State of the Salmon: Informing the survival of Fraser Sockeye returning in 2019 through life cycle observations

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STATE OF THE SALMON:

INFORMING THE SURVIVAL OF FRASER SOCKEYE RETURNING IN 2019 THROUGH LIFE CYCLE OBSERVATIONS

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ABSTRACT

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The 2019 Fraser Sockeye Science Integration workshop brought experts together to compile and integrate environmental and biological observations spanning the life cycle of four year old Fraser sockeye returning in 2019. The goals of this process are to improve our understanding of factors influencing Fraser Sockeye survival, and to provide advice on survival and abundances of these stocks in the upcoming return year. This process concluded that the four year old Fraser Sockeye cohort returning in 2019 will continue to exhibit survival that is lower than the 64 year average.

Experts reported on conditions in ecosystems occupied by this 2019 return cohort during their parental upstream migration and spawning, overwinter egg incubation, freshwater rearing, downstream migration, entry into the Strait of Georgia (SOG), and marine migration and rearing in the Northeast Pacific. Experts identified biological and environmental highlights by life stage, and discussed their potential impacts on life stage survival of the four year old 2019 Fraser sockeye cohort. The group then discussed overall impressions of survival across observations, relative to the official Fraser Sockeye return forecast. This report presents the observations discussed, and their predicted implications for survival.

Four year old Fraser sockeye returning in 2019 experienced notably warm conditions through most of their freshwater residence. This includes well above average Fraser River temperatures during the upstream migration of their parents, and warm water temperatures during egg and juvenile freshwater rearing stages. During the winter prior to their downstream migration as smolts, some environments encountered by the 2019 return cohort transitioned to more typical conditions. Freshwater temperatures and hydrology patterns were closer to average, and some physical and biological processes in the Northeast Pacific Ocean began to transition to more favourable conditions for fish growth. However, similar to the previous few years, warm water southern species continued to dominate the zooplankton composition in nearshore and offshore Vancouver Island surveys, providing a sub-optimal food source, compared to cold water northern zooplankton species.

Conditions observed over most of the life cycle of the four year old 2019 returns are very similar to those experienced by the majority of Fraser sockeye that returned in 2017 and 2018, which exhibited poor survival. From this information, we predict that four year old returns will fall between the 25% and 50% probability levels of the aggregate forecast, excluding Harrison, ranging from 2.0 to 3.4 million. This prediction is slightly more optimistic than the 2018 prediction, since some conditions in the later life-stages of the 2019 Fraser sockeye cohort show improvements over recent years. Nuanced responses are anticipated across populations, though generally survival will be below average.

RÉSUMÉ

MacDonald, B.L., Grant, S.C.H., Patterson, D.A., Robinson, K. A.., Boldt, J.L., Benner, K., King, J., Pon, L., Selbie, D.T., Neville, C.E.M., and J.A. Tadey. 2019. State of the Salmon: Informing the survival of Fraser sockeye returning in 2019 through life cycle observations. Can. Tech. Rep. Fish. Aquat. Sci. 3336: V + 60 p.

L'atelier d'intégration scientifique sur le saumon rouge du Fraser de 2019 a réuni des experts pour compiler et intégrer les observations environnementales et biologiques couvrant le cycle vital des saumons rouges du Fraser de quatre ans remontant en 2019. Ce processus a pour objectifs de mieux comprendre les facteurs qui influent sur la survie du saumon rouge du Fraser et de fournir des avis sur la survie et l'abondance des stocks au cours de la prochaine année de montaison. Ce processus a permis de conclure que le taux de survie de la cohorte de saumons rouges du Fraser de quatre ans remontant en 2019 demeurera inférieur à la moyenne sur 64 ans.

Les experts ont décrit les conditions dans les écosystèmes occupés par la cohorte de 2019 pendant la montaison et la fraye dans la rivière natale, l'incubation des œufs en hiver, la croissance en eau douce, l'avalaison, l'entrée dans le détroit de Georgie (DG) et la migration et la croissance dans le Pacifique Nord-Est. Les experts ont défini les faits saillants biologiques et environnementaux par stade biologique et discuté de leurs impacts potentiels sur la survie à chacun des stades de la cohorte de saumons rouges du Fraser de 2019 âgés de quatre ans. Le groupe a ensuite discuté des impressions générales concernant la survie à partir des observations, par rapport aux prévisions officielles de la montaison du saumon rouge du Fraser. Ce rapport présente les observations discutées et les répercussions prévues sur la survie.

Les saumons rouges du Fraser âgés de quatre ans remontant en 2019 ont connu des conditions particulièrement chaudes pendant la majeure partie de leur séjour en eau douce, notamment des températures bien supérieures à la moyenne dans le fleuve Fraser pendant la montaison de leurs parents et des températures chaudes de l'eau pendant les stades d'incubation des œufs et de croissance des juvéniles en eau douce. Durant l'hiver précédant leur avalaison en tant que saumoneaux, ces saumons ont rencontré des environnements revenant à des conditions plus typiques. Les températures de l'eau douce et les régimes hydrologiques étaient plus proches de la moyenne, et certains processus physiques et biologiques dans l'océan Pacifique Nord-Est ont commencé à revenir à des conditions plus favorables à la croissance des poissons. Cependant, comme cela a été le cas pendant quelques années antérieures, les espèces propres aux eaux chaudes méridionales dominaient encore la composition du zooplancton dans les zones côtières et hauturières de l'île de Vancouver, offrant une source d'alimentation sous-optimale pour le saumon, comparativement aux espèces de zooplancton des eaux froides nordiques.

Les conditions observées pendant la majeure partie du cycle vital des saumons âgés de quatre ans remontant en 2019 ont été très semblables à celles connues par la majorité des saumons rouges du Fraser qui sont remontés en 2017 et 2018 et dont le taux de survie a été faible. À partir de cette information, nous prévoyons que les montaisons de saumons de quatre ans se situeront entre les niveaux de probabilité de 25% et de 50% des prévisions globales, à l'exclusion du stock de la rivière Harrison, donc entre 2 et 3,4 millions d'individus. Cette prévision est légèrement plus optimiste que celle de 2018, car certaines conditions expérimentées par la cohorte de saumons rouges du Fraser de 2019 aux stades biologiques ultérieurs se sont améliorées ces dernières années. On s'attend à des réactions nuancées dans les populations, bien que le taux de survie sera généralement inférieur à la moyenne.

1 INTRODUCTION

Fraser River sockeye salmon migrate through diverse river, lake, and ocean habitats throughout their life cycle. Most Fraser sockeye exhibit a lake-type life history, spending their first two years of life in freshwater and their last two years in the ocean, returning as four year olds. In 2019, five year olds are expected to contribute a higher than average proportion of total returns. This is due to the large spawner escapement in 2014, which is expected to contribute a relatively large number of five olds compared to the four year old contributions produced by the relatively small spawner escapement in 2015. However, despite the skewed expected age composition in 2019, this report assesses life stage conditions for only the four year old 2019 return, originating from the 2015 brood year. Early life stage conditions for the 2014 brood year, returning as five year olds in 2019, can be found in the 2018 version of this report (See MacDonald et al. 2018).

Most Fraser sockeye begin life as eggs in river or lake gravel, and subsequently rear in lakes as fry. In the ocean, they migrate through the Strait of Georgia (SOG) to reach the Northeast (NE) Pacific Ocean 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, which have ranged from as low as 1.5 million, in 2009, to 30 million, in 2010. As a result, quantitative return forecasts are highly uncertain, characterized by wide probability distributions (DFO 2011, 2012, 2013, 2014a, 2015a, 2016, 2017, 2018, 2019a, MacDonald and Grant 2012).

Fisheries and Oceans Canada (DFO) 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. Expanding our understanding of factors that influence salmon population dynamics will also support fisheries management, and habitat and hatchery enhancement activities. Apart from limited smolt and fry data, and select environmental covariates, life cycle observations are not currently incorporated quantitatively into Fraser sockeye population dynamic models (DFO 2011, 2012, 2013, 2014a, 2015a, 2016, 2017, 2018, 2019a, MacDonald and Grant 2012). 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, the annual Fraser Sockeye Science Integration Workshop, held since 2014 (DFO 2014b, 2015b, 2016b; MacDonald et al. 2018), brings together Fraser sockeye experts within DFO Science and Fisheries Management to present and discuss observations from the various ecosystems that 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 qualitatively predict survival of the upcoming four year old Fraser sockeye return, using expert judgement to integrate observations. 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.

This report compiles the results of the 2019 Fraser Sockeye Science Integration Workshop, integrating life cycle observations for the 2019 Fraser sockeye four year old returns. The workshop, held in Delta, B.C., December 11-12, 2018, was broken up into four sessions that represent four key stages of the 2019 four year old Fraser sockeye life cycle:

- Brood year spawners and egg stage (2015-2016)
- Juvenile freshwater rearing (2016-2017)
- Juvenile downstream migration (2017)
- Juvenile and sub-adult marine rearing (2017-early 2019)

During each session, DFO scientists presented their relevant observations, 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 2019 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 a 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, their confidence in those effects, the predicted significance of those effects on overall survival, and where to go in the document for more information. This section is tailored to those looking for a quick list of the key observations and their presumed effects on Fraser sockeye 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 four year old Fraser sockeye returns in 2019 will exhibit lower than average forecasted survival. Four year old returns are expected to fall between the 25% and 50% probability levels of the aggregate four year old forecast, corresponding to returns between 2.0 and 3.4 million. Nuanced responses are anticipated across populations, but the general survival response relative to forecast will be below average. This survival prediction is slightly improved over the 2018 prediction, due to minor improvements in environmental conditions observed in the later freshwater and early marine stages of the four year old 2019 Fraser sockeye return cohort.

Total Fraser sockeye survival has been below the 64 year average since 2015, with returns consistently falling below the 50% probability level of annual forecasts. Returns were particularly low between 2015 and 2017, falling near, or below, the 10% forecast probability level. Survival of the dominant, four year old, brood years contributing to these returns (2011-2013) fell near or below replacement, measured as 2.0 total recruits per effective female spawner (EFS), across stocks excluding Cultus and Harrison, in each of these years (2011 brood year: 1.7 recruits/EFS; 2012 brood year: 2.1 recruits/EFS; 2013 brood year: 1.1 recruits/EFS). Survival of the 2014 brood year, contributing four year olds to the 2018 return, was slightly improved based on preliminary data (~3.5 recruits/EFS), though still well below average (4.9 recruits/EFS).

This recent period of consistently very low Fraser sockeye survival coincided with warmer than average water temperatures, and concurrent changes in freshwater and marine ecosystems, many of which persisted during the lifespan of the four year old 2019 returns.

Similar to recent returns, much of the freshwater residence of the four year old 2019 Fraser sockeye return cohort coincided with consistently warmer than average conditions. Air temperatures in recent years have set daily, monthly, and annual records (Anslow et al. 2016, Anslow 2017, ECCC data). Parental spawners of the four year old 2019 returns migrated through extremely warm water and low flow conditions to reach their spawning grounds, potentially affecting reproductive development and gamete viability, and/or having carryover effects on juveniles. Warm temperatures continued into the spring of 2016, potentially initiating the growing season early in some areas. Warm temperatures also altered streamflow profiles through rapid snowmelt, shifting the spring freshet early as juveniles migrated to their lakes (Anslow 2017). Impacts of warm freshwater temperatures and associated changes in hydrology on Fraser sockeye spawners to outmigrating smolts potentially range from negative to positive (Table 1), and can be confounded by density-dependent responses. However, generally, highly anomalous conditions have a risk of being negative due to a lack of adaptation to such conditions (D. Patterson, DFO Environmental Watch Program, pers. comm.).

Conditions experienced by the four year old 2019 returns began to diverge from those of recent cohorts towards the latter part of their freshwater residence, as air temperatures cooled across the province in December 2016 (Anslow 2017). The 2019 returns outmigrated in a more typical streamflow profile, with average temperatures leading up to an average timed freshet. By the time Fraser sockeye juveniles reached the marine environment in early 2017, some physical processes and biological occurrences associated with the 2013-2016 marine heatwave, referred to as 'The Blob', had reverted to more typical conditions (Chandler et al. 2017, 2018). However, deeper NE Pacific waters remained warm until late 2017 (Ross 2017, Ross and Robert 2018), and less nutritious, lipid-poor zooplankton species continued to be prevalent during this period (Galbraith and Young 2017, 2018). Juvenile sockeye sampled in the Strait of Georgia, Johnstone Strait, Queen Charlotte Strait, and Queen Charlotte Sound were above average in condition.

Forecast models typically take into account density-dependent survival, as represented by the historical data. This includes the high density effects of spawners competing for spawning habitat, and juveniles competing for food, on survival to the next life stage. Density-independent factors affecting survival have been challenging to incorporate effectively into most forecast models for Fraser sockeye (MacDonald and Grant 2012; DFO 2017, 2018). These include effects of ecosystem conditions on salmon survival, independent of salmon densities. Current forecast models, including those with covariates, produce very uncertain forecasts, characterized by wide probability distributions.

Although sea-surface temperature (SST) covariates were used to inform survival of some stocks in the 2019 forecast, they had little effect on the forecasts. This is likely because, in the forecast process, SSTs from the juvenile ocean migration period are applied as covariates, and in the winter-spring of 2017 SSTs were generally not anomalously warm. These 2017 SSTs do not reflect the warmer temperatures measured in deeper marine waters, the continued predominance of lipid-poor, less nutritious zooplankton species in the NE Pacific, or the anomalously warm freshwater conditions experienced by the 2019 four year old cohort prior to ocean entry.

This qualitative integration process attempts to capture such nuanced observations across life-stages, to reduce uncertainty in the quantitative forecast. This process did not simply add up negative and positive observations. Instead experts discussed observations and their individual conclusions about survival, based on their own integration and weighting, supported by published empirical relationships. Weighting of individual observations is not formalized and likely differs between participants. However, during plenary, individual opinions and processes were discussed as participants came to consensus on overall survival.

Given the similarity of conditions encountered by the 2019 four year old return cohort to the most recent returns, workshop participants concluded that survival in 2019 would likely fall below average. Participants noted the warm freshwater conditions and associated effects during the early life stages, and the continuation of less favorable marine conditions for fish growth in terms of zooplankton composition, as significant influences on the determination of poor survival. Participants agreed that observations for the 2019 cohort slightly improved over the most recent two cohorts, returning in 2017 and 2018. Therefore, the group concluded that returns will likely fall between the 25% and 50% probability levels of the official forecast. Participants also noted that though observations appeared slightly improved over the most recent two four year old return cohorts, there has been a trend of consistently lower than average survivals in recent years, which must be taken into consideration.

Ecosystems relied upon by Fraser sockeye are changing rapidly as the effects of global climate change become more prevalent, and unusual events become more frequent. In recent years, all participants of this process have observed profound events or changes in the ecosystems and salmon life-stages they assess. It was generally agreed within the group that with climate change, conditions that salmon experience are no longer ‘normal’ in comparison to historic conditions. Meaning, as climate change proceeds, baselines will also change, and we are less likely to observe conditions that were historically more common.

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 value of current monitoring of salmon and their ecosystems to better understand the impacts of environmental change on salmon survival. This is critically important, as we need to improve not only short term forecasts, but longer term predictions of the broad-scale responses of salmon populations to a changing climate. This is needed to align our fisheries management, salmon recovery, and habitat restoration activities now to future salmon production and biodiversity.

We continue to have major gaps in many of our salmon and ecosystem research and monitoring programs. These include conspicuous gaps in our freshwater lake and stream monitoring programs, non-sockeye salmon species, and marine ecosystem monitoring. New and expanded monitoring in these areas of research will provide valuable information to help ensure sustainability of salmon stocks into the future.

Note that Fraser sockeye returning to the upper watershed in 2019 will be further impacted by a significant landslide that occurred in the Fraser River at Big Bar, B.C. prior to June 23, 2019. Impacts of this landslide have not been incorporated into this report, and may affect the numbers and/or condition of spawners that reach the spawning grounds above the slide site in 2019. This landslide affected a narrow portion of the river, creating a 5 meter waterfall, limiting passage upstream (DFO 2019b, Government of B.C. et al. 2019). As of August 26, 2019 sockeye began to successfully swim past the blockage, enabled by lower water levels and rock scaling to restore the passage (Government of B.C. et al. 2019). Prior to this date, approximately one quarter of sockeye that arrived at the slide site were transported upstream manually by helicopter (Government of B.C. et al. 2019). This obstacle may impact spawners from areas north of the slide, specifically the Takla-Trembleur-Early Stuart, Bowron-ES, Nadina-ES, Taseko-ES, Chilko-S, Late Stuart-S, Quesnel-S, and Stellako-S CUs. It is likely that the only spawners that will reach the spawning grounds of the earliest-timed populations, Takla-Trembleur-Early Stuart, and Bowron-ES, will be those that were manually transported (Government of B.C. et al. 2019).

Highlights below are organized into two tables. Table 1 shows general highlights assumed to affect most or all Fraser sockeye stocks. Table 2 presents highlights specific to certain stocks, organized by run timing group. Highlights are listed with associated categories of effects, confidence levels, and significance, based on expert opinion, as follows:

Column 1: Effect: Negative, Neutral, Positive, Variable

Column 2: Confidence in this effect: Possible, Likely, Very Likely

Column 3: Significance of the effect: General effect across stocks Low, Medium, High, and Incorporated (this means this consideration was included in the quantitative forecast model)

Column 4: Page number for more information.

Details that correspond with the highlights below are in subsequent sections.

Table 1. General highlights for Fraser sockeye stock survival. Columns include expert opinion of potential effect of observation on survival within life stage, confidence of effect within life-stage, significance of effect relative to impact on run size forecast, and page number for more information. Note that significance of effect is subjective.

Overall	**Effect**	**Confidence**	**Significance**	**Page #**
Fraser Sockeye Survival	**Negative**	**Likely**	**NA**	NA
Brood Year Spawners and Egg Stage (Summer/Fall 2015-Spring 2016)	**Effect**	**Confidence**	**Significance**	**Page #**
• Fraser River discharge was below average at Hell's Gate during adult migration of all run timing groups	Neutral	Very Likely	Low	24
• Fraser River temperatures were above average during adult migration for most populations; most Early Stuart, Early Summer, and Summer populations experienced particularly warm conditions above 19°C	Negative	Very Likely	Medium	24
• Spawning ground water temperatures for most populations were favourable during spawning	Positive	Likely	Low	24
• Sockeye reported to be in good condition on spawning grounds in most areas, with some stream-specific exceptions	Positive	Likely	Low	24
• Mean overwinter air temperatures were 1-3°C above average, and 3-5°C above average in Jan/Feb, though no incubation issues were reported for major stocks	Neutral	Possible	Low	27
Juvenile Freshwater Rearing (Spring 2016-Spring 2017)	**Effect**	**Confidence**	**Significance**	**Page #**
• Early onset of spring freshet, producing record discharge levels in April, and average to below average discharge in May and June	Positive	Possible	Low	28

	Effect	Confidence	Significance	Page #
• Warm spring 2016 air temperatures likely lengthened the growing season in some areas	Positive	Possible	Low	29
• Winter 2016-2017 air temperatures below normal, then normal in spring 2017 likely providing normal feeding opportunities for pre-smolt growth in Shuswap and Cultus, where this is known to occur	Neutral	Possible	Low	30

Smolt Downstream Migration (Spring 2017)	**Effect**	**Confidence**	**Significance**	**Page #**
• Normal timing of Fraser River spring freshet, with above average early June flow; average temperatures in major tributaries	Neutral	Possible	Low	32
• Populations experienced different levels of discharge based on their migration timing	Variable	Possible	Low	32
• Aggregated sockeye smolt migration past Mission, B.C. was slightly later than previous years (since 2012), and stocks migrated with similar timing apart from Nahatlatch & Stellako	Neutral	Possible	Low	37

Juvenile Marine Rearing (Spring 2017-Summer/Fall 2019)	**Effect**	**Confidence**	**Significance**	**Page #**
• In 2017 physical processes associated with the marine heat wave of 2013-2016 had begun to revert to more typical conditions	Neutral	Possible	Low	43
• Surface waters cooled in the SOG, whereas, depth-averaged temperatures were still warm compared to the climatology. Salinities were slightly fresher than the climatology during summer	Negative	Likely	High	38
• Winter mixing return to 2011-2013 levels in 2017, suggesting a normal nutrient supply in the NE Pacific	Neutral	Likely	Low	44
• Timing and magnitude of upwelling of nutrient rich waters on the west coast of Vancouver Island were average to below-average for productivity and fish growth	Negative	Likely	Low	44

• Timing of the spring phytoplankton bloom in the SOG was typical in 2017, though it was short in duration and moderate in magnitude. Species composition was typical.	Positive	Likely	Low	38
• Zooplankton composition still dominated by lipid poor, less nutritious species throughout NE Pacific	Negative	Likely	High	44
• Zooplankton biomass in the SOG increased to slightly higher than average in 2017. Common prey species had positive anomalies; however gelatinous zooplankton also had positive anomalies.	Neutral	Likely	Low	39
• Size and condition of juvenile sockeye in the SOG trawl surveys were above average for this cycle	Positive	Likely	Medium	39
• Migration timing through the Discovery Islands was similar to 2010-2014	Neutral	Possible	Low	39
• Condition of juvenile sockeye in Johnstone Strait, Queen Charlotte Strait, and Southern Queen Charlotte Sound (weight residuals) was positive.	Positive	Likely	Low	42
• La Nina conditions had largely dissipated by May 2018. A warm SST anomaly returned in June-November, 2018, affecting the entire NE Pacific. This was due to anomalously high sea level pressure (August-October) that delayed cooling of SSTs. Late in 2018, the ENSO index became weakly positive, associated with a weak El Niño. In January 2019, ENSO-neutral conditions were observed at the equator. El Niño is expected to form and continue through the Northern Hemisphere spring 2019 (~65% chance).	Negative	Likely	High	43

Table 2. Stock-specific highlights of survival. Columns include expert opinion of potential effect of observation on survival within life stage, confidence of effect within life-stage, significance of effect relative to impact on run size forecast, and page number for more information. Note that significance of effect is subjective.

