PRE-SEASON RUN SIZE FORECASTS FOR FRASER RIVER SOCKEYE (*ONCORHYNCHUS NERKA*) SALMON IN 2014

Context

Pre-season run size forecasts of returning Fraser River adult Sockeye salmon in 2014 were requested by Fisheries and Oceans Canada (DFO) Fisheries Management. Forecasts are used for pre-season planning purposes and for in-season management. They are most useful early in the migration of each stock-group before in-season test fisheries provide adjustments to the run size estimates. Forecasts are produced by DFO as stipulated in Annex IV, Chapter 4 of the Pacific Salmon Treaty and are presented by stock and run timing group.

To capture inter-annual random (stochastic) uncertainty in Fraser Sockeye returns (largely attributed to variations in stock survival), forecasts are presented as standardized cumulative probabilities (10%, 25%, 50%, 75%, and 90%), rather than as single deterministic point estimates. The 50% (median) probability level is the mid-point of the forecast distribution, indicating a one in two chance that Fraser Sockeye returns will be at or below these values, assuming that stock survival is similar to past observations. A stock's forecast probability distribution represents the range of survivals it has exhibited historically. Forecast values at the lower probability levels represent lower stock survivals and, conversely, values at the higher probability levels represent higher stock survivals. Since not all stocks will exhibit similar survival, the forecast distribution for total Fraser River sockeye salmon will likely over-estimate total returns, particularly at the high probability levels. It is therefore more appropriate to reference individual stock forecast distributions, versus the total Fraser Sockeye forecast.

To capture the structural uncertainty in the forecasts, which refers to uncertainty in the model forms (i.e. Ricker, Power, Larkin, etc.) selected to describe the stock-recruitment relationships, alternative forecasts using different model forms are presented for each stock.

The 2014 forecasts will be particularly uncertain since the exceptional brood year escapements observed in 2010 for particular stocks (Scotch, Seymour, Harrison, Late Shuswap, and Portage stocks) require the extrapolation of forecast models beyond their observed stock-recruitment data range. However, juvenile (fry and smolt) data for various key stocks in the 2010 brood year (Shuswap and Chilko) provide evidence for density-dependent compensation due to the record high spawner abundances. The juvenile data, therefore, provide support for model forms that predict overcompensation at high spawner abundances.

This Science Response resulted from a DFO Canadian Science Advisory Secretariat (CSAS) meeting of contributors (January 2014) on 'pre-season abundance forecasts for Fraser River Sockeye Salmon returns in 2014. The 2014 forecast relies on past CSAS processes and publications (Cass et al. 2006, DFO 2006, 2007, 2009, 2011, 2012, Grant et al. 2010, Grant and MacDonald 2012, MacDonald and Grant 2012).

To support the 2014 Fraser Sockeye forecast an additional CSAS Science Response meeting occurred January 2014 to summarize data on fish condition and/or survival from the 2010 spawners and their offspring.

Background

Fraser Sockeye Forecasts

Pre-season return forecasts are produced annually for 19 Fraser Sockeye stocks and six additional miscellaneous stock groups using a suite of forecast models. To capture inter-annual random (stochastic) uncertainty in Fraser Sockeye returns (largely attributed to variations in stock survival), forecasts are presented as standardized cumulative probabilities (10%, 25%, 50%, 75%, and 90%) using Bayesian statistics for biological models or residual error for non-parametric models (Grant et al. 2010). At the 25% probability level, for example, there is a one in four chance that the actual return will fall at or below the specified return prediction, given the historical data. Fisheries and Oceans Canada (DFO) fisheries managers use these forecast probability distributions to frame out the range of fishing opportunities that stakeholders may expect in the upcoming year. The return forecasts are also applied, in concert with run timing forecasts, as Bayesian priors for in-season run size estimation models using test-fishery and hydro-acoustic data. As the season proceeds, and more in-season data become available, the pre-season forecasts have a diminishing influence on in-season return estimates.

The 2014 Fraser Sockeye forecast follows the same approach as the 2012 forecast (DFO 2012, MacDonald and Grant 2012) and 2013 forecast (DFO 2011, Grant and MacDonald 2012), which were adapted from methods described in earlier forecasts (Cass et al. 2006; DFO 2006; DFO 2007; DFO 2009; Grant et al. 2010). Additionally, model rankings are based on the analyses performed for the 2012 forecast, described in MacDonald & Grant (2012), and summarized in bullets 2-4 below. Key aspects of the 2014 forecast approach include the following:

1) a single forecast scenario (long-term model performance) is presented in Table 1, which includes the most appropriate model for each stock; models are selected based on model performance (forecasts compared to actual returns) over the full stock-recruitment time series (see #2 & #3 below) and on model selection criteria (see #4);
2) model performance (forecasts compared to actual returns) was compared across all applicable candidate models for each stock, excluding the recent-survival models (RS4yr, RS8yr, & KF) introduced in the 2010 forecast (all model forms are described in Appendices 1 to 3 of Grant et al. 2010);
3) jackknife (leave-one-out) cross-validation analysis was used to generate the historical forecast time series for each stock and model (MacDonald and Grant 2012); performance was then measured by comparing forecasts to observed returns across the full time series;
4) four performance measures (mean raw error, mean absolute error, mean proportional error and root mean square error), which assess the accuracy and/or precision of each model, were used to summarize jackknife cross-validation results, and rank models by their performance (performance measures are described in Appendix 4 of Grant et al. 2010);
5) after ranking models by their performance, the model selection process and criteria identified in the 2012 forecast were used to select the 2014 forecast models for each stock (MacDonald and Grant 2012);
6) an additional sensitivity analysis was conducted to examine model performance for each stock over only the most recent period of low survival, which occurred over the 1997 to 2004 brood years (Appendix 1, Table A1).

Historical Fraser Sockeye Returns

Fraser Sockeye adult returns have historically varied, due to the four-year pattern of abundances (cyclic dominance) observed for many stocks, and variability in annual survival (recruits per spawner) (Figure 1 A). In recent years, Fraser Sockeye have exhibited particularly large variations in total adult returns. The 2009 return (1.6 million) and 2010 return (28.3 million) were respectively, amongst the lowest (2009 cycle average: 8.6 million) and highest (2010 cycle average: 13.3 million) returns on record for their cycles since 1952. In subsequent return years (2011 to 2013), Fraser Sockeye survival has generally returned to average, with return abundances influenced largely by brood year escapements. Total returns in 2011 (5.1 million) were very similar to their cycle average (5.3 million), and preliminary returns in 2012 (~2.2 million) and 2013 (3.8 million) were below their cycle averages of, respectively, 3.6 million and 8.6 million (Figure 1 A).

To provide context for the 2014 forecast, the average returns of Fraser Sockeye are presented across all cycles and on the 2014 cycle (Table 1, columns F & G). The 2014 cycle has the largest average return of the four cycles of Fraser River Sockeye, with an average annual return (1954-2010) of 13.3 million for all 19 forecasted stocks combined (excluding miscellaneous stocks). Late Shuswap (Late Run timing) has historically been the main driver of returns on this cycle line, accounting for 58% of the total on average. Chilko and Quesnel have also contributed relatively high proportions to the 2014 cycle average, at 11%, and 8% respectively. Stellako, Weaver, and Birkenhead have each comprised between 4% and 5% of the average return on the 2014 cycle. All remaining stocks have contributed less than 3%.

Fraser Sockeye Survival Trends

In recent decades, total survival (returns-per-spawner) aggregated across all Fraser Sockeye stocks generally declined to the 2009 return year, and subsequently increased to near average values (Figure 1 B). However, individual stock trends vary (Figure 3, Grant et al. 2011, Grant et al. 2010; Peterman and Dorner, 2012), and specific stocks have displayed below average, average, and above average productivity in recent years (see text below). Most notably, Harrison Sockeye have experienced a large increase in survival in recent years (Grant et al. 2010, Grant et al. 2011); Harrison Sockeye have a unique age-structure and life-history compared to all other stocks.

Considerable mortality and inter-annual variability in mortality occur in the freshwater and marine ecosystems, as indicated by freshwater and marine survival data for Chilko River Sockeye (Fraser Sockeye indicator stock) (Figure 2 A & B). Chilko is the only Fraser Sockeye stock with a long and complete time series of smolt data (counted through an enumeration weir located at the outlet of Chilko Lake), which can be used with escapement and return data to partition total survival into freshwater and 'marine' components ('marine' survival includes their migration downstream from the counting weir to the Strait of Georgia). It is likely that a number of factors in both the freshwater and marine environments influence Fraser Sockeye survival, and these factors may vary between stocks and years.

Smolt data are not available for most stocks; therefore, only total survival can be estimated (recruits-per-spawner). For most Fraser Sockeye stocks, declining survival trends culminated in some of the lowest survivals on record in the 2005 brood year (2009 return year) (Figure 3), including Harrison (which has otherwise increased in survival in recent years). Subsequently, survival appears to have improved for most stocks in the 2006 to 2008 brood years (2010 to 2012 return years for most of these Sockeye) (Figures 3 & 4).

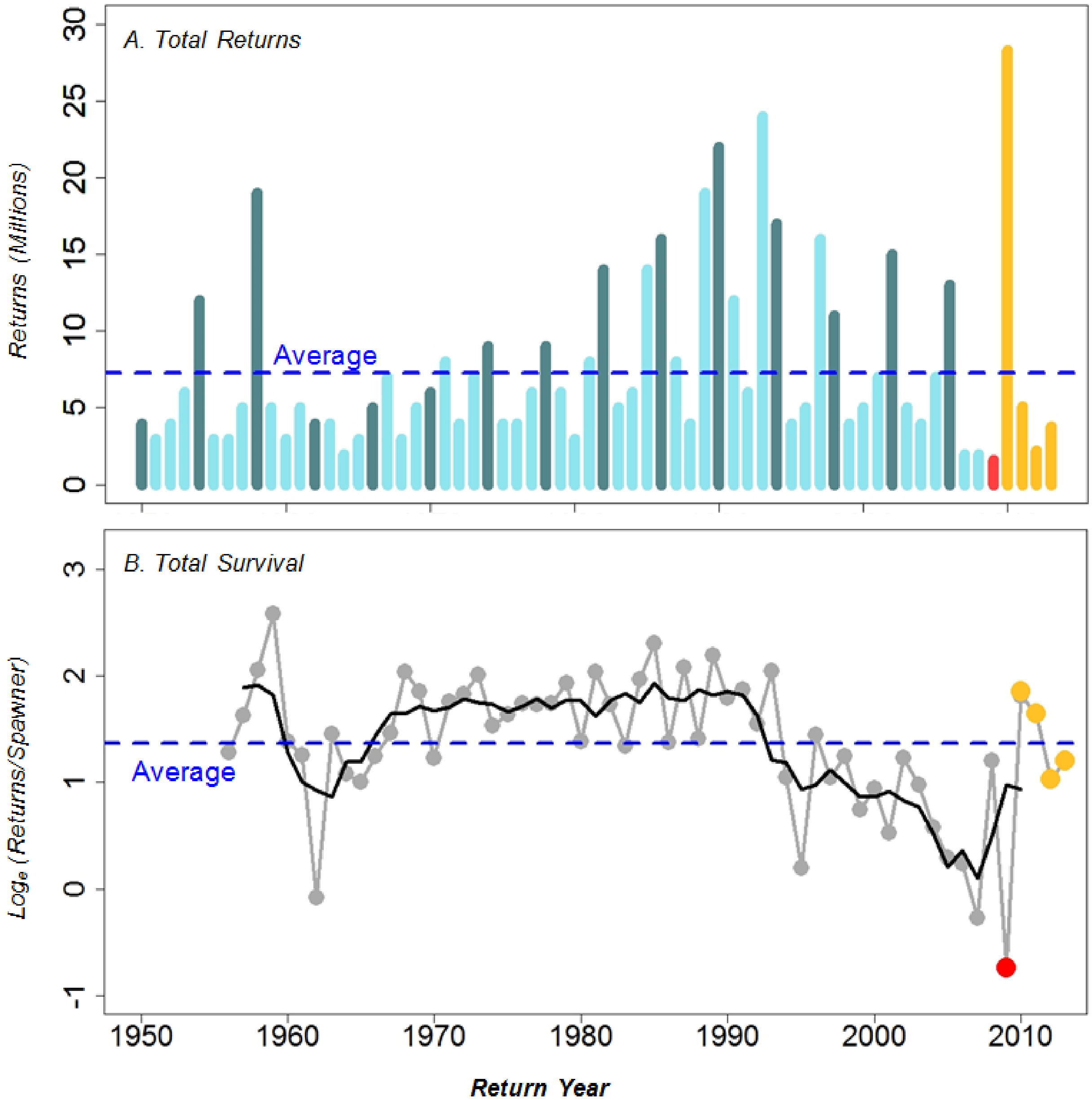

Figure 1. A. Total Fraser Sockeye annual returns (dark blue vertical bars for the 2014 cycle and light blue vertical bars for the three other cycles). All returns from 2009 to 2013 are preliminary. B. Total Fraser Sockeye survival (loge (returns/total spawner)) up to the 2013 return year. The light grey filled circles and lines present annual survival and the black line presents the smoothed four year running average. For both figures, the blue dashed line is the time series average. The red vertical bar in Figure A (or filled circles in B) represents the 2009 returns (low survival), and the yellow vertical bars in Figure A (or filled circles in B) represents the 2010 to 2013 returns (average survival for the Fraser Sockeye aggregate).

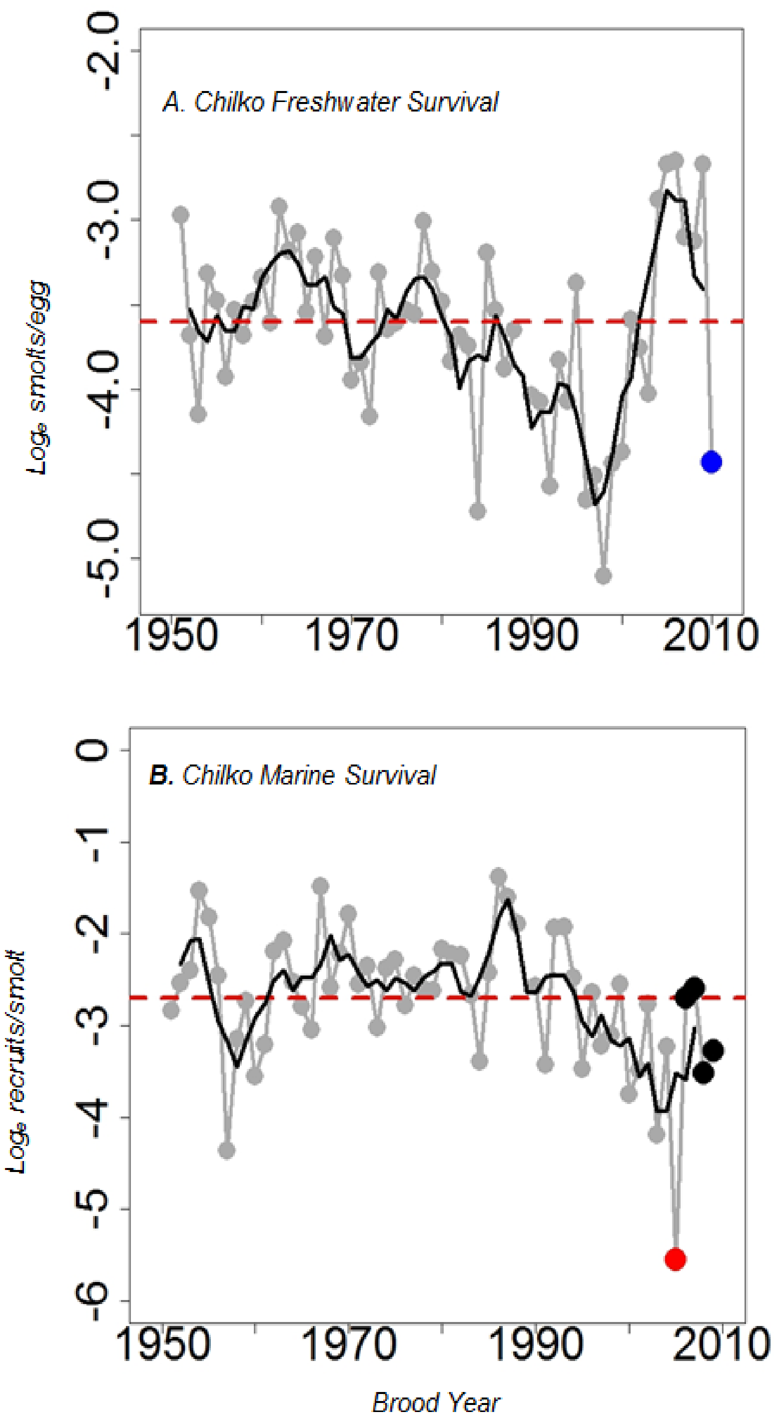

Figure 2. Chilko River Sockeye A. annual freshwater (log_e smolts-per-egg) survival (filled grey circles and lines) with the 2010 brood year survival indicated by the blue filled circle and B. annual marine (log_e recruit-per-smolt) survival (filled grey circles and lines) with the 2005 brood year survival indicated by the red filled circle. The black line in both figures represents the smoothed four-year running average survival and the red dashed lines indicate average survival. Black filled circles denote preliminary survival estimates for the 2006-2009 brood years.

