NPAFC
Doc. 1722
Rev.

Fraser River Sockeye: Abundance and Productivity Trends and Forecasts

by

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Submitted to the

NORTH PACIFIC ANADROMOUS FISH COMMISSION

by

Canada

April 2017

THIS PAPER MAY BE CITED IN THE FOLLOWING MANNER:
Grant, S.C.H., B.L. MacDonald, and C.G.J. Michielsens. 2017. Fraser River sockeye: abundance and productivity trends and forecasts. NPAFC Doc. 1722. 8 pp. Fisheries and Oceans Canada, and Pacific Salmon Commission (Available at http://www.npafc.org).

Keywords: Sockeye Salmon, productivity, survival, forecast

Abstract

Fraser sockeye salmon total returns have varied substantially over time. In the past decade, overall returns improved on the current large cycle year (2010 and 2014) compared to previous decades but declined on the other cycles. In 2016, returns (853,000) were the lowest on the 100+ year record for the Fraser Sockeye aggregate. Marine and freshwater factors both contribute to the variability in returns. Chilko is the only sockeye salmon stock where total survival can consistently be partitioned into freshwater and marine survival over a long time series. This stock also contributes significant proportions to the total returns in most years. In the past decade, Chilko sockeye have generally exhibited average to above average freshwater survival, compared to the previous period in the 1990's where freshwater survival had been below average. Marine survival on the other hand has not improved to the same extent since the decline in the 1990s and remained predominantly below average in the last decade. In the 2015 and 2016 return years, poor marine survival drove the poor returns for Chilko sockeye. In the past few years (second half of 2013 to 2016), warmer ocean temperature anomalies (the 'warm blob') occurred in the Northeast Pacific Ocean. Broadly, both marine and freshwater conditions were generally warmer than average during this period. Although these warm conditions coincided with particularly poor marine survival for Chilko Sockeye, and poor productivity for similar summer-run (based on adult sockeye migration timing in the Fraser River) stocks, productivity of other stocks has been variable. Median predictions of Fraser Sockeye returns in 2017 (4.4 million) are expected to be below the cycle average (8.4 million), due to warmer temperatures that may influence particularly the more abundant summer run stocks, including Chilko sockeye.

Introduction

Understanding mechanisms contributing to Fraser Sockeye population dynamics has been a challenge given the broad range of ecosystems these stocks occupy throughout their life-history. Specifically, after their second winter in freshwater, Fraser sockeye smolts leave their rearing lakes and migrate down the Fraser River to the Strait of Georgia. In the Strait of Georgia, they migrate north in approximately 40 days (Preikshot et al. 2012) and exit this system via the Johnstone Strait. Fraser sockeye juveniles continue their northward migration along the continental shelf, move into the Northeast Pacific Ocean in their first winter at sea (Tucker et al. 2009), and then spend one more winter in the marine environment before they return to their natal freshwater spawning grounds as adults.

Comparisons of time series of productivity and survival for Fraser Sockeye stocks can be used to determine when similar and different mechanisms may be contributing to a stock's population dynamics (Dorner et al. 2008; Peterman and Dorner 2012; Malick and Cox 2016). Periods of similar productivity patterns may indicate mechanisms acting at broader marine or freshwater scales. This could include warmer or cooler seasonal temperatures, which act across freshwater and marine ecosystems. Periods of different productivity patterns may indicate mechanisms acting on a particular stock at unique spatial and/or temporal scales. These differences could result from variation in environmental and/or biological conditions experienced by eggs in their spawning gravel or juveniles in their rearing lakes across stocks. This could also result from the differences in adult return timing, or smolt outmigration timing in the Pacific Ocean and Fraser River (DFO 2016a). Differences in timing between stocks would expose them to different environmental and biological conditions in the freshwater and marine ecosystem. In recent years, there have also been a few major land-slides (Meager Creek landslide in the upper-Lillooet system and in the Portage system) and major events (Mount Polley mine breach into Quesnel Lake), that may have contributed to unique population dynamics for particular stocks.