Stream-Specific Observations

Brood Year Spawners and Egg Stage (Summer/Fall 2015-Spring 2016)		**Effect**	**Confidence**	**Significance**	**Page #**
<u>Run-Timing Group</u>					
Early Summer	• Extreme high flows experienced in Gates, Chilliwack, Nahatlatch, and South Thompson areas	Negative	Possible	Low	24
	• *Ich (Ichthyophthirius multifiliis)* confirmed in Nadina	Negative	Likely	Low	24
	• Gates Creek spawners showed signs of lower ions levels and higher glucose, consistent with observations of above average eyed-egg survival	Positive	Likely	Low	25
Summer	• Chilko spawners plasma ion and metabolite values were within normal ranges	Neutral	Likely	Low	25
	• Harrison spawners plasma ion and metabolite values were within normal ranges	Neutral	Likely	Low	25
	• Harrison survival to eyed-eggs was very poor, though possibly confounded by poor water quality conditions	Negative	Possible	Medium	25
Late	• A natural landslide, caused by extreme rains, blocked flows in Portage Creek for 4 days in late September	Negative	Possible	Low	24
	• Extreme high flows were experienced in Lillooet-Harrison and South Thompson areas	Negative	Possible	Low	24

Juvenile Freshwater Rearing (Spring 2016-Spring 2017)		Effect	Confidence	Significance	Page #
Early Summer	• Nadina: average egg-to-fry survival in spawning channel (incorporated into Nadina forecast through fry-based model)	Neutral	Likely	Incorporated	27
	• Gates: average egg-to-fry survival in spawning channel	Neutral	Likely	High	27
Summer	• Chilko: record high river discharge in spring 2016 likely posed migration challenges to fry migrating upstream to Chilko Lake (freshwater survival incorporated into forecast through smolt model)	Negative	Possible	Incorporated	28
	• Chilko: freshwater survival was well above expected (smolts/EFS), as was smolt size, suggesting good rearing conditions in Chilko (freshwater survival incorporated into forecast through smolt model)	Positive	Very Likely	Incorporated	31
	• Quesnel: above average egg-to-fall fry survival, however this estimate is biased high due to inclusion of age-0 Kokanee	Neutral	Likely	Low	29
Late	• Weaver: record high river discharge in spring 2016 likely posed migration challenges to fry migrating upstream to Harrison Lake	Negative	Possible	Low	28
	• Weaver: slightly below average egg-to-fry survival in spawning channel (not incorporated into Weaver forecast, spawner-based model used)	Negative	Likely	Medium	27
	• Cultus: very poor summer fry-to-smolt in-lake survival (incorporated into forecast through smolt model)	Negative	Very Likely	Incorporated	31

Smolt Downstream Migration (2017)		Effect	Confidence	Significance	Page #
Summer	• Chilko: smolts experienced near average discharge and water temperatures during outmigration	Positive	Possible	Low	33
	• Chilko: smolts migrated out of Chilko Lake with average timing and with similar timing to the previous brood year at Mission	Neutral	Possible	Low	33
	• Chilko: smolts had low lipid levels though better than expected given the brood year abundance. Size at Mission was similar to 2013 brood year	Neutral	Possible	Low	34, 37
Late	• Cultus: smolts migrated out of their rearing lake one week later than average	Negative	Possible	Low	33
	• Cultus: smolts had high lipid levels, which is normal for Cultus. Size at Mission was large compared to other stocks.	Positive	Possible	Low	34, 37
	• Seton: smolts had high lipid values and large body sizes compared to other Fraser populations and years	Positive	Likely	Low	34

3 OVERVIEW (TIER 2)

3.1 BACKGROUND

Fraser Sockeye Life History

Fraser sockeye salmon spawn in rivers, streams, and along lake foreshores in the 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 Fraser sockeye 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 (Clark et al. 2016). They enter the Fraser River estuary and the majority migrate north through the Strait of Georgia (SOG), Johnstone Strait, and along the continental shelf, moving offshore in the fall or winter into the Gulf of Alaska (GOA) (Welch et al. 2009, Tucker et al. 2009). The majority of Fraser sockeye spend an additional winter distributed widely in the Northeast Pacific before returning to their spawning grounds as four year olds. Fraser sockeye return to spawn throughout the summer and fall months, and have been aggregated into four run timing groups based on their spawning location and migration timing through the lower Fraser River: Early Stuart (late-June to late-July); Early Summer (mid-July to mid-August); Summer (mid-July to early-September); and Late (late-August to mid-October).

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). River-type Fraser sockeye will not be covered in this report, given their low forecasted return in 2019.

Review of the 2018 Workshop and Preliminary 2018 Returns

The 2018 Fraser Sockeye Science Integration Workshop correctly predicted that density-independent survival of four year old 2018 Fraser sockeye returns would fall below average. The preliminary total age-4 Fraser sockeye return in 2018 was ~9.4 Million salmon (Steve Latham, PSC, pers. comm.). This return fell between the 25% (8.0 Million age-4 returns) and 50% (12.2 Million age-4 returns) probability levels of the aggregate forecast of four year old returns (DFO Fraser River Stock Assessment). At the individual stock level, most (12 out of 18) returned below their 50% probability level forecasts of four year olds. This included the three key Shuswap stocks, which dominated the 2018 returns, and each fell close to their 25% probability level forecasts.

The qualitative prediction of poor survival for the 2018 four year old returns was based on the anomalously warm temperatures and associated ecosystem conditions this Fraser sockeye cohort experienced throughout their life cycle (MacDonald et al. 2018). Those conditions bore many similarities to those experienced by the 2017 returns, which exhibited very poor survival (2013 brood year: 1.1 recruits/EFS, includes age-4 returns in 2017 and minimal age-5 returns in 2018). Though there is large uncertainty surrounding the specific factors that drive Fraser sockeye survival, workshop participants concluded that survival of four year olds returning in 2018 would likely also fall below average, given the similarities in key ecosystem observations noted for the age-4 cohorts returning in 2017 and 2018 (MacDonald et al. 2018).

The 2018 science integration process (MacDonald et al. 2018) predicted that four year old returns would fall towards the lower end of forecast distributions (DFO 2018), in cases where temperature covariates were not incorporated into the forecasting models, or did not have a significant effect on reducing forecasts. This applied to 90% of Fraser sockeye forecasts, and included forecasts for the dominant Shuswap stocks (Late Shuswap, Scotch, Seymour, and Early Shuswap miscellaneous), as well as Upper Barriere, Gates, Nadina, Pitt, Late Stuart, Stellako, Harrison, and Portage.

Temperature covariates were used to produce forecasts for the 10% of the total aggregate. The effects of warm SSTs were incorporated into these predictions, based on the historical relationship between SSTs during ocean entry and stock survival. However, forecasts that incorporated SSTs at Pine Island were deemed particularly uncertain (Bowron, Chilko, and Cultus), as models were forecasting outside of their range of fitted data for this temperature metric (DFO 2018).

Four year old returns for six stocks fell at or above their 50% probability level forecasts, of which three were forecast using temperature covariates, which substantially pulled down their forecasts (DFO 2018). Had environmental covariates not been used to produce these forecasts, returns would have fallen below the 50% probability level for these stocks (DFO 2018). This provides evidence that warm SSTs correctly indicated poor Fraser sockeye survival for these stocks.

Four year old returns in 2018 were strongly dominated by the Late Shuswap stock, as anticipated (Figure 1). However, the 2016 juvenile sampling project in the lower Fraser River at Mission unexplainably picked up a much smaller proportion of Late Shuswap fish than anticipated. Quesnel made up the second largest proportion of the return, which was indicated by the three juvenile sampling projects in the lower Fraser River at Mission, the Strait of Georgia, and the Discovery Islands, all of which caught higher proportions of Quesnel fish than Chilko (Figure 1). The preliminary Quesnel return estimate came in higher than the 50% probability forecast (~75%), which was produced using an environmental covariate that strongly influenced this forecast. Alternatively, the Chilko return fell somewhat lower than the 50% probability forecast for this stock (~25%), making up a smaller proportion of the return than Quesnel, which was indicated by the SOG and Discovery Island surveys, though was not corroborated by the Mission juvenile survey (Figure 1). Stellako and Early Shuswap returns both came in lower than their median forecasts. The low returns of Stellako relative to other stocks was signaled by the sampling programs (Figure 1).

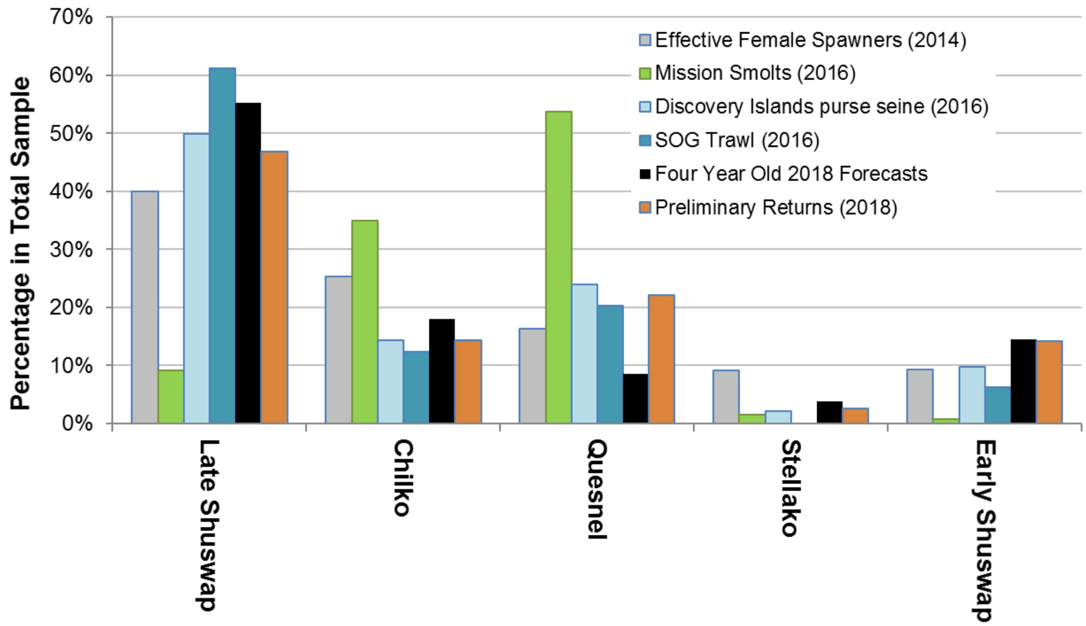


Figure 1. Proportions of dominant Fraser sockeye stocks contributing to the 2018 return, measured through six sampling programs, including preliminary return estimates. Effective female spawner proportions from the 2014 brood year, smolt out-migration in the Fraser River at Mission in 2016, summer juvenile trawl sampling in the Strait of Georgia in 2017, purse seine juvenile surveys in the Discovery Islands in 2017, official four year old forecasts at the 50% probability level (DFO 2018), and preliminary 2018 return estimates derived for stocks using preliminary return data and preliminary 2018 escapements (Steve Latham, PSC; Keri Benner, DFO).

Fraser Sockeye Pre-season Four year Old Return Forecasts for 2019

The 2019 forecast of four year old Fraser sockeye returns ranges from 2.0 million to 6.4 million at the 25% to 75% probability levels, excluding Harrison. The 50%, median, forecast is 3.4 million (Yi Xu, Fraser River Stock Assessment, pers. comm.).

Most models used to generate four year old forecasts are biological, and incorporate the effects of density on the survival of a cohort. These models rely on the historical relationship between spawners and returns of a cohort to predict future returns, therefore assuming that past conditions reflect the future. However, similar to the past few years, this assumption may not be entirely valid for the 2019 forecast, due to the anomalously warm regional conditions observed in recent years.

Models that incorporate SST covariates perform well across the entire time series for eight stocks. For all of these stocks the addition of the covariates improves model performance over the base model in warmer than average years, and produces lower forecasts (DFO

2017).

For 2019, temperature covariate models were used to generate 83% of the total forecast of four year old returns (excluding Harrison), due to the dominance of Chilko in the forecast (DFO 2019a). However, these models did not have a large effect on the total forecasted abundance, reducing it by only 7%. Forecasts were not largely impacted by the temperature covariates because, apart from the SSTs at Pine Island, which were the third highest on record, SST indices used to forecast Fraser sockeye were not highly anomalous in winter-spring 2017. This includes the April to June average SSTs at Entrance Island, B.C., and the standardized winter (Nov-March) Pacific Decadal Oscillation index (DFO 2019a).

3.2 BROOD YEAR SPAWNERS AND EGG STAGE: SUMMER/FALL 2015 - SPRING 2016

The parental generation of the 2019 Fraser sockeye four year old return cohort predominantly encountered high in-river water temperatures during their upstream migration in 2015. Very warm river temperatures were associated with above-average air temperatures and below average precipitation, which prevailed throughout the Fraser basin in the summer of 2015 (based on data from Environment and Climate Change Canada (ECCC) and Pacific Climate Impacts Consortium (PCIC)).

All Fraser sockeye spawners in 2015 encountered below average river flow in the lower Fraser during their upstream migration, with flows approaching a one in 20 year low flow event (Figure 2). Most spawners migrated upstream in water temperatures that were predominantly above 19°C in the lower Fraser River, including populations from the Early Stuart, Early Summer, and Summer run timing groups (Figure 3). The Early Stuart run timing group experienced extreme migratory conditions, with water temperatures falling between 1°C and 5°C+ above average over the course of their migration. Early Stuart spawners arrived on the spawning grounds approximately one week later than normal, and observations suggested that they were in generally good condition. However, spawning success, calculated using female egg retention on the spawning grounds, was below average.

Arrival to the spawning grounds was later than normal and protracted for a few additional stocks from all three remaining run timing groups. DFO’s Fraser Stock Assessment reported that upon arrival at the spawning grounds, water temperatures were favourable for spawning in most areas, while water levels were extremely variable. Many areas had below average water levels in the early summer, while several areas experienced significant high water events. Most notably, a landslide in Portage Creek in September 2015 deposited sediment and debris into this system, blocking flows for four days, and causing considerable changes to the creek. Impacts of this landslide on egg-to-fry survival are unknown.

Spawners appeared to be in good condition in most Fraser areas. Overall spawner success was well above average for the aggregate, at 97% (average: 89%), with some exceptions noted below. Ich (*Ichthyophthirius multifilius)*, an ectoparasite that causes white spot disease, was observed in Nadina sockeye, consistent with low spawning success. Late South Thompson spawners were reported as lethargic, with high pre-spawn mortality, and low spawner success. Early Stuart, Weaver and Cultus also had below average success.

Adult escapement in 2015 was similar to average for this low cycle year, and was dominated by Chilko (56%). Many stocks were skewed towards female spawners, particularly Chilko (65% female), and five-year olds represented a larger than average proportion of the spawners.

DFO's Environmental Watch Program collected biological samples on the spawning grounds of the Harrison River, Gates Creek, and Chilko River in 2015, to further investigate spawner condition. Physiological assessments of spawners from these populations did not indicate anything unusual in terms of plasma ion and metabolite values (Figure 4). Gamete viability, measured as survival to the eyed-egg stage, was above expected values for all but two females of the Gates Creek spawners sampled. Harrison River spawners had very poor survival to eyed eggs; however this was likely confounded by poor water quality (A. Lotto, University of British Columbia, pers. comm.).

At this time, quantifying the effects of parental stress on future year class strength is a challenge. The specific linkages between spawner success, gamete quality, and egg-to-fry survival are not currently quantified. However, exposure of adult salmon 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).

Moving into the overwinter incubation period, mean winter air temperatures for December to February 2015-2016 were 1-3°C above seasonal averages across the Fraser watershed. Further, minimum air temperatures in January and February were 3-5°C above average (ECCC, PCIC). In-river water temperatures are not available for most systems. Early incubation temperature for the Early Stuart system and Gates Channel were average to below average (Gates). However, these data cannot be extrapolated to other systems, because water temperatures are localized, and responses of sockeye salmon to water temperature are adaptive and population specific (D. Patterson, DFO Environmental Watch Program, pers. comm.). High in-river spawning and incubation temperatures can have population-specific negative effects on fertilization success and embryo survival (Whitney et al. 2014), and can affect timing of hatch (Whitney et al. 2014), emergence (Macdonald et al. 1998), and swim performance (Burt et al. 2012).

The Gates, Nadina, and Weaver spawning channels all measure egg-to-fry survivals. The Gates and Nadina channels both had average survivals through this life stage, while Weaver channel had slightly below average survival (DFO Salmon Enhancement Program).

3.3 JUVENILE FRESHWATER STAGE: SPRING 2016 - SPRING 2017

Spring 2016 was very warm compared to normal (1981-2010 period), with mean maximum air temperatures ranging from 3-5°C above typical values. April, in particular, was extremely warm (+5°C) across the watershed (ECCC, PCIC). Warmer than average spring temperatures resulted in an early spring freshet, and well above average April and May water levels in Chilko River and the Fraser River (ECCC). Fry emerging from their spawning gravel experienced higher than normal discharge, which was likely beneficial to 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, which reached record levels at the outlet of Chilko Lake for this time of year.

High spring water levels in lakes increase littoral areas, where fry feed and grow from April to June. This increase in habitat availability (Williams et al. 1989, Morton and Williams 1990) can benefit fry; however, there is limited information on this relationship and its relative importance to juvenile survival from different populations. 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).

Using hydroacoustic and trawl surveys, fall fry abundances were assessed in Quesnel Lake in 2016 by the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, and summer fry were assessed in Cultus Lake (no fall fry trawl in Cultus Lake).by DFO. Survival to fall fry in 2016, measured as fry-per-effective female spawner, was similar to the cycle average for Quesnel (Figure 5; MFLNRORD, unpublished data;); however, this abundance was biased by the inclusion of age-0 Kokanee, which were not genetically identified in the assessment, and thus must be treated as an overestimate. Sizes of juveniles were consistent with the historical data. In Cultus Lake, summer fry abundance was estimated prior to hatchery inputs. Interestingly, the summer survey revealed a very high proportion of Kokanee in Cultus Lake, making up 86% of the total abundance of *O. nerka*; four times higher than any previous estimate.

Air temperatures transitioned from above average in spring 2016, to variable through summer and fall, to below average in winter 2016 (ECCC, PCIC). There is limited information on the impact of overall winter air temperature on lake environments, and overwinter fry survival in lakes.

Moving into spring 2017, air temperatures were average to cool (ECCC, PCIC). The growing season was, therefore, likely initiated with normal timing, and provided typical feeding conditions for populations known to feed prior to outmigrating, such as Shuswap, Cultus, and potentially others that occur at appropriate latitudes/elevations.

Outmigrating smolt abundances were enumerated at the outlets of Cultus and Chilko Lakes. Freshwater survival in Chilko Lake, measured as the number of outmigrating smolts per effective female spawner, was more than double the expected value (Figure 6). Additionally, the mean fork length of smolts outmigrating from Chilko Lake was 6 mm larger than expected based on the relationship between annual mean smolt length and effective female spawner abundance (see below), indicating good survival conditions in Chilko Lake in 2016-2017. In Cultus Lake, in-lake survival from summer fry to smolts was extremely low, continuing the recent trend of low overwinter freshwater survival in this system.

3.4 JUVENILE DOWNSTREAM MIGRATION IN THE FRASER RIVER: SPRING 2017

Average to cool air temperatures in early spring 2017 warmed to above average temperatures in May (ECCC, PCIC), leading to rapid snow-melt through May and early-June (Ministry of Forests Lands and Nautral Resource Operations River Forecast Centre 2017). The spring freshet had average water temperatures and timing, though peak flows were above average during early June, prompting flood warnings in the Lower Fraser River (CBC 2017) (Figure 7; Figure 8). Temperature and discharge patterns in the Chilko, Stellako, and Quesnel Rivers, which dominate the predicted 2019 sockeye return, appeared close to normal, with somewhat above average discharge in the Chilcotin River in May (Figure 9; Figure 10). Since individual populations vary in their outmigration timing between April and

June, they experienced different discharge profiles as the freshet progressed. Chilko smolts experienced near average discharge, and outmigrated from Chilko Lake with average timing for this population. Cultus smolts outmigrated one week later than average. This return to average, or later than average migration timing follows two years of smolts migrating up to two weeks early.

