS) productivity index describes total stock productivity. Other productivity indices that remove density dependent effects of spawner abundance in total $\log_e$(R/EFS) variability include Ricker model residuals (annual model predictions minus observations) and Kalman filtered (KF) Ricker model *a* parameter values (all described in Results). The KF Ricker *a* parameter values further remove short term variability in $\log_e$(R/EFS) productivity (Figure 2 & Figure 3). All three indices of productivity generally exhibit similar trends in productivity for most Fraser stocks (Figure 3). Marine productivity ($\log_e$(R/smolt)) for Chilko and Cultus Sockeye also exhibit similar decreasing trends (Figure 4 B). Only Chilko and Cultus Sockeye have data on smolt outmigration numbers required to partition total productivity into marine and freshwater.

For the 2005 brood year (2009 returns), productivity was amongst the lowest on record for most Fraser Sockeye stocks. At the time of this forecast, preliminary 2009 age-4 return data were available for only a select number of stocks (Figure 3). In particular, Summer Run stocks that were expected to return at high abundances experienced the lowest productivity on record for the 2005 brood year (2009 returns) (Figure 3 J. Chilko; K. Late Stuart; L. Quesnel; and M. Stellako). As a result of these low productivities, returns for 2009 fell below the 2009 forecast distribution's 10% probability level (Figure 5). The 2009 forecast assumed long term average productivities would persist through to 2009 given indicators of ocean productivity suggested that conditions for salmon survival had improved. Chilko marine survival had exhibited coincidental increases in the 2004 brood year (2006 ocean entry and 2008 returns) from the previous brood year (DFO 2009).

In freshwater similar decreasing trends in productivity have generally not been observed, although it is important to note that this observation is based on limited freshwater data. Only Chilko Sockeye has a long term, consistent time series of smolt outmigration data. For Chilko, freshwater production has been exceptional in recent years, although given this system is unique within the Fraser River watershed (high altitude, glacial system) it is not an indicator of freshwater production across all Fraser Sockeye stocks. Other stocks with juvenile data at the fry stage also provide some indication of early freshwater productivity. For stocks with fry data, early freshwater production (fry/EFS) was above the cycle average for Quesnel and Weaver and similar to the cycle average for Early Stuart, Nadina, and Late Shuswap.

FORECASTS

Pre-season forecasts of salmon abundance are generally highly uncertain due the combination of historical variability in annual survival rates (stochastic uncertainty) and uncertainty regarding future survival rates (Cass et al. 2006 and Haeseker et al. 2008). Most Fraser Sockeye forecasts are based on the number of spawners four years prior, therefore, stochastic uncertainty includes variability in survival rates across the entire life cycle from egg to adult. Furthermore, it is typical for forecasts to assume that future survival will be similar to the average survival across all years of historical data. Such assumptions lead to additional uncertainty when actual survival rates deviate from the long term average. For example, the extremely low productivities for most stocks that returned in 2009 (Figure 3) resulted in returns associated with low probabilities (<10%), assuming long-term average stock productivities (Figure 5). Thus, Fraser Sockeye forecasts for 2010 are especially uncertain given the decreasing trends in productivity for most stocks in recent years and, in particular, the unexpectedly poor returns in 2009. Consequently, this paper quantifies the effects of both stochastic uncertainty and uncertainty in future Sockeye survival on expected 2010 return abundances for Fraser Sockeye.

Uncertainty that is attributed to stochastic (random) variability in annual Fraser Sockeye survival rates is communicated in the 2010 forecast paper through a series of forecasted values that correspond to standardized cumulative probabilities (10%, 25%, 50%, 75%, 90%) (Figure 10). For example, there would be a one in four chance at the 25% probability level forecast that the actual number of returning Sockeye will be at or below the forecasted value given the assumptions about future survival. In this paper, note that communication of different probabilities conveying the uncertainty of the forecast has changed from previous year's forecasts. Historically, probabilities were described as "the probability of exceeding the specified forecast" with the lowest probability level associated with the highest forecast. In the 2010 forecast, probabilities were described as "the probability of returning below the specified forecast". In this arrangement, the lowest probability levels are now associated with the lowest forecast. This new format is more appropriate from a conservation perspective.

Uncertainty about future Fraser Sockeye survival is communicated in this paper through the presentation of three alternative cases (forecast tables) to characterize stock productivity for the 2010 returns:

- **Case 1.** "Long Term Average Productivity" assumes that average stock productivity (across entire stock-recruitment time series) will persist through to 2010 (Table 2). Methods and model ranks were identical to the 2009 forecast (DFO 2009).
- **Case 2.** "Recent Productivity" assumes that recent productivity trends will persist through to 2010 (Table 3). To forecast age-4 recruits, this case includes the addition of three new models that consider recent productivity. Model performance was evaluated in recent years only (brood years 1997-2004). Age-5 recruits were forecast using preliminary productivity for the 2005 brood year (2009 returns).
- **Case 3.** "Productivity Equivalent to the 2005 Brood Year (2009 Returns)" assumes this low productivity will re-occur in 2010 (Table 5). Age-4 and age-5 recruits were forecast using preliminary productivity for the 2005 brood year (2009 returns).

Note: At the time of this paper, the 2005 brood year productivity data used to forecast age-5 recruits in the Case 2 forecast and age-4 and age-5 recruits in the Case 3 forecast were preliminary and do not include the age-5 recruits that will return in 2010. In addition, 2009 returns were not available for all 19 stocks individually and final age-structure, abundance, and stock identification of returns were also not available.

METHODS

DATA SOURCES

Biological Data

Annual estimates of Sockeye spawning escapement, fry or smolt abundance (if and when available), and recruits by stock are the primary data used to forecast Fraser Sockeye returns for the 19 forecasted stocks. For miscellaneous stocks, only escapement data are available without paired recruitment data. For most stocks with stock-recruitment data, the time series by brood year extends from 1948 to 2003 with the following exceptions: Fennell (1967-2003), Gates (1968-2003), Nadina (1973-2003), Scotch (1980-2003), Portage (1953 to 2003) and Weaver (1966-2003). For these stocks, earlier data were omitted due to gaps in the time series (Fennell, Scotch, Portage) or because of the effect of spawning channels which began operation in the late 1960's (Gates, Weaver) or late 1970's (Nadina). The last brood year when all recruitment data are available is 2003; age-5 recruitment data by stock from the 2004 brood year that returned in 2009 were not available in time for this publication. Escapement data used in the forecast are effective female spawners (EFS): the product of the number of female spawners and the proportion of eggs (0%, 50%, or 100%) that were successfully spawned based on spawning ground carcass surveys.

Juvenile data are used for the following six stocks: Chilko (smolt), Cultus (smolt), Weaver (fry), Nadina (fry), Quesnel (fall fry) and Late Shuswap (fall fry). Because Chilko juvenile production has been exceptionally high in recent years it would be inappropriate to use EFS data to generate forecasts, therefore, only smolt data were considered for Chilko as predictor variables in biological models (brood years 1949-2008). Similarly, because Cultus Sockeye are enhanced through hatchery production, only smolt data are appropriate to use in biological models. The intermittent smolt time series for Cultus goes back to 1950. Cultus smolt data includes both total number of smolts (wild + hatchery produced) migrating through the Sweltzer Creek enumeration fence plus hatchery produced smolts released downstream of the fence.

Fry data used in the forecast data set for Weaver (brood years 1968-present) and Nadina (brood years 1972-present) include both channel and creek data. In recent years when no fry assessments have been conducted for the creeks in these two systems, creek fry have been estimated by multiplying the EFS enumerated in the brood year by the past average number of fry produced-per-EFS for each creek. Quesnel and Late Shuswap juvenile data only begins in the mid-1970's and annual assessments are intermittent resulting in numerous gaps in the juvenile time series. Therefore, it was not possible to evaluate models relying on Late Shuswap and Quesnel fry data retrospectively and comparisons of fry model forecast outputs must take into consideration these time series effects. Such analyses could be done in future years if alternative evaluation methods (e.g. jack-knife) were used.

Juvenile data not used in forecast models includes the following three stocks: Gates (fry), Early Stuart (fry), and Stellako (fry). Although fry data are collected for Gates and Early Stuart, due to inconsistencies in data collection these data can only be used as an index of fry abundance. Stellako has a very short fry time series from brood years 1991-2003.

In order to provide a visual overview of the biological data input for the models, different biological values such as brood year EFS and productivity ($\log_e$(R/EFS) or $\log_e$(R/smolt)) have been colour coded in Tables 3 & 4 depending on if they are below, above, or on the average.

The time period used to estimate the average and standard deviation for EFS is from the 1980-2003 brood years (1980-2008 for smolts). This time period was selected since it represents a consistent number of years to compare across stocks with varying lengths of stock-recruitment data depending on when the time series begins. The time series average minus half the standard deviation is used to set the lower bound (any value falling below this lower bound is coded red: below average) and the time series average plus half the standard deviation is used to set the upper bound (any value falling above this upper bound is coded green: above average) (Trudel, M., DFO Research Scientist, pers. comm.). Values falling within the upper and lower bounds are coded yellow: average. A similar colour coding will be used for the forecasted returns.

Escapement and wild smolt (Cultus and Chilko) data are provided by DFO Fraser Stock Assessment (DFO, Keri.Benner@dfo-mpo.gc.ca), channel fry data (Nadina and Weaver) are provided by DFO Oceans, Habitat & Enhancement Branch (DFO, Roberta.Cook@dfo-mpo.gc.ca), data for Cultus hatchery smolt numbers and spawner success are obtained by DFO Oceans, Habitat and Enhancement Branch (Stuart.Barnetson@dfo-mpo.gc.ca), hydroacoustic fry data (Late Shuswap and Quesnel) are provided by DFO Salmon and Aquatic Freshwater Ecosystem Section (DFO, Jeremy.Hume@dfo-mpo.gc.ca), and recruitment data are provided by the Pacific Salmon Commission (PSC) (Lapointe@psc.org).

Environmental Data

In additional to biological data on the stocks, several models incorporate environmental data listed below:

1. Pacific Decadal Oscillation (PDO): a broad index of sea surface temperature (SST) in the North Pacific (Mantua et al. 1997); http://jisao.washington.edu/pdo/PDO.latest

2. Sea-Surface-Temperature (SST): data were sampled at lighthouse locations that are thought to best represent conditions experienced by juveniles during their initial stages of migration in the marine environment in the juvenile ocean entry year. The two locations are Entrance Island (Strait of Georgia, proximate to Nanaimo) and Pine Island (NE corner of Vancouver Island).

> **A. Entrance Island:** average SST data (April to June) in the Strait of Georgia where juvenile Fraser Sockeye first enter the marine environment.
> http://www.pac.dfo-mpo.gc.ca/sci/OSAP/data/SearchTools/Searchlighthouse_e.htm
> **B. Sea-Surface-Temperature (SST) Pine Island:** average SST data (April to July) on the northern tip of Vancouver Island (see previous web link).

4. Fraser discharge (peak and average April to June mean discharge): http://www.wsc.ec.gc.ca/hydat/H2O/

PRODUCTIVITY INDICES

For each stock, annual estimates for three productivity indices were calculated: $\log_e$(R/EFS), Ricker model residuals (deviations in observed stock-recruitment data from the Ricker model fit) and KF Ricker model *a* parameter values (Peterman et al. 1998; Dorner et al. 2008). Details on the methodology are described in Peterman et al. 1998 and Dorner et al. 2008. Supplementary data including code for estimating KF Ricker *a* parameter values are available on the National Research Council of Canada, Canadian Journal of Fisheries and Aquatic Science site for the Dorner et al. (2008) paper (http://pubs.nrc-cnrc.gc.ca/rp-ps/suppD.jsp?jcode=cjfas&ftl=f08-094&lang=eng).

To compare of all three productivity indices both within and between stocks, all indices were standardized to a mean of 0 and a standard deviation of 1.

FORECAST TABLES

CASE 1 "Long-Term Average Productivity" Table

The Case 1 ("Long-Term Average Productivity") forecast uses methodology identical to those described in the 2009 Fraser Sockeye forecast paper (DFO 2009). Specifically, model ranks for the 2010 Case 1 forecast uses the first ranked model from the retrospective analysis conducted for the 2009 forecast that uses the entire retrospective time series to calculate performance measures. The three new models used in Case 3 ("Productivity Equivalent to the 2005 Brood Year") forecast (described below) are not used in Case 1 forecast; only models used in the 2009 forecast were used. Age-5 recruits were also forecasted using the 2009 forecast methodology. It was assumed that age-5 recruits would experience average recruitment as opposed to the low recruitment assumed in Case 2 ("Recent Productivity") and Case 3 ("Productivity Equivalent to the 2005 Brood Year") forecasts. The entire stock-recruitment time series was used to generate forecasts for Case 1. Models, age-4 and age-5 recruitment forecasts, and retrospective analysis are described in detail below the overall description of the three cases.

CASE 2 "Recent Productivity" Forecast Table

The Case 2 ("Recent Productivity) forecast varies in methodology from previous year's forecasts and the Case 1 ("Long-Term Average Productivity") forecast. Specifically, this forecast incorporates three new models (RS4yr, RS8yr and KF) that take into account the recent decrease in productivity experienced by most Fraser Sockeye stocks. In addition, the Case 2 retrospective analysis calculates performance measures across all models for a truncated time period (1997-2004 brood years), as opposed to half the time series for Case 1 forecasts and forecasts conducted in previous years (DFO 2009). Therefore, model selection for the Case 2 forecasts focused on which models performed best in the recent low productivity period. In addition, given productivity from the 2005 brood year was extremely poor (low numbers of age-4 recruits in 2009), the Case 2 forecast incorporates this preliminary productivity data to forecast age-5 recruits in 2010 (model 12 in Appendix 1 and detailed in subsequent sections). This assumes that age-5 recruits likely experienced similar poor survival conditions to age-4 recruits that returned in 2009 given they come from the same brood year (2005) and same ocean entry year (2006). To generate Case 2 age-5 recruitment forecasts, a variant of the RS1 (Equation 12 in Appendix 1) was used. The entire stock-recruitment time series was used to generate forecasts for the Case 2 forecast table. Models, age-4 and age-5 recruitment forecasts, and retrospective analysis are described in detail below the overall description of the three cases.

CASE 3 "Productivity Equivalent to the 2005 Brood Year" Table

The Case 3 ("Productivity Equivalent to the 2005 Brood Year") forecast uses preliminary data on productivity (R/EFS or R/smolt) associated with the 2005 brood year (that resulted in 2009 poor returns). This approach is identical to Case 2 ("Recent Productivity") age-5 recruitment forecasts, but extends this method to include age-4 recruitment forecasts. For a number of stocks, particularly Summer Run stocks that were predicted to return at high abundances, productivity for the 2005 brood year was amongst the lowest on record. To generate Case 3 age-4 and age-5 recruitment forecasts, a variant of the RS1 (Equation 12 in Appendix 1) was used.

For Cases 2 and 3 note: At the time of this paper, 2009 returns were not available for all 19 stocks individually and final age-structure, abundance, and stock identification of catch and escapement were also not available. In addition, total productivity associated with the 2005 brood year, also does not include the age-5 component that will return in 2010.

NON-PARAMETRIC MODELS

Nineteen Forecasted Stocks with Escapement (Stock) and Recruitment Data

Non-parametric models forecast future returns based on the historical time series without requiring parameter estimation. Five non-parametric models were considered that do not include spawner (or juvenile) abundance as predictor variables (Cass et al. 2006; Haeseker et al. 2008). An additional six non-parametric models forecast returns by multiplying spawner (or juvenile) abundance and recruits-per-spawner averaged over different time periods. For the Case 2 ("Recent Productivity") forecast only, two (RS4yr and RS8yr) of these six models are new to the 2010 forecast. They are variants of the RS1 and RS2 models used since 2006 (Cass et al. 2006) and are meant to account for recent changes in productivity. Forecast distributions for non-parametric models are estimated as residual error for each model. All non-parametric models are described in Appendix 1.

Miscellaneous Stocks with Escapement Data Only

Miscellaneous stock forecasts were produced only for Case 2 ("Recent Productivity"). Since miscellaneous stocks do not have associated recruitment data they can only be forecasted using non-parametric models and in addition borrow information from similar stocks within the same run timing group. Forecasts for miscellaneous stocks are the product of the EFS in the brood year and the R/EFS for forecasted stocks with paired stock-recruitment data that are in the same run timing group and occupy a similar geographic area. Specifically, South Thompson miscellaneous stocks used the average R/EFS for Scotch and Seymour; North Thompson miscellaneous stocks used the average R/EFS for Raft and Fennell; Nahatlach and Chilliwack miscellaneous stocks used the average R/EFS for Early Summer run timing stocks; and Non-Shuswap (Harrison Lake rearing) miscellaneous stocks used the average R/EFS for Weaver. To account for the recent decline in Fraser Sockeye productivity, the $\log_e$(R/EFS) time series for these miscellaneous stocks are truncated to include only the last eight years. Forecast distributions are estimated using the $\log_e$ mean and standard deviation of the stock-recruitment time series for associated stocks.

BIOLOGICAL MODELS (FOR NINETEEN FORECASTED STOCKS)

In contrast to non-parametric models, biological models (e.g., Ricker, power, or Larkin) forecast returns based on relationships between spawners (or juveniles) and recruits and require parameter estimation. Only stock-recruitment models include environmental variables as covariates. For the Case 2 ("Recent Productivity") forecast, one new Ricker model using a Kalman filter (KF) to estimate the changing productivity has been added to the list of biological models (Peterman et al. 1998; Dorner et al. 2008). A sibling model (age-3 jack recruits vs age-4 recruits) was also added to the suite of models for Case 2. The sibling model, however, was used to compare forecasts between models only and was not assessed retrospectively given it was added at the end of the 2010 forecast process. Bayesian prior probability distributions for the biological model parameters are presented in Appendix 2. Bayes posterior parameter distributions for the biological models were estimated using WinBUGS (Bayesian software Using Gibbs Sampling) (WinBUGS is available on the following website: http://www.mrc-bsu.cam.ac.uk/bugs/welcome.shtml). The R statistical software and the BRugs library were used to automate the analysis (R is available on the following website: http://www.biostat.umn.edu/~brad/software/BRugs/). In each trial the MCMC burn-in length was set to 20,000 samples from the posterior distribution. A further 20,000 MCMC samples were taken to approximate the posterior probability distributions of the model parameters and associated forecast. All biological models are described in Appendix 2.

AGE-4 AND AGE-5 RECRUITMENT FORECASTS

Most Fraser Sockeye stocks are comprised of age-4 (of 4_2) and age-5 (5_2) fish, therefore, the total number of returning recruits in 2010 (for example) is the sum of the forecasted number of age-4 recruits produced from the spawners in the 2006 brood year and the age-5 recruits produced from spawners of the 2005 brood year. In order to generate a forecast for the age-4 recruits, the total number of recruits (age-4 + age-5) produced by spawners from the 2006 brood year are multiplied by the average stock-specific proportion of age-4 recruits (Appendix 3). For miscellaneous stocks, average age-4 proportions were calculated from the recent stock-recruitment time series for associated stocks.

Age-5 recruitment forecasts varied depending on the forecast Case. For Case 1 ("Long-Term Average Productivity"), identical methods to previous years' forecasts were used to forecast age-5 recruits. Specifically, the total number of recruits (age-4 + age-5) produced by spawners from the 2005 brood year are multiplied by the average stock-specific proportion of age-5 recruits (Appendix 3). For Cases 2 ("Recent Productivity") and 3 ("Productivity Equivalent to the 2005 Brood Year"), however, age-5 recruits were forecast using the poor productivities associated with the 2005 brood year. For many stocks including Chilko, Quesnel, and Stellako, productivity (marine survival for Chilko or R/EFS for all other stocks) was the lowest on record. Since age-5 recruits returning in 2010 are from the same brood year as the age-4 recruits that returned 2009 and all entered the ocean in 2007, the age-5 recruits were assumed to have experienced similar poor survival conditions. Therefore, to generate the 2010 age-5 recruits forecast for Cases 2 and 3, the 2005 brood year in the stock-recruitment data series was updated to include preliminary age-4 recruitment data in 2009 (obtained from preliminary 2009 return data from the Pacific Salmon Commission: October 27, 2009). Productivity (R/EFS or R/smolt in the case of Chilko) from the 2005 age-4 recruits was used in a one year (RS1yr or RJ1yr in the case of Chilko) model to forecast 2005 age-5 recruits returning in 2010 (Equation 12, Appendix 1). This model is a variant of the RS4yr or RS8yr models and all are described in Appendix 1 (equations 10-12). For miscellaneous stocks, the preliminary R/EFS associated with 2009 returns for associated stocks were used to forecast age-5 recruits.

A similar adjustment also did not apply to Harrison since this stock does not produce age-5 fish. Unlike all other stocks, the Harrison stock is comprised of varying proportions of age-3 (3_1) fish and age-4 (4_1) fish. Therefore, forecasted returns for the upcoming year (e.g. 2010) are calculated by summing the age-3 (2007 brood year) and age-4 recruit (2006 brood year) forecasts. The proportion of Harrison recruits that return as three or four year olds is highly variable, with higher percentages of age-4 fish (~65%) during odd years when pink salmon are also spawning in this system. Therefore, the proportion of recruits that return as age-3 and age-4 Sockeye is calculated separately for even and odd years for the Harrison stock (Appendix 3). Cultus Sockeye age-5 recruits were also not adjusted since marine survival in the 2005 brood year (~1%) was similar to the recent average.

RETROSPECTIVE ANALYSIS

Forecast performance for candidate models was evaluated using retrospective analysis that compared forecasted returns to estimated (observed) returns (Appendices 4-6). Model inputs were initialized with data from the first half of the stock-recruitment data series and forecasts were generated sequentially for each brood year in the second half of the time series with data that would have been available in each forecast year updated (Cass et al. 2006; Haeseker et al. 2005 & 2008).

Four performance measures (PM's) were used to rank each model's performance: mean raw error (MRE), mean proportional error (MPE), mean absolute error (MAE) and root mean square error (RMSE) (Appendix 4; Cass et al. 2006; Haeseker et al. 2005 & 2008). Each model was ranked for each of the four PM's from best to worst for each stock, with a score of 1 being the best performance; the smaller the differences between the absolute value of forecasted return minus observed return, the better a model performed. For each stock, all four ranks were then averaged to produce a single rank for each model (Appendices 4 & 5). Performance of all models by stock across the full retrospective time period are presented in Appendix 6.

For Case 1 ("Long-Term Average Productivity"), performance measures were calculated over the entire retrospective time series identical to previous year's forecasts (Cass et al. 2006; DFO 2009) (Appendix 6). No retrospective analyses were required for Case 3 ("Productivity Equivalent to the 2005 Brood Year"). For Case 2 ("Recent Productivity), however, to capture recent model performance for the forecasted stocks, performance measures were calculated over a shorter time series (1997-2004 brood years) (Appendices 5-6). In recent years, most stocks have experienced lower productivity ($\log_e$(R/EFS)) relative to the longer time series average from 1980 to 2003 (Table 3, columns E-F; Table 4, columns D-E & Figures 1-4). Cultus is the only exception, where the full retrospective time series was used since the time series is quite intermittent and short. For all retrospective analyses, age-4 recruitment data were included for the 2004 brood year to provide an extra data point in this recent lower productivity period. This assumes that the age-5 component makes up a relatively small proportion of total recruits.

Alternative methods of ranking forecast models, including using cross validation (Adkison & Peterman 1999) or jack-knife approaches to calculate performance measures, would result in a different rank order of forecasts. In addition, simulation modelling could be conducted to assess model performance over varying productivity regimes, such as the recent decreases in productivity observed for Fraser Sockeye. Rank order is also influenced by which PM (s) are used (Haeseker et al. 2008). Given the sensitivity of rank order to different approaches, a wide variety of model forecasts were compared and the underlying assumptions for these models were evaluated. These assumptions include how different models take into consideration variables such as recent stock productivity, brood year escapement and freshwater production (when available).

FORECAST RESULTS

PRODUCTIVITY INDICES

Several productivity indices that combine freshwater and marine mortality are compared across 18 forecasted stocks (Cultus could not be compared due to hatchery enhancement in recent years). The three indices include $\log_e$(R/EFS), Ricker model residuals calculated as the deviations of the model's annual predictions and observations, and the Ricker model *a* parameter values (Ricker 1975) estimated annually using a Kalman filter procedure (KF Ricker *a* parameter) (Peterman et al. 1998 & 2003; Dorner et al. 2008; Figures 2 & 3). The $\log_e$(R/EFS) productivity index describes total stock productivity. The remaining two indices remove density dependent effects of spawner abundance in the total $\log_e$(R/EFS) variability. The KF Ricker *a* parameter values further remove short term variability in $\log_e$(R/EFS) productivity (Figure 2 & Figure 3). Overall, all three indices exhibit similar broad trends in productivity with the KF Ricker *a* parameter time series smoothed relative to the $\log_e$(R/EFS) and Ricker residuals (Figure 3). Both Ricker residuals and $\log_e$(R/EFS) largely overlap despite the fact that the Ricker residuals remove the effects of density dependence due to spawner abundance and $\log_e$(R/EFS) does not.

Most stocks have experienced a general decreasing trend in productivity. Seven stocks have experienced decreasing trends starting in the 1960's-1970's (Figure 2 & Figure 3 A. Early Stuart; B. Bowron; C. Fennell; D. Gates; E. Nadina; I. Seymour; P. Portage). Six populations including the four Summer Run stocks have experienced decreasing trends starting in the 1980's-1990's (Figure 2 & Figure 3 F. Pitt; J. Chilko; K. Late Stuart; L. Quesnel; M. Stellako; R. Birkenhead). Raft, Late Shuswap and Weaver have not exhibited declining trends in the annual KF Ricker *a* parameter values (Figure 2 & Figure 3 G, O & Q). For these last three stocks, all variability in $\log_e$(R/EFS) was attributed by the KF Ricker model *a* parameter values to short-term variability (noise) rather than long-term systematic trends (signal) (Dorner et al. 2008). The KF Ricker *a* parameter and the Ricker residual trends differ from those presented in Dorner et al. 2008 since in the current report they are estimated using EFS rather than total escapement and also include an additional 10 years of data. Harrison is the other exception that exhibits increasing trends in all three indices of productivity (with the exception of the 2005 and 2006 brood years that exhibited below average productivity) in recent years (Figure 2 & Figure 3 N).

The percentage decrease in R/EFS calculated as e^a (where a is the KF Ricker model annual *a* parameter values) (Table 1) has been greater than 40% (average: 66%) for stocks exhibiting declining trends. The percentage change is calculated as the difference from the maximum to minimum data point as a percentage of the maximum data point. These high percentages are comparable to those calculated by Dorner et al. (2008) for Sockeye stocks including Fraser Sockeye. The percentage decrease in the last four years on average has been 19% and the last eight years 33%.

To understand which broad ecosystem is driving changes in stock productivity, total survival can be partitioned into freshwater and marine survival if both outmigrating smolt and adult return data are available. For Fraser Sockeye, only Chilko and Cultus Sockeye stocks have both smolt and adult return data. It is important to note that marine survival estimates generally include some freshwater mortality in the Fraser River between the time smolts are counted exiting their rearing lakes and when they enter the marine environment. Chilko freshwater production has been exceptional and the number of outmigrating smolts in the 2005 (77 million age-1 smolts) and 2006 (71 million age-1 smolts) brood years were well above average (1980-2006 brood years: 24 million age-1 smolts) (Figure 4 A). The percent increase from the lowest freshwater survival on record in 1998 (0.8%) to the 2006 brood year (9%) was approximately 1000%. For Cultus, although the number of EFS has been particularly low in recent years, hatchery supplementation of both fry into Cultus Lake and smolts in Sweltzer Creek (downstream of Cultus Lake) has increased the number of outmigrating smolts to above average in the recent time series.

Both Chilko and Cultus have experienced particularly low marine survival (below their cycle average) in the past four to eight brood years (Figure 4 B). The percentage decrease for both stocks from their peaks in the mid-1980's to the 2005 brood year (2009 returns) is 98%.

INDICATORS OF RETURNS

In recent years, indicators of ocean conditions for Fraser Sockeye productivity were presented in Fraser Sockeye forecast papers (DFO 2009). Most of these indicators for the 2008 ocean entry year for Fraser Sockeye returning in 2010 (including sea-surface-temperature, upwelling, and zooplankton biomass) suggest that ocean conditions were good for early marine survival (Crawford & Irvine 2009). However, in 2007 these indicators also suggested ocean conditions were good and yet returns in 2009 for Fraser Sockeye that entered the ocean in 2007 as smolts were extremely poor (Crawford & Irvine 2008). Since the current suite of indicators are specific to the broader North Pacific or localized to the West Coast of Vancouver Island instead of the Strait of Georgia where Fraser Sockeye first enter the ocean, alternative indicators for Fraser Sockeye are the subject of ongoing work.

Jacks (age 3_2) recruits have been used to provide some indication of return strength of the subsequent year's age-4 recruits (age 4_2). Jacks come from the same brood year and, therefore, experienced the same conditions during early growth and development in both the freshwater and marine environment as the age-4 recruits, but return one year earlier. There has been an increasing trend in delayed maturation in recent years, with jack proportions contributing less to total recruitment than historically (Holt & Peterman 2004). As a result, the relationship between age-3 and age-4 recruits was compared for the recent time series (brood years 1980-2003) only (Figure 8). For this relationship, data with zero age-3 jacks were removed from the time series. For most stocks there is a weak positive relationship between age-3 and age-4 recruits. The age-3 to age-4 recruitment relationship was a bit stronger (R^2>0.3) for the following stocks: Scotch (R^2=0.5), Seymour (R^2=0.5), Chilko (R^2=0.3), Late Stuart (R^2=0.4), Quesnel (R^2=0.4), Stellako (R^2=0.4), Late Shuswap (R^2=0.8), Birkenhead (R^2=0.5) (Figure 8). A sibling jack model was added to the suite of models for the Case 2 ("Recent Productivity") forecast. Preliminary jack data were obtained from near-final estimates of escapements in 2009 since jack recruitment data (escapement plus catch) were not available at the time of this forecast. The 50% probability level forecasts for this model by stock are presented in Figure 8 and probability distributions are presented in Table 6 (sibling (jack) forecasts).

2010 FORECAST

Fraser Sockeye forecasts are highly uncertain (Cass et al. 2006; Haeseker et al. 2008) and vary depending on the assumptions underlying the chosen forecast models. The 2009 forecast is an example of this, with Fraser Sockeye returns falling below the 10% probability forecast (Figure 5). Returns in 2009 were associated with amongst the lowest productivity on record for most stocks. At the time of the 2009 forecast, improvements to stock productivity were assumed given ocean indicators suggested that ocean conditions had improved and increases in stock productivity (Chilko marine survival) were observed in the previous brood year.

The forecast with the greatest degree of belief (as recommended by the March 9, 2010 Canadian Science Advisory Secretariat (CSAS) Regional Advisory Process (RAP)) was Case 2: “Recent Productivity”. For 2010, the Case 2 forecast assume that conditions that resulted in poor productivity for a number of stocks in the past four to eight brood years will continue through to 2010. Based on this assumption, the number of returning Fraser Sockeye in 2010 will range from 7,028,000 to 18,315,000 (25% to 75% probability levels) (Table 3). The same probability range each of the four run timing groups are as follows: Early Stuart Run: 26,000-66,000; Early Summer Run: 374,000-1,601,000; Summer Run: 1,605,000-4,343,000; and Late Run 5,023,000-12,305,000 (Table 3).

Although there is considerable uncertainty (widest probability distributions of all forecasts) associated with Case 2 sibling (jack) forecasts (Table 6), the sibling (jack) models (Table 6) are generally similar to the Case 2 (“Recent Productivity”) forecast models (Table 6, shaded model) at the 50% probability level. This is particularly important for Late Shuswap that dominates return abundances in the 2010 Case 2 forecast (Table 3). The sibling model forecast was similar for Late Shuswap (age-4 recruits: 6.3 million) relative to the Case 2 Ricker-cyc forecast (age-4 recruits: 7.3 million) (Table 6). For Chilko, that is also contributing a relatively large number of returns to the Case 2 forecast (Table 3), the sibling model forecast was also similar (age-4 recruits: 1.2 million) to the Case 2 RJ4yr forecast (age-4 recruits: 1.9 million) (Table 6). Sibling model age-4 forecasts (Table 6) compared to Case 2 models’ age-4 forecasts (Table 6, shaded models) were similar also for Nadina, Seymour, Quesnel, Cultus, Portage, and Weaver. The sibling models were higher for Gates and Late Stuart and lower for Pitt, Scotch, and Birkenhead (Table 6).

In addition to the Case 2 (“Recent Productivity”) forecast table that assumes recent productivity for most stocks (Table 3), two additional forecast tables were produced that include Case 1 (“Long-Term Average Productivity”) and Case 3 (“Productivity Equivalent to the 2005 Brood Year (2009 Returns)”) (Tables 2 & 5) (Figure 11). Under the Case 1 Scenario, the total forecast would range from 8,351,000 to 23,541,000 (25% to 75% probability levels) (Table 2 & Figure 11 A). The Case 1 (“Long-Term Average Productivity”) total forecast does not deviate significantly from the Case 2 (“Recent Productivity”) forecast (Tables 2 & 3). This is because the 2010 Case 2 forecast abundance is dominated by Late Shuswap (Late Run), a stock that has not exhibited similar declines in productivity compared to other stocks (Figure 3 O). The biggest differences between Case 1 (Table 2) and Case 2 (Table 3) forecasts were in the Early Stuart, Early Summer and Summer Run timing groups (Figure 11 B-D) that comprise a considerably smaller fraction of the total forecast and have experienced decreases in productivity in recent years (Figure 3 A-I).

Under Case 3 (“Productivity Equivalent to the 2005 Brood Year”), the forecast would range from 1,562,400 to 7,877,000 (25% to 75% probability levels) (Table 5; Figure 11 A). This forecast is considerably lower than the Case 1 forecast given productivity in the 2005 brood year (2009) return year was amongst the lowest on record for many stocks. The biggest differences in the forecast distributions are for the Summer Run stocks that experienced, in particular, the lowest productivity in the 2005 brood year on record (Figure 11 D; Figure 3 J-M). There was a smaller difference between alternative forecast for the Late Run stocks because they did not experience the same magnitude of declines in productivity compared to other stocks in the 2005 brood year (2009 returns) (Figure 11 E).

CASE 2 (“RECENT PRODUCTIVITY”) FORECAST

To account for the lower productivity observed for most stocks, three new models were added to the suite of models used in previous years for the Case 2 (“Recent Productivity”) forecasts: two non-parametric models (RS4yr & RS8yr) and one biological model (KF: uses a Kalman Filter approach to estimate the Ricker *a* parameter). Model performance was compared using retrospective analysis restricted to the 1997-2004 brood years for the calculation of performance measures. For stocks that have exhibited long term decreasing trends in productivity starting in the early 1960’s-1970’s (Figure 3 A. Early Stuart; B. Bowron; C. Fennell; D. Gates; E. Nadina; I. Seymour; P. Portage), each of these three new models performed the best across all models (they ranked in the top five for an average of 70% of these stocks) (Figure 6 A). All other models for these stocks performed considerably poorer (they ranked in the top five for an average of 20% of these stocks) (Figure 6 A). In contrast, for stocks that have exhibited decreasing productivity trends starting more recently in the 1980’s-1990’s (Figure 3 F. Pitt; J. Chilko; K. Late Stuart; L. Quesnel; M. Stellako; R. Birkenhead), the RS4yr model performed the best across all models for all performance measures (the RS4yr ranked in the top five for an average of 50% of these stocks) (Figure 6 B). The KF and RS8yr did not perform as well as the RS4yr (the KF & RS8yr ranked in the top five for an average of 25% of these stocks) but generally performed better than all other models (all other models ranked in the top five for an average of 20% of these stocks) (Figure 6 B). For stocks that have not exhibited a declining trend (Figure 3. G. Raft, O. Late Shuswap, Q. Weaver), the new models never ranked in the top five for these stocks (Figure 6 C). Instead other biological models (e.g. Ricker, power, Larkin) ranked consistently highest (they ranked in the top five for an average of 50% of these stocks) (Figure 6 C).

Given productivity has declined generally from a peak earlier in the times series (Figure 1), sensitivity analysis was conducted to compare all models’ performance using the full stock-recruitment time series and a truncated time series (brood years 1980-2003) for two stocks, Early Stuart and Late Shuswap. This was to assess whether or not model performance would improve when the earlier, more productive, period in the stock recruitment time series was removed (Table 4, column B). Early Stuart and Late Shuswap were compared given they deviate in their systematic productivity trends based on annual KF Ricker *a* parameter values (Figure 3 A & O). Early Stuart Sockeye have exhibited declining trends in productivity starting in the 1970’s (Figure 3 A) and Late Shuswap Sockeye have not exhibited systematic declining trends (Figure 3 O). Generally, model ranks did not change significantly for these stocks when the length of the stock recruitment time series was varied (Figure 7 A & B). There were some improvements in the performance of biological models for Early Stuart, however, the new models that accounted for recent declines in productivity (RS4yr, RS8yr and KF) still outperformed these models (Figure 7 A). For Late Shuswap, there was no real change to the rank order of models under either scenario (Figure 7 B).

Forecast error (predicted – observed returns) for each of the forecasted stocks for the entire retrospective analysis time period (~1980-2004 brood years depending on the stock) and the restricted period (1997-2004 brood years), suggest that when the RS4yr and RS8yr models performed well over the restricted period they did not necessarily perform as well relative to other models over the full period (Appendix 6). Therefore, although these new models are appropriate to consider in the current lower productivity period, their performance will have to be re-evaluated if stock productivities improve.

EARLY STUART SOCKEYE

The brood year escapement for Early Stuart of 15,900 EFS was similar to the cycle average of 16,900 EFS from the 1980-2005 brood years (Table 3, column C). This brood year is the first of three weaker cycles following the dominant cycle of the previous year (2005 brood year). Spawning success in the brood year was below average (90%); physical conditions (water levels and temperature) on the spawning grounds were generally conducive to successful spawning. Juvenile fry data, used as an index of juvenile abundance, indicate that early freshwater survival in the brood year (770 fry/EFS) was similar to the cycle average from 1990-2005 (735 fry/EFS). Average total productivity (R/EFS) for this stock has declined steadily from a peak in the mid-1960's (~35 R/EFS) (Table 4, column B-E) (Figures 2 & 3 A). In recent years (brood years: 1996-2003), average productivity has been less than one third (3.8 R/EFS; Table 4, column D) of the early time series average prior to 1980 (brood years 1948-1979: 12.8 R/EFS, Table 4, column B). The lowest productivity during this period has occurred in the past four brood years (brood years: 2000-2003: 2.5 R/EFS) (Table 4, column E) (Figures 2 & 3 A).

The top ranked model (RS4yr) based on retrospective analysis was used to generate the Case 2 ("Recent Productivity") 2010 age-4 return forecast for Early Stuart. All three top ranked models (RS4yr, RS8yr, & KF) account for recent decreases in productivity and produced similar forecasts (Table 6). These forecasts were less than one third of the Ricker and power model forecasts using the entire stock-recruitment time series. However, when the stock-recruitment time series was truncated to only include the past fourteen years (1990-2003), the Ricker and power models produced similar forecasts to the top ranked models (Table 6).

If the productivity of the 2006 brood is similar to the average of the last four years, there is a one in four chance (25% probability) that the 2010 return of Early Stuart will be less than 26,000 (1.6 R/EFS) and a three in four chance (75% probability) that the return will be less than 66,000 (4.2 R/EFS). In other words, if the productivity is similar to the average of the last 4 years, we would expect to see up to 26,000 adults returning to the Early Stuart in one out of four similar situations like this one, as defined by similar productivities and spawner abundances (Tables 3 & 4). The median (one in two chance: 50% probability) forecast of 41,000 (2.6 R/EFS) (Tables 3 & 4) falls below the cycle average returns for the brood years 1980-2006 (113,000).

Cases 1-3 compared: In contrast to the Case 2 ("Recent Productivity") forecast described above, the Case 1 ("Long-Term Average Productivity") Early Stuart forecast ranged from 85,000 to 213,000 at the 25% to 75% probability levels and the Case 3 ("Productivity Equivalent to the 2005 Brood Year") Early Stuart forecast ranged from 19,000 to 46,000 (Tables 2 & 5). The Case 1 forecast had the largest return forecast of all three cases and the Case 3 forecast had the smallest return forecast (Figure 11 B). The reasons for these differences are the Case 1 forecast includes historical, more productive periods in the stock-recruitment time series and the Case 3 forecast includes amongst the lowest productivity on record for Early Stuart (Figure 3 A).

EARLY SUMMER SOCKEYE

The Early Summer Run consists of several smaller populations that are usually less abundant that the Summer and Late Run stocks. Eight stocks in this timing group have individual forecasts: Bowron, Fennell, Gates, Nadina, Pitt, Raft, Scotch, and Seymour (Table 3). Of these stocks, the 2010 return year is a dominant cycle for Scotch and Seymour. Escapement in the 2006 brood year was 168,000 EFS for this run-timing group which was above the cycle average of 102,000 EFS (Table 3) Most of these stocks had brood year escapements close to their cycle averages (Gates, Pitt, Raft, Seymour) or at least double their cycle averages (Fennell, Nadina, and Scotch). Bowron was the one exception, with a brood year escapement that was less than 25% of the cycle average. The total EFS for the Early Summer Run, including the miscellaneous stocks (miscellaneous North Thompson, North Thompson River, miscellaneous South Thompson, Dolly Varden/Chilliwack Lake, and Nahatlach) is 206,154.

Spawning success for the Early Summer run aggregate in the 2006 brood year was below average (93%). Despite water levels being at or near record lows for the duration of the Early Summer spawning period in most areas of the watershed in 2006, Sockeye were generally reported to be in good condition on their arrival to the spawning grounds. Although water levels were noted to be either restricting or limiting access to Sockeye at many of the smaller streams, peak water temperatures remained within acceptable ranges for the duration of the spawning period.

Bowron: The 2006 brood year escapement for Bowron (600 EFS) was less than the cycle average of 2,700 EFS (Table 3, column C). In recent years (brood years: 2000-2003), average total productivity has been approximately one sixth (1.9 R/EFS) of the early time series average prior to 1980 (brood years 1948-1979: 12.7 R/EFS) (Table 4, column E & B) (Figures 2 & 3 B).

The first ranked model (RS4yr) was used to generate the Case 2 (“Recent Productivity”) 2010 age-4 return forecast for Bowron. Given productivity for Bowron has declined particularly in the last five years, the top ranked models (RS4yr and KF) produced similar low forecasts (Table 6). The RS4yr (#1) model’s forecast was significantly lower than the Ricker and power models using both the full and truncated (1990-2003) stock-recruitment time series (Table 6).

Given the assumptions underlying the RS4yr model are correct, Bowron for 2010 has a one in four chance (25% probability) of returning below 700 (1.1 R/EFS) and a three in four chance (75% probability) of returning below 2,500 (3.9 R/EFS). The median (one in two chance: 50% probability) forecast of 1,300 (2.0 R/EFS) falls below the cycle average returns (20,000) (Tables 3 & 4).

Fennell: The 2006 brood year escapement for Fennell (8,000 EFS) was double the cycle average (4,000 EFS) (Table 3, column C). Total productivity for Fennell was highest prior to 1980 (brood year average from 1967-1979 was 30.7 R/EFS) (Table 4, column B) (Figures 2 & 3 C). The subsequent decrease in productivity has been relatively small in Fennell from 8.4 R/EFS (1980-2003 brood year average) to 7.4 R/EFS (2000-2003 brood years) (Table 4, column C & E) (Figures 2 & 3 C).

As Fennell has not experienced changes in productivity to the same extent as other stocks during the reference period 1980-2003 (Table 4, column C) (Figures 2 & 3 C), models assuming changes in productivity (RS4yr, RS8yr and KF) were outperformed by models assuming average productivity (Table 6). The first ranked model (power) was used to generate the Case 2 (“Recent Productivity”) 2010 age-4 return forecast for Fennell. The top two ranked models (RAC & TSA) produced similar forecasts. The forth ranked model (R2C) produced a forecast almost double these forecasts due to an almost four times greater than average recruitment in the 2002 brood year. The top two ranked model forecasts were also similar to the forecasts from the KF, Ricker, RS8yr, and Ricker and power models using a truncated stock-recruitment time series (1980-2003 brood years) (Table 6).

Given the assumptions underlying the power model are correct, Fennell for 2010 has a one in four chance (25% probability) of returning below 16,000 (2.0 R/EFS) and a three in four chance (75% probability) of returning below 56,000 (7.0 R/EFS). The median (one in two chance: 50%

probability) forecast of 31,000 (3.9 R/EFS) is above the cycle average returns (20,000) (Tables 3 & 4).

Gates: The 2006 brood year escapement for Gates (1,500 EFS) was similar to the cycle average (1,800 EFS) (Table 3, column C). Total productivity for Gates was highest prior to 1980 (brood year average from 1968-1979 was 33.8 R/EFS) and subsequently decreased to a lower average (13.0 R/EFS from 1980-2003) (Table 4, column B & C; Figures 2 & 3 D). In the last four brood years (2000-2003), productivity was even lower (average 7.2 R/EFS) (Table 4, column E) (Figures 2 & 3 D).

The first ranked model (KF) was used to generate the Case 2 ("Recent Productivity") 2010 age-4 return forecast for Gates. Given the lower productivity observed in Gates in the last four to eight years, the top three ranked models (KF, RS8yr & RS4yr) generated similar forecasts that were close to half the forecast abundance of other models including the power, Ricker and Larkin models (Table 6). However, when the stock-recruitment time series was truncated (1990-2003) to account for recent lower productivity, the power and Ricker models produced similar forecasts to the top three ranked models (Table 6).

Given the assumptions underlying the KF model are correct, Gates for 2010 has a one in four chance (25% probability) of returning below 4,000 (2.7 R/EFS) and a three in four chance (75% probability) of returning below 17,000 (11.3 R/EFS). The median (one in two chance: 50% probability) forecast of 9,000 (6.0 R/EFS) falls below the cycle average returns (17,000) (Tables 3 & 4).

Nadina: The 2006 brood year escapement for Nadina (4,500 EFS) was nearly triple the cycle average (1,800 EFS) (Table 3, column C). Juvenile fry data used as an index of juvenile abundance indicate that early freshwater survival in the brood year (1,600 fry/EFS) was similar to the cycle average (1,500 fry/EFS). In recent years (1996-2003 brood years), average total productivity has been consistently lower (6.6 R/EFS) than the earlier time series prior to 1980 (average of 14.6 R/EFS for brood years 1973-1979) (Table 4, column D & B) (Figures 2 & 3 E).

The first ranked model (Ricker-FrD-mean) was used to generate the Case 2 ("Recent Productivity") 2010 age-4 return forecast for Nadina, which was higher than the second ranked model (Ricker-Ei) and similar to the third ranked model (Ricker) (Table 6). Forecast using the fry data were about two thirds of the estimates based on the first ranked model, but the KF fry model had a low average rank (17; Table 6).

Given the assumptions underlying the Ricker-FrD model are correct, Nadina for 2010 has a one in four chance (25% probability) of returning below 16,000 (3.6 R/EFS) and a three in four chance (75% probability) of returning below 60,000 (13.3 R/EFS). The median (one in two chance: 50% probability) forecast of 30,000 (6.7 R/EFS) is similar to the cycle average returns (22,000) (Tables 3 & 4).

Pitt: The brood year escapement for Pitt in 2005 (for age-5 recruits returning in 2010: 33,000 EFS) and 2006 (for age-4 recruits returning in 2010: 20,000 EFS) are respectively above and similar to average escapement from 1980-2005 (17,000 EFS) (Table 3, column D & C); Pitt has a greater proportion of age-5 recruits (~70%) relative to age-4 recruits. Pitt productivity was relatively high prior to 1980 (brood year average 1948-1979: 11.3 R/EFS) and subsequently declined (1980-2003 average: 6.8 R/EFS) (Table 4, column B & C) (Figures 2 & 3 F). In the last four to eight years further declines in productivity (Table 4, column D & E) have coincided with larger brood year EFS.

The first ranked model (Ricker) was used to generate the Case 2 ("Recent Productivity") 2010 age-4 return forecast for Pitt (Table 6). Despite the lower productivity in recent years for Pitt Sockeye, the Ricker model's retrospective performance was superior to models that take recent productivity into consideration including the KF (#10), RS4yr (#16) and RS8yr (#17) (Table 6).

Given the assumptions underlying the Ricker model are correct, Pitt for 2010 has a one in four chance (25% probability) of returning below 12,000 (0.6 R/EFS) and a three in four chance (75% probability) of returning below 53,000 (2.7 R/EFS). The median (one in two chance: 50% probability) forecast of 26,000 (1.3 R/EFS) is one third of the average returns from 1980-2008 (60,000) (Tables 3 & 4). Note the productivity associated with this forecast is lower than the average productivities over recent years presented in Tables 3 & 4. This is because Pitt has a much higher age-5 proportion than other stocks, and we assumed that these age-5 fish experienced poor marine survival based on the low marine survival experienced by the age-4 fish that outmigrated at the same time and returned in 2009 (see Methods Age-4 and Age-5 Recruitment Forecasts).

Raft: The 2006 brood year escapement for Raft (3,400 EFS) was about 30% greater than the cycle average (2,600 EFS) (Table 3, column C). Productivity was variable throughout the time series and has exhibited no systematic trends (Figure 3 G).

The first ranked model (Ricker-PDO) was used to generate the Case 2 ("Recent Productivity") 2010 age-4 return forecast for Raft. Most models produced similar forecasts with the exception of the RS4yr (#17) model that produced a forecast that was approximately half of all other forecasts (Table 6). The recent productivity decline captured by the RS4yr model, however, coincides with higher brood year escapements (15,000-30,000) and, therefore, is likely linked to density-dependence. The 2006 brood year escapement, however, is average relative to the time series.

Given the assumptions underlying the Ricker-PDO model are correct, Raft for 2010 has a one in four chance (25% probability) of returning below 13,000 (3.8 R/EFS) and a three in four chance (75% probability) of returning below 42,000 (12.4 R/EFS). The median (one in two chance: 50% probability) forecast of 24,000 (7.1 R/EFS) is similar to the cycle average returns (16,000) (Tables 3 & 4).

Scotch: The 2006 brood year escapement for Scotch (73,000 EFS) was nearly triple the cycle average (24,000 EFS) (Table 3, column C). This is a dominant cycle year for Scotch. Productivity was greatest in the early time series and subsequently declined (Figures 2 & 3 H). In the last eight brood years, the population has exhibited relatively stable recruitment (average 8.4 R/EFS), which is similar to the average from 1980-2003 (11.9 R/EFS) (Table 4, column D & C) (Figures 2 & 3 H). The return abundance for Scotch has been increasing on this cycle and the maximum observed to date occurred in the 2006 brood year (700,000 returns).

The first ranked model (KF) was used to generate the Case 2 ("Recent Productivity") 2010 age-4 return forecast for Scotch. The KF model produced a forecast that was approximately two thirds of most other forecasts (Table 6); all other models produced similar forecasts to each other. The brood year returns and escapement were the greatest ever observed for this stock. Given the shorter stock-recruitment time series (1980-2003), information on carrying capacity for this stock is limited. Therefore, forecasts from stock-recruitment models (i.e. KF, power, Ricker) of return at higher spawning abundances are particularly uncertain for this stock.

Given the assumptions underlying the KF model are correct, Scotch for 2010 has a one in four chance (25% probability) of returning below 106,000 (1.5 R/EFS) and a three in four chance (75% probability) of returning below 640,000 (8.8 R/EFS). Return forecasts at the higher abundance end of the forecast distribution (75% probability levels and above) are forecasting abundances well above the maximum returns previously observed for this stock (~700,000); however, carrying capacity estimates are limited for this stock. The median (one in two chance: 50% probability) forecast of 265,000 (3.6 R/EFS) is above the cycle average returns (248,000) (Tables 3 & 4).

Seymour: The 2006 brood year escapement for Seymour (57,000 EFS) was similar to the cycle average (46,000 EFS) (Table 3, column C). This is the dominant cycle year for Seymour. Productivity has been variable throughout the time series with the average productivity from 1949-1979 (average R/EFS: 16.4) greater than more recent brood years (1980-2003 average of 8.1 R/EFS) (Table 4, column B & C) (Figures 2 & 3 I). Productivity was particularly low in the past four brood years (2000-2003 average of 4.7 R/EFS) (Table 4, column E) (Figures 2 & 3 I).

The first ranked model (RS4yr) was used to generate the Case 2 ("Recent Productivity") 2010 age-4 return forecast for Seymour. This forecast was similar to models that took into account the lower productivity observed for this stock in recent years including the RS8yr, KF, and also the Ricker and power models using a truncated stock-recruitment time series (1990-2003) (Table 6). The RS4yr forecast was close to half or even one third of all the other model forecasts (Table 6).

Given the assumptions underlying the RS4yr model are correct, Seymour for 2010 has a one in four chance (25% probability) of returning below 101,000 (1.8 R/EFS) and a three in four chance (75% probability) of returning below 380,000 (6.7 R/EFS). The median (one in two chance: 50% probability) forecast of 195,000 (3.4 R/EFS) is less than the cycle average returns (393,000) (Tables 3 & 4).

Cases 1-3 compared: The total Case 2 ("Recent Productivity") Early Summer Run forecast (detailed stock-by-stock above) ranged from 374,000 to 1,601,000 at the 25% to 75% probability levels (Table 3). In contrast to the Case 2 forecast described above, the Case 1 ("Long-Term Average Productivity") Early Summer forecast ranged from 723,000 to 3,544,000 at the 25% to 75% probability levels and the Case 3 ("Productivity Equivalent to the 2005 Brood Year") Early Summer ranged from 141,400 to 698,000 (Tables 2 & 5). The Case 1 forecast had the largest return forecast of all three cases and the Case 3 forecast had the smallest return forecast (Figure 11 C). The reasons for these differences are the Case 1 forecast includes historical, more productive periods in the stock-recruitment time series and the Case 3 forecast includes amongst the lowest productivity on record for Early Summer Run stocks (Figure 3 B-I).

SUMMER RUN SOCKEYE

The Summer Run consists of four stocks: Chilko, Late Stuart, Quesnel and Stellako (Table 3). Escapement in the 2006 brood year was 446,000 EFS for these four stocks which was below the cycle average of 843,000 EFS (Table 3, column C). Chilko comprised the largest percentage of this total escapement (59%), followed by Quesnel (20%), Stellako (18%), and Late Stuart (3%). For the duration of the 2006 Summer Run spawning period, water levels on the spawning grounds were at or near record lows in all areas of the watershed. However, Sockeye were generally reported to be in good condition on their arrival to the spawning grounds. Despite low water levels that possibly restricted or limited Sockeye accessing several of the smaller streams, water temperatures remained within acceptable ranges for the duration of the spawning period.

Chilko: The 2006 brood year escapement for Chilko (260,000 EFS) was similar to the cycle average (290,000 EFS). Juvenile production in Chilko Lake, however, has been exceptionally high in the 2005 (77 million age-1 smolts) and 2006 (71 million age-1 smolts) brood years (Table 3, column D & C). These smolt numbers are four times the cycle average (24 million age-1 smolts) from brood years 1980-2006, and are also greater than the largest smolt number observed in this system prior to 2005 (40 million age-1 smolts in the 1995 brood year). Smolt body sizes have also been either larger than or similar to (88.4 and 81.9 mm in brood years 2005 and 2006, respectively) the long term average (83.0 mm from 1954 to 2008 outmigrating years). Given the large number of smolts outmigrating in recent years, only models using smolt data were considered; biological models that include EFS as predictor variables and non-parametric models that summarize returns were not considered. Furthermore, given the extremely large smolt abundance estimates from Ricker and power models fit to smolt data were not considered valid because of the need to extrapolate beyond the range of the historical data.

