State of the Salmon: Informing the survival of Fraser Sockeye returning in 2018 through life cycle observations

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2018

STATE OF THE SALMON:

INFORMING THE SURVIVAL OF FRASER SOCKEYE RETURNING IN 2018 THROUGH LIFE CYCLE OBSERVATIONS

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ABSTRACT

We compiled and integrated environmental and biological observations spanning the life cycle of Fraser Sockeye returning in 2018 through a two-day workshop. The most striking observations in recent years have been the extremely warm conditions Fraser Sockeye salmon have been exposed to in both freshwater and marine ecosystems. Such warm temperatures can affect salmon survival directly, given that they are adapted to cooler temperatures, or indirectly, through their effects on the ecosystems Fraser sockeye inhabit.

Fraser Sockeye returning in 2018 experienced notably warm conditions through most of their life cycle. Conditions in many of the environments they occupied were very similar to those experienced by the Fraser Sockeye cohort that returned in 2017. This includes above average Fraser River temperatures during their parental upstream migration, warm air temperatures in British Columbia during egg and juvenile freshwater rearing stages, a very early spring freshet during the downstream migration period of smolts, and notably warm sea surface temperatures upon reaching the ocean. Some physical and biological processes in the Northeast Pacific Ocean began to transition to more favourable conditions for fish growth in 2016, as the 2018 Fraser Sockeye cohort entered marine waters. However, similar to the previous few years, warm water southern copepod species continued to dominate the zooplankton composition of the Northeast Pacific, providing a sub-optimal food source for salmon, compared to cold water northern zooplankton species.

Since most observations throughout the life cycle of the 2018 Fraser Sockeye returns align closely with conditions experienced by the 2017 returns, which exhibited very poor survival, we predict that returning 2018 Fraser Sockeye will also exhibit poor survival. Thus, we expect returns to fall towards the lower end of the 2018 Fraser Sockeye forecast distributions, particularly where temperature covariates were not included or did not have a significant effect on a stock’s forecast. This applies to 88% of the total Fraser Sockeye forecast at the median probability level. Exceptions include forecasts for Early Stuart, Bowron, Quesnel, Raft, Cultus, Weaver and Birkenhead, where temperature covariates were incorporated and reduced expected survival.

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RÉSUMÉ

Dans le cadre d’un atelier de deux jours, nous avons compilé et intégré des observations environnementales et biologiques tout au long du cycle vital des saumons rouges du fleuve Fraser effectuant la montaison en 2018. Les observations les plus saisissantes effectuées dans les dernières années ont été les conditions extrêmement chaudes auxquelles le saumon rouge du fleuve Fraser a été exposé tant en eau douce que dans les écosystèmes marins. La survie du saumon peut être affectée par des températures aussi chaudes, soit directement, du fait qu’il est adapté à des températures plus froides, soit indirectement, en raison des effets sur les écosystèmes où vit le saumon rouge du fleuve Fraser.

Les saumons rouges du fleuve Fraser effectuant la montaison en 2018 ont connu des conditions particulièrement chaudes pendant la majeure partie de leur cycle vital. Dans bon nombre des environnements qu’ils ont occupés, les conditions étaient très semblables à celles vécues par la cohorte de saumons rouges du fleuve Fraser ayant effectué la montaison en 2017. Notons, par exemple, des températures supérieures à la moyenne dans le fleuve Fraser au cours de la montaison des saumons adultes, des températures de l’air chaudes en Colombie-Britannique au cours des stades d’incubation des œufs et d’élevage des juvéniles en eau douce, une crue printanière très précoce au cours de la période d’avalaison des saumoneaux, et des températures de la surface de la mer particulièrement chaudes à l’arrivée à l’océan. Dans le nord-est de l’océan Pacifique, certains processus physiques et biologiques ont commencé une transition vers des conditions plus favorables à la croissance du poisson en 2016, tandis que la cohorte du saumon rouge du fleuve Fraser de 2018 accédait aux eaux marines. Cependant, de façon semblable aux quelques années antérieures, les espèces de copépodes propres aux eaux chaudes continuent de dominer la composition du zooplancton dans la région du nord-est du Pacifique, offrant une source d’alimentation sous-optimale pour le saumon, comparativement aux espèces de zooplancton observées dans les eaux froides nordiques.

La plupart des observations effectuées au cours du cycle vital du saumon rouge du fleuve Fraser effectuant la montaison en 2018 correspondent aux conditions vécues par le saumon effectuant la montaison en 2017. C’est pourquoi, à la lumière du faible taux de survie de la cohorte de 2017, nous prédisons que le saumon du fleuve Fraser effectuant la montaison en 2018 affichera également un bas taux de survie. Ainsi, nous prévoyons que les montaisons se situeront dans les distributions de prévisions inférieures pour le saumon rouge du fleuve Fraser effectuant la montaison en 2018, particulièrement si aucune covariable de température n’a été incluse ou si ces covariables n’ont eu aucune incidence considérable sur la prévision d’un stock. Cette notion s’applique à 88 % des prévisions totales concernant le saumon rouge du fleuve Fraser au niveau de probabilité médian. Cela exclut les prévisions pour Early Stuart, Bowron, Quesnel, Raft, Cultus, Weaver et Birkenhead, où les covariables de température ont été intégrées et ont réduit le taux de survie attendu.

1 INTRODUCTION

Fraser River Sockeye salmon migrate through diverse river, lake, and ocean habitats. These fish typically spend their first two years of life in freshwater and their last two years of life in the ocean. They begin life as eggs in river or lake gravel, and most, respectively, move into, or remain in, lakes as fry. In the ocean, they migrate through the Strait of Georgia (SOG) to reach the Northeast (NE) Pacific before returning to their natal spawning grounds to reproduce and die. This return trip covers roughly 10,000 km.

Their complex life-history makes it challenging to accurately predict the number of Fraser Sockeye that will return in a given year, especially given the dramatic variability in their annual returns, ranging from as low as 1.5 million (2009) to 30 million (2010). As a result, quantitative return forecasts are highly uncertain, characterized by wide probability distributions (DFO 2017, 2018).

Fisheries and Oceans Canada monitors and investigates salmon and their ecosystems with the objective of improving our understanding of factors governing variation in salmon survival and abundance. Biological and ecosystem observations spanning the life cycle of Fraser Sockeye have the potential to improve the precision of return forecasts for a given year. Further understanding of factors that influence salmon population dynamics will also support fisheries management, and habitat and hatchery enhancement activities. However, apart from limited smolt and fry data, life cycle observations are not currently incorporated quantitatively into Fraser Sockeye population dynamic models. This is attributed to the number and complexity of factors that likely contribute to salmon survival, the inter-annual variation in their relative contributions, and the limited understanding of how these factors cumulatively interact.

As an interim step, an annual workshop, held since 2014, brings together Fraser Sockeye experts within DFO Science and Fisheries Management to present and discuss observations from the various ecosystems Fraser Sockeye pass through during their life cycle. Information presented by DFO scientists in this forum includes results from formal analyses, as well as raw data, preliminary results, opportunistic observations, and expert opinion. The purpose of this workshop is to integrate and evaluate these observations in order to provide advice on the potential survival of the upcoming Fraser Sockeye returns. Results from this science integration process can help narrow the range of possible return abundances within the wide forecast distributions presented for Fraser Sockeye (DFO 2018), by providing qualitative assessments of potential survival, ranging from poor to good. Consequently, as we continue to bring these observations together and learn from previous processes, we can begin to more formally assess the utility of this information for informing Fraser Sockeye population dynamics and future returns.

Factors considered as potentially influencing the 2018 returns include:

1. Water temperatures and other environmental conditions at key points throughout salmon life-history that can provide an indication of factors that affect Fraser Sockeye survival directly, or indirectly through shifts in their predator-prey communities;
2. The number of females that successfully laid eggs, an indicator of Sockeye egg numbers in the Fraser watershed; this is the first observation of a cohort;
3. The number, size, and condition of juvenile fry in select lakes, indicating survival and condition of Sockeye in the freshwater ecosystem;

4. Stock and size of juvenile Sockeye monitored downstream of their rearing lakes in the lower Fraser River at Mission, BC, providing an indication of relative abundance and condition immediately prior to ocean entry;
5. Zooplankton species composition in marine waters; used as an indicator of Sockeye prey quality;
6. Juvenile salmon catch indices and fish condition in the SOG and Discovery Islands; used as an indicator of salmon growing conditions;
7. The number of Sockeye salmon returning a year before (2017) the dominant age-class (four-years-old); indicates survival up to their last year at sea;

This report compiles the results of the 2018 workshop integrating life cycle observations for the 2014 brood year of Fraser Sockeye (2018 returns). The workshop, held in Delta, B.C., February 5-6, 2018, was broken up into four sessions that represent four key stages of the 2018 Fraser Sockeye life cycle:

- Brood year spawners and egg stage (2014-2015)
- Juvenile freshwater rearing (2015-2016)
- Smolt downstream migration (2016)
- Juvenile marine rearing and early indicators of survival (2016-early 2018)

During each session, DFO scientists presented their observations pertaining to that stage of the salmon life cycle, and participants discussed and integrated these observations in the context of Fraser Sockeye survival at the corresponding life stage.

This report presents both the contributed observations and points of discussion resulting from the 2018 workshop, organized into life cycle segments, similar to the workshop.

This paper is divided into three tiers, each presenting a different level of detail to communicate to broad range of audiences. The intent is that readers will choose to read the tier that presents the level of detail of interest to them.

Tier 1: Presents a list of highlights identified by meeting participants, along with expert opinion on the potential effects of these observations on Fraser Sockeye survival for the corresponding life stage, and their confidence in those effects. This section is tailored to those looking for a quick list of the key observations and their presumed effects on survival.

Tier 2: Provides an overview that synthesizes the observations and discussions that occurred during the workshop, in the context of the Fraser Sockeye life cycle. This section is appropriate for those looking for a chronological summary of the main observations discussed, with high level background on some of the survival mechanisms and their potential effects by life stage.

Tier 3: Catalogues the detailed contributions from individual scientists and/or work teams according to the salmon life-stage, and program where appropriate. This section presents the greatest depth of information, and associated figures.

2 HIGHLIGHTS (TIER 1)

We predict that Fraser Sockeye salmon density-independent survival (four-year-old returns-per-effective female spawner) in 2018 will be below average. Forecast models typically take into account density-dependent survival mechanisms that include, for example, competition for spawning habitat among adults, or food resources among juveniles. Density-independent factors affecting survival are not incorporated into most forecast models for Fraser Sockeye, except in the few cases where temperature co-variates have been used. Thus, we predict that Fraser Sockeye returns will fall towards the lower end of the 2018 Fraser Sockeye forecast distribution in cases where temperature covariates were not included, or did not have a significant effect on reducing a stock's forecast (DFO 2018). Forecasts that did not quantitatively incorporate environmental covariates make up 88% of the total Fraser Sockeye forecast at the median probability level. These include, by run-timing group:

- **Early Summer:** this applies to 99% of the median forecast for this run-timing group, since environmental covariates were only included for Bowron;
- **Summer Run:** this applies to 72% of the median forecast for the Summer Run since environmental covariates were included for Quesnel and Raft; the Chilko forecast also includes a temperature covariate, but in this case the addition of the covariate increased the forecast, contrary to all other stocks;
- **Late Run:** this applies to 95% of the median forecast for this group, since environmental covariates were included for Cultus, Weaver, and Birkenhead;

The meeting participant's rationale for the qualitative prediction that density-independent Fraser Sockeye survival will be below average in 2018 is as follows:

Warm conditions prevailed in ecosystems used by the 2018 Fraser Sockeye returns during their freshwater and early marine life stages. In the second half of 2016, the marine heatwave dissipated from surface waters, remaining at depth, while a La Niña event brought cooler to average sea surface temperatures to the NE Pacific (Ross 2017, Ross and Robert 2018). In early 2016 some physical and biological processes in the marine environment transitioned to more favourable conditions for fish growth (Chandler et al. 2017). However, workshop participants noted that many environmental and biological observations for the 2018 returns aligned closely with those observed for the 2017 returns, which experienced very poor survival (four-year-old returns-per-effective female spawner). Therefore, though there is large uncertainty surrounding the specific factors that drive Fraser Sockeye survival, workshop participants concluded that survival in 2018 would likely also fall below average, given the similarities in key ecosystem observations between the 2017 and 2018 return years.

Participants further concluded that ecosystems are changing rapidly as the global climate warms, and unusual events are becoming more frequent. In recent years, all programs have observed changes in local ecosystems and salmon populations that are outside the range of historical observations.

These changes emphasize the value of long-term monitoring of salmon and their ecosystems. Without this information, we are limited in our ability to predict salmon responses, and support activities that may ensure the conservation of salmon biodiversity in a changing climate. We continue to have major gaps in many of our programs, such as freshwater lake and stream monitoring programs, monitoring of non-Sockeye salmon species, and marine ecosystem monitoring. Research efforts must increase in these areas if we hope to maintain BC/Yukon salmon populations into the future.

Highlights below are organized into the following effects and confidence levels based on expert opinion:

Effect: Negative, Neutral, Positive, Variable

Confidence: Possible, Likely, Very Likely

Only observations that were considered key to salmon survival for the 2018 return were included. Details that correspond with the highlights below are in subsequent sections.

Overall	**Effect**	**Confidence**
Fraser Sockeye Survival	**Negative**	**Likely**

Brood Year Spawners and Egg Stage (Summer/Fall 2014-Spring 2015)	**Effect**	**Confidence**
▪ Fraser River discharge was average during adult migration	Neutral	Very Likely
▪ Fraser River temperatures were above average during adult migration for most populations; most Early Summer and Summer Run migrants experienced particularly warm conditions, above 19°C	Negative	Very Likely
▪ Spawning ground water temperatures for most populations were favourable during spawning and early incubation period	Positive	Likely
▪ Sockeye reported to be in good condition on spawning grounds; no visible evidence of migration difficulties or issues with spawner success	Positive	Likely
▪ Gamete viability of Adams River (Late Shuswap) Sockeye was average	Neutral	Possible
▪ Gamete viability of Harrison River Sockeye was lower than expected	Negative	Likely

Juvenile Freshwater Rearing (Spring 2015-Spring 2016)	**Effect**	**Confidence**
▪ High river discharge in the spring; likely creates an advantage for most populations where fry migrate downstream to their lakes	Positive	Possible
▪ High river discharge in the spring; likely poses migration challenges for populations where fry migrate upstream to their lakes, such as Chilko and Weaver	Negative	Possible

▪ High lake water levels during fry migration potentially increased habitat availability along the lake shore	Positive	Possible
▪ Warm spring temperatures lengthened the growing season	Positive	Likely
▪ Below average egg-to-fry survival in Nadina spawning channel (incorporated into Nadina forecast through the use of a juvenile model)	Negative	Likely
▪ Below average egg-to-fry survival in Weaver spawning channel (not incorporated into Weaver forecast, spawner-based model used)	Negative	Likely
▪ Average egg-to-fry survival in Gates spawning channel	Neutral	Likely
▪ Average egg-to-fall fry survival for Quesnel.	Neutral	Likely
▪ Shuswap egg -to-fall fry survival for was twice that observed in the previous dominant brood year (2010), and above the 1974-2014 dominant cycle average	Positive	Likely
▪ Chilko Lake freshwater survival was below average, but higher than expected given the large 2014 brood year escapement (incorporated into Chilko forecast through the use of a juvenile model)	Negative	Likely
▪ Low fall fry-to-smolt overwinter in-lake survival for Cultus, similar to recent years	Negative	Likely

Smolt Downstream Migration (2016)	**Effect**	**Confidence**
▪ Early onset of Fraser River spring freshet, producing record discharge levels in April, and average to below average discharge in May and June	Variable	Possible
▪ Early growing season in spring 2016 for Shuswap and Cultus prior to smolt outmigration	Positive	Possible
▪ Chilko and Cultus smolts migrated out of their rearing lakes one and two weeks earlier than average, respectively	Negative	Possible
▪ Aggregated Sockeye smolt migration past Mission, B.C. was 14 days earlier than in 2012, and very similar to 2015 (2017 return)	Negative	Possible
▪ Mean fork length of all Sockeye salmon smolts caught at Mission was the lowest recorded since 2012	Negative	Possible
▪ Chilko smolts had low lipid levels	Negative	Possible

▪ Shuswap smolts had higher lipid levels than the 2010 brood year (previous cycle)	Positive	Possible

Juvenile Marine Rearing (Spring 2016-Summer/Fall 2018)	Effect	Confidence
▪ Ocean temperatures were above average in 2016 but returned to near average in 2017 in the Northeast Pacific Ocean, except deeper waters (below 100 m) which remained warmer than average. Warm sea surface temperatures occurred during August to October, 2017.	Negative	Possible
▪ The timing and magnitude of upwelling of cool nutrient rich waters along the west coast of Vancouver Island were considered favourable for productivity and fish growth in 2016 and average to below average in 2017	Positive	Likely
▪ Timing of the spring phytoplankton bloom in the SOG was typical in 2016 and 2017. This is linked to the survival of sub-yearling Pacific herring and may be linked to juvenile salmon survival	Positive	Likely
▪ The phytoplankton community composition off the West coast of Vancouver Island returned to a more normal distribution in 2016 and 2017, with the exception of the most offshore stations	Positive	Likely
▪ The WCVI zooplankton community was dominated by warm water species that have lower lipid content in 2016. In 2017, more lipid-rich boreal and subarctic species were observed, however, the abundance of warm water species also increased slightly in 2017	Negative	Likely
▪ Trawl survey catches of juvenile coho, Chinook, Chum, and Pinks in the SOG in 2016 suggest that conditions were good during the period when juvenile Sockeye were rearing in this area	Positive	Likely
▪ The average length of juvenile Sockeye captured in the Discovery Islands was similar to those observed previously on this cycle line, in 2012 and 2008	Neutral	Possible
▪ The condition of juvenile Sockeye collected during the 2016 trawl survey was average	Neutral	Possible

Early Indicators of Sockeye Survival (2017 Returns)	Effect	Confidence
▪ The jack return rate was below the cycle average for all stocks except Quesnel, for which it was similar to the cycle average; three-to-four year old sibling	Negative	Likely

forecasts matched lower forecast probability levels for Chilko, Quesnel, and Late Shuswap		
▪ Although the number and condition of juvenile Pink salmon in the SOG in 2016 were both above average, returns to the Fraser River in 2017 were poor, suggesting poor conditions once the fish left the nearshore environment	Negative	Likely

3 OVERVIEW (TIER 2)

3.1 BACKGROUND

Fraser Sockeye Life History

Fraser Sockeye Salmon spawn in rivers, streams, and along lake foreshores throughout the expansive Fraser River watershed. Most Fraser Sockeye return to spawn as four-year-olds, and exhibit a lake-type life history, spending their first two winters in freshwater, followed by two winters in the marine environment. Approximately 20% of Sockeye from each brood year spend an additional winter in the ocean and return to spawn as five-year olds.

