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SUPPLEMENT TO THE PRE-SEASON RETURN FORECASTS FOR FRASER RIVER SOCKEYE SALMON IN 2014

Context

Since most Fraser Sockeye Salmon return as four year old fish after spending two winters in freshwater and two winters in the marine environment, the majority of Sockeye returning in 2014 will be recruits from eggs spawned by adults in 2010 (i.e. the 2010 brood year). Predicting Fraser Sockeye returns in 2014 is a particular challenge, given the exceptional escapements observed for a number of stocks in the 2010 brood year (including Scotch, Seymour, Chilko, Harrison, Late Shuswap, and Portage). These record high brood year escapements require that forecast models be extrapolated beyond the observed stock-recruitment data range, creating additional uncertainty in forecasts for 2014. However, juvenile (fry and smolt) data for various key stocks in the 2010 brood year (Shuswap and Chilko) provide evidence of density-dependent compensation (lower freshwater survival) due to these record high spawner abundances. The juvenile data, therefore, support model forms that predict overcompensation at high spawner abundances.

To provide further context for the 2014 Fraser Sockeye forecasts, additional information on the condition of Fraser Sockeye throughout their various life-history stages is reported in the current document. The Shuswap, Chilko, and Harrison stocks are evaluated, given their unprecedented high escapements in 2010. Quesnel is also included, due to poor survival observed for this stock in recent years, which diverges from the improvements in survival observed for most other Fraser Sockeye stocks between the 2006 and 2009 brood years (2010 to 2013 return years). Fish and environmental conditions are examined for the adults spawners in 2010 (all stocks), fry in 2011 (Shuswap and Quesnel lakes only), outmigrating smolts in 2012 (Shuswap and Chilko), Fraser River downstream smolt migration at Mission (all stocks), and subsequent Strait of Georgia and Johnstone Strait juvenile migrations (all stocks). In addition, the stock composition in the 2010 escapements, and 2012 smolt downstream migration and juvenile ocean surveys, and 2014 return forecasts are compared to evaluate proportional changes through time. This information will be used to supplement DFO’s official Fraser River Sockeye Salmon forecasts.

This Science Response Report results from a Regional Science Response Process held January 2014 to summarize data on fish condition and/or survival (including adults escapement in 2010 and their juvenile offspring). This Science Response is intended to provide context for the official DFO Fraser Sockeye forecasts in 2014.

Background

Returns

Fraser Sockeye adult returns have historically varied, due to the four-year pattern of abundances (cyclic dominance) observed for many stocks, and variability in annual survival (recruits-per-spawner) (Figure 1 A). In recent years, Fraser Sockeye have exhibited particularly large variations in total adult returns. The 2009 return (1.6 million) and 2010 return (28.3 million) were, respectively, amongst the lowest (2009 cycle average: 8.6 million) and highest (2010 cycle average: 13.3 million) returns on record for their cycles since 1952. In subsequent return years (2011 to 2013), Fraser Sockeye survival has generally reverted to average, and return abundances have largely been influenced by brood year escapements. Total returns in 2011 (5.1 million) were very similar to the cycle average (5.3 million), and preliminary returns in 2012 (~2.2 million) and 2013 (3.8 million) were below their respective cycle averages (3.6 million and 8.6 million) (Figure 1 A).

Pre-Season Abundance Forecasts

Pre-season return forecasts for Fraser Sockeye are associated with relatively high uncertainty, due to wide variability in annual salmon survival (recruits-per-spawner), and observation error in the stock-recruitment data (Grant et al. 2010; Grant & MacDonald 2011; Grant & MacDonald, 2012; MacDonald & Grant 2012; Grant & MacDonald 2013). Fraser Sockeye forecasts have been particularly uncertain in recent years due to the systematic declines in survival exhibited by most stocks, which culminated in the lowest survival on record in the 2005 brood year (2009 four year old and 2010 five year old returns) (Figure 1 B). Subsequently (2010 to 2013 return years), survival appears to have improved (Figure 1 B). Currently, there are no leading indicators of Fraser Sockeye survival to predict inter-annual variation or broad shifts between survival periods.

Limited understanding of what drives inter-annual changes in Fraser Sockeye survival is likely attributed to the broad range of ecosystems these stocks inhabit throughout their life-history. Fraser Sockeye generally spend their first two winters in freshwater (egg through to smolt stage), followed by two winters (although the range is one to three winters) in the marine environment, before returning to their natal streams or lakes to spawn. Fraser Sockeye stocks migrate through a broad range of systems within their first year of marine residence, moving rapidly northwards through the Strait of Georgia (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). Considerable inter-annual variability in mortality occurs in both freshwater and marine ecosystems, as indicated by freshwater and marine survival data for Chilko River Sockeye (Fraser Sockeye indicator stock) (Figure 2 A & B). Chilko is the only Fraser Sockeye stock with a long and complete time series of smolt data (counted through an enumeration weir located at the outlet of Chilko Lake), which can be used with escapement and return data to partition total survival into freshwater and ‘marine’ (‘marine’ survival includes their migration downstream from the counting weir to the Strait of Georgia) components. 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.

Forecasting returns for 2014 presents a challenge given the exceptional 2010 brood year escapements of a number of stocks. This is particularly notable for the Shuswap and Harrison stocks, as biological forecast models such as the Ricker must be extrapolated well beyond the range of observed (fitted) data given the record 2010 escapements (Figure 6 A to D). Since different biological models include varying assumptions about population dynamics, and the 2010 brood year escapements for a number of stocks fall above those observed in the historical time series, supplemental information is presented to provide context for the 2014 forecasts. Quesnel, in contrast, presents a forecasting challenge because, unlike other stocks, survival of Quesnel fish has not improved in recent years (Figure 5 B and Figure 6 F). Further, the 2013 return to Quesnel fell at the low end of the forecast distribution, indicating particularly low survival for this stock in the most recent return year. Given the uncertainty in the 2014 forecasts, this presentation of auxiliary data from the 2010 parental spawner generation through to the juvenile marine rearing environment in 2012 and jack returns in 2013 provides context for the 2014 forecasts.

Analysis and Response

The Shuswap System (2010 brood year)

Both Early Summer (Scotch, Seymour, Eagle, etc.) and Late Run (Adams, Little and Lower Shuswap Rivers, etc.) timing stocks use the rearing lakes of the Shuswap system as juveniles. Shuswap stocks exhibit the same pattern of cyclic dominance, with one large dominant line (2010 cycle), followed by a much smaller subdominant line (2011), and two weaker lines (2012 & 2013) (Figure 3 A to C). For Scotch Creek Sockeye, this pattern was established between the 1950’s and 1970’s, due to hatchery transplants from the Seymour River. The smallest escapements on record for these stocks all occurred in 2009, while the largest escapements on record for these three stocks occurred in 2010 (2010 being the parental generation/brood year for four year old fish returning in 2014) (Figures 3 A to C; Figure 6 A to C).

Typical of most Fraser Sockeye stocks, Scotch and Seymour Sockeye have exhibited declines in survival since the 1990’s (Grant et al. 2011, Peterman and Dorner 2012). Late Shuswap is unique amongst Fraser Sockeye stocks, in that it has not exhibited any persistent trends in survival (recruits-per-spawner: R/S) through time (Grant et al. 2011, Peterman and Dorner 2012). All Shuswap stocks exhibited above average survival in the 2006 brood year (2010 returns), and average survival in subsequent years (DFO 2014).

Early Shuswap: Escapement, Spawner Success, and Egg Viability

Return Forecasts

- Stock-recruitment data are available for Scotch (1980-2006 brood years) and Seymour (includes McNomee) (1948-2006 brood year), which comprise two out of the 19 forecasted Fraser Sockeye stocks (Figure 6 A & B).
- Only escapement data (no associated recruitment data) exist for other populations, such as the Eagle River, which are forecasted together as a ‘miscellaneous’ stock.
- Fry data for Shuswap Lake-rearing Sockeye (includes both early- and late-timed Shuswap stocks) have been collected largely on dominant and subdominant cycles from the 1974-2010 brood years. Given the large abundance of Late Shuswap Sockeye in dominant and subdominant cycle years, this stock dominates the fry abundance in samples.
- Biological forecast models that use escapement data as a predictor variable to forecast the 2014 returns must be extrapolated beyond the observed data range, due to the record escapements in the 2010 brood year (Figure 3 A & B; Figure 6 A & B).

Miscellaneous Shuswap-Early Summer Run forecasts also use predictor variable values that exceed historical escapements for these stocks.

Adult Migration and Spawning: Environmental 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 of 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 barrier to migration (> 9,000 cms), leading to increased risk of fish mortality and severe stress (Macdonald et al. 2012). Low discharge on spawning grounds can affect spawning success (crowding due to less available spawning habitat) and egg survival (dewatering of redds). Alternatively, high flow events can cause bed movement, scouring, and egg mortality.
- During the upstream migration period for Early Shuswap stocks in the Lower Fraser River (Qualark, B.C.) (Table 1), water temperatures were above average (Table 2; Figure 7). On approach to their spawning grounds, in the South Thompson and Thompson Rivers, water temperatures were average (Table 2). No water temperature data are available in the Scotch Creek and Seymour River systems, where spawning occurs for these stocks.
- Discharge in the Fraser River (Hope, B.C.) during the Early Shuswap upstream migration period was below average (Table 2; Figure 7). In the South Thompson and Thompson Rivers, discharge was below average. The only environmental data specific to the Early Shuswap system is water discharge in the Seymour River, which was generally average for most of the migration period, with the exception of mid-to-late September, when discharge was above average (Figure 8 A). These data coincide with observations on the spawning grounds of an intense rain on snow event that occurred in the north-east portion of the watershed in late September, and may have negatively impacted egg-to-fry survival in the Seymour, Anstey, and Eagle Rivers.
- Generally, environmental conditions (water levels and temperatures) observed on the spawning grounds were favorable to fish condition and water levels and conditions in the South Thompson Basin did not appear to be limiting or restricting fish access.

Adult Spawners: Escapement

- The 2010 brood year is the dominant cycle year for the cyclic early timed Shuswap stocks (Figures 3 A & B).
- 2010 escapements for early timed Shuswap stocks were the largest on record: effective female spawner abundances (EFS) for Scotch (274,000), Seymour (including McNomee) (288,000), and Eagle (79,000K) were all at least two times greater than their past maximum escapements.
- Scotch, Seymour, and Eagle populations made up 92% of the total escapement in this system in 2010.
- Eagle was assessed using visual methods and was likely biased low, given the high escapements observed in this system.
- Spatial distribution of spawners in the system expanded in 2010 due to the exceptional number of spawners; spawning was observed at nine new sites.

- Scotch had particularly large spawner densities that may have influenced the success of eggs deposited (it is a relatively small creek and high densities may have resulted in individuals digging up each other's redds).

Adult Spawners: Run Timing

- Arrival and spawning timing was normal.

Spawner Success: Egg retention and Egg Viability

- Elevated pre-spawn mortality (PSM) was weighted towards the earliest arrivals (when PSM typically occurs), as indicated by female carcass surveys on the spawning grounds. Spawning success (based on numbers of eggs retained in assessed carcasses) in 2010 (89%) was below average (93%); spawner success is accounted for in Fraser Sockeye forecasts by using EFS as a predictor variable.
- 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 red 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.
- A suite of biological samples was collected from spawning Sockeye in 2010 to assess egg deposition and egg viability: physiology (ions & metabolites), steroids (to assess maturation & stress), condition (energy & lipids), and disease (RNA & histopathology). Ideally, a multivariate analysis of all 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 12 A). For fish that are actively spawning, it is normal for glucose levels to rise well above 10 mmol/L, however these values will lead to rapid senescence. Normal fat content for fish arriving on the spawning grounds is between 2.5-4.0% (Figure 12 B). 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. 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).
- In 2010, Early Shuswap-Scotch adults sampled on their spawning grounds (40 spawners: 20 males & 20 females) had plasma glucose and lipid values of 15.3 mmol/L and 1.7%, respectively (Figures 12 A & B). The high glucose and low lipid levels indicate that some individual fish on the spawning grounds were in very poor condition and were unlikely to be 100% in terms of spawner success (egg deposition and viability). Direct comparisons with metric values for other stocks should be made with some caution due to differences in behavioral state. All fish from Scotch were captured directly from spawning redds during active spawning, while for most other stocks ripe fish were either captured while holding, or while in combinations of holding and spawning.

- Additional genomic samples were taken from all females spawners sampled in 2010. These analyses are underway and will shed light on gene expression patterns associated with key physiological parameters as well as provide information on microbial presence. Therefore, further information will be published on physiological parameters and genomic results in relation to spawning success and egg viability. Archived histology samples are also available for potential disease analysis, but are not being considered for analysis at this time.
- In 2010, eight Fraser River stocks were surveyed for gamete viability. Detailed methods can be found in Whitney et al. (2013). In short, for each stock, 20 males and 20 females were taken on the same day and used to generate over 60 unique individual pairings. Each male and female was crossed with a minimum of three partners. Survival was monitored to the eyed egg stage to assess problems associated with gamete viability at the individual parent level. Based on previous methods, maximum eyed survival for an individual should be above 80% of the maximum eyed survival for a given group of fertilizations (adjustment incubation variability). Population level problems are assessed based on the number of individuals below 80% of maximum survival. This metric can be used to compare across stocks. For Early Shuswap-Scotch, the average eyed egg survival was 80% (Figure 13 A). All male and female spawners assessed in Scotch creek were fertile, with only two females falling below the adjusted 80% value, suggesting minimal problems with egg viability for those eggs successfully deposited.

Late Shuswap: Escapement, Spawner Success, and Egg Viability

Return Forecasts

- Stock-recruitment data are available for Late Shuswap (1974-2006 brood years) (Figure 6 C), which comprises one out of the 19 forecasted Fraser Sockeye stocks.
- Fry data for Shuswap Lake-rearing Sockeye (includes early and late timed Shuswap stocks) have been collected largely on dominant and subdominant cycles from the 1948-2006 brood years. Given the large abundance of Late Shuswap Sockeye in dominant and subdominant cycle years, this stock dominates the fry abundance in samples.
- Biological forecast models that use escapement or juvenile data as predictor variables to forecast the 2014 returns must be extrapolated beyond the observed data range, due to the record escapement and fry abundance observed in the 2010 brood year (Figure 3 C; Figure 6 C).

Adult Migration and Spawning: Environmental Conditions

- During the upstream migration period for the Late Shuswap stock in the Lower Fraser River (Qualark, B.C.) (Table 1), water temperatures experienced by most of the run were average, however, the earliest migrants (prior to mid-August) experienced above average temperatures (Figure 7). On approach to their spawning grounds, in the South Thompson and Thompson Rivers, temperatures were average (Table 2). In the Adams River, where most spawning occurs for Late Shuswap, water temperatures were average (Figure 8 B) during the September and October spawning period.
- Discharge in the Fraser River at Hope, B.C. during the Late Shuswap migration period was below average (Table 2; Figure 7). In the South Thompson and Thompson Rivers, discharge was below average. In the Adams River, discharge was average (Table 2; Figure 8 C).