Marine survival for Chilko has been particularly low in the last eight brood years (3-4% marine survival) relative to the 1980-2003 average (9%) (Table 4, column D & C; Figure 4 B). Marine survival for Chilko observed in the 2009 returns was the lowest on record based on an unprecedented number of Chilko smolts in the 2005 brood year (77 million age-1 smolts). If this low marine survival is assumed to be a result of high density-dependent mortality that occurred post-smolt outmigration from Chilko Lake, then marine survival for the 2006 brood year (71 million age-1 smolts) should be similar to the 2005 brood year. Using the R/EFS observed for the 2005 brood year to predict age-4 recruits in 2010, the forecast would be 217,000 at the 50% probability level. Alternatively, preliminary recruitment from poor 2009 returns that resulted from the large smolt outmigration was added to the stock-recruitment time series to update the 2004 and 2005 brood years and a Ricker model that includes a carrying capacity parameter was used to generate a forecast of 900,000 at the 50% probability level (Table 6). One caveat to using a Ricker model with a carrying capacity parameter for a smolt-to-recruit relationship is that the true capacity in the marine environment would be set by all smolts in the system rather than just Chilko smolts.

For the Case 2 (“Recent Productivity”) 2010 forecast, we however assumed that the extreme mortality observed in 2009 was not solely attributed to high smolt densities but a consequence of other factors that affected most Fraser Sockeye stocks returning in 2009. Therefore, the 2010 forecast assumes that survival will be closer to the recent average over the past four years.

The first ranked model (RJ4yr) was used to generate the Case 2 (“Recent Productivity”) 2010 age-4 return forecast for Chilko. The RJ4yr model multiplied the brood year smolts by the mean recruits-per-smolt over the previous four brood years (Equation 10, Appendix 1). This forecast was similar to most of the other model forecasts, with the exception of the power model that produced much higher forecasts (Table 6). For Chilko, the Sibling (jack) model produced a 50% probability level forecast that was similar to the RJ4yr (#1) model forecast (Table 6).

Given the assumptions underlying the RJ4yr model are correct, Chilko for 2010 has a one in four chance (25% probability) of returning below 1,273,000 (2% marine survival) and a three in four chance (75% probability) of returning below 3,011,000 (4% marine survival). The median (one in two chance: 50% probability) forecast of 1,958,000 (3% marine survival) is similar to the cycle average returns (1,900,000) (Tables 3 & 4).

Late Stuart: The 2006 brood year escapement for Late Stuart (14,000 EFS) was only about one third of the cycle average (44,000 EFS) (Table 3, column C). The 2006 brood year is the first of three weaker cycles following the dominant cycle of the previous brood year (2005). Productivity has been variable throughout the time series up to 1979 (average: 32.5 R/EFS) (Table 4, column B). In recent years (1996-2003), productivity has been particularly low (average: 7.5 R/EFS) and has dropped even further in the last four brood years (2000-2003 average: 3.3 R/EFS) (Table 4, column D & E) (Figures 2 & 3 K).

The third ranked model (RS8yr) was used to generate the Case 2 ("Recent Productivity") 2010 age-4 return forecast for Late Stuart since data for the first ranked model (LLY) was not available at the time of this forecast. The second ranked model (RAC) was also not used given the 2006 brood year escapement was below average and this forecast would be too high for the average productivity on this cycle in the last four brood years (4.3 R/EFS). Given the lower productivity in recent years, the third (RS8yr), fourth (RS4yr) and sixth (KF) ranked models, which all account for this lower productivity, produced forecasts that were substantially lower than other model forecasts. These three models were also similar to the power and Ricker model forecasts using a truncated stock-recruitment time series (1990-2003); all these models capture the lower productivity for this stock in recent years (Table 6).

Given the assumptions underlying the RS8yr model are correct, Late Stuart for 2010 has a one in four chance (25% probability) of returning below 21,000 (1.5 R/EFS) and a three in four chance (75% probability) of returning below 169,000 (12.1 R/EFS). The median (one in two chance: 50% probability) forecast of 60,000 (4.3 R/EFS) is below the cycle average returns (396,000) (Tables 3 & 4).

Quesnel: The 2006 brood year escapement for Quesnel (90,000 EFS) was below the cycle average (430,000 EFS) (Table 3, column C). This brood year was historically the first of three weaker cycles following the dominant cycle of the previous brood year (2005). However, starting in the 1980's the dominant cycle (2005 cycle) started increasing substantially in abundance and age-5 recruits from the dominant cycle started to build up the first cycle (2006 cycle). Although the dominant 2005 cycle started declining from its peak in 1989 of 12 M to the 2009 return of 200,000, the 2006 sub-dominant cycle has only declined starting in 2006 to 800,000 returns from an average return in the previous four cycle years of 3.4 M. Quesnel total productivity in the past eight brood years (1996-2003) has coincidentally declined (average: 4.7 R/EFS) relative to the 1980-2003 brood year average (13.8 R/EFS) (Table 4, column D & C) (Figures 2 & 3 L). Fry production also declined from a 1986 brood year maximum of 154 fall fry/EFS to an average of 47 fall fry/EFS in 1990-2002. The decline in productivity coincides with large escapements that were well above average in these years on the larger dominant and subdominant cycles.

Since EFS abundance in the 2006 brood year (2010 age-4 recturns) is below average and associated juvenile production increased to 168 fall fry/EFS (average weight 3.1 g) compared to the 1986 to 2002 cycle average of 68 fall fry/EFS (average weight 3.5 g), the Case 2 ("Recent Productivity") model selected to generate the 2010 age-4 return forecast was the KF (Table 6). This model captures broader trends in productivity and because it is a biological model it includes the below average EFS abundance as a predictor variable. Other top ranked models, that either do not incorporate recent broad changes in productivity (Larkin (#2)) or do not incorporate the below average EFS as a predictor variable (RAC (#1), R1C (#3) or R2C (#5)), produced higher forecasts than the KF. Alternatively, models that use average recent R/EFS but do not consider the associated higher brood year EFS abundances (in 2001 and 2002) as a contributing factor to this reduction in productivity (e.g. RS4yr (#4)) produced lower forecasts than the KF model (Table 6).

The return forecast of the seventh ranked model (KF) is similar to the Ricker and power models using a truncated stock-recruitment time series (1990-2003) (Table 6). The KF forecast was also similar to an average R/EFS model for three specific years (1995, 1999, 2003) that have relatively similar brood year escapements and freshwater production (fall-fry/EFS) to the 2006 brood year (age-4 recruitment forecasts). For Quesnel, the Sibling (jack) model produced a 50% probability level forecast that was similar to the KF model used to forecast Case 2 returns for 2010 (Table 6).

Given the assumptions underlying the KF model are correct, Quesnel for 2010 has a one in four chance (25% probability) of returning below 215,000 (2.4 R/EFS) and a three in four chance (75% probability) of returning below 909,000 (10.1 R/EFS). The median (one in two chance: 50% probability) forecast of 438,000 (4.9 R/EFS) falls well below the cycle average returns (2.2 million) (Tables 3 & 4). It should however be highlighted that forecasts for Quesnel are substantially different when using different model assumptions which would on average have produced better forecasts based on the retrospective analysis. It is however believed that for the 2010 forecasts these assumptions are less suitable than the assumptions underlying the KF model (considers lower brood year escapement and associated productivity unlike non-parametric models and biological models). The substantial difference among the forecasts for Quesnel from the different models highlights the large uncertainty of the forecast for this stock.

Stellako: The 2006 brood year escapement for Stellako (80,000 EFS) was similar to the cycle average (79,000 EFS) (Table 3, column C). Stellako experienced a decline in productivity in recent years (average of 1996-2003 brood years: 3.6 R/EFS) relative to the productivity of earlier years (average of 1948-1979 brood years: 12.9 R/EFS) (Table 4, column D & B). In the last four brood years (2000-2003) Stellako experienced particularly low productivity (average: 2.3 R/EFS) (Table 4, column E) (Figures 2 & 3 M).

The first ranked model (RS4yr) was used to generate the Case 2 (“Recent Productivity”) 2010 age-4 return forecast for Stellako. This forecast was approximately three quarters of the forecasts produced by other models that take into account change in productivity, KF(rank #2) and RS8yr (rank #10), and nearly half the forecasts from the Ricker and power models using a truncated stock-recruitment time series (1990-2003). Alternative models based on average productivity, produce forecasts that are nearly three times as large as the RS4yr forecast (Table 6).

Given the assumptions underlying the RS4yr model are correct, Stellako for 2010 has a one in four chance (25% probability) of returning below 96,000 (1.4 R/EFS) and a three in four chance (75% probability) of returning below 254,000 (3.6 R/EFS). The median (one in two chance: 50% probability) forecast of 156,000 (2.2 R/EFS) falls below the cycle average returns (563,000) (Tables 3 & 4).

Cases 1-3 compared: The total Case 2 (“Recent Productivity”) Summer Run forecast (detailed stock-by-stock above) ranged from 1,605,000 to 4,343,000 at the 25% to 75% probability levels. In contrast to the Case 2 forecast described above, the Case 1 (“Long-Term Average Productivity”) Summer Run forecast ranged from 2,304,000 to 6,981,000 at the 25% to 75% probability levels and the Case 3 (“Productivity Equivalent to the 2005 Brood Year”) Summer

Run forecast ranged from 159,000 to 548,000 at the 25% to 75% probability levels (Tables 2 & 5). The Case 1 forecast had the largest return forecast of all three cases and the Case 3 forecast had the smallest return forecast (Figure 11). The reasons for these differences are the Case 1 forecast includes historical, more productive periods in the stock-recruitment time series and the Case 3 forecast includes amongst the lowest productivity on record for Summer Run stocks (Figure 3 J-M).

LATE RUN SOCKEYE

The Late Run consists of six stocks: Cultus, Harrison, Late Shuswap, Portage, Weaver, and Birkenhead (Table 3). The 2006 brood year is on a dominant cycle for the highly cyclic Late Shuswap stocks. Escapement for the Late Run stocks in the 2006 brood year was 1.4 million EFS, which was below the cycle average of 1.6 million (Table 3). In contrast, Harrison Sockeye EFS in the 2006 (91,000 EFS) and 2007 (57,000 EFS) brood years have been well above historical escapements; Harrison is comprised of age-4 (4_1) fish and age-3 (3_1). The miscellaneous Late Run stocks (Harrison Lake rearing) brood year EFS was 11,000. With the exception of Cultus, early arrival of Late Run stocks on the terminal spawning grounds was not observed in 2006; however, high levels of pre-spawn mortality were observed in several stocks. This abnormally high pre-spawn mortality at the terminal areas was observed throughout the entire duration of the run, with the highest pre-spawn mortality rates being observed on the latest arrivals. Extreme water levels were also experienced on the spawning grounds during the Late Run spawning period in 2006. For the bulk of the spawning period, water levels were at or near record lows in most areas of the watershed, with extreme flood conditions during the tail end of the spawning period in parts of the lower watershed that may have impacted Birkenhead production. The Late Run spawning success in 2006 is the lowest on record for this cycle (~80%).

Cultus: Although Cultus escapement was particularly low in the 2006 brood year (165 EFS) relative to the cycle average (5,000 EFS), hatchery supplementation (that commenced in the 2001 brood year) of both fry into Cultus Lake and smolts in Sweltzer Creek (downstream of Cultus Lake) has increased the number of outmigrating smolts in recent years. The number of smolts in the brood year (400,000 of which 65% were hatchery origin) was greater than both the cycle average (146,000) and the smolt abundance in the past three brood years (100,000 in each of these years) (Table 3, column C). Marine survival for Cultus has been particularly low in the last eight brood years (3% marine survival) relative to the 1980-2003 average (7%) (Table 4, column D & C; Figure 4 B). Jack abundance (age-3 recruits) has been informative in forecasting Cultus Sockeye returns (Wood and Parken 2004). The number of jacks that have returned to Cultus were relatively high at 736, compared to the recent time series. The last brood year jack numbers were above 100 was in 2002 (182 jacks) and in combination with brood year smolt numbers of 100,000, total recruits from this brood year was 5,000.

The smolt-jack model (Wood and Parken 2004) was used to generate the Case 2 ("Recent Productivity") 2010 forecast for Cultus. Models that use EFS as predictor variables, were excluded from the retrospective analysis. To account for the recent low marine survival for Cultus, the marine survival time series used in this model was truncated to the post-1998 period. The forecast produced by the smolt-jack model is similar to the forecast produced by the KF model but only half the smolt-jack model forecast produced using the full stock-recruitment time series to calculate marine survival (Table 6).

Given the assumptions underlying the smolt-jack model are correct, Cultus for 2010 has a one in four chance (25% probability) of returning below 6,000 (2% marine survival) and a three in four chance (75% probability) of returning below 14,000 (5% marine survival). The median (one in two chance: 50% probability) forecast of 9,000 (3% marine survival) is similar to the cycle average returns (18,000) (Tables 3 & 4).

Harrison: Escapement for Harrison was 91,000 EFS in the 2006 brood year (age-4 recruits in 2010) and 57,000 EFS in the 2007 brood year (age-3 recruits in 2010) (Table 3, column C & D). Harrison Sockeye have a unique life history in that they do not rear in lakes (instead they migrate to the ocean as fry) and have varying proportions of 4_1 relative to 3_1 fish (e.g. 4_1 proportions range from 10% to 90%). Productivity for Harrison has increased in recent years to an average of 24.1 R/EFS in the last 8 brood years (1996-2003) relative to earlier years (1948-1979 average: 13.0 R/EFS) (Table 4, column D & B) (Figures 2 & 3 N). Harrison high returns in 2009 occurred despite preliminary in-season data that indicate that Harrison Sockeye (~95% age 3_1 in 2009 returns) entered the ocean in the same year as most Fraser Sockeye (age 4_2) (Figure 3 N; solid square). Although returns were high in 2009, the associated productivity (from the 2006 brood year) was below average. Productivity in the 2005 brood year (2006 ocean entry year) for Harrison, the same brood year as most other Fraser Sockeye that returned in 2009, was also below average (Figure 3 N; hatched square).

The first ranked model (Ricker-FrD-mean) was used to generate the Case 2 ("Recent Productivity") 2010 forecast for Harrison (Table 6). This forecast is similar to the forecast of the second ranked model (Ricker-FrD-Peak), but almost double the forecast from the third model (KF). Alternative information exists to indicate that returns might be lower than estimated. The preliminary high return estimates (~200,000) of age-3 recruits from the same brood year that returned in 2009 could reduce the relative contribution of age-4 recruits returning in 2010. Given the variability in age-4 and age-3 age proportions, the Harrison forecast is therefore more uncertain. Furthermore, despite higher escapements in the brood year, escapement enumeration was conducted with relatively low precision visual survey (helicopter) methods thereby further increasing the uncertainty in the Harrison forecast.

Given the assumptions underlying the Ricker-FrD-mean model are correct, Harrison for 2010 has a one in four chance (25% probability) of returning below 97,000 (1.1 R/EFS) and a three in four chance (75% probability) of returning below 429,000 (4.8 R/EFS). The median (one in two chance: 50% probability) forecast of 195,000 (2.2 R/EFS) is greater than the 1980-2008 average of 58,000 (Tables 3 & 4).

Late Shuswap: The 2006 brood year escapement for Late Shuswap (1.2 M EFS) was similar to the cycle average (1.4 M EFS) (Table 3, column C). Freshwater production in the brood year (89 fall fry/EFS) was similar to the cycle average (76 fall fry/EFS) and brood year fall fry body sizes were slightly greater (2.7 g) than the cycle average (2.3 g). Total productivity on the 2006 cycle has been relatively consistent (Figure 3 O). One cycle (2005 cycle) out of the four cycles in particular has had much higher total productivity (average: 19.3 R/EFS) in the 1980-2003 brood years relative to the average of the three remaining cycles including the 2006 cycle (average: 7.4 R/EFS).

The first ranked model (Ricker-cyc) was used to generate the Case 2 ("Recent Productivity") 2010 age-4 return forecast for Late Shuswap. The Ricker model using only cycle line data seemed most appropriate because production on the 2006 cycle (1948-2003) has been relatively consistent and because the 2005 cycle has had much higher total productivity than the other three cycles. This forecast was similar to other top performing models at the 50%-probability level, but the distribution was narrower because the 2005 higher productivity cycle was excluded from the analysis (Table 6). The Ricker (Pi) model (#2) however produced a forecast estimate that is almost double the Ricker-cyc estimate. Models accounting for changes in productivity produced lower estimates, but performed very poorly in the retrospective analysis for Late Shuswap (Table 6). Similarly, the power model using fry data (data available only post-1973 and intermittent) and the Ricker and power models using a truncated stock-recruitment time series (1990-2003) across all cycles also produced lower forecasts (Table 6). For Late Shuswap, the Sibling (jack) model produced a 50% probability level forecast that was similar to the Ricker-cyc model (#1) (Table 6).

Given the assumptions underlying the Ricker-cyc model are correct, Late Shuswap for 2010 has a one in four chance (25% probability) of returning below 4,652,000 (4.0 R/EFS) and a three in four chance (75% probability) of returning below 10,791,000 (9.2 R/EFS). The median (one in two chance: 50% probability) forecast of 7,252,000 (6.2 R/EFS) is similar to the cycle average returns (7,640,000) (Tables 3 & 4). Thus far, no clear indication of a decrease in productivity has been observed for Late Shuswap. If it was assumed that the productivity of Late Shuswap is declining similarly to most other stocks, the 2010 forecast for Late Shuswap could be half this forecast. Jack data for Late Shuswap (Figure 8) provide some indication that the median forecast is reasonable given the return of ~38,000 jacks (based on escapement estimates only) to this system in 2009 which would predict a 4 yr old forecast of 6.3 M in 2010 (Table 6; Figure 8).

Portage: The 2006 brood year escapement for Portage (11,000 EFS) was greater than the cycle average (8,000 EFS) (Table 3, column C). Productivity was particularly high in the first part of the time series with an average of 50 R/EFS over the brood years 1953-1979 (Table 4, column B) (Figures 2 & 3 P). Subsequently, from 1980 to 2003, productivity has been consistently lower (average of 16.0 R/EFS) (Table 4, column C). The most recent four brood years (2000-2003) had particularly low productivity (8.0 R/EFS) (Table 4, column E) (Figures 2 & 3 P).

The second ranked model (KF) was used to generate the Case 2 (“Recent Productivity”) 2010 age-4 return forecast. Data for the LLY first ranked model were not available at the time of the forecast. The KF model forecast was less than two thirds of the forecasts produced by alternative models (Table 6).

Given the assumptions underlying the KF model are correct, Portage for 2010 has a one in four chance (25% probability) of returning below 18,000 (1.6 R/EFS) and a three in four chance (75% probability) of returning below 99,000 (9.0 R/EFS). The median (one in two chance: 50% probability) forecast of 42,000 (3.8 R/EFS) is less than the cycle average returns (90,000) (Tables 3 & 4).

Weaver: The 2006 brood year escapement for Weaver (14,000 EFS) was only one third of the cycle average (44,000 EFS) (Table 3, column C). Juvenile production in the 2006 brood year (3,406 fry/EFS) was more than double the cycle average (1,315 fry/EFS). Productivity has been relatively consistent over the time series (Table 4) (Figures 2 & 3 Q).

The first ranked model (Ricker-FrD-peak) was used to generate the Case 2 (“Recent Productivity”) 2010 age-4 return forecast. All top ranked models produced similar forecasts (Table 6). Forecasts from models using fry data were also similar.

Given the assumptions underlying the Ricker-FrD-peak model are correct, Weaver for 2010 has a one in four chance (25% probability) of returning below 126,000 (9.3 R/EFS) and a three in four chance (75% probability) of returning below 472,000 (34.7 R/EFS). The median (one in two chance: 50% probability) forecast of 264,000 (19.4 R/EFS) is less than the cycle average returns (690,000) (Tables 3 & 4).

Birkenhead: The 2006 brood year escapement for Birkenhead (140,000 EFS) was similar to the cycle average (110,000 EFS) (Table 3, column C). Productivity in brood years 1948 to 1979 was relatively high (average of 15.8 R/EFS) compared to recent years (1996 to 2003 average: 4.1 R/EFS) (Table 4, column B & D) (Figures 2 & 3 R).

The first ranked model (KF) was used to generate the Case 2 ("Recent Productivity") 2010 age-4 return forecast. The KF model produced a forecast lower than all other models including the RS4yr and RS8yr models (Table 6).

Given the assumptions underlying the KF model are correct, Birkenhead for 2010 has a one in four chance (25% probability) of returning below 52,000 (0.4 R/EFS) and a three in four chance (75% probability) of returning below 230,000 (1.7 R/EFS). The median (one in two chance: 50% probability) forecast of 109,000 (0.8 R/EFS) is lower than the cycle average returns (688,000) (Tables 3 & 4). Note the productivity associated with this forecast is lower than the average productivities over recent years presented in Tables 2 & 3. This is because Birkenhead has a higher age-5 proportion than other stocks (~30%), and we assumed that these age-5 fish experienced poor marine survival based on the low marine survival experienced by the age-4 fish that outmigrated at the same time and returned in 2009 (See Methods Age-4 and Age-5 Recruitment Forecasts).

Cases 1-3 compared: The total Case 2 ("Recent Productivity") Late Run forecast (detailed stock-by-stock above) ranged from 5,023,000 to 12,305,000 at the 25% to 75% probability levels. In contrast to the Case 2 forecast described above, the Case 1 ("Long-Term Average Productivity") Late Run forecast ranged from 5,239,000 to 12,803,000 at the 25% to 75% probability levels and the Case 3 ("Productivity Equivalent to the 2005 Brood Year") Late Run forecast ranged from 1,243,000 to 6,586,000 at the 25% to 75% probability levels (Tables 2 & 5). The Case 2 forecast was similar to the Case 1 forecast since Late Shuswap dominates Late Run returns and there have been no systematic decreases in Late Shuswap productivity (Figure 11 E and Figure 3 O). The Case 3 forecast was the lowest forecast of all three cases since productivity associated with the 2005 brood year was amongst the lowest on record for Late Run stocks (Figure 3 N-R).

DISCUSSION

Forecasts are associated with relatively high uncertainty, consistent with previous Sockeye forecast PSARC reviews (Cass et al. 2006) and recent research on coast-wide salmon stocks (Haeseker et al. 2007 & 2009). Fraser Sockeye forecasts for 2010 are especially uncertain given the decreasing trends in productivity for most stocks in recent years and, in particular, the unexpectedly poor returns in 2009. Both stochastic (random) uncertainty and uncertainty regarding future survival (productivity) associated with the 2010 Fraser Sockeye forecast is communicated in this paper. Uncertainty that is attributed to stochastic (random) variability in annual survival rates is communicated through a series of forecasted values that correspond to standardized cumulative probabilities (10%, 25%, 50%, 75%, 90%).

In addition to stochastic (random) uncertainty in the forecast estimate, the current document also tries to highlight the uncertainty about future Fraser Sockeye survival through the presentation of three Cases (forecast tables) that vary in their survival assumptions. The Case

2 “Recent Productivity” forecast (recommended for planning purposes by CSAS RAP March 9, 2010) ranged from 4,567,000 to 29,827,000 at the 10% to 90% probability levels. This wide range of uncertainty is not uncommon in salmon forecasts (Haeseker et al. 2007 & 2009; Cass et al. 2006). This forecast (Tables 3 & 4) assumes that the recent period of lower productivity will continue through to 2010 and implemented three new models that are based on recent productivity (R/EFS or R/smolt in last four and eight years and the KF model). For some stocks this decline in productivity has been pronounced and models assuming changes in productivity performed well. Other stocks such as Late Shuswap, have not shown a clear decline in productivity in recent years and, as a result, models that performed best do not take into consideration recent productivity. This does not mean, however, that a decline in the productivity of Late Shuswap is not possible given what has been observed for most other stocks in recent years. Similarly, the Case 2 (“Recent Productivity”) 2010 forecast for Chilko assumes that that 2009 age-4 marine survival was linked to some currently unknown factor(s) rather than a consequence of high smolt density and that 2010 survival will be closer to the recent average over the past four years. Therefore, depending on the assumptions underlying the selected forecast models, the 2010 forecast can change substantially.

In addition to the Case 2 (“Recent Productivity”) forecast, two alternative forecasts for 2010 are presented (Tables 2 & 5). If productivity is assumed for 2010 to be similar to the long-term average (rather than recent lower productivity), this forecast is presented in Table 2 (Case 1: “Long-Term Average Productivity”). Alternatively, if the 2009 (extremely poor) productivities are assumed for 2010, the associated forecasts are presented in Table 5 (Case 3: “Productivity Equivalent to the 2005 Brood Year”). The Case 1 and Case 2 total forecasts are similar since Late Shuswap, the driver of the 2010 return forecasts, has not exhibited systematic decreases in productivity. The Case 3 forecast is the lowest of all three Cases since 2009 was associated with amongst the lowest productivity for most Fraser Sockeye stocks.

Information to predict future Fraser Sockeye survival including environmental indicators and sibling relationships should help to decrease the uncertainty in the forecasts. However, currently environmental covariates (e.g. sea-surface temperature, Fraser discharge, etc.) included within the forecast models do not seem to consistently or significantly improve model performance when compared retrospectively. Efforts are currently being made to develop a suite of environmental indicators for Fraser Sockeye to assist with future forecasts. Sibling (jack) models provide some information on returning age-4 recruits but these predictions are generally more uncertain than the models currently being used to forecast Fraser Sockeye returns. Sibling (jack) models are also limited by recent smaller stock sizes and increased age-at-maturity that result in a smaller to negligible number of jacks returning for most Fraser Sockeye stocks in any given year.

In addition to improvements to Fraser Sockeye forecasts through the development of appropriate environmental indicators, future forecasts may also benefit from changes to methods used to rank forecast models. In the current paper, models were ranked using retrospective analysis (Cass et al. 2006; Haseker et al. 2007 & 2009). However, model ranking using retrospective analysis is quite sensitive to the performance measures used and the time period over which they are evaluated. Alternative methods of ranking forecast models that should be explored include the use of cross validation approaches (Adkison & Peterman 1999), jackknife approaches, or simulation modelling to assess model performance over varying productivity regimes, such as the recent decreases in productivity observed for Fraser Sockeye.

Regardless of the inclusion of new forecasting approaches described above, these recommendations are unlikely to significantly improve future forecast performance. The CSAS

RAP process concluded that the 2010 Fraser Sockeye forecast use the most appropriate and current methods currently available.

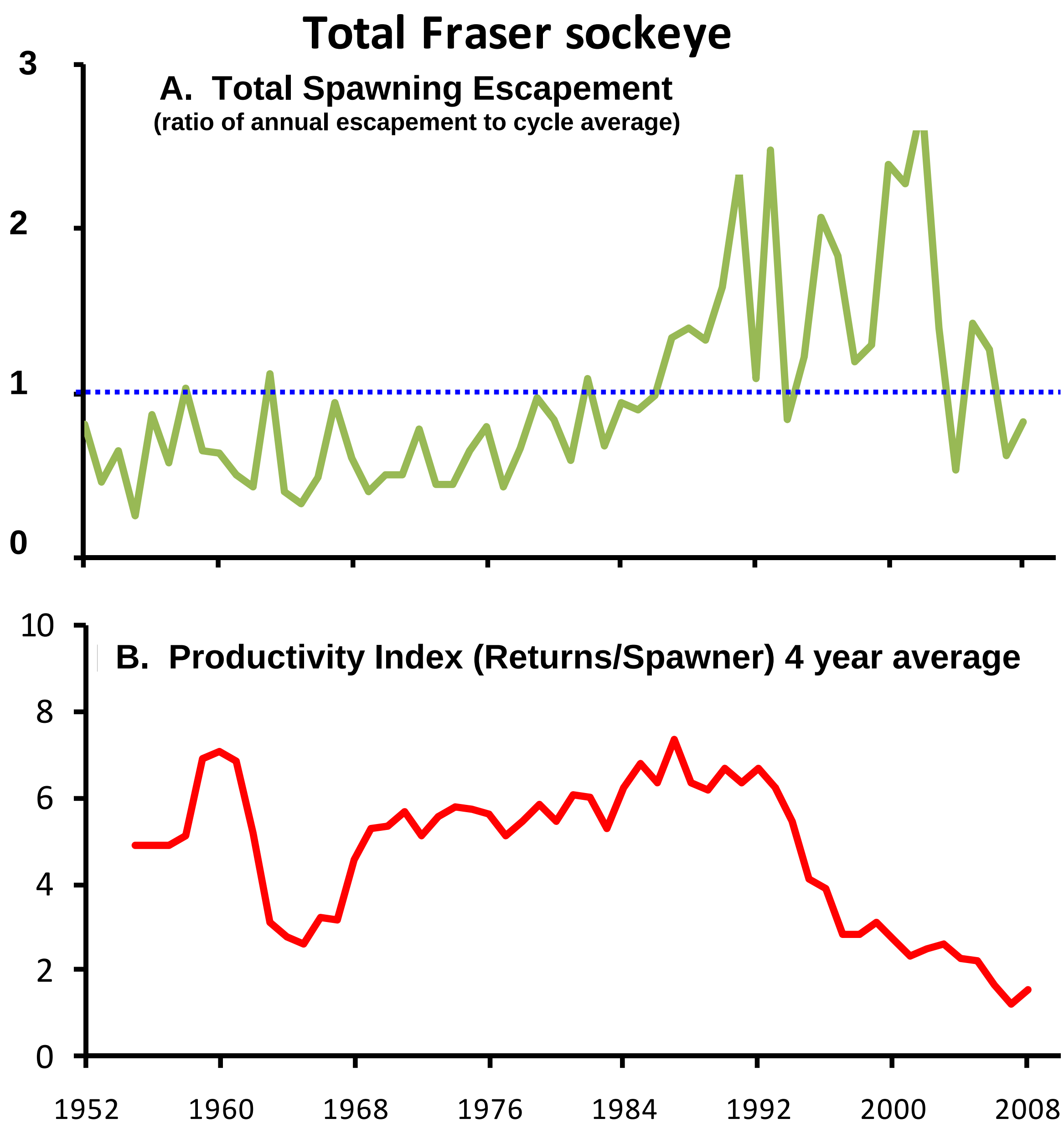


Figure 1. Time series of A. total spawning escapement (ratio of annual escapement to cycle average escapement) and B. productivity index (returns/spawner) smoothed using a running four year average. Note: In plot A, ratios above the blue (dashed) line are years when escapements are greater than the cycle average and ratios below the blue (dashed) line are years when escapements are below the cycle average.

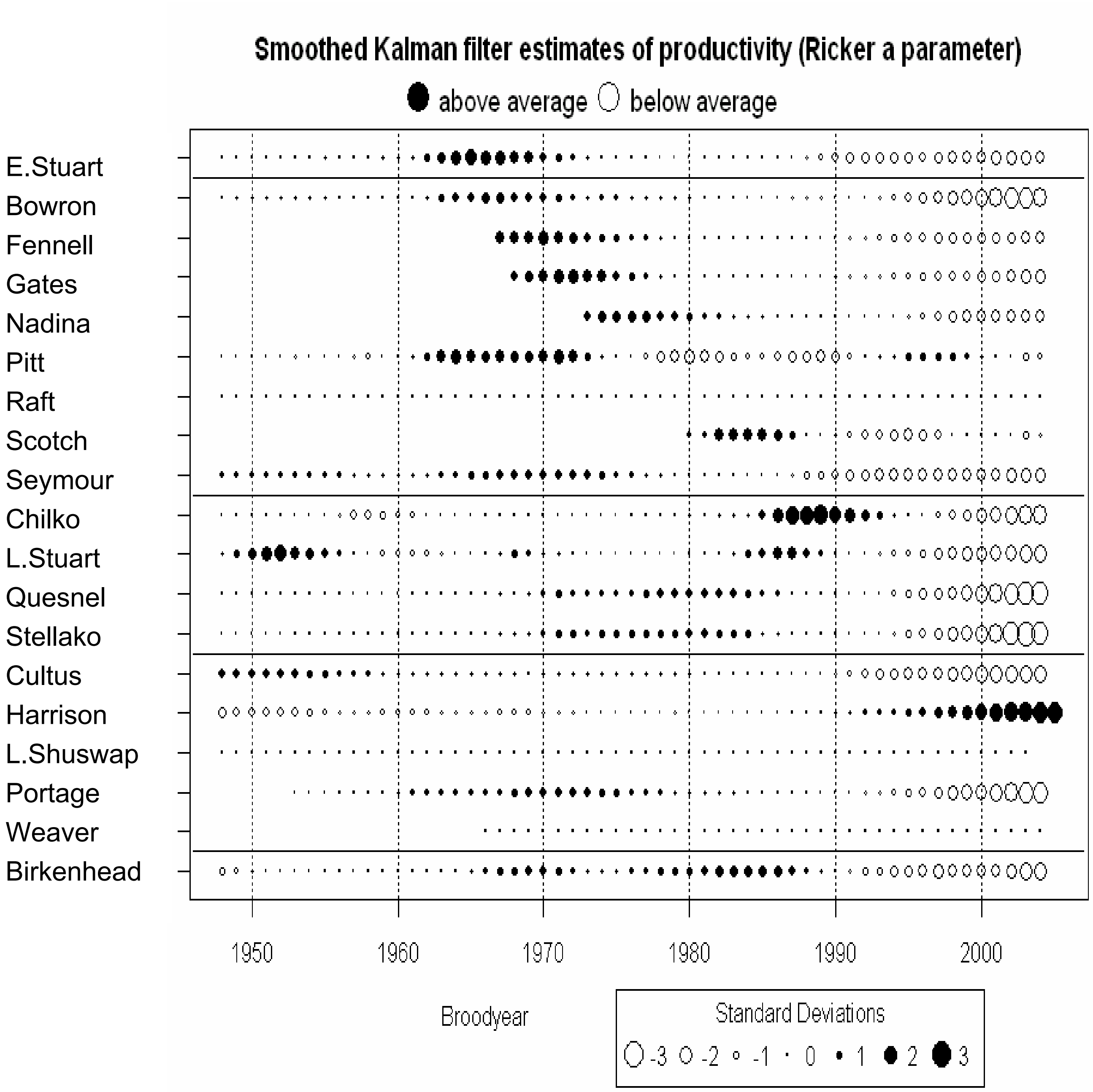


Figure 2. Time series of productivity estimates, scaled to a mean of zero and a standard deviation of one, produced by Kalman filtered Ricker a annual parameter values for the 19 forecasted stocks. Solid circles represent above average values; open circles represent below-average values. The radius of the circles represents the magnitude (absolute value) of indices. Large solid circles, therefore, represent years with very high productivity compared to average, while large open circles represent years with very low productivity compared to average. Years with average productivity are represented by small dots. Methodology and base code from Dorner et al. 2008.

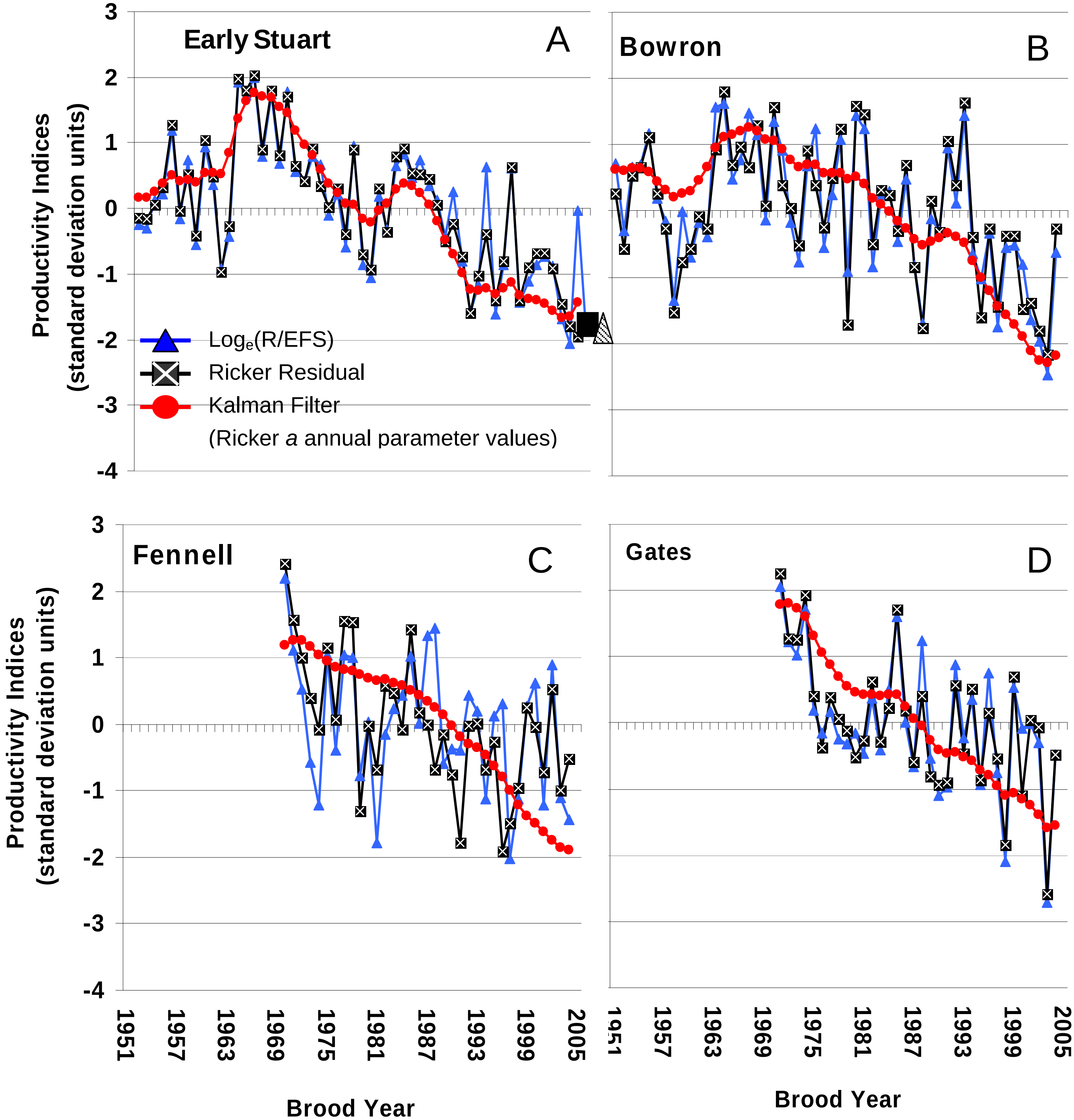


Figure 3. Time series (by brood year) of productivity estimates for 18 of the forecasted stocks (A-D), scaled to a mean of zero and a standard deviation of one (standard deviation units), produced by log_e(R/EFS) (blue triangles), Ricker model residuals (black squares) and Kalman filtered Ricker a annual parameter values (red circles). The 2005 brood year productivity (where available) is indicated by a larger hatched triangle (log_e(R/EFS) and black square (Ricker residual). Cultus Sockeye have not been included given hatchery production in recent years.

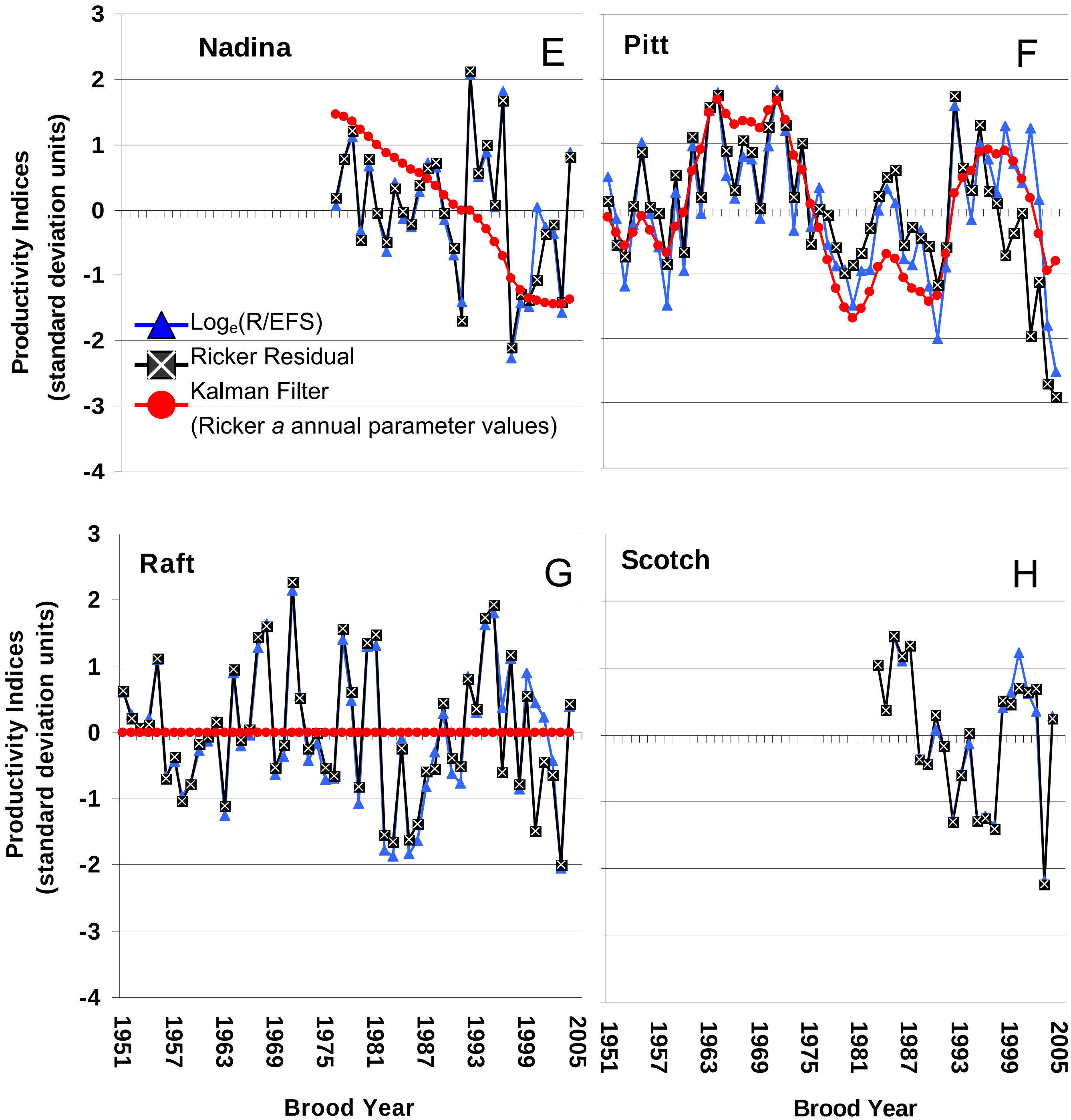


Figure 3. Time series (by brood year) of productivity estimates for 18 of the forecasted stocks (E-H), scaled to a mean of zero and a standard deviation of one (standard deviation units), produced by log_e(R/EFS) (blue triangles), Ricker model residuals (black squares) and Kalman filtered Ricker a annual parameter values (red circles). The 2005 brood year productivity (where available) is indicated by a larger hatched triangle (log_e(R/EFS)) and black square (Ricker residual). Cultus Sockeye have not been included given hatchery production in recent years.

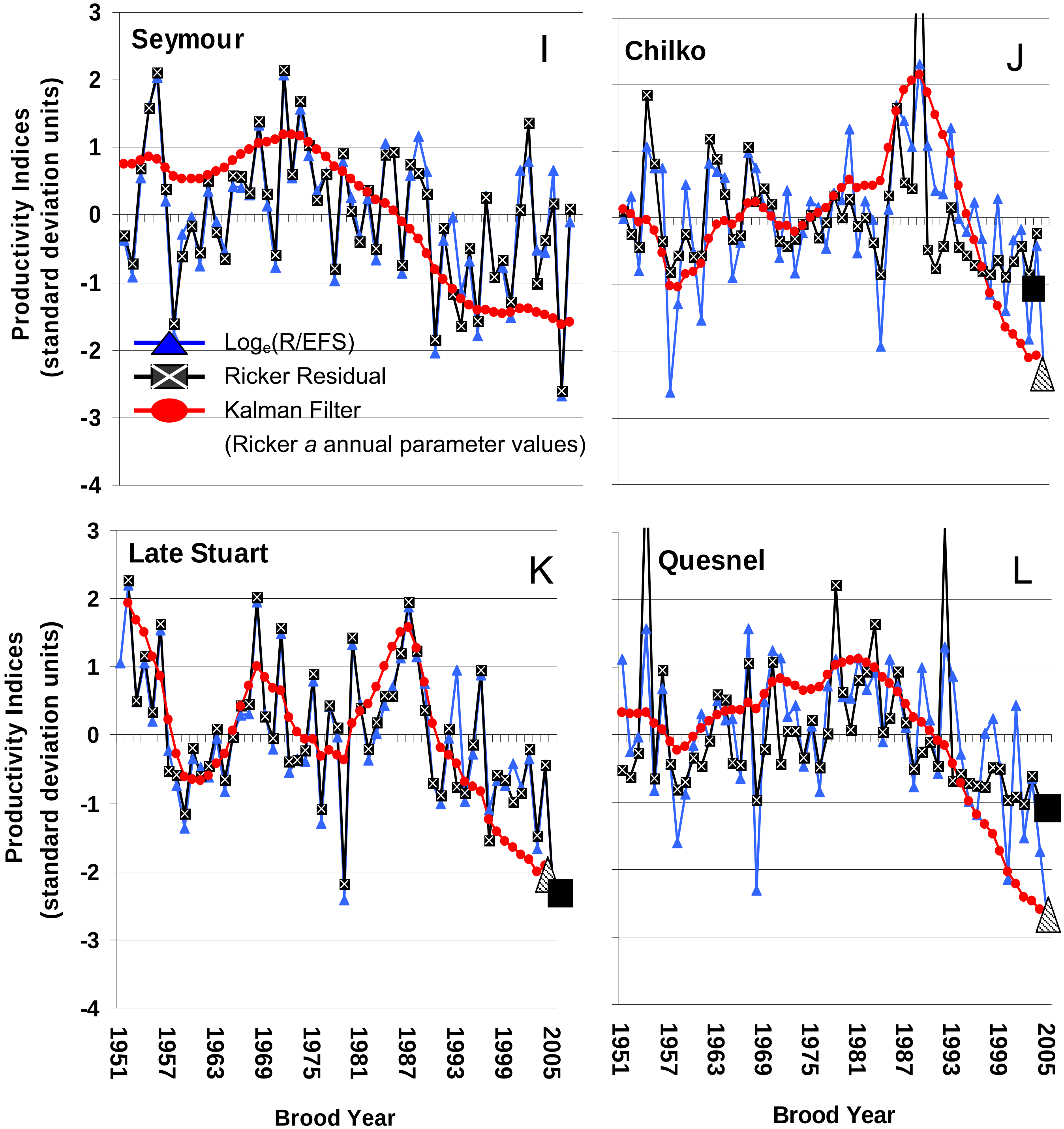


Figure 3. Time series (by brood year) of productivity estimates for 18 of the forecasted stocks (I-L), scaled to a mean of zero and a standard deviation of one (standard deviation units), produced by log_e(R/EFS) (blue triangles), Ricker model residuals (black squares) and Kalman filtered Ricker a annual parameter values (red circles). The 2005 brood year productivity (where available) is indicated by a larger hatched triangle (log_e(R/EFS) and black square (Ricker residual). Cultus Sockeye have not been included given hatchery production in recent years.

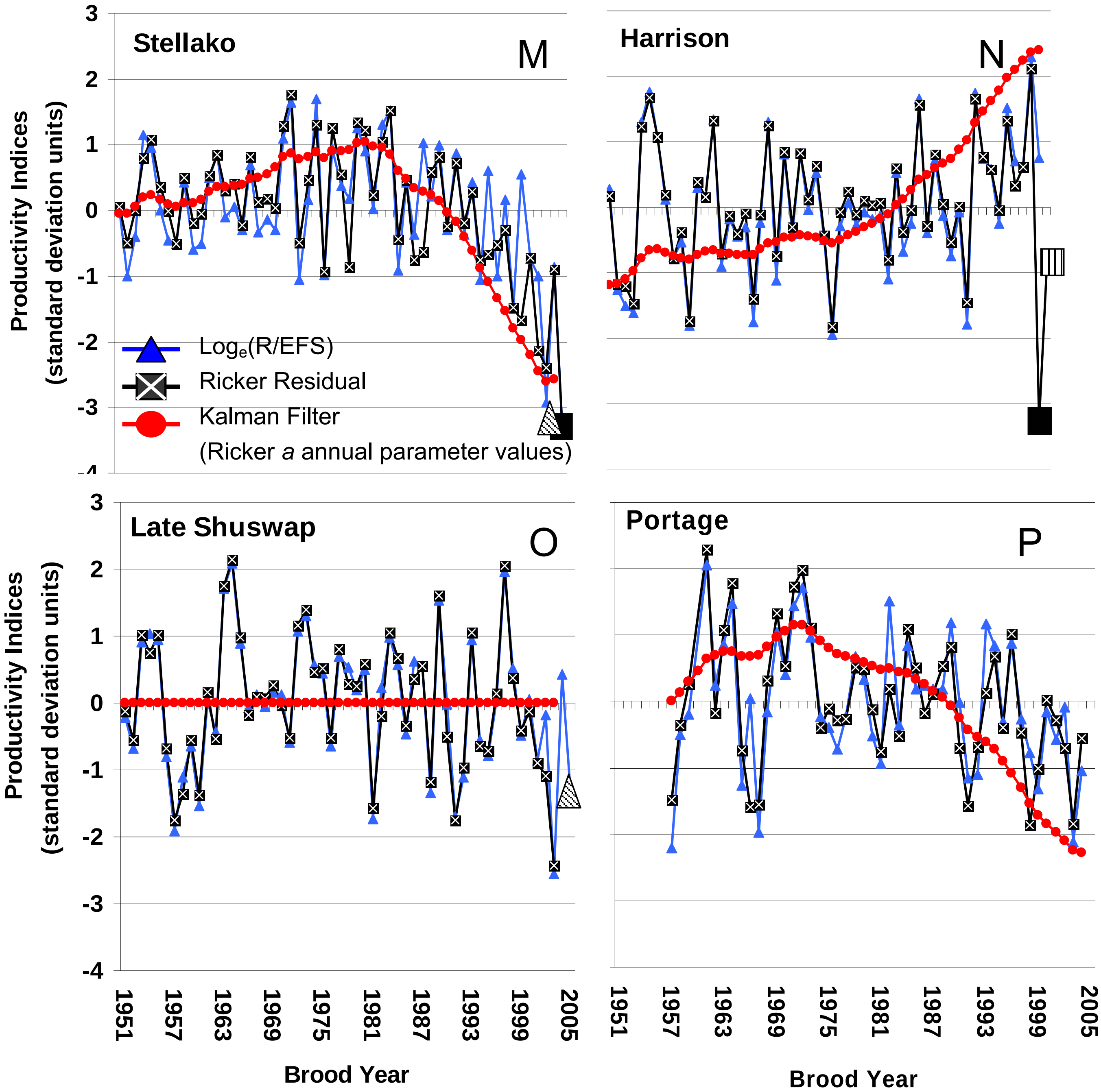


Figure 3. Time series (by brood year) of productivity estimates for 18 of the forecasted stocks (M-P), scaled to a mean of zero and a standard deviation of one (standard deviation units), produced by log$_e$(R/EFS) (blue triangles), Ricker model residuals (black squares) and Kalman filtered Ricker a annual parameter values (red circles). The 2005 brood year productivity (where available) is indicated by a larger hatched triangle (log$_e$(R/EFS) and black square (Ricker residual). For Harrison the 2005 brood year (solid square) and 2006 brood year (hatched square) productivities are presented.

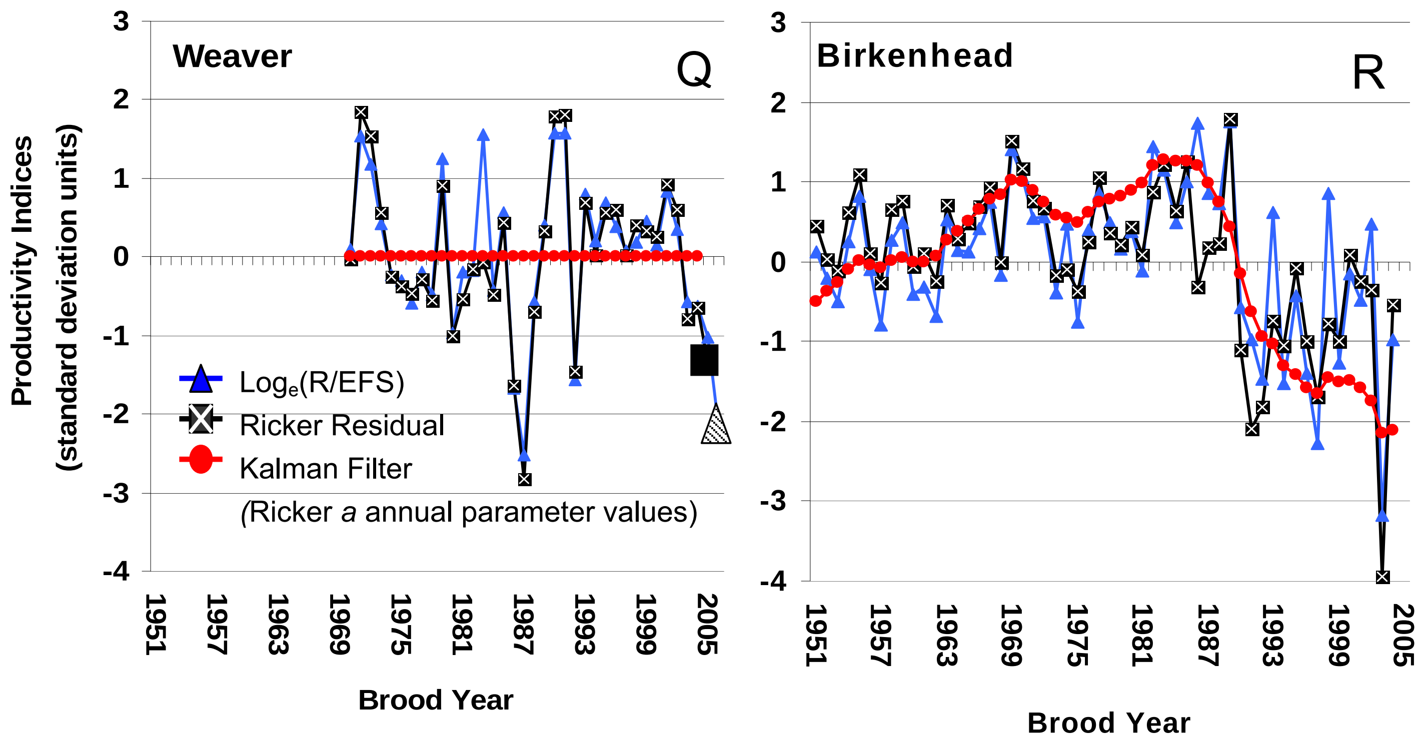
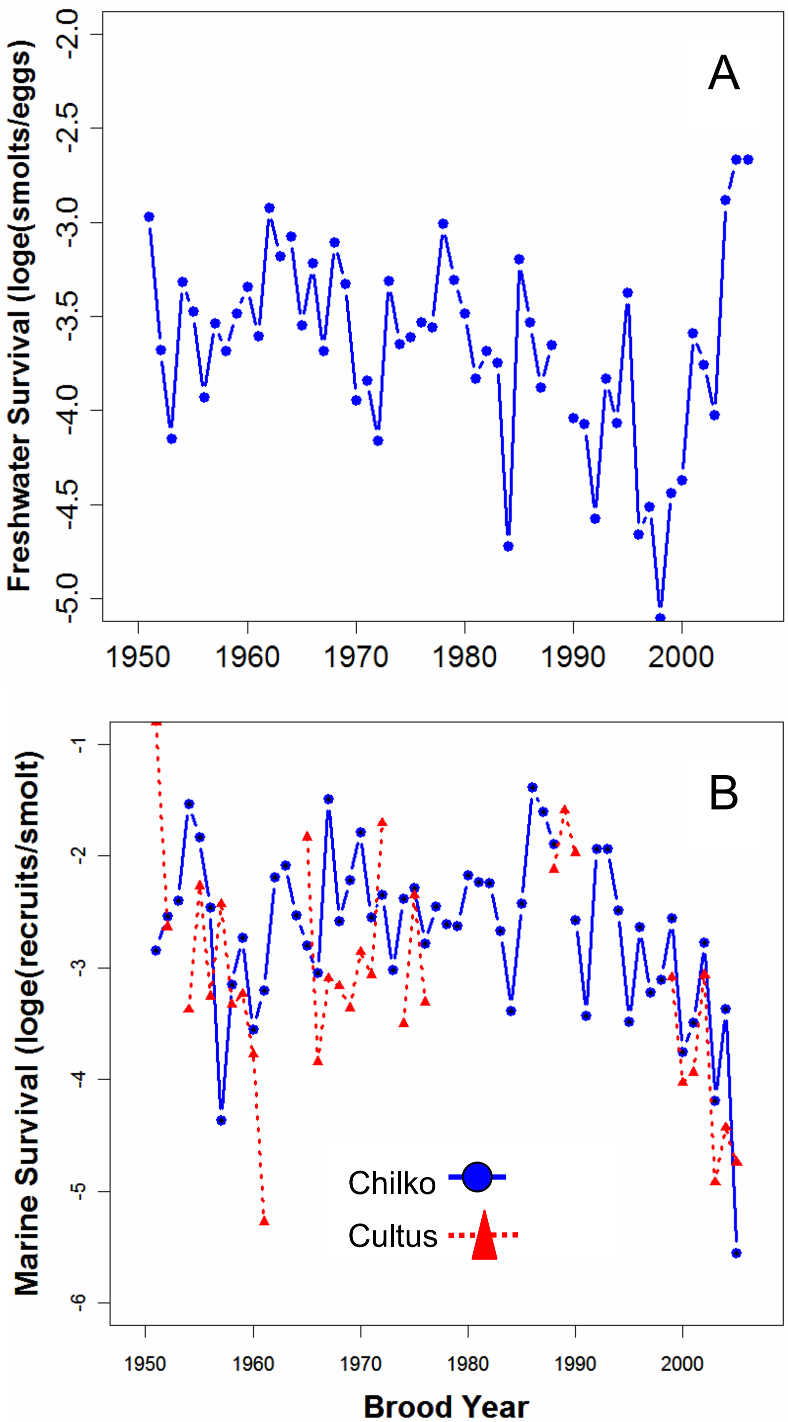


Figure 3. Time series (by brood year) of productivity estimates for 18 of the forecasted stocks (Q-R), scaled to a mean of zero and a standard deviation of one (standard deviation units), produced by log_e(R/EFS) (blue triangles), Ricker model residuals (black squares) and Kalman filtered Ricker a annual parameter values (red circles). The 2005 brood year productivity (where available) is indicated by a larger hatched triangle (log_e(R/EFS) and black square (Ricker residual). Cultus Sockeye have not been included given hatchery production in recent years.



