SUPPLEMENT TO THE PRE-SEASON RETURN FORECASTS FOR FRASER RIVER SOCKEYE SALMON IN 2015

Context

Sockeye that spawn and rear in the Fraser watershed (i.e. Fraser Sockeye) exhibit two distinct life-history types: lake-type (Figure 1) and river-type (Figure 2). Most Fraser Sockeye are lake-type, including the Chilko stock, which is expected to contribute the largest proportion to the total Fraser Sockeye return in 2015 (35%). The predominant age class of lake-type Fraser Sockeye is four year olds. After spending their first two winters in freshwater (one winter as eggs in spawning gravel and one winter as fry in rearing lakes), lake-type Fraser Sockeye yearling-smolts migrate rapidly out of their rearing lakes, down the Fraser River, northward through the Strait of Georgia (SOG) and Johnstone Strait, and along the continental shelf, en-route to the Gulf of Alaska. They spend their final two winters in this ecosystem before returning to spawn (Figure 1).

River-type Sockeye spend a single winter in freshwater, and migrate downstream to the SOG as sub-yearling smolts shortly after emerging from their spawning gravel. Harrison Sockeye, the largest river-type stock in the Fraser watershed (this stock is expected to contribute 21% to total return in 2015), remains in the SOG for several months, after all lake-type Fraser Sockeye stocks have migrated out of this system, and subsequently migrate out into the northeast Pacific via the southern Juan de Fuca Strait route (Figure 2). This stock returns to spawn as three and four year olds.

For both life-history types, mechanisms influencing Fraser Sockeye survival are complex and poorly understood, due to the broad range of ecosystems they inhabit throughout their life-history. This increases uncertainty in the Fraser Sockeye forecasts. To improve our understanding of Fraser Sockeye survival mechanisms, starting in the 2014 forecast year (DFO 2014a), auxiliary information on the parental spawner generation through to the juvenile marine rearing environment is synthesized in a forecast supplement report (DFO 2014b). What was learned retrospectively from this first process is presented in Appendix 1 of the current paper.

To provide context for the 2015 forecast (DFO 2015), this year’s Fraser Sockeye forecast supplement report focuses specifically on the 2011 brood year for lake-type stocks, and the 2011 and 2012 brood years for river-type stocks (i.e. Harrison Sockeye). This report synthesizes information on the adult migration conditions, escapement and spawner success, fry and their lake rearing conditions, smolt and juvenile migration, and ocean conditions. In addition, stock compositions of the 2011 escapements, 2013 downstream smolt migration, juvenile ocean migration, and 2015 return forecasts are compared to evaluate proportional changes in stock composition through time. The 2014 forecast supplement report (DFO 2014b) can be used, in combination with this report, to provide context for the five year olds returning in 2015 (DFO 2015).

This Science Response Report results from the Science Response Process of January 27-28, 2015 on the Supplement to pre-season abundance forecasts for Fraser River Sockeye Salmon returns in 2015.

Background

Returns

Total adult Fraser Sockeye returns have historically varied (Figure 3 A) due to the four-year pattern of abundances (cyclic dominance) exhibited by some of the larger stocks, and variability in annual survival (Figures 3 A & B) and exploitation. After reaching a peak in the early 1990s, returns decreased to a record low in 2009, due to declines in stock survivals (Figures 3A and B). In subsequent years, survival, and consequently returns, have increased. The 2010 and 2014 returns were particularly large, since this is the dominant cycle line for the Late Shuswap stock (i.e. Adams River Sockeye), and the combination of above average escapements relative to other cycle lines, and above average to average survivals contributed to these large returns.

For the 2015 return cycle (the current forecast year), Chilko and Late Shuswap have historically contributed the greatest proportion (30% and 26%, respectively) to the total return. The 2015 cycle has the second smallest average return of the four cycles of Fraser Sockeye, with an average annual return (1955-2011) of 5.2 million for all 19 forecasted stocks combined (excluding miscellaneous stocks).

Fraser Sockeye Survival

Total survival (returns-per-spawner) aggregated across all Fraser Sockeye stocks declined in the 1990s and culminated in the lowest survival on record in the 2009 return year. In subsequent years (2010 to 2014), survival was close to average (Figure 3 B). Individual stock survival trends, however, vary (Grant et al. 2011; Peterman & Dorner 2012). Most notably, Harrison Sockeye, a unique stock with a different age-structure and life-history compared to all other Fraser Sockeye stocks, have exhibited a large increase in survival in recent years (Grant et al. 2010; Grant et al. 2011).

Our understanding of what drives inter-annual changes in Fraser Sockeye survival is complicated by the broad range of ecosystems these stocks inhabit throughout their life-history. Most Fraser Sockeye stocks are lake-type Sockeye, which generally spend their first two winters in freshwater (egg through to smolt stage), followed by two winters (range of one to three winters) in the marine environment, before returning to their natal streams or lakes to spawn (Figure 1). These Sockeye migrate through a broad range of ecosystems during their first year of marine residence, moving rapidly northwards through the SOG (Preikshot et al. 2012), exiting this water body via the Johnstone Strait, migrating along the continental shelf, and finally moving off the shelf into the Gulf of Alaska in the winter months (Tucker et al. 2009). River-type Sockeye are less common in the Fraser watershed. The most abundant river-type Fraser Sockeye is the Harrison stock (Figure 2). Shortly after river-type Sockeye emerge from their spawning gravel as sub-yearling smolts they migrate to the ocean, and spend several months in the SOG, before migrating out into the northeast Pacific via the southern Juan de Fuca Strait. After two to three winters in the ocean they return as adults back to their spawning grounds as, respectively, three or four year old fish.

Considerable mortality occurs in the freshwater and marine ecosystems, as indicated by freshwater and marine survival data for Chilko River Sockeye (Figure 4 A & B). Chilko is the only Fraser Sockeye stock with a long and complete time series of smolt data (estimated at an enumeration weir located at the outlet of Chilko Lake), which can be used with escapement and return data to partition total survival into freshwater and ‘marine’ components (‘marine’ survival includes their migration downstream from the counting weir to the SOG). It is likely that a number of factors in both the freshwater and marine environments influence Fraser Sockeye survival, and these factors may vary between stocks and years.

Pre-Season Abundance Forecasts

The 2015 forecast ranges from 3,824,000 to 12,635,000 at the 25% to 75% probability levels. The 50% (median) forecast is 6,778,000 (DFO 2015). Four year olds comprise 78% of the total return forecast, which is lower than average (87%) due to the large brood year escapements contributing the five year olds returning in 2015, as compared to those contributing the four year olds for a number of stocks. In particular, Nadina (78%), Pitt (63%), Late Stuart (52%), Quesnel (56%), and Stellako (52%) contribute the highest percentages of five year olds to the total forecast. Chilko lake-type Sockeye and Harrison river-type Sockeye are expected to contribute the greatest proportions to the total forecast overall (respectively, 35% and 21%). The forecast for Chilko is dominated by four year olds (89% as a percentage of four plus five year olds) (DFO 2015).

Auxiliary data is presented in this report to provide context for the 2015 Fraser Sockeye forecasts. For lake-type Sockeye, data is presented from the 2011 parental spawner generation through to the juvenile marine rearing environment in 2013. Auxiliary information on the five year old returns of lake-type Fraser Sockeye in 2015 (brood year 2010) is presented in the Supplement to the pre-season return forecasts for Fraser River salmon in 2014 (DFO 2014b). For river-type Sockeye (i.e. Harrison), data from the 2011 and 2012 brood years through to the juvenile rearing environments in 2012 and 2013 are presented.

Analysis and Response

Lake-Type Stocks: Adult Migration and Spawning In 2011

Adult Migration Timing

- The arrival timing of most stocks to their spawning grounds was average, with the following exceptions: arrival timing to the Early Stuart spawning grounds was two to three weeks later than normal, and arrival timing of Summer Run stocks (including Chilko Sockeye) to their spawning grounds in 2011 was slightly delayed (approximately one week later than normal).

Adult Migration and Spawning Conditions

- Salmon migrating in temperatures above 18°C may show signs of decreased swimming performance (Eliason et al. 2011). Sustained temperatures above 20°C can lead to increased mortality, disease, and legacy effects on egg quality (Burt et al. 2011). Optimal spawning ground temperatures are between 10-12°C, while egg survival is reduced once values approach 15°C (Whitney et al. 2013). High discharge in the Fraser Canyon has been associated with migration delays (>7,000 cubic meter per second: cms) and can create a complete hydrological barrier to migration (> 9,000 cms), leading to increased risk of fish mortality and severe stress (Macdonald et al. 2012). Low river discharge on spawning grounds can affect spawning success (crowding due to less available spawning habitat) and egg survival (dewatering of redds). Alternatively, high river discharge events can cause bed movement, scouring, and egg mortality.
- In 2011, Fraser River discharge levels were over 8,000 cms from mid-June to mid-July, peaking near 10,000 cms at the end of June (Figures 5 A & B). The vast majority of Early Stuart, and portions of Early Summer migrants would likely have been affected by

high discharge levels (Figure 5 A), as signs of physiological stress are evident at flows above 7,000 cms, and Hell's Gate becomes a hydrological barrier to migration at flows above 9,000 cms. In conjunction with high flows, the early portion of the Early Stuart migration encountered temperatures below their physiological optimal (16 ^{o}C) (Figure 5 A), which could result in reduced swimming performance. In contrast, Chilko and other Summer stocks experienced moderate flows and temperatures in 2011 (Figure 5 B).

- According to observations by Fraser Sockeye stock assessment staff during the adult escapement enumeration projects, environmental conditions (water levels and temperatures) on the spawning grounds were considered favorable for spawning throughout the Fraser River watershed in 2011. Although high water events were noted at the tail end of the spawning period in the Upper Pitt, Chilliwack and Nahatlatch systems, these events are not expected to have significantly impacted egg-to-fry survival. It is important to note that environmental conditions are not assessed by field crews after the escapement enumeration projects have ended, so environmental events that occur between the end of these projects and the following spring could affect egg-to-fry survival but are not recorded.

Spawner Success: Egg Retention and Egg Viability

Escapement Enumeration Program Observations and Estimates

- Spawner success for a stock is calculated as the proportion of eggs spawned, based on spawning ground carcass surveys conducted during escapement enumeration. Spawner success is recorded as 0%, 50%, or 100% for each female carcass sampled, then averaged across all populations in a stock. Spawning success across all Fraser Sockeye populations was 80% in 2011, which is below the long term average of 89%.
- Pre-spawn mortality (PSM) is 100% minus the spawner success percentage. Very high levels of PSM were observed in several areas of the watershed, including the Nadina (57%), Quesnel (31%), Stellako (40%), Late Stuart (46%) and Late South Thompson (45%) systems.
- For Chilko Sockeye, the dominant stock in the 2015 forecast, pre-spawn mortality levels in the 2011 brood year throughout the duration of the die-off period in 2011 (82%) was below the long term average (1950-2010: 91%).
- Spawner success is incorporated into annual forecasts by using either effective female spawner (EFS) abundances (female escapement multiplied by spawner success) or smolt abundances as predictor variables.

Environmental Watch Program Observations and Estimates

- While spawning success provides a direct measure of eggs released on the spawning grounds, it does not provide a true measure of spawning success from the perspective of egg deposition or egg viability. A number of physiological metrics have been used to evaluate overall health of spawning fish. These can be used to determine the potential for successful redd construction and deposition of eggs into them by the spawners, and not simply their release of eggs. Similarly, direct estimates of egg and sperm quality are used to assess gamete viability of eggs that were deposited. For the few stocks with fry or smolt data such as Chilko, using these data as predictor variables can eliminate uncertainty in, respectively, egg-to-fry or egg-to-smolt survival. However, most stocks do not have fry or smolt data and, therefore, information on spawning success and egg viability from a physiological perspective can be used to qualitatively inform Fraser Sockeye freshwater survival.

- A suite of biological samples was collected from spawning Sockeye in 2011 to assess egg deposition and egg viability: physiology (ions & metabolites), steroids (to assess maturation & stress), condition (energy & lipids), and disease (RNA & histopathology) (Table 1). Ideally, a multivariate analysis of these variables would provide a holistic representation of fish condition. However, in the absence of such in-depth analyses there are some key surrogates of overall condition that can be used. For example, spawner glucose can represent an integrated measure of the ability to maintain metabolic homeostasis, while body fat content is an indicator of energy reserves. Healthy glucose levels are between 4-7 micromol-per-litre (mmol/L) and values above or below this range are considered abnormal and are linked to premature death of fish that have arrived on the spawning grounds but have not already begun spawning (Figure 6). However, the interpretation of any physiological variable, such as glucose or fat content, for fish on the spawning grounds is relative to their behavioral state (i.e. arrival/holding, paired/spawning, spent/moribund). For fish that are actively spawning, it is normal for glucose levels to rise well above 10 mmol/L, though these values will lead to rapid senescence. Normal fat content for fish arriving on the spawning grounds is between 2.5-4.0%. For fish that are actively spawning fat content can drop to just below 2%. If fish have not engaged in active spawning and are close to the 2% threshold it is unlikely they will successfully spawn.
- Returning adult sockeye were intercepted at various locations along their migration route in 2011 (Figure 6). Chilko, Late Shuswap, and Weaver lake-type Sockeye were the primary stocks targeted. Priorities and completion of lab analyses varies from year to year, but all samples are inventoried and stored for possible future analyses including analysis of energetic status, stress and pathogen status. In 2011, plasma glucose concentrations (an indicator of physiological stress) of in-river migrants were slightly above normal (8.0- 8.5 mmol/L) for Chilko and Shuswap, but at their spawning locations only Late Shuswap remained above normal (12.2 mmol/L) (Figure 6). Mean percent lipid (an indicator of condition) for all stocks at all locations was considered within the normal range. Gamete quality (egg survival to eyed stage) was average for Adams (Late Shuswap) (79%), good for Weaver (89%) and below average for Harrison (64%).

Lake-Type Stocks: Freshwater Rearing

Overview

- Fry (predominant age: 1_1) abundances have been assessed on a semi-regular basis (generally on dominant and subdominant cycle years) by DFO’s Freshwater Lakes Division in Quesnel Lake and Lake Shuswap. Limnology has been sporadically assessed for Quesnel, Shuswap and Chilko Lakes.
- The stock contributing the greatest proportion to the 2015 forecast is Chilko Sockeye (35%). For this stock, smolt outmigration (predominant age: 2_2) abundances have been assessed consistently since 1949 by DFO’s Stock Assessment Division.
- Smolt abundances for Cultus Sockeye, which contributes less than 1% to the total 2015 forecast, have been sporadically assessed since the 1920’s. Fry abundances for this stock have been assessed in recent years only. Given the limited contribution of Cultus expected in the 2015 returns, detailed information on this stock is not provided.

Chilko Lake Limnology

- Limnological assessments of Chilko Lake were conducted between 1985 and 1993, and more recently between 2009 and 2012. A full suite of physical, chemical, and biological variables relevant to Sockeye Salmon rearing conditions were measured in these surveys, including, but not limited to, lake thermal structure, photosynthetic rates, and zooplankton species assemblage and biomass. Methods were similar to those used in Shuswap Lake and are generally described in Bradford et al. (2000) and Shortreed (2007).
- Chilko Lake was experimentally fertilized in the late-1980's and early-1990's to evaluate the enhancement of freshwater survival (see Bradford et al. (2000)). Though there was a long hiatus from limnological assessments conducted in Chilko Lake (1994-2008), recent data show that photosynthetic rates (PR) appear to have increased ~ 74% since the early-1990's (unfertilized years) to a new productivity state similar to that observed when over 100 tons of inorganic fertilizers were being applied annually (Selbie et al. 2010). This shift represents a rapid change in lake productivity for such a large system. Increased PR should be correlated with enhanced freshwater survival (Hume et al. 1996; Shortreed et al. 2000).

Chilko Sockeye Freshwater Survival and Fish Condition

- Chilko is the only stock for which a long time series (brood years 1949 to present) of smolt (predominant age: 2_2) abundance data have been collected. Smolt counts are assessed at an enumeration weir located at the outlet of Chilko Lake. Smolt data can then be combined with adult escapement and return data to provide a time series of freshwater (and marine) survival (Figure 4 A & B).
- The relationship between brood year effective female spawners (EFS) and resulting smolt abundance in Chilko Lake exhibits density-dependent freshwater survival at higher EFS spawner abundances, and has been modeled with both a Ricker (R^2<0.4) and Beverton-Holt (R^2<0.4) relationship (Figure 7 A).
- In 2011, the total escapement to the Chilko system was the second largest escapement on this cycle. This escapement fell within the range of updated photosynthetic rate (PR) model optimums for Chilko Lake (Figure 8 A), which suggests the potential for fry rearing limitation (i.e. food availability) provided fry densities were not limited by poor egg-to-fry survival. However, there are several pieces of evidence that indicate that fry rearing conditions were average for Chilko Sockeye in the 2011 brood year, including zooplankton biomass, freshwater survival, and smolt sizes (see subsequent bullets).
- Total zooplankton biomass in Chilko Lake over the growing season in 2012 followed trajectories observed in lower-escapement years, suggesting rearing limitation was likely modest.
- Freshwater survival in the 2011 brood year (97 smolts/EFS) was close to average (1950-2011 average: 117 smolts/EFS) (Figure 4 A; Figure 8 A). This lies in contrast with the suspected poor rearing conditions in the previous brood year (2010 brood year: 47 smolts/EFS freshwater survival), which likely resulted from high fry densities produced by the exceptional escapement of 1.2 million spawners in 2010, leading to high competition for food resources amongst the fry. For the 2011 brood year, the larger escapement and average freshwater survival resulted in smolt abundances (2013 smolt outmigration year: 44.2 million) that were above average (brood years 1950-2011: 19.9 million one year old smolts).

- Chilko Sockeye smolt nose-fork length assessed at the outlet of Chilko Lake at the enumeration weir in 2013 (85.3 mm) was close to the time series average (brood years 1952-2011: 83.2 mm). The average 2011 brood year smolt length was larger than the 2010 brood year average (77.4 mm). This evidence supports the notion that lake rearing conditions were average for the 2011 Chilko Sockeye brood. See subsequent Smolt Outmigration section.
- Condition analyses on Chilko smolts assessed at the outlet of Chilko Lake at the enumeration weir for brood years 2011 and 2010 are still being processed; these data were not available at the time of this report.

Quesnel Lake Limnology

- Limnological assessments of Quesnel Lake were conducted between 1985 and 1994, 2003, and more recently between 2004 and 2007. A full suite of physical, chemical, and biological variables relevant to Sockeye Salmon rearing conditions were measured in these surveys, including, but not limited to, lake thermal structure, photosynthetic rates, and zooplankton species assemblage and biomass. Methods were similar to those used in Shuswap Lake and are generally described in Bradford et al. (2000) and Shortreed (2007). Details were not provided for the current report.