Female Sockeye dig nests in the spawning ground gravel to deposit their eggs. Spawning sites vary in terms of gravel size, ranging from coarse sand to large rubble and boulders; at depths from 0.1 meters to 30 meters of water (Burgner 1991); and temperatures ranging from 7 to 14 degrees Celsius, based on data for nine Fraser Sockeye populations (Whitney et al. 2013).

Eggs are then fertilized by males and incubate in the gravel through the winter. The duration of the incubation period, and timing of emergence as fry - generally mid-April to mid-May - are determined by incubation temperatures and discharge (Burgner, 1991; Macdonald et al., 1998). Following emergence, fry migrate to their rearing lakes, feeding and growing in the littoral zone then moving offshore (Morton and Williams 1990), where they rear for an additional winter.

After their second winter in freshwater, lake-type Fraser Sockeye leave their rearing lakes between April and June, and quickly migrate downstream via the Fraser River (Clark et al. 2016). They enter the Fraser River estuary and migrate north through the SOG, Johnstone Strait, and along the continental shelf, moving offshore in the fall or winter into the GOA (GOA) (Welch et al. 2009, Tucker et al. 2009). The majority of Fraser Sockeye spend an additional winter distributed widely in the NE Pacific before returning to their spawning grounds as four-year-olds.

A small proportion of Fraser Sockeye are river-type fish. The largest river-type population occurs in the Harrison River. These Sockeye do not rear in lakes, but instead migrate downstream in the Fraser River shortly after they emerge from their spawning gravel. They rear in the lower Fraser for 1-5 months (Birtwell et al. 1987), before spending up to six months rearing in the SOG. These salmon migrate out of the SOG through either the southern Juan de Fuca or northern Johnstone Strait route after lake-type stocks have left this area, heading to the GOA (Tucker et al. 2009, Beamish et al. 2016). This life-history type will not be covered in this document, due to the small contribution of these fish to the predicted returns of Fraser Sockeye in 2018, at less than 1%.

Fraser Sockeye Pre-season Return Forecasts

The 2018 forecast for total Fraser Sockeye returns ranges from 8.4 million to 22.9 million at the 25% to 75% probability levels (DFO 2017). The 50%, median, forecast is 14 million. This median forecast across stocks is close to the cycle average of 13.1 million. Most models used to generate these forecasts are biological, and incorporate the effects of density on the productivity of a cohort. These models rely on the historical relationship between spawners and returns of a cohort to predict future returns, therefore assuming that the past conditions reflect the future. Given the anomalously warm regional conditions observed in recent years, this assumption may not be entirely valid for the 2018 forecast. However, the addition of sea-surface temperatures as a covariate improved the historical performance of forecasts for only eight stocks, and only decreased the total forecast by 17% at the median probability level (DFO 2018).

The 2018 cycle-line is dominated by the Late Run Late Shuswap stocks, which make up about 50% of the total forecast at the median probability level. Chilko and Quesnel, both Summer Run stocks, are the next largest contributors to the 2018 forecast, at 16% and 8%, respectively. The remaining stocks are expected to contribute a total of 26% of the forecast, dominated by Stellako (4%), Seymour (4%), and Scotch (2%).

Four-year-olds comprise 95% of the total 2018 return forecast at the median probability level, which is higher than the historic average, 87%, largely due to the high proportion of expected four-year-old Late Shuswap (100%) and Chilko (99%) returns, which dominate the forecasted 2018 return.

3.2 BROOD YEAR SPAWNERS AND EGG STAGE: SUMMER/FALL 2014 - SPRING 2015

The 2014 Fraser Sockeye spawners encountered high in-river water temperatures during their upstream migration period, associated with above-average air temperatures and below average precipitation throughout B.C. in the summer of 2014. Components of all run timing groups, particularly the Early Summer and Summer Runs, experienced water temperatures above 19°C in the Fraser River (Figure 2). River discharge was average during adult upstream migration.

At this time, quantifying the effects of parental stress on future year class strength is a challenge. However, adult salmon exposure to temperatures above 19°C has been linked to impaired reproductive development and gamete viability (Macdonald et al. 2000). In addition, high levels of stress experienced by female salmon decrease the swim performance and predator avoidance abilities of their juvenile offspring (Tierney et al. 2009, Sopinka et al. 2014). Some stocks, such as Early Shuswap, Chilko, Quesnel, and Late Shuswap, had later adult upstream migration timing, which exposed them to lower thermal stress levels as temperatures declined after mid-August.

Despite this thermal experience during upstream migration, total adult escapement in 2014 was one of the largest on record, in large part due to their exceptionally large parental generation, which spawned in 2010. DFO's Fraser Stock Assessment program reported that upon arrival at the spawning grounds, water temperatures were favourable for spawning in most areas, while water levels were variable, potentially limiting access to natal streams. Spawners appeared to be in good condition with no visible evidence of migration difficulties, and attained average to above-average spawner success, depending on the stock. Spawner success is measured as the proportion of eggs absent from female adult carcasses assessed. However, the specific linkages between spawner success, gamete quality, and egg-to-fry survival are not apparent at this time.

DFO's Environmental Watch Program collected biological samples on the spawning grounds in 2014, to further investigate spawner and gamete condition. The largest population expected to return in 2018 is Adams River (Late Shuswap). Physiological assessments of spawners from this population did not indicate anything unusual in terms of ion regulation and gamete viability – survival to eyed-egg stage was within expected values. Weaver Sockeye, another Late Run population expected to contribute considerably less to the total returns than the Adams River, also did not exhibit anything unusual in terms of ion regulation. In contrast, assessments of Summer Run Sockeye spawners from the Harrison River indicated that this population likely experienced problems with ion regulation during their migration. Further, gamete viability of paired spawners from the Harrison River was lower than expected under experimental conditions. Anecdotal evidence suggests that Harrison Sockeye are generally not as robust as other Fraser Sockeye stocks, and have shifted to an earlier return timing in recent years (pers. comm. Keri Benner, DFO Stock Assessment), the cause and effects of which are unknown.

Warmer than seasonal average air temperatures in 2014 spanned the winter Sockeye egg incubation period. High in-river incubation temperatures are generally less favourable for fertilization success and egg survival (Whitney et al. 2014) in streams that are highly temperature sensitive (Braun et al. 2015), and can influence the timing of hatch (Whitney et al. 2014), fry outmigration (Macdonald et al. 1998), and swim performance (Burt et al. 2012). Incubation temperature data are available for the Early Stuart and Gates systems. However, these data cannot be extrapolated to other systems, because water temperatures are localized, and responses of Sockeye Salmon to water temperature are highly adaptive and population specific (pers. comm. D. Patterson, DFO Environmental Watch Program).

Incubation temperatures in the Early Stuart tributaries were above average in the winter of 2014-2015. Incubation temperatures for Gates, Nadina, and Weaver are from spawning channels, where incubation conditions are controlled, and do not necessarily reflect natural conditions. For these channel systems, Gates Sockeye experienced average incubation temperatures and had average egg-to-fry survival. Nadina and Weaver, both experienced below average survival during this life stage.

3.3 JUVENILE FRESHWATER STAGE: SPRING 2015 - SPRING 2016

The spring of 2015 was notably warm, resulting in early spring river freshets, high river discharges and lake water levels, and a longer and warmer growing season than typically experienced by Fraser Sockeye juveniles. Fry emerging from their spawning gravel experienced higher than normal discharge, which is likely beneficial to most populations that migrate downstream to their rearing lakes. However, populations that migrate upstream to reach their rearing lakes, such as Chilko and Weaver, may have experienced migration challenges due to the high discharge.

High lake water levels potentially expanded littoral areas, where fry feed and grow from April to June. This increase in habitat availability (Williams et al. 1989, Morton and Williams 1990) potentially benefitted fry; however, there is limited information on this relationship and its importance to juvenile survival. Warm spring temperatures likely benefitted juveniles by initiating the growing season early in some lakes, since the length of the growing season is temperature dependent (Schindler et al. 2005). Further, the optimal temperature for juvenile Sockeye growth increases with food availability (Brett 1971), therefore warmer lake temperatures can increase growth when prey are not limiting (Edmundson and Mazumder 2001).

Fry abundances migrating into lakes after gravel emergence were estimated for three channel systems: Nadina, Weaver, and Gates. Egg-to-fry survival was below average for Nadina and Weaver, and average for Gates.

Fall fry abundances were assessed in Shuswap Lake and Quesnel Lake in 2015 using hydroacoustic and trawl surveys, allowing us to estimate survival to this life stage. The 2014 brood year is the dominant cycle year for Shuswap Sockeye and subdominant for Quesnel. Survival to fall fry in 2015, measured as fry-per-effective female spawner, was above the cycle average for Shuswap and similar to average for Quesnel. Apart from Cultus Lake (see below), fry survival is not available for other Fraser River systems, due to limited funding for sampling programs.

Above-average air temperatures continued over winter in 2015, but likely did not impact in-lake fry survival directly, as fry have the mobility to choose their temperature exposure. The warming trend strengthened into the spring of 2016, when well above-average air temperatures may have again initiated the growing season early in some systems. Those juveniles with the opportunity to feed prior to their outmigration would have been positively affected by the availability of early spring phytoplankton and zooplankton. This is particularly likely for Cultus and Shuswap Lake Sockeye; not all systems occur at low enough latitudes or elevations to produce early spring feeding opportunities.

Outmigrating smolt abundances are enumerated at the outlets of Cultus and Chilko Lakes. In 2016, very few smolts were counted leaving Cultus Lake, indicating that survival from fall fry to smolt was very low in this system, continuing the recent trend of low freshwater survival in Cultus Lake. Cultus now has a large hatchery enhancement program that contributes fry directly into the lake and also smolts downstream of the lake. In contrast, the count of Chilko smolts was the third largest on record over 50 years of data. However, effective female spawner-to-smolt survival, smolt sizes, and smolt condition (weight by length and % lipids) were all below average, indicating that the density of juveniles limited the growth and survival of this population in freshwater; a density-dependent effect.

3.4 JUVENILE DOWNSTREAM MIGRATION IN THE FRASER RIVER: SPRING 2016

Extremely high air temperatures in the Fraser watershed in spring 2016 led to an early onset of the spring freshet, producing record discharge levels in the Fraser River in early April. Discharge then transitioned to average, then below average in May and June. Since individual populations vary in their outmigration timing between April and June, they experienced different discharge profiles as the freshet progressed, with early migrating juveniles, such as Chilko, experiencing very high discharge, and late migrators, such as Harrison, experiencing low discharge.

There can be large inter-annual variation in downstream smolt survival (Clark et al. 2016). Discharge can impact this response through changes in predation risk with water clarity (Gregory and Levings 1998), decreases in predation risk with increases in water velocity (Ginetz and Larkin 1976), and negative influences on juvenile salmon caused by high suspended sediments associated with high discharge (Martens and Servizi 1993). High flow conditions and associated reductions in water clarity in most of the watersheds during the 2016 outmigration likely had a positive effect on juveniles by reducing predation.

Water temperatures were 1–3°C above average in the lower Fraser River throughout smolt outmigration, and were above average in various tributaries across the watershed. Temperature affects downstream survival by influencing both the optimal smoltification window (Bassett 2015) and swim performance (Brett 1971). The influence on juvenile survival is less clear.

Juvenile enumeration programs at the outlets of Chilko and Cultus Lakes indicated smolts migrated 7 and 14 days earlier than normal, respectively, likely due to the warm spring conditions. Outmigration timing past Mission in the Lower Fraser River was also early, falling two weeks earlier than the 2012 migration, but was similar to that observed in 2015, which had a similarly warm spring and early freshet. Migration timing can be linked to smolt energy status (Westley et al. 2008), and determines the environmental conditions that fish are exposed to during their migration and upon marine entry. Early migration of juveniles in 2016 is assumed to have a negative effect on survival due to potential mismatches with marine conditions, under the assumption of “normal” marine conditions.

The biological condition of outmigrating salmon smolts can be used as a predictor of future smolt-adult marine survival. Previous work on smolt condition has focused on using length and weight to infer carrying capacity of lake habitats (Hume et al. 1996, Griffiths et al. 2014), and to create a mechanistic link for trophic relationships (Ballantyne et al. 2003, Ravet et al. 2010). Smolt samples at Mission had the smallest mean fork length observed since the previous dominant cycle in 2012, likely due to density-dependent effects on the dominant stocks, Shuswap and Chilko.

However, body lipids may be a better predictor of survival, due to starvation, than body size (Gardiner and Geddes 1980, Post and Parkinson 2001, Simpkins et al. 2003, Biro et al. 2004). Lipid content can be used to infer early marine survival, based on the connection between energy status and time to starvation (Naesje et al. 2006), as well as more indirect associations. For example, predator risk can also change as a function of lipid content through changes in swim performance (Litz et al. 2017; S. Wilson SFU pers. comm.).

Smolts were sampled for size and lipid content at the outlets of Chilko, Shuswap, and Cultus Lakes. Chilko smolts had below average lipid levels, with 27% of those sampled falling below the presumed critical survival threshold of 2% for this measure (Gardiner and Geddes 1980). Smolts leaving Shuswap Lake were in better condition than Chilko smolts and had higher lipid levels than the previous cycle; less than 10% fell below the survival threshold. Cultus smolts have previously had the highest condition rating of those stocks sampled, and continued this trend in 2016. Notably, similar to 2015, warm spring conditions likely initiated the growing season early in 2016, benefitting those juveniles known to have an opportunity to feed prior to outmigration, specifically Cultus and Shuswap, and likely affected their outmigration condition.

3.5 JUVENILE MARINE STAGE: SPRING/SUMMER 2016 – FALL 2018

Most Fraser Sockeye returning in 2018 resided in the NE Pacific Ocean from 2016 to 2018. Lake-type Fraser Sockeye entered the ocean in the spring of 2016 via the SOG, and reared in the SOG for four to six weeks prior to migrating north through the Johnstone Strait (Preikshot et al. 2012, Neville et al. 2016). They continued their northward migration, following the continental shelf along coastal BC and Alaska, and migrated out into the GOA (GOA) in the fall and early winter of 2016 (Tucker et al. 2009).

In spring 2016, when the 2018 lake-type Fraser Sockeye cohort entered the SOG, ocean temperatures were above average (Chandler 2017). A marine heatwave, commonly referred to as the warm blob, occurred in the NE Pacific Ocean from 2013-early 2016. Warm temperatures associated with the blob introduced anomalies in ecosystem processes and biological species composition. During this period, the Northeast Pacific Ocean was more stratified, which reduced upwelling of nutrients to surface waters and decreased primary productivity (Chandler et al. 2017). Zooplankton community composition was also affected by the heatwave, favouring less nutritious warm water copepod species (Galbraith and Young 2017, 2018).

Adding to the anomalously warm temperatures, a strong El Niño developed in early 2016, further influencing global temperatures upwards such that 2016 became the warmest year recorded in the U.S. National Oceanic and Atmospheric Administration's (NOAA) 137-year time series (Ross 2017). On the west coast of Vancouver Island, water temperatures were 1-3°C above average, extending down to depths of 100 m. Temperatures in the SOG tend to lag behind the broader NE Pacific, therefore, the effects of the heatwave were being experienced in the SOG as juvenile Fraser Sockeye entered this region in spring 2016. However, the timing of the spring phytoplankton bloom in the SOG was typical, occurring near the end of March in 2016 and 2017 (Gower and King 2017, Sastri et al. 2018).