Figures 4 A & B. A. Chilko freshwater survival ($\log_e$ smolt-per-eggs; eggs: effective female spawners x average fecundity of 3,000 eggs/female) and B. Chilko (blue solid line with circles) & Cultus (red dashed line with triangles) marine survival ($\log_e$ recruits-per-smolt) from the 1951 to 2005 brood years. Note: the 2004 and 2005 brood year marine survivals are preliminary pending final results for 2009 age-4 and age-5 returns. Cultus freshwater production is not plotted because freshwater production in recent years includes hatchery enhancement.

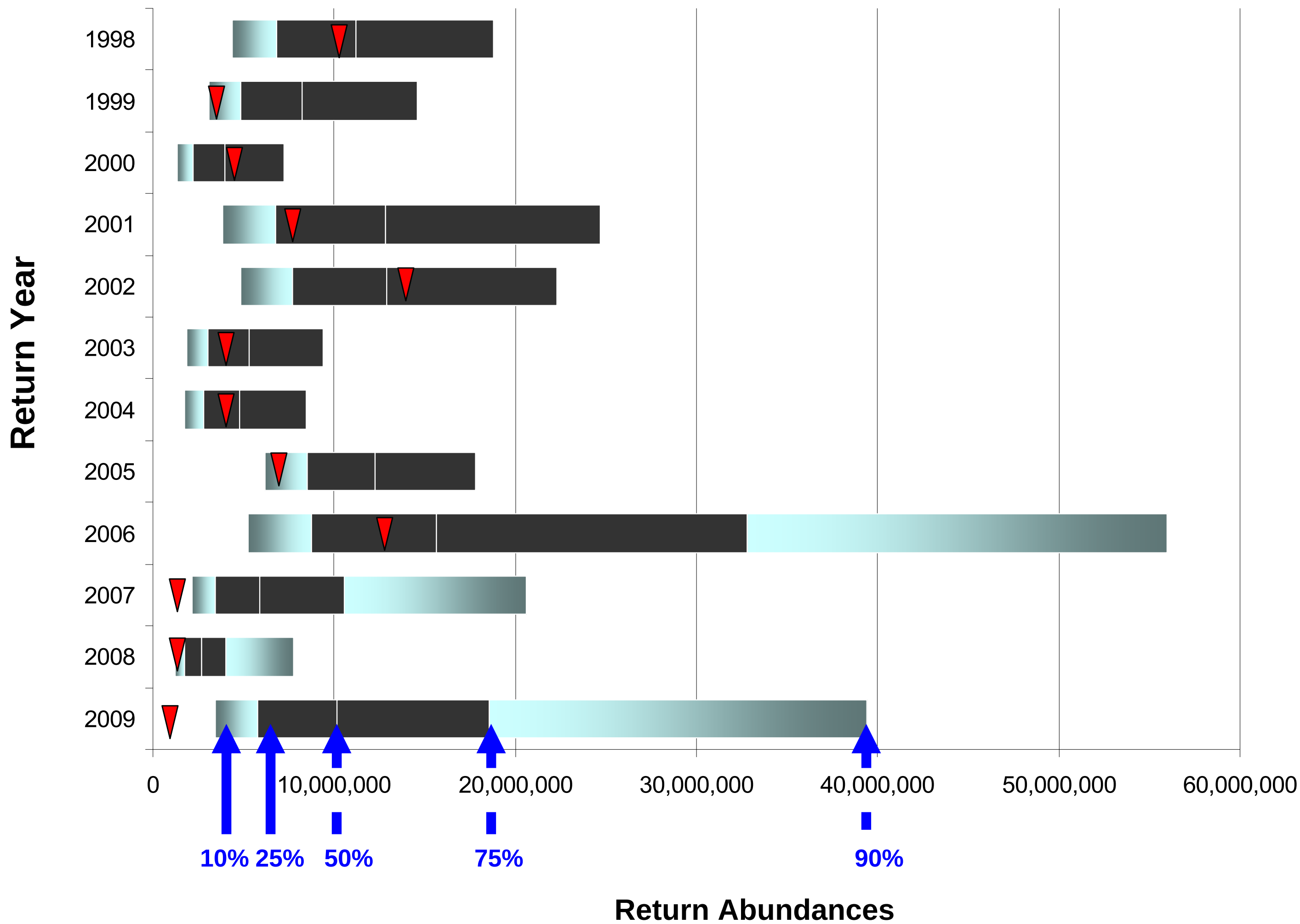


Figure 5. Cumulative probability distributions for the 1998 to 2009 return forecasts. Black bars indicate the probability distribution range from 25% to 75%, blue (shaded) bars indicate the range from 10% to 90%, and the 50% probability level is indicated by the white vertical line. Blue arrows identify the probability levels from 10% to 90% presented in forecast tables. Note: only recent forecasts (2006-2009) included the 90% probability level and, therefore, blue (shaded) bars were not plotted on the right hand side of the annual bar plots from 1998-2005. Red triangles indicate actual return for each return year.

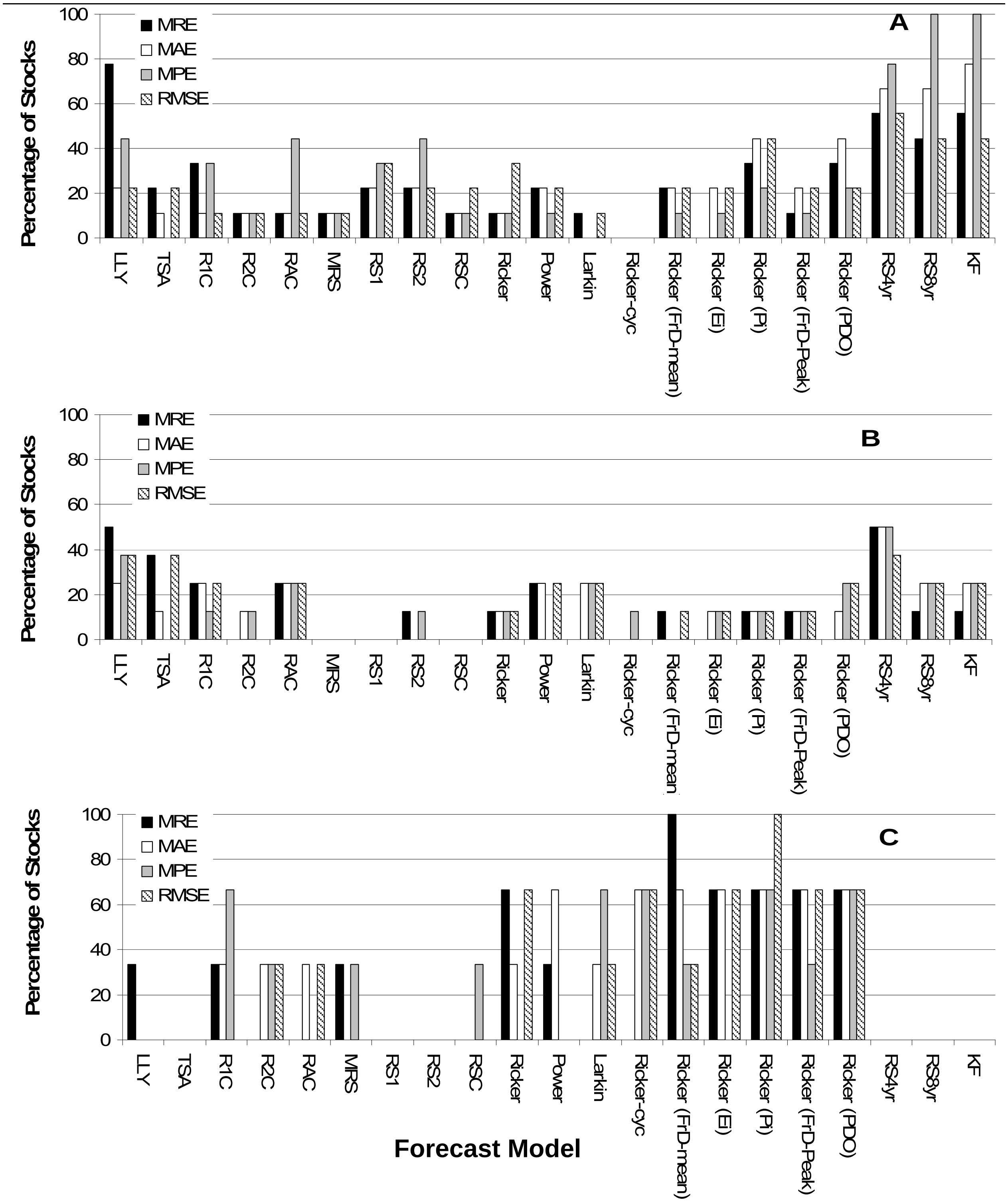


Figure 6. The percentage of stocks that each forecast model ranked in the top five based on four performance measures: mean raw error (MRE), mean absolute error (MAE), mean proportional error (MPE) and root mean square error (RMSE). For stocks that A. have exhibited declines in productivity starting in the early 1970's (Early Stuart, Bowron, Fennell, Gates, Nadina, Seymour, Portage), B. stocks that have exhibited declines starting in the early 1990's (Pitt, Chilko, Late Stuart, Quesnel, Stellako, Birkenhead) and C. stocks that have exhibited no declines (Raft, Late Shuswap, Weaver) based on Kalman filtered Ricker a annual parameter values.

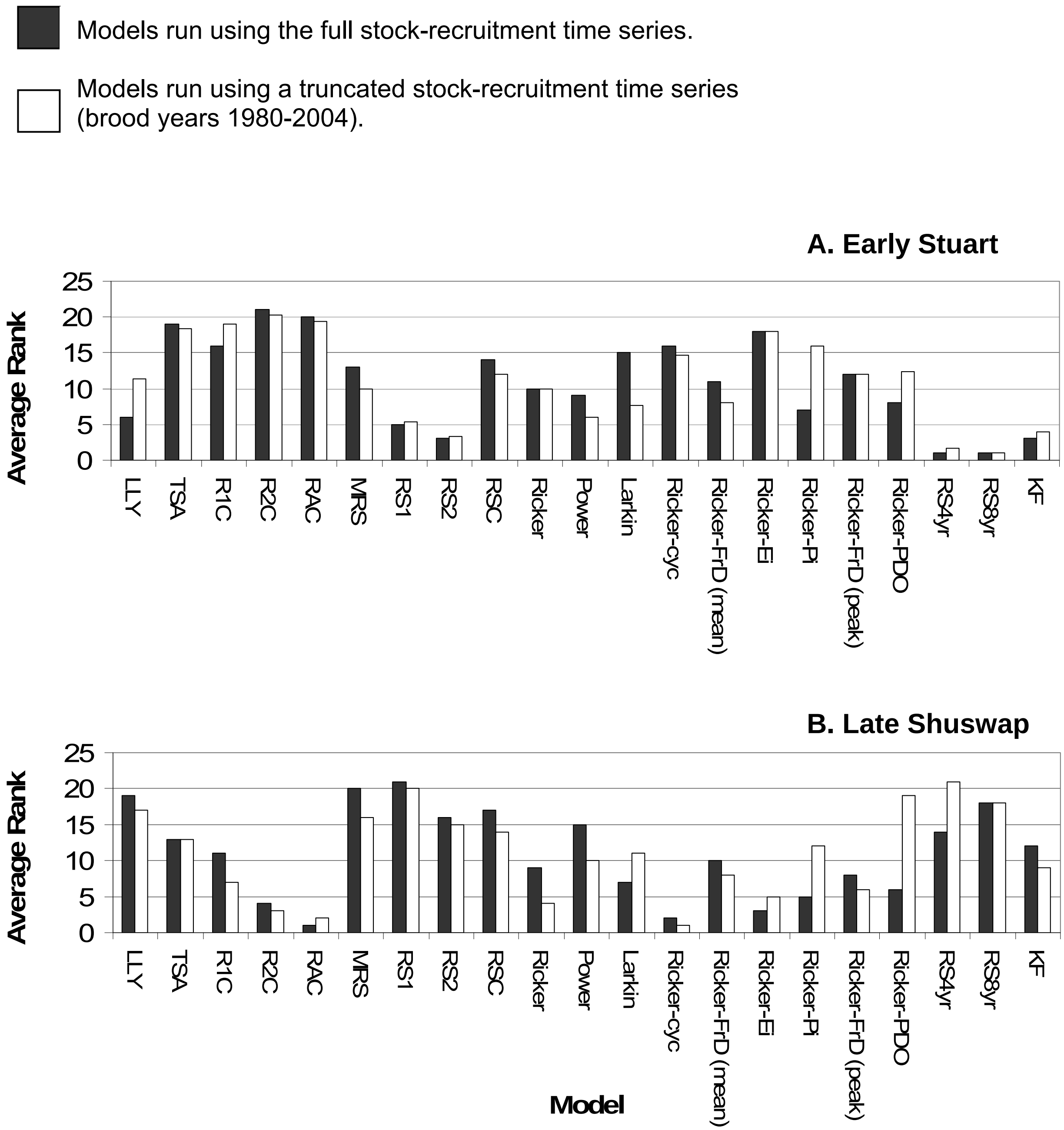


Figure 7. Sensitivity analysis to compare average retrospective ranks of all models used in the Case 2 "Recent Productivity" forecasts (Table 3) for the full stock-recruitment time series (black bars) and a truncated stock-recruitment time series (brood years: 1980-2003)(white bars) for A) Early Stuart (a stock that has exhibited systematic declining trends in productivity starting in the 1970's) and B) Late Shuswap (a stock that has not exhibited systematic declining trends).

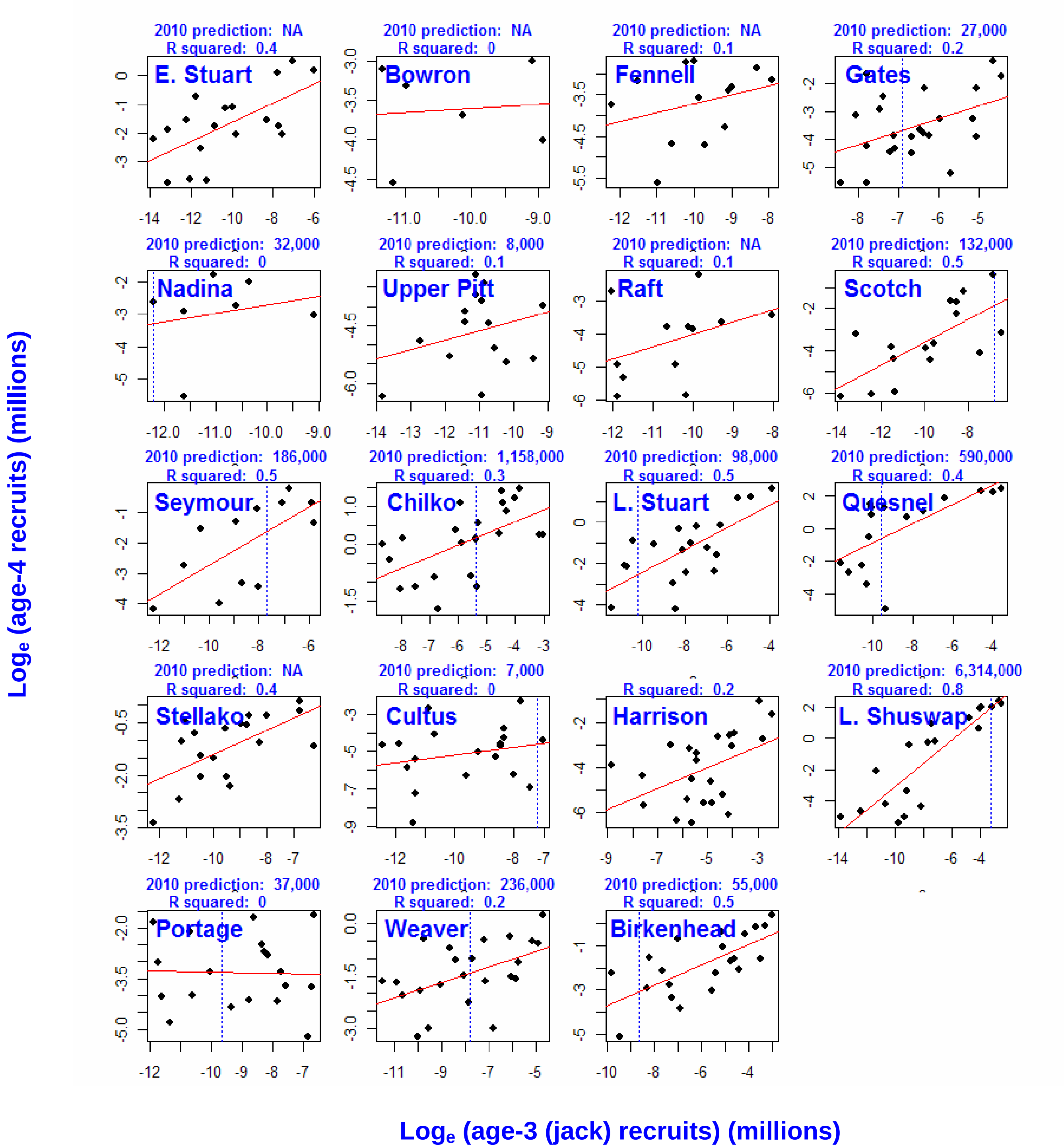


Figure 8. Relationship between age-3 (jack) and age-4 recruits for all 19 forecasted stocks (brood years 1980-2003). Years with zero age-3 recruits (jacks) were excluded. Red (solid) line is regression line fit to the age-3 (jack) versus age-4 recruitment data. Vertical blue (dashed) line is the near-final age-3 (jack) escapement (returns not yet available) for the 2006 brood year which is the same brood year for the age-4 recruits that will return in 2010. The 2010 age-4 predictions (Bayes 50% probability level; see Table 4) are presented by stock. The 2010 predictions are NA if jack recruits were zero in 2009.

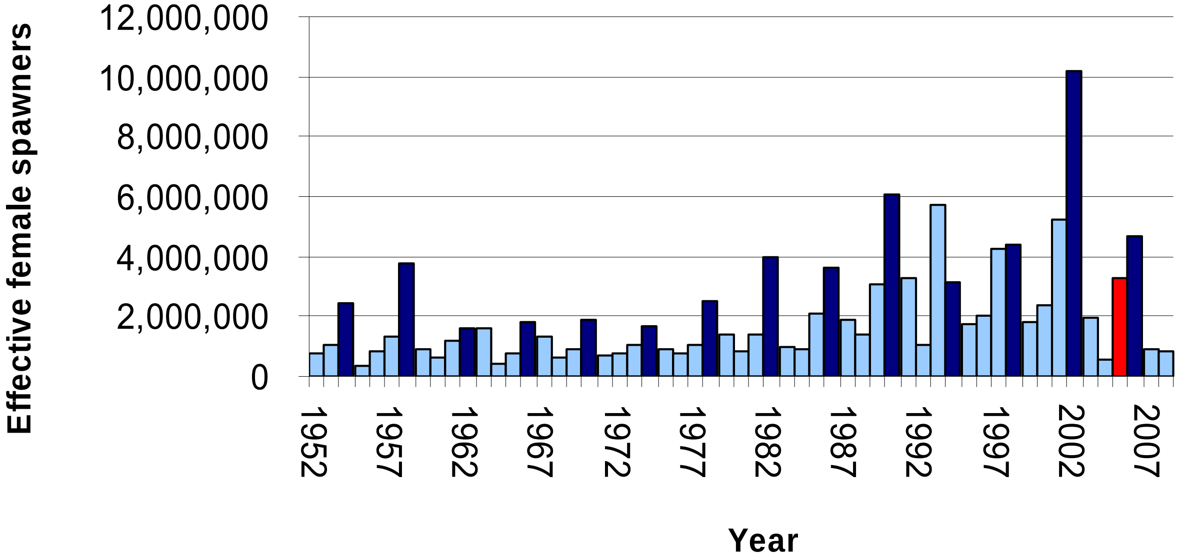


Figure 9. Comparison of the effective female spawner (EFS) total Fraser Sockeye abundances in the 2005 brood year that produced the 2009 (poor) returns (red bar) relative to the entire time series. The dominant Late Shuswap cycle EFS abundances are highlighted in dark blue.

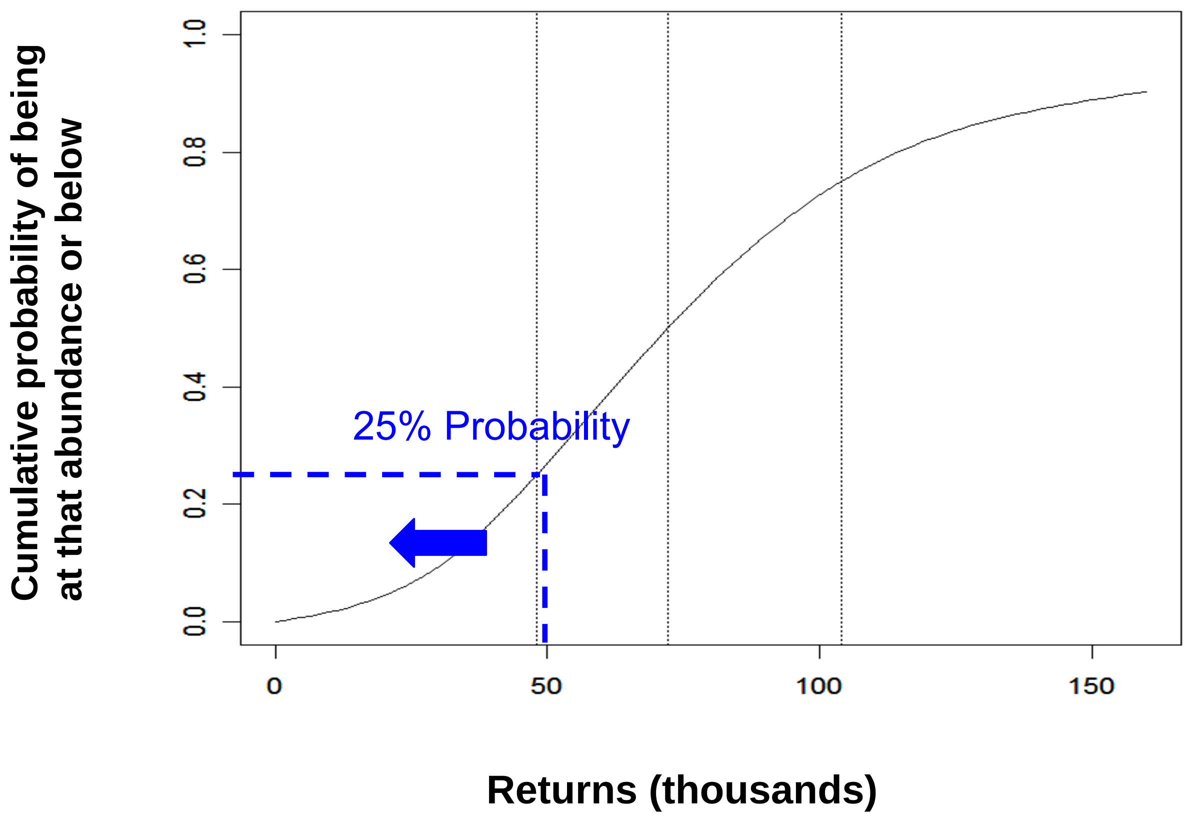


Figure 10. Forecasts presented in Tables 2, 3 and 5 are slices through a cumulative probability distribution. Each slice through the distribution corresponds to different probabilities of returns up to and including the specified run size. For the above example of a hypothetical stock forecast, there is a one in four chance (25% probability) the return will fall below 50,000.

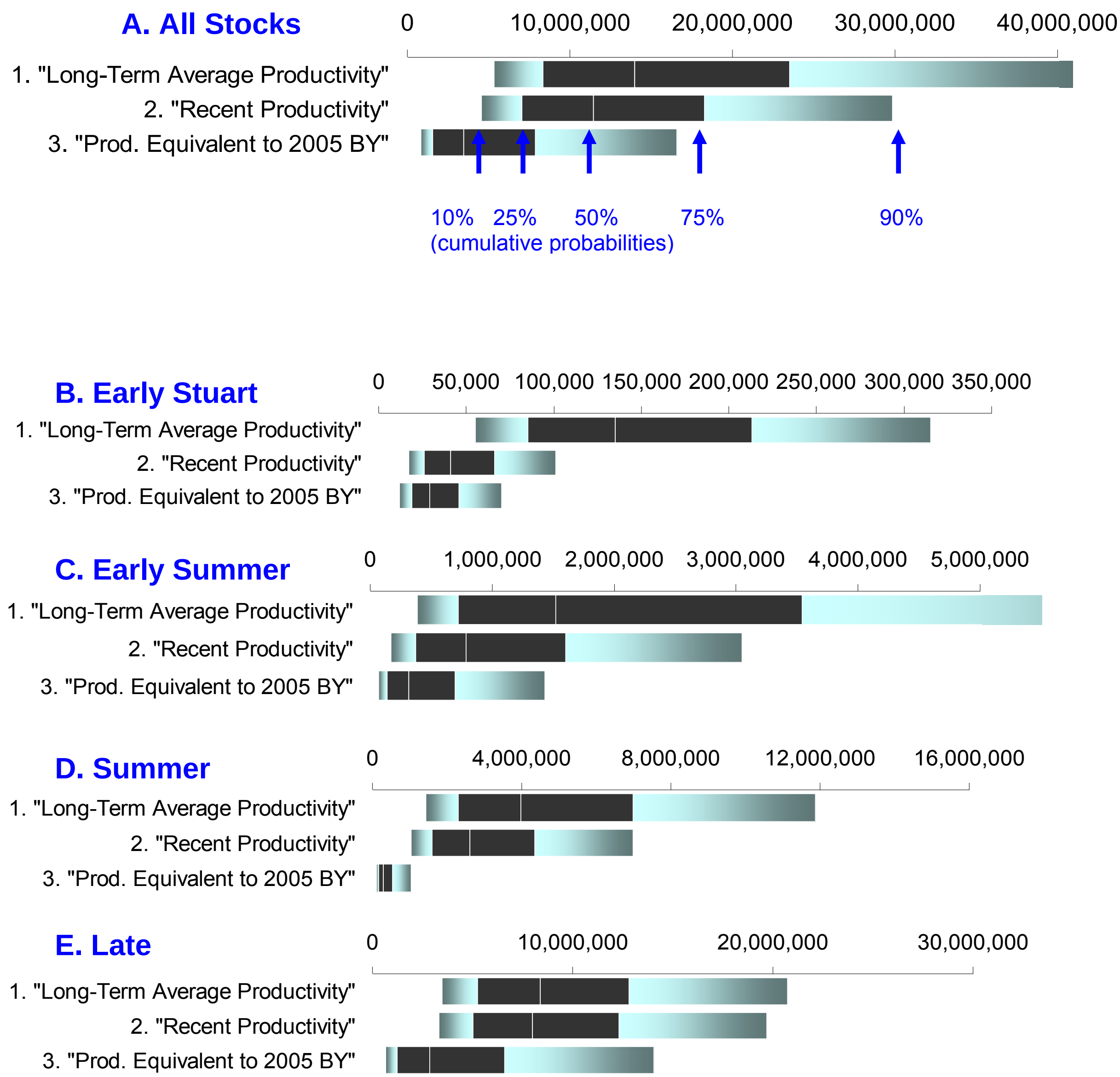


Figure 11. Probability distributions for A. All Stocks; B. Early Stuart; C. Early Summer; D. Summer; and E. Late Run timing groups for the three forecast cases (1. "Long-Term Average Productivity"; 2. "Recent Productivity"; 3. "Productivity Equivalent to the 2005 Brood Year (BY)"). Details for generating these forecasts are described in the text. This table describes both the stochastic (random) uncertainty in forecasts (probability distributions) and the uncertainty associated with future Fraser Sockeye survival (Cases 1-3). Probabilities correspond to those presented in the forecast tables: Table 2 ("Long-Term Average Productivity"); Table 3 ("Recent Productivity"); and Table 5 ("Productivity Equivalent to the 2005 Brood Year").

Table 1. Summary results for Kalman filtered Ricker a parameter values and recruits-per-effective female spawners (R/EFS) calculated from these parameter values (exp (a)). The percent change between the maximum and minimum R/EFS in the time series as well as the last four years and the last eight years is also presented. Note the time series for Scotch was too short and Cultus is confounded by hatchery enhancement in recent years; both stocks are not included in this table. Analysis based on Dorner et al. 2008.

		Stock-Recruit data	Ricker *a* parameter				R/EFS				Percent Change		
Run Timing	**Stock**	**(by brood year)**	**AVG**	**SD**	**Max**	**Min**	**AVG**	**SD**	**Max**	**Min**	**Max-Min**	**4yr**	**8yr**
Early Stuart	Early Stuart	1948-2003	1.99	0.53	2.93	1.08	8.37	4.33	18.70	2.95	-84%	-10%	-25%
Early Summer	Bowron	1948-2003	2.51	0.42	3.04	1.54	13.25	4.63	20.97	4.65	-78%	-16%	-34%
	Fennell	1967-2003	3.13	0.17	3.34	2.78	23.15	3.80	28.36	16.14	-43%	-6%	-18%
	Gates	1968-2003	2.61	0.36	3.26	2.00	14.49	5.43	25.95	7.40	-71%	-15%	-26%
	Nadina	1973-2003	2.11	0.08	2.23	1.99	8.31	0.68	9.33	7.30	-22%	-1%	-6%
	Pitt	1948-2003	2.38	0.39	3.03	1.72	11.68	4.54	20.79	5.57	-73%	-43%	-52%
	Raft	1948-2003	2.36	0.00	2.36	2.36	10.64	0.00	10.64	10.64	0%	0%	0%
	Scotch	1980-2003	NA	NA	NA	NA	NA	NA	NA	NA	0%	0%	0%
	Seymour	1948-2003	2.23	0.26	2.53	1.80	9.55	2.26	12.55	6.03	-52%	-5%	-4%
Summer	Chilko	1948-2003	2.70	0.23	3.20	2.21	15.28	3.64	24.56	9.08	-63%	-84%	-84%
	Late Stuart	1948-2003	2.39	0.58	3.42	0.31	12.69	6.56	30.52	1.37	-96%	-17%	-47%
	Quesnel	1948-2003	2.52	0.53	3.11	1.15	13.86	5.44	22.45	3.14	-86%	-20%	-49%
	Stellako	1948-2003	2.48	0.29	2.79	1.64	12.34	2.99	16.23	5.16	-68%	-18%	-38%
Late	Cultus	1948-2003	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Harrison	1948-2003	2.22	0.28	2.93	1.89	9.62	3.10	18.78	6.60	-65%	15%	45%
	Late Shuswap	1948-2003	2.10	0.00	2.10	2.10	8.15	0.00	8.15	8.15	0%	0%	0%
	Portage	1953-2003	3.16	0.16	3.34	2.78	23.90	3.50	28.36	16.14	-43%	-6%	-18%
	Weaver	1966-2003	2.95	0.00	2.95	2.95	19.13	0.00	0.00	2.95	0%	0%	0%
	Birkenhead	1948-2003	2.73	0.50	3.37	1.59	17.06	7.18	29.09	4.90	-83%	-28%	-25%

Table 2. The Case 1 ("Long-Term Average Productivity") 2010 forecast table (at various probability levels) by stock and timing group. Each forecast sums age-4 and age-5 recruitment forecasts (Harrison: age-3 plus age-4). These forecasts were produced using methodology described in the 2009 Fraser Sockeye forecast paper (DFO 2009). Specifically, model forecasts use the first ranked model based on retrospective analysis conducted for the 2009 forecasts (using the entire retrospective time series to calculate performance measures). The three new models used in the Case 2 ("Recent Productivity") forecast (Table 3) are not used in this table. In addition, age-5 recruits were forecasted using the 2009 forecast methodology (DFO 2009).

		Probability of Return at/or Below Specified Run Size				
Run Timing Group Stocks	**Forecast Model** (2009 Forecast Models)	**10%**	**25%**	**50%**	**75%**	**90%**
Early Stuart	Pooled (RS2 & Power)	**55,000**	**85,000**	**135,000**	**213,000**	**315,000**
Early Summer		**387,000**	**723,000**	**1,518,000**	**3,544,000**	**7,993,000**
Bowron	Ricker-Pi	3,000	6,000	9,000	15,000	24,000
Fennell	Ricker	12,000	20,000	33,000	55,000	86,000
Gates	Ricker-cyc	5,000	10,000	21,000	44,000	98,000
Nadina	Ricker-FrD peak	12,000	20,000	35,000	60,000	99,000
Pitt	Power	29,000	44,000	66,000	113,000	178,000
Raft	Power	20,000	29,000	47,000	74,000	113,000
Scotch	RS1	124,000	315,000	884,000	2,479,000	6,275,000
Seymour	Ricker-cyc	182,000	279,000	423,000	704,000	1,120,000
Summer		**1,434,000**	**2,304,000**	**3,972,000**	**6,981,000**	**11,875,000**
Chilko	Power (smolt)	881,000	1,376,000	2,221,000	3,692,000	5,626,000
Late Stuart	R1C	35,000	82,000	211,000	547,000	1,286,000
Quesnel	Pooled (Larkin & Power (fry))	263,000	475,000	1,019,000	1,968,000	3,867,000
Stellako	Larkin	255,000	371,000	521,000	774,000	1,096,000
Late		**3,484,000**	**5,239,000**	**8,364,000**	**12,803,000**	**20,741,000**
Cultus	Smolt-Jack	6,000	10,000	19,000	36,000	59,000
Harrison	Ricker-PDO	50,000	93,000	262,000	729,000	1,923,000
Late Shuswap	Ricker-cyc	3,184,000	4,746,000	7,414,000	10,848,000	16,752,000
Portage	Ricker	14,000	27,000	62,000	130,000	296,000
Weaver	Larkin	90,000	136,000	219,000	376,000	621,000
Birkenhead	Power	140,000	227,000	388,000	684,000	1,090,000
TOTAL		**5,360,000**	**8,351,000**	**13,989,000**	**23,541,000**	**40,924,000**

Table 3. Case 2 ("Recent Productivity") 2010 forecast table (at various probability levels) by stock and timing group. Each forecast sums age-4 and age-5 recruitment forecasts (Harrison: age-3 plus age-4). Brood year escapements (smolts: Chilko & Cultus) for age-4 (2006) and age-5 (2005) recruits returning in 2010 are presented and colour coded relative to their 1980-2003 cycle average. Forecasted returns and productivity (prod: loge(R/EFS)) are also colour coded relative to their 1980-2008 cycle average: red (< avg); yellow (avg); green (>avg). The Case 2 forecast incorporates new models that take into account recent productivities. Model performance of old and new models were evaluated only for more recent brood years (1997-2004). Methods and results for the Case 2 ("Recent Productivity") 2010 forecast are described in detail in the text.

A	B	C	D	E	F	G	H	I	J	K	L	M	N
Run timing group	Forecast	BY (06)	BY (05)	Prod.	Prod.	Ret	Mean Run Size		Probability that Return will be at/or Below Specified Run Size [a]				
Stocks	Model [b]	(EFS)	(EFS)	(-8yr)	(-4yr)	2010	all cycles[c]	2010 cycle[d]	10%	25%	50%	75%	90%
Early Stuart	RS4yr	15,900	51,000				304,000	113,000	**17,000**	**26,000**	**41,000**	**66,000**	**101,000**
Early Summer							--	--	**174,000**	**374,000**	**783,000**	**1,601,000**	**3,047,000**
(total exlcuding miscellaneous)							***(504,000)***	***(797,000)***	***(129,000)***	***(269,000)***	***(581,000)***	***(1,251,000)***	***(2,543,000)***
Bowron	RS4yr	600	900				21,000	20,000	400	700	1,300	2,500	4,600
Fennell	Power	8,000	3,000				29,000	26,000	9,000	16,000	31,000	56,000	90,000
Gates	KF	1,500	9,000				59,000	17,000	2,000	4,000	9,000	17,000	33,000
Nadina	Ricker-FrD-mean	4,500	12,000				79,000	22,000	9,000	16,000	30,000	60,000	107,000
Pitt	Ricker	20,000	33,000				60,000	55,000	7,000	12,000	26,000	53,000	96,000
Raft	Ricker-PDO	3,400	17,000				33,000	16,000	7,000	13,000	24,000	42,000	71,000
Scotch	KF	73,000	3,000				73,000	248,000	40,000	106,000	265,000	640,000	1,450,000
Seymour	RS4yr	57,000	2,000				150,000	393,000	55,000	101,000	195,000	380,000	691,000
Misc [e]	RS (Sc/Se)						--	--	13,000	58,000	134,000	242,000	302,000
Misc [f]	RS (Ra/Fe)						--	--	7,000	10,000	14,000	22,000	42,000
Misc [g]	RS (Ra/Fe)						--	--	24,000	35,000	48,000	76,000	144,000
Misc [h]	RS (Esum)						--	--	1,000	1,000	4,000	6,000	10,000
Misc [i]	RS (Esum)						--	--	0	1,000	2,000	4,000	6,000
Summer							**5,332,000**	**5,059,000**	**1,045,000**	**1,605,000**	**2,612,000**	**4,343,000**	**6,984,000**
Chilko [j]	RJ4yr (smolt)	71M	77M				1,740,000	1,900,000	864,000	1,273,000	1,958,000	3,011,000	4,435,000
Late Stuart	RS8yr	14,000	160,000				750,000	396,000	8,000	21,000	60,000	169,000	429,000
Quesnel	KF	90,000	800,000				2,350,000	2,200,000	111,000	215,000	438,000	909,000	1,727,000
Stellako	RS4yr	80,000	100,000				492,000	563,000	62,000	96,000	156,000	254,000	393,000
Late							**3,193,000**	**9,126,000**	**3,331,000**	**5,023,000**	**8,003,000**	**12,305,000**	**19,695,000**
(total exlcuding miscellaneous)							***(3,193,000)***	***(9,126,000)***	***(3,264,000)***	***(4,951,000)***	***(7,871,000)***	***(12,035,000)***	***(19,352,000)***
Cultus [j]	Smolt-Jack	400,000	100,000				17,000	18,000	5,000	6,000	9,000	14,000	19,000
Harrison [k]	Ricker-FrD-mean	91,000	57,000				58,000	NA	53,000	97,000	195,000	429,000	1,167,000
Late Shuswap	Ricker-cyc	1.2M	12,000				2,210,000	7,640,000	3,101,000	4,652,000	7,252,000	10,791,000	16,702,000
Portage	KF	11,000	8,000				55,000	90,000	8,000	18,000	42,000	99,000	221,000
Weaver	Ricker-FrD-peak	14,000	24,000				406,000	690,000	71,000	126,000	264,000	472,000	799,000
Birkenhead	KF	140,000	27,000				447,000	688,000	26,000	52,000	109,000	230,000	444,000
Misc. non-Shuswap [l]	RS (Weaver)								67,000	72,000	132,000	270,000	343,000
TOTAL							-	-	**4,567,000**	**7,028,000**	**11,439,000**	**18,315,000**	**29,827,000**
(TOTAL excluding miscellaneous)							***(9,333,000)***	***(15,095,000)***	***(4,455,000)***	***(6,851,000)***	***(11,105,000)***	***(17,695,000)***	***(28,980,000)***

a. probability that return will be at/or below specified projection.
b. see Methods & Appendix 1 & 2 for model descriptions.
c. sockeye: 1980-2006 (excluding miscellaneous stocks)
d. sockeye: 1980-2008 (excluding miscellaneous stocks)
g. North Thompson River
h. Nahatlach River & Lake (Esum)
i. Chilliwack Lake and Dolly Varden Creek (Esum)
j. Brood year smolts (not effective females)
k. Harrison are age-4 (2006 brood year) and age-3 (2007 brood year)
l. unforecasted miscellaneous Late Run stocks (Harrison L.)
e. unforecasted mis. Early Summer Stocks (Early Shuwap stocks: S.Thompson); return timing most similar to Scotch/Seymour (Sc/Se)
f. unforecasted misc. Early Summer stocks (N. Thomson tributaries; return timing most similar to Raft/Fennell (Ra/Fe)).

Definitions: BY06: brood year 2006; BY05: brood year 2005; EFS: effective female spawners; Prod. 8yr or Prod. 4yr: Productivity in loge recruits-per-effective females in the last 8 yrs or last 4 yrs; Pi (Pine Island SST covariate); Ei (Entrance Island SST covariate); FrD (Fraser discharge); PDO (Pacific Decadal Oscillation (PDO) covariate); cyc (cycle line stock-recruit data only); KF (Ricker model using Kalman Filter for 'a' parameter estimation); RS4yr (product of R/S from last 4 brood years & EFS in brood year); RJ4yr (product of R/smolt from last 4 brood years & smolts in brood year); RS8yr (product of R/S from last 8 brood years and EFS in brood year); R/S (used for stocks with no recruit data: product of R/S for stocks as indicated and EFS).

Table 4. For each of the 19 forecasted stocks, average productivities (recruits-per-effective female spawner: R/EFS) of the first part of the time series (up to and including 1979) (B), the last eight brood years (1996-2003) (D), and the last four brood years (2000-2003) (E) relative to the average over the 1980-2003 brood years (C) are presented. The Case 2 ("Recent Productivities") 2010 forecast productivities are presented over their range of probabilities (F-J). Average R/EFS (B-E) are colour coded relative to the 1980-2008 reference period: red (< average); yellow (average); green (>average). Loge(R/EFS) was used to determine colour codes (see Methods), but productivities in below table are presented in R/EFS.

A	B	C	D	E	F	G	H	I	J
Run timing group	**Early Time Series Relative to Ref. Period**	**Reference Period**	**Last 8 yrs relative to Ref. Period**	**Last 4 yrs relative to Ref. Period**	**Case 2 ("Recent Productivity") 2010 forecast productivities (R/EFS) for each probability level in Table 3 by stock**				
Stocks	**Avg R/EFS (up to 1979)**	**Avg R/EFS (1980-2003)**	**Avg R/EFS (1996-2003)**	**Avg R/EFS (2000-2003)**	**10%**	**25%**	**50%**	**75%**	**90%**
Early Stuart	12.8	5.7	3.8	2.5	**1.1**	**1.6**	**2.6**	**4.2**	**6.4**
Early Summer									
Bowron	12.7	9.8	3.6	1.9	0.6	1.1	2.0	3.9	7.2
Fennell	30.7	8.4	5.8	7.4	1.1	2.0	3.9	7.0	11.3
Gates	33.8	13.0	9.5	7.2	1.3	2.7	6.0	11.3	22.0
Nadina	14.6	9.7	6.6	4.1	2.0	3.6	6.7	13.3	23.8
Pitt	11.3	6.8	3.7	2.1	0.4	0.6	1.3	2.7	4.8
Raft	12.8	11.1	7.5	3.8	2.1	3.8	7.1	12.4	20.9
Scotch	NA	11.9	8.4	10.3	0.5	1.5	3.6	8.8	19.9
Seymour	16.4	8.1	7.9	4.7	1.0	1.8	3.4	6.7	12.1
Summer									
Chilko[a]	0.09	0.09	0.04	0.03	0.01	0.02	0.03	0.04	0.06
Late Stuart	32.5	22.2	7.5	3.3	0.6	1.5	4.3	12.1	30.6
Quesnel[b]	26.3	13.8	4.7	0.5	1.2	2.4	4.9	10.1	19.2
Stellako	12.9	10.2	3.6	2.3	0.9	1.4	2.2	3.6	5.6
Late									
Cultus[a]	0.08	0.07	0.03	0.02	0.02	0.02	0.03	0.05	0.06
Harrison	13.0	21.0	24.1	19.6	0.6	1.1	2.2	4.8	13.0
Late Shuswap[b]	9.0	6.2	6.5	2.5	2.6	4.0	6.2	9.2	14.3
Portage	50.0	16.0	11.8	8.0	0.7	1.6	3.8	9.0	20.1
Weaver	24.6	19.8	17.8	17.9	5.2	9.3	19.4	34.7	58.7
Birkenhead	15.8	12.5	4.1	5.6	0.2	0.4	0.8	1.7	3.2

a. Chilko and Cultus are marine survival (recruits per smolt).
b. Quesnel and Late Shuswap are cycle averages.

Table 5. The Case 3 ("Productivity Equivalent to the 2005 Brood Year") 2010 forecast table (at various probability levels) by stock and timing group. Each forecast sums age-4 and age-5 recruitment forecasts (Harrison: age-3 plus age-4). For a number of stocks, particularly Summer Run stocks that were predicted to return at high abundances, productivity for the 2005 brood year was amongst the lowest on record. These forecasts were produced by using preliminary productivity data (R/EFS or R/smolt) associated with the 2005 brood year (that resulted in 2009 poor returns). A variant of the RS1 model was used to predict 2010 age-4 recruits (see Methods). At the time of this paper, 2009 returns were not available for all 19 stocks individually and final age-structure, abundance, and stock identification of catch and escapement were also not available. In addition, total productivity associated with the 2005 brood year, also cannot include the age-5 component that will return in 2010. Therefore, forecasts are grouped by broader run-timing groups only and cannot be provided for each of the 19 forecasted stocks separately.

Run Timing Group	Probability of Return at/or Below Specified Run Size				
	10%	25%	50%	75%	90%
Early Stuart	12,000	19,000	29,000	46,000	70,000
Early Summer	68,700	141,400	314,000	698,000	1,430,000
Summer	94,000	159,000	290,000	548,000	1,029,000
Late	645,000	1,243,000	2,842,000	6,586,000	14,068,000
TOTAL	819,700	1,562,400	3,475,000	7,878,000	16,597,000

Table 6. Case 2 ("Recent Productivity") age-4 pre-season Sockeye return forecasts at various probability levels for 2010 by stock and timing group (Table 3). For Harrison these are age-3 plus age-4 forecasts and for Cultus these are age-4 plus age-5 forecasts. Top ranked models (within double-lined rectangle) and a standard suite of alternative models across stocks are presented. Ranking based on retrospective analysis methods (using retrospective outputs for brood years 1997-2004 only) is described in report. Models not ranked retrospectively are indicated by an NA.
NOTE: shaded model age-4 return forecasts below were added to age-5 return forecasts and inserted into the Case 2 ("Recent Productivity") forecasts (Table 3).

RUN TIMING GROUP: EARLY STUART

EARLY STUART	Rank	Age-4 Return Forecasts 10%	25%	50%	75%	90%
RS4yr	**1**	**14,000**	**22,000**	**35,000**	**55,000**	**85,000**
RS8yr	1	18,000	28,000	45,000	73,000	113,000
KF	3	12,000	19,000	32,000	55,000	87,000
RS2	3	13,000	21,000	35,000	59,000	94,000
Ricker (Pi)	7	62,000	104,000	174,000	287,000	466,000
Power	9	44,000	70,000	114,000	188,000	301,000
Ricker	10	36,000	65,000	111,000	183,000	296,000
Larkin	15	46,000	76,000	126,000	224,000	352,000
Ricker-cyc	16	33,000	50,000	84,000	141,000	214,000
Ricker (trunc 1990-2003)	NA	20,000	27,000	40,000	59,000	81,000
Power (trunc 1990-2003)	NA	18,000	25,000	38,000	56,000	79,000
Sibling (jack)	NA	NA	NA	NA	NA	NA

RUN TIMING GROUP: EARLY SUMMER

BOWRON	Rank	Age-4 Return Forecasts 10%	25%	50%	75%	90%
RS4yr	**1**	**300**	**600**	**1,100**	**2,200**	**3,900**
KF	2	500	900	1,700	3,000	5,100
LLY (not available yet)	2	NA	NA	NA	NA	NA
RS8yr	4	500	900	1,700	3,300	5,800
Power	7	3,000	5,100	9,300	16,400	25,600
Ricker (Pi)	9	2,200	3,800	7,200	12,700	21,600
Larkin	11	1,500	2,700	5,200	9,000	15,900
Ricker	12	1,700	3,000	5,700	10,000	16,100
Ricker-cyc	16	1,500	2,800	5,200	9,400	16,600
Ricker (trunc 1990-2003)	NA	600	1,300	2,600	5,100	9,400
Power (trunc 1990-2003)	NA	2,200	3,900	7,900	16,000	30,300
Sibling (jack)	NA	NA	NA	NA	NA	NA

FENNELL	Rank	Age-4 Return Forecasts 10%	25%	50%	75%	90%
Power	**1**	**9,000**	**16,000**	**31,000**	**55,000**	**89,000**
RAC	2	7,000	11,000	20,000	34,000	57,000
TSA	3	9,000	15,000	26,000	44,000	71,000
R2C	4	13,000	22,000	40,000	74,000	127,000
RS8yr	6	7,000	13,000	27,000	55,000	105,000
KF	7	6,000	11,000	21,000	40,000	72,000
Ricker	8	8,000	14,000	26,000	47,000	78,000
RS4yr	13	9,000	19,000	43,000	96,000	197,000
Ricker (Pi)	15	19,000	31,000	58,000	115,000	191,000
Larkin	NA	13,000	23,000	42,000	80,000	130,000
Ricker-cyc	NA	9,000	22,000	68,000	173,000	453,000
Ricker (1980-2003)	NA	7,000	13,000	24,000	40,000	73,000
Power (1980-2003)	NA	10,000	17,000	30,000	54,000	93,000
Sibling (jack)	NA	NA	NA	NA	NA	NA

Table 6. Continued.

GATES	Rank	Age-4 Return Forecasts 10%	25%	50%	75%	90%
KF	**1**	**2,000**	**4,000**	**7,000**	**15,000**	**28,000**
RS8yr	2	3,000	5,000	9,000	16,000	27,000
RS4yr	2	2,000	4,000	7,000	13,000	24,000
Power	4	6,000	11,000	20,000	34,000	57,000
RAC	5	5,000	8,000	14,000	23,000	37,000
Ricker (PDO)	8	5,000	9,000	17,000	34,000	59,000
Ricker	10	5,000	9,000	17,000	33,000	62,000
Larkin	NA	5,000	8,000	14,000	25,000	42,000
Ricker-cyc	NA	4,000	8,000	19,000	42,000	98,000
Ricker (1990-2003)	NA	3,000	5,000	9,000	19,000	38,000
Power (1990-2003)	NA	2,000	5,000	10,000	21,000	44,000
Sibling (jack)	NA	6,000	13,000	27,000	60,000	125,000

NADINA	Rank	Age-4 Return Forecasts 10%	25%	50%	75%	90%
Ricker (FrD-mean)	**1**	**9,000**	**15,000**	**28,000**	**54,000**	**93,000**
Ricker(Ei)	2	3,000	8,000	19,000	47,000	109,000
Ricker	3	10,000	17,000	31,000	58,000	98,000
KF	4	5,000	10,000	20,000	38,000	66,000
RS4yr	7	3,000	7,000	15,000	35,000	76,000
RS8yr	14	3,000	7,000	15,000	32,000	63,000
Power	17	9,000	15,000	29,000	55,000	92,000
KF (fry)	17	5,000	11,000	22,000	44,000	79,000
Larkin	NA	9,000	15,000	31,000	59,000	98,000
Ricker-cyc	NA	9,000	15,000	29,000	49,000	84,000
Ricker (1990-2003)	NA	5,000	10,000	22,000	43,000	95,000
Power (1990-2003)	NA	4,000	9,000	20,000	44,000	96,000
Sibling (jack)	NA	4,000	11,000	32,000	89,000	233,000

PITT	Rank	Age-4 Return Forecasts 10%	25%	50%	75%	90%
Ricker	**1**	**6,000**	**12,000**	**25,000**	**50,000**	**91,000**
Ricker (Pi)	2	7,000	16,000	31,000	59,000	108,000
Ricker (FrD-Peak)	2	7,000	14,000	31,000	63,000	111,000
Power	2	5,000	9,000	18,000	35,000	60,000
Larkin	8	2,000	5,000	12,000	26,000	45,000
KF	10	9,000	20,000	41,000	81,000	147,000
Ricker-cyc	12	8,000	18,000	33,000	67,000	116,000
RS4yr	16	1,000	2,000	6,000	15,000	36,000
RS8yr	17	2,000	4,000	12,000	31,000	75,000
Ricker (1980-2003)	NA	3,000	6,000	14,000	27,000	50,000
Power (1980-2003)	NA	2,000	5,000	11,000	22,000	40,000
Sibling (jack)	NA	2,000	4,000	8,000	17,000	32,000

Table 6. Continued.

RAFT	Rank	Age-4 Return Forecasts 10%	25%	50%	75%	90%
Ricker (PDO)	**1**	**7,000**	**12,000**	**21,000**	**36,000**	**61,000**
Ricker (Pi)	1	9,000	16,000	29,000	53,000	93,000
Ricker-cyc	3	5,000	9,000	18,000	34,000	56,000
Ricker	5	6,000	12,000	22,000	39,000	68,000
Larkin	6	7,000	12,000	22,000	42,000	70,000
Power	10	6,000	11,000	20,000	36,000	57,000
KF	15	4,000	8,000	16,000	30,000	54,000
RS4yr	17	2,000	5,000	10,000	21,000	43,000
RS8yr	19	3,000	7,000	16,000	37,000	78,000
Ricker (1990-2003)	NA	4,000	8,000	18,000	36,000	65,000
Power (1990-2003)	NA	4,000	8,000	17,000	35,000	65,000
Sibling (jack)	NA	NA	NA	NA	NA	NA

SCOTCH	Rank	Age-4 Return Forecasts 10%	25%	50%	75%	90%
KF	**1**	**40,000**	**106,000**	**264,000**	**638,000**	**1,446,000**
Ricker (PDO)	2	81,000	179,000	385,000	932,000	2,073,000
RS4yr	3	76,000	180,000	467,000	1,213,000	2,863,000
RS1	3	107,000	222,000	498,000	1,117,000	2,312,000
Ricker	5	91,000	214,000	458,000	996,000	2,048,000
RS8yr	11	61,000	144,000	370,000	954,000	2,235,000
Power	13	76,000	167,000	423,000	977,000	1,957,000
Larkin	time series too short (1980-2003)					
Ricker-cyc	time series too short (1980-2003)					
Sibling (jack)	NA	20,000	49,000	132,000	356,000	864,000

SEYMOUR	Rank	Age-4 Return Forecasts 10%	25%	50%	75%	90%
RS4yr	**1**	**55,000**	**100,000**	**195,000**	**379,000**	**689,000**
RS2	2	150,000	297,000	632,000	1,348,000	2,663,000
MRS	3	121,000	225,000	449,000	898,000	1,674,000
Larkin	4	132,000	233,000	416,000	784,000	1,400,000
RS8yr	5	78,000	142,000	275,000	532,000	966,000
Ricker (Pi)	6	231,000	388,000	732,000	1,269,000	2,278,000
KF	7	62,000	114,000	226,000	438,000	792,000
Power	7	79,000	153,000	323,000	647,000	1,117,000
Ricker-cyc	7	176,000	270,000	419,000	692,000	1,119,000
Ricker	10	109,000	206,000	392,000	723,000	1,379,000
Ricker (trunc 1990-2003)	NA	52,000	100,000	210,000	456,000	848,000
Power (trunc 1990-2003)	NA	58,000	108,000	206,000	387,000	746,000
Sibling (jack)	NA	37,000	82,000	186,000	417,000	904,000

Table 6. Continued.

