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# An Introduction to Canada's New State of the Salmon Program

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Fisheries and Oceans Canada (DFO) has recently initiated a State of the Salmon (SOS) Program within its Pacific Region. The goal of this new program is to improve our shared understanding of the state of Pacific salmon populations, and the factors that contribute to their state, both within and outside of DFO. Fostering collaboration among scientific experts on salmon and their ecosystems is a key feature of this emerging program, and is necessary to accomplish its goals. Trends in abundance, productivity, and other biological characteristics of Pacific Salmon, such as fecundity, size-at-age, and run timing, will be tracked and compared across populations. Information on salmon will be linked to more detailed stock assessment monitoring, trends in the freshwater and marine ecosystems they occupy, and broader scientific research conducted on these populations and their ecosystems.

Fraser Sockeye have been used as a case study to build an initial framework for the SOS Program. Since this group of salmon is data rich, they have been monitored and studied extensively. Fraser Sockeye was the first group of Pacific salmon to undergo status assessments under Canada's Wild Salmon Policy (WSP) (Grant et al. 2011; Grant and Pestal 2012). Populations are tracked annually through the preparation of pre-season return forecasts (Grant et al. 2010; MacDonald and Grant 2012; Fisheries and Oceans Canada (DFO) 2017, 2018). Additionally, considerable research has been conducted on Fraser Sockeye populations in their marine and freshwater ecosystems (Tucker et al. 2009; Beamish et al. 2012; Peterman and Dorner 2012; Preikshot et al. 2012; Irvine and Akenhead 2013; Ruggerone and Connors 2015; Freshwater et al. 2017a; Freshwater et al. 2017b).

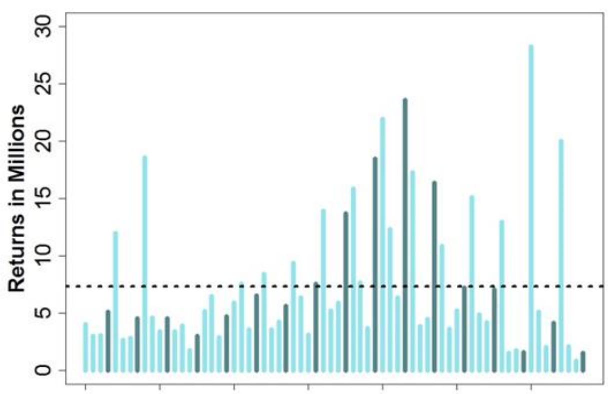


**Fig. 1a.** Total Fraser Sockeye annual returns (dark blue vertical bars for the 2017 cycle and light blue vertical bars for the three other cycles). Recent returns from 2012 to 2017 are preliminary, and 2017 (the last data point) is an in-season estimate only.

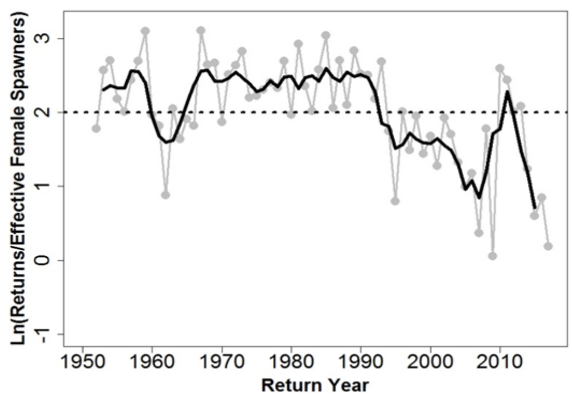


**Fig. 1b.** Total Fraser Sockeye productivity ($\log_e$ (returns/total spawner)) is presented up to the 2017 return year. The grey dots and lines represent annual productivity estimates and the black line represents the smoothed four year running average. For both figures, the dashed line is the time series average.

