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PRE-SEASON RUN SIZE FORECASTS FOR FRASER RIVER SOCKEYE *(ONCORHYNCHUS NERKA)* SALMON IN 2018

Context

Fraser Sockeye survival has been low in the last three years (2015-2017). Most of these salmon would have been deposited in the gravel as eggs from 2011 to 2013, migrated to the Northeast (NE) Pacific Ocean as smolts from 2013 to 2015, and returned to spawn as adults from 2015 to 2017. During this period, unusually warm land and ocean temperatures have been observed. In the NE Pacific, a 'warm blob' developed late 2013 and persisted through to 2016, characterized by anomalously warm waters 3-4°C above seasonal averages and extending down to 100 m depths in some regions. A strong El Niño also occurred from 2015 to 2016, which also contributed to warmer land-ocean temperatures in local Pacific and British Columbia waters. Fraser River temperatures were warmer than average in spring and summer months during this period, and spring freshets were particularly early in 2015 and 2016. Although exact temperatures experienced by salmon throughout their life will vary, along with their specific responses, warmer conditions are generally linked to poorer salmon survival. In the ocean, for example, 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), and warm conditions as early as one year prior to outmigration may influence juvenile growth (Beamish and Mahnken 2001). Fraser Sockeye that will return in 2018 will have experienced many of these same freshwater and marine warm conditions as recent returns (2015-2017).

Fraser Sockeye forecasts are presented as standardized cumulative probabilities (10%, 25%, 50%, 75%, and 90%) to capture inter-annual random (stochastic) uncertainty in returns, largely attributed to variations in stock survival. The probability distribution for each stock generally spans the range of survival it has exhibited historically for a given brood year escapement, with forecast values at the lower probability levels representing lower observed stock survivals, and values at the higher probability levels representing higher observed survivals. Total Fraser Sockeye returns have either been near or below the 50% probability level forecast for the past 13 years, excluding 2010, indicating average to below average survival for this aggregate during this period. In the last three return years (2015-2017), total Fraser Sockeye returns have fallen at the lowest (10%) probability level forecast, consistent with very poor survival.

The combined Fraser Sockeye forecast for 2018 has a median estimate of 14 million, which is similar to the long-term average return for this cycle line (13.1 million), and above the all-year average (7.4 million). At the lower end of the forecast distribution, the forecast for 2018 is 5.3 million at the 10% probability level and 8.4 million at the 25% probability level. Warm temperatures in BC freshwater and Pacific marine ecosystems have occurred in recent years, coinciding with poor total Fraser Sockeye survival. If these recent trends in Fraser Sockeye survival persist, then 2018 total returns are likely to be at the lower (10%-25%) probability level forecast. At the individual stock level, however, responses are likely to vary. Pre-season fisheries' planning considers a range of possible return outcomes based on the forecast distribution, with some emphasis on lower p-levels (10%-25%) in recent years. In-season management decisions are based on in-season data, compared with forecast parameters.

The effects of extremely warm water temperatures on survival have been incorporated quantitatively into the forecasts for eight stocks where temperature covariate models historically perform well (Early Stuart, Bowron, Chilko, Quesnel, Raft, Cultus, Weaver, Birkenhead). Together, these eight stocks account for 24% to 32% of the total 2018 forecast, depending on the probability level. Incorporating temperature covariates into these forecasts reduced the total forecast by only 17%, since most of the total forecast was not informed by these warmer temperature data. Additionally, since not all stocks will exhibit similar survival, the forecast distribution for total Fraser River Sockeye salmon will likely over-estimate total returns, particularly at the high probability levels, and it is more appropriate to reference individual stock forecast distributions, versus the total summed forecast.

The Late Run Shuswap stock dominates the 2018 forecast (50% at the median probability level). Unlike the 2016 and 2017 forecasts, the Larkin model was not specifically chosen to generate the Late Shuswap forecast, as the extremely large 2010 brood year escapement is no longer expected to impact survival of this stock. Instead, the Ricker-cyc model (see Table 4) was used based on the model selection criteria. The Larkin model forecast is slightly lower than the selected Ricker-cyc model, though it is similar to the Ricker model forecasts, which means that this difference is not due to delayed-density dependence.

The Summer Run Chilko (16%) and Quesnel (8%) stocks are the next largest contributors to the 2018 forecast. Usually a smolt-power model is used to generate Chilko forecasts. However, given smolt data were only available for the 2014 brood year, and not the 2013 brood year, a blended smolt-sibling model was used. Specifically, four year olds were forecast with a smolt-power model, and five year olds were forecast using a four-to-five year old sibling model (using preliminary four year old returns in 2017 to predict five year old returns in 2018). The five year old forecast for Chilko is very small, due to the low return of four year old fish in 2017. Quesnel was forecast using the same model as 2017: a Ricker model using sea-surface temperature measured at the Entrance Island lighthouse station. This addition of the Entrance Island covariate in this model has a strong effect on the forecast for Quesnel, reducing it by more than 50%. However, preliminary return estimates for 2017 indicate that this model performed very well under similar environmental conditions as those used to generate the 2018 forecast.

The remaining stocks are expected to contribute a total of 26% of the forecast, dominated by Stellako (4%), Seymour (4%), and Scotch (2%).

This Science Response Report results from the Science Response Process of December 15, 2017 on Pre-season abundance forecast for Fraser River Sockeye returns in 2018. The 2018 forecast relies on methods of past CSAS processes and publications (Cass et al. 2006; DFO 2006, 2008, 2009, 2011, 2012, 2013, 2014a, 2014b, 2015a, 2015b, 2016, 2017; Grant et al. 2010; Grant and MacDonald 2012, 2013; MacDonald and Grant 2012).

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 (See Methods)., 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) to capture inter-annual random (stochastic) uncertainty in returns largely attributed to variations in stock survival. 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, the model fit estimates 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. A short-hand notation is used in some parts of this document for efficiency (e.g. p50 to denote the 50% probability level).

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 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.

Forecasted values generally reflect the historical survival (recruits-per-spawner) of each stock 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.

A total return forecast for Fraser Sockeye is calculated by combining all individual stock forecast ranges. The current method sums individual stock forecasts at each probability level (i.e. each column in Table 1A), and the resulting total range implies that all stocks return at the same probability level (i.e. variation over time is fully correlated, and all stocks have either above-average or below-average survival in 2018). This produces very wide bounds for the total forecast, which are likely an over-estimate of the uncertainty range of potential total returns. A more statistically accurate approach would be to combine the full forecast distributions based on observed correlations between all stocks (Y. Xie, Pacific Salmon Commission, Vancouver, B.C., pers. comm.). However, this approach faces several challenges: (a) estimating the covariance matrix among 19 modelled and eight miscellaneous stocks; (b) expanding the statistical concepts to many stocks; (c) developing computing-efficient code to implement the calculations; (d) communicating the interpretation of a revised Table 1A, where the columns don't add up. A simple illustration has been included as Appendix 3.

Given these challenges, the 2018 forecast materials retained the summing approach used for more than 20 years. It is therefore important to keep in mind that the upper and lower bounds on the total forecast imply that all stocks return at the same probability level, and that it is more appropriate, where possible, to reference individual stock forecasts as opposed to the total Fraser Sockeye forecast, to avoid misinterpretation.

Fraser Sockeye Returns

Total Fraser Sockeye adult returns have historically varied (Figure 1, top panel) due to the four-year cyclic pattern of abundances exhibited by some of the larger stocks, variability in annual survival (Figure 1, bottom panel, and Figure 2), and variability in harvest levels. After reaching a peak in the early 1990s, returns subsequently decreased and were particularly low in 2009 (Figure 1, top panel). 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, total returns in the next 3 years (2015 to 2017) again declined compared to the respective brood year abundances.

The 2018 cycle line (which includes the current forecast year) is historically the most abundant return of the 4-year cycle, because it includes the dominant Late Shuswap cycle line.

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 three 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 2013-2015 ocean entry years. On an individual stock level, survival trends vary (Figure 4; Grant et al. 2011b; Peterman and Dorner 2012). Most notably, Harrison Sockeye have exhibited a large increase in survival in the past decade (Grant et al. 2010; Grant et al. 2011b), 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 until their return to the spawning grounds) (Figure 2). Chilko exhibits similar marine survival trends (Figure 2, bottom panel) to the total Fraser Sockeye aggregate (Figure 1, bottom panel), 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 2017 return was also poor, but an estimate of smolt abundance could not be made from the standard method because high water during the 2015 smolt outmigration prevented the typical installation of the smolt weir. Thus, an estimate of marine survival is not available for the 2013 brood (2017 return).

The last three years of poor returns, particularly poor for Summer-run stocks such as Chilko, correspond to the notably warm sea surface temperatures (SST) in the NE Pacific Ocean, referred to as the 'warm blob'. Although the extremely warm SSTs associated with the warm blob dissipated to some degree during the 2016 ocean entry year, ocean temperatures remained substantially greater than historic averages along the continental shelf throughout most of 2016 and during the summer in the Gulf of Alaska in 2016 (See Ross 2017 and Chandler et al. 2017).

Environmental Conditions

Poor survival in recent years (2015-2017) coincided with unusually warm temperatures in the NE Pacific Ocean, in the years when these fish entered the ocean (2013-2015), referred to as the 'warm blob'. This phenomenon developed in the NE Pacific in late 2013 and persisted through 2016, exhibiting ocean temperatures that were 3-4C° above the seasonal average. The majority of Fraser Sockeye returning as four-years olds in the last three return years would have entered the ocean between 2013 and 2015, when ocean temperatures were abnormally warm. 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), and warm conditions as early as one year prior to outmigration may influence juvenile growth (Beamish and Mahnken 2001). However, although many returning Pacific Sockeye stocks exposed to warm ocean temperatures experienced poor survival from 2015 to 2017, there were some Sockeye stocks where survival was not poor (DFO 2016b, Grant and Michielsens 2016; K. Hyatt, DFO, Nanaimo, B.C., pers. comm.). Variation in stock survival attributed to differences in distribution in freshwater conditions during egg incubation and lake rearing stages (DFO 2016b) and/or within the Gulf of Alaska during ocean residence (Blackbourn 1987; Welch and Parsons 1993), may account for the variability in Sockeye stock returns from 2015 to 2017.

Given the presence of extremely warm ocean temperatures throughout the egg incubation, juvenile rearing, and ocean entry period of Fraser Sockeye returning in 2018 (2014-2016), survivals in the lower half of the range observed historically (below the median) are expected.

2018 Forecast Brood Year Escapements (2013 and 2014)

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 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 2018 were produced by the 2014 brood year escapement. In the 2014 brood year, the effective female spawner (EFS) abundance for the 19 forecasted stocks combined (excluding miscellaneous stocks) was 2,925,000, which was about 50% larger than the cycle average of 2,020,000 EFS. For the Early Stuart, Early Summer, and Summer Run timing groups the 2014 brood year EFS abundances were near or above the long-term (1952-2014) cycle averages (Appendix 1). Escapements of the Late Run timing group in 2014 were around the long-term cycle average for modelled stocks, but below the average of the last four cycles for the total timing group including miscellaneous stocks. Stocks within each timing group differed in terms of 2014 brood year escapement relative to cycle averages. Details are listed in Table 1B and Appendix 2, but briefly summarizing the 19 modelled stocks: Early Summer had 3 stocks near average and 4 stocks above average, Summer had 5 stocks above average and 1 stock near average, and Late had 3 stocks below average (Cultus juveniles, Weaver, Birkenhead), 1 stock near average, and 1 stock above average.

Late Shuswap contributed the bulk of the total 2014 EFS abundance (36% of modelled stocks; Table 6). The next largest contributors to the total EFS abundance were Chilko (23%) and Quesnel (15%). Stellako and Harrison contributed about 8% each, and the remaining stocks contributed less than 10% combined.

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 2018 forecast is 2011, with the exception of Harrison Sockeye (data are included to the 2012 brood year).
- EFS data are included up to the 2014 brood year (2015 for Harrison).
- Juvenile fry data for the 2014 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 smolt data in the 2014 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. Juvenile smolt for the 2014 Chilko

brood year are available, and were used in the selected forecast model, in combination with a sibling model to fill in the 5 year olds that could not be calculated with a juvenile-based model.

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 sea-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 2018 Fraser Sockeye forecasts follow the same approach as recent forecasts (DFO 2012;

MacDonald and Grant 2012; DFO 2013; Grant and MacDonald 2013; DFO 2014a; DFO 2015a; DFO 2016a; DFO 2017), which were adapted from methods used in earlier forecasts (Cass et al. 2006; DFO 2006, 2008, 2009).

Forecasts for 19 modelled stocks are based on a model selected from a shortlist of top-ranked models. Table 4 lists the full suite of candidate models. For most miscellaneous stocks, forecasts are based on brood year escapements and long-term observed survival rates for proxy stocks. Chilliwack was forecasted like other miscellaneous stocks until recently, but is now based on a Ricker fit to a short time series.

Model performance, ranking, and the primary model selection process for Fraser Sockeye Salmon are based on the analyses conducted in 2012 (MacDonald and Grant 2012). Given the environmental conditions in the past few years, an additional criterion to address temperature effects on survival was added to the 2017 model selection process, and has been retained for the 2018 forecast. Methods are summarized in the bullets below (see Appendix 2 for model selection process by stock for 2018 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, and 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 and Grant 2012); performance was then measured by comparing forecasts to observed returns across the full time series.
4. Four performance measures (mean raw error, mean absolute error, mean proportional error and root mean square error; 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 and Grant 2012);

5. The model selection criteria identified in the 2012 forecast (see Appendix 2; taken from MacDonald and Grant 2012) were applied. In addition, new since 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 of DFO 2017). Due to the additional information contained in the covariate, the superior ranking of these models in anomalously warm years, and the consistent signal of lower survival implied by the addition of the covariate across the applicable stocks, a temperature covariate forecast was adopted for seven stocks (Early Stuart, Bowron, Quesnel, Raft, Cultus, Weaver, Birkenhead) in 2017 (Table A2 in Appendix 3 of DFO 2017). A temperature covariate forecast was selected for the same seven stocks in 2018, and also for Chilko 4-yr olds.
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).
8. Non-parametric models using cycle-line returns (R1C, R2C, and RAC) have been modified compared to previous forecast papers. Uncertainty bounds are now being calculated using only cycle-line residuals rather than residuals for all years in the time series. This change produced considerably narrower bounds for most stocks. See the statistical notes in Appendix 2 for stock-specific details.

Results

Fraser Sockeye 2018 Forecasts

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 (e.g. DFO 2014a, DFO 2017) and research conducted on coast-wide salmon stocks (Haeseker et al. 2007, 2008).

Table 1A lists the selected models and associated forecast ranges for 27 stocks (19 modelled stocks, Chilliwack, 7 miscellaneous stocks). Assuming that all stocks are fully correlated (i.e. all return at the same probability level), the total Fraser Sockeye return in 2018 is estimated to be about 14 Million, with an estimated 50% probability that the return will be between 8.5 Million and 23 Million, and an estimated 90% probability the return will be between 5.3 Million and 37 Million. As noted above and in Appendix 3, less than full correlation would imply a narrower range of potential outcomes, particularly relative to the 90% probability interval.

Models selected for the 2018 forecast were mostly the same as those used for the 2017 forecast, with the exception of Seymour, Chilko, Late Stuart, Late Shuswap, and Weaver (Table 9). Appendix 2 describes the stock-specific rationale for model selections. At the mid-point of the forecast, the total 2018 return would be about 70% of the total 2014 return (14 Million vs. 20 Million).

Table 1B summarizes stock-specific estimates of spawner abundance in the brood years and compares the mid-point of the forecast range to observed returns on the 2018 cycle line. The Early Stuart forecast is below cycle average. Forecasts for stocks in the Early Summer timing group are either around the cycle average (4 stocks) or above the cycle average (3 stocks). Forecasts for stocks in the Summer timing group are either around the cycle average (4 stocks) or above the cycle average (2 stocks). Forecasts for stocks in the Late timing group are either around the cycle average (2 stocks) or below the cycle average (2 stocks).

Table 1C lists the abundance ranges used to assign the colour-coding in Column E of Table 1b.

Table 2 compares observed survival rates for different time periods with the survival rate implied in the forecasts from Table 1A. Early Stuart implied survival at p50 is lower than long-term and recent averages, but higher than the 2005 brood year (2009 returns). For Early Summer stocks, implied survival at p50 is roughly 1/3 to 2/3 of the long-term geometric average for 5 of the seven modelled stocks, but substantially lower for Pitt (12%; implied age 5 survival is 0.4 compared to long-term geometric average of 3.4) and above average for Seymour (9.5 vs. 7.3 average). For Summer stocks, implied survival at p50 is roughly 1/2 of the long-term geometric average for three of the six modelled stocks, about 1/3 for Stellako, and 1/4 for Quesnel. For the Late Management Unit, Late Shuswap contributes most of the abundance and implied survival at the 50% probability level is roughly at the long-term average (6.6 vs. 6.4) the largest forecast abundance. Implied survival for the three other modelled stocks ranges from roughly 2/3 of the long-term average (Portage, Birkenhead) to slightly below long-term average (Weaver). Implied survival for Cultus is calculated as recruits/smolt, and falls at about 1/2 of the long-term average. Survival for Harrison is calculated using total returns due to variability in age composition, and the mid-point of the forecast falls at roughly 10% of the long-term average.

Table 3 shows the mid-point forecast separately for age 4 and age 5 returns, and the corresponding proportion of 4yr olds. The forecasts for most stocks consist mostly of 4yr old returns (>75%). Notable exceptions are Pitt (mostly age 5), Chilliwack (roughly half age 5), Harrison (mostly age 3), Widgeon (mostly age 5), Weaver (2/3 age 4), and Birkenhead (1/3 age 4).

Appendix 3 compares two alternative approaches for summing the forecast distributions of two stocks, to illustrate that both mid-point and the range are affected by assumptions about covariation between stocks.

Conclusions

Pre-season fisheries' planning considers a range of possible return outcomes based on the forecast distribution, with some emphasis on lower p-levels (10%-25%) in recent years. In-season management decisions are based on in-season data, compared with forecast parameters.

The forecast models selected were very similar between 2017 and 2018. Since warmer land-ocean temperatures persisted between these two forecast years, considerations of temperature co-variate models were identical in 2017 and 2018. The effects of extremely warm water temperatures on survival have been incorporated quantitatively into the forecasts for eight stocks where temperature covariate models historically perform well (Early Stuart, Bowron, Chilko, Quesnel, Raft, Cultus, Weaver, Birkenhead). However, together these eight stocks account for 24% to 32% of the total 2018 forecast, depending on the probability level. Therefore, most of the total forecast does not include considerations of environmental covariates since these models do not rank high in terms of model performance.

The key difference in model selection between the 2017 and 2018 forecast years included the consideration of delayed-density dependence and the selection of the Larkin model. Delayed-density dependence considers the lag effect of high escapements on up to three subsequent brood year's survival, likely attributed to mechanisms acting in freshwater lakes during Sockeye rearing stages in these ecosystems. Since 2010 was an exceptionally high escapement year for a number of stocks, survival in subsequent brood years (2011-2013) could have been affected to some extent. These considerations led to the selection of the Larkin model for the 2017 forecast (2013 brood year) for three of the five stocks (Seymour, Chilko, Late Shuswap) for which the selected model changed in the 2018 forecast (2014 brood year (Table 7).

In recent years (2015-2017), total Fraser Sockeye returns were at the low end (~10% probability level) of the forecast range (Table 5). During the 2013 and 2014 brood years in particular, land-ocean temperature conditions were warm. The 'warm blob' from 2013 to 2016 in the NE Pacific, and El Niño from 2015-2016, contributed to the high observed temperatures. Temperatures throughout Fraser Sockeye life-history (NE Pacific Ocean, Fraser watershed during adult upstream migration, egg incubation, and smolt downstream migration) were warmer than average during these periods. In the Fraser River, spring freshet also was unusually early in 2015 and 2016. Based on the consistency in these broad scale observations of warm temperatures and ecosystem responses between the 2013 and 2014 brood years, and the recent poor Fraser Sockeye survival and total returns, in 2018 Fraser Sockeye total returns are expected to be at lower probability levels (10%-25%) below the median (50% probability level) of the forecast range. At these lower probability levels, the Fraser Sockeye total forecast for 2018 ranges from 5.3 million at the 10% probability level to 8.4 million at the 25% probability level. At the individual stock level, however, there likely will be some variability in survival, and therefore, the probability level that will correspond to their returns.

