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PRE-SEASON RUN SIZE FORECASTS FOR FRASER RIVER SOCKEYE *(ONCORHYNCHUS NERKA)* AND PINK (*O. GORBUSCHA*) SALMON IN 2017

Context

Low numbers of Fraser Sockeye salmon are expected to return in 2017 compared to both the cycle average (8.4 million) and the all-year average (7.9 million). The median (50% probability level) total Fraser Sockeye forecast of 4.4 million is close to half of the 2017 cycle average. The 2017 forecast ranges from 1.3 million to 17.6 million at the 10% and 90% probability-levels. Fraser Sockeye returns have fallen at or below the median forecasts for the past 12 years, excluding 2010, indicating average to below average survivals. In the past two return years (2015 and 2016), total returns corresponded to the 10% probability level forecasts, indicating poor survival for the Fraser Sockeye aggregate. Although the more abundant Summer-run stocks exhibited notably poor survival in these years, individual stock survival ranged from poor to above average. Most Fraser Sockeye that returned in 2015 and 2016 entered the Northeast Pacific Ocean in 2013 and 2014, respectively. This timing coincided with the development of unusually warm temperatures in the Northeast Pacific Ocean in late 2013, referred to as the ‘warm blob’. During this period, ocean temperatures were 3°C to 4°C above the seasonal average, and extended down to depths of 100 m. Given the persistence of extremely warm ocean temperatures through 2016, and the known association between warm ocean conditions and reduced survival of British Columbia (BC) salmon populations (Mueter et al. 2005), below average survivals are anticipated for the 2017 total Fraser Sockeye returns.

The effects of extremely warm water temperatures on survival have been incorporated quantitatively into the forecasts for seven stocks where temperature covariate models historically perform well. Although the effect of the warm coastal temperatures on Fraser Sockeye survival is highly uncertain, forecasts for these stocks using temperature covariate models were consistently smaller than forecasts produced by models that exclude these covariates. However, these stocks account for only 15% of the total forecast at the median forecast level. Given that the warm ocean conditions that developed in late 2013 have persisted, median (50% probability level) forecasts based on models that do not include indices of environmental conditions may overestimate returns. Therefore, for the remaining stocks, emphasis on the 25% probability level of the 2017 forecasts is recommended. This is particularly important for the Summer-run timing group because the forecasts for key Summer-run stocks such as Chilko, Late Stuart and Stellako, which are expected to contribute a high proportion (63%) to the total 2017 Fraser Sockeye forecast, were not produced with temperature covariate models. Furthermore, these Summer-run stocks exhibited particularly low survivals in the last two return years (2015 & 2016) (Table 2, column F). Thus, the overall Summer-run return may more closely align with the 25%, rather than the 50% probability level of the forecast.

For some stocks, other factors, such as survival due to delayed-density dependence in freshwater rearing areas, are better at explaining variation in historic returns than models that include environmental covariates. For 2017, a number of stocks (Gates, Scotch, Seymour, Stellako, and Late Shuswap) are expected to exhibit reduced survival due to delayed-density dependence, as represented by the Larkin model. For the Shuswap Lake complex, in particular, the extremely large escapements in 2010 continue to affect the forecasted survival of stocks that rear in this system (Scotch, Seymour, Late Shuswap, and miscellaneous Early Shuswap).

Chilko dominates the 2017 forecast of Fraser Sockeye (48% of the total median forecast); however, this forecast is highly uncertain, especially compared to previous years when smolt data were available. In the absence of reliable smolt abundance data, the forecast uses the brood year escapement to predict returns. The brood year escapement for Chilko in 2013 was the second highest on record (the largest escapement occurred in 2010). Since only one data point exists above the 2013 brood year escapement, the model used to generate the Chilko forecast is not well informed by data in this high abundance range. Additionally, the Chilko forecast was generated by the Larkin model, which includes the unprecedented 2010 brood year escapement as a predictor of delayed-density dependent effects. This data point has a strong positive effect on the forecast distribution, which is more pronounced at the higher probability levels. The large Chilko component of the total Fraser Sockeye forecast (48%) is therefore associated with high uncertainty, due to the lack of data at high escapements to inform the Larkin model.

The non-Chilko Summer-run stocks combined are expected to contribute 28% (Late Stuart: 8%; Stellako: 8%; Harrison: 6%; Quesnel: 4%) to the total median forecast. Although Quesnel historically dominated total Fraser Sockeye returns on the 2017 cycle-line (42%), the 2017 Quesnel forecast is extremely low compared to the cycle average. Quesnel is expected to contribute only 4% of the total 2017 median forecast, due to the combined effects of very low escapement in the 2013 brood year, and poor environmental conditions. The Late Run is expected to contribute 13% of the total Fraser Sockeye median forecast (Late Shuswap: 4%, Weaver: 4%, and Birkenhead: 3%) and the Early Summer Run is expected to contribute 8% to the total. The Early Stuart Run is expected to contribute only a small proportion (2%) to the total median forecast. Note that in the Late Run, Cultus sockeye, which are listed as ‘endangered’ by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), have a 2017 forecast that falls below the WSP abundance benchmark of 12,000 wild spawners (Grant and Pestal 2012) across all probability levels.

The total 2017 forecast of Fraser Pink Salmon ranges from 4 million to 16 million at the 10% and 90% probability-levels, with a median (50% probability level) forecast of 8.7 million. This median forecast is below average (12.4 million). Fraser Pink Salmon forecasts are extremely uncertain given the shifts in enumeration methodology over time, particularly with regards to the recruitment data (changes in escapement and catch methods). Pink Salmon fry abundance in the 2013 brood year was 230 million, which was almost half of the long term average (441 million).

This Science Response Report results from the Science Response Process of December 14, 2016 on the Pre-season abundance forecast for Fraser River Sockeye and Pink Salmon returns in 2017. The 2017 forecast relies on methods of past CSAS processes and publications (Cass et al. 2006, DFO 2006, 2009, 2011, 2012, 2013, 2014a, 2014b, 2015a, 2015b, Grant et al. 2010, Grant and MacDonald 2011, 2013, MacDonald and Grant 2012). To support the 2017 Fraser Sockeye forecast, an additional Science Response process occurred on January 17-18 to summarize data and information on fish condition and/or survival from the 2013 spawners and their offspring.

Background

Fraser Sockeye Salmon Forecasts

Pre-season return forecasts are produced annually for 19 Fraser Sockeye stocks and eight additional miscellaneous stock groups using a suite of forecast models (Table 4). To capture inter-annual random (stochastic) uncertainty in 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 (naïve) models (Grant et al. 2010). Forecast values at each probability level represent the chance that returns will fall at or below that value. 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. The median (50% probability level) forecast, represents an equal chance that returns will fall above or below the forecast value. Forecast values are affected by the assumptions underlying the model (e.g. Ricker vs. power vs. Larkin) used to forecast each stock. For example, model assumptions about density dependence (cohort densities in the brood year) and delayed-density dependence (cohort densities in the brood year, and up to three previous brood years) can affect survivals associated with individual forecasts. Structural uncertainties are explored in the forecast process through the comparison of alternative (lower ranked in terms of model performance) model forecasts (Table 6).

Forecasted values generally reflect the historical survival of each stock (recruits-per-spawner) for a given brood year escapement (or juvenile abundance): lower forecast values represent the low end of historical survivals, and high values the upper end. Since not all stocks exhibit the same survival in a given year, the current method used to estimate the total Fraser Sockeye Salmon return forecast distribution, which involves summing individual stock forecasts at each probability level, over-estimates the range of potential total returns. It is, therefore, more appropriate to reference individual stock forecasts as opposed to the total Fraser Sockeye forecast, where possible, to avoid misinterpretation.

Fraser Sockeye Returns

Total Fraser Sockeye adult returns have historically varied (Figure 1A) due to the four year cyclic pattern of abundances exhibited by some of the larger stocks, and variability in annual survival (Figures 1B & 2) and fisheries. After reaching a peak in the early 1990s, returns subsequently decreased and were particularly low in 2009 (Figure 1A). From 2010 to 2014, returns improved over their brood years. The 2010 and 2014 returns were particularly large since these are years of the dominant Late Shuswap (Adams run) cycle. However, in 2015 and 2016, returns again declined. Preliminary returns in 2016 (~850,000) were the lowest on record (dating back to 1893).

The 2017 cycle-line (which includes the current forecast year) has the second largest average return of the four cycles of Fraser Sockeye, which has an average annual return (1953-2013) of 8.4 million for all 19 forecasted stocks combined (excluding miscellaneous stocks) (Table 1B, column G; Figure 1A). The largest cycle line is the 2014 dominant Late Shuswap cycle line. For the 2017 cycle, Quesnel has historically (until 2009) contributed the greatest proportion (44%) to the total return (Table 1B, column G), followed by Late Stuart (19%), Chilko (11%), Early Stuart (9%), then Birkenhead (4%) and Weaver (3%). All other stocks have historically contributed less than 3% to the total return abundance.

Fraser Sockeye Survival

Total Fraser Sockeye survival (returns-per-spawner) declined in the 1990s and culminated in the lowest survival on record in the 2009 return year. Although survival improved from 2010 to 2014, preliminary estimates of returns in the past two years indicate poor survival (Figure 1 B). The recent low total survivals are driven by the more abundant Summer-run stocks, particularly Chilko Sockeye, and correspond to the 2013 and 2014 ocean entry years. On an individual stock level, survival trends vary (Figure 4; Grant et al. 2011; Peterman & Dorner 2012). Most notably, Harrison Sockeye have exhibited a large increase in survival in the past decade (Grant et al. 2010; Grant et al. 2011), which is likely attributed to their unique age-structure and life-history.

Chilko is the only Fraser Sockeye stock with a long and complete time series of smolt data (estimated using 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) (Figure 2 A & B). Chilko exhibits similar marine survival trends (Figure 2B) to the total Fraser Sockeye aggregate (Figure 1B), since Chilko contributes a relatively large proportion of the total abundance in most years. Chilko exhibited very poor survival associated with the 2015 and 2016 returns, corresponding to the 2013 and 2014 ocean entry years.

The last two years of poor returns, particularly poor for Summer-run stocks such as Chilko, correspond to the notably warm sea surface temperatures in the Northeast Pacific Ocean, referred to as the 'warm blob'.

Environmental Conditions

In the second half of 2013, a warm temperature anomaly, commonly referred to as the 'warm blob', developed in the Northeast Pacific Ocean, and has persisted to date (DFO 2015b). Temperatures observed in 2014 and 2015 were the highest on record over 65 years of modern data collection, reaching 3°C to 4°C above the seasonal average for the upper water column (<100 m depth) of the Gulf of Alaska in early 2014. In late 2014, this 'warm blob' moved coastward, resulting in record high temperatures in some coastal areas of BC.

Warm coastal ocean temperatures during and following salmon ocean entry are associated with reduced survival of salmon stocks in BC and Washington (Mueter et al. 2005). Warm ocean conditions as early as one year prior to outmigration may influence growth (Beamish and Mahnken 2001) and survival (Mueter et al. 2005). Though this may be due to the correlation between coastal conditions and those experienced in freshwater (Mueter et al. 2005). Warm ocean temperatures can trigger changes in the local marine composition of zooplankton, resulting in a larger abundance of warm water copepod species, which are lipid-poor, and a smaller abundance of large cold water copepods, which are lipid-rich and are generally considered to be a good food source for salmonids (DFO 2016b). Warm water may also affect the timing of the peak copepod (*Neocalanus plumchrus*) abundance in the Fraser estuary, which can cause a mis-match between the timing of this peak and the outmigration of Sockeye smolts (Healey 2011).

Poor survival of some Fraser Sockeye stocks in the 2015 (DFO 2016a: Table 5; 2016b; Grant and Michielsens 2016) and 2016 return year (Table 5) could be symptomatic of the warm conditions that persisted throughout the early coastal, ocean feeding, and return migration portions of their life history (DFO 2015b). Chilko marine survival (which includes their downstream migration in the Fraser River), is an indicator of marine survival for other Fraser Sockeye stocks. In the 2011 and 2012 brood years (2015 and 2016 returns), Chilko marine survival was very low (Figure 2 B). However, it is not clear whether the high ocean temperatures influenced the poor Fraser Sockeye returns in 2015 and 2016 since not all Fraser Sockeye experienced poor survival during this time (DFO 2016b, Grant and Michielsens 2016; Table 5). In addition, other Sockeye stocks outside the Fraser River exhibited a substantial increase in returns (e.g. Smith and Rivers Inlet Sockeye to the Central Coast) or strong returns (Somass sockeye and Columbia River sockeye) (K. Hyatt, DFO, Nanaimo, B.C., pers. comm.). Variation in survival amongst stocks may be attributed to differences in their distribution within the Gulf of Alaska during ocean residence (Blackbourn 1987, Welch and Parsons 1993), and the migration of some stocks further north under warmer climate conditions (Welch et al. 1998, Abdul-Aziz et al. 2011). Variation in freshwater conditions during egg incubation and lake rearing stages may have also resulted in survival differences between stocks (DFO 2016b).

The Fraser Sockeye forecasting process has incorporated environmental covariates as part of the suite of models annually explored for the 19 forecasted stocks with stock-recruitment data. Two such environmental variables are measurements of sea surface temperatures (SST): Entrance Island SST (Ei) and Pine Island SST (Pi), and the third is an index of SST: the Pacific decadal oscillation (PDO) (Figure 3). Sea surface temperature data for the Pine Island (average from April to July) lighthouse station, located in Queen Charlotte Strait, indicate a record high temperature in 2015 (10.7 ˚C), falling 1.6˚C above the historical average (1950-2015: 9.1 ˚C), and 0.5˚C above the next highest recorded temperature, which occurred in 1990 (10.2 ˚C) (Figure 3). At the Entrance Island lighthouse station, located in the Strait of Georgia, the average temperature from April to June 2015 (14.6 ˚C) was the second highest on record, falling 2.3 ˚C above the historical average (1950-2015: 12.3 ˚C), and only 0.01˚C below the highest temperature, recorded in 2002. These extreme temperature anomalies are reflected in the PDO index (November to March), which indicates a deviation of 2.2 ˚C above average for the winter of 2014/2015 (Figure 3).

Additional uncertainty is associated with forecasts produced for 2017 using the temperature covariate data. Specifically, since the 2015 temperatures fall out of the range of previously observed data for the Pi and PDO variables, models that use these data are extrapolated outside of their fitted range to generate forecasts. For the Ei covariate, there is only one other observation in the range of the recorded temperature for 2015, therefore additional uncertainty also affects forecasts produced using these data.

The majority of Fraser Sockeye returning in 2017 (four year olds) entered the marine environment in 2015 during record high temperatures. In light of these high temperatures, a separate analysis was conducted to investigate forecast model performance in warm years (Appendix 2). In this analysis, models were ranked based on their performance in years that fell within the highest 25% of the observed environmental variable range (warmest temperatures). Stocks were included in the analysis if a temperature covariate model ranked in the top three performing forecast models, and the highest ranking model was a Ricker-based (power(juv)-based where juvenile data are available) or non-biological model. In this analysis, models that include temperature covariates (Ei, Pi & PDO) performed better than the basic Ricker or power(juv) models for all seven stocks examined (Early Stuart, Bowron, Quesnel, Raft, Cultus, Weaver & Birkenhead) (Table A2). For these stocks, forecasts produced by the temperature covariate models are consistently lower than forecasts produced without these covariates (Table 6 & A2).

Understanding the effects of warm ocean conditions on Fraser Sockeye survival is challenging, given the mixed response of stocks to the recently observed ‘warm blob’ conditions in the Northeast Pacific Ocean (DFO 2014b, 2015b, 2016b). However, where ocean temperatures were quantitatively accounted for in the forecasts, there is a consistent, and in some cases quite strong, signal that many Fraser Sockeye stocks will experience lower survival in the 2017 return.

2017 Forecast Brood Year Escapements (2012 & 2013)

Most Fraser Sockeye return as four year olds, typically spending their first two winters in freshwater and their last two winters in the ocean. A smaller proportion of returns (average: 20%) spend an additional winter in the marine environment and return as five year olds. The proportion of four and five year old fish in Fraser Sockeye returns varies, due to the combination of varying age-at-maturity among stocks, differences in escapements between the four and five year old brood years, and differences in survival of each of these cohorts.

Fraser Sockeye that will return as four year olds in 2017 were produced by the 2013 brood year escapement. In the 2013 brood year, the effective female spawner (EFS) abundance for the 19 forecasted stocks combined (excluding miscellaneous stocks) was 1,221,600, which was greater than the cycle average (1,088,500 EFS). For all stocks, including miscellaneous stocks, the 2013 brood year EFS abundances were near or above the long-term (1952-2013) cycle averages, with the exception of five stocks that were below average (Early Stuart, Nahatlach, Late Stuart, Quesnel, and Weaver) (Table 1B). Nine of the 19 stocks had 2013 escapements (or 2015 smolt abundances) that were close to the cycle averages: Bowron, Upper Barriere (Fennell), Nadina, Taseko, Chilliwack, North Thompson River, North Thompson tributaries, Cultus, and Portage, and thirteen stocks had escapements that were well above average: Gates, Pitt, Scotch, Seymour, Miscellaneous Early Shuswap, Chilko, Stellako, Harrison, Raft, Widgeon, Late Shuswap, Birkenhead and Miscellaneous Lillooet-Harrison.

The Chilko stock contributed half (50%) of total 2013 EFS abundance. The next largest contributors to the total EFS abundance were Quesnel (8%), Late Shuswap (7%), Harrison (6%), and Late Stuart (6%). The remaining 14 stocks combined contributed 24% to the total EFS abundance. Although Quesnel was the second largest contributor to the 2013 brood year escapement (8%), note that the Quesnel escapement was well below average for this cycle, as Quesnel generally contributes a large component (average 42%) of the escapement on this cycle.

Pink Salmon Escapement

Fraser Pink returns have varied throughout the time series (Figure 5A), and the average returns have been 12.4 million (Table 1B, column F; Figure 5A). Pink fry abundance in the 2015 brood year was 230 million, which was almost half of the long term average (441 million) (Table 1; Figure 6). Survival (recruits-per-fry) in the last brood year in the time series (2013) was 0.9%, which is well below average (1967-2011 brood years: 3%; Figure 5B). The maximum survival on record for this time series was 10% in 1999 (Figure 5B).

Analysis and Response

Data

Fraser Sockeye data used in the forecast process includes the following:

- The last brood year for which full recruitment data (four and five year olds) are available for the 2017 forecast is 2011, with the exception of Harrison Sockeye (data are included to the 2012 brood year); recruitment estimates for the 2011 (and 2011 and 2012 for Harrison) brood year(s) are preliminary.
- EFS data are included up to the 2013 brood year (2014 for Harrison).
- Juvenile fry data in the 2013 brood year are available for Nadina, Weaver, and Gates. Due to inconsistencies in data collection methods over time, juvenile data are not used to produce forecasts for Gates. Historically, fry data were available for both the channels and

rivers/creeks for these three stocks. In recent years, only channel fry data have been available for Nadina and Weaver; while both channel and creek fry data are available for Gates. Gaps in the historical time series' associated with years without fry data for rivers/creeks were filled using the average historical fry/EFS production multiplied by the relevant brood year EFS.

- Juvenile fall fry data are not available for Shuswap Lake from the 2013 brood year (four year old returns in 2017), as fry assessments are typically only conducted on the dominant (2014 cycle) and subdominant (2015 cycle) brood years in this system. Juvenile trawls were conducted in the Quesnel system for the 2013 brood year, although they were not conducted for the 2012 brood year.
- Juvenile smolt data in the 2013 brood year are available for Cultus.
- Juvenile smolt data in the 2013 brood year are not available for Chilko. High water at the smolt assessment site prohibited the typical weir installation during the 2015 smolt outmigration. Although a rotary screw trap (RST) was deployed *ad hoc* in the 2013 brood year, these smolt estimates are not considered reliable.

In addition to stock-recruitment data, several biological models incorporate environmental data (See MacDonald and Grant (2012) for further details):

- Pacific Decadal Oscillation (PDO) in winter (November to March)
- Average seas-surface temperature (SST) from Entrance Island (Ei; Strait of Georgia, near Nanaimo, B.C. from April to June and Pine Island (Pi; Northeast corner of Vancouver Island) from April to July
- Fraser Discharge (peak (FrD-peak) and average (FrD-average) from April to June measure at Hope, B.C.)

Fraser Sockeye Forecast Methods

The 2017 Fraser Sockeye forecasts follow the same approach as recent forecasts (DFO 2012b; MacDonald & Grant 2012; DFO 2013; Grant and MacDonald 2013; DFO 2014a; DFO 2015a; DFO 2016a), which were adapted from methods used in earlier forecasts (Cass et al. 2006, DFO 2006, 2008, 2009). Model performance, ranking, and the primary model selection process for Fraser Sockeye Salmon are based on the analyses conducted in 2012 (MacDonald & Grant 2012). Given the environmental conditions in the past few years, an additional criterion was added to the 2017 model selection process. Methods are summarized in the bullets below (see Appendix 1 for model selection process by stock for 2017 forecasts):

1. Forecasts are presented in Table 1A. The most appropriate model for each stock is selected based on model performance measures that compare forecasts to observed returns across the full stock-recruitment time series (see #2 - #4 below) in combination with model selection criteria (see #5) and Bayesian convergence criteria (see #6).
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, and sibling models (all model forms are described in Appendices 1 to 3 of Grant et al. 2010).
3. A jackknife (leave-one-out) cross-validation analysis was used to generate the historical forecast time series for each stock and model (MacDonald & 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) (described in Appendix 4 of Grant et al. 2010), which assess the accuracy and/or precision of each model, were used to summarize jackknife cross-validation results and rank models (results are summarized in MacDonald & Grant 2012);
5. The model selection criteria identified in the 2012 forecast (see page 8 of MacDonald and Grant 2012) were applied. In addition, new to the 2017 forecast, a criterion was developed to address the anomalous environmental conditions that have persisted since late 2013 (see Figure 3 for sea-surface temperature anomalies). In cases where the top ranked forecast was a Ricker, power (juvenile), or non-biological model, and a temperature covariate model (Ricker (Ei), Ricker (Pi), or Ricker (PDO)) ranked within the top three models, the forecasting performance of the covariate model specifically in warmer than average years was examined (Appendix 2). Due to the additional information contained in the covariate, the superior ranking of these models in anomalously warm years (Appendix 2; A2), and the consistent signal of lower survival implied by the addition of the covariate across the applicable stocks (A2), the temperature covariate forecast was adopted for these stocks;
6. Forecasts were produced using the top ranked models for each stock, and Bayesian diagnostics were applied to ensure model convergence (see DFO 2015a for an explanation of diagnostic usage).
7. Miscellaneous stocks (except Chilliwack in the 2016 and 2017 forecasts where we used a Ricker model), which do not have recruitment data, were forecast using the product of their brood year escapements and the geometric 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 1A).

Results

Fraser Sockeye 2017 Forecasts: Overview

Fraser Sockeye forecasts are associated with relatively high uncertainty (Table 1A), 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 (DFO 2014a) and research conducted on coast-wide salmon stocks (Haeseker et al. 2007 & 2008).