RUN TIMING GROUP: SUMMER	Rank	Age-4 Return Forecasts				
CHILKO		**10%**	**25%**	**50%**	**75%**	**90%**
RJ4yr	**1**	**859,000**	**1,265,000**	**1,945,000**	**2,989,000**	**4,401,000**
RJ8yr	2	1,134,000	1,717,000	2,723,000	4,316,000	6,534,000
LLY	3	NA	NA	NA	NA	NA
KF (smolt)	4	509,000	850,000	1,488,000	2,540,000	4,134,000
Power (smolt)	10	1,475,000	2,204,000	3,528,000	5,595,000	8,343,000
Power (FrD-mean)(smolt)	11	1,474,000	2,278,000	3,564,000	5,799,000	9,183,000
Power (smolt) (trunc 1990-2003)	NA	559,000	1,000,000	1,774,000	3,183,000	5,409,000
Ricker (smolt)	NA	820,000	1,312,000	2,221,000	3,831,000	6,173,000
Ricker (smolt) (trunc 1990-2003)	NA	350,000	750,000	1,461,000	2,743,000	4,577,000
Ricker (smolt): 04 & 05 brood year recruits incl.	NA	318,000	552,000	900,000	1,620,000	2,752,000
Sibling (jack)	NA	395,000	705,000	1,158,000	1,891,000	3,077,000

	Rank	Age-4 Return Forecasts				
LATE STUART		**10%**	**25%**	**50%**	**75%**	**90%**
LLY	1	NA	NA	NA	NA	NA
RAC	2	41,000	94,000	235,000	587,000	1,337,000
RS8yr	**3**	**7,000**	**18,000**	**49,000**	**137,000**	**341,000**
RS4yr	4	6,000	14,000	39,000	106,000	262,000
Power	4	27,000	57,000	126,000	283,000	598,000
KF	6	8,000	20,000	53,000	147,000	357,000
Ricker-cyc	9	366,000	694,000	1,412,000	2,730,000	5,401,000
Ricker (Ei)	10	18,000	51,000	141,000	361,000	816,000
Larkin	11	24,000	53,000	132,000	289,000	671,000
Ricker	17	24,000	60,000	160,000	384,000	888,000
Ricker (trunc 1990-2003)	NA	16,000	29,000	56,000	110,000	206,000
Power (trunc 1990-2003)	NA	22,000	43,000	84,000	158,000	321,000
Sibling (jack)	NA	17,000	40,000	98,000	229,000	537,000

	Rank	Age-4 Return Forecasts				
QUESNEL		**10%**	**25%**	**50%**	**75%**	**90%**
RAC	1	226,000	470,000	1,061,000	2,397,000	4,988,000
Larkin	2	274,000	472,000	882,000	1,692,000	2,940,000
R1C	3	263,000	423,000	719,000	1,221,000	1,966,000
RS4yr	4	44,000	76,000	140,000	256,000	441,000
R2C	5	760,000	1,399,000	2,753,000	5,418,000	9,965,000
LLY	6	NA	NA	NA	NA	NA
KF	**7**	**108,000**	**207,000**	**416,000**	**850,000**	**1,584,000**
Ricker-cyc	8	292,000	608,000	1,248,000	2,337,000	4,338,000
RS8yr	10	74,000	133,000	256,000	493,000	887,000
Ricker	13	336,000	594,000	1,157,000	2,220,000	3,692,000
Power	19	231,000	435,000	809,000	1,580,000	2,945,000
Ricker (trunc 1990-2003)	NA	135,000	250,000	504,000	1,031,000	2,018,000
Power (trunc 1990-2003)	NA	119,000	229,000	496,000	1,029,000	2,026,000
RS(1995,1999,2003)	NA	130,000	239,000	467,000	915,000	1,675,000
Sibling (jack)	NA	42,000	143,000	590,000	2,193,000	8,915,000

Table 6. Continued.

STELLAKO	Rank	Age-4 Return Forecasts 10%	25%	50%	75%	90%
RS4yr	**1**	**62,000**	**95,000**	**154,000**	**250,000**	**385,000**
KF	2	78,000	126,000	209,000	346,000	544,000
R1C	2	128,000	194,000	308,000	488,000	739,000
LLY	4	NA	NA	NA	NA	NA
Larkin	7	208,000	313,000	469,000	727,000	1,062,000
Ricker (FrD-mean)	8	231,000	345,000	543,000	890,000	1,317,000
RS8yr	10	72,000	122,000	219,000	395,000	672,000
Ricker	14	201,000	307,000	506,000	833,000	1,259,000
Power	17	178,000	274,000	435,000	724,000	1,069,000
Ricker-cyc	18	300,000	400,000	536,000	723,000	979,000
Ricker (trunc 1990-2003)	NA	85,000	153,000	289,000	525,000	898,000
Power (trunc 1990-2003)	NA	84,000	143,000	277,000	507,000	872,000
Sibling (jack)	NA	NA	NA	NA	NA	NA

RUN TIMING GROUP: LATE CULTUS	Rank	Age-4 Return Forecasts 10%	25%	50%	75%	90%
Smolt-Jack (recent MS)	**NA**	**5,000**	**6,000**	**9,000**	**14,000**	**19,000**
KF (smolt)	1	2,000	3,000	7,000	14,000	26,000
Smolt-Jack (entire MS time series)	2	6,000	10,000	19,000	36,000	59,000
Power (FrD-peak)(smolt)	3	5,000	11,000	20,000	41,000	87,000
Power (smolt)	9	5,000	9,000	19,000	36,000	69,000
Sibling (jack)	NA	1,000	2,000	7,000	25,000	75,000

HARRISON	Rank	Age-4 Return Forecasts 10%	25%	50%	75%	90%
Ricker (FrD-Mean)	**1**	**53,000**	**97,000**	**195,000**	**429,000**	**1,167,000**
Ricker (FrD-Peak)	2	57,000	115,000	248,000	616,000	1,447,000
KF	2	20,000	47,000	118,000	291,000	651,000
Ricker	6	35,000	63,000	135,000	289,000	522,000
Power	8	20,000	36,000	69,000	124,000	229,000
Sibling (jack)	NA	NA	NA	NA	NA	NA

LATE SHUSWAP	Rank	Age-4 Return Forecasts 10%	25%	50%	75%	90%
Ricker-cyc	**1**	**3,100,000**	**4,652,000**	**7,251,000**	**10,788,000**	**16,695,000**
Ricker (Pi)	2	3,889,000	6,768,000	12,640,000	21,578,000	36,039,000
Ricker (Ei)	3	2,206,000	4,042,000	7,503,000	13,910,000	23,982,000
R2C	4	1,556,000	3,218,000	7,214,000	16,173,000	33,448,000
RAC	4	1,763,000	3,407,000	7,081,000	14,721,000	28,442,000
Ricker (PDO)	6	1,886,000	3,542,000	6,979,000	13,560,000	24,141,000
Larkin	7	2,334,000	3,909,000	7,358,000	13,993,000	25,086,000
Ricker (FrD-Peak)	9	2,119,000	3,900,000	7,496,000	15,143,000	28,030,000
Ricker	9	2,119,000	4,069,000	7,473,000	13,780,000	24,391,000
Power	12	1,779,000	3,224,000	6,291,000	11,695,000	20,802,000
KF	13	1,378,000	2,637,000	5,297,000	10,470,000	19,370,000
RS4yr	14	743,000	1,451,000	3,056,000	6,433,000	12,570,000
RS8yr	18	1,732,000	3,222,000	6,422,000	12,799,000	23,810,000
Power (fry)	NA	665,000	1,756,000	5,563,000	14,690,000	36,905,000
Ricker (trunc: 1990-2003)	NA	971,000	2,171,000	4,639,000	10,268,000	21,396,000
Power (trunc: 1990-2003)	NA	765,000	1,417,000	2,665,000	5,465,000	10,163,000
Sibling (jack)	NA	713,000	1,874,000	6,314,000	17,300,000	54,194,000

Table 6. Continued.

PORTAGE	Rank	Age-4 Return Forecasts 10%	25%	50%	75%	90%
LLY	1	NA	NA	NA	NA	NA
KF	**2**	**8,000**	**17,000**	**41,000**	**97,000**	**216,000**
Ricker (FrD-mean)	3	12,000	25,000	60,000	148,000	358,000
Ricker (Pi)	4	17,000	40,000	94,000	219,000	508,000
RS8yr	8	18,000	34,000	70,000	144,000	276,000
Power	9	20,000	38,000	75,000	160,000	328,000
Ricker	11	13,000	26,000	60,000	127,000	296,000
RS4yr	14	17,000	32,000	67,000	139,000	269,000
Larkin	15	21,000	40,000	83,000	181,000	359,000
Ricker (trunc 1990-2003)	NA	18,000	35,000	67,000	170,000	328,000
Power (trunc 1990-2003)	NA	11,000	23,000	47,000	98,000	230,000
Sibling (jack)	NA	8,000	16,000	37,000	77,000	144,000

WEAVER	Rank	Age-4 Return Forecasts 10%	25%	50%	75%	90%
Ricker (FrD-peak)	**1**	**70,000**	**124,000**	**258,000**	**459,000**	**773,000**
Ricker (FrD-mean)	2	64,000	109,000	199,000	358,000	601,000
Ricker (PDO)	3	71,000	114,000	190,000	332,000	544,000
Ricker	4	56,000	96,000	179,000	337,000	616,000
Power	6	78,000	128,000	216,000	365,000	675,000
KF (fry)	9	100,000	169,000	297,000	529,000	897,000
KF	11	47,000	92,000	181,000	358,000	668,000
Power (juv)	12	117,000	187,000	315,000	523,000	921,000
RS8yr	20	45,000	91,000	196,000	422,000	842,000
RS4yr	21	39,000	80,000	180,000	403,000	833,000
Larkin	NA	60,000	93,000	167,000	309,000	554,000
Ricker (trunc 1990-2003)	NA	84,000	130,000	216,000	373,000	624,000
Power (trunc 1990-2003)	NA	83,000	131,000	219,000	348,000	554,000
Sibling (jack)	NA	79,000	134,000	236,000	416,000	738,000

BIRKENHEAD	Rank	Age-4 Return Forecasts 10%	25%	50%	75%	90%
KF	**1**	**24,000**	**48,000**	**100,000**	**206,000**	**389,000**
Ricker	2	64,000	114,000	238,000	496,000	965,000
RS1	2	84,000	212,000	588,000	1,633,000	4,096,000
Ricker (Pi)	4	95,000	194,000	367,000	774,000	1,652,000
Larkin	5	69,000	138,000	309,000	639,000	1,369,000
RS8yr	9	41,000	96,000	251,000	654,000	1,550,000
Power	12	76,000	138,000	264,000	537,000	993,000
Ricker-cyc	13	208,000	351,000	697,000	1,281,000	2,257,000
RS4yr	14	47,000	104,000	254,000	618,000	1,376,000
Ricker (trunc 1990-2003)	NA	23,000	55,000	141,000	351,000	809,000
Power (trunc 1990-2003)	NA	20,000	42,000	97,000	243,000	475,000
Sibling (jack)	NA	12,000	25,000	55,000	122,000	225,000

APPENDICES

APPENDIX 1: NON-PARAMETRIC MODELS

Eleven non-parametric models were considered (including two new models RS4yr and RS8yr that are variants of the RS1 and RS2 models), where Ret_t is the forecasted return for year t, and ε_t is the residual error, with $\varepsilon_t \sim N(0,\sigma^2)$.

LLY is the return from the previous year

(1) $$\mathrm{Ret}_t = \mathrm{Ret}_{t-1} + \varepsilon_t ,$$

where Ret_{t-1} is the observed return during the previous year (t-1).

TSA is the geometric mean return of the entire time series of available data

(2) $$\mathrm{Ret}_t = \exp\left[\frac{\log_e(\mathrm{Ret}_{t-1}) + \log_e(\mathrm{Ret}_{t-2})... + \log_e(\mathrm{Ret}_{t-N})}{N} + \varepsilon_t\right],$$

where N is the number of years with return data.

RAC is the geometric mean return of all cycle-line years in the time series

(3) $$\mathrm{Ret}_t = \exp\left[\frac{\log_e(\mathrm{Ret}_{t-4}) + \log_e(\mathrm{Ret}_{t-8})... + \log_e(\mathrm{Ret}_{t-x})}{n} + \varepsilon_t\right],$$

where t-x is the first cycle-line year with return data, and n is the number of cycle-line years with return data.

R1C is the return from the previous cycle year (assuming a 4 year generation)

(4) $$\mathrm{Ret}_t = \mathrm{Ret}_{t-4} + \varepsilon_t ,$$

where Ret_{t-4} is the observed return four years prior to the forecasted return.

R2C is the geometric mean return in the previous two cycle-line years

(5) $$\mathrm{Ret}_t = \exp\left[\frac{\log_e(\mathrm{Ret}_{t-4}) + \log_e(\mathrm{Ret}_{t-8})}{2} + \varepsilon_t\right],$$

where Ret_{t-4} and Ret_{t-8} are the observed returns four and eight years prior to the forecasted return.

MRS is the product of the EFS in the brood year (eff_t) and the mean recruits per spawner (i.e., R/EFS) over the entire time series,

(6) $$R_t = \exp\left[\frac{\log_e\left(\frac{R_{t-1}}{eff_{t-1}}\right) + \log_e\left(\frac{R_{t-2}}{eff_{t-2}}\right)... + \log_e\left(\frac{R_{t-N}}{eff_{t-N}}\right)}{N} + \log_e(eff_t) + \varepsilon_t\right],$$

where R_t are the recruits (3, 4, and 5 year old fish) resulting from spawners in the brood year, and N is the number of years with data.

RSC is the product of the number of EFS in the brood year and the mean recruits per spawner (i.e., R/EFS) over all cycle line years,

(7) $$R_t = \exp\left[\frac{\log_e\left(\frac{R_{t-4}}{eff_{t-4}}\right) + \log_e\left(\frac{R_{t-8}}{eff_{t-8}}\right) ... + \log_e\left(\frac{R_{t-x}}{eff_{t-x}}\right)}{n} + \log_e(eff_t) + \varepsilon_t\right],$$

where *t-x* is the first cycle-line year with data, and *n* is the number of cycle line years with data.

RS1 is the product of the EFS in the brood year (eff_t) and recruits per spawner (i.e., recruits per EFS) from the previous cycle line year

(8) $$R_t = \left(\frac{R_{t-4}}{eff_{t-4}}\right) \times (eff_t) + \varepsilon_t \text{ ,}$$

where R_{t-4} is the recruits resulting from the EFS (eff_{t-4}) in the brood year four years prior to most recent brood year.

RS2 is the product of the EFS in the brood year and the mean recruits per spawner (i.e., R/EFS) of the previous two cycle-line years (four and eight years previous),

(9) $$R_t = \exp\left[\frac{\log_e\left(\frac{R_{t-4}}{eff_{t-4}}\right) + \log_e\left(\frac{R_{t-8}}{eff_{t-8}}\right)}{2} + \log_e(eff_t) + \varepsilon_t\right]$$

where R_{t-4} and R_{t-8} are the recruits resulting from the previous two cycle-line brood years (four and eight years prior to most recent brood year), and eff_{t-4} and eff_{t-8} are the number of EFS in the previous two cycle-line brood years.

Two additional models to the 2010 forecast are variants of models (6) through (9).

RS4yr is the product of the EFS in the brood year (eff_t) and the mean recruits per spawner (i.e., R/EFS) over the last four years,

(10) $$R_t = \exp\left[\frac{\log_e\left(\frac{R_{t-1}}{eff_{t-1}}\right) + \log_e\left(\frac{R_{t-2}}{eff_{t-2}}\right) + \log_e\left(\frac{R_{t-3}}{eff_{t-3}}\right) + \log_e\left(\frac{R_{t-4}}{eff_{t-4}}\right)}{4} + \log_e(eff_t) + \varepsilon_t\right],$$

where R_t are the recruits (3, 4, and 5 year old fish) resulting from spawners in the brood year.

RS8yr is the product of the EFS in the brood year (eff_t) and the mean recruits per spawner (i.e., R/EFS) over the last eight years,

(11) $$R_t = \exp\left[\frac{\log_e\left(\frac{R_{t-1}}{eff_{t-1}}\right) + \log_e\left(\frac{R_{t-2}}{eff_{t-2}}\right) + \log_e\left(\frac{R_{t-3}}{eff_{t-3}}\right) ... + \log_e\left(\frac{R_{t-8}}{eff_{t-8}}\right)}{8} + \log_e(eff_t) + \varepsilon_t\right],$$

where R_t are the recruits (3, 4, and 5 year old fish) resulting from spawners in the brood year.

RS(2005BY) is the product of the EFS in the brood year (*eff_t*) and the recruits per spawner (i.e., R/EFS) from the 2005 brood year (2009 return year),

(12) $$R_t = \left(\frac{R_{t(2005BY)}}{eff_{t(2005BY)}} \right) \times \left(eff_t \right)$$

note: 2005 brood year productivities were not available for all 19 stocks individually and final age-structure, abundance, and stock identification of catch and escapement were also not available. In addition, total productivity associated with the 2005 brood year, also cannot include the age-5 component that will return in 2010

For stocks with juvenile data, the seven models above (MRS, RSC, RS1, RS2, RS4yr, RS8yr, and RS2005BY) were also calculated using historical recruit per juvenile information. The total recruits resulting from a brood year (R_t) were forecasted by multiplying the number of juveniles in the brood year (juv_t) by historical recruits-per-juvenile information. These new models were called MRJ, RJ1, RJ2, RJ4yr, RJ8yr, and RJC, and the forecasts were calculated by substituting juvenile data (*juv*) for EFS data (*eff*) in equations 6-11.

APPENDIX 2: BIOLOGICAL MODELS

Three escapement-based models were considered. Two Ricker models (Ricker 1954) of the form:

(13) $\log_e(R_t / S_t) = a - bS_t + \varepsilon_t$

and a power model

(14) $\log_e(R_t) = a + b\log_e(S_t) + \varepsilon_t$

and one Larkin model

(15) $\log_e(R_t) = a + b_1\log_e(S_t) + b_2\log_e(S_t) + b_3\log_e(S_t) + \varepsilon_t$

and one Sibling model (new to 2010 forecasts and not evaluated retrospectively)

(16) $\log_e(R_{4,t}) = a + b\log_e(R_{3,t-1}) + \varepsilon_t$

were based on the relationship between total recruits R_t and spawning escapement S_t or in the case of the sibling model the relationship between age-4 recruits (R_4) and age-3 recruits (R_3) that returned one year prior to age-4 recruits. Prior distributions for *a* are $Normal(\mu, \sigma^2)$ and beta <-1/C; C~ dlnorm(1,0.1) to restrict the beta distribution to values greater than 0. We assumed non-informative prior distributions of a parameter $Normal(0,1e6)$ (i.e., a normal distribution with large variance) and allowed the model to estimate the parameters from the data. For stocks with escapement data extending back to the 1950s, the performance of the Ricker model was also evaluated for data restricted to each cycle line.

Juvenile data were used for 6 of the 19 stocks. A power model used fry (Nadina and Weaver), in-lake fall-fry (Quesnel & Late Shuswap) or smolt data (Chilko and Cultus) to forecast adult abundance.

Annual estimates of spring Fraser River discharge measured at Hope and spring SST data in the juvenile ocean-entry year were added to equations (12) and (13). When included in a Ricker model for example:

(17) $\log_e(R_t / S_t) = a - bS_t + \gamma X_{t+2} + \varepsilon_t$,

γ represents the added effect of variable X_{t+2} in addition to spawning escapement S_t on recruitment variation.

The final biological model is a sibling model that includes priors for modeling smolt-to-adult survival and age-3 jack proportions (Wood & Parken 2004). The priors were based on the recent distribution (1998-2003 brood years) of Cultus smolt survival rates and jack proportions. The joint posterior distribution for smolt survival s_s and jack proportion p_3 given the smolt N_t and jack $E_{3,t}$ abundance for brood year *t* is

(18) $\Pr(s_s, p_3 \mid N_t, E_{3,t}) \propto Beta(\alpha_s, \beta_s)Beta(\alpha_3, \beta_3)Poisson(N_t s_s p_3)$

where s_s is beta distributed with prior parameters α_s *and* β_s. Parameter p_3 is beta distributed with parameters α_3 *and* β_3 estimated from age-3 proportion data

(19) $p_3 = \dfrac{R_3}{R_3 + R_4 + R_5}$.

The likelihood function is Poisson with an expected value equal to the predicted jack abundance based on smolt abundance N_t, smolt survival s_s, and the age-3 proportion p_3. A posterior forecast for the total return (age-4 plus age-5) is

(20) $$R_t = N_{t-1} s_t (1 - p_{t,3}) .$$

A version of this model was used to forecast 2005 Cultus Lake Sockeye returns (Wood and Parken 2005). Equation (15) includes the additional prior for jack proportions and therefore admits added uncertainty in the historical jack proportion that was fixed in the 2005 forecast.

APPENDIX 3: PROPORTION AT AGE

The proportion of recruits that return as four year olds (P_4) is

(22) $$P_4 = \frac{\left(\frac{r4_t}{r4_t + r5_t}\right) + \left(\frac{r4_{t-1}}{r4_{t-1} + r5_{t-1}}\right) ... + \left(\frac{r4_{t-N}}{r4_{t-N} + r5_{t-N}}\right)}{N},$$

where $r4_t$ and $r5_t$ are the number of four and five year old recruits, respectively, resulting from a brood year (*t*), and *N* is the number of years with data.

The predicted returns in the forecast year (Ret_t) for each stock is the total number of four and five year old fish returning in that year,

(23) $$\mathrm{Ret}_t = P_4 R_t + (1 - P_4) R_{t-1} ,$$

where P_4 is the estimated proportion of recruits (R_t) returning at age-4 in 2010, and R_{t-1} is the recruits from the previous brood year returning at age-5 in 2010. In the biological models, the prior distribution of P_4 is beta distributed with parameters estimated from the historical data series. In the non-parametric models P_4 is the historical mean.

The proportion of recruits that return as three or four year olds is calculated separately over even and odd years for the Harrison stock.

(24) $$P_4 = \frac{\left(\frac{r4_t}{r4_t + r3_t}\right) + \left(\frac{r4_{t-2}}{r4_{t-2} + r3_{t-2}}\right) ... + \left(\frac{r4_{t-X}}{r4_{t-X} + r3_{t-X}}\right)}{(N/2)},$$

where r3 and r4 are the number of three and four year old recruits, respectively, resulting from a brood year, *t-X* is the first even or odd year, and N/2 is the number of even or odd years of data.

For Harrison, the recruits from a given brood year are multiplied by the appropriate proportion (based on whether the brood year was an even or odd year) in order to forecast returns for the upcoming year,

(25) $$\mathrm{Ret}_t = P_4 R_t + (1 - P_4) R_{t+1} ,$$

where P_4 is the estimated proportion of recruits R_t returning at age-4 in 2010, and R_{t+1} is the recruits from the subsequent brood year (three years prior to forecast year) returning at age-3 in 2010.

APPENDIX 4: RETROSPECTIVE ANALYSIS PERFORMANCE MEASURES

Four quantitative measures of model performance, referred to as *performance measures (PM's)* (Haeseker et al. 2005 & 2008; Cass *et al* 2006), were used in the 2010 retrospective analysis and included the following:

(26) Mean Raw Error (MRE) = $$\frac{\sum_{t=1}^{n}\left(\hat{R}_t - R_t\right)}{n}$$

(27) Mean Absolute Error (MAE) = $$\frac{\sum_{t=1}^{n}\left|\hat{R}_t - R_t\right|}{n}$$

(28) Mean Proportional Error (MPE)= $$\frac{\sum_{t=1}^{n}\frac{\left(\hat{R}_t - R_t\right)}{R_t}}{n}$$

(29) Root Mean Square Error (RMSE) = $$\sqrt{\frac{\sum_{t=1}^{n}\left(\hat{R}_t - R_t\right)^2}{n}}$$

Where $\hat{R}$ is the forecasted return and R is the actual return for *t* brood years. The number of brood years used to evaluate model performance is *n*.

APPENDIX 5: RETROSPECTIVE ANALYSIS (BROOD YEARS 1997-2004)

RUN-TIMING: EARLY STUART

EARLY STUART	MRE	Abs(MRE)	Rank	MAE	Rank	MPE	Abs(MPE)	Rank	RMSE	Rank	Rank
LLY	0.043	0.04	6	0.10	6	6.00	6.00	12	0.11	6	**6**
TSA	0.243	0.24	17	0.24	17	35.73	35.73	21	0.25	16	**19**
R1C	0.263	0.26	20	0.26	20	5.15	5.15	7	0.53	20	**16**
R2C	0.335	0.34	21	0.34	21	12.76	12.76	19	0.51	19	**21**
RAC	0.249	0.25	18	0.25	18	20.10	20.10	20	0.37	18	**20**
MRS	0.140	0.14	13	0.14	13	6.29	6.29	14	0.20	12	**13**
RS1	0.038	0.04	5	0.06	5	2.68	2.68	5	0.09	5	**5**
RS2	**0.027**	**0.03**	**3**	**0.03**	**3**	**2.39**	**2.39**	**4**	**0.05**	**3**	**3**
RSC	0.151	0.15	14	0.15	14	6.86	6.86	16	0.22	14	**14**
Ricker	0.125	0.13	10	0.13	10	6.02	6.02	13	0.18	9	**10**
Power	0.098	0.10	7	0.10	6	7.07	7.07	17	0.13	7	**9**
Larkin	0.159	0.16	15	0.16	15	6.72	6.72	15	0.23	15	**15**
Ricker-cyc	0.199	0.20	16	0.20	16	10.73	10.73	18	0.30	17	**16**
Ricker (FrD-mean)	0.127	0.13	11	0.13	11	5.92	5.92	11	0.19	11	**11**
Ricker (Ei)	0.255	0.26	19	0.26	19	5.53	5.53	9	0.53	21	**18**
Ricker (Pi)	0.111	0.11	8	0.11	8	3.95	3.95	6	0.18	10	**7**
Ricker (FrD-Peak)	0.133	0.13	12	0.13	12	5.40	5.40	8	0.20	13	**12**
Ricker (PDO)	0.120	0.12	9	0.12	9	5.69	5.69	10	0.17	8	**8**
RS4yr	**0.014**	**0.01**	**2**	**0.02**	**1**	**2.12**	**2.12**	**2**	**0.03**	**2**	**1**
RS8yr	**0.011**	**0.01**	**1**	**0.03**	**2**	**2.35**	**2.35**	**3**	**0.03**	**1**	**1**
KF	**0.029**	**0.03**	**4**	**0.04**	**4**	**1.83**	**1.83**	**1**	**0.06**	**4**	**3**

RUN-TIMING: EARLY SUMMER

BOWRON	MRE	Abs(MRE)	Rank	MAE	Rank	MPE	Abs(MPE)	Rank	RMSE	Rank	Rank
LLY	**0.002**	**0.00**	**1**	**0.01**	**3**	**0.59**	**0.59**	**1**	**0.01**	**3**	**2**
TSA	0.032	0.03	20	0.03	20	5.11	5.11	20	0.03	20	**20**
R1C	0.007	0.01	4	0.01	5	1.44	1.44	5	0.01	4	**5**
R2C	0.010	0.01	6	0.01	6	1.77	1.77	6	0.01	6	**6**
RAC	0.033	0.03	21	0.03	21	5.19	5.19	21	0.04	21	**21**
MRS	0.019	0.02	16	0.02	15	2.55	2.55	18	0.02	16	**18**
RS1	0.015	0.02	7	0.02	15	2.08	2.08	10	0.03	19	**13**
RS2	0.015	0.02	7	0.02	8	1.86	1.86	7	0.02	10	**7**
RSC	0.021	0.02	19	0.02	19	2.69	2.69	19	0.02	18	**19**
Ricker	0.018	0.02	13	0.02	12	2.24	2.24	13	0.02	10	**12**
Power	0.015	0.02	7	0.02	7	2.12	2.12	11	0.02	7	**7**
Larkin	0.017	0.02	12	0.02	11	2.18	2.18	12	0.02	10	**11**
Ricker-cyc	0.019	0.02	16	0.02	15	2.43	2.43	16	0.02	13	**16**
Ricker (FrD-mean)	0.018	0.02	13	0.02	12	2.28	2.28	14	0.02	13	**14**
Ricker (Ei)	0.019	0.02	16	0.02	15	2.50	2.50	17	0.02	16	**17**
Ricker (Pi)	0.016	0.02	10	0.02	8	1.96	1.96	8	0.02	9	**9**
Ricker (FrD-Peak)	0.018	0.02	13	0.02	12	2.31	2.31	15	0.02	13	**15**
Ricker (PDO)	0.016	0.02	10	0.02	8	2.01	2.01	9	0.02	8	**9**
RS4yr	**0.003**	**0.00**	**2**	**0.01**	**1**	**0.62**	**0.62**	**2**	**0.01**	**1**	**1**
RS8yr	0.008	0.01	5	0.01	3	1.02	1.02	4	0.01	4	**4**
KF	**0.006**	**0.01**	**3**	**0.01**	**1**	**0.81**	**0.81**	**3**	**0.01**	**1**	**2**

FENNELL	MRE	Abs(MRE)	Rank	MAE	Rank	MPE	Abs(MPE)	Rank	RMSE	Rank	Rank
LLY	0.001	0.00	2	0.02	14	0.56	0.56	7	0.03	15	8
TSA	**-0.001**	**0.00**	**2**	**0.02**	**3**	**0.58**	**0.58**	**8**	**0.02**	**1**	**3**
R1C	-0.001	0.00	2	0.02	12	0.80	0.80	10	0.03	11	5
R2C	0.000	0.00	1	0.02	4	0.66	0.66	9	0.02	5	4
RAC	**-0.002**	**0.00**	**6**	**0.01**	1	0.41	**0.41**	3	**0.02**	**3**	2
MRS	0.020	0.02	18	0.03	17	2.13	2.13	18	0.03	18	18
RS1	-0.002	0.00	6	0.03	17	0.87	0.87	11	0.03	17	17
RS2	-0.006	0.01	9	0.02	12	0.54	0.54	5	0.03	13	10
RSC	0.024	0.02	19	0.03	19	2.53	2.53	19	0.04	19	19
Ricker	0.010	0.01	13	0.02	7	1.28	1.28	13	0.02	5	8
Power	**-0.001**	**0.00**	**2**	**0.02**	**2**	**0.54**	**0.54**	**6**	**0.02**	**1**	**1**
Ricker (FrD-mean)	0.009	0.01	11	0.02	9	1.28	1.28	14	0.02	7	13
Ricker (Ei)	0.012	0.01	16	0.02	5	1.33	1.33	15	0.02	3	10
Ricker (Pi)	0.010	0.01	13	0.02	7	1.36	1.36	16	0.03	9	15
Ricker (FrD-Peak)	0.010	0.01	13	0.02	9	1.38	1.38	17	0.03	9	16
Ricker (PDO)	0.009	0.01	11	0.02	9	1.21	1.21	12	0.02	7	10
RS4yr	-0.008	0.01	10	0.02	14	0.34	0.34	2	0.03	15	13
RS8yr	-0.013	0.01	17	0.02	5	0.03	0.03	1	0.03	13	6
KF	-0.004	0.00	8	0.02	14	0.51	0.51	4	0.03	11	7
Larkin	time series too short to evaluate retrospectively										
Ricker-cyc	time series too short to evaluate retrospectively										

GATES	MRE	Abs(MRE)	Rank	MAE	Rank	MPE	Abs(MPE)	Rank	RMSE	Rank	Rank
LLY	0.02	0.02	5	0.04	15	1.77	1.77	4	0.07	15	10
TSA	0.02	0.02	6	0.03	6	3.16	3.16	17	0.03	5	9
R1C	0.03	0.03	10	0.04	12	2.03	2.03	6	0.05	12	12
R2C	0.04	0.04	16	0.04	13	2.07	2.07	8	0.06	13	14
RAC	0.03	0.03	10	0.03	10	1.26	1.26	1	0.05	10	5
MRS	0.04	0.04	17	0.04	15	3.00	3.00	15	0.06	14	16
RS1	0.03	0.03	15	0.05	17	4.07	4.07	19	0.07	16	17
RS2	0.03	0.03	14	0.04	14	2.08	2.08	9	0.07	18	15
RSC	0.04	0.04	18	0.05	18	3.21	3.21	18	0.07	17	18
Ricker	0.03	0.03	10	0.03	9	2.72	2.72	11	0.04	9	10
Power	0.02	0.02	4	0.02	4	2.07	2.07	7	0.03	4	4
Ricker (FrD-mean)	0.02	0.02	6	0.03	6	2.79	2.79	14	0.03	6	6
Ricker (Ei)	0.06	0.06	19	0.06	19	3.04	3.04	16	0.10	19	19
Ricker (Pi)	0.03	0.03	13	0.03	10	2.56	2.56	10	0.05	11	13
Ricker (FrD-Peak)	0.02	0.02	6	0.03	6	2.75	2.75	12	0.03	8	6
Ricker (PDO)	0.03	0.03	9	0.03	5	2.78	2.78	13	0.03	6	8
RS4yr	**0.01**	**0.01**	**1**	**0.02**	**2**	**1.79**	**1.79**	**5**	**0.03**	**1**	**2**
RS8yr	**0.01**	**0.01**	**3**	**0.02**	**1**	**1.34**	**1.34**	**2**	**0.03**	**3**	**2**
KF	**0.01**	**0.01**	**1**	**0.02**	**2**	**1.51**	**1.51**	**3**	**0.03**	**1**	**1**
Larkin	time series too short to evaluate retrospectively										
Ricker-cyc	time series too short to evaluate retrospectively										

NADINA	MRE	Abs(MRE)	Rank	MAE	Rank	MPE	Abs(MPE)	Rank	RMSE	Rank	Rank
LLY	0.03	0.03	18	0.12	25	4.48	4.48	28	0.16	24	25
TSA	0.01	0.01	4	0.06	18	5.46	5.46	30	0.07	12	17
R1C	0.04	0.04	21	0.06	16	1.31	1.31	20	0.11	21	21
R2C	0.03	0.03	18	0.05	10	2.14	2.14	23	0.06	10	16
RAC	0.01	0.01	5	0.06	14	5.32	5.32	29	0.07	12	15
MRS	0.04	0.04	21	0.08	23	1.25	1.25	19	0.13	23	23
RS1	0.21	0.21	29	0.27	29	2.50	2.50	26	0.54	29	29
RS2	0.27	0.27	30	0.30	30	2.45	2.45	25	0.67	30	30
RSC	0.10	0.10	26	0.14	26	1.61	1.61	22	0.26	26	26
MRJ	-0.06	0.06	25	0.06	14	-0.60	0.60	3	0.06	7	10
RJ1	0.15	0.15	28	0.20	28	2.90	2.90	27	0.37	28	28
RJ2	0.15	0.15	27	0.18	27	2.38	2.38	24	0.35	27	27
RJC	0.04	0.04	20	0.08	22	1.40	1.40	21	0.11	22	22
Ricker	**0.00**	**0.00**	**1**	**0.04**	**7**	**0.95**	**0.95**	**8**	**0.05**	**3**	**3**
Power	0.02	0.02	16	0.06	18	1.03	1.03	12	0.09	18	17
Ricker (FrD-mean)	**-0.01**	**0.01**	**2**	**0.04**	**3**	**0.95**	**0.95**	**9**	**0.05**	**2**	**1**
Ricker (Ei)	**-0.01**	**0.01**	**9**	**0.03**	**1**	**0.82**	**0.82**	**6**	**0.05**	**1**	**2**
Ricker (Pi)	-0.01	0.01	5	0.04	6	0.88	0.88	7	0.05	3	4
Ricker (FrD-Peak)	-0.01	0.01	7	0.05	8	1.03	1.03	13	0.06	7	8
Ricker (PDO)	-0.01	0.01	2	0.04	5	1.00	1.00	11	0.05	3	4
Power (juv)	0.02	0.02	12	0.06	13	1.11	1.11	15	0.08	15	13
Power (juv)(FrD-mean)	0.06	0.06	24	0.10	24	1.15	1.15	16	0.19	25	24
Power (juv) (Ei)	0.01	0.01	8	0.05	9	1.00	1.00	10	0.08	16	9
Power (juv) (Pi)	0.02	0.02	14	0.06	12	1.08	1.08	14	0.08	14	12
Power (juv) (FrD-Peak)	0.02	0.02	12	0.05	11	1.15	1.15	17	0.07	11	11
Power (juv) (PDO)	0.02	0.02	15	0.06	16	1.20	1.20	18	0.08	17	20
RS4yr	-0.03	0.03	17	0.03	2	0.39	0.39	1	0.06	6	7
RS8yr	0.01	0.01	11	0.07	21	0.79	0.79	5	0.10	20	14
KF	-0.01	0.01	9	0.04	3	0.56	0.56	2	0.06	7	4
KF (juv)	-0.04	0.04	21	0.06	20	0.75	0.75	4	0.09	19	17
Larkin	**time series too short to evaluate retrospectively**										
Ricker-cyc	**time series too short to evaluate retrospectively**										

PITT	MRE	Abs(MRE)	Rank	MAE	Rank	MPE	Abs(MPE)	Rank	RMSE	Rank	Rank
LLY	0.01	0.01	8	0.03	10	0.24	0.24	12	0.04	10	9
TSA	-0.01	0.01	14	0.03	11	0.17	0.17	9	0.04	11	11
R1C	0.01	0.01	10	0.05	15	0.50	0.50	15	0.06	15	15
R2C	-0.01	0.01	12	0.05	14	0.23	0.23	11	0.06	14	14
RAC	-0.01	0.01	15	0.04	12	0.20	0.20	10	0.04	12	13
MRS	0.15	0.15	19	0.16	19	3.01	3.01	19	0.19	18	19
RS1	0.21	0.21	21	0.21	21	2.94	2.94	18	0.23	21	20
RS2	0.18	0.18	20	0.18	20	3.71	3.71	21	0.23	20	20
RSC	0.15	0.15	18	0.15	18	3.29	3.29	20	0.19	17	18
Ricker	**0.00**	**0.00**	**2**	**0.01**	**2**	**0.07**	**0.07**	**5**	**0.02**	**2**	**1**
Power	**0.00**	**0.00**	**2**	**0.01**	**1**	**0.11**	**0.11**	**8**	**0.02**	**1**	**2**
Larkin	-0.01	0.01	11	0.02	8	-0.09	0.09	7	0.02	4	8
Ricker-cyc	0.01	0.01	8	0.05	13	0.44	0.44	14	0.05	13	12
Ricker (FrD-mean)	0.00	0.00	1	0.01	6	0.09	0.09	6	0.02	4	6
Ricker (Ei)	0.00	0.00	6	0.01	2	0.02	0.02	1	0.02	4	5
Ricker (Pi)	**0.00**	**0.00**	**5**	**0.01**	**2**	**0.05**	**0.05**	**3**	**0.02**	**2**	**2**
Ricker (FrD-Peak)	**0.00**	**0.00**	**2**	**0.01**	**2**	**0.06**	**0.06**	**4**	**0.02**	**4**	**2**
Ricker (PDO)	0.00	0.00	6	0.01	6	0.03	0.03	2	0.02	4	7
RS4yr	0.12	0.12	16	0.13	16	1.64	1.64	16	0.15	16	16
RS8yr	0.14	0.14	17	0.15	17	2.45	2.45	17	0.19	18	17
KF	0.01	0.01	12	0.02	9	0.32	0.32	13	0.03	9	10

RAFT	MRE	Abs(MRE)	Rank	MAE	Rank	MPE	Abs(MPE)	Rank	RMSE	Rank	Rank
LLY	0.01	0.01	11	0.03	14	0.26	0.26	12	0.03	15	13
TSA	-0.02	0.02	14	0.02	11	-0.30	0.30	13	0.03	13	12
R1C	0.00	0.00	3	0.02	10	0.00	0.00	1	0.02	10	9
R2C	-0.01	0.01	12	0.02	13	-0.14	0.14	11	0.03	11	11
RAC	-0.02	0.02	15	0.02	12	-0.38	0.38	15	0.03	12	14
MRS	0.04	0.04	16	0.04	16	0.61	0.61	16	0.06	17	16
RS1	0.07	0.07	21	0.08	21	1.49	1.49	21	0.10	21	21
RS2	0.07	0.07	20	0.07	19	1.32	1.32	20	0.09	19	20
RSC	0.04	0.04	17	0.05	17	0.65	0.65	17	0.07	18	17
Ricker	0.00	0.00	1	0.02	4	0.08	0.08	9	0.02	3	5
Power	0.00	0.00	7	0.02	4	0.09	0.09	10	0.02	7	10
Larkin	0.00	0.00	7	0.02	4	0.06	0.06	5	0.02	3	6
Ricker-cyc	**-0.01**	**0.01**	**10**	**0.01**	**1**	**-0.04**	**0.04**	**3**	**0.02**	**1**	**3**
Ricker (FrD-mean)	0.00	0.00	1	0.02	4	0.07	0.07	7	0.02	7	6
Ricker (Ei)	0.00	0.00	3	0.02	4	0.07	0.07	8	0.02	7	8
Ricker (Pi)	**0.00**	**0.00**	**3**	**0.02**	**3**	**0.05**	**0.05**	**4**	**0.02**	**3**	**1**
Ricker (FrD-Peak)	0.00	0.00	3	0.02	4	0.06	0.06	6	0.02	3	4
Ricker (PDO)	**0.00**	**0.00**	**7**	**0.01**	**2**	**0.01**	**0.01**	**2**	**0.02**	**2**	**1**
RS4yr	0.04	0.04	17	0.05	18	0.76	0.76	18	0.06	16	17
RS8yr	0.06	0.06	19	0.07	19	1.05	1.05	19	0.09	20	19
KF	0.02	0.02	13	0.03	15	0.33	0.33	14	0.03	13	15

SCOTCH	MRE		MAE	Rank		Abs(MPE)	Rank	RMSE	Rank	Mean	Rank
LLY	0.00	0.00	1	0.22	19	6.29	6.29	19	0.34	19	19
TSA	-0.05	0.05	13	0.14	18	6.28	6.28	18	0.23	18	18
R1C	-0.06	0.06	17	0.07	13	0.84	0.84	13	0.17	16	15
R2C	-0.06	0.06	15	0.08	14	0.66	0.66	12	0.17	17	16
RAC	-0.06	0.06	15	0.07	12	0.96	0.96	14	0.17	15	14
MRS	-0.04	0.04	12	0.06	10	0.60	0.60	11	0.12	10	11
RS1	**-0.03**	**0.03**	**6**	**0.05**	**5**	**0.42**	**0.42**	**8**	**0.07**	**5**	**3**
RS2	-0.04	0.04	11	0.05	9	0.11	0.11	3	0.10	9	9
RSC	0.02	0.02	4	0.03	2	1.01	1.01	15	0.04	2	5
Ricker	-0.04	0.04	10	0.05	7	0.29	0.29	4	0.10	8	5
Power	-0.07	0.07	18	0.08	15	0.32	0.32	6	0.16	14	13
Ricker (FrD-mean)	-0.04	0.04	8	0.05	6	0.33	0.33	7	0.10	7	8
Ricker (Ei)	-0.03	0.03	7	0.08	15	1.70	1.70	16	0.15	12	16
Ricker (Pi)	0.02	0.02	5	0.02	1	2.22	2.22	17	0.03	1	5
Ricker (FrD-Peak)	-0.05	0.05	14	0.06	11	0.31	0.31	5	0.13	11	10
Ricker (PDO)	**-0.01**	**0.01**	**2**	**0.03**	**3**	**0.45**	**0.45**	**9**	**0.04**	**3**	**2**
RS4yr	**-0.02**	**0.02**	**3**	**0.04**	**4**	**0.53**	**0.53**	**10**	**0.07**	**4**	**3**
RS8yr	-0.07	0.07	19	0.08	17	-0.11	0.11	2	0.15	12	11
KF	**-0.04**	**0.04**	**9**	**0.05**	**7**	**-0.05**	**0.05**	**1**	**0.08**	**6**	**1**
Larkin	time series too short to evaluate retrospectively										
Ricker-cyc	time series too short to evaluate retrospectively										

SEYMOUR	MRE		MAE	Rank		Abs(MPE)	Rank	RMSE	Rank	Mean	Rank
LLY	0.00	0.00	1	0.18	21	4.02	4.02	20	0.26	21	17
TSA	0.02	0.02	10	0.14	20	5.73	5.73	21	0.17	18	19
R1C	-0.03	0.03	16	0.11	19	1.57	1.57	15	0.17	19	19
R2C	-0.03	0.03	15	0.10	16	1.20	1.20	9	0.15	17	16
RAC	0.02	0.02	10	0.09	14	1.90	1.90	18	0.12	13	15
MRS	**0.01**	**0.01**	**2**	**0.06**	**2**	**1.44**	**1.44**	**14**	**0.09**	**2**	**3**
RS1	0.04	0.04	20	0.11	18	3.45	3.45	19	0.20	20	21
RS2	**-0.01**	**0.01**	**4**	**0.06**	**2**	**0.98**	**0.98**	**6**	**0.10**	**3**	**2**
RSC	0.04	0.04	18	0.07	8	1.64	1.64	16	0.10	5	13
Ricker	-0.01	0.01	6	0.08	11	1.23	1.23	11	0.11	11	10
Power	-0.02	0.02	8	0.07	8	1.19	1.19	8	0.11	9	7
Larkin	-0.01	0.01	2	0.08	10	1.21	1.21	10	0.10	6	4
Ricker-cyc	0.01	0.01	7	0.07	7	1.31	1.31	13	0.10	6	7
Ricker (FrD-mean)	-0.02	0.02	8	0.08	12	1.25	1.25	12	0.12	12	11
Ricker (Ei)	-0.02	0.02	13	0.10	17	1.74	1.74	17	0.15	16	17
Ricker (Pi)	-0.03	0.03	14	0.07	5	0.69	0.69	3	0.11	10	6
Ricker (FrD-Peak)	-0.02	0.02	12	0.08	13	1.18	1.18	7	0.12	14	12
Ricker (PDO)	-0.03	0.03	16	0.09	15	0.96	0.96	5	0.14	15	14
RS4yr	**-0.01**	**0.01**	**4**	**0.05**	**1**	**0.86**	**0.86**	**4**	**0.08**	**1**	**1**
RS8yr	-0.04	0.04	21	0.07	5	0.35	0.35	1	0.10	4	5
KF	-0.04	0.04	19	0.07	4	0.47	0.47	2	0.10	8	7

RUN-TIMING: SUMMER CHILKO	MRE	Abs(MRE)	Rank	MAE	Rank	MPE	Abs(MPE)	Rank	RMSE	Rank	Rank
LLY	**0.11**	**0.11**	**1**	**0.57**	**6**	**0.68**	**0.68**	**2**	**0.69**	**5**	**3**
TSA	0.59	0.59	12	0.63	8	1.29	1.29	14	0.71	7	8
R1C	0.59	0.59	10	0.92	26	1.25	1.25	8	1.19	26	18
R2C	0.94	0.94	28	1.02	28	1.73	1.73	28	1.26	28	27
RAC	0.60	0.60	13	0.64	9	1.53	1.53	25	0.89	20	16
MRS	1.99	1.99	30	1.99	30	3.42	3.42	30	2.33	30	30
RS1	0.93	0.93	27	1.37	29	1.54	1.54	27	2.08	29	27
RS2	0.24	0.24	3	0.61	7	0.87	0.87	5	0.70	6	6
RSC	2.22	2.22	31	2.23	31	3.63	3.63	31	2.63	31	31
MRJ	0.82	0.82	25	0.82	22	1.53	1.53	24	1.00	23	25
RJ1	0.51	0.51	7	0.86	25	1.14	1.14	7	1.08	25	14
RJ2	0.52	0.52	8	0.83	23	1.34	1.34	16	1.05	24	19
RJC	0.83	0.83	26	0.83	24	1.53	1.53	26	0.96	22	26
Ricker	0.71	0.71	22	0.71	17	1.42	1.42	23	0.87	19	23
Power	0.99	0.99	29	0.99	27	1.84	1.84	29	1.23	27	27
Larkin	0.53	0.53	9	0.56	5	1.25	1.25	9	0.81	8	7
Ricker (FrD-mean)	0.68	0.68	21	0.68	14	1.39	1.39	21	0.85	16	20
Ricker (Ei)	0.59	0.59	11	0.73	20	1.27	1.27	12	0.84	15	12
Ricker (Pi)	0.71	0.71	23	0.71	18	1.40	1.40	22	0.86	18	23
Ricker (FrD-Peak)	0.73	0.73	24	0.73	19	1.38	1.38	20	0.82	11	21
Ricker (PDO)	0.68	0.68	20	0.68	12	1.35	1.35	18	0.82	10	13
Power (juv)	0.66	0.66	17	0.67	11	1.29	1.29	13	0.81	9	10
Power (juv)(FrD-mean)	0.64	0.64	15	0.68	13	1.26	1.26	10	0.83	13	11
Power (juv) (Ei)	0.65	0.65	16	0.76	21	1.35	1.35	17	0.91	21	22
Power (juv) (Pi)	0.64	0.64	14	0.66	10	1.27	1.27	11	0.82	11	9
Power (juv) (FrD-Peak)	0.67	0.67	19	0.69	16	1.35	1.35	19	0.84	14	17
Power (juv) (PDO)	0.67	0.67	18	0.69	15	1.32	1.32	15	0.85	17	15
RJ4yr	**0.14**	**0.14**	**2**	**0.43**	**1**	**0.41**	**0.41**	**1**	**0.49**	**1**	**1**
RJ8yr	**0.33**	**0.33**	**4**	**0.48**	**2**	**0.70**	**0.70**	**3**	**0.57**	**2**	**2**
KF (juv)	0.38	0.38	5	0.50	3	0.84	0.84	4	0.59	3	4
KF	0.47	0.47	6	0.51	4	0.97	0.97	6	0.67	4	5

LATE STUART	MRE	Abs(MRE)	Rank	MAE	Rank	MPE	Abs(MPE)	Rank	RMSE	Rank	Rank
LLY	**0.07**	**0.07**	**1**	**0.23**	**1**	**1.46**	**1.46**	**4**	**0.24**	**1**	**1**
TSA	0.28	0.28	2	0.28	2	4.36	4.36	20	0.32	2	**6**
R1C	0.48	0.48	8	0.49	8	1.64	1.64	6	0.97	12	**8**
R2C	0.76	0.76	15	0.77	15	2.19	2.19	10	1.40	17	**15**
RAC	**0.28**	**0.28**	**3**	**0.45**	**6**	**0.90**	**0.90**	**1**	**0.72**	**5**	**2**
MRS	1.30	1.30	20	1.30	20	4.20	4.20	19	1.89	19	**20**
RS1	1.04	1.04	19	1.11	19	2.41	2.41	11	2.52	21	**19**
RS2	0.81	0.81	18	0.84	18	2.07	2.07	9	1.48	18	**17**
RSC	1.48	1.48	21	1.48	21	4.57	4.57	21	2.15	20	**21**
Ricker	0.80	0.80	17	0.80	17	3.17	3.17	15	1.13	14	**17**
Power	0.31	0.31	4	0.31	3	1.66	1.66	8	0.45	3	**4**
Larkin	0.70	0.70	11	0.70	11	2.67	2.67	12	1.08	13	**11**
Ricker-cyc	0.57	0.57	9	0.66	10	1.65	1.65	7	1.19	15	**9**
Ricker (FrD-mean)	0.73	0.73	14	0.73	14	3.32	3.32	16	0.92	9	**13**
Ricker (Ei)	0.64	0.64	10	0.64	9	3.46	3.46	18	0.88	8	**10**
Ricker (Pi)	0.79	0.79	16	0.79	16	2.79	2.79	13	1.22	16	**16**
Ricker (FrD-Peak)	0.72	0.72	13	0.72	13	3.36	3.36	17	0.94	10	**13**
Ricker (PDO)	0.71	0.71	12	0.71	12	2.97	2.97	14	0.96	11	**12**
RS4yr	0.33	0.33	5	0.38	5	0.99	0.99	2	0.75	6	**4**
RS8yr	**0.35**	**0.35**	**6**	**0.38**	**4**	**1.12**	**1.12**	**3**	**0.71**	**4**	**3**
KF	0.43	0.43	7	0.46	7	1.55	1.55	5	0.87	7	**6**

QUESNEL	MRE	Abs(MRE)	Rank	MAE	Rank	MPE	Abs(MPE)	Rank	RMSE	Rank	Rank
LLY	0.006	0.006	1.000	2.014	10	2	2.045	8	2.474	8	**6**
TSA	-0.349	0.349	2.000	1.622	7	5	4.719	19	1.853	2	**9**
R1C	**0.655**	**0.655**	**4.000**	**1.303**	**3**	**2**	**1.709**	**7**	**1.966**	**4**	**3**
R2C	0.951	0.951	6.000	1.517	5	2	1.505	4	2.170	6	**5**
RAC	**-0.393**	**0.393**	**3.000**	**0.829**	**1**	**0**	**0.150**	**1**	**1.484**	**1**	**1**
MRS	6.416	6.416	20.000	6.416	20	9	8.557	20	9.216	20	**20**
RS1	1.818	1.818	11.000	2.157	15	4	4.286	18	3.954	17	**17**
RS2	2.126	2.126	13.000	2.126	12	4	4.002	16	3.528	16	**14**
RSC	7.103	7.103	21.000	7.103	21	10	10.073	21	10.086	21	**21**
Ricker	2.139	2.139	15.000	2.139	14	4	3.680	13	2.893	13	**13**
Power	3.667	3.667	19.000	3.667	19	4	3.912	15	5.552	19	**19**
Larkin	**1.148**	**1.148**	**7.000**	**1.204**	**2**	**1**	**1.028**	**3**	**1.878**	**3**	**2**
Ricker-cyc	1.262	1.262	8.000	1.761	9	1	0.971	2	2.586	10	**8**
Ricker (FrD-mean)	2.211	2.211	16.000	2.211	16	4	3.854	14	2.915	14	**15**
Ricker (Ei)	3.022	3.022	18.000	3.022	18	4	3.528	10	4.577	18	**18**
Ricker (Pi)	2.459	2.459	17.000	2.459	17	4	3.540	11	3.334	15	**15**
Ricker (FrD-Peak)	2.061	2.061	12.000	2.061	11	4	4.191	17	2.744	11	**11**
Ricker (PDO)	2.134	2.134	14.000	2.134	13	4	3.678	12	2.829	12	**11**
RS4yr	0.838	0.838	5.000	1.402	4	2	1.541	5	2.169	5	**4**
RS8yr	1.623	1.623	10.000	1.710	8	2	2.198	9	2.538	9	**10**
KF	1.608	1.608	9	1.615	6	1.66	1.660	6	2	7	**7**

juvenile data starts in 1976 and intermittment; difficult to compare retrospectively