Pre-season return forecasts are produced annually for Fraser sockeye stocks, and rely on some understanding of Fraser Sockeye population dynamics (DFO 2016b). These return forecasts are used pre-season to provide a preview of potential fishing opportunities to stakeholders and are used early in-season to manage fisheries until sufficient in-season test-fishery data are available. To capture inter-annual random (stochastic) uncertainty in the pre-season return forecasts, which are largely attributed to Fraser sockeye productivity, return forecasts are presented as standardized cumulative probabilities (10%, 25%, 50%, 75%, and 90%), using Bayesian statistics, rather than as single deterministic point estimates (Grant et al. 2010). At the 25% probability level, for example, there is a one in four chance the actual return will fall at or below the specified return prediction, given the historical data. Currently, these probability distributions are wide, and the goal is to decrease this uncertainty through improved understanding of factors that drive population dynamics of these stocks (Grant et al. 2010).

Results

Total Fraser Sockeye adult returns have historically varied (Figure 1-1A) due to the four-year pattern of abundances (cyclic dominance) exhibited by some of the larger stocks, and variability in annual productivity (returns-per-spawner) (Figure 1-1B) and spawning escapement. After reaching a peak in the early 1990s, returns decreased to a record low in 2009 due to declines in stock productivities. Although from 2010 to 2014, productivity, and consequently returns have increased, 2015 and 2016 productivity and returns were again poor for the total aggregate. The total Fraser Sockeye return and productivity trends largely represent stocks that comprise the greatest proportion of total Fraser Sockeye abundance, namely Summer Run stocks (based on return timing of adults to their spawning grounds) such as Chilko and Quesnel.

Chilko is the only Fraser Sockeye stock with a long and complete time series of smolt data (counted through an enumeration weir located at the outlet of Chilko Lake), which can be used with this stock's 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, and their entire marine residence period). Freshwater survival has generally improved in recent years (Figure 1-2A). 'Marine' survival data for Chilko is similar to the aggregated Fraser Sockeye survival trend (Figure 1-2B and Figure 1-1B). Chilko exhibited 'marine' survival declines in the 1990's, which culminated in the lowest survival on record in the 2005 brood year (2009 return year). Although 'marine' survival has improved in recent years (with the exception of the last two year's 2011 and 2012 brood year, which were poor), it has remained generally below average.

Across the individual Fraser Sockeye stocks, however, there has been considerable variability in productivity (recruits-per-spawner) (Figure 1-3). Although most stocks, such as Chilko and Stellako have exhibited declining trends in the 1990's, some stocks, such as Late Shuswap, have not exhibited any systematic trends, and one stock in particular (Harrison Sockeye) has increased in productivity during this period (Figure 1-3).

The 2017 return forecast indicates a one in four chance (25% probability) the total Fraser Sockeye return will be at or below 1.3 million and a three in four chance (75% probability) it will be at or below 17.6 million, assuming productivity is similar to past observations. The mid-point of this distribution (50% probability) is 4.4 million (there exists a one in two chance the return will be at or below this value), which falls below the cycle average of 8.4 million (DFO 2017 (in press)).

Discussion

Fraser sockeye productivity varies across years and stocks. There are periods in the 1980's to mid-1990's, where many stocks exhibited an increase in productivity. In subsequent years, many stocks exhibited decreases in productivity. Of note, is the extremely poor productivity experienced by almost all stocks in the 2005 brood year (2009 return year) (Figure 1-3). Marine survival of the 2005 brood year for Chilko, was also the lowest on record (Figure 1-2b). The poor returns in 2009 have been attributed to poor marine survival given this common response across stocks, the extremely poor marine survival for Chilko of the 2005 brood year, and observation in the Strait of Georgia in the 2007 ocean entry year (Thomson et al. 2012). Chilko also had an operating channel for spawning adults, and lake fertilization, which contributed to the observed population dynamics throughout the time series (Grant et al. 2011; Akenhead et al. 2016).