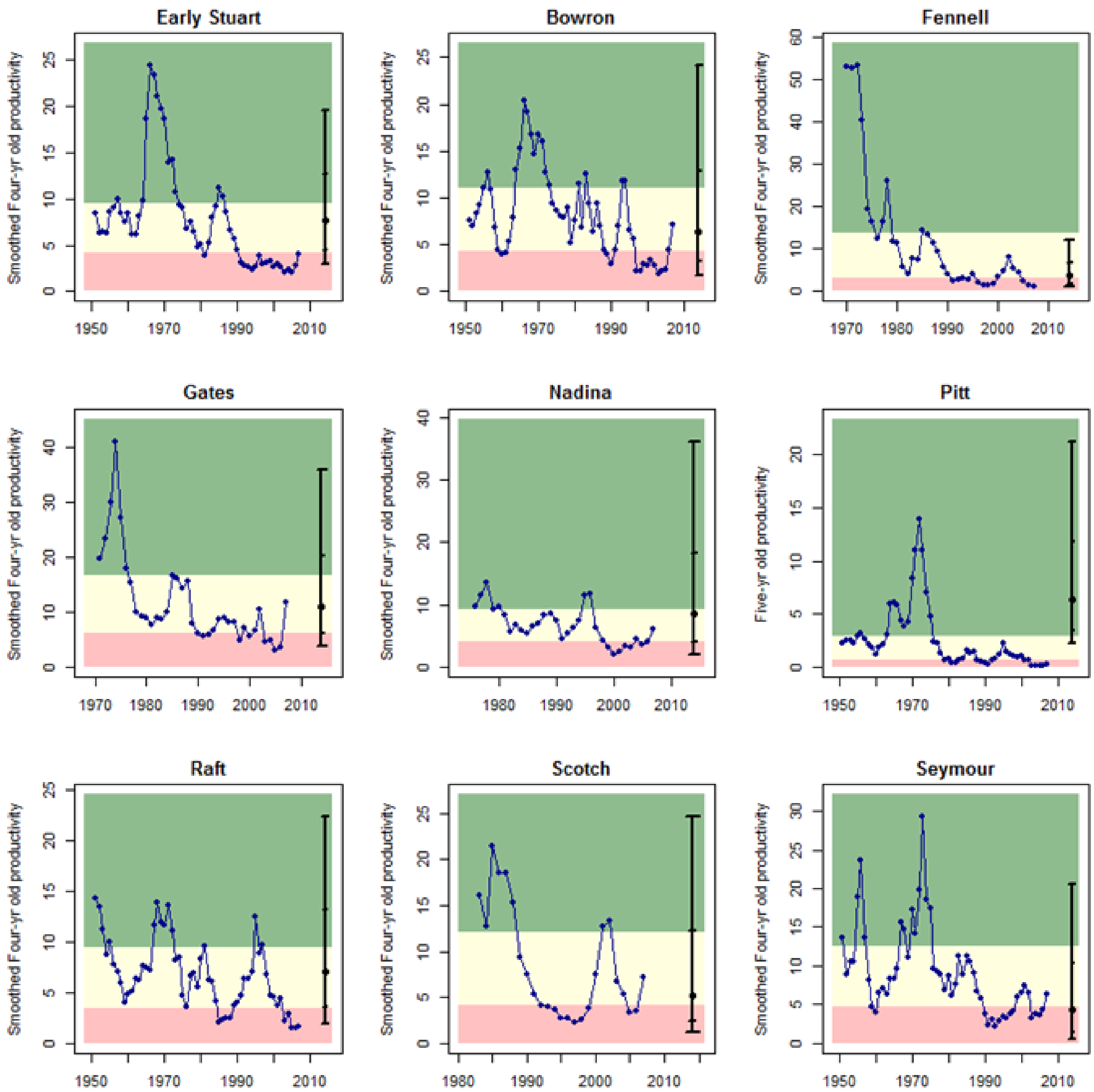

Figure 3. Blue lines present each stock's smoothed four year old survival (four year running geometric mean) using data from the beginning of the time series to the 2007 brood year. For Pitt, five-year old survival is used (up to 2006 brood year). For Quesnel and Late Shuswap, survival on the 2014 cycle-line is presented (not smoothed geometric mean). For Chilko and Cultus, recruits-per-smolt are used. Black bars indicate the range of survivals associated with the 2014 forecasts, at the 10% (lower horizontal bar), 25%, 50% (black filled circle), 75%, and 90% (upper horizontal bars) probability levels. Colours (Red, Amber, Green) show where the productivities fall out in terms of the long-term geometric average (+/- 0.5 standard deviation): Red (< average), yellow (average) and green (>average).*

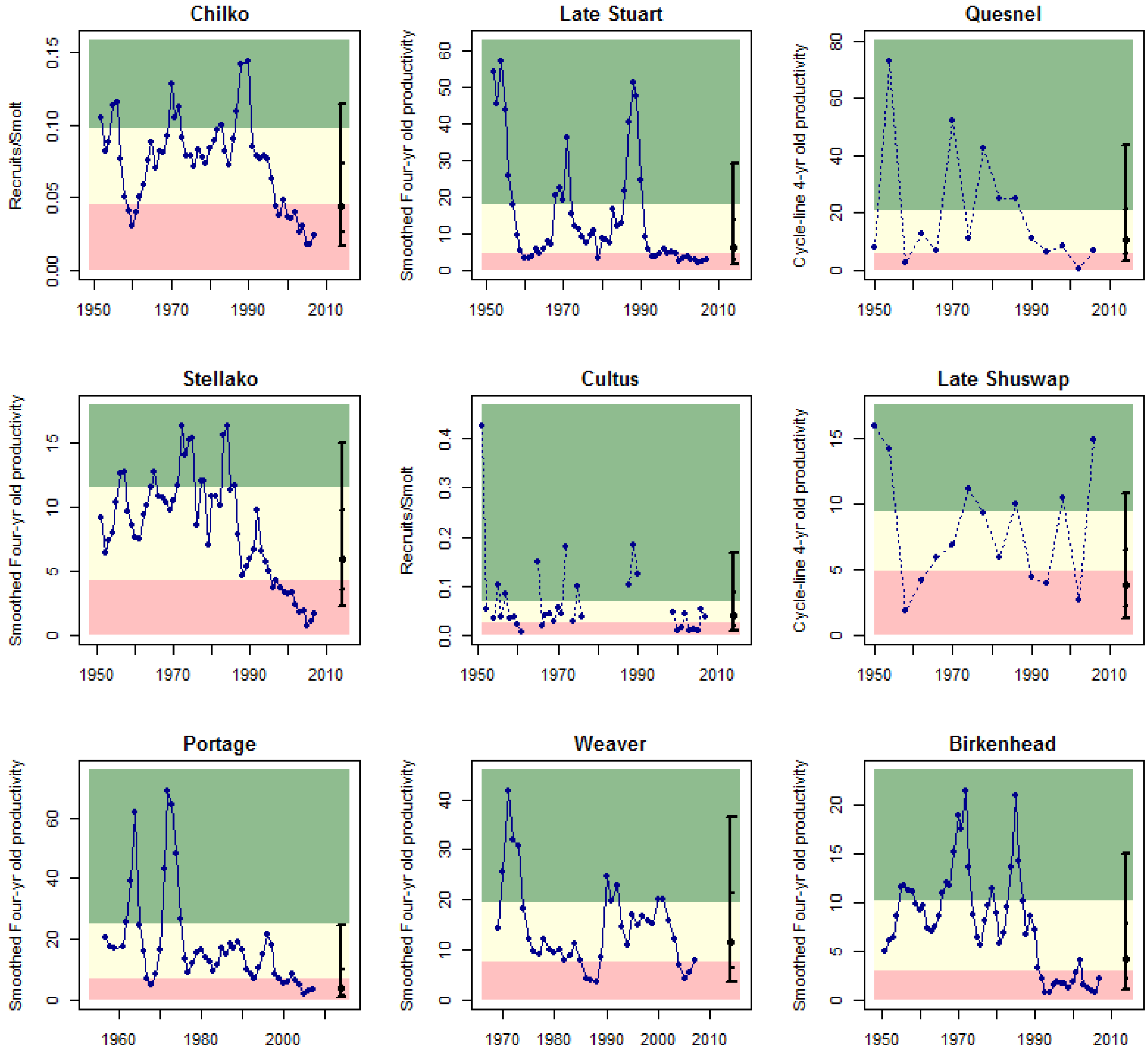

Figure 3 Continued. Blue lines present each stock's smoothed four year old survival (four year running geometric mean) using data from the beginning of the time series to the 2007 brood year. For Pitt, five-year old survival is used (up to 2006 brood year). For Quesnel and Late Shuswap, survival on the 2014 cycle-line is presented (not smoothed geometric mean). For Chilko and Cultus, recruits-per-smolt are used. Black bars indicate the range of survivals associated with the 2014 forecasts, at the 10% (lower horizontal bar), 25%, 50% (black filled circle), 75%, and 90% (upper horizontal bars) probability levels. Colours (Red, Amber, Green) show where the productivities fall out in terms of the long-term geometric average (+/- 0.5 standard deviation): Red (< average), yellow (average) and green (>average).*

2009 Forecast and Returns

Run timing group Stocks	Probability that Return will be at/or Below Specified Run Size [a]				
	10%	25%	50%	75%	90%
Early Stuart	107,000	165,000	255,000	426,000	645,000
Early Summer	264,000	443,000	739,000	1,338,000	2,284,000
Summer	2,858,000	4,914,000	8,677,000	16,071,000	31,813,000
Late (excl Harrison)	294,000	471,000	838,000	1,456,000	2,502,000
(Harrison Only)	33,000	46,000	69,000	160,000	373,00
TOTAL	**4,567,000**	**7,028,000**	**11,439,000**	**18,315,000**	**29,827,000**

2010 Forecast and Preliminary Returns

Run timing group Stocks	Probability that Return will be at/or Below Specified Run Size [a]				
	10%	25%	50%	75%	90%
Early Stuart	55,000	85,000	135,000	213,000	315,000
Early Summer	387,000	723,000	1,518,00	3,544,000	7,993,000
Summer	1,434,000	2,304,000	3,972,00	6,981,000	11,875,000
Late (excl Harrison)	3,434,000	5,146,000	8,102,000	12,074,00	18,818,000
(Harrison Only)	50,000	93,000	262,000	729,00	1,923,000
TOTAL	**4,567,000**	**7,028,000**	**11,439,000**	**18,315,000**	**29,827,000**

2011 Forecast and Preliminary Returns

Run timing group Stocks	Probability that Return will be at/or Below Specified Run Size [a]				
	10%	25%	50%	75%	90%
Early Stuart	21,00	30,000	47,000	71,000	100,000
Early Summer	164,000	284,000	518,00	958,000	1,785,000
Summer	1,067,00	1,598,000	2,464,000	4,138,000	6,579,000
Late (excl Harrison)	411,000	682,000	1,218,000	2,247,000	3,985,000
(Harrison Only)	37,000	99,000	380,00	1,660,000	2,637,000
TOTAL	**1,700,000**	**2,693,000**	**4,627,000**	**9,074,000**	**15,086,000**

2012 Forecast and Preliminary Returns

Run timing group Stocks	Probability that Return will be at/or Below Specified Run Size [a]				
	10%	25%	50%	75%	90%
Early Stuart	39,000	61,000	99,000	161,0	270,000
Early Summer	109,000	195,000	359,00	665,000	1,214,000
Summer	529,000	828,00	1,420,000	2,449,000	4,160,000
Late (excl Harrison)	46,000	80,000	158,00	304,000	589,000
(Harrison Only)	20,000	39,000	83,00	184,000	401,000
TOTAL	**595,000**	**939,000**	**1,670,000**	**3,194,000**	**5,867,000**

2013 Forecast and Preliminary Returns

Run timing group Stocks	Probability that Return will be at/or Below Specified Run Size [a]				
	10%	25%	50%	75%	90%
Early Stuart	92,000	137,00	211,000	331,000	507,000
Early Summer	73,000	130,000	253,000	468,00	844,000
Summer (exl. Harrison)	1,210,000	2,064,00	3,636,000	6,458,000	11,662,000
(Harrison Only)	12,000	31,000	82,000	205,00	469,000
Late	167,000	293,000	583,00	1,133,000	2,126,000
TOTAL	**595,000**	**939,000**	**1,670,000**	**3,194,000**	**5,867,000**

Figure 4. Return versus long-term model performance scenario forecasts from 2009 to 2013 (note: 2012 is the only year when the forecast used recent (low) survival models for some stocks, including Bowron, Gates, Pitt, Chilko, Harrison, and Cultus). Actual returns are indicated by the coloured circles: red: returns are associated with below average stock survivals (below the 25% probability level forecasts); yellow: returns are associated with average stock survivals (returns falling between the 25% to 75% probability level forecasts); and green: returns are associated with above average stock survivals (above the 75 % probability level forecasts).

Analysis and Response

Fraser Sockeye Forecasts

The methods used for the 2014 forecast follow those reviewed for the 2012 and 2013 Fraser Sockeye forecasts (Grant & MacDonald 2012; MacDonald & Grant 2012). Biological and environmental data, and biological and non-parametric models are identical to those presented in the 2012 (MacDonald & Grant 2012) and 2013 (Grant & MacDonald 2012) forecasts. Additionally, model ranks for the 2014 forecast are based on the cross-validation analysis performed for the 2012 forecast (DFO 2012, MacDonald and Grant 2012). Similar to the 2013 forecast, three model forms (RS4yr, RS8yr and KF) introduced in the 2010 forecast were excluded from the 2014 forecast, as the currently available survival data do not capture the past three years of improved survival (recruitment data from 2011 to 2013 is not yet available).

Escapement and wild smolt (Cultus and Chilko) data were provided by DFO Fraser Stock Assessment (K. Brenner, pers. comm), channel fry data (Nadina and Weaver) were provided by DFO Oceans, Habitat & Enhancement Branch (D. Willis, pers. comm), Cultus hatchery smolt numbers (released downstream of the Sweltzer Creek enumeration fence) were obtained by DFO Oceans, Habitat and Enhancement Branch (C. McLean, pers. comm.) and recruitment data were provided by the Pacific Salmon Commission (PSC).

The last brood year for which full recruitment data (four and five year olds) are available for the 2014 forecast is 2006, with the exception of Harrison Sockeye, which, given its unique age structure, has recruitment data available to the 2007 brood year. Shuswap (fall fry) juvenile data are only available for the 2010 brood year (four year old returns in 2014); therefore only four year old return forecasts could be produced using juvenile data for Shuswap stocks. In contrast, Quensel (fall fry) juvenile data are available for both the 2010 brood year (four year old returns in 2014) and 2009 brood year (five year old returns in 2014); therefore total return forecasts (age 4 plus age 5 returns) could be produced using juvenile data for Quesnel. For both Late Shuswap and Quesnel, fry assessments are conducted sporadically (large gaps in the fry time series) and, as a result, the performance of fry models was not evaluated in the 2012 cross-validation analysis (Table 5 in MacDonald and Grant, 2012).

For the 2014 forecasts, biological model fit was re-examined for each of the top three ranked models by stock to ensure successful convergence of two separate Bayesian runs (each run was started using different initial parameter values). Though model convergence cannot be concretely demonstrated, diagnostics can be used to indicate if convergence has not occurred (Toft et al. 2007). Specifically, four diagnostics (trace plots, Gelman-Rubin diagnostics, Geweke values, and MC Error) were used to confirm that Monte-Carlo Markov-Chains (MCMC) exhibited the three stages of convergence: exploration, stationarity, and estimation (Mengersen et al. 1999) as described by Dodds and Vicini (2004). Exploration involved the visual confirmation that trace plots of the two MCMC chains effectively mixed. Further, the Gelman-Rubin diagnostic (modified by Brooks and Gelman), which compares the within-chain to the between-chain variance (Cowles & Carlin 1996), was considered acceptable as long as values were less than 1.1. To test for stationarity, Geweke's convergence diagnostic provides Z-scores for each parameter by comparing the first 10% of the MCMC chain to the last 50%. Z-scores below -2.5 and above +2.5 were determined significant, which indicates that chains were not stationary and therefore had not converged. In all cases where models did not satisfy these three convergence criteria, the burn-in was increased in size until they were satisfied, to a maximum of 100,000 iterations (default 20,000 iterations).

Finally, to evaluate the estimation component of convergence, the Markov Chain standard error (MC Error) was used to measure how well the mean estimate of the posterior sample represents the true value of the parameter (Toft et al. 2007). The general rule requires that the MC error be less that 5% of the sample standard deviation when the posterior sample size is sufficient (Toft et al. 2007). For models that did not satisfy the MC Error criteria, the size of the posterior sample was increased until this criterion was satisfied.

The final model selected for each stock for the 2014 forecast (presented in Tables 1 - 3) is based on a combination of their relative ranks and a set of consistent selection criteria (see MacDonald and Grant 2012). Although Bayesian diagnostics were conducted with the intention to discard models that did not converge within the 100,000 iteration burn-in limit, this did not occur for models explored for the 2014 forecast; all models converged.

Miscellaneous stocks, for which recruitment data are unavailable, were forecast using the product of their brood year escapements and the average survival (across the entire available time-series) for spatially and temporally similar stocks with stock recruitment data (index stocks) (see Appendix 1 of Grant et al. 2010, as identified in Table 1).

Overview of the 2014 Fraser Sockeye Returns

Fraser Sockeye forecasts are associated with relatively high uncertainty, in large part due to wide variability in annual salmon survival (recruits-per-spawner), and observation error in the stock-recruitment data. High forecast uncertainty is consistent with previous Fraser Sockeye forecasts (Cass et al. 2006, DFO 2006, 2007, 2009, 2011, 2012, Grant et al. 2010, Grant and MacDonald 2012, MacDonald and Grant 2012) and recent research conducted on coast-wide salmon stocks (Haeseker et al. 2007; Haeseker et al. 2008).

The 2014 Fraser Sockeye return forecasts are associated with additional uncertainty due to the record (high) 2010 brood year escapements for a number of stocks (Scotch, Seymour, Harrison, Late Shuswap and Portage). As a result, the 2014 return forecasts produced by biological spawner-recruit models are extrapolated beyond the range of fitted escapement values, thereby increasing their uncertainty. For Harrison Sockeye, the escapement in the 2011 brood year (3-year old returns) was also well above any escapement observed previously with exception of 2010. This, in addition to the high annual variability in Harrison Sockeye age proportions, makes the Harrison forecast for 2014 particularly uncertain. The large escapements observed for a number of stocks in the 2010 (and 2011 for Harrison) brood year can lead to two forms of uncertainty. First, the precision of forecasts from all models decreases when input variables (in this case escapements) vary from average values; the greater the deviation from average, the larger the variation associated with the forecast. Second, the form of the stock-recruit model at extremely large values is poorly known (e.g. the amount that recruitment may decline at extreme escapements) because there are few observations of outcomes from these extreme values. Thus the model predictions at these extreme levels may be biased and misleading (e.g. Ricker model predictions for Harrison Sockeye; see Table 5). To guard against potential biases associated with the lack of observations at high escapements, juvenile data were used where available to provide alternative forecast estimates, and results were compared with those obtained from escapement data. Fortunately, inferences from juvenile data are available for the stocks contributing most of the 2014 forecast abundance (i.e. Scotch, Seymour, miscellaneous Early Shuswap, Chilko, and Late Shuswap).

Given the absence of leading quantitative or qualitative indicators of Fraser Sockeye survival, stochastic (random) uncertainties associated annual variation in survival are presented as a series of forecasted values that correspond to standardized cumulative probabilities (10%, 25%, 50%, 75%, and 90%). The 50% (median) probability level is the mid-point of the forecast distribution, indicating a one in two chance that Fraser Sockeye returns will be at or below these values, assuming that stock survival is similar to past observations. Forecast distributions represent the range of survivals Fraser Sockeye stocks have exhibited historically. Forecasts at the 10% probability level (Table 1, column H) represent lower survivals within the time series (Table 2, column F), and at the opposite end of the probability distribution (Table 1, column L), forecasts represent higher survivals within the time series (Table 2, column J). For example, if the low survival period that most stocks experienced from the 1990's up to the 2005 brood year resumes, returns in 2014 could fall at the bottom end of the forecast distributions (Table 1). Although these forecast distributions bracket a wide range of potential returns, they may not capture extreme survival events such as occurred with the 2005 brood year (2009 return).

It is more appropriate to reference individual stock forecast distributions (Table 1), versus the total Fraser Sockeye forecast presented, since not all stocks will exhibit the same survival. Therefore, the total forecast distribution (from 7,237,000 to 72,014,000 at the 10% to 90% probability levels) will likely under-estimate or over-estimate total returns at the, respectively, low and high probability levels. The mid-point of the total forecast distribution (50% probability) is 22,854,000 (there exists a one in two chance the return will be at or below this value). The four year old proportion of the total forecast is 95% (ranges from 23% (Pitt) to 100%, depending on the stock) (Table 3). Similar to the 2013 forecast, Raft, Harrison, and the miscellaneous stocks of the North Thompson River and its tributaries are included as part of the Summer Run timing group, consistent with their reassignment following a re-evaluation of the migration timing of these stocks.