Outmigration timing past Mission in the Lower Fraser River was slightly later than observed in previous years, since 2012 (Tadey 2018). Chilko smolts migrated with similar timing to the previous brood year on this cycle (2013). This Chilko timing was approximately one week later than the average across all years sampled at Mission (2012-2016) (Tadey 2018); however, this average has been skewed early by the outmigration timing observed in recent years, specifically in 2015 and 2016. 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.

In recent years, Chilko smolts have been consistently larger than expected based on the relationship between effective female spawners and smolt length. In 2017, the mean fork length of smolts measured at the outlet of Chilko Lake was 88 mm, 6 mm longer than expected (82 mm) given the large brood year effective female abundance (Figure 11). Chilko smolts sampled at Mission were similar in length to the 2013 brood year, and were larger than all other years sampled since 2012, apart from 2014 (2012 brood year) (Tadey 2018). Across stocks, smolt lengths at Mission were highly variable, ranging from 73 mm for Nahatlatch sockeye, to 124.6 mm measured for Weaver sockeye (Tadey 2018). 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 biological condition of outmigrating salmon smolts can be used as a measure of habitat quality and overwinter survival, and as a potential predictor of future smolt-adult marine survival. Previous work on smolt condition has focused on using length and weight to infer the 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. Predator risk can also change as a function of lipid content through changes in swim performance (Litz et al. 2017; S. Wilson, Simon Fraser University, pers. comm.).

Smolts were sampled for size and lipid content at the outlets of Chilko, Seton, and Cultus Lakes. Chilko smolts had low lipid levels, with 15% of those sampled falling below the presumed critical survival threshold of 2% for this measure (Gardiner and Geddes 1980). However, Chilko lipid levels were better than expected based on the large brood year abundance. Smolts leaving Seton Lake had surprisingly high lipid values and large bodies compared to other Fraser populations. This is anomalous for this population, as generally Seton Lake has not been this productive. Cultus smolts continued to have the highest condition rating of stocks sampled, potentially benefitted by the opportunity to feed prior to outmigration, and very low fry densities.

3.5 JUVENILE MARINE STAGE: SPRING/SUMMER 2017 – FALL 2019

Most Fraser sockeye returning in 2019 resided in the NE Pacific Ocean from 2017 to 2019. Lake-type Fraser sockeye entered the ocean in spring 2017 and reared in the Strait of Georgia (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 British Columbia and Alaska, and migrated out into the Gulf of Alaska (GOA) in the fall to early winter of 2017 (Tucker et al. 2009).

Although Fraser sockeye juveniles entered into cooler surface waters in the Strait of Georgia (SOG) in 2017, deeper waters down to 100 m were still warmer than average (Figure 12; Chandler 2018). Surface waters cooled to near-average conditions in 2017, following a period of well above average SSTs in the NE Pacific that began in 2013 and lasted until early 2016 (Ross and Robert 2018, Ross et al. 2019). Above average SSTs were amplified in early 2016 by a strong El Niño, which dissipated into spring and summer 2016 and was followed by a weak La Niña in late 2016. This La Niña balanced the persistent global temperature rise (Ross and Robert 2018), though temperature anomalies were still present in deep waters (>100m) of the NE Pacific (Ross and Robert 2018, Ross et al. 2019).

The SOG was slightly fresher than usual during summer 2017, due to above average Fraser River discharge in June (Figure 7) (Chandler 2018). The spring SOG phytoplankton bloom was typical in timing, species composition, and magnitude, though short in duration (Gower and King 2018, Costa et al. 2018). Linked to the spring bloom timing (Boldt et al. 2018b), the relative abundance of age-0 herring was low but stable compared to recent years since 2013, and their condition was good, as has been observed since 2007 (Figure 13; Boldt et al. 2018a). Alternatively, the spawning biomass of adult herring in the SOG was near historic levels (Cleary et al. 2018). Zooplankton biomass increased to slightly above average, with surveys measuring positive anomalies of both common fish prey, such as decapods, hyperiid amphipods and euphausiids, and gelatinous zooplankton (Figure 14; Young et al. 2018). Large copepods, i.e. those that are lipid-rich and more favorable for fish growth, were near average in abundance, though their peak biomass was early, potentially creating a mismatch with predators (Young et al. 2018).

Juvenile salmon surveys in the northern SOG measured an average relative abundance of sockeye for this cycle line, though CPUE's on this cycle are highly variable (Neville 2018a). The proportion of juvenile sockeye with empty stomachs (24%) was similar to average (Neville 2018b), though their size and condition was above average for this cycle (C. Neville, DFO Salmon Marine Interactions, pers. comm.). Additionally, juvenile coho, which migrate into the SOG with similar timing to Fraser sockeye and overlap in both their distribution and prey species (DFO 2016), had an average relative abundance and were above-average in mean size in June/July 2017 surveys, suggesting that conditions were good in the SOG in 2017 (Neville 2018a). However, stomach samples of juvenile sockeye showed that they were consuming an unusual diet, consisting of high proportions of chaetonath and euphausiids, and lower than typical proportions of hyperiids and crab larvae (Neville 2018b), despite abundance anomalies indicating a higher than average presence of these groups within the SOG (Young et al. 2018). Upon reaching the southern portion of the Discovery Islands juveniles of all stock components sampled had grown an average of one mm per day, excluding potential size-dependent mortalities (Neville 2018b).

Moving northward into the Johnstone Strait, Queen Charlotte Strait, and Southern Queen Charlotte Sound, early summer trawl survey CPUE anomalies of juvenile sockeye were negative, indicating a below average abundance (Figure 15). However, sockeye collected were above average in condition, measured as weight residuals (Figure 16).

The 2019 return cohort presumably moved into the Gulf of Alaska (GOA) in the fall/winter of 2017 (Tucker et al. 2009). Some physical processes had reverted to more typical conditions in the NE Pacific by this time, including winter mixing of nutrients (Ross 2017, Ross and Robert 2018). However, nutrient conditions in the GOA in 2017 were average to below-average for fish survival and growth, due to an average-to-late spring transition from winter downwelling to summer nutrient upwelling, which was below-average in strength (Figure 17) (Hourston and Thomson 2017, 2018). The phytoplankton community had a normal distribution apart from offshore stations (Peña and Nemcek 2017, 2018). The zooplankton community, on the other hand, continued to display characteristics consistent with a warmer ocean, and was less favourable for fish growth than normal (Galbraith and Young 2017, 2018). This was characterised by a higher than average abundance of southern, lipid-poor, copepods, and an average to above-average abundance of northern and boreal, lipid-rich, copepods (Figure 18) (Galbraith and Young 2018).

Cool, La Niña conditions had largely dissipated by May 2018, and deep water warm temperature anomalies were no longer present by late 2018. However, a warm SST anomaly did return in June-November, 2018 (Figure 19) (Ross et al. 2018) throughout the entire NE Pacific. In the fall, marine heat waves were observed offshore and on the shelf with varying spatial and temporal scales (Ross and Robert, in press, Hannah et al. in press). In January 2019, ENSO-neutral conditions were observed at the equator.

Prior to June 23rd, 2019 a significant landslide occurred on a narrow portion of the Fraser River at Big Bar, B.C, creating a 5 meter waterfall (DFO 2019b, Government of B.C. et al. 2019). Impacts of this landslide have not been incorporated into this report, and may affect the numbers and/or condition of spawners that reach the spawning grounds above the slide site in 2019. As of August 26, 2019 sockeye began to successfully swim past the blockage, enabled by lower water levels and rock scaling to restore the passage (Government of B.C. et al. 2019). Prior to this date, approximately one quarter of sockeye that arrived at the slide site were transported upstream manually by helicopter (Government of B.C. et al. 2019). This obstacle may impact spawners from areas north of the slide, specifically the Takla-Trembleur-Early Stuart, Bowron-ES, Nadina-ES, Taseko-ES, Chilko-S, Late Stuart-S, Quesnel-S, and Stellako-S CUs. It is likely that the only spawners that will reach the spawning grounds of the earliest-timed populations, Takla-Trembleur-Early Stuart, and Bowron-ES, will be those that were manually transported (Government of B.C. et al. 2019).

3.6 PROPORTIONS

Proportions of six key stocks returning in 2019 were compared across programs representing two life stages for which we have information on relative abundances: effective female spawners in 2015; and migrating smolts at Mission, SOG, and Discovery Islands in 2017 (Figure 20). Forecasted four year old returns in 2019 are also included in this comparison, using the 50% probability forecasts provided by DFO Fraser Stock Assessment (DFO 2019a). Relative abundances were compared for Chilko, Stellako, Quesnel, Birkenhead, Raft/North Thompson combined, and Gates, as these stocks had sufficient abundances to be evaluated across programs. As anticipated, Chilko dominated the relative abundances sampled in all programs, representing >70% of samples across programs (Figure 20).

Quesnel, Raft and Gates were all sampled in similar proportions across programs (Figure 20). Stellako and Birkenhead, however, have interesting patterns across sampling program, each showing a large drop in their proportional contribution in one of the surveys. Stellako made up 9% of the effective female spawner abundance across the selected stocks, and 16% of the smolts at Mission; however, it dropped to only 3% of the smolts sampled in the SOG trawl (Figure 20). This may be due to the migration timing of this stock, as the SOG surveys sample only the tail end of the Fraser sockeye migration. Birkenhead made up 5% of the effective female spawner abundance but nearly dropped out of the Mission juvenile samples, contributing only 0.5% to this survey, with only 12 smolts observed (Figure 20). Birkenhead was picked up in a larger proportion in the SOG trawl survey, making up 4% of the total across the selected stocks presented here (Figure 20). It is not clear why this stock was not present in representative abundances in the Mission samples.

3.7 PREDICTIONS: 2019 RETURNS

Aggregate returns of Fraser sockeye have fallen below the 50% probability level of the annual forecasts since 2015, indicating that survival has been below average. Between 2015 and 2017, returns were particularly low in comparison to forecast distributions, falling near, or below, the 10% probability level forecasts. Survival of the dominant, four year old, brood years contributing to these returns (2011-2013) fell near or below replacement, 2.0 recruits per effective female spawner, across stocks excluding Cultus and Harrison, in each of these years (2011 brood year: 1.7 recruits/EFS; 2012 brood year: 2.1 recruits/EFS; 2013 brood year: 1.1 recruits/EFS). Four year old returns in 2018 exhibited somewhat improved survival over the previous three brood years (2014 brood year: 3.5 age-4 recruits/EFS), and total survival for the 2014 brood year will be higher once it includes the five year old component returning in 2019. However it will very likely still fall below average (7.2 recruits/EFS).

Survival responses of individual stocks have been variable during these recent years; however, the majority of Fraser sockeye stocks have exhibited below average survival. The recent period of very low Fraser sockeye survival coincided with the development of the 2013-2016 marine heatwave in coastal waters off British Columbia, referred to as 'The Blob'. This marine heatwave was associated with abnormal conditions and ecosystem effects in both marine and freshwater systems (Chandler et al. 2015, 2016, 2017, 2018).

Similar to recent returns, particularly those of 2017 and 2018, most of the freshwater residence of four year old Fraser sockeye returning in 2019 occurred during a time of consistently warmer than average conditions in this environment, setting daily, monthly, and annual temperature records. Spawners migrated through extremely warm water and low flow conditions to reach their spawning grounds. Warm temperatures continued into the spring of 2016, potentially initiating the growing season early in some areas, though also altering streamflow profiles through rapid snowmelt, shifting the spring freshet early, and depleting snowmelt reserves prior to the onset of summer, by the end of May (Anslow 2017). This streamflow profile, marked by higher flows in spring, an early, lower peak freshet, and low summer flows, as was observed in 2015, and again in 2016, closely resembles future streamflow patterns projected under various climate change scenarios for snow-dominated watershed (Anslow et al. 2016, Anslow 2017). Thus, we can expect that future cohorts of Fraser sockeye will encounter similar conditions.

Early winter 2016 marked the divergence of conditions experienced by the 2019 four year old returns from those encountered by recent cohorts, as air temperatures cooled across the province (Anslow 2017) and the marine heatwave dissipated from surface waters (Ross 2017). The 2019 returns outmigrated in a more typical streamflow profile, with average temperatures leading up to an average timed freshet. As Fraser sockeye juveniles reached the marine environment some physical processes and biological occurrences associated with the marine heatwave had reverted to more 'normal' conditions, such as the strength of winter vertical stratification in the water column (Ross 2017, Ross and Robert 2018), and phytoplankton community composition (Peña and Nemcek 2017, 2018). However, other warm water-related observations persisted, such as the dominating presence of southern, lipid-poor copepods, and pyrosomes along the coast of British Columbia (Galbraith and Young 2017, 2018).

Based on the observations discussed in this report, the 2019 Fraser Sockeye Science Integration Workshop participants predicted that the 2019 Fraser sockeye four year old returns will exhibit lower than average survival. This corresponds to the lower portion of the four year old forecast probability distribution, falling below the 50% probability level. Experts discussed observations and their individual conclusions about survival, based on their own integration and weighting, supported by published empirical relationships. Weighting of individual observations is not formalized and likely differs between participants. However, during plenary, individual opinions and processes were discussed as participants came to consensus on overall survival. Participants noted the warm freshwater conditions and associated effects during the early life stages, and the continuation of less favorable marine conditions for fish growth in terms of zooplankton composition, as significant influences on the determination of poor survival. However, participants agreed that observations and data presented did not mirror conditions observed leading into the 2017 and 2018 returns, which precipitated high levels of confidence that those returns would have low survival. Conditions experienced by the 2019 returns were closer to those typically observed, for at least part of their life cycle. Participants, therefore, predicted that returns will likely fall between the 25% and 50% probability levels of the official forecast.

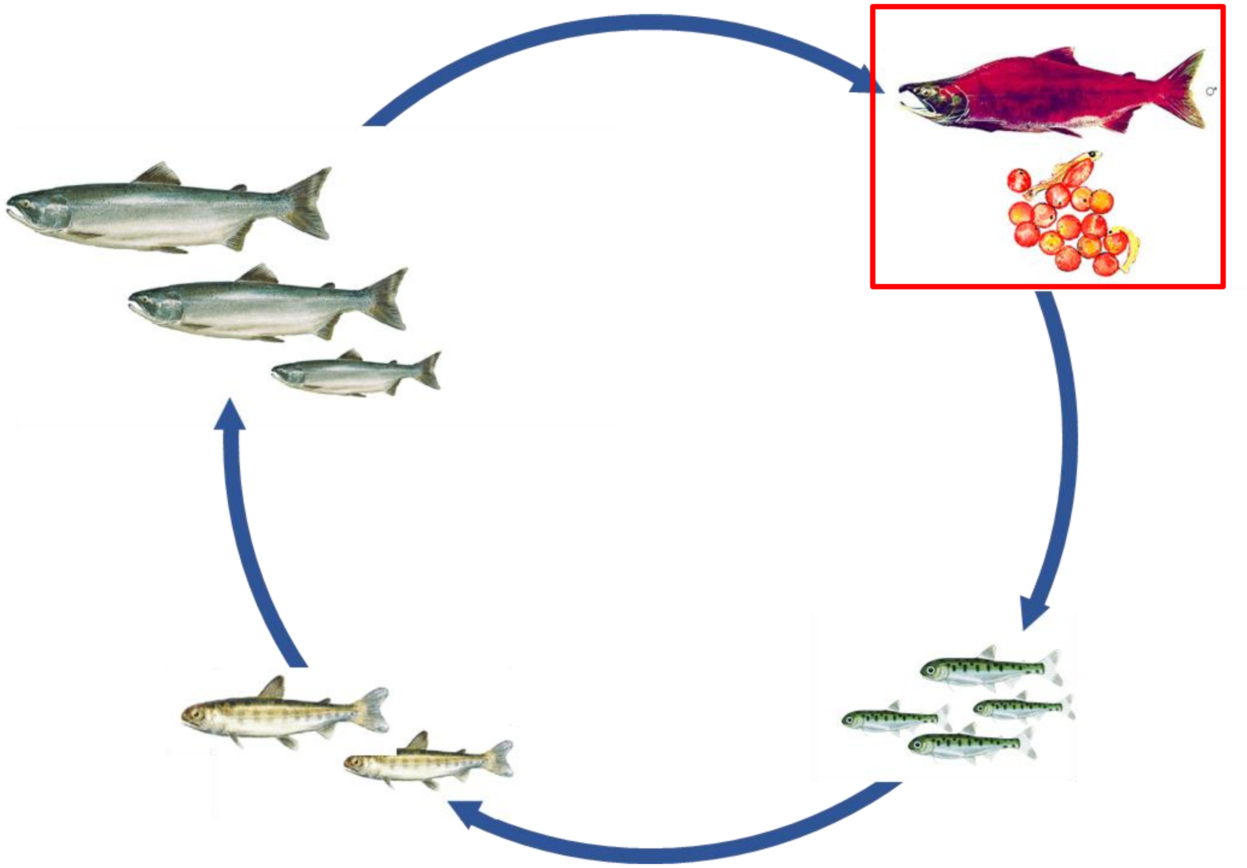
Though observations appeared slightly improved over the most recent two return cohorts, there has been a trend of consistently lower than average survivals in recent years, which must be taken into consideration. The return to more typically observed conditions during the latter half of the life cycle of the 2019 returns should not be interpreted as a 'return to normal'.

Participants of the science integration process concluded that ecosystems are changing rapidly as the effects of global climate change become more prevalent, and unusual events are becoming more frequent. In recent years, all programs have observed profound events or changes in the ecosystems and salmon life-stages they assess. Further, Fraser sockeye returns have consistently fallen at the lower end of forecast distributions for four consecutive years, and have fallen above the 50% probability level as an aggregate, indicating above average survival, only once since 2004. Workshop participants cautioned that in light of climate change, there is no longer a 'normal' state of conditions, as the systems being studied are experiencing continuous change. 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. It is, therefore, more important than ever that research and monitoring of Fraser sockeye be expanded across their life stages, to improve our ability to predict their responses

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. Current and additional research efforts must be supported and developed to ensure sustainability of these stocks.

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

4.1 BROOD YEAR SPAWNERS AND EGG STAGE



Upstream Migration and Spawning: Summer/Fall 2015

- Mean maximum summer air temperatures (June-August) in the Fraser basin were above normal (climatology from 1971-2000): June was very warm with maximum air temperatures at least 3–5°C warmer 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 below the median: sockeye from all run-timing groups would have experienced flows near the

20-year low return period (Figure 2).

- Lower Fraser River water temperatures were predominately above average during adult sockeye salmon migration, and notably above 19°C for most of July and August when sockeye from the Early Stuart, Early Summer and Summer run-timing groups are present (Figure 3).
- Early Stuart sockeye salmon migrating through the lower Fraser River experienced water temperatures well above normal, with the largest daily deviation from the mean (>5°C) in more than 60 years.
- Exposure to water temperatures >19°C during upstream migration has been associated with impaired reproductive development and reduced gamete viability (Macdonald et al. 2000).
- Parental experience during upstream migration can have intergenerational effects on offspring survival and phenotype. For example, high maternal stress can affect swim offspring performance and predator avoidance behaviour (Tierney et al. 2009, Sopinka et al. 2014).
- Fall air temperature anomalies varied in the Fraser basin: September and November were cooler than normal; October was warm, with maximum and minimum air temperatures 2–4°C above normal (ECCC, PCIC).

Spawner Surveys

- The number of Fraser sockeye that returned to the spawning grounds in 2015, 1.2 million, was similar to the cycle average, 1.3 million. Individual escapements were similar to or above average for most stocks with the exception of the Harrison, Birkenhead and Adams River populations.
- The 2015 spawning escapement was dominated by a single stock, Chilko, which accounted for 56% of the total Fraser sockeye escapement.
- Sockeye arrival timing to the spawning grounds was notably later and more protracted than normal for several stocks from all run-timing groups in 2015, specifically Early Stuart, Bowron, Early North and South Thompson, Raft and Portage.
- Sockeye were reported to be in good condition on the spawning grounds in most areas of the watershed, with the exception of the Nadina system where Ich (*Ichthyophthirius multifilius*) was confirmed, and the Late South Thompson system where sockeye were reported as lethargic and pre-spawn mortality was 34%, much higher than the average of 6%. Spawning success was at or above average for most other stocks.
- Water levels on the spawning grounds were highly variable throughout the watershed during the 2015 sockeye spawning period ranging from lower than average in the Early Stuart and North and South Thompson systems to extreme highs following major rain events in the Chilliwack, Seton-Anderson, Nahatlatch, Harrison-Lillooet and South Thompson areas. A natural landslide blocked flows in Portage Creek for 4 days in late September causing considerable changes to the creek and depositing significant sediment and debris. Impacts to spawning success and egg-to-fry survival as a result of these events are unknown.
- Water temperatures on the spawning grounds were considered favorable for spawning in most areas of the Fraser River watershed.