In recent years, the Weaver and Birkenhead stocks exhibited exceptionally poor productivity. This coincided with a major landslide above Lillooet Lake. Birkenhead fry enter Lillooet Lake to rear, and in the 2010 brood year, the upper Lake contained high amounts of suspended sediment. The sediment plume moved south, entering the adjacent Harrison Lake, where Weaver first enter the system in 2011. Given the synchronous response for these two stocks, which diverged from other stocks, it is suspected that the landslide contributed to these poor returns (DFO 2016a).

Other stocks like Late Shuswap, Scotch and Seymour, all have exhibited close to average productivity over the time series, including recent years. The productivity time series for these stocks was derived using a Larkin model that accounts for density-dependent mechanism in both the current and preceding three escapement years (Figure 1-3). No notable density-independent productivity trends are apparent following the exceptional escapement of 2010 once density-dependent mechanism have been accounted for.

To further improve our understanding of Fraser sockeye salmon population dynamics, a supplemental Canadian Science Advisory Secretariat paper is being prepared as part of the 2017 forecast process. This supplement will provide additional information on the condition, survival and abundance of various stocks, summarizing information ranging from the 2013 brood year escapement through to 2016 jack returns. Recent previous years have similarly included a supplemental process (example: DFO 2016b).

Acknowledgments

Information used to understand Fraser Sockeye population dynamics is provided by a number of sources. These include the DFO Sockeye Stock Assessment Program, in the Fraser Stock Assessment Division, and also DFO Fisheries Management and Salmonid Enhancement Branches. A number of First Nations groups also contribute to Fraser sockeye abundance data and include the following: Carrier Sekani Tribal Council, Tl'azt'en Nation, Upper Fraser Fisheries Conservation Alliance, Tsilhqot'in National Government, N'Quatqua Fisheries, Lil'wat First Nations, Little Shuswap Indian Band, Shuswap Nation Tribal Council / Secwepemc Fisheries Commission, Instream Fisheries Research Inc., Pacific Salmon Commission (PSC), PSC, Southern Boundary Restoration and Enhancement Fund.