At the 50% probability level, Late Shuswap is the single largest contributor to the 2014 forecast, making up 52% of the total return forecast. This forecast is particularly uncertain given the exceptional escapement in the 2010 brood year, which required that the forecast model be extrapolated beyond the observed data range. However, juvenile data available for this stock support the overcompensation (density-dependence) described by the Ricker-cyc model used for this stock's forecast. Overall the Late Run comprises 56% of the 2014 forecast, while the Summer Run (25%), the Early Summer Run (18%), and the Early Stuart Run (1%) make up the remainder (Table 1). There is close to a three in four chance that the total return will fall close to or above the cycle average (13.5 million). This is attributed to the large brood year escapements observed in 2010 for a number of stocks, particularly those that contribute the largest proportion to total returns (i.e. Shuswap stocks). There is, however, a one in four chance (25% probability level and below) that the total return will fall below the cycle average if Fraser Sockeye survival falls at the low end of past observations.

A separate sensitivity analysis was conducted to evaluate model performance over the recent period of lower survival (1997 to 2005 brood year) (Table A1). In this scenario, recent survival models that cover this low survival period were added to the standard suite used to forecast the 2014 returns (Kalman Filter; RS4yr; RS8yr) (Grant et al. 2011; MacDonald & Grant 2012). Top ranked models were then selected, based on their performance (returns versus forecasts) in the recent low survival period (1997-2004). Despite the inclusion of recent survival models, this scenario (Table A1) does not differ considerably from the forecast (Table 1, Table A1), although it does produce much wider probability distributions, particularly for Scotch and Late Shuswap.

An additional CSAS Special Response was developed to provide context for the 2014 forecasts (DFO 2014). The proportion of each forecasted stock relative to the total forecast is dominated by the following stocks: Late Shuswap: 51%; Early Shuswap: 16%; Chilko: 11%; Quesnel: 7%; Stellako: 3% and Harrison 2%. These proportions are supported by stock proportions observed in the 2012 downstream Sockeye smolt assessments at Mission, B.C. (smolts from the 2010 brood year), and the 2012 juvenile surveys in the Strait of Georgia and Queen Charlotte Sound (DFO 2014). Other information evaluated in this second CSAS SR (DFO 2014) includes adult fish condition in the 2010 brood year and subsequent fry and smolt condition in the 2012 smolt year, environmental conditions during spawning in the 2010 brood year, Strait of Georgia (the

2012 CPUE is the highest observed on record) and Queen Charlotte Sound CPUE, Herring surveys (Herring CPUE in the SOG relative to Chilko marine survival), and jack information.

Individual Stock Forecasts

Early Stuart Run (Takla-Trembleur-Early Stuart CU)

The 2010 brood year EFS for the Early Stuart stock (34,200) was the second largest on record for this cycle (the 1990 brood year was largest on record at 47,000), and almost double the average (2010 cycle average 1950-2006: 17,400) (Table 1, column C). The 2010 escapement estimate, however, is associated with reduced accuracy (likely biased low) and precision, for two key reasons. First, due to security-related concerns in the area, a modified assessment of the Early Stuart Sockeye escapement was implemented in 2010, where, although most sites were visually assessed, survey effort (number of site visits) was reduced, and a large number (~50%) of streams were assessed visually using aerial methods (as opposed to ground methods typically used). Reduced survey effort could result in a biased escapement estimate if surveys were not conducted during peak spawning. Additionally, aerial methods generally result in lower Sockeye counts relative to the ground methods typically used, which, given that expansion factors are based on ground counts, can result in a negative bias to the estimate. The second factor contributing to a possible negatively biased escapement estimate is that Gluske Creek was not assessed in 2010, and this stream typically contributes ~10% to the total system. Overall, the bias in Early Stuart was approximately 25% (K. Benner, DFO, pers. comm.).

Water temperatures on the spawning grounds were within an acceptable range for successful spawning during the 2010 Early Stuart spawning season. However, access to many streams was restricted or limited due to low water levels and/or beaver activity. Sockeye on the spawning grounds were reported to be in good condition, with no evidence of migration difficulties. Spawning success in 2010 was 92% for Early Stuart (time series average: 89%).

Average four year old survival (age-4 R/EFS) for Early Stuart Sockeye declined from a peak of 24.5 R/EFS in the mid-1960 brood years (four year consecutive peak average) to one of the lowest survivals on record (1.5 R/EFS) in the 2005 brood year (i.e. 2009 four year old return year) (Table 2, columns B to E; Figures 3 & 4). In recent years (2006 and 2007 brood years), survival (5.2 R/EFS) has been closer to the long-term average (6.3 R/EFS).

For Early Stuart, the top ranked models (based on the average rank across all four performance measures: MRE, MAE, MPE, RMSE) are the Ricker (Ei) (tied first), Ricker (Pi) (tied first), Ricker (tied third), and Ricker (PDO) (tied third) (Table 5). For each individual performance measure, these models each ranked within the top 50% (10 out of 20) of all models compared for this stock (see Table 5 in MacDonald & Grant 2012). Forecasts produced by the top ranked models were similar, with the smallest forecast (Ricker) deviating by 23% from the largest forecast (Ricker (Ei)) (percent difference between smallest and largest forecasts at the 50%-median probability level, calculated as a percentage of the largest forecast) (Table 5). The Ricker (Ei) model was used for the 2014 Early Stuart forecast, as it ranked first on average across performance measures, and it outperformed the other first-ranked model (Ricker (Pi)) on two of the four individual performance measures (and tied on one) (Table 5 in MacDonald & Grant, 2012). Given the assumptions underlying the Ricker (Ei) model, there is a one in four chance (25% probability) the Early Stuart Sockeye return will be below 189,000 (4.5 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 476,000 (12.7 age-4 R/EFS) in 2014. The median (one in two chance: 50% probability) forecast of 299,000 (7.7 age-4 R/EFS) is more than twice the average return on this cycle (126,000) (Tables 1 & 2; Figure 3). The five year old component of the 2014 return is expected to contribute 12% of the total forecasted return (at the 50% probability level) (Table 3).

For each of the subsequent stock-specific sections, the following was consistently applied: top ranked model forecasts were compared according to the percent difference between smallest and largest forecasts at the 50%-median probability level (calculated as a percentage of the largest forecast); unless otherwise noted, in all subsequent sections the top three models (ranked according to their average rank across all performance measures) each ranked within the top half of all models compared for the stock on each of the four performance measures evaluated individually.

Early Summer Run

The Early Summer Run consists of a number of less abundant stocks relative to the more abundant Summer and Late Run stock groups. Seven stocks in this timing group are forecast using the standard suite of forecast models: Bowron, Fennell, Gates, Nadina, Pitt, Scotch, and Seymour (Table 1). In 2012, the Fraser River Panel re-assigned Raft River, the North Thompson mainstem and several stocks associated with miscellaneous streams that are tributary to the North Thompson River to the Summer Run timing group (from the Early Summer-run group), following a re-evaluation of their migration timing. Thus, these reassigned stocks are excluded from the Early Summer-run data and forecasts in this section. Escapement in the 2010 brood year for all Early Summer stocks combined, excluding miscellaneous stocks, was 598,000 EFS (dominated by Scotch and Seymour, which comprise 94% of this total). This is the largest escapement on record for this run timing group, and is more than eight times the long term cycle average of 70,000 EFS.

All of the Early Summer stocks, with the exception of Pitt, had 2010 brood year escapements (EFS) that were higher than their cycle averages. For some stocks, the 2010 escapements were the highest on record for the 2010 cycle (Nadina & Gates), or across all cycle years (Scotch & Seymour). Pitt Sockeye, which are comprised of predominantly five year old recruits, had average brood year escapements for both the 2009 and 2010 brood years (all cycle average 1948-2009: 13,900). The total 2010 brood year EFS for the Early Summer Run, including the miscellaneous stocks (miscellaneous South Thompson & Taseko, Dolly Varden/Chilliwack Lake, and Nahatlatch) was 722,000.

Physical conditions on the majority of spawning grounds were normal for most of the Early Summer spawning period. Nadina experienced warm water in the early portion of the spawning period, and high water towards the end of spawning; Nahatlatch experienced high water; and Seymour, Anstey, Eagle and Perry experienced extremely high water levels, debris loading and heavy sediment due to a snow on rain event towards the end of the spawning period. Arrival and spawning timing were normal for most stocks. Exceptions included Nadina, which had an early, protracted arrival, and Dolly Varden, which also arrived early. Elevated levels of pre-spawn mortality were observed particularly in Gates Creek and the Nadina spawning channel. Spawning success for the Early Summer aggregate in 2010 was 88% (time series average for the Early Summer aggregate: 89%).

Bowron (Bowron-ES CU)

The 2010 brood year escapement for Bowron (4,400 EFS) was larger than the long-term cycle average (1950-2006 average: 3,000 EFS) (Table 1, column C).

Average four year old survival (R/EFS) for Bowron Sockeye declined from a peak of 20.4 R/EFS in the mid-1960 brood years (four year average at peak) to one of the lowest survivals on record (2.2 R/EFS) in the 2005 brood year (i.e. 2009 four year old return year) (Table 2, columns B to

E; Figures 3 & 4). In recent years (2006 and 2007 brood years), survival (13.4 R/EFS) has been above average (6.9 R/EFS).

For Bowron, the top ranked models are MRS, Ricker (Pi), and Ricker (Ei) (Table 5). Forecasts produced by the top ranked models varied by 17% (Table 5), with the MRS model producing a slightly lower forecast than the two Ricker-environmental covariate models. The MRS model was used for the 2014 Bowron forecast, as it ranked first on average across performance measures, and it ranked well on each individual performance measure (Table 5 in MacDonald & Grant 2012). Given the assumptions underlying the MRS model, there is a one in four chance (25% probability) the Bowron Sockeye return will be below 15,000 (3.2 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 60,000 (12.9 age-4 R/EFS) in 2014. The median (one in two chance: 50% probability) forecast of 30,000 (6.4 age-4 R/EFS) is similar to the average return on this cycle (26,000) (Tables 1 & 2; Figure 3). The five year old component of the 2014 return is expected to contribute 7% of the total forecasted return (at the 50% probability level) (Table 3).

Fennell (North Barriere-ES (de novo) CU)

The 2010 brood year escapement for Fennell (5,500 EFS) was much larger than the cycle average (3,200 EFS) from 1970 to 2006 (Table 1, column C).

Average four year old survival (R/EFS) for Fennell Sockeye declined from a peak of 53.5 R/EFS in the early 1970's brood years (four year average at peak) to one of the lowest survivals on record (0.3 R/EFS) in the 2005 brood year (i.e. 2009 four year old return year) (Table 2, columns B to E; Figure 3). In recent years (2006 and 2007 brood years), survival (1.3 R/EFS) has remained below average (6.9 R/EFS).

For Fennell, the top ranked models are the power, RAC, and Ricker models (Table 5). Since the brood year escapement for Fennell was above average, only top ranked models that use brood year escapement as a predictor variable were considered to generate the 2014 forecast. The power model was used for the 2014 Fennell forecast, as it ranked first on average across performance measures, and it ranked as well as, or better than other top ranked models on each individual performance measure except MAE (ranked third) (Table 5 in MacDonald & Grant 2012). Forecasts produced by the top ranked biological models (power & Ricker) varied by 25% (Table 5). Given the assumptions underlying the power model, there is a one in four chance (25% probability) the Fennell Sockeye return will be below 13,000 (1.9 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 41,000 (6.7 age-4 R/EFS) in 2014. The median (one in two chance: 50% probability) forecast of 24,000 (3.7 age-4 R/EFS) is slightly larger than the average return on this cycle (20,000) (Tables 1 & 2; Figure 3). The five year old component of the 2014 return is expected to contribute 17% of the total forecasted return (at the 50% probability level) (Table 3).

Gates (Anderson-Seton-ES CU)

The 2010 brood year escapement for Gates (5,900 EFS) was more than four times larger than the cycle average (1,300 EFS) from 1970 to 2006 (Table 1, column C). Spawning success in 2010 was 67% (time-series average: 74%). Gates juvenile data are not used in the forecast process due to inconsistencies in data collection methods over time.

Average four year old survival (R/EFS) for Gates Sockeye declined steadily from a peak of 41.0 R/EFS in the early-1970 brood years (four year average at peak) to one of the lowest survivals on record (1.6 R/EFS) in the 2005 brood year (i.e. 2009 four year old return year) (Table 2, columns B to E; Figure 3). In recent years (2006 and 2007 brood years), survival (41.0 R/EFS) has been identical to the record high survival period in the early-1970 brood years and well above average (9.6 R/EFS).

For Gates, the top ranked models are the RAC, R2C, Larkin (tied third) and MRS (tied third) models (Table 5). Since the brood year escapement for Gates was well above average, only top ranked models that use brood year escapement as a predictor variable were considered to generate the 2014 forecast. For each individual performance measure, the Larkin and MRS models each ranked within the top 50% (10 out of 20) of all models compared for this stock (Table 5 in MacDonald & Grant 2012). These two models produced similar forecasts that varied by 20% (Table 5). Additional highly ranked models (Ricker (Pi) & power, both ranked 6th) also produced similar forecasts to the Larkin model, varying by 6% and 30%, respectively, from the Larkin forecast. The Larkin model was used for the 2014 Gates forecast, as its average across performance measures was high, and it ranked well relative to alternative models on each individual performance measure. Given the assumptions underlying the Larkin model, there is a one in four chance (25% probability) the Gates Sockeye return will be below 47,000 (6.2 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 131,000 (20.3 age-4 R/EFS) in 2014. The median (one in two chance: 50% probability) forecast of 79,000 (11.1 age-4 R/EFS) is much larger than the average return on this cycle (18,000) (Tables 1 & 2; Figure 3). The five year old component of the 2014 return is expected to contribute 18% of the total forecasted return (at the 50% probability level) (Table 3).

Nadina (Nadina-Francois-ES CU)

The 2010 brood year escapement for Nadina (11,900 EFS) was greater than five times the cycle average (2,100 EFS) from 1974-2006 (Table 1, column C). As mentioned in the Early Summer Run introduction, the arrival timing to Nadina was early and protracted, running much later than normal. Early Sockeye arrivals to the Nadina channel experienced warm water temperatures and high pre-spawn mortality rates. Spawning success in the channel (74%) was lower than in the Nadina River (98%). Juvenile fry data, used as an index of juvenile abundance, indicate that early freshwater survival in the 2010 brood year (1,500 fry/EFS) was above average (brood years 1973-2010 average: 1,300 fry/EFS), and juvenile abundance (19.3 million fry) was well above the average (brood years 1973-2010 average: 9.5 million fry).

Average four year old survival (R/EFS) for Nadina Sockeye declined from a peak of 13.5 R/EFS in the mid-1970 brood years (four year average at peak) to one of the lowest survivals on record (1.0 R/EFS) in the 2005 brood year (i.e. 2009 four year old return year) (Table 2, columns B to E; Figure 3). In recent years (2006 and 2007 brood years), survival (9.9 R/EFS) has been above average (6.1 R/EFS).

For Nadina, the top ranked models are the MRJ, Ricker (FrD-peak) (tied second), and power (juv) (FrD-peak) (tied second) (Table 5). These three models each ranked within the top 50% (17 out of 33 models) of all models compared for this stock on three of the four individual performance measures. However, all three models each ranked in the bottom 50% (ranked ≥ 19 out of 33 models) on the MRE performance measure (Table 5 in MacDonald & Grant 2012). Of the 33 models explored for Nadina, none ranked in the top 50% for all four performance measures (all models either ranked well on MRE and poorly on all other performance measures, or vice versa). Therefore, the MRE performance measure was not used to inform model selection and top models were based on the average ranks for the three remaining performance measures. Forecasts produced by the top ranked models were different, varying by 61% (Table 5). The juvenile-based models (MRJ & power (juv) (FrD-peak) produced higher forecasts than the effective female-based model (Ricker (FrD-peak)) due to the above average early freshwater survival in the 2010 brood year. The MRJ model was used for the 2014 Nadina forecast, as it ranked first on average across performance measures, and it ranked first on each individual performance measure except MRE (ranked 28th) (Table 5 in MacDonald & Grant, 2012). Given the assumptions underlying the MRJ model, there is a one in four chance (25% probability) the Nadina Sockeye return will be below 51,000 (4.0 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 233,000 (18.3 age-4 R/EFS) in 2014. The median (one in two chance: 50% probability) forecast of 109,000 (8.6 age-4 R/EFS) is four times the average return on this cycle (26,000) (Tables 1 & 2; Figure 3). The five year old component of the 2014 return is expected to contribute 6% of the total forecasted return (at the 50% probability level) (Table 3).

Pitt (Pitt-ES CU)

Due to the greater proportion of five year old recruits (~70%) relative to four year old recruits for Pitt, brood year escapements were compared to the time-series average, rather than the cycle average. The brood year escapement for Pitt in 2009 (for five year old recruits returning in 2014: 18,800 EFS, which includes hatchery broodstock females) was greater than the average escapement from 1948-2009 (13,900 EFS, which includes hatchery broodstock females). The 2010 escapement (for four year old recruits returning in 2014: 8,800 EFS) was smaller than average. However, both estimates (2009 & 2010) still fell within the average range (average ± 0.5 standard deviations) (Table 1, columns D & C).

Average five year old survival (R/EFS) for Pitt Sockeye has been variable throughout the time series, with a second peak of 13.3 five year old R/EFS (four year average at peak) occurring in the early 1990's. Subsequently, survival declined for this stock, culminating in one of the lowest survivals on record (0.2 R/EFS) in the 2005 brood year (i.e. 2009 four year old return year) (Table 2, columns B to E; Figure 3). In the most recent brood year with age-5 recruitment data (2006), survival (2.5 R/EFS) was close to average (3.6 R/EFS).

For Pitt, the top ranked models are the Larkin, TSA and Ricker (PDO) models (Table 5). Since the brood year escapement for Pitt was above average, only top ranked models that use brood year escapement as a predictor variable were considered to generate the 2014 forecast. For each individual performance measure, only the Larkin model ranked within the top 50% (10 out of 20) of all models compared for this stock (Table 5 in MacDonald & Grant, 2012). Forecasts produced by the top ranked biological models varied by 27% (Table 5). The top performing Larkin model was used to generate the 2014 forecast for Pitt (Table 5). Given the assumptions underlying the Larkin model, there is a one in four chance (25% probability) the Pitt Sockeye return will be below 46,000 (1.6 age-5 R/EFS) and a three in four chance (75% probability) the return will be below 127,000 (5.6 age-5 R/EFS) in 2013. The median (one in two chance: 50% probability) forecast of 73,000 (3.0 age-5 R/EFS) is very similar to the average return (71,000) (Tables 1 & 2; Figure 3). The five year old component of the 2014 return is expected to contribute 76% of the total forecasted return for Pitt (at the 50% probability level) (Table 3).

Scotch (a component of the Shuswap-ES CU)

The 2010 brood year is the dominant cycle year for Scotch Creek. The 2010 brood year escapement for Scotch (273,900 EFS) was almost nine times the cycle average (30,700 EFS) (Table 1, column C) from 1982-2006. Scotch Creek became dominant on this 2010 cycle line in 1982 as a result of hatchery transplants on this cycle from the Seymour River. This dominant cycle line now coincides with that of Seymour and Late Shuswap stocks.