Low numbers of Fraser Sockeye are expected to return in 2017 compared to both the cycle average (8.4 million) and the all-cycle average (7.9 million). The total forecast of Fraser Sockeye ranges from 1.3 million to 17.7 million at the 10% and 90% probability-levels, with a median forecast of 4.5 million. This median forecast across stocks is slightly more than half the cycle average. The 2017 cycle-line has historically been dominated by Quesnel, which has contributed 42% of the return on average. However, in 2017 the forecast for Quesnel is extremely low compared to average. Quesnel is expected to contribute only 4% of the total median forecast, due to the combined effect of well below average EFS in the 2013 brood year, and environmental conditions. In 2017, Chilko dominates the total median forecast (48% of the total) (Table 1A). The remaining Summer-run stocks are expected to contribute 28% to the total median forecast (Late Stuart: 8%; Stellako: 8%; Harrison: 6%; Quesnel: 4%), the Late Run is expected to contribute 13% (Late Shuswap: 4%, Weaver: 4%, and Birkenhead: 3%) and the Early Summer Run is expected to contribute 8%. The Early Stuart Run is expected to contribute only a small proportion (2%) to the total median forecast (Table 1A).

Returns have generally fallen at or below the median probability level for the past 12 years, excluding 2010, indicating average to below average survivals (Table 7). In the past two years

(2015 and 2016), total returns have fallen at the lowest probability level (10%) (Table 7). Poor survival of some Fraser Sockeye stocks in the 2015 (DFO 2016a: Table 5; DFO 2016b; Grant and Michielsens 2016) and 2016 return year (Table 5) could be symptomatic of the warm conditions that persisted throughout the early coastal, ocean feeding, and return migration portions of their life history (DFO 2015b), and continue to affect coastal waters. Models that include SST covariates were used to generate 2017 forecasts for seven stocks, based on the model selection process identified in this and previous forecast documents. These stocks represent approximately 21% of the 2013 brood year EFS, and 15% of the total median forecast.

The 2017 returns for most stocks are expected to be dominated by four year olds (87%) from the 2013 brood year. Exceptions are two stocks from the Early Summer Run: Chilliwack (85% five year olds) and Pitt (87% five year olds). Harrison is expected to be dominated by three year olds (84%). For Harrison, a sibling model was applied to forecast four year olds in 2017, due to the poor survival of three year olds in 2016. This reduced the four year old forecast for this stock relative to forecasts produced by other models.

Individual Stock Forecasts (See Appendix 1 for Model Selection Rationale)

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

The 2017 return year (2013 brood year) is the dominant cycle year for the Early Stuart stock. The 2013 brood year EFS for the Early Stuart stock (39,700) was less than half the cycle average for this stock (1949-2013 cycle average: 104,600; Table 1B, column C). Spawner success in 2013 was 87% (average: 89%). In the 2012 brood year (five year olds in 2017), EFS for the Early Stuart stock (6,800) was also less than half the cycle average (18,700, Table 1B, column D).

Average (geometric) four year old survival for Early Stuart Sockeye declined from a peak of 24.5 age-4 R/EFS in the mid-1960 brood years (four year consecutive peak average) to one of the lowest survivals on record (1.5 age-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 the most recent generation (2009 to 2012 brood years), the average age-4 survival (5.7 age-4 R/EFS) has been similar to the long-term average (1948-2012 average: 6.3 age-4 R/EFS).

The Ricker (Ei) model was used for the 2017 Early Stuart forecast (Appendix 1). 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 64,000 (the age-4 component of this forecast implies 1.5 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 158,000 (3.8 age-4 R/EFS) in 2017 (Tables 1A & 2; Figure 4). The median forecast of 99,000 (2.4 age-4 R/EFS) is less than 15% of the average return on this cycle (754,000) (Tables 1A, 1B, & 2; Figure 4).

Five year olds contribute 4% (4,000) to the Early Stuart total median forecast due to the small escapement in the 2012 brood year (6,800 EFS), and the high proportion of four year old recruits produced by each brood year on average (Table 3).

Due to the extremely high temperature observed at Entrance Island in 2015, forecasts produced using this covariate fall in a range that is informed by little data, and are therefore associated with increased uncertainty.

Early Summer Run

The Early Summer Run generally contributes less to the total Fraser Sockeye return, compared to the Summer and Late-run timing groups. Seven stocks in the Early Summer Run are forecast using the standard suite of forecast models: Bowron, Upper Barriere (Fennell), Gates, Nadina, Pitt, Scotch, and Seymour (Table 1A). There are also four miscellaneous stocks in this run timing group: Early Shuswap, Taseko, Chilliwack and Nahatlatch. Starting in the 2013 forecast process, Raft River, the North Thompson mainstem, and several stocks associated with miscellaneous streams that are tributary to the North Thompson River, were reassigned to the Summer-run timing group (from the Early Summer-run group), following a re-evaluation of their migration timing by the Fraser Panel in 2012. These reassigned stocks are excluded from the Early Summer Run forecasts in this section.

Escapement in the 2013 brood year for all Early Summer stocks combined (94,700 EFS), was the second largest on record for this cycle. Escapements increased relative to the brood year (2009) for all Early Summer-run stocks in 2013, and were most notable for Gates and South Thompson stocks. The Pitt and Gates stocks comprised more than half of the Early Summer-run total (38% and 24%, respectively); for Gates, the 2013 escapement was the second highest on record. Seymour (15%) and Scotch (12%) contributed the next highest percentages to the total Early Summer-run escapement. Pitt Sockeye, which are comprised of predominantly five year old recruits, had above average brood year escapements in 2013 (35,900 EFS versus an average of 14,900 EFS across cycles) and 2012 (41,400 EFS versus average of 14,900 EFS). Although age-at-maturity for Chilliwack is predominantly four years, Chilliwack is also expected to have a higher contribution of five year old returns in 2017 due to its record escapement in 2012 (79,000 EFS).

Bowron (Bowron-ES CU)

The 2013 brood year escapement for Bowron (1,900 EFS) was 69% of the cycle average (1949-2013 average: 2,800 EFS; Table 1B, column C). The sex ratio for Bowron in 2013 was 40% males and spawner success was 99% (average: 91%). The 2012 brood year escapement for Bowron (30 EFS) (Table 1B, column D) was the lowest on record (1948-2013).

Average (geometric) four year old survival for Bowron Sockeye declined from a peak of 20.4 age-4 R/EFS in the mid-1960 brood years (four year average at peak) to one of the lowest survivals on record (2.2 age-4 R/EFS) in the 2005 brood year (i.e. 2009 four year old return year) (Table 2, columns B to E; Figure 4). In the most recent generation (2009 to 2012 brood years), the average age-4 survival (10.7 age-4 R/EFS) has been average (6.9 age-4 R/EFS).

The Ricker (Pi) model was used for the 2017 Bowron forecast (Appendix 1). Given the assumptions underlying the Ricker (Pi) model, there is a one in four chance (25% probability) the Bowron Sockeye return will be below 4,000 (the age-4 component of this forecast implies 1.9 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 12,000 (6.2 age-4 R/EFS) in 2017 (Tables 1A & 2; Figure 4). The median forecast of 7,000 (3.6 age-4 R/EFS) is less than one third of the average return on this cycle (23,000) (Tables 1A, 1B, & 2; Figure 4).

Five year olds contribute 0% (<100) to the Bowron total median forecast (Table 3).

Due to the extremely high temperature observed at Pine Island in 2015, forecasts produced using this data as a covariate are extrapolated outside the range of the fitted model and, therefore, are associated with increased uncertainty.

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

The 2013 brood year escapement for Upper Barriere (2,000 EFS) was similar to the cycle average (1969-2013 average: 1,900 EFS; Table 1B, column C). Spawner success for Upper Barriere in 2013 was 93% (average: 90%). The 2012 brood year escapement for Upper Barriere (700 EFS) was only 16% of the cycle average (1968-2012 average: 4,700 EFS; Table 1B, column D).

Average (geometric) four year old survival for Upper Barriere Sockeye declined from a peak of 53.5 age-4 R/EFS in the early 1970s brood years (four year average at peak) to one of the lowest survivals on record (0.3 age-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 the most recent generation (2009 to 2012 brood years), the average survival (3.0 age-4 R/EFS) has been below the long term average (6.4 age-4 R/EFS).

The power model was used for the 2017 Upper Barriere forecast (Appendix 1). Given the assumptions underlying the power model, there is a one in four chance (25% probability) the Upper Barriere Sockeye return will be below 8,000 (the age-4 component of this forecast implies 2.9 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 25,000 (11.1 age-4 R/EFS) in 2017 (Tables 1A & 2; Figure 4). The median forecast of 14,000 (5.7 age-4 R/EFS) is similar to the average return on this cycle (12,000) (Tables 1A, 1B, & 2; Figure 4)

Five year olds contribute 12% (2,000) to the Upper Barriere total median forecast (Table 3).

Gates (Anderson-Seton-ES CU)

The 2013 brood year escapement for Gates (23,100 EFS), which includes both the channel and creek, was four times greater than the cycle average (1969-2013 average: 5,600 EFS) (Table 1B, column C). This escapement was the second largest on record for Gates, exceeded only by the 2011 escapement (26,400 EFS). Spawning success in the Gates system was 80%. Juvenile data for Gates are not used in the forecast process due to historical inconsistencies in the data collection methods. However, in recent years (2011 to 2013 brood years), juveniles have been consistently assessed and early freshwater survival in the 2013 brood year (676 fry/EFS) was below the three year average (992 fry/EFS), and also below the long-term average for the Gates stock (1,300; similar to Nadina: 1,100 and Weaver: 1,400). The 2012 brood year escapement for Gates (6,900 EFS) was somewhat lower than the cycle average (1968-2012 average: 9,000 EFS) (Table 1B, column D). Spawning success in the Gates system in 2012 was the lowest in the watershed at 38% (average: 74%). Spawning samples collected in Gates Creek in 2012 indicated a high level of IHN (infectious haematopoietic necrosis) in these fish.

Average (geometric) four year old survival for Gates Sockeye declined steadily from a peak of 41.0 age-4 R/EFS in the early-1970 brood years (four year average at peak) to one of the lowest survivals on record (1.6 age-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 the most recent generation (2009 to 2012 brood years), the average age-4 survival (5.6 R/EFS) has been below the long-term average (10.0 R/EFS). Survival was particularly low in the 2011 brood year (1.3 age-4 R/EFS); the most recent two year (2011-2012 brood years) average was 2.8 age-4 R/EFS (Table 2, columns E to F).

The Larkin model was used for the 2017 Gates forecast (Appendix 1). Given the assumptions underlying the Larkin model, there is a one in four chance (25% probability) the Gates Sockeye return will be below 25,000 (the age-4 component of this forecast implies 0.8 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 96,000 (3.6 age-4 R/EFS) in 2017 (Tables 1A & 2; Figure 4). The median (50% probability) forecast of 49,000 (1.7 age-4 R/EFS) is very similar to the average return on this cycle (46,000) (Tables 1A, 1B, & 2; Figure 4). Additionally, the age-4 survival implied by the median forecast produced by the Larkin model is very similar to that exhibited by the 2011 brood year for Gates (26,400 EFS), which was of a similar size to the 2013 brood year (23,100 EFS). The Larkin model forecast for 2017 is lower than forecasts produced by other models, due to the modelled delayed-density dependence, resulting from the large 2011 brood year EFS abundance (26,400 EFS). Fry data indicate that survival in the Gates system (676 fry/EFS) in the 2013 brood year was below both the recent and long-term averages.

Five year olds contribute 10% (5,000) to the Gates total median forecast (Table 3).

Nadina (Nadina-Francois-ES CU)

The 2013 brood year escapement for Nadina (7,100 EFS), which includes both the channel and river, was similar to the cycle average (1973-2013 average: 8,300 EFS) (Table 1B, column C). Spawning success in Nadina was 96% (average: 89%). The channel loading strategy in 2012 and 2013 differed from the typical procedure. Sockeye were allowed to passively enter the channel without use of the river diversion fence and channel counting fence, and therefore, escapement estimates to the channel were derived from live counts in the channel rather than fence counts at the channel entrance. The 2012 brood year escapement for Nadina (16,800 EFS) was ~20% larger than the cycle average (1976-2012 average: 13,700 EFS) (Table 1B, column D). Spawning success in Nadina in 2012 was 97% (average: 89%).

In the 2013 brood year, the fry abundance in Nadina (8.4 million fry) was average (brood years 1973-2013 average: 9.5 million fry). Freshwater survival in the 2013 brood year (1,200 fry/EFS) was also average (1975-2013 average: 1,200 fry/EFS). The fry abundance in Nadina in the 2012 brood year (16.6 million fry) was above average (brood years 1973-2012 average: 9.5 million fry). Freshwater survival in the 2012 brood year (1,000 fry/EFS) was average.

Average (geometric) four year old survival for Nadina Sockeye declined from a peak of 13.5 age-4 R/EFS in the mid-1970 brood years (four year average at peak) to one of the lowest survivals on record (1.0 age-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 the most recent generation (2009 to 2012 brood years), the average survival (5.2 R/EFS) has been similar to the long term average (6.1 R/EFS), although, in the last two brood years it was below average (3.9 R/EFS) (Table 2, columns E to F).

The MRJ model was used for the 2017 Nadina forecast (Appendix 1). Given the assumptions underlying the MRJ model, there is a one in four chance (25% probability) the Nadina Sockeye return will be below 35,000 (the age-4 component of this forecast implies 3.3 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 129,000 (12.3 age-4 R/EFS) in 2017 (Table 1A & 2; Figure 4). The median forecast of 67,000 (6.4 age-4 R/EFS) is equal to the average return on this cycle (average: 67,000) (Tables 1A, 1B, & 2; Figure 4).

Five year olds contribute 28% (19,000) to the Nadina total median forecast, influenced by the larger brood year EFS (16,800), and resulting fry estimate (16.6 million) in 2012 compared to 2013 (7,100 EFS resulting in 8.4 million fry) (Table 3).

Pitt (Pitt-ES CU)

Due to the high average proportion of five year old recruits (~70%) relative to four year old recruits for Pitt, brood year escapements are compared to the time-series average, rather than the cycle average. The brood year escapement for Pitt in 2013 (four year old recruits returning in 2017: 35,900 EFS, including hatchery broodstock females) was two-and-a-half times larger than the average escapement from 1948-2013 (14,900 EFS, including hatchery broodstock females, (Table 1B, column C). The 2012 escapement (for five year old recruits returning in 2017: 41,400 EFS) was almost three times larger than the time series average (Table 1B, column D). Estimates of spawning success in the Upper Pitt in 2013 and 2012 were 93% and 98%, respectively (average: 89%).

Average (geometric) five year old survival for Pitt Sockeye (which includes hatchery broodstock females) has been variable throughout the time series, with a peak of 13.3 five year old R/EFS (four year average at peak) occurring in the early 1990s. Subsequently, survival declined for this stock, culminating in one of the lowest survivals on record (0.2 age-5 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 generation (2008 to 2011 brood years), the average five year old survival (3.3 age-5 R/EFS) was close to the long-term average (3.4 R/EFS). Although in the last two brood years it was below average (1.6 R/EFS) (Table 2, columns E to F).

The Larkin model was used to generate the 2017 forecast for Pitt (Appendix 1). Given the assumptions underlying the Larkin model, there is a one in four chance (25% probability) the Pitt Sockeye return will be below 52,000 (the age-5 component of this forecast implies 1.1 age-5 R/EFS) and a three in four chance (75% probability) the return will be below 140,000 (3.4 age-5 R/EFS) in 2017 (Tables 1A & 2; Figure 4). The median forecast of 84,000 (1.9 age-5 R/EFS) is similar to the average return (71,000) (Tables 1A, 1B, & 2; Figure 4).

Five year olds contribute 87% (73,000) to the Pitt total median forecast (Table 3).

Scotch (a component of the Shuswap-ES CU)

The 2013 brood year escapement for Scotch (11,000 EFS) was nearly three times larger than the cycle average (3,800 EFS; Table 1B, column C) from 1981-2013 (time series commences in 1980 for this stock). Spawner success in Scotch was 94% (average: 94%). The 2012 brood year escapement for Scotch (680 EFS) was similar to the cycle average (800 EFS) (Table 1B, column D) from 1980-2012. Spawner success in Scotch was very low in 2012 (57%) compared to average (94%). However in 2012, access to carcasses was limited by the low spawner abundance, so recoveries were pooled across the South Thompson system to create a system-wide estimate of sex ratio and spawner success that was applied to each component’s spawner abundance to generate an estimate of the EFS.

Average (geometric) four year old survival 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 (2.2 age-4 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 the most recent generation (2009 to 2012 brood years), the average survival (2.4 age-4 R/EFS) was well below the long-term average (6.5 age-4 R/EFS), and was particularly low in the 2011 brood year (0.6 age-4 R/EFS), dropping the most recent two year average to 1.2 age-4 R/EFS (Table 2, columns E to F). This brood year (2011) represents the sub-dominant cycle line for Scotch and immediately followed the record high escapement observed in Scotch in 2010 (273,900).

The Larkin model was used to produce the 2017 forecasts for the Scotch (Appendix 1). Given the assumptions underlying the Larkin model, there is a one in four chance (25% probability) the Scotch Sockeye return will be below 1,000 (the age-4 component of this forecast implies 0.05 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 90,000 in 2017 (4.7 age-4 R/EFS) (Table 1A & 2; Figure 4). The median return forecast of 9,000 (0.5 age-4 R/EFS) is less than half the cycle average (22,000) (Tables 1A, 1B, & 2; Figure 4). The Larkin model forecast for 2017 is lower than forecasts produced by other models, due to delayed-density dependence resulting from the large 2010 brood year EFS abundance (273,900 EFS). Note that this forecast is associated with extreme uncertainty, particularly at higher probability levels, as indicated by its wide distribution. This high uncertainty is attributed to the exceptional brood year escapement in 2010, and the short time-series available for Scotch.

Five year olds contribute 1% (<200) of the Scotch total median forecast (Table 3).

Seymour (a component of the Shuswap-ES CU)

The 2013 brood year escapement for Seymour (13,900 EFS) was almost four times greater than the cycle average (3,800 EFS) from 1949-2013 (Table 1B, column C). Spawner success in Seymour in 2013 was 97% (average: 94%). The 2012 brood year escapement for Seymour (300 EFS) was much smaller than the cycle average (3,800 EFS) from 1948-2012 (Table 1B, column D), and was the smallest on record. Spawner success in Seymour was low in 2012 (57%) compared to the average (94%) and like Scotch, spawner success and the sex ratio was based on the South Thompson system-wide estimates in this year.

Average (geometric) four year old survival for Seymour Sockeye declined steadily from a peak of 29.2 age-4 R/EFS at the start of the time series in the 1970s (four year average at peak) to one of the lowest survivals on record (3.4 age-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 the most recent generation (2009 to 2012 brood years), the average survival (3.4 age-4 R/EFS) was below the long-term average (7.3 R/EFS). Recent survival was particularly low in both the 2010 (1.0 age-4 R/EFS) and 2011 (2.1 age-4 R/EFS) brood years.

The Larkin model was used to produce the 2017 forecasts for Seymour (Appendix 1). Given the assumptions underlying the Larkin model, there is a one in four chance (25% probability) the Seymour Sockeye return will be below 7,000 (the age-4 component of this forecast implies 0.5 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 71,000 (5.1 age-4 R/EFS) in 2017 (Table 1A & 2; Figure 4). The median forecast of 20,000 (1.4 age-4 R/EFS) is below the average return on this cycle (28,000) (Tables 1A, 1B, & 2; Figure 4). The Larkin model forecast for 2017 is lower than forecasts produced by other models, due to delayed-density dependence resulting from the large 2010 brood year EFS abundance (287,500 EFS).

Five year olds contribute 0% (0) of the Seymour total median forecast (Table 3).

Miscellaneous Early Shuswap (Shuswap-ES)

The 2013 brood year EFS for the miscellaneous Early Shuswap tributary populations was 5,000 EFS (this group includes all Early Shuswap populations, excluding Seymour River, and Scotch and McNomee Creeks) (Table 1B, column C). In 2013, this group was dominated by the Eagle River and its tributaries (49%) and Anstey River (39%). The 2013 escapement to the Early Shuswap tributary miscellaneous populations was two times higher than the average EFS for these populations for the most recent four years in the 2013 brood cycle (2001-2013: 2,400 EFS). The 2012 brood year EFS for the miscellaneous Early Shuswap tributary populations was 200 EFS (Table 1B, column D), which was well below the average EFS for this system for the last four years in the brood cycle (2000-2012: 10,600 EFS).

Since the Early Shuswap miscellaneous populations rear in Shuswap Lake alongside the Scotch and Seymour stocks, it is likely that these tributary populations experience similar delayed-density-dependent mechanisms to Scotch and Seymour. A Larkin model was used to produce forecasts for Scotch and Seymour in light of the delayed-density dependence assumed to occur in Shuswap Lake. However, a Larkin model cannot be directly applied to the miscellaneous Shuswap populations, due to the lack of recruitment data for these populations. Therefore, the age-4 and age-5 survival implied by the Larkin forecast for Seymour was used in combination with the 2013 (age-4 forecasts) and 2012 (age-5 forecasts) brood year EFS abundances for the combined miscellaneous Early Shuswap populations to generate their forecasts. Given the assumptions underlying the Larkin model, there is a one in four chance (25% probability) the return will be below 2,000 (the age-4 component of this forecast implies

0.4 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 24,000 (4.8 age-4 R/EFS) in 2017 (Tables 1A & B). The median forecast is 7,000 (1.4 age-4 R/EFS).

Five year olds contribute 0% (0) to the Early Shuswap miscellaneous total median forecast (Table 3).

Miscellaneous Taseko (Taseko-ES)

The 2013 brood year EFS for the miscellaneous Taseko population (includes Taseko Lake and Yohetta Creek) was 70 EFS, well below the average for this system (1994-2010: 900 EFS). The 2012 brood year EFS for the miscellaneous Taseko population (includes Taseko Lake and Yohetta Creek) was 40 EFS, which was also well below the average EFS for this system (Table 1B, column D). Note: due to the extremely turbid nature of Taseko Lake, the Taseko escapement should be considered an index of abundance only, as it is derived from visual surveys of carcasses.

The model used to generate the miscellaneous Taseko forecast uses the geometric mean of the recruits-per-EFS from the Chilko stock (from brood years 1948-2011) multiplied by the Taseko brood year escapement (see Appendix 1 to 3 in Grant et al. 2011). Given the assumptions underlying the Taseko miscellaneous stock model, there is a one in four chance (25% probability) the return will be below 300 (the age-4 component of this forecast implies 3.8 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 900 in 2017 (13.0 age-4 R/EFS) (Table 1A). The median forecast is 500 (7.0 age-4 R/EFS).

Five year olds contribute 0% (<30) to the miscellaneous Taseko total median forecast (Table 3).

Miscellaneous Chilliwack (Chilliwack-ES)

The 2013 brood year EFS for the miscellaneous Chilliwack populations includes Upper Chilliwack River (5,000) and Chilliwack Lake (400) (total EFS: 5,400) (Table 1B, column C). The 2013 escapement is about half the average EFS for this system, calculated using only years when both Chilliwack Lake and the upper Chilliwack River were surveyed (2001 to 2015: 10,500). The 2012 brood year EFS for the miscellaneous Chilliwack populations (78,800; Table 1B, column D) was 7.5 times greater than the average EFS for this system, and is the largest escapement on record for this stock.