Tables

Table 1A: The 2018 Fraser River Sockeye 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 listed in the second column. Bold numbers show totals for stock groups (i.e. run timing groups, total Fraser)

Run timing group / Stocks	Forecast Model [a]	Probability that Return will be at/or Below Specified Run Size				
		10%	25%	50%	75%	90%
Early Stuart	*Ricker (Ei)*	***37,000***	***54,000***	***84,000***	***133,000***	***199,000***
Early Summer		**584,000**	**1,102,000**	**2,155,000**	**3,765,000**	**6,587,000**
(total excluding miscellaneous)		***393,000***	***674,000***	***1,175,000***	***2,168,000***	***3,750,000***
Bowron	*Ricker (Pi)*	*7,000*	*12,000*	*20,000*	*35,000*	*59,000*
Upper Barriere (Fennell)	*Power*	*9,000*	*14,000*	*25,000*	*46,000*	*80,000*
Gates	*Larkin*	*11,000*	*20,000*	*38,000*	*76,000*	*149,000*
Nadina	*MRJ*	*45,000*	*81,000*	*153,000*	*291,000*	*518,000*
Pitt	*Larkin*	*22,000*	*32,000*	*53,000*	*84,000*	*130,000*
Scotch	*Larkin*	*89,000*	*166,000*	*330,000*	*750,000*	*1,513,000*
Seymour	*RickerCyc*	*210,000*	*349,000*	*556,000*	*886,000*	*1,301,000*
Misc (EShu) [b]	*R/S*	*186,000*	*416,000*	*956,000*	*1,546,000*	*2,736,000*
Misc (Taseko) [c]	*R/S*	*-*	*-*	*-*	*1,000*	*1,000*
Misc (Chilliwack)	*Ricker*	*2,000*	*5,000*	*11,000*	*25,000*	*53,000*
Misc (Nahatlatch) [d]	*R/S*	*3,000*	*7,000*	*13,000*	*25,000*	*47,000*
Summer		**1,470,000**	**2,473,000**	**4,344,000**	**7,669,000**	**13,173,000**
(total excluding miscellaneous)		***1,442,000***	***2,417,000***	***4,250,000***	***7,473,000***	***12,778,000***
Chilko	*4-PowJuvPi; 5-Sib*	*833,000*	*1,345,000*	*2,259,000*	*3,801,000*	*6,098,000*
Late Stuart	*R1C*	*55,000*	*88,000*	*149,000*	*251,000*	*401,000*
Quesnel	*RickerEi*	*292,000*	*573,000*	*1,148,000*	*2,223,000*	*4,152,000*
Stellako	*Larkin*	*229,000*	*347,000*	*559,000*	*895,000*	*1,454,000*
Harrison [e]	*3-Ricker; 4-sibling*	*13,000*	*33,000*	*87,000*	*225,000*	*548,000*
Raft [e]	*Ricker (PDO)*	*20,000*	*31,000*	*48,000*	*78,000*	*125,000*
Misc (N. Thomp. Tribs) [e & f]	*R/S*	*2,000*	*4,000*	*7,000*	*15,000*	*31,000*
Misc (N. Thomp River) [e & f]	*R/S*	*25,000*	*50,000*	*84,000*	*175,000*	*354,000*
Misc (Widgeon) [g]	*R/S*	*1,000*	*2,000*	*3,000*	*6,000*	*10,000*
Late		**3,174,000**	**4,794,000**	**7,398,000**	**11,370,000**	**16,934,000**
(total excluding miscellaneous)		***3,164,000***	**4,776,000**	**7,363,000**	**11,303,000**	***16,818,000***
Cultus	*power (juv) (Pi)*	*-*	*1,000*	*1,000*	*3,000*	*6,000*
Late Shuswap	*RickerCyc*	*3,045,000*	*4,548,000*	*6,923,000*	*10,415,000*	*15,091,000*
Portage	*Larkin*	*22,000*	*44,000*	*102,000*	*234,000*	*479,000*
Weaver	*Ricker PDO*	*38,000*	*78,000*	*150,000*	*318,000*	*655,000*
Birkenhead	*Ricker (Ei)*	*59,000*	*105,000*	*187,000*	*333,000*	*587,000*
Misc Harrison/Lillooet [g]	*R/S*	*10,000*	*18,000*	*35,000*	*67,000*	*116,000*
TOTAL SOCKEYE SALMON		**5,265,000**	**8,423,000**	**13,981,000**	**22,937,000**	**36,893,000**
(*TOTAL excluding miscellaneous*)		***5,036,000***	***7,921,000***	***12,872,000***	***21,077,000***	***33,545,000***

a. See Table 4 for model descriptions
b. Misc. Early Shuswap uses Scotch and Seymour R/EF
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 and 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 (BY14) and five year old (BY13) recruits returning in 2018 are presented and colour coded relative to their cycle average from 1949-2014 brood years (columns C and D). Fraser Sockeye average run sizes are presented across all cycles (column F) and the 2018 cycle (column G) for each stock. Forecasted 2018 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 (See Table 1C).

A	C	D	E	F	G
Run timing group			**FC**	**Mean Run Size**	
Stocks	**BY14 (EFS)**	**BY13 (EFS)**	**RET 2018**	**All cycles [a]**	**2018 cycle [b]**
Early Stuart	23,300[Y]	39,700[R]	R	**298,000**	**132,000**
Early Summer (excl. misc.)				**523,000**	**868,000**
Bowron	6,300	1,900	Y	37,000	25,000
Upper Barriere (Fennell)	6,800	2,000	Y	24,000	20,000
Gates	8,500	23,100	G	56,000	22,000
Nadina	30,700	7,100	G	75,000	36,000
Pitt	14,400	30,200	Y	71,000	59,000
Scotch	68,800	11,000	Y	116,000	352,000
Seymour	57,400	13,900	G	144,000	354,000
Misc (Early Shuswap)	118,000	5,100	-	-	-
Misc (Taseko)	50	100	-	-	-
Misc (Chilliwack)	3,000	11,500	-	-	-
Misc (Nahatlatch)	2,100	800	-	-	-
Summer (excl. misc.)				**3,873,000**	**3,769,000**
Chilko	666,000	624,500	G	1,415,000	1,557,000
Late Stuart	27,900	70,900	Y	527,000	227,000
Quesnel	431,000	93,700	Y	1,304,000	1,135,000
Stellako	240,400	54,100	Y	466,000	606,000
Harrison [c]	238,400	58,300	Y	130,000	220,000
Raft	9,500	9,000	G	31,000	24,000
Misc (N. Thomp. Tribs)	800	1,400	-	-	-
Misc (N. Thomp River)	12,000	8,460	-	-	-
Misc (Widgeon)	100	700	-	-	-
Late (excl. misc.)				**3,171,000**	**8,913,000**
Cultus [d] *JUV*	50,900	109,900	R	37,000	35,000
Late Shuswap	1,053,500	87,950	Y	2,409,000	7,839,000
Portage	12,300	4,200	Y	41,000	77,000
Weaver	10,400	15,500	R	332,000	499,000
Birkenhead	19,600	46,800	R	352,000	463,000
Misc Lillooet-Harrison	3,600	5,200	-	-	-
Total Sockeye Salmon (excl. misc)				**7,865,000**	**13,682,000**

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 and D (not EFS)

Table 1C: Median forecasted Fraser Sockeye returns (p50) are presented and colour-coded relative to their cycle average from 1949-2013 brood years. 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.

	All Years	2018 Cycle Line			2018 FC (p50)	
Stock	**Mean**	**Mean**	**Mn-0.5SD**	**Mn+0.5SD**	**Value**	**Colour**
Early Stuart	293,046	131,512	99,683	163,342	84,000	RED
Early Summer						
Bowron	36,203	25,415	15,977	34,853	20,000	YELLOW
Upper Barriere (Fennell)	23,187	20,283	10,155	30,411	25,000	YELLOW
Gates	53,688	19,026	10,530	27,523	38,000	GREEN
Nadina	77,686	35,638	18,000	53,275	153,000	GREEN
Pitt	70,783	58,838	42,711	74,965	53,000	YELLOW
Scotch	116,082	393,220	239,664	546,777	330,000	YELLOW
Seymour	141,077	353,418	222,665	84,172	556,000	GREEN
Summer						
Chilko	1,393,899	1,539,434	853,621	2,225,247	2,259,000	GREEN
Late Stuart	518,509	226,275	106,842	345,708	149,000	YELLOW
Quesnel	1,281,821	1,135,274	378,467	1,892,081	1,148,000	YELLOW
Stellako	460,773	606,037	425,257	86,816	559,000	YELLOW
Harrison	129,496	220,141	5,449	434,833	87,000	YELLOW
Raft	30,734	23,527	15,756	31,298	8,000	GREEN
Late						
Cultus	35,272	32,767	19,067	46,466	1,000	RED
Late Shuswap	2,329,764	7,824,125	5,713,609	9,934,642	6,923,000	YELLOW
Portage	40,297	76,148	49,406	102,890	102,000	YELLOW
Weaver	335,434	534,673	323,458	745,888	150,000	RED
Birkenhead	326,713	441,097	236,740	645,454	187,000	RED

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 2018 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
Run timing group Stock	**Total Survival: Four Year Old Recruits-Per-Effective Female Spawner (Smolt for Cultus)**									
						2018 forecast four year old R/EFS for each probability level in Table 1A by 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]	1.1	1.7	2.8	4.8	7.7
Early Summer										
Bowron	6.9	20.4	2.2	10.7[G]	19.5[G]	0.8	1.4	2.8	4.9	9.1
Upper Barriere	6.4	53.5	0.3	3.0[Y]	1.3[R]	0.8	1.5	2.9	5.9	10.7
Gates	10.0	41.0	1.6	5.6[Y]	2.8[R]	0.7	1.6	3.4	7.7	14.3
Nadina	6.1	13.5	1.0	5.2[Y]	3.9[R]	1.4	2.4	4.6	8.8	15.6
Pitt (age5 survival)[a]	3.4	13.3	0.2	3.3[Y]	1.6[R]	0.1	0.2	0.4	0.9	1.6
Scotch	6.5	21.5	2.2	2.4[R]	1.2[R]	1.2	2.2	4.6	10.4	20.7
Seymour	7.3	29.2	3.4	3.4[Y]	3.1[R]	3.5	5.9	9.5	15.1	22.1
Misc (Early Shuswap)	-	-	-	-	-	1.6	3.6	8.3	13.3	23.6
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	2.1	5.6	14.1
Misc (Nahatlatch)[c]	-	-	-	-	-	1.4	3.1	5.7	10.8	20.2
Summer										
Chilko	6.7	14.5	0.9	3.1[Y]	1.9[R]	1.2	2.0	3.4	5.6	9.0
Late Stuart	8.2	57.2	0.6	3.0[R]	2.2[R]	1.8	2.9	4.8	8.2	13.1
Quesnel[d]	11.3	18.1	0.3	3.5[Y]	6.7[Y]	0.6	1.2	2.5	5.0	9.6
Stellako	6.6	15.1	0.1	3.5[Y]	1.1[R]	0.7	1.1	2.0	3.4	5.9
Harrison[e]	3.3	33.8	0.1	1.8[R]	1.0[R]	-	-	-	-	-
Raft	5.7	13.6	0.4	6.4[Y]	5.6[Y]	0.9	1.7	3.1	5.7	10.6
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]	0.4	0.8	1.8	4.5	10.4
Late Shuswap[d]	6.4	10.8	2.8	18.7[G]	2.7[R]	2.9	4.3	6.6	9.8	14.3
Portage	11.6	61.7	0.3	3.5[R]	1.8[R]	1.4	2.9	7.3	18.0	36.7
Weaver	10.2	41.8	2.6	1.3[R]	0.2[R]	1.5	3.6	8.8	20.9	49.6
Birkenhead	5.0	21.5	1.2	1.3[R]	1.8[R]	0.9	1.8	3.6	8.3	15.6
Misc Lillooet-Harrison[c]	-	-	-	-	-	1.4	2.7	5.1	9.7	16.8

a. Pitt compares 5 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,1.8 = 1.8 age4 from 100 smolts)

Table 3: Four and five year old and total 2018 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	2018 Fraser Sockeye Forecasts				
	FOUR YEAR OLDS 50%[a]	FIVE YEAR OLDS Approx. 50%[c]	TOTAL 50%[a]	Four Year Old Proportion	Five Year Old Proportion
Early Stuart	66,000	18,000	84,000	79%	21%
Early Summer					
Bowron	17,000	3,000	20,000	85%	15%
Upper Barriere (Fennell)	20,000	5,000	25,000	80%	20%
Gates	29,000	9,000	38,000	76%	24%
Nadina	142,000	11,000	153,000	93%	7%
Pitt	12,000	41,000	53,000	11%	89%
Scotch	317,000	13,000	330,000	96%	4%
Seymour	547,000	9,000	556,000	98%	2%
Misc (EShu)	952,000	4,000	956,000	100%	0%
Misc (Taseko)	400	100	400	87%	13%
Misc (Chilliwack)	9,978	11,138	21,000	47%	53%
Misc (Nahatlatch)	11,780	,640	13,000	88%	12%
Summer					
Chilko	2,240,000	19,000	2,259,000	99%	1%
Late Stuart	135,000	14,000	149,000	91%	9%
Quesnel	1,060,000	88,000	1,148,000	92%	8%
Stellako	475,000	84,000	559,000	85%	15%
Harrison[b]	5,000	82,000	87,000	6%	94%
Raft	29,000	19,000	48,000	60%	40%
Misc (N. Thomp. Tribs)	4,000	3,000	7,000	61%	39%
Misc (N. Thomp River)	67,000	17,000	84,000	79%	21%
Misc (Widgeon)	1000	2,000	3,000	24%	76%
Late					
Cultus	1,000	-	1,000	100%	0%
Late Shuswap	6,904,000	19,000	6,923,000	100%	0%
Portage	90,000	12,000	102,000	88%	12%
Weaver	92,000	58,000	150,000	61%	39%
Birkenhead	71,000	116,000	187,000	38%	62%
Misc Lillooet-Harrison	18,000	17,000	35,000	52%	48%
Total	**12,628,000**	**657,000**	**13,994,000**	**90%**	**10%**

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
c. Note that the age 5 column was filled in as the difference between median total and median for the predominant age class. This is consistent with past practice, but differs from a more sophisticated approach used in recent years to match probability distributions.

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.

MODEL CATEGORY	DESCRIPTION
A. Non-Parametric (Naïve) Models	
R1C	Return from 4 years before to forecast year
R2C	Average return from 4 and 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 and 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	
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))	
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 and Amphitrite Point light house stations) from July to September

Table 5: The total Fraser Sockeye forecasts for 1998 to 2017 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 2017 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**
2017	NA	1,315,000[R]	2,338,000	4,432,000	8,873,000	17,633,000	**1,500,000***

*preliminary return estimate in 2017

Table 6: Stock composition of 2013-2015 Brood Years and 2018 Forecast (Excluding Miscellaneous Stocks). The 5 largest stocks in each column are highlighted in bold font, and the largest stock marked in red font.

Stock	2013 EFS	2014 EFS	2015 EFS	2018 FC Ret (p50)
Early Stuart	3.3%	0.8%	0.6%	0.7%
Early Summer				
Bowron	0.2%	0.2%	0.3%	0.2%
Upper Barriere (Fennell)	0.2%	0.2%	0.1%	0.2%
Gates	1.9%	0.3%	1.5%	0.3%
Nadina	0.6%	1.1%	1.4%	1.2%
Pitt	2.5%	0.5%	2.8%	0.4%
Scotch	0.9%	2.4%	0.5%	2.6%
Seymour	1.1%	2.0%	0.6%	4.3%
Summer				
Chilko	**51.5%**	**22.8%**	**65.3%**	17.5%
Late Stuart	**5.8%**	1.0%	0.7%	1.2%
Quesnel	**7.7%**	**14.7%**	**3.9%**	8.9%
Stellako	4.5%	**8.2%**	**7.2%**	4.3%
Harrison	**6.4%**	**8.1%**	**8.9%**	0.7%
Raft	0.7%	0.3%	1.3%	0.4%
Late				
Cultus	NA	NA	NA	NA
Late Shuswap	**7.2%**	**36.0%**	0.5%	**53.8%**
Portage	0.3%	0.4%	0.0%	0.8%
Weaver	1.3%	0.4%	0.2%	1.2%
Birkenhead	3.9%	0.7%	4.1%	1.5%
Total Number		***2,925,000***		***12,872,000***

Table 7: Overview of model selections for 2014, 2017 and 2018 FC. Models that changed from 2017 to 2018 are highlighted grey. Note that in these cases the specific model changed, but the same criteria for selecting a model have been used. Appendix 2 lists the general criteria at the beginning, and then documents the stock-specific rationale.

	2014 Model	2017 Model	2018 Model
Early Stuart	*Ricker Ei*	*Ricker (Ei)*	*Ricker (Ei)*
Early Summer			
Bowron	*MRS*	*Ricker (Pi)*	*Ricker (Pi)*
Upper Barriere (Fennell)	*Power*	*Power*	*Power*
Gates	*Larkin*	*Larkin*	*Larkin*
Nadina	*MRJ*	*MRJ*	*MRJ*
Pitt	*Larkin*	*Larkin*	*Larkin*
Scotch	*Ricker*	*Larkin*	*Larkin*
Seymour	*Ricker*	*Larkin*	***RickerCyc***
Misc (EShu)	*R/S*	*R/S*	*R/S*
Misc (Taseko)	*R/S*	*R/S*	*R/S*
Misc (Chilliwack)	*R/S*	*Ricker*	*Ricker*
Misc (Nahatlatch)	*R/S*	*R/S*	*R/S*
Summer			
Chilko	*Power Juv (Pi)*	*Larkin*	***4-PowJuvPi / 5-Sibling***
Late Stuart	*Power*	*Power*	***R1C***
Quesnel	*Ricker-Cyc*	*Ricker (Ei)*	*Ricker (Ei)*
Stellako	*Larkin*	*Larkin*	*Larkin*
Harrison [e]	*Adj. R1C*	*3-Ricker; 4-sibling*	*3-Ricker; 4-Sibling*
Raft [e]	*Ricker (PDO)*	*Ricker (PDO)*	*Ricker (PDO)*
Misc (N. Thomp. Tribs)	*R/S*	*R/S*	*R/S*
Misc (N. Thomp River)	*R/S*	*R/S*	*R/S*
Misc (Widgeon)	*R/S*	*R/S*	*R/S*
Late			
Cultus	*MRJ*	*Power (juv) (Pi)*	*PowerJuv (Pi)*
Late Shuswap	*Ricker Cyc*	*Larkin*	***Ricker (Cyc)***
Portage	*Larkin*	*Larkin*	*Larkin*
Weaver	*MRS*	*power (juv) (Ei)*	***Ricker (PDO)***
Birkenhead	*Ricker (Ei)*	*Ricker (Ei)*	*Ricker (Ei)*
Misc Harrison/Lillooet	*R/S*	*R/S*	*R/S*

Figures

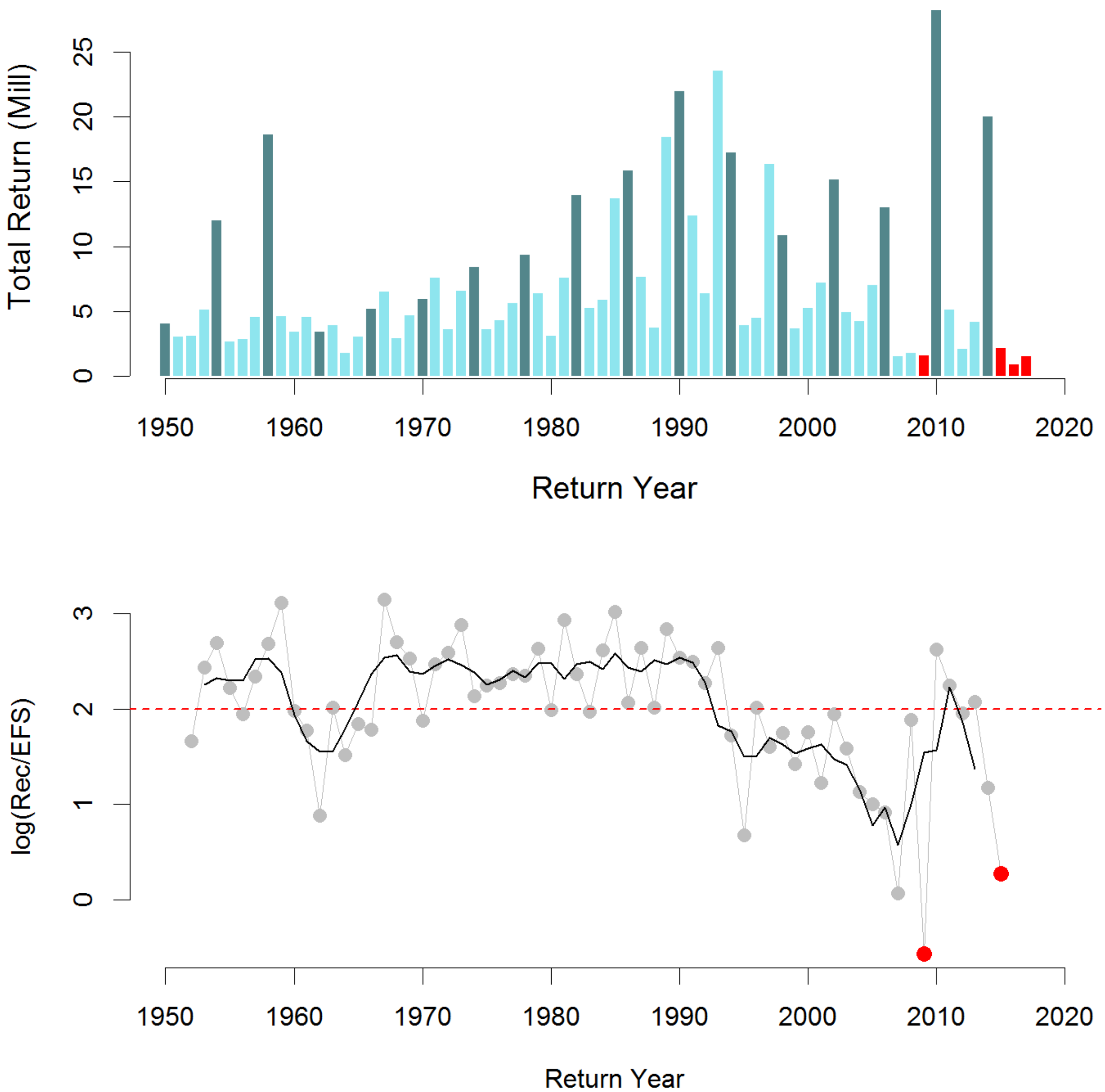

Figure 1: Total returns and overall survival rate of Fraser Sockeye. Top panel shows total adult annual returns (dark blue vertical bars for the 2018 cycle and light blue vertical bars for the three other cycles). Adult returns from 2017 are preliminary. Bottom panel shows overall Fraser Sockeye adult survival ($\log_e$(recruits / effective females) up to the 2015 return year for the 19 stocks with long time series of spawner and recruit estimates. 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 both panels, the 2009, and 2015-2017 returns (low survival) are highlighted in red.