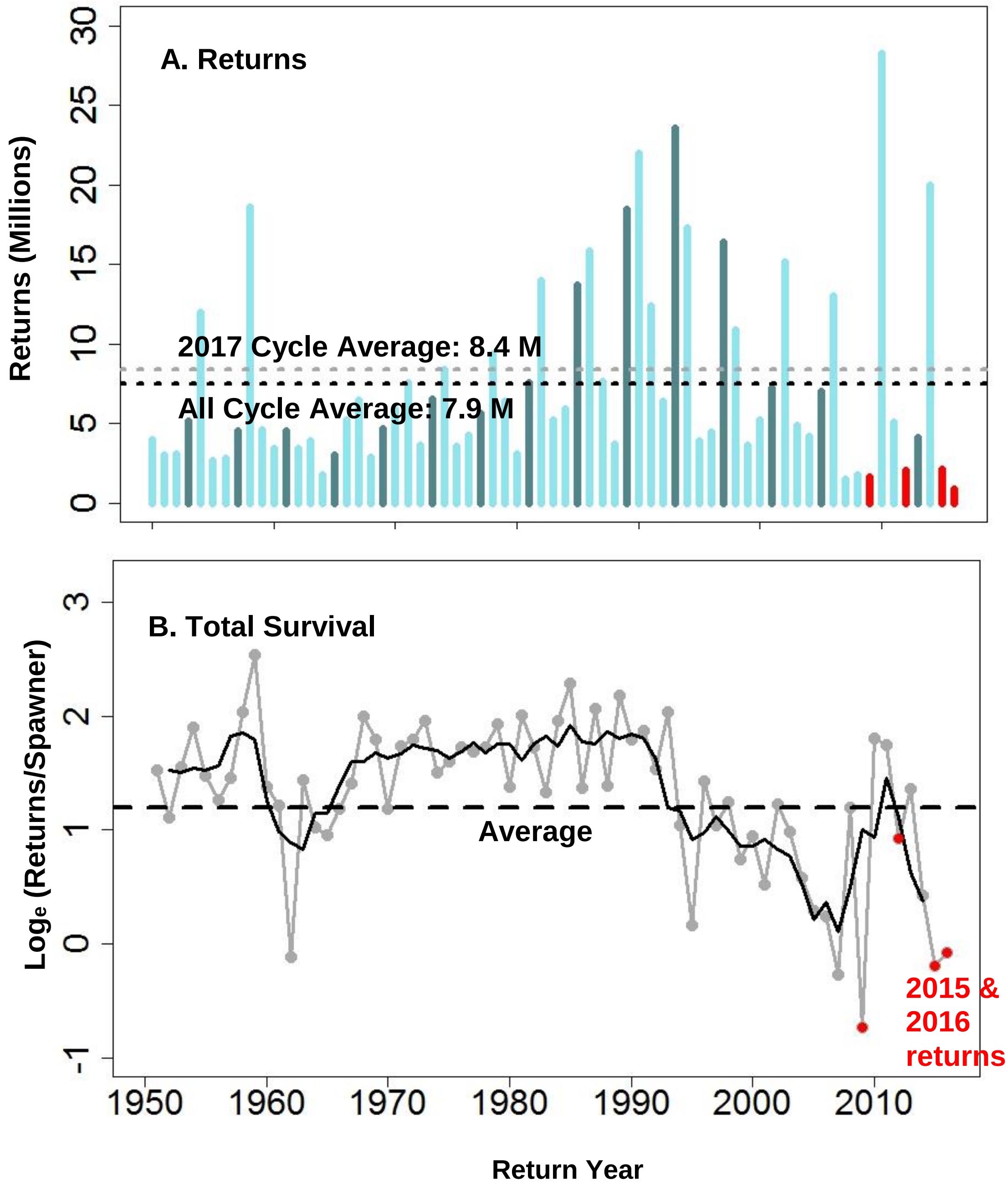

Figure **Error! No text of specified style in document.**-1. A) Total Fraser sockeye annual returns (dark blue vertical bars for the 2017 cycle and light blue vertical bars for the three other cycles). Recent returns from 2012 to 2016 are preliminary, and 2016 is an in-season estimate only. Total Fraser sockeye productivity (log_e (returns/total spawner)) is presented up to the 2016 return year. The grey dots and lines represent annual productivity estimates and the black line represents the smoothed four year running average. For both figures, the dashed line is the time series average. The first red vertical bar in A (or first red dot in B) represents the 2009 returns (low productivity across the majority of the stocks), and the following three red vertical bars in A (or red dots in B) represents the 2012, 2015 and 2016 returns (low productivity for the Fraser sockeye aggregate).