The model typically used to generate the miscellaneous Chilliwack forecast uses the geometric mean of the recruits-per-EFS from the Early Summer stocks (Bowron, Upper Barriere (Fennell), Gates, Nadina, Pitt, Scotch, Seymour) (from brood years 1948-2009) multiplied by the total Chilliwack brood year escapement (see Appendix 1 to 3 in Grant et al. 2011; Table 7). However, due to the large EFS abundance in 2012, and the availability of a limited time-series of recruitment data (brood years 2001-2011) for Chilliwack, a Ricker model was used to forecast the 2017 return. Given the assumptions underlying the Ricker model, there is a one in four chance (25% probability) the Chilliwack miscellaneous stocks' return will be below 28,000 (the age-4 component of this forecast implies 0.8 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 191,000 (6.3 age-4 R/EFS) in 2017 (Tables 1A & B). The median forecast is 78,000 (2.3 age-4 R/EFS).

Five year olds contribute 85% (66,000) to the miscellaneous Chilliwack total median forecast (Table 3).

Due to the limited spawner-recruit dataset for Chilliwack (brood years 2001-2011), an additional analysis was performed using a prior on the Ricker model beta parameter to potentially inform the forecast. The prior was derived from information on the juvenile rearing capacity of Chilliwack Lake, generated using a Sockeye-specific photosynthetic rate (PR) model, which was then translated into EFS (Hume et al. 1996; Grant et al. 2011). The prior is log-normally distributed, with a median of 25,000 EFS (Beta=1/C, C~LN(-3.689, 5)). The forecast for Chilliwack using the Ricker model with the prior falls much lower than the Ricker forecast, ranging from 11,000 to 57,000 returns at the 25% and 75% probability levels, respectively. The median probability of this forecast is 25,000.

Miscellaneous Nahatlach (Nahatlach-ES)

The 2013 brood year EFS for the miscellaneous Nahatlach populations includes Nahatlach River (300) and Nahatlach Lake (500) (total EFS: 800; Table 1B, column C). The 2013 escapement is smaller than the average EFS for this system (cycle average from 1976 to 2013: 1,500). The 2012 brood year EFS for the miscellaneous Nahatlach populations (total EFS: 1,100; Table 1B, column D) is also less than the average EFS for this system (cycle average from 1976 to 2012: 2,500).

The model used to generate the miscellaneous Nahatlach forecast uses the geometric mean of the recruits-per-spawner from the Early Summer stocks (Bowron, Upper Barriere (Fennell), Gates, Nadina, Pitt, Scotch, Seymour) (from brood years 1948-2011) multiplied by the Nahatlach miscellaneous stock's total brood year escapement (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 4,000 (the age-4 component of this forecast implies 1.6 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 13,000 (5.5 age-4 R/EFS) in 2017 (Tables 1A & 2). The median forecast is 7,000 (2.9 age-4 R/EFS).

Five year olds contribute 29% (2,000) to the miscellaneous Nahatlach total median forecast (Table 3).

Summer Run

In most years, the Summer Run dominates total Fraser Sockeye returns. Six stocks in this timing group are forecast using the standard suite of forecast models: Chilko, Late Stuart, Quesnel, Stellako and the recently added Raft and Harrison (Table 1A). There are also three miscellaneous stocks in this run timing group: North Thompson River, North Thompson Tributaries, and Widgeon. Starting in the 2013 forecast process, Raft River, the North Thompson mainstem, and several stocks associated with miscellaneous streams that are tributary to the North Thompson River, were re-assigned to the Summer-run timing group (from the Early Summer-run group), following a re-evaluation of their migration timing by the Fraser Panel in 2012. Widgeon was similarly re-assigned to the Summer-run timing group starting in the 2015 forecast year.

Escapement in the 2013 brood year for all Summer-run stocks combined (932,700 EFS), was slightly larger than the long-term cycle average (893,200 EFS). Chilko (67%) contributed the most to the Summer-run EFS, followed by Quesnel (10%), Harrison (8%) and Late Stuart (8%). The remaining Summer-run stocks contributed 8% of the total 2013 brood year escapement.

Due to extremely high water levels in the spring of 2015 (2013 brood year) in the Chilko River, no reliable smolt assessments were conducted. This represents a major gap in the forecast process, since smolts are used as the predictor variable to generate forecasts for Chilko, and this is not possible in the 2017 forecast year. The only previous gap in the Chilko smolt time-series was in 1991.

Chilko (Chilko-S & Chilko-ES CU)

The 2013 brood year escapement for Chilko (624,500 EFS) was four times greater than the cycle average (1948-2013: 154,100 EFS), and the second highest on record. Spawning success in this system in 2013 was 99% (cycle average: 90%). The 2012 brood year escapement for Chilko (90,800 EFS) was below the cycle average (1949-2012: 252,800 EFS). Spawning success in this system in 2012 (67%) was well below the cycle average (92%), though this estimate is likely biased low due to high bear predation in the area, which limited access to carcasses after the peak of spawn.

Estimates of juvenile (smolt) abundance and freshwater survival are not available for the 2013 brood year (2015 smolts). Unusually high water levels during the spring of 2015 prevented installation of the weir used to enumerate smolts. Although an alternative enumeration method (rotary screw trap: RST) was trialed in 2015, this method did not produce a reliable estimate of smolt abundance. The lack of a smolt estimate for 2015 prevents estimation of freshwater survival (smolt/EFS), which may have been reduced by the extremely large escapement in the 2013 brood year. The average smolt body length sampled from the RST program in 2015 was 78 mm, which falls below the long-term average (83 mm; range from 74 mm to 100 mm). These small body sizes suggest that some compensation possibly occurred in the Chilko freshwater ecosystem in the 2013 brood year (2015 smolt outmigration). In the 2012 brood year (2014 smolt outmigration year) a smolt enumeration program was conducted. Chilko freshwater survival for the 2012 brood year (126 yearling smolts/EFS) was similar to average (1950-2012 average: 117 yearling smolts/EFS), and the average yearling body size (98.3 mm) was above the long-term average (brood years 1952-2012; average: 83.5 mm).

Due to the lack of smolt data for the 2013 brood year, Chilko survival is described as R/EFS in the 2017 forecast. Average (geometric) four year old survival for Chilko Sockeye declined from a peak of 14.5 age-4 R/EFS in the late-1960's to the lowest survival on record (0.9 age-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 the most recent generation (2009 to 2012 brood years), the average survival (3.1 age-4 R/EFS) was below the long-term average (6.7 age-4 R/EFS), and the most recent years of data (2011-2012) indicate very low survival (1.9 age-4 R/EFS) (Table 2, columns E to F). Freshwater survival has generally been above average in recent years, apart from the 2010 brood year when low survival was associated with an exceptional escapement (Figure 2A). Marine survival has been close to average or below average in the last two brood years (2010 & 2011) (Figure 2B).

The lack of smolt data for the 2013 brood year precludes Chilko from being forecast using the standard juvenile-based models. Instead, the EFS-based Larkin model was used to generate the 2017 Chilko forecast (Appendix 1). Given the assumptions underlying the Larkin model, there is a one in four chance (25% probability) the Chilko Sockeye return will be below 1,168,000 (the age-4 component of this forecast implies 1.8 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 4,090,000 (6.5 age-4 R/EFS) in 2017 (Tables 1A & 2; Figure 4). The median forecast of 2,142,000 (3.3 age-4 R/EFS) is much larger than the average return on this cycle (881,000) (Tables 1A, 1B, & 2; Figure 4). Despite the above average median forecast for Chilko in 2017, the survival implied by this forecast (3.3 age-4 R/EFS) is similar to the below average survival observed in the last generation (3.1 R/EFS). This survival, however, is greater than what has been observed in the last two available brood years (1.9 R/EFS), which coincided with warmer ocean temperatures in the Northeast Pacific Ocean.

The upper end of the Chilko Larkin model forecast distribution (90% probability level) is extremely uncertain, and encompasses returns that are well above the largest return observed for Chilko. The degree to which the extremely large 2013 escapement causes compensatory reductions in survival is a large source of uncertainty in the Chilko forecast. Although alternative Ricker models have much poorer performance than the Larkin model, their forecasts indicate lower survival than the Larkin forecast, with median forecast values in the 0.9 – 1.5 M range (Table 6).

Five year olds contribute 1% (21,000) to the Chilko total median forecast (Table 3). For comparison, this five year old forecast is similar to the five year old forecast (20,000) calculated using last year's four year old returns (~200,000) and average age proportions of four year olds post-1980 (90%).

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

The 2013 brood year escapement (70,900 EFS) for Late Stuart was three times lower than the cycle average (218,000 EFS) from 1949-2013 (Table 1B, column C). Spawning success in 2013 brood year was 100% (average: 91%). The 2012 brood year escapement (31,800 EFS) for Late Stuart was similar to the cycle average (26,000 EFS) from 1948-2012 (Table 1B, column D). Spawning success in 2012 (61%) was well below average.

Average (geometric) four year old survival for Late Stuart Sockeye declined from a peak of 57.2 age-4 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 (0.6 age-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 the most recent generation (2009 to 2012 brood years), the average survival (3.0 age-4 R/EFS) has been below the long-term average (8.2 age-4 R/EFS).

The power model was used to generate the 2017 forecast for Late Stuart (Appendix 1). Given the assumptions underlying the power model, there is a one in four chance (25% probability) the Late Stuart Sockeye return will be below 190,000 (the age-4 component of this forecast implies 2.0 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 789,000 (9.5 age-4 R/EFS) in 2017 (Tables 1A & 2; Figure 4). The median forecast of 375,000 (4.4 age-4 R/EFS) is less than one third of the average return on this cycle (1.56 million) (Tables 1A, 1B, & 2; Figure 4); however, it is similar to the more recent average observed on this cycle since 2001 (343,000).

Five year olds contribute 5% (19,000) to the Late Stuart total median forecast (Table 3).

Quesnel (Quesnel-S CU)

Quesnel has historically dominated the total Fraser Sockeye returns on 2017 cycle-line. However, the 2013 brood year escapement for Quesnel (96,100 EFS) fell well below the cycle average (458,900 EFS) from 1949-2013 (Table 1B, column C). Spawner success in 2013 was 98% (average: 84%). Fry surveys (hydroacoustic), conducted for the 2013 brood year produced an estimate of 15.4 million fall fry, falling below the average of 30 million (brood years 1976-2014), and indicating average EFS-to-fry survival (160.6 fry/EFS). The 2012 brood year escapement for Quesnel (100 EFS) was extremely small, though it was not the smallest EFS on record for this stock. The 2012 EFS fell well below the cycle average (4,500 EFS) from 1948-2012 (Table 1B, column D). Spawner success in 2012 was the second lowest on record at 33%. Fry surveys were not conducted during the 2012 brood year.

In August 2014, a tailing pond at the Mount Polley mine spilled into Polley Lake, flooding Hazeltine Creek, and spilling into Quesnel Lake, releasing mining waste comprised of various metal contaminants into these waters. This mine breach coincided with the lake rearing period for the 2013 brood year.

Average (geometric) four year old survival on the 2013 cycle for Quesnel Sockeye declined from a peak of 18.1 age-4 R/EFS in the early-1980's to one of the lowest productivities on record (0.3 age-4 R/EFS) in the 2005 brood year (i.e. 2009 four year old return year) (Table 2, columns B to E; Figure 3). Since 2005 was the dominant cycle for Quesnel historically, this poor survival contributed to low returns on this cycle in subsequent years including the 2013 brood year. Survival for the most recent cycle (2009 brood year survival: 3.5 R/EFS) was also well below the long-term 2013 cycle average (8.8 R/EFS).

The Ricker (Ei) model was used to generate the 2017 forecast for Quesnel. Given the assumptions underlying the Ricker (Ei) model , there is a one in four chance (25% probability) the Quesnel Sockeye return will be below 91,000 (the age-4 component of this forecast implies 0.9 age-4 R/EFS) and a three in four (75% probability) the return will be below 466,000 (4.8 age-4 R/EFS) in 2017 (Table 1A & 2; Figure 4). The median forecast of 192,000 (2.0 age-4 R/EFS) is extremely low compared to the average return on this cycle (3.72 million) (Tables 1A, 1B, & 2; Figure 4). Although the 2017 forecast for Quesnel is low, the age-4 survival implied by the median forecast (2.0 age-4 R/EFS), is similar to the recent average (2009-2012: 3.3 age-4 R/EFS).

Five year olds contribute 0% (<100) to the Quesnel total median forecast (Table 3).

The Entrance Island covariate has a very large effect on the forecast for Quesnel, reducing this forecast to much lower values than the Ricker model forecast without the covariate (Table 6). The effect of this covariate is much stronger for Quesnel than for other Fraser Sockeye stocks for which Ei models were examined, implying a large reduction in survival (Table 6). Due to the extremely high temperatures observed at Entrance Island in 2015, forecasts produced using this data fall in a range that is informed by little data, and are therefore associated with increased uncertainty. For Quesnel, forecasts are particularly uncertain, due to the combination of the low brood year EFS and high Ei value.

An additional power (fry) model was used to produce a four year old forecast for Quesnel, for comparison to other four year old forecasts. A forecast of total returns was not produced using the fry model, because there is no fry data available for Quesnel in the 2012 brood year. This model has not been evaluated for performance and is used as an indication of possible returns only. The four-year old power (fry) median forecast (554,000) falls between the four year old components of the Ricker-cyc (1,164,000) and Ricker (Ei) (192,000) forecasts (Table 6).

Stellako (Francois-Fraser-S CU)

The 2013 brood year escapement for Stellako (54,100 EFS) was nearly double the cycle average (30,500 EFS) from 1949-2013 (Table 1B, column C). Spawner success for Stellako was 99% (average: 91%). The 2012 brood year escapement for Stellako (50,600 EFS) was very similar to the cycle average (61,500 EFS) from 1948-2012 (Table 1B, column D). Spawner success for Stellako in 2012 was the second lowest on record, at 57%. Spawning behavior in Stellako was unusual in 2012. Fish held for an abnormally long time in the system, and very little active spawning was observed. DFO stock assessment biologists indicate that the reported spawner success could be biased high in 2012 (i.e. higher egg retention was observed for females reported as 100% spawned).

Average (geometric) four year old survival for Stellako Sockeye declined from a peak of 15.1 age-4 R/EFS in the early 1970s to one of the lowest survivals on record (0.1 age-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 the most recent generation (2009 to 2012 brood years), survival (3.5 age-4 R/EFS) was below average (6.6 age-4 R/EFS).

The Larkin model was used to generate the 2017 forecast for Stellako (Appendix 1). Given the assumptions underlying the Larkin model, there is a one in four chance (25% probability) the Stellako Sockeye return will be below 247,000 (the age-4 component of this forecast implies 1.9 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 503,000 (5.3 age-4 R/EFS) in 2017 (Table 1A & 2; Figure 4). The median forecast of 355,000 (3.3 age-4 R/EFS) is larger than the average return on this cycle (241,000) (Tables 1A, 1B, & 2; Figure 4).

Five year olds contribute 41% (146,000) to the total Stellako median forecast (Table 3).

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

Harrison Sockeye have a unique life history and age structure compared to other Fraser Sockeye stocks. They 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) as subyearling smolts. After two to three years in the ocean, Harrison Sockeye return 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 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, while even years produce similar proportions of three and four year olds (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 variation in age-at-maturity for Harrison Sockeye increases the level of forecast uncertainty for this stock.

The 2013 brood year escapement (four year old recruits in 2017) for this stock (78,000 EFS) was nearly three times larger than the long-term average (26,300 EFS; Table 1B, column C). 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 (Table 1B, columns C & D). The 2014 brood year escapement (three year old recruits in 2017) for Harrison (238,400 EFS) was nine times larger than the long-term average (26,300 EFS) (Table 1B, column D). Conditions in 2013 (four year old returns in 2017) and 2014 (three year old recruits in 2017) were favorable for spawning; spawning success was 96% and 97% in, respectively, 2013 and 2014 (average: 99%).

Unlike most other Fraser Sockeye stocks, average (geometric) 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 the most recent generation (2009 to 2012 brood years), survival (1.8 R/EFS) has been below average (7.1 R/EFS). Survival for Harrison in the 2011 brood year (three year olds in 2014 and four year olds in 2015) was very low (0.5 R/EFS).

In recent years Harrison Sockeye have been extremely challenging to forecast due to the large increases in their 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). Escapement methodology has also changed considerably, from visual aerial surveys over most of the time series, to mark-recapture methods in recent years when escapements were expected to exceed 75,000. Historically (up to the year 2000), Harrison Sockeye escapements averaged 6,500 EFS, while survival averaged 15 R/EFS. In recent years (post-2000), escapements have averaged 100,000 EFS, and survival was well above average, (average: 30 R/EFS excluding the 2005 brood year) up to the 2008 brood year, although survival has since declined. As a result, various naïve and biological model forms have been explored in recent forecasts, but a rigorous retrospective evaluation of forecast performance for these alternative models is confounded by the dramatic shifts in survival for this stock.

For Harrison, the Ricker model was used to forecast three year olds, and a sibling (three-to-four year old) model was used to forecast four year olds returns in 2017 (Figure 5). Post-1980, three and four year old recruitment data were used for the three-to-four year old sibling models, given the shifts in age of maturity observed after 1980. Data was also restricted to odd years only. This was due to the tendency for odd years to produce a higher fraction of four year olds than even years (even years produce on average 58% four year olds compared to 75% in odd years), and given that the brood year (2013) is an odd year.

Given the assumptions underlying the Ricker (three year olds) and sibling (four year olds) models, there is a one in four chance (25% probability) the Harrison Sockeye return will be below 109,000 and a one in three chance (75% probability) the return will be below 603,000 in 2017 (Table 1A). The median forecast of 251,000 is larger than the average for Harrison (130,000) (Table 1A & B).

Three year olds contribute 84% (211,000) to the Harrison total median forecast (Table 3).

For comparison, both even and odd years (post-1980) were used in the sibling three-to-four year old model relationship. The forecast of four year olds, and therefore the total forecast, is somewhat lower using this approach. This is attributed to the lower proportion of four year olds that occur on even versus odd years (Table 6).

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

The 2013 brood year escapement for Raft (9,000 EFS) was double the cycle average (4,400 EFS) from 1949-2013 (Table 1B, column C). Spawning success for Raft in 2013 was 97% (average: 87%). The 2012 brood year escapement for Raft (1,700 EFS) was four times lower than the cycle average (6,600 EFS) from 1948-2012 (Table 1B, column D). Spawning success in 2012 (32%) was the lowest on record.

This stock has not exhibited any systematic survival trends over time. Average (geometric) four year old survival for Raft Sockeye has been variable, with the largest peak of 13.6 age-4 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 age-4 R/EFS) in the 2005 brood year (i.e. 2009 four year old return year) (Table 2, column E; Figure 3). In the most recent generation (2009 to 2012 brood years), survival (6.4 age-4 R/EFS) was similar to the average (5.7 age-4 R/EFS).

The Ricker (PDO) model was used for the 2017 Raft forecast (Appendix 1). Given the assumptions underlying the Ricker (PDO) model, there is a one in four chance (25% probability) the Raft Sockeye return will be below 21,000 (the age-4 component of this forecast implies 1.6 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 57,000 (5.4 age-4 R/EFS) in 2017 (Table 1A & 2; Figure 4). The median forecast of 33,000 (2.9 age-4 R/EFS) is similar to the average return on this cycle (26,000) (Tables 1A, 1B, & 2; Figure 4).

Five year olds contribute 12% (4,000) to the Raft total median forecast (Table 3).

Due to the extremely high temperature anomalies captured by the PDO index in 2015, forecasts produced using this data as a covariate are extrapolated outside the range of the fitted model and, therefore, are associated with increased uncertainty.

Miscellaneous North Thompson Tributaries (Kamloops-ES)

The 2013 brood year EFS for the North Thompson tributaries was 1,400 (populations: Barriere and Clearwater Rivers, and Dunn, Finn, Grouse, Harper, Hemp, Lemieux, Lion, Mann Creeks) (Table 1B, column C), which is similar to the average EFS for this system (2000-2013: 1,200). Of the North Thompson tributaries, an estimate of spawning success in 2013 is only available for Lemieux Creek (97%). The 2012 brood year EFS for the miscellaneous North Thompson tributaries (200; Table 1B, column D) was well below the average EFS for this system. Spawning success in these tributaries in 2012 averaged only 50%.

The model used to generate the miscellaneous North Thompson tributaries forecast uses the geometric mean of the recruits-per-spawner from the Raft and Upper Barriere stocks (from brood years 1948-2011) multiplied by the North Thompson Tributaries miscellaneous stocks' brood year escapement (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 5,000 (the age-4 component of this forecast implies 3.3 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 17,000 (11.6 age-4 R/EFS) in 2017 (Table 1A & 2). The median forecast is 8,000 (5.6 age-4 R/EFS).

Five year olds contribute 0% (<500) to the miscellaneous North Thompson tributaries total median forecast (Table 3).

Miscellaneous North Thompson River (Kamloops-ES)

The 2013 brood year EFS for the miscellaneous North Thompson River (8,500) was average (2000-2013: 13,900 EFS) (Table 1B, column C). The 2012 brood year EFS for the miscellaneous North Thompson River was extremely low (30). However, given the extreme variability in inter-annual assessment conditions for this river, escapement estimates are associated with considerable variability in precision and accuracy relative to other stocks. Spawning success in the North Thompson River mainstem was very high in 2013 (100%), and at a record low in 2012 (32%).

The model used to generate the miscellaneous North Thompson River forecast uses the geometric mean of the recruits-per-spawner from the Raft and Upper Barriere stocks (from brood years 1948-2011) multiplied by the North Thompson River miscellaneous stock's brood year escapement (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 28,000 (the age-4 component of this forecast implies 3.3 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 98,000 (11.6 age-4 R/EFS) in 2017 (Table 1A & 2). The median forecast is 47,000 (5.6 age-4 R/EFS).

Five year olds contribute 0% (<100) to the miscellaneous North Thompson River total median forecast (Table 3).

Miscellaneous Widgeon (Widgeon (River-Type))

The 2013 brood year EFS for the miscellaneous Widgeon River was 700, which is close to the average for this system (1950-2013: 600; Table 1B, column C). Spawning success in Widgeon River was 97% in 2013 and 99% in 2012 (99.6%). The 2012 brood year EFS was 230 (Table 1B, column D). Like Harrison River Sockeye, Widgeon Sockeye have a unique life history and an age structure where the majority of Sockeye migrate to the ocean as sub-yearling smolts. However, a small to moderate fraction of fry overwinter, presumably in Widgeon Slough or Pitt Lake, before migrating to the ocean as smolts.

The model used to generate the Widgeon miscellaneous forecast uses the geometric mean of the recruits-per-spawner from the Birkenhead stock (from brood years 1948-2011) multiplied by the Widgeon 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 Widgeon miscellaneous stocks' return will be below 2,000 (the age-4 component of this forecast implies 2.7 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 8,000 (9.7 age-4 R/EFS) in 2017 (Table 1A & 2). The median forecast is 4,000 (5.1 age-4 R/EFS)

Five year olds contribute 20% (1,000) to the miscellaneous Widgeon total median forecast (Table 3).

Late Run

The Late Run consists of five forecasted stocks (Cultus, Late Shuswap, Portage, Weaver, and Birkenhead) and one miscellaneous stock (miscellaneous Harrison/Lillooet, which includes stocks that migrate downstream as fry to rear in Harrison Lake) (Table 1A). Harrison and Widgeon were recently re-assigned to the Summer-run timing group following a re-evaluation of the migration timing of these stocks. The total escapement for the Late-run aggregate in 2013 was 159,700 EFS, which was nearly three times larger than the cycle average of 55,400 EFS (Table 1B).