There are currently 24 Fraser Sockeye conservations units (CUs) (Grant et al. 2011). Biological statuses for each of these CUs have been assessed using methods developed for the WSP. Under the WSP, a conservation unit (CU) has been identified as the fundamental unit of Canadian Pacific salmon biodiversity, based on salmon life-history, genetics, and ecological traits (Holtby and Ciruna 2007). Approaches used to identify WSP status for CUs provide not only an assessment of biological status but also a systematic method for tracking and communicating trends in salmon abundance and productivity (recruits-per-spawner). Overall, the Fraser Sockeye aggregate has exhibited declines in total returns and productivity throughout the last decade (Fig. 1). However, underlying the Fraser Sockeye aggregate is considerable biodiversity, and variation in abundance and productivity trends and biological status. WSP statuses vary across Fraser Sockeye CUs from Red (poor status), to Amber (moderate status), to Green (good status). Nine of these CUs have been recently assessed as Red or Red/Amber status zones (DFO 2018; Fig. 2).

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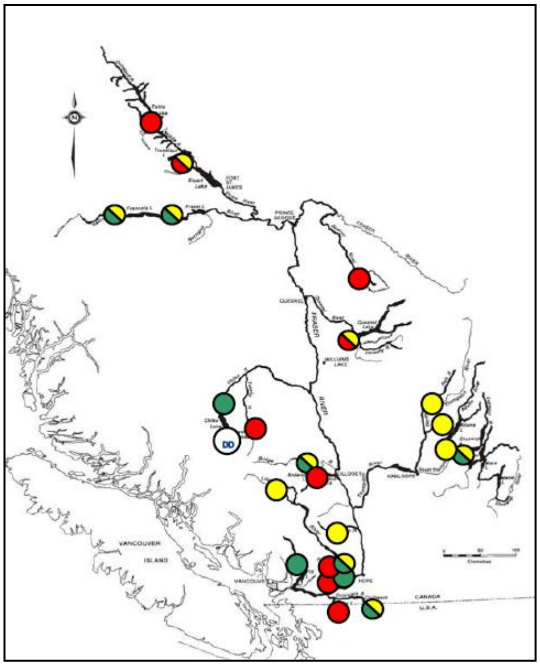

**Fig. 2.** Map of the spawning distribution (darkened black lines) of Fraser River Sockeye Salmon CUs in south-western British Columbia with the 2017 integrated statuses indicated for each CU (DFO 2018). There is one data deficient CU (DD) (Chilko-ES), indicated on the map. Red colours are poor status CUs, Amber are intermediate status, and Green are good status CUs. Assessments are based on the CU's trends in abundance and, where available, productivity.