STELLAKO	MRE	Abs(MRE)	Rank	MAE	Rank	MPE	Abs(MPE)	Rank	RMSE	Rank	Rank
LLY	0.058	0.058	1.000	0.206	5	1	0.716	2	0.246	5	4
TSA	0.193	0.193	5.000	0.212	6	1	1.426	13	0.231	4	5
R1C	0.135	0.135	3.000	0.167	3	1	0.756	3	0.202	3	2
R2C	0.215	0.215	7.000	0.227	7	1	0.996	6	0.263	8	5
RAC	0.198	0.198	6.000	0.201	4	2	1.660	17	0.276	14	11
MRS	0.648	0.648	20.000	0.648	20	3	3.045	20	0.781	20	20
RS1	0.281	0.281	16.000	0.310	17	1	1.210	8	0.370	17	15
RS2	0.464	0.464	19.000	0.479	19	2	1.878	19	0.612	19	19
RSC	0.705	0.705	21.000	0.705	21	3	3.307	21	0.857	21	21
Ricker	0.252	0.252	14.000	0.252	14	1	1.451	16	0.267	12	14
Power	0.282	0.282	17.000	0.282	16	1	1.431	14	0.330	16	17
Larkin	0.234	0.234	9.000	0.234	8	1	0.948	5	0.266	11	7
Ricker-cyc	0.351	0.351	18.000	0.383	18	2	1.798	18	0.453	18	18
Ricker (FrD-mean)	0.236	0.236	10.000	0.236	9	1	1.378	12	0.259	6	8
Ricker (Ei)	0.256	0.256	15.000	0.256	15	1	1.451	15	0.275	13	15
Ricker (Pi)	0.247	0.247	13.000	0.247	13	1	1.370	10	0.264	10	13
Ricker (FrD-Peak)	0.242	0.242	11.000	0.242	11	1	1.366	9	0.263	8	9
Ricker (PDO)	0.243	0.243	12.000	0.243	12	1	1.374	11	0.262	7	12
RS4yr	0.099	0.099	2.000	0.137	1	1	0.599	1	0.164	1	1
RS8yr	0.226	0.226	8.000	0.239	10	1	1.093	7	0.278	15	10
KF	0.144	0.144	4.000	0.166	2	1	0.806	4	0.197	2	2

RUN-TIMING: LATE

CULTUS	MRE	Abs(MRE)	Rank	MAE	Rank	MPE	Abs(MPE)	Rank	RMSE	Rank	Rank
LLY	0.00	0.00	4	0.02	15	4.02	4.02	14	0.04	17	15
TSA	0.03	0.03	17	0.03	18	53.7	53.70	18	0.04	15	17
R1C	0.00	0.00	9	0.02	12	5.43	5.43	16	0.02	12	13
R2C	0.01	0.01	13	0.02	13	5.14	5.14	15	0.02	13	16
RAC	0.03	0.03	18	0.03	16	36.6	36.60	17	0.04	18	18
MRS	-0.01	0.01	15	0.01	11	1.38	1.38	4	0.02	11	11
MRJ	0.00	0.00	12	0.01	6	1.53	1.53	5	0.02	5	7
RJ1	-0.01	0.01	13	0.02	14	0.92	0.92	2	0.03	14	12
RJ2	-0.02	0.02	16	0.03	16	0.56	0.56	1	0.04	16	13
RJC	0.00	0.00	1	0.01	10	1.85	1.85	7	0.02	7	6
Smolt-Jack	0.00	0.00	6	0.01	2	1.17	1.17	3	0.01	3	2
Power (juv)	0.00	0.00	9	0.01	6	2.86	2.86	11	0.02	7	9
Power (juv)(FrD-mean)	0.00	0.00	9	0.01	6	2.56	2.56	8	0.02	7	8
Power (juv) (Ei)	0.00	0.00	6	0.01	6	2.94	2.94	13	0.02	10	10
Power (juv) (Pi)	0.00	0.00	1	0.01	4	2.89	2.89	12	0.02	4	5
Power (juv) (FrD-Peak)	0.00	0.00	6	0.01	2	2.6	2.60	9	0.01	2	3
Power (juv) (PDO)	0.00	0.00	1	0.01	4	2.72	2.72	10	0.02	5	4
KF	0.00	0.00	4	0.01	1	1.72	1.72	6	0.01	1	1

entire juvenile time series used since smolt assessments were intermittment

HARRISON	MRE	Abs(MRE)	Rank	MAE	Rank	MPE	Abs(MPE)	Rank	RMSE	Rank	Rank
LLY	0.00	0.00	1	0.11	13	3.55	3.55	15	0.14	12	15
TSA	-0.09	0.09	14	0.10	10	0.2	0.20	2	0.13	9	8
R1C	-0.05	0.05	12	0.11	12	0.35	0.35	3	0.15	13	14
R2C	-0.07	0.07	13	0.10	11	-0	0.00	1	0.14	11	10
RAC	-0.09	0.09	15	0.09	9	-0.54	0.54	4	0.14	10	12
MRS	-0.01	0.01	2	0.14	14	2.47	2.47	7	0.21	14	11
RS1	0.41	0.41	16	0.48	16	23.6	23.58	17	1.11	16	16
RS2	0.44	0.44	17	0.55	17	15.9	15.94	16	1.45	17	17
RSC	-0.01	0.01	2	0.14	15	2.46	2.46	6	0.21	15	12
Ricker	-0.04	0.04	6	0.08	7	2.51	2.51	8	0.12	7	6
Power	-0.03	0.03	5	0.09	8	2.92	2.92	14	0.12	8	8
Ricker (FrD-mean)	**-0.04**	**0.04**	**8**	**0.07**	**1**	**2.34**	**2.34**	**5**	**0.11**	**1**	**1**
Ricker (Ei)	-0.04	0.04	8	0.07	5	2.62	2.62	10	0.11	4	4
Ricker (Pi)	-0.04	0.04	6	0.07	5	2.64	2.64	11	0.12	5	4
Ricker (FrD-Peak)	**-0.04**	**0.04**	**8**	**0.07**	**2**	**2.56**	**2.56**	**9**	**0.11**	**3**	**3**
Ricker (PDO)	-0.04	0.04	11	0.07	2	2.82	2.82	12	0.12	5	7
KF	**-0.02**	**0.02**	**4**	**0.07**	**2**	**2.91**	**2.91**	**13**	**0.11**	**2**	**2**

LATE SHUSWAP	MRE	Abs(MRE)	Rank	MAE	Rank	MPE	Abs(MPE)	Rank	RMSE	Rank	Rank
LLY	0.01	0.01	1	3.53	21	11.91	11.91	20	4.85	19	16
TSA	0.29	0.29	10	2.76	19	84.89	84.89	21	3.04	13	17
R1C	-0.49	0.49	14	0.65	4	1.24	1.24	5	1.59	11	9
R2C	-0.44	0.44	13	0.63	2	1.17	1.17	3	1.08	4	4
RAC	0.28	0.28	9	0.30	1	1.75	1.75	11	0.57	1	4
MRS	1.94	1.94	20	2.40	18	2.92	2.92	16	5.18	20	20
RS1	2.35	2.35	21	3.50	20	4.02	4.02	18	7.70	21	21
RS2	0.89	0.89	15	2.04	15	2.48	2.48	14	3.96	16	15
RSC	1.55	1.55	19	2.20	16	2.94	2.94	17	4.45	17	19
Ricker	0.16	0.16	6	0.83	9	1.41	1.41	10	1.26	9	9
Power	1.10	1.10	16	1.82	14	1.37	1.37	8	3.63	15	12
Larkin	-0.37	0.37	11	0.76	8	0.67	0.67	1	1.21	7	7
Ricker-cyc	**0.18**	**0.18**	**7**	**0.65**	**3**	**1.20**	**1.20**	**4**	**0.95**	**2**	**1**
Ricker (FrD-mean)	0.13	0.13	2	0.83	9	1.30	1.30	6	1.29	10	7
Ricker (Ei)	**-0.13**	**0.13**	**2**	**0.65**	**4**	**1.92**	**1.92**	**12**	**1.05**	**3**	**3**
Ricker (Pi)	**0.15**	**0.15**	**5**	**0.73**	**6**	**0.81**	**0.81**	**2**	**1.12**	**5**	**2**
Ricker (FrD-Peak)	0.19	0.19	8	0.84	11	1.33	1.33	7	1.26	8	9
Ricker (PDO)	0.15	0.15	4	0.75	7	1.38	1.38	9	1.13	6	6
RS4yr	1.37	1.37	17	1.72	13	2.30	2.30	13	3.52	14	14
RS8yr	1.54	1.54	18	2.31	17	2.67	2.67	15	4.71	18	18
KF	0.43	0.43	12	0.91	12	6.45	6.45	19	1.80	12	13

juvenile data starts in 1974 and intermittment; difficult to compare retrospectively

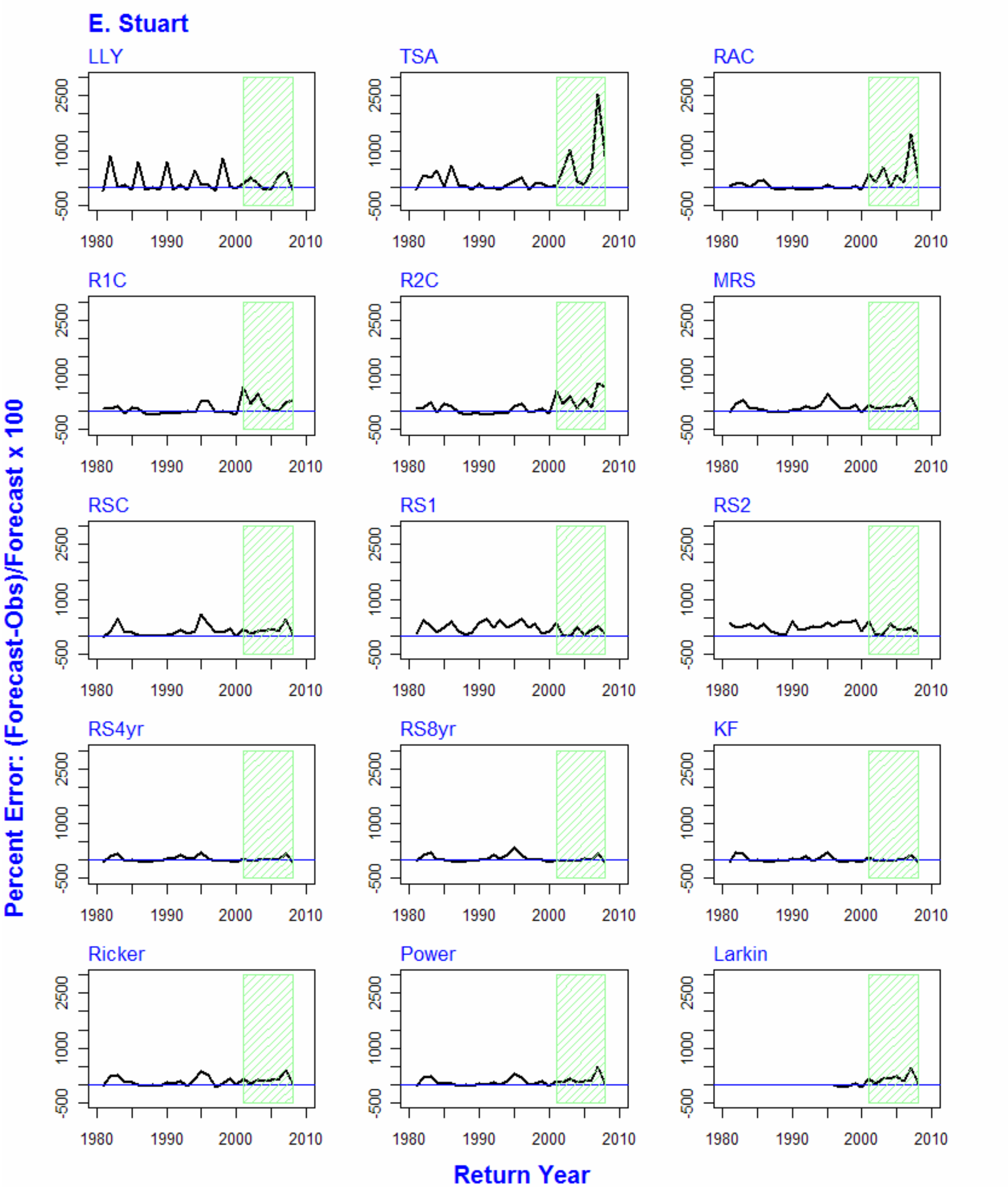
PORTAGE	MRE	Abs(MRE)	Rank	MAE	Rank	MPE	Abs(MPE)	Rank	RMSE	Rank	Rank
LLY	**0.01**	**0.01**	**1**	**0.02**	**1**	**1.38**	**1.38**	**1**	**0.03**	**1**	**1**
TSA	0.02	0.02	7	0.03	9	3.06	3.06	16	0.03	6	**10**
R1C	0.04	0.04	16	0.05	17	2.73	2.73	15	0.07	16	**16**
R2C	0.05	0.05	19	0.05	18	3.62	3.62	19	0.07	16	**18**
RAC	0.03	0.03	9	0.03	7	1.97	1.97	4	0.03	6	**6**
MRS	0.05	0.05	19	0.05	18	3.79	3.79	20	0.08	19	**19**
RS1	0.05	0.05	18	0.06	20	3.42	3.42	18	0.13	20	**19**
RS2	0.04	0.04	13	0.04	13	2.14	2.14	5	0.06	15	**13**
RSC	0.04	0.04	17	0.04	16	3.41	3.41	17	0.06	14	**16**
Ricker	0.03	0.03	11	0.03	11	2.63	2.63	13	0.03	9	**11**
Power	0.03	0.03	9	0.03	7	2.15	2.15	6	0.04	11	**9**
Larkin	0.04	0.04	15	0.04	14	2.69	2.69	14	0.05	13	**15**
Ricker (FrD-mean)	**0.02**	**0.02**	**4**	**0.02**	**2**	**2.45**	**2.45**	**9**	**0.03**	**2**	**3**
Ricker (Ei)	0.03	0.03	11	0.03	12	2.60	2.60	12	0.03	10	**12**
Ricker (Pi)	0.02	0.02	5	0.02	3	2.29	2.29	8	0.03	2	**4**
Ricker (FrD-Peak)	0.02	0.02	5	0.02	3	2.46	2.46	10	0.03	2	**5**
Ricker (PDO)	0.02	0.02	2	0.02	6	2.48	2.48	11	0.03	8	**7**
RS4yr	0.04	0.04	13	0.04	15	2.24	2.24	7	0.07	18	**14**
RS8yr	0.02	0.02	7	0.03	9	1.67	1.67	2	0.04	12	**8**
KF	**0.02**	**0.02**	**2**	**0.02**	**3**	**1.84**	**1.84**	**3**	**0.03**	**5**	**2**
Ricker-cyc	time series too short to evaluate retrospectively										

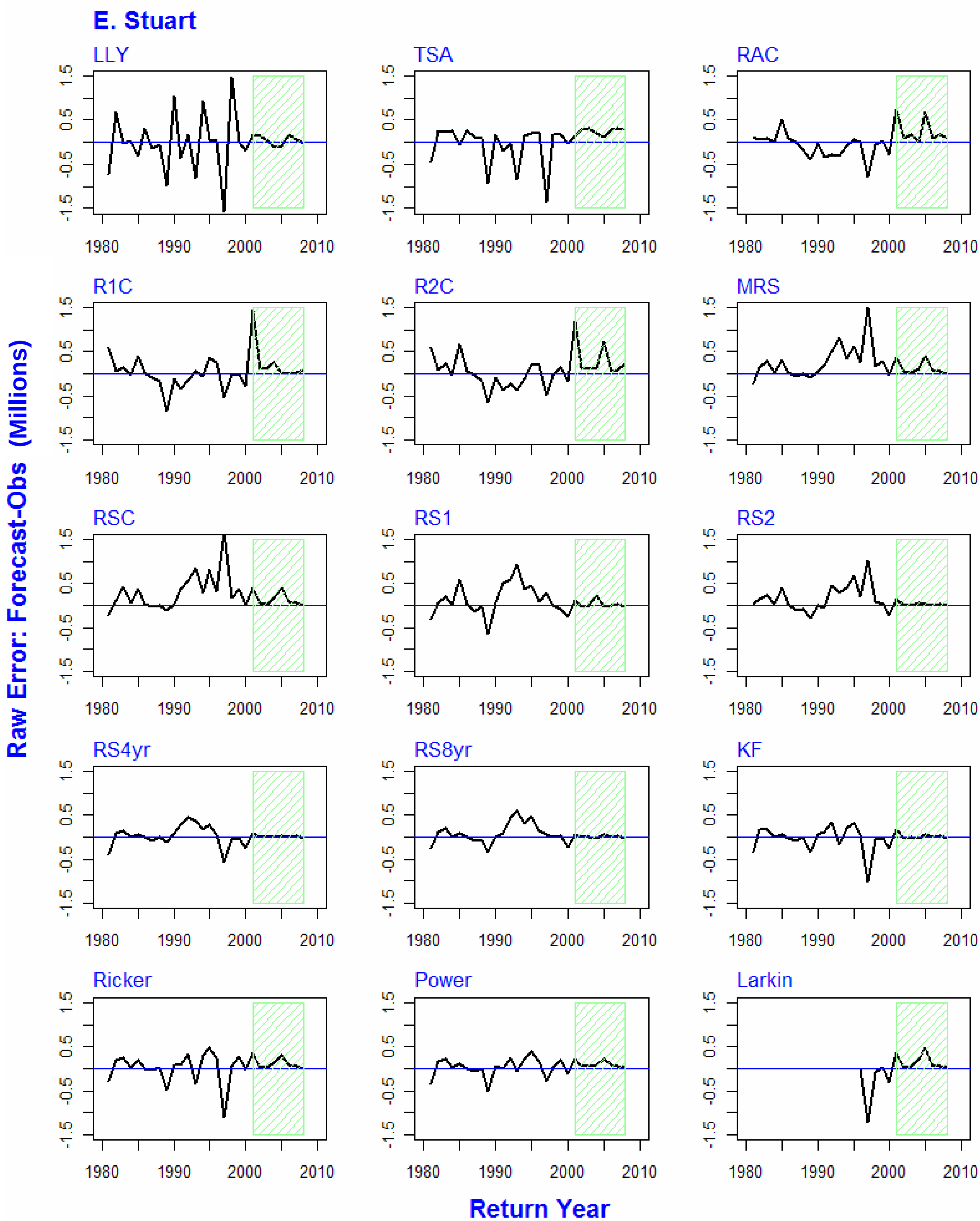
WEAVER	MRE	Abs(MRE)	Rank	MAE	Rank	MPE	Abs(MPE)	Rank	RMSE	Rank	Rank
LLY	0.04	0.04	10	0.15	20	0.37	0.37	11	0.18	19	**16**
TSA	0.16	0.16	26	0.19	28	1.09	1.09	29	0.20	23	**27**
R1C	0.15	0.15	25	0.16	23	0.76	0.76	23	0.19	22	**23**
R2C	0.22	0.22	31	0.25	31	1.23	1.23	31	0.28	30	**31**
RAC	0.17	0.17	27	0.18	27	0.98	0.98	28	0.21	25	**28**
MRS	0.03	0.03	4	0.11	14	0.23	0.23	4	0.13	15	**8**
RS1	0.15	0.15	23	0.16	25	0.79	0.79	25	0.21	26	**25**
RS2	0.21	0.21	30	0.24	30	0.88	0.88	27	0.31	31	**30**
RSC	0.03	0.03	8	0.11	16	0.24	0.24	5	0.13	14	**10**
MRJ	0.12	0.12	20	0.13	18	0.72	0.72	21	0.18	18	**19**
RJ1	0.15	0.15	24	0.16	24	0.77	0.77	24	0.18	21	**23**
RJ2	0.20	0.20	29	0.21	29	0.85	0.85	26	0.27	29	**29**
RJC	0.14	0.14	22	0.15	22	0.73	0.73	22	0.20	24	**22**
Ricker	0.03	0.03	4	0.09	6	0.25	0.25	7	0.10	5	**4**
Power	0.03	0.03	4	0.08	4	0.30	0.30	9	0.11	7	**6**
Larkin	0.18	0.18	28	0.18	26	1.10	1.10	30	0.18	19	**26**
Ricker (FrD-mean)	**0.02**	**0.02**	**1**	**0.08**	**2**	**0.20**	**0.20**	**3**	**0.10**	**3**	**2**
Ricker (Ei)	0.03	0.03	7	0.09	7	0.25	0.25	6	0.10	5	**7**
Ricker (Pi)	0.03	0.03	9	0.08	3	0.26	0.26	8	0.10	3	**5**
Ricker (FrD-Peak)	**0.02**	**0.02**	**1**	**0.07**	**1**	**0.19**	**0.19**	**2**	**0.09**	**1**	**1**
Ricker (PDO)	**0.02**	**0.02**	**3**	**0.08**	**4**	**0.15**	**0.15**	**1**	**0.10**	**2**	**3**
Power (juv)	0.07	0.07	14	0.11	9	0.52	0.52	14	0.12	10	**12**
Power (juv)(FrD-mean)	0.07	0.07	13	0.11	11	0.51	0.51	13	0.12	12	**13**
Power (juv) (Ei)	0.08	0.08	17	0.12	17	0.56	0.56	17	0.13	13	**17**
Power (juv) (Pi)	0.07	0.07	16	0.11	11	0.52	0.52	15	0.12	11	**15**
Power (juv) (FrD-Peak)	0.07	0.07	15	0.11	11	0.52	0.52	16	0.12	9	**14**
Power (juv) (PDO)	0.09	0.09	18	0.11	15	0.56	0.56	18	0.15	17	**18**
RS4yr	0.13	0.13	21	0.15	20	0.64	0.64	20	0.24	28	**21**
RS8yr	0.12	0.12	19	0.14	19	0.59	0.59	19	0.21	26	**20**
KF	0.06	0.06	11	0.11	9	0.34	0.34	10	0.15	16	**11**
KF (fry)	0.06	0.06	12	0.10	8	0.40	0.40	12	0.12	8	**9**

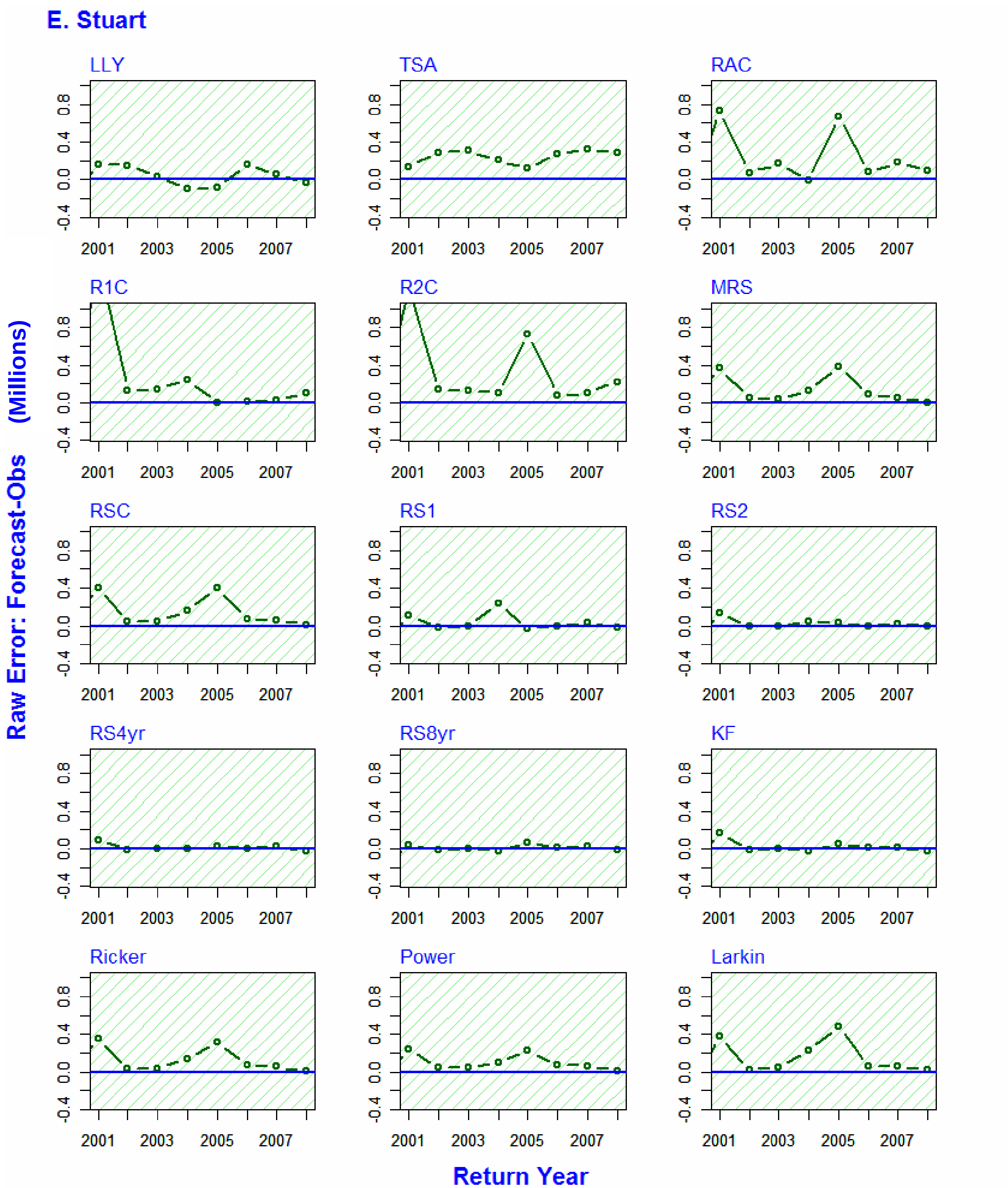
BIRKENHEAD	MRE	Abs(MRE)	Rank	MAE	Rank	MPE	Abs(MPE)	Rank	RMSE	Rank	Rank
LLY	0.00	0.00	1	0.23	17	0.99	0.99	5	0.28	17	**10**
TSA	0.15	0.15	18	0.23	16	2.32	2.32	19	0.24	15	**19**
R1C	-0.01	0.01	3	0.18	11	0.53	0.53	2	0.22	12	**6**
R2C	0.08	0.08	8	0.23	17	1.95	1.95	17	0.35	19	**17**
RAC	0.15	0.15	19	0.20	14	2.02	2.02	18	0.22	11	**18**
MRS	0.47	0.47	20	0.47	20	3.67	3.67	20	0.65	20	**20**
RS1	**0.00**	**0.00**	**2**	**0.15**	**8**	**0.58**	**0.58**	**3**	**0.18**	**5**	**2**
RS2	0.05	0.05	6	0.24	19	1.26	1.26	13	0.27	16	**14**
RSC	0.50	0.50	21	0.50	21	4.04	4.04	21	0.69	21	**21**
Ricker	**0.08**	**0.08**	**8**	**0.13**	**1**	**1.09**	**1.09**	**8**	**0.17**	**1**	**2**
Power	0.10	0.10	14	0.16	10	1.23	1.23	12	0.20	9	**12**
Larkin	0.08	0.08	13	0.14	6	1.06	1.06	6	0.17	2	**5**
Ricker-cyc	0.13	0.13	17	0.16	9	1.42	1.42	15	0.21	10	**13**
Ricker (FrD-mean)	0.08	0.08	8	0.14	7	1.17	1.17	11	0.19	6	**8**
Ricker (Ei)	0.11	0.11	16	0.18	12	1.30	1.30	14	0.22	13	**16**
Ricker (Pi)	**0.07**	0.07	7	0.13	2	1.07	1.07	7	0.17	**3**	**4**
Ricker (FrD-Peak)	0.08	0.08	11	0.14	3	1.15	1.15	10	0.18	4	**6**
Ricker (PDO)	0.10	0.10	15	0.14	5	1.43	1.43	16	0.19	6	**11**
RS4yr	0.08	0.08	12	0.21	15	1.11	1.11	9	0.30	18	**14**
RS8yr	0.01	0.01	3	0.18	12	0.62	0.62	4	0.23	14	**9**
KF	**-0.03**	**0.03**	**5**	**0.14**	**3**	**0.14**	**0.14**	**1**	**0.19**	**8**	**1**

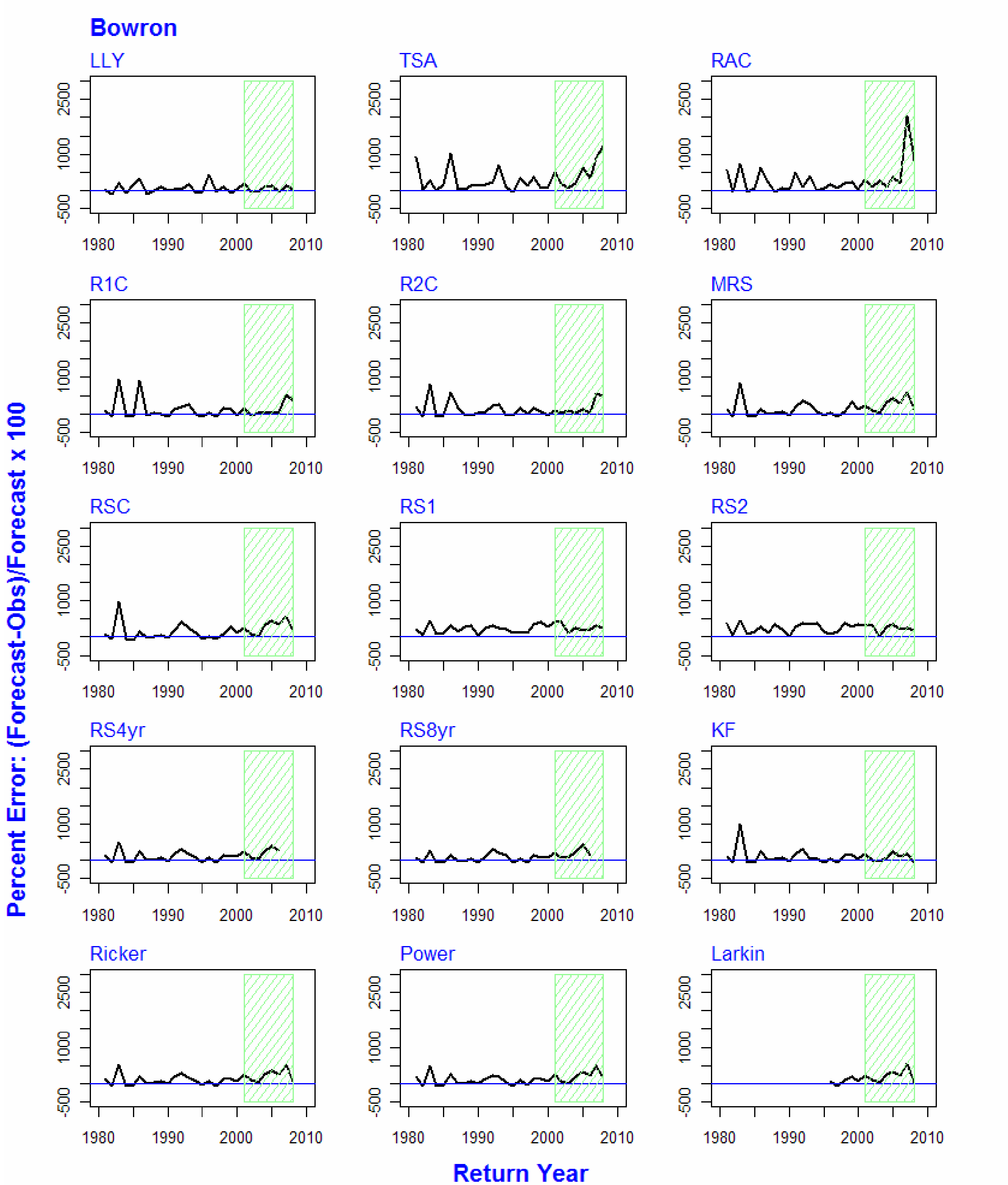
APPENDIX 6. FORECAST PERFORMANCE FOR EACH OF 19 FORECASTED STOCKS.

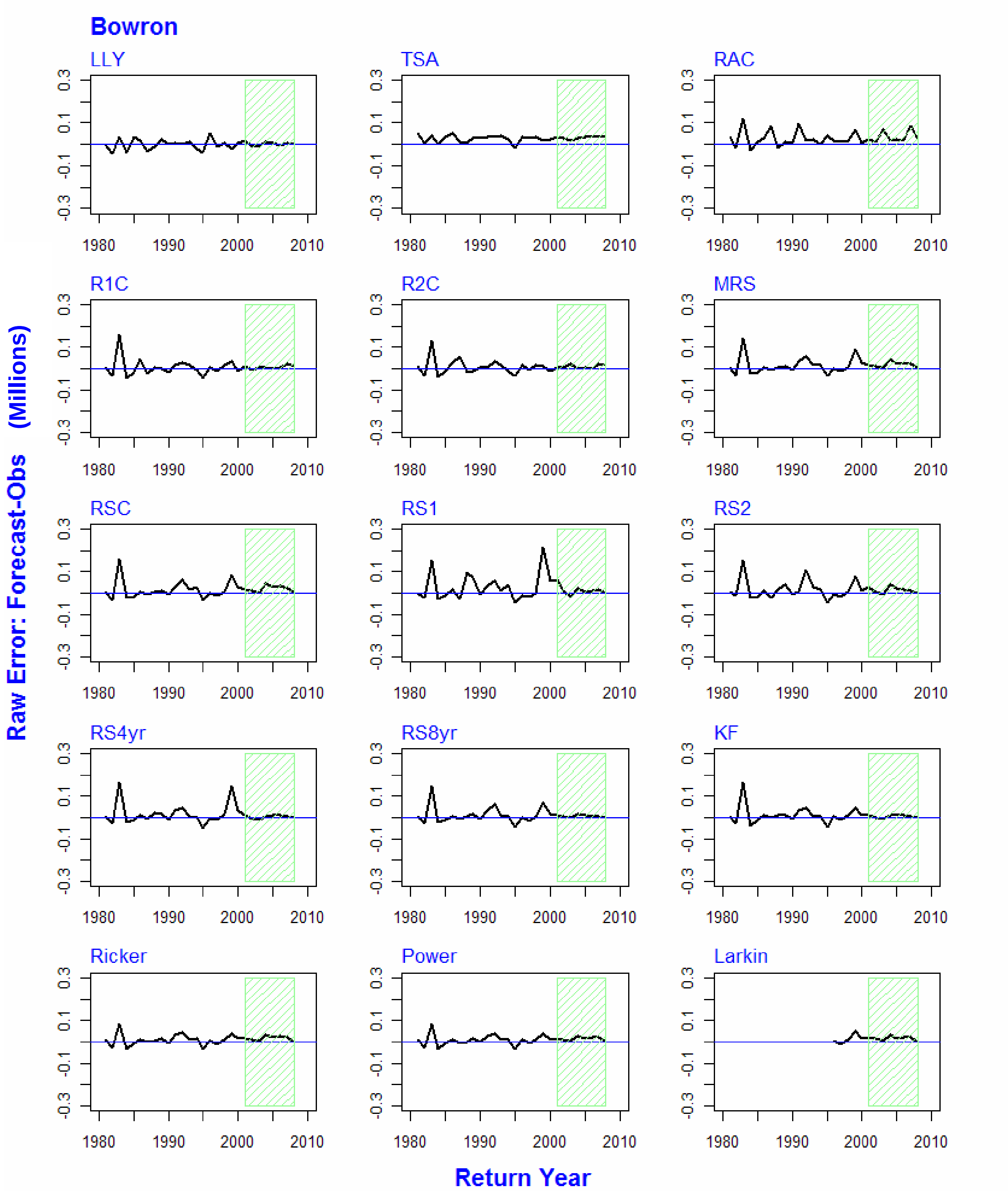
For each stock the first series of plots is percent error (returns years: 1980-2008), the second series of plots is raw error (return years: 1980-2008) in millions of fish and the third series of plots is raw error (returns years: 2001 to 2008) in millions of fish. These plots provide information on forecast model performance for the full retrospective period (used in the Case 1 “Long-Term Average Productivity” forecast) and the truncated retrospective period (used in the Case 2 “Recent Productivity” forecast highlighted by green (hatched) shading).
(NOTE: Cultus has been excluded given gaps in time juvenile time series)

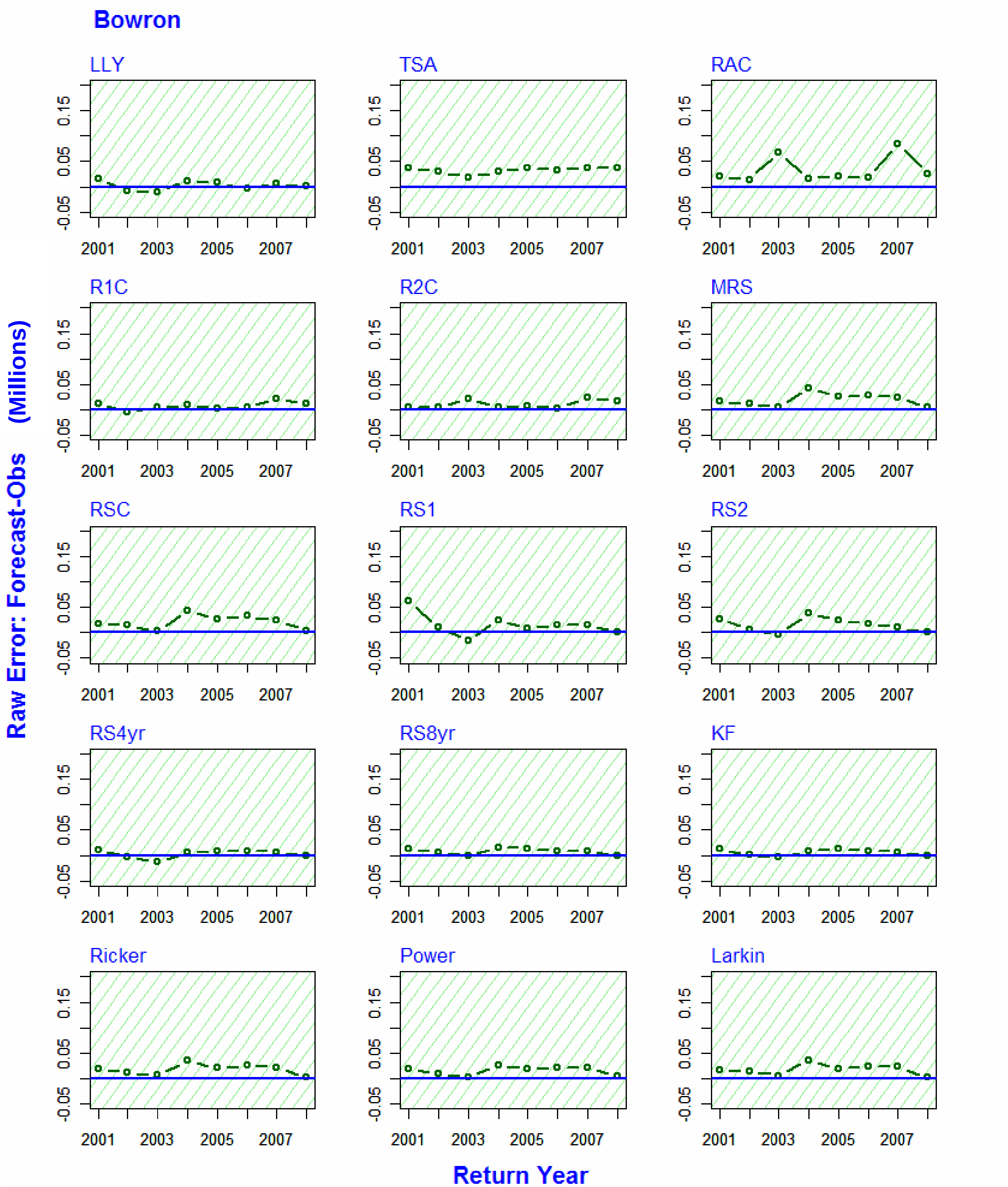


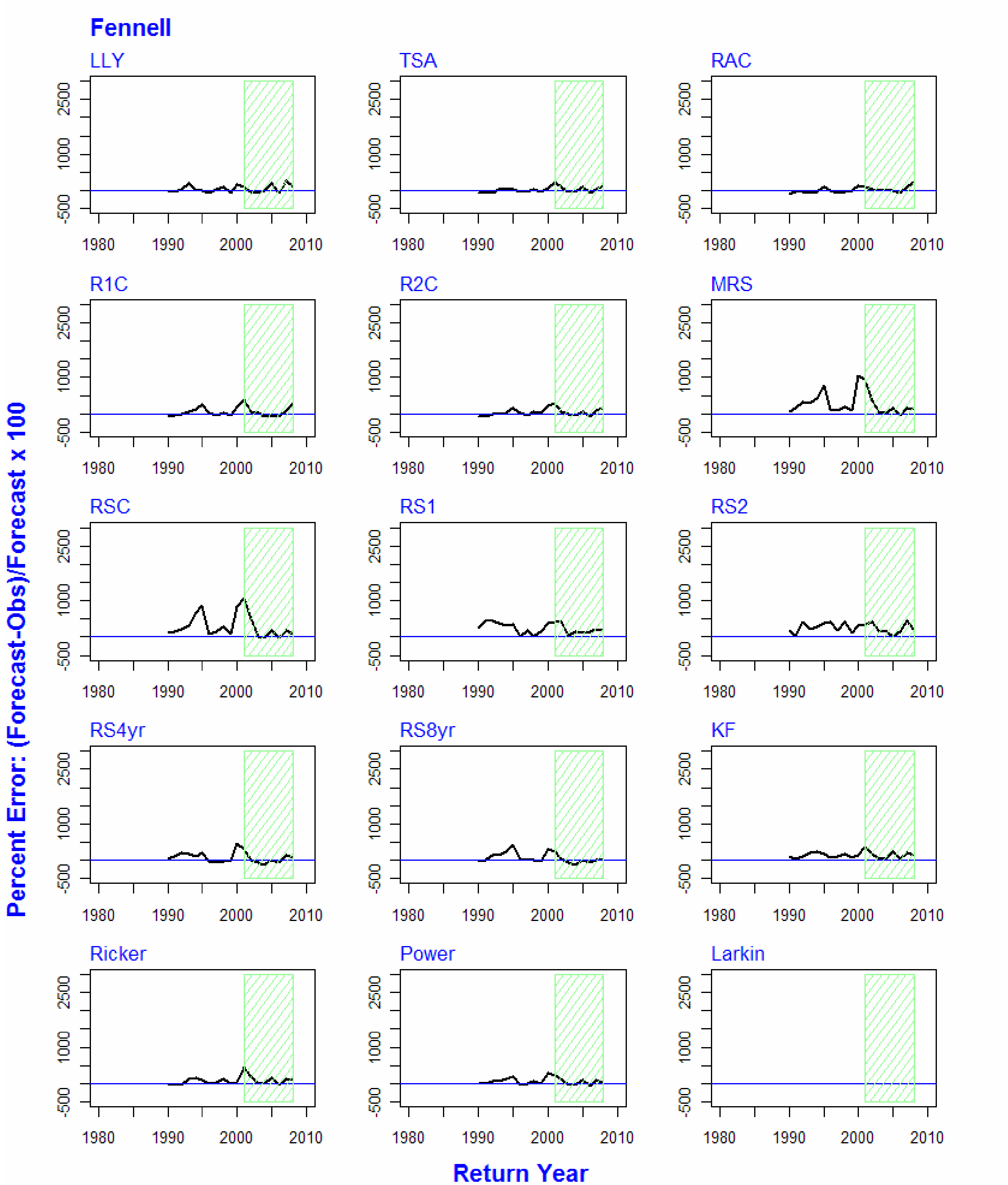

E. Stuart
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
Raw Error: Forecast-Obs (Millions)
Return Year
1980
1990
2000
2010
1.5
0.5
-0.5
-1.5


E. Stuart
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
Raw Error: Forecast-Obs (Millions)
Return Year
2001
2003
2005
2007
-0.4
0.0
0.4
0.8

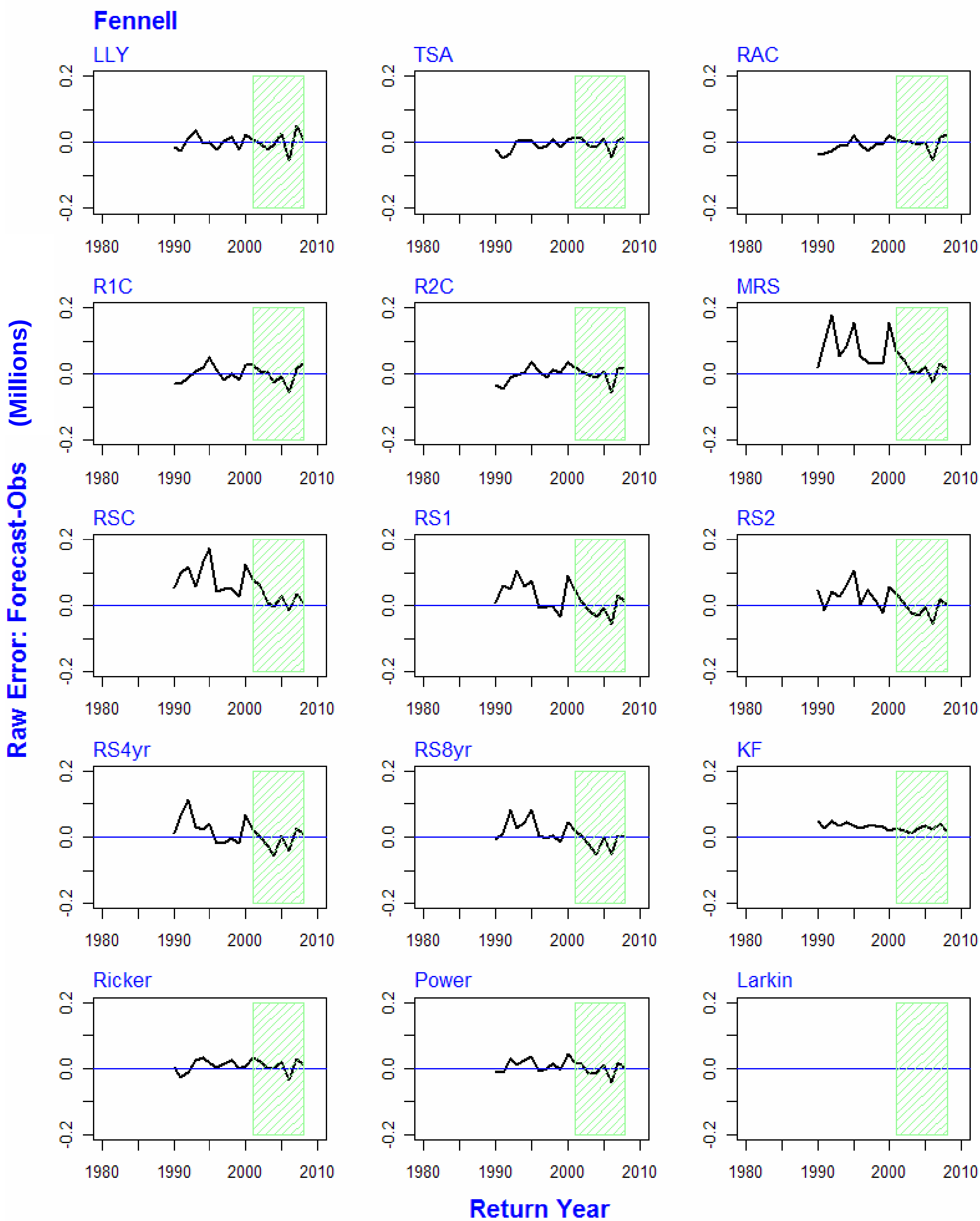

Bowron
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
-500
1000
2500
1980
1990
2000
2010
Percent Error: (Forecast-Obs)/Forecast x 100
Return Year

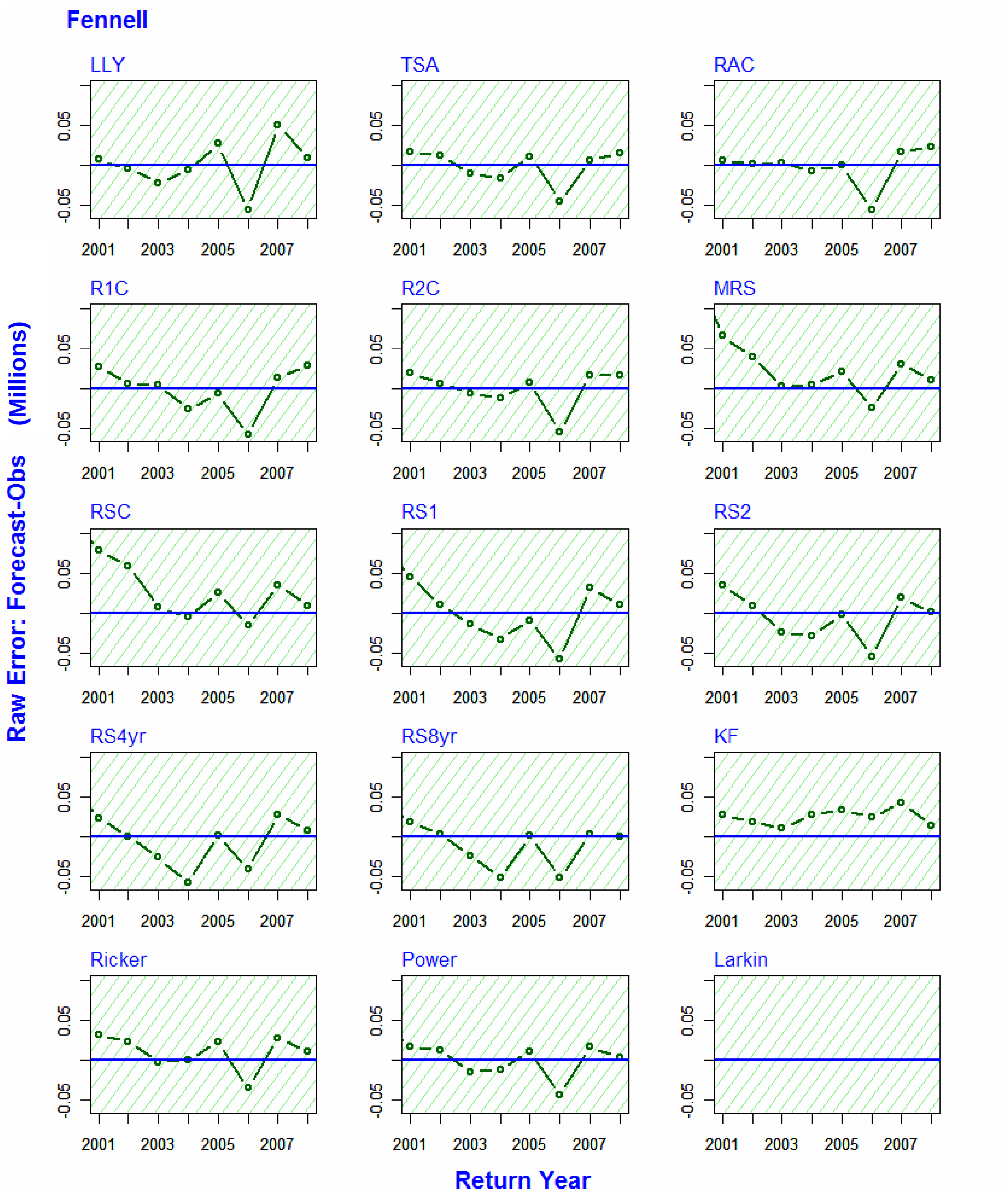

Bowron
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
Raw Error: Forecast-Obs (Millions)
Return Year
0.3
0.1
-0.1
-0.3
1980
1990
2000
2010

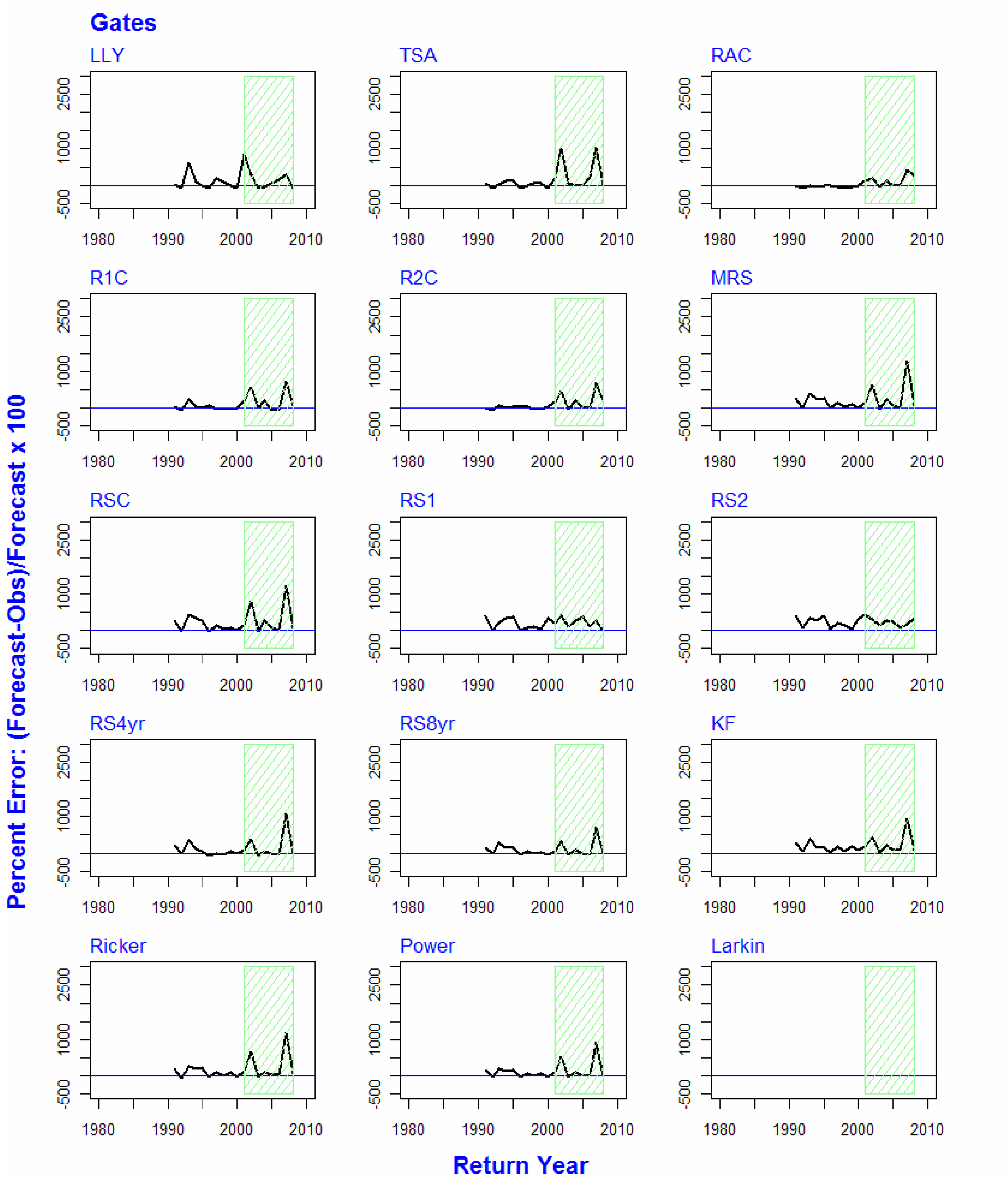

Bowron
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
Raw Error: Forecast-Obs (Millions)
Return Year
0.15
0.05
-0.05
2001
2003
2005
2007