- Water levels, visibility, and temperatures were generally favorable for spawning and enumeration at most South Thompson streams in 2010.

Adult Spawners: Escapement

- The 2010 brood year is the dominant cycle year for the highly cyclic Late Shuswap stock (Figure 3 C), which predominantly spawns in the lower Adams, Little, and Lower Shuswap Rivers.
- 2010 escapement for the late timed Shuswap stock was the largest on record at 3.1 million EFS, exceeding the previous maximum escapement of 2.8 million EFS in 2002 (Figure 3 C; Figure 6 C).
- Given the large escapement in 2010, spawning was observed in areas where it had not been previously reported (although the extent of spawning was smaller than what was observed in 2002).

Adult Spawners: Run Timing

- Late Shuswap Sockeye exhibited markedly different migration behavior from the lake to the spawning grounds in 2010 compared to the previous record escapement in 2002. In 2002, all fish moved into the spawning grounds as a group, whereas, in 2010, migration was protracted (late August through November) with Sockeye moving into the Adams River (main spawning site for Late Shuswap Sockeye) to spawn in waves, spawning on top of each other's redds. The abundance in 2010, therefore, did not appear as visually striking as in 2002.

Spawner Success: Egg Retention and Egg Viability

- Elevated pre-spawn mortality (PSM) was weighted towards the earliest arrivals (when PSM typically occurs), as indicated by female carcass surveys on the spawning grounds, but remained abnormally high throughout the duration of run. Spawner success (based on the number of eggs retained in assessed carcasses) in 2010 (73%) was below average (94%); spawner success is accounted for in Fraser Sockeye forecasts by using EFS as a predictor variable.
- See Early Shuswap section for description of biological samples and methods for assessing egg deposition and egg viability (Figures 12 A & B).
- In 2010, Late Shuswap adults were sampled for plasma glucose in the marine approach areas, upon entry into the Fraser River, and on the spawning grounds. Sockeye were also sampled for lipids on the spawning grounds. The overall condition of the fish at each sample location was consistent with healthy fish. For example, glucose levels of migrating Sockeye (marine and river locations) were well within the normal range (Figure 12 A). Higher glucose levels on the spawning grounds (~10 mmol/L) are consistent with a portion of fish being engaged in spawning activity (Figure 12 A). The average fat content of Adams spawners in 2010 (2.7%) was comparable to other stocks (Figure 12 B) and values from previous years (Crossin et al. 2004).
- See Early Shuswap section for description of biological samples and methods for assessing gamete viability. For Late Shuswap-Adams, the average eyed egg survival was 81% (Figure 13 A). There was some individual variability amongst females (Figure 13 B), but only a few females had average eyed success rates that fell below the adjusted 80% of the averaged maximum for the population. For comparison, egg

survival for 2006 and 2002 were 97% and 81% respectively. For 2010, there is no indication of widespread declines in gamete quality.

All Shuswap stocks: Freshwater (Fry and Smolt) Stages

Juvenile (Fry)

- Pelagic surveys of juvenile Sockeye Salmon in the Shuswap Lake system (includes Shuswap & Mara Lakes) have been conducted since 1975, largely on the dominant and subdominant cycles. 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 juvenile Sockeye Salmon population. For complete methods, see MacLellan and Hume (2010).
- The relationship between brood year EFS and resulting fall fry 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 14 A).
- In 2010, the total escapement of Early and Late Shuswap stocks combined (8.9 million), both of which use Shuswap and Mara lakes for fry rearing, was well above the spawner abundance that maximizes juvenile production for the lake system (S_{max}), as calculated from photosynthetic rate (PR)(Hume et al. 1996; Shortreed et al. 2000) values (2.2 million, updated from Grant et al. 2011), or from stock-recruitment data (2.5 million). Compensation (reduction in growth and/or survival) due to high densities of fry is therefore expected (Figure 15 A).
- Due to the large number of spawners (as an index of egg abundance) in the system in dominant cycle years (average EFS: 1.2 million) relative to the subdominant cycle years (average EFS: 180,000), average early freshwater survival is lower for the dominant cycle (91 fall fry/EFS*,* *n*=10) than for the subdominant cycle (202 fall fry/EFS, *n*=8). In recent years (post-1990 brood year) early-freshwater survival in dominant cycle years (average = 66 fall fry/EFS; *n*=7) has been below the long-term average. Despite the exceptional escapement of 3.1 million in 2010 (dominant cycle), survival (52 fall fry/EFS) in this brood year was similar to the recent dominant cycle average (Figure 15 A).
- Lower freshwater survival in dominant years is likely largely attributable to lake food web limitations at high fry densities, but may also be an effect of spawning ground limitation for certain stocks receiving large numbers of spawners in spatially-restricted tributaries (e.g. observed in Scotch Creek in 2010).
- Despite below average freshwater survival (see previous two paragraphs), the 2010 brood year fry abundance (187 million) in the Shuswap Lake system was the largest observed on record; previously the largest abundance of fry (173 million) was observed in 1978, while the second largest brood year escapement (2002) resulted in a fry abundance of 132 million (Figure 14 A).
- Fall-fry body size in the 2010 brood year (average weight: 2.3 g; average length: 60 mm) was similar to the dominant cycle average (average weight: 2.3 g; average length: 60 mm; *n*=9 years), and was slightly larger than the average fry size from the previous record escapement in the 2002 brood year (average weight: 2.0 g; average length: 58 mm). On average, fall fry from the historical subdominant cycles (1975-2003) attained ~22% more mass than those from the dominant cycle.

Juvenile (Smolt)

- Smolts from the 2010 and 2011 brood 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.
- As expected, given differences in fry densities between the dominant and subdominant cycles, overall growth of juvenile Sockeye in Shuswap Lake in the 2010 brood year was slower than in the 2011 brood year when compared across on-shore, pelagic and smolt life stages. Mean smolt fork lengths and weights in the 2010 brood year (average length: 67.9 mm ± 0.7 mm 95% CI; average weight: 2.7 ± 0.1 g 95% CI) were significantly lower (both $p < 0.001$) than those of the 2011 brood year (average length: 80.7 ± 3.7 mm 95% CI; average weight: 4.6 ± 2.3 g 95% CI). Over winter growth from fall fry to smolt was considerably less in the 2010 brood year (0.4 g) than in the 2011 brood year (1.4 g). 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. 2000).
- In 2012 (2010 brood year), Sockeye smolts preparing to leave Shuswap Lake were sampled via lake trawls in late April and Sockeye smolts emigrating from Shuswap Lake were captured via beach seining in Little River for further analysis of condition. Weekly samples were collected from May 1st through to June 15th, at which point sampling was concluded due to high water. At least 50 smolts-per-night were captured with the peak smolt numbers occurring in mid-May. Additional samples of Shuswap smolts were taken at Mission from late April to the end of May. These samples were analyzed for fat content (total body lipids) and triacylglycerides (these analyses are on-going).
- The majority of information on smolt condition comes from hatchery reared fish and other Pacific salmon species (Biro et al. 2004; Naesje et al. 2006). There are very few published values of fat content in out-migrating wild Sockeye smolts (Powell et al. 2010; Farley et al. 2011) and there are no historic records of fat content in Shuswap smolts for direct comparison with recent studies. A cautionary threshold for lipid content has been estimated at approximately 2%, based on work on adult salmon and reports on other species (Gardiner & Geddes 1980; Crossin et al. 2003; Powell et al. 2010; Farley et al. 2011). The lower limit of body fat for juvenile salmonids at death is 1%, derived from studies of starved juvenile rainbow trout in lab conditions (*Oncorhynchus mykiss*). However, it is not clear at what point fish approaching the 1% limit can still recover from this severe level of starvation. We have set 2% as a cautionary limit and 1.5% as a critical level for wild fish, meaning that individual survival will likely be compromised as a result of having a fat content <2%, and survival is unlikely if less than 1.5%. Low lipid values are also associated with slow growth rates and elevated risk of predation (Post & Parkinson 2001; Farley et al. 2011).
- The average fat content for Shuswap Sockeye smolts captured at Little River, and Mission was 3.0% (SD = 0.8%) and 2.2 % (SD = 0.7), respectively. During the main outmigration period there was no temporal pattern in fat content within a location. However, low fat content in Shuswap smolts near the end of their downstream migration at Mission presents a concern given the proximity of a number fish to the critical minimal threshold of 1.5%. The same fat content (2.2%) at Mission was observed for Chilko smolts in 2012.

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 juvenile salmonids and comprise 85% to 95% of the fall diet of age-0 Sockeye in Shuswap Lake) was lower in 2011 than in 2012 (2010 vs. 2011 brood years), providing evidence of strong density-dependent fry grazing pressure. As expected, depressions in zooplankton biomass in 2011 (2010 brood year) were greatest in the Main Arm of Shuswap Lake where Sockeye Salmon fry were most abundant. In 2011, *Daphnia* biomass within the Main Arm generally declined after June (period when juvenile Sockeye Salmon move offshore), corroborating the strong top-down pressures in the food web that were commensurate with slower juvenile growth rates.
- 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), may have resulted in density-dependent effects on food web structure and function, and thus reduced freshwater growth and survival.

Chilko Stocks

Similar to the Shuswap system, Chilko Sockeye have both an Early Summer and Summer Run timing component, though the Early Summer timed stock comprises only a small percentage (<10%) of the total Chilko abundance and is combined with the Summer Run timing group in the escapement and smolt estimates. The Chilko stock-recruitment time series extends from 1948-present (Figure 6 D). Chilko currently does not exhibit cyclic dominance (Figure 4 A). The largest escapement on record for Chilko occurred in the 2010 brood year (parental generation for four year old fish returning in 2014) (Figure 4 A).

Similar to most Fraser Sockeye stocks, Chilko Sockeye have exhibited persistent declines in total survival since the 1990's. In recent years survival has been average. Chilko is the only stock with a long-term time series of smolt abundance data that can be used to partition total survival into freshwater and marine components. Chilko freshwater survival has been variable in recent years (Figure 2 A), while marine survival has improved in recent years following a period of declines in the 1990's (Figure 2 B).

Return Forecasts

- Stock-recruitment data are available for Chilko (1948-2006 brood years) (Figure 6 D), which comprises one out of the 19 forecasted Fraser Sockeye stocks.
- Smolt data are collected during their outmigration from Chilko Lake (1949-2006 brood years) (Figure 4 B).

- Biological forecast models that use escapement data as a predictor variable to forecast the 2014 returns must be extrapolated beyond the observed data range due to the record escapement in the 2010 brood year (Figure 4 A; Figure 6 D). However, due to exceptionally poor freshwater survival in the 2010 brood year (Figure 2 B), the estimated smolt abundance falls at the high end (but not outside) of the historical range (Figure 4 B). Therefore, biological models that use smolts as a predictor variable, which were used to forecast the 2014 return, are not being extrapolated beyond the observed data range.

Adult Spawners: Environmental Conditions

- During the upstream migration period for Chilko Sockeye in the Lower Fraser River (Table 1), water temperatures (Qualark, B.C.) were above average in the first half of their migration period and were average in the second half of their migration period (Figure 7). Discharge (Hope, B.C.) was below average (Figure 7). No water temperature data are available in the Chilko River system in 2010. Discharge in the Chilko system during migration and spawning was above average in August and below average in September (Table 2; Figure 9 B).
- Environmental conditions (water levels and temperatures) observed on the spawning grounds were generally favorable for spawning.

Adult Spawners: Escapement

- The 2010 escapement for Chilko was the largest on record at 1.2 million EFS. This was approximately double the previous maximum escapement of 598,000 (Figure 4 A). Chilko is not considered a cyclic stock.

Adult Spawners: Run Timing

- Arrival and spawning timing was normal.

Spawner Success: Egg retention and Egg Viability

- Elevated pre-spawn mortality (PSM) was weighted towards the earliest arrivals (when PSM typically occurs), based on female carcass surveys on the spawning grounds. Spawning success (based on numbers of eggs retained in assessed carcasses) in 2010 (86%) was similar to average (91%); spawner success is accounted for in Fraser Sockeye forecasts by using EFS as a predictor variable.
- See Early Shuswap section for description of biological samples and methods for assessing egg deposition and egg viability (Figures 12 A & B).
- In 2010, adult spawners collected from the Chilko River spawning grounds had high glucose levels and fat content (Figure 12 A & B). High fat content is expected, based on the location of capture and corresponding observations that spawning had not yet been undertaken by the majority of fish (Crossin et al. 2004). However, at the spawning grounds high glucose is normally associated with individuals that have very low energy levels (<2%) and are actively spawning. This disassociation indicates that a portion of the run were not in healthy condition.
- See Early Shuswap section on gamete viability methods and background. The overall gamete viability was 59% for the 2010 brood year Chilko sample, which is considered low in comparison to other stocks (Figure 13 A) and years (2002 survival was 80%). Moreover, seven females fell below the 80% threshold, and the %CV (65) for the population was very high (Figure 13 A). Therefore, there is concern for both the condition of the adults and the overall viability of eggs deposited in 2010.

Juvenile (Smolt)

- Chilko is the only stock for which a long time series (brood years 1949 to present) of smolt abundance data have been collected. Smolt counts are collected using 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 2 A & B).
- The relationship between brood year EFS and resulting smolt abundance in Chilko Lake exhibits density-dependent freshwater survival at higher spawner abundances, and has been modeled with both a Ricker (R^2<0.4) and Beverton-Holt (R^2<0.4) relationship (Figure 14 B). This stock is not considered cyclic, showing no consistent abundance patterns between years.
- In 2010, total escapement for Chilko (2.5 million) was well above spawner abundance that maximizes juvenile production for the lake system (S_{max}), as calculated from photosynthetic rate (PR) model values (Hume et al. 1996; Shortreed et al. 2000; 710,685, updated from Grant et al. 2011) or stock-recruitment data (430,000; Grant et al. 2011). Compensation (reduction in growth and/or survival) is therefore expected due to the high density of lake rearing fry (Figure 15 B).
- Given the exceptional escapement to Chilko Lake in the 2010 brood year (1.2 million; Figure 4 A), freshwater survival for this brood (47 smolts/EFS) was one of the lowest observed within the historical time series (Figure 2 A), falling almost three times lower than the average (118 smolt/EFS). Freshwater survival of the 2010 brood year was approximately 70% that of the freshwater survival observed for the second largest escapement on record in 1991 (66 smolts/EFS; escapement: 600,000 Sockeye Salmon). Limnological data suggest that freshwater survival may have been limited by strong overcropping of the Chilko Lake food web, though it could be additionally due to spawning ground limitations at such high spawner densities.
- Most Chilko Sockeye Salmon spawn at the outlet of Chilko Lake (north end), which would likely create spawning ground limitations in years of high abundance, such as the 2010 brood year. Further, hydroacoustic evidence from lake fertilizations during the 1980's and 1990's suggests that fry concentrate at the north end of the lake. This is the area where most Sockeye Salmon fry first enter the Chilko Lake rearing environment, and it is also where the largest abundance of zooplankton (prey) occurs. A north-south gradient of food web productivity exists in Chilko Lake, most likely due to the influence of differential glacial turbidity.
- Despite below-average freshwater survival, one year old smolt abundances produced by the 2010 brood year (55 million) was still above average (19.5 million). Though this abundance falls within the historical range of data (Figures 4 B & 14 B).
- Smolt lengths in the 2010 brood year (77 mm) were below average (83 mm).