Cultus (Cultus-L CU)

Cultus Sockeye are listed as 'endangered' by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). The latest update on the lower relative abundance biological benchmark is 12,000 wild effective total spawners (Grant and Pestal 2012). It is this value that is recommended for use with the Cultus Conservation Plan's recovery objective three (Cultus Sockeye Recovery Team 2009).

Cultus Sockeye adult escapement (counted through the Sweltzer Creek enumeration fence) in the 2013 brood year was 2,200 (not including 161 adults taken for brood stock), which was double the 1993-2013 cycle average (1,100). In 2013, 73% of adults were hatchery marked. Due to low spawning success (53%), the EFS abundance in 2013 was only 700 spawners. However, this estimate is likely low, as carcass sampling is biased towards unsuccessful spawners. 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. Although in recent years, due to the termination of the captive broodstock program, this number has decreased. The smolt abundance for the 2013 brood year was 110,000. This includes 65,000 'wild' smolts from naturally spawning parents, 21,000 smolts originating from hatchery fry releases in Cultus Lake, and 24,000 hatchery smolts released downstream of the fence (Table 1B, column C). This smolt abundance is close to the post-1980 cycle average (90,000 smolts), but is well below the long-term cycle average (1949-2013 cycle average: 254,000 smolts; note that there are many gaps in the Cultus smolt time series, estimates are only available for 38 years since 1952).

Total Cultus Sockeye adult escapement (800) counted through the Sweltzer Creek enumeration fence in the 2012 brood year was similar to the cycle average from 1992-2012 (1,000); 97% of these adults were hatchery marked. Due to extremely low spawning success (4%), the EFS abundance was much smaller, at only 20 spawners. This estimate may be biased low (see above), but low spawning success in 2012 is consistent with the low number of wild smolts produced in 2014. The smolt abundance for the 2012 brood year was 103,200, which included 61,650 smolts originating from hatchery fry releases in Cultus Lake, 39,600 hatchery smolts released downstream of the fence, and only 1,900 'wild' smolts from naturally spawning parents

(Table 1B, column D). This smolt abundance exceeds the post-1980 cycle average (1980-2013 cycle average: 86,000 smolts), but is well below the long-term cycle average (1948-2012 cycle average: 399,000 smolts; note that there are many gaps in the Cultus smolt time series).

Average four year old post-smolt (mostly marine) (geometric) 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 the most recent generation (2009 to 2012 brood years), survival (3% R/smolt) has been similar to average (4% R/smolt). Note: the survival time series is patchy as smolt abundances were not assessed in all years.

The power (juv) (Pi) model was used to generate the Cultus forecast for 2017 (Appendix 1). Given the assumptions underlying the power (juv) (Pi) model, there is a one in four chance (25% probability) the Cultus Sockeye return will be below 1,000 (the age-4 component of this forecast implies 1% age-4 marine survival) and a three in four chance (75% probability) the return will be below 6,000 (5% age-4 marine survival) in 2017 (Table 1A & 2; Figure 4). The median forecast of 3,000 (2% age-4 marine survival) is well below the average return on this cycle (14,000) (Tables 1A, 1B, & 2; Figure 4). The forecast distribution for the Cultus return indicates a 90% probability of a return that is fewer than 8,000 'wild' fish (given that 60% of outmigrating smolts were from naturally spawning parents and the total 90% probability forecast is 13,000). The entire forecast return distribution for Cultus Sockeye falls below the Wild Salmon Policy lower benchmark of 12,000 wild effective total spawners.

Five year olds contribute 2% (<100) to the Cultus total median forecast (Table 3).

Due to the extremely high temperature observed at Pine Island in 2015, forecasts produced using this data as a covariate are extrapolated outside the range of the fitted model and, therefore, are associated with increased uncertainty.

Late Shuswap (Shuswap-L CU)

The 2013 brood year is an off-cycle (low abundance) year for the highly cyclic Late Shuswap population. Adult escapement for Late Shuswap in 2013 (87,900 EFS) was 10 times larger than the cycle average (1949-2013: 8,800 EFS), and was four times larger than largest escapement previously observed on this cycle (Table 1B, column C). Spawning success in the South Thompson system in 2013 was 97% (average: 95%). The 2012 brood year is also an off-cycle (low abundance) year for the Late Shuswap population. Adult escapement for Late Shuswap in 2012 (6 EFS) was the smallest on record across all cycles, falling well below the cycle average (1948-2012: 2,800 EFS) (Table 1B, column D). Since only 12 spawners were estimated to have returned to the Late Shuswap spawning grounds, few carcasses were available for sampling, therefore the sex ratio (50%) and spawner success (100%) were assumed. No fry assessments were conducted in the 2013 brood year for stocks that rear in Shuswap Lake (i.e. Scotch, Seymour and Late Shuswap).

Average (geometric) four year old survival for Late Shuswap Sockeye has been variable, with the largest peak of 10.8 age-4 R/EFS (four year average at peak) occurring in the early-1970's. This is one of the Fraser Sockeye stocks that have not exhibited systematic declines in survival (Grant et al. 2010; Grant et al. 2011). Survival for the most recent 2013 cycle (2009 brood year survival: 18.7 age-4 R/EFS) was well above the long-term 2013 cycle average (9.8 age-4 R/EFS). However, the brood year escapement in that cycle was much smaller than that in 2013.

The Larkin model was used to produce the 2017 forecast for Late Shuswap (Appendix 1). Given the assumptions underlying the Larkin model, there is a one in four chance (25% probability) the Late Shuswap Sockeye return will be below 58,000 (implies 0.7 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 444,000 (5.0 age-4 R/EFS) in 2017 (Tables 1A & 2; Figure 4). The median return forecast of 174,000 (2.0 age-4 R/EFS) is similar to the cycle average (200,000) (Tables 1A, 1B, & 2; Figure 4). The Larkin model forecast for 2017 is lower than forecasts produced by most other models, due to the impact of delayed-density dependence resulting from the large 2010 brood year EFS abundance (3.1 million EFS).

Five year olds contribute 0% (0) to the Late Shuswap total median forecast (Table 3).

Portage (Seton-L (de novo) CU)

The 2013 brood year escapement for Portage (4,200 EFS) was average (1961-2013: 2,900 EFS) (Table 1B, column C) and was five times larger than the previous escapement for this cycle in 2009 (800 EFS). Spawning success for Portage in 2013 was 95% (average: 95%). In contrast, the 2012 brood year escapement for Portage (10 EFS) was much smaller than the cycle average (1964-2012: 600 EFS) (Table 1B, column D). The 2012 escapement was the smallest observed on this cycle since the population was restored with hatchery transplants in the 1960's. Due to the small number of spawners, few carcasses were available for sampling, therefore the sex ratio (50%) and spawner success (100%) were assumed.

Average (geometric) four year old survival for Portage Sockeye declined from a peak of 61.7 age-4 R/EFS in the early 1960 brood years (four year average at peak), to one of the lowest survivals on record (0.3 age-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 the most recent generation (2009 to 2012 brood years), the average survival (3.5 age-4 R/EFS) was below the long-term average (11.6 age-4 R/EFS). In the 2011 brood year, survival was particularly low (0.2 age-4 R/EFS; however, the 2012 brood year survival was above average (18.7 age-4 R/EFS).

The Larkin model was used for the 2017 Portage forecast (Appendix 1). Given the assumptions underlying the Larkin model, there is a one in four chance (25% probability) the Portage Sockeye return will be below 20,000 (implies 4.8 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 139,000 (33.2 age-4 R/EFS) in 2017 (Table 1A & 2; Figure 4). The median forecast of 51,000 (12.2 age-4 R/EFS) is similar to the average return on this cycle (45,000) (Tables 1A, 1B, & 2; Figure 4).

Five year olds contribute 0% (0) to the Portage total median forecast (Table 3).

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

The 2013 brood year escapement for Weaver (15,500 EFS) was average (1969-2013: 20,400 EFS) (Table 1B, column C). Spawning success in Weaver Channel in 2013 was 91% (average: 90%); however, spawning success in Weaver Creek (60%) was well below average (87%). Early freshwater survival in the 2013 brood year (2,300 fry/EFS) was above average (1966-2013 average: 1,600 fry/EFS), and the resulting juvenile abundance (36 million fry) was average (1966-2013 average: 31 million fry). The 2012 brood year escapement for Weaver (400 EFS) was the smallest escapement on record, falling well below the cycle average (1968-2012: 18,300 EFS) (Table 1B, column D). Spawning success in Weaver Channel in 2012 was 89%; however, spawning success in Weaver Creek (61%) was well below average (87%). Early freshwater survival in the 2012 brood year (1,000 fry/EFS) was below average (1966-2012 average: 1,600 fry/EFS), and the resulting juvenile abundance (470,000 fry) was also considerably below average (1966-2012 average: 31 million fry).

Average (geometric) four year old survival for Weaver Sockeye has been variable, with the largest peak of 41.8 age-4 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 (2.6 age-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 the most recent generation (2009 to 2012 brood years), the average survival (1.3 age-4 R/EFS) was well below the long-term average (10.2 age-4 R/EFS), and below the low survival observed in the 2005 brood year. This low survival was particularly affected by the exceptionally poor survival of the 2011 brood year (0.02 age-4 R/EFS). In that brood year, fry assessments indicated average egg-to-fry survival; however this stock was not detected in expected proportions (based on brood year escapements) by the Mission smolt program or Strait of Georgia surveys in the 2013 outmigration year (DFO 2015b). Hence, one hypothesis that may explain the extremely poor survival of this brood year is poor lake rearing conditions, assuming there was no bias in the Mission or SOG sampling programs in 2013. Notably, this brood year would have moved into Harrison Lake 1.5 years after the large Meager Creek landslide in 2010.

The power (juv) (Ei) model was used for the 2017 forecast for Weaver (Appendix 1). Given the assumptions underlying the power (juv) (Ei) model, there is a one in four chance (25% probability) the Weaver Sockeye return will be below 84,000 (implies 4.2 age-4 R/EFS) and a three in four chance (75% probability) the return will be below 398,000 (23.7 age-4 R/EFS) in 2017 (Table 1A & 2; Figure 4). The median forecast of 186,000 (10.3 age-4 R/EFS) is relatively similar to the average return on this cycle (282,000) (Tables 1A, 1B, & 2; Figure 4).

Five year olds contribute 3% (6,000) to the Weaver total median forecast (Table 3).

Due to the extremely high temperature observed at Entrance Island in 2015, forecasts produced using this data fall in a range that is informed by little data, and are therefore associated with increased uncertainty.

Birkenhead (Lillooet-Harrison-L CU)

The 2013 brood year escapement for Birkenhead (46,800 EFS) was larger than the cycle average (29,500 EFS) from 1949-2013 (Table 1B, column C). Spawning success was 94% (average: 91%). Arrival timing to the Birkenhead River was one week earlier than normal. The 2012 brood year escapement for Birkenhead (2,500 EFS) was much smaller than the cycle average (32,300 EFS) from 1948-2012 (Table 1B, column D), and was the smallest escapement on record for this stock. Arrival timing to the Birkenhead River in 2012 was also one week earlier than normal. Spawning success was the lowest on record in 2012 (11%), falling well below average (91%).

Average (geometric) four year old survival for Birkenhead Sockeye declined from a peak of 21.5 age-4 R/EFS in the early 1970 brood years (four year average at peak), to one of the lowest survivals on record (1.2 age-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 the most recent generation (2009 to 2012 brood years), survival (1.3 age-4 R/EFS) was below average (5.0 age-4 R/EFS). Survival of Birkenhead Sockeye was particularly low between 2009 and 2011, falling from 1.9 age-4 R/EFS in the 2009 brood year to 0.4 and 0.6 age-4 R/EFS in the 2010 and 2011 brood years, respectively. Note that the extremely large Meager Creek landslide occurred in the Harrison-Lillooet system in 2010, affecting Lillooet and Harrison Lakes.

The Ricker (Ei) model was used for the 2017 Birkenhead forecast (Appendix 1). Given the assumptions underlying the Ricker (Ei) model, there is a one in four chance (25% probability) the Birkenhead Sockeye return will be below 71,000 (implies 1.2 age-4 R/EFS) and a three in four (75% probability) the return will be below 257,000 (5.1 age-4 R/EFS) in 2017 (Table 1A & 2; Figure 4). The median forecast of 143,000 (2.7 age-4 R/EFS) is approximately half the average return on this cycle (296,000) (Tables 1A, 1B, & 2; Figure 4).

Five year olds contribute 7% (10,000) to the Birkenhead total median forecast (Table 3).

Due to the extremely high temperature observed at Entrance Island in 2015, forecasts produced using this data fall in a range that is informed by little data, and are therefore associated with increased uncertainty.

Miscellaneous Harrison/Lillooet (Harrison (downstream)-L)

The 2013 brood year EFS for the miscellaneous Harrison/Lillooet stocks was 4,300 (Table 1B, column C). Populations in this group include those that rear in the Harrison-Lillooet Lake system, and are not included in the Harrison or Birkenhead forecasts (Big Silver, Cogburn, Crazy, Douglas, Green, Pemberton, Pool, Railroad/Sampson, Ryan, Sloquet and Tipella Creeks). The 2013 escapement is comparable to the average EFS for this system (2000 to 2011: 6,500). The 2012 escapement was 1,100 (Table 1B, column D).

The model used to generate the miscellaneous Harrison/Lillooet forecast uses the geometric mean of the recruits-per-spawner from the Birkenhead stock (from the brood years 1948-2011) multiplied by the miscellaneous Harrison/Lillooet 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 miscellaneous Harrison/Lillooet stocks' return will be below 13,000 (the age-4 component of this forecast implies 2.7 age-4 E/EFS) and a three in four chance (75% probability) the return will be below 48,000 (9.7 age-4 R/EFS) in 2017 (Table 1A). The median forecast is 26,000 (5.1 age-4 R/EFS).

Five year olds contribute 15% (4,000) to the miscellaneous Harrison/Lillooet total median forecast (Table 3).

Pink Salmon

Fraser Pink Salmon forecasts are particularly uncertain given the shifts in methodology over time, particularly in regards to the recruitment data (changes in escapement and catch methods). The power model including the average sea-surface-salinity (SSS) environmental covariate, measured from July to September at the Race Rocks and Amphitrite Point lighthouse stations, ranked first in a jackknife analysis of Fraser Pink Salmon forecast models (see DFO 2015, Table 6). The Power (fry) model without a covariate and a naïve MRS model tied for third in terms of model performance over the time series.

Given the assumptions underlying the Power (fry)-SSS model there is a one in four chance (25% probability) the Pink returns will be below 6,177,000 (3% recruits/fry) and a three in four chance (75% probability) the return will be below 12,353,000 (10% recruits/fry) in 2017 (Table 1A). The median forecast of 8,693,000 (5% recruits/fry) is below average (12,400,000) (Table 1A). This forecast is similar (11% difference) to that produced by the second ranked power model with no environmental covariate (median forecast: 7,763,000) (Table 6). The slightly higher forecast produced by the power model with the SSS covariate is attributed to the above average SSS in the Juan de Fuca (Race Rocks lighthouse station) and West Coast of Vancouver Island (Amphitrite Point lighthouse station) in the summer of 2016 (July to August) (Figure 6).

Conclusions

Low numbers of Fraser Sockeye salmon are expected to return in 2017, compared to both the cycle average (8.4 million) and the all-year average (7.9 million). The median (50% probability level) total Fraser Sockeye forecast of 4.4 million is close to half the 2017 cycle average. The 2017 forecast ranges from 1.3 million to 17.6 million at the 10% and 90% probability-levels. Fraser Sockeye returns have fallen at or below the median forecasts for the past 12 years, excluding 2010, indicating average to below average survivals. In the past two return years (2015 and 2016), total returns corresponded to the 10% probability level forecasts, indicating poor survival for the Fraser Sockeye aggregate. In the past two years, Summer-run stocks, in particular, experienced low survival, which contributed to the low total Fraser Sockeye returns in the past few years. Among stocks, however, survival has ranged from below to above average.

The Summer Run contributes 77% to the 2017 total median forecast, with Chilko expected to contribute the largest proportion (48%). The remaining Summer-run stocks combined are expected to contribute 28% (Late Stuart: 8%; Stellako: 8%; Harrison: 6%; Quesnel: 4%) to the total median forecast. Although Quesnel historically dominated total Fraser Sockeye returns on the 2017 cycle-line (42%), the 2017 Quesnel forecast is extremely low compared to the cycle average. Quesnel is expected to contribute only 4% of the total 2017 median forecast, due to the combined effects of very low escapement in the 2013 brood year, and poor environmental conditions. The Late Run is expected to contribute 13% of the total Fraser Sockeye median forecast (Late Shuswap: 4%, Weaver: 4%, and Birkenhead: 3%) and the Early Summer Run is expected to contribute 8% to the total. The Early Stuart Run is expected to contribute only a small proportion (2%) to the total median forecast. Note that in the Late Run, Cultus sockeye, which are listed as 'endangered' by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), have a 2017 forecast that falls below the WSP abundance benchmark of 12,000 wild spawners (Grant and Pestal 2012) across all probability levels.

Poor returns of some Fraser Sockeye stocks in 2015 and 2016 have coincided with the development of unusually warm ocean temperatures in the Northeast Pacific Ocean. In this forecast process the extreme environmental conditions were taken into consideration where applicable. Specifically, models with temperature covariates were selected for stocks for which these models rank high in terms of performance, and are not outranked by models that suggest different population dynamics (i.e. delayed-density-dependent mechanisms suggested by high ranking Larkin models). High ranking Ricker and power-based models that use the temperature covariates in predicting returns consistently reflect lower survival in their forecasts of 2017 returns compared to those generated without the covariates (basic Ricker or power model forecasts), due to the historical effect of temperature on survival (Table 6). This lower survival has been incorporated into forecasts for seven Fraser Sockeye stocks, representing approximately 21% of the 2013 brood year EFS, and 15% of the total median forecast. However, temperature covariate models were not applied to all stocks, due to the previously-approved model selection process used to produce Fraser Sockeye forecasts. In such cases, to account for the strong possibility of reduced survival, an emphasis on the 25% probability level forecasts is recommended for the 2017 Fraser Sockeye returns. For the Summer Run, in particular, forecasts for key stocks, such as Chilko, Late Stuart and Stellako were not produced with temperature covariate models. Thus, in light of the models used, and the recent low survivals exhibited by most Summer-run stocks, the overall Summer Run return may more closely align with the 25%, rather than 50%, probability level of the forecast

For some stocks, specific freshwater mechanisms may contribute to low survival. Birkenhead and Weaver have both exhibited very poor survival, beginning in the 2010 brood year for Birkenhead, and the 2011 brood year for Weaver. Poor survival in these systems may be linked to the Meager Creek landslide, which occurred in August 2010, and released considerable amounts of sediment into the lakes where these fish rear as juveniles. For the stocks that rear in Shuswap Lake (Scotch, Seymour, and Late Shuswap), survival is likely linked to delayed-density-dependent mechanisms occurring in the freshwater lake system. Still, these freshwater mechanisms do not preclude marine effects from also contributing to reduced survival.

The total 2017 forecast of Fraser Pink Salmon ranges from 4 million to 17 million at the 10% and 90% probability-levels, with a median (50% probability level) forecast of 8.7 million. This median forecast is below average (12.4 million). Fraser Pink Salmon forecasts are extremely uncertain given the shifts in enumeration methodology over time, particularly with regards to the recruitment data (changes in escapement and catch methods). Pink Salmon fry abundance in the 2013 brood year was 230 million, which was almost half of the long term average (441 million). It is unclear how the ‘warm blob’ and other environmental conditions in both the freshwater and marine ecosystem will affect Fraser Pink salmon survival.

Despite research efforts to expand our understanding of freshwater and marine mechanisms that influence salmon population dynamics (e.g. Tucker et al. 2009, Beamish et al. 2012, Irvine et al. 2014, Ye et al. 2015), predicting future salmon survival continues to be associated with high uncertainty. To assist with improving our understanding of Fraser Sockeye population dynamics and survival, a separate CSAS Science Response process was conducted on January 17th and 18th, 2017 to supplement the 2017 forecast process. Through this DFO Science process, attendees from DFO and the Pacific Salmon Commission synthesized information on the different life-history stages of Fraser Sockeye from the 2013 brood year through to current ocean conditions and jack returns in 2016. This process also reviews the 2016 returns in the context of the 2016 forecast supplement (DFO 2016b) and forecast (DFO 2016a). It is hoped that this process, and the number of new and expanded projects that cover all the life-history stages of Fraser Sockeye, will help improve our understanding of what drives fluctuations in the annual survival of these stocks. Forecasts of return abundances are one tool where this type of information can be explored quantitatively, to determine factors that influence population dynamics.

Tables

Table 1A. The 2017 Fraser River Sockeye and Pink forecasts. Forecasts are presented from their 10% to 90% probability levels (probability that returns will be at or below the specified run size). At the mid-point (median value) of the forecast distribution (50% probability level), there is a one in two chance the return will fall above or below the specified forecast value for each stock, based on the historical data. The model used to generate the forecast for each stock is in the second column.

Run timing group	Forecast	Probability that Return will be at/or Below Specified Run Size				
Stocks	Model [a]	10%	25%	50%	75%	90%
Early Stuart	*Ricker (Ei)*	**42,000**	**64,000**	**99,000**	**158,000**	**253,000**
Early Summer		**95,000**	**166,000**	**343,000**	**792,000**	**1,971,000**
(total excluding miscellaneous)		***78,000***	**132,000**	**250,000**	**563,000**	**1,444,000**
Bowron	*Ricker (Pi)*	2,000	4,000	7,000	12,000	21,000
Upper Barriere (Fennell)	*power*	5,000	8,000	14,000	25,000	43,000
Gates	*Larkin*	15,000	25,000	49,000	96,000	197,000
Nadina	*MRJ*	19,000	35,000	67,000	129,000	232,000
Pitt	*Larkin*	35,000	52,000	84,000	140,000	227,000
Scotch	*Larkin*	0	1,000	9,000	90,000	533,000
Seymour	*Larkin*	2,000	7,000	20,000	71,000	191,000
Misc (EShu) [b]	*R/S*	1,000	2,000	7,000	24,000	71,000
Misc (Taseko) [c]	*R/S*	100	300	500	900	1,000
Misc (Chilliwack)	*Ricker*	14,000	28,000	78,000	191,000	431,000
Misc (Nahatlatch) [d]	*R/S*	2,000	4,000	7,000	13,000	24,000
Summer		**1,065,000**	**1,861,000**	**3,407,000**	**6,631,000**	**12,560,000**
(total excluding miscellaneous)		***1,048,000***	***1,826,000***	***3,348,000***	***6,508,000***	***12,312,000***
Chilko	*Larkin*	663,000	1,168,000	2,142,000	4,090,000	7,588,000
Late Stuart	*power*	100,000	190,000	375,000	789,000	1,561,000
Quesnel	*Ricker (Ei)*	45,000	91,000	192,000	466,000	951,000
Stellako	*Larkin*	174,000	247,000	355,000	503,000	734,000
Harrison [e]	*3-Ricker; 4-sibling*	52,000	109,000	251,000	603,000	1,390,000
Raft [e]	*Ricker (PDO)*	14,000	21,000	33,000	57,000	88,000
Misc (N. Thomp. Tribs) [e & f]	*R/S*	2,000	5,000	8,000	17,000	34,000
Misc (N. Thomp River) [e & f]	*R/S*	14,000	28,000	47,000	98,000	199,000
Misc (Widgeon) [g]	*R/S*	1,000	2,000	4,000	8,000	15,000
Late		**113,000**	**247,000**	**583,000**	**1,292,000**	**2,849,000**
(total excluding miscellaneous)		***106,000***	***234,000***	***557,000***	***1,244,000***	***2,765,000***
Cultus	*power (juv) (Pi)*	1,000	1,000	3,000	6,000	13,000
Late Shuswap	*Larkin*	12,000	58,000	174,000	444,000	1,027,000
Portage	*Larkin*	8,000	20,000	51,000	139,000	331,000
Weaver	*power (juv) (Ei)*	43,000	84,000	186,000	398,000	880,000
Birkenhead	*Ricker (Ei)*	42,000	71,000	143,000	257,000	514,000
Misc Harrison/Lillooet [g]	*R/S*	7,000	13,000	26,000	48,000	84,000
TOTAL SOCKEYE SALMON		**1,315,000**	**2,338,000**	**4,432,000**	**8,873,000**	**17,633,000**
(TOTAL excluding miscellaneous)		***1,274,000***	***2,256,000***	***4,254,000***	***8,473,000***	***16,774,000***
TOTAL PINK SALMON	*Power (fry) SSS*	**4,447,000**	**6,177,000**	**8,693,000**	**12,353,000**	**16,682,000**

a. See Table 4 for model descriptions
b. Misc. Early Shuswap uses Scotch & Seymour R/EFS
c. Misc. Taseko uses Chilko R/EFS
d. Misc. Nahatlach uses Early summer-run stocks R/EFS
e. Raft, Harrison, Misc. North Thompson stocks moved to Summer run-timing group
f. Misc. North Thompson stocks use Raft & Fennel R/EFS
g. Misc. Late Run stocks (Harrison Lake down-stream migrants including Big Silver, Cogburn, etc.), and river-type Widgeon use Birkenhead R/EFS

Table 1B. Fraser Sockeye brood year (BY) escapements (EFS, except smolts for Cultus) for the four (BY13) and five year old (BY12) recruits returning in 2017 are presented and colour coded relative to their cycle average from 1949-2013 brood years (columns C & D). Fraser Sockeye average run sizes are presented across all cycles (column F) and the 2017 cycle (column G) for each stock. Forecasted 2017 returns at the median (50%) probability level (column E) from Table 1A are 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 deviation of historical time series.