Average four year old survival (R/EFS) for Scotch Sockeye declined from a peak of 21.5 R/EFS in the early 1980 brood years (four year average at peak) to one of the lowest survivals (2.1 R/EFS) on record in the 2005 brood year (i.e. 2009 four year old return year) (Table 2, columns B to E; Figure 3). In recent years (2006 and 2007 brood years), survival (11.9 R/EFS) has been close to average (6.9 R/EFS).

There are a number of issues that complicate the return forecast process for Scotch in 2014. First, the time series is relatively short (brood years 1980-2006) for Scotch Creek. Further, in the past three cycle years, escapements have increased to a record (high) number in the 2010 brood year. These factors result in challenges in the estimation of both Larkin and Ricker carrying capacity parameter values. Further, given the exceptional and unprecedented escapement in the 2010 brood year, biological models are being extrapolated well beyond the observed stock-recruitment time series to produce forecasts for the 2014 return year. Therefore, the 2014 forecasts for Scotch Creek are extremely uncertain.

For Scotch, the top ranked models are the Larkin, Ricker and RS1 (Table 5). For each individual performance measure, the Larkin and Ricker models each ranked within the top 50% (10 out of 20) of all models compared for this stock (Table 5 in MacDonald & Grant 2012). Forecasts produced by the Larkin and Ricker models differed by 32% (Table 5). Due to the extremely large 2010 escapement in Scotch (and other Shuswap stocks), additional considerations were taken into account in determining the most appropriate forecast model for this stock. The first ranked Larkin model forecast was not selected to generate the 2014 forecast. Given that the EFS abundance for Scotch Creek represents less than 5% of the total EFS for Scotch and Late Shuswap stocks combined on the dominant 2010 cycle (from 1980 to 2006), a large component of the cycle line interactions that occur amongst juveniles in the rearing lake (Shuswap Lake) is not captured by a Larkin model that uses only stock-recruitment data from Scotch Creek. The second ranked Ricker model was therefore used to generate the 2014 forecast for Scotch. Since the spawning ground capacity is more limiting than the rearing lake capacity for Scotch Creek, it is appropriate to use stock-recruitment data for this stock to estimate the Ricker beta carrying capacity parameter (see Appendix 2 in Grant et al. 2010 for model). The Ricker model additionally accounts for in-stream competition, which likely occurred in Scotch in 2010 given the extremely large escapement.

Due to the large (record) 2010 escapement, forecasts produced for this stock are extrapolated outside the range of the fitted model and, therefore, increase the uncertainty of the 2014 Scotch forecast. Given the assumptions underlying the Ricker model, there is a one in four chance (25% probability) the Scotch Sockeye return will be below 678,000 (2.5 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 3,328,000 (12.1 age-4 R/EFS) in 2014. The median (one in two chance: 50% probability) forecast of 1,542,000 (5.6 age-4 R/EFS) is very large compared to the average return on this cycle (390,000) (Tables 1 & 2; Figure 3). The five year old component of the 2014 return is expected to contribute 0% of the total forecasted return (at the 50% probability level) (Table 3).

Additional forecasts were generated using models not part of the official suite, to provide further context for the 2014 Scotch Creek forecast. Although also uncertain, the first alternative forecast produced was the power (fry) model. This model uses an estimate of all fry in Shuswap Lake (including Scotch, Seymour, miscellaneous Early Shuswap populations, and Late Shuswap) from the 2010 brood year (i.e. 2011 fall fry) to predict age-4 returns in 2014. The age-4 power (fry) forecast was then partitioned into the Scotch Creek component using the proportion of the 2010 Scotch Creek Sockeye effective female spawner escapement, relative to the total Scotch, Seymour, Early Shuswap miscellaneous stocks, and Late Shuswap Sockeye EFS escapement. The power (fry) age-4 forecast for Scotch Creek is 964,000 at the 50% probability level, and ranges from 297,000 to 2,816,000 at the 25% to 75% probability levels. At the 50% probability level, the power (fry) age-4 forecast differs from the selected Ricker age-4 forecast by 37%. This fry model's forecast could potentially be biased high given it uses 2010 escapement to partition the total fry to Scotch Creek, and particularly high densities of Sockeye were observed on the Scotch Creek spawning grounds that could decrease egg-to-fry survival and, therefore, decrease the proportion of fry represented by Scotch Creek. An additional model used to generate an alternative forecast was a jack sibling model, which uses preliminary jack escapement data in 2013 to predict age-4 recruits in 2014. This forecast is also highly uncertain, with further uncertainty attributed to the use of preliminary escapement as a predictor variable, rather than recruits (catch plus escapement). Recruitment data were, however, not available at the time of the forecast. This sibling model age-4 forecast is 680,000 at the 50% probability level and ranges from 500,000 to 930,000 at the 25% to 75% probability levels. At the 50% probability level, the sibling forecast differs from the Ricker age-4 forecast by 56%. Further information on freshwater and marine stock composition to support the forecast is presented in a separate CSAS Science Response.

Seymour (a component of the Shuswap-ES CU)

The 2010 brood year is the dominant cycle line for the Seymour River. The 2010 brood year escapement for Seymour (287,500 EFS) was almost nine times the cycle average (33,400 EFS) from 1950-2006 (Table 1, column C). A rain on snow event that occurred towards the end of the Early Summer spawning period in 2010 caused high water levels, heavy sediment, and debris loading in this system, and may have negatively impacted egg-to-fry survival for this stock.

Average four year old survival (R/EFS) for Seymour Sockeye declined steadily from a peak of 29.2 R/EFS at the start of the time series in the 1970's (four year average at peak) to one of the lowest survivals on record (3.4 R/EFS) in the 2005 brood year (i.e. 2009 four year old return year) (Table 2, columns B to E; Figure 3). In recent years (2006 and 2007 brood years), survival (7.5 R/EFS) has been close to average (7.8 R/EFS).

For Seymour, the top ranked models are the Ricker-cyc, Larkin (tied second) and R1C (tied second) (Table 5). Due to the extremely large and unprecedented 2010 escapement in Seymour (and other Shuswap stocks), additional considerations and model forms were explored for the model selection process. Models that do not use the large 2010 escapement as a predictor variable in their forecasts (R1C) were not considered for the 2014 forecast. In addition, both the Ricker-cyc and Larkin models were down-weighted because of the influence of the Late Shuswap stocks on the population dynamics of this system. Given that the EFS abundance for Seymour represents less than 3% of the total EFS for Seymour and Late Shuswap stocks combined on the dominant 2010 cycle (from 1950 to 2006), a large component of the cycle line interactions that occur amongst juveniles in the rearing lake is not captured by a Larkin or Ricker-cyc model that uses only stock-recruitment data from Seymour. The 10^{th} ranked Ricker model was therefore used to generate the 2014 forecast for Seymour. Since the spawning ground capacity is more limiting than the rearing lake capacity for Seymour, it is appropriate to use stock-recruitment data for this stock to estimate the Ricker beta carrying capacity parameter (see Appendix 2 in Grant et al. 2010 for model). The Ricker model additionally accounts for in-stream competition, which likely occurred in Seymour in 2010 given the extremely large escapement.

Due to the large (record) 2010 escapement, forecasts produced for this stock are extrapolated outside the range of the fitted model and, therefore, increase the uncertainty of the 2014 Seymour forecast. Given the assumptions underlying the Ricker model, there is a one in four chance (25% probability) the Seymour Sockeye return will be below 429,000 (1.5 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 2,925,000 (10.3 age-4 R/EFS) in 2014. The median (one in two chance: 50% probability) forecast of 1,254,000 (4.4 age-4 R/EFS) is well above the average return on this cycle (358,000) (Tables 1 & 2; Figure 3). The five year old component of the 2014 return is expected to contribute 0% of the total forecasted return (at the 50% probability level) (Table 3).

Additional forecasts were generated using models not part of the official suite, to provide further context for the 2014 Seymour forecast. Although also uncertain, the first alternative forecast produced was the power (fry) model. This model uses an estimate of all fry in Shuswap Lake (including Scotch, Seymour, miscellaneous Early Shuswap populations, and Late Shuswap) from the 2010 brood year (i.e. 2011 fall fry) to predict age-4 returns in 2014. The age-4 power (fry) forecast was then partitioned into the Seymour component using the proportion of Seymour

Sockeye 2010 escapement, relative to the total Scotch, Seymour, Early Shuswap miscellaneous stocks, and Late Shuswap Sockeye escapement. The power (fry) age-4 forecast for Seymour River is 1,009,000 at the 50% probability level, and ranges from 311,000 to 2,950,000 at the 25% to 75% probability levels. At the 50% probability level the power (fry) age-4 forecast differs from the selected Ricker age-4 forecast by 24%. This fry model's forecast could potentially be biased high given it uses 2010 escapement to partition the total fry to Seymour, and this system had a high water event near the end of the spawning period that could, therefore, decrease, the proportion of fry represented by Seymour. An additional model used to generate an alternative forecast was a jack sibling model, which uses preliminary jack escapement data in 2013 to predict age-4 recruits in 2014. This forecast is also highly uncertain, with further uncertainty attributed to the use of preliminary escapement as a predictor variable, rather than recruits (catch plus escapement). Recruitment data were, however, not available at the time of the forecast. This sibling model age-4 forecast is 560,000 at the 50% probability level and ranges from to 360,000 to 880,000 at the 25% to 75% probability levels. At the 50% probability level, the sibling forecast differs from the selected Ricker age-4 forecast by 55%. Further information on freshwater and marine stock composition to support the forecast is presented in a separate CSAS Science Response.

Miscellaneous Early Shuswap

The 2010 brood year EFS for the miscellaneous Early Shuswap and Taseko populations is largely comprised of the Eagle (68% of the total) and Anstey (12%) Rivers. Taseko made up only 0.5% of the total EFS for this miscellaneous group and, therefore, 95% of the escapement was comprised of Early Shuswap populations. Since Eagle River was assessed using visual survey methods, the escapement estimate was likely biased low. The model used to generate the miscellaneous Early Shuswap 2014 forecast was a non-parametric model that used the recruits-per-spawner from Scotch and Seymour multiplied by the miscellaneous stocks' brood year escapements (see Appendix 1 to 3 in Grant et al. 2011). Given the assumptions underlying the miscellaneous stocks model, there is a one in four chance (25% probability) the Shuswap-Taseko miscellaneous stocks' return will be below 444,000 and a three in four chance (75% probability) the return will be below 1,565,000 in 2014. The median (one in two chance: 50% probability) forecast is 982,000 (Table 1). Although also uncertain, an alternative forecast was produced for this miscellaneous group using the power (fry) model. This model uses an estimate of all fry in Shuswap Lake (including Scotch, Seymour and Late Shuswap and miscellaneous populations) from the 2010 brood year (i.e. 2011 fall fry) to predict age-4 returns in 2014. The age-4 power (fry) forecast was then partitioned into the Early Shuswap miscellaneous component using the proportion of the Early Shuswap miscellaneous escapement in 2010, relative to the total Scotch, Seymour, Early Shuswap miscellaneous populations, and Late Shuswap Sockeye escapement in 2010. The power (fry) age-4 forecast for Miscellaneous Early Shuswap is 409,000 at the 50% probability level, and ranges from 126,000 to 1,195,000 at the 25% to 75% probability levels. At the 50% probability level the power (fry) age-4 forecast differs from the Early Shuswap miscellaneous stocks age-4 forecast by 58%.

Miscellaneous Chilliwack

The 2010 brood year EFS for the miscellaneous Chilliwack populations includes Upper Chilliwack River (375) and Chilliwack Lake (1,127) (total EFS: 1,502). The 2010 escapement is below the average EFS for this system (average from 2000 to 2011: 6,100). The model used to generate the miscellaneous Chilliwack forecast was a non-parametric model that used the recruits-per-spawner from the Early Summer stocks (Bowron, Fennell, Gates, Nadina, Pitt, Scotch, Seymour) multiplied by the Chilliwack miscellaneous stock's brood year escapements (see Appendix 1 to 3 in Grant et al. 2011). Given the assumptions underlying the miscellaneous stocks model, there is a one in four chance (25% probability) the Chilliwack miscellaneous stocks' return will be below 8,000 and a three in four chance (75% probability) the return will be below 26,000 in 2014. The median (one in two chance: 50% probability) forecast is 14,000 (Table 1).

Miscellaneous Nahatlach

The 2010 brood year EFS for the miscellaneous Nahatlach populations includes Nahatlach River (2,699) and Nahatlach Lake (195) (total EFS: 2,894). The 2010 escapement is above the average EFS for this system (average from 1975 to 2011: 2,284). The model used to generate the miscellaneous Nahatlach forecast was a non-parametric model that used the recruits-per-spawner from the Early Summer stocks (Bowron, Fennell, Gates, Nadina, Pitt, Scotch, Seymour) multiplied by the Nahatlach miscellaneous stock's brood year escapements (see Appendix 1 to 3 in Grant et al. 2011). Given the assumptions underlying the miscellaneous stocks model, there is a one in four chance (25% probability) the Nahatlach miscellaneous stocks' return will be below 10,000 and a three in four chance (75% probability) the return will be below 34,000 in 2014. The median (one in two chance: 50% probability) forecast is 19,000 (Table 1).

Summer Run

The Summer Run consists of six forecasted stocks: Chilko, Late Stuart, Quesnel, Stellako and the recently added Raft and Harrison (Table 1); Raft, North Thompson River and miscellaneous stocks associated with North Thompson tributaries and Harrison were re-assigned to this run timing group as of the 2013 forecast, following a re-evaluation of the migration timing, which is more similar to the Summer Run timing. Escapement in the 2010 brood year for these six stocks combined (1.9 million EFS), excluding miscellaneous stocks, was well above the long-term cycle average (444,800 EFS). Chilko (63%) contributed the most to the Summer Run EFS, followed by Harrison (21%). The total 2010 brood year EFS for the Summer Run, including miscellaneous stocks (North Thompson tributaries and North Thompson River) was also 1.9 million EFS, given the low escapements in the Thompson system relative to other stocks. Physical conditions on the Summer Run aggregate spawning grounds were adequate for spawning in most areas in 2010. Water levels were lower than average in the Stuart and Quesnel systems, though there was no indication of fish access being impeded. Arrival timing on the Summer Run spawning grounds was within the normal range, though the earliest arrivals for most stocks experienced elevated pre-spawn mortality. Additionally, en-route mortality was observed for the Harrison stock. The spawning success for the Summer Run aggregate in 2010 was 88% (time series average for the Summer Run aggregate: 90%).

Chilko (Chilko-S & Chilko-ES CU)

The 2010 brood year escapement for Chilko (1.2 million EFS) was seven times the cycle average (164,000 EFS) from 1950-2006. This is the largest escapement on record for this stock. Spawning success in this system in 2010 was 86% (time series average: 91%). Chilko freshwater survival for the 2010 brood year (47 smolts/EFS) was well below the average (1950-2010 average: 118 smolts/EFS) (Figure 2). However, given the exceptional escapements, juvenile (smolt) abundance for the 2010 brood year (54.9 million one year old smolts) was still well above the long-term average (brood years 1950-2006: 19.5 million one year old smolts), and was the third largest estimate on record (Table 1, column C). Smolt abundance in the previous (2009) brood year, for the five year old Sockeye returning in 2014 (34.4 million one year old smolts), was also much larger than the long-term average (19.5 million one year old smolts). Average smolt body lengths in the 2009 (87.3 mm) and 2010 (77.4 mm) brood years were respectively above and below the long-term (brood years 1953-2009) average (83.3 mm).

Average four year old post-smolt (Fraser downstream migration plus marine) survival (R/smolt) for Chilko Sockeye declined steadily from a peak of 18% in the late-1980 brood years (four year average at peak) to one of the lowest post-smolt survivals on record (0.3%) in the 2005 brood year (i.e. 2009 four year old return year) (Table 2, columns B to E; Figures 2 B & 3). In recent years (2006 and 2007 brood years), survival (5% R/smolt) has been closer to average (7% R/smolt).

The 2014 forecasts for Chilko were restricted to juvenile-based models only given the low freshwater survival observed for this stock in the 2010 brood year. Though the 2010 brood year escapement to Chilko was unprecedented (falling well outside the observed escapement data range), the low freshwater survival resulted in a smolt abundance that fell within the range of observed data.

The top ranked juvenile models for Chilko are the power (juv) (Pi), power (juv), and power (juv) (FrD-peak) models (Table 5). None of these models ranked within the top 50% (17 out of 33) of all models compared for this stock (including spawner-based models) for all performance measures (Table 5 in MacDonald & Grant 2012). All three models ranked poorly on MRE, therefore the average ranks across the remaining three performance measure were used to inform model selection. Forecasts produced by the top ranked models were similar, varying by 15% (Table 5). The power (juv) model generated the lowest forecast, while the power (juv) (Pi) model produced the largest forecast (Table 5). Water temperatures were cooler at Pine Island (Pi) in 2012 during smolt migration through the Strait of Georgia (May to June) (Irvine & Crawford 2013), and cooler water temperatures are generally are associated with improved salmon survival. The power (juv) (Pi) model was used to generate the Chilko forecast, as it ranked best overall for the juvenile models. Given the assumptions underlying the power (juv) (Pi) model, there is a one in four chance (25% probability) the Chilko Sockeye return will be below 1,670,000 (3% age-4 marine survival) and a three in four chance (75% probability) the return will be below 4,274,000 (7% age-4 marine survival) in 2014. The median (one in two chance: 50% probability) forecast of 2,615,000 (4% age-4 marine survival) is above the average return on this cycle (1,484,000) (Tables 1 & 2; Figure 3). The five year old component of the 2014 return is expected to contribute 8% of the total forecasted return (at the 50% probability level) (Table 3). A sibling model forecast that predicts four year old recruits in 2014 from the jack (three year olds) recruits in 2013 across all cycles post-1980 ranged from 1,470,000 to 4,494,000 at the 25% to 75% probability level, with a median (50% probability) forecast of 2,569,000. Jack recruitment data were not available at the time of this forecast for the 2013 sibling model relationship. Instead, the preliminary escapement data were used, which represents a biased estimate of recruitment given that the age-composition of the escapements has not been verified to confirm the jack escapement, and catch has not been added to generate a jack recruitment estimate. At the 50% probability level, the sibling forecast differs from the selected power (juv) (Pi) age-4 forecast by 7%.

Late Stuart (Takla-Trembleur-Stuart-S CU)

The 2010 brood year escapement (43,500 EFS) for Late Stuart was almost double the cycle average (22,000 EFS) from 1950-2006 (Table 1, column C). Spawning success in the Late Stuart system in 2010 was 98% (time series average: 92%).

Average four year old survival (R/EFS) for Late Stuart Sockeye declined from a peak of 57.2 R/EFS in the early 1950’s, with subsequent, lower peaks in the late 1960’s and mid-1980’s to one of the lowest survivals on record (0.7 R/EFS) in the 2005 brood year (i.e. 2009 four year old return year) (Table 2, columns B to E; Figure 3). In recent years (2006 and 2007 brood years), survival (3.8 R/EFS) has been below average (9.3 R/EFS).