Biological Condition of Spawners and Gametes

- The physiological condition of sockeye salmon captured from Harrison River (n=18), Gates Creek (n=30), and Chilko River (n=20) spawning areas was assessed. Plasma ion and metabolite values from ripe Harrison and Chilko fish indicated that they were not close to death, with chloride levels (Harrison mean 130 + SD 10 mmol/L; Chilko 132 + 7 mmol/L) and glucose levels (Harrison 5.3 + 1.1; Chilko 6.4 + 0.8) being higher than expected for active spawners (Shrimpton et al. 2005) (Figure 4). Gates spawners were showing signs of lower ion levels, and higher glucose, consistent with senescence and healthy active spawning (Chloride 117.0 + 14.6; Glucose 7.6 + 5.4); this matches the above average eyed-survival in 2015.
- Survival to eyed-egg stage was assessed under experimental conditions for 20 females and 20 males for Gates Creek and from 5 females and 10 males for Harrison River sockeye salmon (A. Lotto, University of British Columbia). Eyed survival was above the expected 80% (Whitney et al. 2013; Sopinka et al. 2016) for all but two females from Gates Creek. Harrison sockeye salmon had very poor survival but this was likely confounded by water quality conditions (A. Lotto, UBC, pers. comm). Note: Gamete viability was only measured in two populations in 2015.
- 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.

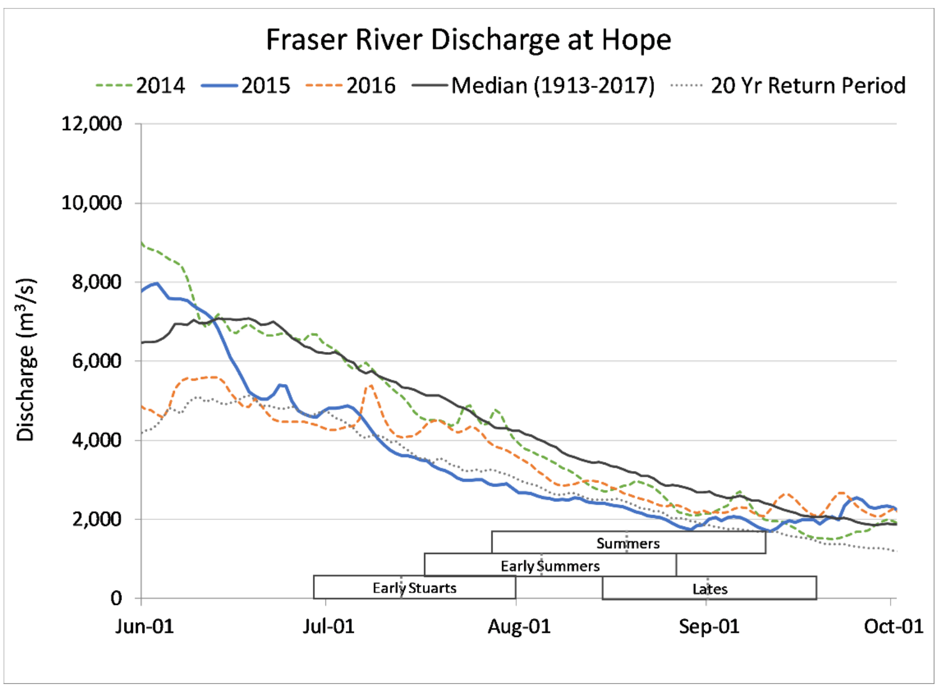


Figure 2. Lower Fraser River discharge at Hope during adult sockeye salmon spawning migration in 2014, 2015 and 2016. The 20-year low return period is based on day-of-the-year values. Each run-timing group block depicts the medial 95% of migrants estimated to have passed the Mission hydroacoustic site in 2015; 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.

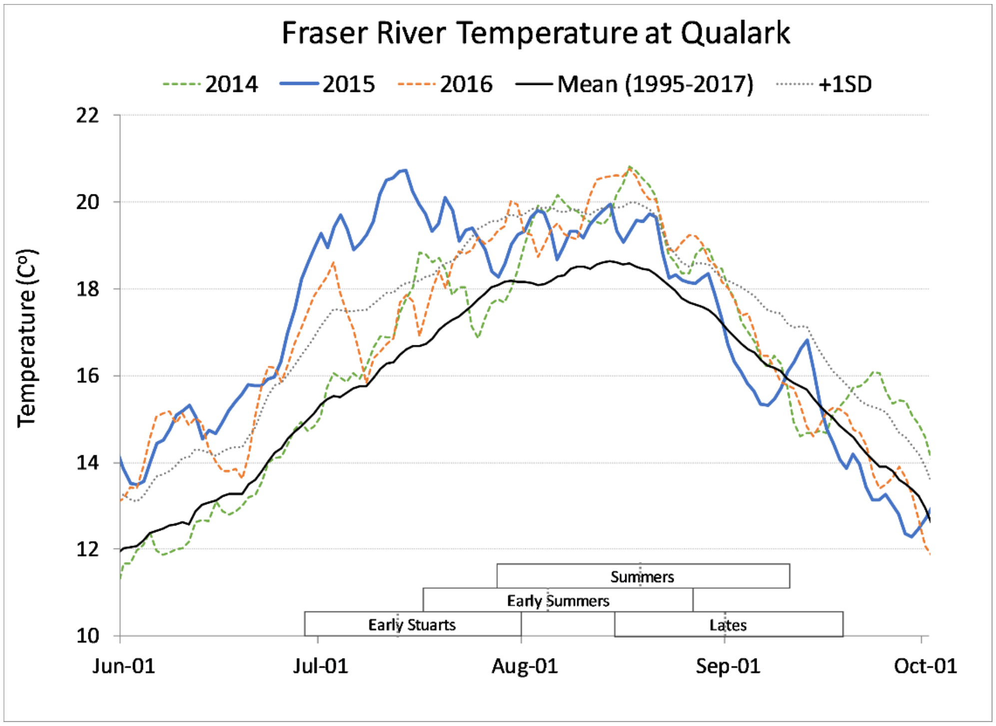


Figure 3. Lower Fraser River water temperature at Qualark during adult sockeye salmon spawning migration in 2014, 2015, and 2016. Each run-timing group block depicts the medial 95% of migrants estimated to have passed the Mission hydroacoustic site in 2015; the associated dotted grey lines depict the 50% migration date for each group. Data sources for this figure include the DFO Environmental Watch Program and the Pacific Salmon Commission

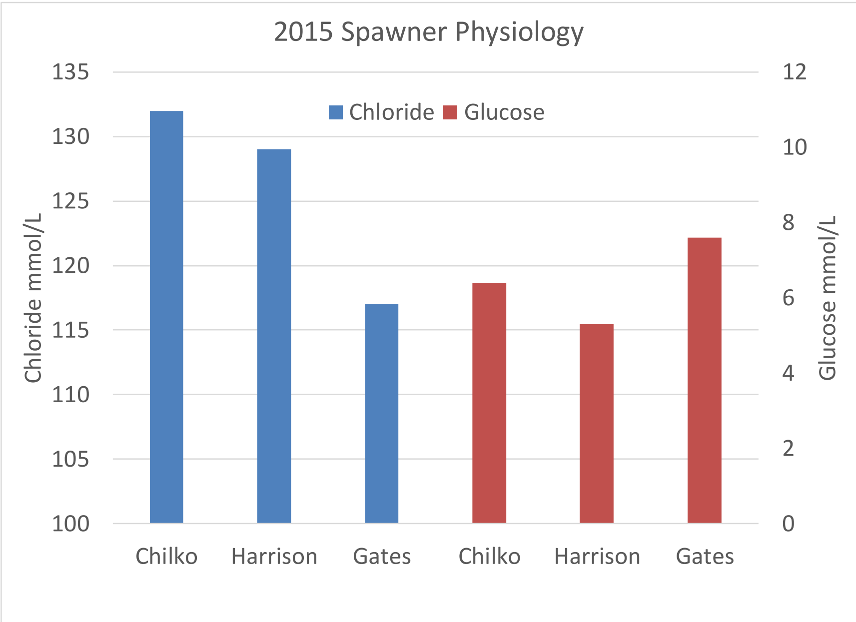
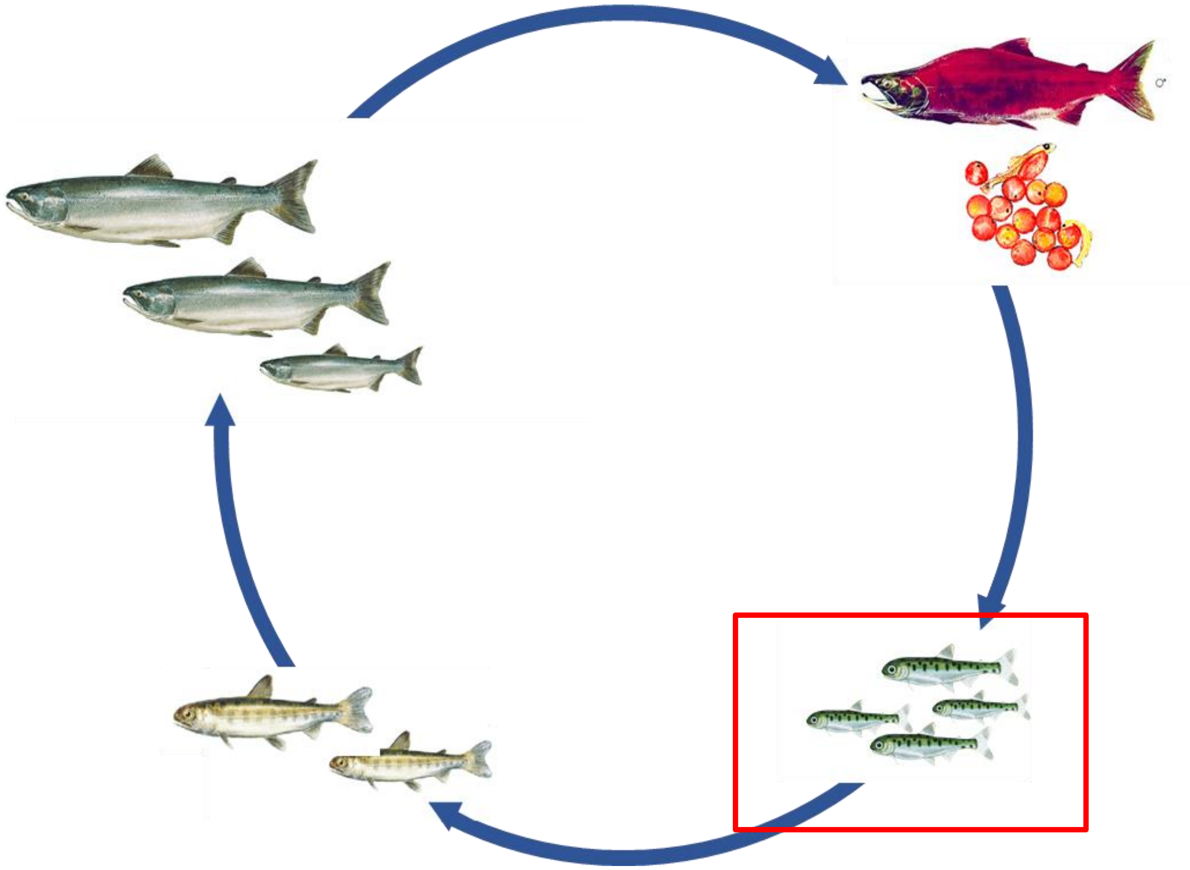


Figure 4. Plasma chloride and glucose results from spawning Chilko River, Harrison River, and Gates Creek sockeye salmon in 2015. The values are within normal ranges expected for healthy spawners (Patterson et al. 2004, Shrimpton et al. 2005, Hruska et al. 2010, Jeffries et al. 2011). The data for this figure was provided by the DFO Environmental Watch Program.

Overwinter Incubation: Winter 2015

- Mean winter (December-February) air temperatures were 1–3°C above normal across the Fraser watershed: notably, the minimum air temperatures in January and February were 3–5°C above normal (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, Chilko, and Stellako populations did not experience abnormal seasonal flows during incubation. Abnormally high winter flows increase the risk of redd scouring and suspended sediments.
- Early Stuart spawning tributaries were average during the early incubation period. Warm temperatures can 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).
- Early incubation temperatures experienced in Gates Creek spawning channel were at or below normal. Gates Creek experienced average egg-to-fry survival reported for the channel (2015 brood year survival: 30%; 12-year average survival: 25%; DFO Salmon Enhancement Program).
- Nadina River spawning channel had average egg-to-fry survival in the past 12 years (2015 brood year survival: 31%; 12-year average survival: 30%).
- Weaver Creek spawning channel had slightly below average egg-to-fry survival (2015 brood year survival: 39%; 12-year average survival: 49%; DFO Salmon Enhancement Program).

4.2 JUVENILE FRESHWATER STAGE



Emergence and Migration to Rearing Lakes: Spring 2016

- Spring air temperatures in the Fraser basin were above normal in 2016: mean maximum temperatures throughout the season were 3–5°C above normal, with April temperatures being close to 5°C above across the watershed (ECCC, PCIC).
- The Fraser River freshet was earlier than normal; discharge in the watershed was well above the median in April and early May (ECCC).
- Record high Chilko River discharge in mid-April to the end of May might have had an impact on upstream migration of Chilko fry.
- 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 2016

- Summer and fall air temperature anomalies varied: notably, October mean maximums were 1–3°C below normal and November mean maximums were at least 3–5°C above normal (ECCC, PCIC).
- Water temperatures in major tributaries downstream of sockeye nursery lakes were above average in the summer of 2016, with temperatures being 2-3 °C above average for the Fraser River at Hope (DFO Environmental Watch website).
- 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 higher growth rates within littoral zone by fry.
- The length of the growing season is temperature-dependent (Schindler et al. 2005), and was likely long for many Fraser sockeye populations in 2016.
- 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 was conducted in 2016 by Tyler Weir of The Ministry of Forests, Lands, Natural Resource Operations and Rural Development (MFLNRORD) in BC. MFLNRORD has surveyed Quesnel Lake primarily on non-dominant years in the past, using the same transect study design as DFO, making the *O. nerka* fry estimates between organisations comparable. A lake-wide total abundance of 10.3 million age-0 *O. nerka* was made in fall of 2016 (MFLNRORD, unpublished data; Figure 5). Based on an EFS (effective female spawners) estimate of 25,749 (DFO Stock Assessment near finals) for Quesnel in 2015, this yielded a fall fry per EFS value of 398.5. Notably, the estimate for 2016 fall fry includes age-0 kokanee, as they were not discriminated by genetic ID. Thus, the estimate for this year should be considered an over-estimate of the total number of juvenile sockeye as suggested by the relatively high fall fry per EFS value.
- As in the previous year, juvenile sockeye size was again consistent with historic ranges, supporting the observation that the significant growth observed in the West Arm of Quesnel Lake following the 2014 Mount Polley tailings spill was a one-off event. On average, *O. nerka* fry from the West Arm in 2016 were 64.1 ± 4.9 mm in length and 2.5 ± 0.6 g in mass.

Cultus Lake

- Summer and fall surveys were conducted on Cultus Lake in 2016. The July hydroacoustic estimate yielded a total of 155,641 age-0 *O. nerka* in the lake and was conducted prior to any hatchery reared inputs. The vast majority (86%) of juvenile *O. nerka* in the lake at this time of year were genetically identified as kokanee. This put the estimate of age-0 sockeye (± 95% CI) at 21,478 ± 4,057. This high proportion of kokanee was unusual in that it was four times higher than any other relative kokanee abundance seen in Cultus Lake since juvenile *O. nerka* have been reliably distinguished as either kokanee or sockeye based on genetic samples taken from the trawl catch.
- Between the summer and fall surveys, approximately 184,000 hatchery-reared sockeye fry were released into Cultus Lake as part of the stock conservation and rebuilding program. Unfortunately, problems with deployment of the trawl in the fall survey meant that a reliable estimate of sockeye abundance could not be produced.

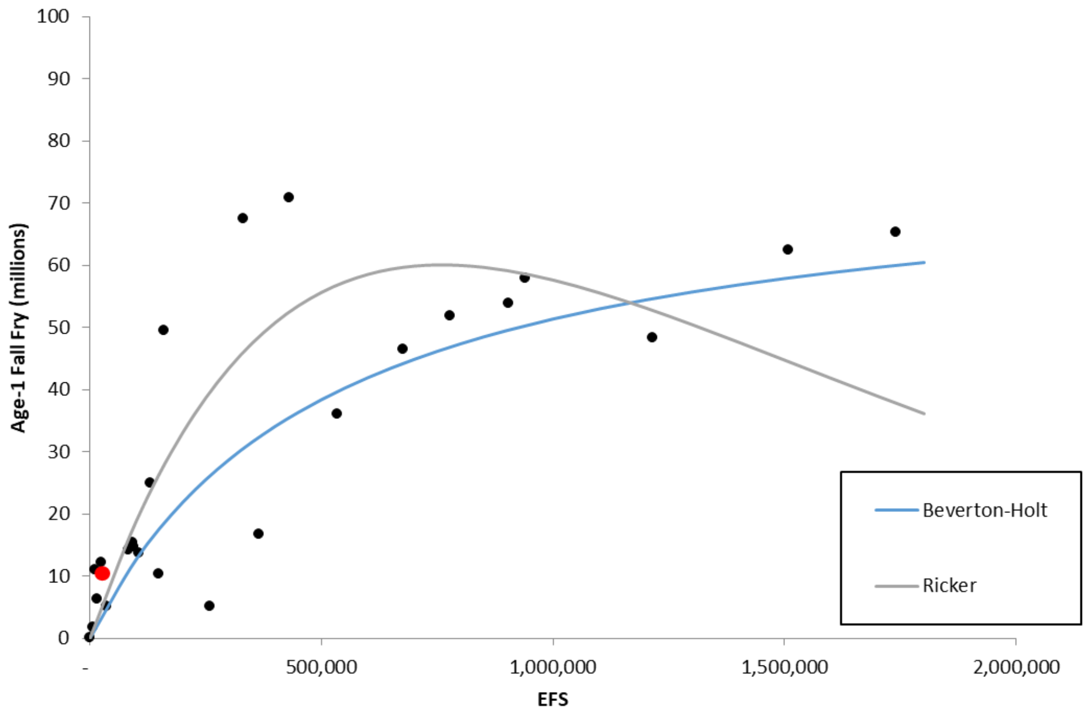


Figure 5. Acoustic fall fry estimates from most years between 1976 and 2016 are plotted against corresponding brood year effective female spawners (EFS) for Quesnel Lake. Beverton-Holt and Ricker curves fit to this data are displayed. The red dot indicates data from brood year 2015. Although above the curves, it is important to note that this should be considered an overestimate of fall sockeye fry as kokanee were not genetically excluded from this estimate based on trawl catch.

Overwinter in Lakes: Fall 2016 – Spring 2017

- Winter (December-February) air temperatures during the fry overwintering period were generally below normal across the Fraser watershed (ECCC, PCIC).
- There is limited information on the impact of overall winter air temperature on overwinter fry survival.

- Average spring water temperatures in early 2017 likely provided normal opportunities for pre-smolt growth for Shuswap and Cultus populations – two populations known to feed in the spring, prior to outmigration.
- The freshwater productivity in Chilko Lake, measured as the number of age-1 smolts produced in 2017 per effective female spawner (EFS) in 2015, of 166 was more than double what was expected (80) based on the relationship between the number of smolts/EFS and effective female spawner abundance (Figure 6). The resulting Chilko smolt outmigration was the 3rd largest on record (71.7 million). The age-1 component of the 2017 smolt population (99% of the total) was produced by an effective female spawner population of 429,000, which is the 11th largest on record, providing evidence of favorable conditions experienced by sockeye smolts in Chilko Lake during the winter/spring of 2016-17.
- Fall fry abundance was not available for Cultus Lake. However, based on the number of hatchery fish introduced to the lake between summer-fall 2016, in-lake survival from fry to smolt was very low, as only 3,752 fish were counted out of the lake at the Sweltzer Creek fence (71% hatchery).