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 in limnological assessments conducted in Chilko Lake (1994-2008), recent data show that lake 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). However, increases in fry densities, in addition to potential spawning ground limitations in the 2010 brood year, may have induced density-dependent effects on food web structure and function, and thus reduced freshwater growth and survival.

- Zooplankton biomass was measured across four limnological sampling stations spanning a gradient of productivity in Chilko Lake. A 20%-32% reduction in seasonal mean zooplankton biomass was observed in Chilko Lake during the lake residency of the 2010 brood year fry, relative to the average zooplankton biomass in years when the 2008, 2009 and 2011 brood year fry resided in the lake. Biomass of *Daphnia*, the preferred and most energetically-beneficial prey item for juvenile salmonids, was reduced by 94%-99% throughout the growing season in 2011, indicating strong top-down grazing pressures on the Chilko lake food web. This was likely responsible, in part, for the large decrease in freshwater survival and stunted growth observed for the 2010 brood year.

Harrison (High Level Overview Only)

- Harrison Sockeye have experienced exceptional returns and escapements since the 2001 brood year: pre-2001, average escapement was 6,000 EFS (maximum: 24,000 EFS) and post-2005 average escapement was 110,000 EFS (maximum: 400,000 EFS) (Figure 5 A).
- Harrison Sockeye are unique amongst most Fraser Sockeye stocks, in that they migrate to the ocean shortly after they emerge from the gravel and do not spend an additional year rearing in freshwater lakes. Further, after they enter the SOG they remain in this system for up to six months, and largely migrate out via the southern Juan de Fuca Strait. All other Fraser Sockeye stocks migrate rapidly through the SOG and out to the North Pacific via the northern Johnstone Strait.
- Harrison Sockeye are also unique in terms of age structure, returning with varying proportions of three (3_1) and four (4_1) year old fish. Age-3 proportions are lower in odd years (average: 0.26) compared to even (average: 0.45) years, likely due to interactions with Pink Salmon spawning in the Harrison system, which results in a delay in the age of maturation of Harrison Sockeye (Grant et al. 2011). Similar to other stocks, the proportion of three year olds has declined post-1980 (Grant et al. 2011).
- Harrison escapements in the 2010 and 2011 brood years, corresponding to age-4 and age-3 returns in 2014, were exceptional, at 400,000 EFS in both years (Figure 5 A and Figure 6 E).
- During the upstream migration period for Harrison Sockeye in the Lower Fraser River (Table 1), water temperatures (Qualark, B.C.) were above average in the first half of their migration period and were average in the second half of their migration period (Figure 7). Discharge (Hope, B.C.) was below average (Table 2; Figure 7). In the Harrison River,

during the period of adult migration and spawning, water temperatures ranged from below average to average (Figure 10 A), and discharge was above average (although discharge data are patchy during migration and spawning timing) (Table 2; Figure 10 B).

- Adult spawners collected from Harrison River in 2010 had glucose and lipid levels within the normal range (Figure 12 A & B).
- The combination of large escapements in 2010 and 2011 and the dramatic increase in survival and abundance of Harrison Sockeye since the 2000 brood year, make forecasting returns for this stock impossible using standard stock-recruitment models (Figure 6 E). More data are required to partition the stock-recruitment time series into this recent period of high production to model this relationship.
- Currently, there is no clear understanding of what is driving the dramatic changes in survival and abundance in Harrison since the 2000 brood year, though mechanisms are likely linked to Harrison Sockeye's unique life-history and age structure.

Quesnel (High Level Overview Only):

- Quesnel is the only Fraser Sockeye stock that demonstrates evidence of delayed-density dependence at larger spawner abundances (Peterman & Dorner 2012). Unlike most other Fraser Sockeye stocks, survival of Quesnel fish has not improved in recent years (2013 returns fell at the low end of the forecast distribution, which indicates poor survival).
- Unlike Shuswap, Chilko and Harrison Sockeye, Quesnel did not exhibit an exceptional escapement (133,000) in the 2010 brood year relative to the cycle average (179,000). Spawner success in 2010 (95%) was above average (84%). During the upstream migration period for Quesnel Sockeye in the Lower Fraser River (Table 1), water temperatures (Qualark, B.C.) were above average in the first half of their migration period and were average in the second half of their migration period (Figure 7). Discharge (at Hope, B.C.) was below average (Figure 7). During adult migration and spawning in the Quesnel system, water temperatures ranged from above average to average (Figure 11 A) and discharge was below average (Figure 11 B).
- Adult spawners collected from the Horsefly River spawning channel in 2010 had high levels of glucose and low fat content (Figure 12 A & B). This is a normal observation on the spawning grounds, associated with individuals that are actively spawning or have spawned.
- The relationship between EFS and resulting fall fry in Quesnel 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 14 C).
- Freshwater survival in the brood year (189 fall fry/EFS) was average compared to all cycles (1976-2010 brood year: 189 fall fry/EFS), and the resulting fry abundance (25 million) was average (1976-2010 average: 29.8 million). The 2010 brood year fall fry body sizes (3.8 g) were also similar to the average (1976-2010 all cycle average: 3.7 g).

All Stocks

2010 total escapement-stock composition:

- The percent contribution of each stock to the overall adult Fraser River escapement (excluding Harrison) in 2010 (5.4 million Sockeye total) is compared to stock compositions sampled in the following locations in 2012 (2010 brood year): in the Fraser River at Mission during downstream smolt migration (rotary screw trap); in the SOG (purse seines and trawl surveys); and during juvenile migration out of the SOG through the Johnstone Strait (trawl surveys) (Table 3; Figure 19). Harrison Sockeye are not included in the percent stock composition calculations due to their unique life history. Specifically, sampling outmigrating Harrison fry at Mission is ineffective due to their small size relative to larger smolt sized stocks, and sampling of Harrison juveniles in the marine surveys is not comparable to other stocks, as Harrison juveniles occupy a different spatial distribution to other Fraser Sockeye.

- The Shuswap system (both the early and late run timing components) contributed the largest component of the total EFS in 2010, at 70%; Late Shuswap contributed 57% and Early Shuswap contributed 13%. Chilko also contributed a high percentage at 22%, followed by Quesnel and Stellako at 2% each. All remaining stocks contributed <2% to the total EFS (Table 3; Figure 19 B).

Smolt Outmigration (at Mission)

- *Smolt Outmigration Conditions at Mission*: The majority of smolt migration at Mission occurred prior to peak discharge (Figure 16 A). Water temperature generally increased from ~6°C to 9°C over the period of sampling (Figure 16 B) (Mahoney et al. 2013)
- *Methods:* During the spring and early summer (April 16-June 15) of 2011 and 2012, two mobile traps were fished every fourth day from 0630-1430 hours in the lower Fraser River near Mission, B.C. The goal of this project was to evaluate the timing, size, abundance and stock composition of downstream migrating juvenile Sockeye Salmon (Mahoney et al. 2013). The two traps were fished simultaneously: a rotary-screw trap (RST) was attached to the starboard side of the vessel and an incline plane trap (IPT) was attached to the port side. Both traps were modified through structural reinforcement and screen mesh adaptations for use in the freshet water conditions experienced on the Fraser River at Mission during this time period. All salmon species trapped were counted. Bio-samples were collected from a subset of the trapped juvenile Sockeye. Bio-sampling involved collecting fish length, weight, adipose fin clip status, and tissue samples for genetic stock identification (GSI) and health assessments (analysis performed by other researchers).
- *Mission smolt stock composition:* A total of 4,156 downstream migrating juvenile Sockeye were caught in the RST/IPT traps in 2012 (2010 brood year). A sample of 2,307 Sockeye smolts was taken for genetic stock identification (GSI) and biological sampling (such as disease, parasite, histology, etc.) (Table 3). The Shuswap system (both the early and late run timing components) comprised the largest component of the total sample, at 53%; Late Shuswap contributed 44% and Early Shuswap contributed 9%. Similar to the escapement stock composition, Chilko contributed a large percentage of the total sample (16%) and Stellako contributed 6%. Unlike the escapement stock composition, however, Quesnel contributed a larger share, at 14% of the total sample (Table 3; Figure 19 A).
- *Smolt outmigration timing at Mission*: Two major pulses were observed in the temporal migration pattern of smolts at Mission in 2012 (Figure 16 C). The first group of stocks to migrate past Mission included the Summer Run timed Chilko, Quesnel, and Stellako, and Gates stocks, with a 50% migration date that ranged from April 24-28. The second group (with overlap with the first) included Early and Late Run timed Shuswap stocks, and Late Run timed Seton, with a 50% migration date that ranged from May 14-18

(Figure 16 C; Mahoney et al. 2013). Note: run timings groups are based on adult return migration timing to their spawning grounds.

- Chilko is the only stock for which smolt abundances are assessed at the outlet of the rearing lake, and smolt numbers are high enough to be detected in the Mission smolt traps. Smolt outmigration from Chilko Lake in 2012 (2010 brood year) exhibited average outmigration timing, based on the date when 50% of the smolts had migrated past the Chilko River enumeration weir (April 27), compared to the historical range, which extends from late-April to early-May.
- At Mission, Chilko smolts had a 50% migration date of April 29, which is only a few days later than their outmigration from Chilko Lake (Figure 16 C; Mahoney et al. 2013). Based on these observations, Chilko Sockeye appear to move rapidly out of the Fraser system (covering a distance of 700 km), facilitated by Fraser River discharge.
- *Smolt sizes at Mission:* Juvenile Sockeye lengths were measured at Mission in 2012. Stellako Sockeye were the largest on average (91 mm), followed by Quesnel (84 mm), Gates (78 mm) and Chilko (76 mm) (Mahoney et al. 2013). The smallest juvenile Sockeye Salmon were from the Shuswap stocks (72 mm). Note that the Chilko smolts were a similar size to those sampled at the outlet of Chilko Lake (average: 77 mm), as little growth would be expected between their outmigration from Chilko Lake and their migration past Mission, given the limited time spent migrating. Alternatively, Shuswap Lake smolts sampled in 2012 at the outlet of Shuswap Lake were smaller on average (68 mm) than those sampled at Mission (Mahoney et al. 2013); although at this time sample distributions have not been tested for significance.

Strait of Georgia Juveniles

- *Ocean Migration*: Most juvenile Fraser Sockeye spend four to six weeks rearing and growing in the SOG prior to moving north through Johnstone Strait (Preikshot et al. 2012). Harrison Sockeye Salmon are the exception; they enter the SOG later than lake-type Sockeye (that rear for two winters in freshwater on average) and may remain in the SOG for up to six months.
- *Methods:* Trawl surveys have been conducted in the SOG since 1998 (with one missed early summer assessment in 2003) to assess juvenile salmonid abundances. These surveys are conducted in early summer from late-June to early-July, and in September. 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 17). Although the timing of the June-July trawl survey is focused on Coho salmon, all salmon species are collected. For Sockeye, about 10% of the total migration remains in the SOG at the time of the June-July survey, and Thompson et al. (2012) demonstrated that the stock structure presented during this survey is representative of the expected stock structure of the total run. Between 2010 and 2012, additional purse seine surveys were conducted in May and June specifically for juvenile Sockeye salmon. These surveys, funded by the Program for Aquaculture Regulatory Research (PARR), were conducted throughout the SOG and the Discovery Island region (Figure 17; Neville et al. 2013). Information collected during both trawl and purse seine surveys included catch-per-unit-effort (CPUE), length/weight, diet, stock composition, scales and otoliths, and tissues for fish health, genomic and energetic studies.
- *Juveniles in the SOG purse seine and trawl surveys:* In the first SOG purse seine survey in 2012 (May 19-June 1), a total of 1,241 Fraser Sockeye were caught (Table 3; Figure 19; Neville et al. 2013). The Shuswap system (both the early at late run timing

components) contributed 51% (the highest amount) of the total sample; Late Shuswap contributed 43% and Early Shuswap contributed 8%. The Shuswap percentages were similar to those seen in the escapement and the Mission smolt survey. Similarly, Chilko contributed a high percentage to the total sample (13%). Proportions of both Quesnel and Stellako remained higher than what was observed on the spawning grounds in 2010, and similar to what was observed in the Mission smolt traps in 2012. Although Fraser River Sockeye were captured throughout the Strait of Georgia, none were captured in the Discovery Islands during this survey (Neville et al. 2013).

- In the second SOG purse seine survey in 2012 (June 11-25), a total of 1,226 Fraser Sockeye were caught (Table 3; Figure 19; Neville et al. 2013). The percentage of fish from the Shuswap system (both the early and late run timing components) increased to 77% and was higher than that seen in the previous SOG survey, Mission smolt traps, and 2010 escapement. The increase was observed for both Late Shuswap (63%) and Early Shuswap (14%) stocks. The percentage of Chilko (12%) Sockeye remained similar to all previous surveys, while Quesnel (6%) and Stellako (1%) decreased in proportion and were primarily caught in the northern Discovery Islands.
- In the 2012 trawl survey (June 20-July 2) a total of 677 Fraser Sockeye were caught (Table 3; Figures 18 & 19). The Fraser Sockeye CPUE of 86 juvenile Sockeye Salmon-per-hour in this survey was the highest observed in the time series (1998 to 2012) (Figure 18 A; Neville and Sweeting section pages 125-130 in Irvine and Crawford 2013). There is high uncertainty associated with the relationship between Fraser Sockeye trawl survey CPUE in the SOG and subsequent Fraser Sockeye returns, particularly since the survey only covers approximately 10% of Fraser Sockeye juvenile outmigration. Nevertheless, the SOG trawl surveys show no signal that juvenile abundance was low in this system for the 2012 juvenile year (2010 brood year). The percentage of fish from the Shuswap system (both the early and late run timing components) again increased from the previous surveys to 96%; Late Shuswap contributed 79% and Early Shuswap 17%. Other stock percentages dropped to 0%, except Chilko, which dropped to 2% and Quesnel, which dropped to 1% (Table 3; Figures 18 & 19).
- The shift in stock composition across the three SOG survey (two purse seines and one trawl) periods (Figure 19) may be related to the variability in downstream timing observed at the Mission smolt trap. The increase in the percentage of Shuswap Sockeye through time is likely attributed to their later peak downstream migration timing and larger abundances at Mission relative to other stocks (Figure 16 C; Mahoney et al. 2013).
- The average sizes of Sockeye caught in the May and June purse seine surveys in 2012 (95.2 and 94.9 mm, respectively) were not significantly different from the trawl surveys (96.8 mm); although they were smaller than those caught during the same periods in the previous year (2011: 103.6 mm and 119.9 mm respectively; Neville et al. 2013). The average size of Sockeye caught in the trawl survey (96.8 mm, SD 11.62 mm, n = 1,107) was the smallest observed in trawl surveys since 1998. However, the small size may not relate directly to poor production. For example, fish that went to sea in the previous dominant Shuswap year (2006 brood year) were also smaller than average, and the resulting return in 2010 was the highest on record for Fraser Sockeye (~28 million) (Figure 1 A).
- A possible indicator of survival in the SOG may be the availability of food for the juveniles. Beamish et al. (2012) indicated that in the 2007 ocean entry year, trawl surveys captured a higher percentage of juvenile Coho, Chinook and Sockeye Salmon

with empty stomachs (40% of Sockeye had empty stomachs), which coincided with poor survivals and particularly low returns (i.e. low Fraser Sockeye returns in 2009 of 1.6 million: Figure 1 A). In 2012 (2010 brood year), 25% of Sockeye captured in trawl surveys had empty stomachs, which is close to the average for the past seven years, and is similar to the value observed for fish that went to sea in 2008 (27%) (associated with the large return in 2010).