Zooplankton composition is more challenging to compare in the SOG, though a high proportion of southern copepods were reported. Despite the altered zooplankton community composition, conditions appeared to be good for juvenile salmon in the SOG during May and June, when juvenile Sockeye were rearing in this area. Catches of juvenile Coho and Chinook in the SOG were the highest in 2016 compared to the previous 6-7 years of surveys, and both species were above average in length, while Coho were in the best condition observed since 2000. Catches of juvenile Chum and Pink salmon were also high, and their condition was good. Condition of juvenile Fraser Sockeye sampled by the 2016 SOG trawl was average compared to previous years and did not indicate abnormal conditions for these fish during their early marine residence.

Migration of juvenile Sockeye salmon northward from the SOG through the Discovery Islands was earlier in 2016 than observed in 2014 and 2015, and earlier than reported for 2010-2012 (Neville et al. 2013). The average length of juveniles in the Discovery Islands in 2016 was similar to previous observations on this cycle, in 2012 (Neville and Sweeting 2013) and 2008 (Beamish et al. 2012), and the proportion of empty stomachs was lower than observed in 2014.

The 2018 return cohort likely moved into the GOA in the fall/winter of 2016. Although the marine heatwave had dissipated in surface waters, temperatures remained warm at depths of 100-200 meters until 2017 (Ross 2017, Ross and Robert 2018). The El Niño event of 2016 gradually weakened through the late spring and summer, and transitioned into a La Niña by the end of 2016, contributing to the decline in sea surface temperatures in the NE Pacific (Ross 2017).

While the 2018 return cohort was rearing in the GOA in 2016 and 2017, some physical processes started to revert to more typical conditions in the NE Pacific. The 2016 spring transition from winter downwelling to summer upwelling of cool nutrient-rich waters to the surface occurred early, and was average to above average in strength, creating conditions that are beneficial to primary production and fish growth (Hourston and Thomson 2017). During this period, winter mixing returned to 2011-2013 levels, implying that there was a normal nutrient supply in the NE Pacific heading into 2017 (Ross 2017, Ross and Robert 2018). Upwelling of nutrient rich waters started later than usual in 2017, and was not as intense as previous years. However, conditions were still considered somewhat favourable (average to below average) for productivity and fish growth (Hourston and Thomson 2017, 2018). Species composition within the phytoplankton community was typical in 2017, except for at the most offshore stations sampled, where diatom abundances were high (Peña and Nemcek 2017, 2018). The zooplankton community composition in 2017 remained less favourable for fish growth than average, but better compared to 2016. The abundance of lipid-rich northern copepod species, favourable for fish growth, is expected to increase as ocean temperatures continue to cool (Galbraith and Young 2017, 2018).

3.6 EARLY INDICATORS OF SURVIVAL: 2017 RETURNS

Returns of three-year-old jack Fraser Sockeye, precocious males, in 2017 are used as a potential indicator of four-year-old returns in 2018. Fraser Sockeye jacks that returned in 2017 are offspring of the same spawners as the four-year-old adult fish returning in 2018, having spent two winters together in freshwater and one in marine waters.

The escapement of jacks in 2017 relative to the 2014 brood year spawners was below the cycle average for all stocks apart from Quesnel, which was similar to the cycle average. Using the relationship of three year old jacks to four-year-old returns, jack returns in 2017 indicate below average survival for Chilko, Quesnel, and Late Shuswap in 2018. These predictions fall at the 25% probability level of the return forecasts for these stocks (DFO 2018).

There has been a recent shift in the pattern of age-at-return between the dominant Adams River population and the Lower Shuswap River population, in the Late Shuswap stock group. Escapements to the Late Shuswap were historically dominated by jacks on the 2017 cycle, averaging at 90%, because this cycle falls one year prior to the dominant cycle for this stock. The majority of these returns were from the Adams River, as this system normally dominates the Late Shuswap Sockeye returns every four years, on the 2018 cycle line.

Since 2001, the proportion of jacks escaping to the Late Shuswap on this cycle has been declining, due to a decline in the jack returns to the Adams River. Meanwhile, jack escapements to the Lower Shuswap River have been increasing. This downward trend continued in 2017, with jacks comprising only 20% of the total Late Shuswap escapement, the majority of which returned to the Lower Shuswap River. The mechanism behind the shift in jack proportions is currently unknown.

Although Pink salmon return as two year old fish and rear for part of their life in the SOG, Fraser Pink and Sockeye survival are not correlated. As indicated in the previous section, catches of juvenile Pink salmon were high in the SOG in 2016, and their condition was rated as above average, indicating that early marine conditions were beneficial for this species. However, the 2017 return of Pink salmon to the Fraser River was poor, suggesting that these animals experienced poor conditions upon leaving the nearshore environment.

3.7 PROPORTIONS

Proportions of five key stocks returning in 2018 were compared across programs representing three life stages for which we have information on relative abundances: effective female spawners in 2014; migrating smolts at Mission, SOG, and Discovery Islands in 2016; and forecasted four-year-old returns in 2018. Relative abundances were compared for Late Shuswap, Chilko, Quesnel, Stellako, and Early Shuswap stock groups, as these stocks had sufficient numbers to be evaluated across programs. As anticipated, Late Shuswap dominated the abundances sampled in all programs, except the Mission smolt outmigration surveys. A number of caveats and potential biases identified for the Mission program indicate that relative abundances of stocks sampled by this program may not be representative of true relative abundances.

Chilko and Quesnel are the next largest in terms of relative abundances, though the patterns observed for these stocks differ across programs. Chilko made up a larger proportion of the effective female spawners in 2014 and forecasted four-year-olds for 2018; however, Quesnel made up a larger proportion of the catches in all three juvenile salmon programs. This may indicate that survival to the smolt outmigration stage was high for Quesnel, and is supported by the high EFS-to-fall fry survival estimated for this system with fall Quesnel Lake hydroacoustic surveys. Also, Chilko freshwater survival was below average in the 2014 brood year, which may have contributed to these differences in proportions. Of note is that lipid content of outmigrating Chilko and Quesnel smolts indicated that many of these fish were in poor condition upon leaving their lakes.

3.8 PREDICTIONS: 2018 RETURNS

Based on the observations discussed, we predict that the 2018 Fraser Sockeye returns will exhibit lower than average survival. This corresponds to the lower end of the forecast probability distribution for most of the Early Summer, Summer, and Late Run stocks where environmental covariates did not reduce the forecasts. This prediction is consistent with recent years. In particular, in the last three return years (2015-2017), total Fraser Sockeye returns have fallen at the lowest (10%) probability level presented for the forecast, indicating very poor survival for the stock aggregate, though survivals exhibited by individual stocks varied from average to poor.

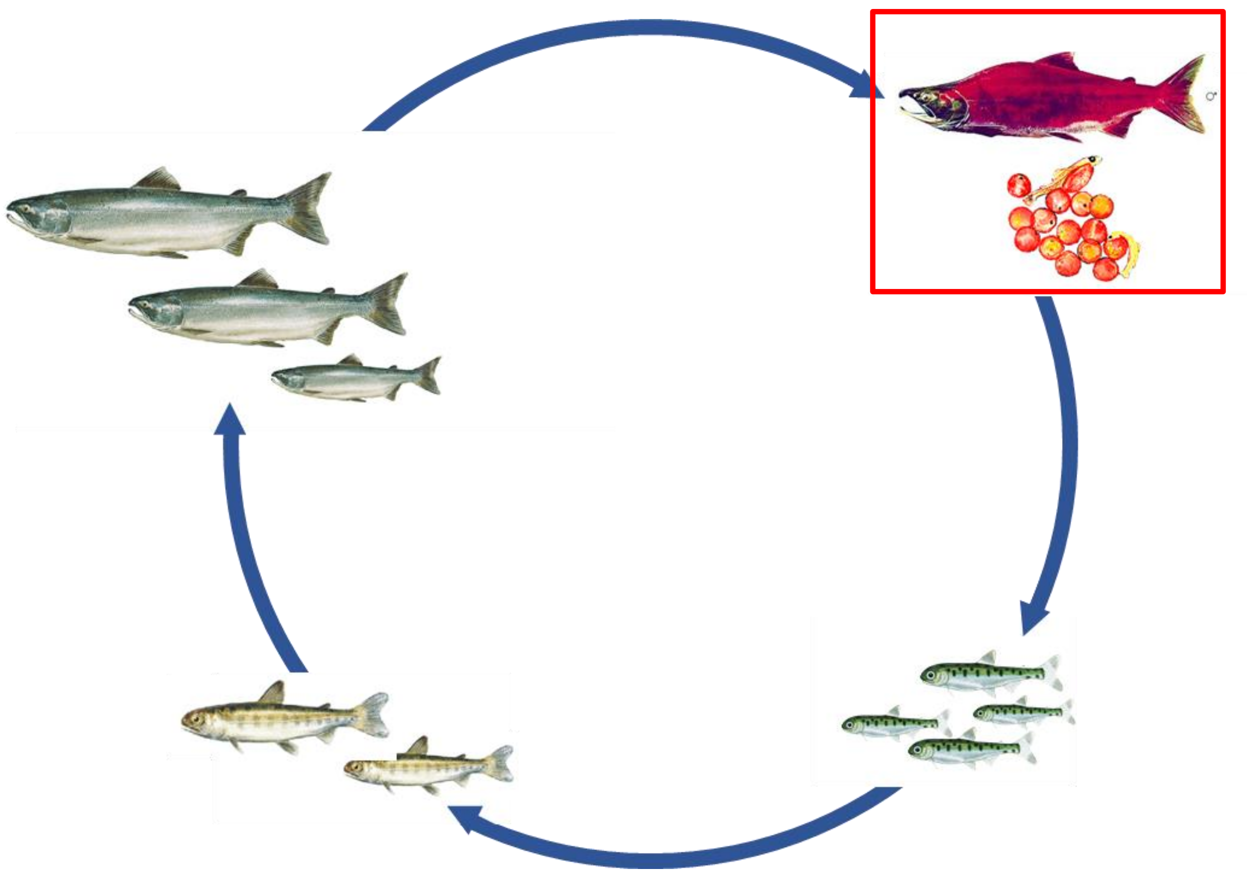
Warm conditions and the associated ecosystem effects prevailed throughout the lifespan of the 2018 returns. This does not necessarily translate into poor survival; many of the observations recorded here are linked to neutral or positive impacts on survival. However, with the exception of somewhat improved circumstances for early marine survival, the conditions encountered by the 2018 returns closely resemble those experienced by the 2017 returns, which exhibited very poor survival across all stocks. We therefore anticipate the overall impact of the observations recorded throughout the lifespan of the 2014 brood year to be negative for Fraser Sockeye survival.

Participants also concluded that ecosystems are changing rapidly as the global climate warms, and unusual events are becoming less infrequent. In recent years, all programs have observed profound events or changes in the local ecosystems and salmon life-stages they assess. Such changes increase the uncertainty in our ability to predict future Fraser Sockeye survival, as all life-history stages are affected with largely unknown consequences.

These changes emphasize the critical value of long-term monitoring of salmon and their ecosystems. Without this information, we will not be able to predict salmon responses, and support activities that will ensure the conservation of biodiversity in a changing climate. We continue to have major gaps in many of our programs, such as freshwater lake and stream monitoring programs, monitoring of non-Sockeye salmon species, and marine ecosystem monitoring. Research efforts must increase to ensure sustainability of these stocks.

4 DETAILED OBSERVATIONS FROM FRASER SOCKEYE LIFE STAGES (TIER 3)

4.1 BROOD YEAR SPAWNERS AND EGG STAGE



<u>Upstream Migration and Spawning: Summer/Fall 2014</u>

- Mean maximum summer air temperatures (June-August) in the Fraser basin were above normal (climatology from 1971-2000): July was extremely warm with maximum air temperatures 3–5°C higher than normal (Environment and Climate Change Canada (ECCC), Pacific Climate Impacts Consortium (PCIC))
- Mean summer precipitation for the Fraser basin was below normal (ECCC, PCIC)
- Discharge in the lower Fraser River during adult Sockeye salmon migration was average

to low. The mid-September discharge, affecting Late Run stocks, was near the 20-year low return period (Figure 1).

- Lower Fraser River water temperatures were predominately above average during adult migration, notably above 18°C for a week in mid-July and the entire month of August (Figure 2).
- Most Early Summer Run migrants experienced temperatures above 19°C throughout their entire migration, while some Summer and Late Run migrants experienced these high temperatures for part of their migration.
- Parental experience during upstream migration can have intergenerational effects on offspring survival and phenotype. For example, high maternal stress can affect swim performance and predator avoidance behaviour (Tierney et al. 2009, Sopinka et al. 2014).
- Exposure to water temperatures >19°C during upstream migration has been associated with impaired reproductive development and reduced gamete viability (Macdonald et al. 2000).
- September-November air temperatures varied in the Fraser basin. September and October were warm, with minimum air temperatures of 3–5°C above normal for October. November minimum air temperatures were 1–3°C cooler than normal (ECCC, PCIC).

Spawner Surveys

- The number of Fraser Sockeye that returned to the spawning grounds in 2014, 5.9 million, was one of the largest on record, with individual stock escapements falling well above cycle average for most stocks and at or near record for several.
- Sockeye arrival to the spawning grounds was notably 7-10 days later than average for several stocks in 2014, specifically Early Shuswap, Chilko, Quesnel and Late Shuswap. Spawning timing and behaviour was normal for most other stocks.
- Sockeye were reported to be in good condition on the spawning grounds with no obvious external evidence of migratory difficulties. Spawning success was at or above average for most stocks.
- Water levels on the spawning grounds were highly variable throughout the watershed during the 2014 Sockeye spawning period, ranging from very low in the Stuart system to above average in the Shuswap and Harrison systems. Water temperatures on the spawning grounds were favourable for spawning in most areas of the Fraser River watershed.

Biological Condition of Spawners and Gametes

- The physiological condition of spawning Harrison River, Adams River, and Weaver Creek Sockeye salmon were assessed. Plasma ion results indicated that Harrison spawners were likely experiencing ion regulation problems. The average plasma sodium (mean ± SD: 164.60 ± 13.62) and chloride (mean ± SD: 138.93 ± 13.34) levels for these spawners (n=28) were higher than expected for healthy Sockeye at this life stage (Shrimpton et al. 2005) (Figure 3). Adams and Weaver spawners were normal. These results combined with the experimental assessment of egg survival elicit concern for the gamete viability of Harrison River Sockeye salmon in 2014.
- Survival to eyed-egg stage was assessed under experimental conditions for 13 females paired with 2 males from the Adams River population and 10 females paired with 2 males

from the Harrison River population in 2014. The mean survival at 10°C was 93% and 54%, respectively (Mandy Banet, University of British Columbia). Approximately 80% survival was expected under these experimental conditions (Whitney et al. 2013, Sopinka et al. 2016). Note: Gamete viability was only measured in two populations in 2014.

- Physiological condition and gamete viability results were based on a limited sample size and populations. This should be considered when interpreting these snapshots in time and space for population-level effects.
- Quantifying the effect and uncertainty of the parental experience on future recruitment is challenging.

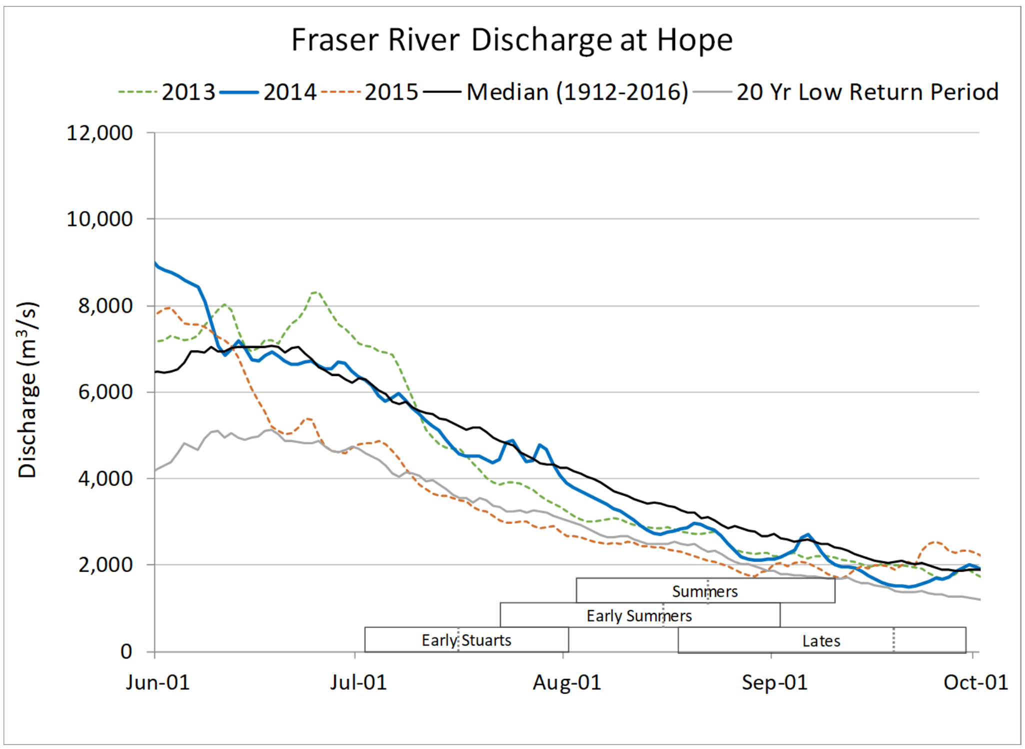


Figure 1. Lower Fraser River discharge at Hope in 2013, 2014, and 2015 during adult Sockeye salmon spawning migration. The 20-year low return period is based on day-of-the-year values. Each run-timing group block depicts the medial 95% of migrants estimated to have passed the Mission hydroacoustic site in 2014; the associated dotted grey lines depict the 50% migration date for each group. Data sources for this figure include the ECCC Water Survey of Canada and the Pacific Salmon Commission.