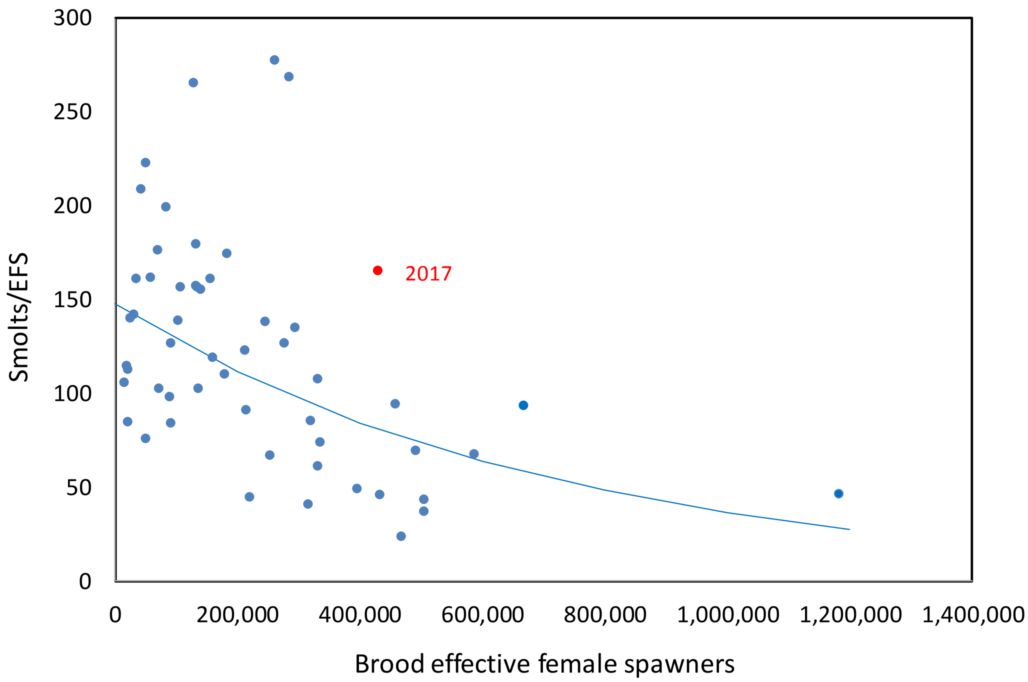
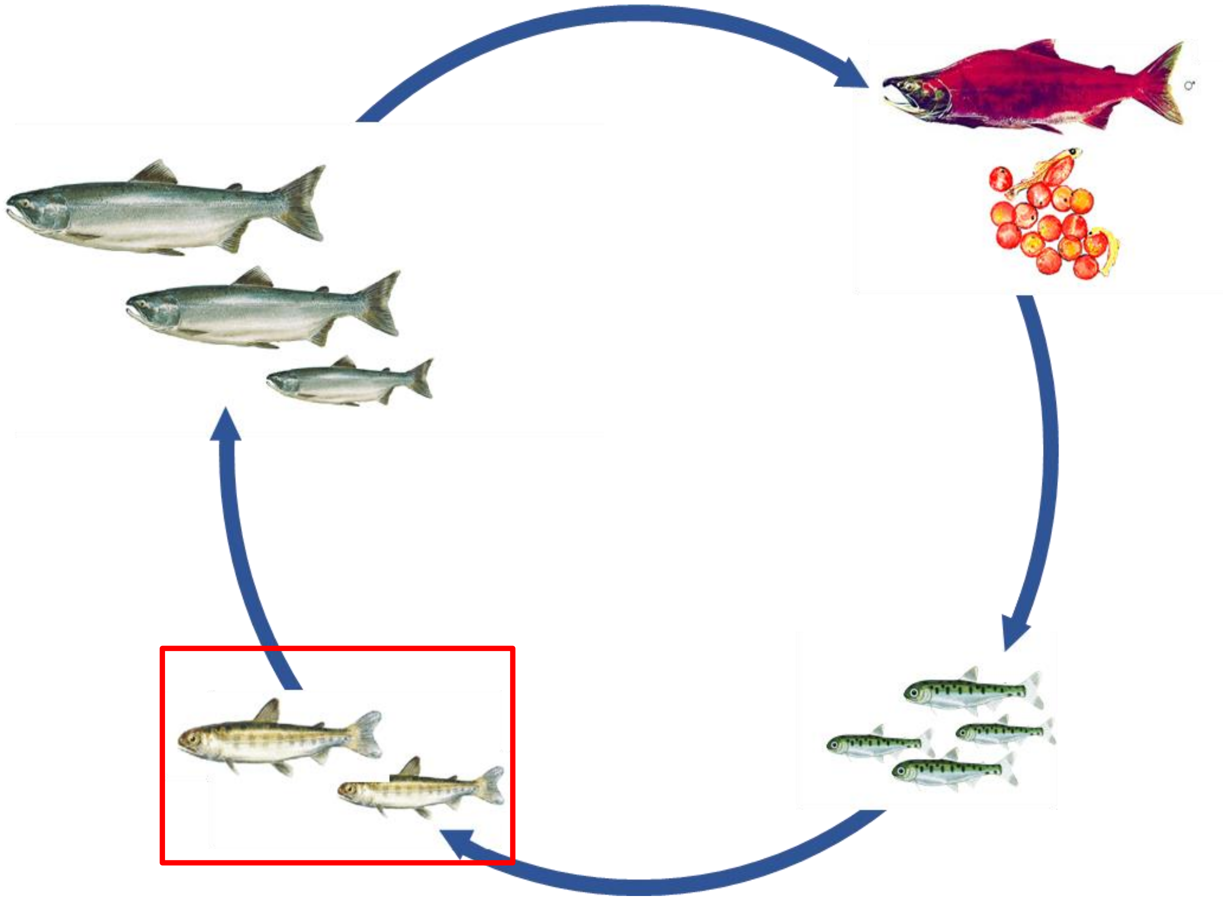


Figure 6. The relationship between Chilko Lake freshwater survival (number of smolts produced per effective female spawner) and brood year abundance (effective female spawners).

4.3 JUVENILE DOWNSTREAM MIGRATION



Migration at Lake Outlets: Spring 2017

- Snowpack in the Fraser basin was near normal leading into spring 2017 (Ministry of Environment River Forecast Centre).
- Winter and early spring air temperatures in the Fraser basin were generally cooler than normal. May was warm, with mean maximum air temperatures 2–4°C above normal (ECCC, PCIC).
- Normal timing of the Fraser River freshet was observed: freshet flows were recorded in late May and early June (Figure 7).
- Fraser sockeye populations experience different discharge exposure in the Fraser basin due to differences in the timing of median outmigration and flow regime.

- Water temperatures in the major migration tributaries were average across the watershed (Figure 8).
- 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 during outmigration likely have a positive effect by reducing predation.
- Chilko smolts experienced near average discharge and average water temperature during their outmigration in 2017 (Figure 9; Figure 10).
- The Chilko smolt 50% outmigration date in 2017, defined as the date when 50% of the run had moved through the counting fence at the outlet of Chilko Lake, was April 29th, which is very close to the average (May 1st).
- The Cultus smolt 50% outmigration date in 2017 was May 3rd, one week later than average (April 25th).

Smolt Condition

- The mean fork length of age-one smolts outmigrating from Chilko Lake in 2017 was 88 mm. This is 6 mm larger than expected (82 mm) based on the relationship between annual mean smolt length and effective female spawner abundance (Figure 11), providing further evidence of favorable conditions experienced by sockeye smolts in Chilko Lake during the winter/spring of 2016-17.
- 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 large 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.
- Chilko smolts had low lipid levels for the 2015 brood year, but better than expected based on large brood: 15% of the sampled smolts (n=20) were below the presumed 2% lipid threshold value(Gardiner and Geddes 1980).
- Cultus smolts continue to have high lipid values (5.5%), the highest of the sockeye stocks sampled.
- Smolts from Seton Lake were also had high lipid values and large body size compared to other populations in the Fraser.
- 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.

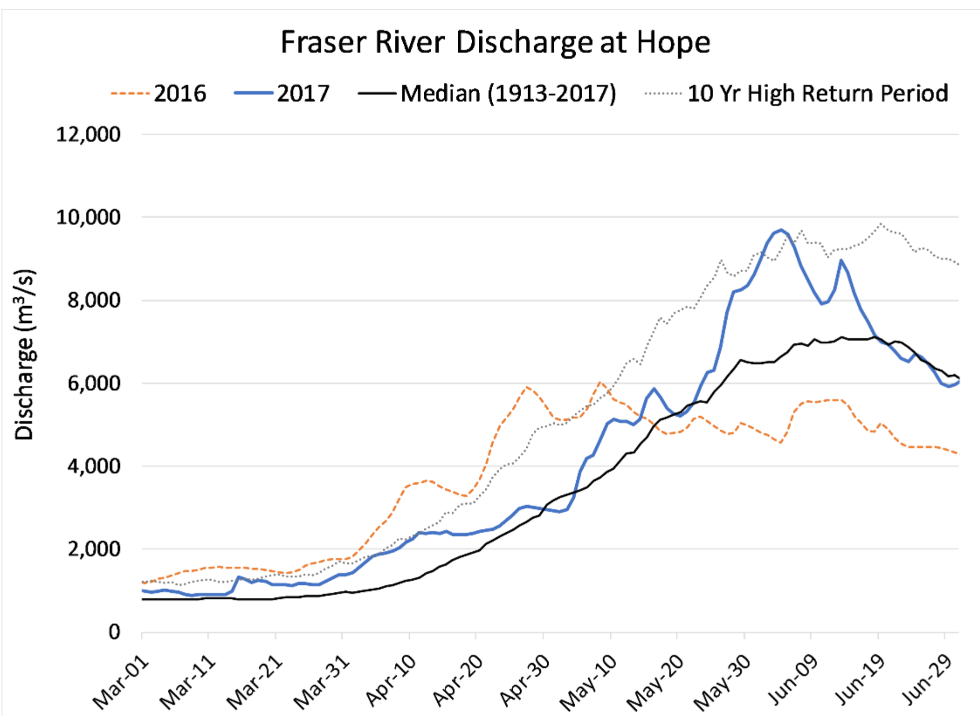


Figure 7. Lower Fraser River discharge at Hope during sockeye salmon smolt outmigration in 2016 and 2017. The 10-year high return period is based on day-of-year values. Data sources for this figure include the DFO Environmental Watch Program and the ECCC Water Survey of Canada.

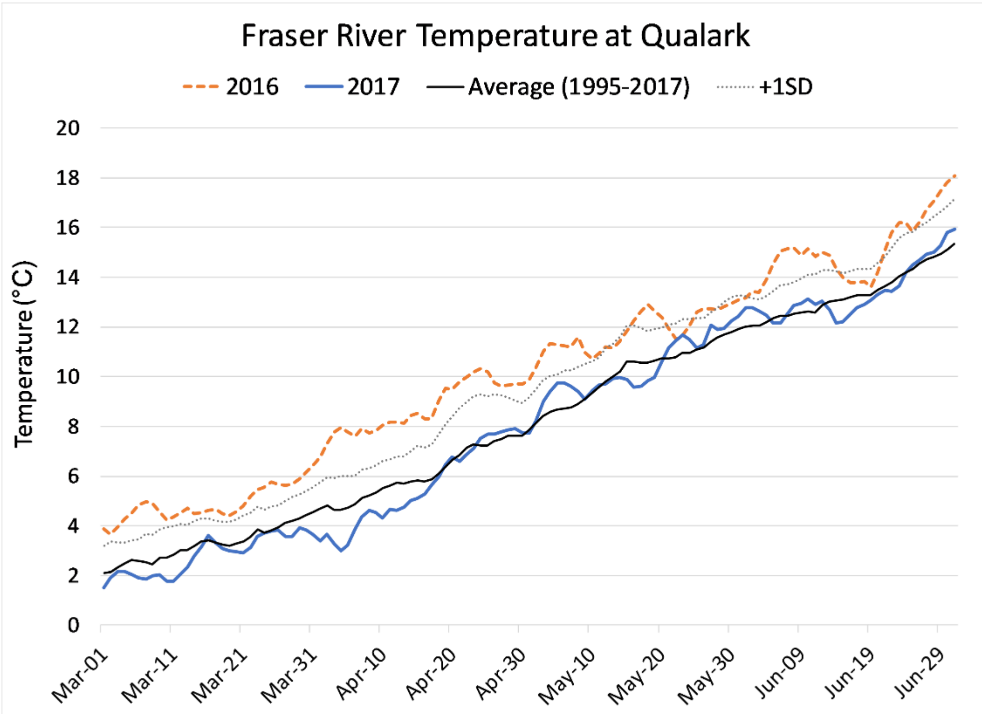


Figure 8. Lower Fraser River water temperature at Qualark during sockeye salmon smolt outmigration in 2016 and 2017. Data sources for this figure include the DFO Environmental Watch Program and the ECCC Water Survey of Canada

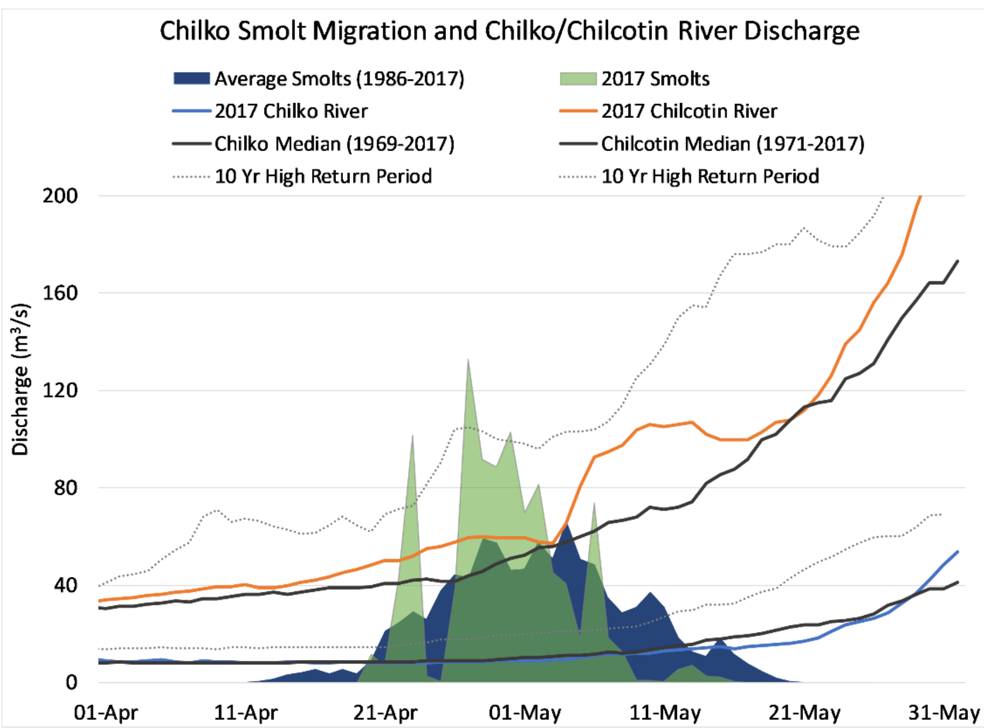


Figure 9. Chilko River and Chilcotin River discharge during 2017 Chilko sockeye salmon smolt outmigration. The 10-year high return period is based on day-of-year values. Data sources for this figure include the DFO Stock Assessment and the ECCC Water Survey of Canada.

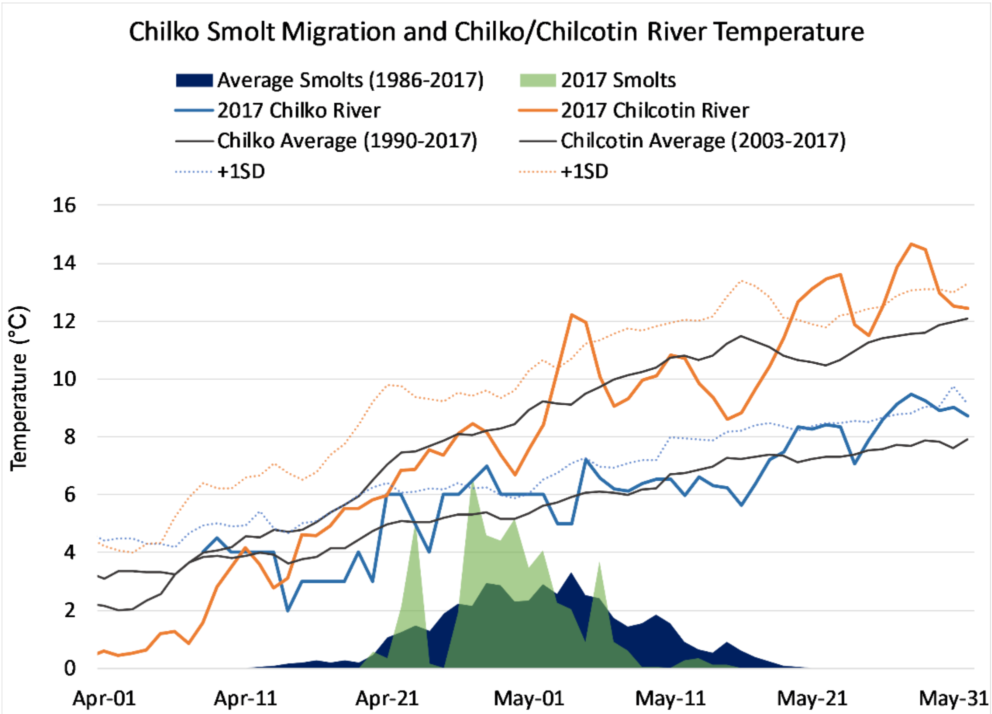


Figure 10. Chilko River and Chilcotin River water temperature during 2017 Chilko sockeye salmon smolt outmigration. Data sources for this figure include the DFO Environmental Watch Program, the DFO Stock Assessment, and the ECCC Water Survey of Canada

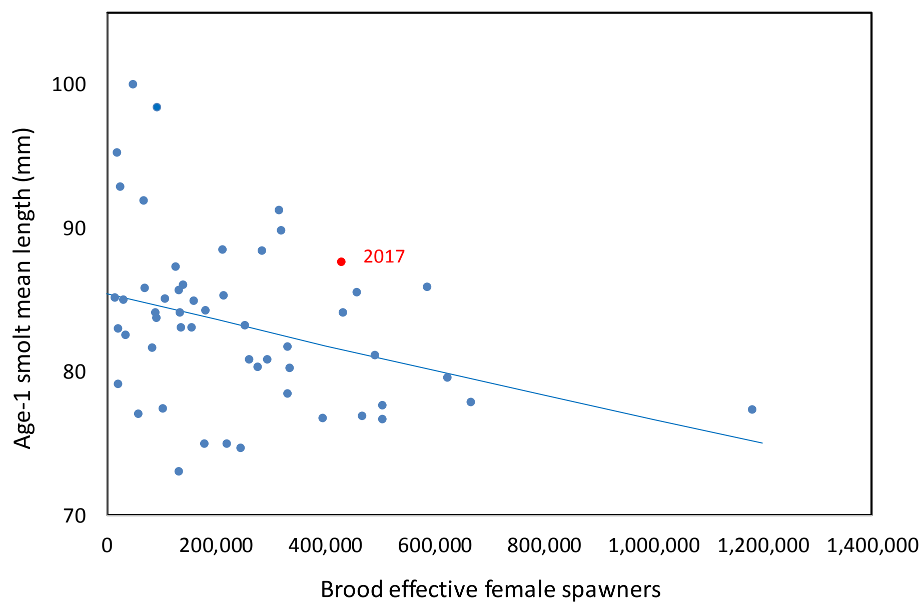
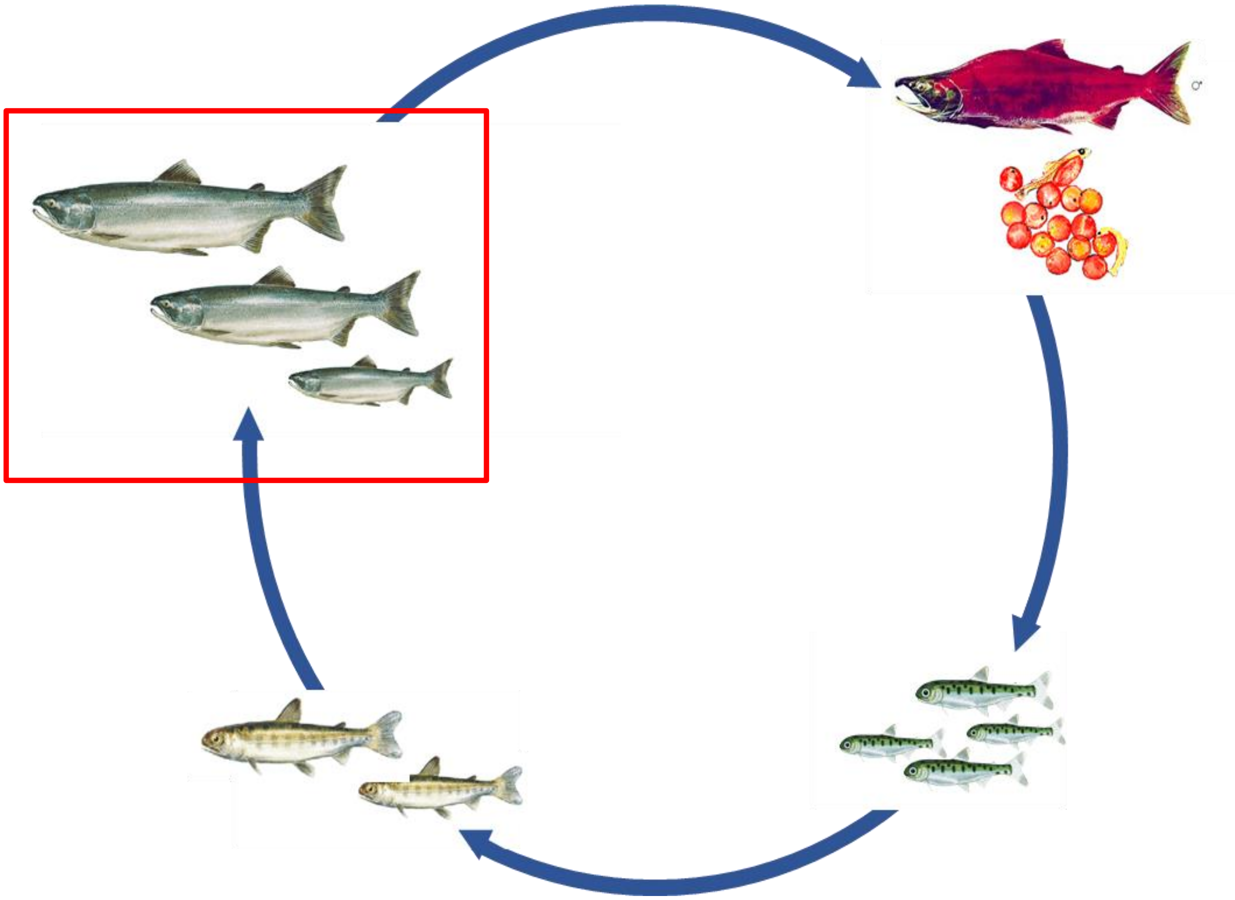


Figure 11. The relationship between mean fork length (mm) of age-1 smolts and brood year abundance (effective female spawners) for Chilko sockeye. Blue solid line indicates predicted smolt length based on the regression relationship between the two variables.