For Late Stuart, the top ranked models are the R1C, R2C, and power models (Table 5) (Note: there is an error in the Ricker model performance measures in Table 5 of MacDonald & Grant 2012. The Ricker model is not actually tied for the third ranked model, but instead is ranked eighth. Performance measure values for Ricker are MRE: -0.033, MAE: 0.521, MPE: -1.673, RMSE: 0.9.). For each individual performance measure, the R1C and R2C models ranked within the top 50% (10 out of 20) of all models compared for this stock (Table 5 in MacDonald & Grant, 2012). Since the brood year escapement for Late Stuart was above average, the top ranked model that uses brood year escapement as a predictor variable (i.e. power model) was used to generate the 2014 forecast. For reference, the power model produced a relatively similar forecast to the next highest ranking biological model (Ricker (FrD-mean)), falling 26% lower than this forecast. Given the assumptions underlying the power model, there is a one in four chance (25% probability) the Late Stuart Sockeye return will be below 172,000 (2.8 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 672,000 (13.7 age-4 R/EFS) in 2014. The median (one in two chance: 50% probability) forecast of 329,000 (6.2 age-4 R/EFS) is larger than the average return on this cycle (232,000) (Tables 1 & 2; Figure 3). The five year old component of the 2014 return is expected to contribute 18% of the total forecasted return (at the 50% probability level) (Table 3).

Quesnel (Quesnel-S CU)

The 2010 cycle line is the sub-dominant cycle for Quesnel. Brood year escapement for Quesnel in 2010 (133,000 EFS) was similar to the cycle average (178,600 EFS) from 1950-2006 (Table 1, column C). Spawner success was 95% (average: 84%). Freshwater survival in the brood year (189 fall fry/EFS) was average across all cycles (1976-2010 brood years: 189 fall fry/EFS), and the resulting fall fry abundance (25 million) was average (1976-2010 average: 29.8 million). The 2010 brood year fall fry body sizes (3.8 g) were also similar to the average (1976-2010 all cycle average: 3.7 g).

Average four year old survival (9.4 R/EFS) for Quesnel Sockeye declined from a peak of 18.1 R/EFS in the late-1960's to one of the lowest productivities on record (0.3 R/EFS) in the 2005 brood year (i.e. 2009 four year old return year) (Table 2, columns B to E; Figure 3). In recent years (2006 and 2007 brood years), survival (3.7 R/EFS) has been below average (9.4 R/EFS). This stock exhibits evidence of delayed-density dependence, which may explain post-1990 declines in survival (Peterman and Dorner 2012).

For Quesnel, the top ranked models are the R1C, R2C and Ricker-cyc (Table 5). For each individual performance measure, each of these models ranked within the top 50% (10 out of 20) of all models compared for this stock (Table 5 in MacDonald & Grant, 2012). Forecasts produced by the top ranked models differed, varying by 60% (Table 5). The non-parametric models (R1C & R2C) produced lower forecasts due to low returns in recent years, while the Ricker-cyc biological model produced the largest forecast. As a result of the poor returns in recent years, and uncertainty in future returns, the top ranked biological model (Ricker-cyc) was selected to generate the 2014 forecast.

The Ricker-cyc model was used to generate the 2014 forecast for Quesnel, as it is the top-ranked biological model, and its forecast is supported by the juvenile model (Table 5). Given the assumptions underlying the Ricker-cyc model, there is a one in four chance (25% probability) the Quesnel Sockeye return will be below 845,000 (5.6 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 2,950,000 (21.1 age-4 R/EFS) in 2014. The median (one in two chance: 50% probability) forecast of 1,524,000 (10.5 age-4 R/EFS) is larger than the average return on this cycle (1.05 million) (Tables 1 & 2; Figure 3). The five year old component of the 2014 return is expected to contribute 9% of the total forecasted return (at the 50% probability level) (Table 3).

Additional models forecasts (Larkin, Ricker & power (juv)) were generated for Quesnel to investigate the effect of alternative model forms and predictor variables on this stock's forecast (Table 5). The extra analysis was conducted for this stock in particular as Quesnel appears to have exhibited interactions between cycle lines (delayed-density dependence) in recent years (Peterman and Dorner 2012), therefore the population dynamics of this stock are more uncertain. The Larkin model (ranked 5^{th}) was used to produce a forecast for comparison to other biological models (Ricker-cyc & Ricker), since this model form considers delayed-density dependence. The Larkin model forecast is the largest of all models, varying by 29% and 34%, respectively, from those produced by the Ricker-cyc and Ricker models (Table 5). Quesnel has juvenile (fall fry) data for both the 2009 and 2010 brood years; therefore juvenile model return forecasts were generated. The forecast produced by the power (juv) model was very similar to those of the Ricker and Ricker-cyc models (Table 5), given that freshwater survival and juvenile abundances were average. This forecast provides additional support for use of the selected Ricker-cyc model form in forecasting the Quesnel return.

Stellako (Francois-Fraser-S CU)

The 2010 brood year escapement for Stellako (110,300 EFS) was well above the cycle average (63,000 EFS) from 1950-2006 (Table 1, column C).

Average four year old survival (R/EFS) for Stellako Sockeye declined from a peak of 15.1 R/EFS in the early 1970's to one of the lowest survivals on record (0.1 R/EFS) in the 2005 brood year (i.e. 2009 four year old return year) (Table 2, columns B to E; Figure 3). In recent years (2006 and 2007 brood years), survival (5.3 R/EFS) has been close to average (7.0 R/EFS).

For Stellako, the top ranked models are the R2C, Larkin and Ricker (Ei) (Table 5). Since the brood year escapement for Stellako was above average, only top ranked models that use brood year escapement as a predictor variable were considered to generate the 2014 forecast. The Larkin and Ricker (Ei) models ranked, respectively, 13th and 11th on the MRE performance measure (MacDonald & Grant 2012). Forecasts produced by the two biological models (Larkin & Ricker (Ei)) produced similar forecasts, varying by only 11% (Table 5). Given the above average brood year escapement for Stellako, the top ranked biological model (Larkin) was used to generate the 2014 forecast (Table 5). Given the assumptions underlying the Larkin model, there is a one in four chance (25% probability) the Stellako Sockeye return will be below 437,000 (3.6 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 1,119,000 (9.7 age-4 R/EFS) in 2014. The median (one in two chance: 50% probability) forecast of 690,000 (5.9 age-4 R/EFS) is larger than the average return on this cycle (548,000) (Tables 1 & 2; Figure 3). The five year old component of the 2014 return is expected to contribute 6% of the total forecasted return (at the 50% probability level) (Table 3).

Raft (Kamloops-ES CU): Recently re-assigned to Summer from the Early Summer Run Group

The 2010 brood year escapement for Raft (2,400 EFS) was close to the cycle average (2,900 EFS) from 1950-2006 (Table 1, column C).

This stock has not exhibited any systematic survival trends over time (Grant et al. 2011, Peterman and Dorner 2012). Average four year old survival (R/EFS) for Raft Sockeye has been variable over the time series, with the largest peak of 13.6 R/EFS in the late-1960's/early-1970 brood years (four year average at peak). However, similar to other Fraser Sockeye stocks, Raft exhibited its lowest survival on record (0.4 R/EFS) in the 2005 brood year (i.e. 2009 four year old return year) (Table 2, column E; Figure 3). In recent years (2006 and 2007 brood years), survival (2.1 R/EFS) has been below average (5.9 R/EFS).

For Raft, the top ranked models are Ricker (PDO), Ricker-cyc (tied second) and power (tied second) (Table 5). For each individual performance measure, only the Ricker (PDO) model ranked within the top 50% (10 out of 20) of all models compared for this stock (Table 5 in MacDonald & Grant, 2012). Forecasts produced by the three top ranked models varied by 38%, with the Ricker (PDO) model producing the largest forecast (Table 5). The Ricker (PDO) model was used for the 2014 Raft forecast, as it ranked first on average across performance measures, and it ranked highest on each individual performance measure except RMSE (ranked fourth). Given the assumptions underlying the Ricker (PDO) model, there is a one in four chance (25% probability) the Raft Sockeye return will be below 25,000 (3.5 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 63,000 (13.2 age-4 R/EFS) in 2014. The median (one in two chance: 50% probability) forecast of 39,000 (7.1 age-4 R/EFS) is larger than the average return on this cycle (22,000) (Tables 1 & 2; Figure 3). The five year old proportion of the 2014 return is expected to contribute 56% of the total forecasted return (at the 50% probability level) (Table 3). Raft has variable age five contributions to total returns, with a recent average age five proportion of 37% (1980-2010 return years).

Harrison (Harrison-River Type CU): Recently re-assigned from Late Run Group to the Summer group

Harrison Sockeye have a unique life history and age structure compared to other Fraser Sockeye stocks. Harrison Sockeye migrate to the ocean shortly after gravel emergence (most Fraser Sockeye rear in lakes for one year after gravel emergence prior to their ocean migration). After two to three years in the ocean, Harrison Sockeye return predominantly as three or four year old fish (most Fraser Sockeye return as four and five year old fish). Proportions of three and four year old Harrison recruits vary considerably inter-annually, with four year old proportions ranging from 10% to 90% of total recruits (Grant et al. 2010). Odd brood years, on average, produce a higher proportion of four year old recruits, and even years produce a higher proportion of three year old recruits (Grant et al. 2010). Though the difference in odd versus even year age proportions is accounted for in the Harrison forecast models (MacDonald & Grant 2012), the extreme annual variation in age proportions for Harrison Sockeye increases the level of forecast uncertainty for this stock.

The 2010 brood year escapement (four year old recruits in 2014) for Harrison Sockeye (399,700 EFS) was the largest on record, and was almost 30 times greater than the long-term average (13,500 EFS). The 2011 brood year escapement (three year old recruits in 2014) for this stock (387,100 EFS) was the second largest (after the 2010 brood year escapement) on record, and similarly was almost 30 times greater than the long-term average (13,500 EFS). Harrison Sockeye escapements are compared to the entire time series instead of the cycle average, since Harrison has variable proportions of four year old returns, and is therefore not cyclic (Table 1, columns C & D). En-route mortalities, observed in the Harrison River and the Lower Fraser River (downstream of the Harrison confluence) in 2010 and 2011, were attributed the exceptional abundances in this system in both of these years. Harrison Sockeye spawning success in 2010 was 94% in 2010 (four year old returns in 2014) and 91% in 2011 (three year old returns in 2014) (time series average: 99%).

Unlike most other Fraser Sockeye stocks, average survival (R/EFS) for Harrison Sockeye increased to a maximum of 33.8 R/EFS in mid-1990’s (Table 2, columns B to E). Similar to other stocks, however, the 2005 brood year survival (i.e. 2009 four year old return year) (Table 2, column E) of 0.1 R/EFS was the lowest on record. In recent years (2006 to 2008 brood years), survival (26.0 R/EFS) has been well above average (7.0 R/EFS).

Harrison Sockeye have been extremely challenging to forecast in recent years due to large increases in escapements and survival (Grant et al. 2010; Grant et al. 2011), and the inter-annual variation in this stock’s four year old proportions (see first paragraph of this Harrison forecast section). Historically (up to the year 2000), Harrison Sockeye escapements averaged 6,500 EFS, while survival was ~15 R/EFS. In recent years (post-2000), escapements have averaged 100,000 EFS, and survival has been well above average at 26 R/EFS. Given the relatively recent increase in production, extremely preliminary recruitment data were included in the stock-recruitment data set to capture this period of increased abundance and survival (brood years 2007-2009).

Given the unprecedented escapements in the 2010 and 2011 brood years, all biological models for this stock generate extremely low forecasts, even with the inclusion of additional years of preliminary stock-recruitment data to capture this period. Since the carrying capacity parameter of the fitted Ricker model is largely based on the lower abundance/survival component of the time series (80% of the stock-recruitment data), strong compensation is modeled when using the unprecedented 2010 and 2011 brood year escapements as predictor variables. As a result, forecasts are negligible (Table 5). However, given that the 2010 brood year (the predictor variable for age-4 recruits in 2014) produced relatively large numbers of age-3 recruits in 2013 (~300,000), it can be assumed that the current Ricker model fit does not correctly estimate the capacity parameter of the stock-recruitment relationship for this stock.

Instead, the 2014 forecast was modeled as follows:

- the foundation of the 2014 forecast is the preliminary estimate of age-3 recruits from the 2010 brood year (2013 return year), since this is the only information available on potential recruitments resulting from an exceptional brood year escapement of ~400,000 in Harrison;
- specifically, the 2014 forecast for Harrison relies on the preliminary estimate (262,700) of age-3 recruits from the 2010 brood year (2013 returns) and a non-parametric model that uses returns from this previous (2013 age-3 recruit) year (i.e. the R1C model code was modified to use returns from previous year rather than the previous cycle year);
- the forecast distribution was estimated based on forecast error (difference between observed and predicted returns) typical to all non-parametric models, however, given the recent dramatic shifts in production for Harrison, only post-2000 brood year data were included;
- to forecast the age-4 recruits in 2014 (2010 brood year), each value of the forecast distribution estimated from the previous step was multiplied by the average age-4 proportion of recruits (relative to age-3 plus age-4) in even brood years (0.55), divided by the age-3 proportion of recruits (relative to age-3 plus age-4) in even brood years (0.45); this step assumes average proportions, though, given the extreme variability in age proportions annually, actual proportions are highly uncertain.
- to forecast the age-3 recruits in 2014 (2011 brood year), each value of the forecast distribution estimated from the previous step, was multiplied by the average age-3 proportion of recruits (relative to age-3 plus age-4) in odd brood years (0.26), divided by the age-3 proportion of recruits (relative to age-3 plus age-4) in even brood years (0.45); this step assumes average proportions, though, given the extreme variability in age proportions annually, actual proportions are highly uncertain.

Given the numerous assumptions underlying the above-described non-parametric model, there is a one in four chance (25% probability) the Harrison Sockeye return will be below 228,000 and a three in four chance (75% probability) the return will be below 980,000 in 2014. The median (one in two chance: 50% probability) forecast of 473,000 is larger than the average return across all cycles (83,000) (Tables 1 & 2; Figure 3). The four year old component of the 2014 return is expected to contribute 68% of the total forecasted return (at the 50% probability level).

Additional forecasts were generated using models not part of the official suite, to provide further context for 2014 Harrison River forecasts. An age-3 sibling model, which uses preliminary age-3 escapement data in 2013 to predict age-4 recruits in 2014, was used to produce an age-4 forecast for Harrison. This forecast is also highly uncertain, with further uncertainty attributed to the use of preliminary escapement as a predictor variable, rather than recruits (catch plus escapement), which are typically used. Recruitment data were, however, not available at the time of the forecast. This age-4 forecast is 150,000 at the 50% probability level and ranges from 50,000 to 470,000 at the 25% to 75% probability levels. At the 50% probability level the sibling forecast differs from the selected Ricker age-4 forecast by 26%. Further information on freshwater and marine stock composition to support the forecast is presented in a separate CSAS Science Response.

The forecast for Harrison Sockeye is associated with extreme uncertainty. Additional years of data at high escapements, similar to those observed in 2010 and 2011 are required to reduce the uncertainty of the Harrison Sockeye forecasts.

Miscellaneous North Thompson Tributaries

The 2010 brood year EFS for the miscellaneous North Thompson tributaries is 600. The model used to generate the miscellaneous North Thompson tributaries miscellaneous forecast was a non-parametric model that used the recruits-per-spawner from the Raft and Fennell stocks multiplied by the North Thompson Tributaries miscellaneous stocks' brood year escapements (see Appendix 1 to 3 in Grant et al. 2011). Given the assumptions underlying the miscellaneous stocks' model, there is a one in four chance (25% probability) the North Thompson tributaries miscellaneous stocks' return will be below 3,000 and a three in four chance (75% probability) the return will be below 12,000 in 2014. The median (one in two chance: 50% probability) forecast is 6,000 (Table 1).

Miscellaneous North Thompson River

The 2010 brood year EFS for the miscellaneous North Thompson River is 3,246. The model used to generate the miscellaneous North Thompson River miscellaneous forecast was a non-parametric model that used the recruits-per-spawner from the Raft and Fennell stocks multiplied by the North Thompson River miscellaneous stock's brood year escapements (see Appendix 1 to 3 in Grant et al. 2011). Given the assumptions underlying the miscellaneous stock's model, there is a one in four chance (25% probability) the North Thompson River miscellaneous stocks' return will be below 13,000 and a three in four chance (75% probability) the return will be below 46,000 in 2014. The median (one in two chance: 50% probability) forecast is 23,000 (Table 1).

Late Run

The Late Run consists of five stocks: Cultus, Late Shuswap, Portage, Weaver, and Birkenhead (Table 1); Harrison was recently re-assigned to the Summer Run timing group following a re-evaluation of the migration timing of this stock. The total escapement for the Late Run aggregate in 2010 was the largest on record, with 3.2 million EFS (excluding Cultus). This escapement was larger than the cycle average of 1.2 million EFS (Table 1). The miscellaneous Late Run stocks (e.g. Harrison Lake rearing stocks such as Big Silver and Cogburn) combined brood year EFS was 6,600 (Table 1). Early arrival on the spawning grounds was observed for two Late Run stocks in 2010, Cultus and Late Shuswap. Arrival at the Cultus fence was the earliest on record, continuing the trend towards earlier migration that has been observed in this stock since the mid-1990's. Arrival of the Late Shuswap stock was approximately three weeks early. Elevated levels of pre-spawn mortality were observed across the watershed. Generally, early arrivals experienced the highest pre-spawn mortality, though for Cultus and the South Thompson system, mortality was high across the duration of the runs. En-route mortality of Late run stocks was observed in the lower Fraser and Cultus systems. Physical conditions on the

Late Run aggregate spawning grounds were favorable, with the exception of Birkenhead, which experienced high water in late September. Spawning success was variable across the Late Run aggregate stocks in the 2010 brood year, ranging from 18% to 95% in the Lower Fraser; 67-98% in the Harrison-Lillooet; 66-99% in the South Thompson; and 83% in the Seton-Anderson system. Overall, average spawner success for the Late Run aggregate in 2010 was 75% (time series average for the Late Run aggregate: 88%).

Cultus (Cultus-L CU)

Total Cultus Sockeye adult escapement (counted through the Sweltzer Creek enumeration fence) in the 2010 brood year (9,700) was the largest escapement observed since 1999, and fell above the post-1980 cycle average (1982-2006 cycle average: 5,200). Of the 2010 adult escapement, 60% were hatchery marked. Cultus Sockeye have been exhibiting early migration to the Cultus fence since the mid-1990's, which continued in 2010 with the earliest migration timing on record. Spawning success was estimated at 18.2%, based on the 600 female carcasses sampled. Hatchery supplementation of fry into Cultus Lake and smolts into Sweltzer Creek (downstream of the enumeration fence) has increased the number of outmigrating smolts since the hatchery program commenced in the 2000 brood year. The smolt abundance for the 2010 brood year was 318,000, of which 41% were hatchery origin. This smolt abundance falls above the post-1980 cycle average (1982-2006 cycle average: 228,000 smolts), and below the long-term cycle average (1954-2006 cycle average: 988,000 smolts). For the 2013 return year, jack escapement was 1,100. The escapement estimate is similar to the time series (1949-2008) average for three year old recruits (1,000), and is larger than the recent (1980-2008) average (200).