Juveniles caught in Queen Charlotte Sound

- DFO's High Seas Salmon Program has conducted integrated pelagic ecosystem surveys from the west coast of Vancouver Island to northern British Columbia/Southeast Alaska in June-July and October-November since 1998, and in February-March 2001 (Trudel et al. 2013). The sampling locations have changed over the years partly due to weather conditions and the availability of ship time. Nevertheless, a few standard transects are performed during each survey, including one in Queen Charlotte Sound (QCS) and one in Hecate Strait. Since 2012, sampling effort has expanded in Johnstone Strait and QCS to increase the sample size of juvenile Fraser River Sockeye Salmon as they leave the Strait of Georgia.
- The trawl net (approximately 30 m wide by 15 m deep) is towed for approximately 30 minutes at the ocean surface to sample juvenile salmon. A subsample of the salmon catch is taken for stock identification. To date, DNA analysis has been used to determine the origin more than 8,600 juvenile Sockeye Salmon caught by the High Sea Salmon Program, and an additional 1,000 juvenile Sockeye Salmon caught by National Ocean and Atmospheric Administration (NOAA) along the Washington and Alaska Coasts (Tucker et al. 2009; Trudel et al. 2011; Beacham et al. 2014 (in press))
- Surveys were conducted in 2012 in the Central Coast region, extending from Johnstone Strait to 53°N and including both Hecate Strait and the west coast of the Haida Gwaii. From these surveys, a total of 583 Sockeye were assigned to Fraser Sockeye stocks (Table 3; Figures 19). Similar to all previous sampling components (escapement, Mission smolts, juveniles in the Strait of Georgia), the Shuswap stocks comprised the largest proportion of the samples (total: 73%; Late Shuswap: 61%; Early Shuswap: 11%), followed by Chilko (11%), Quesnel (10%) and Stellako (2%). For Shuswap, the Central Coast stock percentages are somewhat in-between the three Strait of Georgia samples, likely attributed to the increasing proportion of Shuswap fish (and decreasing proportion of Summer Run timed fish) in the Strait of Georgia through time. For all other stock groups the Central Coast proportions are similar to the first Strait of Georgia sampling period, when the largest component of these Summer Run stocks would be expected in the system, based on the smolt migration timing observed at Mission (Figure 16 C).
- Catch-per-unit effort (CPUE) of juvenile Sockeye Salmon on the central coast of British Columbia was the second highest in 2012 since 1998 (the highest being 2004). However, the timing of this survey has not been constant over time (earlier in 2004-2006 compared to 2007-2012). The high CPUE on the Central Coast is consistent with the high CPUE observed in the SOG. The correlation between CPUE on the central coast of British Columbia and subsequent Fraser River Sockeye returns has not yet been examined.

Other SOG and Queen Charlotte Sound Indicators in 2014:

- *Coho in SOG:* 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 trawl survey acts as an index of Coho returns for the following year. In 2012 the CPUE of Coho salmon in the trawl surveys was the highest in 14 years (see Irvine & Crawford 2013). This suggests good conditions for early marine rearing for this species within the SOG, and suggests higher marine survival for SOG Coho salmon that entered the SOG in 2012. This may mean favorable ocean conditions for Fraser Sockeye during their residence in the SOG, although the linkages between these two species in terms of survival are uncertain.
- *Herring in the SOG:* A relationship exists between Chilko marine survival and Herring CPUE in the SOG (1992 to present) (Rensel et al. 2010). In the 2012 ocean year (2010 brood year), Herring CPUE was average (Figure 20). There is high uncertainty associated with the relationship between Herring CPUE in the SOG and Chilko Sockeye marine survival. Nonetheless, the Herring surveys show no signals that Chilko marine survival was exceptionally low for the 2012 juvenile year (2010 brood year).
- *Sea-Birds in Johnstone Strait/Queen Charlotte Sound (QCS):* Marine birds can be indicators of the state of marine ecosystems because they gather in large and highly visible aggregations to breed, and, as a group, they feed at a variety of trophic levels (zooplankton to fish). Seabird breeding success is closely tied to the availability of key prey species', and as a result, can vary widely amongst years, depending on ocean conditions. Triangle Island (50°52' N, 129°05' W) in the Scott Island chain off northern Vancouver Island, supports the largest and most diverse seabird colony along the coast of British Columbia.
- The Rhinoceros Auklet (*Cerorhinca monocerata*) feeding ecology is similar to Fraser Sockeye juveniles migrating through QCS. However, the Rhinoceros Auklet monitoring program was terminated in 2009; therefore, no data on this species is available for the 2010 brood year (2012 juvenile migration period).
- Data for Cassin's Auklet (*Ptychoramphus aleuticus*) nestlings (25 days old) are available. However, this species is not as directly relevant to Fraser Sockeye juveniles as the Rhinoceros Auklet, as they feed in different ecosystems in QCS: Cassin's Auklets feed offshore beyond the shelf break and Fraser Sockeye feed in waters on the shelf. In 2012, nestling success of Cassin's Auklet was higher than the 1996-2011 average. In general, the Auklets' offspring grow more quickly and fledge at heavier masses in cold-water years, because timing of their hatching is strongly temporally matched with the phenology of an important prey species, the copepod *Neocalanus cristatus*. Thus, the above-average 25-day mass was expected based on the relatively cold spring sea-surface temperatures in 2012 (Irvine and Crawford 2013). How this relates to Fraser Sockeye juvenile survival, however, is currently uncertain.

Ocean Conditions in the Strait of Georgia:

- Fraser Sockeye enter the Strait of Georgia and rear and feed in this region for about four to six weeks (Preikshot et al. 2012). In this region juvenile Sockeye must adjust to the saline environment. During the juvenile Sockeye migration through the SOG in 2012 (2010 brood year), Fraser River discharge (April-June) was above average and sea-surface temperature and salinity (May-July) were both below average, though conditions were not anomalous. Fraser discharge was generally above average in April (2012:

2,520 cubic meters per second: cms; average: 1950 cms), May (2012: 5,750 cms; average: 5,020), June (2012: 9,380; average: 7,070), and at peak flow (2012: 8,680 cms; average: 8,678). Sea surface temperatures at the Entrance Island lighthouse station, located in the SOG (where Fraser Sockeye first enter the ocean as smolts), were similar to the 1950-2011 averages in April (2012: 9.1°C; average: 9.3°C), May (2012: 12.3°C; average: 12.3°C) and June (2012: 13.7°C; average: 15.1°C). Sea surface temperatures at the Pine Island lighthouse station, located at the Northern tip of Vancouver Island, were similar (slightly below) to the 1950-2011 averages in April (2012: 7.8°C; average: 8.0°C), May (2012: 8.4°C; average: 8.8°C), June (2012: 9.1°C; average: 9.5°C) and July (2012: 9.2°C; average: 10.1°C) (Figure 21).

- Although these factors suggest average to good ocean conditions in the SOG during juvenile Sockeye migration, it is important to note that such conditions have not been good predictors on their own in forecasting even extreme survival events (low or high) for Fraser River Sockeye Salmon.
- A zooplankton time series for the SOG is currently being developed and requires more work prior to interpretation and investigation of linkages to Fraser Sockeye survival.

Ocean Conditions in the Gulf of Alaska

- After a relatively rapid migration northward through the SOG, out the Johnstone Strait, and along the continental shelf, Fraser Sockeye move into the Gulf of Alaska, where they remain for the majority of their ocean residence. From 2011 to February 2013, ocean conditions in this system were relatively cool, which generally indicates good conditions for salmonid survival (Figure 22; DFO 2013, Irvine and Crawford 2013). However, ocean conditions have not been specifically good predictors of Fraser Sockeye survival to date.
- In more recent months ocean conditions have warmed in the Gulf of Alaska (Figure 23), which may present better conditions during the winter prior to the homeward migration, and hence better conditions for Fraser Sockeye from the 2010 brood year; however the effect on their survival is uncertain (see McKinnell pg. 81 of DFO 2007).
- The mesozooplankton biomass estimate for 2012 in the Gulf of Alaska was the largest in the 13-year time series (S. Batten, personal communication). The mid-point timing of the seasonal biomass cycle was also late in 2012. These features of large diatoms and zooplankton are consistent with the cool conditions observed in the Gulf of Alaska (DFO 2013; Irvine and Crawford 2013). Again, linkages with zooplankton biomass data in the Gulf of Alaska and Fraser Sockeye survival is currently uncertain.

Jacks (age-3_2)

- Jack (age 3_2) recruits can be used to provide some indication of the return of age-4 recruits (age 4_2) in the subsequent year. Jacks come from the same brood year as the age-4 recruits, and, therefore, experience the same conditions during early growth and development in both the freshwater and marine environment, but return one year earlier (e.g. jack returns in 2013 and age-4_2 returns in 2014).
- There has been a rise in delayed maturation in recent years for Fraser Sockeye stocks, with jack proportions contributing less to total recruitment than historically observed (Figure 24 A to D). As a result, the relationship between age-3 and age-4 recruits used for the sibling forecast is restricted to the recent time series (brood years 1980-2003). Years with zero age-3 jacks were removed from the time series for each stock.

- The jack to age-4 recruitment relationship is highly uncertain given the inter-annual variation in age of maturity. Further, for the 2014 forecast, jack recruitment data were not yet available, therefore jack escapements were used as predictor variables. As a result, jack escapement-to-four year old recruitment forecasts will be biased low (Figures 25 and 26).
- *Early Shuswap-Scotch*: the jack relationship using post-1980 dominant cycle brood years (*n*=6; note this sample size is extremely small) had an R^2 of 0.9 (Figure 25 B). Given the preliminary 2010 brood year jack escapement estimate of 840 fish, the forecast for four year old returns in 2014 ranges from 200,000 to 2 million (at the 10% to 90% probability levels) (DFO 2014).
- *Early Shuswap-Seymour*: the jack relationship using post-1980 dominant cycle brood years (*n*=5; note that sample size is extremely small) had an R^2 of 0.6 (Figure 25 D). Given the preliminary 2010 brood year jack escapement estimate of 950 fish, the forecast for four year old returns in 2014 ranges from 100,000 to 3 million (at the 10% to 90% probability level) (DFO 2014).
- *Late Shuswap:* The abundance of jacks that returned in 2013 from the dominant 2010 brood year (preliminary estimate of 32,000) was close to the post-1980 average (average: 39,000). Jacks historically dominate total returns on the weak cycle year immediately preceeding the dominant cycle year for this stock. However, in 2013 adult escapement comprised 80% of the total return. Unique to this stock, there has been a recent increase in 3_1 adult returns to this system on the 2013 cycle line, though there is no relationship between these returns and the 4_2 fish returning in the subsequent year. The jack relationship using post-1980 dominant cycle brood years (*n*=7; note sample size is extremely small) had an R^2 of 0.8 (Figure 25 F). Given the preliminary 2010 brood year jack escapement estimate of 335,000 fish, the forecast for four year old returns in 2014 ranges from 5.5 million to 14.2 million (at the 10% to 90% probability level) (DFO 2014)
- *Chilko:* the jack relationship using post-1980 brood years (*n*=24) had an R^2 of 0.4 (Figure 26). Given the preliminary 2010 brood year jack escapement estimate of 36,000 fish, the forecast for four year old returns in 2014 ranges from 1 million to 7 million (at the 10% to 90% probability level (DFO 2014).
- *Jacks in Juan de Fuca (Area 20) and Johnstone Strait (Area 12) test fisheries:* There is a positive relationship between the total CPUE of Fraser Sockeye jacks assessed in the purse seine test fisheries (Blinkhorn: Area 12 and Juan de Fuca: Area 20) and the subsequent year's CPUE or total returns of adult Sockeye (McKinnell et al. 2012). This relationship is not considered reliable when jack CPUE is <0.1 per set and most of the signal is linked to the dominant Shuswap Sockeye cycle years (2014 cycle) (McKinnell et al. 2012). In 2013 (2010 brood year, dominant Late Shuswap cycle year), jack abundances were relatively large (Figure 27) on the time series. This does not present a negative signal for 2014 Late Shuswap returns. However, since this time series is relatively short and only covers three dominant Adams cycle years, it is highly uncertain.

Conclusions

To provide support for the official 2014 Fraser Sockeye forecast, supplemental data on fish condition, survival, and relative abundances of Fraser Sockeye stocks were compared for the 2010 brood year, from the parental spawners in 2010 through to the 2013 jack returns. Environmental conditions were also compared throughout their life-history, from the 2010 brood year to 2013. This information was summarized in light of the exceptional brood year escapements observed for a number of stocks in 2010 and, separately, the poor survivals for Quesnel in recent years. This synthesis of existing data represents a starting point for reducing uncertainty in Fraser Sockeye forecasts, through greater understanding of inter-annually variability of survival in these stocks.

The stocks contributing the highest percentage of the total escapement in 2010 are the Shuswap stocks (65%), with Late Shuswap contributing 53% and Early Shuswap contributing 12%). Other prominent stocks include Chilko (20%), Harrison (7%), Quesnel (2%), and Stellako (2%) (DFO 2014). Conditions in the mainstem Fraser during the adult migration period for Early Shuswap, Late Shuswap, Chilko and Quesnel stocks in 2010 consisted of above average water temperatures and below average discharge; however, Late Shuswap experienced water temperatures that were closer to average, and cooler (<16°C) than those encountered by stocks that migrate earlier in the season. Generally, conditions were conducive to spawning in the Shuswap, Chilko and Quesnel systems, apart from a rain on snow event in the Seymour watershed, which may have impacted egg-to-fry survival in this system. In the Harrison, water temperatures were average and discharge was above average during the migration and spawning period.