Quesnel Sockeye Freshwater Survival and Fish Condition

- Quesnel is the only Fraser Sockeye stock that demonstrates evidence of delayed-density dependence (Peterman & Dorner 2012), likely caused by the influence of fry density on the lake ecosystem, which persists through to a subsequent year, consequently influencing fry productivity of that next year.
- Unlike most other Fraser Sockeye stocks, survival of Quesnel Sockeye has only improved in the most recent return year (2014); survival for most other stocks improved starting in the 2010 return year.
- Pelagic surveys of Sockeye fry in the Quesnel Lake system have been conducted since 1975, largely on the dominant and subdominant cycles. These surveys are conducted in the summer (August) and fall (October). Hydroacoustic estimates of fry abundance and distribution, coupled with biosamples (including length and weight) from mid-water trawls, provide density and biomass estimates of the Sockeye fry population. For complete methods, see MacLellan and Hume (2010).
- The relationship between EFS and resulting fall fry in Quesnel Lake exhibits density dependent freshwater survival at higher spawner abundances, and has been modeled with both a Ricker (R^2=0.6) and Beverton-Holt (R^2=0.3) relationship (Figure 7 B).
- Freshwater survival in the 2011 brood year (380 fall fry/EFS) was above average compared to all cycles (1976-2010 brood year: 189 fall fry/EFS), and given the low brood year escapement, the resulting fry abundance (6.4 million) was below average (1976-2010 average: 29.8 million).
- The lake-wide estimate of fall fry Sockeye (± 95% CI) was 6.4 ± 1.4 million fish. In terms of density this equated to 246 ± 54 fish/ha. Fry weighed 3.11 ± 0.23 g and were 65 ± 1.3 mm in nose-fork length. Condition metrics were not taken from fish collected in Quesnel Lake.
- Given the relatively small number of Sockeye fry in the lake in 2012, the Quesnel stock should not be expected to be a strong contributor to the 2015 returns (DFO 2015).

Shuswap Lake Limnology

- Limnological assessments of the Shuswap system (Shuswap and Mara lakes) were conducted in the years 1987-1993, 2011, and 2012. This sampling coverage includes rearing years (brood year+1) for dominant (1991, 2011), subdominant (1988, 1992, 2012) and weak cycles (1989, 1990, 1993). A full suite of physical, chemical, and biological variables relevant to Sockeye Salmon rearing conditions were measured in these surveys, including, but not limited to, lake thermal structure, photosynthetic rates, and zooplankton species assemblages and biomass. Methods for these surveys are generally described in Nidle and Shortreed (1996), Morton and Shortreed (1996) and Shortreed (2007).
- Macrozooplankton and *Daphnia* biomass (the latter is preferentially preyed upon by salmon fry and comprise 85-95% of the fall diet of age-0 Sockeye in Shuswap Lake) was higher in 2012 versus 2011 (2011 vs. 2010 brood years), given the much lower fry densities, and therefore lower density-dependent grazing pressure, in 2012.
- Freshwater survival (fry/EFS) in Shuswap Lake has declined post-1990, particularly on the subdominant cycle line. Though there was a long hiatus from conducting limnological assessments in Shuswap Lake (no assessments were conducted from 1994-2010), recent data show that photosynthetic rates (PR) increased ~ 45% between the early 1990's and 2011-2012. Increasing PR should be correlated with enhanced freshwater survival (Hume et al. 1996; Shortreed et al. 2000). However, increases in fry densities in the past decade (in several cases exceeding the lake's carrying capacity), and other stressors in Shuswap Lake (research in progress), should have resulted in density-dependent effects on food web structure and function, and thus reduced freshwater growth and survival.

Shuswap Sockeye Freshwater Survival and Fish Condition

- Pelagic surveys of Sockeye fry in the Shuswap Lake system (includes Shuswap & Mara Lakes) have been conducted since 1975, largely on the dominant and subdominant cycles. These surveys are conducted in the summer (August) and fall (October). Hydroacoustic estimates of fry abundance and distribution, coupled with biosamples (including length and weight) from mid-water trawls, provide density and biomass estimates of the Sockeye fry population. For complete methods, see MacLellan and Hume (2010).
- The relationship between brood year EFS and resulting fall-fry in the Shuswap Lake system exhibits density dependent freshwater survival at higher spawner abundances, and has been modeled with both a Ricker (R^2=0.8) and Beverton-Holt (R^2=0.6) relationship (Figure 7 C).
- The Early and Late Shuswap stocks both use the Shuswap and Mara Lake complex for rearing as fry. In 2011, the total escapement of Early and Late Shuswap stocks combined (74,000) was well below the spawner abundance that maximizes fry production for the lake system (S_{max}), as calculated from photosynthetic rate (PR) models (2.2 million, updated from Grant et al. 2011; see Hume et al. 1996 and Shortreed et al. 2000 for methods), or from stock-recruitment data (2.5 million) (Figure 8 B). Although compensation (increased growth and/or survival due to low densities) of fry would be expected in the 2011 brood year, freshwater survival (168 fall fry/EFS) was in fact well below the average across all cycles (380 fall fry/EFS) and below the cycle average (207 fall fry/EFS). This might be attributed to delayed-density-dependence from

the previous brood year escapement (2010), which was exceptionally large for the Shuswap system (DFO 2014a).

- In-lake estimates of Sockeye fry (± 95% CI) were 16.8 ± 3.5 million in August, and 11.2 ± 2.2 million in October. This translates into densities of 533 ± 112 fish/ha in August and 354 ± 68 fish/ha in October. While the absolute number of fry in the lake in 2012 was the lowest on record for the sub-dominant cycle (previous estimates ranged from 16.5 million (1995 BY) to 153.5 million (1987 BY)), the number of fry-per-EFS (154 fry/EFS) was within the historic range across all cycles (67 in 1995 BY to 422 in 1987 BY) (Figure 8 B).
- Summer fry weighed 2.24 ± 0.09 g and were 58 ± 0.7 mm in nose-fork length. Fall fry weighed 3.18 ± 0.12 g and were 67 ± 0.8 mm in nose-fork length. As in previous cycles, fry from the sub-dominant brood year (2011) were larger than those from the dominant brood (2010 brood year). This carried through to out-migrating smolts in 2013. Fry in 2012 (2011 brood year) had higher lipid proportions as summer fry through to smolts, than those in 2011 (2010 brood year). Morphologically, fish sampled in 2012 (2011 brood year) were more robust than those sampled in 2011 (2010 brood year), and were characterized by deeper bellies.
- Total zooplankton biomass was relatively abundant throughout the mid-to-late growing season, suggesting negligible rearing limitation in Shuswap Lake for the 2011 brood.
- Given the relatively small number of Sockeye fry in the lake in 2012, the Shuswap stocks are not be expected to be a strong contributor to the 2015 returns (DFO 2015).
- Smolts (predominant age: 2_2) in the Shuswap system from the 2010 and 2011 brood years (2012 and 2013 outmigration years) were sub-sampled to study the effects of density dependence on fish condition and survival. Sampling occurred on a weekly basis from early-May to mid-June at Little River, as smolts migrated out of the Shuswap system.
- The 2012 and 2013 samples indicate that peak migration occurs through mid-May, later than the Chilko and Cultus stocks (Figure 9 C). In 2013, a high proportion of smolts caught were two (3_3) year olds (~30%), based on length, although these were not observed in lake trawl surveys. This may indicate a possible return of age 5_3 adults to the Shuswap system in 2015. The average fat content of smolts leaving Shuswap Lake in 2013 was similar to fish leaving in 2012 (~2.8%).

Lake -Type Stocks: Smolt Outmigration

Smolt Outmigration Timing-Lake Outlet

- Three smolt assessment programs at the outlet of major rearing lakes were conducted in the 2013 outmigration year, including Cultus, Chilko, and Shuswap Lakes (Figure 9):
    - Cultus smolt assessments have been sporadically conducted from 1926 to present. The Cultus smolt 50% outmigration date in 2013 (2011 brood year) was April 20 (Figure 9 A).
    - Chilko smolt outmigration has been assessed consistently using a weir and counting system located at the outlet of Chilko Lake from 1951-present. The Chilko smolt 50% outmigration date (when 50% of the run had moved through the counting weir) in 2013 (2011 brood year) was April 29 (Figure 9 B).

- o Shuswap smolts have been opportunistically assessed, starting in 2012 to coincide with the exceptionally large run in the associated (2010) brood year, and also including 2013 (Figure 9 C). For this stock, sampling of smolts occurred weekly, and the 50% migration date in 2013 was in mid-May, later than Cultus and Chilko.

Smolt Outmigration Timing-Mission

- The Mission smolt project assesses smolt outmigration of virtually all stocks using mobile traps mounted to a vessel that operates in the Fraser River at Mission, B.C. (Figure 10). Only a few stocks entering the Fraser River downstream of Mission (e.g. upper Pitt River) are unavailable for capture at this location. During the spring and early summer (March 22-July 25) of 2013, combinations of three mobile traps were fished four days a week (M, T, Th, F) from 0600-1400 hours. This 2013 survey frequency differed from the survey frequency in 2012 of once every four days. A survey gap occurred between May 17 and June 1 due to vessel malfunction. As a result, estimates of stock proportions (for all stocks upstream of Mission) and outmigration timing (for later timed stocks) at Mission might not be accurate (Figure 11). The goal of this project was to evaluate the timing, size, abundance and stock composition of downstream migrating Sockeye smolts. Bio-samples were collected from a subset of the trapped Sockeye smolts. Bio-samples collected included fish length (nose-fork length), weight, adipose fin clip status, and tissue samples for genetic stock identification (GSI) and health assessments (analysis performed by other researchers).
- Stock proportion and outmigration timing at Mission is somewhat challenging to interpret in 2013, given the results of the 2012 assessment coupled with the assessment gap in the later component of the migration period in 2013. Stocks that migrate later, such as those from the Shuswap system (Figure 9), were likely not representatively sampled throughout their migration past Mission. This influences the relative abundance estimates for all trapped stocks. Additionally, this affects the estimated 50% outmigration date of any stock with significant numbers passing Mission between May 17 and June 1. The Chilko 50% outmigration date at Mission was May 5th (Figure 11) compared to April 30 in 2012 (see Figure 16 in DFO 2014b). For Chilko, similar to the supplement prepared for the 2014 forecast (DFO 2014), outmigration timing at the enumeration weir (Figure 9 B) was closely coupled with outmigration timing downstream at Mission (Figure 12 A), with a travel time of roughly 6 days.

Smolt Outmigration Conditions

- The effect of discharge on Sockeye smolt survival is unclear, for example higher discharge could increase smolt outmigration rates and increase water turbidity, both of which could reduce their exposure to predators in this ecosystem (McCormick et al. 1998).
- Peak freshet measured at Hope, B.C., on the Fraser mainstem occurred in mid-May in 2013 (Figure 12 B), largely after the peak outmigration of Fraser Sockeye smolts (late-April) (Figures 9 - 12). During Chilko smolt outmigration (April-May 2013; Figures 9A, 11, and 12 A), discharge in the lower Fraser River was slightly above average in April 2013, and above average in May 2013 (Figures 12 B), although the majority of Chilko smolt outmigration would have occurred prior to peak flows and temperatures (Figure 13). Discharge in the Chilcotin River, the first river system Chilko smolts migrate through en-route to the Fraser River, was also below average during Chilko smolt outmigration

(Figure 13). Depending on the outmigration timing of other stocks, there could be some overlap between higher flow and smolt outmigration from these other stocks.

- Temperatures in the Lower Fraser (measured at Hope, B.C.) were also largely average in 2013 for the majority of the smolt outmigration, although some stocks that out-migrate later, in early to mid-May, experienced above average temperatures (Figure 14).

Smolt Outmigration Sizes

- Smolt size is positively correlated with smolt-to-adult survival in Sockeye (Ricker 1962; Henderson and Cass 1991; Koenings et al. 1993; Bradford et al. 2000).
- Smolt length sampled at the outlet of Chilko Lake in the 2013 outmigration year (average nose-fork length: 85.3 mm) was greater than the 1954-2011 time series average (83.2 mm). The 2013 smolts were also larger than the previous outmigration year (2012) smolts, which exhibited below average nose-fork lengths (77.4 mm). The difference in average smolt length between 2013 and 2012 is likely attributed to density-dependent growth. Adult escapement (EFS) was much smaller in the 2011 brood year (2013 smolt outmigration year: 458,000 EFS) compared to the previous brood year in 2010 (2012 smolt outmigration year: 1.2 million), therefore density dependence likely restricted growth in the 2010 brood year.
- Smolt size sampled at the outlet of Shuswap Lake in the 2013 outmigration year (average nose-fork length: 80.7 ± 3.7 mm 95% CI; average weight: 4.6 ± 2.3 g 95% CI) was significantly larger (nose-fork length and weight both $p < 0.001$) than in the 2012 outmigration year (average length: 67.9 mm ± 0.7 mm 95% CI; average weight: 2.7 ± 0.1 g 95% CI). As expected, given differences in fry densities between the dominant (2012 smolt outmigration year) and subdominant (2013 smolt outmigration year) cycles, overall growth of Sockeye fry in Shuswap Lake occurred more quickly in the 2011 brood year (2013 outmigration year) than in the 2010 brood year (2012 outmigration year) when compared across on-shore, pelagic and smolt life stages.
- Sockeye smolt nose-fork lengths were also measured at Mission, B.C. in 2013, and were larger on average for most stocks compared to 2012 (Table 2; Figure 15). This difference can likely be attributed to density-dependent growth resulting from the exceptional escapements observed in a number of systems in the 2010 brood year (2012 outmigration year), particularly the Shuswap system and Chilko. Two exceptions were the Fraser-Summer (Stellako) and Quesnel-Summer (Horsefly/Mitchell) Sockeye stocks, where the average nose-fork lengths were larger in 2012 despite a much larger escapement in the 2010 brood year (2012 smolt outmigration year) (Table 2; Figure 15).
- Note that the Chilko smolts sampled in the Fraser River at Mission, B.C. in 2013 had a similar average nose-fork length to those sampled at the outlet of Chilko Lake. Given the limited time between their outmigration from Chilko Lake and their migration past Mission (approximately 6 days between the 50% migration dates; Figure 12 A), little growth would be expected.

Lake-Type Stocks: Juvenile Migration in the Strait of Georgia

Background

- Most juvenile Fraser Sockeye spend four to six weeks rearing and growing in the Strait of Georgia (SOG) prior to moving north through Johnstone Strait (Preikshot et al. 2012). Trawl surveys have been conducted in the SOG since 1998 (with one missed early summer assessment in 2003) to assess juvenile salmon abundances. These surveys have been consistently conducted between late-June to early-July and again between September to early-October. The surveys follow a standard track line that is fished over a nine to ten day period (Beamish et al. 2000; Sweeting et al. 2003) (Figure 16).

- In 2013, an additional trawl survey was conducted during the first ten days of June, specifically to target juvenile Sockeye during their peak abundance in the SOG. This early June survey followed the standard track line fished during the annual surveys (Figure 16). In addition, sets were conducted in the Discovery Island region during this survey. The purse seine surveys conducted in May and June 2010 to 2012 (Figure 16; Neville et al. 2013) were not replicated in 2013. However, results from these earlier purse seine surveys are used as a reference to compare the distribution of juveniles between years. Information collected during all marine surveys included catch-per-unit-effort (CPUE), length/weight, diet, stock composition, scales and otoliths, and tissues for fish health, genomic and energetic studies.

Juvenile Migration Timing

- Although the annual (1998-present) trawl surveys conducted in late-June/early-July target Coho Salmon, all salmon species are collected. Given the late timing of these surveys, however, only about 10% of juvenile Sockeye Salmon remain in the SOG during this period. For a single year in 2008, Thompson et al. (2012) reported that the stock structure present during the survey conducted was roughly representative of the expected stock composition based on brood year escapements in the 2006 brood year. However, based on last year's results from the Mission smolt outmigration project and the temporally expanded SOG Program, there is evidence of differences in outmigration timing amongst Fraser Sockeye stocks (DFO 2014b). Further, the 2013 early June surveys (conducted annually starting in 2010) indicated that Fraser Sockeye juvenile migration through the SOG was earlier than in previous years (see subsequent bullets) (Figure 18). Therefore, relative abundance (CPUE) from this annual survey could change depending on the dominant stock(s) migrating through the SOG and inter-stock and inter-annual variation in outmigration timing (Figure 17).
- The CPUE of juvenile Sockeye Salmon in the standard trawl survey in late June/early July of 2013 was the lowest (CPUE 4.7 fish/hr) observed for the particular cycle year since the survey was initiated in 1998, however, see previous and subsequent bullets for interpretation (Figure 17). The few Sockeye Salmon that were captured in the survey were in the central and northern portions of the SOG and the Gulf Islands, typical of the distribution generally observed during this time period (Figure 18 B). The timing of the survey in 2013 was consistent with the previous survey on this cycle line in 2009, however the catches in 2009 were 11 times greater (CPUE 53.0 fish/hr) than in 2013 (Figure 17). Brood year escapements were three times larger for the 2013 juvenile outmigration (2011 brood year EFS: 1.2 million EFS) than for the 2009 juvenile outmigration (2007 brood year: 400,000 EFS), therefore, assuming survival was similar, a larger Fraser Sockeye juvenile CPUE would be expected in the SOG in 2013 compared to 2009. On the 2013 cycle, there was one other brood year (2003; EFS: 1 million) that had a similar low CPUE (in the SOG during their 2005 juvenile outmigration 9.4 fish/hr) compared to 2013 (4.7 fish/hr). However, the 2005 survey was conducted even later than usual for this sampling program, commencing in the middle of July and, therefore, a larger percentage of the Fraser Sockeye juveniles likely would have left the SOG by this time (Preikshot et al. 2012).

- In 2013, an earlier timed trawl survey (June 1-11, 2013) was conducted, in addition to the standard annual survey described in the previous paragraph (Figure 18 A). During this earlier trawl survey (Figure 16), the CPUE for the standard survey area in the SOG was 59.0 fish/hr. The largest catches of juvenile Sockeye Salmon during this period were within the Discovery Islands (June 3, Area 6, CPUE 942.6 fish/hr) (Figure 18 A). When compared to similarly timed surveys conducted from 2010 to 2012, the migration of the juveniles out of the SOG in 2013 may have been earlier (June 3) than observed in 2010-2012 (June 10, see subsequent bullet).
- There are no comparable data on this cycle for the early June trawl surveys. However, juvenile salmon distribution can be compared with recent late-May/early-June surveys conducted on other cycle years. The catch distribution of juvenile Sockeye Salmon from the trawl survey (June 1-10, 2010) and from purse seine surveys (late-May/early-June 2010 to 2012) indicated that the migration of the majority of Sockeye Salmon out of the SOG occurred in early-June. Neville et al. (2013) reported that between 2010 and 2012, very few Sockeye Salmon were observed leaving the SOG before the beginning of June, with virtually no juvenile Sockeye Salmon captured in the northern SOG (Discovery Islands; Figure 16, Area 6) during the last week of May. The few Sockeye Salmon that were captured from the Discovery Islands region in these earlier surveys were B.C. mainland stocks and were not from the Fraser River. Similar to estimates by Preikshot et al. (2012), peak Fraser Sockeye abundance for the 2010 to 2012 years was estimated during early-June (June 10).
- It is not known if this variation in Fraser Sockeye juvenile timing observed between 2013 and the 2010-2012 years is specific to the stocks dominating the 2013 cycle line, is due to environmental conditions in 2013, or can be attributed to other factors. It is important to note that this shift in timing did not occur in 2014, when the distribution of juveniles was consistent with observations in 2010-2012.
- The proportions of empty stomachs in both trawl surveys in 2013 were average (27%), therefore suggesting that conditions were not out of the normal range observed in the SOG.