Average four year old post-smolt (mostly marine) survival (R/smolt) for Cultus Sockeye declined from a peak of 15% in the late-1980 brood years (four year average at peak) to one of the lowest post-smolt survivals on record (1%) in the 2005 brood year (i.e. 2009 four year old return year) (Table 2, columns B to E). In recent years (2006 and 2007 brood years), survival (4% R/smolt) has been identical to average (4% R/smolt).

For Cultus, the top ranked models are the MRJ, power (juv) (FrD-peak), and power (juv) (Pi) models (Table 5). Due to significant gaps in the smolt time-series that severely restricted the number of years that could be forecasted by certain smolt models (RJ1, RJ2 & RJC) with jack-knife analysis, these models were excluded from the model evaluation process for this stock. In addition, all models that use EFS as a predictor variable were excluded, as EFS data for Cultus do not take into consideration the significant hatchery supplementation (fry & smolts) to this stock since the 2000 brood year. The individual performance measures for each of the top ranked models were within the top 50% (7 out of 14) of performance measures for all models compared for this stock (Table 5 in MacDonald & Grant, 2012). Forecasts produced by the top ranked models were similar, varying by 13% (Table 5). The MRJ model was used to generate the forecast for 2014, as it has the highest average rank across performance measures and ranked better than, or equal to, the other top models on each individual performance measure. Given the assumptions underlying the MRJ model, there is a one in four chance (25% probability) the Cultus Sockeye return will be below 6,000 (2% age-4 marine survival) and a three in four chance (75% probability) the return will be below 28,000 (9% age-4 marine survival) in 2014. The median (one in two chance: 50% probability) forecast of 13,000 (4% age-4 marine survival) is well below the average return on this cycle (36,000) (Tables 1 & 2; Figure 3). The five year old component of the 2014 return is expected to contribute 0% of the total forecasted return (at the 50% probability level) (Table 3).

A jack sibling model, which uses preliminary jack escapement data in 2013 to predict age-4 recruits in 2014, was run as an additional model for comparison to the Cultus forecast. This forecast is highly uncertain, with further uncertainty attributed to the use of preliminary escapement, rather than recruits (catch plus escapement), as a predictor variable. Recruitment data were, however, not available at the time of this forecast. The sibling model age-4 forecast is 14,000 at the 50% probability level and ranges from 5,000 to 39,000 at the 25% to 75% probability levels. The sibling model was also run with post-2000 data only, to exclude the pre-hatchery supplementation portion of the time-series. Using the truncated data, the sibling model age-4 forecast is 16,000 at the 50% probability level and ranges from 11,000 to 24,000 at the 25% to 75% probability levels. At the 50% probability level, the sibling model and truncated sibling model forecasts differ from the selected MRJ forecast by 7% and 19%, respectively.

Late Shuswap (Shuswap-L CU)

The 2010 brood year is the dominant cycle year for the highly cyclic Late Shuswap stock. Adult escapement for Late Shuswap in 2010 (3.1 million EFS) was the highest on record for this stock, falling well above the cycle average (1950-2006: 1.1 million EFS) (Table 1, column C). Spawning was observed in areas where it had not been previously, while record escapements were observed in several streams within this system. Arrival timing was early and protracted in the Late Shuswap system, and pre-spawn mortality was abnormally high throughout the run. Spawning success in 2010 was 73% (time series average: 95%). Freshwater survival in the brood year (52 fall fry/EFS) was below the cycle average (cycle average 1974-2006: 96 fall fry/EFS). This freshwater survival, however, was close to average on the last three dominant cycle years (cycle average 1998-2006: 60 fall fry/EFS). However, given the exceptional brood year escapements, fall fry abundance from the 2010 brood year (187 million fall fry) was the largest on record (average 1974-2010: 72 million fall fry). Fry body sizes from the 2010 brood year were average (2.3 g) for the cycle (cycle average 1974-2010: 2.3 g).

Average four year old survival (R/EFS) for Late Shuswap Sockeye has been variable, with the largest peak of 10.8 R/EFS occurring in the early-1970 brood years (four year average at peak); this is one of the Fraser Sockeye stocks that has not exhibited systematic declines in survival (Grant et al. 2010; Grant et al. 2011). Cycle-line survival however, peaked in the early 1990's, and subsequently declined (Figure 3). Similar to other stocks, Late Shuswap exhibited one if it's lowest productivities on record (3.0 R/EFS) in the 2005 brood year (i.e. 2009 four year old return year) (Table 2, columns B to E; Figure 3). In recent years (2006 to 2007 brood years), survival (9.8 R/EFS) has been similar to average (9.3 R/EFS).

For Late Shuswap, the top ranked models are the R1C, Ricker-cyc & RAC models (Table 5). However, due to the extremely large 2010 escapement in Late Shuswap (and Early-Summer timed Shuswap stocks), only top ranked models that use brood year escapement as a predictor variable were considered to generate the 2014 forecast. For comparison, the top ranked biological model (Ricker-cyc) forecast was compared to other biological models (Ricker, power, Larkin); forecasts produced by the Ricker, power and Ricker-cyc models were similar, varying by 17%, while the Larkin model produced a much smaller forecast (Table 5).

The Ricker-cyc model was used to generate the Late Shuswap forecast for 2014, as this model ranked high on average across performance measures, and it ranked high on each individual performance measure (Table 5 in MacDonald & Grant 2012). Further, this forecast is supported by other biological model forms, including the juvenile model age-4 forecast (presented in the subsequent paragraph). Given the assumptions underlying the Ricker-cyc model, there is a one in four chance (25% probability) the Late Shuswap Sockeye return will be below 6,894,000 (2.2 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 20,240,000 (6.5 age-4 R/EFS) in 2014. The median (one in two chance: 50% probability) forecast of 11,730,000 (3.8 age-4 R/EFS) is larger than the average return on this cycle (7,791,000) (Tables 1 & 2; Figure 3). This forecast is particularly uncertain given the exceptional brood year escapement; the forecast model is being extrapolated beyond the observed stock-recruitment data range. The five year old component of the 2014 return is expected to contribute 0% of the total forecasted return (at the 50% probability level) (Table 3).

Additional forecasts were generated using models not part of the official suite, to provide further context for the 2014 Late Shuswap forecast. Although also uncertain, the first alternative forecast produced was the power (fry) model. This model uses an estimate of all fry in Shuswap Lake (including Scotch, Seymour, miscellaneous Early Shuswap populations, and Late Shuswap) from the 2010 brood year (i.e. 2011 fall fry) to predict age-4 returns in 2014. The age-4 power (fry) forecast was then partitioned into the Late Shuswap component using the proportion of Late Shuswap Sockeye escapement in 2010, relative to the total Scotch, Seymour, miscellaneous Early Shuswap, and Late Shuswap Sockeye escapement in 2010. The power (fry) age-4 forecast for Late Shuswap is 10,808,000 at the 50% probability level, and ranges from 3,329,000 to 31,584,000 at the 25% to 75% probability levels. At the 50% probability level the fry forecast differs from the selected Ricker age-4 forecast by 8%. A jack sibling model, which uses preliminary jack escapement data in 2013 to predict age-4 recruits in 2014, was run as an additional model for comparison to the Late Shuswap forecast. This forecast is highly uncertain, with further uncertainty attributed to the use of preliminary escapement, rather than recruits (catch plus escapement), as a predictor variable. Recruitment data were, however, not available at the time of this forecast. The sibling model age-4 forecast is 8,830,000 at the 50% probability level and ranges from 7,000,000 to 11,180,000 at the 25% to 75% probability levels. At the 50% probability level the sibling forecast differs from the selected Ricker age-4 forecast by 25%. Further information on freshwater and marine stock composition to support the forecast is presented in a separate CSAS Science Response.

Given the record high escapement observed in Late Shuswap in 2010, additional uncertainty is associated with the 2014 forecast for this stock. Since the brood year escapement for 2010 fell outside the range of previously observed Sockeye escapements in Late Shuswap, biological models (including the selected Ricker-cyc model) must be extrapolated outside their fitted range in order to produce forecasts for 2014, translating into uncertain biological forecasts for this stock. The 2002 brood year provides the only paired escapement and recruitment data at escapements above 1.7 million EFS. This large 2002 brood year escapement (2.8 million EFS) resulted in a total recruitment of 7.4 million Sockeye.

Portage (Seton-L (de novo) CU)

The 2010 brood year escapement for Portage (26,700 EFS) was more than three times the cycle average (1954-2006: 7,000 EFS), and was the largest on record for this stock (Table 1, column C). Sockeye were observed spawning along the shoreline of Anderson Lake, where they had not been previously observed.

Average four year old survival (R/EFS) for Portage Sockeye declined from a peak of 61.7 R/EFS in the early 1960 brood years (four year average at peak), to one of the lowest survivals on record (0.3 R/EFS) in the 2005 brood year (i.e. 2009 four year old return year) (Table 2, columns B to E; Figure 3). In recent years (2006 and 2007 brood years), survival (7.0 R/EFS) has been below average (13.5 R/EFS).

For Portage, the top ranked models are the Larkin, Ricker-cyc, and power models (Table 5). For each individual performance measure, the Larkin and Ricker-cyc models each ranked within the top 50% (10 out of 20) of all models compared for this stock; the power model ranked low on the MRE performance measure in particular (Table 5 in MacDonald & Grant, 2012). Forecasts produced by the top models were not similar, varying by 47% (Table 5), with the Ricker-cyc model producing a lower forecast than the Larkin and power models. The Larkin model was used for the 2014 Portage forecast, as it ranked first on average across performance measures, and it ranked well on each individual performance measure. Given the assumptions underlying the Larkin model, there is a one in four chance (25% probability) the Portage Sockeye return will be below 45,000 (1.6 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 265,000 (9.8 age-4 R/EFS) in 2014. The median (one in two chance: 50% probability) forecast of 111,000 (4.1 age-4 R/EFS) is larger than the average return on this cycle (76,000) (Tables 1 & 2; Figure 3). This forecast is particularly uncertain given the exceptional brood year escapement; the forecast model is being extrapolated beyond the observed stock-recruitment data range. The five year old component of the 2014 return is expected to contribute 1% of the total forecasted return (at the 50% probability level) (Table 3).

Given the record high escapement observed in Portage in 2010, additional uncertainty is associated with the 2014 forecast for this stock. Since the brood year escapement for 2010 fell outside the range of previously observed Sockeye escapements in Portage, biological models (including the selected Larkin model) must be extrapolated outside their fitted range in order to produce forecasts for 2014, translating into uncertain biological forecasts for this stock.

Weaver (Harrison (U/S)-L CU)

The 2010 brood year escapement for Weaver (25,300 EFS) was within the cycle average range (1966-2006: 32,800 EFS), however, it was similar to the average across all cycles (1966-2010: 22,900 EFS) to which fry survivals and fry abundances are compared (Table 1, column C). Early freshwater survival in the 2010 brood year (1,700 fry/EFS) was similar to average (1966-2010 average: 1,600 fry/EFS), and the resulting juvenile abundance (45 million fry) was greater than the average (1966-2010 average: 31 million fry).

Average four year old survival (R/EFS) for Weaver Sockeye has been variable, with the largest peak of 41.8 R/EFS occurring in the late-1960 brood years (four year average at peak). This stock has not exhibited systematic survival trends through time (Grant et al. 2011; Peterman & Dorner 2012). Similar to other stocks, however, Weaver exhibited one of its lowest survivals on record (1.7 R/EFS) in the 2005 brood year (i.e. 2009 four year old return year) (Table 2, columns B to E; Figure 3). In recent years (2006 and 2007 brood years), survival (18.6 R/EFS) has been above average (11.9 R/EFS).

For Weaver, the top ranked models are the MRS, Ricker (PDO), and RJC (Table 5). None of the top models based on average ranks across performance measures had performance measure that were within the top 50% across all performance measures (17 out of 33) of all models compared for this stock (Table 5 in MacDonald & Grant, 2012); the MRS model ranked particularly low on the MPE performance measure, and the Ricker (PDO) and RJC models ranked poorly on the MRE performance measure. Forecasts produced by the top ranked models were similar, varying by 33% (Table 5). The MRS model was used for the 2014 Weaver forecast, because it had the highest average rank across all four performance measures. Given the assumptions underlying the MRS model, there is a one in four chance (25% probability) the Weaver Sockeye return will be below 176,000 (6.3 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 591,000 (21.1 age-4 R/EFS) in 2014. The median (one in two chance: 50% probability) forecast of 323,000 (11.5 age-4 R/EFS) is smaller than the average return on this cycle (576,000), though it is similar to the average return across cycles (361,000) (Tables 1 & 2; Figure 3). The five year old component of the 2014 return is expected to contribute 10% of the total forecasted return (at the 50% probability level) (Table 3).

Birkenhead (Lillooet-Harrison-L CU)

The 2010 brood year escapement for Birkenhead (67,800 EFS) was similar to the cycle average (69,600 EFS) from 1950-2006 (Table 1, column C). Heavy rainfall and high water levels in the Birkenhead system resulted in the breach and subsequent removal of the Birkenhead counting fence. Although the assessment for this system was considered incomplete in 2010, the bias of the near-final estimate was considered low at 1% (K. Benner, DFO, per. comm.). Spawning success in 2010 was 98% (time series average: 91%).

Average four year old survival (R/EFS) for Birkenhead Sockeye declined from a peak of 21.5 R/EFS in the early 1970 brood years (four year average at peak), to one of the lowest survivals on record (1.2 R/EFS) in the 2005 brood year (i.e. 2009 four year old return year) (Table 2, columns B to E; Figure 3). In recent years (2006 and 2007 brood years), survival (2.6 R/EFS) has been below average (5.5 R/EFS).

For Birkenhead, the top ranked models are the Ricker (Ei), Ricker (tied second) and RAC (tied second) (Table 5). For each individual performance measure, no top model ranked within the top 50% (10 out of 20) of all models compared for this stock (Table 5 in MacDonald & Grant, 2012). Forecasts produced by the top ranked models were similar, varying by 13% (Table 5). The first ranked Ricker (Ei) model was used for the 2014 Birkenhead forecast (Table 5). Given the assumptions underlying the Ricker (Ei) model, there is a one in four chance (25% probability) the Birkenhead Sockeye return will be below 311,000 (2.1 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 831,000 (7.8 age-4 R/EFS) in 2014. The median (one in two chance: 50% probability) forecast of 493,000 (4.2 age-4 R/EFS) is very similar to the average return on this cycle (488,000) (Tables 1 & 2; Figure 3). The five year old component of the 2014 return is expected to contribute 43% of the total forecasted return (at the 50% probability level) (Table 3). Birkenhead has variable age five contributions; the recent average age five proportion of returns is 39% (1980-2010 return years).

All Shuswap Forecasts Combined

Given the large contribution of Shuswap stocks to the total forecast (Early and Late Shuswap stocks contribute 70% to the total forecast), a combined forecast was produced for the entire system (Table 1). Given the assumptions underlying the various models used to forecast Early Shuswap, Early Shuswap miscellaneous, and Late Shuswap stocks, there is a one in four chance (25% probability) the entire Shuswap return will be below 8,443,000 and a three in four chance (75% probability) the return will be below 28,050,000 in 2014. The median (one in two chance: 50% probability) forecast is 15,503,000 (Table 1). The total fry forecast for the entire Shuswap system ranged from 4,062,000 to 38,545,000 at the 25% to 75% probability levels and the median (50% probability level) was 13,190,000. The fry forecast provides support for the use of largely Ricker-based models for the Scotch, Seymour, and Late Shuswap forecasts, given that they predict over-compensation at the high spawner abundances observed in 2010. At the 50% probability level the two forecasts (summed Ricker forms plus non-parametric miscellaneous forecasts versus the fry (Power) forecasts) differ by 15%.

Miscellaneous Non-Shuswap

The 2010 brood year EFS for the miscellaneous Non-Shuswap stocks is 7,423 (this includes populations that rear in the Harrison-Lillooet Lake system not included in the Harrison or Birkenhead forecasts, such as Big Silver and Cogburn). The model used to generate the Non-Shuswap miscellaneous forecast was a non-parametric model that used the recruits-per-spawner from the Birkenhead stock multiplied by the Non-Shuswap miscellaneous stock's brood year escapements (see Appendix 1 to 3 in Grant et al. 2011). Given the assumptions underlying the miscellaneous stocks model, there is a one in four chance (25% probability) the Non-Shuswap miscellaneous stocks' return will be below 33,000 and a three in four chance (75% probability) the return will be below 104,000 in 2014. The median (one in two chance: 50% probability) forecast is 60,000 (Table 1).

Conclusions

The majority of stocks (13 out of 19) had escapements that were above average in the 2010 brood year, while a few (specifically Scotch, Seymour, Harrison, Late Shuswap, and Portage) experienced their largest escapement on record. As a result, these select stocks (Scotch, Seymour, Chilko, Late Shuswap and Portage) together make up the majority (75%) of the forecasted returns.

The high escapements observed for a number of stocks in the 2010 (and 2011 for Harrison) brood year can lead to two forms of uncertainty. First, the precision of forecasts from all models decreases when input variables (in this case escapements) vary from average values; the greater the deviation from average, the larger the variation associated with the forecast. Second, the form of the model at extremely large escapement values is poorly known (e.g. the amount that recruitment may decline at extreme escapements) because there are few observations of outcomes from these extreme values. Thus, model predictions at these extreme levels may be biased and misleading (e.g. Ricker model predictions for Harrison Sockeye; see Table 5). To guard against potential biases associated with the lack of observations at high escapements, juvenile data were used where available to provide alternative forecasts, and results were compared with those obtained from escapement data. Fortunately, inferences from juvenile data are available for the stocks contributing most of the 2014 forecast abundance (i.e. Scotch, Seymour, miscellaneous Early Shuswap, Chilko and Late Shuswap). Generally, forecasts from juvenile data were similar to the selected forecasts based on escapements, which suggests that the degree of compensation implied by the model forms used was reasonable, and the exceptionally large escapements have not caused significant biases in the total Fraser Sockeye forecast. For example, the assumption of overcompensation at higher spawner abundance for the total Shuswap system (Scotch, Seymour, Early Summer miscellaneous, and Late Shuswap), as assumed by the Ricker model forms, is supported by a fry model forecast for the entire system (forecasts using these two approaches differ by 15%).

Similar to 2013, a single forecast scenario is presented for the 2014 forecast (Table 1). Although survival in the 2006 to 2008 brood years (corresponding to the 2010 to 2012 return years) improved for most stocks, following a multi-decadal period of systematic declines in survival observed in most stocks (Grant et al. 2010; Grant et al. 2011; Grant et al. 2012; Peterman & Dorner 2011), in the absence of leading indicators, it is unclear whether average survival will persist through to 2014. Forecast distributions therefore represent the range of survival that Fraser Sockeye stocks have historically exhibited. Survivals associated with each stock's forecast at the different probability levels are presented in both tabular and graphical form (Table 2; Figure 3), so they can be placed in the context of historical survival levels for each stock. Forecasts at the 10% probability level (Table 1, column H) represent lower survivals within the time series of each stock (Table 2, column F), while at the opposite end of the probability distribution (Table 1, column L), forecasts represent higher survivals within the time series' (Table 2, column J). If survival for the 2014 brood year falls below average, as seen within the past decade for most stocks (1995-2005 brood years), returns will fall at the lowest end of the probability distribution (10% probability level). Conversely, if survival falls near the historical time series maximum, returns will fall at the highest end of the probability distribution (90% probability level) (Figures 3 and 4). The median forecast (50% probability level) generally represents long-term average survival for each stock. Therefore, when stock productivities are average, returns will fall close to this median probability level, as was seen in the 2011, 2012, and 2013 return years (see Figures 3 & 4). Although the forecast distributions bracket a wide range of potential returns, they may not capture extreme survival events such as occurred in the 2005 brood year (2009 return).