A	C	D	E	F	G
Run timing group	**BY13**	**BY12**	**Ret**	**Mean Run Size**	
Stocks	**(EFS)**	**(EFS)**	**2017**	**All cycles [a]**	**2017 cycle [b]**
Early Stuart	39,700 [R]	6,800 [R]	R	298,000	754,000
Early Summer (excl. misc.)				**523,000**	**272,000**
Bowron	1,900 [Y]	30 [R]	R	37,000	23,000
Upper Barriere (Fennell)	2,000 [Y]	700 [R]	Y	24,000	12,000
Gates	23,100 [G]	6,900 [Y]	Y	56,000	46,000
Nadina	7,100 [Y]	16,800 [Y]	Y	75,000	67,000
Pitt	35,900 [G]	41,400 [G]	Y	71,000	74,000
Scotch	11,000 [G]	700	R	116,000	22,000
Seymour	13,900 [G]	300 [R]	R	144,000	28,000
Misc (Early Shuswap)	5,000 [G]	200 [R]		--	--
Misc (Taseko)	70 [Y]	40 [R]		--	--
Misc (Chilliwack)	5,000 [Y]	78,800 [G]		--	--
Misc (Nahatlatch)	800 [R]	1,100 [Y]		--	--
Summer (excl. misc.)				**3,873,000**	**6,546,000**
Chilko	624,000 [G]	90,800 [R]	G	1,415,000	881,000
Late Stuart	70,900 [R]	31,800 [Y]	R	527,000	1,564,000
Quesnel	96,100 [R]	100 [R]	R	1,304,000	3,726,000
Stellako	54,100 [G]	50,600 [Y]	G	466,000	241,000
Harrison [c]	78,000 [G]	238,400	G	130,000	108,000
Raft	9,000 [G]	1,700 [R]	Y	31,000	26,000
Misc (N. Thomp. Tribs)	1,400 [Y]	200 [R]		--	--
Misc (N. Thomp River)	8,500 [Y]	30 [R]		--	--
Misc (Widgeon)	700 [G]	200 [Y]		--	--
Late (excl. misc.)				**3,171,000**	**837,000**
Cultus [d]	110,000 [Y]	103,200 [R]	R	37,000	14,000
Late Shuswap	87,900 [G]	10 [R]	Y	2,409,000	200,000
Portage	4,200 [Y]	10 [R]	Y	41,000	45,000
Weaver	15,500 [R]	400 [R]	Y	332,000	282,000
Birkenhead	46,800 [G]	2,500 [R]	Y	352,000	296,000
Misc Lillooet-Harrison	4,300 [G]	1,100 [Y]		--	--
Total Sockeye Salmon				**7,865,000**	**8,409,000**
Total Pink Salmon	Fry in 2015: 230M [R]			**12,400,000**	

a. Sockeye: 1953-2014 (start of time series varies across stocks)
b. Sockeye: 1955-2013 (start of time series varies across stocks)
c. 2014 brood year is presented in the 2012 brood year column
d. Cultus brood year smolts presented in columns C & D (not EFS)

Table 2. For each of the 19 forecasted Fraser Sockeye stocks (column A), geometric average four-year old survivals (four year old recruits-per-EFS) are presented for the following: the entire time series (brood years: 1948-2012) (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), the most recent generation with recruitment data (2009-2012) (column E), and the most recent two years of available data (2011-2012) (column F). Cultus is presented as four year old recruits-per-smolt. Four-year old survivals associated with the various probability levels of the 2017 forecast (based on age-4 forecasts in Table 3 and escapements in Table 1B) are presented in columns (G) to (K) for comparison. Red (< average), yellow (average) and green (>average), with the average range defined as average +/- 0.5 standard deviation of historical time series.

A	B	C	D	E	F	G	H	I	J	K
	Total Survival: Four Year Old Recruits-Per-Effective Female Spawner (Smolt for Cultus)					2017 forecast four year old R/EFS for each probability level in Table 1A by stock				
Run timing group Stock	Geo. Ave.[Y]	Peak Geo. Ave.[G]	2005 Brood Year[R]	Recent Gen. Geo Ave. (2009-2012)	Recent Data Geo. Ave. (2011-2012)	10%	25%	50%	75%	90%
Early Stuart	6.3	24.5	1.5	5.7 [Y]	4.9 [Y]	0.9	1.5	2.4	3.8	6.2
Early Summer										
Bowron	6.9	20.4	2.2	10.7 [Y]	19.5 [G]	1.1	1.9	3.6	6.2	10.8
Upper Barriere	6.4	53.5	0.3	3.0 [R]	1.3 [R]	1.5	2.9	5.7	11.1	20.6
Gates	10.0	41.0	1.6	5.6 [R]	2.8 [R]	0.4	0.8	1.7	3.6	8.0
Nadina	6.1	13.5	1.0	5.2 [Y]	3.9 [R]	1.8	3.3	6.4	12.3	22.1
Pitt (age5 survival) [a]	3.4	13.3	0.2	3.3 [Y]	1.6 [R]	0.7	1.1	1.9	3.4	6.0
Scotch	6.5	21.5	2.2	2.4 [R]	1.2 [R]	0.0	0.05	0.5	4.7	39.2
Seymour	7.3	29.2	3.4	3.4 [R]	3.1 [R]	0.2	0.5	1.4	5.1	13.7
Misc (Early Shuswap)	-	-	-	-	-	0.2	0.4	1.4	4.8	14.1
Misc (Taseko)	-	-	-	-	-	1.6	3.8	7.0	13.0	17.7
Misc (Chilliwack) [b &c]	2.5	NA	0.6	2.4 [Y]	1.8 [Y]	0.3	0.8	2.3	6.3	14.0
Misc (Nahatlatch) [c]	-	-	-		-	0.7	1.6	2.9	5.5	10.3
Summer										
Chilko	6.7	14.5	0.9	3.1 [R]	1.9 [R]	1.0	1.8	3.3	6.5	12.1
Late Stuart	8.2	57.2	0.6	3.0 [R]	2.2 [R]	1.0	2.0	4.4	9.5	20.0
Quesnel [d]	8.8	18.1	0.3	3.5 [R]	6.7 [Y]	0.5	0.9	2.0	4.8	9.9
Stellako	6.6	15.1	0.1	3.5 [R]	1.1 [R]	1.2	1.9	3.3	5.3	8.1
Harrison[e]	7.1	33.8	0.1	1.8 [R]	1.0 [R]	NA	NA	NA	NA	NA
Raft	5.7	13.6	0.4	6.4 [Y]	5.7 [Y]	0.9	1.6	2.9	5.4	9.1
Misc (N. Thomp.Tribs) [c]	-	-	-	-	-	1.7	3.3	5.6	11.6	23.5
Misc (N. Thomp River) [c]	-	-	-	-	-	1.7	3.3	5.6	11.6	23.5
Misc (Widgeon) [c]	-	-	-	-	-	1.4	2.7	5.1	9.7	16.8
Late										
Cultus (% R/smolt) [f]	4%	15%	1%	3% [Y]	3% [Y]	1%	1%	2%	5%	12%
Late Shuswap [d]	9.8	10.8	2.8	18.7 [G]	2.7 [R]	0.1	0.7	2.0	5.0	11.7
Portage	11.6	61.7	0.3	3.5 [R]	1.8 [R]	2.0	4.8	12.2	33.2	79.1
Weaver	10.2	41.8	2.6	1.3 [R]	0.2 [R]	1.8	4.2	10.3	23.7	52.8
Birkenhead	5.0	21.5	1.2	1.3 [R]	1.8 [R]	0.6	1.2	2.7	5.1	10.4
Misc Lillooet-Harrison [c]	-	-	-	-	-	1.4	2.7	5.1	9.7	16.8

a. Pitt compares five year old survival;
b. Chilliwack recruitment data began in the 2001 brood year;
c. Naïve (non-biological) models do not have recruitment time series; so averages could not be compiled in columns B to F
d. Quesnel and Late Shuswap survivals are cycle averages;
e. Harrison is presented as total survival; forecast survival was not calculated due to the variability in ages
f. Cultus survivals are presented as marine survival (recruits-per-smolt)

Table 3. Four and five year old and total 2017 Fraser Sockeye median (50% probability) forecasts for each stock. The four and five year old proportions of the total median forecast are presented in the final two columns.

Sockeye stock/timing group	2017 Fraser Sockeye Forecasts				
	FOUR YEAR OLDS 50%[a]	FIVE YEAR OLDS 50%[a]	TOTAL 50%[a]	Four Year Old Proportion	Five Year Old Proportion
Early Stuart	**95,000**	**4,000**	**99,000**	**96%**	**4%**
Early Summer	**176,000**	**167,000**	**343,000**	**51%**	**50%**
Bowron	7,000	0	7,000	100%	0%
Upper Barriere (Fennell)	12,000	2,000	14,000	88%	12%
Gates	44,000	5,000	49,000	90%	10%
Nadina	48,000	19,000	67,000	72%	28%
Pitt	11,000	73,000	84,000	13%	87%
Scotch	9,000	0	9,000	99%	1%
Seymour	20,000	0	20,000	100%	0%
Misc (EShu)	7,000	0	7,000	100%	0%
Misc (Taseko)	500	0	500	100%	0%
Misc (Chilliwack)	12,000	66,000	78,000	15%	85%
Misc (Nahatlatch)	5,000	2,000	7,000	71%	29%
Summer	**3,006,000**	**402,000**	**3,408,000**	**88%**	**12%**
Chilko	2,121,000	21,000	2,142,000	99%	1%
Late Stuart	356,000	19,000	375,000	95%	5%
Quesnel	192,000	0	192,000	100%	0%
Stellako	209,000	146,000	355,000	59%	41%
Harrison[b]	40,000	211,000	251,000	16%	84%
Raft	29,000	4,000	33,000	88%	12%
Misc (N. Thomp. Tribs)	8,000	0	8,000	100%	0%
Misc (N. Thomp River)	47,000	0	47,000	100%	0%
Misc (Widgeon)	4,000	1,000	5,000	80%	20%
Late	**563,000**	**20,000**	**583,000**	**97%**	**3%**
Cultus	3,000	0	3,000	98%	2%
Late Shuswap	174,000	0	174,000	100%	0%
Portage	51,000	0	51,000	100%	0%
Weaver	180,000	6,000	186,000	97%	3%
Birkenhead	133,000	10,000	143,000	93%	7%
Misc Lillooet-Harrison	22,000	4,000	26,000	85%	15%
Total	**3,837,000**	**596,000**	**4,433,000**	**87%**	**13%**

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/naïve and biological) with descriptions. 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 1A), where fry data or smolt data are used instead.

A. Non-Parametric (Naïve) Models

MODEL CATEGORY	DESCRIPTION
R1C	Return from 4 years before to forecast year
R2C	Average return from 4 & 8 years before the forecast year
RAC	Average return on the forecast cycle line for all years
TSA	Average return across all years
RS1 (or RJ1)	Product of average survival from 4 years before the forecast year and the forecast brood year EFS (or juv/smolt)
RS2 (or RJ2)	Product of average survival from 4 & 8 years before the forecast year and the forecast brood year EFS (or juv/smolt)
RS4yr (or RJ4yr)	Product of average survival from the last 4 consecutive years and the forecast brood year EFS (or juv/smolt)
RS8yr (or RJ8yr)	Product of average survival from the last consecutive 8 years and the forecast brood year EFS (or juv/smolt)
MRS (or MRJ)	Product of average survival for all years and the forecast brood year EFS (or juv/smolt)
RSC (or RJC)	Product of average cycle-line survival (entire time-series) and the forecast brood year EFS (or juv/smolt)
RS (used for miscellaneous stocks)	Product of average survival on time series for specified stocks and the forecast brood year EFS

B. Biological Models

MODEL CATEGORY	DESCRIPTION
power	Bayesian
power-cyc	Bayesian (cycle line data only)
Ricker	Bayesian
Ricker-cyc	Bayesian (cycle line data only)
Larkin	Bayesian
Kalman Filter Ricker	Bayesian
Smolt-jack	Bayesian
Sibling model (4 year old)	Bayesian
Sibling model (5 year old)	Bayesian

C. Biological Models Covariates (e.g. Power (FrD-mean))

MODEL CATEGORY	DESCRIPTION
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. Last year's 2016 forecasts from the 10% to 90% p-levels with preliminary in-season returns (final returns were not available at the time of this publication at the individual stock level). Note the following stocks are grouped together for single in-season estimates: [1]Bowron, Gates, Nadina and Nahatlatch returns: 91K; [2]Scotch, Seymour and Early Shuswap miscellaneous: 10K; [3]Raft, North Thompson River and Tributaries: 48K; [4]Cultus, Weaver: 11K; [5]Late Shuswap/Portage: 500; [6]Birkenhead/Harrison/Lillooet: 58K. Where returns fall relative to forecast provides a preliminary indication of total survival for a stock. Highlighted rectangles (red, yellow or green), indicate where preliminary returns fell relative to the pre-season forecast. Returns falling at the lower p-levels (<25%) are highlighted red (indicating lower survival), those falling at the mid p-levels (25%-50%) are highlighted yellow (indicating average survival), and those at the higher p-levels (>75%) are highlighted green (>avg survival).

Run timing group		**Probability that Return will be at/or Below Specified Run Size**				
Stocks		**10%**	**25%**	**50%**	**75%**	**90%**
Early Stuart		**13,000[R]**	**22,000[R]**	**36,000**	**59,000**	**89,000**
Early Summer		**120,000**	**217,000[Y]**	**447,000[Y]**	**1,003,000**	**2,703,000**
Upper Barriere (Fennell)		6,000	9,000	14,000	23,000	39,000
Bowron [1]		1,000	2,000[Y]	4,000	8,000	13,000
Gates [1]		24,000	40,000[Y]	76,000	138,000	231,000
Nadina [1]		24,000	45,000[Y]	90,000	179,000	331,000
Misc (Nahatlatch) [1]		4,000	8,000[Y]	14,000	26,000	49,000
Pitt		42,000	60,000[Y]	90,000	147,000	212,000
Scotch [2]		300	2,000[Y]	12,000[Y]	89,000	698,000
Seymour [2]		0	100[Y]	400[Y]	1,000	3,000
Misc (EShu) [2]		2,000	4,000[Y]	8,000[Y]	13,000	24,000
Misc (Taseko)		100	400	1,000	1,000	2,000
Misc (Chilliwack)		17,000	46,000[Y]	138,000[Y]	378,000	1,101,000
Summer	R	**640,000**	**992,000**	**1,677,000**	**2,962,000**	**5,023,000**
Chilko	R	459,000	658,000	1,002,000	1,573,000	2,283,000
Quesnel		6,000	9,000[Y]	15,000	25,000	40,000
Late Stuart		42,000[R]	86,000	192,000	427,000	880,000
Stellako		86,000[R]	144,000	256,000	454,000	761,000
Harrison		33,000	73,000[Y]	176,000	425,000	957,000
Raft [3]		11,000	16,000	26,000	38,000[Y]	62,000
Misc (N. Thomp. Tribs) [3]		600	1,000	2,000	4,000[Y]	9,000
Misc (N. Thomp River) [3]		1,000	3,000	4,000	9,000[Y]	19,000
Misc (Widgeon)		1,000	2,000	4,000	7,000	12,000
Late		**41,000**	**65,000[Y]**	**111,000**	**203,000**	**366,000**
Cultus [4]		1,000	2,000	4,000[Y]	9,000	17,000
Weaver [4]		2,000	4,000	8,000[Y]	15,000	29,000
Late Shuswap [5]		0	100[Y]	4,000[Y]	25,000	76,000
Portage [5]		0	200[Y]	400[Y]	1,000	2,000
Birkenhead [6]		30,000	45,000[Y]	68,000	105,000	158,000
Misc Harrison/Lillooet [6]		8,000	14,000[Y]	27,000	48,000	84,000
TOTAL SOCKEYE SALMON		**814,000[R]**	**1,296,000**	**2,271,000**	**4,227,000**	**8,181,000**

Table 6. Top ranked model forecasts evaluated for each of the Fraser River Sockeye stocks and Fraser Pink stock for the 2017 forecast. Miscellaneous stocks, except Chilliwack, are excluded since they have escapement data only and only one model is used for each of these stocks. Model ranks were determined from the 2012 forecast jackknife analysis (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). Models shaded grey were used to forecast 2017 returns (in Table 1).*

RUN TIMING GROUP: EARLY STUART

		Return Forecast				
EARLY STUART	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**
Ricker (Ei)	**1**	**42,000**	**64,000**	**99,000**	**158,000**	**253,000**
Ricker (Pi)	1	44,000	62,000	98,000	158,000	239,000
Ricker	3	101,000	155,000	252,000	458,000	723,000
Ricker (PDO)	3	63,000	101,000	171,000	287,000	458,000

RUN TIMING GROUP: EARLY SUMMER

		Return Forecast				
BOWRON	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**
MRS	1	4,000	6,000	12,000	23,000	40,000
Ricker (Pi)	**2**	**2,000**	**4,000**	**7,000**	**12,000**	**21,000**
Ricker (Ei)	3	3,000	4,000	8,000	13,000	22,000
Ricker	11	4,000	8,000	14,000	25,000	43,000

		Return Forecast				
UPPER BARRIERE (FENNELL)	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**
power	**1**	**5,000**	**8,000**	**14,000**	**25,000**	**43,000**
RAC	2	3,000	5,000	12,000	26,000	53,000
Ricker	3	8,000	13,000	23,000	46,000	82,000

		Return Forecast				
GATES	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**
RAC	1	14,000	25,000	45,000	81,000	139,000
R2C	2	20,000	35,000	67,000	127,000	227,000
Larkin	**3**	**15,000**	**25,000**	**49,000**	**96,000**	**197,000**
MRS	3	49,000	104,000	238,000	544,000	1,147,000
Ricker (Pi)	6	21,000	37,000	72,000	131,000	251,000
power	6	43,000	76,000	135,000	257,000	459,000

		Return Forecast				
NADINA	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**
MRJ	**1**	**19,000**	**35,000**	**67,000**	**129,000**	**232,000**
Ricker (FrD-peak)	2	27,000	42,000	70,000	113,000	178,000
power (juv) (FrD-peak)	2	29,000	44,000	71,000	112,000	167,000

PITT	Rank	Return Forecast 10%	25%	50%	75%	90%
Larkin	**1**	**35,000**	**52,000**	**84,000**	**140,000**	**227,000**
TSA	2	23,000	39,000	71,000	128,000	220,000
Ricker (PDO)	3	27,000	41,000	64,000	101,000	151,000
Ricker (Ei)	4	27,000	41,000	63,000	97,000	145,000
Ricker	9	30,000	44,000	66,000	105,000	162,000

SCOTCH	Rank	Return Forecast 10%	25%	50%	75%	90%
Larkin	**1**	**0**	**1,000**	**9,000**	**90,000**	**533,000**
Ricker	2	15,000	33,000	80,000	176,000	335,000
RS1	3	15,000	49,000	178,000	646,000	2,059,000

SEYMOUR	Rank	Return Forecast 10%	25%	50%	75%	90%
Ricker -cyc	1			Does not converge		
Larkin	**2**	**2,000**	**7,000**	**20,000**	**71,000**	**191,000**
R1C	2	11,000	21,000	43,000	88,000	168,000
RAC	4	5,000	11,000	26,000	59,000	123,000
Ricker (Ei)	5	11,000	21,000	39,000	75,000	136,000
Ricker	8	28,000	51,000	104,000	186,000	339,000

CHILLIWACK	Rank	Return Forecast 10%	25%	50%	75%	90%
Ricker	**NA**	**14,000**	**28,000**	**78,000**	**191,000**	**431,000**
R/S (Esum)	NA	21,000	47,000	109,000	176,000	311,000
R/S (Chilliwack)	NA	37,000	53,000	97,000	158,000	228,000
Ricker (prior)	NA	5,000	11,000	25,000	57,000	121,000

RUN TIMING GROUP: SUMMER

CHILKO	Rank	Return Forecast 10%	25%	50%	75%	90%
Larkin	**1**	**663,000**	**1,168,000**	**2,142,000**	**4,090,000**	**7,588,000**
Ricker-cyc	7	277,000	466,000	890,000	1,810,000	3,763,000
Ricker (FrD-mean)	10	614,000	915,000	1,531,000	2,523,000	3,982,000
Ricker	12	585,000	888,000	1,508,000	2,604,000	3,998,000

		Return Forecast				
LATE STUART	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**
R1C	1	51,000	103,000	223,000	485,000	975,000
R2C	2	34,000	73,000	174,000	410,000	889,000
power	**3**	**100,000**	**190,000**	**375,000**	**789,000**	**1,561,000**
Ricker (FrD-mean)	4	161,000	338,000	739,000	1,646,000	3,497,000
Ricker-cyc	5	138,000	275,000	603,000	1,203,000	2,426,000

		Return Forecast				
QUESNEL	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**
R1C	1	66,000	134,000	293,000	641,000	1,296,000
R2C	2	45,000	101,000	249,000	614,000	1,387,000
Ricker-cyc	3	260,000	541,000	1,164,000	2,551,000	4,866,000
Larkin	4	345,000	566,000	1,059,000	2,058,000	3,501,000
Ricker (Ei)	**5**	**45,000**	**91,000**	**192,000**	**466,000**	**951,000**
Ricker	6	190,000	400,000	823,000	1,815,000	3,575,000
Four Year Old Forecasts						
Ricker-cyc		259,000	541,000	1,164,000	2,551,000	4,866,000
Ricker (Ei)		44,000	91,000	192,000	466,000	951,000
power(juv)		94,000	222,000	554,000	1,384,000	3,214,000