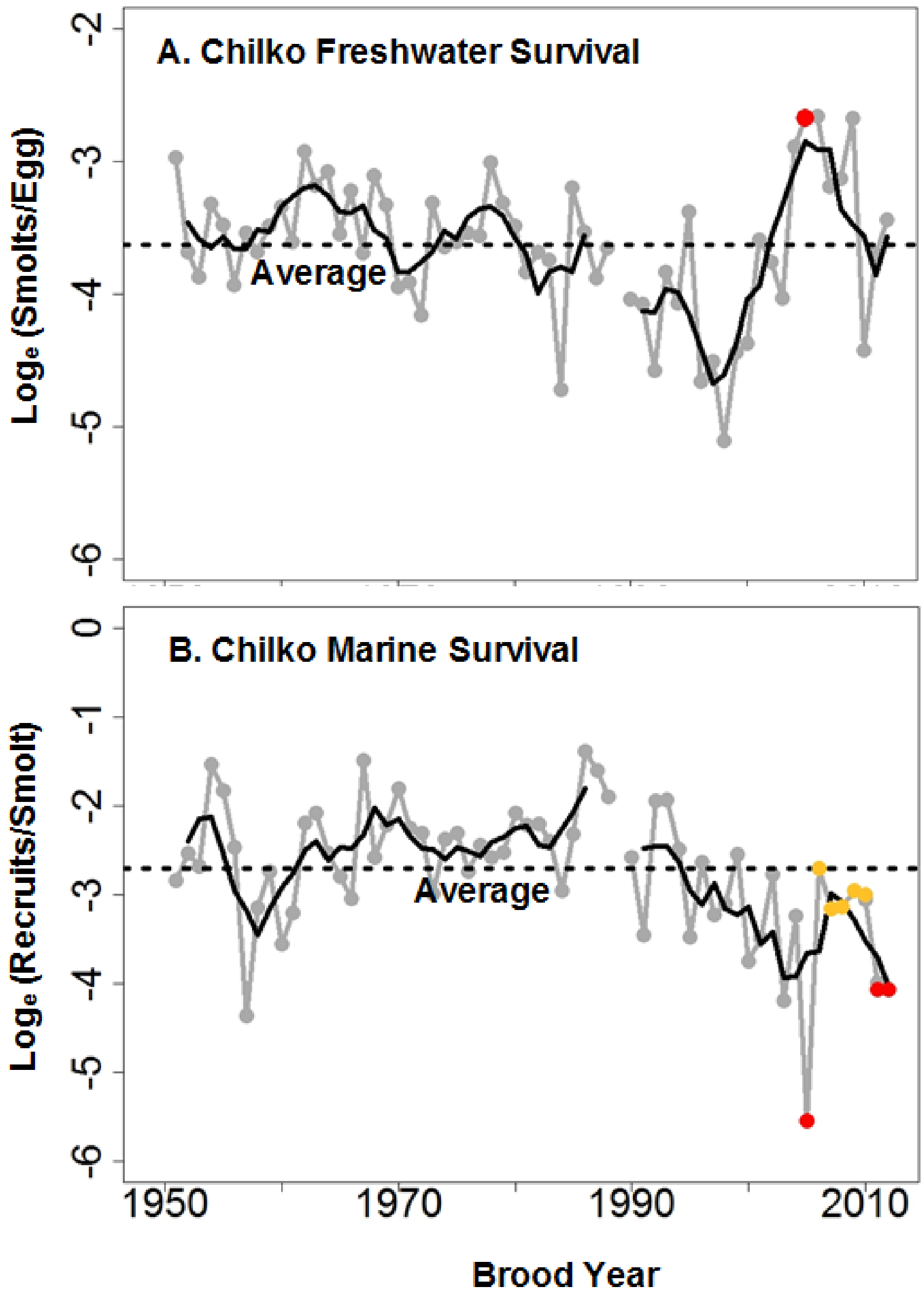

*Figure 2: Chilko River Sockeye **A**. annual freshwater (log_e smolts/egg) survival (filled grey circles and lines); the red filled circle represents the 2005 brood year (2009 returns); note no smolt assessment was conducted in the 2013 brood year representing a gap in the current 2017 Chilko forecast 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. Note that this figure has not changed from the 2017 forecast paper, because the 2013 brood year juvenile abundance (2015 smolt year) estimate is not available since this program was not conducted in this year.*

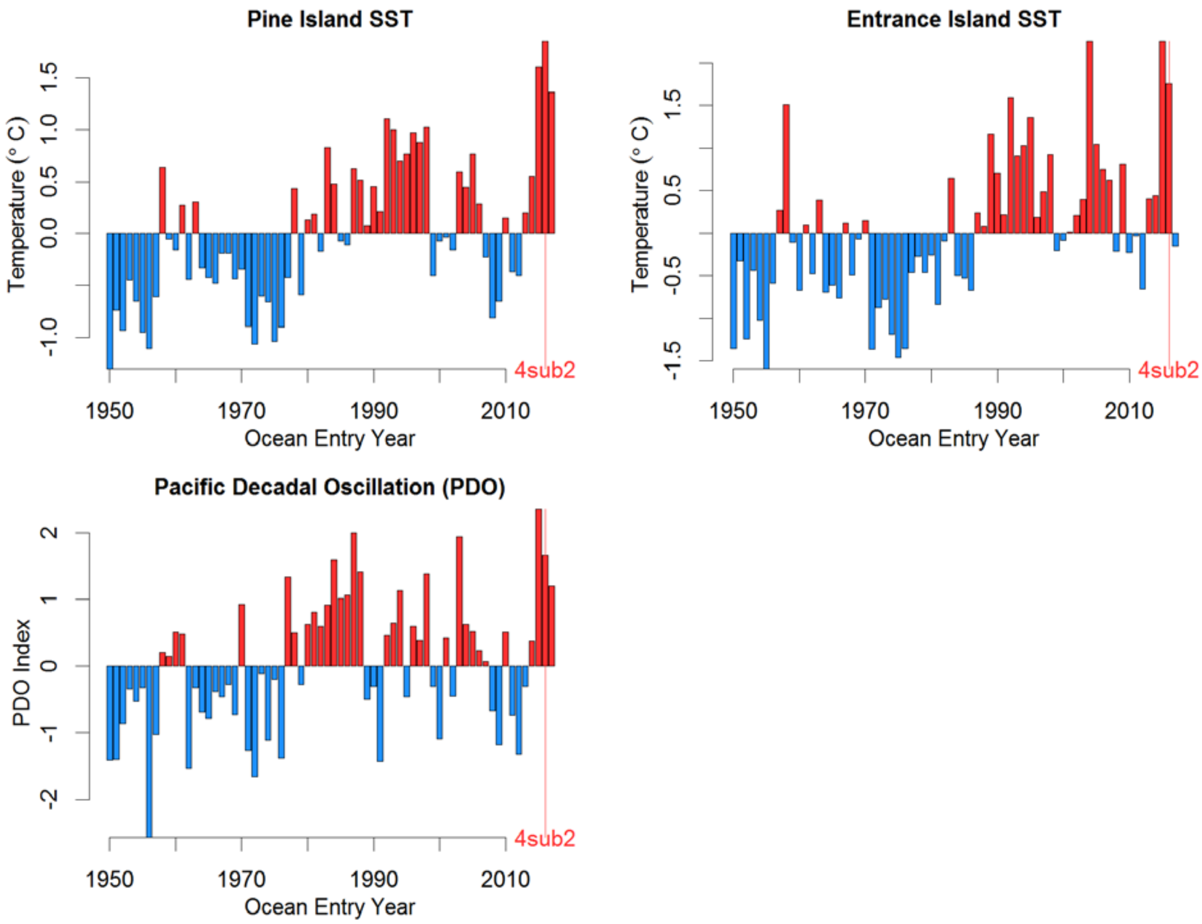

Figure 3: Sea surface temperatures (SST) measured at Entrance Island (Strait of Georgia) (April-June average), Pine Island (Queen Charlotte Strait) (April-July average), and standardized winter PDO index (Nov-March). Temperatures are presented as raw deviations from time-series averages (1950-2015). The 2016 ocean entry year, highlighted with a red vertical line, marks the temperature anomalies that most Fraser Sockeye from the 2014 brood year entered into upon outmigration as smolts (i.e. a 4_2 life cycle). Red bars (positive values) indicate warm temperature anomalies (above average) and blue bars (negative values) indicate cool temperature anomalies (below average).

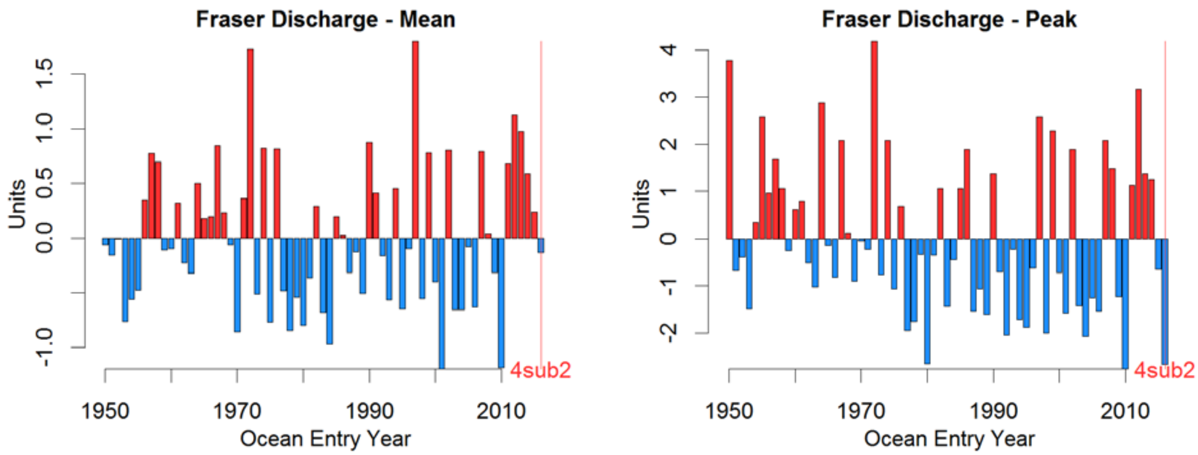

Figure 4: Fraser River discharge shown as mean over April-June and peak discharge. Values are presented as raw deviations from time-series averages (1950-2015). The 2016 ocean entry year, highlighted with a red vertical line, marks the discharge anomalies that most Fraser Sockeye from the 2014 brood year entered into upon outmigration as smolts (i.e. a 4_2 life cycle). Red bars (positive values) indicate high discharge anomalies (above average) and blue bars (negative values) indicate low discharge anomalies (below average).

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Appendix 1. Stock Group data summaries

Early Stuart (Takla-Trembleur-Early Stuart CU)

Run Timing Group	**Escapement**				**2014 Stock Contributions**
Early Stuart	Avg. (1950-2014)	Cyc. Avg. (1950-2014)	BY (2014)	BY Trend[a]	Early Stuart
All stocks	42,000	18,700	23,300		100%

a. Trend refers to change from previous brood year (2010)

Early Summer

Run Timing Group	**Escapement**				**2014 Stock Contributions**										
Early Summer	Avg. (1950-2014)	Cyc. Avg. (1950-2014	BY (2014)	BY Trend[a]	Bow.	N. Barr.	Gates	Nad.	Pitt	Scot.	Sey.	Misc. (E. Shu.)	Misc. (Tas.)	Misc. (Chill.)	Misc. (Nah.)
Primary stocks [b]	60,600	107,500	192,900		3%	0%	**4%**	16%	**7%**	36%	30%	NA	NA	NA	NA
Total (including misc.) [c]	75,500	359,400	314,800		2%	2%	**3%**	10%	**5%**	22%	18%	37%	0%	1%	1%

a. Trend refers to change from previous brood year (2010)
b. Escapement and cycle year average 1948-2014
c. Escapement and cycle year average 2002-2014

Summer

Run Timing Group	Escapement				2014 Stock Contributions								
Summer	Avg. (1950-2014)	Cyc. Avg. (1950-2014)	BY (2014)	BY Trend[a]	Chilk.	L. Stu.	Ques.	Stell.	Raft	Harr.	Misc. (N. Thom.) [c]	Misc. (N. Thom. R.) [c]	Misc. (Widg.)[c]
Primary stocks [b]	60,600	597,200	1,613,100	↓	41%	2%	**27%**	15%	**1%**	15%	NA	NA	NA
Total (including misc.) [c]	580,000	1,453,200	1,626,000	↓	41%	2%	**27%**	15%	**1%**	15%	0%	1%	0%

a. Trend refers to change from previous brood year (2010)
b. Escapement and cycle year average 1948-2014
c. Escapement and cycle year average 2002-2014

Late

Run Timing Group	Escapement				2014 Stock Contributions					
Late	Avg. (1950-2014)	Cyc. Avg. (1950-2014)	BY (2014)	BY Trend[a]	L. Shu.	Birk.	Cultus[b]	Portage	Weaver	Misc. (Harrison)
Primary stocks [c]	411,600	1,297,000	1,095,900	↓	96%	2%	**--**	1%	**1%**	NA
Total (including misc.) [d]	426,600	2,163,900	1,099,400	↓	96%	2%	**--**	1%	**1%**	0%

a. Trend refers to change from previous brood year (2010)
b. Cultus Is not included because only juvenile data are used for this stock
c. Escapement and cycle year average 1948-2014
d. Escapement and cycle year average 2002-2014

Appendix 2. Individual Stock Forecast Summaries

Note on Model Labels

Distribution plots for alternative forecast in this Appendix were automatically generated from the model output, and retained the labels used in the R code. These match up with the labels used in the corresponding table, but may contain additional information if the estimation approach was modified from the default.

- Default forecasts use a 20,000 sample burn-in for the MCMC sampling, but for some stocks and models larger burn-ins have been established in previous forecast papers to ensure convergence (MacDonald and Grant 2012). These were carried over for this report and are identified in the plot labels in this appendix (e.g. Ricker40k, Larkin 80k).
- Some models use cycle-specific age proportions, which are also flagged in the plot labels.
- The prefix "N_" identifies non-parametric models (e.g. based on average returns on cycle year)
- The prefix "Ext_" identifies forecasts that are special cases developed outside of the main code package.

General Model Selection Criteria

Unless otherwise noted, models were selected for each stock using the following process:

1. For each stock, models are ranked according to their relative performance on each of four performance measures (MRE, MAE, MPE and RMSE). Ranks across the four performance measures are then averaged to generate an average rank for each model evaluated (See Table 5 in MacDonald and Grant 2012). Forecasts are generated for the top three ranked models for each stock (based on their average rank);

2. To ensure that selected models do not perform poorly on individual performance measures, top ranked models for each stock are evaluated for consistent performance across each of the four performance measures (MRE, MAE, MPE and RMSE). For each stock, models that do not consistency rank within the top half of all models (e.g. if 20 models were evaluated, the models must rank within the top 10) on each performance measure (i.e. MRE, MAE, MPE and RMSE) are generally not considered. There are individual cases where this criterion is relaxed; these are indicated;
3. Brood year escapements (or juvenile abundances) for each stock are compared to stock-specific cycle averages. If the brood year escapement (or juvenile abundance) falls above or below the cycle average range (+/- one standard deviation from the mean), only top ranked models that use EFS (or juveniles) as a predictor variable are considered;
4. 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)) ranks within the top three models, the forecasting performance of the covariate model specifically in warmer than average years is examined (Appendix 3 of DFO 2017). If these models rank superior under extreme conditions (e.g. periods of high SST), and there is a consistent signal in terms of forecasted survival implied by the addition of the covariate across the applicable stocks, temperature covariate forecasts are adopted for these stocks;
5. Error checks include a comparison of stock-specific forecasts across all top-ranked models to investigate mechanisms underlying similarities and differences in forecasts. In addition, the four year old survivals associated with each forecast are compared to averages for each stock, to analyze where forecast survivals fall out in terms of recent and long-term observations.

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

Table A2 1: Spawning Ground Summary - Early Stuart. This table summarizes abundance and composition of the brood years producing the 2018 return, with 4-year old returns from the 2014 brood year and 5-year olds from the 2013 brood year. EFS are effective female spawners. Cyc Avg are mean values for the cycle line (e.g. 2014, 2010, 2006 etc. for the 4-year olds). Colour-coding compares the brood year to historic values on that cycle line, using mean ± 0.5 SD as the reference values).

		Four Year Olds		Five Year Olds	
		Cyc Avg[a]	2014 BY	Cyc. Avg.[b]	2013 BY
Spawning Ground Summary	% Female	54%	51%	53%	53%
	Spawner Success	87%	67%	88%	87%
	EFS	18,700	23,300	104,600	39,700

a. Brood years 1950-2014 b. Brood years 1949-2013

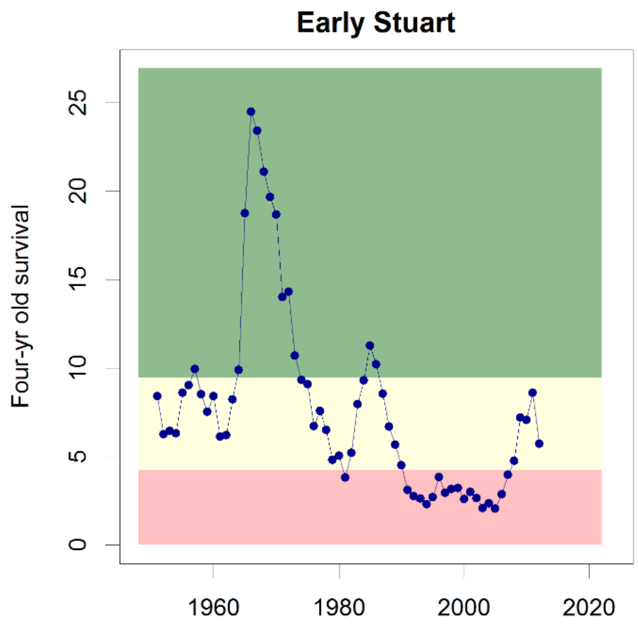

Figure A2 1: Historical Age-4 Survival – Early Stuart.The plot shows survival as recruits / spawner, with reference zones based on log-transformed mean ± 0.5 SD.

Table A2 2: Top Ranked Forecasts Table – Early Stuart.The table shows forecasts of total returns and associated age-4 survival based on alternative models. The suite of alternative models was chosen based For each forecast, the table lists model rank (based on the analyses in Grant and MacDonald, 2012), percentiles of the total return distribution, and corresponding percentiles of forecasted age-4 survival. The selected model for the 2018 forecast is highlighted with grey shading and bold font. Model selection rationale is summarized below.

		Forecasted Return					Forecasted Age-4 Survival				
Model	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**	**10%**	**25%**	**50%**	**75%**	**90%**
Ricker (Ei)	**1**	**37,000**	**54,000**	**84,000**	**133,000**	**199,000**	**1.1**	**1.7**	**2.8**	**4.8**	**7.7**
Ricker (Pi)	1	31,000	45,000	67,000	102,000	151,000	0.8	1.3	2.2	3.5	5.3
Ricker	3	85,000	125,000	198,000	300,000	483,000	2.4	3.7	6.3	10.7	18.4
Ricker (PDO)	3	59,000	87,000	141,000	218,000	335,000	1.7	2.7	4.6	8.1	12.9

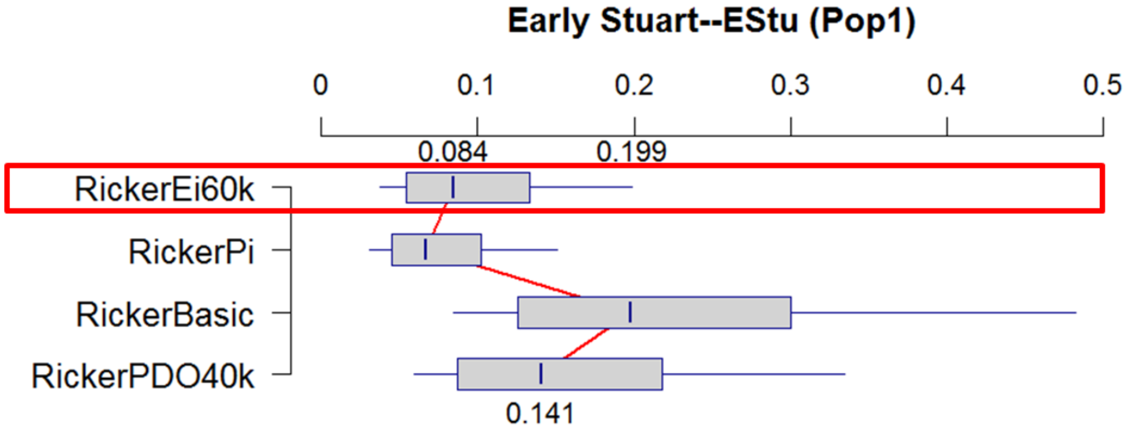

Figure A2 2: Top Ranked Forecasts Plot – Early Stuart.The bar plots show the percentile distribution for the top-ranked models, with values listed in the table above. For each bar, the whiskers show 10th and 90th percentiles, the boxes show 25th and 75th percentiles, and the vertical line marks the median. The selected model is highlighted with a red box. All numbers in Millions of Fish.

Model Selection

- The Ricker (Ei) model was used for the 2018 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 and Grant, 2012). The same model was selected for the 2017 forecast.
- Additionally, the Entrance Island, Pine Island, and PDO temperature covariates all indicate lower survival for Early Stuart returns in 2018 than the Ricker model with no temperature covariate. This signal is consistent with other stocks for which temperature covariate models rank well (see DFO 2017, Appendix 2). The median forecast of 84,000 (2.8 age-4 R/EFS) is just over half the average return on this cycle (132,000) (Tables 1A, 1B, and 2; Figure 4).
- Due to the extremely high temperature observed at Entrance Island in 2016, forecasts produced using this covariate fall in a range that is informed by little data, and are therefore associated with increased uncertainty.

Statistical Notes

- **All 4 models**: visual check of posterior parameters shows that Ricker productivity parameter *a* environmental covariate *g*, and error term *sigma* converged on a stable posterior distribution. However, the capacity parameter beta converged on a highly skewed posterior distribution, indicating large uncertainty in the capacity estimate.

Bowron (Bowron-ES) – Early Summer Mgmt Unit

Table A2 3: Spawning Ground Summary – Bowron.Table details as per Table A2 1.