Juvenile Sizes in the Strait of Georgia

- Juveniles caught in the early June trawl survey were an average (± standard error) nose-to-fork length of 106.2 ± 13.9 mm (Figure 19). The average length of the juveniles captured in the standard survey in late June-early July was 123.4 ± 12.0mm (Figure 19), and was the largest observed in the 15 year time series. In 2013, the largest fish observed in the surveys were in the regions adjacent to and south of Texada Island (Figure 16, Area 3 and 4). The smallest fish were the juveniles captured within the Discovery Islands (Area 6). This is in contrast to 2010-2012 when the largest fish were captured in the Discovery Islands (Area 6), northern SOG (Area 5) and Gulf Island (Area 2) regions and the smallest fish were captured just off the mouth of the Fraser River (Area 1). The mechanisms underlying these size differences in the different areas of the SOG are currently unclear.

River-Type Stocks: Adult Migration and Spawning In 2011 and 2012

Adult Migration and Spawning

- In 2011, Harrison Sockeye (contributing four year olds to 2015 returns) were reported to be in poor condition on the spawning grounds with several en-route mortalities reported in the near terminal areas. This may be due to the exceptional escapement observed in this system in this brood year (387,100 effective female spawners). Spawning success at Harrison was 91% in 2011 (long-term average: 99%). Physical conditions (water levels and temperatures) on the spawning grounds were favorable throughout this stock's spawning period.

- In 2012, Harrison Sockeye (contributing three year olds to 2015 returns) were reported to be in good condition on the spawning grounds with a spawner success of 99%. Escapement in this year was much lower than the previous brood year at 32,900 effective female spawners.

River-Type Stocks: Sub-Yearling Smolt Outmigration

Fry Outmigration Conditions

- Since this stock does not rear in freshwater but migrates to the ocean as sub-yearling smolts (age: 1_1) shortly after they emerge from the gravel, there is no rearing lake sampling for this stock, and given their size and outmigration timing (Birtwell et al. 1987), no Mission smolt sampling of this stock.
- Harrison Sockeye migrate out later than most Fraser Sockeye stocks as subyearling smolts (Birtwell et al. 1987), rather than as yearling smolts, and would have experienced slightly above average to slightly below average discharge levels in 2013 (four year olds returning in 2015) (Figure 12 B).

River-Type Stocks: Juvenile Migration in the Strait of Georgia

Juvenile Migration Timing

- Harrison River Sockeye Salmon enter the SOG in late June/early July (later than river-type Fraser Sockeye) and are typically captured in Howe Sound during that time period. In September, Harrison River Sockeye are the dominant stock of Sockeye Salmon captured in the SOG and Howe Sound regions (Beamish et al. 2012). Since Harrison Sockeye return as three and four year old fish, the Harrison River Sockeye Salmon that will return in 2015 will include juveniles that entered the ocean in both 2012 (brood year escapement of 400,000) and 2013 (brood year escapement of 33,000). There is considerable inter-annual variability in Harrison Sockeye age of maturity, although on average they return at older ages (greater proportion of four year olds relative to three year olds) in years when Pink Salmon are also spawning in the Harrison system (Grant et al. 2010).
- The catch (CPUE) of juvenile Sockeye Salmon in the SOG in September 2012 and 2013 was below average for the survey time series (Figure 20). In both 2012 and 2013 during this month, the largest catches of Sockeye Salmon were in Howe Sound (73% and 70% respectively) rather than the SOG. These fish are not included in the CPUE (Figure 18) as this region is not part of the standard survey track line. We cannot compare the catch in Howe Sound between years, as the effort in this region varies. Although Beamish et al (2012) demonstrate that typically by September the majority of Harrison Sockeye have moved into the SOG, the 2013 results may suggest that the timing of movement in 2012 and 2013 into the general SOG region was later than typically observed and, therefore, our September CPUE may be an underestimate for these years. Overall, there appeared to be a shift in distribution of juvenile Harrison River Sockeye Salmon in 2012 and 2013, with the majority of the fish observed in September occurring in the Howe Sound region.

Therefore, although the CPUE's observed in the standard survey were some of the lowest on record this may be an underestimate of true abundance, as the fish in Howe Sound are not included in the estimates.

- In 2012, the average length of juvenile Sockeye Salmon captured from all regions was 113.3 mm and the distribution was bimodal (Figure 19). Using DNA analysis, Beamish et al. (2012) demonstrated that in years of bimodal distribution Harrison River Sockeye comprise the lower mode of the distribution. In 2012, this lower mode represents about 85% of the total catch. The average length of the lower mode was 103.4 mm; the smallest fish in the time series. Overall, the average length was the fifth smallest average size observed between 1998 and 2013. In 2013, the average length of juvenile Sockeye Salmon was 131.1 mm, or slightly above the long term average (Figure 19).

Stock Proportions (Escapements in 2011 to Juveniles in 2013)

- Fraser Sockeye stock proportions were calculated for the 2011 escapement, and assessed in the various mixed stock sampling components: 2013 Fraser Sockeye smolt outmigration at Mission (sample size: 1,409 fish), 2013 juveniles in the SOG (sample size: 295 fish) (Figure 21; Table 3) and 2013 juveniles in the Queen Charlotte Sound (sample size: 15 fish). Due to the small abundances of other stocks in the various sampling components, strict interpretation of percentages is not possible, particularly in light of the sampling gap that occurred in the latter part of the sampling period for the Mission smolt project in 2013. As a result of the gap in sampling, estimates of stock proportions from the Mission project are likely biased high for early migrating stocks like Cultus and Chilko, and biased low for later migrating stocks like Shuswap (Figures 9, 11 and 21). Note that Harrison Sockeye are not included in this comparison, despite their relatively large predicted contribution to the 2015 returns, as they have a unique life history (DFO 2015).
- Queen Charlotte Sound samples of Fraser Sockeye juveniles, collected by DFO's High Seas Salmon Program were excluded from Figure 21 and Table 3 due to the extremely low sample size (n=15). Note, however, that Chilko comprised 33% of this sample, along with Late Shuswap (33%), and all Early Summer stocks combined (33%). See documentation of this project in previous publications (Tucker et al. 2009; Trudel et al. 2011; Beacham et al. 2015) and the 2014 Fraser Sockeye supplement report (DFO 2014 b).
- The dominant stock in all sampling components, excluding Queen Charlotte Sound, was Chilko. The contribution of this stock to the total escapement or forecast, or total sample size for the Mission and SOG surveys is as follows: escapement (62%), Mission (55%), SOG (60%), and four year old forecast (60%).
- The Shuswap stocks (both the early and later timed groups combined) were present in all sampling components: escapement (10%), Mission (3%), SOG (12%), and four year old forecast (17%). Note, again, the Mission percentages might be biased low due to the gap later in this sampling program.
- Birkenhead, a stock that exhibited anomalously low survival in the 2010 brood year relative to all other stocks, also appeared in similar proportions across all sampling components in 2013: escapement (13%), Mission (<1%), SOG (4%), and four year old forecast (7%). This might indicate that the anomalously poor survival observed in the 2014 return (predominantly 2010 brood year) did not affect the 2011 brood year.

- Weaver was one exception, this stock has a similar four year old forecast (274,000 at the 50% probability level) to Birkenhead (236,000) yet it did not appear in any of the sampling components (Mission, SOG)
- Other Summer Run stocks that were detected in all sampling components included Quesnel (on average 5% in all samples) and Stellako (on average 6% in all samples).

Strait of Georgia Coho

- Coho that enter the SOG remain and rear in the Strait through September. Beamish et al. (2010) demonstrated that the CPUE of Coho Salmon in the September SOG trawl survey is an index of Coho returns for the following year. In 2013, the trawl catch of Coho Salmon was the largest on record suggesting good returns of Coho to the SOG in 2014, and indicating that conditions within the Strait were favorable for juvenile salmon that entered the ocean in 2013 (Figure 22).

Fraser Sockeye Jack Returns in 2014

- Jack (age: 3_2) recruits can be used to provide some indication of the return of four year old recruits (age: 4_2) in the subsequent year. Jacks that returned in 2014 came from the same brood year as the four year old recruits that will return in 2015 and, therefore, will have experienced the same conditions during early growth and development in both the freshwater and marine environment, but return one year earlier (e.g. jacks from the 2011 brood year return in 2014 and four year olds return in 2015).
- For the 2015 forecast, a sibling jack (age 3_2) to four year old (4_2) model, based on $\log_e$ transformed variables, was used to predict the four year old returns in 2015 (Figure 23)
- Chilko had sufficient jack (3_2) recruit data from the 2014 preliminary returns to use a sibling model (Figure 23). Jack recruits in 2014 (2.4 million) are preliminary estimates only, and were generated from near-final escapements, preliminary return age proportions, and preliminary information on exploitation rates (55%). The jack-sibling model predicted a four year old return of 1.2 million in 2015 at the 50% probability level (range: 721,000 to 2.1 million at the 25% to 75% probability levels), which was half the abundance predicted by the official forecast (50% probability level 2.4 million; range: 1.6 to 3.8 million at the 25% to 75% probability level) (DFO 2015).
- Although uncertain, jack data from 2014 do indicate a lower return for Chilko than generated by the official forecast, which predicted that Chilko would contribute the largest proportion to the 2015 returns (DFO 2015), at 35%.

Ocean Conditions

Background

Ocean conditions affect the survival of Fraser Sockeye during their entire marine life-history phase (typically two years out of their four years of life). Specifically, marine conditions in nearshore and shelf waters influence the survival and growth of juvenile salmon when they first enter the ocean and migrate north along the continental shelf, and conditions in the Gulf of Alaska influence the juveniles as they mature to adults and return to coastal and fresh waters to spawn. Historically, high survival of various species of salmon that migrate along the west coast of Vancouver Island has been associated with cooler water temperatures and higher abundance of lipid-rich zooplankton, among other processes (Mackas et al. 2007). In the SOG, higher survival of various species of salmon has been associated with (among other processes) cooler water temperatures and larger abundances of zooplankton (Beamish et al. 2010; Araujo et al. 2013). DFO annually reviews observations of ocean conditions in its State of the Pacific Ocean workshops and publications. The highlights below are summarised from the State of the Ocean reports for 2013 (Perry 2014), when Fraser Sockeye entered the ocean and migrated north along the B.C. coast as juveniles, and 2014, when these fish were feeding and maturing into adults in the central Gulf of Alaska. Note that the information for 2014 is preliminary, pending the DFO State of the Ocean meeting scheduled for March 2015.

Highlights

Overall, physical ocean conditions were in transition in 2013: cooler temperatures dominated the first half of the year, with conditions becoming warmer during the second half of the year. Biological responses, however, were muted, likely because of time lags between physical and biological systems. In the Gulf of Alaska, cooler temperatures prevailed early in 2013, but warmed in the fall and became very warm at the end of 2013 and into 2014. This produced very strong vertical stratification in the central Gulf of Alaska during summer-fall 2013, which is believed to have reduced the mixing of deep nutrients into the upper layers, leading to observations of reduced chlorophyll in the NE Pacific in spring 2014 (Whitney 2015). Along the outer B.C. coast, the first half of 2013 was generally cooler than the 30-year (1981-2010) average, but the second half of 2013 was warmer. On an annual basis, the zooplankton composition along the west coast of Vancouver Island had above normal biomass of large lipid-rich copepods, which are generally favourable for growth of juvenile salmon. On a seasonal basis, however, there was a larger biomass of warm water, typically lipid-poor, zooplankton in summer and fall of 2013 than earlier in the year. In the SOG, the timing of the spring phytoplankton bloom returned to earlier blooms (end of March) after a series of late blooms (mid-April) from 2007 to 2012 (Figure 24).

The very warm conditions in the Gulf of Alaska that started towards the end of 2013 persisted through 2014, continued to strengthen (Figure 25), and shifted eastward towards the B.C. coast, so that by September 2014 this warm water occurred close to the continental shelf break of B.C.. Very warm sea surface temperatures occurred along the outer B.C. coast, especially in autumn 2014, when record high temperatures were measured at several locations (Figure 26). The biological consequences of these warm temperatures along the B.C. coast and continental shelf are in the process of being analysed. As of 23 January 2015, there is only a moderate (50-60%) likelihood of El Niño conditions in the NE Pacific in the first half of 2015 (NOAA 2015).

Assuming that Fraser Sockeye migrated north along the B.C. coast during summer 2013 as juveniles, then out into the central Gulf of Alaska in Fall 2013 where they were located through all of 2014, they would likely have been exposed to the following ocean conditions. In the SOG in April-May 2013 they would have experienced normal to slightly above normal water temperatures (with "normal" defined as conditions during 1981-2010), and normal timing of the spring plankton bloom (late March; based on 1981-2010) compared with the late blooms (mid to late April) that had occurred from 2007 to 2012. Along the northern shelf of B.C. during summer 2013, the migrating juveniles would have encountered slightly cooler than normal temperatures up to the end of August, then warmer than normal temperatures in September (Figure 26). Once in the central Gulf of Alaska, however, these Fraser Sockeye would have encountered warmer than normal conditions in Fall 2013, followed by much warmer than normal temperatures (at times 4 °C above normal) through most of 2014. These high temperatures are speculated to have influenced the food web (more lipid-poor zooplankton) and possibly introduced unusual predators (such as various warm water tuna and squid species) into the Gulf of Alaska and Canadian continental shelf areas.

Conclusions

Key Conclusions

To provide support for the official 2015 Fraser Sockeye forecast, supplemental data on Fraser Sockeye condition, survival, and relative abundances were presented for the parental spawners in 2011 through to the 2014 jack returns, including ocean conditions during their ocean residence (2013 to present). This synthesis of existing data represents a starting point for reducing uncertainty in Fraser Sockeye forecasts, through improving our understanding of inter-annual variability of survival in these stocks. A learning component to the 2014 forecast supplement, following the returns in 2014 (Appendix 1), is being built upon in the current paper. The key stocks contributing the highest percentages to the forecasted total returns in 2015 are the lake-type Chilko stock (35% of the total forecast at the 50% probability level) and the river-type Harrison stock (21% of the total forecast at the 50% probability level). Both of these stocks are in the Summer Run timing group.

Information that indicated average conditions for Fraser Sockeye survival during their life-history from 2011 adult spawners through to 2015 returns:

- Relatively good upstream migration conditions for dominant stocks in 2011;
- Above average lake productivity for assessed stocks (Chilko, Late Shuswap);
- Larger smolt and juvenile sizes in 2013 for most assessed stocks (Chilko; Shuswap; Gates);
- Average proportion of empty stomachs in juveniles in the Strait of Georgia (no red flags with regards to empty stomachs, as was observed in the 2007 ocean entry year (Thomson et al. 2012);
- Stock percentages in the Mission smolt project and SOG juvenile surveys in 2015 indicate that Chilko dominated stock proportions, which reflects this stock's contribution to the brood year EFS in 2011 and, consequently, the 2015 forecast;
- High CPUE of Coho Salmon in the Strait of Georgia in 2013.

Other pieces of information that provide possibly poor signals for Fraser Sockeye returns in 2015:

- Anomalously warm ocean conditions commenced in the 2013 ocean entry year of most stocks returning in 2015. These conditions have persisted through to present (May 2015), which is immediately prior to the return of Fraser Sockeye in 2015. This warm water coincided with low nutrient, and consequently, low chlorophyll concentrations in surface waters, and shifts in coastal zooplankton communities to warmer water species with lower lipid content (and, therefore, poorer food quality for fish). Warmer ocean conditions are typically linked to poorer salmonid survival, although direct linkages to Fraser Sockeye survival remain currently unclear.
- The sibling jack model forecast for Chilko suggests that this return will be half the size of the official forecast; Chilko contributes the largest proportion to the total 2015 forecast at the 50% probability level (DFO 2015).
- For lake-type Fraser Sockeye stocks, CPUE assessed in the SOG surveys was below average, although this assessment period is late for Fraser Sockeye migration timing and, further, there were indications that outmigration was earlier than normal in 2013.

- Harrison Sockeye CPUE in 2012 and 2013 was also low, despite the exceptional escapements in the 2011 brood year, which might indicate poorer returns than expected for this stock in 2015 as well. However, the largest catches of these fish occurred in Howe Sounds outside of the standard study area, and therefore, were excluded from the CPUE, which may reflect an underestimate of true abundance.

Lake-Type Stocks Summary

- On their return to the spawning grounds in 2011 (the parental generation that will produce the four year old returns in 2015), Early Stuart and Early Summer migrants experienced higher discharge in the Fraser mainstem (>8,000 cms), which can create a hydrological barrier to fish passage in the Fraser Canyon. Early Stuart migrants also experienced low temperatures, below their optimum (16°C). Migration conditions for the dominant Chilko and Harrison stocks were considered benign. Spawner success was slightly depressed for a number of smaller stocks, although this was accounted for in the 2015 forecast variables. Physiological metrics of adult Fraser Sockeye health were generally close to normal in the 2011 returns, though this information is not currently accounted for in the official forecasts.
- Chilko escapements in the 2011 brood year were within the range of spawners at maximum production (Smax), although data on zooplankton biomass, freshwater survival, and smolt sizes, indicate that the rearing capacity was average in this brood year. Late Shuswap escapements in the 2011 brood year were well below the Smax, and compensation (increased survival) would therefore be expected. However, freshwater survival in this brood year (168 fall fry/EFS) was well below the all cycle average (380 fall fry/EFS), and the cycle average (207 fall fry/EFS). This might be attributed to delayed density dependence from the previous brood year escapement for the Shuswap system, which was exceptionally large (3.1 million). Primary productivity (as measured in photosynthetic rates) in Chilko and Shuswap Lakes has increased in recent years (although major sampling gaps exist between the beginning and current sampling periods).
- Smolt outmigration conditions (discharge and temperature) were largely average for Fraser Sockeye in the Fraser River in 2013.
- Smolt size is positively correlated with smolt-to-adult survival in Sockeye Salmon (Ricker 1962; Henderson and Cass 1991; Koenings et al. 1993; Bradford et al. 2001). Smolt sizes were above average in 2013 for most assessed stocks, including Chilko and Shuswap stocks assessed at the outlet of their rearing lakes, and at Mission. Quesnel was one exception, where average fork length at Mission was slightly smaller in 2013 compared to 2012. Similarly, the average size of juveniles caught in the SOG was larger in 2013 compared to the time series (1998-2012), and was in fact the largest on record.
- The 50% smolt outmigration date for Chilko in 2013 at the outlet of Chilko Lake was April 29th. Late Shuswap outmigration timing at the outlet of the Shuswap Lake system in Little River was mid-May. Although the Mission smolt project operated in 2013, a gap in the sampling program resulted in challenges interpreting migration timing for later outmigrating stocks such as Shuswap stocks. The Chilko outmigration timing at Mission was approximately May 5th (50% date), which was roughly a week after they migrated out of Chilko Lake.
- Fraser Sockeye CPUE in the Strait of Georgia was amongst the lowest on record, based on the standard annual late-June/early-July sampling program (1998-2013) which is

thought to include 10% of the Fraser Sockeye juveniles during their SOG residence. However, given inter-annual and intra-stock differences in smolt outmigration timing (DFO 2014b), and also given evidence that juvenile migration through the SOG was later than normal based on earlier timed surveys (late-May/early-June) that were initiated in recent years, this CPUE might not be comparable across all years.