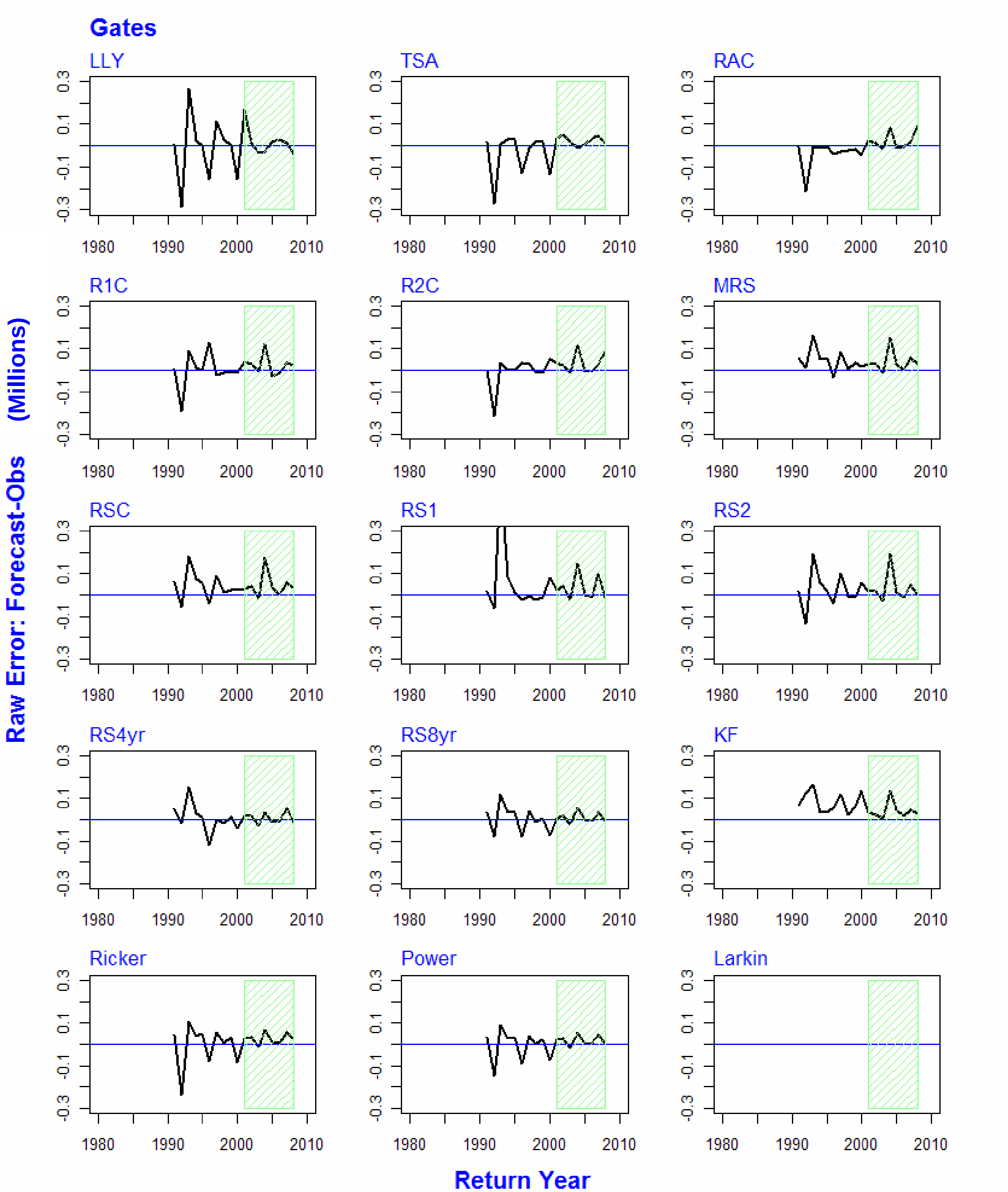


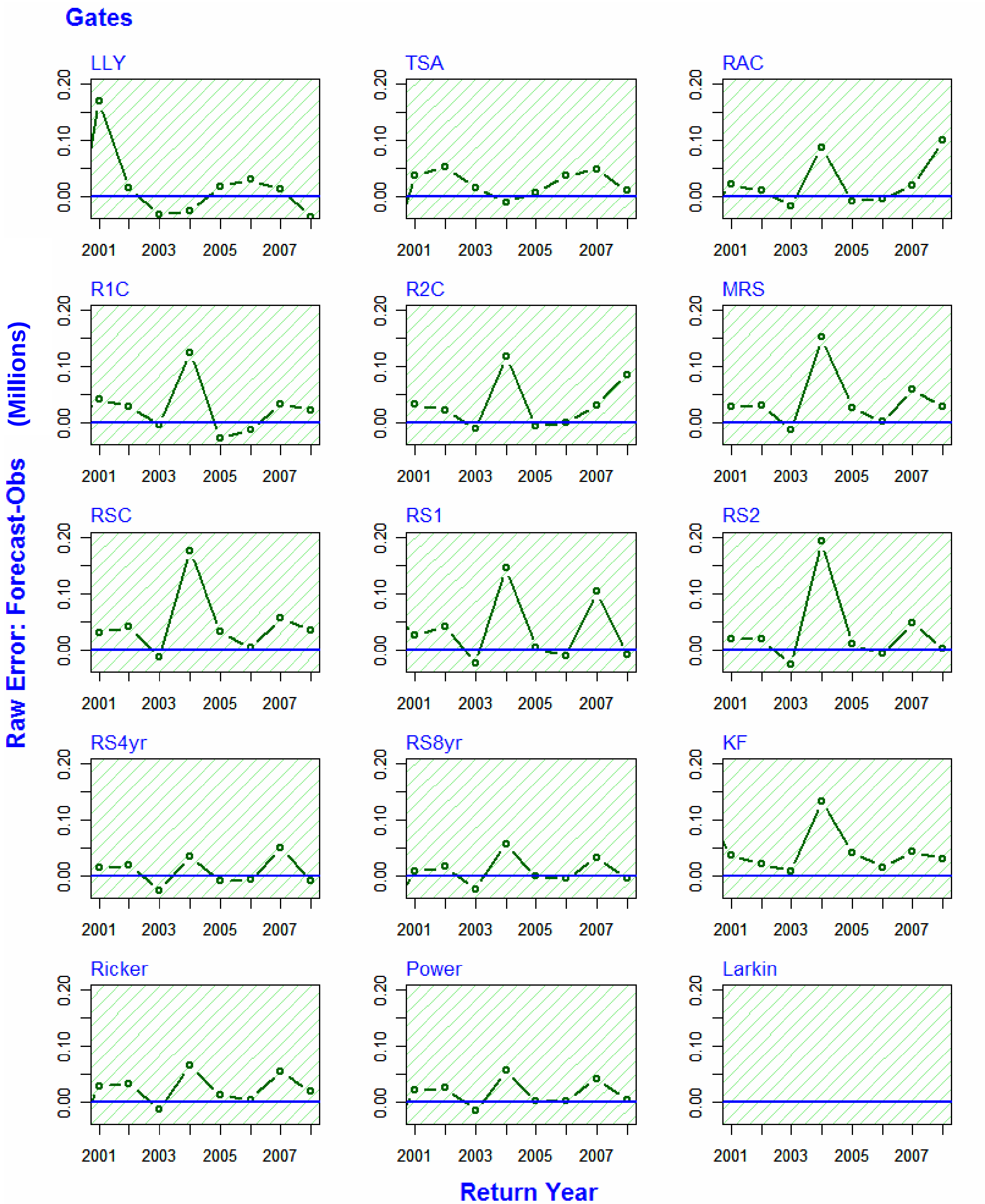
Fennell
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
-500
1000
2500
1980
1990
2000
2010
Percent Error: (Forecast-Obs)/Forecast x 100
Return Year

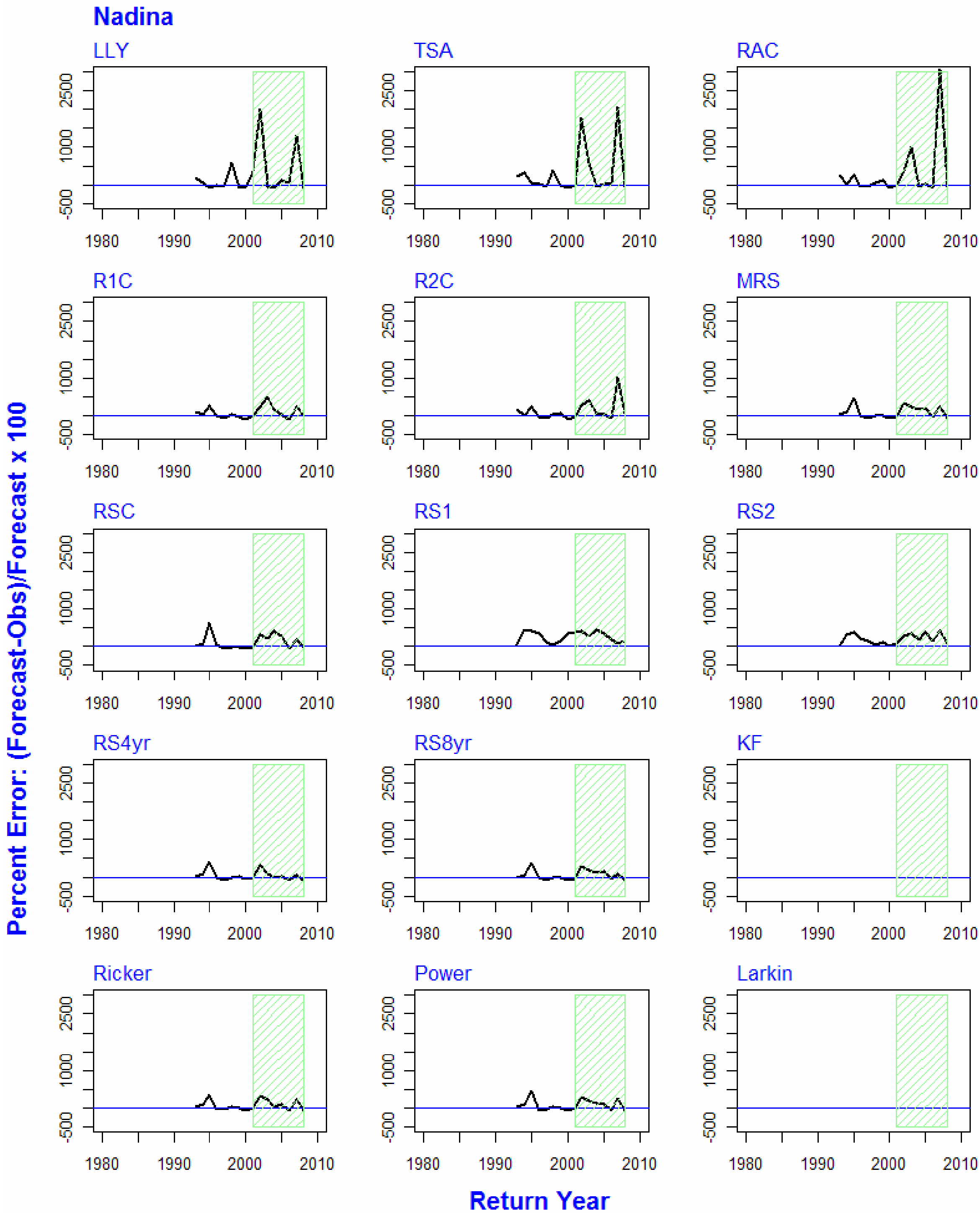

Fennell
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
Raw Error: Forecast-Obs (Millions)
Return Year
0.2
0.0
-0.2
1980
1990
2000
2010

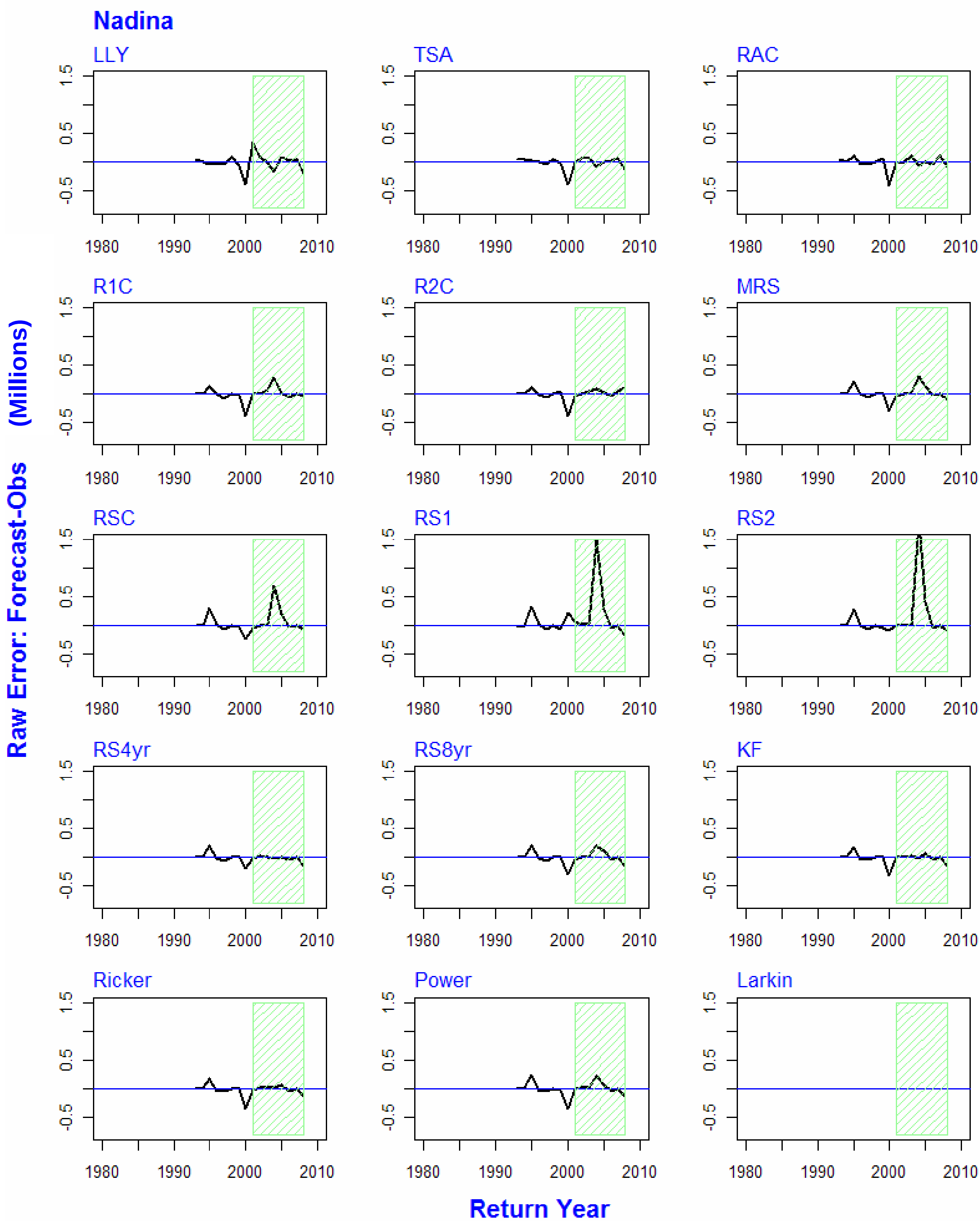

Fennell
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
0.05
-0.05
2001
2003
2005
2007
Raw Error: Forecast-Obs (Millions)
Return Year

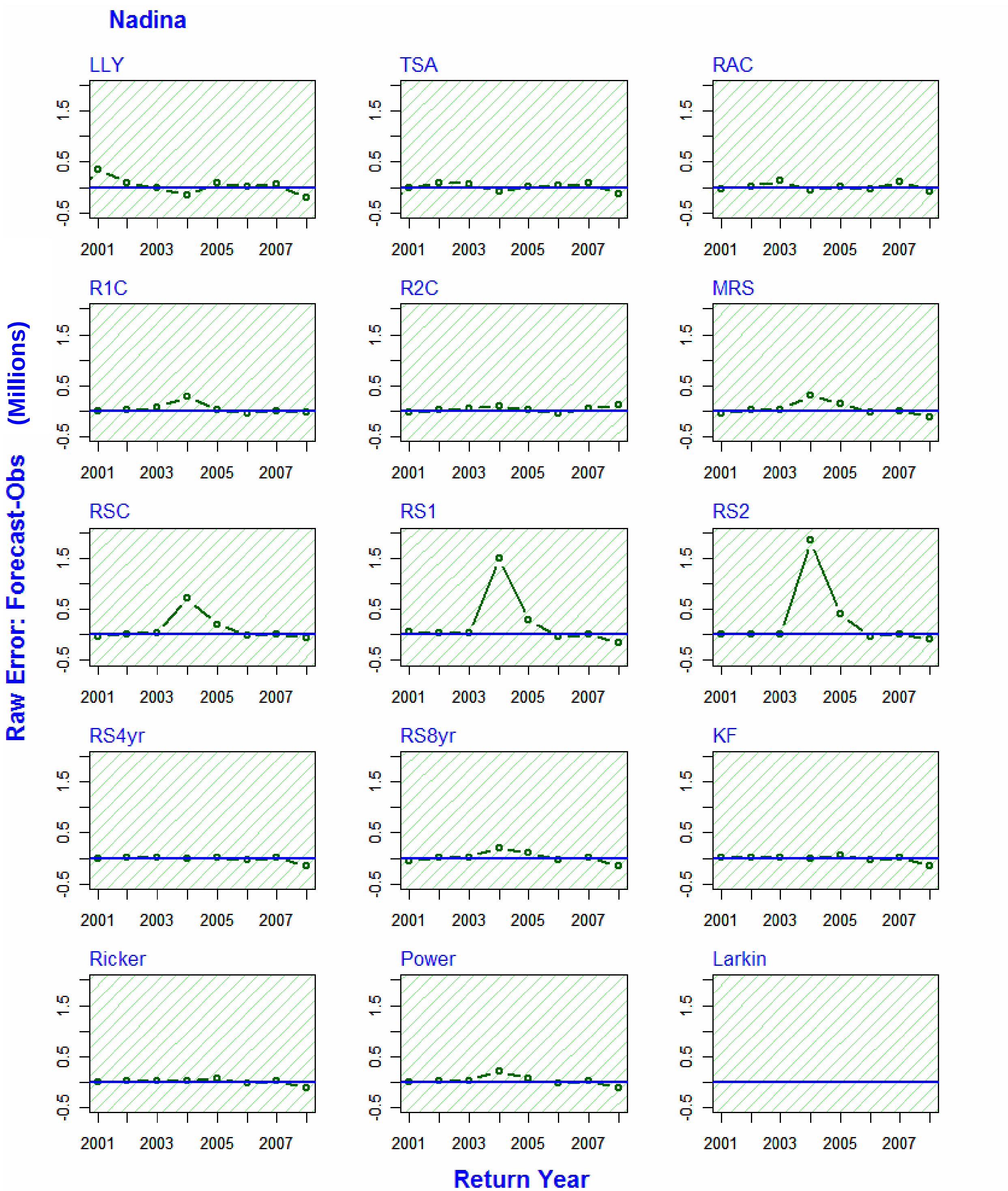

Gates
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
Percent Error: (Forecast-Obs)/Forecast x 100
Return Year
-500
1000
2500
1980
1990
2000
2010


Gates
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
Raw Error: Forecast-Obs (Millions)
Return Year
0.3
0.1
-0.1
-0.3
1980
1990
2000
2010

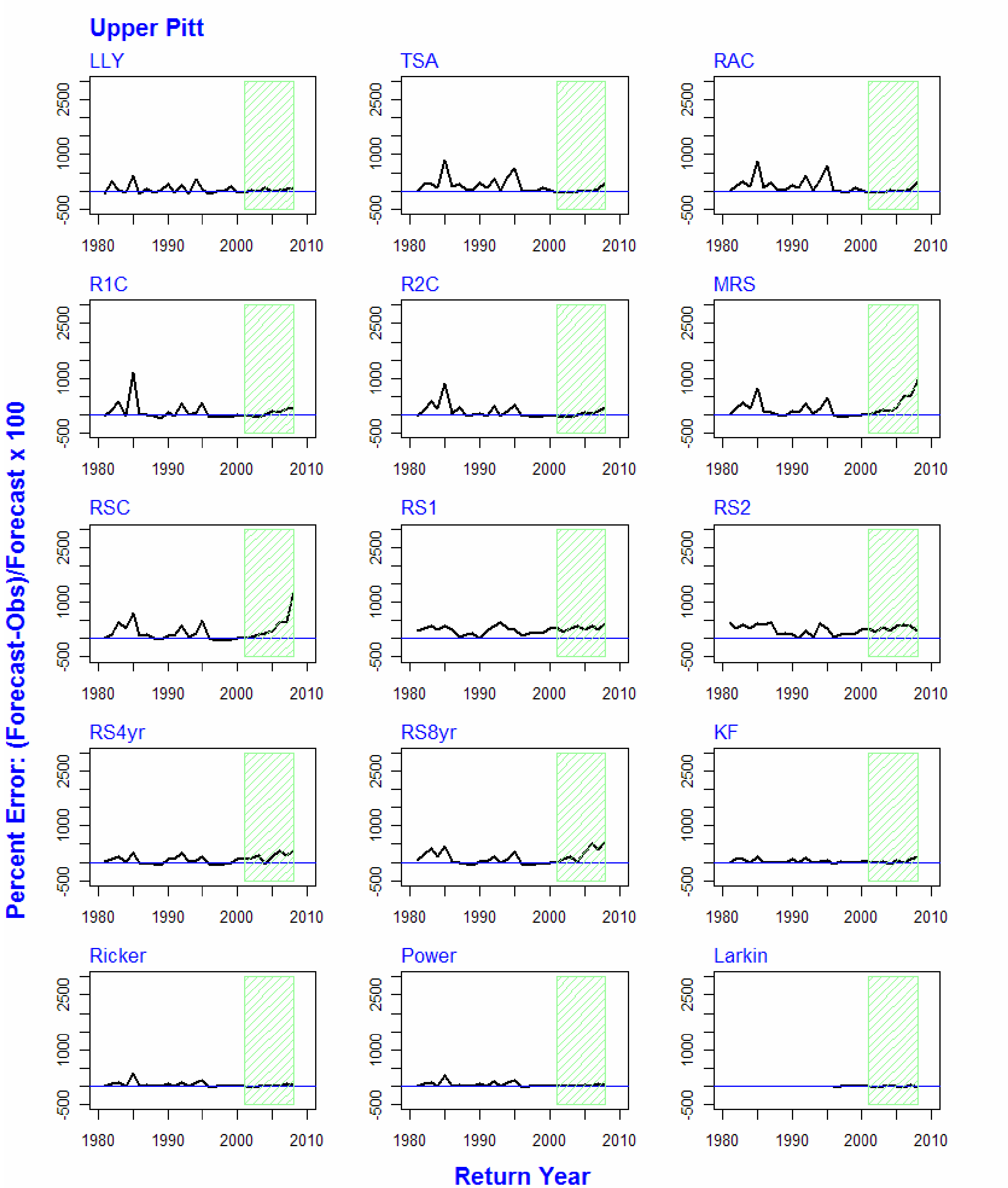

Gates
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
0.00
0.10
0.20
2001
2003
2005
2007
Raw Error: Forecast-Obs (Millions)
Return Year


Nadina
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
-500
1000
2500
1980
1990
2000
2010
Percent Error: (Forecast-Obs)/Forecast x 100
Return Year

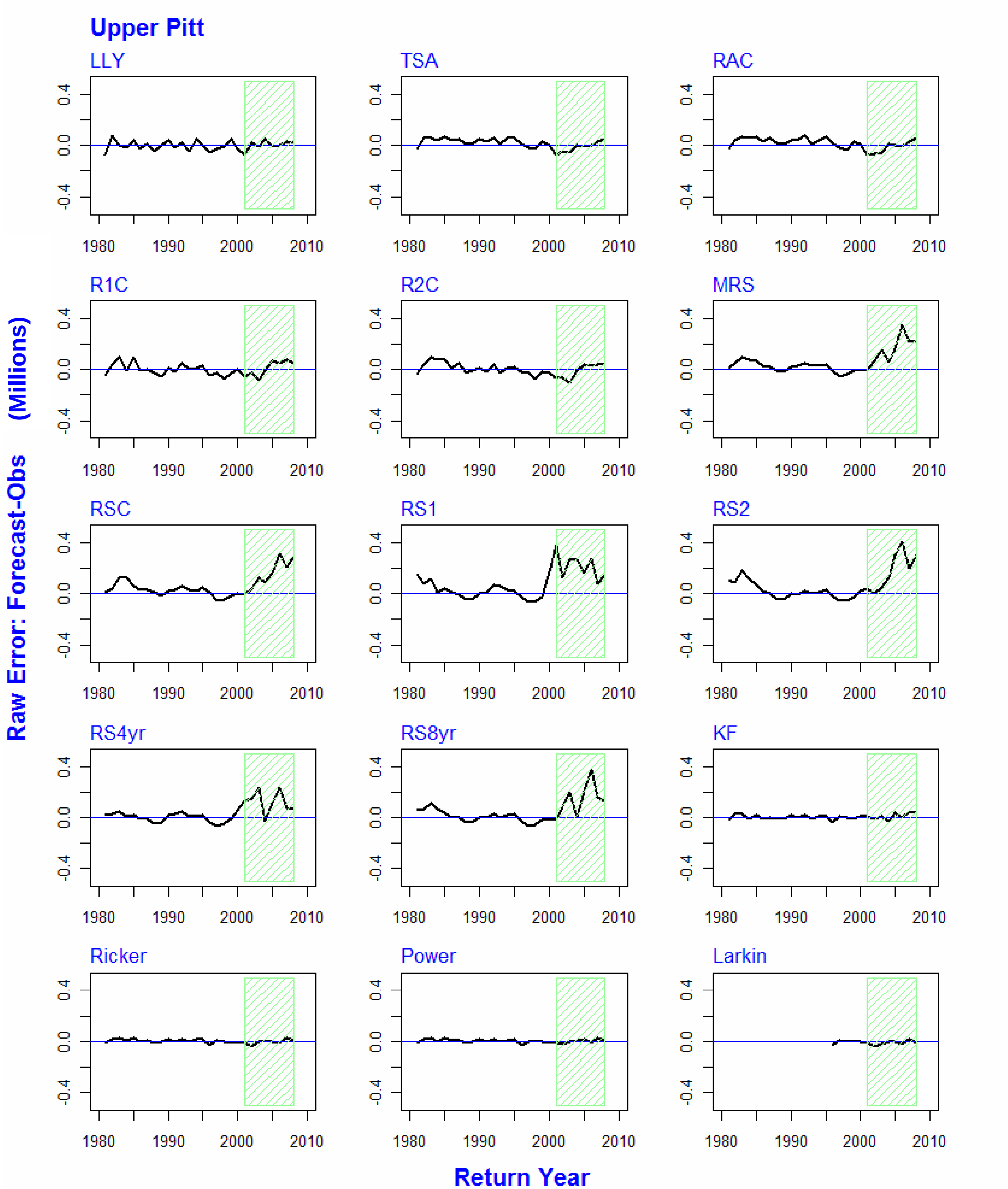

Nadina
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
Raw Error: Forecast-Obs (Millions)
Return Year
-0.5
0.5
1.5
1980
1990
2000
2010



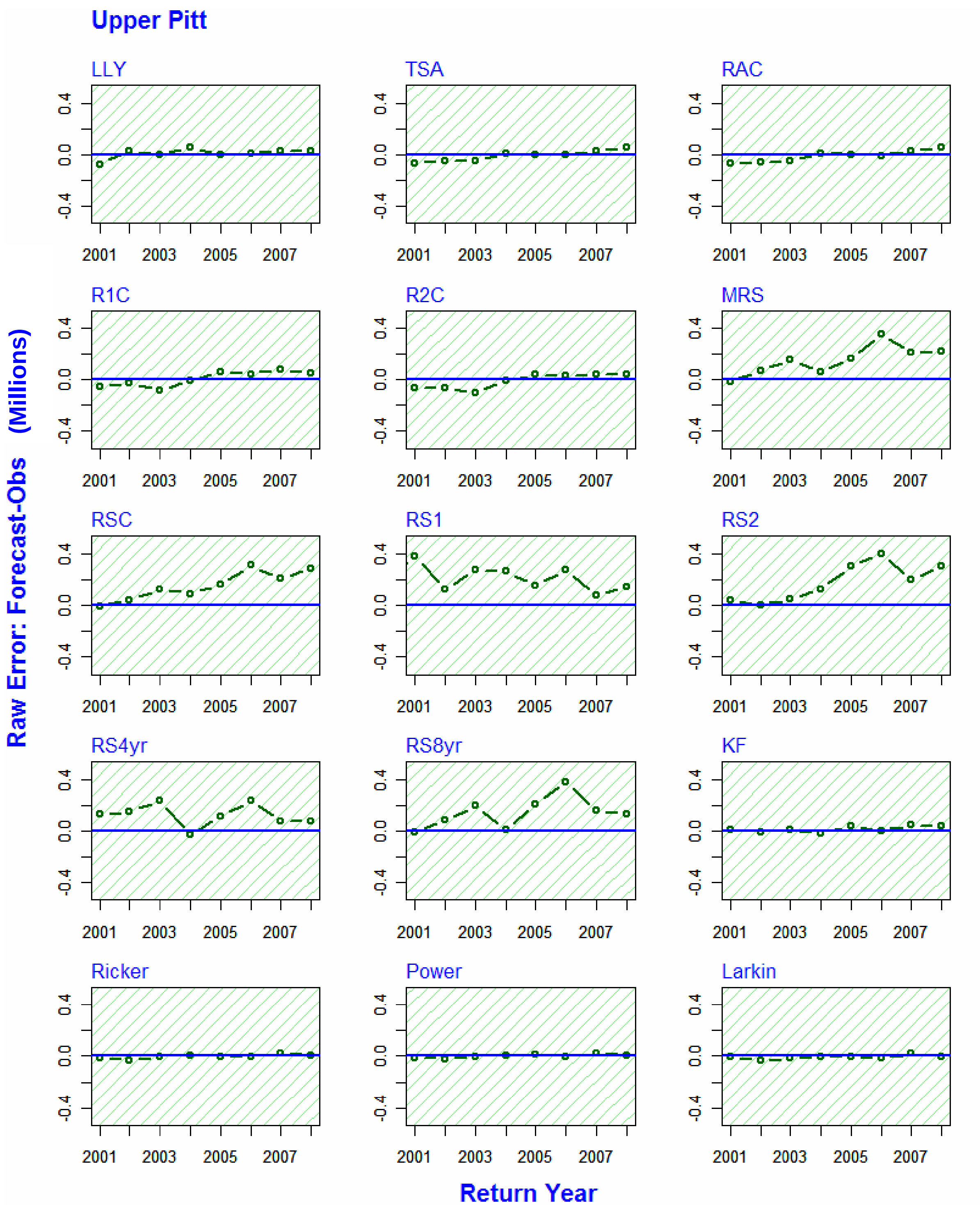
Nadina
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
1.5
0.5
-0.5
2001
2003
2005
2007
Raw Error: Forecast-Obs (Millions)
Return Year



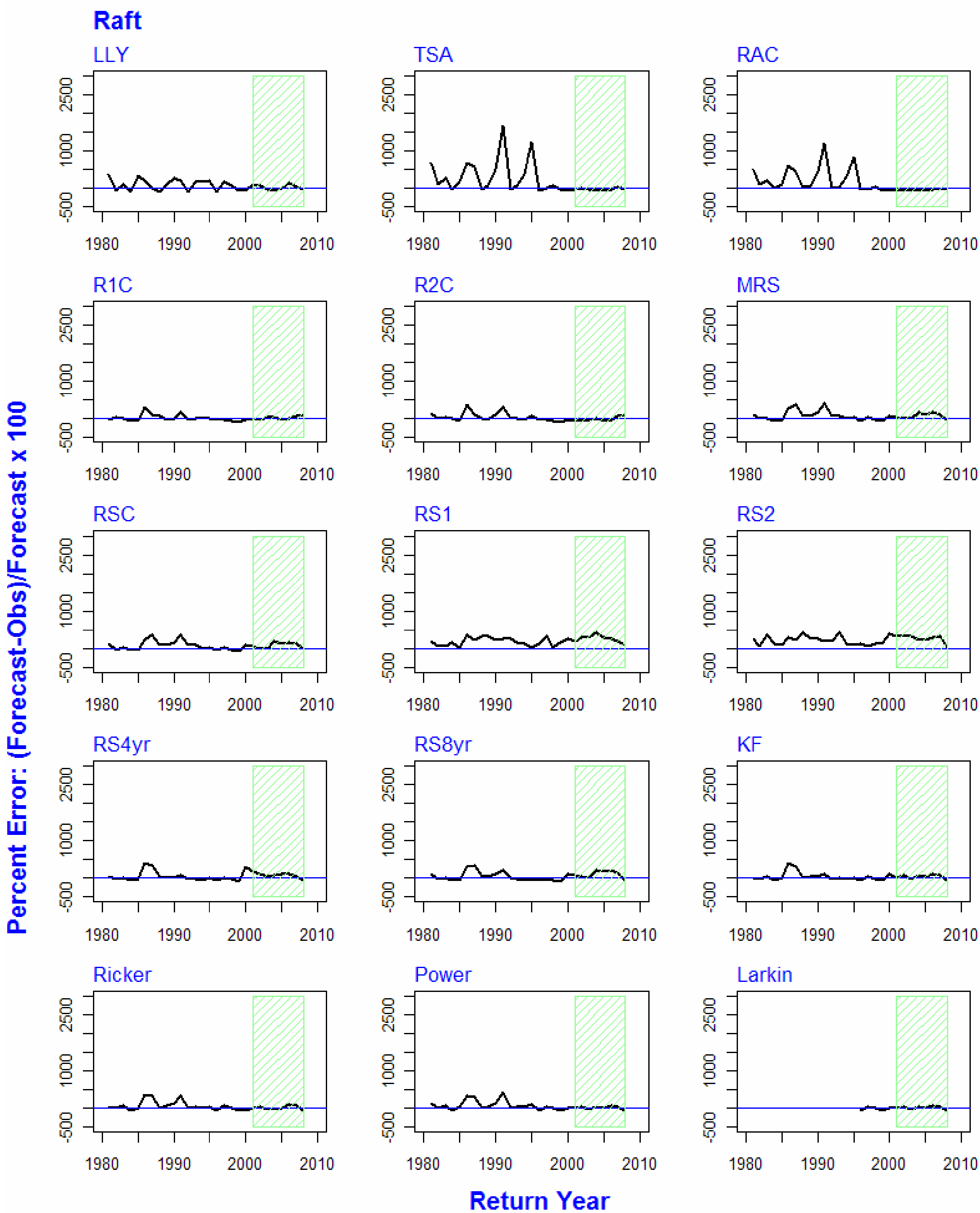
Upper Pitt
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
-500
1000
2500
1980
1990
2000
2010
Percent Error: (Forecast-Obs)/Forecast x 100
Return Year

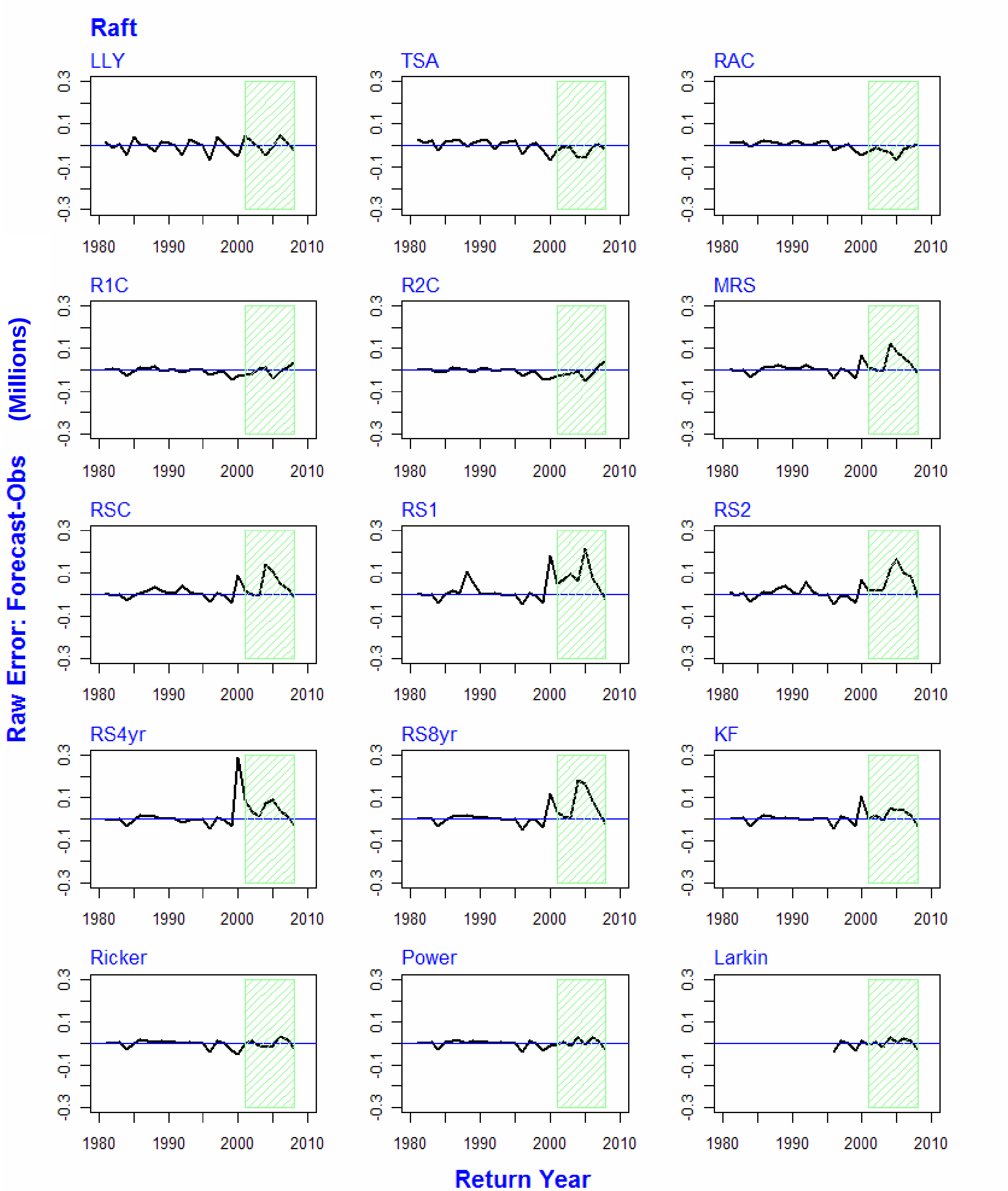


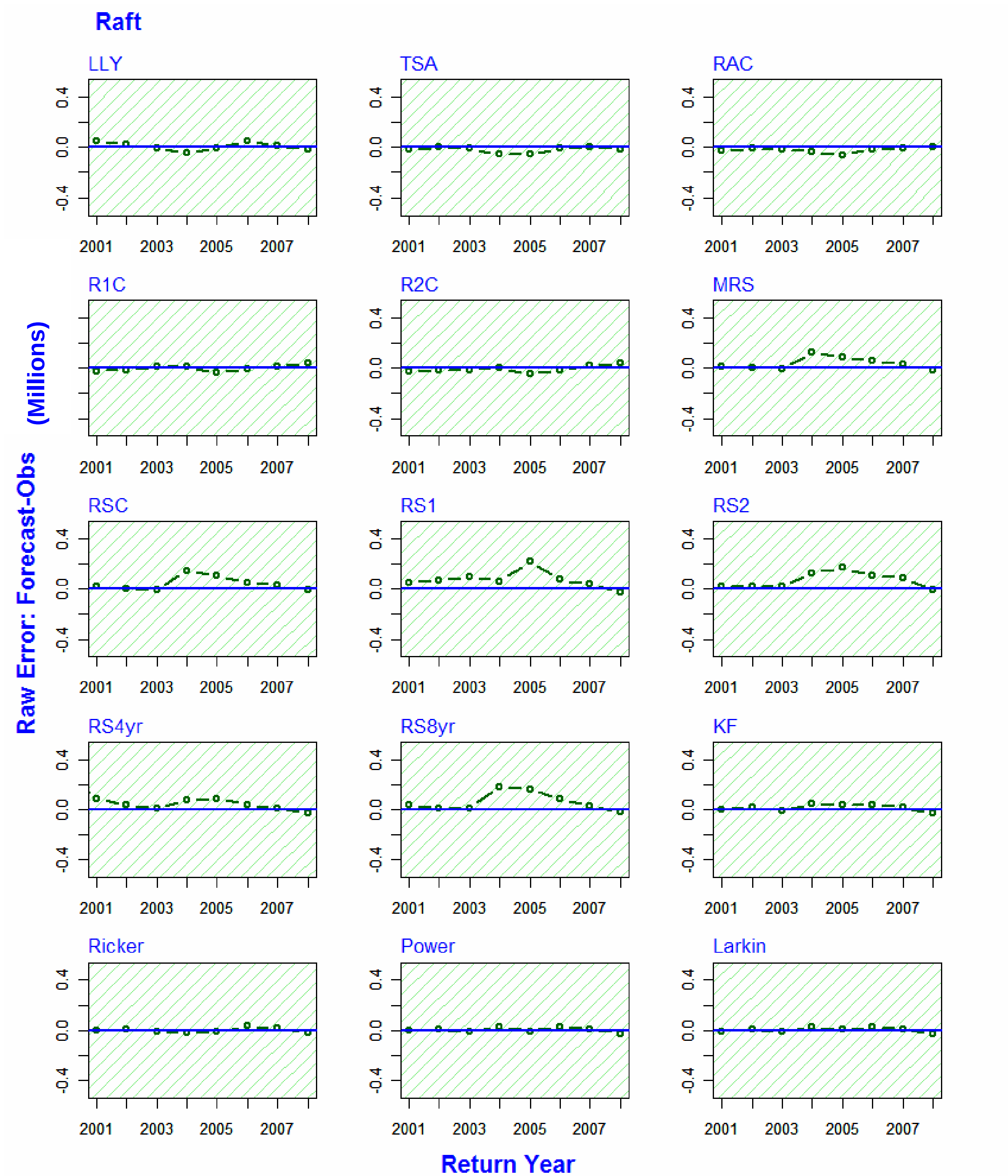
Upper Pitt
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
Raw Error: Forecast-Obs (Millions)
Return Year
0.4
0.0
-0.4
1980
1990
2000
2010

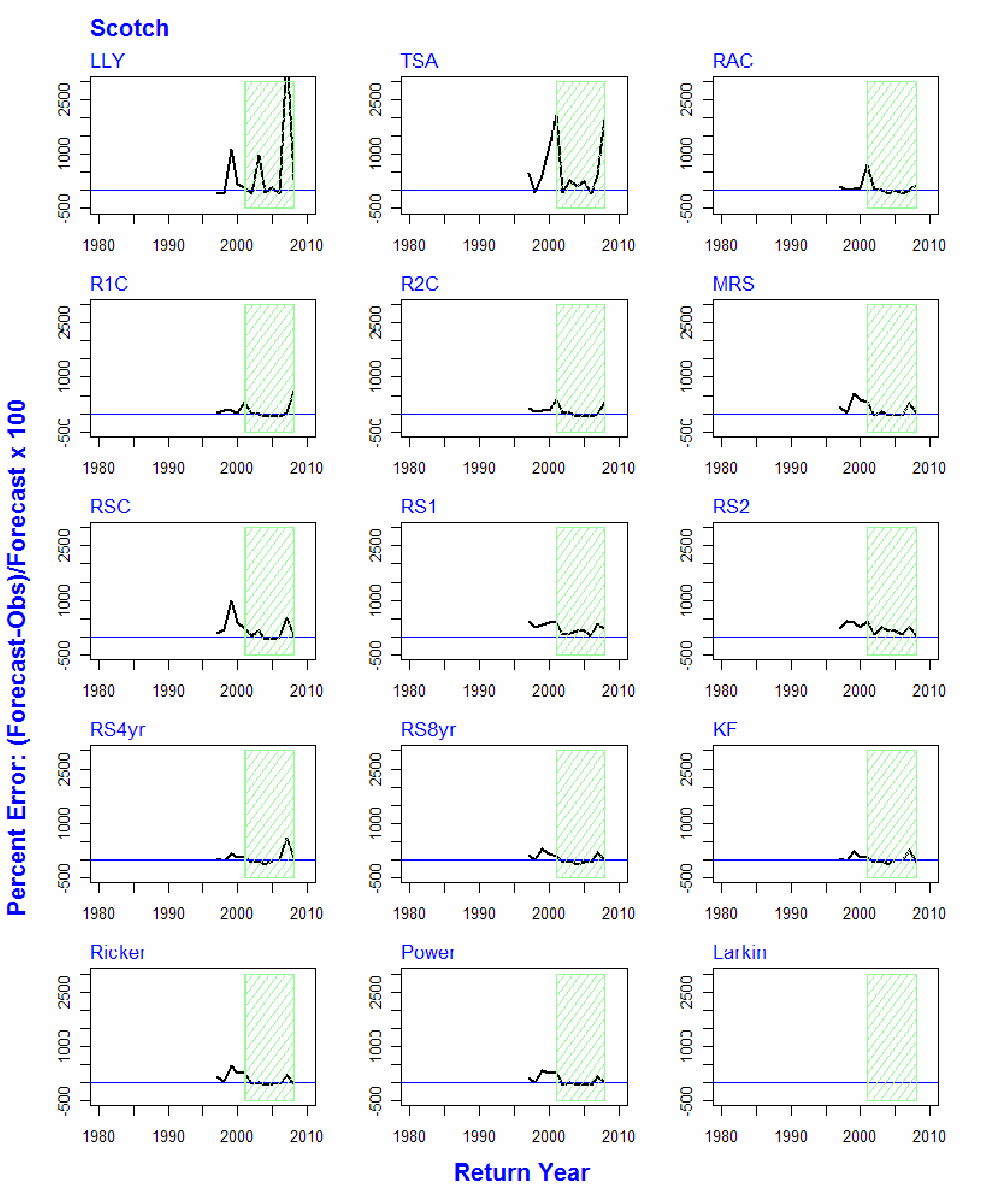


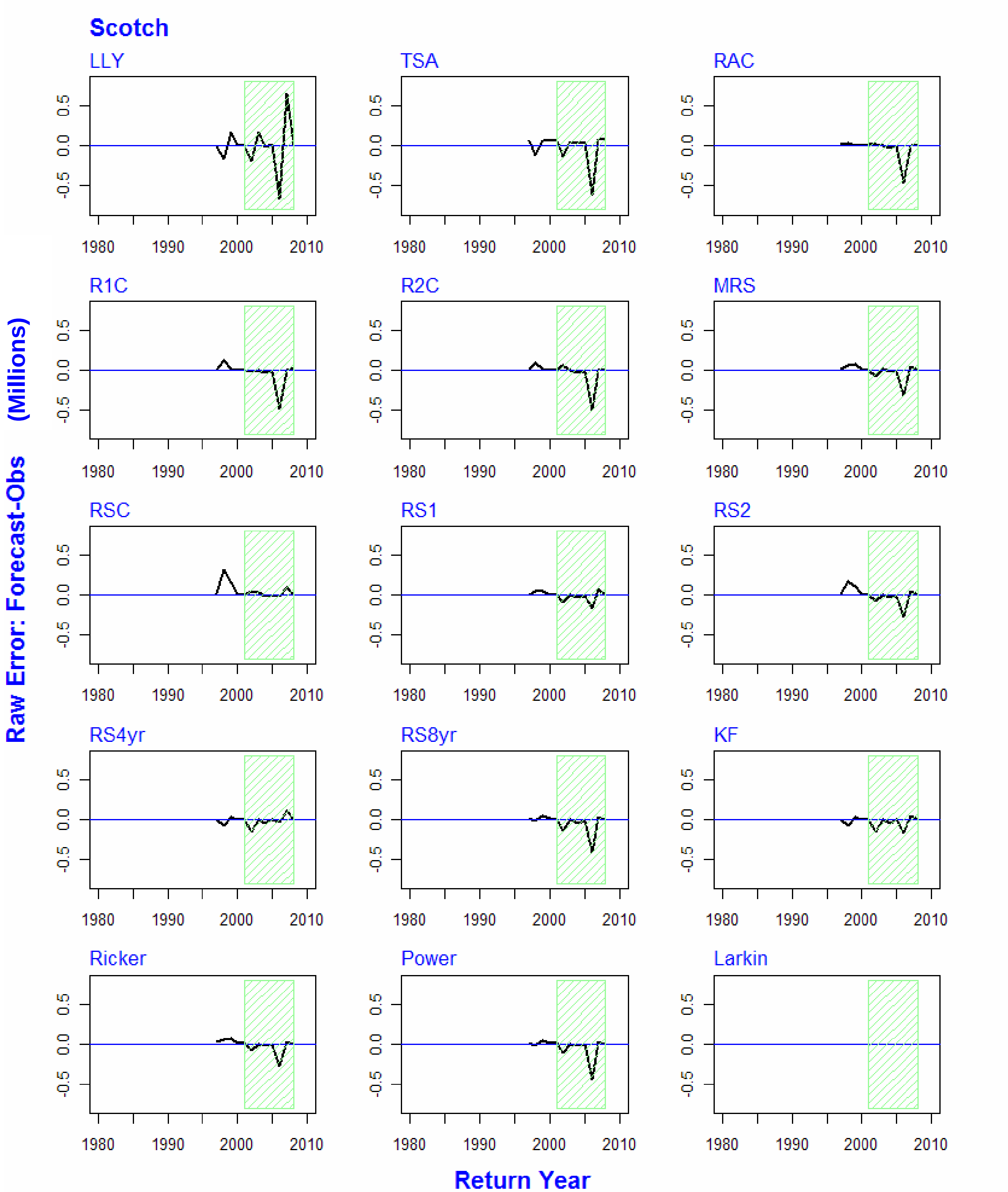
Upper Pitt
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
0.4
0.0
-0.4
2001
2003
2005
2007
Raw Error: Forecast-Obs (Millions)
Return Year

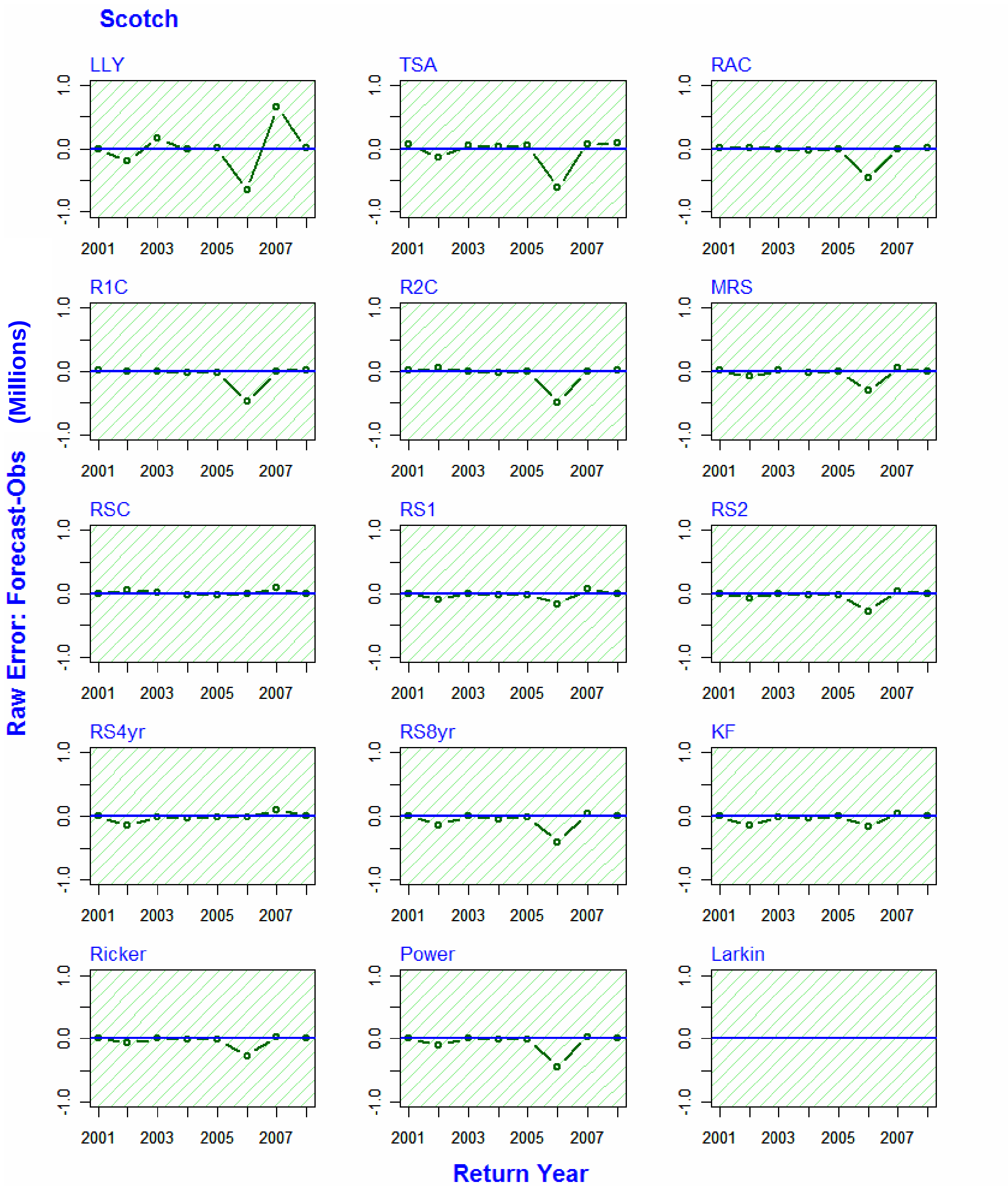

Raft
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
Percent Error: (Forecast-Obs)/Forecast x 100
Return Year
-500
1000
2500
1980
1990
2000
2010


Raft
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
Raw Error: Forecast-Obs (Millions)
Return Year
0.3
0.1
-0.1
-0.3
1980
1990
2000
2010

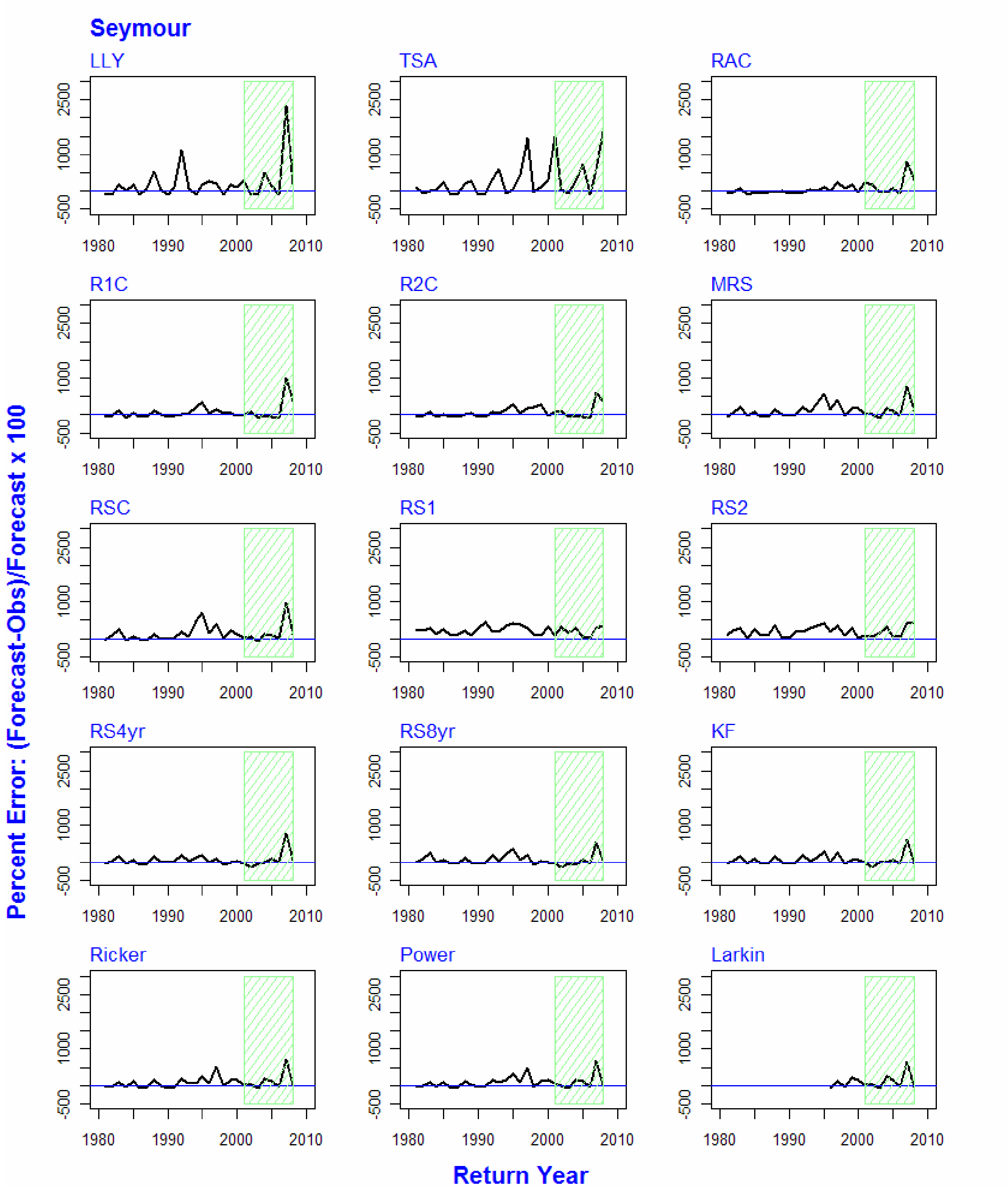

Raft
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
Raw Error: Forecast-Obs (Millions)
Return Year
0.4
0.0
-0.4
2001
2003
2005
2007