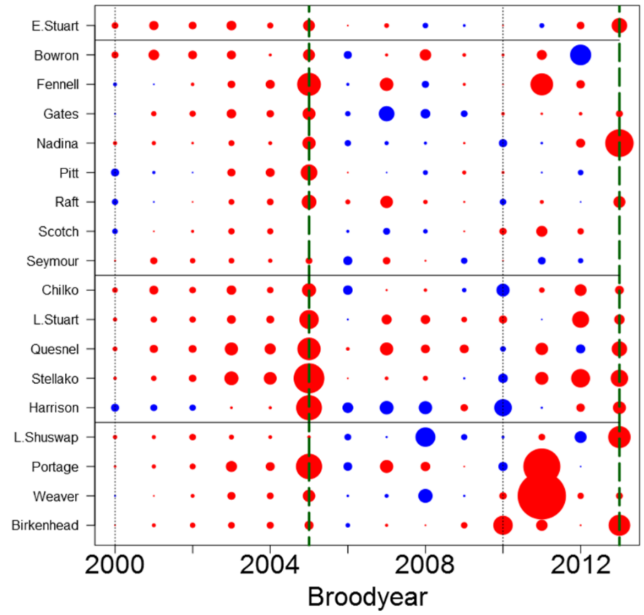


**Fig. 3.** Fraser Sockeye productivity (z-scores of Ricker model residuals for all populations except Scotch, Seymour and Late Shuswap, which are Larkin residuals) from the 2000 to 2013 brood year, respectively the 2005 and 2017 return years. Prior to the 2005 brood year, four year moving averages are plotted, while annual estimates are provided for the more recent years. For the 2013 brood year (2017 return year), preliminary in-season estimates of returning four-year-old fish were not yet available and five-year-old returns will not be available until after the 2018 season. Both freshwater and marine factors contribute to the observed productivities. Red filled circles indicate below average productivity and blue filled circles indicate above average productivity. The smallest filled circles represent average annual productivity and the larger the diameter, the greater the deviation from average. The 2005, 2010 and 2013 brood years (2009, 2014 and 2017 return years) have been highlighted using a broken vertical line.

There are 19 Fraser Sockeye CUs that are relatively data rich, with stock-recruitment data extending back to the 1950's, depending on the CU (Grant et al. 2010, 2011). Comparisons of Fraser Sockeye CU productivity (recruits-per-spawner) have been conducted to identify periods of common and divergent patterns across CUs and time (Grant et al. 2010; Peterman and Dorner 2012). These comparisons can be used to identify drivers of these patterns at, respectively, broad regional or local scales. Specifically, differences in productivity trends between CUs can uncover unique aspects of their adult upstream migration, spawning and egg incubation, juvenile lake rearing, juvenile downstream migration, and/or ocean distribution that contribute to this variation.

Productivity for Fraser Sockeye CUs has been generally poor over the last decade, spanning the 2000 to 2013 brood years, corresponding to the 2003 to 2017 return years (Fig. 3). In particular, the 2005 and 2013 brood years (2009 and 2017 returns) of Fraser Sockeye exhibited extremely poor productivity across almost all CUs, producing two of the lowest returns on record for the Fraser Sockeye aggregate (Fig. 1). Declining productivity and returns leading up to the 2005 brood year (2009 return year), precipitated a legal inquiry into the cause of the declines, which was referred to as the Cohen Inquiry. There is some evidence that marine conditions in the Strait of Georgia, where all Fraser Sockeye CUs rear for a small portion of their life-history, contributed to synchronously poor productivity across most CUs specifically in the 2005 brood year (2009 return year) (Beamish et al. 2012). However, the Cohen Inquiry concluded that no single ecosystem or factor was responsible for the declining trend

(Cohen 2012). Instead, available evidence indicated that both freshwater stressors and region-wide influences contributed to the long-term decline.

Poor productivity in the 2013 brood year (2017 return year), occurred during a period of notably warm conditions in both freshwater and marine ecosystems (D. Patterson, DFO, David.Patterson@dfo-mpo.gc.ca, personal communication; I. Perry, DFO, Ian.Perry@dfo-mpo.gc.ca, personal communication; Chandler et al. 2016). DFO Science annually integrates research and monitoring across life-history stages and ecosystems to inform survival conditions for the upcoming Fraser Sockeye return year. For the 2017 returns, this integrative process noted warmer conditions throughout the life-history of Fraser Sockeye. This was particularly notable during the summer months of their adult upstream migration and also during their marine rearing stage. As these warm conditions were developing, Fraser Sockeye CUs increasingly converged towards poor productivity, affecting the 2011 and 2012 brood years. Most recently, the 2013 brood year exhibited particularly poor productivity across all stocks, the synchrony and magnitude of which looked very similar to the 2005 brood year. However, the poor productivity of the 2013 brood year was likely linked to warm conditions throughout their life-history, as opposed to being isolated in the marine rearing stage, as in the 2005 brood year.