		Four Year Olds		Five Year Olds	
		Cyc Avg[a]	2014 BY	Cyc. Avg.[b]	2013 BY
Spawning Ground Summary	% Female	55%	55%	53%	60%
	Spawner Success	91%	95%	91%	99%
	EFS	3,300	6,300	2,800	1,900

a. Brood years 1950-2014 b. Brood years 1949-2013

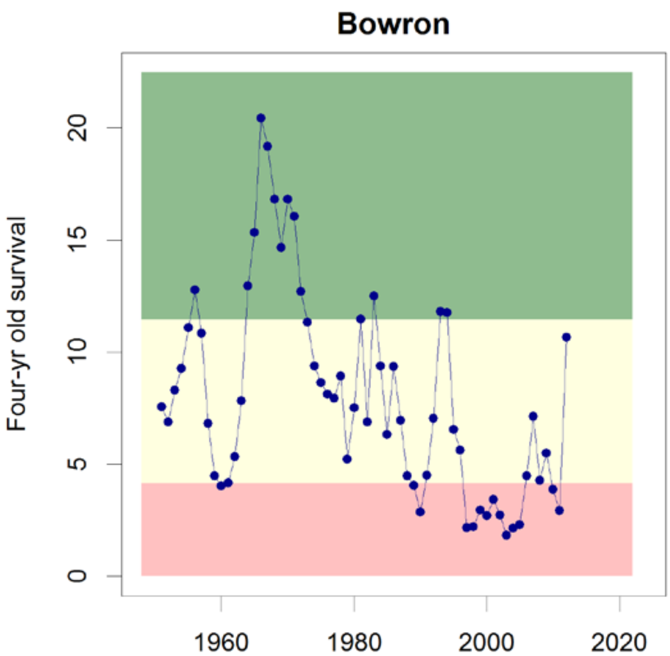

Figure A2 3: Historical Age-4 Survival – Bowron: Figure details as per Figure A2 1

Table A2 4: Top Ranked Forecasts Table – Bowron.Table details as per Table A2 2.

		Forecasted Return					Forecasted Age-4 Survival				
Model	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**	**10%**	**25%**	**50%**	**75%**	**90%**
MRS	1	13,000	22,000	42,000	80,000	142,000	1.9	3.3	6.2	11.7	20.8
Ricker (Pi)	**2**	**7,000**	**12,000**	**20,000**	**35,000**	**59,000**	**0.8**	**1.4**	**2.8**	**4.9**	**9.1**
Ricker (Ei)	3	10,000	15,000	26,000	46,000	79,000	1.1	1.9	3.7	6.9	11.8
Ricker	11	18,000	26,000	42,000	70,000	116,000	1.8	3.3	5.9	10.5	17.8

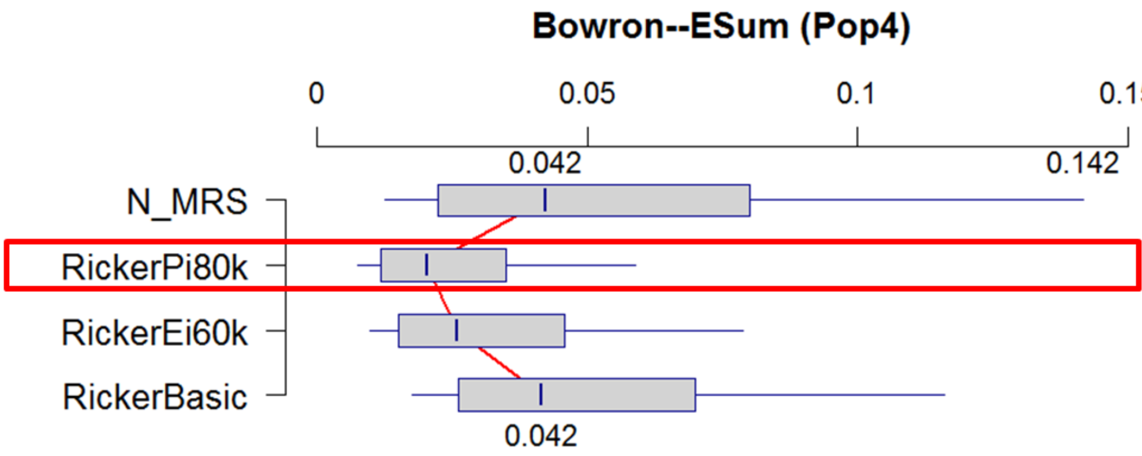

Figure A2 4: Top Ranked Forecasts Plot – Bowron.Figure details as per Figure A2 2. All numbers in Millions of Fish.

Model Selection

- Ricker models with environmental covariates produced lower forecasts than basic Ricker model. Basic Ricker model did not do well across performance measures in the retrospective evaluation (Rank 11, see Macdonald and Grant 2012). The Mean Rec/Spn (MRS) model produced a similar forecast as the basic Ricker model, but with wider uncertainty bounds.
- The Ricker - Pine Island was selected for the 2018 forecast, based on Criterion 4 (i.e. go to top-performing environmental model for warmer than usual ocean-entry years). However, this forecast needs to be interpreted with caution, because it is extrapolating the effect of the environmental covariate beyond the range observed in years with recruit estimates. The same model was selected for the 2017 forecast.

Statistical Notes

- **3 Variations of Ricker model**: visual check of posterior parameters shows that Ricker productivity parameter a , environmental covariate g, and error term sigma converged on a stable posterior distribution. However, the capacity parameter *beta* converged on a skewed posterior distribution, indicating large uncertainty in the capacity estimate.

Fennel (North Barriere CU) – Early Summer Mgmt Unit

Table A2 5: Spawning Ground Summary – Fennel. Table details as per Table A2 1.

		Four Year Olds		Five Year Olds	
		Cyc Avg[a]	2014 BY	Cyc. Avg.[b]	2013 BY
Spawning Ground Summary	% Female	63%	61%	61%	60%
	Spawner Success	96%	98%	96%	93%
	EFS	3,700	6,800	1,900	2,000

a. Brood years 1950-2014　b. Brood years 1949-2013

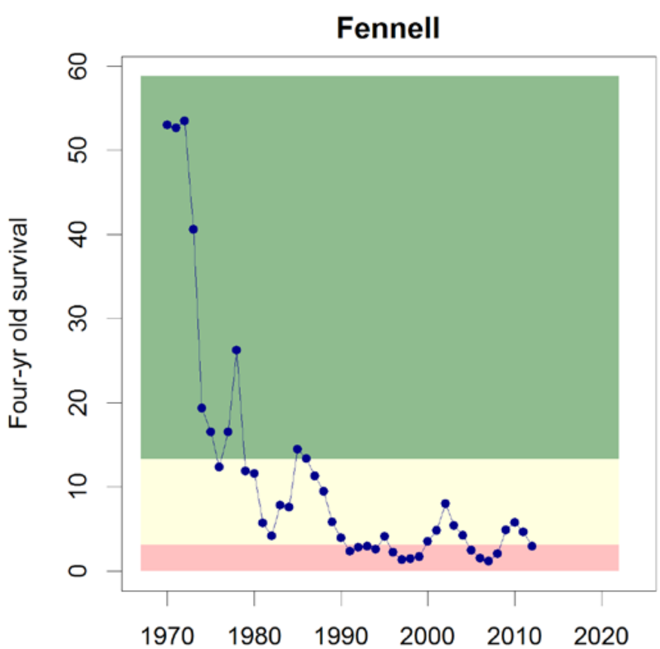

Figure A2 5: Historical Age-4 Survival – Fennel. Figure details as per Figure A2 1

Table A2 6: Top Ranked Forecasts Table – Fennel. Table details as per Table A2 2.

		Forecasted Return					Forecasted Age-4 Survival				
Model	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**	**10%**	**25%**	**50%**	**75%**	**90%**
Power	1	9,000	14,000	25,000	46,000	80,000	0.8	1.5	2.9	5.9	10.7
RAC	2	4,000	8,000	20,000	51,000	117,000	0.4	1.0	2.4	6.1	13.9
Ricker	3	10,000	17,000	33,000	59,000	112,000	0.8	1.6	3.3	6.8	14.2

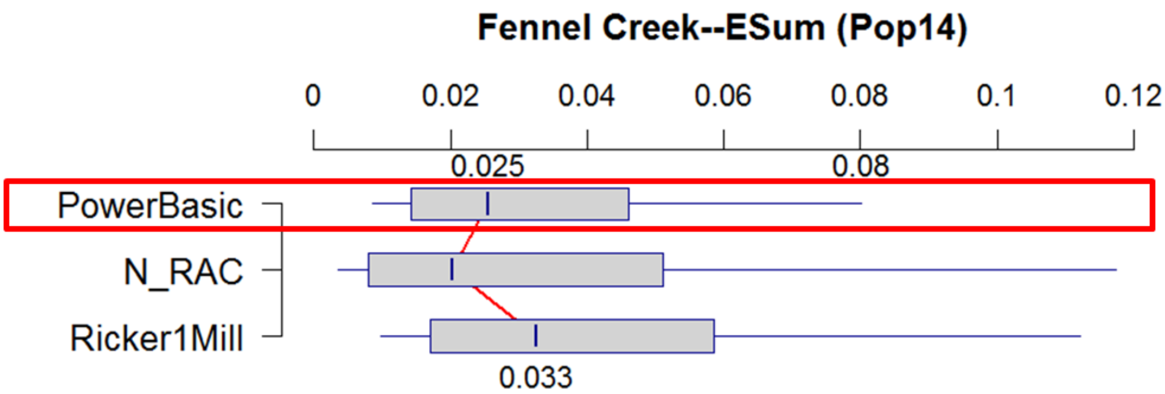

Figure A2 6: Top Ranked Forecasts Plot – Fennel. Figure details as per Figure A2 2. All numbers in Millions of Fish.

Model Selection

- All 3 short-listed models produced similar forecasts.
- Brood year spawner abundance (EFS) was average.
- The Power model was selected for the 2018 forecast, because it was the top-performing model in the most recent performance test. The same model was selected for the 2017 forecast.

Statistical Notes

- **RAC:** This is the only stock where change the calculation forecast bounds for the non-parametric models based on cycle returns (RAC) actually produced wider ranges with cycle line residuals than with all-year residuals. For example, the upper bound (p90) for the RAC model increased from 95k to 120k.
- **Ricker:** Based on past work, parameter estimates for the Ricker model use a much longer MCMC burn-in than for most other stocks and models (i.e. 1 Mill vs. 20k).

Gates (Anderson-Seton-ES CU) – Early Summer Mgmt Unit

Table A2 7: Spawning Ground Summary – Gates. Table details as per Table A2 1.

		Four Year Olds		Five Year Olds	
		Cyc Avg[a]	2014 BY	Cyc. Avg.[b]	2013 BY
Spawning Ground Summary	% Female	61%	63%	59%	53%
	Spawner Success	77%	85%	78%	80%
	EFS	2,200	8,500	5,600	23,100

a. Brood years 1950-2014 b. Brood years 1949-2013

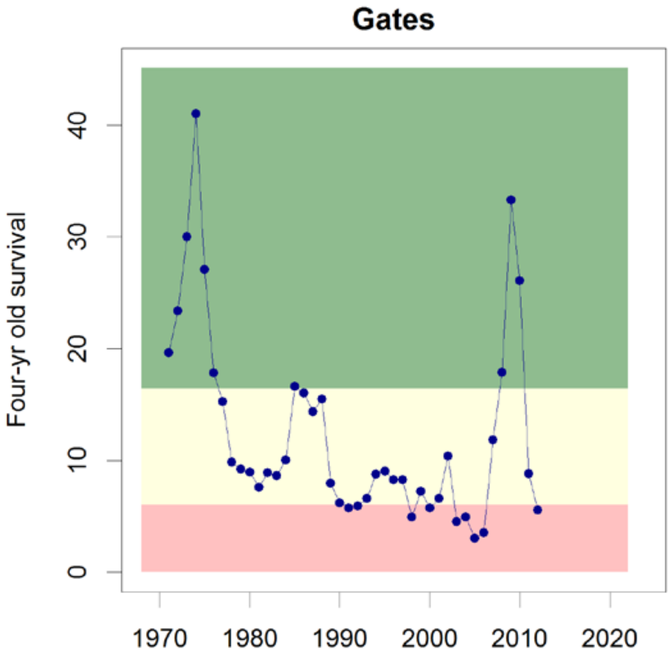

Figure A2 7: Historical Age-4 Survival – Gates. Figure details as per Figure A2 1

Table A2 8: Top Ranked Forecasts Table – Gates. Table details as per Table A2 2.

		Forecasted Return					Forecasted Age-4 Survival				
Model	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**	**10%**	**25%**	**50%**	**75%**	**90%**
RAC	1	6,000	10,000	19,000	35,000	62,000	0.4	0.7	1.3	2.5	4.3
R2C	2	13,000	22,000	41,000	77,000	134,000	1.2	2.1	4.0	7.4	12.9
Larkin	**3**	**11,000**	**20,000**	**38,000**	**76,000**	**149,000**	**0.7**	**1.6**	**3.4**	**7.7**	**14.3**
MRS	3	23,000	49,000	113,000	259,000	546,000	NA	NA	NA	NA	NA
Power	6	29,000	48,000	87,000	152,000	249,000	1.9	3.6	7.0	13.4	23.6
Ricker (Pi)	6	14,000	24,000	42,000	82,000	153,000	1.0	1.8	3.5	7.3	14.6
Power (Juv)	-	19,000	32,000	64,000	122,000	208,000	1.3	2.6	5.7	12.2	21.5

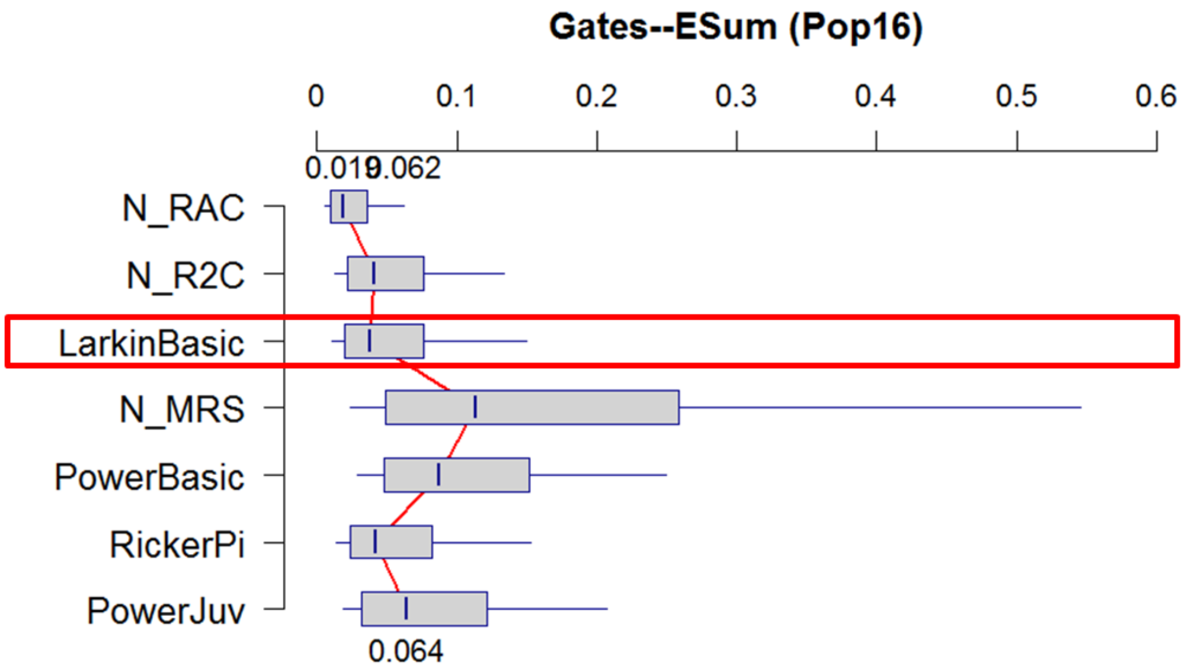

Figure A2 8: Top Ranked Forecasts Plot – Gates. Figure details as per Figure A2 2. All numbers in Millions of Fish.

Model Selection

- Many alternative models tested, and they produced a wide range of different forecasts.
- Brood year spawner abundance (EFS) was above average, so return-based non-parametric models (RAC, R2C) were not considered.
- Larkin Model was selected for the 2018 forecast, because it is the top-ranked SR-based model. The same model was selected for the 2017 forecast.
- Notable points:
  - o fry data indicate that egg-to-fry survival was poor in the 2014 brood year, but abundance has been above the long-term average.
  - o Preliminary estimates of returns to Gates in 2017 are falling close to the 25% probability level of the 2017 forecast.”
  - o Ricker Pine Island forecast, which is the top-ranked environmental covariate model, is very similar to the Larkin fit. The Larkin fit is pulled down by the delayed-density effect of the 2011 spawner abundance (~26k, largest since 1968), while the Ricker Pine Island forecast is pulled down by the warmer-than-average conditions in the ocean-entry years (2016 for 4 year olds).

Nadina (Nadina-Francois-ES CU) – Early Summer Mgmt Unit

Table A2 9: Spawning Ground and Juvenile Summary – Nadina. Table details as per Table A2 1.

		Four Year Olds		Five Year Olds	
		Cyc Avg[a]	2014 BY	Cyc. Avg.[b]	2013 BY
Spawning Ground Summary	% Female	58%	57%	54%	56%
	Spawner Success	88%	88%	86%	96%
	EFS (channel and river)	5,600	30,700	8,300	7,100
Juvenile Summary	Freshwater Surv.(fry/EFS)	1,443	859	1,007	1,184
	Fry Abundance	7M	26M	9M	8M

a. Brood years 1974-2014 b. Brood years 1973-2013

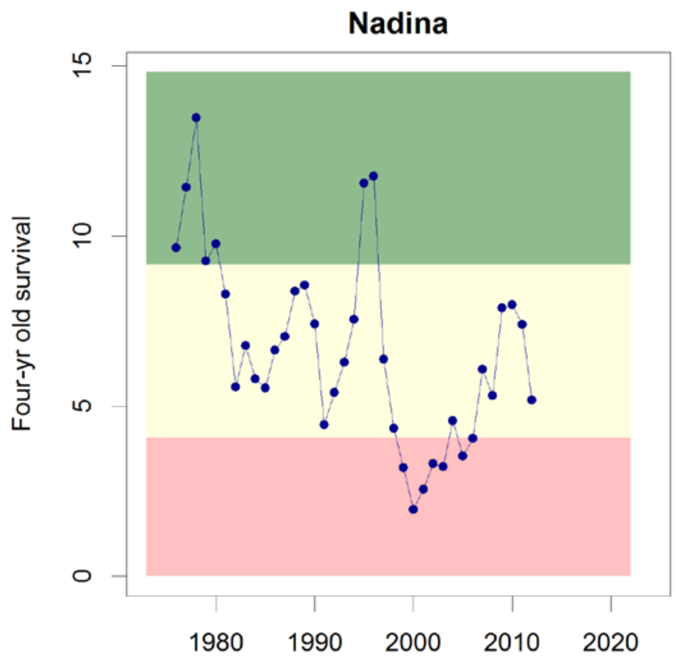

Figure A2 9: Historical Age-4 Survival – Nadina. Figure details as per Figure A2 1.

Table A2 10: Top Ranked Forecasts Table – Nadina. Table details as per Table A2 2.

		Forecasted Return					Forecasted Age-4 Survival				
Model	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**	**10%**	**25%**	**50%**	**75%**	**90%**
MRJ	**1**	45,000	81,000	153,000	291,000	518,000	**1.4**	**2.4**	**4.6**	**8.8**	**15.6**
Power JvFRDpk	2	63,000	101,000	174,000	292,000	481,000	1.6	2.8	5.1	9.2	15.3
Ricker (FrDPk)	2	83,000	139,000	231,000	417,000	732,000	2.3	4.1	7.1	13.1	23.8
Power (Juv)	9	61,000	98,000	164,000	272,000	464,000	1.6	2.7	4.9	8.4	14.7

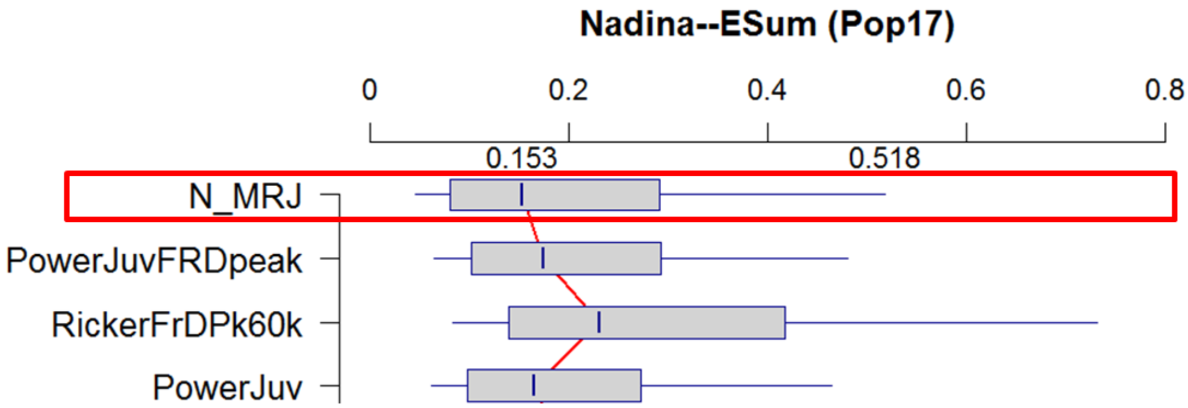

Figure A2 10: Top Ranked Forecasts Plot – Nadina. Figure details as per Figure A2 2. All numbers in Millions of Fish.

Model Selection

- The MRJ (mean recruits / juvenile) model was selected for the 2018 forecast, because it is the top-ranked model for average brood year abundances and incorporates additional information on juvenile abundance. The same model was selected for the 2017 forecast.
- Notable points:
  - All 3 models based on juvenile data (MRJ, PowerJuvFRDPeak, and PowerJuv) pull the forecast down compared to the adult-based model (RickerFRDPeak).
  - Freshwater survival was poor for the 2014 brood year, but fry abundance and brood year spawner abundance (EFS) were above average.

Statistical Notes

- None of the models did well across all performance measures during the most recent evaluation (MacDonald and Grant 2012), so all the short-listed models were considered.