Biological indicators for the Early Shuswap spawners in 2010 showed high glucose and low lipid content, indicating that some individuals were in very poor condition and would likely not be 100% successful in terms of egg deposition and viability. However, gamete quality for the assessed Scotch spawners suggested that these fish were fertile. Samples from Late Shuswap spawners were consistent with healthy, fertile fish, though spawners in this system were observed spawning in waves, depositing eggs over top of previously deposited redds. Chilko spawners had high levels of glucose and fat content, indicating that a portion of the run was not healthy. Gamete viability of Chilko spawners was also considered low. Extensions from such spawning ground data may indicate poor egg to fry survival for the Early Shuswap and Chilko stocks, based on fish health, and likewise, poor egg to fry survival for the Late Shuswap stocks based on spawner competition.

Juvenile (fry and smolt) data from the 2010 brood year are available for some key stocks (Shuswap, Chilko, and Quesnel), providing information on early freshwater survival (spawner-to-fry/smolt survival). For all of these stocks, juvenile data indicate density-dependent compensation at high spawner abundances and poor juvenile fish condition. Specifically, for Shuswap and Chilko, both of which exhibited record escapements in the 2010 brood year, low freshwater survival and small fry and smolt body sizes provide support for model forms that predict overcompensation at high spawner abundances (i.e. the Ricker model used to forecast returns for these stocks in 2014). For Quesnel, given that its 2010 brood year escapements were average, freshwater survival, and fry body sizes were also average, providing support for models that assume average productivity.

The downstream migration sampling program at Mission identified two key migration periods for outmigrating smolts in 2012. The first group of stocks to migrate past Mission includes Chilko, Quesnel, Stellako, and Gates, with a 50% migration date that ranged from April 20-28. The second group (overlaps with the first) includes Late and Early Shuswap stocks, and Seton, with a 50% migration date that ranges from May 14-18. Relative stock composition at Mission in 2012 (proportional contribution of each stock to the total sample) was generally similar to that of the total 2010 escapement. Key differences in proportional contributions of stocks include an increase in Quesnel (from 2% to 14%) and Stellako Sockeye (from 2% to 6%), and a decrease in total Shuswap (from 70% to 53%) and Chilko Sockeye (22% to 6%) at Mission. Smolt sizes varied between stocks. The largest smolts on average were from Stellako, followed by Quesnel, Gates, and Chilko, while smolts from the Shuswap (both Early and Late) were the smallest.

In the Strait of Georgia purse seine survey (May 19-June 1), the relative stock composition was similar to Mission, with an increase in the percentage of Stellako Sockeye (from 6% to 14%). Subsequent purse seine (June 11-25) and trawl surveys (June 20-July 2) appear to reflect stock timing at Mission, showing an increase in the relative contribution of Shuswap Sockeye in these later surveys, due their later-timed migration through the area. Other key stocks (Chilko, Quesnel & Stellako) disappeared from the survey catches as they migrated North beyond the survey area. Smolts sampled in the trawl surveys (June 20-July 2) were the smallest on record (since 1998) for this survey, though this likely reflects the high proportion of small-sized Shuswap Sockeye caught in this period rather than necessarily indicating poor production. Ocean conditions in the 2012 ocean entry year indicate average to above-average conditions, based on discharge, sea-surface temperatures, and salinity data, and high CPUE of juvenile Coho salmon in the September survey. Further, the prevalence of empty stomachs in sampled Sockeye smolts (25%) was average based on seven years of data, suggesting nothing anomalous in the early marine feeding stage.

Juvenile surveys on the Central Coast in 2012 found similar proportions of the major stock groups to those seen in the SOG and Mission smolt surveys. Relative stock composition was most similar to the second set of SOG surveys, due to the timing of the QSC surveys. Shuswap stocks contributed the most at 73% (61% were Late Shuswap and 11% were Early Shuswap), followed by Chilko (11%), Quesnel (10%) and Stellako (2%). There appears to be consistency in relative stock composition from the spawning grounds in 2010, through to the QSC surveys, with the exception of Quesnel (percentage of Quesnel Sockeye was higher in all juvenile surveys relative to 2010 brood year escapement).

All stock percentages from the different sampling periods (2010 through to 2012) were similar to the stock breakdown of the official 2014 forecast (DFO 2014). The Shuswap stocks make up the largest component of the forecasted returns in 2014 (67%), with Late Shuswap contributing 51% and Early Shuswap contributing 16% of the forecast. Other stocks that contribute large proportions of the total forecast include Chilko (11%), Quesnel (7%), and Stellako (3%) (DFO 2014). Though specific proportions vary, the relative contribution of each stock to the total forecast reflects what was documented in the brood year escapements, Mission downstream surveys, Strait of Georgia purse seine and trawl surveys, and Queen Charlotte Sound surveys.

Overall, environmental indicators (Fraser discharge, sea-surface-temperatures & salinity) during juvenile outmigration from the Fraser River in 2012, were generally considered favorable for salmonid survival. However, linking these data to Fraser Sockeye survival remains highly uncertain. Other indicators of Fraser Sockeye survival, such as juvenile CPUE in the Fraser, the SOG and QCS, Herring and Coho abundance in the SOG, and jack returns in 2013, do not provide any evidence of extreme survival events (high or low) in this system in 2012. However, these relationships are again highly uncertain.

Although there are no indications of exceptionally poor or good survival conditions leading up to the 2014 Fraser Sockeye return, there are large gaps in our understanding of what drives inter-annual variation in Fraser Sockeye survival. Further, information on Fraser Sockeye survival in the Gulf of Alaska, where these fish spend the majority of their marine residence, is limited. Jacks returns in 2013 provide some indication of survival conditions encountered by the four year old returns in 2014, including their first year of marine residence in the Gulf of Alaska. However, variability in age of maturity, the small numbers of jack returns for most stocks, and the extra year most Fraser Sockeye (i.e. four year olds) spend in the Gulf of Alaska, create large uncertainties in the relationships between jacks and subsequent four year old returns. To improve our understanding of Fraser Sockeye, further work is being conducted on fish health, condition, and growth, and on the cumulative effects of factors that influence Fraser Sockeye population dynamics.

Table 1. For each key Fraser Sockeye stock, adult return migration and smolt out migration dates are indicated, and water temperature stations and discharge stations are identified.

Stock	Adult migration timing	Smolt outmigration timing	Water Temperature Stations	Discharge Stations
Early Shuswap-Scotch	Aug (river), Sept (spawning)	May to mid-June 2012	Scotch Creek (DFO FFP) South Thompson River @ Chase (DFO EWP) Thompson River @ Ashcroft (DFO EWP) Fraser River @ Qualark (DFO EWP)	NA South Thompson River @ Chase (EC WSC - 08LE031) Thompson River @ Spences Bridge (EC WSC- 08LF051) Fraser River @ Hope (EC WSC - 08MF005)
Early Shuswap-Seymour	Aug (river), Sept (spawning)	May to mid-June 2012	NA South Thompson River @ Chase (DFO EWP) Thompson River @ Ashcroft (DFO EWP) Fraser River @ Qualark (DFO EWP)	Seymour River Near Seymour Arm (EC WSC -08LE027) South Thompson River @ Chase (EC WSC- 08LE031) Thompson River @ Spences Bridge (EC WSC - 08LF051) Fraser River @ Hope (EC WSC - 08MF005)
Late Shuswap-Adams	Sep (in river), Oct (spawning)	May to mid-June 2012	Adams River @ Spawning Grounds (DFO EWP & DFO STAD) South Thompson River @ Chase (DFO EWP) Thompson River @ Ashcroft (DFO EWP) Fraser River @ Qualark (DFO EWP)	Adams River Near Squilax (EC WSC - 08LD001) South Thompson River @ Chase (EC WSC - 08LE031) Thompson River @ Spences Bridge (EC WSC - 08LF051) Fraser River @ Hope (EC WSC - 08MF005)
Chilko	Aug (river), Sept (spawning)	mid-April to mid-May 2012	Chilko River @ Spawning Grounds (DFO EWP) Chilcotin River Below Big Creek (DFO EWP) Fraser River Above Texas Creek (DFO EWP) Fraser River @ Qualark (DFO EWP)	Chilko River Near Redstone (EC WSC -08MA001) Chilcotin River Below Big Creek (EC WSC- 08MB005) Fraser River Above Texas Creek (EC WSC - 08MF040) Fraser River @ Hope (EC WSC - 08MF005)
Quesnel	Aug (river), Sept (spawning)	mid-April to mid-May 2012	Quesnel River @ Quesnel (DFO EWP) Fraser River Above Texas Creek (DFO EWP) Fraser River @ Qualark (DFO EWP)	Quesnel River Near Quesnel (EC WSC -08KH006) Fraser River Above Texas Creek (EC WSC - 08MF040) Fraser River @ Hope (EC WSC- 08MF005)
Harrison	Aug, Sep (river), Nov (spawning)	June, July, Aug 2011	Harrison River (DFO STAD) Fraser River @ Qualark (DFO EWP)	Harrison River Below Morris Creek (EC WSC -08MG022) Fraser River @ Hope (EC WSC - 08MF005)

DFO FFP refers to Fisheries and Ocean's Fish Forestry Program
DFO EWP refers to Fisheries and Oceans' Environmental Watch Program
DFO STAD refers to Fisheries and Ocean's Stock Assessment Program
EC WSC refers to Environment Canada's Water Survey of Canada program

Table 2. For each key waterbody and stock, river water temperatures and discharges associated with the 2010 brood year adult up-river migration and smolt outmigration (in 2012) are presented. Water temperatures and discharges are identified in Table 1. Temperatures and discharges for the two river migration periods (adult upstream migration to the spawning grounds in 2010 and smolt outmigration in 2012) are compared to the time series and are classified as average, above average (indicated by up arrow), or below average (indicated by down arrow).

Waterbody	**Key Stocks**	**Adult Up-river migration**		**Smolt Outmigration**	
		Water temp.	**Discharge**	**Water temp.**	**Discharge**
Scotch Creek	Scotch	No data	No data	No data	No data
South Thompson River	Adams Scotch Seymour	average	↓	↓	↑
Thompson River	Adams Scotch Seymour	average	↓	average	↑
Adams River	Adams	average	average	No data	average
Chilko River	Chilko	No data	↑ (Aug); ↓ (Sep)	↓	No data
Chilcotin River	Chilko	↑	≈ then large ↑ (Oct)	≈	No data
Mid-Fraser River	Adams Seymour Chilko Quesnel	average	↓	average	No data
Lower-Fraser River	Adams Seymour Chilko Quesnel Harrison	↑	↓	average	average
Quesnel	Quesnel	↑ (Aug); ↓ (Sep)	↓	≈	No data
Harrison River	Harrsion	↓ or average	No data	↓	No data

Table 3. Proportion of each stock estimated on the spawning grounds in 2010, relative to the total escapement excluding Harrison (EFS: effective female spawners), proportion of each stock detected as smolts at the Mission hydroacoustic site in 2012 relative to the total sample size, proportion of each stock detected as juveniles in the SOG sampled by purse seine (SOG: Seine) and trawl at different time periods (as indicated) and in the Queen Charlotte Sound in 2012, relative to the total sample size. Harrison is removed from all calculations, as, due its unique age structure and migration pattern, this stock is not proportionally sampled in the Mission, SOG and QCS surveys. Only stocks that contribute relatively high percentages to the total are included.

Stock	CU Name	EFS	Mission	SOG: Seine (May19-Jun1)	SOG: Seine (Jun11-25)	SOG: Trawl (Jun20-Jul2)	QCS (Jun-Jul)	Return Forecasts
		total: 5.4 M	n=2,307	n=1,241	n=1,226	n=677	n=583	total: 23 M
All Shuswap	**Shuswap-L/Shuswap-ES**	**70%**	**53%**	**51%**	**77%**	**96%**	**73%**	**67%**
Late Shuswap	Shuswap-L	**57%**	**44%**	**43%**	**63%**	**79%**	**61%**	**51%**
Early Shuswap (all)	Shuswap-ES (total)	**13%**	**9%**	**8%**	**14%**	**17%**	**11%**	**16%**
Scotch		5%	7%	3%	6%	7%	8%	7%
Seymour		5%	2%	5%	9%	10%	3%	5%
Eagle etc.		2%	--	--	--	--	--	4%
Chilko	Chilko-S/Chilko-ES	22%	16%	13%	12%	2%	11%	11%
Quesnel	Quesnel-S	2%	14%	12%	6%	1%	10%	7%
Stellako	Francois-Fraser-S	2%	6%	14%	1%	0%	2%	3%