		Return Forecast				
STELLAKO	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**
R2C	1	33,000	56,000	103,000	187,000	321,000
Larkin	**2**	**174,000**	**247,000**	**355,000**	**503,000**	**734,000**
Ricker (Ei)	3	117,000	186,000	295,000	467,000	702,000
Ricker (PDO)	4	178,000	262,000	429,000	707,000	1,145,000
Ricker	8	190,000	284,000	463,000	780,000	1,258,000

		Return Forecast				
RAFT	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**
Ricker (PDO)	**1**	**14,000**	**21,000**	**33,000**	**57,000**	**88,000**
power	2	16,000	24,000	36,000	59,000	99,000
Ricker	7	18,000	27,000	46,000	75,000	116,000

		Return Forecast				
HARRISON	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**
Ricker	NA	144,000	306,000	681,000	1,428,000	2,923,000
Ricker three yr old + sibling four year old ODD	**NA**	**52,000**	**109,000**	**251,000**	**603,000**	**1,390,000**
Ricker three yr old + sibling four year old ALL	NA	38,000	86,000	217,000	561,000	1,347,000
Ricker (Ei)	NA	219,000	416,000	910,000	2,034,000	4,711,000

RUN TIMING GROUP: LATE

		Return Forecast				
CULTUS	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**
MRJ	1	1,000	2,000	4,000	9,000	17,000
power (juv) (FrD-peak)	2	1,000	2,000	4,000	8,000	16,000
power (juv) (Pi)	**3**	**1,000**	**1,000**	**3,000**	**6,000**	**13,000**
power(juv)		1,000	2,000	4,000	7,000	13,000

		Return Forecast				
LATE SHUSWAP	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**
R1C	1	63,000	149,000	388,000	1,006,000	2,374,000
Ricker-cyc*	2	55,000	236,000	646,000	1,577,000	3,255,000
RAC	3	8,000	19,000	52,000	140,000	345,000
R2C	4	33,000	80,000	211,000	560,000	1,346,000
Larkin	**5**	**12,000**	**58,000**	**174,000**	**444,000**	**1,027,000**
Ricker (Ei)	6	12,000	51,000	142,000	333,000	744,000
Ricker	7	36,000	159,000	379,000	893,000	1,910,000

		Return Forecast				
PORTAGE	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**
Larkin	**1**	**8,000**	**20,000**	**51,000**	**139,000**	**331,000**
Ricker-cyc	2		**Does not**	**converge**		
power	3	6,000	13,000	32,000	79,000	177,000

		Return Forecast				
WEAVER	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**
RJC	3	36,000	90,000	254,000	713,000	1,809,000
power (juv) (FrD-peak)	6	60,000	112,000	236,000	499,000	1,029,000
power (juv) (Ei)	**8**	**43,000**	**84,000**	**186,000**	**398,000**	**880,000**
power(juv)	12	53,000	105,000	235,000	511,000	1,058,000

		Return Forecast				
BIRKENHEAD	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**
Ricker (Ei)	**1**	**42,000**	**71,000**	**143,000**	**257,000**	**514,000**
Ricker	2	66,000	116,000	216,000	384,000	675,000
RAC	2	47,000	108,000	269,000	672,000	1,531,000
Ricker (Pi)	4	50,000	85,000	162,000	321,000	612,000
TSA	4	56,000	129,000	322,000	806,000	1,841,000

FRASER RIVER PINK SALMON

		Return Forecast				
Fraser River Pink Salmon	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**
Power (fry)-SSS	**1**	**4,447,000**	**6,177,000**	**8,693,000**	**12,353,000**	**16,682,000**
Power (fry)	3	3,862,000	5,303,000	7,763,000	10,985,000	15,194,000
MRS	3	5,338,000	7,644,000	11,392,000	16,979,000	24,315,000

Table 7. The total Fraser Sockeye forecasts for 1998 to 2016 from the 10% to 90% p-levels. Note, all p-level values are not available for all years. The forecast value that corresponded to the actual return is highlighted. For returns that fell above the 50% p-level, the cells are highlighted green. For returns that fell at the 50% p-level, cells are highlighted yellow. Returns falling below the 50% p-level are highlighted orange, and below the 25% p-level are highlighted red. Since 2005 (past 12 years), total returns have fallen at or below the 50% p-level, with the exception of the 2010 returns. Returns for 2016 are preliminary based on in-season estimates only at the time of this publication.

Return Year	Forecast Probability Level						Actual Returns
	<10%	10%	25%	50%	75%	90%	
1998	NA	4,391,000	6,040,000	6,822,000	11,218,000[G]	18,801,000	**10,870,000**
1999	NA	3,067,000[R]	4,267,000	4,843,000	8,248,000	14,587,000	**3,640,000**
2000	NA	1,487,000	2,449,000	4,304,000[Y]	7,752,000	NA	**5,200,000**
2001	NA	3,869,000	6,797,000[O]	12,864,000	24,660,000	NA	**7,190,000**
2002	NA	4,859,000	7,694,400	12,915,900[Y]	22,308,500	NA	**15,130,000**
2003	NA	1,908,000	2,742,000	3,141,000[Y]	5,502,000[G]	9,744,000	**4,890,000**
2004	NA	1,858,000	2,615,000	2,980,000[Y]	5,139,000[G]	9,107,000	**4,180,000**
2005	NA	5,149,000[O]	8,734,000[O]	16,160,000	30,085,000	53,191,000	**7,020,000**
2006	NA	5,683,000	9,530,000[O]	17,357,000	31,902,000	56,546,000	**12,980,000**
2007	NA[R]	2,242,500	3,602,000	6,247,000	11,257,000	19,706,000	**1,510,000**
2008	NA	1,258,000[O]	1,854,000[O]	2,899,000	4,480,000	7,057,000	**1,740,000**
2009	NA[R]	3,556,000	6,039,000	10,578,000	19,451,000	37,617,000	**1,590,000**
2010	NA	5,360,000	8,351,000	13,989,000	23,541,000[G]	40,924,000	**28,250,000**
2011	NA	1,700,000	2,693,000	4,627,000[Y]	9,074,000	15,086,000	**5,110,000**
2012	NA	743,000	1,203,000	2,119,000[Y]	3,763,000	6,634,000	**2,050,000**
2013	NA	1,554,000	2,655,000	4,765,000[Y]	8,595,000	15,608,000	**4,130,000**
2014	NA	7,237,000	12,788,000	22,854,000[Y]	41,121,000	72,014,000	**20,000,000**
2015	NA	2,364,000[R]	3,824,000	6,778,000	12,635,000	23,580,000	**2,120,000**
2016	NA	814,000[R]	1,296,000	2,271,000	4,227,000	8,181,000	**853,000***

*preliminary return estimate in 2016

Figures

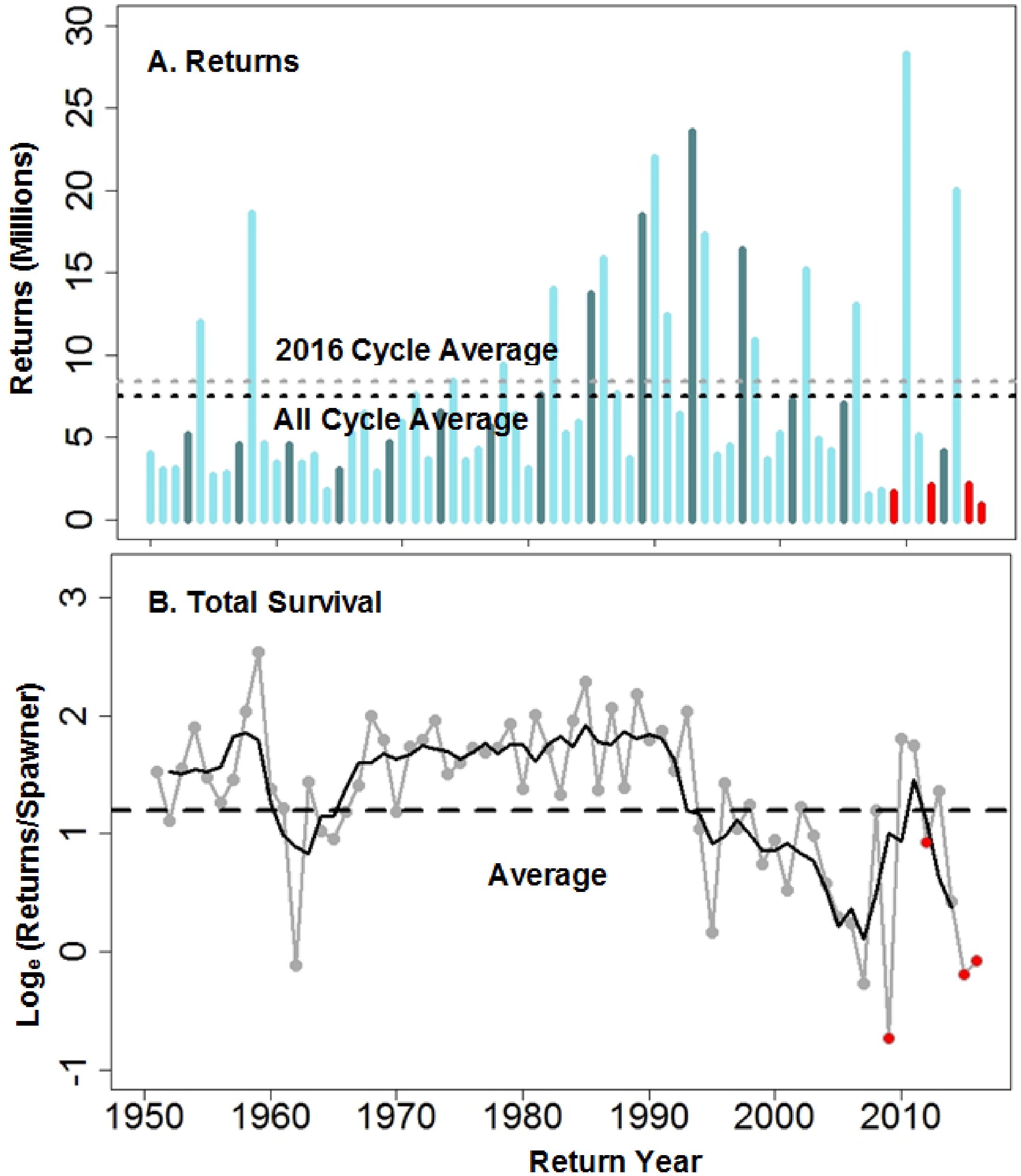


*Figure 1. **A**. Total Fraser Sockeye adult annual returns (dark blue vertical bars for the 2017 cycle and light blue vertical bars for the three other cycles). Recent adult returns from 2012 to 2016 are preliminary. **B**. Total Fraser Sockeye adult survival (log$_e$(returns/total spawner)) up to the 2016 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 dashed horizontal line is the time series average. In Figure A the lighter dashed horizontal line is the 2017 cycle line average. For Figures A and B, the 2009, 2012, 2015 and 2016 returns (low survival) are coloured in red.*

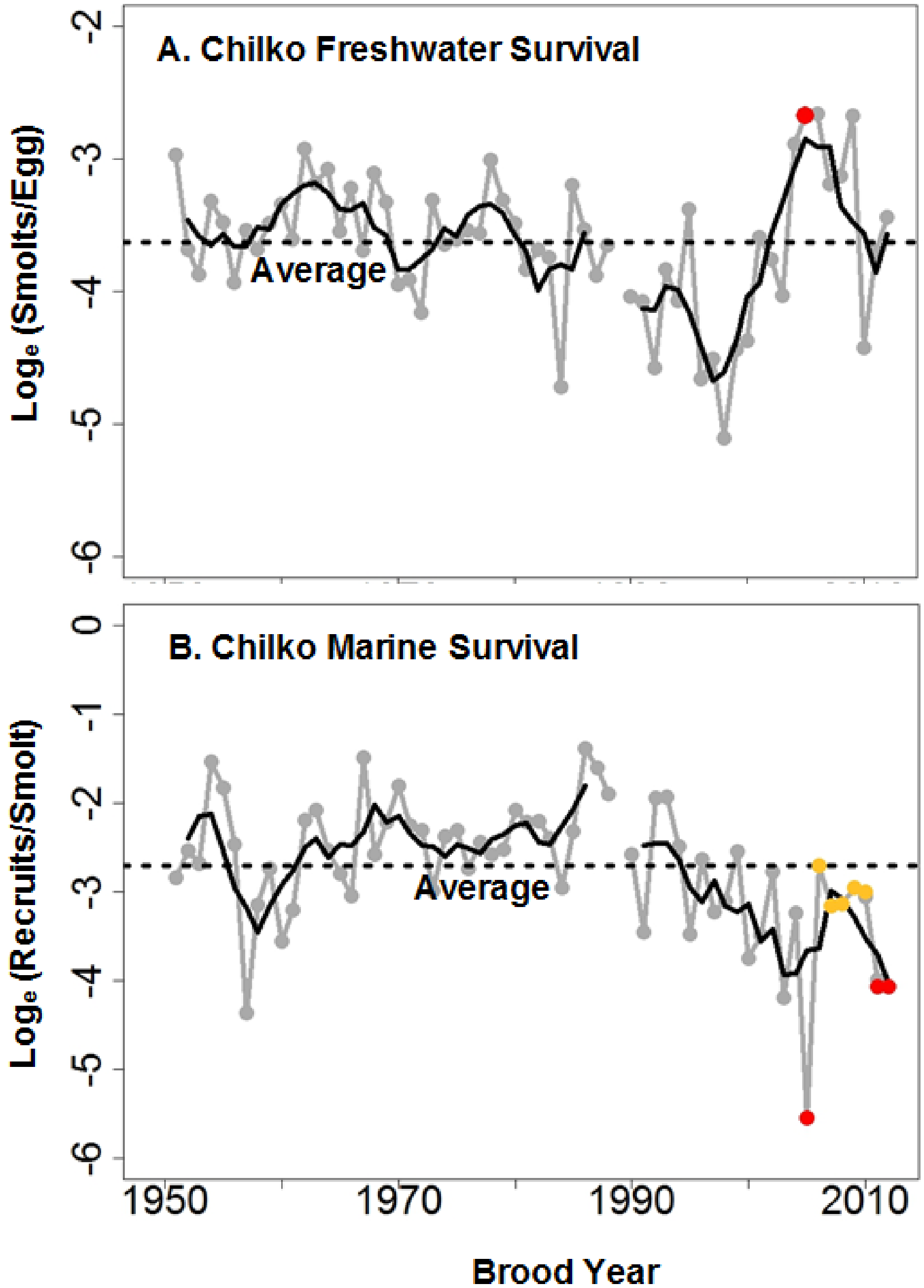
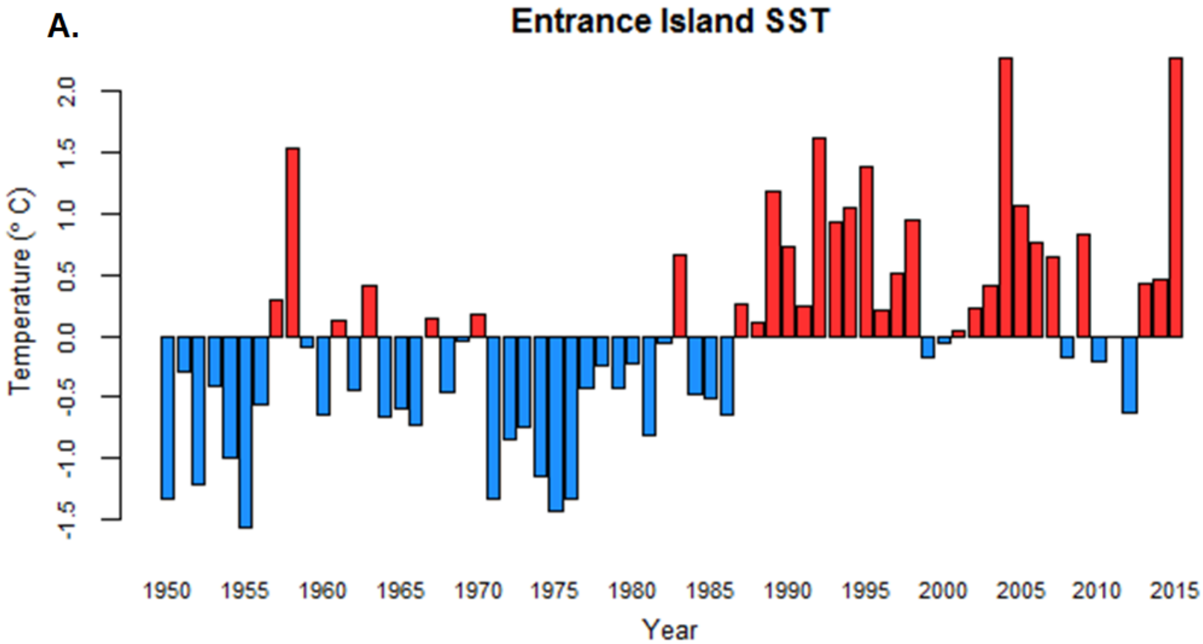


*Figure 2. Chilko River Sockeye **A**. annual freshwater (log_e smolts/egg) survival (filled grey circles and lines); the red filled circle represents the 2005 brood year (2009 returns); note no smolt assessment was conducted in the 2013 brood year representing a gap in the current 2017 Chilko forecast process; **B**. annual 'marine' (log_e recruits/smolt) survival (filled grey circles and lines) with the 2005 brood year survival indicated by the first red filled circle. 'Marine survival' includes the period of time smolts spend migrating from the outlet of Chilko Lake (where they are enumerated) to when they return as adults and includes their downstream migration in the Fraser River as smolts. The 2006 to 2010 brood year survivals are indicated by the amber filled circles and the preliminary 2011 and 2012 brood year survivals are indicated by the final red filled circles. The black line in both figures represents the smoothed four-year running average survival and the black dashed lines indicate average survival.*



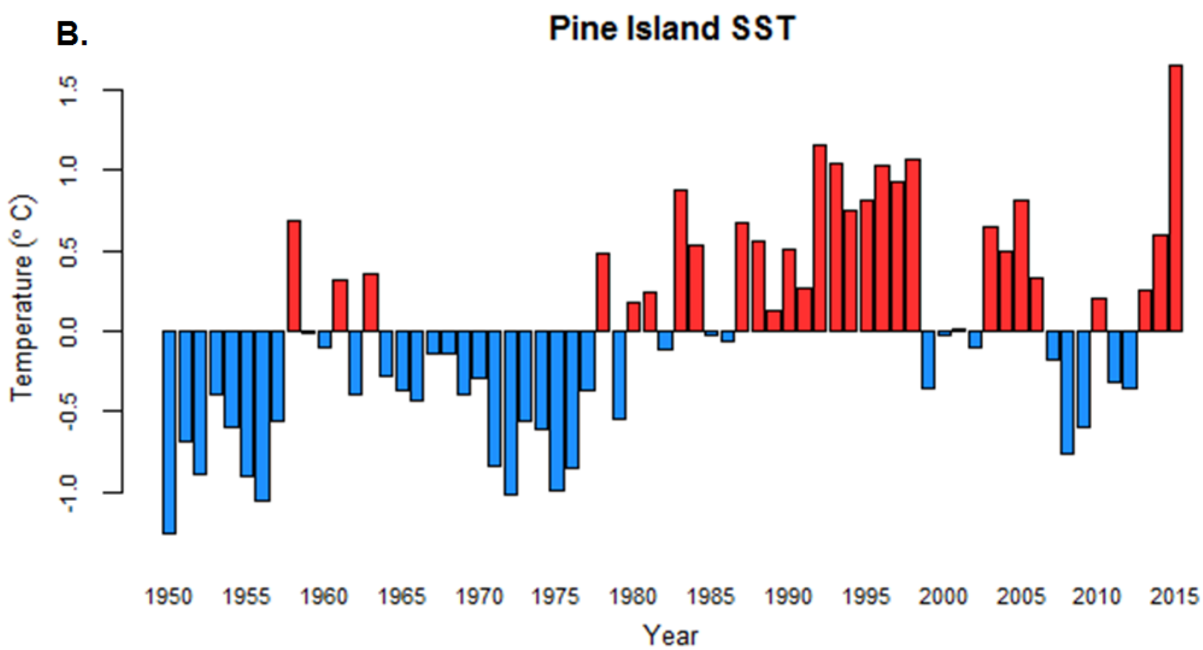


*Figure 3. Sea surface temperatures measured at **A**. Entrance Island (Strait of Georgia) (April-June average), **B**. Pine Island (Queen Charlotte Strait) (April-July average), and **C**. standardized winter PDO index (Nov-March). Temperatures are presented as raw deviations from time-series averages (1950-2015).The last data point presented for each (2015) depicts the temperature anomalies that Fraser Sockeye from the 2013 brood year entered into upon outmigration as smolts. Red bars (positive values) indicate warm temperature anomalies (above average) and blue bars (negative values) indicate cool temperature anomalies (below average).*

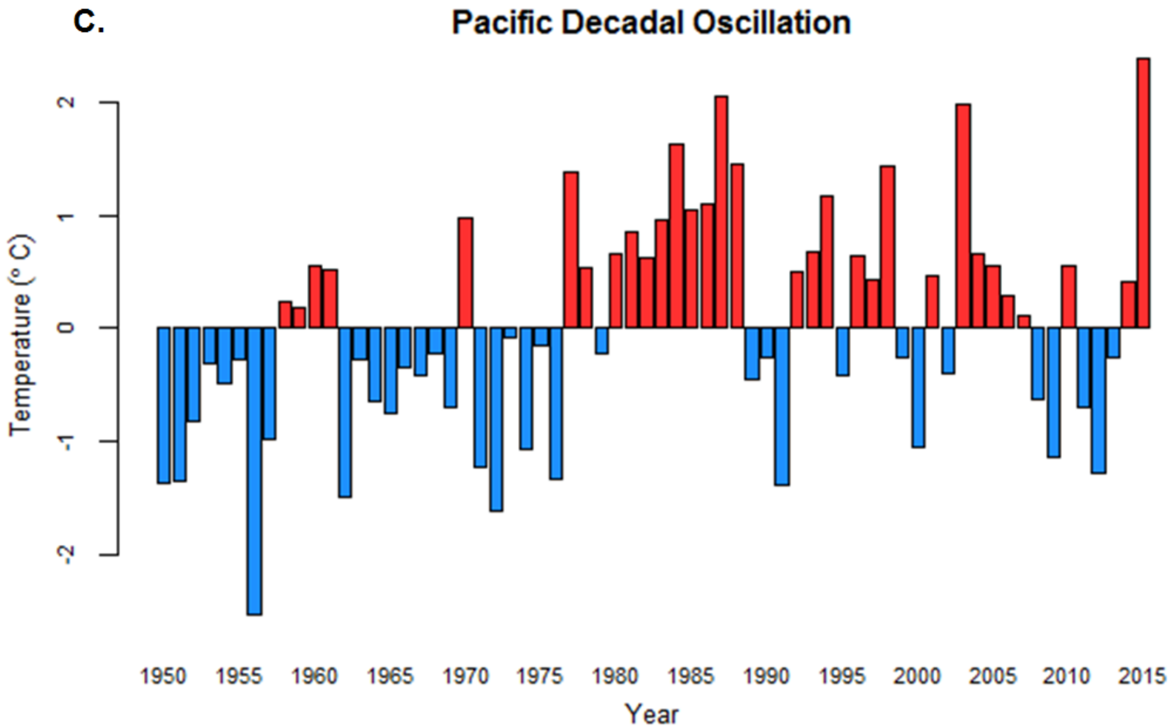


*Figure 3 continued. Sea surface temperatures measured at **A.** Entrance Island (Strait of Georgia) (April-June average), **B.** Pine Island (Queen Charlotte Strait) (April-July average), and **C.** standardized winter PDO index (Nov-March). Temperatures are presented as raw deviations from time-series averages (1950-2015).The last data point presented for each (2015) depicts the temperature anomalies that Fraser Sockeye from the 2013 brood year entered into upon outmigration as smolts. Red bars (positive values) indicate warm temperature anomalies (above average) and blue bars (negative values) indicate cool temperature anomalies (below average).*