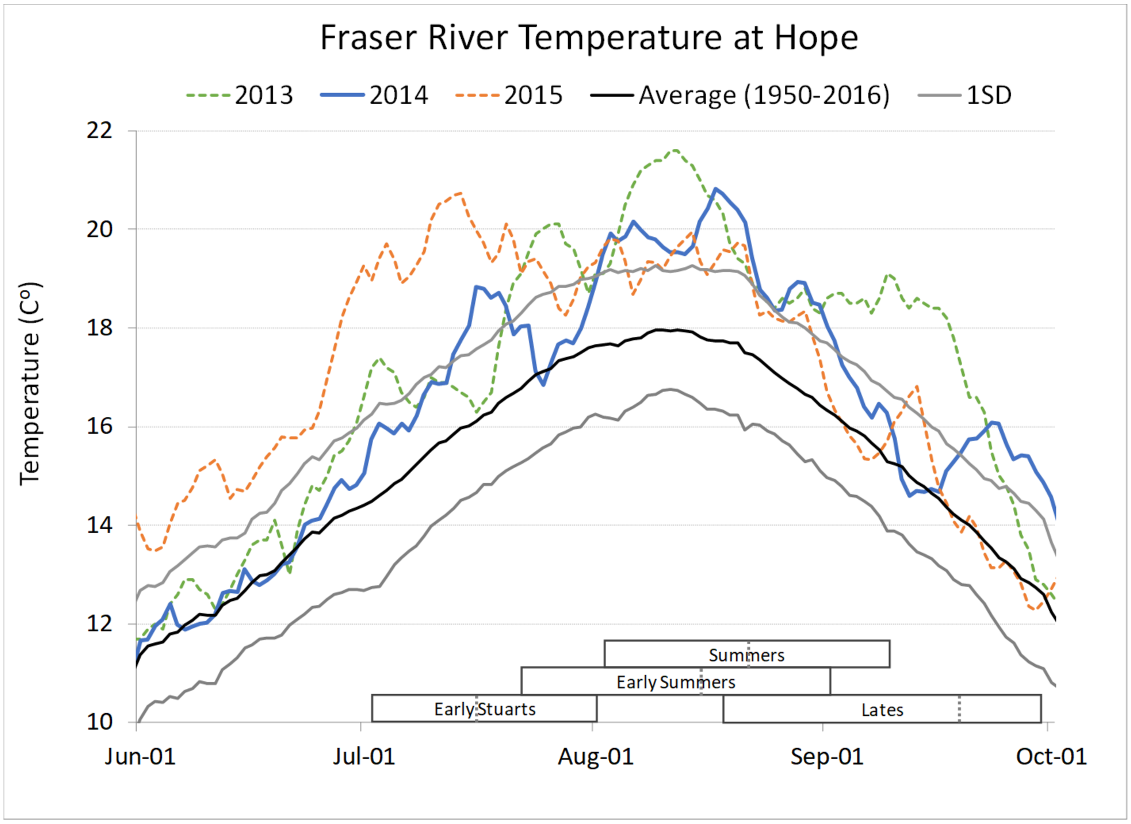


Figure 2. Lower Fraser River water temperature at Hope in 2013, 2014, and 2015 during adult Sockeye salmon spawning migration. Each run-timing group block depicts the medial 95% of migrants estimated to have passed the Mission hydroacoustic site in 2014; the associated dotted grey lines depict the 50% migration date for each group. Data sources for this figure include the DFO Environmental Watch Program, the ECCC Water Survey of Canada, and the Pacific Salmon Commission.

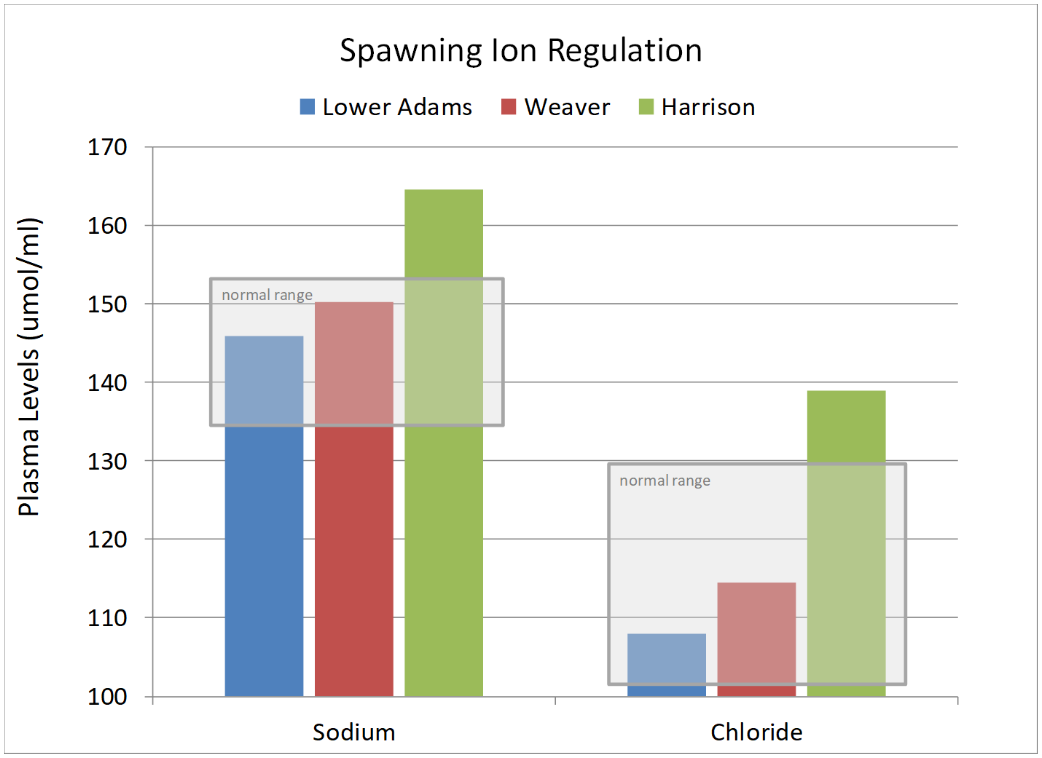


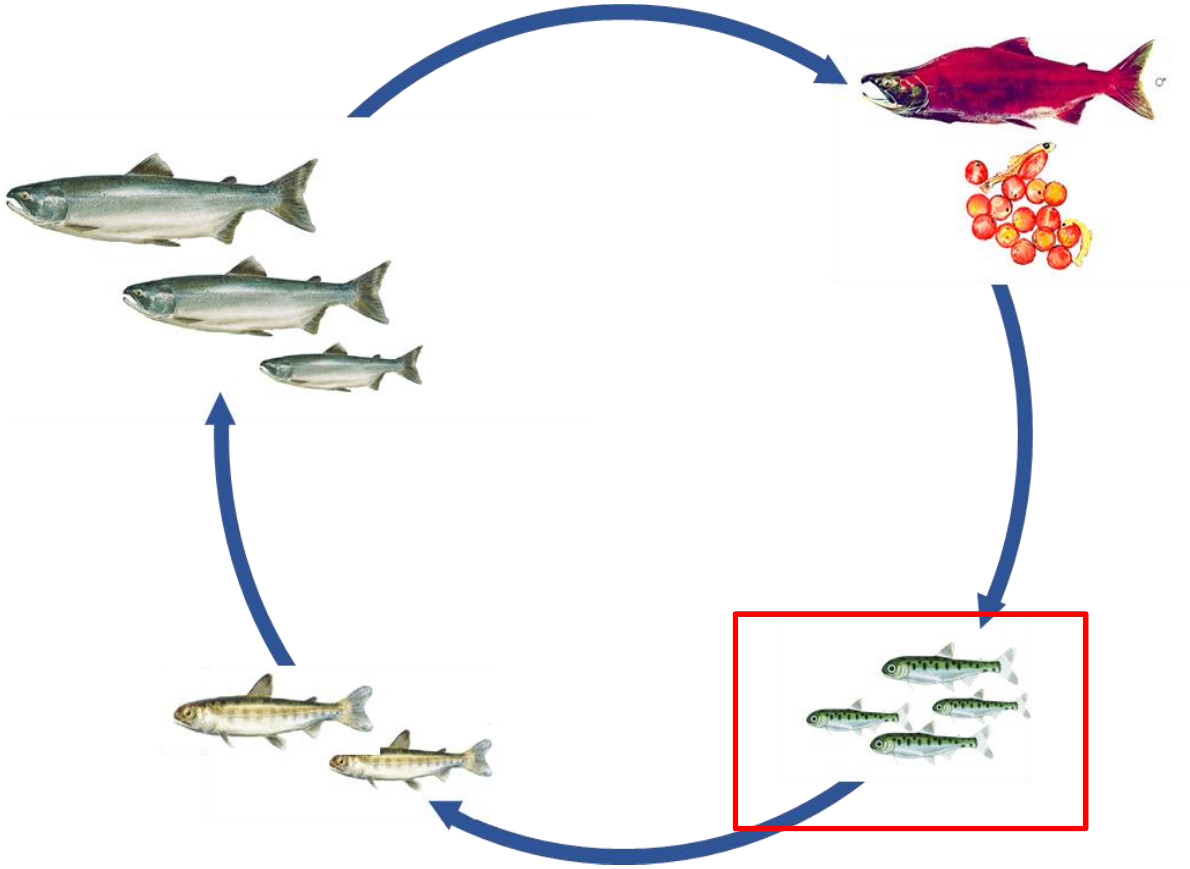
Figure 3. Plasma ion results from spawning Harrison River, Lower Adams River, and Weaver Creek Sockeye salmon in 2014. The grey boxes depict the normal ranges expected for healthy spawners (Patterson et al. 2004, Shrimpton et al. 2005, Hruska et al. 2010, Jeffries et al. 2011). The data for this figure was provided by the DFO Environmental Watch Program.

Overwinter Incubation: Winter 2014

- December-February air temperatures were 2–4°C above normal across the Fraser watershed, and these conditions persisted into early spring (ECCC, PCIC).
- Environmental conditions are not assessed by stock assessment field crews in spawning areas after the escapement enumeration projects have ended. Environmental events that occur between the end of the spawning period and the following spring that could affect egg-to-fry survival are not recorded for the majority of systems.
- High water temperatures during spawning and incubation have direct negative effects on fertilization success and embryo survival that are population specific (Whitney et al. 2014). Incubation temperature affects swim performance (Burt et al. 2012) and phenology of hatch (Whitney et al. 2014) and emergence (Macdonald et al. 1998). Low water levels can cause dewatering and, in combination with very cold air temperatures, intergravel freezing and embryo mortality (Cope and Macdonald 1998). Conversely, high flows can scour eggs from the incubation environment and increase suspended sediment concentrations, reducing embryo survival (Thorne and Ames 1987, Montgomery et al. 1996, Newcombe and Jensen 1996, DeVries 1997).
- Quesnel and Early Shuswap populations experienced very high seasonal flows (i.e. >25-year return period for early November). These high winter flows increase the risk of redd scouring and suspended sediments.

- Early Stuart spawning tributaries were warm during the early incubation period. This could have negative effects on fertilization success and early embryo survival for temperature sensitive streams within this watershed (e.g. Frypan Creek; Braun et al. 2015), as well as influence the timing of fry outmigration (Macdonald et al. 1998).
- Average incubation temperatures were experienced in Gates Creek spawning channel, consistent with the typical egg-to-fry survival reported for the channel (2014 brood year survival: 28%; 12-year average survival: 25%; DFO Salmon Enhancement Program).
- Nadina River spawning channel had the lowest egg-to-fry survival in the past 12 years (2014 brood year survival: 21%; 12-year average survival: 30%); Weaver Creek spawning channel also had slightly lower egg-to-fry survival than average (2014 brood year survival: 41%; 12-year average survival: 49%; DFO Salmon Enhancement Program).

4.2 JUVENILE FRESHWATER STAGE



Emergence and Migration to Rearing Lakes: Spring 2015

- Air temperatures were generally 2–4°C above normal for March-May and June-August, and were near normal for September-November in the Fraser basin (ECCC, PCIC).
- Discharge in the Fraser River watershed was above median in March-May, and the freshet was earlier than normal (ECCC).
- High discharge in Chilko might have had an impact on upstream migration of Chilko fry.
- Water temperatures in major tributaries downstream of Sockeye nursery lakes were above average in the summer of 2015, with near record temperatures in mid-July (DFO Environmental Watch website).
- Downstream migration timing of emergent fry is dependent on incubation temperatures

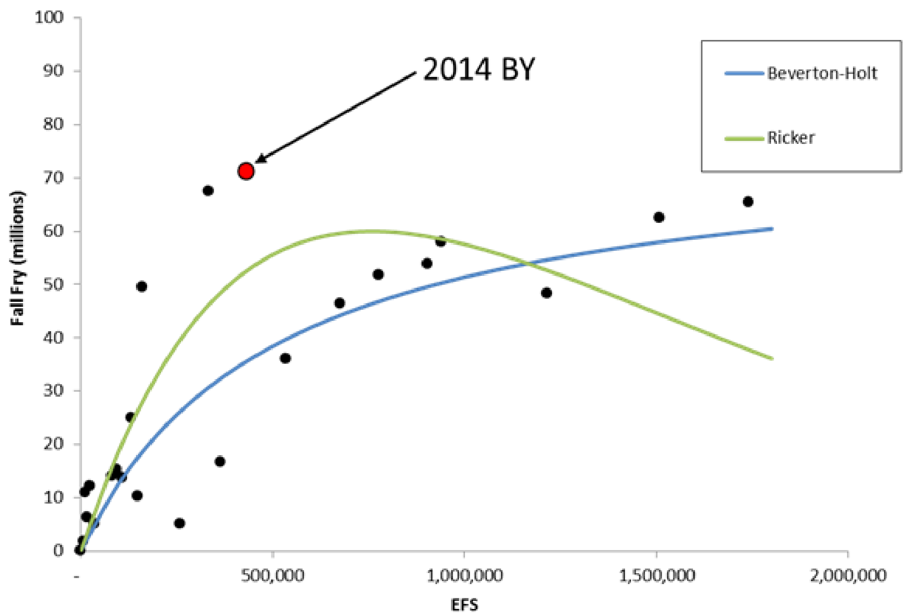
as well as proximate cues from water temperature and discharge (Macdonald et al. 1998) 1998). Population variation in mean fry migration timing has been associated with food availability in rearing lakes (Brannon 1987).

Lake Rearing: Summer - Fall 2015

- Typically, fry transit to feed and grow from April to June in lake littoral zones, where habitat availability is related to water levels (Williams et al. 1989, Morton and Williams 1990).
- Warm spring conditions are connected to high water levels during fry migration, potentially increasing littoral zone habitat availability.
- The length of the growing season is temperature-dependent (Schindler et al. 2005), and was likely long for many Fraser Sockeye populations in 2015.
- Juvenile Sockeye growth is temperature- and ration- dependent. The optimal temperature for growth increases with increasing food availability (Brett 1971), so that warmer lake temperatures can increase growth when prey are not limiting (Edmundson and Mazumder 2001).
- The benefits of the long growing season or expanded littoral zone habitat assume that habitat is not limited by a density-dependent response. Ultimately, there are both density-dependent and density-independent relationships with survival during the fry rearing stage (Ricker 1954).

Quesnel Lake

- The fall hydroacoustic and trawl survey of Quesnel Lake yielded a total abundance estimate of 70.8 million ± 35.3 million (95% CI) age-0 Sockeye fry, which was the highest value recorded for all historic hydroacoustic estimates made at Quesnel (



- Figure **4**). Based on an EFS (effective female spawners) estimate of 430,993 (DFO

Stock Assessment near finals) for Quesnel in 2014, this yielded a fall fry per EFS value of 164.3 fry/EFS.

- Following the Mount Polley tailings spill in 2014, juvenile Sockeye rearing in the directly-impacted West Arm were found to be significantly larger than fry found elsewhere in the lake in the fall of 2014. This observation did not persist into 2015, in which fry captured in the West Arm were consistent in size with fry from other parts of the lake, as well as historic means.

Shuswap Lake

- High discharge levels in early spring in Little River can increase diversion of Adams River fry to Little Shuswap Lake (Williams et al. 1989).
- Summer and fall acoustic surveys yielded a total abundance estimate of 188.6 million± 27.4 million (95% CI) age-0 Sockeye fry in August, and 129.2 million ± 25.4 million in October. Based on an EFS of 1,206,501, fall fry per EFS for the 2014 brood year (BY) was 107, which was twice that observed in the previous dominant brood year (2010 BY; 52 fall fry/EFS), and above the 1974 to 2014 average for the dominant cycle (93 fall fry/EFS; *n* = 11) (Figure 5).