Scotch
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
Percent Error: (Forecast-Obs)/Forecast x 100
Return Year
-500
1000
2500
1980
1990
2000
2010

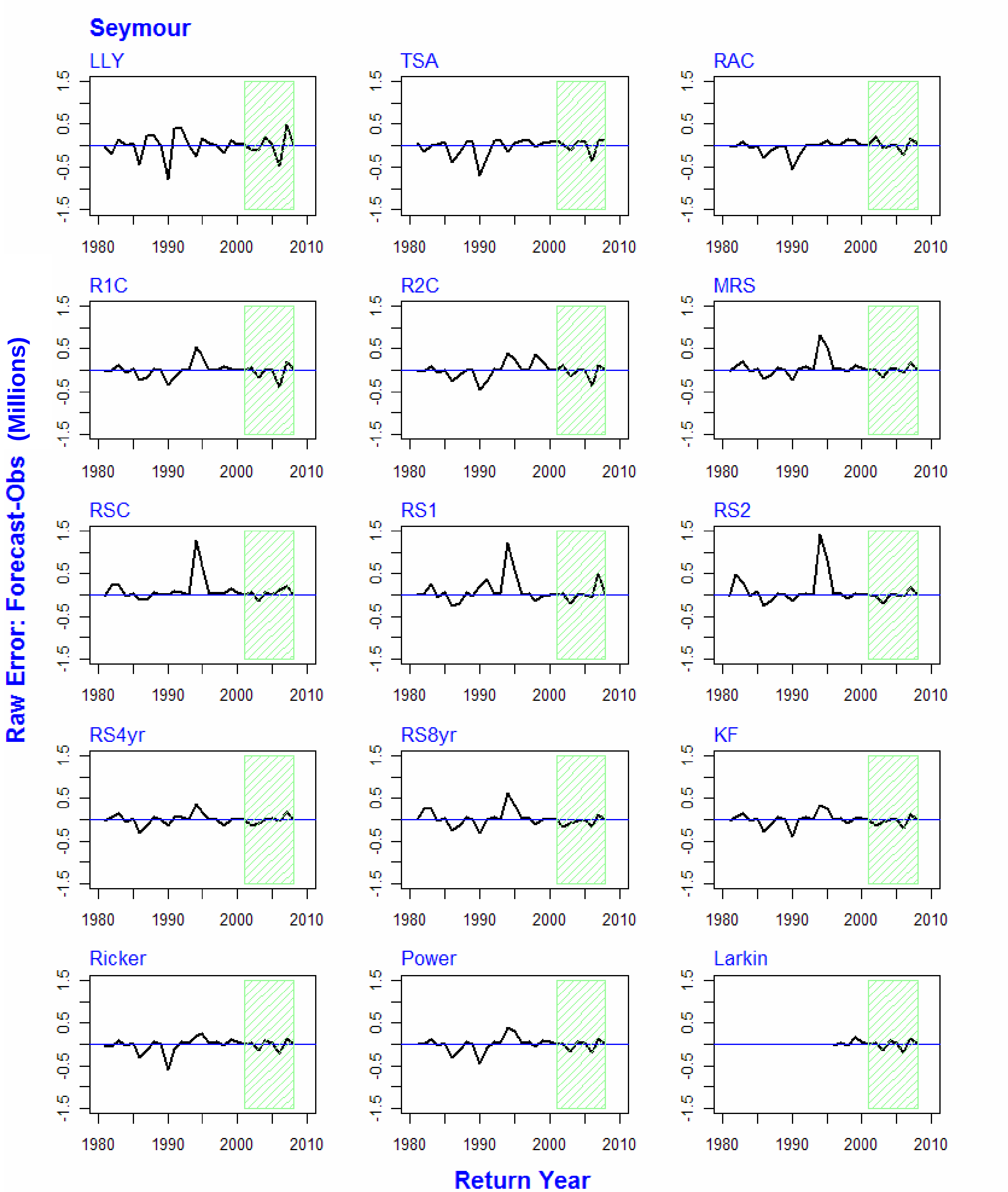

Scotch
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
Raw Error: Forecast-Obs (Millions)
Return Year
0.5
0.0
-0.5
1980
1990
2000
2010



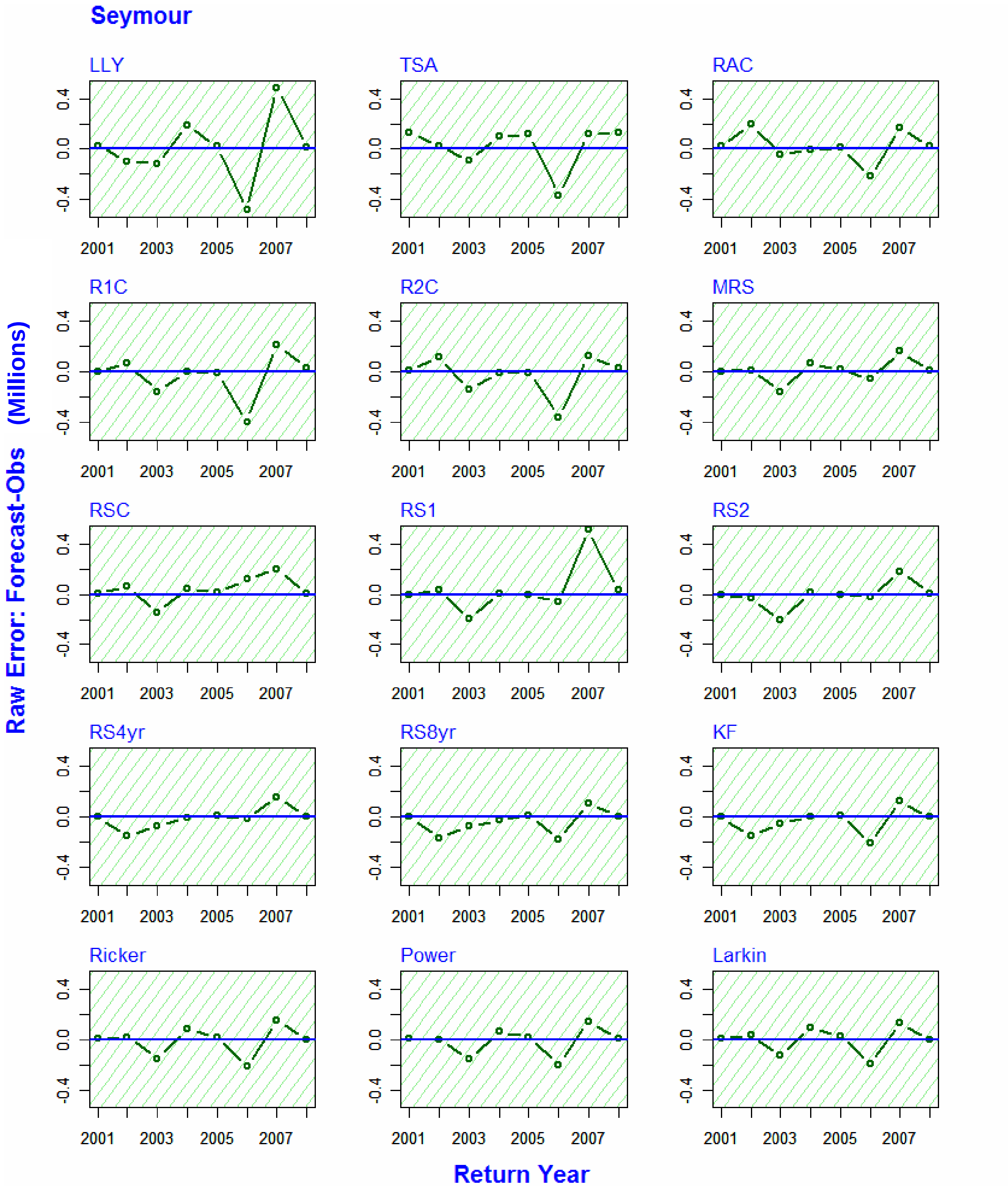
Scotch
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
1.0
0.0
-1.0
2001
2003
2005
2007
Raw Error: Forecast-Obs (Millions)
Return Year

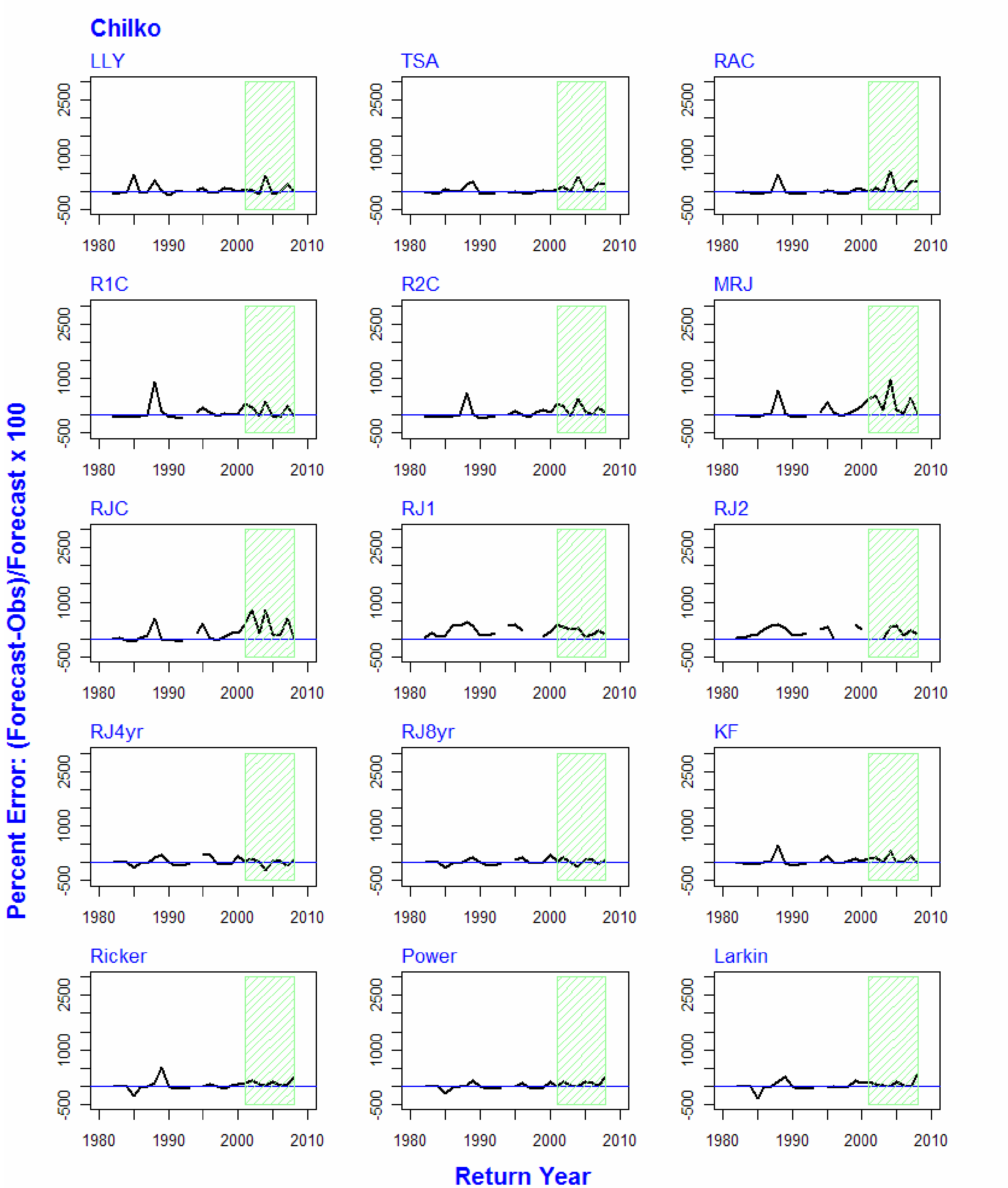


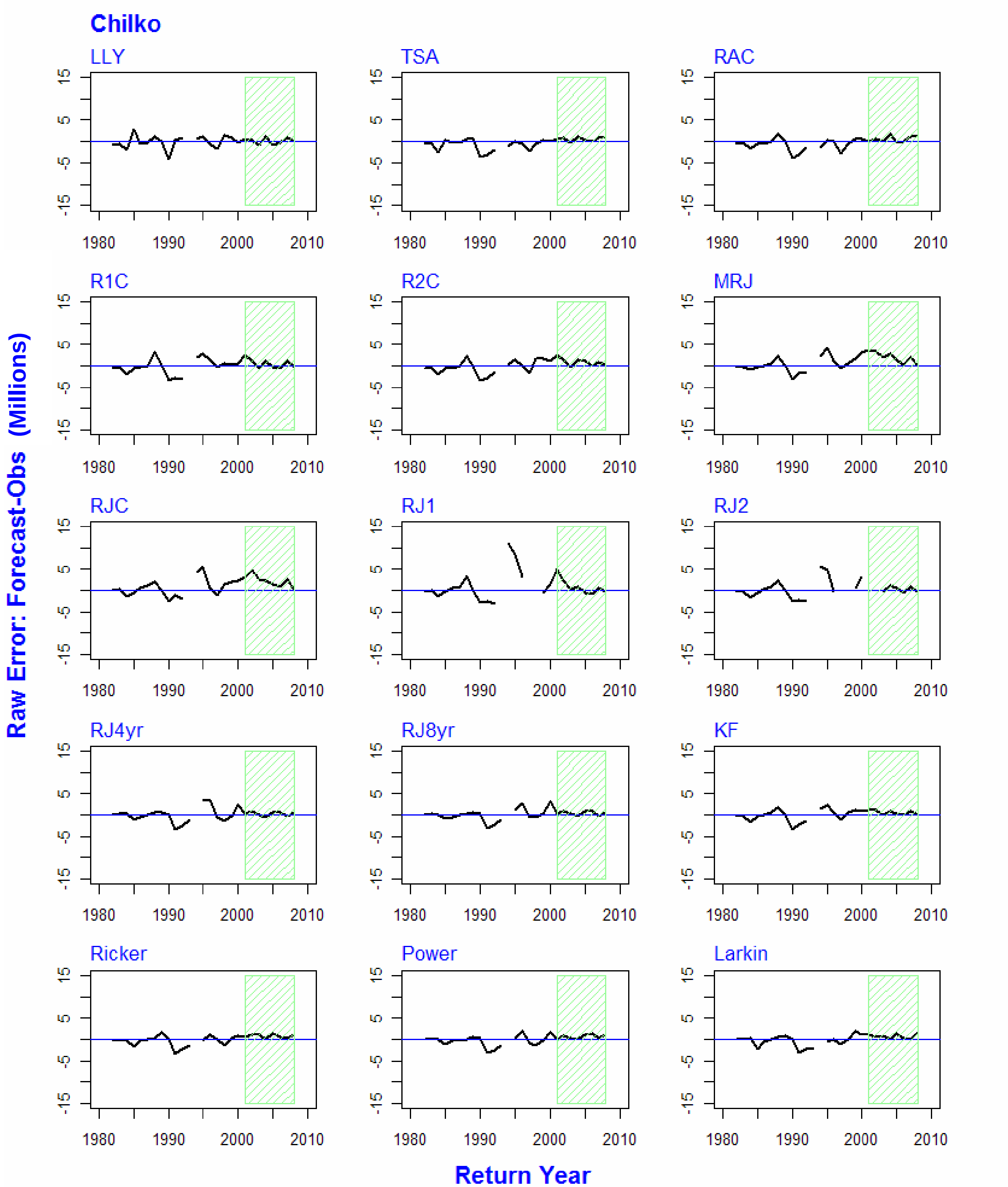
Seymour
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
Percent Error: (Forecast-Obs)/Forecast x 100
Return Year
-500
1000
2500
1980
1990
2000
2010



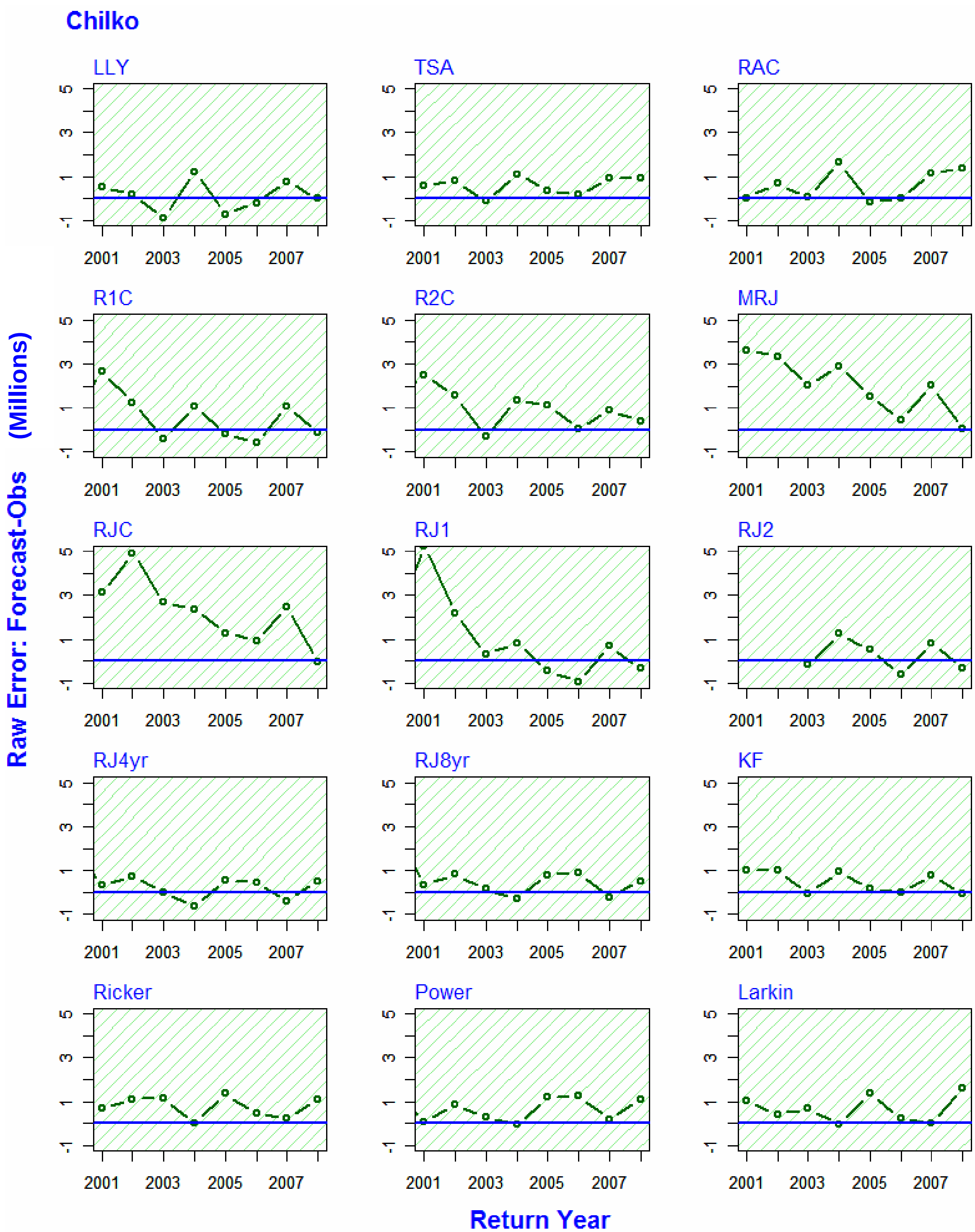
Seymour
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
Raw Error: Forecast-Obs (Millions)
Return Year
1.5
0.5
-0.5
-1.5
1980
1990
2000
2010

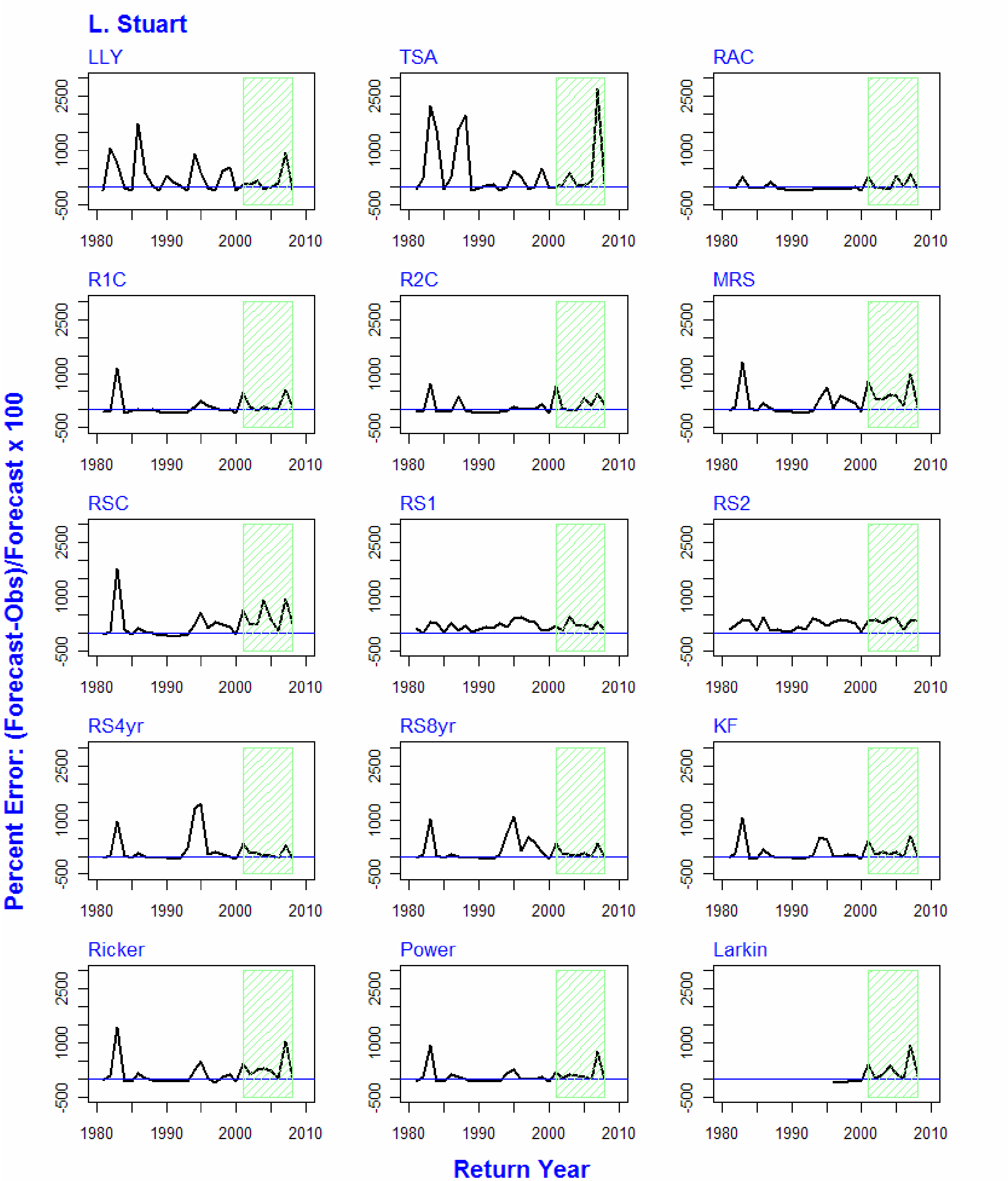

Seymour
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
Raw Error: Forecast-Obs (Millions)
Return Year
0.4
0.0
-0.4
2001
2003
2005
2007


Chilko
LLY
TSA
RAC
R1C
R2C
MRJ
RJC
RJ1
RJ2
RJ4yr
RJ8yr
KF
Ricker
Power
Larkin
Percent Error: (Forecast-Obs)/Forecast x 100
-500
1000
2500
1980
1990
2000
2010
Return Year



Chilko
LLY
TSA
RAC
R1C
R2C
MRJ
RJC
RJ1
RJ2
RJ4yr
RJ8yr
KF
Ricker
Power
Larkin
15
5
-5
-15
1980
1990
2000
2010
Raw Error: Forecast-Obs (Millions)
Return Year


Chilko
LLY
TSA
RAC
R1C
R2C
MRJ
RJC
RJ1
RJ2
RJ4yr
RJ8yr
KF
Ricker
Power
Larkin
Raw Error: Forecast-Obs (Millions)
Return Year
2001
2003
2005
2007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LLY
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RSC
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RS2
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KF
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Power
Larkin
Percent Error: (Forecast-Obs)/Forecast x 100
Return Year
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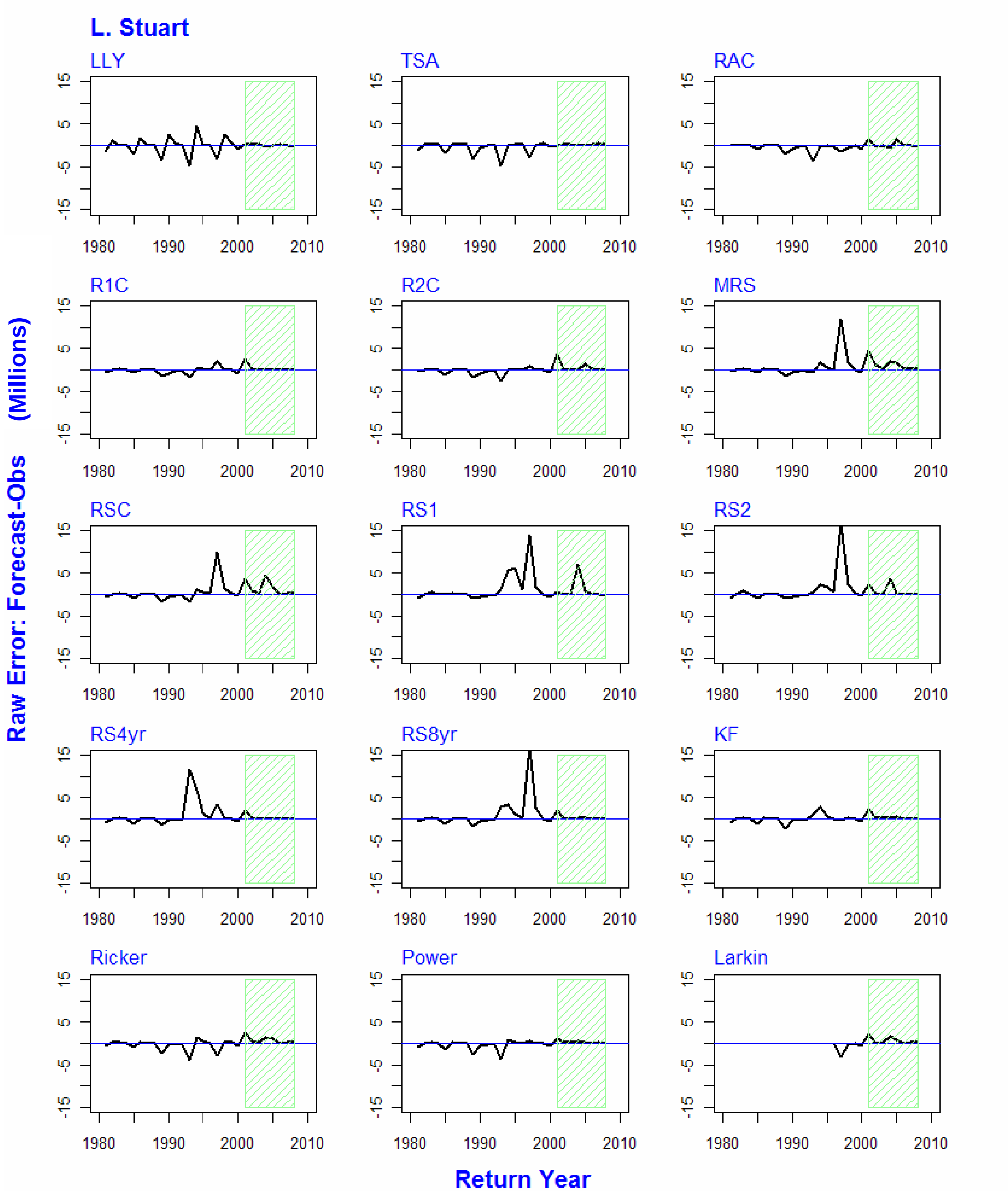
2010