- The average proportion of empty stomachs sampled in both trawl surveys in 2013 was similar (27%) to what is typically observed and would therefore suggest that conditions were not out of the normal range in the SOG.

River Type Stocks (Harrison Sockeye) Summary

- Harrison Sockeye in 2015 will come from the 2011 and 2012 brood years, returning respectively as, four and three year olds. The four year old brood year escapement was 400,000 and the three year old brood year escapement was 33,000. Despite the large difference in brood year escapements, CPUE for Harrison was particularly low in the 2012 and 2013 SOG September surveys (<15) for both years. These results contrast with the 2011 survey year, which was also associated with a high brood year escapement of 300,000 in 2010, and resulted in exceptional returns in 2014 of greater than one million Sockeye. The CPUE in this 2011 survey year was much higher (~60) than the two subsequent years (2012 and 2013) relevant to the 2015 returns. Although a large proportion of Harrison Sockeye were assessed in Howe Sound, this area is not part of the standard survey area, and therefore, is excluded from the CPUE.

All Stocks

- Coho CPUE in the annual SOG surveys was above average in 2013.
- Jack abundance in Chilko in 2014 indicates a return that is half the size of the official forecast at the 50% probability level. This could be a signal of poor ocean survival for stocks in 2015, although the jack relationship is uncertain.
- Relative proportions of stocks in all sampling components (escapements, Mission smolts, SOG juveniles, and 2015 forecasts) were dominated by Chilko Sockeye (on average comprising 60% of the total escapement/forecast or sample). Shuswap stocks were also present in all sampling components (on average 10%), as well as Quesnel (5%) and Stellako (6%). Birkenhead also contributed a consistent percentage (6%) despite the anomalously poor survival of this stock in the previous brood year. The only stock that dropped out of the sampling components outside of the escapement and forecasts was Weaver.
- Ocean conditions in the second half of 2013, when Fraser Sockeye juveniles that will return as four year olds in 2015 first entered the ocean, coincided with a warming pattern. The warming in the northeast Pacific has persisted to the timing of this report (April 2015), and is considered anomalously warm (referred to as the ‘warm blob’ by oceanographers). The warm water has contributed to increased vertical stratification, decreased nutrient inputs and lower chlorophyll in the surface waters. Further, a shift to warm water copepods has coincided with this warming pattern in the northeast Pacific waters. It is unclear how this major shift in ocean conditions will influence Fraser Sockeye survival, however, it does introduce considerable additional uncertainty into the 2015 forecast, given that these conditions have not previously been observed.

Table 1. Adult Fraser Sockeye sample sizes for blood physiology, disease and fish condition in the 2011 migration year in three sampling locations (marine, in-river, and on the spawning grounds). See corresponding Figure 6.

Location		**Blood Physiology**	**Disease**		**Condition**
		Stress, Metabolism, Osmoregulatory	RNA	Histology	Lipid Metrics
Marine	Johnstone St.	30	30	30	30
	Port Renfrew	60	60	30	60
In-River	Whonnock	24	24	24	24
	Chilliwack	31	31	31	20
	Harrison	88	88	88	88
Spawning	Adams	20	20	20	-
	Chilko	20	20	20	-
	Harrison	40	40	40	-
	Weaver	40	40	40	40
TOTAL		**354**	**354**	**324**	**374**

Table 2. Average nose-fork length of Sockeye smolts sampled at the Mission, B.C. by year for select stocks. See corresponding Figure 15.

Year	**Fraser-S (Stellako)**	**Quesnel-S (Horsefly/ Mitchell)**	**Chilko-ES (Lake spawners**	**Chilko-S (River spawners)**	**Shuswap-L (Adams/ Low & Mid Shuswap)**	**Anderson-ES (Gates)**
2012	91.9 ± 9.4 mm (*n*=130)	84.1 ± 6.7 mm (*n*=301)	74.4 ± 6.1 mm (*n*=64)	76.8 ± 6.8 mm (*n*=233)	71.8 ± 6.5 mm (*n*=968)	77.9 ± 4.1 mm (*n*=71)
2013	88.0 ± 9.0 mm (*n*=90)	79.9 ± 4.8 mm (*n*=166)	86.8 ± 12.1 mm (*n*=98)	85.5 ± 9.1 mm (*n*=543)	86.9 ± 8.6 mm (*n*=32)	97.4 ± 5.4 mm (*n*=140)

Table 3. Stock composition (relative percentages) in the various sampling components: 2011 brood year escapement; 2013 smolt outmigration at Mission, B.C.; 2013 Strait of Georgia surveys; and 2015 four year old return forecasts. See corresponding Figure 21. Note: Harrison river-type Sockeye are not assessed given their differential migration timing from lake-type stocks.

Stock Name	**Effective Female Spawners (2011)**	**Mission Smolts (March 22 - May 16 and June 2 - July 25 2013) *n*=1,409**	**Strait of Georgia Juveniles (June 1-11, 2013) *n*=295**	**Four Year Old Return Forecasts (2015)**
Chilko	62%	49%	60%	60%
Shuswap (Early & Late)	10%	3%	12%	17%
Weaver	3%	0%	0%	8%
Birkenhead	13%	<1%	4%	7%
Stellako	4%	7%	6%	5%
Quesnel	2%	12%	6%	5%
Gates	4%	10%	1%	4%
Pitt	4%	0%	4%	1%
North Thompson	2%	10%	4%	1%

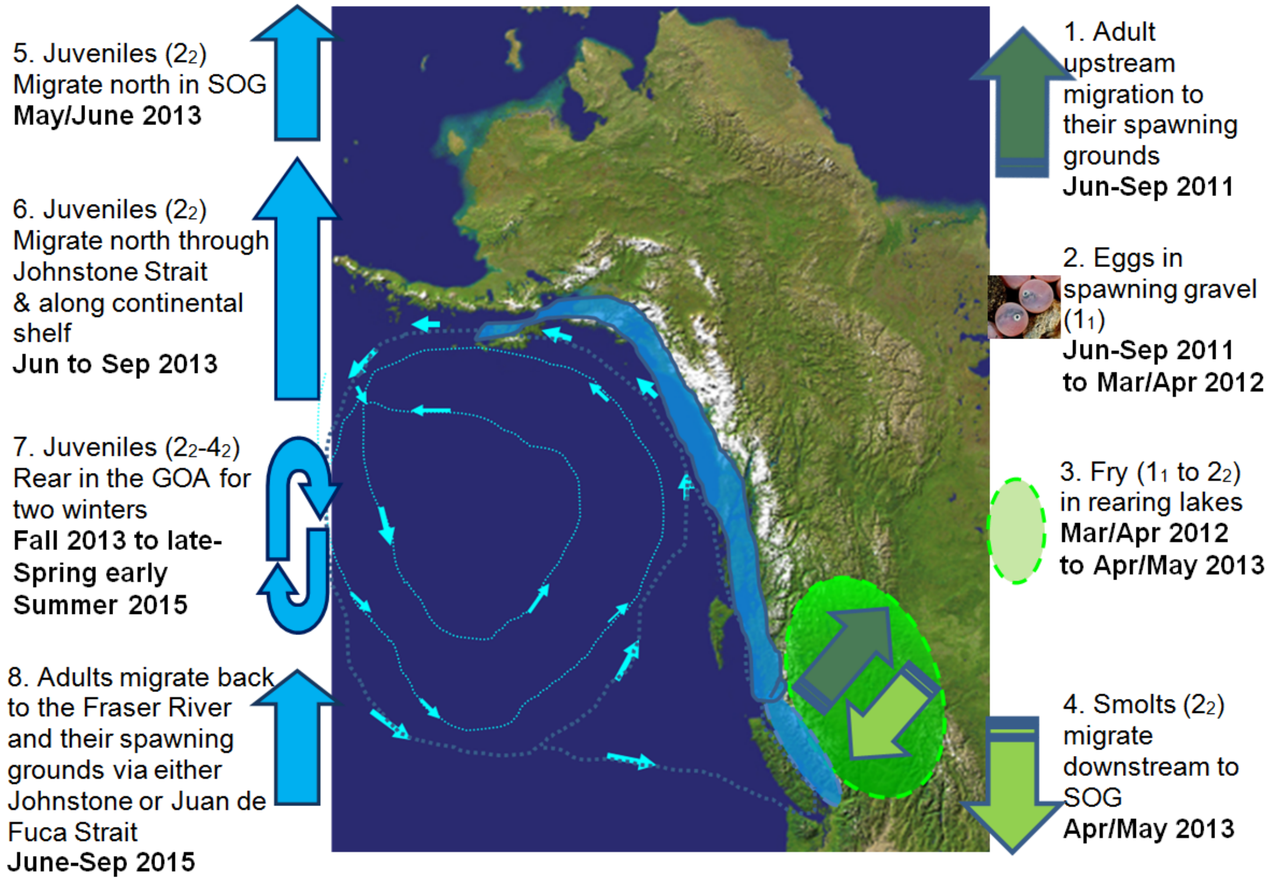


Figure 1. Lake-type Fraser Sockeye life-history for individuals that will return to spawn in 2015 as four year olds. Most Fraser Sockeye return as 4_2 fish (Gilbert-Rich ageing convention), where the total age is indicated by the '4' (that includes the freshwater and marine stages) and the winters spent in freshwater are indicated by the subscript '2'. The 4_2 Fraser Sockeye expected to return in 2015 will come from spawners that spawned in 2011, and will have spent their first two winters in freshwater (one winter as eggs in the gravel and one winter as fry in their rearing lakes) and their last two winters in the marine environment. After their second winter in freshwater (2013), these fish migrated downstream through the Fraser River and entered the Strait of Georgia (SOG). From here they migrated north, through the Johnstone Strait and along the continental shelf out into the northeast Pacific. They spent two winters (2013 & 2014) in the Gulf of Alaska and will return back to their spawning grounds in the late-summer/fall of 2015.

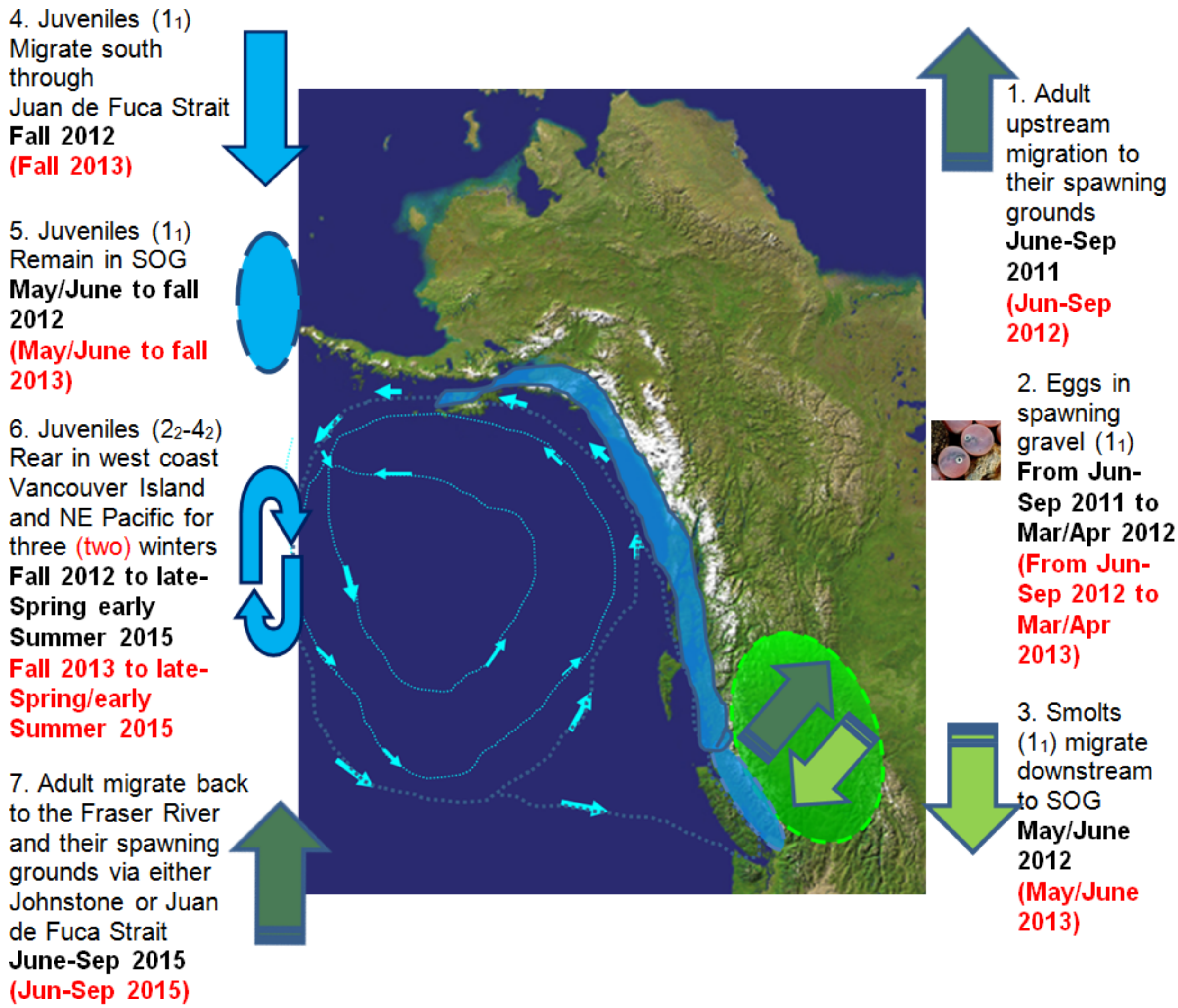


*Figure 2. River-Type Fraser Sockeye (specifically Harrison Sockeye) life-history for individuals that will return to spawn in 2015 as three (red text) and **four year olds (black text)**. River-Type Fraser Sockeye return as 4_1 or 3_1 fish (Gilbert-Rich ageing convention), where the total age is indicated by the '4' (or '3') and the freshwater residence years are indicated by the subscript '1'. River-Type Fraser Sockeye returning in 2015 will have come from spawners that spawned in 2011 (or 2012 for 3_1 fish), and will have spent one winter in freshwater (as eggs in their spawning gravel) then migrated about a month later than river-type stocks downstream to the Strait of Georgia (SOG) in 2012 (or 2013 for 3_1 fish). They migrated south out of the SOG (they remain in the Strait of Georgia longer than other stocks, leaving in the fall of 2012) through the Juan de Fuca Strait to rear along the west coast of Vancouver Island and in the north east Pacific. After three winters (or two for 3_1 fish) in the marine environment they will return back to their spawning grounds in the late-summer of 2015.*

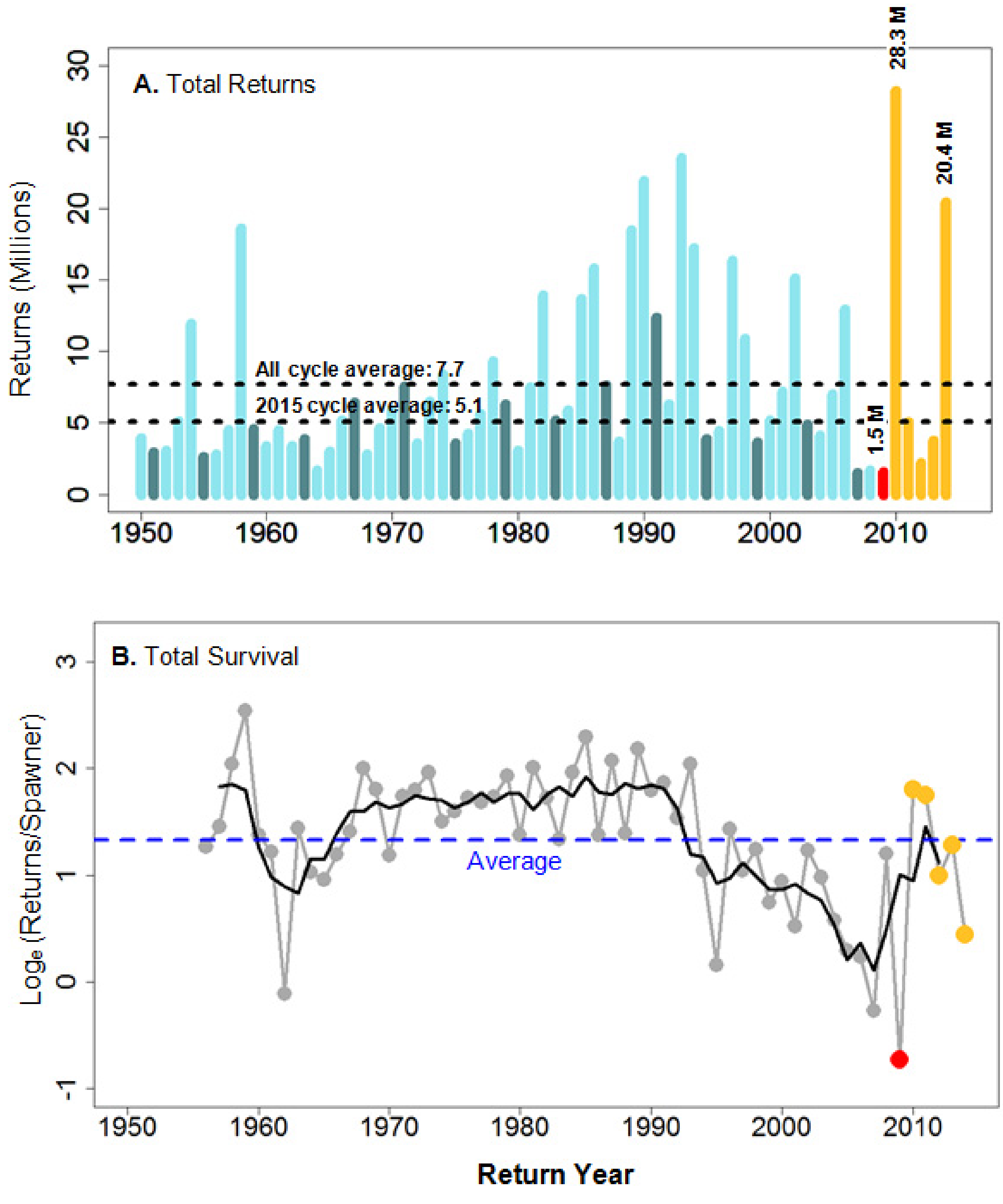


*Figure 3 **A**. Total Fraser Sockeye annual returns (dark blue vertical bars for the 2015 cycle and light blue vertical bars for the three other cycles). Recent returns from 2012 to 2014 are preliminary. **B**. Total Fraser Sockeye survival (log_e (returns/total spawner)) up to the 2014 return year. The light grey filled circles and lines present annual survival and the black line presents the smoothed four year running average. For both figures, the dashed line is the time series average. The red vertical bar in Figure A (or filled circles in B) represents the 2009 returns (low survival), and the yellow vertical bars in Figure A (or filled circles in B) represent the 2010 to 2014 returns (average survival for the Fraser Sockeye aggregate).*