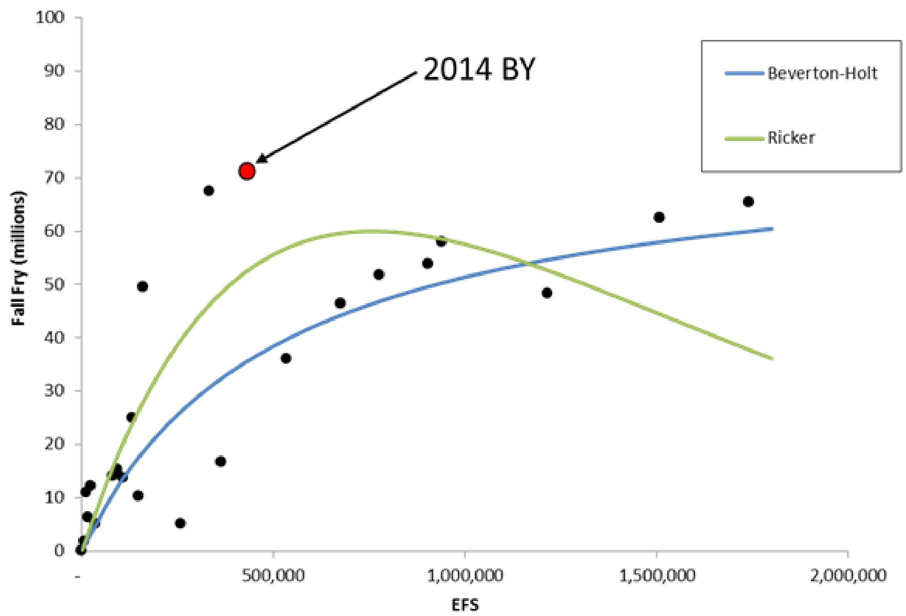


Figure 4. Fall fry estimates are plotted against corresponding brood year effective female spawners (EFS) for Quesnel Lake. Ricker and Beverton-Holt models fit to this data are displayed. The 2014 brood year fall fry abundance is indicated by the red dot, falling above expected values for this EFS abundance based on both Ricker and Beverton-Holt model fits.

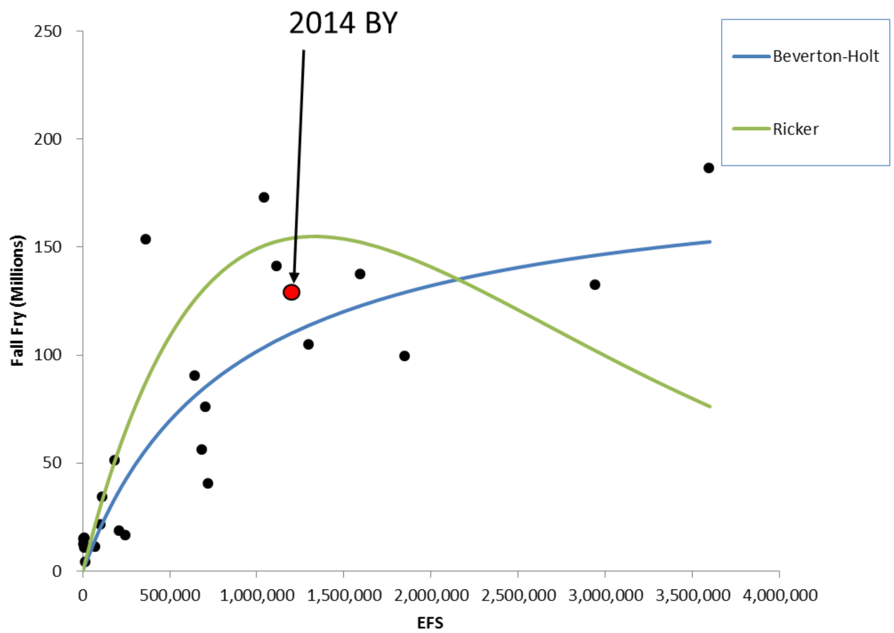


Figure 5. Fall fry estimates are plotted against corresponding brood year effective female spawners (EFS) for Shuswap Lake. Ricker and Beverton-Holt models fit to this data are displayed. The 2014 brood year fall fry abundance is indicated by the red dot, falling between the expected values for this EFS abundance according to the Ricker and Beverton-Holt model fits.

Overwinter in Lakes: Fall 2015 – Spring 2016

- Air temperature anomalies for the fry overwintering period, December 2015-February 2016, were above normal across the Fraser watershed (ECCC, PCIC). However, there is limited information on the impact of overall winter air temperature on overwinter fry survival.
- Warm spring conditions in early 2016 likely benefitted pre-smolt growth for Shuswap and Cultus populations – two populations known to feed in the spring, prior to outmigration.
- Although the 2014 brood year freshwater survival (95 smolts/EFS) in Chilko Lake was lower than average (125 smolts/EFS), it was higher than expected given the large 2014 brood year escapement (Figure 6), and the resulting Chilko smolt outmigration was the 3rd largest on record (62.7 million).
- Fall fry abundance data from Cultus (493,874 ± 71,605 (95% CI)) coupled with the smolt fence counts in the following spring (23,939 smolts) suggest an overwinter in-lake survival of only 4.8%; a low value, but one that has been consistent with recent years (Figure 7).

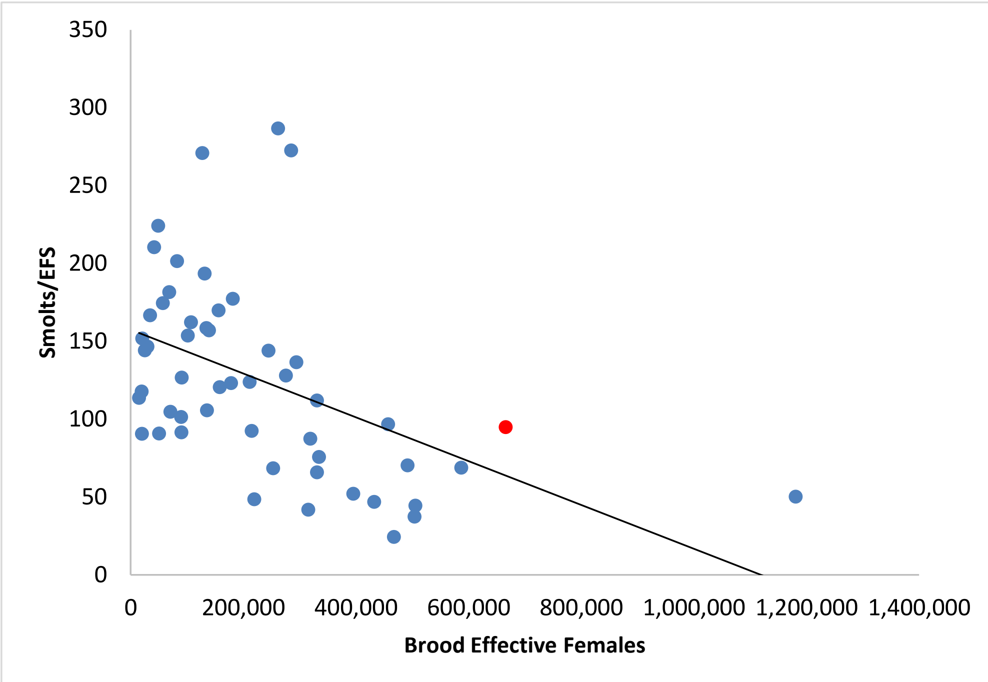


Figure 6. The relationship between Chilko Lake freshwater survival (number of smolts produced per effective female spawner) and brood year abundance (effective female spawners). Solid line indicates time series average (125 smolts/effective female).

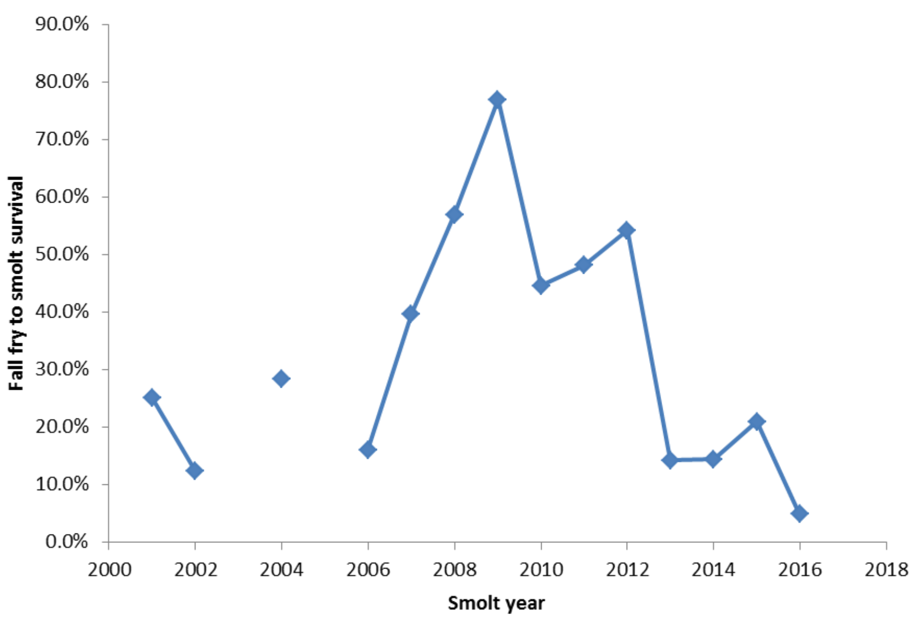
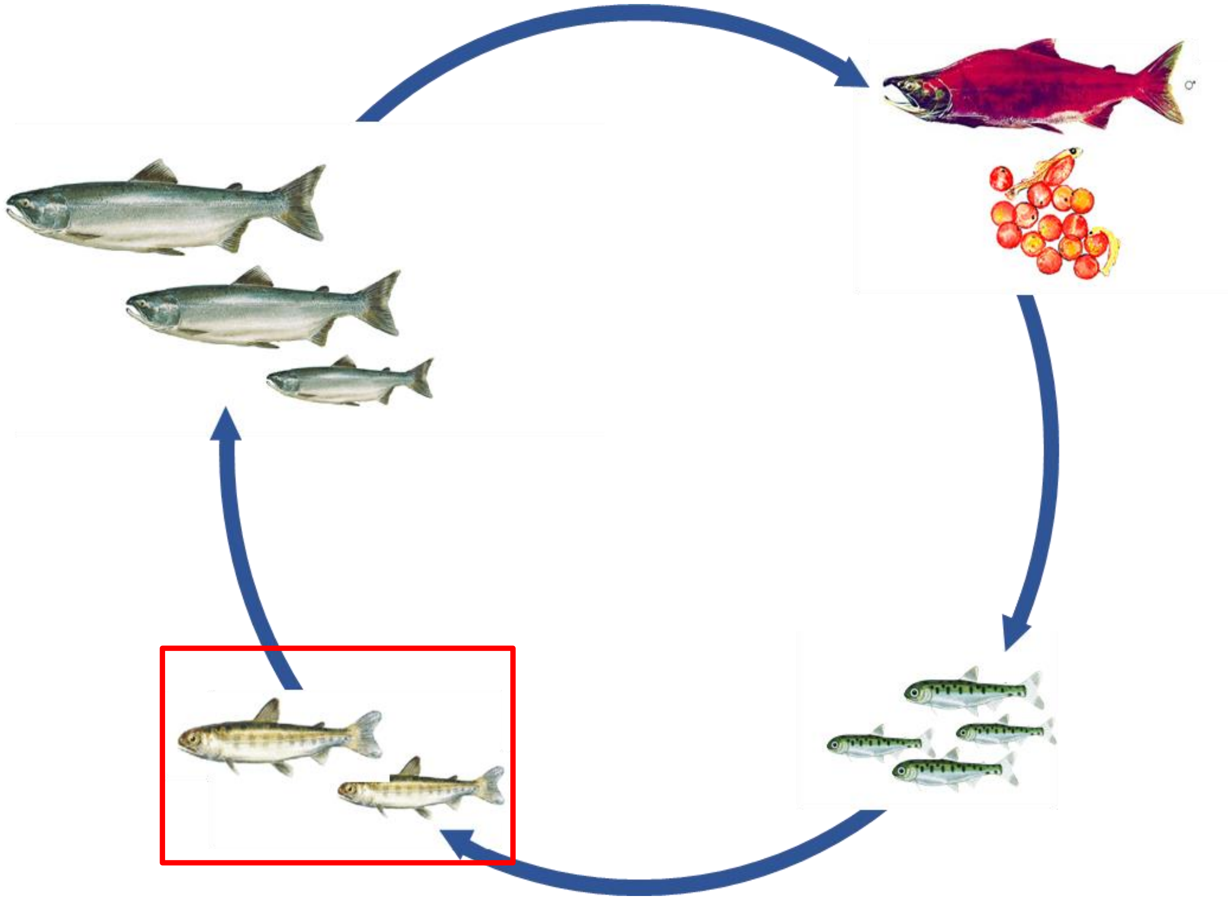


Figure 7. Overwinter survival from fall fry to smolt is shown for Cultus Lake Sockeye, using combined estimates of age-1 fall fry from lake trawl surveys, and estimates of outmigrating smolts the following spring through the smolt fence.

4.3 JUVENILE DOWNSTREAM MIGRATION



Migration at Lake Outlets: Spring 2016

- Winter 2015-2016 snowpack in the Fraser basin was normal. Snowpack as of April 1st 2016 was at or just below normal. (Ministry of Environment River Forecast Centre).
- December-May air temperatures in the Fraser basin were above normal. Most notably the April maximum air temperature was 4–5°C above normal (ECCC, PCIC).
- The result was a May 1st snowpack that was well below normal and an early freshet with high run-off in April. Day-of-year discharge records for early April were set in the lower Fraser River, transitioning to median and below median Fraser River discharge in May and June (Figure 8).

- Fraser Sockeye populations experienced different discharge exposure, due to differences in median outmigration timing (Chilko – very high, Shuswap – mixed, and Harrison – low discharge).
- Water temperatures in the migration tributaries were above average across the watershed.
- We have assumed any large anomaly in environmental conditions has a higher risk of being negative given the potential lack of adaptation of fish to more extreme or uncommon conditions (e.g. Burgner 1991). This is in part because of limited information on population-level effects of adverse migration conditions on smolt survival.
- There can be large interannual variation in downstream smolt survival (Clark et al. 2016) and some of the potential discharge-related factors regulating this response include changes in predation risk with water clarity (Gregory and Levings 1998), decreases in predation with increases in water velocity (Ginetz and Larkin 1976), and negative influences on juvenile salmon caused by high suspended sediments associated with high discharge (Martens and Servizi 1993). Temperature can also affect downstream survival by influencing both the optimal smoltification window (Bassett 2015) and swim performance (Brett 1971).
- High flow conditions and associated reductions in water clarity in most of the watersheds during outmigration likely had a positive effect by reducing predation.
- Water levels in the Chilko system were abnormally high during the smolt outmigration period in 2016 (Figure 10). Chilko smolts experienced above average discharge and water temperature during their entire migration (Figure 10; Figure 11).
- The Chilko smolt 50% outmigration date in 2016, defined as the date when 50% of the run had moved through the counting fence at the outlet of Chilko Lake, was April 23rd, one week earlier than average. The Cultus smolt 50% outmigration date in 2016 was April 13th, two weeks earlier than average. It is uncertain if the early smolt outmigration observed at Cultus and Chilko in 2016 will have implications on survival.

Smolt Condition

- The average age-one smolt nose-fork length, assessed at the outlet of Chilko Lake in 2016, 78 mm, was smaller than the 84 mm average from brood years 1954-2016. This may reflect compensatory mechanisms in Chilko Lake as a result of the large 2014 escapement.
- The connection between juvenile size and marine survival has been previously documented in Sockeye salmon (West and Larkin 1987), but with mixed results across populations (Bailey 1971, Henderson and Cass 1991, Freshwater et al. 2017). The lack of consistent connection between body size and early marine survival has also been noted in juvenile Coho salmon (Beacham et al. 2017).
- The biological condition of salmon smolts can be used as both an integrated measure of habitat quality and fry over-winter survival, as well as a potential predictor of future smolt-adult marine survival. Previous work on smolt condition has focused on using length and weight to infer carrying capacity of lake habitats (Hume et al. 1996, Griffiths et al. 2014), and to create a mechanistic link for trophic relationships (Ballantyne et al. 2003, Ravet et al. 2010). However, body lipids may be a better predictor of survival, due to starvation, than body size (Gardiner and Geddes 1980, Post and Parkinson 2001, Simpkins et al. 2003, Biro et al. 2004). Lipid content can be used to infer early marine survival, based on

the connection between energy status and time to starvation (Naesje et al. 2006), as well as more indirect associations. For example, energy status is linked to immune response (Martin et al. 2010), which can affect infection status which in turn has been connected with downstream survival (Jeffries et al. 2014) and predation risk (Miller et al. 2014) in Sockeye salmon smolts. Predator risk can also change as a function of lipid content through changes in swim performance (Litz et al. 2017; S. Wilson SFU pers. comm.).

- It is nearly impossible to observe dead fish in river systems (Patterson et al. 2007), therefore, survival is inferred from a relationship between sub-optimal fish condition and performance. The assumption is that most fish die from predation.
- Smolt energy status can also be linked to migration timing (Westley et al. 2008), which in turn will determine the environmental conditions that fish are exposed to.
- Shuswap 2014 brood year smolts had higher lipid levels than the 2010 brood year cycle line, with only 10% of the sampled smolts (n=60) measuring below the 2% lipid threshold value (Gardiner and Geddes 1980).
- Chilko smolts had low lipid levels for the 2014 brood year: 27% of the sampled smolts (n=56) were below the presumed 2% lipid threshold value
- Cultus smolts continue to have high lipid values (5.6%), the highest of the Sockeye stocks sampled.
- Note that it is difficult to interpret the combined effect of environmental and biological conditions on population-level survival. Also, sample sizes were small for some stocks.