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Larkin
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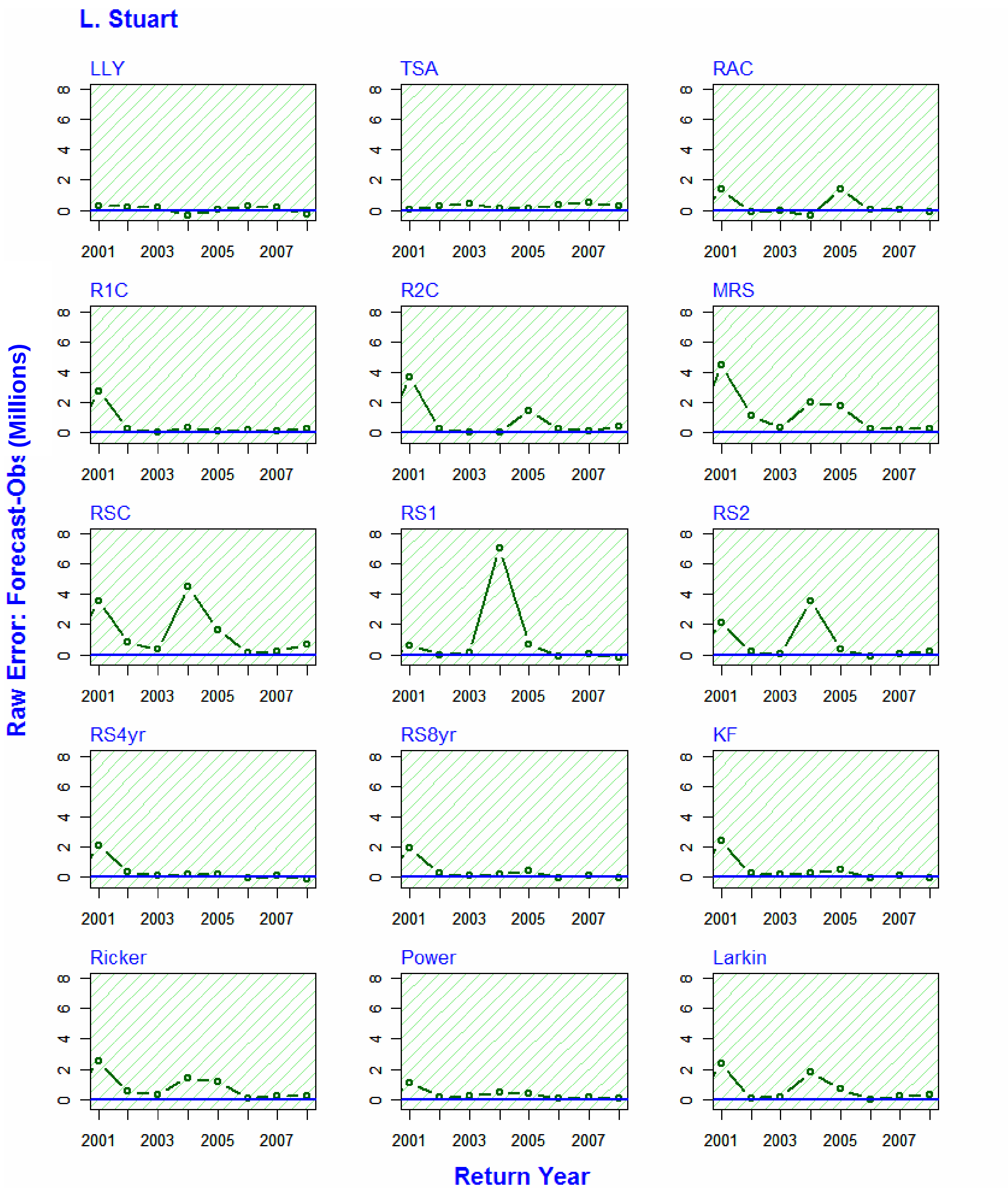
2000
2010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2003
2005
2007
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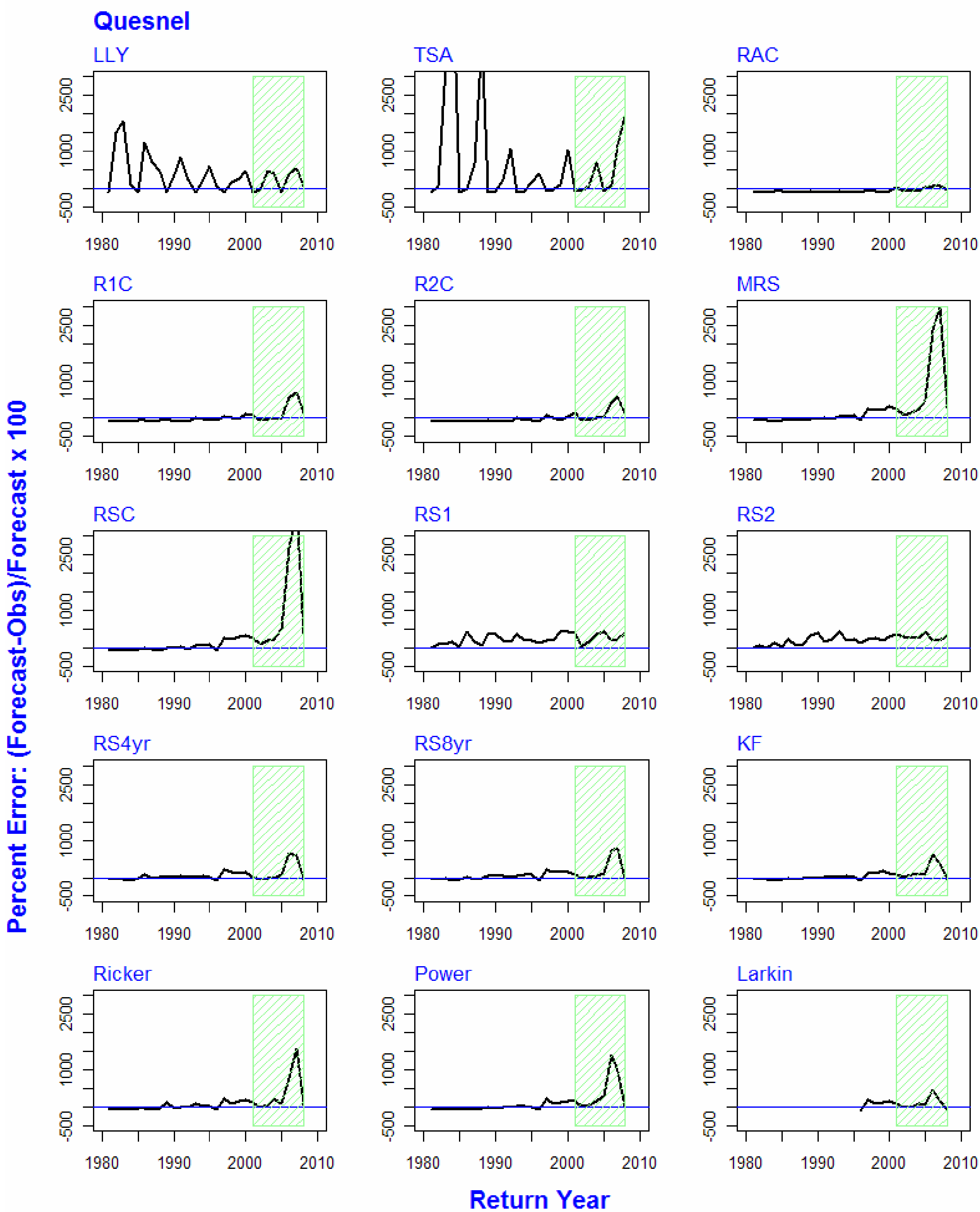
Return Year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2000
2010
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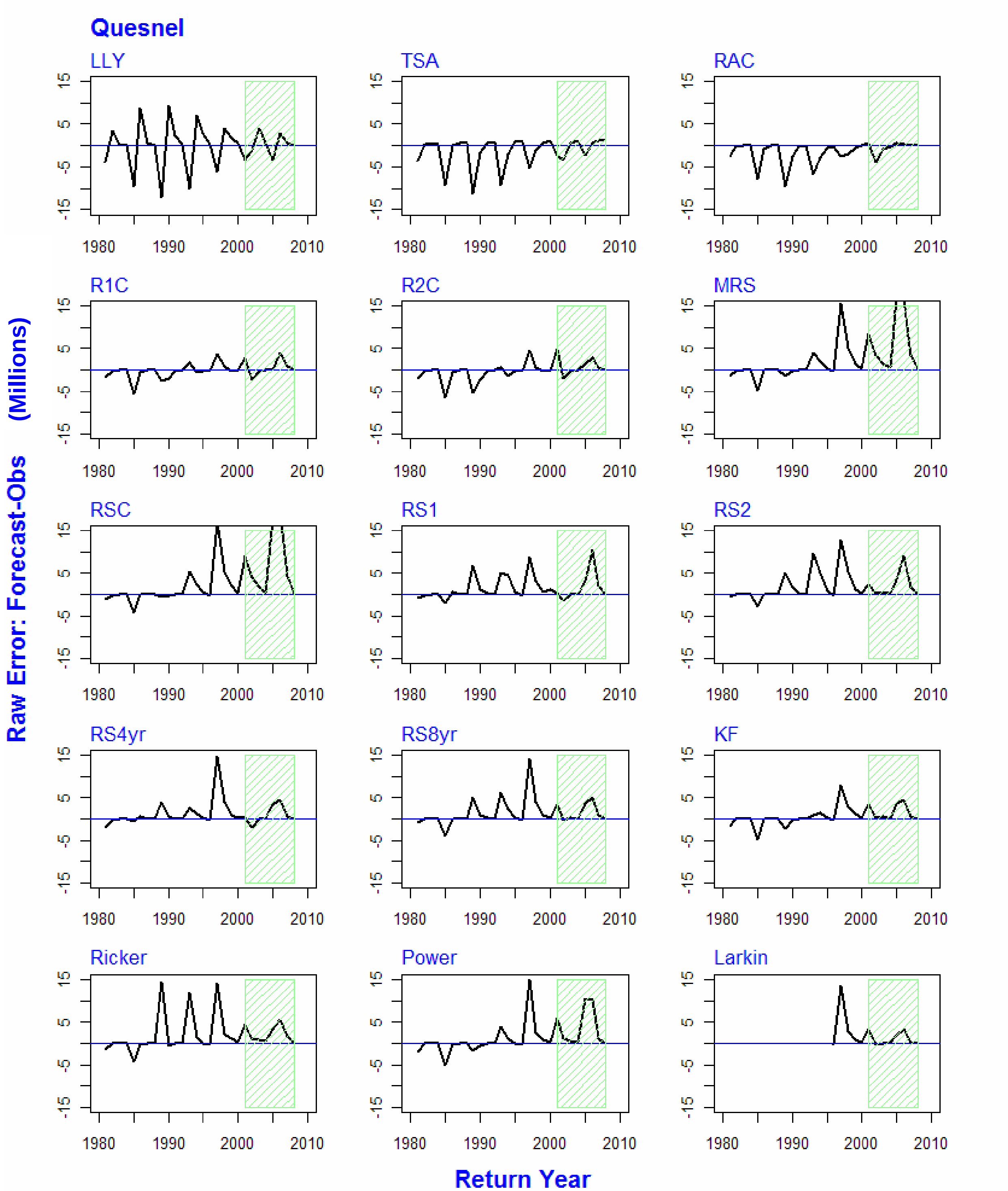
Return Year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2000
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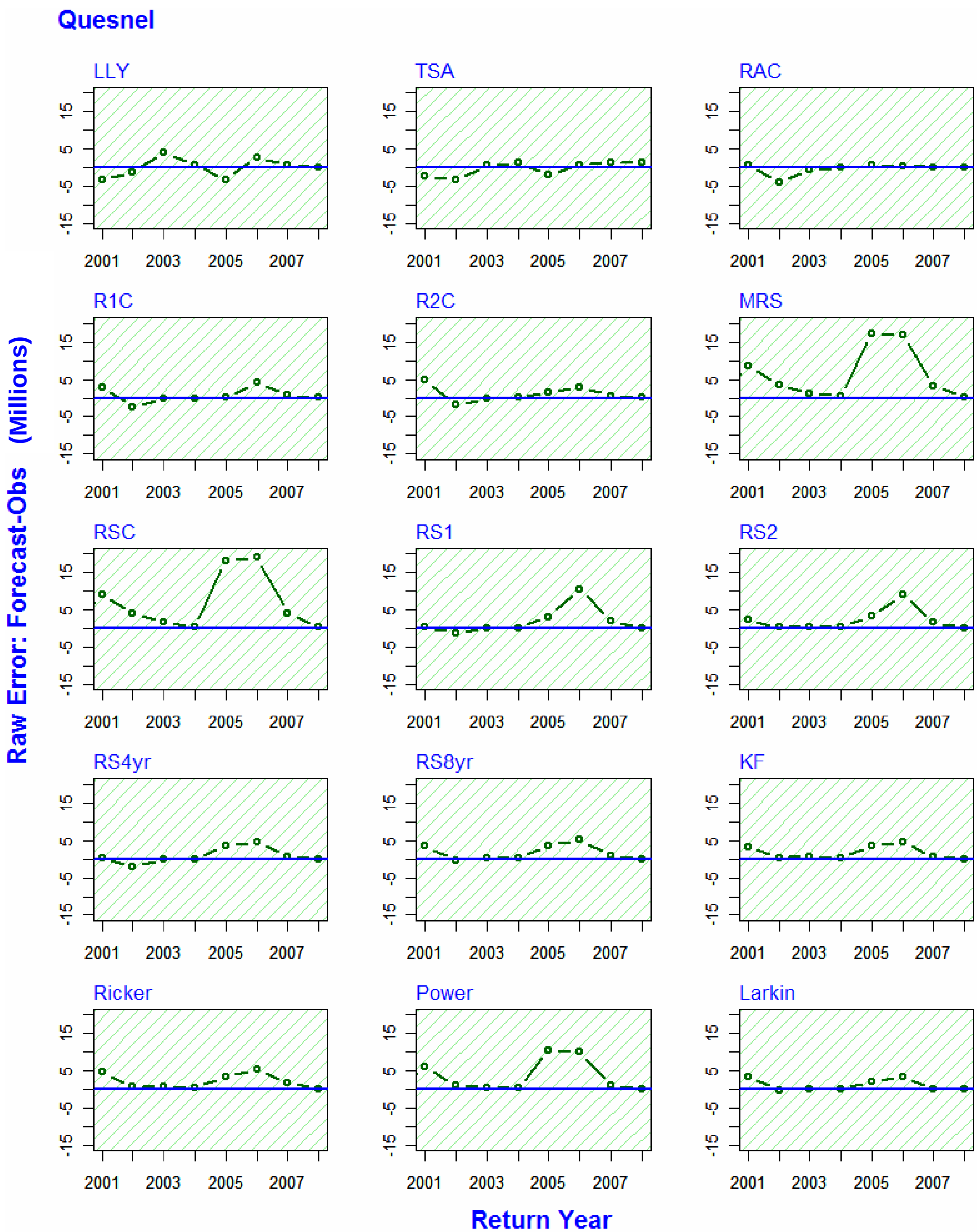
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2001
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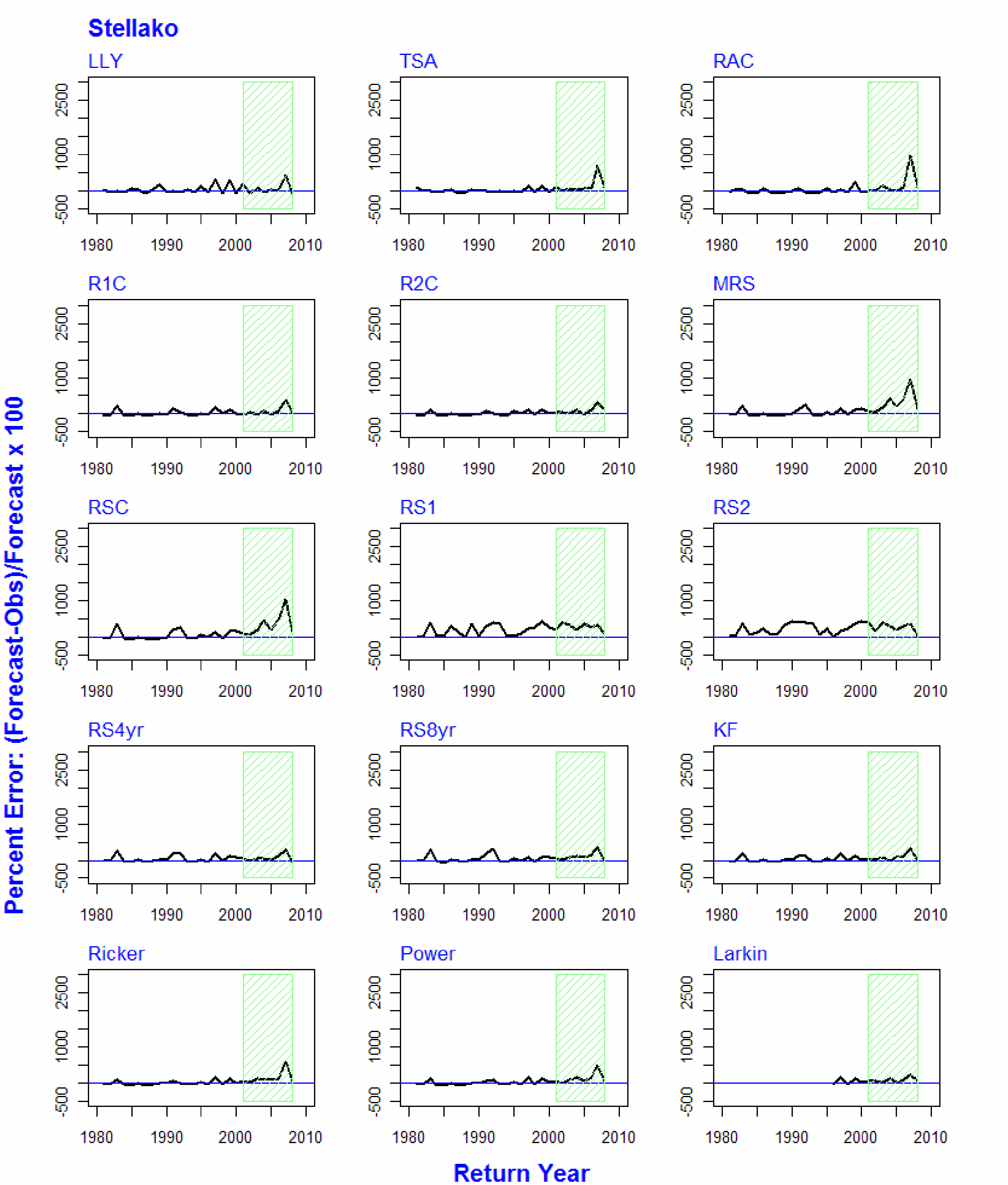
2005
2007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2000
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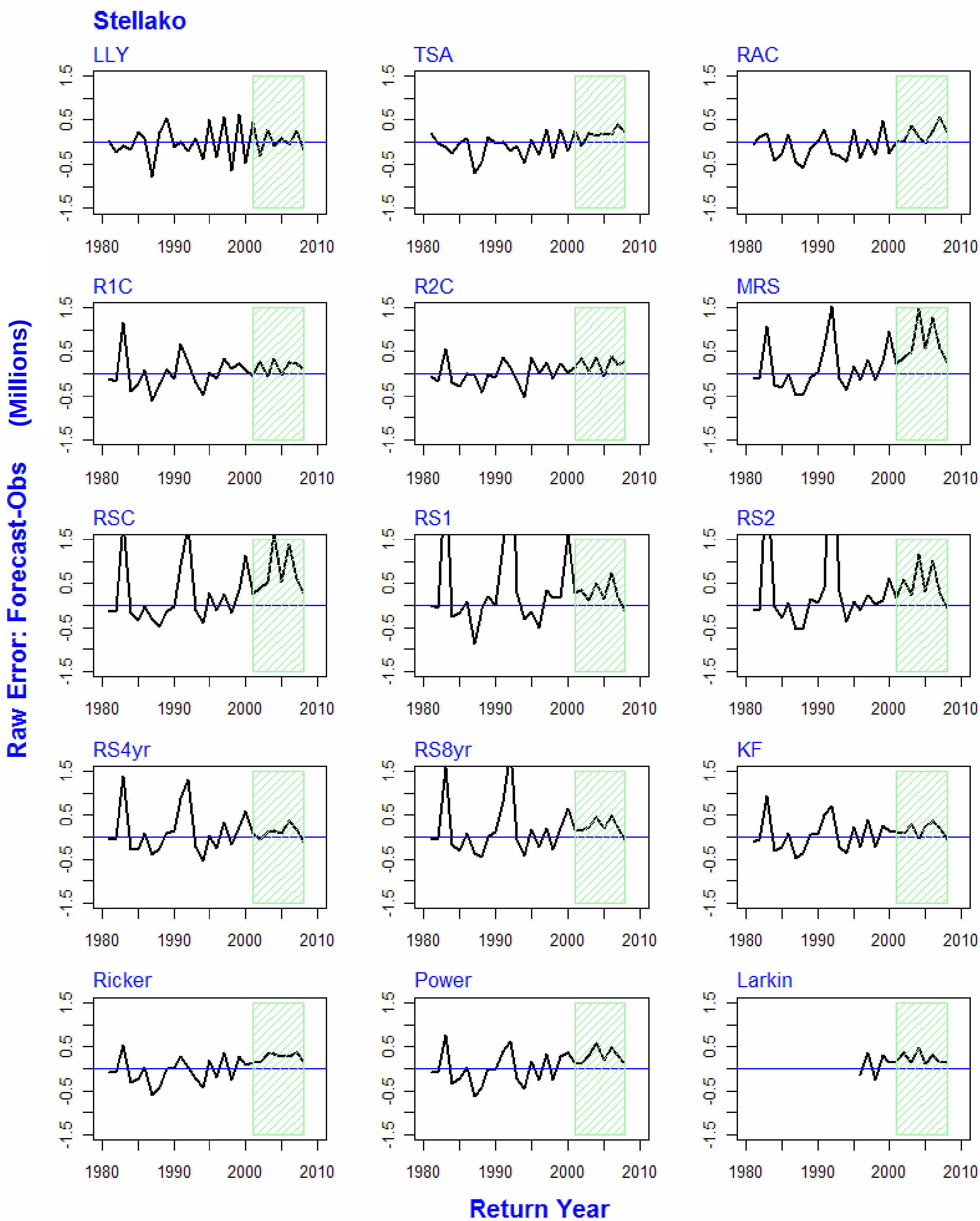
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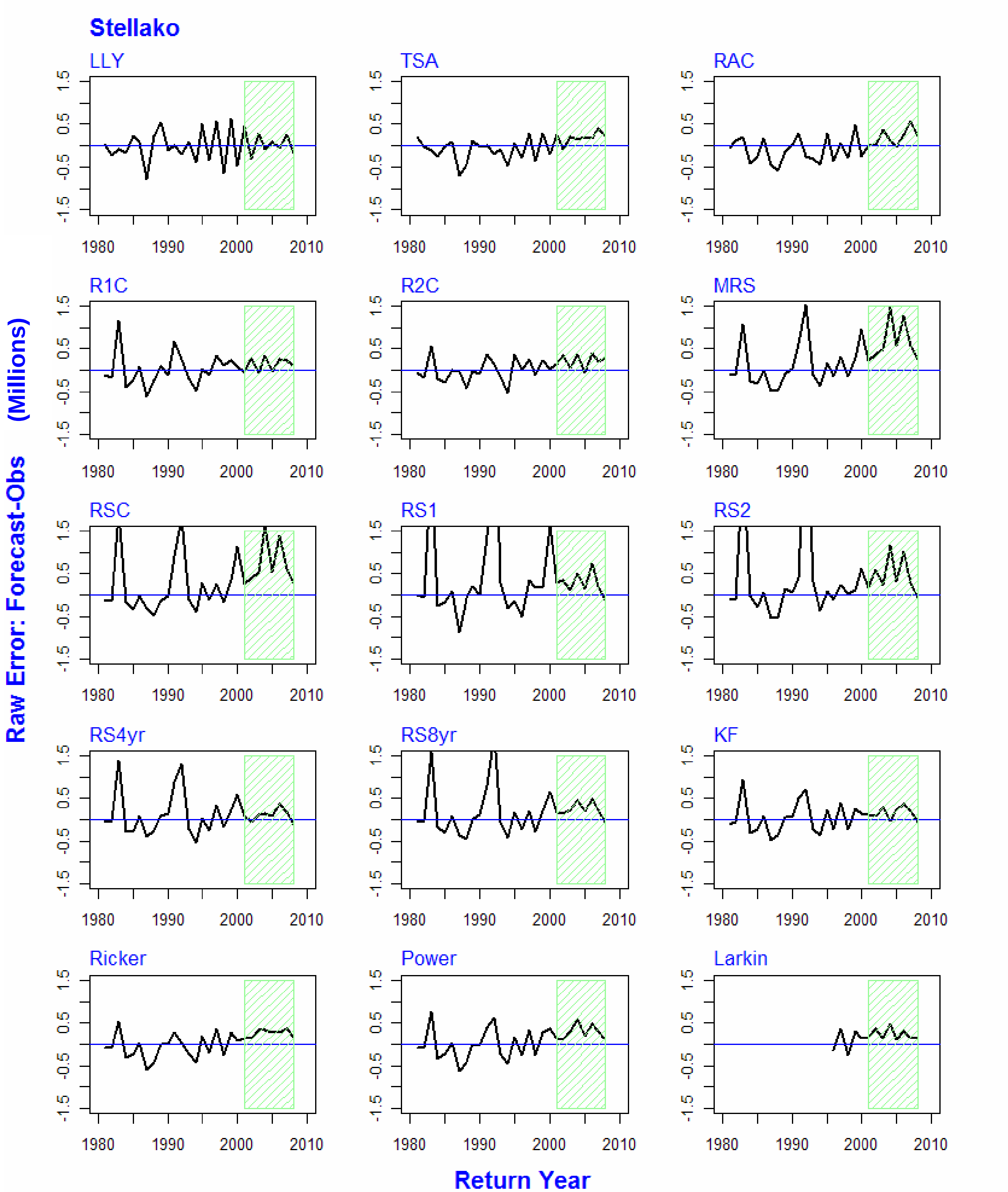
1980
1990
2000
2010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RS8yr
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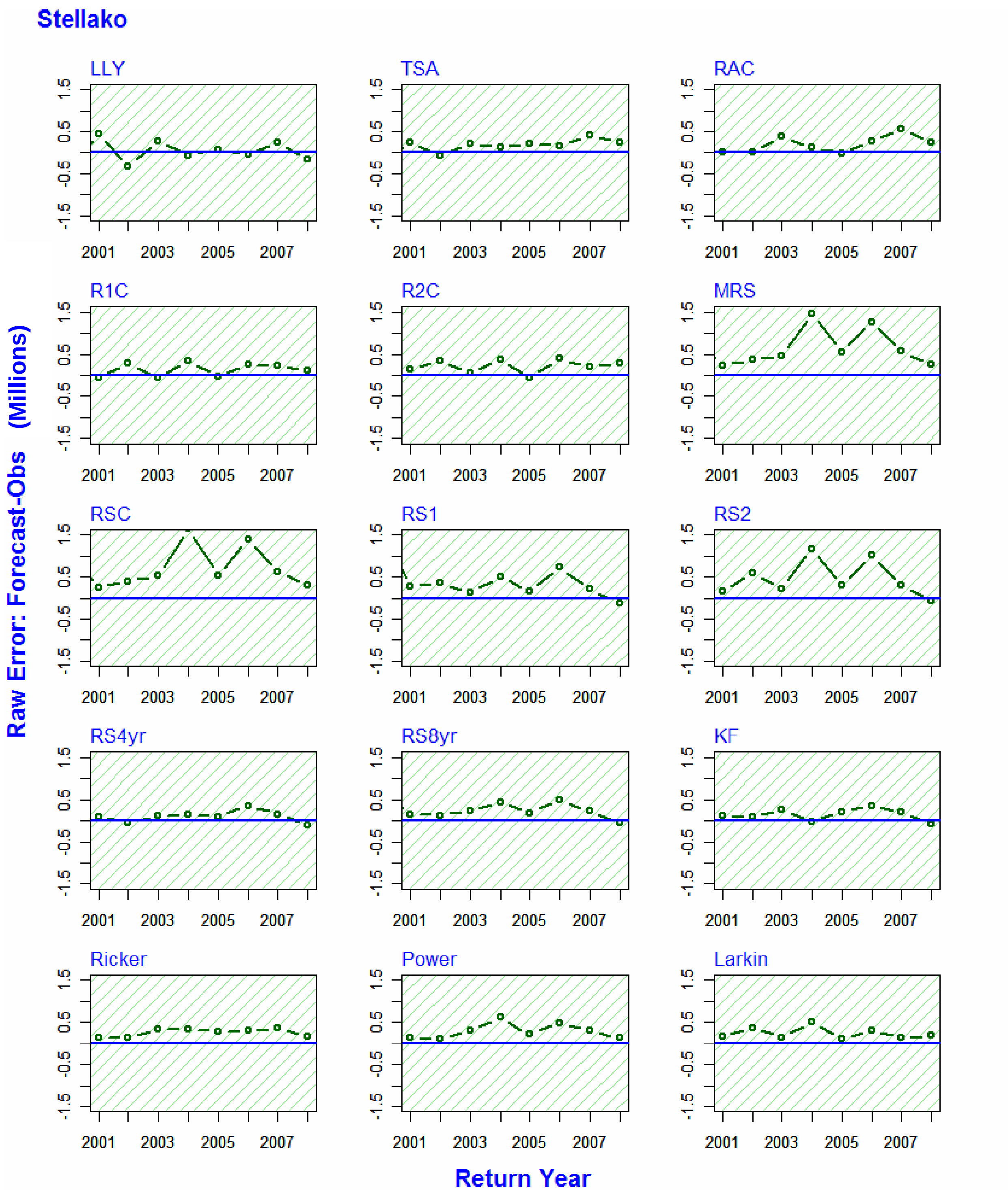
1990
2000
2010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Power
Larkin
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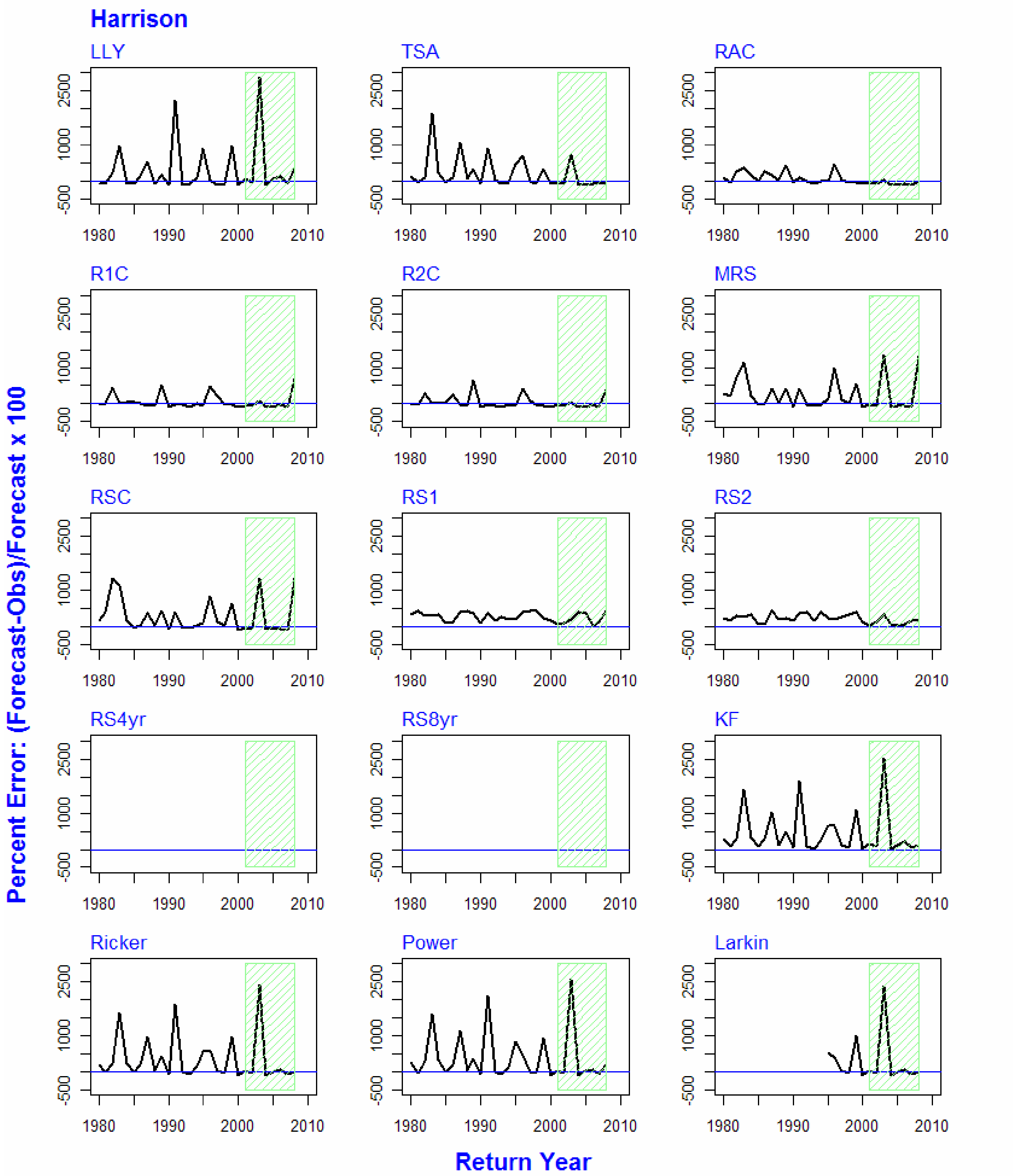
1.5
2001
2003
2005
2007
Return Year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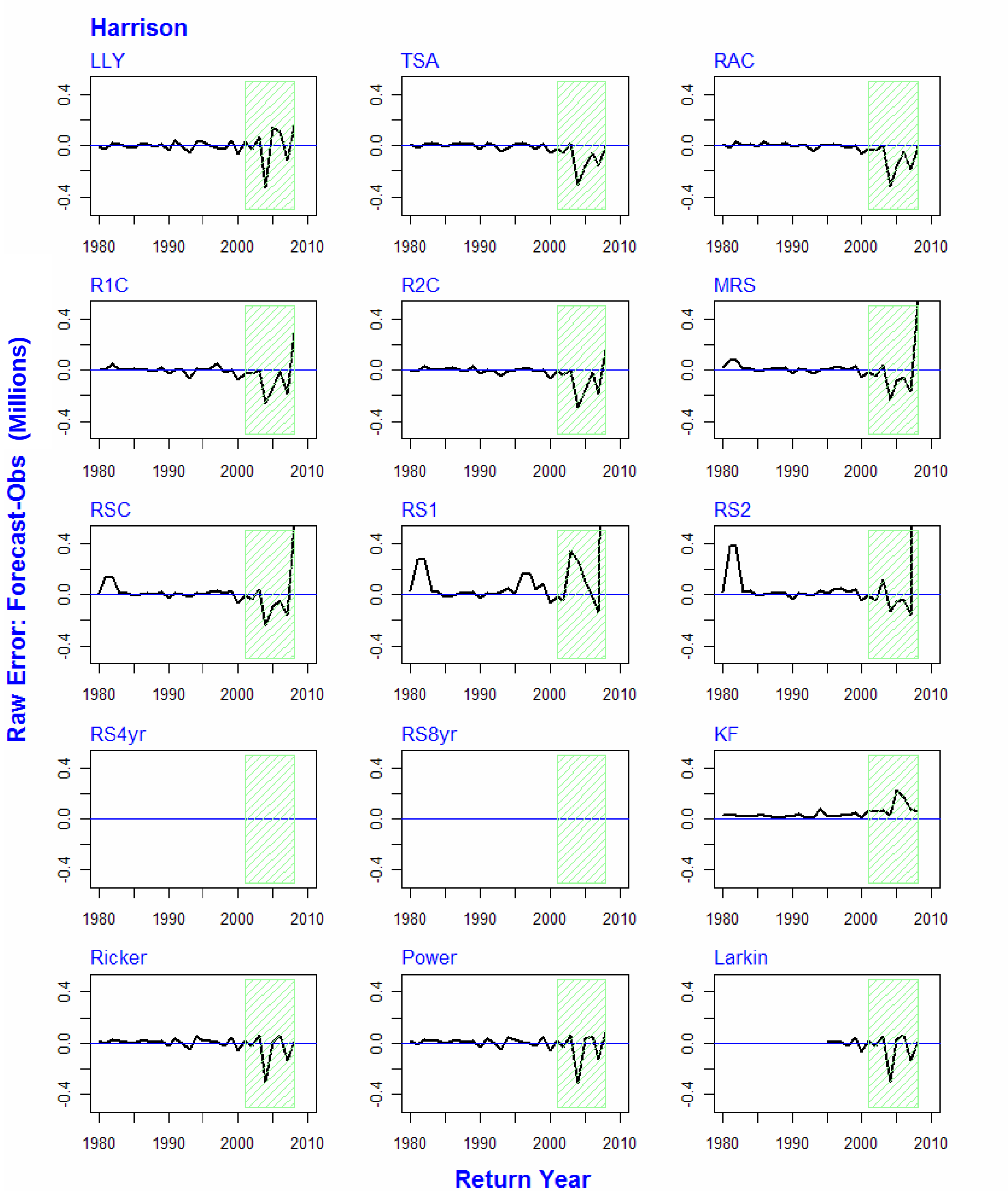
2000
2010
Percent Error: (Forecast-Obs)/Forecast x 100
Return Year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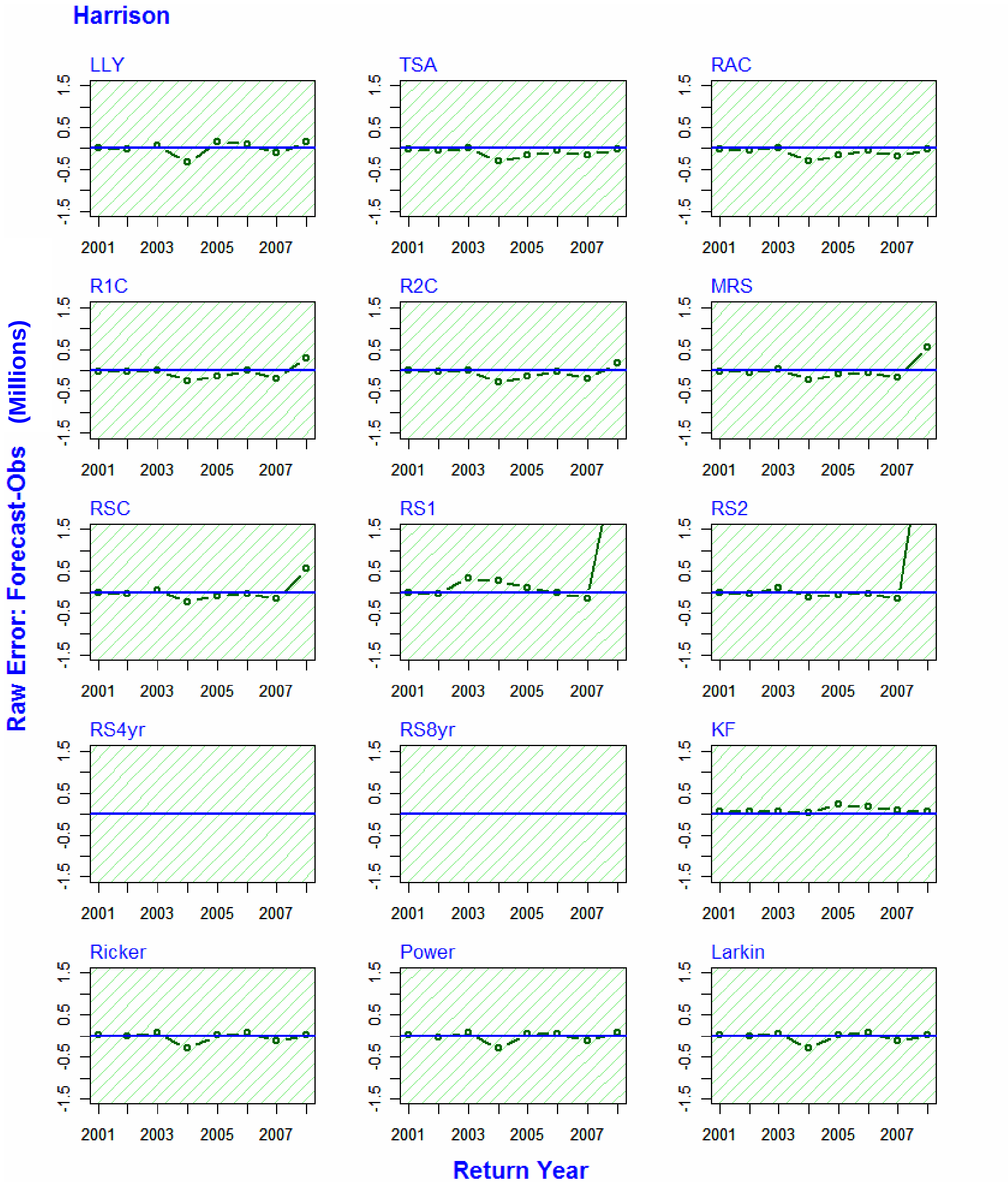
1980
1990
2000
2010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RS8yr
KF
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Power
Larkin
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Return Year
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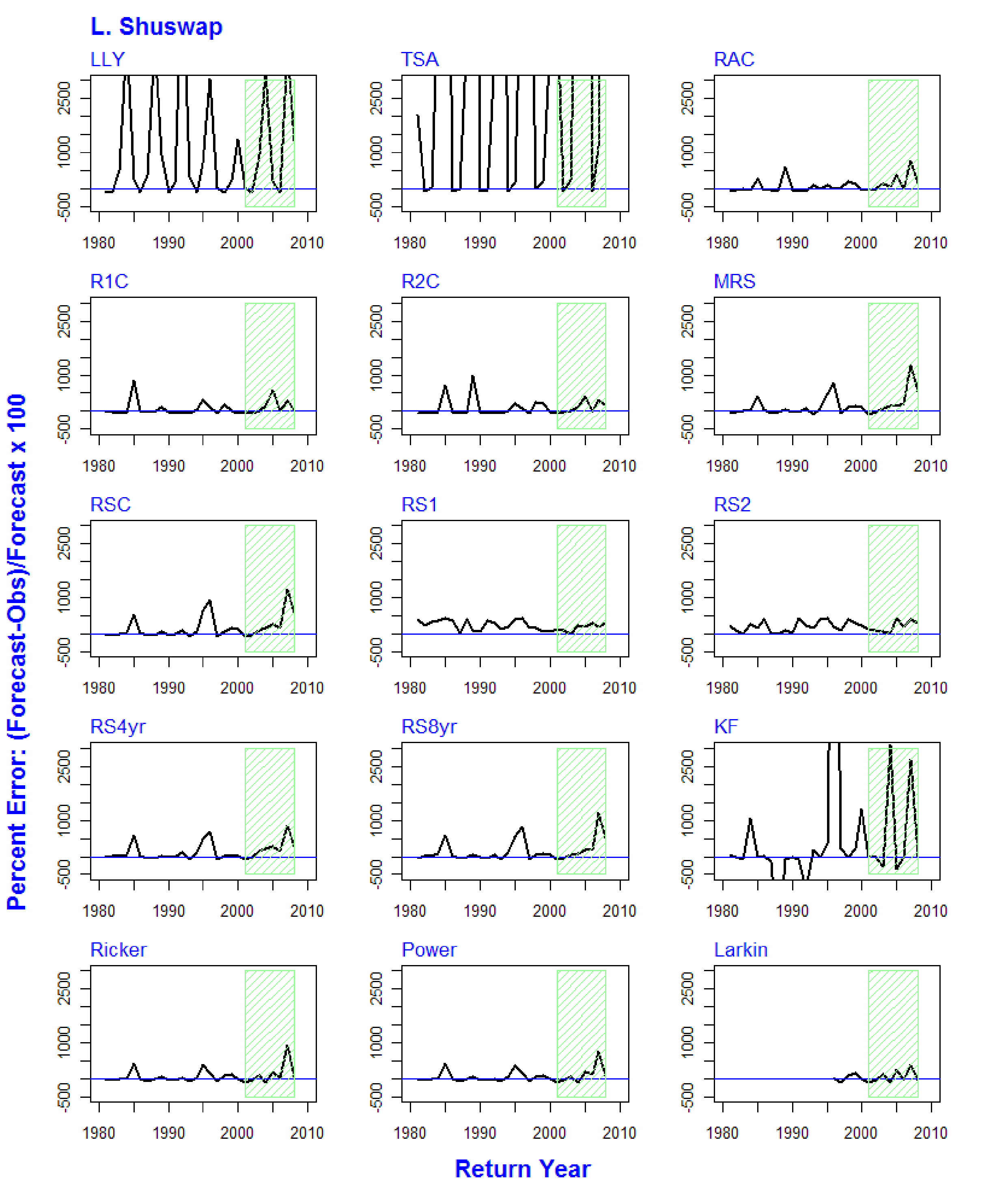
-0.5
-1.5
2001
2003
2005
2007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Ricker
Power
Larkin
Percent Error: (Forecast-Obs)/Forecast x 100
Return Year
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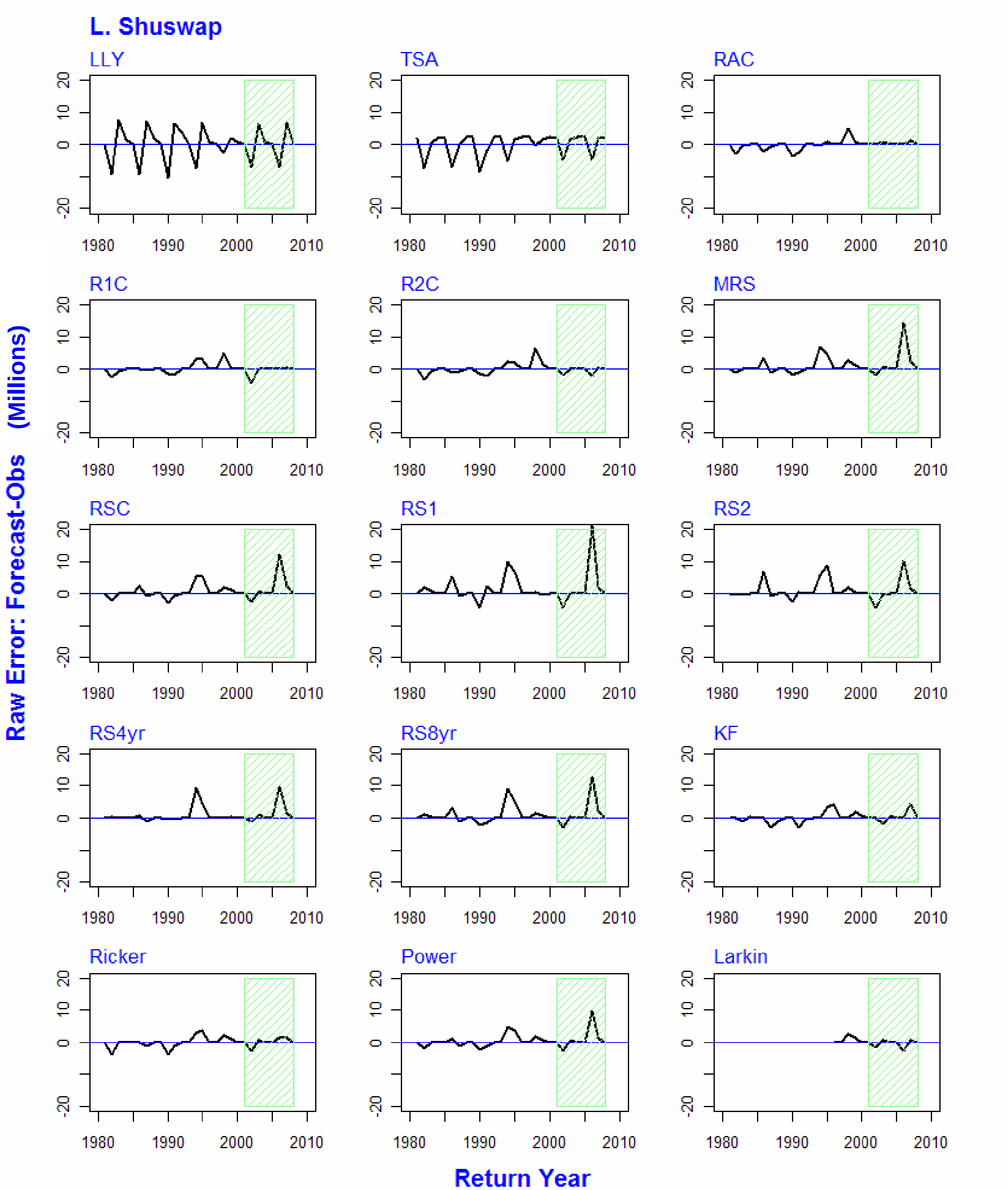
1000
2500
1980
1990
2000
2010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RS2
RS4yr
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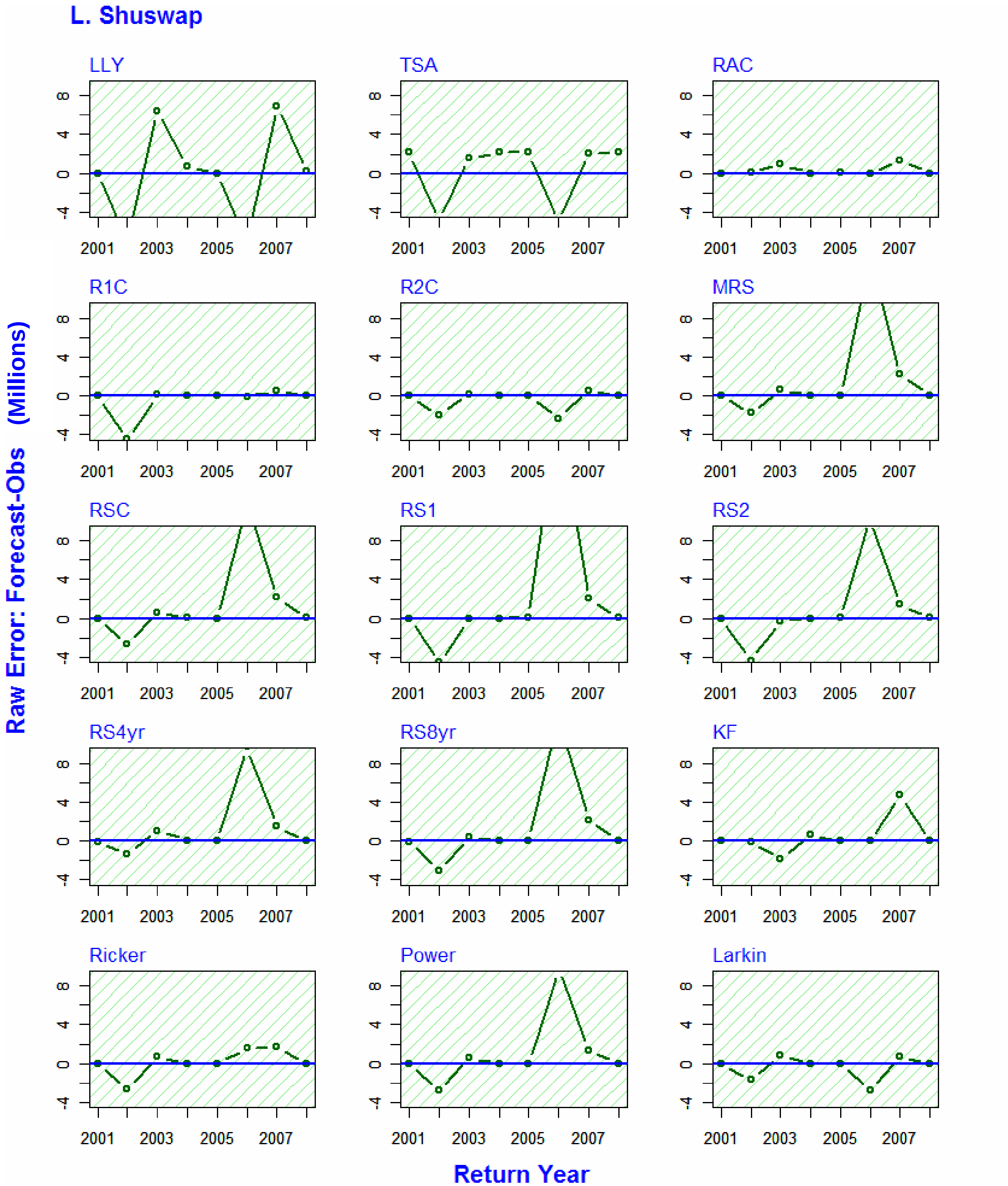
2000
2010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RS2
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Ricker
Power
Larkin
Raw Error: Forecast-Obs (Millions)
Return Year
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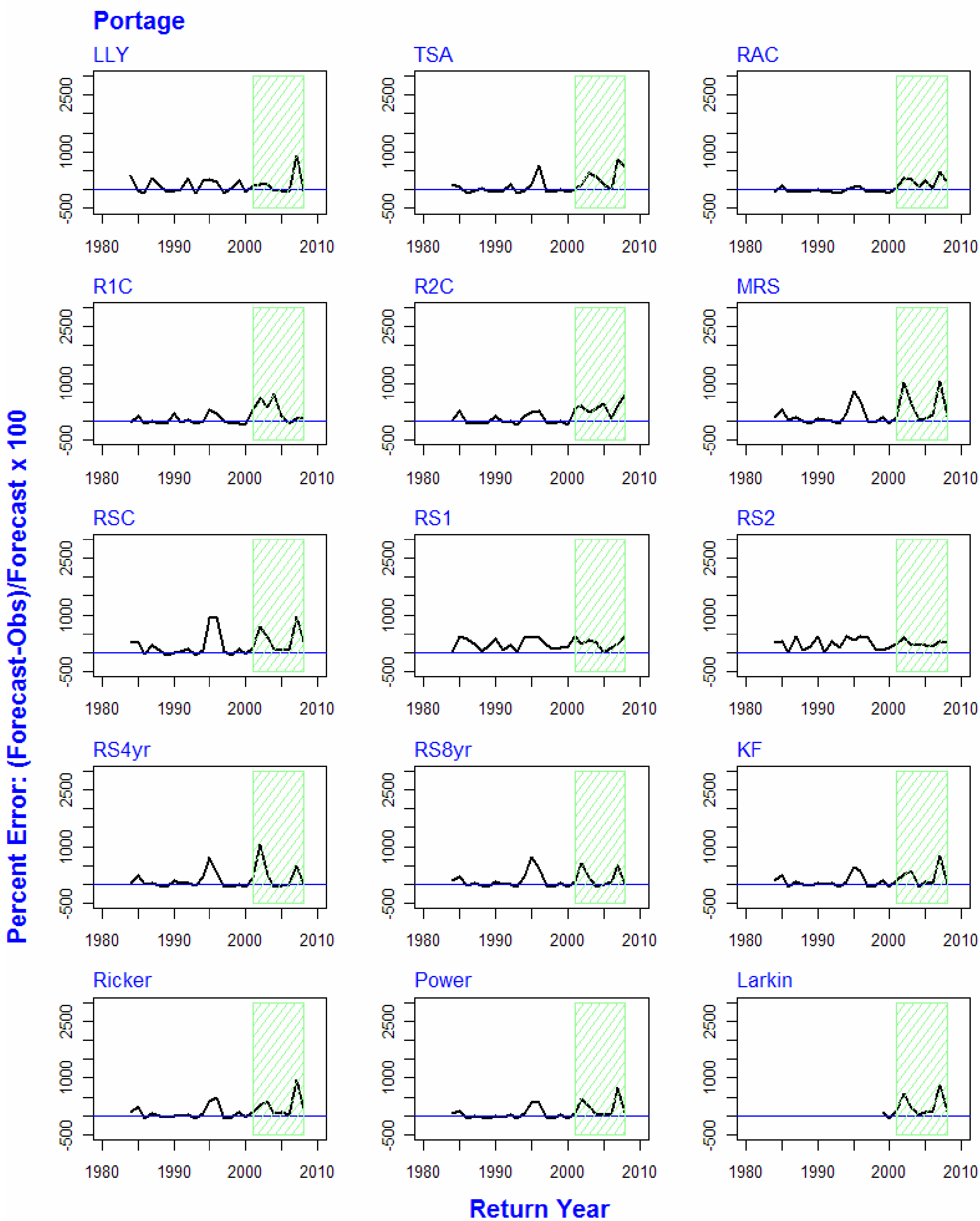
2003
2005
2007
-4
0
4
8



Portage
LLY
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MRS
RSC
RS1
RS2
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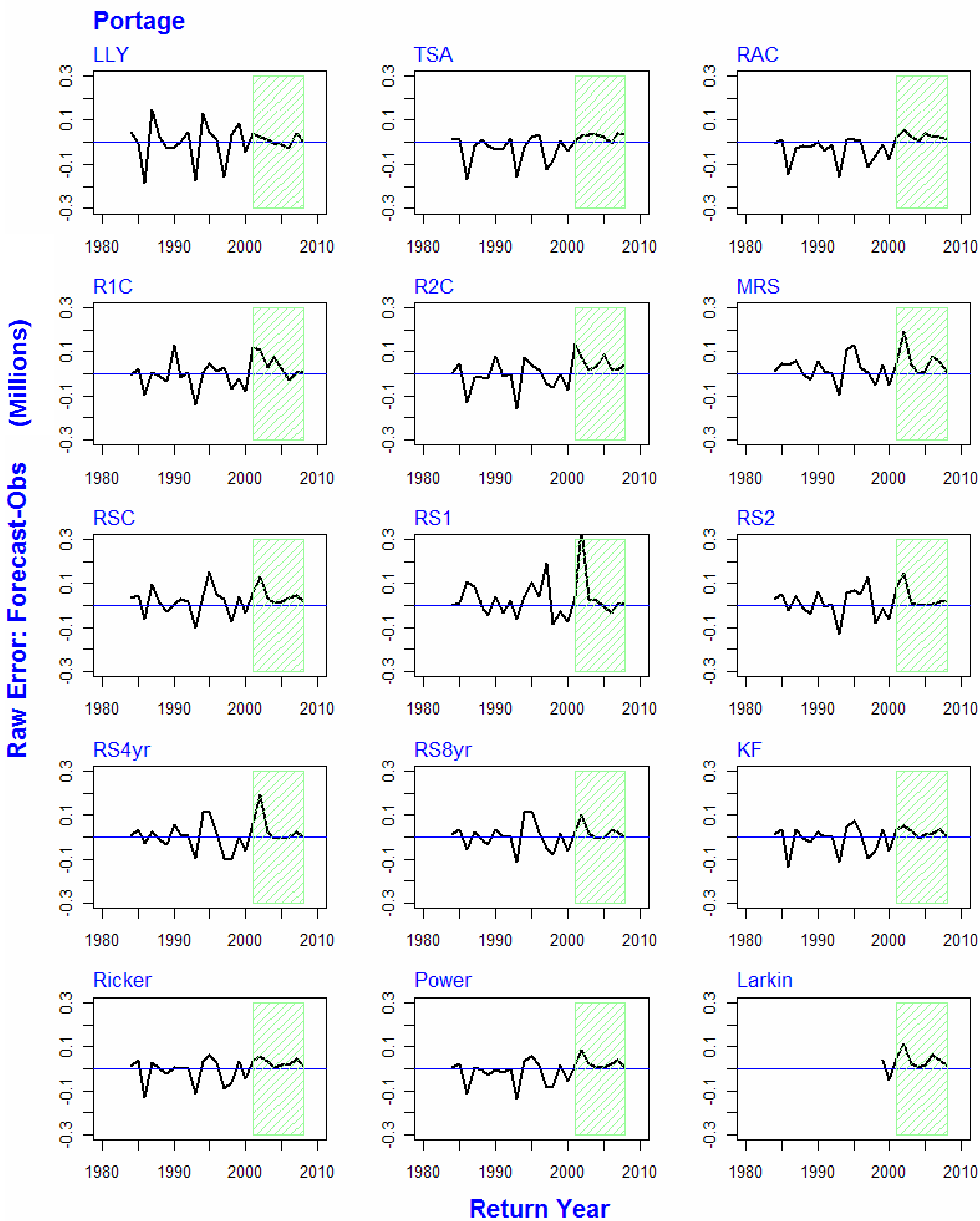
1990
2000
2010
Percent Error: (Forecast-Obs)/Forecast x 100
Return Year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1990
2000
2010
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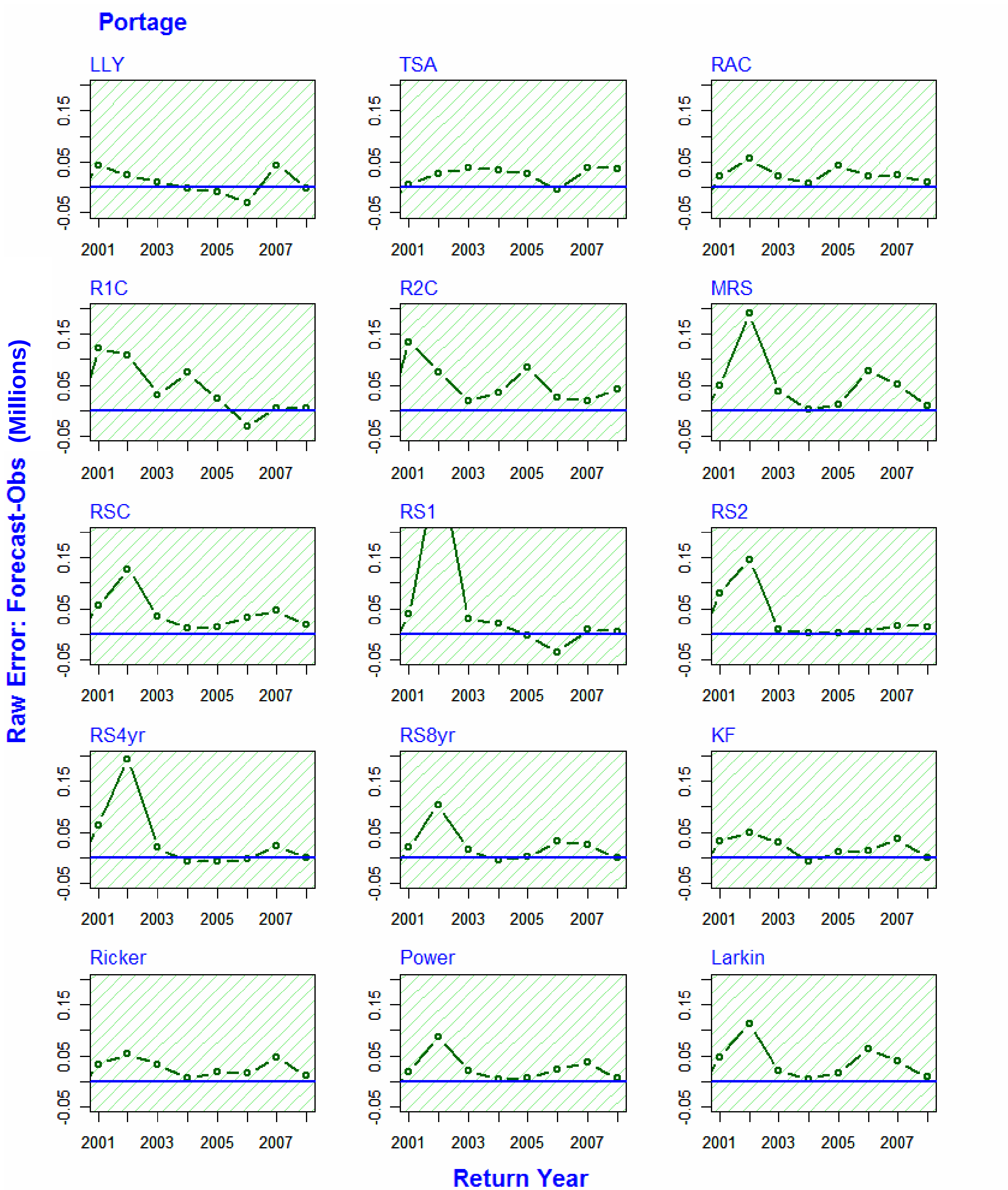
Return Year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RS2
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Return Year
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0.05
0.15
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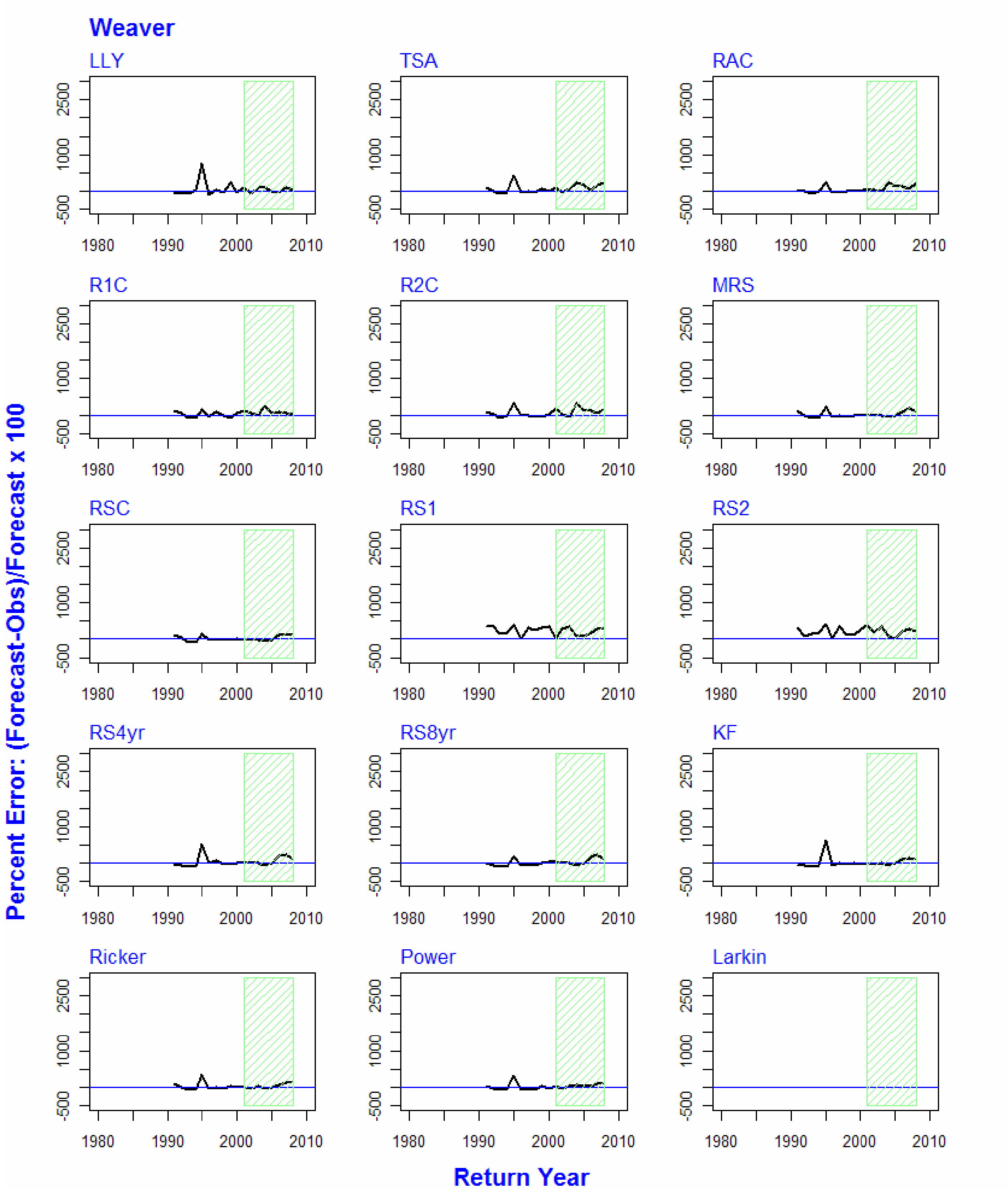
2003
2005
2007


Weaver
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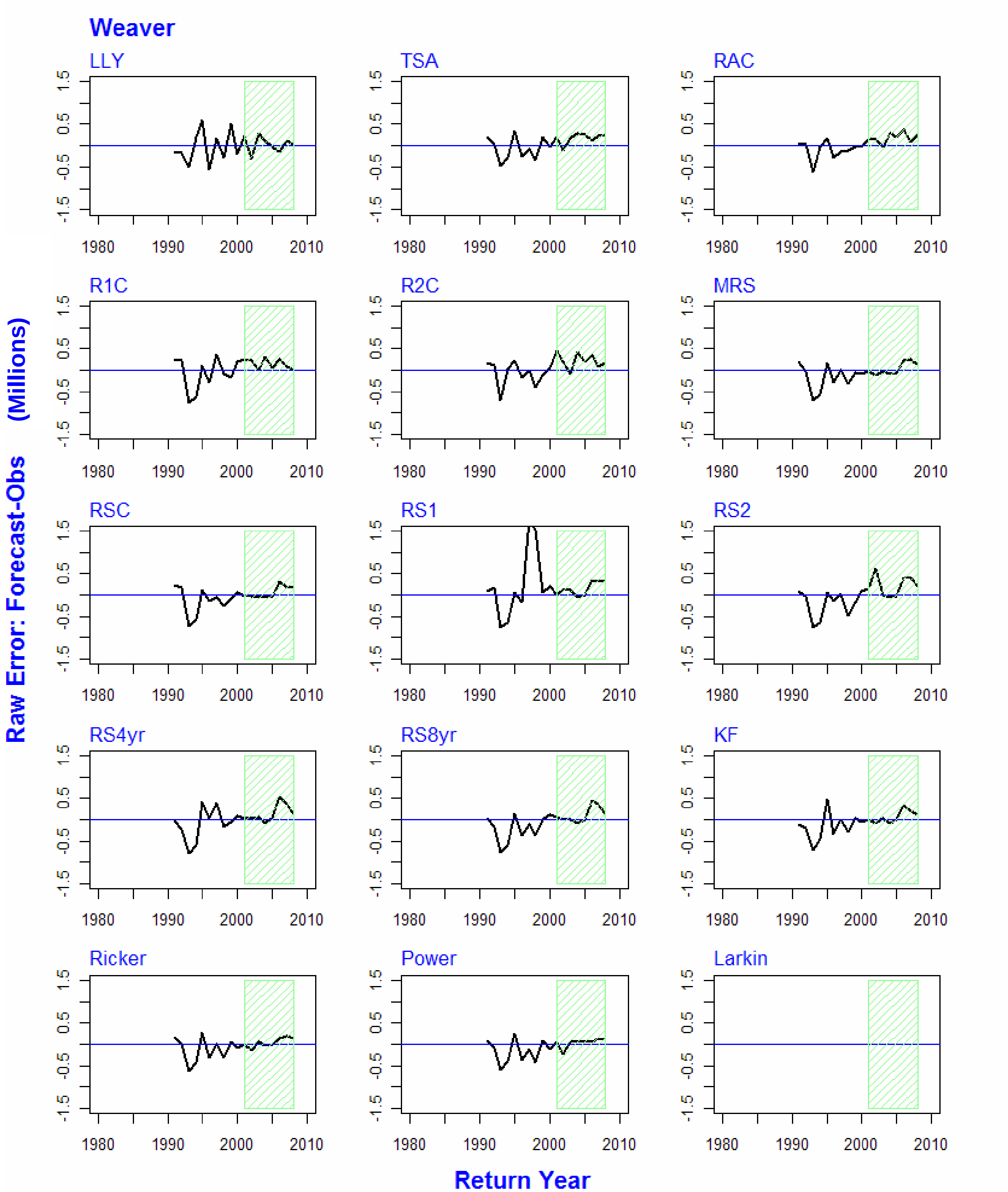
1980
1990
2000
2010
Percent Error: (Forecast-Obs)/Forecast x 100
Return Year


Weaver
LLY
TSA
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R2C
MRS
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RS1
RS2
RS4yr
RS8yr
KF
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Power
Larkin
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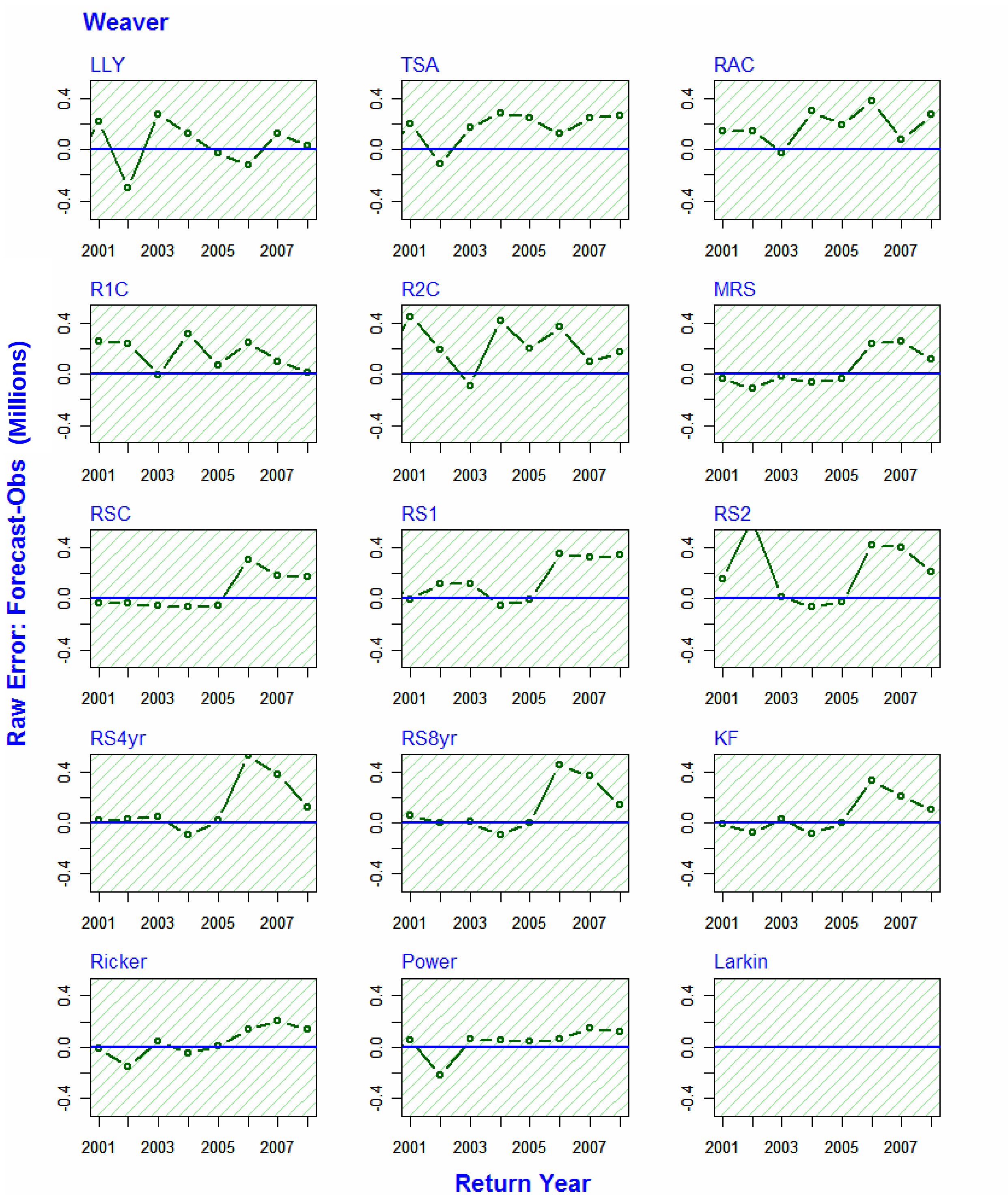
-0.5
-1.5
1980
1990
2000
2010
Raw Error: Forecast-Obs (Millions)
Return Year


Weaver
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R1C
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RS2
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RS8yr
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2005
2007
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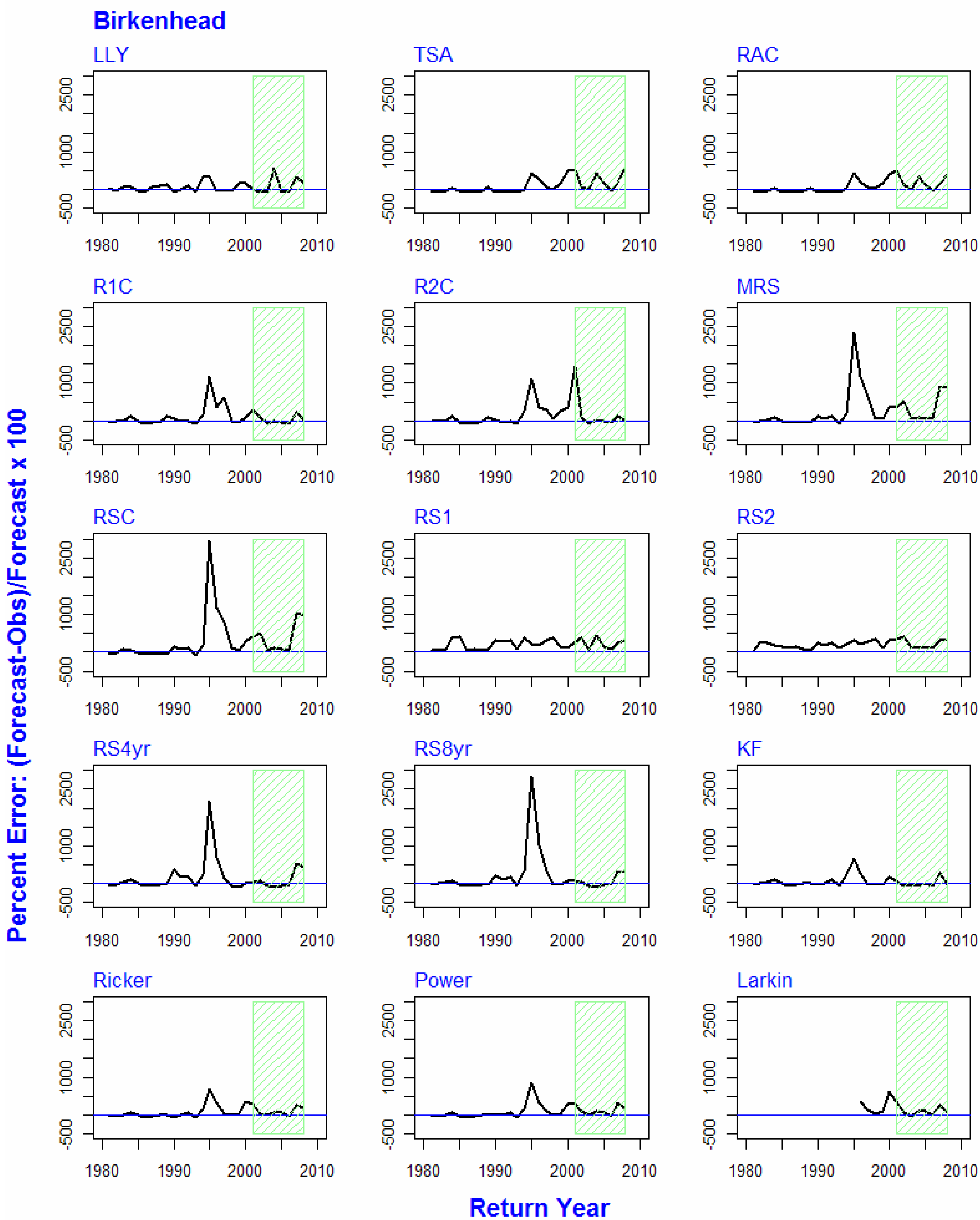
Return Year



Birkenhead
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RS2
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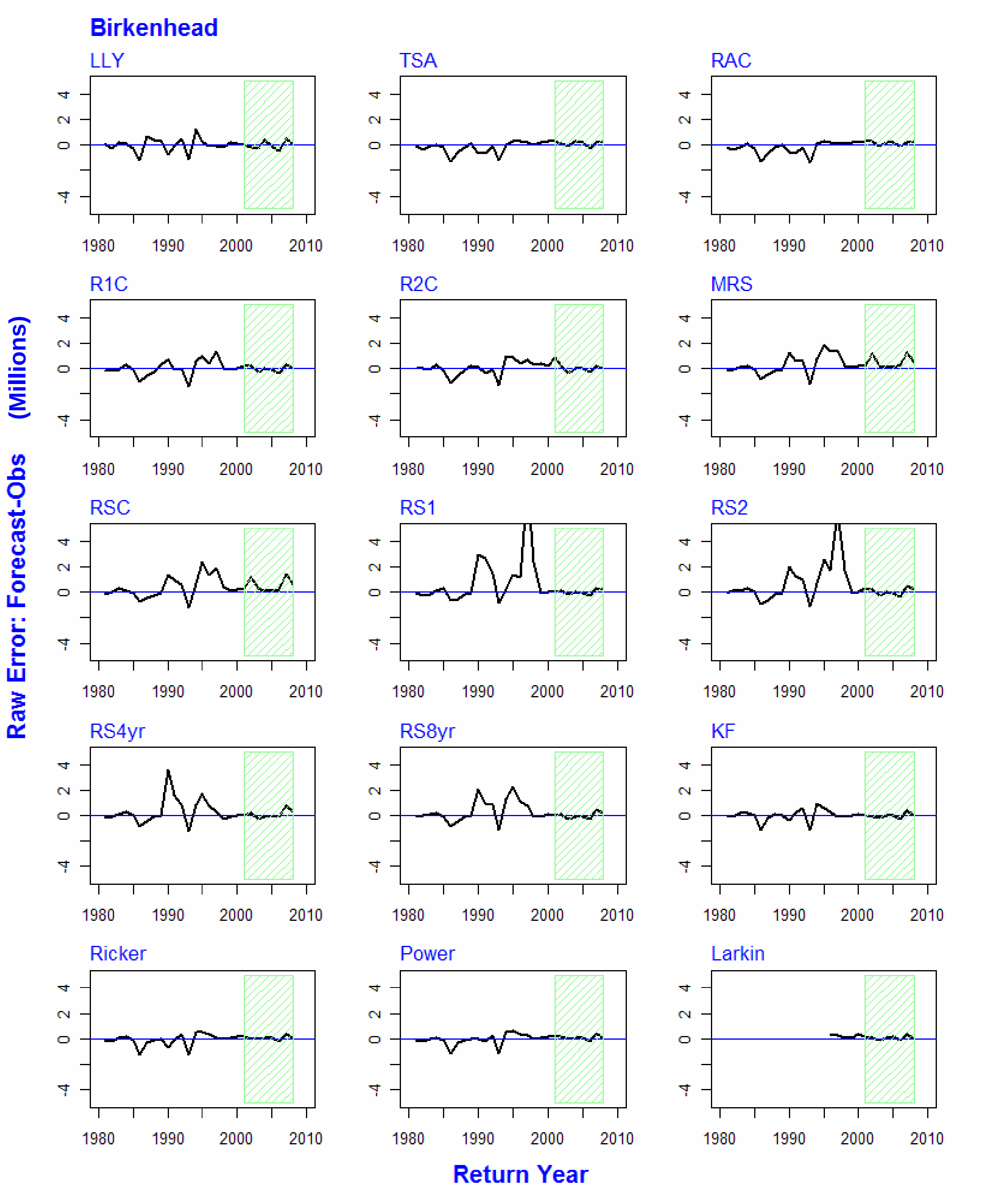
1980
1990
2000
2010
Percent Error: (Forecast-Obs)/Forecast x 100
Return Year


Birkenhead
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RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
Raw Error: Forecast-Obs (Millions)
Return Year
1980
1990
2000
2010
4
2
0
-4


Birkenhead
LLY
TSA
RAC
R1C
R2C
MRS
RSC
RS1
RS2
RS4yr
RS8yr
KF
Ricker
Power
Larkin
Raw Error: Forecast-Obs (Millions)
Return Year

ACKNOWLEDGEMENTS

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