Although most CUs exhibited declining productivity trends from the 2000 to 2005 brood years, there are a few key exceptions. The Harrison river-type CU improved in productivity during this period (Grant et al. 2011). This CU has a unique life-history, ecology, and age composition compared to other Fraser Sockeye CUs (Grant et al. 2011). Harrison river-type salmon do not rear in freshwater lakes as juveniles prior to their migration to the ocean. Instead, these sockeye migrate to the ocean shortly after they emerge from their spawning gravel, and have a unique ocean distribution, spending more time in the Strait of Georgia than other Fraser Sockeye CUs (Beamish et al. 2016). Harrison river-type sockeye also return as three- and four-year old fish, in roughly equal proportions (Grant et al. 2011), whereas most other CUs largely return predominantly as four-year old fish. Though the exact factors contributing to the divergent patterns exhibited by Harrison Sockeye during 2000–2005 are unknown, their unique ecology and life-history likely contribute.

Another key exception to the declining productivity trend includes the populations that spawn and rear in the Shuswap Lake complex. These CUs have exhibited variable productivity that has oscillated around their long-term average in the past decade. Although their life-history is very similar to other Fraser Sockeye CUs, there is evidence that the density of juveniles in the Shuswap Lake complex in any year influences the productivity of subsequent cohorts (D. Selbie, DFO, Daniel.Selbie@dfo-mpo.gc.ca, personal communication; Levy and Wood 1992; Grant et al. 2011). Productivity for most fish populations is influenced by the density of adult spawners, or their cohorts, only in a single year (Ricker 1954). Therefore, although these CUs largely exhibit a similar life-history, age-at-return, and ocean distribution to other CUs, delayed-density dependent factors may contribute to the unique productivity patterns experienced by Shuswap Lake CUs.

From the 2006 to 2012 brood years, productivity patterns were mixed across CUs. This again suggests that there are localized factors influencing individual CU survival. Two CUs exhibited uniquely poor productivity in 2010 and 2011, and monitoring suggests that this can be attributed to factors occurring in their shared lake ecosystem (DFO 2014). Juvenile data for the Weaver CU (formally named Harrison (U/S)-L) shows average egg-to-fry survival in the 2011 brood year; however, juveniles from this CU were not detected in a smolt sampling program, located downstream of Harrison Lake, where these juveniles rear (DFO 2015). Therefore, a lake factor likely contributed to their observed poor survival. Birkenhead Sockeye (Lillooet-Harrison CU) also exhibited extremely poor productivity during this period, and coincidentally rears in Lillooet Lake, located a short distance upstream of Harrison Lake. Concurrently, a major landslide at the top end of this connected lake system dumped a large amount of sediments into the Lillooet River and subsequently Lillooet, and Harrison Lakes in August 2010. This increased turbidity in the Lillooet-Harrison lake system for a number of years. Empirical linkages between increased turbidity and poor productivity of these Sockeye CUs cannot be confirmed, however, since limnological and fry monitoring did not directly occur in these lakes.

Work on status evaluation, and tracking and comparing trends, such as that performed for Fraser Sockeye, has started to expand to other populations and species. Canadian WSP statuses have been assessed for Fraser River Coho (DFO 2015) and Southern B.C. Chinook (DFO 2016) salmon. Methods developed for Fraser Sockeye to compare and understand productivity trends (Peterman and Dorner 2012) have been extended to pink, Chinook, and chum salmon (Malick and Cox 2016; Malick et al. 2017; Dorner et al. 2018). The State of the Salmon Program will further consolidate and integrate this type of work across salmon populations in the Pacific Region through collaborative effort. This program recently hosted a Pacific Region State of the Salmon meeting to initiate integration and collaboration among scientists in the Pacific Region. It is also developing analytical approaches to improve our ability to explore trends. As this program evolves, these comparisons can be used in dialogue with local and regional experts on salmon and their ecosystems. Through initiatives like the International Year of the Salmon (IYS), this program will connect with salmon and ecosystem experts working globally on salmonid populations to better understand the global state of salmon and factors that influence them. The key to this program will be to develop integrative processes to synergize our collective knowledge.

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