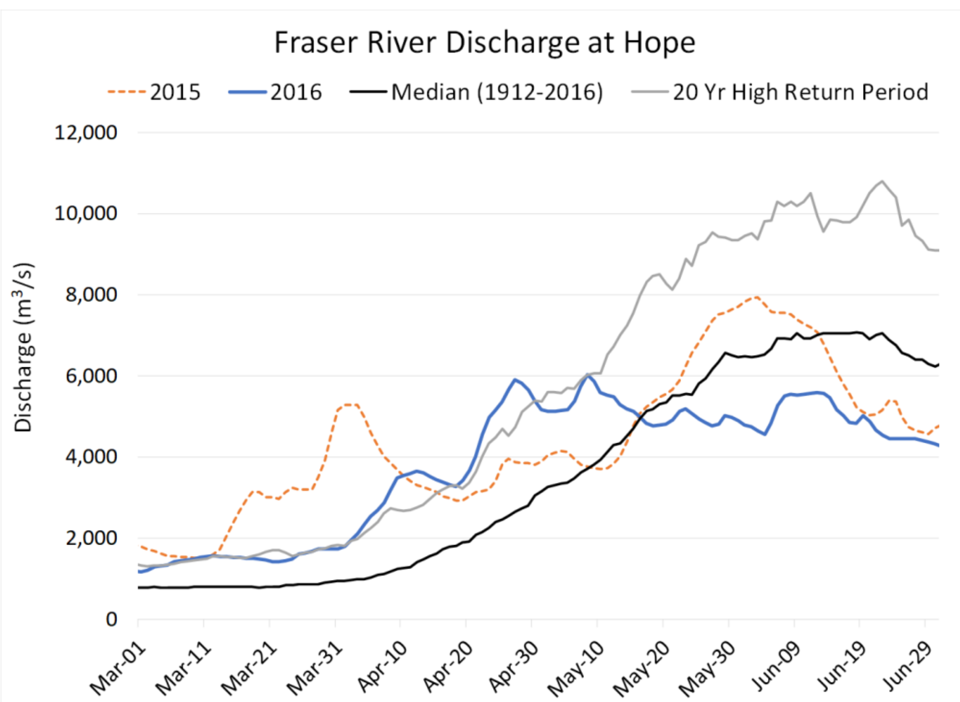


Figure 8. Lower Fraser River discharge at Hope in 2015 and 2016 during Sockeye salmon smolt outmigration. The 20-year high return period is based on day of the year values. Data sources for this figure include the DFO Environmental Watch Program and the ECCC Water Survey of Canada.

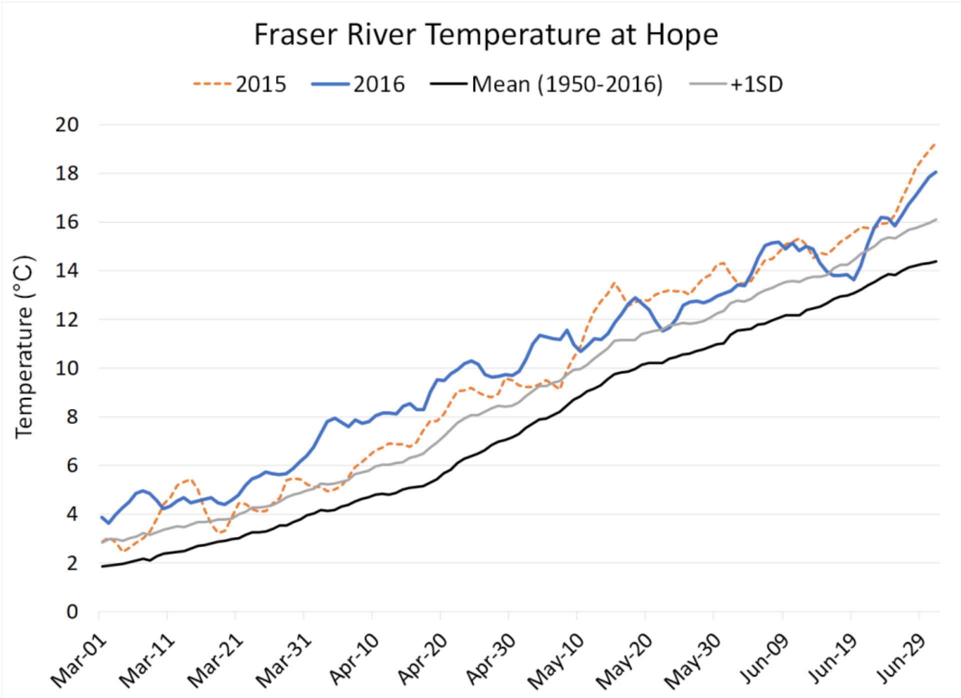


Figure 9. Lower Fraser River water temperature at Hope in 2015 and 2016 during Sockeye salmon smolt outmigration. Data sources for this figure include the DFO Environmental Watch Program and the ECCC Water Survey of Canada.

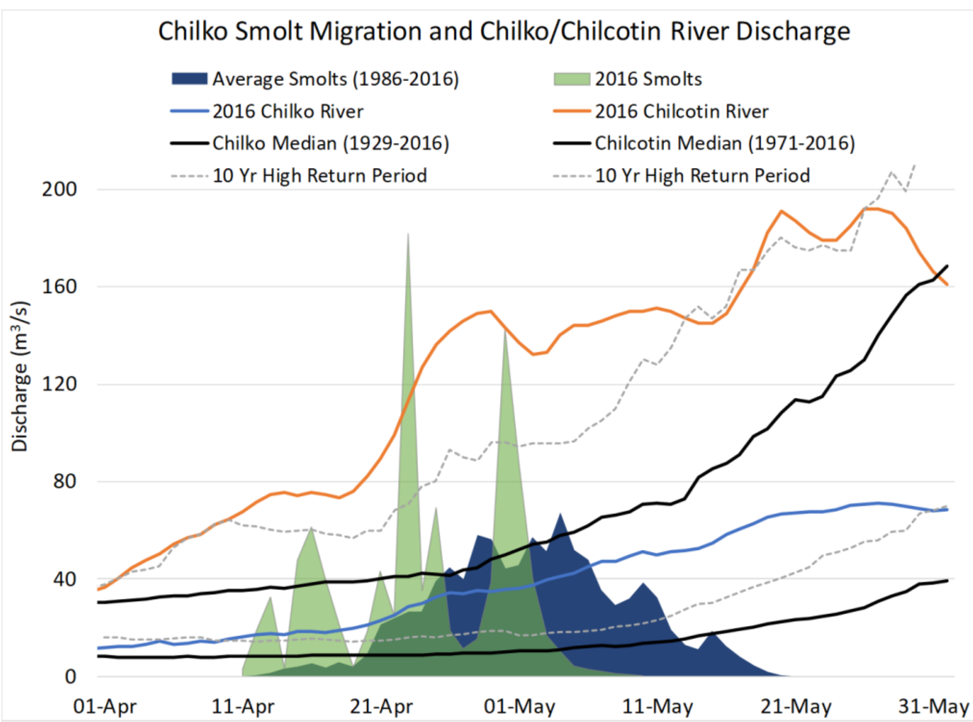


Figure 10. Chilko River and Chilcotin River discharge in 2016 during Chilko Sockeye salmon smolt outmigration. The 10-year high return period is based on day-of-the-year values. Data sources for this figure include the DFO Stock Assessment and the ECCC Water Survey of Canada.

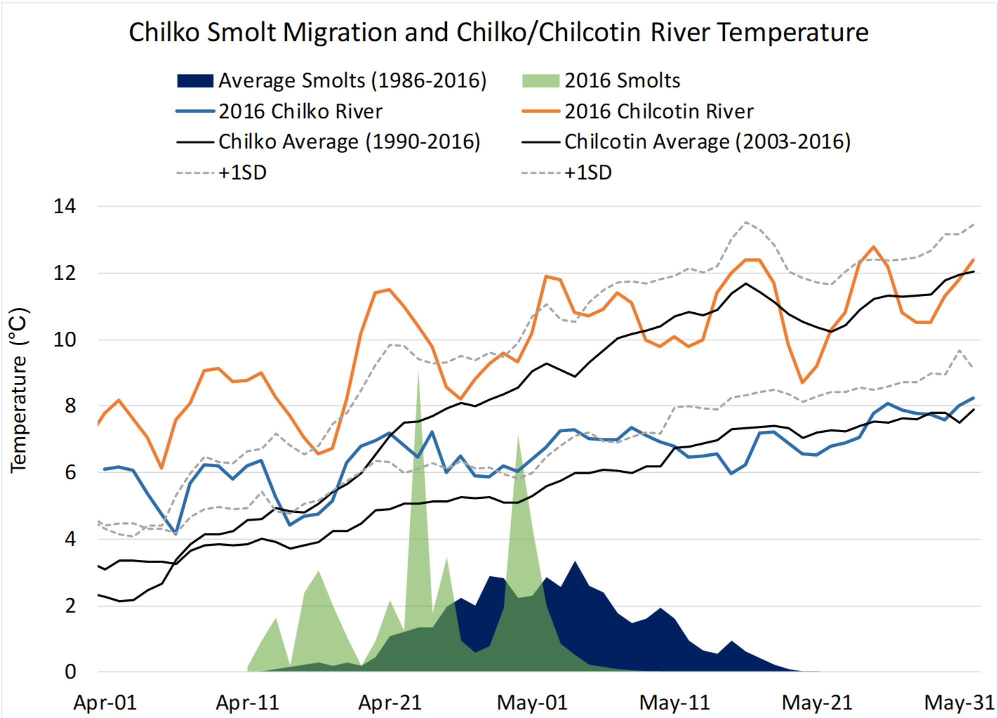


Figure 11. Chilko River and Chilcotin River water temperature in 2016 during Chilko Sockeye salmon smolt outmigration. Data sources for this figure include the DFO Environmental Watch Program, the DFO Stock Assessment, and the ECCC Water Survey of Canada.

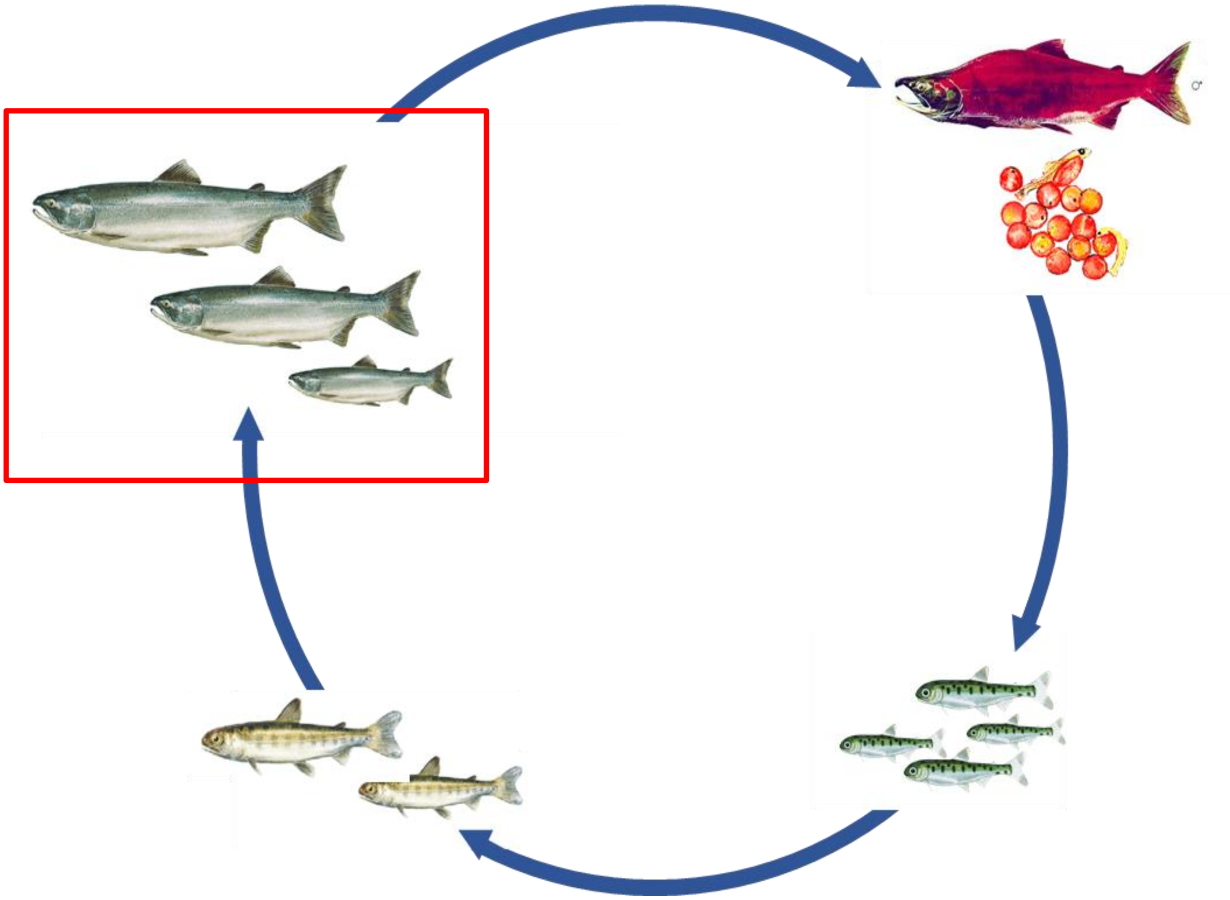
Migration in the Lower Fraser at Mission, B.C.: Spring 2016

- Water temperature was 1–3°C above average in the lower Fraser River during smolt outmigration. The warmest April water temperatures on record were recorded at about 3°C above average (Figure 9).
- Mean fork length of juvenile Sockeye Salmon at Mission B.C. varied by stock in 2016. However, mean fork length across all Sockeye salmon smolts sampled was the lowest recorded since 2012. Whether mean fork length was below some critical threshold that meaningfully influences Fraser Sockeye marine survival is not known.
- Migration timing of juvenile Sockeye salmon at Mission B.C. varied by stock in 2016. However, 50% of all the Sockeye Salmon smolts captured had migrated past Mission by April 26, 14 days earlier than the 50% migration date exhibited in 2012, yet within a day or two of 2015 captures. Linkages between the state of the ocean environment and the date of ocean entry need to be made at a finer resolution (e.g. weekly to bi-weekly time scale, not seasonal) to meaningfully capture the range of ocean entry dates exhibited by Fraser River Sockeye stocks.
- Outmigration timing at Mission is challenging to interpret given the need to maintain the water velocity at the trap mouth (1.0 m/s) and the consistent increase in discharge experienced as the study progressed. Outmigration timing for all stocks may be biased

early if a correction is not made for the inverse relationship between the proportion of water volume sampled at Mission and discharge at Mission.

- Caution should be exercised with the results of the Mission surveys until this data can be corrected for seasonal discharge, location-specific flow, and processing limitations.

4.4 MARINE ENTRY TO RETURNING ADULTS



Strait of Georgia Marine Conditions and Observations: Spring/Summer 2016

- Warmer than normal temperatures were observed throughout the entire water column, with above average temperatures for the first part of the year and average temperatures during much of the second part of the year (Figure 12: Chandler 2017).
- A rapid and early snowmelt introduced large volumes of fresh water during the late spring resulting in negative sea-surface salinity anomalies (Chandler 2017).
- The timing of the spring bloom near the end of March was typical in 2016, as measured using indicators of primary production such as chlorophyll concentration (Allen et al. 2017). This is linked to survival of age-0 herring and may be linked to juvenile salmon.
- The spring spawning biomass of herring varied among assessed stock areas in B.C. but showed near historic high levels in the Strait of Georgia (Cleary et al. 2017).

- The relative abundance of age-0 herring was low in the fall but their condition was relatively high. (Figure 13; Boldt et al. 2017, 2018a). Survival of age-0 herring is linked to the timing of the spring bloom (Boldt et al. 2018b).
- The SOG trawl survey samples all species of salmon. The 2016 catch of juvenile Coho and Chinook salmon was the highest in 6 and 7 years respectively; the catch of juvenile Chum salmon was the second highest in 6 years; and the catch of Pink salmon was the third highest in survey history.
- Coho salmon captured in the summer trawl survey in the SOG were the longest and had the best overall condition (K) since 2000; Chum salmon were the longest since 2005; Pink salmon had the second largest length and condition in the survey time series; and the average length of juvenile Chinook salmon was above average. These early summer indicators all suggest that conditions were good for juvenile salmon in the SOG during May and June of 2016, when juvenile Sockeye are rearing in this area.
- Interesting Observations:
    - A large bloom of coccolithophorids occurred in August in the southern Strait of Georgia. The cause of this harmless event is unknown (Gower and King 2017).
    - There was an increase in the proportion of survey samples containing anchovies in 2016 and 2017 surveys (Boldt et al. 2018a).
    - Fraser River Eulachon continue to show a long-term decline (MacConnachie et al. 2017).
    - In late March, Pacific Hake aggregations were mainly distributed in the central-northern Strait, while Walleye Pollock were mainly distributed in the central-southern Strait, displaying a north-south separation with overlap (Guan et al. 2017).
    - No adult Pacific Hake aggregations and only small Walleye Pollock aggregations were observed in the July survey, suggesting the possibility of out migration from the open Strait (Guan et al. 2017).
    - Harbour seals in the Strait of Georgia remain at carrying capacity; 2014 aerial survey results estimated a population of approximately 40,000 individuals in this region (Majewski and Ellis, In press).
    - Steller sea lions continue to exhibit population growth, with an estimated B.C. summer breeding season population of 39,200 individuals in 2013 (Olesiuk, In press).