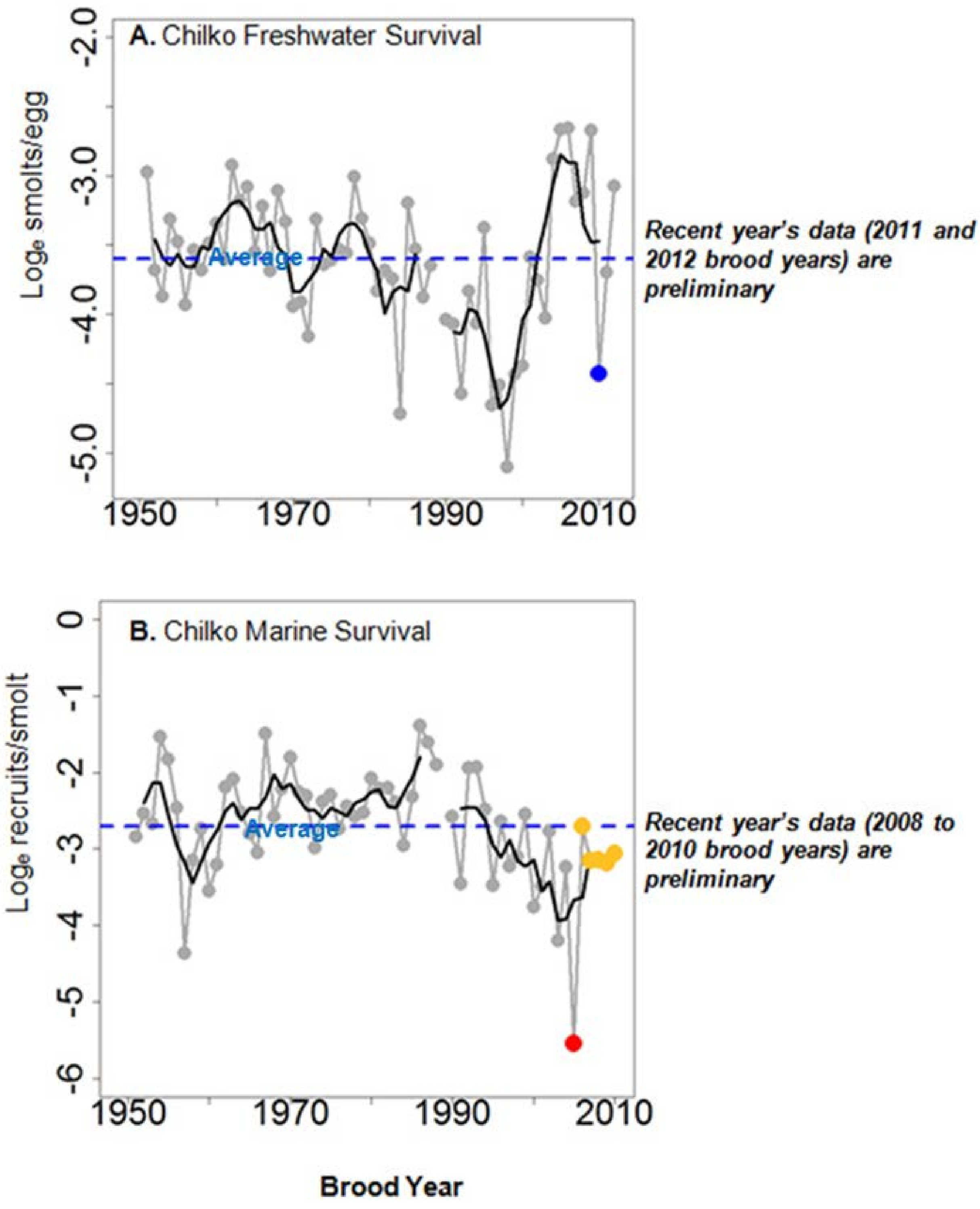


*Figure 4. Chilko River Sockeye **A**. annual freshwater (log_e smolts-per-egg) survival (filled grey circles and lines) with the 2010 brood year survival indicated by the blue filled circle and **B**. annual marine (log_e recruit-per-smolt) survival (filled grey circles and lines) with the 2005 brood year survival indicated by the red filled circle. The black line in both figures represents the smoothed four-year running average survival. The dashed blue lines indicate average survival.*

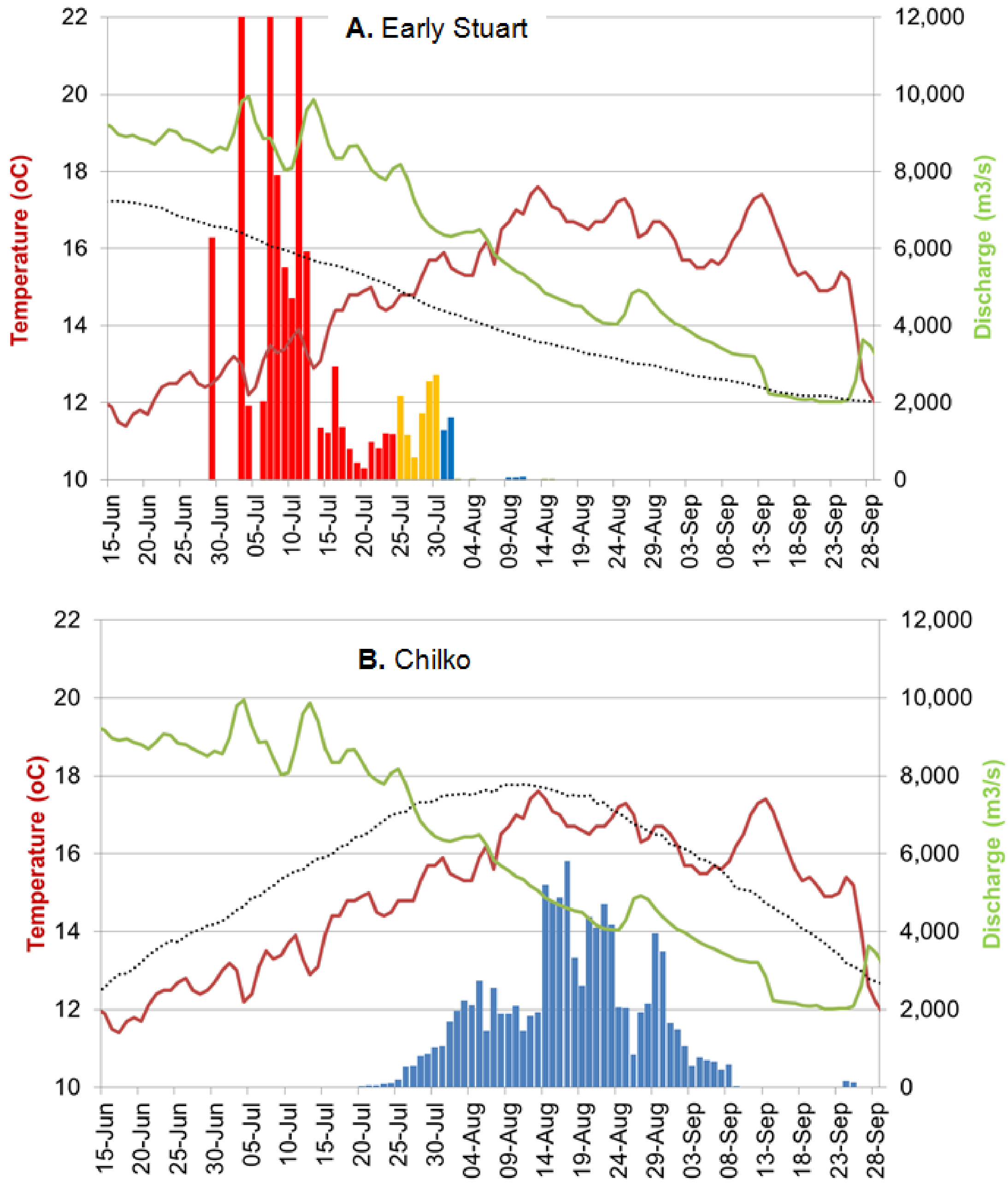


*Figure 5. Migration conditions in 2011 (red line: temperature; green line: discharge; black dashed line: historical average temperatures 1941-2009) for **A.** Early Stuart (low temperature and high discharge conditions) and **B.** Chilko Sockeye stocks (benign temperature and discharge conditions). The vertical coloured bars represent relative abundance of migrating salmon for each of these stocks; bars coloured blue represent the portion of the run that experienced benign temperature and discharge conditions (water temperatures between 14°C and 16^{o}C and discharge below 6,000 m^3/s); red coloured bars represent the portion of the run that experienced conditions thought to negatively influence upstream migration and survival to the spawning grounds (water temperatures above 20°C and discharge above 8,000 m^3/s); amber coloured bars represent the portion of the run that experienced conditions thought to moderately influence upstream migration and survival to the spawning grounds (water temperatures between 18°C and 20°C and discharge between 6,000 m^3/s and 8,000 m^3/s).*

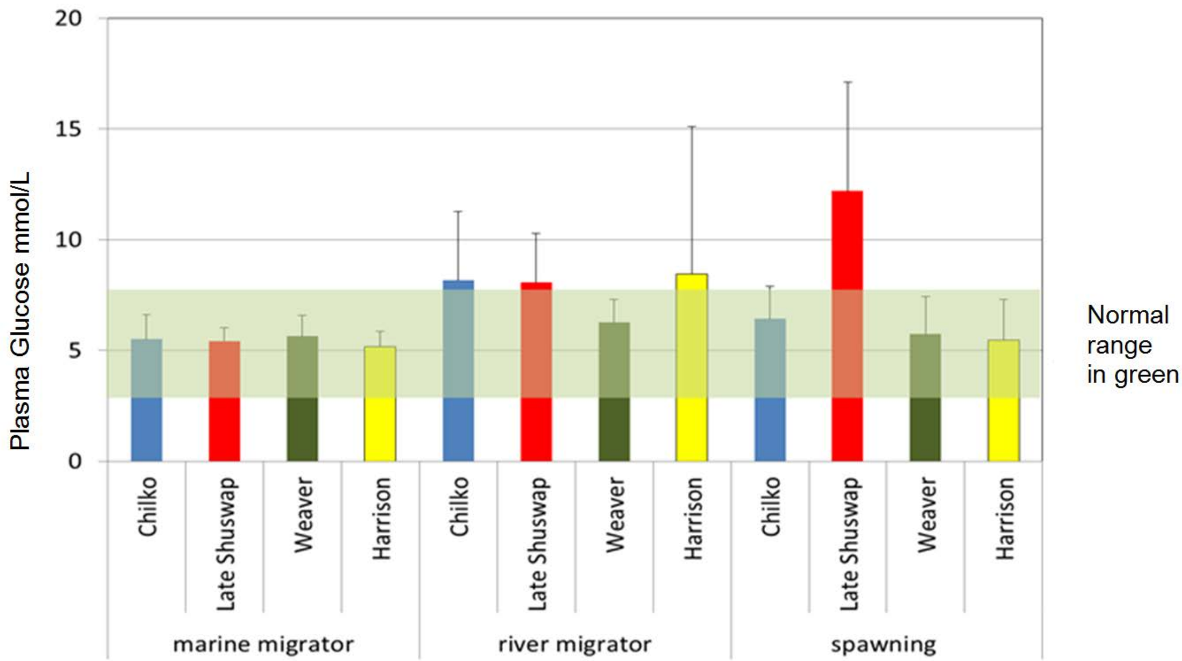


Figure 6. Fraser Sockeye plasma glucose results assessed for 2011 returning adults in three different sampling locations (marine, Fraser River, and spawning grounds) for four key stocks (Chilko: blue bars; Late Shuswap: red bars; Weaver: green bars; Harrison: yellow bars). The normal range is represented by the green shaded area, coloured bars below or above this range are outside the normal range. See corresponding Table 1.

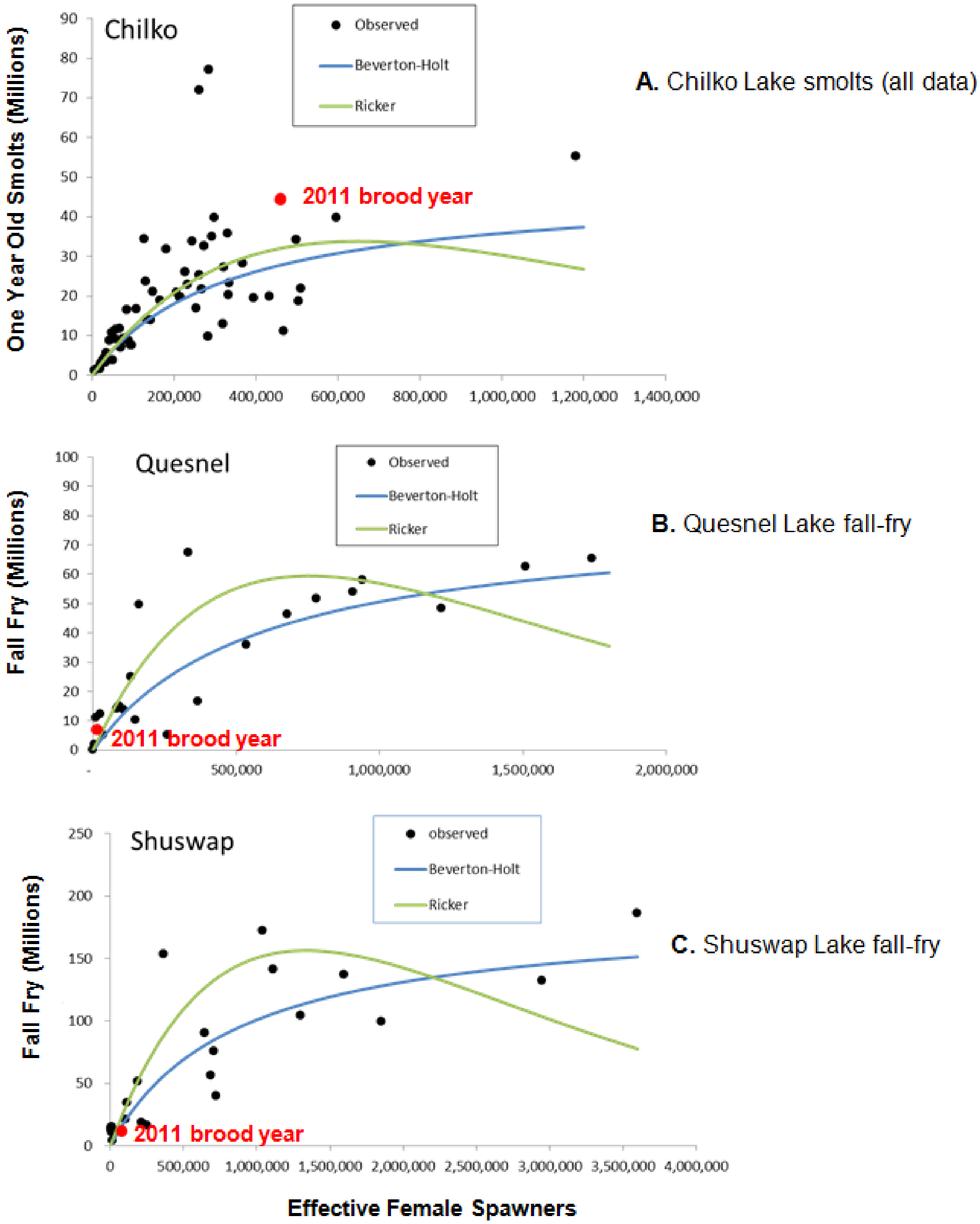


*Figure 7 **A.** Smolts-per-effective female spawner in Chilko Lake for all years (brood years 1949-2010, excluding 1989). **B.** Fall fry-per-effective female spawner in Quesnel Lake (brood years 1974 to 2011 non-inclusive). **C.** Fall fry-per-effective female spawner in Shuswap Lake (brood years 1974 to 2011). In each figure the 2011 brood year value is indicated by a red filled circle and text. Ricker (green line) and Beverton-Holt (blue line) models are fit through each of these time series'.*

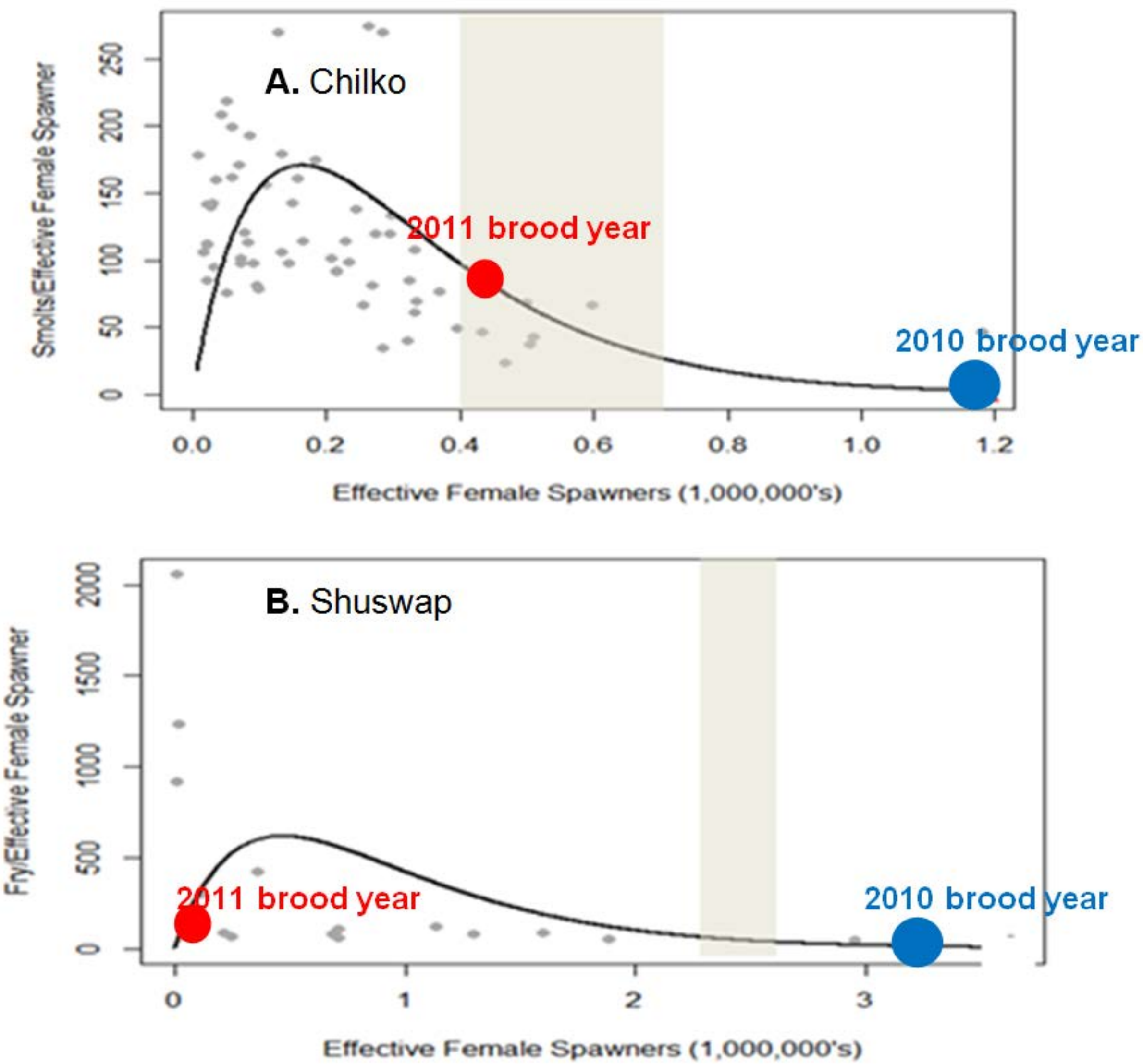


*Figure 8. Early freshwater survival (Chilko: smolt-per-effective female spawner; Shuswap: fall-fry-per-effective female spawner) versus effective female spawners, with a Ricker model fit through the data set. The range of spawners at maximum production (Smax) estimated from photosynthetic rate models and stock-recruitment data are represented by the shaded grey areas on each plot. Large red filled circles represent the 2011 brood year escapements and associated freshwater survivals (blue filled circles represent the 2010 brood year escapements) for **A.** Chilko (smolt/EFS: 96; EFS: 457,000) and **B.** Shuswap (early- and late-run stocks) (fry/EFS: 150; EFS: 74,000).*