Migration in the Lower Fraser at Mission, B.C.: Spring 2017

- Water temperature was average in the lower Fraser River during smolt outmigration. (Figure 8).
- Mean fork length of juvenile sockeye salmon at Mission B.C. varied by stock in 2017, from a mean length of 73.4 mm for Nahatlatch sockeye, to 124.6 mm for Weaver sockeye, followed by Cultus sockeye at 122.8 mm. Chilko smolts were similar in length (85.5 mm) to the previous brood year on this cycle (2013) (Tadey 2018).
- Migration timing of juvenile sockeye salmon at Mission B.C. was slightly later than observed since 2012 (Tadey 2018). The 50% migration date of Chilko, the dominant stock for this cohort, was May 7th, similar to the 2013 50% migration date, though approximately one week later than the average across all years assessed (2012-2016) (Tadey 2018).
- 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 2017

- Surface waters cooled, whereas, depth-averaged temperatures were still warm compared to the climatology. Salinities were slightly fresher than the climatology during summer (Figure 12, Chandler 2018).
- Annual Fraser River discharge was near the 100-year normal; however, the discharge in late May/early June was higher than normal (Chandler 2018).
- The 2017 spring phytoplankton bloom had average start and peak times, was short in duration, and was moderate in magnitude relative to historical records (Costa et al. 2018, Gower and King 2018). Species composition of the 2017 spring bloom was typical with a mix of three diatom species (Esenkulova et al. 2018). The timing of the spring bloom is linked to the survival of age-0 herring and perhaps 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. 2018).
- Relative abundance of age-0 herring was lower and stable during 2013-2017, compared to the peaks within the time series. Age-0 herring condition increased during 1997-~2010; fish were heavier for a given length in 2007-2017 compared to herring sampled prior to 2007 (Figure 13, Boldt et al. 2018).
- Overall zooplankton biomass increased, with 2017 having slightly higher than average biomass.
- Abundance anomalies of zooplankton that are common fish prey items (decapods, hyperiid amphipods, adult euphausiids) were positive; however, abundance anomalies of gelatinous zooplankton were also positive (Figure 14, Young et al. 2018).
- The abundance of large copepods (*Neocalanus plumchrus*) was near average in 2017 but the timing of peak biomass shifted to earlier in the year, potentially creating a mismatch with its predators (Young et al. 2018).
- Northern anchovy continue to be abundant in surveys; in 2017, the proportion of net samples (in the fall age-0 herring survey) containing anchovy was the highest recorded (Boldt et al. 2018a).
- Juvenile coho had an average relative abundance and were above-average in mean size in June/July 2017 surveys, suggesting that conditions were good in the SOG in 2017 (Neville 2018a).
- The population of Harbour Seals (*Phoca vitulina*) in the Strait of Georgia appears to have remained stable since the 1990s (Majewski and Ellis, in press).
- In 2017, the index of Eulachon spawning stock biomass in the Fraser River remained relatively low (Flostrand et al. 2018).

Strait of Georgia and Discovery Islands Juvenile Sockeye Surveys: Early Summer 2017

- Catch-per-unit-effort (CPUE) from the northern SOG trawl survey in 2017 was considered average for this cycle line; however, CPUE on the 2017 cycle line has been highly variable (Neville 2018a).
- Size and condition of juvenile sockeye were both above average for this cycle (C. Neville, DFO Salmon Marine Interactions, pers. comm.).
- Juvenile coho, which migrate into the SOG with similar timing to Fraser sockeye and overlap in distribution and prey species (DFO 2016), had average relative abundance and were above-average in mean size in June/July 2017 surveys, suggesting conditions were good in the SOG in 2017 (Neville 2018a).
- The proportion of sockeye with empty stomachs was 24%, which is similar to average for the time series. However, stomach contents were abnormal. Higher than normal proportions of chaetonath and euphasiids were observed in stomachs sampled, offsetting lower than normal proportions of hyperiids and crab larvae, which typically dominate the diet of juvenile sockeye (Neville 2018b).
- Juvenile size comparisons between Mission, BC, and the Discovery Islands indicated that survivors had grown approximately one mm per day during their migration (Neville 2018b).Timing through the Discovery Islands was similar to 2010-2014 (Neville 2018b).

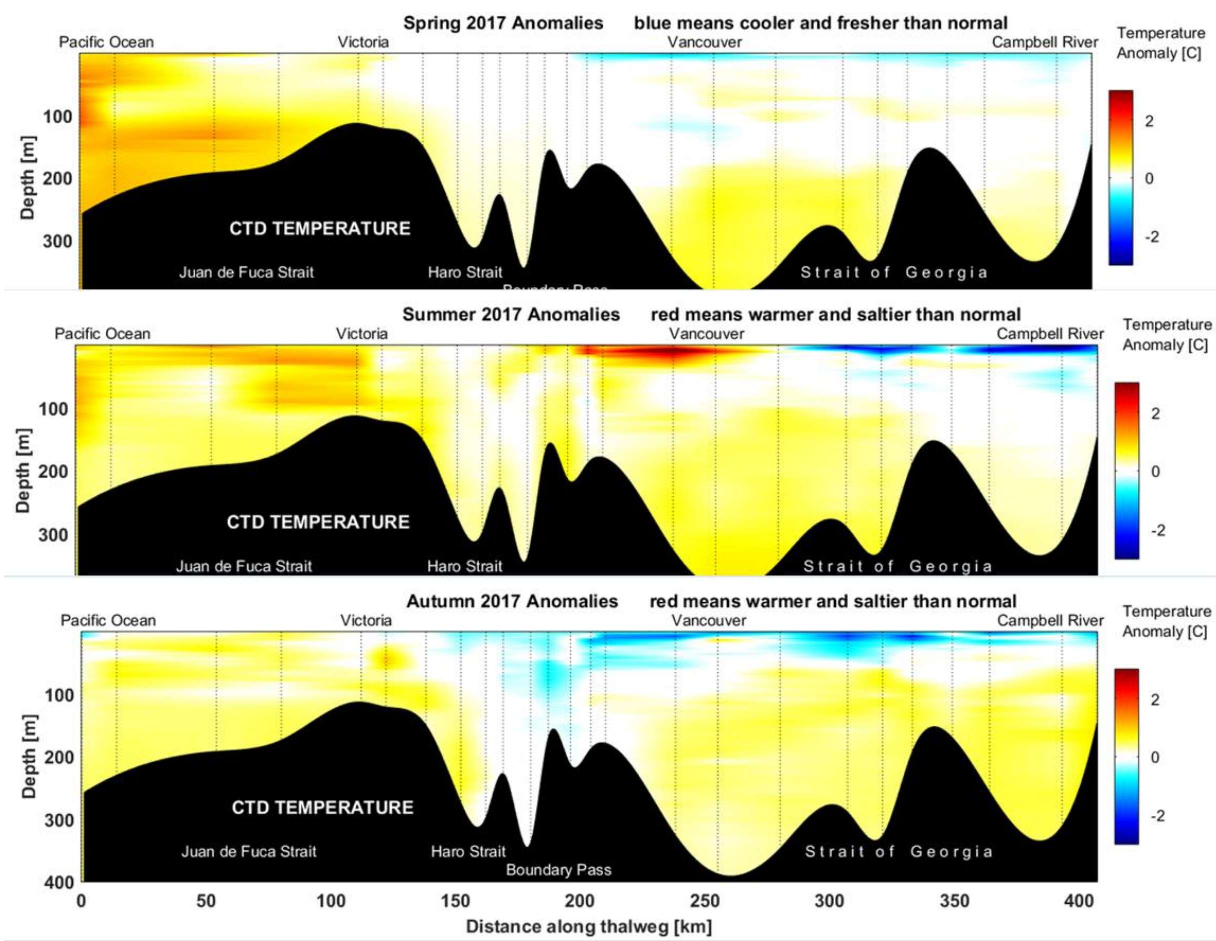


Figure 12. Temperature anomalies along the thalweg joining the deepest stations along the centreline of the survey in the Strait of Georgia observed in spring (upper), summer (centre), and autumn(lower) in 2017. Figure adapted from Chandler (2018).

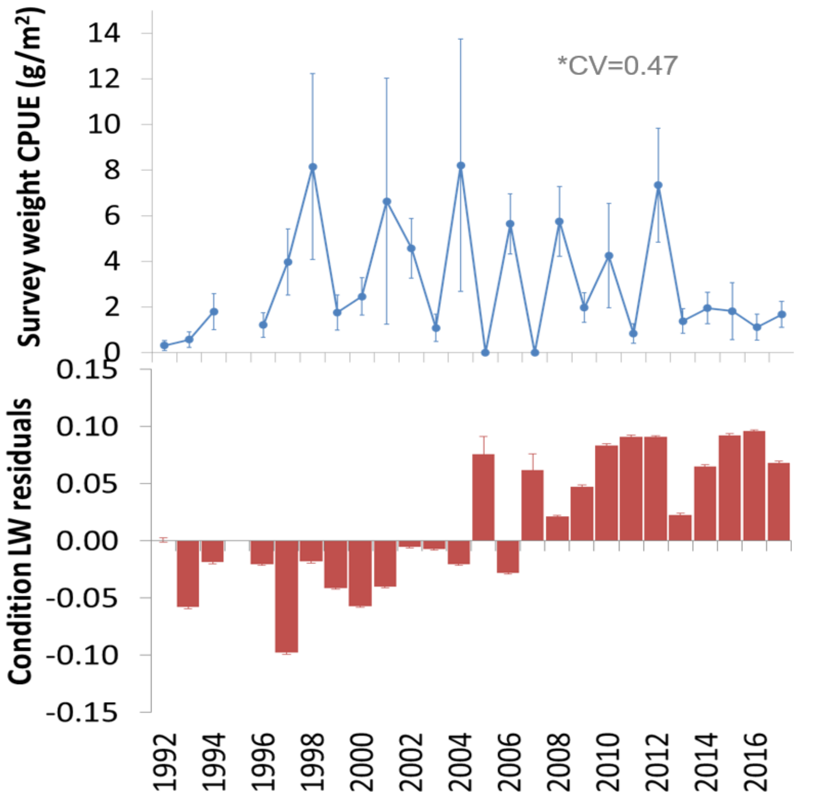


Figure 13. Mean catch weight per-unit-effort (CPUE; g/m^2; top panel) and mean condition (residuals from a double log-transformed length-weight regression; bottom panel) of age-0 herring caught in the SOG survey at core transects and stations during 1992-2017 (no survey in 1995; updated from Boldt et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

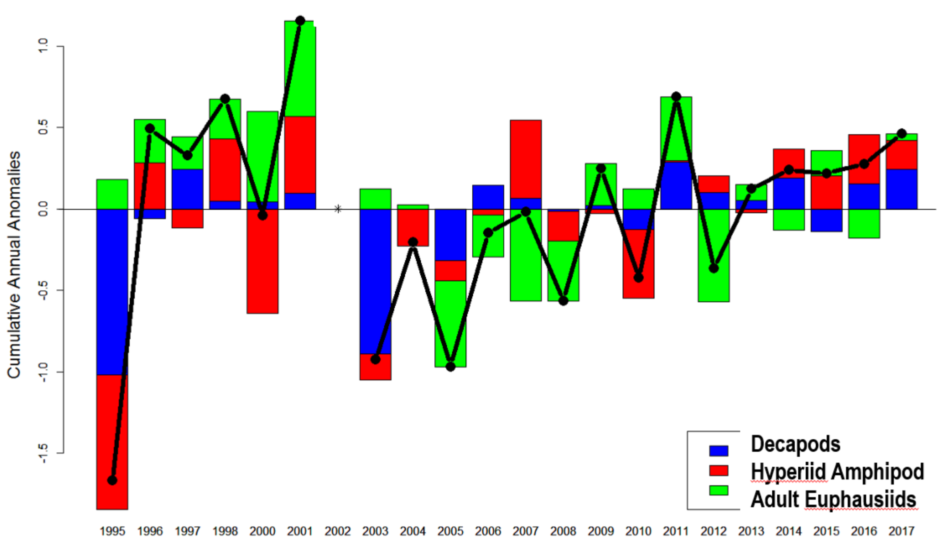


Figure 14. Annual biomass anomalies of 'Fish food' crustacean groups: decapods, hyperiid amphipods, and adult euphausiids. Years with no data represented by '*'. Figure adapted from Young et al. (2018).

Johnstone Strait-Queen Charlotte Strait- Southern Queen Charlotte Sound Juvenile Sockeye Surveys: Early Summer 2017

- Surface trawls for juvenile salmon are conducted in late-June to early-July in areas of the northern migratory corridor, including Johnstone Strait, Queen Charlotte Strait and the continental shelf of southern Queen Charlotte Sound.
- Catch-per-unit-effort (CPUE) anomalies from these surveys indicate that sockeye Salmon were below average in 2017 (Figure 15).
- The condition of juvenile sockeye salmon collected during these surveys was above average in 2017 (Figure 16). Condition is estimated as the weight residuals from the length-weight relationship derived from samples across the whole survey time series. The above average condition in 2017 reflects either size-dependent mortality prior to Johnstone Strait, or overall improved condition of fish.

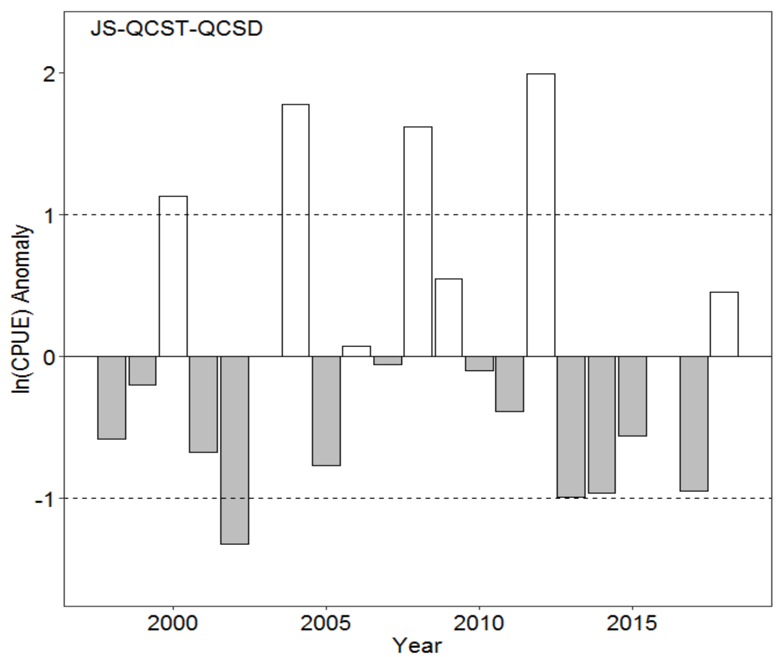


Figure 15. Standardized CPUE anomalies (mean of zero: solid line; ± 1 standard deviation: dashed lines) for juvenile sockeye salmon from summer juvenile salmon surveys conducted in areas in the north migratory corridor including Johnstone Strait (JS), Queen Charlotte Strait (QCST) and the continental shelf of southern Queen Charlotte Sound (QCSD). Figure provided by J. King, DFO.

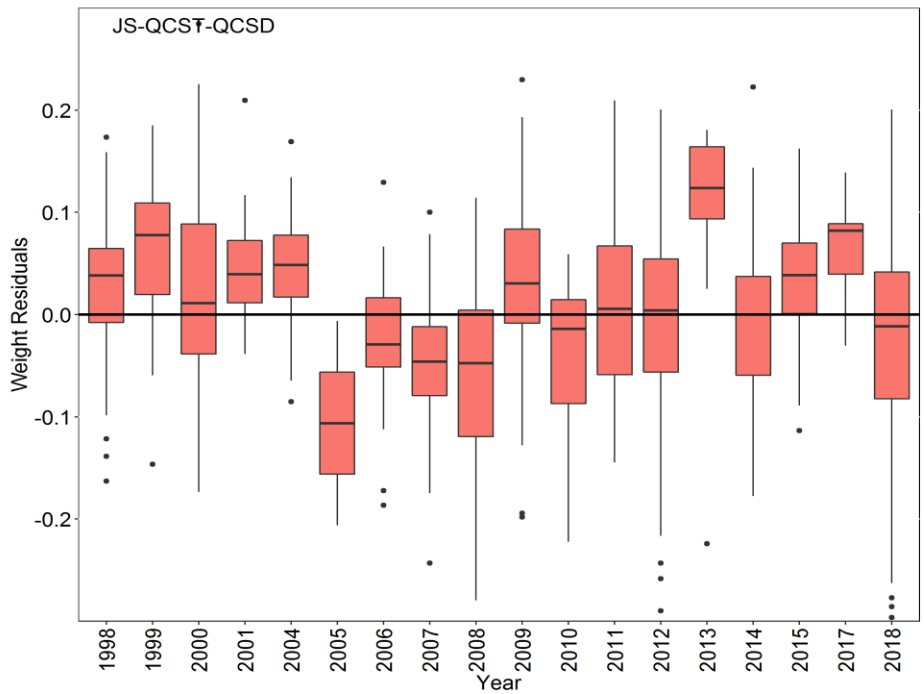


Figure 16. Annual weight residuals for juvenile sockeye salmon sampled in summer juvenile salmon surveys conducted in areas in the north migratory corridor including Johnstone Strait (JS), Queen Charlotte Strait (QCST) and the continental shelf of southern Queen Charlotte Sound (QCSD). Residuals were calculated from length-weight regression (all years combined). Boxes are quartiles; solid lines are median values; solid circles denote outliers. Figure provided by J. King, DFO.

Northeast Pacific Ocean Conditions and Observations: 2017-2019

- Globally, 2017 was the third warmest year on record (Ross and Robert 2018).
- Sea surface temperatures in the NE Pacific were near-average in 2017 after the marine heatwave of 2013-2016. However, there were 1) still strong SST anomalies in August-October and 2) deep water (>100 m) temperature anomalies that dissipated in late 2018 (Ross and Robert 2018, Ross et al. 2019).
- In early 2017, the cooling effect of a La Niña balanced the persistent global temperature rise (Ross and Robert 2018). La Niña conditions had largely dissipated by May 2018. Late in 2018, the ENSO index became weakly positive associated with a weak El Niño. In January 2019, ENSO-neutral conditions were observed at the equator. El Niño is expected to form and continue through the Northern Hemisphere spring 2019 (~65% chance).
- In June-November, 2018, a warm SST anomaly returned (Figure 19) (Ross et al. 2018), but unlike the 2013-2016 marine heatwave, the entire NE Pacific was warmer than average. This was due to anomalously high sea level pressure (August-October) that resulted in delayed cooling of SSTs (Ross et al. 2019). The Western North Pacific SSTs were also warmer than average. In the fall, marine heat waves were observed offshore and on the shelf with varying spatial and temporal scales (Hannah et al. in press, Ross and Robert. in press). As of late 2018, the anomalous temperatures had not been

observed in coastal areas, and the ENSO index became weakly positive, associated with a weak El Niño. In January 2019, ENSO-neutral conditions were observed at the equator. El Niño is expected to form and continue through the Northern Hemisphere spring 2019 (~65% chance).