Strait of Georgia and Discovery Islands Juvenile Sockeye Surveys: Early Summer 2016

- Catch-per-unit-effort (CPUE) from the SOG trawl survey in 2016 should be compared to previously surveyed years on this cycle line, 2008 and 2012, with caution, due to a two-week delay in survey timing.
- The condition of juvenile Sockeye salmon collected during the 2016 SOG trawl survey was average for our time series and did not suggest conditions out of the norm for these fish during their early marine residence.
- The majority of the juvenile Sockeye salmon passed through the Discovery Islands, North of the SOG, over a three-week period from May 17 to June 1, 2016. Peak catch was the week of May 24, 2016, earlier than the peaks observed in 2014 and 2015, and earlier

than reported in Neville et al. (2013) (Figure 14).

- The average length of the juvenile Sockeye captured in the Discovery Islands was 100.7 mm, similar to those observed previously on this cycle line, in 2012 (Neville and Sweeting 2013) and 2008 (Beamish et al. 2012).
- There was no significant difference in length between samples collected in the Discovery Islands and the northern SOG/Sutil Channel, where juveniles tend to hold prior to leaving the SOG (100.7 and 98.7 mm , respectively).
- Juvenile Chilko Sockeye salmon in 2016 were significantly smaller than those observed in either 2014 or 2015, although their overall condition was greater, suggesting that the early marine period within the SOG did not negatively impact the feeding and growth of these fish (Figure 15).
- In the Discovery Islands in 2016, 46% of all Sockeye examined for stomach contents were classified as empty, lower than observation of 58% in 2014 (Neville et al. 2016). The highest proportion of empty stomachs (~63%) occurred June 7-15, 2016 following the peak migration through this region.

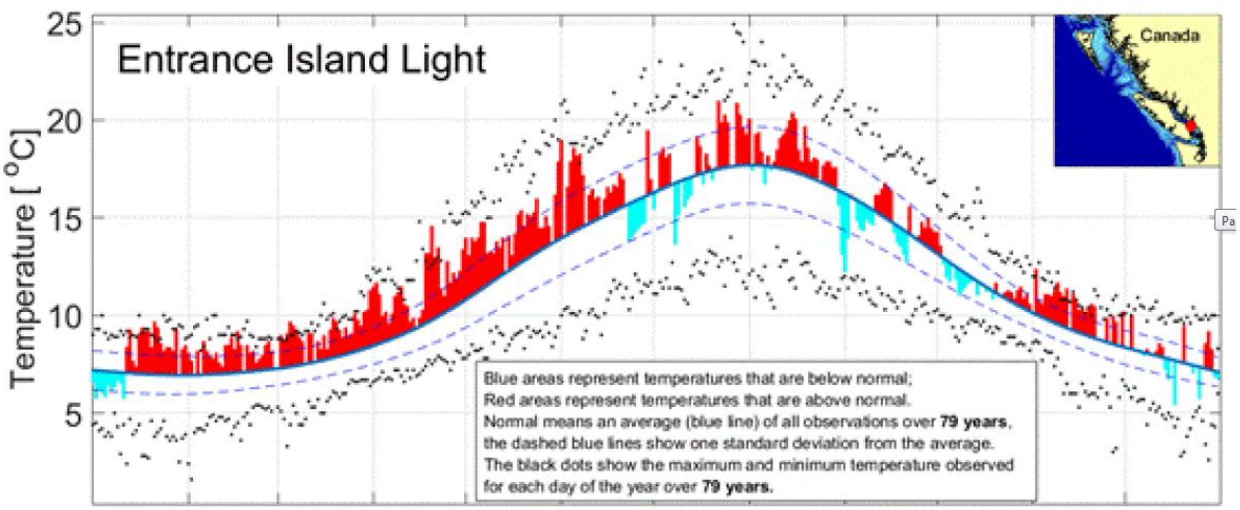


Figure 12. Daily sea surface temperatures at Entrance Island Lighthouse in the SOG, 2016. Blue areas represent temperatures that are below normal, red areas represent temperatures that are above normal. Normal means an average (blue line) of all observations and the dashed blue lines show one standard deviation from the average. The black dots show the maximum and minimum temperature observed for each day of the year. Figure adapted from Chandler 2017.

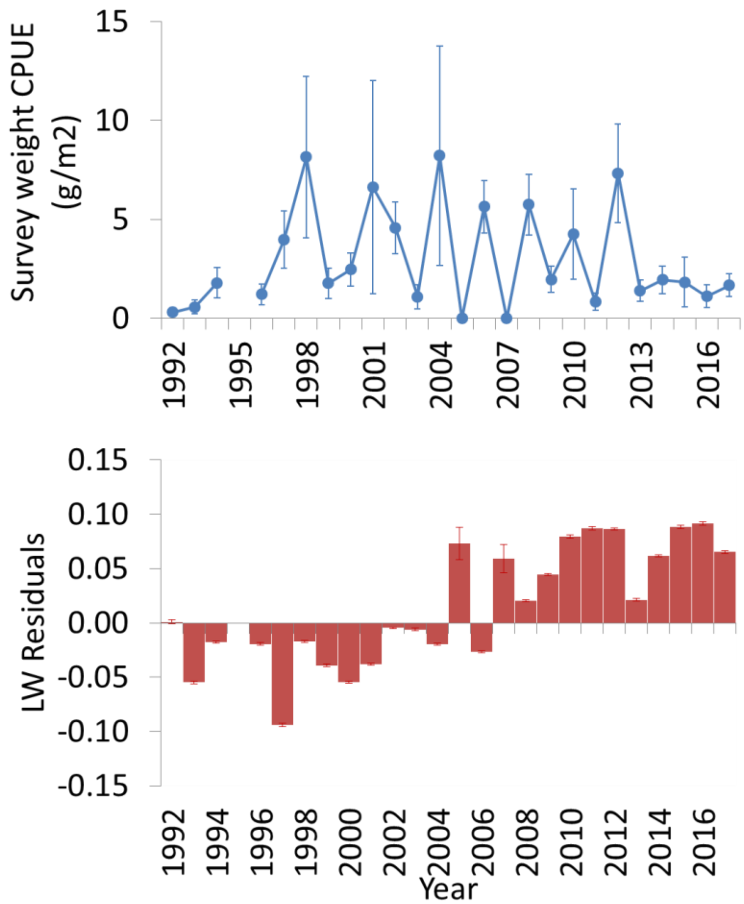


Figure 13. Mean catch weight per-unit-effort (CPUE; g/m^2; top panel) and mean condition (residuals from a double log-transformed length-weight regression; bottom panel) of age-0 herring caught in the SOG survey at core transects and stations during 1992-2017 (no survey in 1995; updated from Boldt et al. 2018a). Standard error bars are shown.

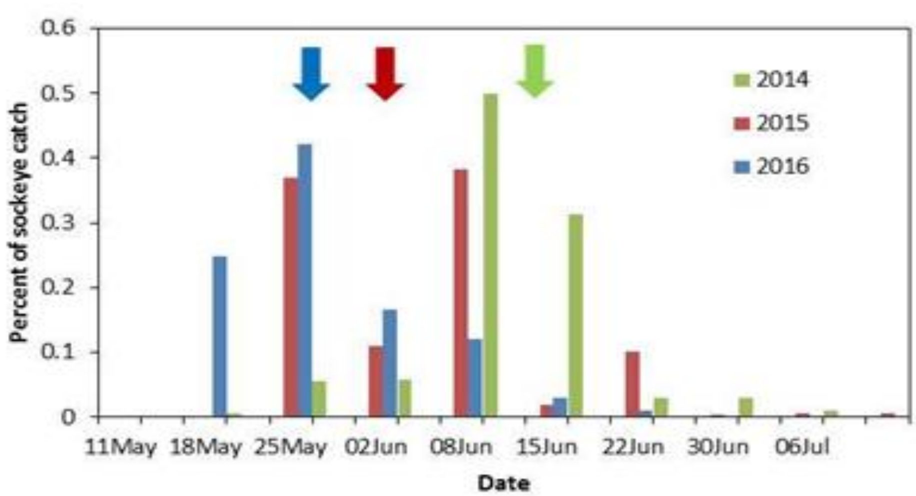


Figure 14. Timing of juvenile Sockeye migration through the Discovery Islands 2014-2016 demonstrating early migration of juvenile Sockeye in 2016.

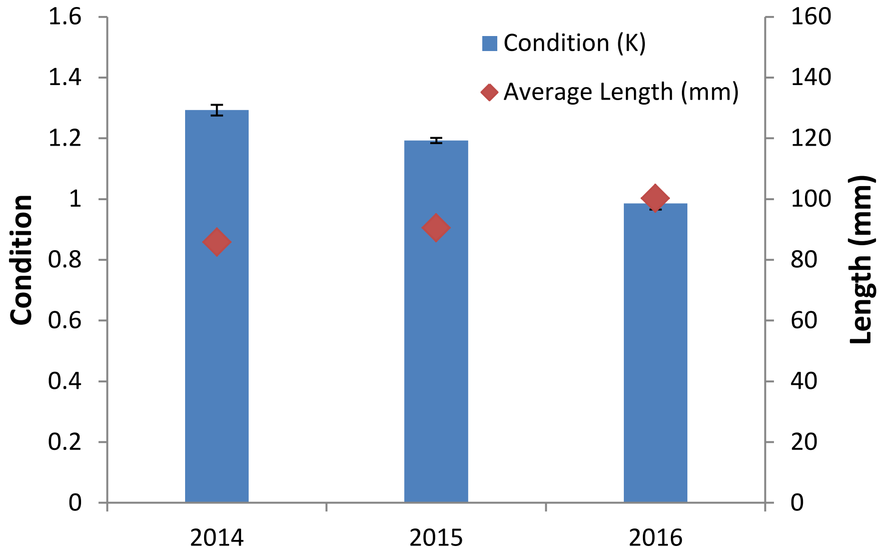
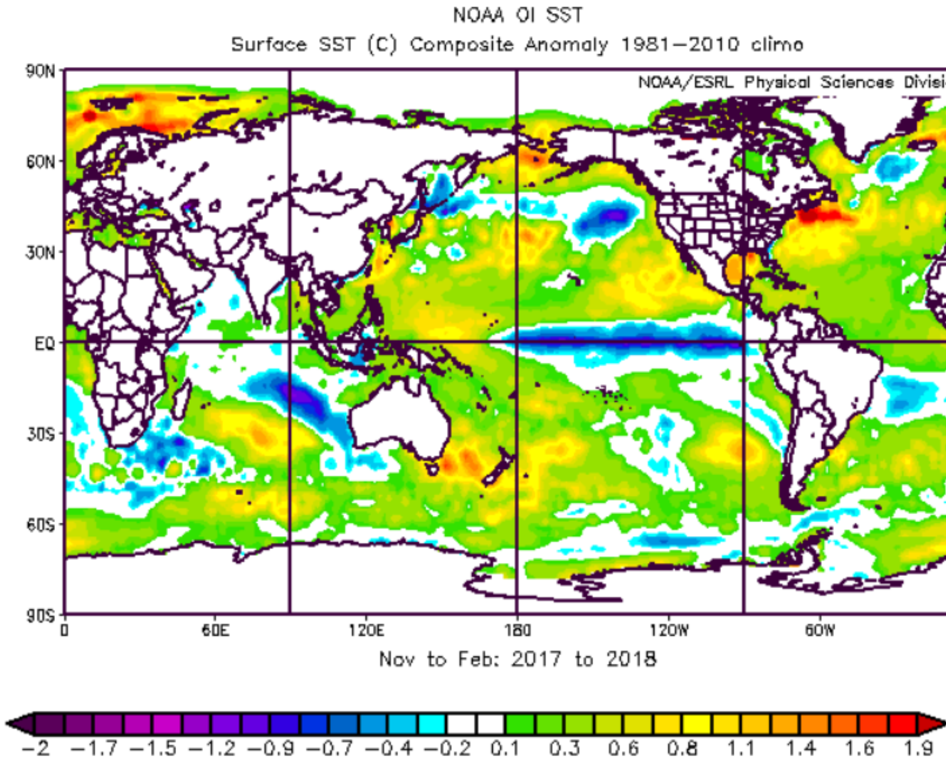


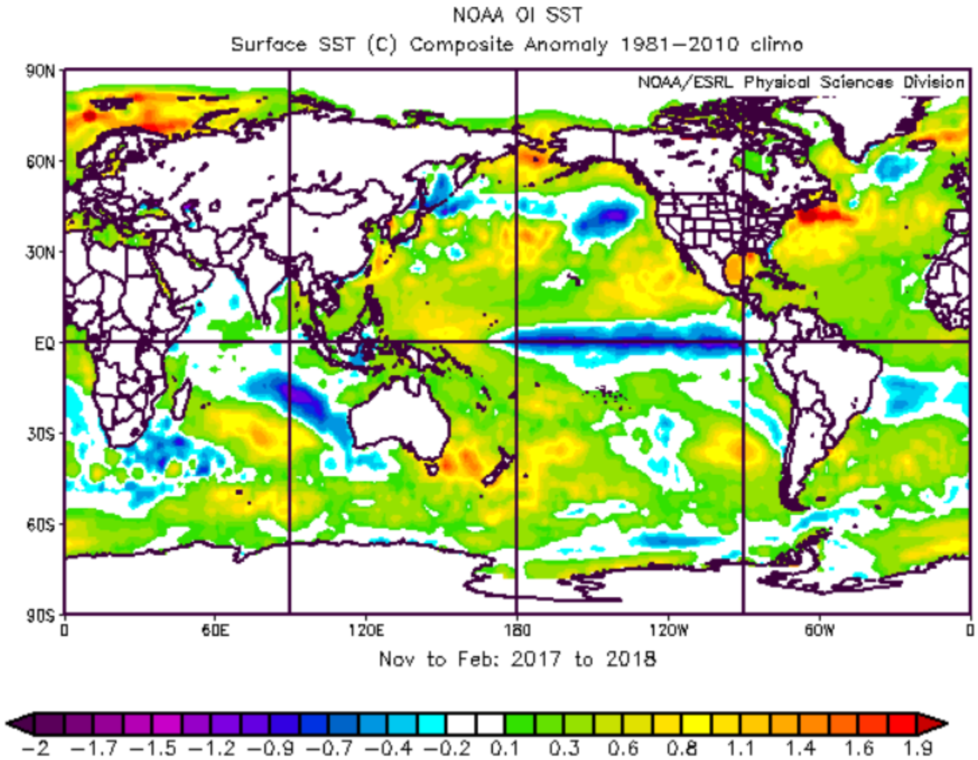
Figure 15. The average length (blue bars) and condition (K, red diamonds) of juvenile Sockeye salmon identified as Chilko stock in 2014-2016.

Northeast Pacific Ocean Conditions and Observations: 2016-2018

- The marine heatwave in the GOA was a dominant feature of this region from 2013 to early 2016, but disappeared from surface waters by fall 2016. Relatively warm subsurface temperatures persisted at depths of 100-200 m through 2016, and dissipated during 2017 to early 2018 (



- Figure **16**) (Ross 2017, Ross and Robert 2018).
- A strong El Niño event at the beginning of 2016 influenced the annual global temperature and 2016 became the warmest year in the U.S. National Oceanic and Atmospheric Administration's (NOAA) 137-year time series (Ross 2017). By the summer of 2016, the El Niño event had weakened, and transitioned to cooler La Niña conditions by the end of 2016.
- In early 2017, cooler sea surface temperatures in the NE Pacific were associated with La Niña conditions in the equatorial Pacific. The El Niño/Southern Oscillation (ENSO) index indicated neutral conditions from February until the fall when below-average sea surface conditions again indicated the presence of a strengthening La Niña. As of February 2018, the La Niña was still in place but was weakening, with a 55% chance of ENSO-neutral during March-May, 2018 (https://www.climate.gov/enso) (



- Figure **16**).
- In 2016, physical processes associated with the marine heat wave started to revert to more typical conditions that better supported primary production and fish growth, including reduced stratification of the water column and increased upwelling of nutrients to surface waters. In 2017, winter mixing returned to 2011-2013 levels, suggesting that there was a normal nutrient supply in the NE Pacific (Ross 2017, Ross and Robert 2018).
- The timing and magnitude of upwelling-favourable winds along the west coast of Vancouver Island (WCVI) suggest average to above-average upwelling-based productivity in 2016. In 2017, the upwelling of cool, nutrient-rich waters started later than usual, and was not as intense as previous years; however, conditions were still considered somewhat favourable (average to below average) for productivity and fish growth (Hourston and Thomson 2017, 2018).
- The phytoplankton community composition showed a return to a more normal distribution in 2016 and 2017 (Peña and Nemcek 2017, 2018), with the exception of the most offshore stations in 2017.
- In 2016, the zooplankton community continued to exhibit characteristics consistent with warmer ocean temperatures. Samples indicated fewer lipid-rich subarctic and boreal copepods and a greater abundance of lipid-poor southern copepods. In 2017, the zooplankton community continued to exhibit characteristics consistent with warmer ocean temperatures, with a greater abundance of southern copepods but also near-neutral or above-average abundance of subarctic and boreal copepods (abundance varied by region). The 2017 zooplankton community composition was less favourable for fish growth than average, but better when compared to 2016. A greater abundance of the lipid-rich northern copepod species, favourable for fish growth, is expected as ocean temperatures continue to cool (Galbraith and Young 2017, 2018).