Due to uncertainty in stock survival through to 2014, an additional sensitivity analysis was conducted as part of the 2014 forecast process, to explore model performance over the generally low survival stock-recruitment time series from the 1997 to 2004 brood years. This scenario could occur if stock productivities observed during this period resume. Unlike the 2014 forecast, the 2014 'Recent Model Performance' sensitivity analysis evaluates the performance of all candidate models, including the recent survival models added in the 2010 forecast (KF, RS4yr, RS8yr). Model performance was evaluated over only the low survival period observed for most stocks (1997-2004 brood years). The median 'Recent Model Performance' forecast is similar to the median 2014 forecast, though the range of forecasts from the 10% to the 90% probability levels is wider. This is due to the models selected, which, for some stocks (Scotch and Late Shuswap), resulted in more uncertain forecasts.

To date, the inclusion of environmental variables has not significantly decreased forecast uncertainty (i.e. it has not significantly explained inter-annual variation in survival). In response to previous forecast recommendations to explore environmental and biological variables, a separate CSAS RPR process was conducted for the 2014 Fraser Sockeye forecast process. Included in the CSAS Special Response are comparisons of the proportional representation of each stock within the Fraser Sockeye forecast to their corresponding proportions in other sampling programs (i.e. adult escapements in 2010, and smolt and juvenile programs in 2012). The 2014 forecast is dominated by the following stocks: Late Shuswap: 51%; Early Shuswap: 16%; Chilko: 11%; Quesnel: 7%; Stellako: 3% and Harrison 2%. These proportions are supported by stock proportions observed in the 2012 downstream Sockeye smolt assessments at Mission, B.C. (smolts from the 2010 brood year), and the 2012 juvenile surveys in the Strait of Georgia and Queen Charlotte Sound (DFO 2014). Other information evaluated in this second CSAS RPR (DFO 2014) includes adult fish condition in the 2010 brood year, subsequent fry and smolt condition in the 2012 smolt year, environmental conditions from 2010 to 2014 following the life-history of this cohort, Strait of Georgia catch-per-unit effort (CPUE), indicators of marine conditions from other species', and jack information.

The 2014 forecast distribution (7.2 million to 72.0 million at the 10% to 90% probability levels) extends beyond the observed frequency distribution of historical Fraser Sockeye returns (Figure 5 A & B). This is in part due to the extremely large brood year escapements observed for many Fraser Sockeye stocks in 2010, particularly Late Shuswap. However, it is also attributed to the practice of summing the forecasts across all stocks for each probability level, which does not take into account inter-stock variability in survival (Figure 4). Therefore, it is recommended that individual stock, or Run Timing group forecasts, are emphasized, as opposed to the total forecast.

Table 1. Fraser Sockeye forecasts for 2014 are presented by stock and timing group from the 10% to 90% probability levels (columns A and H to L). The selected models for each stock are presented in column B. Average run sizes are presented across all cycles (F) and for the 2014 cycle (G). Brood year escapements (smolts for Chilko and Cultus) for four (2010) and five year old (2009) recruits returning in 2014 (columns C & D) are presented and colour coded relative to their cycle average from 1950-2006 (brood year). Forecasted returns (column E), corresponding to the 50% probability level (column J) are also colour coded relative to their cycle average. Color codes represent the following: red (< average), yellow (average) and green (> average), with the average range defined as average +/- 0.5 standard deviations.

A	B	C	D	E	F	G	H	I	J	K	L
Run timing group / Stocks	Forecast Model [b]	BY (10) (EFS)	BY (09) (EFS)	Ret 2014	Mean Run Size: All cycles[c]	Mean Run Size: 2014 cycle[d]	Probability that Return will be at/or Below Specified Run Size [a]: 10%	25%	50%	75%	90%
[xx]Early Stuart	*Ricker (Ei)*	34,200	21,900	-	**308,000**	**126,000**	**132,000**	**189,000**	**299,000**	**476,000**	**709,000**
Early Summer				-	--	--	**730,000**	**1,741,000**	**4,126,000**	**8,470,000**	**16,805,000**
(total excluding miscellaneous)				-	527,000	897,000	523,000	1,279,000	3,111,000	6,845,000	13,898,000
Bowron	*MRS*	4,400	1,000	-	39,000	26,000	8,000	15,000	30,000	60,000	113,000
Fennell	*power*	5,500	700	-	25,000	20,000	9,000	13,000	24,000	41,000	68,000
Gates	*Larkin*	5,900	5,300	-	53,000	18,000	31,000	47,000	79,000	131,000	228,000
Nadina	*MRJ*	11,900	3,700	-	79,000	26,000	26,000	51,000	109,000	233,000	460,000
Pitt	*Larkin*	8,800	18,800	-	71,000	59,000	31,000	46,000	73,000	127,000	208,000
**Scotch	*Ricker*	273,900	2,700	-	113,000	390,000	264,000	678,000	1,542,000	3,328,000	6,993,000
**Seymour	*Ricker*	287,500	3,100	-	147,000	358,000	154,000	429,000	1,254,000	2,925,000	5,828,000
Misc (EShu & Taseko) [e]	*RS (Sc/Se)+RS(Chilko)*	119,500	1,600	-	--	--	198,000	444,000	982,000	1,565,000	2,795,000
Misc (Chilliwack) [f]	*RS (Esum)*	1,500	2,400	-	--	--	4,000	8,000	14,000	26,000	48,000
Misc (Nahatlatch) [f]	*RS (Esum)*	2,900	700	-	--	--	5,000	10,000	19,000	34,000	64,000
Summer					--	--	**2,127,000**	**3,393,000**	**5,699,000**	**10,116,000**	**17,781,000**
(total excluding miscellaneous)					3,879,000	3,483,000	2,118,000	3,377,000	5,670,000	10,058,000	17,667,000
Chilko [g]	*power (juv) (Pi)*	54.9 M	34.4 M	-	1,405,000	1,484,000	1,121,000	1,670,000	2,615,000	4,274,000	6,790,000
Late Stuart	*power*	43,500	43,300	-	554,000	232,000	92,000	172,000	329,000	672,000	1,308,000
Quesnel	*Ricker-cyc*	133,000	82,800	-	1,345,000	1,050,000	467,000	845,000	1,524,000	2,950,000	5,864,000
Stellako	*Larkin*	110,300	15,900	-	461,000	548,000	303,000	437,000	690,000	1,119,000	1,719,000
Raft [h]	*Ricker (PDO)*	2,400	6,000	-	31,000	22,000	17,000	25,000	39,000	63,000	98,000
**Harrison [h & i]	*Adjusted R1C*	399,700	387,100	-	83,000	147,000	118,000	228,000	473,000	980,000	1,888,000
Misc (N. Thomp. Tribs) [h & j]	*R/S (Ra/Fe)*	600	1,000	-	--	--	2,000	3,000	6,000	12,000	23,000
Misc (N. Thomp River) [h & j]	*R/S (Ra/Fe)*	3,200	1,700	-	--	--	7,000	13,000	23,000	46,000	91,000
Late					--	--	**4,248,000**	**7,465,000**	**12,730,000**	**22,059,000**	**36,719,000**
(total excluding miscellaneous)					3,222,000	8,967,000	4,230,000	7,432,000	12,670,000	21,955,000	36,534,000
Cultus [g]	*MRJ*	318,400	174,000	-	39,000	36,000	3,000	6,000	13,000	28,000	56,000
**Late Shuswap	Ricker-cyc	3.1 M	20,200	-	2,414,000	7,791,000	3,900,000	6,894,000	11,730,000	20,240,000	33,503,000
Portage	*Larkin*	26,700	800	-	43,000	76,000	20,000	45,000	111,000	265,000	657,000
Weaver	*MRS*	25,300	12,900	-	361,000	576,000	102,000	176,000	323,000	591,000	1,019,000
[xx]Birkenhead	*Ricker (Ei)*	67,800	34,500	-	365,000	488,000	205,000	311,000	493,000	831,000	1,299,000
Misc. non-Shuswap [k]	*R/S (Lillooet-Harrison)*	7,400	5,100	-	--	--	18,000	33,000	60,000	104,000	185,000
TOTAL SOCKEYE SALMON					--	--	**7,237,000**	**12,788,000**	**22,854,000**	**41,121,000**	**72,014,000**
(TOTAL excluding miscellaneous)					**7,936,000**	**13,473,000**	**7,003,000**	**12,277,000**	**21,750,000**	**39,334,000**	**68,808,000**

****Note that for Scotch, Seymour, Harrison, Late Shuswap and Portage Creek, these stocks were forecast using record brood year EFS, as a result, these forecasts are particularly uncertain given the forecast models are extrapolating beyond the observed data range.**

****Note that Early Stuart and Birkenhead, for different reasons, have biased brood year escapement estimates in 2010, which adds additional uncertainty to the 2014 forecasts.**

a. Probability that return will be at, or below, specified projection
b. See Table 5 for model descriptions
c. Sockeye: 1953-2010 (depending on start of time series
d. Sockeye: 1954-2010 (depending on start of time series
e. Misc. Early Shuswap stocks use Scotch and Seymour R/EFS in forecast; Misc. Taseko uses Chilko R/EFS in forecast
f. Misc. Chilliwack & Nahatlach use Early Summer Run stocks R/EFS in forecast
g. Brood year smolts in columns C & D (not effective females)
h. Raft, Harrison, Miscellaneous North Thompson stocks moved in current forecast to Summer Run timing group due to changes in run timing of these stocks
i. Harrison are age-4 (column C) and age-3 (column D
j. Misc. North Thompson stocks use Raft & Fennel R/EFS in forecast
k. Misc. Late Run stocks (Harrison Lake downstream migrants including Big Silver, Cogburn, etc.) use Birkenhead R/EFS in forecast

** Harrison forecasts are extremely uncertain due to age-proportion variations and brood year escapements (2010/2011) that are out of the historical data range

Definitions: BY: Brood year; BY9: brood year 2009; BY10: brood year 2010; EFS: effective female spawners; Ei (Entrance Island sea-surface-temperature); PDO (Pacific Decadal Oscillation).

Table 2. For each of the 19 forecasted stocks (column A), geometric average four-year old survivals are presented for the entire time series (brood years: 1948-2006) (column B), the highest four consecutive years (column C), the 2005 brood year (one of the lowest survivals on record for all stocks) (column D), and the two most recent brood years with recruitment data (2006 & 2007) (column E). Four-year old survivals associated with the various probability levels of the 2014 forecast (based on Table 1 forecasts and escapements) are presented in columns (F) to (J) for comparison. Forecast survivals are presented as R/EFS. Colour codes represent the following: Red (< average), yellow (average) and green (>average), with the average range defined as average +/- 0.5 standard deviation.

A	B	C	D	E	F	G	H	I	J
Run timing group / Stocks	Average	Peak Average (Over Four Consecutive Years)	2005 Brood Year	Avg R/EFS (2006-07)	2014 forecast survivals (R/EFS) for each probability level in Table 3 by stock				
					10%	25%	50%	75%	90%
Early Stuart	6.3	24.5	1.5	5.2	3.0	4.5	7.7	12.7	19.6
Early Summer									
Bowron	6.9	20.4	2.2	13.4	1.7	3.2	6.4	12.9	24.2
Fennell	6.9	53.5	0.3	1.3	1.0	1.9	3.7	6.7	12.0
Gates	9.6	41.0	1.6	41.0	3.9	6.2	11.1	20.3	35.7
Nadina	6.1	13.5	1.0	9.9	2.0	4.0	8.6	18.3	36.2
Pitt (age5 prod) [a]	3.6	13.3	0.2	2.5	1.0	1.6	3.0	5.6	10.0
Scotch	6.9	21.5	2.1	11.9	1.0	2.5	5.6	12.1	25.5
Seymour	7.8	29.2	3.4	7.5	0.5	1.5	4.4	10.2	20.3
Summer									
Chilko (% R/smolt) [b]	7%	18%	0.3%	5%	2%	3%	4%	7%	11%
Late Stuart	9.3	57.2	0.7	3.8	1.5	2.8	6.2	13.7	29.0
Quesnel [c]	9.4	18.1	0.3	3.7	2.8	5.6	10.5	21.1	43.7
Stellako	7.0	15.1	0.1	5.3	2.3	3.6	5.9	9.7	15.0
Raft	5.9	13.6	0.4	2.1	2.0	3.5	7.1	13.2	22.3
Harrison [d]	7.3	33.8	0.1	26.0	NA	NA	NA	NA	NA
Late									
Cultus (% R/smolt) [b]	4%	15%	1%	4%	1%	2%	4%	9%	17%
Late Shuswap [c]	9.3	10.8	3.0	9.8	1.3	2.2	3.8	6.5	10.8
Portage	13.5	61.7	0.3	7.0	0.7	1.6	4.1	9.8	24.5
Weaver	11.9	41.8	1.7	18.6	3.7	6.3	11.5	21.1	36.4
Birkenhead	5.5	21.5	1.2	2.6	1.0	2.1	4.2	7.8	15.0

a. Pitt is dominated by five-year olds, therefore, five-year old survival is presented;
b. Chilko and Cultus are marine survival (recruits per smolt)
c. Quesnel and Late Shuswap are cycle averages
d. Harrison is presented as total survival given the variable four year old proportion; therefore, forecasts could not be compared (NA)

Table 3. Age composition of forecasted returns for each stock at the 50% probability level

Sockeye stock/timing group	2014 Fraser Sockeye Forecasts				
	Model	FOUR YEAR OLDS 50%[a]	FIVE YEAR OLDS 50%[a]	TOTAL 50%[a]	Four Year Old Proportion
Early Stuart	*Ricker (Ei)*	**263,000**	**36,000**	**299,000**	**88%**
Early Summer		**4,030,000**	**96,000**	**4,126,000**	**98%**
Bowron	*MRS*	28,000	2,000	30,000	93%
Fennell	*power*	20,000	4,000	24,000	83%
Gates	*Larkin*	65,000	14,000	79,000	82%
Nadina	*MRJ*	102,000	7,000	109,000	94%
Pitt	*Larkin*	17,000	56,000	73,000	23%
Scotch	*Ricker*	1,540,000	2,000	1,542,000	100%
Seymour	*Ricker*	1,251,000	3,000	1,254,000	100%
Misc (EShu & Taseko)	*RS (Sc/Se)+RS(Chilko)*	981,000	1,000	982,000	100%
Misc (Chilliwack)	*RS (Esum)*	9,000	5,000	14,000	64%
Misc (Nahatlatch)	*RS (Esum)*	17,000	2,000	19,000	89%
Summer		**5,069,000**	**630,000**	**5,699,000**	**89%**
Chilko	*power (juv) (Pi)*	2,394,000	221,000	2,615,000	92%
Late Stuart	*power*	271,000	58,000	329,000	82%
Quesnel	*Ricker-cyc*	1,392,000	132,000	1,524,000	91%
Stellako	*Larkin*	652,000	38,000	690,000	94%
Raft	*Ricker (PDO)*	17,000	22,000	39,000	44%
Harrison[b]	*Adjusted LLY*	321,000	152,000	473,000	68%
Misc (N. Thomp. Tribs)	*R/S (Ra/Fe)*	3,000	3,000	6,000	50%
Misc (N. Thomp River)	*R/S (Ra/Fe)*	19,000	4,000	23,000	83%
Late		**12,453,000**	**277,000**	**12,730,000**	**98%**
Cultus	*MRJ*	13,000	0	13,000	100%
Late Shuswap	*Ricker-cyc*	11,715,000	15,000	11,730,000	100%
Portage	*Larkin*	110,000	1,000	111,000	99%
Weaver	*MRS*	292,000	31,000	323,000	90%
Birkenhead	*Ricker (Ei)*	282,000	211,000	493,000	57%
Misc. non-Shuswap	*R/S (Lillooet-Harrison)*	41,000	19,000	60,000	68%
Total		**21,815,000**	**1,039,000**	**22,854,000**	**95%**

a. Probability that actual return will be at or below specified run size

b. Harrison are four (in four year old columns) and three (in five year old columns) year old forecasts

Table 4. List of candidate models organized by their two broad categories (non-parametric and biological) with descriptions. Models that emphasize recent stock survival are indicated. Models are described in detail in Appendices 1 to 3 of Grant et al. (2010). Where applicable, models use effective female spawner data (EFS) as a predictor variable unless otherwise indicated by '(juv)' or '(smolt)' next to the model (Tables 1 & 2), where fry data or smolt data are used instead.

MODEL CATEGORY		DESCRIPTION
A. Non-Parametric Models		
R1C	(recent survival)	Return from 4 years previous
R2C	(recent survival)	Average return from 4 & 8 years previous
RAC		Average return on the cycle line on the time series
TSA		Average return across all cycles lines on the time series
RS1	(recent survival)	Product of average survival from 4 years previous and EFS (or juv/smolt)
RS2	(recent survival)	Product of average survival from 4 & 8 years previous and EFS (or juv/smolt)
RS4yr	(recent survival)	Product of average survival from the last 4 years and EFS (or juv/smolt)
RS8yr	(recent survival)	Product of average survival from the last 4 & 8 years and EFS (or juv/smolt)
MRS		Product of average survival from entire time series and brood year EFS (or juv/smolt)
RSC		Product of average cycle-line survival (entire time-series) and brood year EFS (or juv/smolt)
RS (used for miscellaneous stocks)		Product of average survival on time series for specified stocks and EFS (or juv/smolt)
B. Biological Models		
power		Bayesian
power-cyc		Bayesian (cycle line data only)
Ricker		Bayesian
Ricker-cyc		Bayesian (cycle line data only)
Larkin		Bayesian
Kalman Filter Ricker	(recent survival)	Bayesian
Smolt-jack		Bayesian
C. Biological Models Covariates		(e.g. Power (FrD-mean))
FrD-mean		Mean Fraser discharge (April - June)
Ei		Entrance Island spring sea-surface temperature
Pi		Pine Island spring sea-surface temperature
FrD-peak		Peak Fraser Discharge
PDO		Pacific Decadal Oscillation
SSS		Sea Surface Salinity (Race Rocks & Amphitrite Point light house stations) from July to September

Table 5. Top three ranked model forecasts evaluated for each stock for the 2014 forecast. Model ranks determined from the 2010 forecast jackknife analysis results (MacDonald & Grant 2012) using four performance measures (mean raw error: MRE, mean absolute error: MAE, mean proportional error: MPE, and root mean square error: RMSE). Forecasts marked with an asterisks (*) indicate that the model is being extrapolated outside its fitted range due to large brood year escapements.