Pitt (Pitt-ES CU) – Early Summer Mgmt Unit

Table A2 11: Spawning Ground Summary – Pitt. Table details as per Table A2 1.

		Four Year Olds		Five Year Olds	
		Avg[a]	2014 BY	Avg.[b]	2013 BY
Spawning Ground Summary	% Female	52%	48%	54%	54%
	Spawner Success	91%	80%	92%	93%
	EFS	15,000	14,400	15,000	30,200

a. **All** brood years 1948-2014 b. Brood years 1949-2013

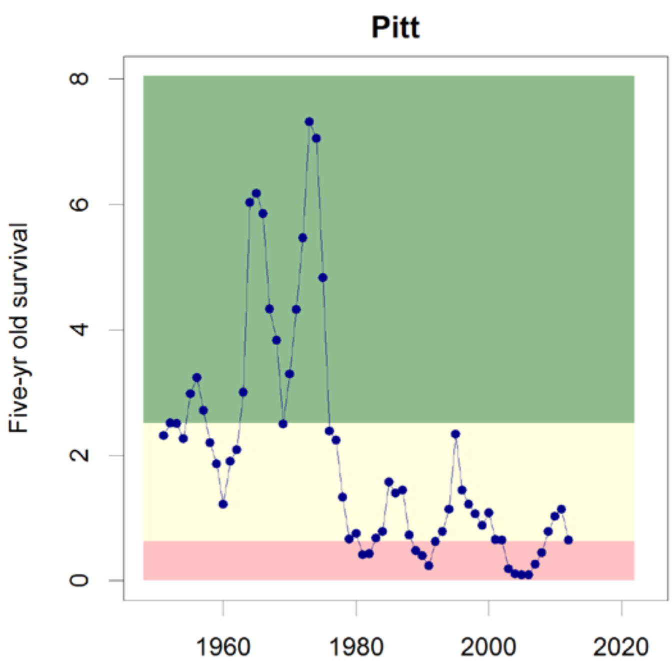

Figure A2 11: Historical Age-4 Survival – Pitt. Figure details as per Figure A2 1.

Table A2 10: Top Ranked Forecasts Table – Pitt. Table details as per Table A2 2.

		Forecasted Return					Forecasted Age-5 Survival				
Model	Rank	**10%**	**25%**	**50%**	**75%**	**90%**	**10%**	**25%**	**50%**	**75%**	**90%**
Larkin	**1**	**22,000**	**32,000**	**53,000**	**84,000**	**130,000**	**0.5**	**0.8**	**1.4**	**2.4**	**3.9**
TSA	2	23,000	39,000	71,000	128,000	220,000	0.5	0.9	1.7	3.1	5.3
Ricker (PDO)	3	29,000	43,000	65,000	99,000	154,000	0.6	0.9	1.6	2.7	4.4
Ricker (Ei)	4	25,000	37,000	58,000	92,000	142,000	0.5	0.8	1.4	2.4	3.9
Ricker	9	35,000	51,000	77,000	119,000	180,000	0.7	1.1	1.8	3.1	5.1

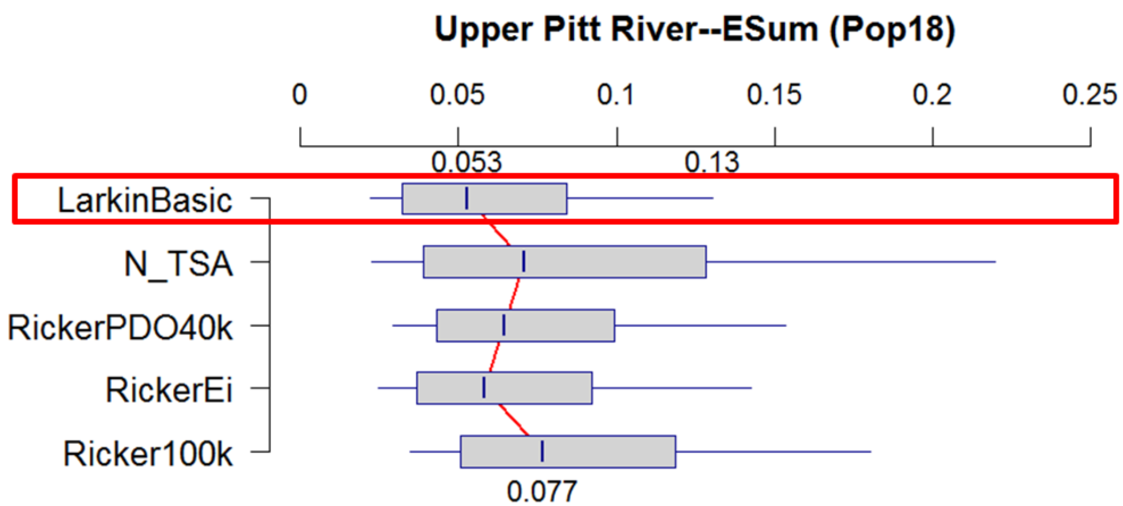

Figure A2 10: Top Ranked Forecasts Plot – Pitt. Figure details as per Figure A2 2. All numbers in Millions of Fish.

Model Selection

- brood year spawner abundance was average, so keep non-parametric model (TSA) in the shortlist.
- Larkin model was selected for 2018 forecast, because it is the top-ranked model. The same model was selected for the 2017 forecast.

Scotch (Part of Shuswap-ES CU) – Early Summer Mgmt Unit

Table A2 11: Spawning Ground Summary – Scotch. Table details as per Table A2 1.

		Four Year Olds		Five Year Olds	
		Cyc Avg[a]	2014 BY	Cyc. Avg.[b]	2013 BY
Spawning Ground Summary	% Female	54%	55%	49%	49%
	Spawner Success	92%	93%	94%	94%
	EFS	62,000	68,800	3,800	11,000

a. Brood years 1982-2014 b. Brood years 1981-2013

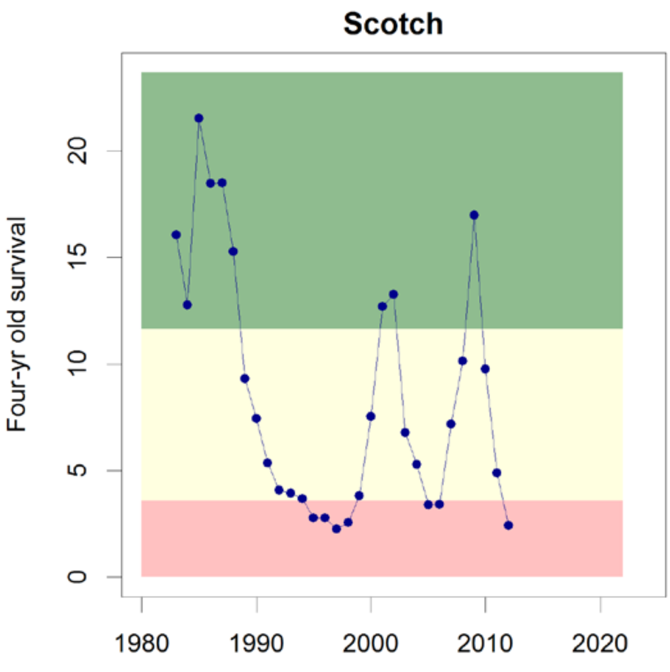

Figure A2 11: Historical Age-4 Survival – Scotch. Figure details as per Figure A2 1.

Table A2 12: Top Ranked Forecasts Table – Scotch. Table details as per Table A2 2.

		Forecasted Return					Forecasted Age-4 Survival				
Model	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**	**10%**	**25%**	**50%**	**75%**	**90%**
Larkin	**1**	**89,000**	**166,000**	**330,000**	**750,000**	**1,513,000**	**1.2**	**2.2**	**4.6**	**10.4**	**20.7**
Ricker	2	91,000	208,000	471,000	959,000	2,073,000	1.2	2.9	6.7	13.7	29.9
RS1	3	10,000	32,000	115,000	416,000	1,324,000	0.1	0.4	1.4	5.0	16.0
RickerCyc	-	295,000	477,000	726,000	1.081M	1.684M	4.2	6.9	10.5	15.7	24.4

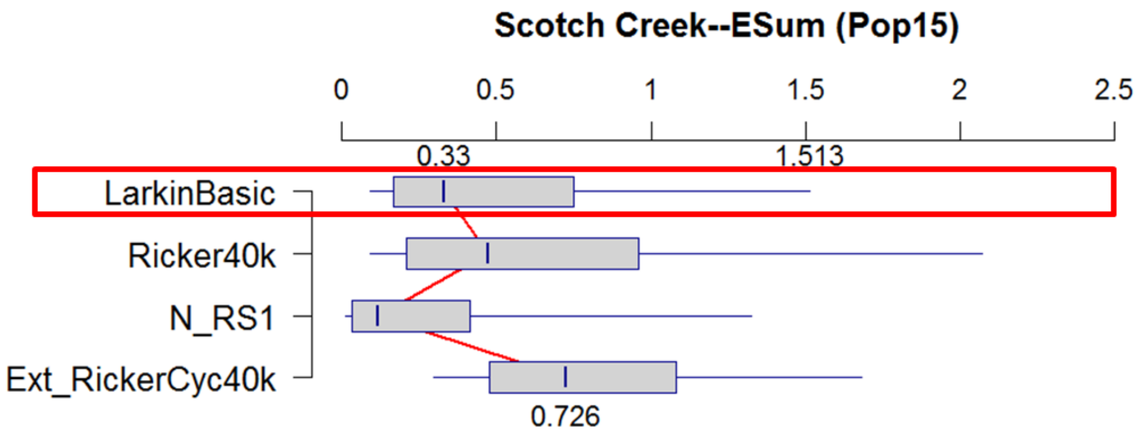

Figure A2 12: Top Ranked Forecasts Plot – Scotch. Figure details as per Figure A2 2. All numbers in Millions of Fish.

Model Selection

- The Larkin model was selected for the 2018 forecast, because it was the top-ranked model in the most recent performance evaluation (MacDonald and Grant 2012), and there are no environmental or juvenile-based models in the shortlist. The same model was selected for the 2017 forecast.
- Notable points:
  - RS1 model is strongly influenced by small R/S from large 2010 spawner abundance (EFS)

Statistical Notes

- **Ricker**: Note that the Ricker model fit resulted in a highly skewed posterior distribution for the capacity parameter *beta*, which indicates a highly uncertain capacity estimate, and translates into wide bounds on the Ricker-based forecast.

Seymour (Part of Shuswap-ES CU) – Early Summer Mgmt Unit

Table A2 13: Spawning Ground Summary – Seymour. Table details as per Table A2 1.

		Four Year Olds		Five Year Olds	
		Cyc Avg[a]	2014 BY	Cyc. Avg.[b]	2013 BY
Spawning Ground Summary	% Female	51%	54%	54%	64%
	Spawner Success	94%	93%	96%	97%
	EFS	49,700	57,400	3,800	13,900

a. Brood years 1950-2014 b. Brood years 1949-2013

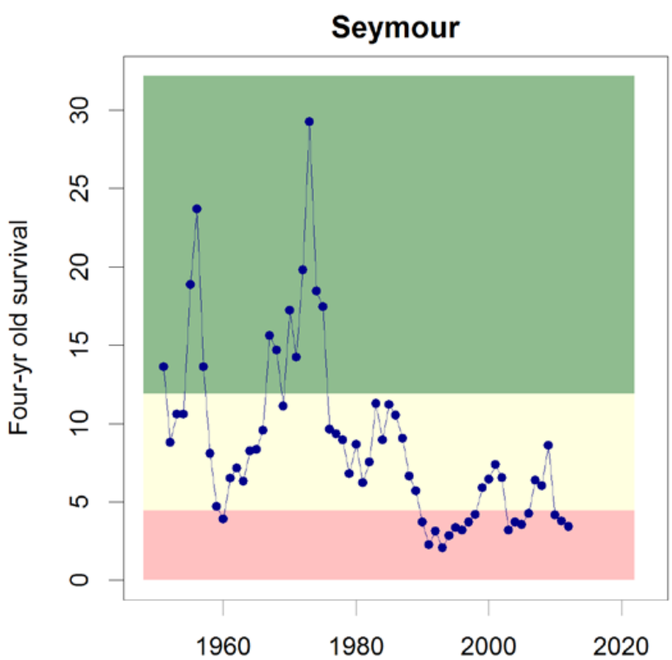

Figure A2 13: Historical Age-4 Survival – Seymour. Figure details as per Figure A2 1.

Table A2 14: Top Ranked Forecasts Table – Seymour. Table details as per Table A2 2.

		Forecasted Return					Forecasted Age-4 Survival				
Model	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**	**10%**	**25%**	**50%**	**75%**	**90%**
RickerCyc	1	**210,000**	**349,000**	**556,000**	**886,000**	**1,301,000**	**3.5**	**5.9**	**9.5**	**15.1**	**22.1**
Larkin	2	123,000	207,000	376,000	679,000	1,138,000	2.1	3.5	6.5	11.8	19.8
R1C	2	122,000	185,000	295,000	468,000	710,000	2.1	3.2	5.1	8.1	12.2
RAC	4	165,000	236,000	353,000	528,000	758,000	2.9	4.1	6.1	9.2	13.2
Ricker (Ei)	5	54,000	86,000	165,000	305,000	496,000	0.9	1.5	2.7	5.2	8.6
Ricker	8	106,000	180,000	339,000	649,000	1,249,000	1.6	2.9	5.7	11.2	21.7
Power	-	89,000	160,000	275,000	519,000	952,000	1.4	2.6	4.6	8.9	16.5

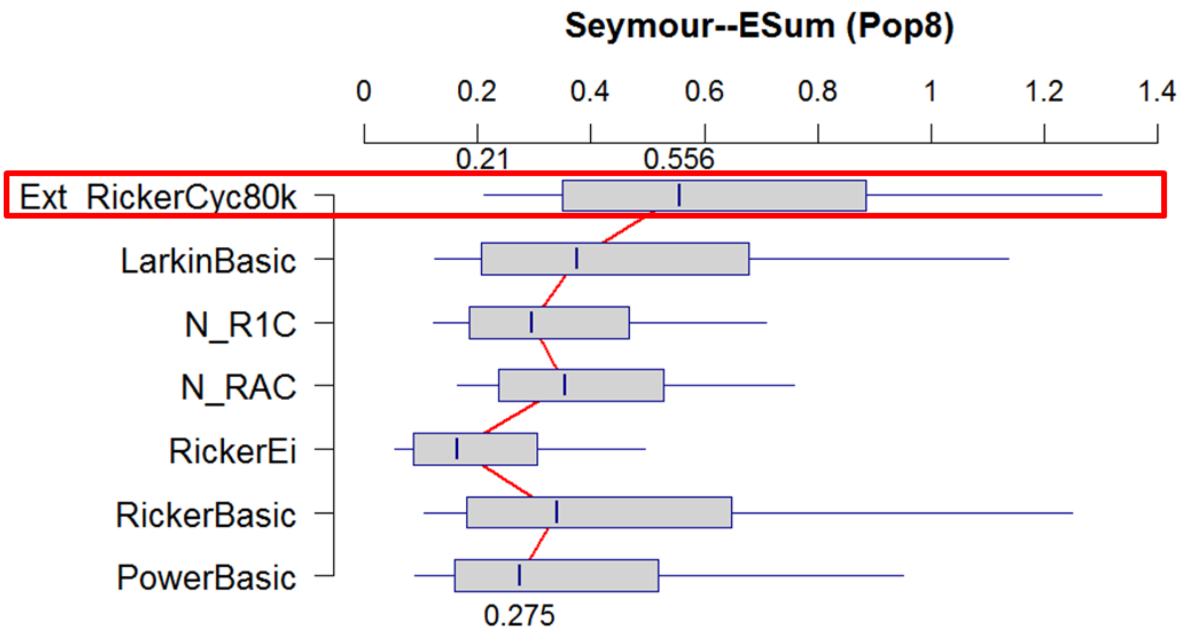

Figure A2 14: Top Ranked Forecasts Plot – Seymour. Figure details as per Figure A2 2. All numbers in Millions of Fish.

Model Selection

- The Ricker (Cycle) model was selected for the 2018 forecast, because it is the top-ranked model. In 2017, the Larkin model was selected, because the Ricker (Cyc) model did not converge. The 2018 forecast did converge (see below)
- Notable points:
    - Have a history of similar spawner abundances (EFS) with similar ranges of returns.
    - Ricker (Ei) model produces a 2018 forecast much lower than all the other models, but was not tested for “warm years only” as part of the 2017.

Statistical Notes

- **Ricker** (**Cyc**)**:** Visual check of posterior distributions shows that the Ricker parameters for productivity (*a*) and capacity *(b)* converged for both the 4-year old model and the 5-year old model. The autocorrelation (acf) plot of total returns also does not flag any fitting issues.
- R1C and RAC models have much narrower bounds with revised approach to calculating standard deviation (i.e. cycle line residuals only)

Chilko (Chilko-S CU) – Summer Mgmt Unit

Table A2 15: Spawning Ground and Juvenile Summary – Chilko. Table details as per Table A2 1.

		Four Year Olds		Five Year Olds	
		Cyc Avg[a]	2014 BY	Cyc. Avg.[b]	2013 BY
Spawning Ground Summary	% Female	59%	65%	55%	53%
	Spawner Success	93%	100%	95%	99%
	EFS (channel and river)	253,400	666,000	154,100	624,500
Juvenile Summary	Freshwater Surv.(fry/EFS)	119	94	NA	NA
	Fry Abundance	20M	60M	NA	NA

a. Brood years 1974-2014 b. Brood years 1973-2013

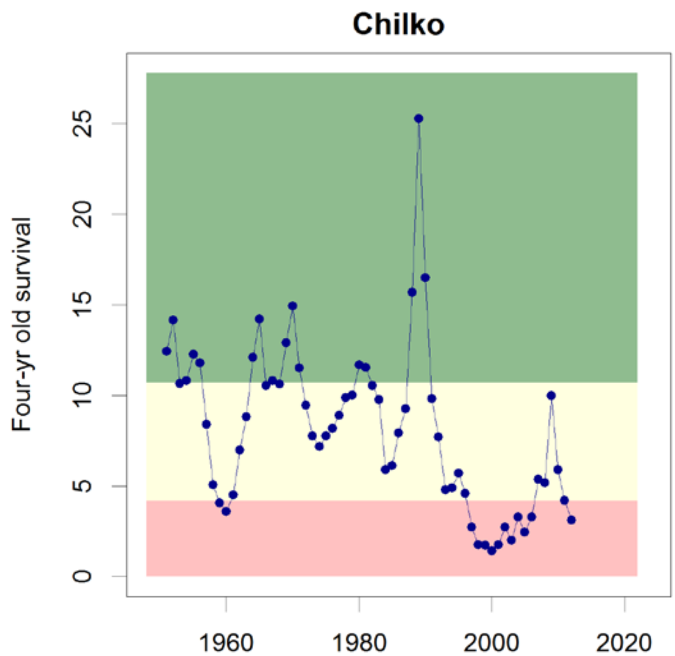

Figure A2 15: Historical Age-4 Survival – Chilko. Figure details as per Figure A2 1

Table A2 16: Top Ranked Forecasts Table – Chilko. Table details as per Table A2 2.

		Forecasted Return					Forecasted Age-4 Survival				
Model	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**	**10%**	**25%**	**50%**	**75%**	**90%**
LarkinBasic	1	579,000	911,000	1.443M	2.443M	3.844M	0.6	1.0	1.6	3.0	5.0
PowerJuvPi*	1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PowerJuv*	3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PowerJuvFRDpk*	4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
RickerCyc	7	935,000	1.626M	2.840M	4.917M	8.045M	1.1	6.3	3.5	1.9	10.9
RickerFrDMn80k	10	622,000	949,000	1.528M	2.479M	3.968M	0.7	1.2	2.0	3.4	5.7
Ricker	12	656,000	969,000	1.544M	2.497M	4.282M	0.8	1.2	2.0	3.4	6.0
Age4PowJuvPi/Age5Sibling	**-**	**833,000**	**1.345M**	**2.259M**	**3.801M**	**6.098M**	**1.2**	**2.0**	**3.4**	**5.6**	**9.0**
Ricker (Ei)	-	586,000	879,000	1.440M	2.514M	4.168M	0.6	1.1	1.9	3.3	5.7

* Juvenile-based forecasts for 5-year old Chilko returns are not available, because there is no juvenile abundance estimate for the 2013 brood year. However, these top-ranked models are still listed in the table for context.

Table A2 17: Top Ranked Forecasts Table – Chilko Age-4 Only. Table details as per Table A2 2.

		Forecasted Age 4 Returns				
Model	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**
LarkinBasic	1	394,000	664,000	1.089M	2.011M	3.332M
PowerJuvPi*	1	NA	NA	NA	NA	NA
PowerJuv*	3	NA	NA	NA	NA	NA
PowerJuvFRDpk*	4	NA	NA	NA	NA	NA
RickerCyc	7	713,000	1.264M	2.341M	4.215M	7.235M
RickerFrDMn80k	10	450,000	793,000	1.331M	2.233M	3.769M
Ricker	12	522,000	792,000	1.355M	2.257M	3.976M
Age4PowJuvPi / Age5Sibling	**-**	**829,000**	**1.336M**	**2.240M**	**3.758M**	**6.007M**
Ricker (Ei)	-	428,000	725,000	1.274M	2.202M	3.785M

* Juvenile-based forecasts for 5-year old Chilko returns are not available, because there is no juvenile abundance estimate for the 2013 brood year. However, these top-ranked models are still listed in the table for context.