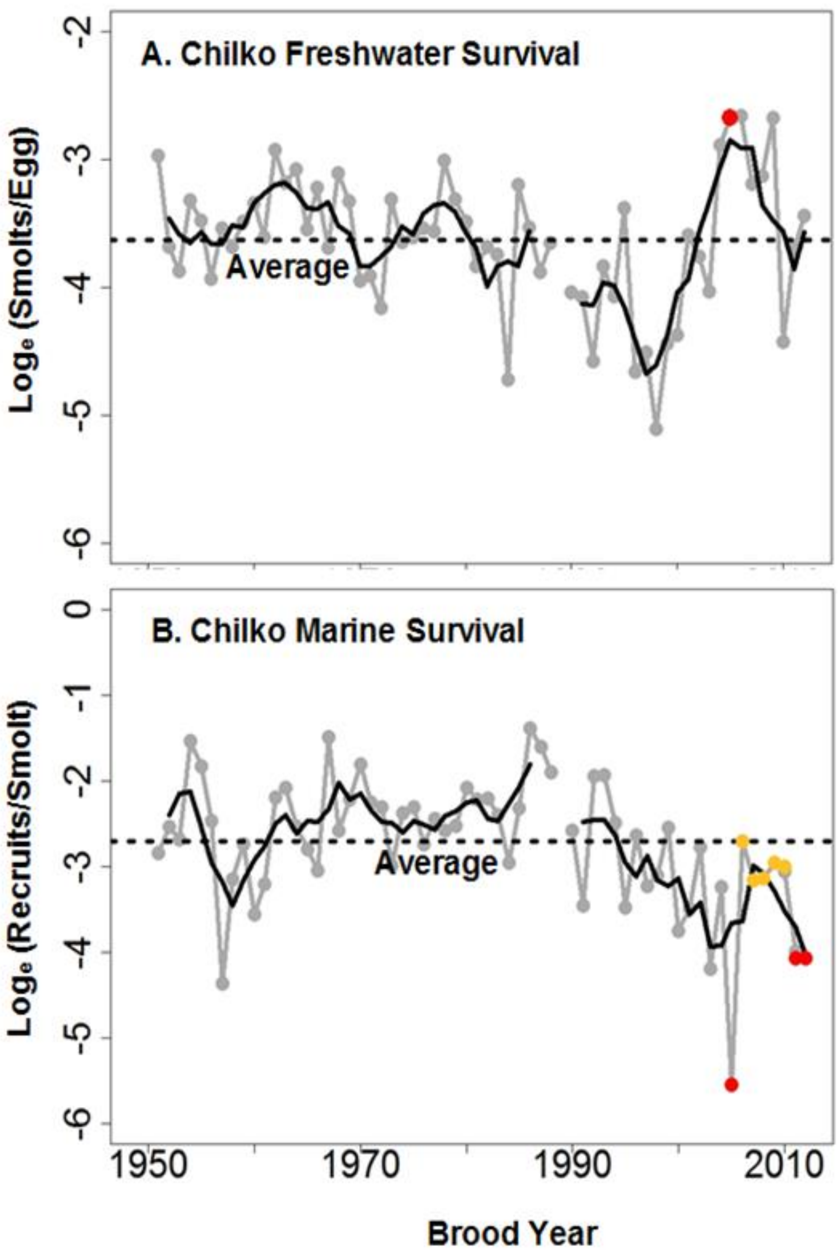

Figure **Error! No text of specified style in document.**-2. A) Chilko River sockeye freshwater survival ($\log_e$ smolts-per-egg) and B) 'marine' ($\log_e$ recruits-per-smolt) annual survival. The filled grey circles and grey lines are annual values and the black line is the smoothed four-year running average survival. Freshwater survival has generally increased in the past decade, with the notable exception of 2010 (red filled circle in A), when poor survival was associated with density-dependent factors caused by the large escapements in this brood year. Marine survival has generally been below average for the past decade, and particularly low in the 2005 and last two brood years: 2011 and 2012 (two red filled circles in B). Note: Chilko 'marine' survival includes a freshwater period during their downstream migration as smolts from the outlet of Chilko Lake to the Strait of Georgia, and their entire marine residence period. The horizontal dashed line indicates average survival.