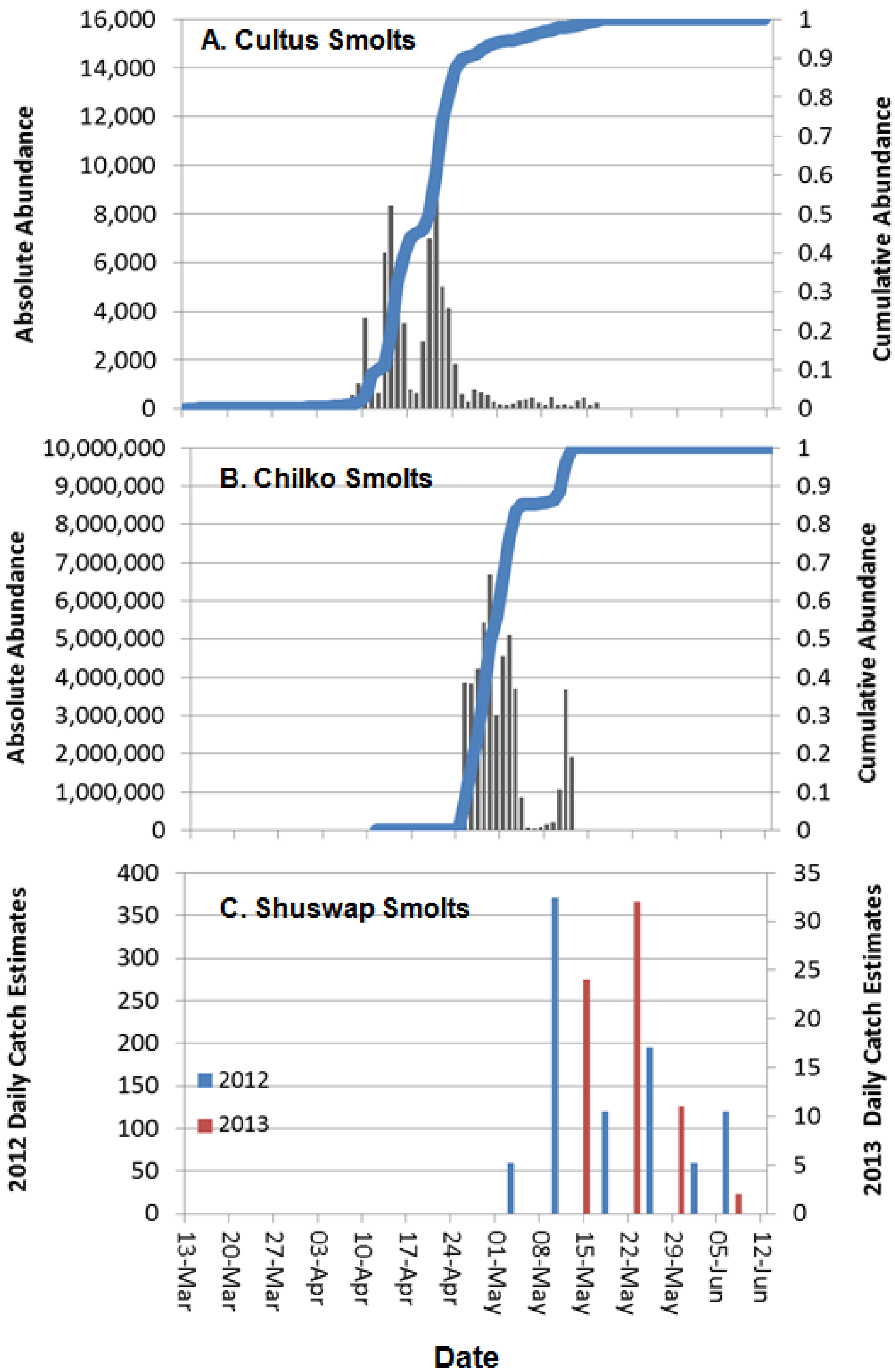


*Figure 9. Smolt outmigration timing at lake outlets for **A.** Cultus; **B.** Chilko; and **C.** Shuswap stocks in the 2013 outmigration year. The vertical bars for Cultus and Chilko are the absolute abundances and the blue lines these stocks are the cumulative smolt abundances over the smolt out-migration period. The 50% outmigration date for Cultus is April 20th, for Chilko is April 29th, and for Shuswap is mid-May. Note: smolt sampling for Cultus and Chilko are, respectively, fence and weir counts conducted throughout the migration period, while Shuswap smolt sampling was based on weekly sampling only and is not part of an annual assessment program.*

Figure 10. Aerial image of the Mission juvenile project located in the Fraser mainstem at Mission, B.C. The white rectangle outlines the study area and the dashed arrows indicate the direction of Fraser River flow.

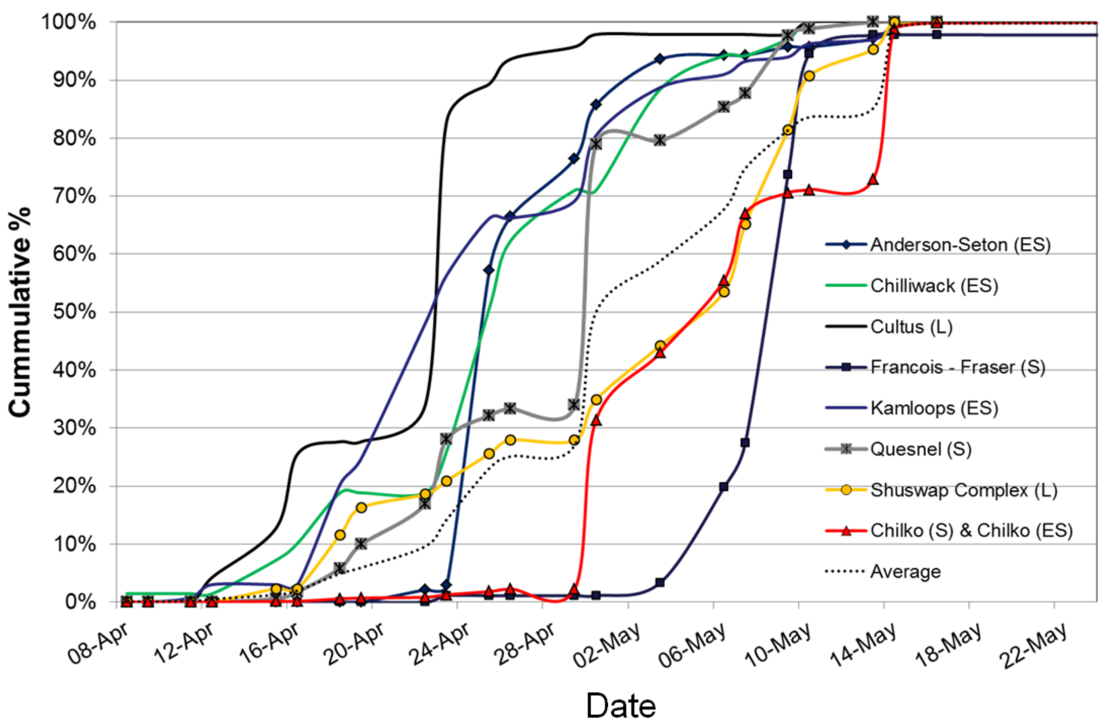


Figure 11. Sockeye smolt outmigration timing for select stocks at Mission, B.C. from March 22 to July 25, 2013. There was a gap in operations between May 17 and June 1 due to a vessel breakdown, therefore, stock composition has to be interpreted with caution. The combined 50% migration date for all stocks presented was April 30 (dotted line), with the Chilko 50% migration date being May 5th(red line).

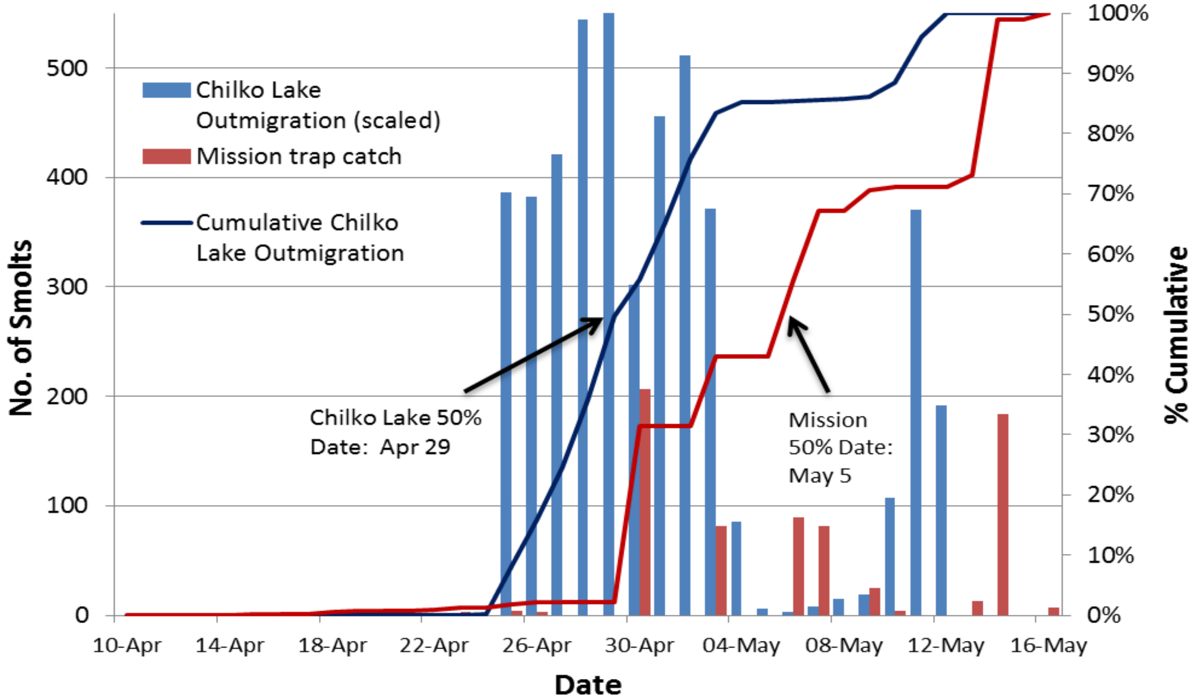


Figure 12 A. Chilko Lake outmigration abundance estimates (scaled) and Chilko trap catches at Mission with the corresponding percent cumulative abundance for each. There was a six day difference between the 50% cumulative migration date at the Chilko Lake outlet (April 29) and that at Mission (May 5) in 2013.

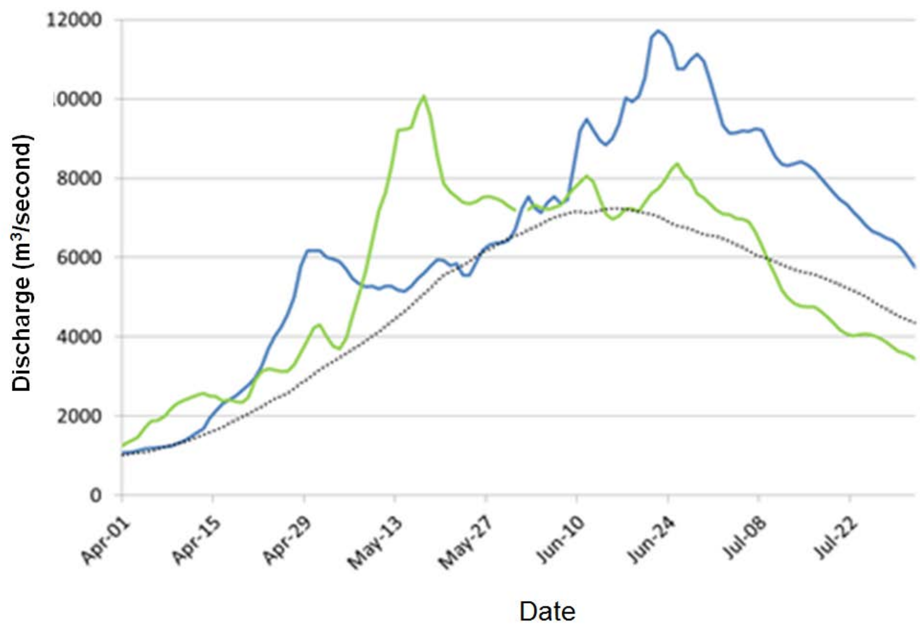


Figure 12 B. During the Fraser Sockeye smolt outmigration period, Fraser River discharge levels at Hope, B.C., in 2012 (blue line) and 2013 (green line) ranged from average to above average (1912-2009 average: dashed line).

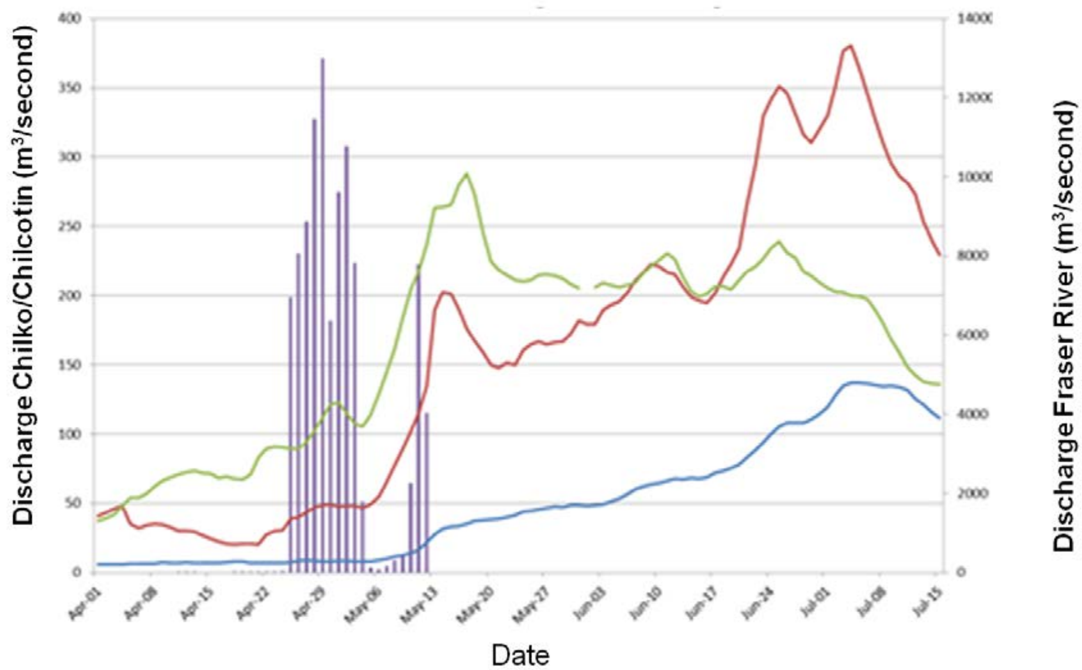


Figure 13. Discharge levels for the Chilko River (blue line), Chilcotin River (red line) and Fraser River at Hope (green line) compared to the relative abundance of Chilko smolts during their outmigration from Chilko Lake (purple vertical bars).

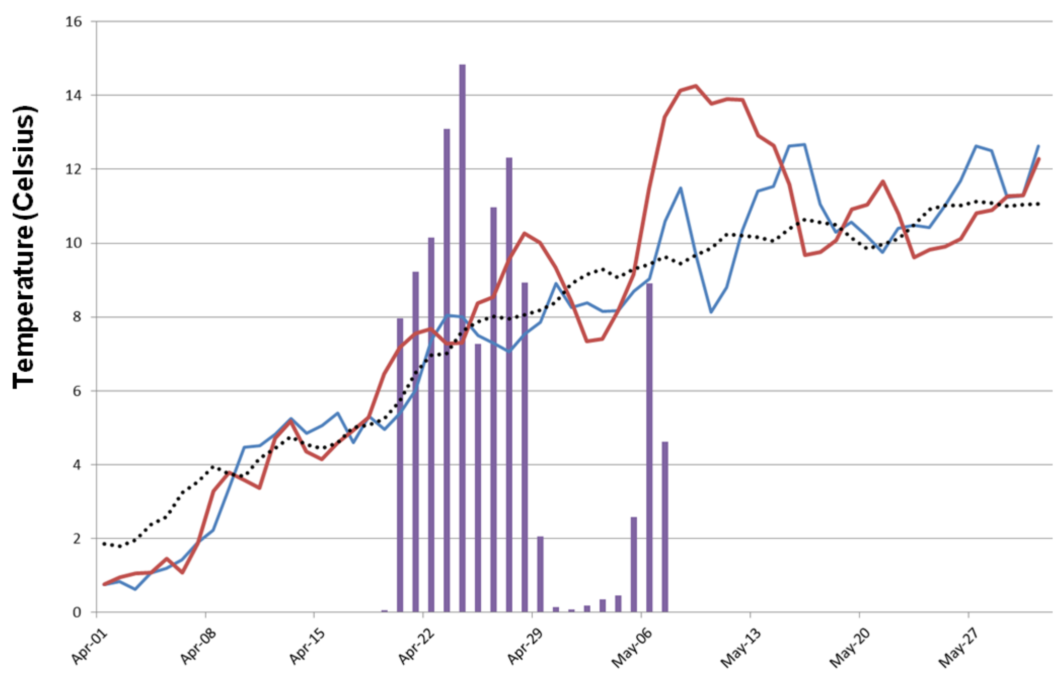


Figure 14. River temperature conditions at the Chilko Lake outlet for the 2012 (blue line) and 2013 (red line) outmigration years compared to the relative abundance of Chilko smolts during their outmigration from Chilko Lake (purple vertical bars). Average temperatures are indicated by the dotted line.