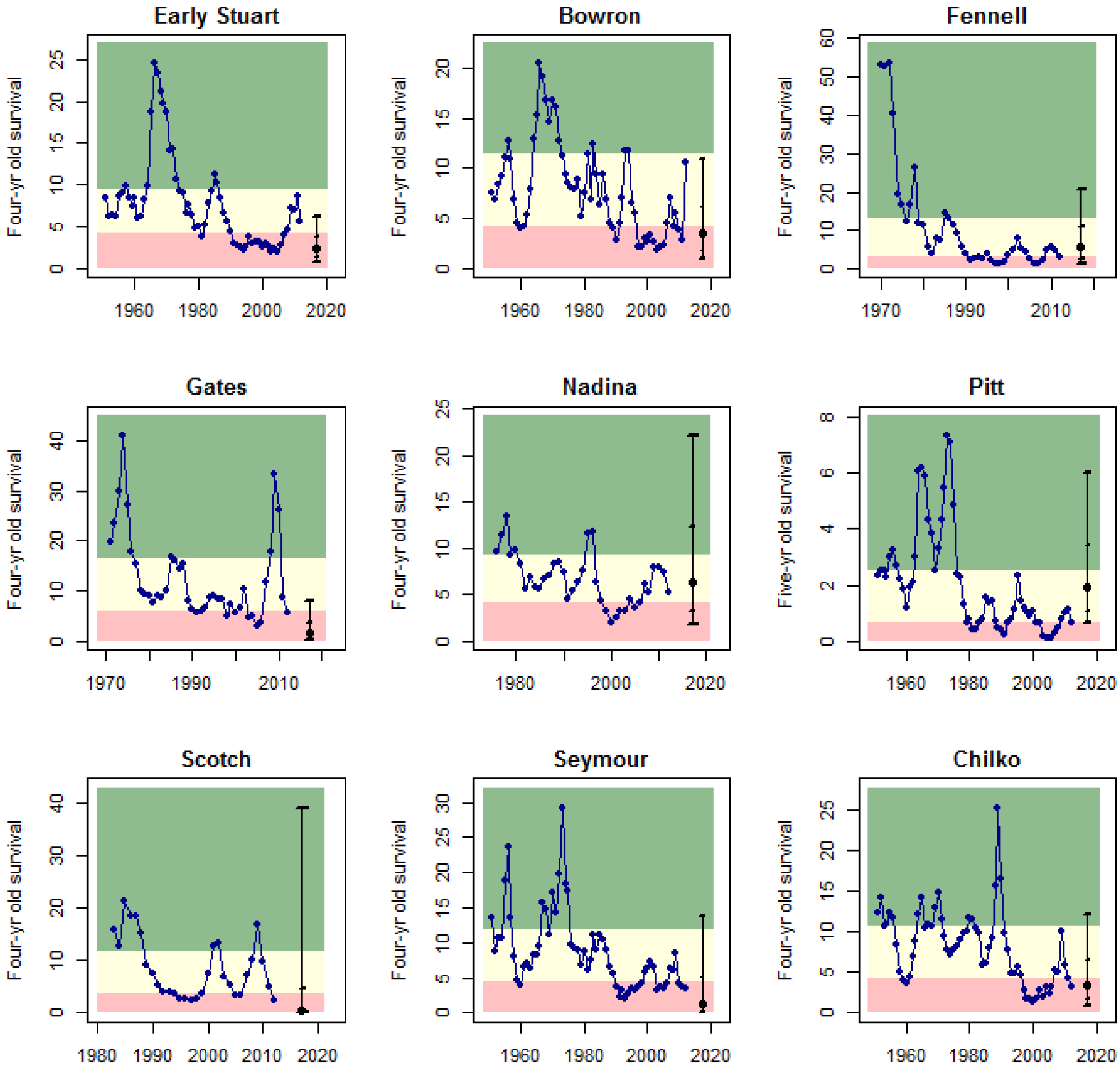


Figure 4. Smoothed four year old survival time-series' (blue lines) calculated as the four year running geometric average four year old recruits/brood year EFS for all stocks except Pitt (five year old recruits/EFS), and Cultus (four year old recruits/smolts); Harrison was also excluded given its variable age composition. Unsmoothed cycle-line data is presented for Quesnel and Late Shuswap. Colours (Red-bottom band, Amber-middle band, Green-top band) show where the productivities fall relative to the long-term geometric average (+/- 0.5 multiplied by the standard deviation): red (< average), yellow (average) and green (>average). Black bars indicate the range of survivals associated with the 2017 forecasts, at the 10% (lower horizontal bar), 25%, 50% (black filled circle), 75%, and 90% (upper horizontal bars) p-levels. Forecast productivities are not presented for stocks where recruitment data are unavailable (i.e. miscellaneous stocks).

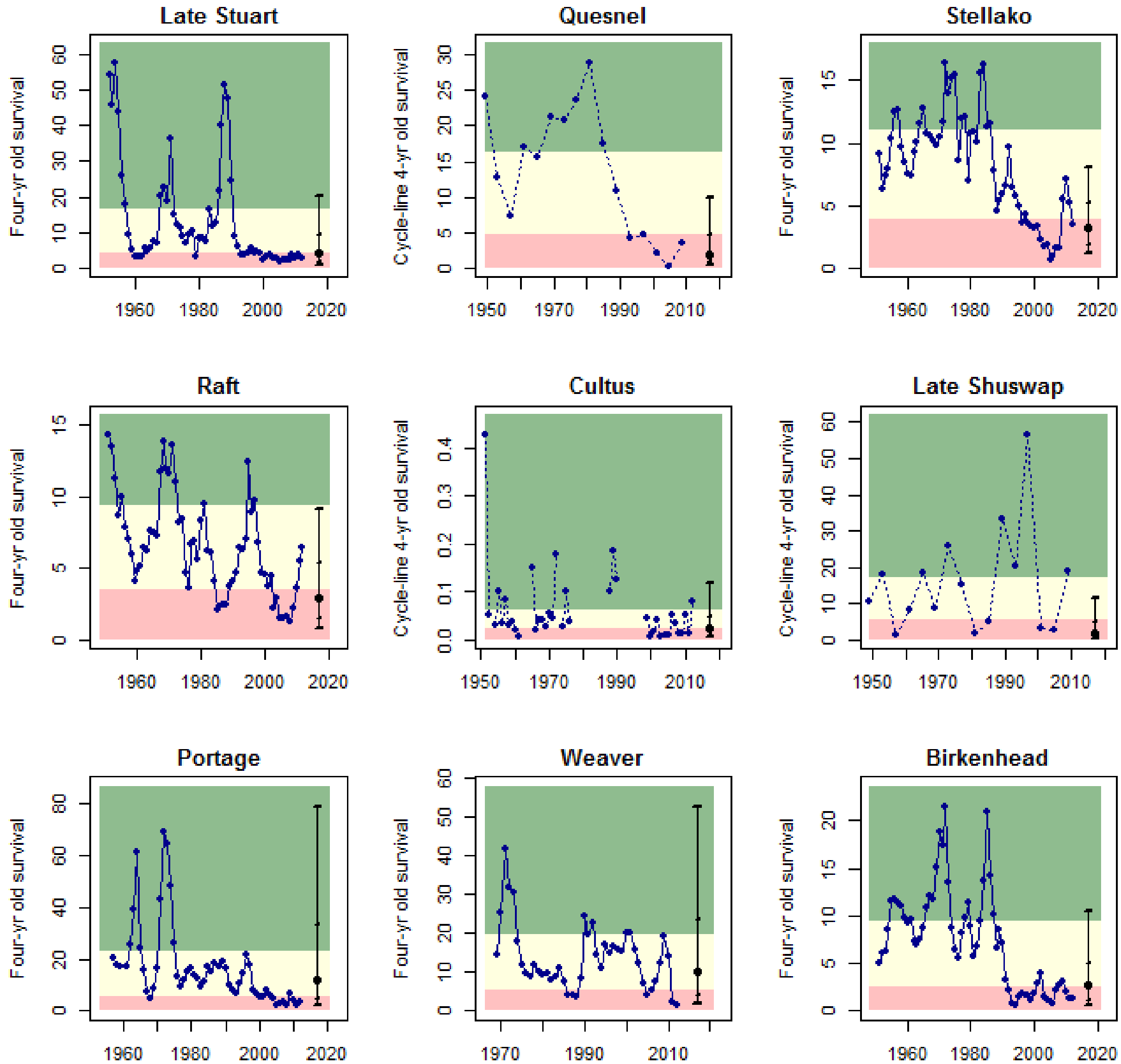


Figure 4 cont'd. Smoothed four year old survival time-series' (blue lines) calculated as the four year running geometric average four year old recruits/brood year EFS for all stocks except Pitt (five year old recruits/EFS), and Cultus (four year old recruits/smolts); Harrison was also excluded given its variable age composition. Unsmoothed cycle-line data is presented for Quesnel and Late Shuswap. Colours (Red-bottom band, Amber-middle band, Green-top band) show where the productivities fall relative to the long-term geometric average (+/- 0.5 multiplied by the standard deviation): red (< average), yellow (average) and green (>average). Black bars indicate the range of survivals associated with the 2017 forecasts, at the 10% (lower horizontal bar), 25%, 50% (black filled circle), 75%, and 90% (upper horizontal bars) p-levels. Forecast productivities are not presented for stocks where recruitment data are unavailable (i.e. miscellaneous stocks).

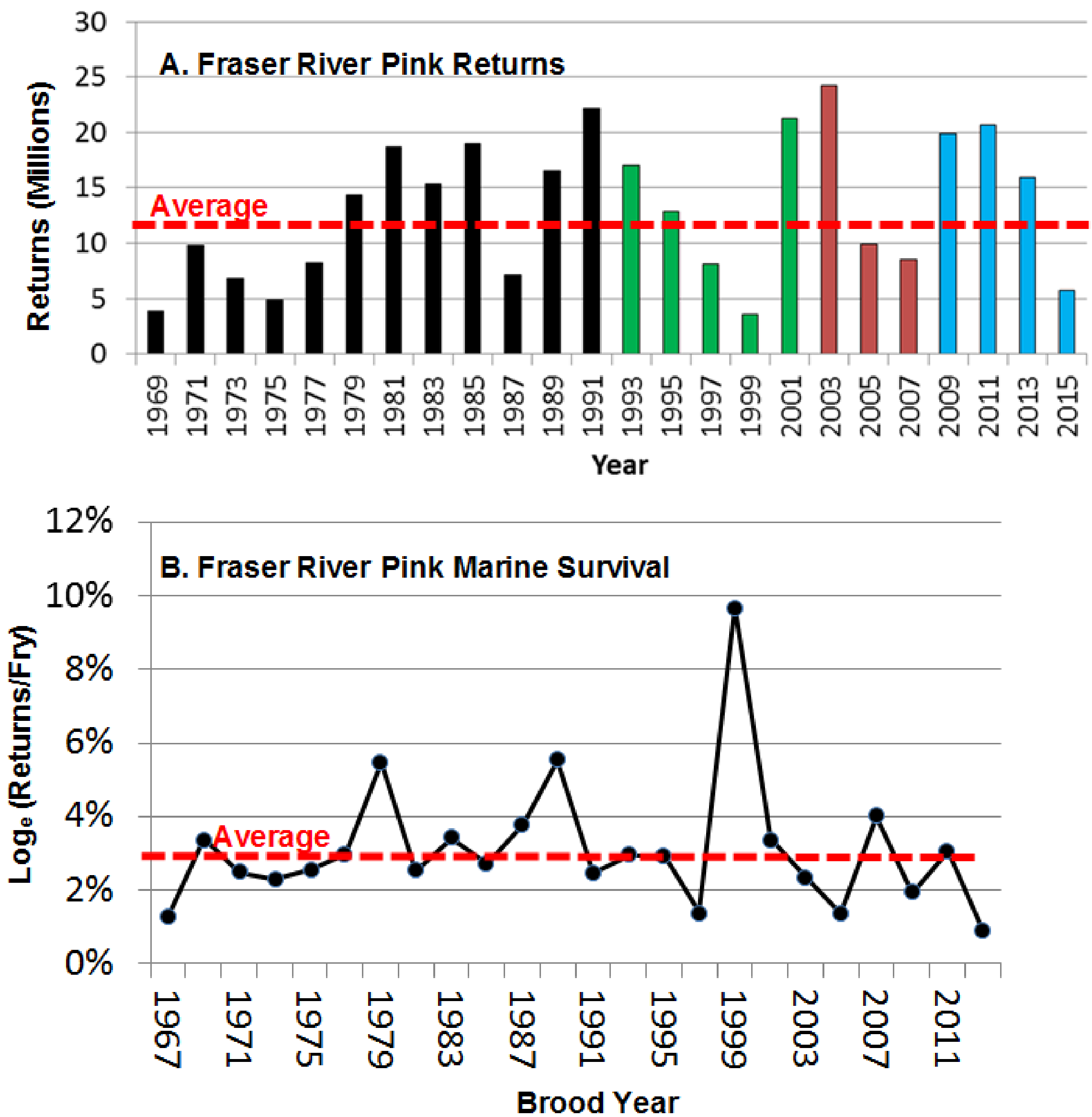


*Figure 5. **A**. Fraser River Pink Salmon returns (black or coloured bars) estimates. Escapement estimates were generated from system-specific programs from 1957 to 1991 (black bars), system-wide single mark recaptures from 1993 to 2001 (green bars), indirect system-wide marine test fisheries estimates from 2003 to 2007 (red bars), and system-wide hydroacoustic estimate from 2009 to 2015 (blue bars). Given the lack of calibration work between methods, escapement estimates between years are not entirely comparable. The red dashed line is the average Pink return (12.4 M); **B**. Fraser Pink marine survival (recruits-per-fry) from the 1967 to 2011 brood years; these estimates are uncertain and not entirely comparable inter-annually due to differences in return (catch and escapement) estimation methods over time. The red dashed line is the average survival (3%).*

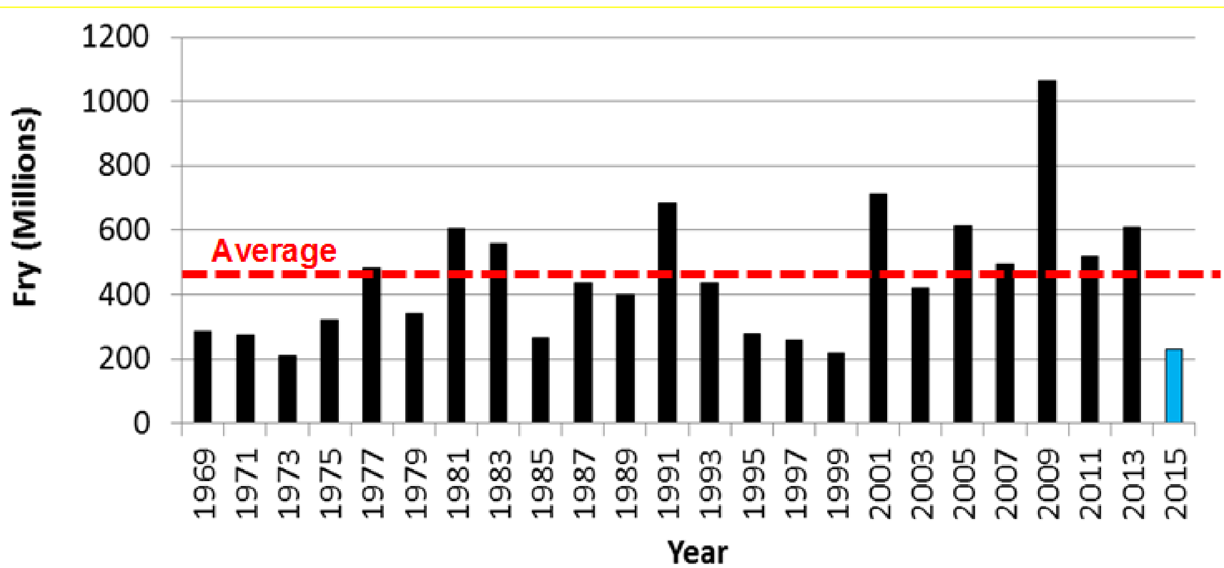


Figure 6. Fraser River Pink Salmon fry abundance. The 2015 fry abundance (230 million), which is the brood year for 2017 returns, is the last bar in the figure (blue bar). The average fry abundance over the time series is 441 million (dashed red line).

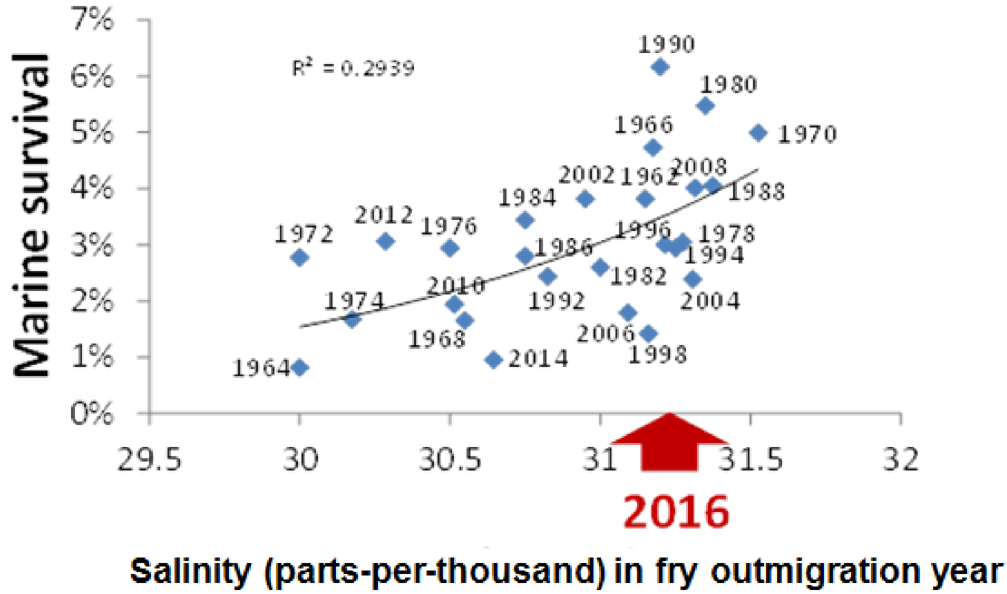


Figure 7. Fraser Pink marine survival (returns/fry) versus salinity (parts-per-thousand: ppt) in the Strait of Georgia in the pink fry outmigration year. The 2016 salinity estimate that coincides with the 2017 returning Fraser pink ocean entry year is indicated.

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February 9, 2017

Sources of Information

Abdul-Aziz, O.I., Mantua, N.J., and Myers, K.W. 2011. Potential climate change impacts on thermal habitats of Pacific salmon (*Oncorhynchus sp.*) in the North Pacific Ocean and adjacent seas. Can. J. Fish. Aquat. Sci. 68(9): 1660–1680.

Beamish, R.J., and Mahnken, C. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. Prog. Ocean. 49(1-4): 423–437.

Beamish, R.J., Neville, C., Sweeting, R., and Lange, K. 2012. The synchronous failure of juvenile Pacific salmon and herring production in the Strait of Georgia in 2007 and the poor return of Sockeye salmon to the Fraser River in 2009. Mar. Coast. Fish. Dyn. Manag. Ecosyst. Sci. 4(1): 403–414.

Blackbourn, D.J. 1987. Sea surface temperature and the pre-season prediction of return timing in Fraser River sockeye salmon (*Oncohrynchus* spp.). *In* Sockeye Salmon (*Oncohrynchus nerka*) population biology and future management. Can. Spec. Publ. Fish. Aquat. Sci. *Edited by* H.D. Smith, S.L. Margolis, and C.C. Wood. pp. 296–306.

Cass, A., Folkes, M., Parken, C., and Wood, C. 2006. Pre-season run size forecasts for Fraser River sockeye in 2006. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/060. iii + 72 p.

Cultus Sockeye Recovery Team. 2009. National Conservation Strategy for Cultus Lake Sockeye Salmon (*Oncorhynchus nerka*). Can. Tech. Rep. Fish. Aquat. Sci. 2846: pp. viii+ 46.

DFO. 2006. Pre-season run size forecasts for Fraser River sockeye and pink salmon in 2007. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2006/043.

DFO. 2008. Pre-season run size forecasts for Fraser River sockeye salmon in 2008. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2007/049.

DFO. 2009. Pre-season run size forecasts for Fraser River sockeye and pink salmon in 2009. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/022.

DFO. 2011. Pre-season run forecasts for Fraser River sockeye and pink salmon in 2011. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2011/052.

DFO. 2012. Pre-season run size forecasts for Fraser River sockeye salmon in 2012. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/011.

DFO. 2013. Pre-season run size forecasts for Fraser River Sockeye and Pink Salmon in 2013. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/074.

DFO. 2014a. Pre-season run size forecasts for Fraser River Sockeye (*Oncorhynchus nerka*) Salmon in 2014. DFO Can. Sci. Advis. Sec. Sci. Resp. 2014/040.

DFO. 2014b. Supplement to the pre-season return forecasts for Fraser River Sockeye Salmon in 2014. DFO Can. Sci. Advis. Sec. Sci. Resp. 2014/041.

DFO. 2015a. Pre-Season Run Size Forecasts for Fraser River Sockeye (*Oncorhynchus nerka*) and Pink (*O . gorbuscha*) Salmon in 2015. DFO Can. Sci. Advis. Sec. Sci. Resp. 2015/014.

DFO. 2015b. Supplement to the pre-season return forecasts for Fraser River Sockeye Salmon in 2015. DFO Can. Sci. Advis. Sec. Sci. Resp. 2015/028.

DFO. 2016a. Pre-Season run size forecasts for Fraser River Sockeye (*Oncorhynchus nerka*) in 2016. DFO Can. Sci. Advis. Sec. Sci. Resp. 2016/021.

DFO. 2016b. Supplement to the pre-season run size forecasts for Fraser River Sockeye (*Oncorhynchus nerka*). DFO Can. Sci. Advis. Sec. Sci. Resp. 2016/047.

Grant, S.C.H., and MacDonald, B.. 2013. Pre-season run size forecasts for Fraser River Sockeye (*Oncorhynchus nerka*) and Pink (*O. gorbuscha*) salmon in 2013. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/145. vi + 42 p.

Grant, S.C.H., and MacDonald, B.L. 2011. Pre-season run size forecasts for Fraser River sockeye (*Oncorhynchus nerka*) and pink (*O. gorbuscha*) salmon in 2011. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/134. vi + 48 p.