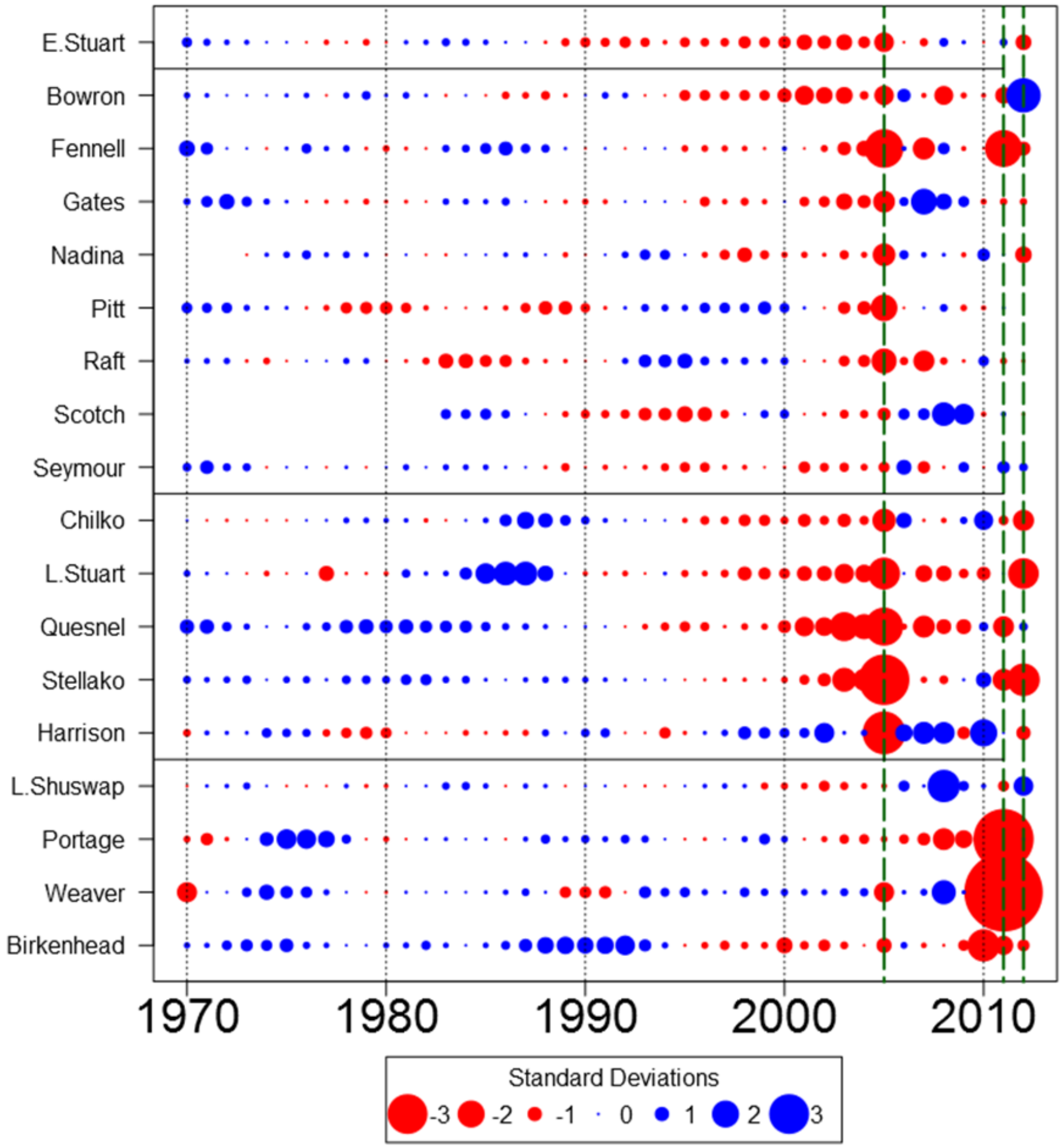

Figure **Error! No text of specified style in document.**-3. Fraser sockeye productivity (standardized z-scores of Ricker model residuals for all stocks except Scotch, Seymour and Late Shuswap, which are Larkin residuals) up to the 2012 brood year (2016 return year). For the 2012 brood year (2016 return year), preliminary in-season estimates of returning four year old were used as post-season estimates were not yet available and five year old returns will not be available until after the 2017 season. Both freshwater and marine factors contribute to the observed productivities. Red dots indicate below average productivity and blue dots indicate above average productivity. The smallest dots represent average annual productivity and the larger the diameter, the greater the deviation from average. The 2005, 2011 and 2012 brood years (2009, 2015 and 2016 return years) have been highlighted using a broken vertical green line.

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