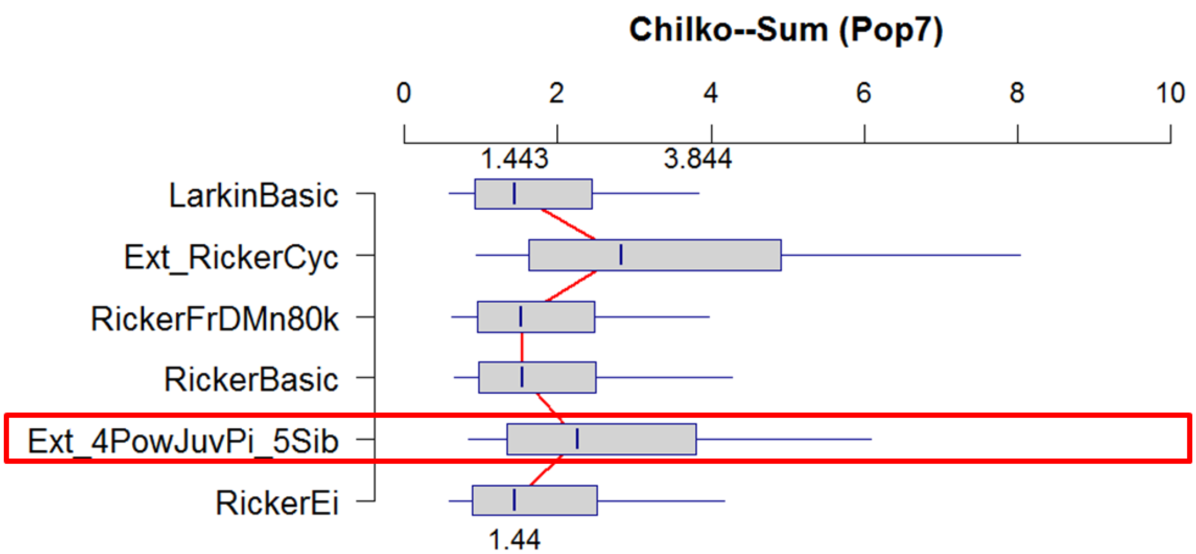

Figure A2 16: Top Ranked Forecasts Plot – Chilko. Figure details as per Figure A2 2. All numbers in Millions of Fish.

Model Selection

- Chilko presented a special challenge for model selection. Applying model selection criteria consistent with recent years would lead to choosing the highest-ranking model that includes juvenile data and an environmental covariate. Three of the 4 top-ranked models in the most recent performance review (MacDonald and Grant 2012) are based on juvenile data (see table on previous page). However, juvenile-based forecasts for 5year-old Chilko Sockeye are not available, because there is no juvenile abundance estimate for the 2013 brood year.
- As a result, a mixed forecast was selected for 2018, using the juvenile power model with Pine Island SST as a covariate to forecast 4-year old returns (PowerJuvPi) and a sibling model to forecast 5-year olds. This approach uses established model selection criteria for the predominant age class, and supplements the forecast with an alternative for the 5-year olds. Note that the Larkin model was selected for the 2017 forecast, because the missing estimate precluded a 4-year old forecast based on juveniles.

- The forecast needs to be interpreted with caution, because it is extrapolating the effect of the environmental covariate (Pine Island SST) beyond the range observed in years with recruit estimates.
- Notable points:
  - o Juvenile abundance for the 2014 brood year (2016 outmigration) was the 3rd largest ever observed, and observed survival from juvenile abundances in this range has been highly variable (see plot on next page). This introduces additional uncertainty into the forecast.

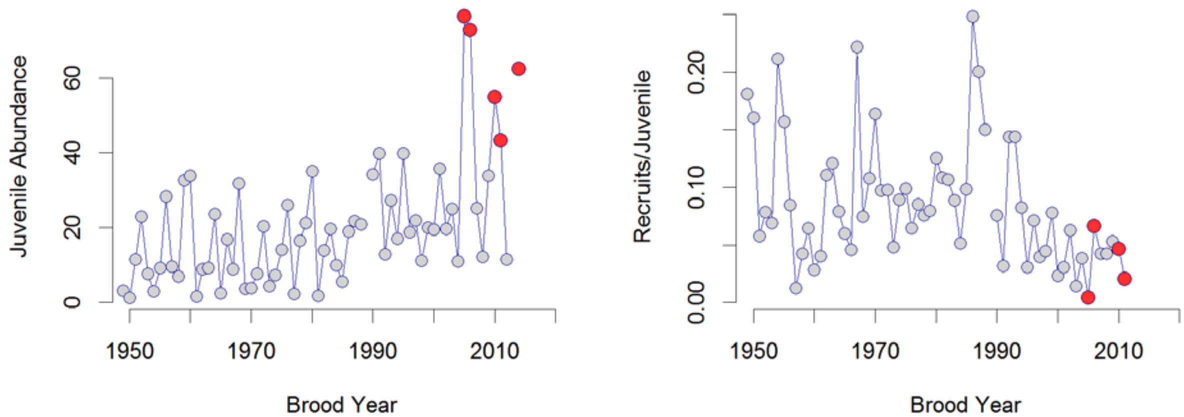

Figure A2 19: Juvenile abundance and survival rate for Chilko Sockeye, highlighting the 5 largest abundances.

Late Stuart (Takla-Trembleur-S CU) – Summer Mgmt Unit

Table A2 18: Spawning Ground Summary – Late Stuart. Table details as per Table A2 1.

		Four Year Olds		Five Year Olds	
		Cyc Avg[a]	2014 BY	Cyc. Avg.[b]	2013 BY
Spawning Ground Summary	% Female	55%	58%	58%	54%
	Spawner Success	98%	95%	93%	99%
	EFS	23,600	27,900	218,000	70,900

a. Brood years 1950-2014 b. Brood years 1949-2013

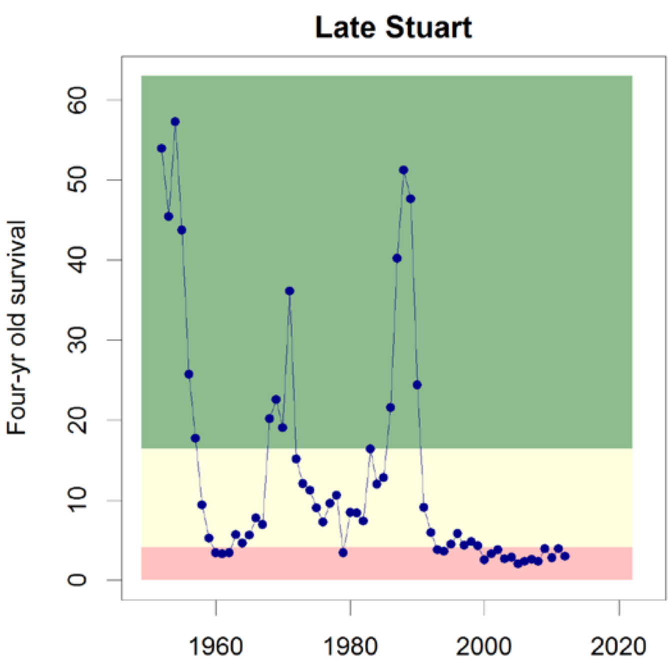

Figure A2 17: Historical Age-4 Survival – Late Stuart. Figure details as per Figure A2 1.

Table A2 19: Top Ranked Forecasts Table – Late Stuart . Table details as per Table A2 2

		Forecasted Return					Forecasted Age-4 Survival				
Model	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**	**10%**	**25%**	**50%**	**75%**	**90%**
R1C	**1**	**55,000**	**88,000**	**149,000**	**251,000**	**401,000**	**1.8**	**2.9**	**4.8**	**8.2**	**13.1**
R2C	2	68,000	104,000	166,000	267,000	410,000	2.2	3.4	5.5	8.8	13.4
Power	3	73,000	136,000	274,000	547,000	1,031,000	1.4	2.9	6.4	14.3	28.8
Ricker (FrDMn)	4	95,000	194,000	412,000	948,000	2,032,000	1.6	3.6	8.8	23.0	52.3
Larkin	-	101,000	200,000	417,000	892,000	1,873,000	1.7	3.5	9.3	20.9	48.6
Larkin (CycAge)	-	104,000	199,000	409,000	805,000	1,656,000	1.9	3.8	9.8	22.3	49.1
Power (CycAge)	-	75,000	136,000	272,000	517,000	985,000	1.5	3.2	6.7	15.0	32.8

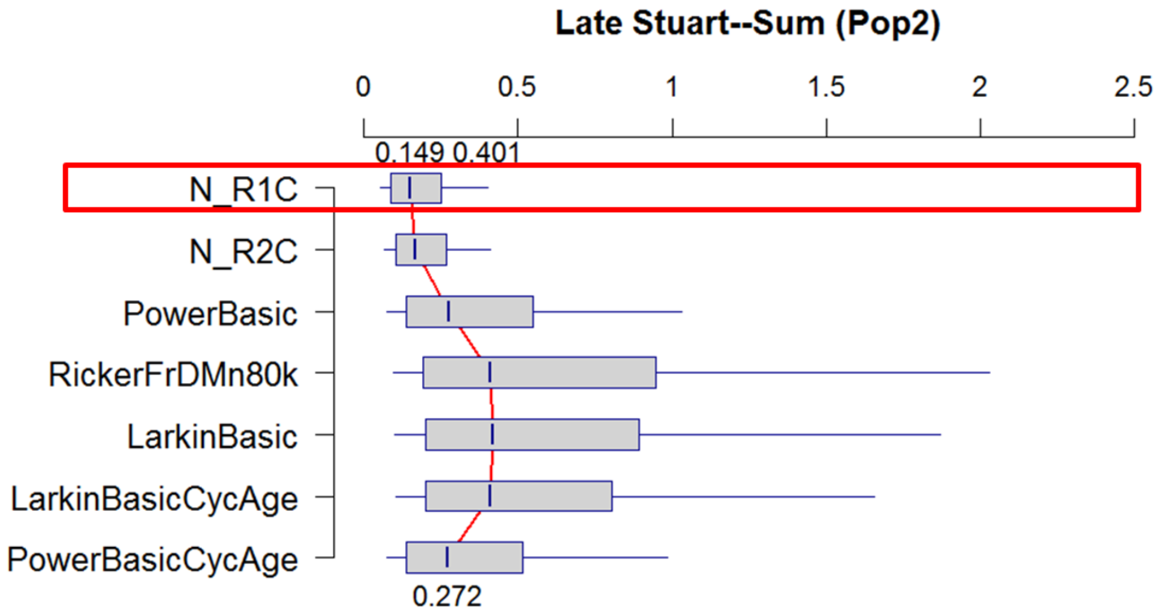

Figure A2 18: Top Ranked Forecasts Plot – Late Stuart. Figure details as per Figure A2 2. All numbers in Millions of Fish.

Model Selection

- Alternative forecasts for Late Stuart differ widely, with medians ranging from about 150k to about 420k, and upper bounds (p90) ranging from 400k to 2M.
- The 1 Cycle Return (R1C) model was selected for the 2018 Late Stuart forecast. Spawner abundance (EFS) in the brood year was roughly average for the cycle, so the non-parametric models (R1C,R2C) were retained for consideration, and R1C was the top-ranked model in the most recent evaluation (MacDonald and Grant 2012). This is a change from the 2017 forecast, when the power model was selected due to the below-average spawner abundance in the 2013 brood year (i.e. used the highest-ranked SR-based model)

Statistical Notes

- **R1C and R2C**: much narrower bounds with revised approach to calculating standard deviation (i.e. cycle line residuals only). For example, R1C upper bound changed from 663,000 to 401,000.
- **Larkin and Power**: forecasts not affected by alternative age proportions (i.e. all years vs. cycle years only).

Quesnel (Quesnel-S CU) - Summer Mgmt Unit

Table A2 20: Spawning Ground Summary – Quesnel. Table details as per Table A2 1.

		Four Year Olds		Five Year Olds	
		Cyc Avg[a]	2014 BY	Cyc. Avg.[b]	2013 BY
Spawning Ground Summary	% Female	52%	53%	55%	54%
	Spawner Success	95%	98%	89%	98%
	EFS	190,600	431,000	458,800	93,700
		a. Brood years 1950-2014		b. Brood years 1949-2013	

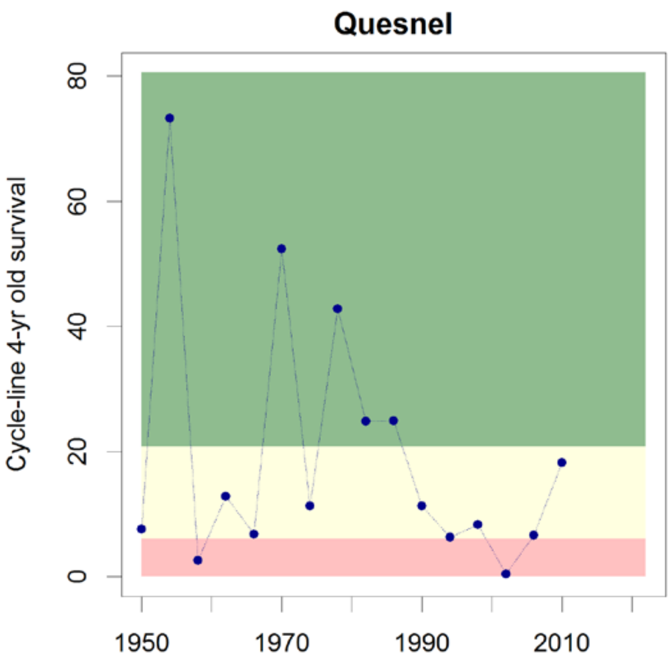

Figure A2 19: Historical Age-4 Survival – Quesnel. Figure details as per Figure A2 1, except that only estimates for the 2018 cycle line are shown.

Table A2 21: Top Ranked Forecasts Table – Quesnel. Table details as per Table A2 2.

		Forecasted Return					Forecasted Age-4 Survival				
Model	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**	**10%**	**25%**	**50%**	**75%**	**90%**
R1C	1	566,000	1,126M	2,417M	5,187M	10,315M	1.3	2.6	5.6	11.9	23.7
R2C	2	330,000	679,000	1,513M	3,373M	6,940M	0.8	1.6	3.5	7.7	15.9
RickerCyc	3	912,000	1,724M	3,382M	6,387M	11,310M	NA	NA	NA	NA	NA
Larkin	4	1,458M	2,475M	4,449M	8,242M	14,304M	2.8	4.9	9.5	18.6	33.0
Ricker (Ei)	**5**	**292,000**	**573,000**	**1,148M**	**2,223M**	**4,152M**	**0.6**	**1.2**	**2.5**	**5.0**	**9.6**
Ricker	6	796,000	1,479M	3,028M	6,138M	11,785M	1.4	2.8	6.4	13.7	26.9
Larkin (CycAge)	-	1,454M	2,566M	4,640M	8,693M	15,277M	3.1	5.6	10.6	19.8	35.1
Power (Juv)	-	1,003M	2,008M	4,772M	11,166M	26,683M	1.6	4.1	10.4	25.5	60.1

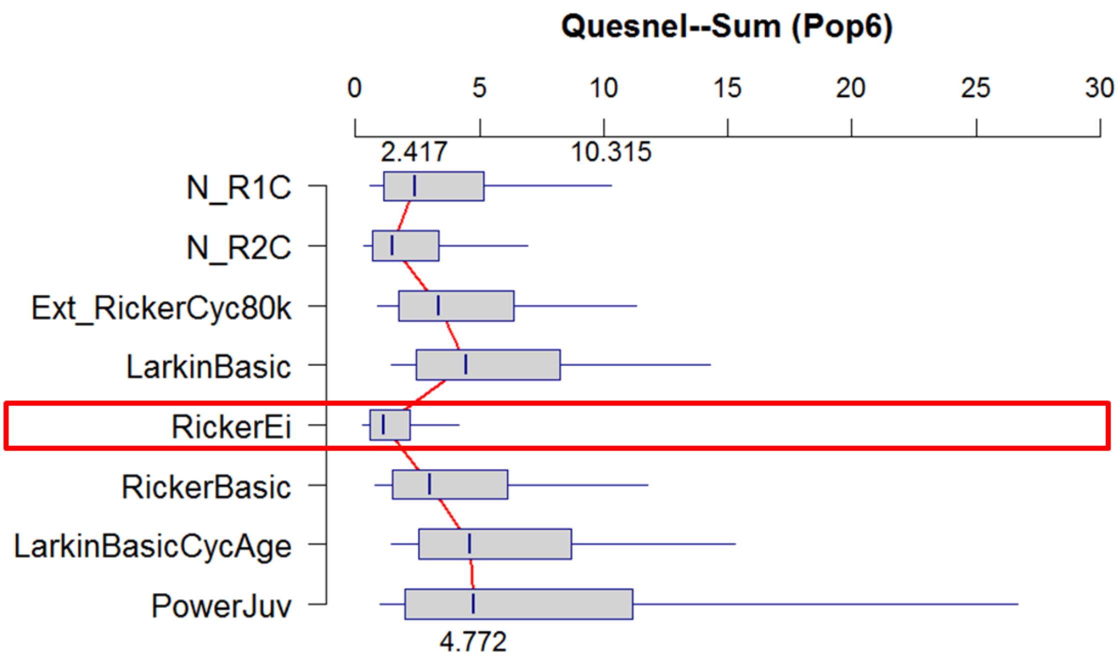

Figure A2 20: Top Ranked Forecasts Plot – Quesnel. Figure details as per Figure A2 2. All numbers in Millions of Fish.

Model Selection

- Alternative forecasts for Quesnel differ widely, with medians ranging from about 1.5M to about 4.8M, and upper bounds (p90) ranging from 4M to 26M. Note however, that the largest upper bound among the top 5 models is much smaller at 14M. The juvenile Power model was not tested in the most recent evaluation (MacDonald and Grant 2012).
- The Ricker Cycle model was selected for the 2018 Quesnel forecast. Brood year spawner abundance (EFS) was above average, so the return-based non-parametric models were excluded from consideration (R1C, R2C). The Ricker Cycle model has the next highest rank overall, but the Ricker model with Entrance Island SST performed better in warmer-than-average years (DFO 2017)
- The Ricker model with Entrance Island SST (Ricker Ei) covariate was chosen for the 2018 Quesnel forecast. The same model was chosen for the 2017 forecast.
- Notable points:
    - o Implied productivity for Ricker Ei model in 2017 was about 2 recruits/spawner, and the 2018 forecast for this model is similar. The 2017 preliminary return for Quesnel was close to the mid-point (50% probability level) of the forecast from the Ricker Ei model.

Statistical Notes

- **R1C, R2C:** Calculation of error bounds was revised to using only cycle-line residuals. For most stocks, this narrowed the bounds substantially, and so it did for the Quesnel R2C forecast. However, the bounds for the R1C forecast stayed almost the same.
- **Larkin**: forecast not affected by alternative age proportions (i.e. all years vs. cycle years only).

Stellako (Francois-Fraser-S CU) – Summer Mgmt Unit

Table A2 22: Spawning Ground Summary – Stellako. Table details as per Table A2 1

		Four Year Olds		Five Year Olds	
		Cyc Avg[a]	2014 BY	Cyc. Avg.[b]	2013 BY
Spawning Ground Summary	% Female	56%	53%	53%	56%
	Spawner Success	94%	91%	92%	100%
	EFS	76,100	240,400	30,500	54,100

a. Brood years 1950-2014

b. Brood years 1949-2013

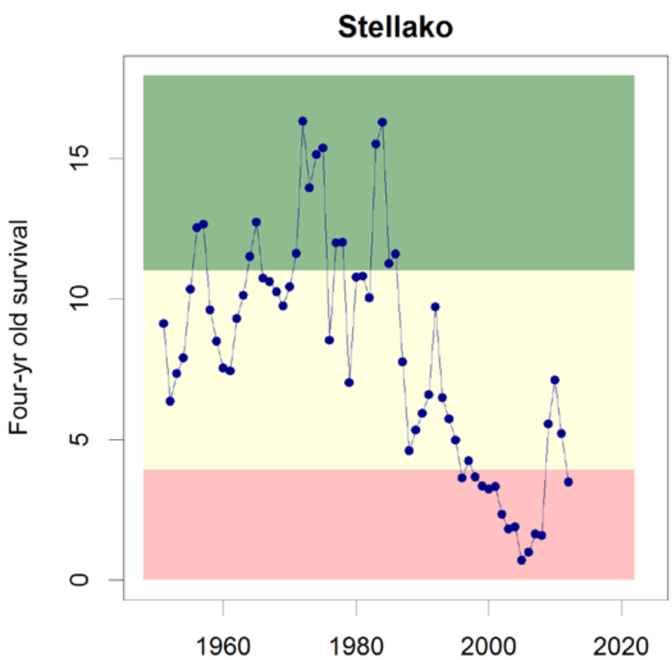

Figure A2 21: Historical Age-4 Survival – Stellako. Figure details as per Figure A2 1

Table A2 23: Top Ranked Forecasts Table – Stellako. Table details as per Table A2 2.

		Forecasted Return					Forecasted Age-4 Survival				
Model	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**	**10%**	**25%**	**50%**	**75%**	**90%**
R2C	1	413,000	611,000	943,000	1,455,000	2,151,000	1.7	2.5	3.8	5.9	8.7
Larkin	**2**	**229,000**	**347,000**	**559,000**	**895,000**	**1,454,000**	**0.7**	**1.1**	**2.0**	**3.4**	**5.9**
Ricker (Ei)	3	137,000	211,000	357,000	627,000	1,048,000	0.3	0.6	1.1	2.2	4.1
Ricker (PDO)	4	182,000	286,000	490,000	883,000	1,505,000	0.4	0.7	1.4	2.9	5.7
Ricker	8	193,000	303,000	506,000	935,000	1,739,000	0.4	0.8	1.5	3.1	6.4

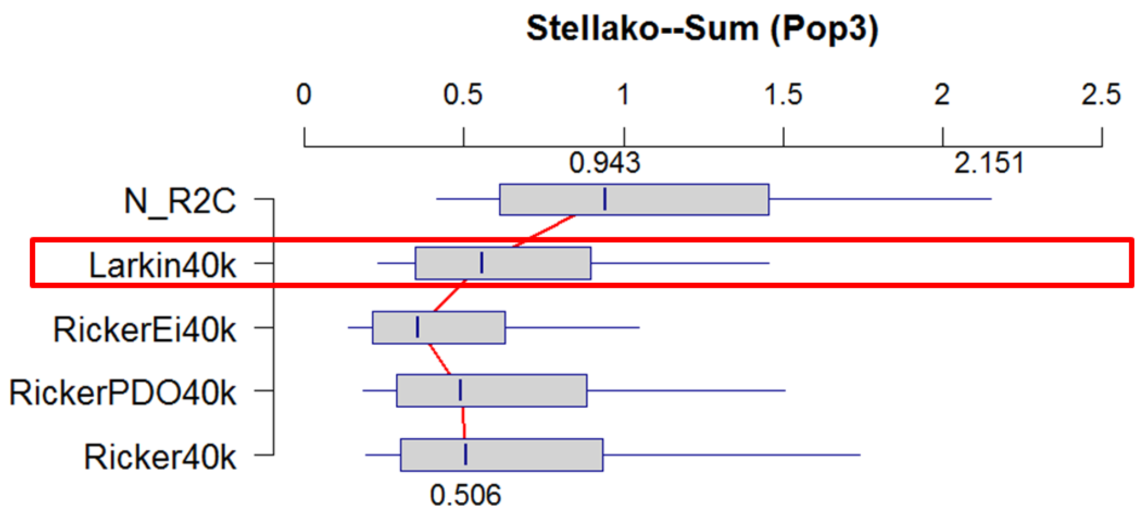

Figure A2 22: Top Ranked Forecasts Plot – Stellako. Figure details as per Figure A2 2. All numbers in Millions of Fish.