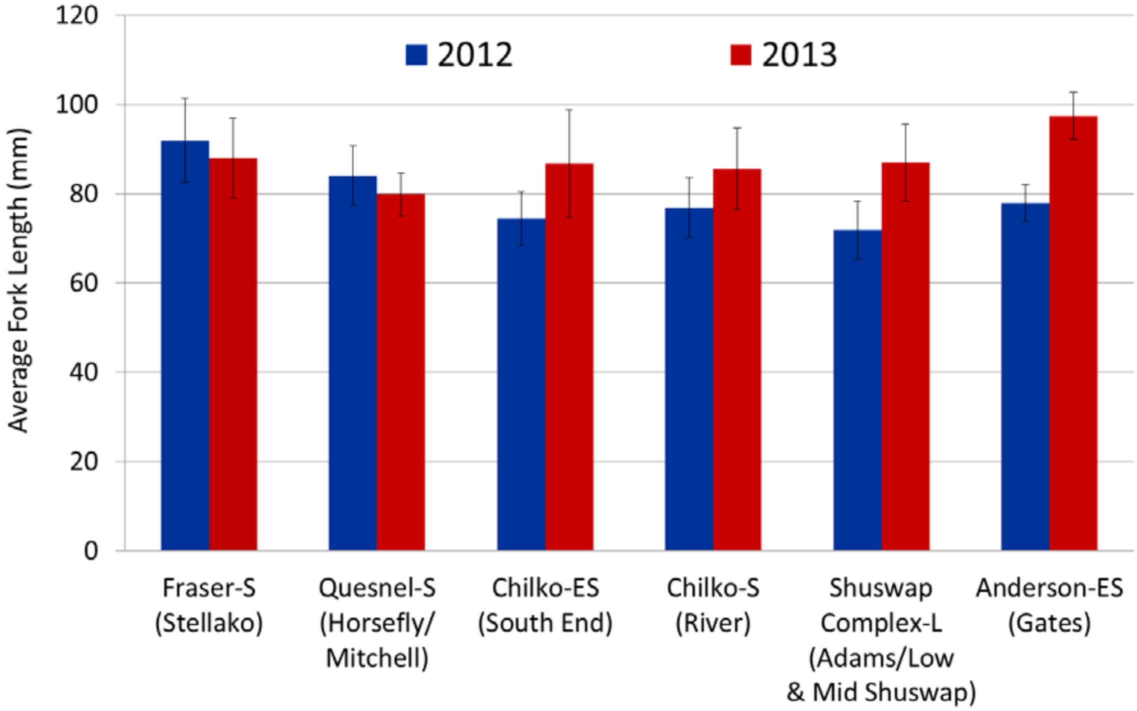


Figure 15. Average Sockeye smolt fork length at Mission for stocks with n>30 in both 2012 (blue bars) and 2013 (red bars). For each of the six conservation units in this figure the following applies: S: Summer Run timing group; ES: Early Summer Run timing group; L: Late Run timing group. See corresponding Table 2.

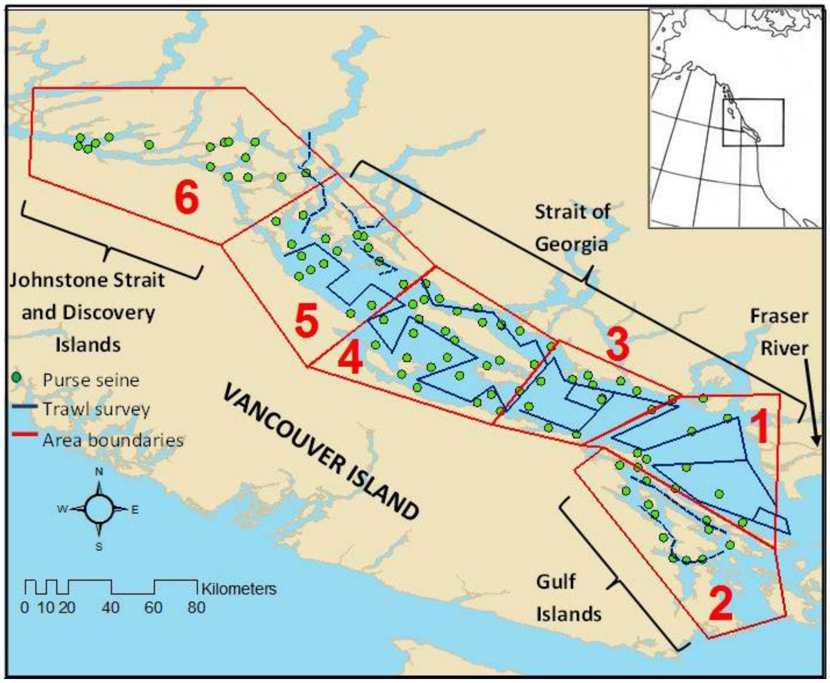


Figure 16. Location of the trawl survey standard track line (solid blue line) conducted annually (1998-2013, excluding 2003) in late-June/early July. In recent years, 2010-2013, additional survey periods (early-June and September) also follow these survey track lines. Dashed blue lines in Areas 5 and 6 are sampled during the trawl survey but are not included in inter-annual comparisons (Figure 15). The purse seine surveys conducted in the SOG and Discovery Islands in 2010-2012 are identified by green dots. The areas represented by red polygons are used for spatial catch comparisons. Areas 1, 3, 4, and 5 are the Strait of Georgia, Area 2 is the Gulf Islands, and Area 6 is the Discovery Islands.

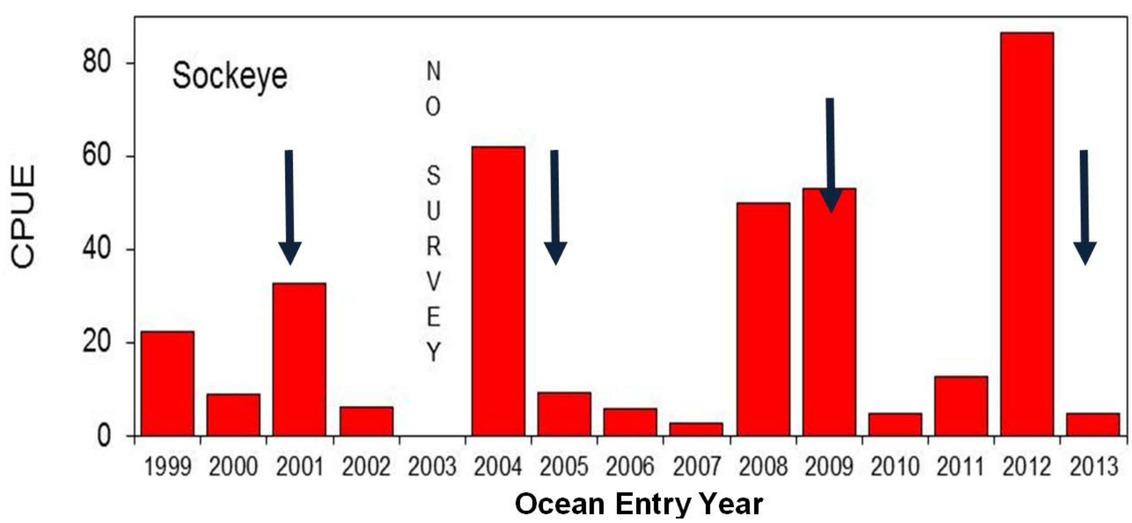
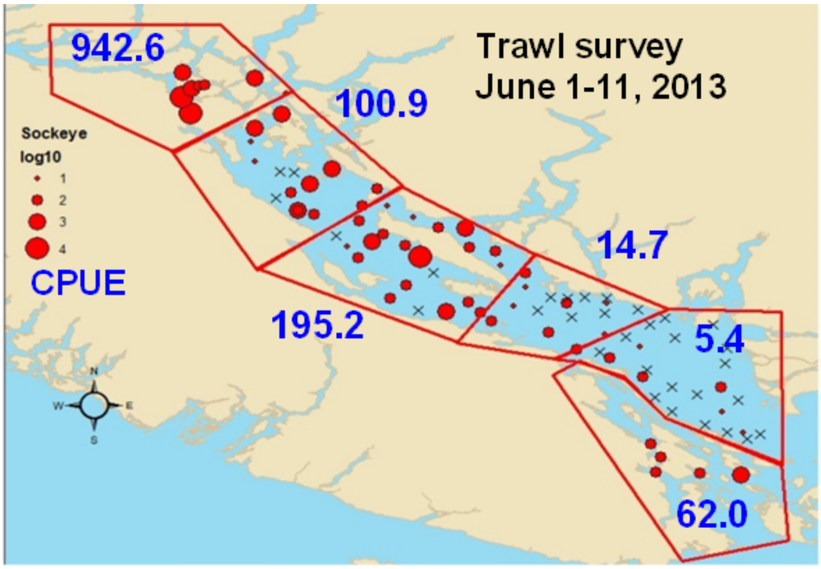
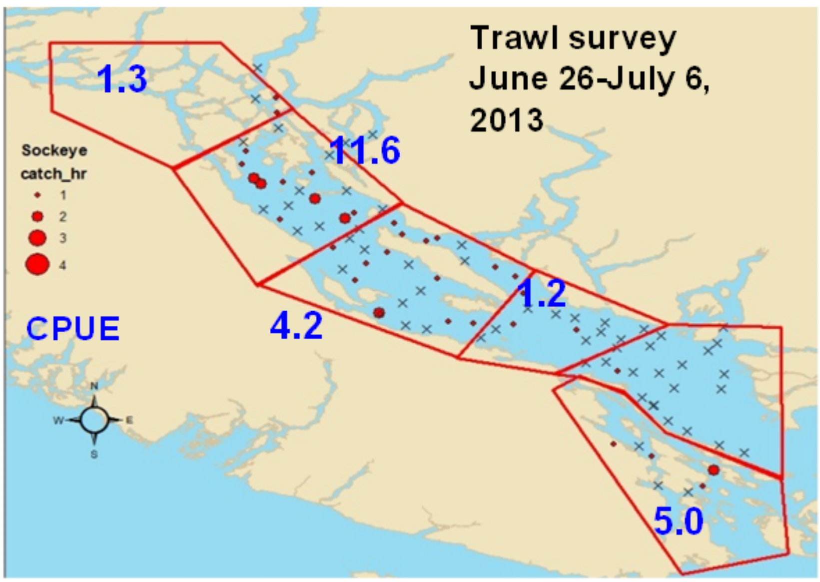


Figure 17. Catch-per-unit effort (CPUE) of juvenile Sockeye Salmon in the annual late June- early July survey from 1998 to 2013 (CPUE data is comparable starting in 1999). Arrows indicate the 2013 cycle years. See Figure 18 B relative to A for densities of Sockeye juveniles during this standard trawl survey timing; note: this standard survey period typically only captures ~10% of the total juvenile Fraser Sockeye outmigration and there were some indications that migration through the SOG in 2013 was early.



A. Additional trawl survey conducted in early June (1-11, 2013) to specifically capture a greater proportion of the juvenile Fraser Sockeye migration



B. Standard timing of annual surveys (1998-2013): the target species is Coho Salmon, although all salmon species are sampled. Roughly 10% of the Fraser Sockeye run is likely assessed during this sampling period.

*Figure 18. The distribution of juvenile Sockeye Salmon in **A.** June 1-11, 2013 and **B.** June 26-July 6, 2013 trawl surveys. The number in each polygon is the catch-per-hour for sets conducted with headrope (rope along the upper edge of the net) depth of 0 or 15 m in that region. The X's on both maps indicate sets where no Sockeye Salmon were caught.*

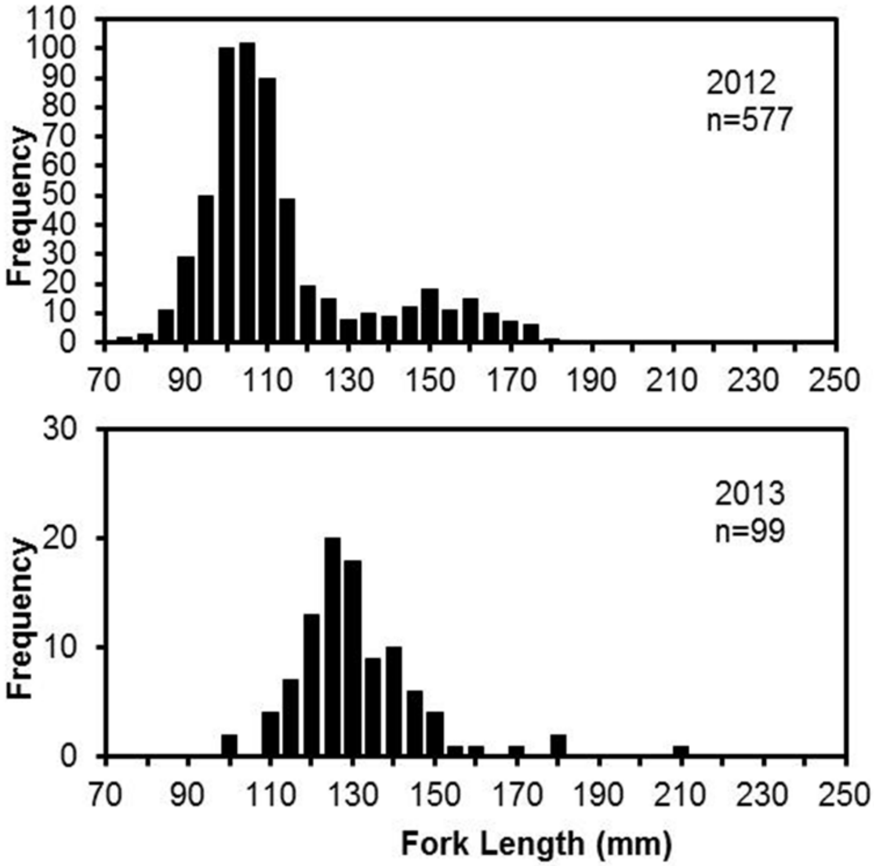


Figure 19. The length frequency of juvenile Sockeye Salmon captured in the Strait of Georgia and Howe Sound in 2012 and 2013.

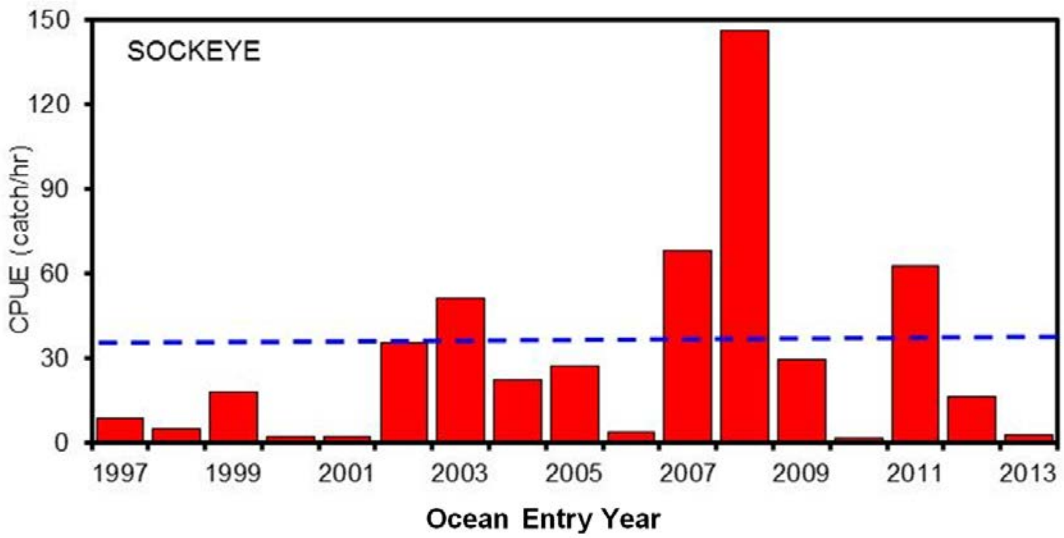


Figure 20. The CPUE of Sockeye Salmon, largely comprised of the Harrison Sockeye stock, in the September trawl survey in the Strait of Georgia. Juveniles captured in 2012 and 2013 could return as four and three year olds in 2015.

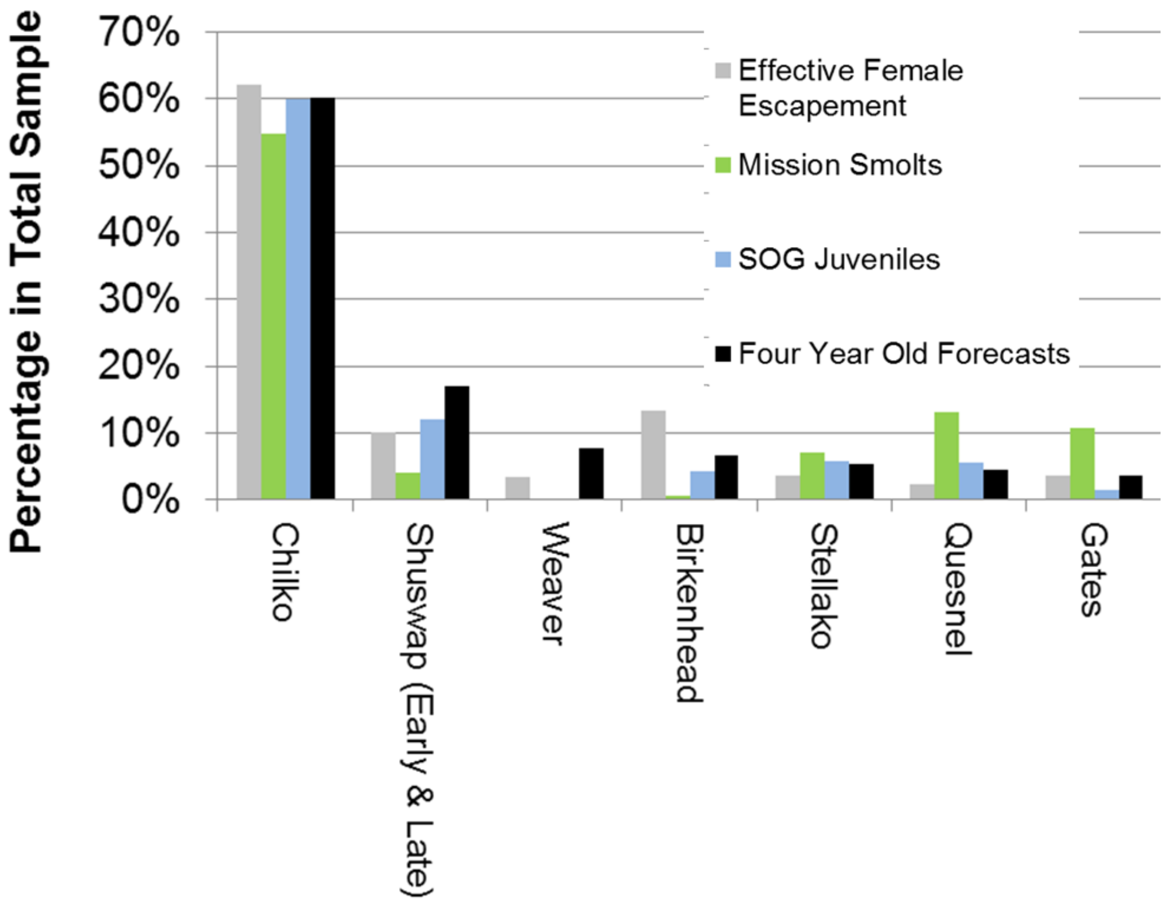


Figure 21. Stock composition (percentages) in the various Fraser Sockeye sampling components: 2011 escapements (effective female escapement), 2013 smolt outmigration at Mission, Strait of Georgia juvenile sampling (SOG juveniles sampled in the June 1-June 11 period), and the official four year old forecasts at the 50% probability level (DFO 2015). Note: because Mission sampling was disrupted from May 16 to June 1, percentages of early migrating stocks (e.g. Chilko, Stellako, Quesnel) may be biased high, and later migrating stocks (e.g. Shuswap) biased low. See corresponding Table 3.