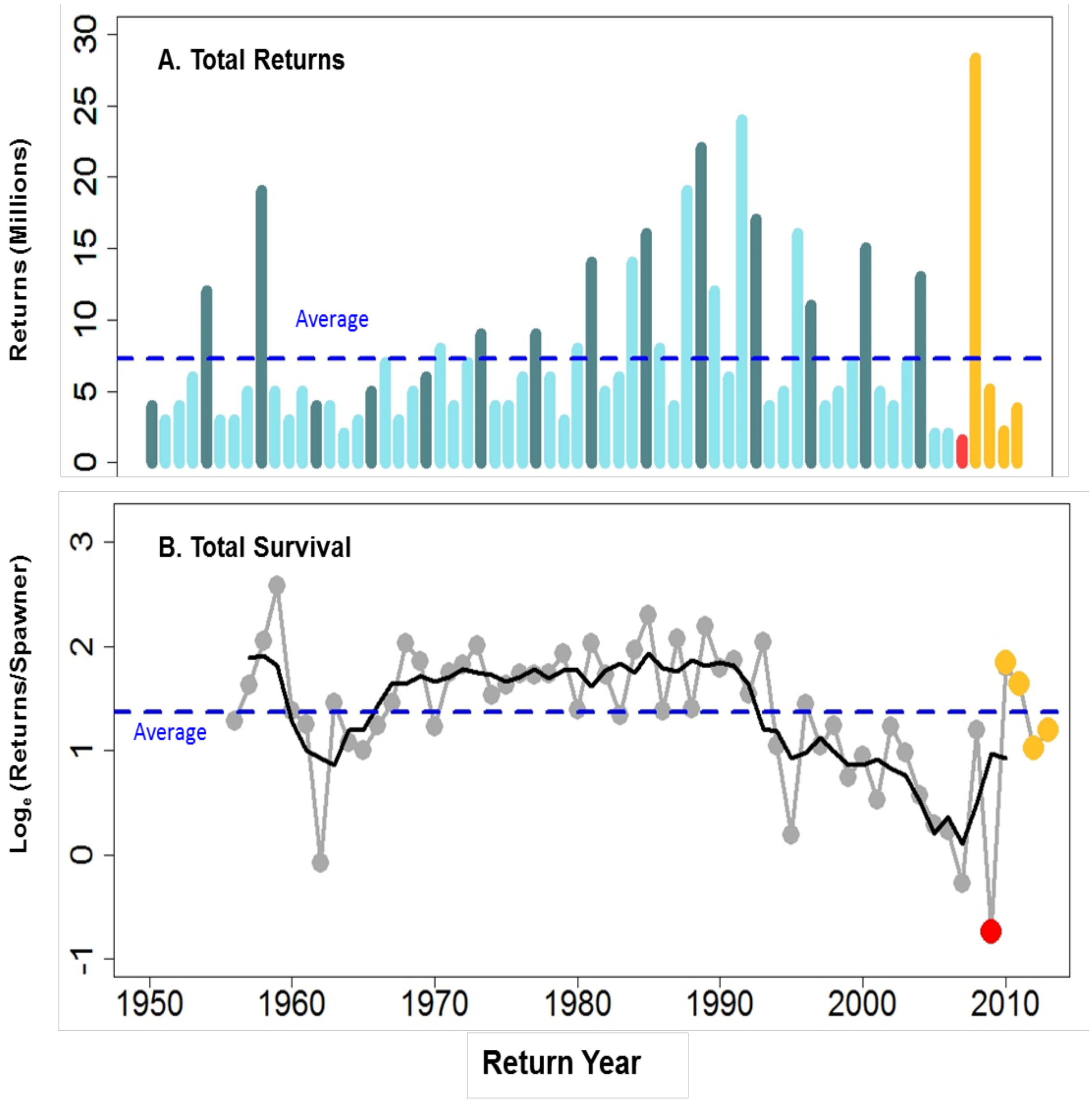


Figure 1. A. Total Fraser Sockeye annual returns (dark blue vertical bars indicate the 2014 cycle and light blue vertical bars for the three other cycles). All returns from 2009 to 2013 are preliminary. B. Total Fraser Sockeye survival (loge (returns/total spawner)) up to the 2013 return year. The light grey filled circles and lines represent annual survival and the black line represents the smoothed four year running average. For both figures, the blue dashed line is the time series average. The red vertical bar in Figure A (or filled circles in B) represents the 2009 return (low survival), and the yellow vertical bars in Figure A (or filled circles in B) represent the 2010 to 2013 returns (average survival for the Fraser Sockeye aggregate).

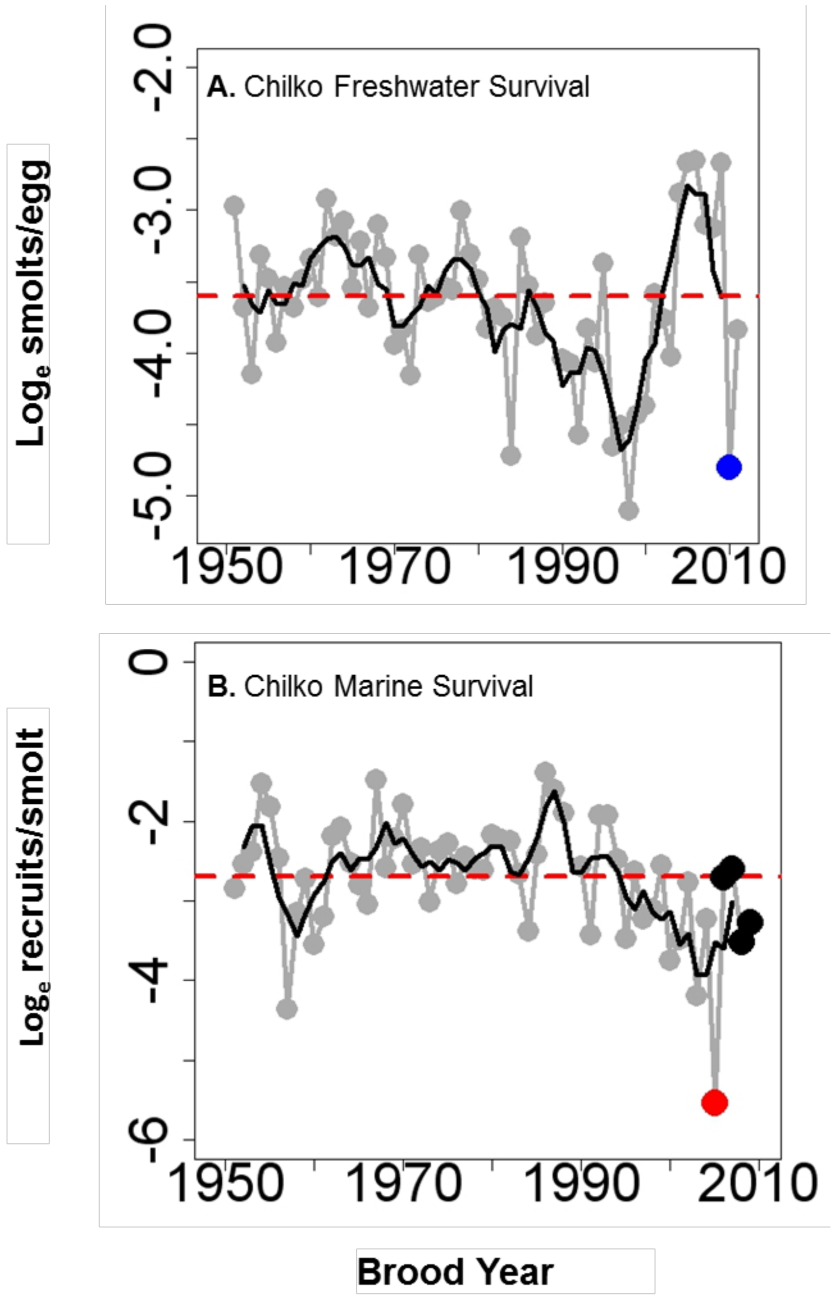


Figure 2. Chilko River Sockeye A. annual freshwater (log$_e$ smolts-per-egg) survival (filled grey circles and lines) with the 2010 brood year survival indicated by the blue filled circle, and B. annual marine (log$_e$ recruit-per-smolt) survival (filled grey circles and lines) with the lowest survival (2005 brood year) indicated by the red filled circle. The black line in both figures represents the smoothed four-year running average survival and the red dashed lines indicate average survival. Black filled circles denote preliminary survival estimates for brood years 2006-2009.

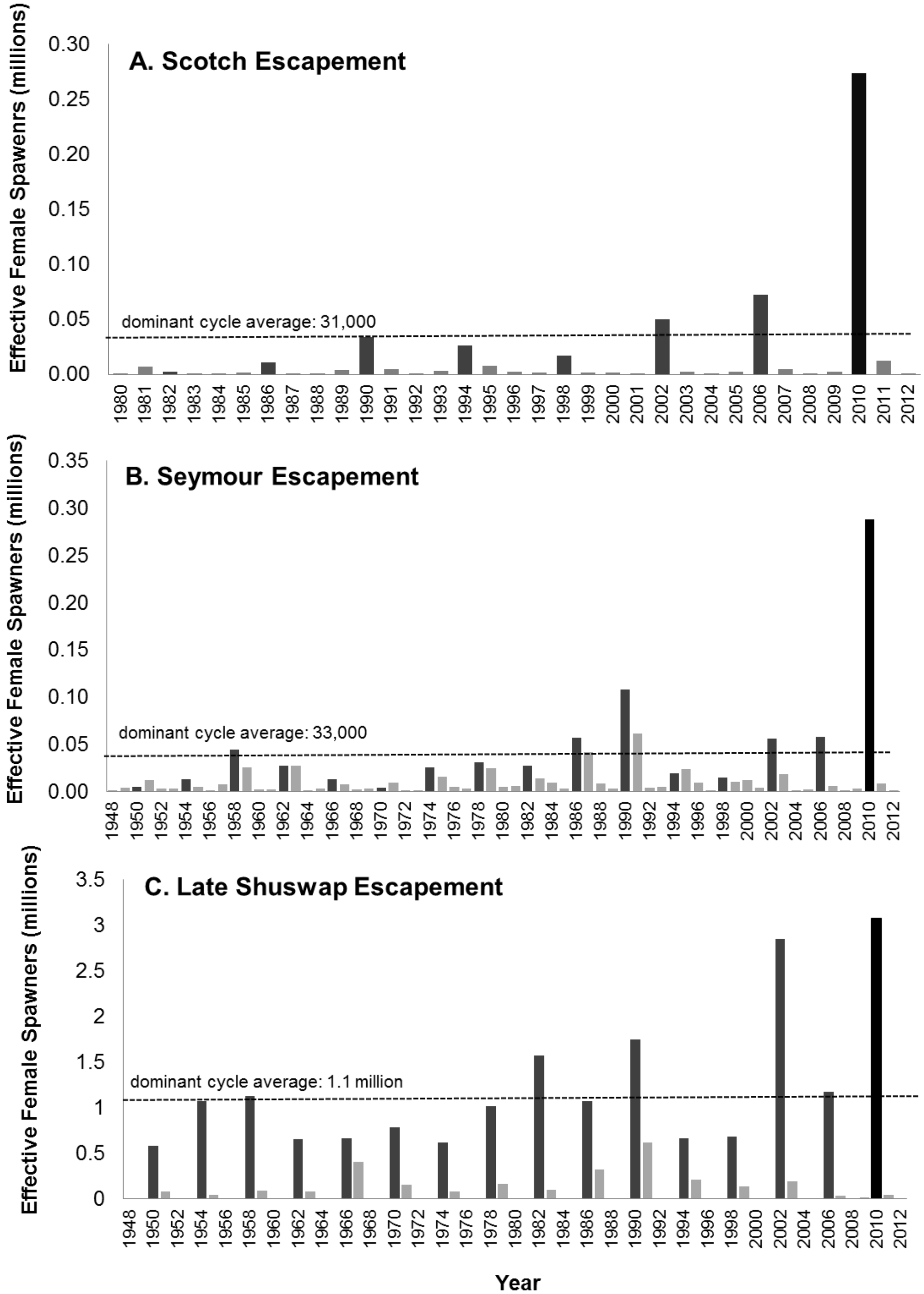


Figure 3. A. Scotch, B. Seymour, and C. Late Shuswap escapement (effective female spawners) (grey bars) with the dominant 2010 cycle indicated by the black bars. Dashed horizontal line represents each stock's dominant (2014) cycle average escapement.

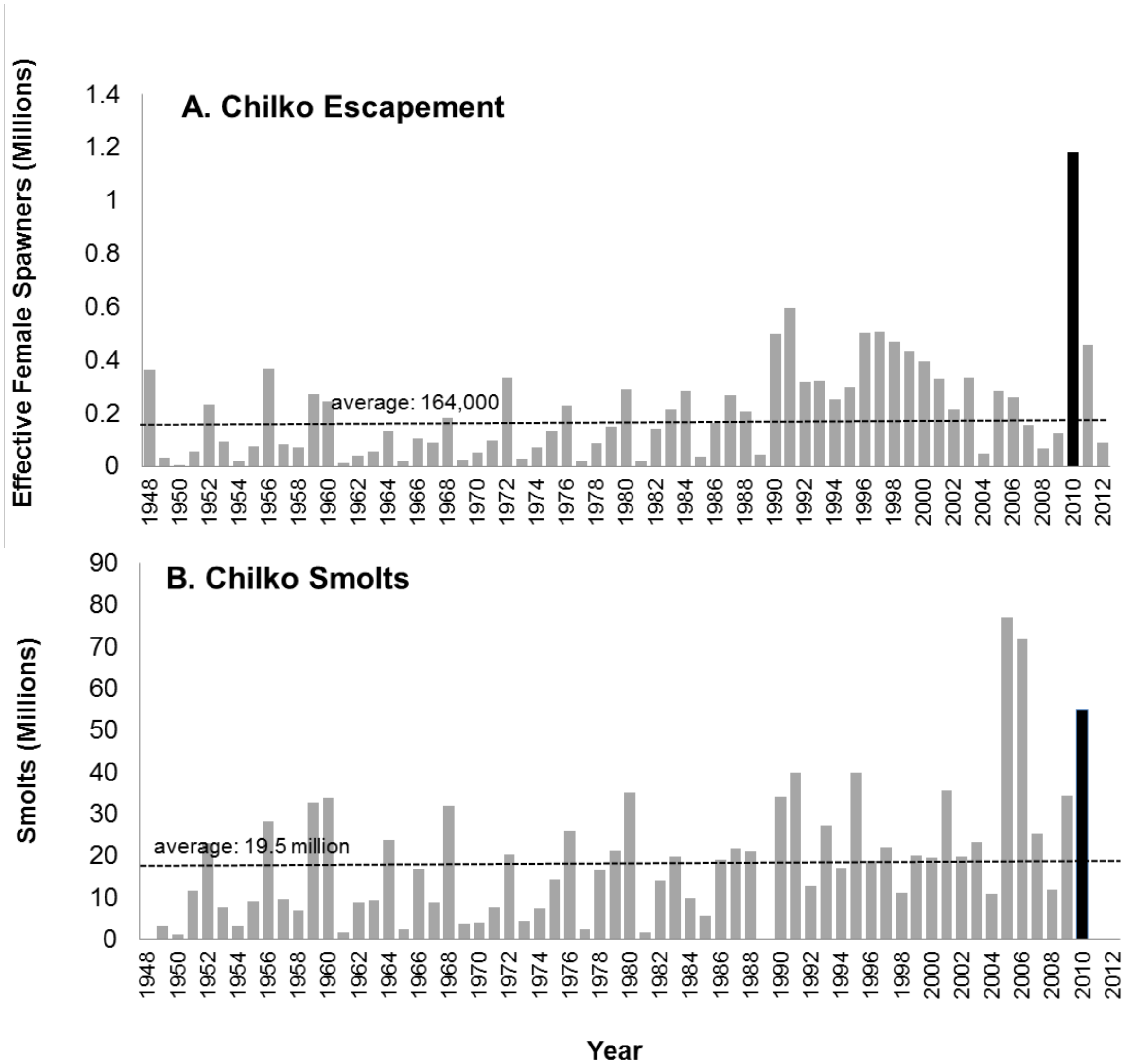


Figure 4. A. Chilko escapement (effective female spawners) and B. Chilko smolt abundances (grey bars) with the 2010 brood year escapement and smolt years indicated by the black bar. Note: Chilko is not considered a cyclic stock. Dashed horizontal line represents average escapement or smolt abundance for Chilko.