- 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).
- In 2017, the upwelling of cool, nutrient-rich waters along the West Coast of Vancouver Island was average to below-average in magnitude and average to later-than-average in timing. Conditions were therefore average to below average for productivity and fish growth (Figure 17) (Hourston and Thomson 2017, 2018).
- The phytoplankton community composition showed a return to a more normal distribution in 2017 (Peña and Nemcek 2017, 2018), with the exception of the most offshore stations in 2017.
- 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) (Figure 18). The 2017 zooplankton community composition was less favourable for fish growth than average, but better when compared to 2016 (Galbraith and Young 2017, 2018). Along Line P, fall zooplankton diversity was lower compared to the long-term mean at all stations except the outer station (P26), where diversity increased due to warm water, open-ocean species (Ross et al. 2019).
- Steller sea lions continue to exhibit population growth, with an estimated B.C. summer breeding season population of 39,200 individuals in 2013 (Olesiuk 2018).
- 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. Pyrosomes were still present in 2018 but not as abundant off of B.C. as in 2017.
    - 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

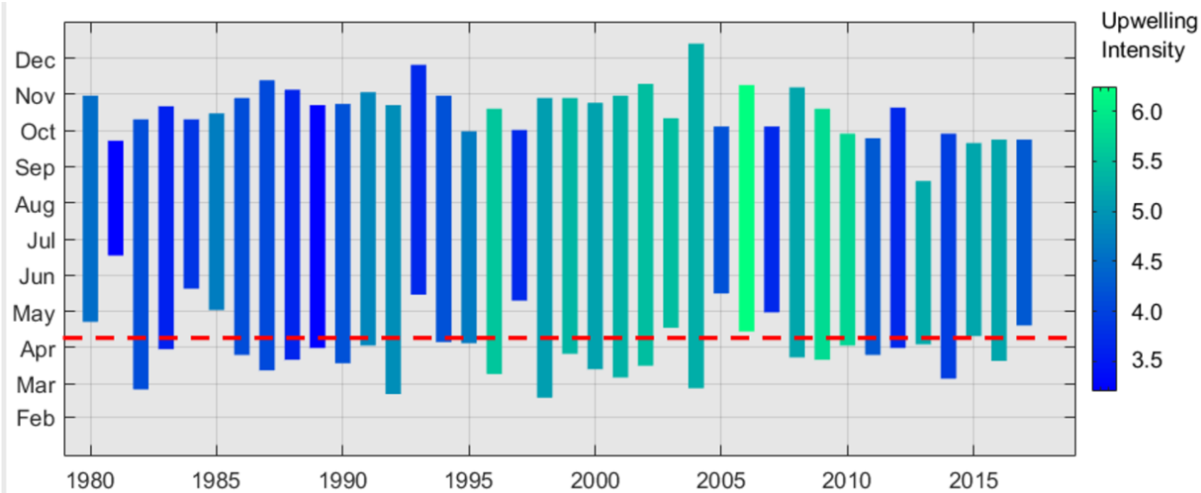


Figure 17. The upwelling index for the west coast of British Columbia. The length of the bar corresponds to the duration of the upwelling season, coloured by the intensity of the upwelling. The dashed red line indicates the average start to the upwelling season. Data source: NOAA/OAR/ESRL/Physical Sciences Division – University of Colorado at Boulder; https://www.esrl.noaa.gov/psd/data/. Figure from Chandler et al. (2018).

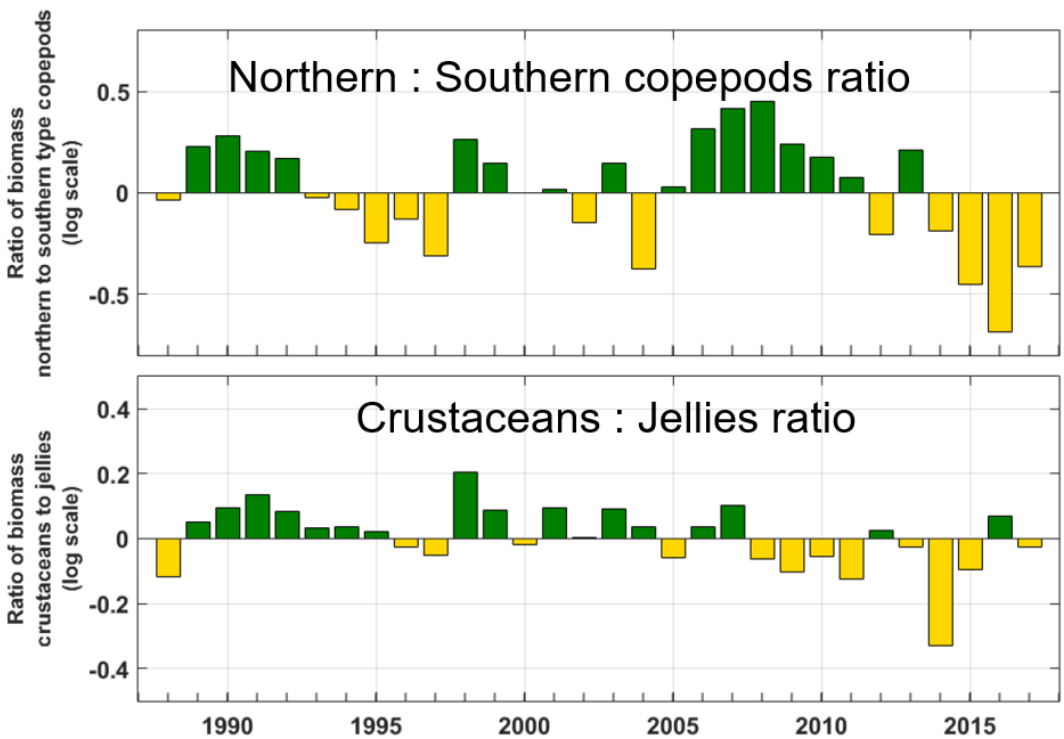


Figure 18. The 1988-2017 time series of yearly averaged anomalies of zooplankton biomass off southern Vancouver Island. (Top) the ratio of northern to southern species of copepods; (Bottom) the ratio of crustaceans to jellies. Green – fish food favourable, amber - less favourable fish food conditions. Source: Moira Galbraith (Figure from Chandler et al. 2018).

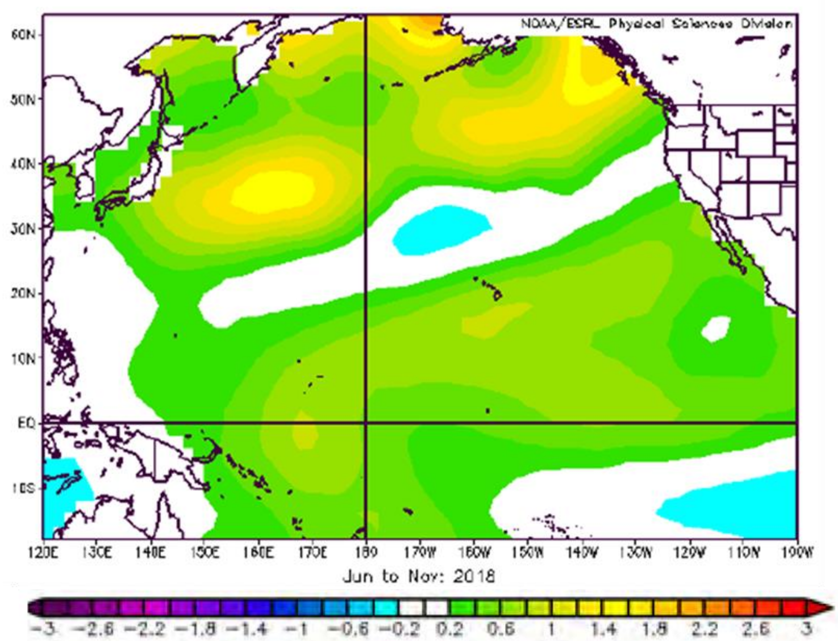


Figure 19. Temperature anomalies in the Pacific Ocean for June–November 2018. The colour bar on the bottom, showing the temperature anomaly in °C. Source: NOAA Extended SST v4 http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl. Figure adapted from Ross et al. (2019).

4.5 PROPORTIONS OF STOCKS OBSERVED THROUGH SAMPLING PROGRAMS

- We compared proportions of six dominant lake-type sockeye stocks on the 2019 cycle line across sampling programs to evaluate the consistency of observed relative abundances across life stages (Figure 20). Proportions were examined for the 2015 brood year effective female spawner escapements, outmigrating smolts at Mission, B.C. in spring 2017, SOG trawl survey samples collected in June-July 2017, and the four year old forecasts 50% probability for 2019 (DFO 2019a). Stocks were selected according to their order of prevalence in the sampling programs, and include Chilko, Stellako, Quesnel, Birkenhead, Raft/North Thompson, and Gates. All other stocks were removed from calculations of stock proportions for each sampling component.
- 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 may be biased high, and proportions of stocks that predominately

migrate later in the migration season 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 in 2017 were performed every day.

- Chilko heavily dominates the key stocks observed in all sampling programs, representing between 70% and 80% of the Fraser sockeye abundance measured by each program.
- Of the five remaining stocks compared, Quesnel, Raft/N.Thompson and Gates were all sampled in similar proportions across programs (Figure 20). Quesnel represents between 4% and 5% of the sampling components (EFS and smolt surveys), and 7% of the four year old forecast. Raft/North Thompson varies between 2% and 4% across surveys, and Gates represents 2% of the EFS and smolt abundances, and makes up 1% of the four year old forecast (Figure 20).
- Stellako and Birkenhead each display a large drop in their proportional contribution to one of the surveys (Figure 20). Stellako made up 9% of the effective female spawner abundance across the selected stocks, and 16% of the smolts at Mission; however, it dropped to only 3% of the smolts sampled in the SOG trawl. (Figure 20) This may be due to the migration timing of this stock, as the SOG surveys sample only the tail end of the Fraser sockeye migration. Birkenhead made up 5% of the effective female spawner abundance but dropped out of the Mission juvenile samples, contributing only 0.5% to this survey, with only 12 smolts observed. Birkenhead was picked up in a larger proportion in the SOG trawl survey, making up 4% of the total across the selected stocks presented here (Figure 20). It is not clear why this stock was not present in representative abundances in the Mission samples.

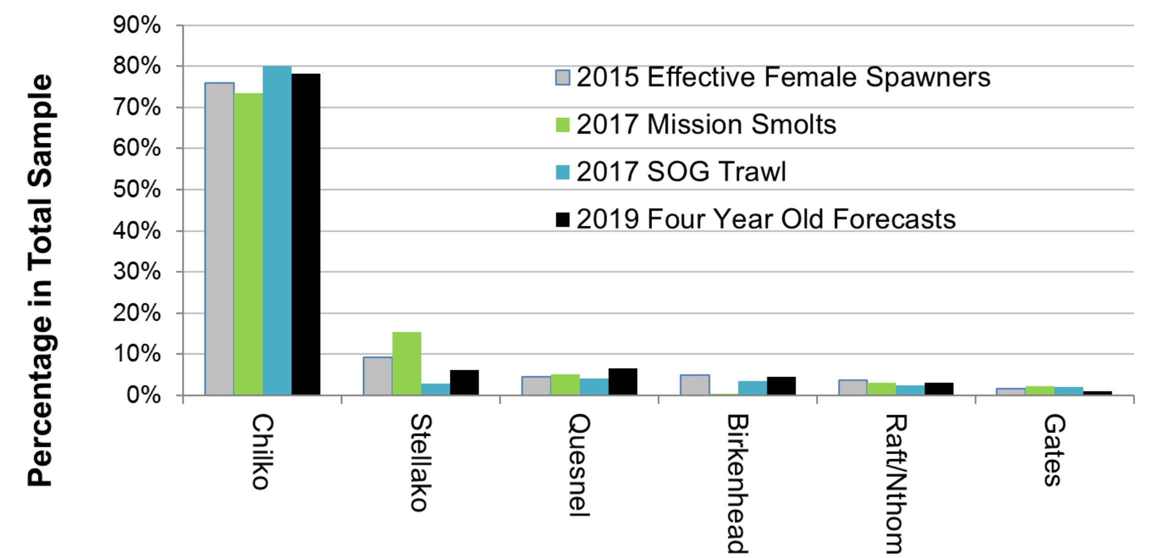


Figure 20. Proportions of the six most dominant Fraser sockeye stock groups expected to return in 2019, caught in sampling programs at two life stages. Effective female spawner proportions are from the 2015 brood year parental generation, while outmigrating smolts were sampled during surveys at Mission in the Lower Fraser River, and in the SOG trawl surveys in 2017. Four year old 2019 forecasts are also included and were produced using various model forms (DFO 2019a).

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 Summer 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 water temperature 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 is 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.

LITERATURE CITED

Anslow, F. 2017. British Columbia hydroclimatological conditions, 2016. In State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2016. Edited by P.C. Chandler, S.A. King, and J.L. Boldt. Can. Tech. Rep. Fish. Aquat. Sci. 3225. pp. 10–20.

Anslow, F., Schnorbus, M., and Campbell, D. 2016. British Columbia hydroclimatological conditions, 2015. In State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2015. Edited by P.C. Chandler, S.A. King, and R.I. Perry. Can. Tech. Rep. Fish. Aquat. Sci. 3179. pp. 12–21.

Bailey, J. 1971. Osmoregulatory capability in juvenile sockeye salmon (*Oncorhynchus nerka*). Can. J. Zool. 49(6): 841–845. doi:10.1139/z71-126.

Ballantyne, A.P., Brett, M.T., and Schindler, D.E. 2003. The importance of dietary phosphorus and highly unsaturated fatty acids for sockeye (*Oncorhynchus nerka*) growth in Lake Washington — a bioenergetics approach. Can. J. Fish. Aquat. Sci. 60(1): 12–22. doi:10.1139/f02-166.

Bassett, M.C. 2015. Temporal and spatial differences in smolting among sockeye salmon (*Oncorhynchus nerka*) populations throughout fresh- and seawater migration and the effect of water temperature on the smolt window. M.Sc. Thesis, Natural Resources and Environmental Studies, University of Northern British Columbia, Prince George, B.C.

Beacham, T.D., Neville, C.E., Tucker, S., and Trudel, M. 2017. Is there evidence for biologically significant size-selective mortality of coho salmon during the first winter of marine residence? Trans. Am. Fish. Soc. 146(3): 395–407. doi:10.1080/00028487.2017.1285349.

Beamish, R.J., Neville, C.E., Sweeting, R.M., Beacham, T.D., Wade, J., and Li, L. 2016. Early ocean life history of Harrison River sockeye salmon and their contribution to the biodiversity of sockeye salmon in the Fraser River, British Columbia, Canada. Trans. Am. Fish. Soc. 145(2): 348–362. doi:10.1080/00028487.2015.1123182.

Biro, P.A., Morton, A.E., Post, J.R., and Parkinson, E.A. 2004. Over-winter lipid depletion and mortality of age-0 rainbow trout (*Oncorhynchus mykiss*). Can. J. Fish. Aquat. Sci. 61: 1513–1519. doi:10.1139/f04-083.

Birtwell, I.K., Nassichuk, M.D., and Beune, H. 1987. Underyearling sockeye salmon (*Oncorhynchus nerka*) in the estuary of the Fraser River. Can. Spec. Publ. Fish. Aquat. Sci. 96: 25–35.

Boldt, J., Thompson, M., Grinnell, M., Cleary, J., Dennis-Bohn, H., Rooper, C., Schweigert, J., Quinn II, T.J., and Hay, D. 2018a. Strait of Georgia juvenile herring survey. In State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2017. Edited by P.C. Chandler, S.A. King, and J.L. Boldt. Can. Tech. Rep. Fish. Aquat. Sci. 3266. pp. 185–189.

Boldt, J., Thompson, M., Rooper, C., Hay, D., Schweigert, J., Quinn TJ, I., Cleary, J., and Neville, C. 2018b. Bottom-up and top-down control of small pelagic forage fish: factors affecting age-0 herring in the Strait of Georgia, British Columbia. Mar. Ecol. Prog. Ser. (1914): 1–14. doi:10.3354/meps12485.

Brannon, E.L. 1987. Mechanisms stabilizing salmonid fry emergence. Can. Spec. Publ. Fish.

Aquat. Sci. 96: 120–124. doi:10.1371/journal.pone.0095853.

Braun, D.C., Reynolds, J.D., and Patterson, D.A. 2015. Using watershed characteristics to inform cost-effective stream temperature monitoring. Aquat. Ecol. 49(3): 373–388. doi:10.1007/s10452-015-9531-6.

Brett, J.R. 1971. Energetic responses of salmon to temperature. A study of some thermal relations in the physiology and freshwater ecology of sockeye salmon (*Oncorhynchus nerka*). Am. Zool. 11(1): 99–113. doi:198.103.39.129.

Burgner, R.L. 1991. Life history of sockeye salmon (*Oncorhynchus nerka*). Edited by C. Groot and L. Margolis. University of British Columbia Press, Vancouver, BC. p. 117.

Burt, J.M., Hinch, S.G., and Patterson, D.A. 2012. Developmental temperature stress and parental identity shape offspring burst swimming performance in sockeye salmon (*Oncorhynchus nerka*). Ecol. Freshw. Fish 21(2): 176–188. doi:10.1111/j.1600-0633.2011.00535.x.

CBC. 2017. Hot weather and snow melt causes Fraser River to swell. CBC News Online. British Columbia. Available from https://www.cbc.ca/news/canada/british-columbia/fraser-river-rising-1.4141564.

Chandler, P. 2018. Temperature and salinity observations in the Strait of Georgia and Juan de Fuca Strait in 2017. In State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2016. Edited by P.C. Chandler, S.A. King, and J. Boldt. Can. Tech. Rep. Fish. Aquat. Sci. 3266. pp. 146–149.

Chandler, P.C., King, S.A., and Boldt, J. (Editors). 2017. State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2016. Can. Tech. Rep. Fish. Aquat. Sci. 3225. pp. vi + 243.

Chandler, P.C., King, S.A., and Boldt, J.L. (Editors). 2018. State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2017. Can. Tech. Rep. Fish. Aquat. Sci. 3266.: viii + 245 p.

Chandler, P.C., King, S.A., and Perry, R.I. (Editors). 2016. State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2015. Can. Tech. Rep. Fish. Aquat. Sci. 3179: viii + 230 pp.

Chandler, P.C., King, S., and Perry, R.I. (Editors). 2015. State of the physical , biological and selected fishery resources of Pacific Canadian marine ecosystems in 2014. Can. Tech. Rep. Fish. Aquat. Sci. 3131: vi + 211 pp.

Clark, T.D., Furey, N.B., Rechisky, E.L., Gale, M.K., Jeffries, K.M., Porter, A.D., Casselman, M.T., Lotto, A.G., Patterson, D.A., Cooke, S.J., Farrell, A.P., Welch, D.W., and Hinch, S.G. 2016. Tracking wild sockeye salmon smolts to the ocean reveals distinct regions of noturnal movement and high mortality. Ecol. Appl. 26(4): 959–978. doi:10.13748/j.cnki.issn1007-7693.2014.04.012.

Cleary, J., Hawkshaw, S., Grinnell, M., Grandin, C., Daniel, K., and Thampson, M. 2018. Pacific herring in British Columbia, 2017. In State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2017. Edited by P.C. Chandler, S.A. King, and J. Boldt. Can. Tech. Rep. Fish. Aquat. Sci. 3266. pp. 80–84.

Cope, R.S., and Macdonald, J.S. 1998. Responses of sockeye salmon (*Oncorhynchus nerka*) embryos to intragravel incubation environments in selected streams within the Stuart-Takla watersheds. In Forest-fish Conference: Land Management Practices Affecting

Aquatic Ecosystems. Edited by M.K. Brewin and D.M.A. Monita. Nat. Resour. Can. Inf. Rep. NOR-X-356, Edmonton, AB. pp. 283–294.

Costa, M., Hilborn, A., Suchy, K., and King, S. 2018. Chlorophyll-a phenology in the Salish Sea: spatial-temporal satellite observations and buoy data. In State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2017. Edited by P.C. Chandler, S.A. King, and J. Boldt. Can. Tech. Rep. Fish. Aquat. Sci. 3266. pp. 170–173.

DeVries, P. 1997. Riverine salmonid egg burial depths: review of published data and implications for scour studies. Can. J. Fish. Aquat. Sci. 54(8): 1685–1698. doi:10.1139/f97-090.

DFO. 2011. Pre-season run forecasts for Fraser River sockeye and pink salmon in 2011. Can. Sci. Advis. Sec. Sci. Advis. Rep. 2011/052: 15 pp.

DFO. 2012. Pre-season run size forecasts for Fraser River sockeye salmon in 2012. Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/011: 10 pp.

DFO. 2013. Pre-season run size forecasts for Fraser River sockeye and pink salmon in 2013. Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/074: 17 pp.

DFO. 2014a. Pre-season run size forecasts for Fraser River sockeye (*Oncorhynchus nerka*) salmon in 2014. Can. Sci. Adv. Sec. Sci. Resp. 2014/040: 46 pp.

DFO. 2014b. Supplement to the pre-season return forecasts for Fraser River sockeye salmon in 2014. Can. Sci. Adv. Sec. Sci. Resp. 2014/041: 57 pp.

DFO. 2015a. Pre-season run size forecasts for Fraser River sockeye (*Oncorhynchus nerka*) and pink (*O . gorbuscha*) salmon in 2015. Can. Sci. Adv. Sec. Sci. Response 2015/014: 55 pp.

DFO. 2015b. Supplement to the pre-season return forecasts for Fraser River sockeye salmon in 2015. Can. Sci. Adv. Sec. Sci. Resp. 2015/028: 49 pp.

DFO. 2016. Pre-Season run size forecasts for Fraser River sockeye (*Oncorhynchus nerka*) in 2016. Can. Sci. Adv. Sec. Sci. Resp. 2016/021: 68 pp.

DFO. 2017. Pre-season run size forecasts for Fraser River sockeye (*Oncorhynchus nerka*) and pink (*O. gorbuscha*) salmon in 2017. Can. Sci. Advis. Sec. Sci. Resp. 2017/016: 61 pp.

DFO. 2018. Pre-season run size forecasts for Fraser River sockeye salmon (*Oncorhynchus nerka*) in 2018. Can. Sci. Advis. Sec. Sci. Resp. 2018/034: 70 pp.