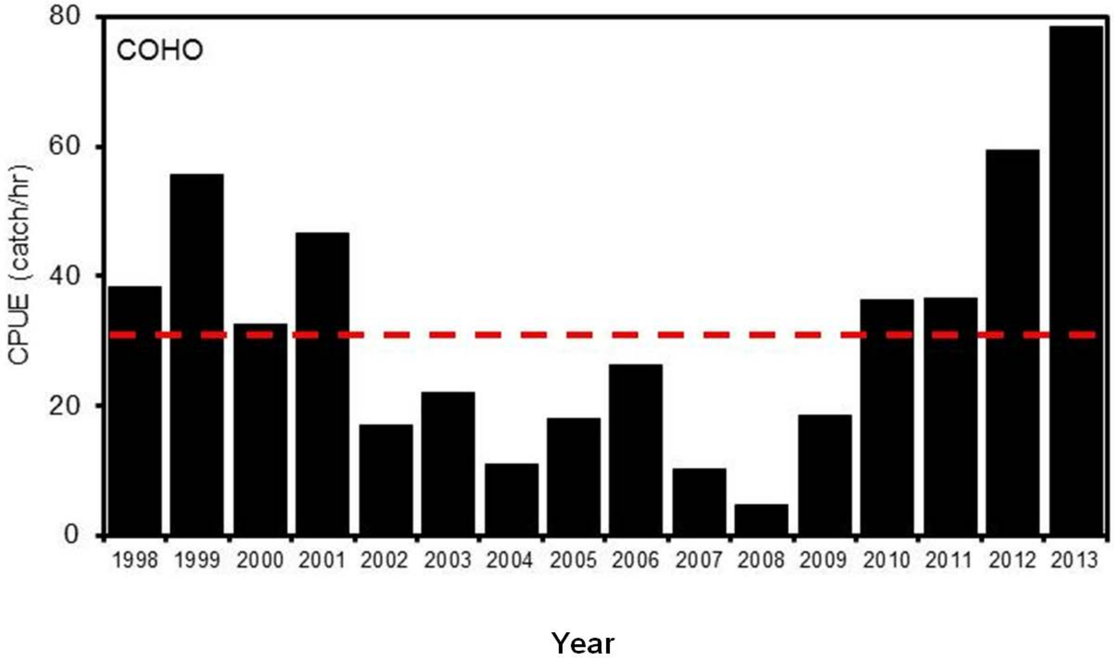


Figure 22. The catch-per-hour (CPUE) of Coho Salmon on the standard track line in the SOG in September 1998-2013.

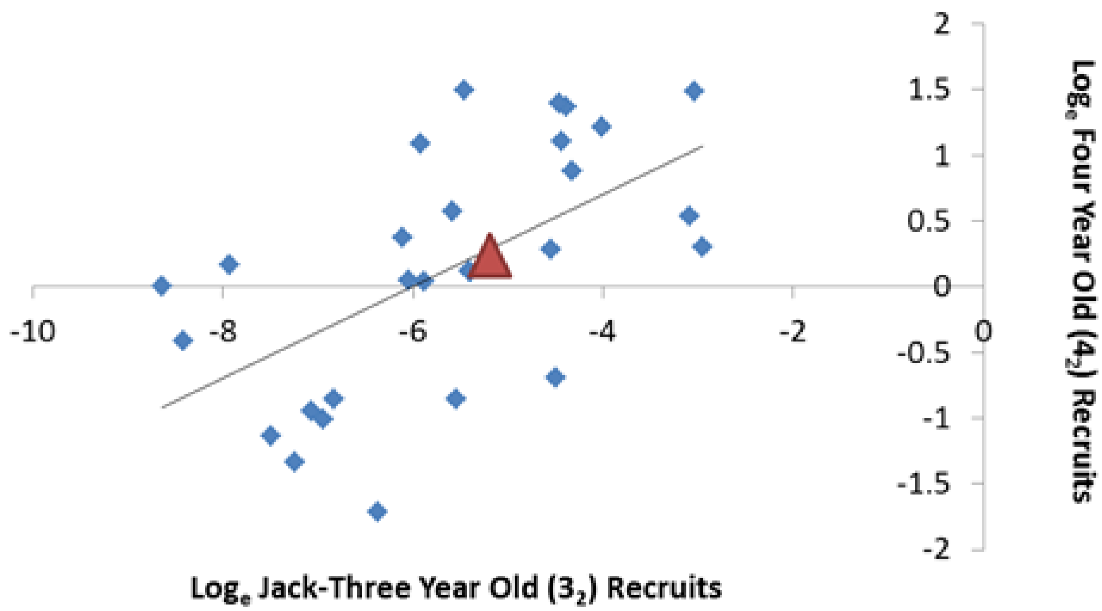


Figure 23. Chilko Sockeye sibling model: four year old (4_2) versus jack (3_2) recruits with model equation and R^2 indicated. The 2014 jack returns used to predict 2015 four year old returns for Chilko are indicated by the red triangle. At the 50% probability level (median) forecast, the four year old sibling model forecast using 2015 jack data as a predictor variable is 1.2 million, compared to the official forecast of 2.4 million (DFO 2015).

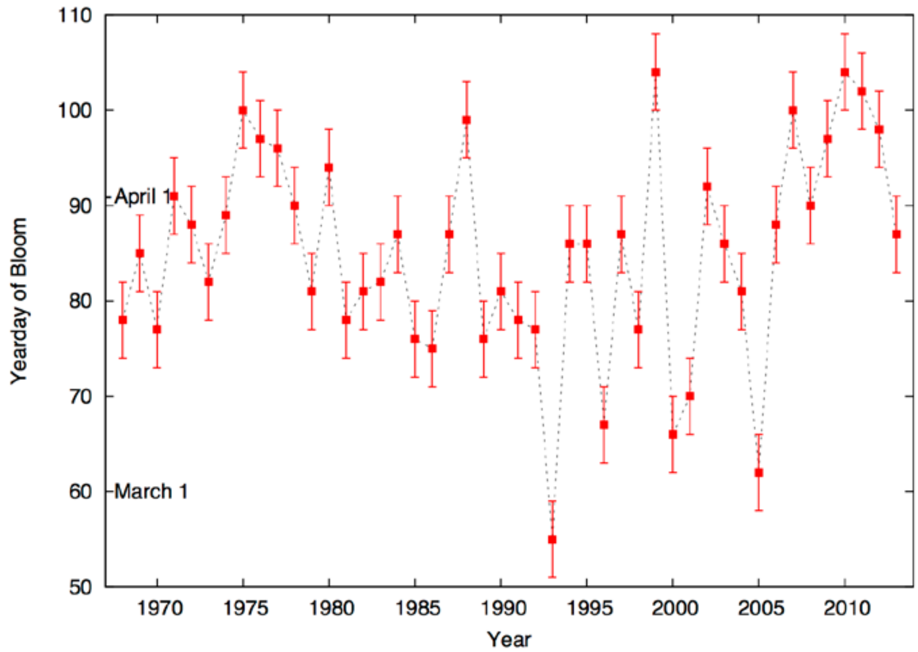


Figure 24. Model-based analysis of the timing of the spring phytoplankton bloom in the Strait of Georgia. Note the predicted shift to an earlier bloom in 2013 (Allen et al. 2014. Can. Tech. Rep. Fish. Aquat. Sci. 3102: 97).

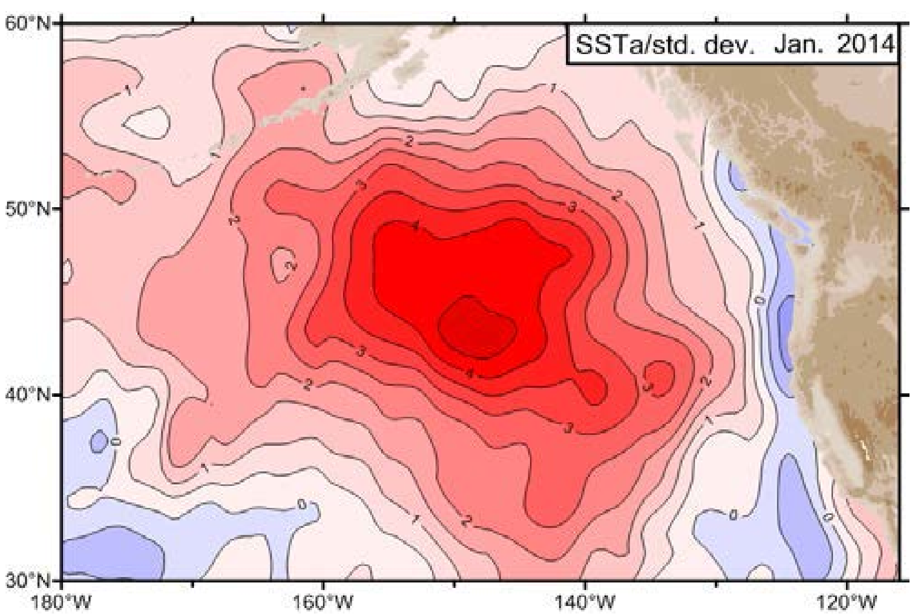


Figure 25. Spatial pattern of sea surface temperature anomalies in January 2014 (i.e. January 2014 compared with conditions in January 1981-2013). Maximum difference is over 4°C, which is considered very large (H. Freeland. 2014. Can. Tech. Rep. Fish. Aquat. Sci. 3102: 23).

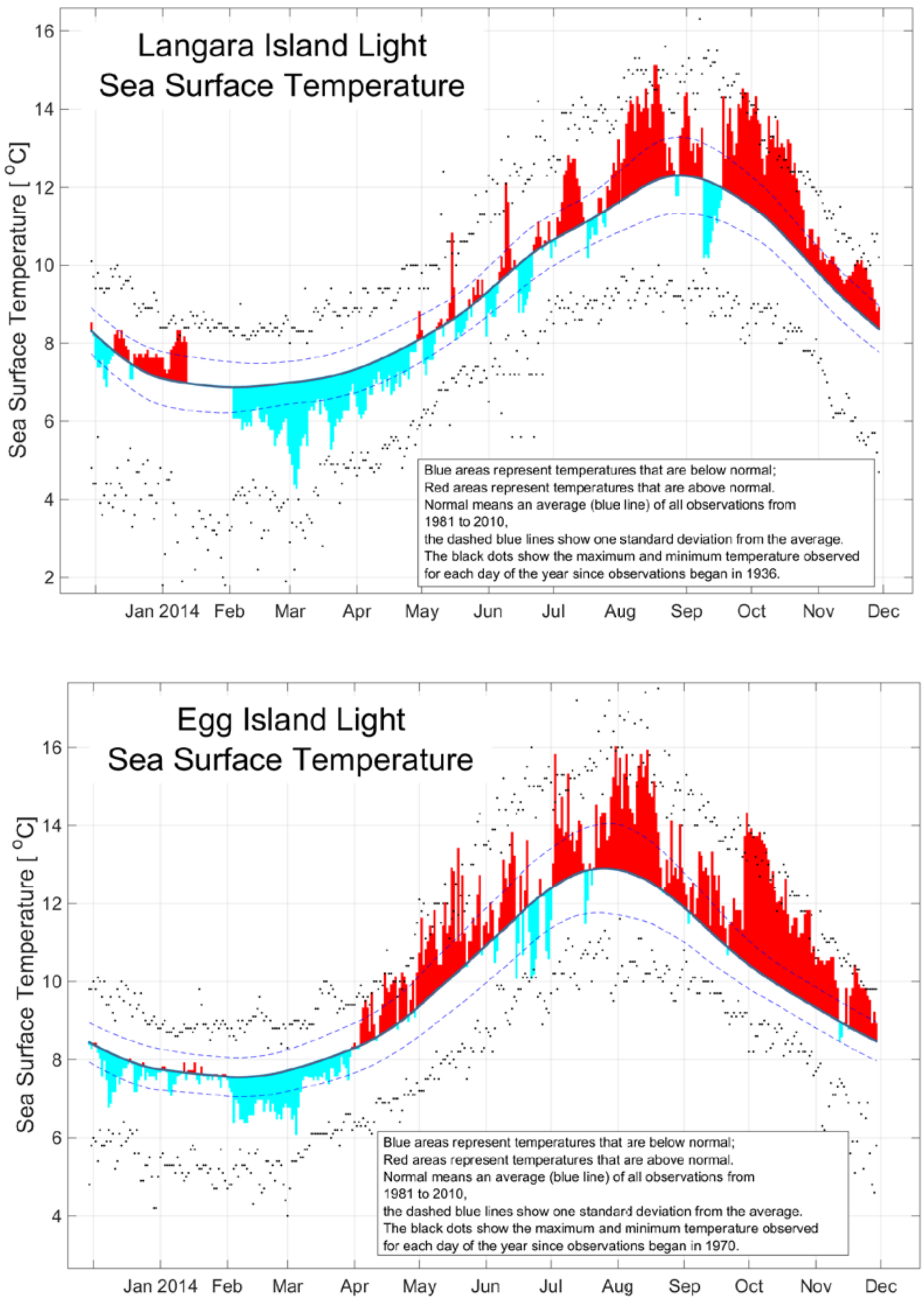


Figure 26. Sea surface temperatures for Egg Island (central coast) and Langara Island (Dixon Entrance) lighthouse stations, 2014. Cool temperatures prevailed from February to May, but warm temperatures are evident from May to December, especially in the autumn. Some record daily high temperatures were observed in Oct-Nov 2014 (P. Chandler, in preparation for DFO State of the Ocean workshop, March 2015).

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Science Branch, Pacific Region
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May 14, 2015

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Appendix 1

Learning Component to the Previous Year's (2014) Forecast Supplement Process

- The CSAS Fraser Sockeye forecast supplement process occurred for the first time concurrently with the 2014 forecast (DFO 2014b). In this forecast the Shuswap complex, and Chilko stocks, were expected to contribute the greatest proportion to the 2014 return (DFO 2014a). The preliminary return estimates in 2014 largely reflect average survival for most stocks, although Early Shuswap stocks exhibited slightly below average survival, and Birkenhead Sockeye exhibited extremely poor survival.
- The following information, documented in the 2014 supplement (DFO 2014b), provided some indication that the returns to the Early Shuswap in 2014 may be lower than expected. For early Shuswap stocks, forecasts were particularly uncertain, given that brood year escapements were exceptionally high and forecast models were being extrapolated beyond their observed stock-recruitment range. Therefore, the low returns observed for the early Shuswap stocks in 2014 improve our understanding of the various carrying capacities within this system. Carrying capacity in this case likely represents spawning ground capacity, as the Shuswap stocks all share the Shuswap Lake system as a juvenile rearing area, and Shuswap Late did not exhibit below average survival, unlike the Early Summer stocks. Additionally, a rain on snow event in the Seymour system may have decreased egg-to-fry survival of this stock. Sibling-jack model forecasts were lower for Scotch and Seymour relative to the official forecasts, also possibly indicated that survival could be lower for these stocks in the 2010 brood year. Relative stock proportions at Mission and Queen Charlotte Sound were slightly lower for Early Shuswap stocks. Spawner success based on physiological metrics was flagged as being poor particularly for Scotch Creek (Early-Shuswap) Sockeye, although egg viability assessments indicated minimal issues with this factor.
- In the Birkenhead system, a major landslide that occurred in September 2010 was not documented in the 2014 Fraser Sockeye forecast supplement (DFO 2014b). Although the specific mechanism linking this landslide to the exceptional poor survival observed in this system is not clear, it is possible that increased turbidity in the lake during smolt outmigration may have contributed to this low survival.
- For the other key stocks (Late Shuswap and Chilko), a number of pieces of information did not suggest any significant departures in survival from that indicated by the official forecasts:
    - Upstream migration conditions in 2010 were generally considered average for the dominant stocks (Chilko and Late Shuswap).
    - Given the exceptional escapements observed in Late Shuswap and Chilko in the 2010 brood year, which were above the calculated Smax for these stocks based on stock-recruitment data and photosynthetic (PR) model results, compensation (lower survival) was expected, and was observed in juvenile data. Further, large escapements in these key systems (Chilko and Shuswap) led to smaller fish sizes in the smolt and juvenile (ocean) stages compared to average. Growth of Shuswap Lake Sockeye was slower in the 2010 brood year, compared to 2011 (the only two years this was evaluated). Fat content was also low during the downstream migration of Shuswap smolts, both at the outlet of Shuswap Lake and at Mission. Fat content in Chilko Sockeye indicated that a portion of the run was not in healthy condition, and gamete viability was low compared to other

stocks. There was strong density-dependent zooplankton grazing pressure by the high fry abundances in both the Chilko and Shuswap systems (lower zooplankton biomass in 2011 compared to 2012).

  - Official forecasts directly included freshwater compensation by using smolt data (Chilko and Cultus Sockeye) as a predictor variable in models
  - Other key stocks in the 2014 forecast included Shuswap stocks (Scotch, Seymour, and Late Shuswap), which relied on escapement based predictor variables. The official forecasts were compared to those estimated with fry based predictor variables (DFO 2014a), which indicated that these model forms largely corroborated one another.
  - Jack-sibling model forecasts for Chilko and Late Shuswap corroborated the official forecasts, providing no indication of departures in survival from that indicated by the official forecasts (DFO 2014a).
  - Stock proportions in all sampling components (Mission smolts, Strait of Georgia juveniles, Queen Charlotte Sound juveniles) largely reflected the key stocks in the 2011 brood year escapements (and, therefore, the 2014 forecasts): Late Shuswap, Early Shuswap, Chilko, Quesnel and Stellako.
- For all stocks, SOG conditions were not flagged as anomalous:
  - Coho in the SOG in 2012 was the highest in 14 years of assessments
  - Herring CPUE in the SOG in 2012, also did not provide any unusual signals (high or low) for survival of Fraser Sockeye juveniles in 2012.
  - Ocean conditions were cool and salinity was below average in the 2012 ocean entry year, which suggests good ocean conditions for salmonids, although linkages to Fraser Sockeye are not quantitatively correlated.
  - In their final winter in the ocean (2013), Fraser Sockeye from the 2011 brood year experienced above average temperatures, although there is some evidence that warmer conditions in their final year have been linked to better Fraser Sockeye survival.
- Smolt outmigration timing:
  - During the 2012 outmigration, there were two clear outmigration periods. The first group to migrate out at Mission were Summer Run stocks such as Chilko, Stellako and Quesnel, with an average 50% outmigration date of April 24. These were followed by Shuswap stocks (early and late timed), with a 50% outmigration date of May 17 (see Figure 16 C in DFO 2014b).
  - In the SOG there were three juvenile Sockeye sampling periods (May 19-June 1; June 11-25; June 20-July 2), and relative stock proportions changed significantly between these periods to reflect the same pattern seen in their outmigration at Mission. Specifically, Summer Run stocks were observed in the earlier sampling periods, dropping off in the later periods, with the opposite occurring for Shuswap stocks (relative proportions increase with time).

This Report is Available from the

Centre for Science Advice
Pacific Region
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ISSN 1919-3769

Correct Citation for this Publication:

DFO. 2015. Supplement to the pre-season return forecasts for Fraser River Sockeye Salmon in 2015. DFO Can. Sci. Advis. Sec. Sci. Resp. 2015/028.

Aussi disponible en français :

MPO. 2015. Supplément aux prévisions d'avant-saison concernant les montaisons du saumon rouge du fleuve Fraser en 2015. Secr. can. de consult. sci. du MPO, Rép. des Sci. 2015/028.