- The number of humpback whales observed in B.C. waters continues to increase (Nichol et al. 2017).
- Unusual observations in 2017 (Perry et al. 2017) off the WCVI included:
  - A high abundance of fire salps (pyrosomes) in 2017 from California to B.C. to Alaska.
  - High numbers of juvenile rockfish
  - Large amounts of *Velella velella* at sea and washed on shore
  - Unexplained mortalities of Rhinoceros auklets on Juan de Fuca beaches
  - Isolated die-offs of sea cucumbers and sea urchins

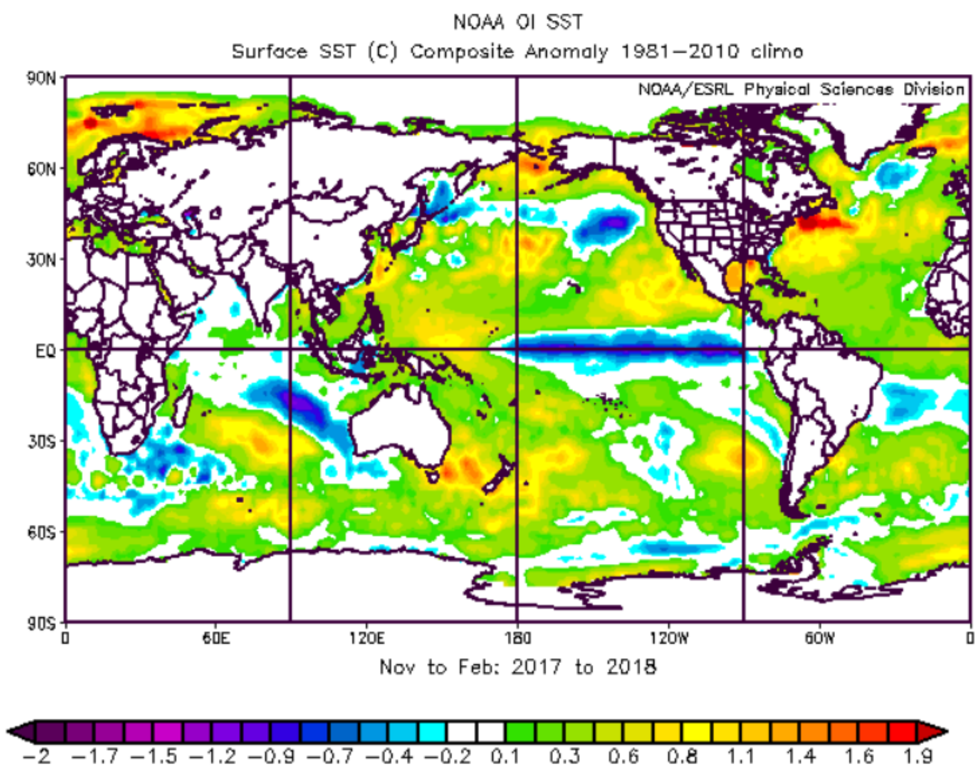


Figure 16. Seasonal maps of sea surface temperature anomalies in the Pacific Ocean for late 2017 to early 2018 (letters in upper left corner of each pane refer to months). The colour bar on the right, showing the temperature anomaly in °C, applies to all panels. Image provided by the NOAA/ESRL Physical Sciences Division, Boulder Colorado from their Web site at http://www.esrl.noaa.gov/psd/.

4.5 EARLY INDICATORS OF SURVIVAL: JACKS, PINKS AND COHO

- The number of jacks returning in 2017 relative to the 2014 brood year escapement, referred to as the relative jack escapement, can be used as a potential indicator of marine conditions and/or survival for the 2018 return. The 2017 relative jack escapement was below the long-term cycle average for all stocks except Quesnel, for which it was similar to the cycle average. Using three-to-four year old return modeled relationships, jack returns in 2017 indicate below average survival for Chilko, Quesnel, and Late Shuswap in 2018.
- Although the number and condition of juvenile Pink salmon in the SOG in 2016 were both above average, returns to the Fraser River in 2017 were poor, suggesting poor conditions once the fish left the nearshore environment.

4.6 PROPORTIONS OF STOCKS OBSERVED THROUGH SAMPLING PROGRAMS

- We compared proportions of five dominant lake-type Sockeye stocks on the 2018 cycle line across sampling programs to evaluate the consistency of observed relative abundances across life stages (Figure 17). Proportions were examined for the 2014 brood year escapements, outmigrating smolts at Mission, B.C. in spring 2016, Discovery Island purse seine samples from early May to mid-July 2016, SOG trawl survey samples collected in July 2016, and the four-year-old forecasts for 2018. Stocks were selected according to their order of prevalence in the sampling programs, and include Late Shuswap, Chilko, Quesnel, Stellako, and Early Shuswap (Scotch, Seymour, and miscellaneous Early Shuswap stocks) (Figure 17). All other stocks were removed from calculations of stock proportions for each sampling component.
- This year in particular there are major caveats to interpreting proportions derived from the Mission juvenile smolt program, and the SOG trawl surveys.
    - Stock proportions at Mission are challenging to interpret given the need to maintain a consistent water velocity at the trap mouth (1.0 m/s) paired with the steady increase in discharge experienced in the Fraser River as the study progressed. Stock proportions have not been adjusted for the inverse relationship between the proportion of water volume sampled and discharge at Mission, and should be considered preliminary pending this correction. As a result, proportions of stocks that predominately migrate early in the migration season, such as Quesnel in 2016, may be biased high, and proportions of stocks that predominately migrate later in the migration season, such as Shuswap Complex, may be biased low. Similarly, sampling must be corrected for locational differences in flow within the channel, which may affect proportions if stocks differ in their horizontal distribution within the water column. Lastly, fewer runs were conducted on survey days with higher catches, due in part to catch processing delays. This processing limitation potentially biased stock proportions low for stocks encountered on these survey days, and subsequently biased proportions high for

stocks not encountered on these days. Surveys were also only performed every fourth day, which differs from the study design followed in previous years, and may have biased the representative sampling of stocks.

  - The 2016 SOG trawl survey was delayed by approximately two weeks to July 4-15 due to the breakdown of the research vessel, *W.E. Ricker.* Hence, sampling took place towards the tail end of the Fraser Sockeye juvenile migration, when only ~10% of juveniles remain in this area, and therefore was biased towards later migrating stocks.

- Late Shuswap dominated the key stocks observed in all sampling programs apart from the Mission smolt survey. Of the five stocks compared, Late Shuswap represents 40% of the 2014 effective female spawner abundance, 50% of the 2016 Discovery Islands seine samples, 61% of the 2016 SOG trawl surveys, and 55% of the 2018 age-4 forecast. These proportions were as expected, based on the large brood year escapement in 2014, and the average-to-above-average freshwater survival observed in Shuswap Lake. Interestingly, this stock was not captured in substantial numbers at Mission, making up only 9% of the abundance across the five selected stocks (Figure 17). This may be due to biases in the Mission samples introduced by seasonal discharge patterns, and processing limitations, as described above.

- Early Shuswap stocks followed the same pattern of observations as the Late Shuswap, though in smaller proportions. Early Shuswap stocks make up roughly 10% of the selected stocks across sampling programs except Mission, where they comprise only 1% (Figure 17). Again, this may be due to the biases described for the Mission program.

- Based on effective female spawners and the age-4 forecasts, Chilko is the second largest contributor to this cycle line. However, juvenile sampling programs at Mission and in the SOG and Discovery Islands encountered higher proportions of Quesnel Sockeye in 2016 than Chilko Sockeye. In fact, a very large proportion of Quesnel Sockeye was caught at Mission in 2016, making up 54% of the catch in relation to the other four selected stocks, though this is likely biased high by the seasonal discharge patterns as described. Higher than expected proportions of Quesnel fish caught in the SOG and Discovery Islands sampling programs reinforce the notion that freshwater survival of Quesnel Sockeye was high for the 2014 brood year, aligning with the record high EFS-to-fall fry survival estimate for this system (Figure 17). However, note that the average lipid content of sampled outmigrating Quesnel smolts was the lowest of all stocks surveyed, falling at 2.4%, while 20% of those sampled fell below the 2% critical threshold.

- Chiko Sockeye were observed in higher proportions than expected at Mission in 2016, likely skewed by the biases already discussed, and slightly lower proportions in the SOG and Discovery Islands (Figure 17). Smolt outmigration data from the Chilko fence estimated below-average freshwater survival, due to density-dependent effects from the large brood escapement in 2014. Therefore, it is not unexpected that the SOG and Discovery Islands programs sampled smaller proportions of Chilko Sockeye than observed on the spawning grounds. Also note that samples of Chilko smolts leaving Chilko Lake were smaller than average and of poor condition according to their lipid levels, with 27% of samples falling below 2%.

- Stellako Sockeye were not observed in any of the smolt sampling programs in the proportions expected based on the EFS or the 2018 forecast (Figure 17). We have no lake or smolt survival data from Stellako to further inform these observations.

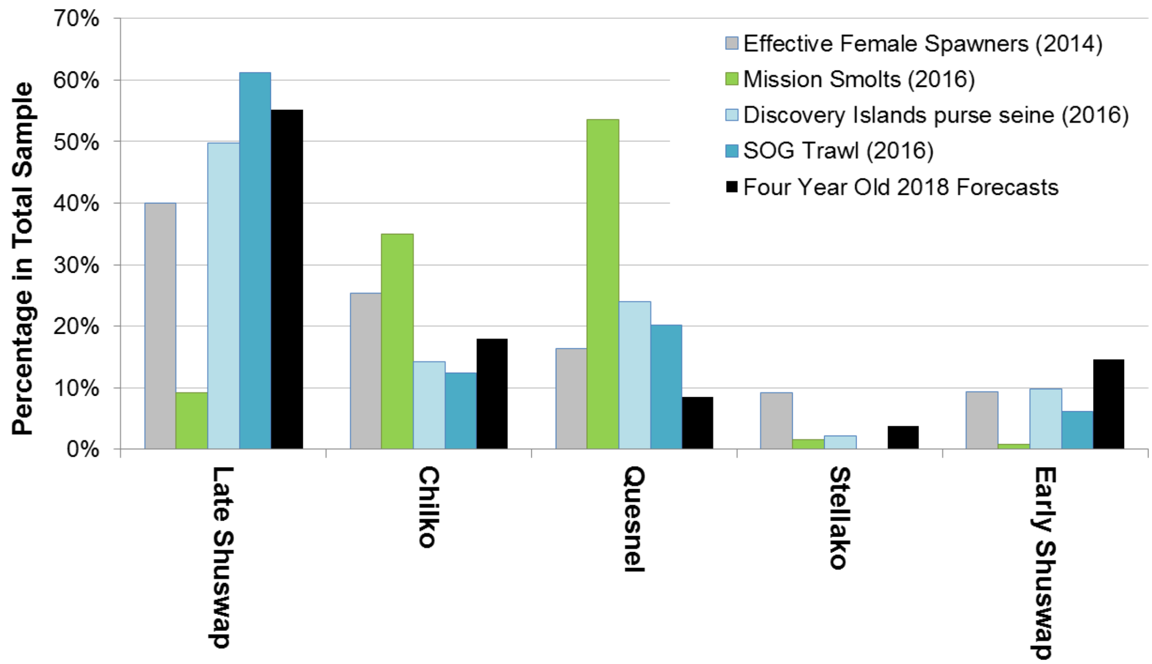


Figure 17. Proportions of the five most dominant Fraser Sockeye stock groups expected to return in 2018, caught in five sampling programs throughout their life history. Effective female spawner proportions are from the 2014 brood year parental generation, while Mission smolts, Discovery Island purse seine, and SOG trawl proportions are measured for outmigrating smolts caught in 2016 at these locations. Four-year-old 2018 forecasts were produced using various model forms and are described in DFO (2018).

5 KNOWLEDGE GAPS AND FURTHER WORK

5.1 BROOD YEAR SPAWNERS AND EGG STAGE

- En-route loss and pre-spawn mortality are accounted for in the run size forecasts, but a better understanding of the contribution of intergenerational effects on offspring would help link brood year experience to future recruitment.
- Limited data on incubation temperatures and discharge are available. This is especially critical for spawning populations that utilize systems not dominated by the moderating influence of upstream lakes, such as Early Shuswap populations.
- More information on the shear stress from peak river flows events is required for bedload movement in specific systems is necessary for the assessment of redd scouring events and survival implications.
- Improvements are needed in our understanding of the impacts of adult migratory experience in the Fraser River - particularly timing, fish condition, temperatures, and flows - on survival, as reflected by en-route mortality, success of spawn, gamete quality, egg to fry survival, fry and smolt condition, and abundance.

5.2 JUVENILE FRESHWATER STAGE

- Currently there is limited information on the following, all of which require further research:
    - upstream fry migration challenges due to high discharge for those populations that migrate upstream (e.g. Chilko, Weaver) from spawning locations to lakes
    - littoral zone habitat as a function of lake water levels and their relative importance to overall juvenile freshwater survival
    - the impacts of overall winter air temperature on overwinter fry survival
- Additionally, there is no standard metric for quantifying variation in length of growing season among lakes and across years
- Juvenile Sockeye experience high mortality during their freshwater residence phases from egg to fry (87%) and from fry to smolt (74%) (Quinn 2005), highlighting the importance of abundance estimates at early life stages. Currently Chilko Lake represents the only wild Sockeye stock in the Fraser River watershed where survival can be partitioned into freshwater and marine components. However, Chilko Lake is a unique system that is not representative of other Sockeye nursery lakes in the Fraser River watershed. Additional juvenile monitoring (fry and smolt) for condition and abundance in other key nursery lakes in the Fraser watershed would provide information on the survival (freshwater and marine) and population and ecosystem dynamics for these systems. Our ability to assess abundances of juvenile Sockeye during their residence in nursery lakes is limited by budgets and capacity, and requires the identification of priorities on an annual basis. As a result, many lakes are assessed infrequently, and some are not

assessed at all. We recommend increased assessments as permitted by capacity and budgets.

- Additional work on the effects of fry size and condition on later life-stage survival is important to understanding the dynamics of Fraser River Sockeye returns

5.3 JUVENILE DOWNSTREAM MIGRATION

- Conduct additional lake-outlet juvenile downstream assessments like those for Chilko and Cultus stocks. Focus should be on assessing stocks most likely to contribute to the current year juvenile outmigration and capture at Mission. Additional health and abundance assessments from lake-outlets would further our capacity to predict total Fraser Sockeye outmigration abundance and subsequent marine survival.
- It is necessary to complete the data adjustments required to account for the known parameters that bias stock composition and ocean entry estimates from Mission juvenile catch estimates. Additionally, improvements could be made to the study design by incorporating currently existing technologies to accurately measure these parameters in future studies.
- Further work on the impact of juvenile abundance entering the SOG on marine survival is another interesting but unstudied factor. If we presume the marine environment, in a given year, is the best it could be, there are two outcomes: either that strong abundance has no effect on marine survival, or the abundance saturates/overwhelms even the most favourable habitat capacity, decreasing marine survival.
- Additional knowledge gaps exist in the following areas, all of which require further research:
    - Proximate environmental or biological cues for outmigration timing of smolts, particularly temperature and discharge metrics.
    - Inter and intra-population differences in outmigration timing and therefore environmental experience
    - Critical energy condition levels in relation to starvation risk, burst swim performance, sustained swim performance, and potential interaction with disease.
    - Influences of different migratory corridors (lakes versus rivers, availability of discharge and thermal refugia, predation risk, turbidity) on migration timing and survival.
    - The potential relevance of high encounter velocities on physical damage to smolts (washing machine effect).
    - Quantifiable links between outmigration conditions and survival. We have observed deviations from the norm, but are not confident in the net effect on freshwater migration survival.

5.4 MARINE ENTRY TO RETURNING ADULTS

- A knowledge gap exists in terms of how the recent increase in the frequency of unusual observations in the physical (e.g., marine heat wave) and biological environment (e.g., doliolids in 2016, pyrosomes in 2017) affect the survival of pelagic fish species (such as juvenile salmon and Pacific Herring) in the NE Pacific.
- Research is required to understand the trophodynamic interactions and linkages among juvenile salmon, age-0 herring, other small pelagic forage fishes, and zooplankton (timing and magnitude, and species composition) in the SOG. For example, age-0 herring could potentially be: 1) competitors for zooplankton with juvenile Sockeye, Chum, and Pink salmon, 2) prey for juvenile Chinook and Coho salmon, and/or 3) a buffer to predation. Understanding these interactions would elucidate factors that can affect fish survival in the SOG.

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