Model Selection

- Three of the 4 SR-based models produce forecasts with similar means and ranges (Larkin, Ricker, and Ricker PDO), but the Ricker Ei forecast is quite a bit lower and the non-parametric forecast substantially higher.
- The Larkin model was selected for the 2018 Stellako forecast. Brood year spawner abundance (EFS) was above average, so return-based non-parametric models were excluded from consideration (R1C). The Larkin model has the next highest rank, and was therefore selected. The same model was selected for the 2017 forecast.

Statistical Notes

- **R2C**: much narrower bounds with revised approach to calculating standard deviation (i.e. cycle line residuals only). For example, the upper bound changed from 2.95M to 2.15M.

Harrison (Harrison River – River Type CU) – Summer Mgmt Unit

Table A2 24: Spawning Ground Summary – Harrison. Table details as per Table A2 1

		Four Year Olds		Five Year Olds	
		Cyc Avg[a]	2014 BY	Cyc. Avg.[b]	2013 BY
Spawning Ground Summary	% Female	57%	62%	53%	51%
	Spawner Success	96%	97%	94%	99%
	EFS	29,500	238,400	29,900	58,300

a. Brood years 1950-2014 b. Brood years 1949-2013

Plot not included because of the variable age structure, the escapement methodology changes in the 2000's and the drastic jump in both productivity and spawner abundance in recent years.

Table A2 25: Top Ranked Forecasts Table – Harrison.Table details as per Table A2 2

		Forecasted Return				
Model	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**
Age3 Ricker/ Age4 Sibling	-	13, 000	33, 000	87, 000	225, 000	548, 000

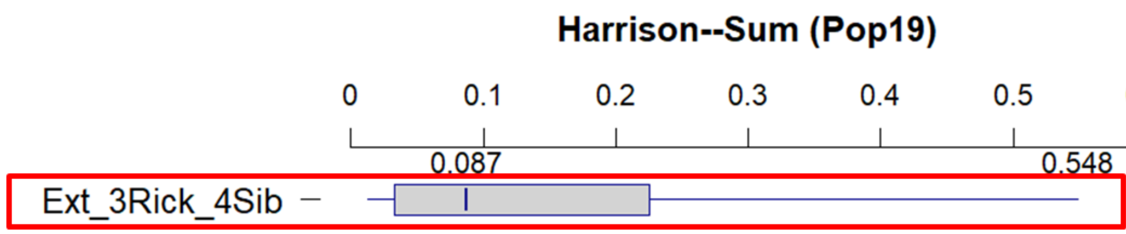

Figure A2 23: Top Ranked Forecasts Plot – Harrison. Figure details as per Figure A2 2. All numbers in Millions of Fish.

Model Selection

- Only a single forecast was prepared for Harrison. Recent high variability in abundance and productivity has caused challenges with fitting spawner-recruit models for Harrison.
- Due to very poor survival of 3 year old Harrison Sockeye returning in 2016, the sibling model was used to forecast 4year old returns in 2017. The same model was selected for the 2018 forecast.

Statistical Notes

- In recent years Harrison Sockeye have been extremely challenging to forecast due to the large increases in escapements and survival (Grant et al. 2010; Grant et al. 2011b), and the inter-annual variation in this stock's four-year old proportions. 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, though survival has since declined. As a result, various naïve and biological 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 productivity for this stock.

- A sibling model (three to four year old) was used to forecast four year olds returns in 2017. Post-1980 three and four year old recruitment data were used for the sibling models given the shifts in age of maturity after 1980, and only even years were used given the tendency for even years to produce a lower fraction of four year olds than odd years (even years produce on average 58% four year olds, which is lower than the 75% in odd years).

Raft (Kamloops-ES CU) – Summer Mgmt Unit

Table A2 26: Spawning Ground Summary – Raft. Table details as per Table A2 1

		Four Year Olds		Five Year Olds	
		Cyc Avg[a]	2014 BY	Cyc. Avg.[b]	2013 BY
Spawning Ground Summary	% Female	54%	57%	56%	57%
	Spawner Success	92%	98%	91%	97%
	EFS	3,300	9,500	4,400	9,000

a. Brood years 1950-2014
b. Brood years 1949-2013

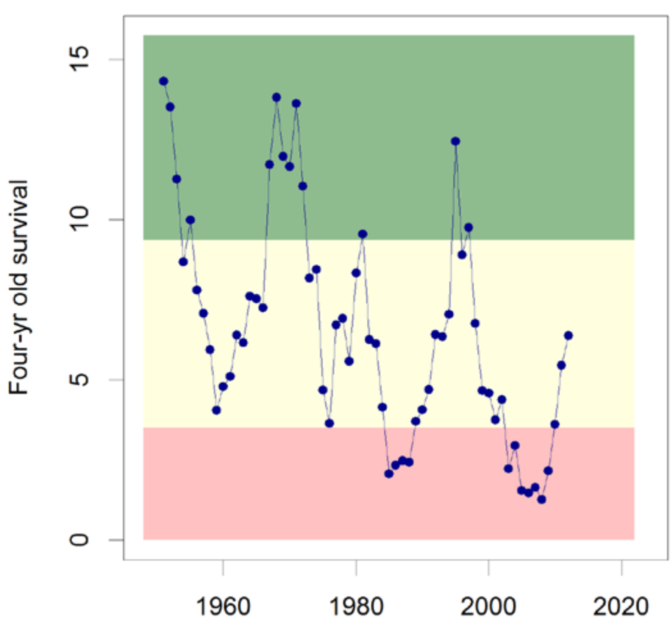

Figure A2 24: Historical Age-4 Survival – Raft. Figure details as per Figure A2 1.

Table A2 27: Top Ranked Forecasts Table – Raft. Table details as per Table A2 2

		Forecasted Return					Forecasted Age-4 Survival				
Model	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**	**10%**	**25%**	**50%**	**75%**	**90%**
Ricker (PDO)	**1**	**20,000**	**31,000**	**48,000**	**78,000**	**125,000**	**0.9**	**1.7**	**3.1**	**5.7**	**10.6**
Ricker (Cyc)	2	16,000	25,000	43,000	72,000	116,000	0.5	1.1	2.3	4.5	7.8
Power	2	22,000	32,000	51,000	81,000	122,000	1.0	1.8	3.2	6.0	9.6
Ricker	7	28,000	41,000	64,000	103,000	166,000	1.2	2.3	4.0	7.5	13.3

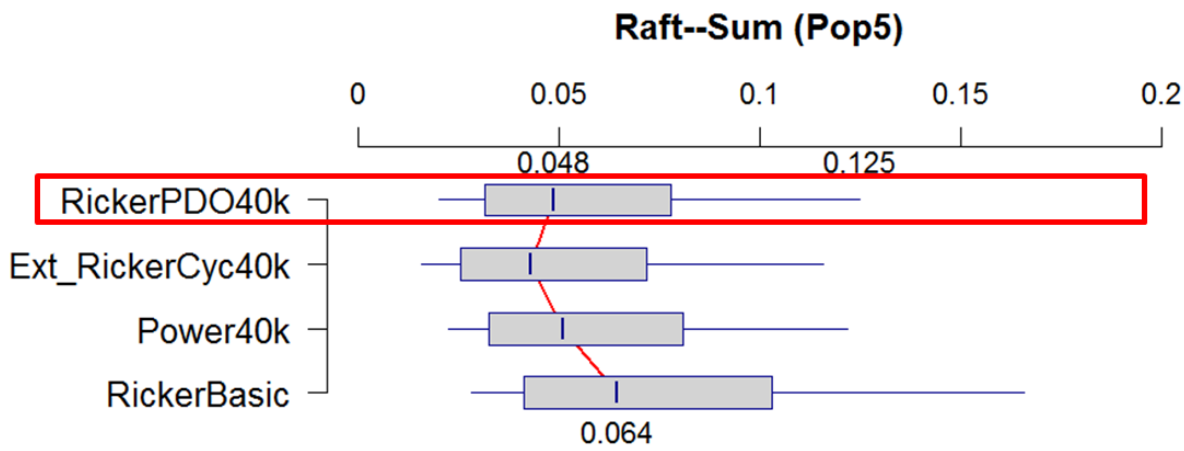

Figure A2 25: Top Ranked Forecasts Plot – Raft. Figure details as per Figure A2 2. All numbers in Millions of Fish.

Model Selection

- The 3 top-ranked models produce forecasts with similar medians and ranges, which are lower than the forecast produced by the basic Ricker model. In this case, including an environmental covariate has a similar effect as fitting cycle-specific Ricker curves or using the Power model.
- Brood year spawner abundance (EFS) was above average for both age classes (4s,5s).
- The Ricker model with Pacific Decadal Oscillation index as a covariate (RickerPDO) was selected for the 2018 Raft forecast, because it was the top-ranked model in the most-recent performance evaluation (MacDonald and Grant 2012). The same model was selected for the 2017 forecast.

Cultus (Cultus-L CU) – Late Mgmt Unit

Table A2 28: Spawning Ground and Juvenile Summary – Cultus. Table details as per Table A2 1

		Four Year Olds		Five Year Olds	
		Cyc Avg[a]	**2014 BY**	**Cyc. Avg.[b]**	**2013 BY**
Spawning Ground Summary	% Female	62%	50%	58%	47%
	Spawner Success	21%	64%	8%	53%
	EFS	NA	NA	NA	NA
Juvenile Summary	Freshwater Surv.(fry/EFS)	NA	NA	NA	NA
	Smolt Abundance	827,200	50,900	254,000	109,900

a. Brood years 1950-2014 b. Brood years 1949-2013

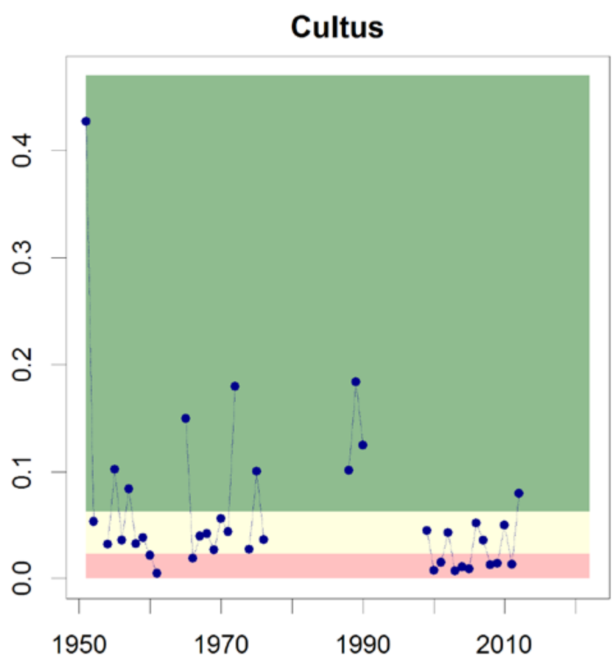

Figure A2 26: Historical Marine Survival – Cultus. Figure details as per Figure A2 1, except that the time series is based on recruits / smolt.

Table A2 29: Top Ranked Forecasts Table – Cultus. Table details as per Table A2 2

		Forecasted Return					Forecasted Age-4/Smolt (%)				
Model	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**	**10%**	**25%**	**50%**	**75%**	**90%**
MRJ	1	1,000	1,000	2,000	4,000	9,000	0.9%	1.7%	3.7%	7.7%	15.0%
PowerJuv(FRDpeak)	2	0	1,000	2,000	3,000	7,000	0.6%	1.3%	2.7%	5.8%	12.4%
PowerJuv (Pi)	**3**	**0**	**1,000**	**1,000**	**3,000**	**6,000**	0.4%	0.8%	1.8%	4.5%	10.4%
PowerJuv	-	0	1,000	2,000	3,000	6,000	0.8%	1.4%	3.0%	6.1%	10.7%

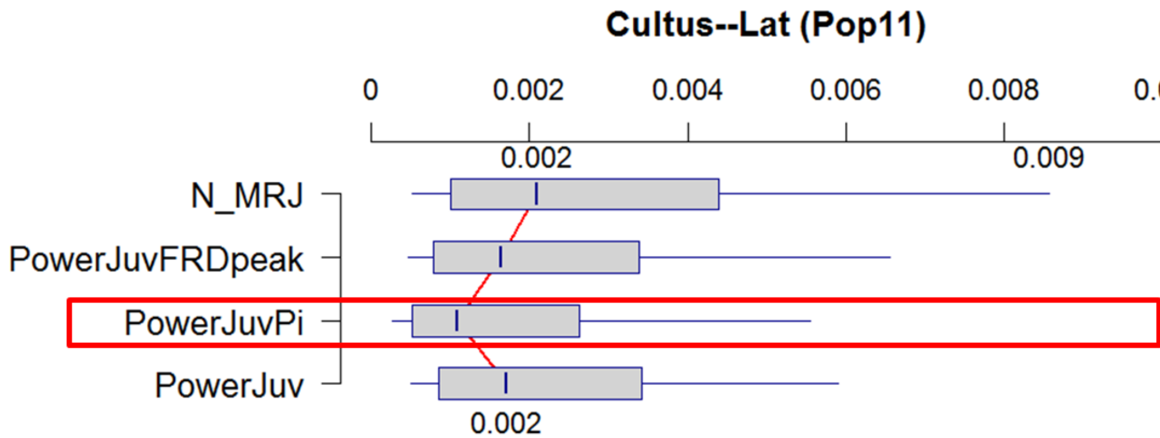

Figure A2 27: Top Ranked Forecasts Plot – Cultus. Figure details as per Figure A2 2. All numbers in Millions of Fish.

Model Selection

- Juvenile abundance from the 2014 brood year was below average, so return-based non-parametric models would be excluded from consideration, but this does not affect the consideration of the other non-parametric models (i.e. the mean-recruits-per-juvenile model; MRJ).
- The other 3 top-ranked models are all variations of the power model, and the selection criteria point to using environmental co-variates when they create a strong signal (i.e. change the forecast from the basic model).
- The juvenile-based Power model with Pine Island SST as a covariate was selected for the 2018 Cultus forecast, because it incorporates an environmental covariate that creates a strong signal, and it performed better for warmer-than-average years (DFO 2017). The same model was selected for the 2017 forecast.
- Due to the extremely high temperature observed at Pine Island in 2016, 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) – Late Mgmt Unit

Table A2 30: Spawning Ground Summary – Late Shuswap. Table details as per Table A2 1

		Four Year Olds		Five Year Olds	
		Cyc Avg[a]	2014 BY	Cyc. Avg.[b]	2013 BY
Spawning Ground Summary	% Female	55%	58%	59%	59%
	Spawner Success	98%	95%	97%	97%
	EFS	1,199,100	1,053,500	8,800	87,900

a. Brood years 1950-2014 b. Brood years 1949-2013

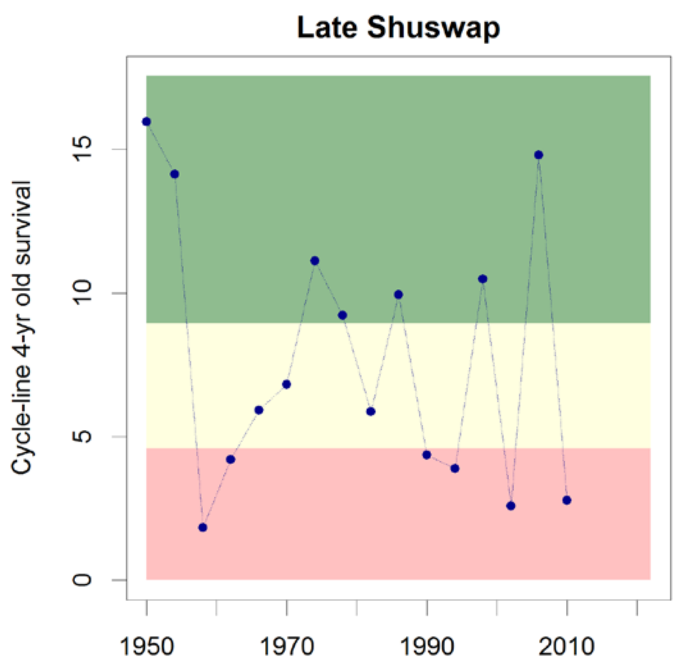

Figure A2 28: Historical Age-4 Survival – Late Shuswap.Figure details as per Figure A2 1, except that only estimates for the 2018 cycle line are shown.

Table A2 31: Top Ranked Forecasts Table – Late Shuswap. Table details as per Table A2 2.

		Forecasted Return					Forecasted Age-4 Survival				
Model	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**	**10%**	**25%**	**50%**	**75%**	**90%**
R1C	1	3,319M	5.196M	8.549M	14.068M	22.024M	3.2	4.9	8.1	13.4	20.9
Ricker (Cyc)	**2**	**3.045M**	**4.548M**	**6.923M**	**10.415M**	**15.091M**	2.9	4.3	6.6	9.8	14.3
RAC	3	3.489M	5.115M	7.824M	11.968M	17.545M	3.3	4.9	7.4	11.4	16.7
R2C	4	4,881M	7,746M	12,942M	21,622M	34,317M	4.6	7.4	12.3	20.5	32.6
Larkin (CycAge)	5	2,405M	4,223M	8,255M	16,346M	28,960M	2.3	4.0	7.8	15.5	27.5
Ricker (Ei)	6	406,000	895,000	2,093M	4,759M	9,230M	0.2	0.7	1.9	4.5	8.8
Ricker(CycAge)	7	1,557M	3,284M	7.122M	14.091M	29.069M	1.4	3.1	6.8	13.4	27.6
Larkin	-	843,000	2,400M	5,819M	12,517M	23,480M	0.4	2.1	5.5	11.8	22.3
Power	-	773,000	1,636M	3,547M	7,434M	16,069M	0.3	1.2	3.2	6.9	15.1
Power(CycAge)	-	1,292M	2,516M	4,840M	9,832M	19,280M	1.2	2.4	4.6	9.3	18.3
Ricker (Basic)	-	908,000	2,055M	5,026M	10,846M	23,761M	0.3	1.4	4.4	10.2	22.6

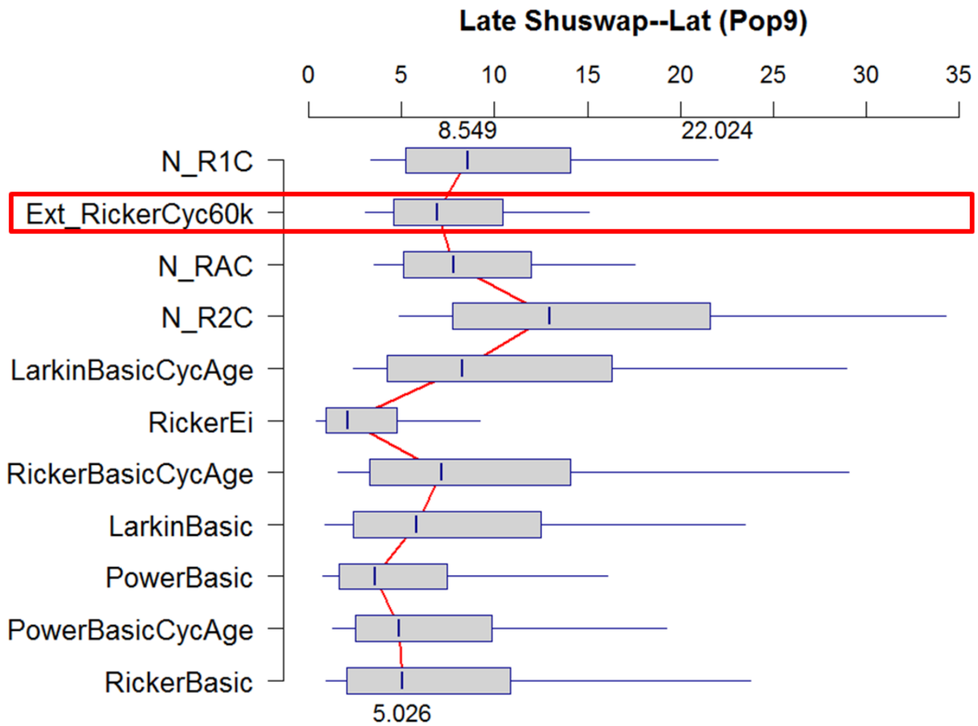

Figure A2 29: Top Ranked Forecasts Plot – Late Shuswap. Figure details as per Figure A2 2. All numbers in Millions of Fish.

Model Selection

- Brood years spawner abundance (EFS) was average, so retain return-based non-parametric models (R1C, R2C, RAC) for consideration based on standard criteria. However, the R1C model for this particular brood year was rejected, because it is using the 2014 return as the forecast, and the 2010 brood year EFS that produced that return was 3X larger than the 2014 brood year EFS, so it does not seem reasonable to assume that we would get a similar return to 2014.
- The Ricker- Cycle model was selected for the 2018 Late Shuswap forecast, because it was the highest-ranked model after the R1C.
- This differs from the 2017 forecast, where the Larkin model was selected to capture the delayed-density effect from the 2010 spawner abundance (3M, largest observed). However, this is not affecting the 2018 forecast, which uses 2011-2013 spawner abundances for the lag terms.