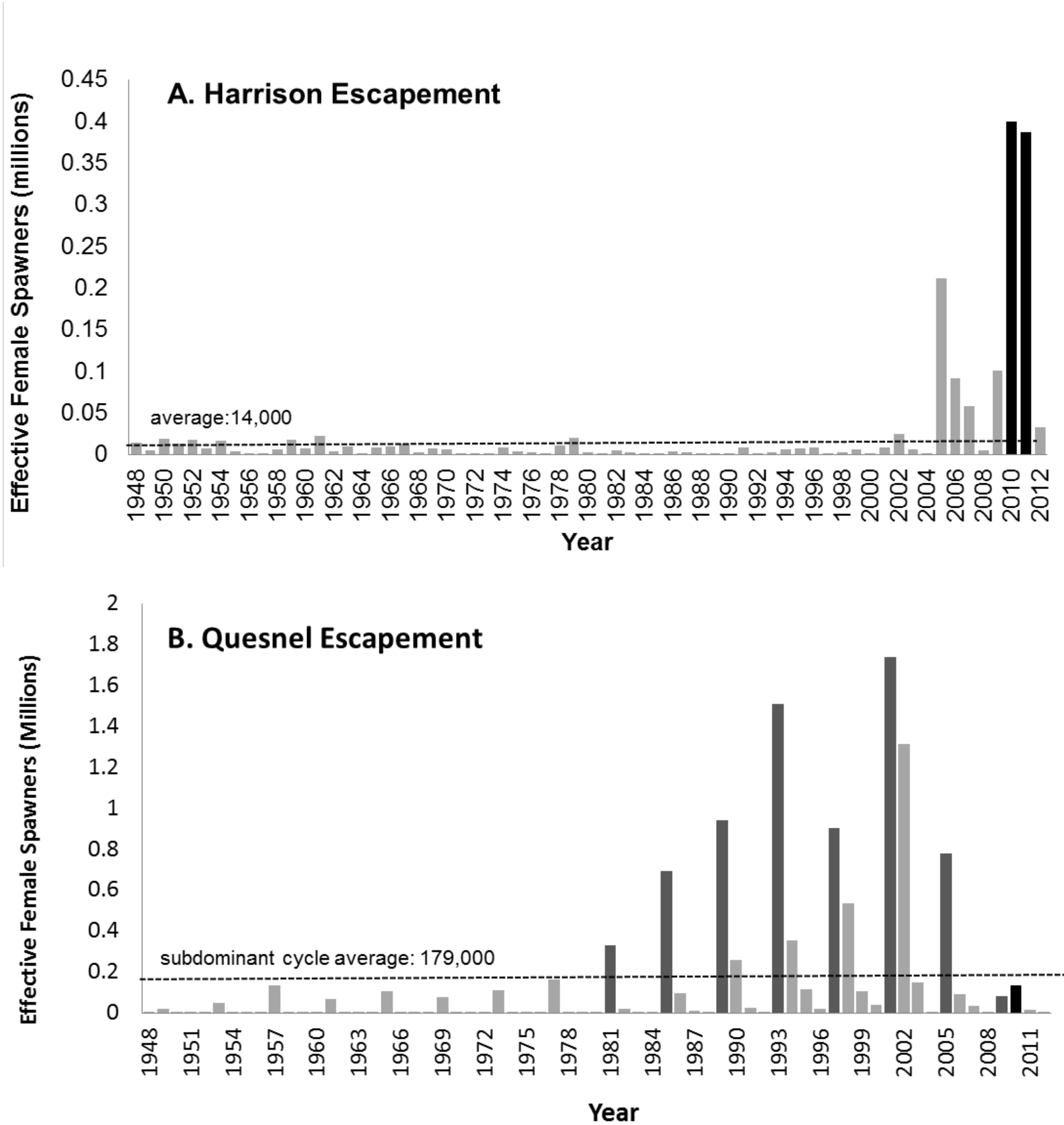


Figure 5. A. Harrison and B. Quesnel escapement (effective female spawners) with the dominant 2010 cycle indicated by the dark grey bars for Quesnel (Harrison does not exhibit cyclic dominance). The 2010 brood year escapement for Quesnel, and the 2010 and 2011 brood year escapements for, respectively, four and three year old Harrison returns in 2014 are indicated by the black bars. Dashed horizontal lines represent average escapement for Harrison and subdominant cycle (2014) average escapement for Quesnel.

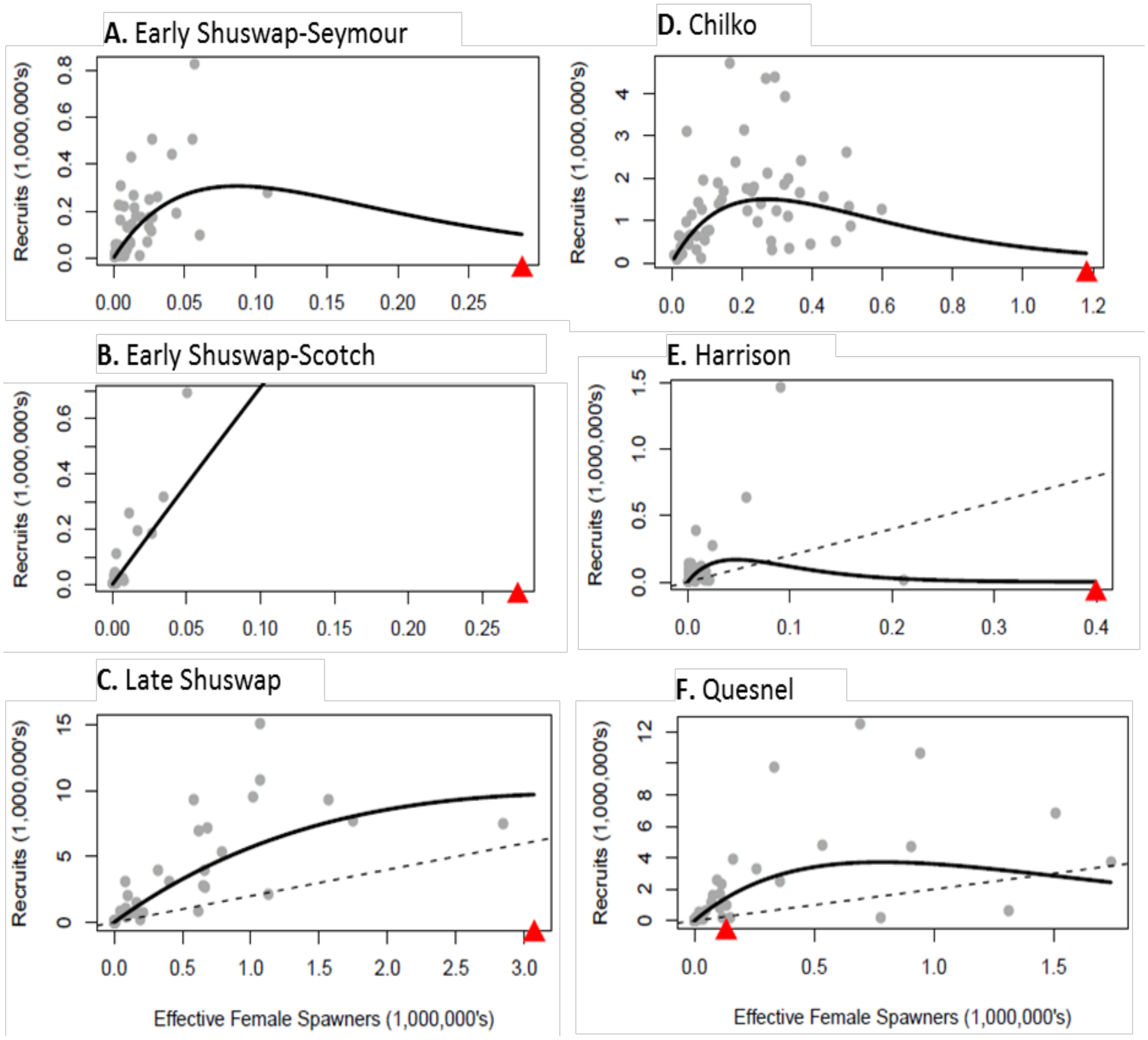


Figure 6. Stock-recruitment data (grey dots), deterministic Ricker model fit (black line) with alpha and beta parameter values obtained from the loge recruits/effective female spawners versus effective female spawners relationship, and 2010 brood year escapements (red triangle) for A. Early Shuswap-Scotch; B. Early Shuswap-Seymour; C. Late Shuswap; D. Chilko; E. Harrison; and F. Quesnel.

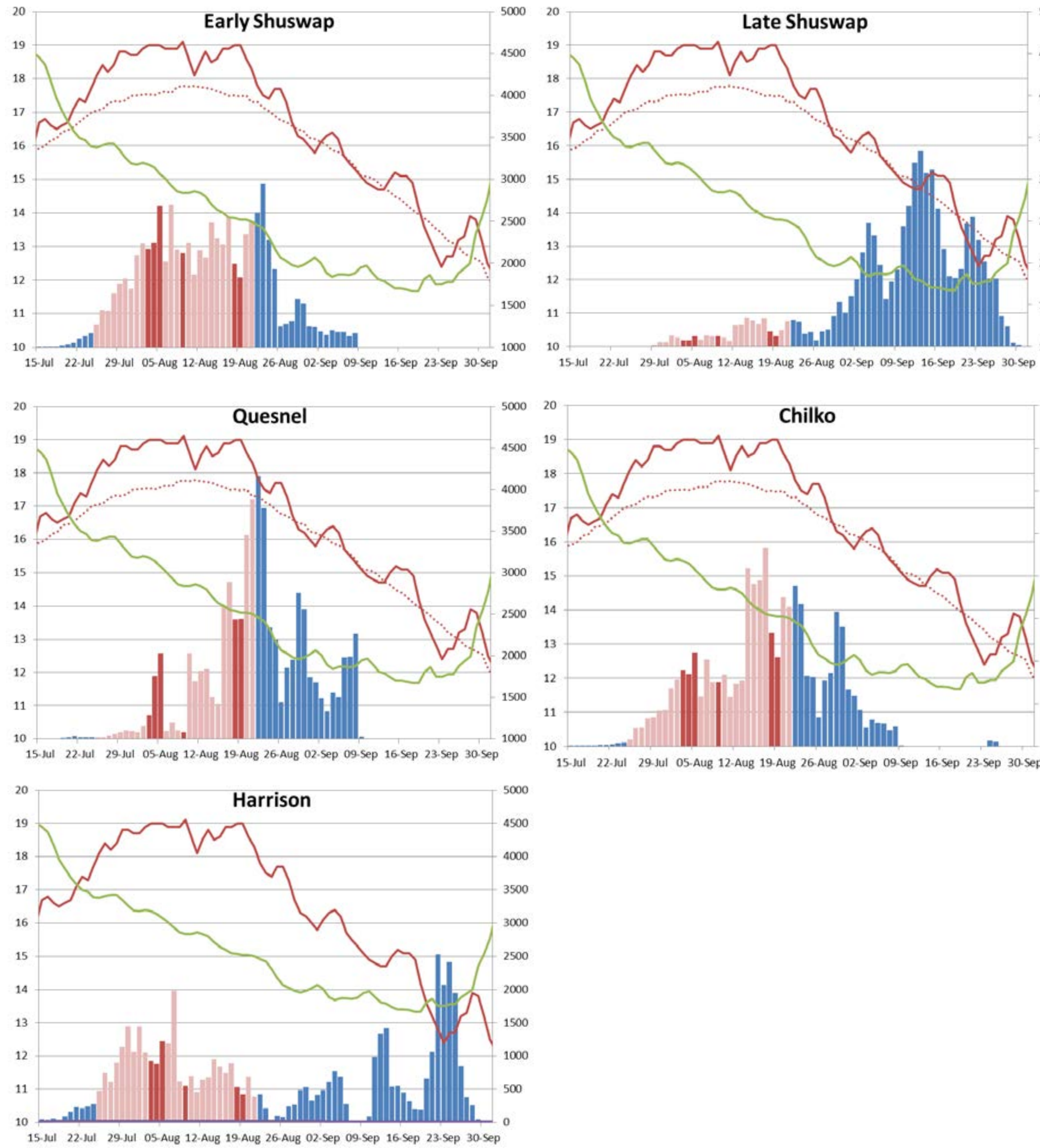


Figure 7. Lower Fraser River water temperature (measured at Qualark, B.C. by DFO's Environmental Watch Program) and discharge (measured at Hope, B.C. by Environmental Canada's Water Survey of Canada Program) experienced by upriver migrating Sockeye salmon stocks in 2010. Solid red line indicates the 2010 average daily water temperature, dotted red line indicates the historical average water temperature (1941-2009), solid green line indicates the 2010 daily mean discharge (m3/s). The blue vertical bars indicate the relative daily abundance of each stock at Mission, pink vertical bars represent days with daily mean water temperatures of 18-18.9 (°C) and red bars represent days with daily mean water temperatures of greater than 19 (°C).