RUN TIMING GROUP: EARLY STUART

	Rank	Return Forecast				
EARLY STUART		**10%**	**25%**	**50%**	**75%**	**90%**
Ricker (Ei)	**1**	**132,000**	**189,000**	**299,000**	**476,000**	**709,000**
Ricker (Pi)	1	128,000	182,000	301,000	440,000	710,000
Ricker	3	95,000	139,000	237,000	428,000	639,000
Ricker (PDO)	3	117,000	189,000	307,000	499,000	870,000

RUN TIMING GROUP: EARLY SUMMER

	Rank	Return Forecast				
BOWRON		**10%**	**25%**	**50%**	**75%**	**90%**
MRS	**1**	**8,000**	**15,000**	**30,000**	**60,000**	**113,000**
Ricker (Pi)	2	14,000	22,000	36,000	58,000	99,000
Ricker (Ei)	3	14,000	21,000	36,000	61,000	96,000

	Rank	Return Forecast				
FENNELL		**10%**	**25%**	**50%**	**75%**	**90%**
power	**1**	**9,000**	**13,000**	**24,000**	**41,000**	**68,000**
RAC	2	5,000	10,000	20,000	38,000	70,000
Ricker	3	11,000	17,000	32,000	58,000	91,000

	Rank	Return Forecast				
GATES		**10%**	**25%**	**50%**	**75%**	**90%**
RAC	1	6,000	9,000	15,000	26,000	42,000
R2C	2	7,000	12,000	22,000	40,000	68,000
Larkin	**3**	**31,000**	**47,000**	**79,000**	**131,000**	**228,000**
MRS	3	15,000	30,000	63,000	133,000	260,000
Ricker (Pi)	6	30,000	50,000	84,000	138,000	248,000
power	6	21,000	32,000	55,000	94,000	149,000

	Rank	Return Forecast				
NADINA		**10%**	**25%**	**50%**	**75%**	**90%**
MRJ	**1**	**26,000**	**51,000**	**109,000**	**233,000**	**460,000**
Ricker (FrD-peak)	2	15,000	23,000	42,000	70,000	126,000
power (juv) (FrD-peak)	2	31,000	52,000	97,000	176,000	323,000

	Rank	Return Forecast				
PITT		**10%**	**25%**	**50%**	**75%**	**90%**
Larkin	**1**	**31,000**	**46,000**	**73,000**	**127,000**	**208,000**
TSA	2	20,000	37,000	71,000	138,000	250,000
Ricker (PDO)	3	39,000	61,000	100,000	164,000	265,000

	Rank	Return Forecast				
SCOTCH		**10%**	**25%**	**50%**	**75%**	**90%**
Larkin*	1	105,000	415,000	1,847,000	10,943,000	38,625,000
Ricker*	**2**	**264,000**	**678,000**	**1,542,000**	**3,328,000**	**6,993,000**
RS1	3	462,000	1,201,000	3,473,000	10,040,000	26,104,000
Four-Year Old Forecasts						
(Shuswap Power(fry) x prop Scotch EFS)	NA	96,000	297,000	964,000	2,816,000	6,897,000
(sibling)	NA	220,000	500,000	680,000	930,000	2,120,000

	Rank	Return Forecast				
SEYMOUR		**10%**	**25%**	**50%**	**75%**	**90%**
Ricker-cyc*	1	6,000	22,000	91,000	549,000	2,544,000
Larkin*	2	42,000	120,000	474,000	1,778,000	5,085,000
R1C	2	295,000	543,000	1,071,000	2,112,000	3,892,000
Ricker*	**10**	**154,000**	**429,000**	**1,254,000**	**2,925,000**	**5,828,000**
power*	10	346,000	645,000	1,313,000	2,515,000	4,669,000
Four-Year Old Forecasts						
(Shuswap Power(fry) x prop Seymour EFS)	NA	101,000	311,000	1,009,000	2,950,000	7,224,000
(sibling)	NA	110,000	360,000	560,000	880,000	2,940,000

RUN TIMING GROUP: SUMMER

CHILKO	Rank	Return Forecast 10%	25%	50%	75%	90%
power (juv) (Pi)	**1**	**1,121,000**	**1,670,000**	**2,615,000**	**4,274,000**	**6,790,000**
power (juv)	3	1,170,000	1,696,000	2,505,000	4,005,000	6,100,000
power (juv) (FrD-peak)	4	954,000	1,388,000	2,210,000	3,675,000	5,645,000
Four-Year Old Forecasts						
(sibling)	NA	878,000	1,470,000	2,569,000	4,494,000	7,427,000

LATE STUART	Rank	Return Forecast 10%	25%	50%	75%	90%
R1C	1	36,372	78,434	184,210	432,636	932,958
R2C	2	36,825	81,645	197,752	478,975	1,061,933
power	**3**	**92,041**	**172,200**	**329,050**	**672,200**	**1,307,600**

QUESNEL	Rank	Return Forecast 10%	25%	50%	75%	90%
R1C	1	144,000	285,000	609,000	1,301,000	2,580,000
R2C	2	143,000	295,000	664,000	1,492,000	3,092,000
Ricker-cyc	**3**	**467,000**	**845,000**	**1,524,000**	**2,950,000**	**5,864,000**
Larkin	4	783,000	1,276,000	2,138,000	3,657,000	6,282,000
Ricker	6	427,000	756,000	1,416,000	2,737,000	4,987,000
Power(juv)	N/A	296,000	603,000	1,318,000	2,904,000	6,495,000

STELLAKO	Rank	Return Forecast 10%	25%	50%	75%	90%
R2C	1	114,000	194,000	352,000	638,000	1,090,000
Larkin	**2**	**303,000**	**437,000**	**690,000**	**1,119,000**	**1,719,000**
Ricker (Ei)	3	239,000	371,000	613,000	1,063,000	1,668,000

RAFT	Rank	Return Forecast 10%	25%	50%	75%	90%
Ricker (PDO)	1	**17,000**	**25,000**	**39,000**	**63,000**	**98,000**
Ricker-cyc	2	9,000	15,000	24,000	39,000	60,000
power	2	12,000	19,000	29,000	45,000	72,000

HARRISON	Rank	Return Forecast 10%	25%	50%	75%	90%
Ricker (Ei)	1	100	300	2,000	10,000	52,000
Ricker (FrD-peak)	2	200	800	5,000	27,000	159,000
R2C	2	155,000	328,000	756,000	1,741,000	3,689,000
Adjusted R1C*	**N/A**	**118,000**	**228,000**	**473,000**	**980,000**	**1,888,000**
Four-Year Old Forecasts						
Adjusted R1C*	NA	80,000	155,000	321,000	665,000	1,282,000
(sibling)	NA	20,000	50,000	150,000	470,000	1,440,000

RUN TIMING GROUP: LATE

CULTUS	Rank	Return Forecast 10%	25%	50%	75%	90%
MRJ	**1**	**3,000**	**6,000**	**13,000**	**28,000**	**56,000**
Power (juv) (FrD-peak)	2	4,000	7,000	15,000	34,000	69,000
Power (juv) (Pi)	3	4,000	8,000	15,000	32,000	66,000
Four Year Old Forecasts						
(sibling)		2,000	5,000	14,000	39,000	95,000
(sibling - post 2000)		7,000	11,000	16,000	24,000	37,000

LATE SHUSWAP	Rank	Return Forecast 10%	25%	50%	75%	90%
R1C	1	3,279,000	7,216,000	17,334,000	41,641,000	91,641,000
Ricker-cyc*	**2**	**3,900,000**	**6,894,000**	**11,730,000**	**#######**	**33,503,000**
RAC	3	1,724,000	3,519,000	7,776,000	17,180,000	35,064,000
Larkin*	5	625,000	1,501,000	3,592,000	8,570,000	18,890,000
Ricker*	7	1,587,000	3,987,000	9,699,000	22,333,000	42,173,000
power*	11	1,971,000	4,722,000	10,640,000	24,070,000	48,076,000
Four Year Old Forecasts						
Ricker-cyc*		3,897,000	6,875,000	11,715,000	20,225,000	33,485,000
Larkin*		480,000	1,447,000	3,554,000	8,567,000	18,890,000
Ricker*		1,507,000	3,906,000	9,692,000	22,328,000	42,173,000
power*		1,699,000	4,647,000	10,545,000	24,038,000	48,076,000
(Shuswap Power(fry) x prop L-Shuswap EFS)		1,078,000	3,329,000	10,808,000	31,584,000	77,350,000
(sibling)		5,470,000	7,000,000	8,830,000	11,180,000	14,240,000

TOTAL SHUSWAP (ALL STOCKS)	Rank	Return Forecast 10%	25%	50%	75%	90%
Various (includes misc. stocks)	**10**	**4,515,000**	**8,443,000**	**15,503,000**	**28,050,000**	**49,108,000**
Four-Year Old Forecasts						
Shuswap Power(fry)	NA	1,316,000	4,062,000	13,190,000	38,545,000	94,398,000

PORTAGE	Rank	Return Forecast 10%	25%	50%	75%	90%
Larkin*	**1**	**20,000**	**45,000**	**111,000**	**265,000**	**657,000**
Ricker-cyc*	2	14,000	29,000	65,000	142,000	308,000
power*	4	27,000	54,000	122,000	276,000	503,000

WEAVER	Rank	Return Forecast 10%	25%	50%	75%	90%
MRS	**2**	**102,000**	**176,000**	**323,000**	**591,000**	**1,019,000**
Ricker (PDO)	3	176,000	285,000	479,000	870,000	1,524,000
RJC	5	150,000	255,000	460,000	829,000	1,409,000

BIRKENHEAD	Rank	Return Forecast 10%	25%	50%	75%	90%
Ricker (Ei)	**1**	**205,000**	**311,000**	**493,000**	**831,000**	**1,299,000**
Ricker	2	181,000	273,000	429,000	704,000	1,114,000
RAC	2	90,000	196,000	464,000	1,101,000	2,396,000

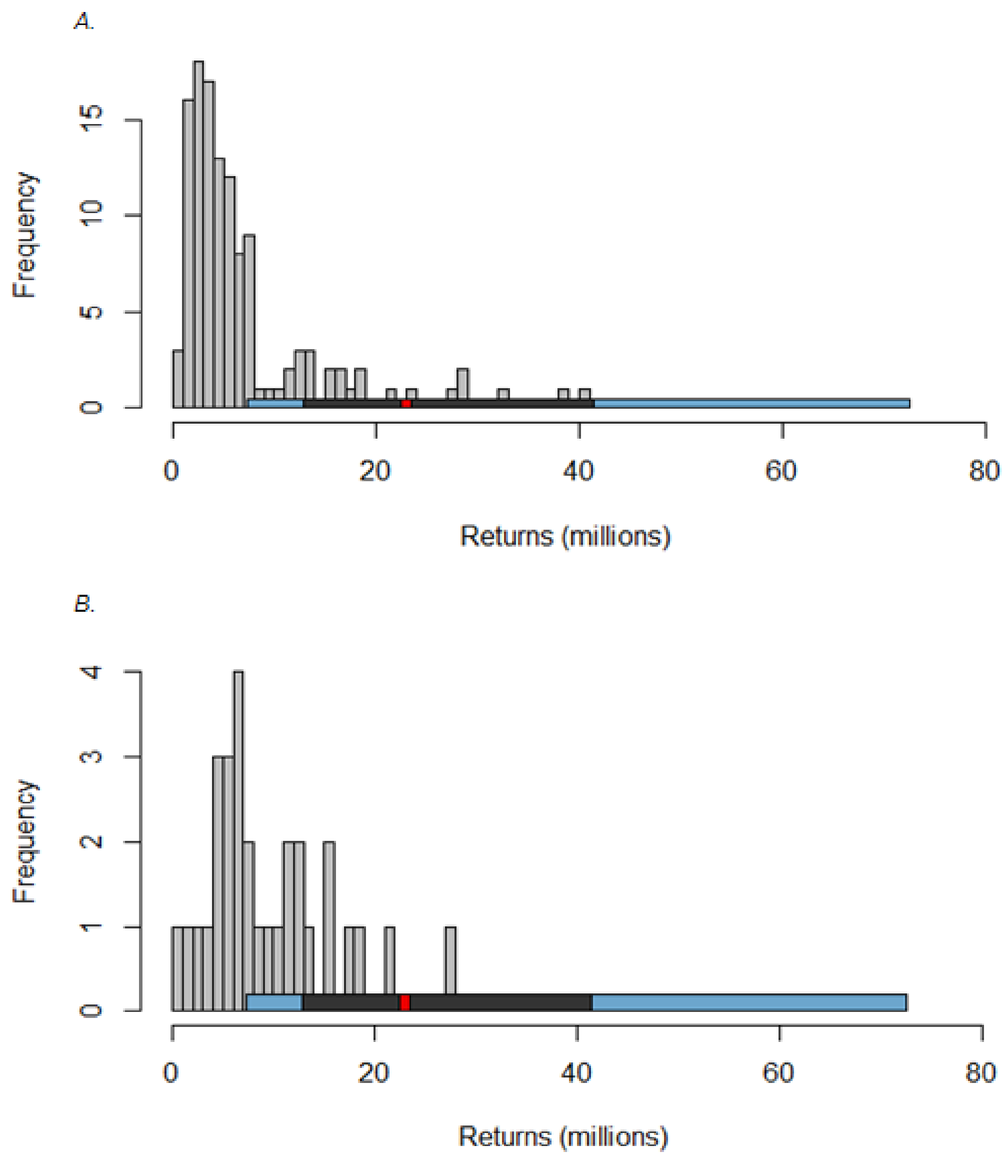

Figure 5. *Frequency distributions of historical Fraser Sockeye returns (1893-2012) on A. all cycles, and B. the 2014 cycle line. X-axes indicate return abundances in millions and y-axes indicate the frequency of abundances in each interval. Plots are overlaid with the total 2014 forecast cumulative probability distribution, from the 10% to the 90% probability levels. Colour-coding differentiates the probability levels with the full width of the blue bars representing the 10% to 90% probability levels, the width of the black bars representing the 25% to 75% probability levels, and the red vertical line representing the 50% probability level.*

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Sources of information

This Science Response Report results from the Science Special Response Process of January 2014 on the review of pre-season run size forecasts for Fraser River Sockeye (*Oncorhynchus nerka*) salmon in 2014.

Additional publications from this process will be posted on the Fisheries and Oceans Canada Science Advisory Schedule as they become available.

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Appendix 1: 'Recent Model Performance' Sensitivity Analysis (this is not the forecast)

An additional sensitivity analysis was conducted to determine the 'Recent Model Performance' forecasts for 2014, using the models identified in the 2012 forecast model selection process (including the Kalman Filter, the RS4yr, and RS8yr). This evaluation identified models that specifically performed well over the range of lower survival seen during the brood years 1997-2004 (see MacDonald & Grant 2012 for details).

Based on this analysis there is a one in four chance (25% probability) the Sockeye return will be at or below 8.9 million, and a three in four chance (75% probability) it will be at or below 42.4 million (*the upper range of this distribution is inflated by the forecast for Scotch, which is extremely uncertain). The mid-point of this distribution (50% probability) is 19.2 million (there exists a one in two chance the return will be above or below this value assuming the productivities implied by the best models evaluated over the recent data set).

Table A1. Sensitivity Analysis (not the forecast) Fraser Sockeye "Recent Model Performance" forecasts for 2014 are presented by stock and timing group from the 10% to 90% probability levels (columns A and C to G). The selected models for each stock, as determined by assessing the jack-knife results for 1997-2004, are presented in column B. Note: the forecast for Scotch is particularly uncertain.

A	B	C	D	E	F	G
Run timing group		**Probability that Return will be at/or Below Specified Run Size**				
Stocks	**Forecast Model** [b]	**10%**	**25%**	**50%**	**75%**	**90%**
Early Stuart	*KF*	**47,000**	**74,000**	**123,000**	**195,000**	**324,000**
Early Summer		**379,000**	**1,203,000**	**3,677,000**	**14,713,000**	**46,409,000**
(total excluding miscellaneous)		**211,000**	**653,000**	**2,559,000**	**13,197,000**	**44,637,000**
Bowron	*KF*	8,000	12,000	20,000	33,000	58,000
Fennell	*Power*	9,000	13,000	24,000	41,000	68,000
Gates	*KF*	13,000	24,000	44,000	79,000	142,000
Nadina	*MRJ*	26,000	51,000	109,000	233,000	460,000
Pitt	*KF*	8,000	18,000	41,000	90,000	199,000
Scotch	*Larkin*	105,000	415,000	1,847,000	10,943,000	38,625,000
Seymour	*Larkin*	42,000	120,000	474,000	1,778,000	5,085,000
Misc (Eshu & Taseko)	*RS (Sc/Se)+RS(Chilko)*	164,000	541,000	1,097,000	1,464,000	1,709,000
Misc (Chilliwack)	*RS (Esum)*	2,000	4,000	9,000	22,000	27,000
Misc (Nahatlatch)	*RS (Esum)*	2,000	5,000	12,000	30,000	36,000
Summer		**892,000**	**1,443,000**	**2,358,000**	**3,915,000**	**6,480,000**
(total excluding miscellaneous)		**888,000**	**1,433,000**	**2,342,000**	**3,877,000**	**6,426,000**
Chilko	*KF(juv)*	488,000	809,000	1,263,000	1,917,000	2,888,000
Late Stuart	*RS4yr*	17,000	43,000	117,000	318,000	781,000
Quesnel	*KF*	68,000	125,000	241,000	468,000	914,000
Stellako	*Larkin*	303,000	437,000	690,000	1,119,000	1,719,000
Raft	*Power*	12,000	19,000	29,000	45,000	72,000
Harrison	*Ricker (Ei)*	100	300	2,000	10,000	52,000
Misc (N. Thomp. Tribs)	*R/S (Ra/Fe)*	1,000	2,000	3,000	8,000	11,000
Misc (N. Thomp River)	*R/S (Ra/Fe)*	3,000	8,000	13,000	30,000	43,000
Late		**2,450,000**	**6,244,000**	**12,754,000**	**25,762,000**	**50,537,000**
(total exlcuding miscellaneous)		***2,440,000***	***6,223,000***	***12,731,000***	***25,724,000***	***50,488,000***
Cultus[c]	*Smolt-Jack (trunc)*	4,000	6,000	8,000	12,000	15,000
Late Shuswap	*Ricker (Pi)*	2,316,000	6,003,000	12,310,000	24,903,000	48,974,000
Portage	*KF*	2,000	4,000	11,000	34,000	84,000
Weaver	*MRS*	102,000	176,000	323,000	591,000	1,019,000
Birkenhead	*RS4yr*	16,000	34,000	79,000	184,000	396,000
Misc. non-Shuswap	*R/S (Lillooet-Harrison)*	10,000	21,000	23,000	38,000	49,000
TOTAL SOCKEYE SALMON		**3,768,000**	**8,964,000**	**18,912,000**	**44,585,000**	**103,750,000**
(TOTAL excluding miscellaneous)		***(3,586,000)***	***(8,383,000)***	***(17,755,000)***	***(42,993,000)***	***(101,875,000)***

a. Probability that return will be at, or below, specified projection
b. See Table 5 for model descriptions
c. Cultus smolt-jack model uses a truncated post-1991 marine survival time series

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