Grant, S.C.H., MacDonald, B.L., Cone, T.E., Holt, C.A., Cass, A., Porszt, E.J., Hume, J.M.B., and Pon, L.B. 2011. Evaluation of uncertainty in Fraser Sockeye (*Oncorhynchus nerka*) Wild Salmon Policy status using abundance and trends in abundance metrics. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/087. viii + 183 p.

Grant, S.C.H., and Michielsens, C.G.J. 2016. Fraser River sockeye: abundance and productivity trends. *In* State of the Physical , Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2014 Canadian Technical Report of Fisheries and Aquatic Sciences 3131. *Edited by* P.C. Chandler, S.A. King, and R.I. Perry. pp. 172–176.

Grant, S.C.H., Michielsens, C.G.J., Porszt, E.J., and Cass, A.J. 2010. Pre-season run size forecasts for Fraser River sockeye salmon (*Oncohrynchus nerka*) in 2010. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/042. vi + 125 p.

Grant, S.C.H., and Pestal, G. 2012. Integrated biological status assessments under the Wild Salmon Policy using standardized metrics and expert judgement: Fraser River Sockeye Salmon (*Oncorhynchus nerka*) case studies. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/106. v + 132 p.

Haeseker, S.L., Dorner, B., Peterman, R.M., and Su, Z. 2007. An improved sibling model for forecasting chum salmon and sockeye salmon abundance. N. Am. J. Fish. Manag. 27(2): 634–642.

Haeseker, S.L., Peterman, R.M., Su, Z., and Wood, C.C. 2008. Retrospective evaluation of preseason forecasting models for sockeye and chum salmon. N. Am. J. Fish. Manag. 28(1): 12–29.

Healey, M. 2011. The cumulative impacts of climate change on Fraser River sockeye salmon (*Oncorhynchus nerka*) and implications for management. Can. J. Fish. Aquat. Sci. 68(4): 718–737.

Hume, J.M.B., Shortreed, K.S., and Morton, K.F. 1996. Juvenile sockeye rearing capacity of three lakes in the Fraser River system. Can. J. Fish. Aquat. Sci. 53(4): 719–733.

Irvine, J.R., Akenhead, S., and A. 2014. Understanding Smolt Survival Trends in Sockeye Salmon. Coast. Mar. Fish. Dyn. Manag. Ecosyst. Sci. 5(1): 303–328.

MacDonald, B.L., and Grant, S.C.H. 2012. Pre-season run size forecasts for Fraser River sockeye salmon (*Oncorhynchus nerka*) in 2012. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/011. v + 64 p.

Mueter, F.J., Pyper, B.J., and Peterman, R.M. 2005. Relationships between coastal ocean conditions and survival rates of northeast Pacific salmon at multiple lags. Trans. Am. Fish. Soc. 134(1): 105–119.

Peterman, R.M., and Dorner, B. 2012. A widespread decrease in productivity of sockeye salmon (*Oncorhynchus nerka*) populations in western North America. Can. J. Fish. Aquat. Sci. 69(8): 1255–1260.

Tucker, S., Trudel, M., Welch, D.W., Candy, J.R., Morris, J.F.T., Thiess, M.E., Wallace, C., Teel, D.J., Crawford, W., Farley, E. V., and Beacham, T.D. 2009. Seasonal stock-specific migrations of juvenile sockeye salmon along the west coast of North America: implications for growth. Trans. Am. Fish. Soc. 138(6): 1458–1480.

Welch, D.W., Ishida, Y., and Nagasawa, K. 1998. Thermal limits and ocean migrations of sockeye salmon (*Oncorhynchus nerka*): long-term consequences of global warming. Can. J. Fish. Aquat. Sci. 55(4): 937–948.

Welch, D.W., and Parsons, T.R. 1993. δ13C-δ15N values as indicators of trophic position and competitive overlap for Pacific salmon (*Oncorhynchus* spp.). Fish. Oceanogr. 2(1): 11–23.

Ye, H., Beamish, R.J., Glaser, S.M., Grant, S.C.H., Hsieh, C., Richards, L.J., and Schnute, J.T. 2015. Equation-free mechanistic ecosystem forecasting using empirical dynamic modeling. Proc. Nat. Acad. Sci.: pp. 1–8.

Appendix 1. Model selection rationale for the 2017 forecasts for each stock

For each of the subsequent stock-specific results sections the following procedure was consistently applied:

- When comparing the forecast of the top ranked models, the percentage difference between estimates has been calculated using the 50%-median probably levels (p-levels);
- Unless otherwise noted, the top three models (ranked according to their average rank across all performance measures) only contained those models that also ranked within the top half of all models for each of the four performance measures individually.

Early Stuart

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 6). For each individual performance measure, these models all rank within the top 50% (10 out of 20) of models for this stock (see Table 5 in MacDonald & Grant 2012). Forecasts produced by the top ranked models are variable. The Ricker model produces the largest forecast, while the addition of environmental variables decreases the forecasts. The smallest forecasts (Ricker (Pi) and Ricker (Ei)) are 61% smaller than the Ricker forecast, while the Ricker-PDO forecast is 32% smaller (Table 6). The Entrance Island, Pine Island, and PDO temperature covariates indicate lower survival for Early Stuart returns in 2017 than the basic Ricker model with no temperature covariate. This signal is consistent with other stocks for which temperature covariate models rank well (Appendix 2). The Ricker (Ei) model was used for the 2017 Early Stuart forecast, as it ranked first on average across performance measures, 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), and the signal of the environmental variable (Ei) is consistent with other stocks (Table 6).

Bowron

The Bowron top ranked models include MRS, Ricker (Pi), and Ricker (Ei) (Table 6). Forecasts produced by the top ranked models varied by 42% (Table 6), with the MRS model producing the largest forecast under the assumption of average survival, and the Ricker models with environmental covariates producing lower forecasts (Ricker (Pi) and Ricker (Ei) varying by 11% from each other). The Ei and Pi temperature covariates indicate lower survival for Bowron returns in 2017 than models with no temperature covariate (Table 6). This signal is consistent with other stocks for which temperature covariate models are top ranked (Appendix 2). The Ricker (Pi) model was used for the 2017 Bowron forecast, as it ranks high on average (2nd) across performance measures, it ranks well on each individual performance measure (Table 5 in MacDonald & Grant 2012), and the signal implied by the environmental covariate is consistent with other stocks (Table 6).

Upper Barriere (Fennell)

The Upper Barriere top ranked models include the power, RAC, and Ricker models (Table 6). All three top models ranked within the top 50% of all evaluated models on each individual performance measure. Forecasts produced by the top ranked models varied by 50%, with the Ricker model generating the largest forecast and the RAC model producing the smallest (Table 6). The power model was used for the 2017 Upper Barriere 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).

Gates

The Gates top ranked models include the RAC, R2C, Larkin (tied third), MRS (tied third), power (tied sixth) and Ricker (Pi) (tied sixth) models (Table 6). For each individual performance measure, the RAC, 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). However, since the brood year escapement for Gates was above average, only models that use brood year escapement as a predictor variable were considered to generate the 2017 forecast. The Larkin and MRS models produce forecasts that vary by 79% (Table 6). The MRS model assumes average survival, while the Larkin model forecast for 2017 is reduced by the assumption of delayed-density dependence resulting from the large 2011 brood year EFS abundance (26,400 EFS). Fry data indicate that survival in the Gates system (676 fry/EFS) in the 2013 brood year was below recent and long-term averages. The Larkin model was used for the 2016 Gates forecast, as it ranked high on average across performance measures, it ranked well relative to alternative models on each individual performance measure, and the forecast indicates that delayed-density dependence is occurring in this system.

Nadina

The Nadina top ranked models include the MRJ, Ricker (FrD-peak) (tied second), and power (juv) (FrD-peak) (tied second) (Table 6). Both EFS-based models and juvenile-based models were considered for Nadina because freshwater survival was average in the 2013 brood year. 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. Forecasts produced by the top ranked models differed by only 6% (Table 6). The MRJ model was used for the 2017 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 6 in MacDonald & Grant, 2012).

Pitt

The Pitt top ranked models include the Larkin, TSA, Ricker (PDO), and Ricker (Ei) models (Table 6). Since the brood year escapements for Pitt (2013 & 2012) were above average, only models that use brood year escapement as a predictor variable were considered to generate the 2017 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 models varied by 25% (Table 6), with the Larkin model producing the largest forecast. The top performing Larkin model was used to generate the 2017 forecast for Pitt (Table 1A), as this model is the top performing model on average, and across individual performance measures.

Scotch

The Scotch top ranked models include the Larkin, Ricker and RS1 (Table 6). For each individual performance measure, the Larkin and Ricker models each ranked within the top 50% (10 out of

20) of all models for this stock (Table 5 in MacDonald & Grant 2012). Forecasts produced by the Larkin and Ricker models differed by 88% (Table 6), with the Larkin model producing a much smaller forecast than the Ricker model. The forecast processes for 2014 and 2015 recommended against using the Larkin model for both Scotch and Seymour, given that most of the delayed-density dependence in Shuswap Lake should be influenced by the dominant cycle of the Late Shuswap stock, and is not explicitly accounted for in the Scotch or Seymour Larkin models when fit to individual stock-recruitment data. However, over the past two return years for which we have data (2014 and 2015), all stocks that rear in Shuswap Lake (Scotch, Seymour and Late Shuswap) experienced low survival that more closely aligned with forecasts produced by the Larkin model, as opposed to the Ricker model. These two return years encompass returns from the extremely large escapements observed in the Shuswap system in 2010 (four and five year old returns), and the escapements on the sub-dominant cycle line in 2011 (four year old returns). This low survival suggests that delayed-density dependence occurs within the Shuswap Lake stocks, and is best represented by forecasts from the Larkin model. Therefore, the Larkin model was used to produce the 2017 forecasts for the Scotch, Seymour and Late Shuswap stocks.

Seymour

The Seymour top ranked models include the Ricker-cyc, Larkin (tied second), R1C (tied second), RAC, and Ricker-Ei; note the Ricker-cyc model forecast did not converge so it was excluded from consideration (Table 6). For each individual performance measure, the Larkin and R1C models each ranked within the top 50% (10 out of 20) of all models for this stock (Table 5 in MacDonald & Grant 2012). Since the brood year escapement for Seymour was above average, only models that use brood year escapement as a predictor variable were considered to generate the 2017 forecast. The forecast processes for 2014 and 2015 recommended against using the Larkin model for both Scotch and Seymour, given that most of the delayed-density dependence in Shuswap Lake should be influenced by the dominant cycle of the Late Shuswap stock, and is not explicitly accounted for in the Scotch or Seymour Larkin models when fit to individual stock-recruitment data. However, over the past two return years for which we have data (2014 and 2015), all stocks that rear in Shuswap Lake (Scotch, Seymour and Late Shuswap) experienced low survival that more closely aligned with forecasts produced by the Larkin model, as opposed to the Ricker model. These two return years encompass returns from the extremely large escapements observed in the Shuswap system in 2010 (four and five year old returns), and the escapements on the sub-dominant cycle line in 2011 (four year old returns). This low survival suggests that delayed-density dependence occurs within the Shuswap Lake stocks, and is best represented by forecasts from the Larkin model. Therefore, the Larkin model was used to produce the 2017 forecasts for the Scotch, Seymour and Late Shuswap stocks.

Chilko

The 2017 forecasts for Chilko were restricted to EFS-based models because a smolt estimate was not available for the 2013 brood year. The Chilko top ranked EFS-based models are the Larkin (tied for first overall), Ricker-cyc (ranked seventh overall), and Ricker (FrD-mean) (ranked tenth overall) models (Table 6). 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 all four performance measures were compared to inform model selection, with juvenile-based models removed. Forecasts produced by the top ranked models varied by 58% (Table 6), with the Larkin model producing a larger forecast than the Ricker-cyc and Ricker (FrD-mean) models. The Ricker-cyc model uses only cycle-line data, and for Chilko the 2013 brood year EFS was the largest observed on this cycle; therefore the Ricker-cyc model is extrapolating beyond its fitted range in generating forecasts based on this abundance, increasing the uncertainty in the Ricker-cyc forecast. The Larkin model was used to generate the 2017 forecast for Chilko, as this model ranked first among the EFS-based models for this stock, and also ranked first (tied with power (juv) (Pi)) across all models (EFS and juvenile-based), performing similarly to the power(juv) (Pi) model. In the 2012 cross-validation analysis, the Larkin and power (juv) (Pi) models performed very similarly on the RMSE and MAE performance measures, while the power (juv) (Pi) model outperformed the Larkin on the relative precision metric, MPE, and vice versa for the bias metric, MRE. The high ranking performance of the Larkin model when juvenile-based models are included in the cross-validation analysis, indicates that the Larkin model accounts for the freshwater dynamics that occur in Chilko Lake, suggesting that delayed-density-dependent mechanisms are present.

Late Stuart

The Late Stuart top ranked models include the R1C, R2C, power, Ricker (FrD-mean), and Ricker-cyc models (Table 6) (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 below average, only models that use brood year escapement as a predictor variable were considered to generate the 2017 forecast. Forecasts produced by the three biological models (power, Ricker (FrD-mean) & Ricker-cyc) varied by 49%, with the Ricker (FrD-mean) model producing the largest forecast, and the power producing the smallest (Table 6).The power model was used to generate the 2017 forecasts for Late Stuart, as it is the highest ranked EFS-based model for Late Stuart.

Quesnel

The Quesnel top ranked models include the R1C, R2C, Ricker-cyc, Larkin, and Ricker (Ei) (Table 6). For each individual performance measure, each of these models apart from the Larkin 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 Quesnel was below average, only models that use brood year escapement as a predictor variable were considered to generate the 2017 forecast. The Ricker-cyc and Ricker (Ei) models produced quite different forecasts, varying by 83%. The Ei covariate indicates lower survival for Quesnel returns in 2017 than models with no temperature covariate (Table 6). This signal is consistent with other stocks for which temperature covariate models are top ranked (Appendix 2). The Ricker (Ei) model was used for the 2017 Quesnel forecast, because the highest ranked EFS-based model for this stock is a Ricker model form, and the signal implied by the environmental covariate is consistent with other stocks (Table 6). This model also ranks high on average (5th) across performance measures, and it ranks well on each individual performance measure (Table 5 in MacDonald & Grant 2012).

Stellako

The Stellako top ranked models include the R2C, Larkin, Ricker (Ei), and Ricker (PDO) (Table 6). Only the R1C model performed within the top 50% of all models on each performance measure (MacDonald & Grant 2012); however, since the brood year escapement for Stellako was above average, only models that use brood year escapement as a predictor variable were considered to generate the 2017 forecast Forecasts produced by the top three EFS-based models varied by 31%, with the Ricker (PDO) model generating a slightly larger forecast than the Larkin, followed by the Ricker (Ei) model (Table 6). The Larkin model was used to generate the 2017 forecast for Stellako, as this is the top ranked EFS-based model. The performance of the Larkin model indicates that delayed-density-dependent mechanisms may occur within the Stellako system.

Harrison

A sensitivity analyses was conducted to explore the effect of varying the Harrison data set used to fit the biological model (Ricker). The Ricker model applied to both three and four year old forecasts produced a much higher estimate at 681,000 (50% p-level). Another sensitivity analysis was conducted to explore three-to-four year old sibling forecasts using all years post-1980 (both odd and even) recruitment data (Table 6). This total forecast (217,000 at the 50% p-level) was similar to the odd year post-1980 forecast (251,000 at the 50% p-level). This was expected given the higher proportion of four year olds produced in odd years compared to even years, and the decrease in four year old proportions when all years are combined.

Raft

The Raft top ranked models include Ricker (PDO), Ricker-cyc (tied second) and power (tied second) (Table 6). 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 top ranked models varied by 8%, with the Ricker (PDO) model producing the smallest forecast; however, a forecast could not be generated using the Ricker-cyc model due to a lack of model convergence within the pre-defined range, as described in the Methods (Table 6). The Ricker (PDO) model was used for the 2017 Raft forecast, as it ranked first on average across performance measures, and it ranked highest on each individual performance measure except RMSE (ranked fourth).

Cultus

The Cultus top ranked models include the MRJ, power (juv) (FrD-peak), and power (juv) (Pi) models (Table 6). Due to significant gaps in the smolt time-series, the number of years that could be forecasted by certain smolt models (RJ1, RJ2 & RJC) in the jack-knife analysis was severely restricted. These models were therefore 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 do not account for the significant hatchery supplementation (fry & smolts) to this stock since the 2000 brood year. The top models all ranked within the top 50% (7 out of 14) of all models compared for this stock on each individual performance measure (Table 5 in MacDonald & Grant, 2012). Forecasts produced by the top ranked models varied by 36%, with the MRJ and power (juv) (FrD-peak) models producing larger forecasts than the power (juv) (Pi) model (Table 6). The Pine Island sea surface temperature covariate indicates lower survival for Cultus returns in 2017 than models that do not include a temperature covariate. This signal is consistent with other stocks for which models that include temperature covariates rank within the top three of all models assessed. The power (juv) (Pi) model was used for the 2017 Cultus forecast, as this model ranks within the top three models, and the signal of the environmental covariate is consistent with other stocks (Appendix 2).

Late Shuswap

The Late Shuswap top ranked models include the R1C, Ricker-cyc, RAC, R2C, Larkin, and Ricker (Ei) models (Table 6). Due to the large escapement in Late Shuswap in 2013, which was well above the cycle average, only models that use brood year escapement as a predictor variable were considered to generate the 2017 forecast. Forecasts produced by the Ricker-cyc Larkin, and Ricker (Ei) models differed by 78% (Table 6), with the Ricker (Ei) model producing a much smaller forecast than the Ricker-cyc model, and Larkin forecast falling between these two. In the past two return years for which we have data (2014 and 2015), all stocks that rear in Shuswap Lake (Scotch, Seymour and Late Shuswap) experienced low survival that more closely aligned with forecasts produced by the Larkin model, as opposed to the Ricker model. These two return years encompass returns from the extremely large escapements observed in the Shuswap system in 2010 (four and five year old returns), and the escapements on the sub-dominant cycle line in 2011 (four year old returns). This low survival suggests that delayed-density dependence occurs within the Shuswap Lake stocks, and is best represented by forecasts from the Larkin model. Additionally, the Ricker-cyc model is fit using only cycle-line data, and for Late Shuswap the 2013 brood year EFS was by far the largest observed on this cycle. The Ricker-cyc model is therefore extrapolating beyond its fitted range in generating forecasts based on the 2013 brood year abundance, increasing the uncertainty in these forecasts. The Larkin model was, therefore, used to produce the 2017 forecasts for the Late Shuswap.

Portage

The Portage top ranked models include the Larkin, Ricker-cyc, and power models (Table 6). 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). However, the Ricker-cyc model was excluded from consideration due to a lack of model convergence within the pre-defined range, as described in the Methods. Forecasts produced by the top remaining models varied by 37% (Table 6), with the power model producing a smaller forecast than the Larkin model. The Larkin model was used for the 2017 Portage forecast, as it ranked first on average across performance measures, and it ranked well on each individual performance measure. The performance of the Larkin model indicates that delayed-density-dependent mechanisms may occur within the Portage system.

Weaver

For Weaver, the juvenile abundance observed for the 2013 brood year was above average due to above average early freshwater survival; therefore forecasts were restricted to models that use juveniles as a predictor variable. The Weaver top ranked juvenile-based models include the RJC (ranked 3rdoverall), power (juv) (FrD-peak) (ranked 6th overall), and power (juv) (Ei) (ranked 8th overall) models (Table 6). None of the top models ranked within the top 50% (17 out of 33) of all models compared for this stock on all four performance measures (Table 5 in MacDonald & Grant, 2012); all ranked poorly on the MRE performance measure. Forecasts produced by the top ranked juvenile models varied by 27% (Table 6), with the RJC and power (juv) (FrD) models producing very similar forecasts, and the power (juv) (Ei) model producing a lower forecast. These forecasts are all larger than those produced by EFS-based models due to the above average juvenile survival in the 2013 brood year for Weaver. The power (juv) (Ei) model was used for the 2017 Weaver forecast, because it is a top-ranked juvenile-based model for Weaver, and the signal implied by the environmental covariate is consistent with that of other stocks (Appendix 2).

Birkenhead

The Birkenhead top ranked models include the Ricker (Ei), Ricker (tied second), RAC (tied second), Ricker (Pi) (tied fourth), and TSA (tied fourth) models (Table 6). Due to the above average Birkenhead escapement in 2013, only the top ranked models that use brood year escapement as a predictor variable (Ricker (Ei), Ricker & Ricker (Pi)) were considered to generate the 2017 forecast. For each individual performance measure, none of the remaining models ranked within the top 50% (10 out of 20) of all models (Table 5 in MacDonald & Grant, 2012). Forecasts produced by the top ranked models varied by 34% (Table 6), with the Ricker (Ei) and Ricker (Pi) models producing a lower forecasts than the basic Ricker model. The first ranked Ricker (Ei) model was used for the 2017 Birkenhead forecast, as it is the highest ranked model.

Appendix 2. Cross-validation of warm years

In light of the extremely warm ocean conditions observed in covariate data for the 2015 ocean entry year, and the consistent response of stock forecasts to this additional information, we added an additional step to the model selection process for 2017. In cases where the top ranked forecast was a Ricker, power (juvenile), or non-biological model, and a temperature covariate model (Ricker (Ei), Ricker (Pi), Ricker (PDO), power (juv) (Ei), power (juv) (Pi), or power (juv) (PDO)) ranked within the top three models, the forecasting performance of the covariate model was examined specifically in warmer than average years. The purpose of this re-evaluation was to inform model selection, by identifying whether the addition of SST as a model covariate improved forecasting performance in years when temperatures were above average.

For each temperature covariate (Ei, Pi & PDO), the warmest 25% of years were identified according to the highest temperature anomalies within the time-series of each stock. Using the jack-knife results (historical forecasts and true returns to the 2004 brood year) from the formal model evaluation performed in the 2012 Fraser Sockeye forecast (MacDonald and Grant 2012), performance measures were re-calculated for all models using only the warm years identified for each applicable covariate. All applicable models were then re-ranked by stock.

Results of the model re-rank show that in all cases the addition of sea surface temperature covariates (Ei, Pi, PDO) to the basic model forms (Ricker or power (juv)) improves forecasting performance according to the average rank across the four performance measures (MacDonald and Grant 2012) (Table A2: Ranks). The addition of temperature covariates also reduces the 2017 forecasts for each stock at the 50% probability level (Table A2: 50% Forecasts), consistently indicating that implied survival is reduced with the addition of the temperature covariate.

Table A2. Re-rank of model forms using subset of years with the highest 25% of sea surface temperature data for each stock. The number of years of data used for each re-rank is indicated under the column entitled "n". Each covariate model form is compared to the Ricker model form without the covariate, unless otherwise indicated. Forecasts for each model are presented at the 50% probability level.

STOCK	COVARIATE	n	RANK		50% FORECAST	
			Basic Model	Covariate Model	Basic Model	Covariate Model
Early Stuart	Pi	12	7	3	252,000	98,000
	Ei	11	5	3	252,000	99,000
	PDO	13	9	8	252,000	171,000
Bowron	Pi	12	5	2	14,000	7,000
	Ei	11	6	4	14,000	8,000
Quesnel	Ei	11	12	6	823,000	192,000
Raft	PDO	13	6	2	46,000	33,000
Cultus[a]	Pi	5	6	1	4,000	3,000
Weaver[a]	Ei	7	25	13	235,000	186,000
Birkenhead	Ei	11	7	3	216,000	143,000

a. Cultus and Weaver both use juvenile data, therefore the basic model form is the power(juv)

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