Statistical Notes

- **R1C, R2C, and RAC**: Much narrower spread with revised calculation of standard deviations using only cycle line residuals. For example, the upper bound at 90th percentile for R2C moves from about 80 Million to about 35 Million, which is still the largest upper bound across all alternative models, but more consistent with the upper bounds for some of the spawner-recruit based models.
- **Ricker, Larkin, Power**: Forecast median and range for these 3 models are strongly affected by the age proportions used. Specifically, the median (p50) forecast increases from 5M to 7M for Ricker, 3.5M to 5M for Power, and from 6M to 8M for Larkin when using only cycle-line age proportions rather than all-year age proportions.

Portage (Seton-L CU) – Late Mgmt Unit

Table A2 32: Spawning Ground Summary – Portage. Table details as per Table A2 1

		Four Year Olds		Five Year Olds	
		Cyc Avg[a]	2014 BY	Cyc. Avg.[b]	2013 BY
Spawning Ground Summary	% Female	53%	57%	58%	60%
	Spawner Success	92%	90%	96%	95%
	EFS	8,600	12,300	2,900	4,200

a. Brood years 1950-2014 b. Brood years 1949-2013

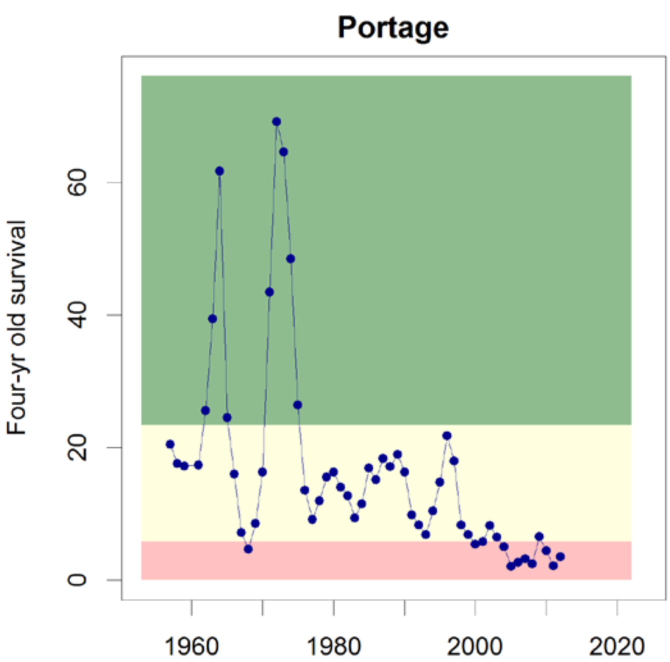

Figure A2 30: Historical Age-4 Survival – Portage. Figure details as per Figure A2 1

Table A2 33: Top Ranked Forecasts Table – Portage. Table details as per Table A2 2

		Forecasted Return					Forecasted Age-4 Survival				
Model	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**	**10%**	**25%**	**50%**	**75%**	**90%**
Larkin	**1**	**22,000**	**44,000**	**102,000**	**234,000**	**479,000**	**1.4**	**2.9**	**7.3**	**18.0**	**36.7**
Ricker (Cyc)	2	31,000	52,000	87,000	149,000	242,000	2.4	4.0	6.8	11.8	19.3
Power	3	17,000	33,000	77,000	185,000	356,000	1.1	2.3	5.9	14.0	28.3

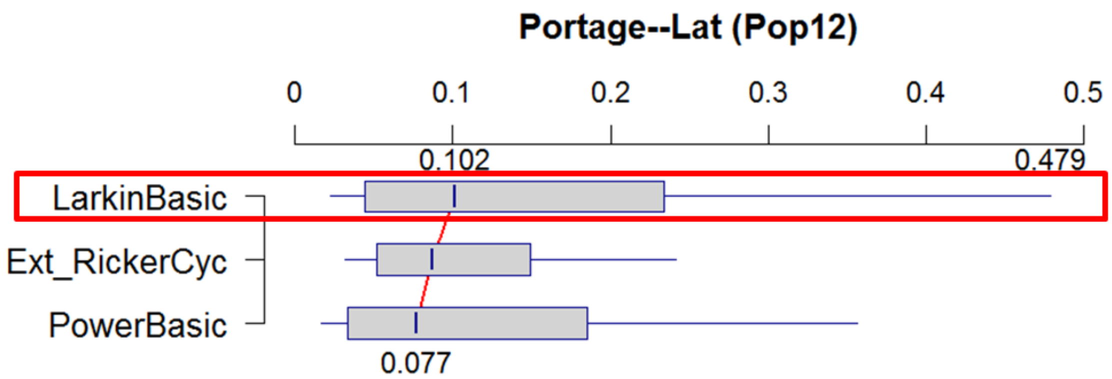

Figure A2 31: Top Ranked Forecasts Plot – Portage. Figure details as per Figure A2 2. All numbers in Millions of Fish.

Model Selection

- Brood year spawner abundance (EFS) was average, but this does not affect model selection, because there are no non-parametric models in the shortlist. Also, there are no models with environmental covariates in the short-list, so model selection defaulted to the ranking in the most recent performance evaluation (MacDonald and Grant 2012).
- The Larkin model was selected for the 2018 Portage forecast, because it is the top-ranked model. The same model was selected for the 2017 forecast.
- Notable points:
    - The Larkin model forecast is not affected by the delayed-density effects of the 2010 brood year spawner abundance, which was about 3 times the cycle-line average at 27k. Note that the 2010 brood year abundance and recruits are included in the estimate of Larkin parameters, but the specific values are not used when applying those parameters to the 2018 forecast.

Weaver (Harrison (U/S)-L CU) – Late Mgmt Unit

Table A2 34: Spawning Ground and Juvenile Summary – Weaver. Table details as per Table A2 1

		Four Year Olds		Five Year Olds	
		Cyc Avg[a]	2014 BY	Cyc. Avg.[b]	2013 BY
Spawning Ground Summary	% Female	52%	50%	55%	52%
	Spawner Success	86%	85%	91%	97%
	EFS	30,500	10,400	20,400	15,500
Juvenile Summary	Freshwater Surv.(fry/EFS)	1,600	1,700	1,600	2,300
	Fry Abundance	36M	17M	29M	36M

a. Brood years 1950-2014 b. Brood years 1949-2013

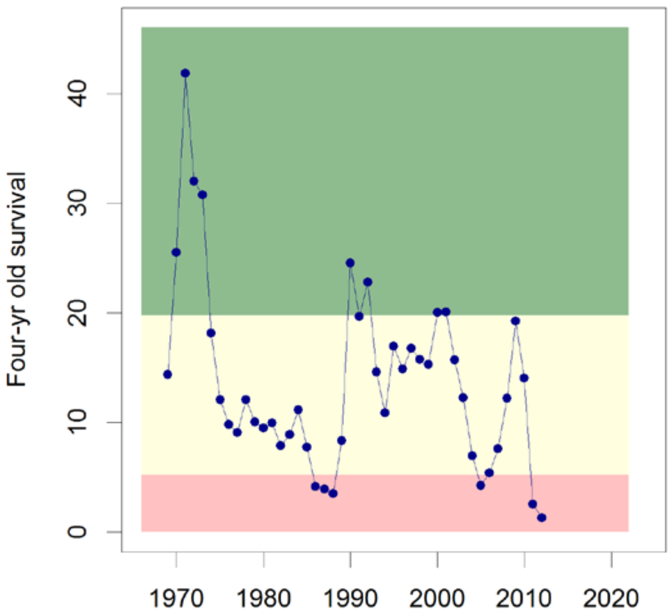

Figure A2 32: Historical Age-4 Survival – Weaver. Figure details as per Figure A2 1.

Table A2 35: Top Ranked Forecasts Table – Weaver. Table details as per Table A2 2

		Forecasted Return					Forecasted Age-4 Survival				
Model	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**	**10%**	**25%**	**50%**	**75%**	**90%**
MRS	1	19,000	49,000	143,000	420,000	1.104M	1.3	3.5	10.3	30.1	79.1
Ricker (PDO)	**2**	**38,000**	**78,000**	**150,000**	**318,000**	**655,000**	**1.5**	**3.6**	**8.8**	**20.9**	**49.6**
RJC	3	28,000	70,000	197,000	554,000	1,406M	1.9	4.8	13.4	37.7	95.7
RSC	4	21,000	54,000	154,000	435,000	1.113M	1.6	4.0	11.3	32.0	81.9
PowerJuvFRDpk	6	79,000	146,000	283,000	560,000	1.072M	3.6	8.0	18.3	42.1	88.9
PowerJuv (Ei)	8	52,000	98,000	210,000	377,000	817,000	2.3	5.0	12.1	26.9	57.4
PowerJuv	12	68,000	120,000	233,000	443,000	851,000	3.0	6.1	14.0	30.0	63.3
Ricker	25	55000	97000	204000	411000	802000	2.2	4.6	11.5	27.9	58.4

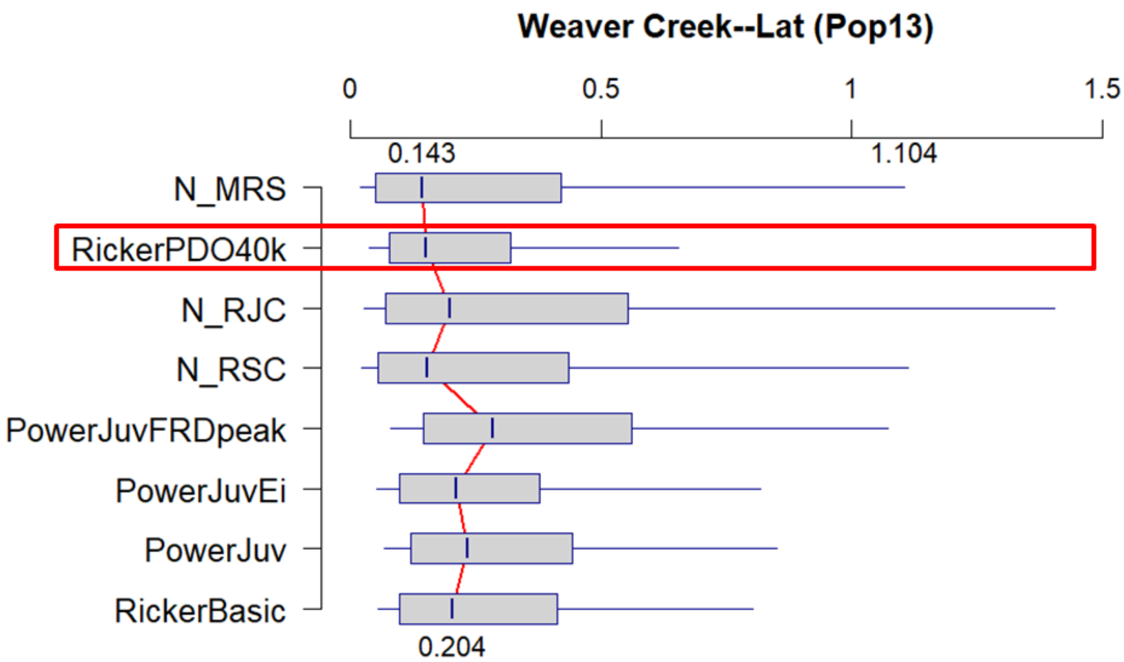

Figure A2 33: Top Ranked Forecasts Plot – Weaver. Figure details as per Figure A2 2. All numbers in Millions of Fish

Model Selection

- There are no return-based non-parametric models in the short list, so model selection was not influences by the observation that brood year spawner abundance (EFS) and resulting juvenile abundance were both below average.
- The juvenile-based models all ranked much lower than the top-ranked model using adult spawners and recruits.
- The Ricker model with Pacific Decadal Oscillation index (Ricker PDO) was selected for the 2018 Weaver Creek forecast, because the top-ranked model is a non-parametric model, the environmental model ranks within the top 3, and the signal provided by adding the covariate is consistent with other stocks (i.e. forecast pulled down).
- This differs from the 2017 forecast when the PowerJuvEi model was selected because 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 used juveniles as a predictor variable (DFO 2017).
- Due to the extremely high temperature observed at Entrance Island in 2016, 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) – Late Mgmt Unit

Table A2 36: Spawning Ground Summary – Birkenhead. Table details as per Table A2 1

		Four Year Olds		Five Year Olds	
		Cyc Avg[a]	2014 BY	Cyc. Avg.[b]	2013 BY
Spawning Ground Summary	% Female	61%	59%	60%	61%
	Spawner Success	97%	94%	94%	96%
	EFS	66,500	19,600	29,500	46,800

a. Brood years 1950-2014　　b. Brood years 1949-2013

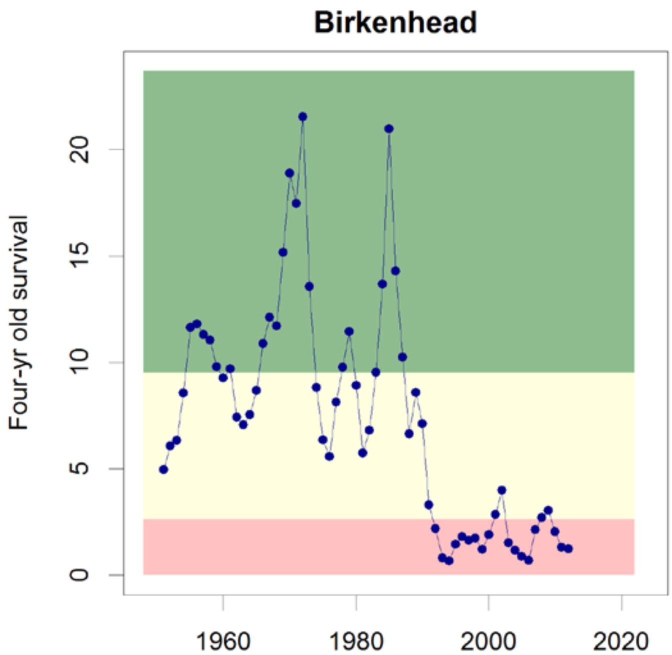

Figure A2 34: Historical Age-4 Survival – Birkenhead. Figure details as per Figure A2 1

Table A2 37: Top Ranked Forecasts Table – Birkenhead. Table details as per Table A2 2

		Forecasted Return					Forecasted Age-4 Survival				
Model	**Rank**	**10%**	**25%**	**50%**	**75%**	**90%**	**10%**	**25%**	**50%**	**75%**	**90%**
RickerEi	**1**	**59,000**	**105,000**	**187,000**	**333,000**	**587,000**	**0.9**	**1.8**	**3.6**	**8.3**	**15.6**
RAC	2	130,000	231,000	441,000	840,000	1,502,000	5.1	9.1	17.3	32.9	58.8
Ricker	2	106,000	170,000	292,000	491,000	796,000	1.6	2.9	5.6	11.5	21.5
TSA	4	56,000	129,000	322,000	806,000	1,841,000	1.1	2.6	6.5	16.4	37.4
Ricker (Pi)	4	67,000	113,000	197,000	348,000	618,000	0.9	1.9	3.9	8.0	16.1
Ricker (Ei)	-	67,000	108,000	184,000	340,000	585,000	1.0	1.9	4.0	8.2	15.7

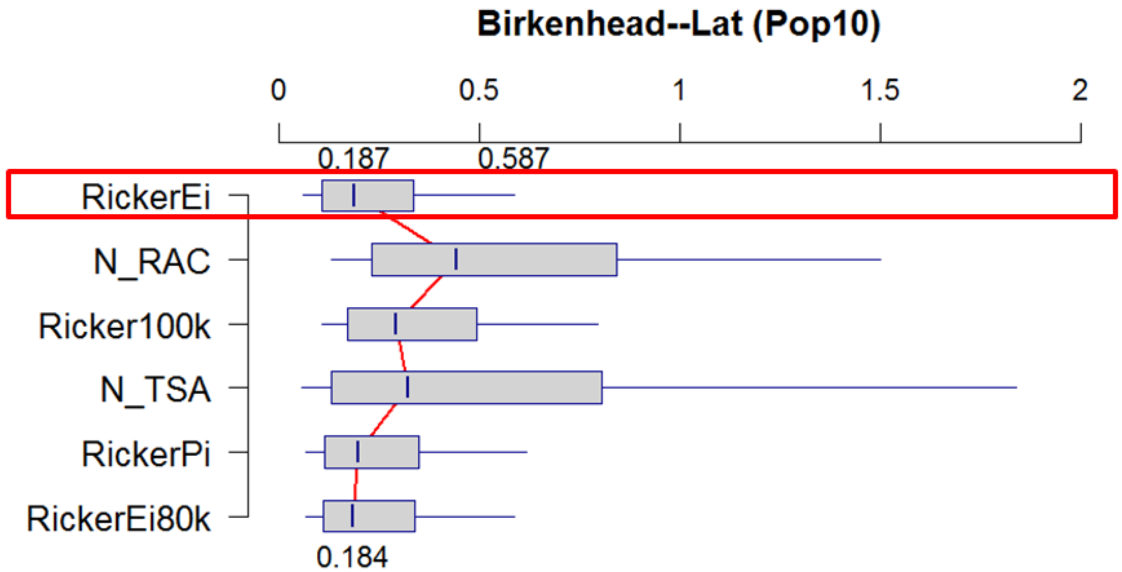

Figure A2 35: Top Ranked Forecasts Plot – Birkenhead. Figure details as per Figure A2 2. All numbers in Millions of Fish.

Model Selection

- Brood year spawner abundance (EFS) was below average, so return-based non-parametric models were dropped from consideration.
- Ricker models with environmental covariates (Entrance Island or Pine Island SST) produced forecasts that are very similar to each other, and about 1/3 lower than the basic Ricker forecast.
- The Ricker model with Entrance Island SST as a covariate was selected for the 2018 Birkenhead forecast, because it is the top-ranked model and the other selection criteria point using a SR-based model with environmental covariate (2 previous bullets). The same model was selected for the 2017 forecast.

Statistical Notes

- **RAC**: The distribution estimate for the RAC model (average return across all years on this cycle line) is much narrower using the revised approach based on cycle-line residuals only. For example, the upper bound (p90) is 1.5M compared to the all-year residual estimate of 2.5M.
- **Ricker Ei**: rerunning the MCMC with longer burn-in (RickerEi80k vs Ricker Ei with 20k burn-in) gives basically the same forecast.

Miscellaneous Stocks – All Management Units

Table A2 40: Miscellaneous Stocks – Populations Covered

Forecast Unit	Populations
Early Summer	
South Thompson Tributaries	all South Thompson except 4: Scotch, Seymour, McNomee, and Upper Adams
Taseko	Taseko, Yohetta
Chilliwack	Chilliwack Lake, Upper Chilliwack
Nahatlatch	Nahatlatch River, Mahatlatch Lake
Summer	
North Thompson Tributaries	all North Thompson except Raft and Fennel (e.g. Barriere, Clearwater, Lemieux)
North Thompson River	North Thompson River
Widgeon	Widgeon
Late	
Non-Shuswap	Big Silver, Douglas, Green, Cogburn, Poole, Railroad/Sampson, Sloquet, Tipella

Table A2 41: Miscellaneous Stocks – Forecasts based on Long-term Productivity of Proxy Stocks.

	Effective Females		**Proxy for long-term Prod.**	**Forecasted Return**					**Forecasted Age-4 Survival**				
	2013	2014		10%	25%	50%	75%	90%	10%	25%	50%	75%	90%
Early Summer													
Sth Th. Tribs	5,049	115,367	Scotch/Seymour	186,060	415,772	956,364	1,545,538	2,735,538	1.6	3.6	8.3	13.3	23.6
Taseko	86	54	Chilko	102	237	435	808	1,106	1.6	3.8	7.0	13.0	17.7
Chilliwack - DV	5,433	1,744	**Bio Model***	2,479	4,970	10,560	24,712	52,618	0.3	0.8	2.1	5.6	14.1
Nahatlach	800	2,059	All ES Stocks	3,226	7,281	13,420	25,287	47,398	1.4	3.1	5.7	10.8	20.2
Summer													
Nth Th. Tribs	1,374	799	Raft/Fennell	2,165	4,308	7,303	15,136	30,666	1.7	3.3	5.6	11.6	23.5
Nth Th. River	8,461	11,963	Raft/Fennell	25,013	49,785	84,387	174,901	354,362	1.7	3.3	5.6	11.6	23.5
Widgeon	729	146	Birkenhead	879	1,636	3,134	5,903	10,259	1.4	2.7	5.1	9.7	16.8
Late													
Misc. Lillooet Harrison	5,213	3,568	Birkenhead	9,922	18,464	35,368	66,614	115,763	1.3	2.5	4.8	9.0	15.6

* Chilliwack was forecasted using a Ricker model applied to a very limited time series of recruitment data (2001 to 2012). For the 2017 forecast, a sensitivity 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. 2011b). The prior is log-normally distributed, with a median of 25,000 EFS (Beta=1/C, C~LN(-3.689, 5)). In the 2017 forecast, the PR-based prior produced a much lower forecast, but the basic Ricker forecast was selected. A similar sensitivity test was not completed for the 2018 forecast

Appendix 3. Illustration of Forecast Sums

The forecasts for Quesnel and Stellako can be summed in each column as in Table 1A, which assumes that both stocks will return at the same probability level (i.e. variation over time is fully correlated, and both stocks have either above-average or below-average survival in 2018). An alternative approach is to assume that the two stocks are completely independent, add up a shuffled set of samples from each stock's distribution (i.e. MCMC samples), and then calculate the percentiles of the sum. This produces narrower bounds, but also shifts the median forecast (p50). A more statistically correct approach would incorporate the observed correlation between the two stocks, and produce a range that falls between the two bookends in this table.

	p 10	p 25	p 50	p 75	p 90
Quesnel	292,343	573,172	1,148,290	2,222,625	4,152,369
Stellako	228,579	346,688	558,609	895,289	1,453,767
Sum (p-levels)	520,922	919,860	1,706,899	3,117,914	5,606,136
Sum (shuffle)	802,886	1,201,584	1,916,934	3,107,526	5,101,293

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