DFO. 2019a. Pre-season run size forecasts for Fraser River sockeye (*Oncohrynchus nerka*) and pink (*O. gorbuscha*) salmon in 2019. DFO Fraser Stock Assessment Technical Memo. 55 p.

DFO. 2019b, June 27. Significant rockslide in the Fraser Canyon. Media Release. Fisheries and Oceans Canada & Government of B.C. Joint Statement. Available from https://www.canada.ca/en/fisheries-oceans/news/2019/06/significant-rock-slide-in-the-fraser-canyon.html.

Edmundson, J.A., and Mazumder, A. 2001. Linking growth of juvenile sockeye salmon to habitat temperature in Alaskan lakes. Trans. Am. Fish. Soc. 130: 644–662. doi:10.1577/1548-8659(2001)130<0644:LGOJSS>2.0.CO;2.

Esenkulova, S., Pawlowicz, R., and Pearsall, I. 2018. Nutrients, the phytoplankton community and harmful algae in the Salish Sea. In State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2017. Edited by P.C. Chandler, S.A. King, and J.L. Boldt. Can. Tech. Rep. Fish. Aquat. Sci. 3266. pp. 174–179.

Flostrand, L., MacConnachie, S., and Boldt, J. 2018. Eulachon status and trends in B.C. In State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2017. Edited by P.C. Chandler, S. King, and J. Boldt. Can. Tech. Rep. Fish. Aquat. Sci. 3266. pp. 85–89.

Freshwater, C., Trudel, M., Beacham, T.D., Grant, S.C.H., Johnson, S.C., Neville, C.E., Tucker, S., and Juanes, F. 2017. Effects of density during freshwater and early marine rearing on juvenile sockeye salmon size, growth, and migration. Mar. Ecol. Prog. Ser. 579: 97–110. doi:10.3354/meps12279.

Galbraith, M., and Young, K. 2017. Zooplankton along the B.C. continental margin 2016. In State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2016. Edited by P.C. Chandler, S.A. King, and J.L. Boldt. Can. Tech. Rep. Fish. Aquat. Sci. 3225. pp. 67–75.

Galbraith, M., and Young, K. 2018. West Coast British Columbia zooplankton biomass anomalies 2017. In State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2017. Edited by P.C. Chandler, S.A. King, and J.L. Boldt. Can. Tech. Rep. Fish. Aquat. Sci. 3266. pp. 69–75.

Gardiner, W.R., and Geddes, P. 1980. The influence of body composition on the survival of juvenile salmon. Hydrobiologica 69: 67–72. doi:10.1007/BF00016537.

Ginetz, R.M., and Larkin, P.A. 1976. Factors affecting rainbow trout (*Salmo gairdneri*) predation on migrant fry of sockeye salmon (*Oncorhynchus nerka*). J. Fish Res. Board Can. 33(1): 19–24. doi:10.1139/f76-003.

Government of B.C., DFO, and FRAFS. 2019, September 8. Salmon swimming past Big Bar. Information Bulletin prepared by the Government of B.C., Fisheries and Oceans Canada, and the Fraser River Aboriginal Fisheries Secretariat. Available from https://www2.gov.bc.ca/assets/gov/public-safety-and-emergency-services/emergency-preparedness-response-recovery/embc/big-bar-landslide-2019/19_71w20ay_information_bulletin_-_fish_passage.pdf.

Gower, J., and King, S. 2018. Satellite and in situ observations. In State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2017. Edited by P.C. Chandler, S.A. King, and J.L. Boldt. Can. Tech. Rep. Fish. Aquat. Sci. 3266. pp. 49–54.

Gregory, R.S., and Levings, C.D. 1998. Turbidity reduces predation on migrating juvenile Pacific Salmon. Trans. Am. Fish. Soc. 127(2): 275–285. doi:10.1577/1548-8659(1998)127<0275:TRPOMJ>2.0.CO;2.

Griffiths, J.R., Schindler, D.E., Ruggerone, G.T., and Bumgarner, J.D. 2014. Climate variation is filtered differently among lakes to influence growth of juvenile sockeye salmon in an Alaskan watershed. Oikos 123(6): 687–698. doi:10.1111/j.1600-0706.2013.00801.x.

Hannah, C., Page, S., and Ross, T. (in press). Ocean surface temperatures in 2018: another marine heat wave? In State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2018. Edited by J.L. Boldt, J. Leonard, and P.C. Chandler. Can. Tech. Rep. Fish. Aquat. Sci. 3314. p. ##-##.

Henderson, M.A., and Cass, A.J. 1991. Effect of smolt size on smolt-to-adult survival for Chilko Lake sockeye salmon (*Oncorhynchus nerka*). Can. J. Fish. Aquat. Sci. 48: 988–994. doi:10.1139/f91-115.

Hourston, R.A.S., and Thomson, R.E. 2017. Wind-driven upwelling/downwelling along the northwest coast of North America: timing and magnitude. In State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2016. Edited by P.C. Chandler, S.A. King, and J.L. Boldt. Can. Tech. Rep. Fish. Aquat. Sci. 3225. pp. 21–27.

Hourston, R.A.S., and Thomson, R.E. 2018. Wind-driven upwelling/downwelling along the Northwest coast of North America: timing and magnitude. In State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2017. Edited by P.C. Chandler, J.L. Boldt, and S.A. King. Can. Tech. Rep. Fish. Aquat. Sci. 3266. pp. 21–26.

Hruska, K.A., Hinch, S.G., Healey, M.C., Patterson, D.A., Larsson, S., and Farrell, A.P. 2010. Influences of sex and activity level on physiological changes in individual adult sockeye salmon during rapid senescence. Physiol. Biochem. Zool. 83(4): 663–676. doi:10.1086/652411.

Hume, J.M.B., Shortreed, K.S., and Morton, K.F. 1996. Juvenile sockeye rearing capacity of three lakes in the Fraser River system. Can. J. Fish. Aquat. Sci. 53(4): 719–733. doi:10.1139/f95-237.

Jeffries, K.M., Hinch, S.G., Donaldson, M.R., Gale, M.K., Burt, J.M., Thompson, L.A., Farrell, A.P., Patterson, D.A., and Miller, K.M. 2011. Temporal changes in blood variables during final maturation and senescence in male sockeye salmon *Oncorhynchus nerka*: reduced osmoregulatory ability can predict mortality. J. Fish Biol. 79(2): 449–465. doi:10.1111/j.1095-8649.2011.03042.x.

Jeffries, K.M., Hinch, S.G., Gale, M.K., Clark, T.D., Lotto, A.G., Casselman, M.T., Li, S., Rechisky, E.L., Porter, A.D., Welch, D.W., and Miller, K.M. 2014. Immune response genes and pathogen presence predict migration survival in wild salmon smolts. Mol. Ecol. 23(23): 5803–5815. doi:10.1111/mec.12980.

Litz, M.N.C., Miller, J.A., Copeman, L.A., and Hurst, T.P. 2017. Effects of dietary fatty acids on juvenile salmon growth, biochemistry, and aerobic performance: a laboratory rearing experiment. J. Exp. Mar. Bio. Ecol. 494: 20–31. doi:10.1016/j.jembe.2017.04.007.

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

MacDonald, B.L., Grant, S.C.H., Patterson, D.A., Robinson, K.A., Boldt, J.L., Benner, K., Neville, C.M., Pon, L., Tadey, J.A., Selbie, D.T., and Winston, M.L. 2018. State of the Salmon: informing the survival of Fraser sockeye returning in 2018 through life cycle observations. Can. Tech. Rep. Fish. Aquat. Sci. 3271: v + 53 pp.

Macdonald, J.S., Foreman, M.G.G., Farrell, T., Williams, I. V, Grout, J., Cass, A., Woodey, J.C., Enzenhofer, H., Clarke, W.C., Houtman, R., Donaldson, E.M., and Barnes, D. 2000. The influence of extreme water temperatures on migrating Fraser River sockeye salmon (*Oncorhynchus nerka*) during the 1998 spawning season. Can. Tech. Rep. Fish. Aquat. Sci. 2326: 117 pp.

Macdonald, J.S., Scrivener, J.C., Patterson, D.A., and Dixon-Warren, A. 1998. Temperatures in aquatic habitats: the impacts of forest harvesting and the biological consequences to sockeye salmon incubation habitats in the interior of B.C. In Forest-fish conference: land mananagment practices affecting aquatic ecosystems. Proc. Forest-Fish Conf., May 1-4, 1996, Calgary, AB. Edited by M.K. Brewin and D.M.A. Monita. Natural Resources Canada, Edmonton, AB. pp. 313–324.

Majewski, S.P., and Ellis, G.M. (in press). Abundance and distribution of harbour seals (*Phoca vitulina*) in the Strait of Georgia, British Columbia. Can. Sci. Advis. Sec. Res. Doc. XXXX/XXX: xx+ xx pp.

Martens, D.W., and Servizi, J.A. 1993. Suspended sediment particles inside gills and spleens of juvenile Pacific Salmon (*Oncorhynchus spp.*). Can. J. Fish. Aquat. Sci. 50: 586–590. doi:10.1139/f93-067.

Martin, S.A., Douglas, A., Houlihan, D.F., and Secombes, C.J. 2010. Starvation alters the liver transcriptome of the innate immune response in Atlantic salmon (*Salmo salar*). BMC Genomics 11(1): 418. doi:10.1186/1471-2164-11-418.

Miller, K.M., Teffer, A., Tucker, S., Li, S., Schulze, A.D., Trudel, M., Juanes, F., Tabata, A., Kaukinen, K.H., Ginther, N.G., Ming, T.J., Cooke, S.J., Hipfner, J.M., Patterson, D.A., and Hinch, S.G. 2014. Infectious disease, shifting climates, and opportunistic predators: cumulative factors potentially impacting wild salmon declines. Evol. Appl. 7(7): 812–855. doi:10.1111/eva.12164.

Ministry of Forests Lands and Natural Resource Operations River Forecast Centre. 2017. Snow Survey and Water Supply Bulletins for 2017. In Snow survey and water supply bulletin. Available from https://www2.gov.bc.ca/assets/gov/environment/research-monitoring-and-reporting/monitoring/river-forecast-centre/snow-survey-archive/snow_bulletins_2017.pdf.

Montgomery, D.R., Buffington, J.M., Peterson, N.P., Schuett-Hames, D., and Quinn, T.P. 1996. Stream-bed scour, egg burial depths, and the influence of salmonid spawning on bed surface mobility and embryo survival. Can. J. Fish. Aquat. Sci. 53(5): 1061–1070. doi:10.1139/f96-028.

Morton, K.F., and Williams, I. V. 1990. Sockeye salmon (*Oncorhynchus nerka*) utilization of Quesnel Lake, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 1756: iv + 29 pp.

Naesje, T.F., Thorstad, E.B., Forseth, T., Aursand, M., Saksga, R., and Finstad, A.G. 2006. Lipid class content as an indicator of critical periods for survival in juvenile Atlantic salmon (*Salmo salar*). Ecol. Freshw. Fish 15: 572–577. doi:10.1111/j.1600-0633.2006.00173.x.

Neville, C.E.M. 2018a. Juvenile salmon in the Strait of Georgia, 2017. In State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2017. Edited by P.C. Chandler, S. King, and J. Boldt. Can. Tech. Rep. Fish. Aquat. Sci. 3266. pp. 195–199.

Neville, C.E.M. 2018b. Early marine conditions - Sockeye 2017 ocean entry year. Presentation at the 2019 Fraser Sockeye Science Integration Workshop, Delta, B.C.

Neville, C.E.M., Johnson, S., Beacham, T., Whitehouse, T., Tadey, J., and Trudel, M. 2016. Initial estimates from an integrated study examining the residence period and migration timing of juvenile sockeye salmon from the Fraser River through coastal waters of British Columbia. N. Pac. Anadr. Fish Comm. Bull. 6(1): 45–60. doi:10.23849/npafcb6/45.60.

Newcombe, C.P., and Jensen, J.O. 1996. Channel suspended sediment and fisheries: a synthesis for quantitative assessment of risk and impact. N. Am. J. Fish. Manag. 16(4):

693–727. doi:10.1577/1548-8675(1996)016<0693:CSSAFA>2.3.CO;2.

Olesiuk, P.F. 2018. Recent trends in abundance of steller sea lions (*Eumetopias jubatus*) in British Columbia. Can. Sci. Advis. Sec. Res. Doc. 2018/006: v + 67 p.

Patterson, D.A., Macdonald, J.S., Hinch, S.G., Healey, M.C., and Farrell, A.P. 2004. The effect of exercise and captivity on energy partitioning, reproductive maturation and fertilization success in adult sockeye salmon. J. Fish. Biol. 64(4): 1039–1059. doi:10.1111/j.1095-8649.2004.0370.x.

Patterson, D.A., Skibo, K.M., Barnes, D.P., Hills, J.A., and Macdonald, J.S. 2007. The influence of water temperature on time to surface for adult sockeye salmon carcasses and the limitations in estimating salmon carcasses in the Fraser River, British Columbia. N. Am. J. Fish. Manag. 27(3): 878–884. doi:10.1577/M06-098.1.

Peña, A., and Nemcek, N. 2017. Phytoplankton in surface waters along Line P and off the west coast of Vancouver Island. In State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2016. Edited by P.C. Chandler, S.A. King, and J. Boldt. Can. Tech. Rep. Fish. Aquat. Sci. 3225. pp. 58–62.

Peña, A., and Nemcek, N. 2018. Results from phytoplankton monitoring at Line P and WCVI. In State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2017. Edited by P.C. Chandler, S.A. King, and J.L. Boldt. Can. Tech. Rep. Fish. Aquat. Sci. 3266. pp. 55–59.

Perry, I., King, S.A., Boldt, J., and Chandler, P.C. 2017. Unusual events in Canada's Pacific marine waters in 2016. In State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2016. Edited by P.C. Chandler, S.A. King, and J. Boldt. Can. Tech. Rep. Fish. Aquat. Sci. 3225. pp. 233–236.

Post, J.R., and Parkinson, E.A. 2001. Energy allocation strategy in young fish: allometry and survival. Ecology 82(4): 1040–1051. doi:10.1890/0012-9658(2001)082[1040:EASIYF]2.0.CO;2.

Preikshot, D., Beamish, R.J., Sweeting, R.M., Neville, C.E., and Beacham, T.D. 2012. The residence time of juvenile Fraser River sockeye salmon in the Strait of Georgia. Mar. Coast. Fish. Dyn. Manag. Ecosyst. Sci. 4(1): 438–449. doi:10.1080/19425120.2012.683235.

Quinn, T.P. 2005. The behaviour and ecology of Pacific salmon and trout. American Fisheries Society. University of Washington Press, Seattle, Washington.

Ravet, J.L., Brett, M.T., and Arhonditsis, G.B. 2010. The effects of seston lipids on zooplankton fatty acid composition in Lake Washington, Washington, USA. Ecology 91(1): 180–190. doi:10.1890/08-2037.1.

Ricker, W.E. 1954. Stock and recruitment. J. Fish. Res. Board Can. 11: 559–623. doi:10.1139/f54-039.

Ross, T. 2017. La Niña, the blob and another warmest year. In State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2016. Edited by P.C. Chandler, S.A. King, and J.L. Boldt. Can. Tech. Rep. Fish. Aquat. Sci. 3225. pp. 30–34.

Ross, T., Fisher, J., Bond, N., Galbraith, M., and Whitney, F. 2019. The Northeast Pacific: Current status and recent trends. PICES Press 27(1): 36–39. Available from https://meetings.pices.int/publications/pices-press/volume27/PPJan2019.pdf.

Ross, T., Fisher, J., and Galbraith, M. 2018. The Northeast Pacific: Current status and recent trends. PICES Press 26(2): 61–63. Available from https://meetings.pices.int/publications/pices-press/volume26/PPJul2018.pdf.

Ross, T., and Robert, M. (in press). Another warm, but almost normal, year in the Northeast Pacific Ocean. In State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2018. Edited by J.L. Boldt, J. Leonard, and P.C. Chandler. Can. Tech. Rep. Fish. Aquat. Sci. 3314. pp. xx–xx.

Ross, T., and Robert, M. 2018. La Niña and another warm year. In State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2017. Edited by P.C. Chandler, S.A. King, and J.L. Boldt. Can. Tech. Rep. Fish. Aquat. Sci. 3266. pp. 27–32.

Schindler, D.E., Rogers, D.E., Scheuerell, M.D., and Abrey, C.A. 2005. Effect of changing climate on zooplankton and juvenile sockeye salmon growth in Southwestern Alaska. Ecology 86(1): 198–209. doi:10.1890/03-0408].

Shrimpton, J.M., Patterson, D.A., Richards, J.G., Cooke, S.J., Schulte, P.M., Hinch, S.G., and Farrell, A.P. 2005. Ionoregulatory changes in different populations of maturing sockeye salmon *Oncorhynchus nerka* during ocean and river migration. J. Exp. Biol. 208(21): 4069–4078. doi:10.1242/jeb.01871.

Simpkins, D.G., Hubert, W.A., del Rio, C.M., and Rule, D.C. 2003. Interacting effects of water temperature and swimming activity on body composition and mortality of fasted juvenile rainbow trout. Can. J. Zool. 81(10): 1641–1649. doi:10.1139/z03-157.

Sopinka, N.M., Hinch, S.G., Middleton, C.T., Hills, J.A., and Patterson, D.A. 2014. Mother knows best, even when stressed? Effects of maternal exposure to a stressor on offspring performance at different life stages in a wild semelparous fish. Oecologia 175(2): 493–500. doi:10.1007/s00442-014-2915-9.

Tadey, J.A. 2018. Evaluation of timing, size, abundance, and stock composition of downstream migrating juvenile sockeye salmon in the lower Fraser River in 2017. Project Summary Presentation at the 2019 Fraser Sockeye Science Integration Workshop, Delta, B.C.

Thorne, R.E., and Ames, J.J. 1987. A note on variability of marine survival of sockeye salmon (*Oncorhynchus nerka*) and effects of flooding on spawning success. Can. J. Fish. Aquat. Sci. 44(10): 1791–1795. doi:10.1139/f87-222.

Tierney, K.B., Patterson, D.A., and Kennedy, C.J. 2009. The influence of maternal condition on offspring performance in sockeye salmon *Oncorhynchus nerka*. J. Fish Biol. 75(6): 1244–1257. doi:10.1111/j.1095-8649.2009.02360.x.

Tucker, S., Trudel, M., Welch, D.W., Candy, J.R., Morris, J.F.T., Thiess, M.E., Wallace, C., Teel, D.J., Crawford, W., Farley, E. V., and Beacham, T.D. 2009. Seasonal stock-specific migrations of juvenile sockeye salmon along the west coast of North America: implications for growth. Trans. Am. Fish. Soc. 138(6): 1458–1480. doi:10.1577/T08-211.1.

Welch, D.W., Melnychuk, M.C., Rechisky, E.R., Porter, A.D., Jacobs, M.C., Ladouceur, A., McKinley, R.S., and Jackson, G.D. 2009. Freshwater and marine migration and survival of endangered Cultus Lake sockeye salmon (*Oncorhynchus nerka*) smolts using POST, a large-scale acoustic telemetry array. Can. J. Fish. Aquat. Sci. 66(5): 736–750. doi:10.1139/F09-032.

West, C.J., and Larkin, P.A. 1987. Evidence for size-selective mortality of juvenile sockeye salmon (*Oncorhynchus nerka*) in Babine Lake, British Columbia. Can. J. Fish. Aquat. Sci. 44(4): 712–721. doi:10.1139/f87-086.

Westley, P.A.H., Hilborn, R., Quinn, T.P., Ruggerone, G.T., and Schindler, D.E. 2008. Long-term changes in rearing habitat and downstream movement by juvenile sockeye salmon (*Oncorhynchus nerka*) in an interconnected Alaska lake system. Ecol. Freshw. Fish 17(3): 443–454. doi:10.1111/j.1600-0633.2008.00296.x.

Whitney, C.K., Hinch, S.G., and Patterson, D.A. 2013. Provenance matters: thermal reaction norms for embryo survival among sockeye salmon *Oncorhynchus nerka* populations. J. Fish Biol. 82(4): 1159–1176. doi:10.1111/jfb.12055.

Whitney, C.K., Hinch, S.G., and Patterson, D.A. 2014. Population origin and water temperature affect development timing in embryonic sockeye salmon. Trans. Am. Fish. Soc. 143(5): 1316–1329. doi:10.1080/00028487.2014.935481.

Williams, I. V, Gilhousen, P., Saito, W., Gjernes, T., Morton, K., Johnson, R., and Brock, D. 1989. Studies of the lacustrine biology of the sockeye salmon (*Oncorhyncus nerka*) in the Shuswap system. International Pacific Salmon Fisheries Commission Bulletin No. 24.

Young, K., Galbraith, M., and Perry, I. 2018. Zooplankton status and trends in the central Strait of Georgia, 2017. In State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2017. Edited by P.C. Chandler, S. King, and J. Boldt. Can. Tech. Rep. Fish. Aquat. Sci. 3266. pp. 180–184.

APPENDIX: WORKSHOP PARTICIPANTS

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