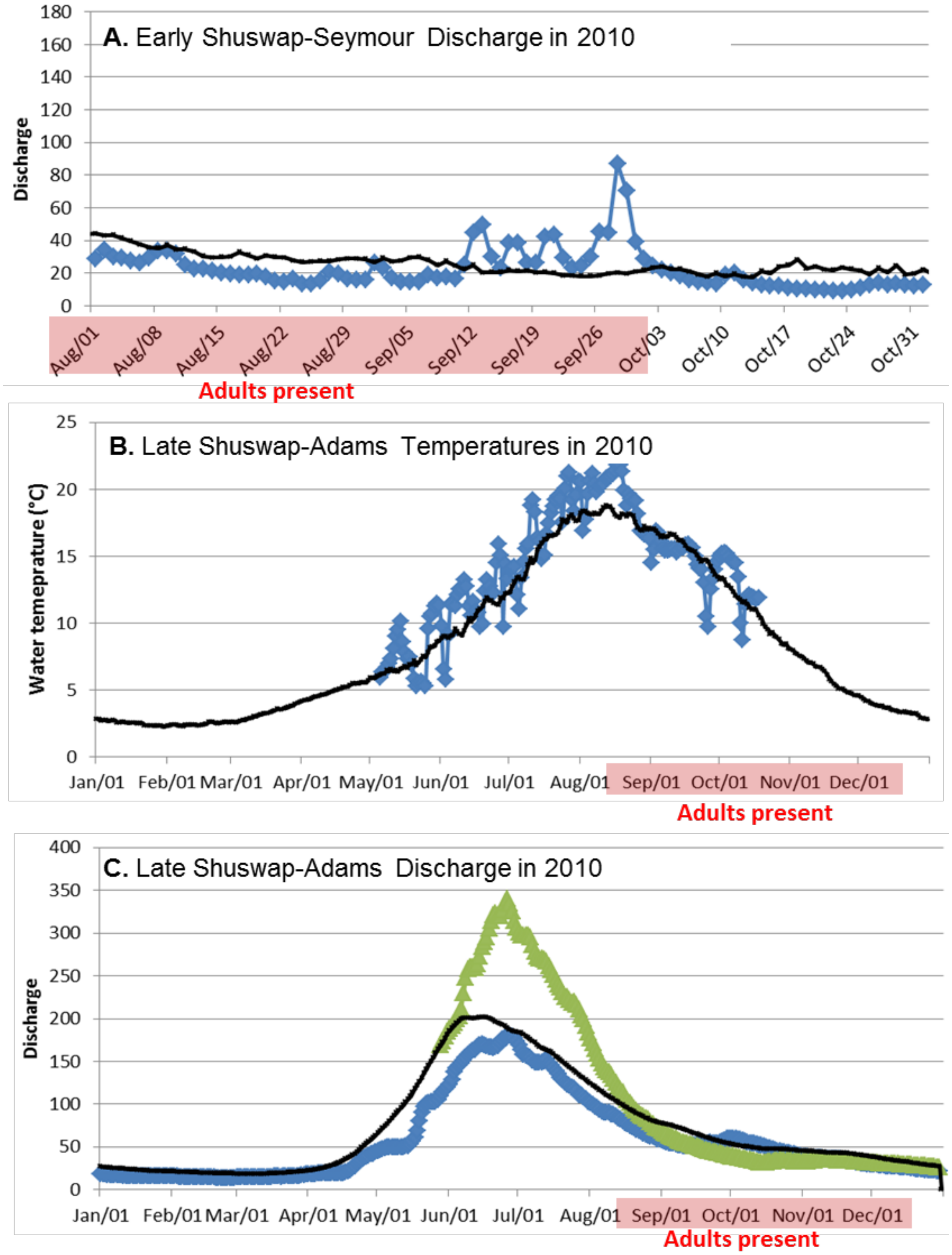


Figure 8. The 2010 water temperature and discharge data (blue lines). Time series averages (black lines) are presented where available: A. Early Shuswap system water discharge data for Seymour River; B. Late Shuswap water temperature, and C. Late Shuswap discharge data (green line is 2012 data).

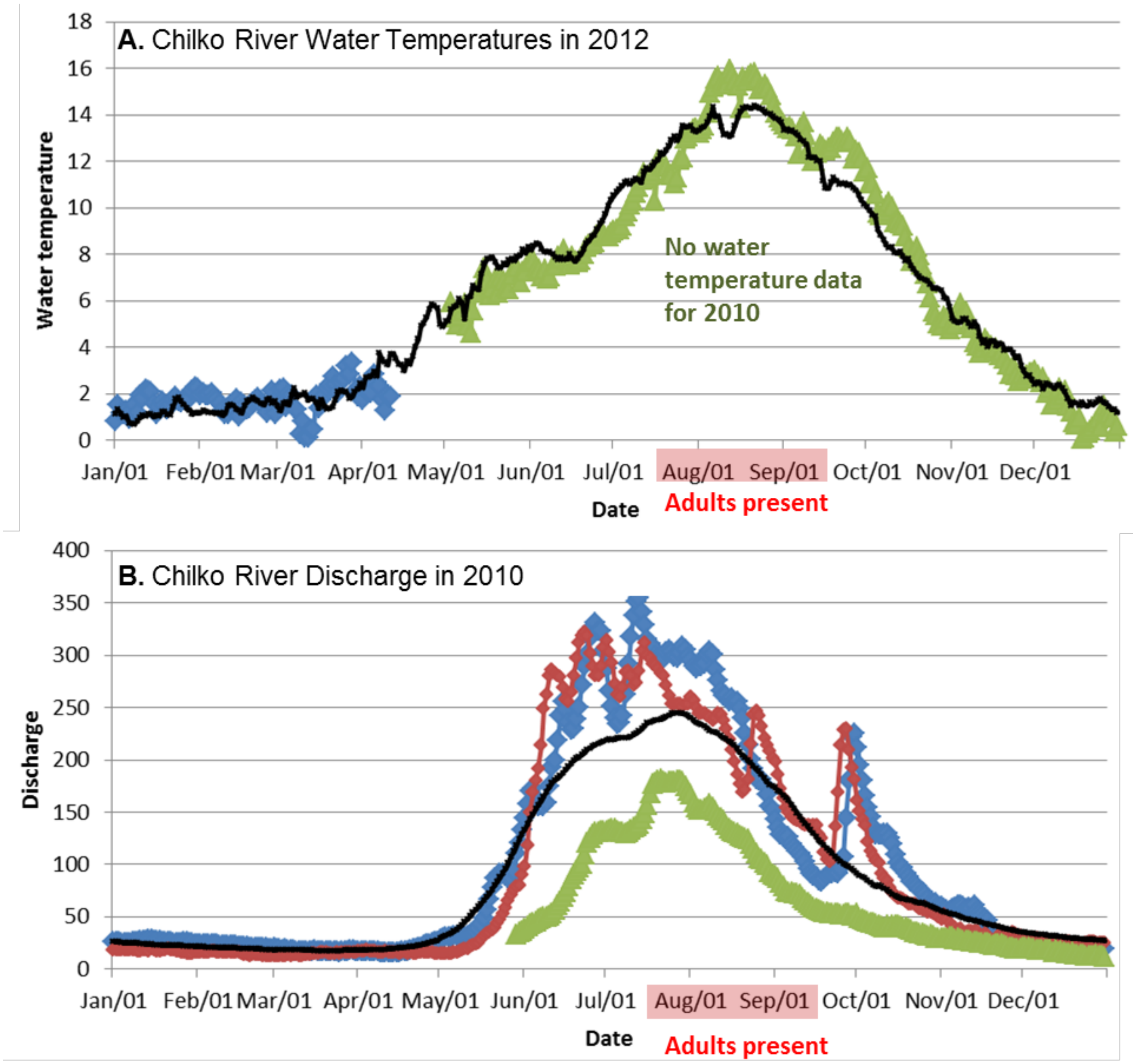
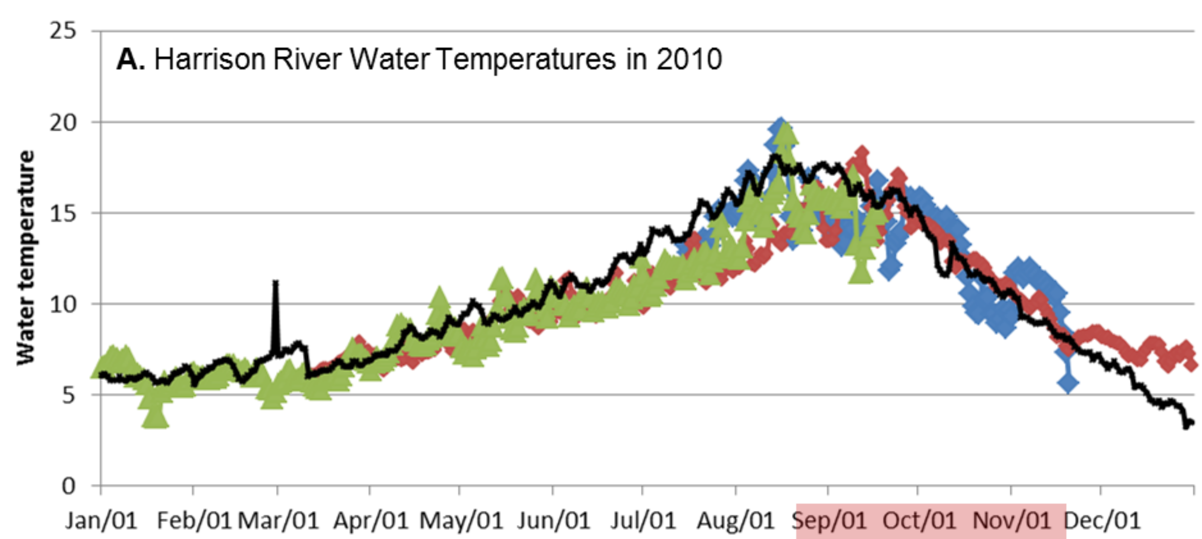


Figure 9. The 2010 water temperature and discharge data (blue lines), and time series averages (black lines) for Chilko River: A. water temperatures data are not available for 2010 during adult migration and spawning (2012 and average data are presented); B. discharge (red line represents 2011 data and green line represents 2012 data).



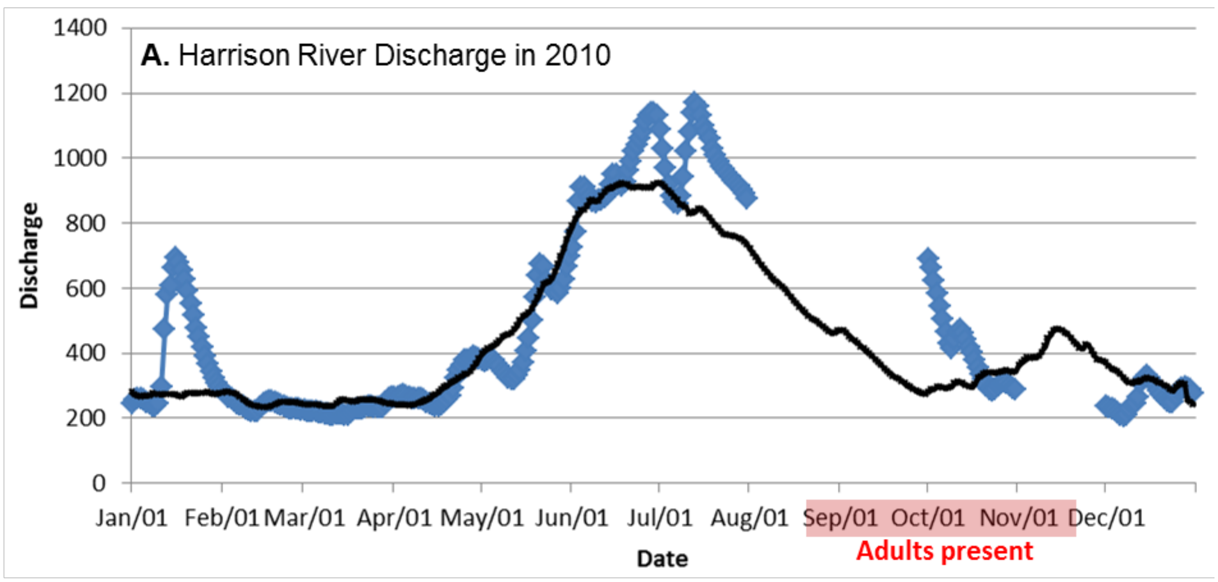


Figure 10. The 2010 water temperature and discharge data (blue lines), and time series averages (black lines) for Harrison River: A. water temperatures data (red line represents 2011 data and green line represents 2012 data); B. discharge.

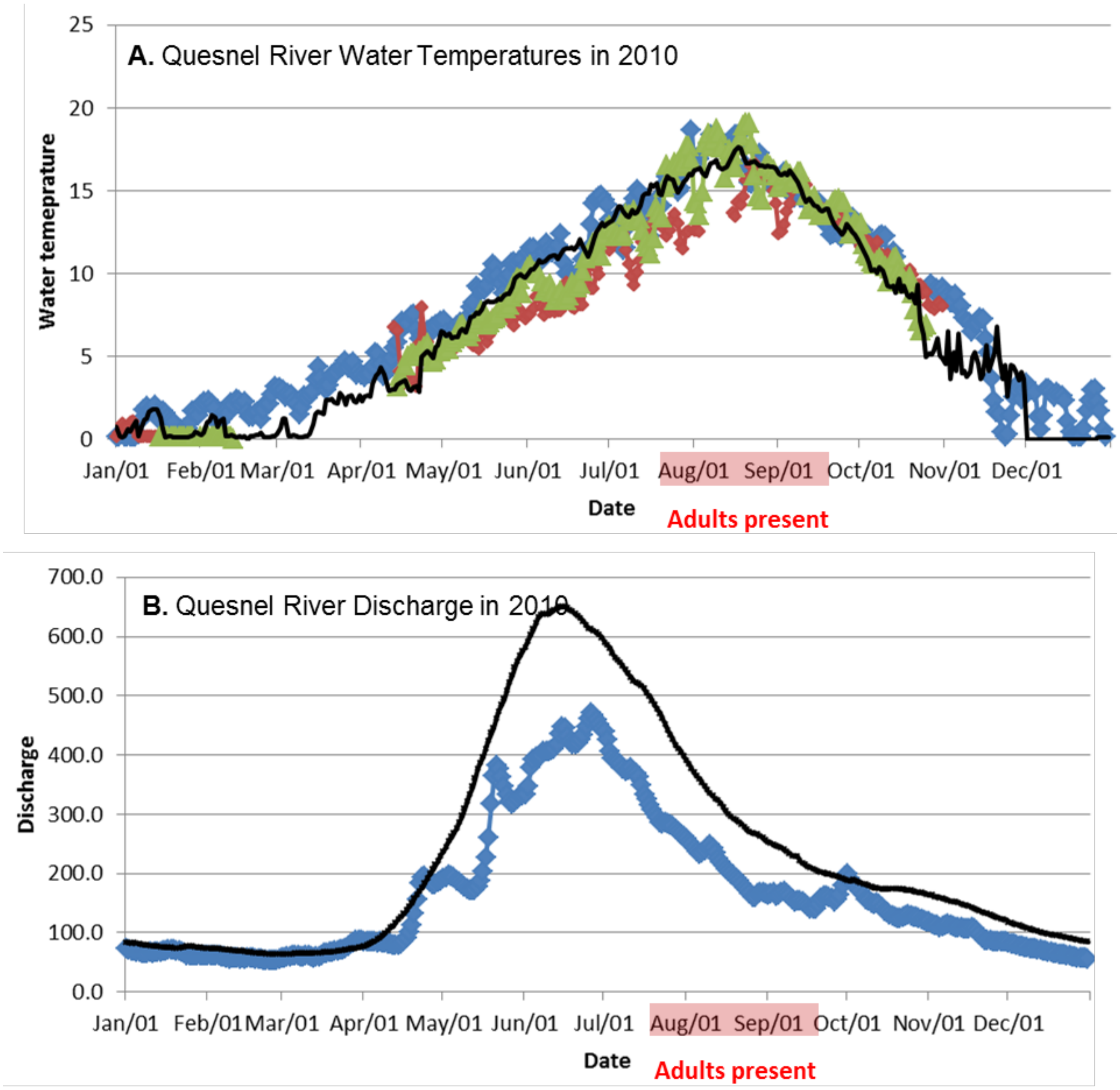


Figure 11. The 2010 water temperature and discharge data (blue lines), and time series averages (black lines) for Quesnel River: A. water temperature data; B. discharge (red line represents 2011 data and green line represents 2012 data).

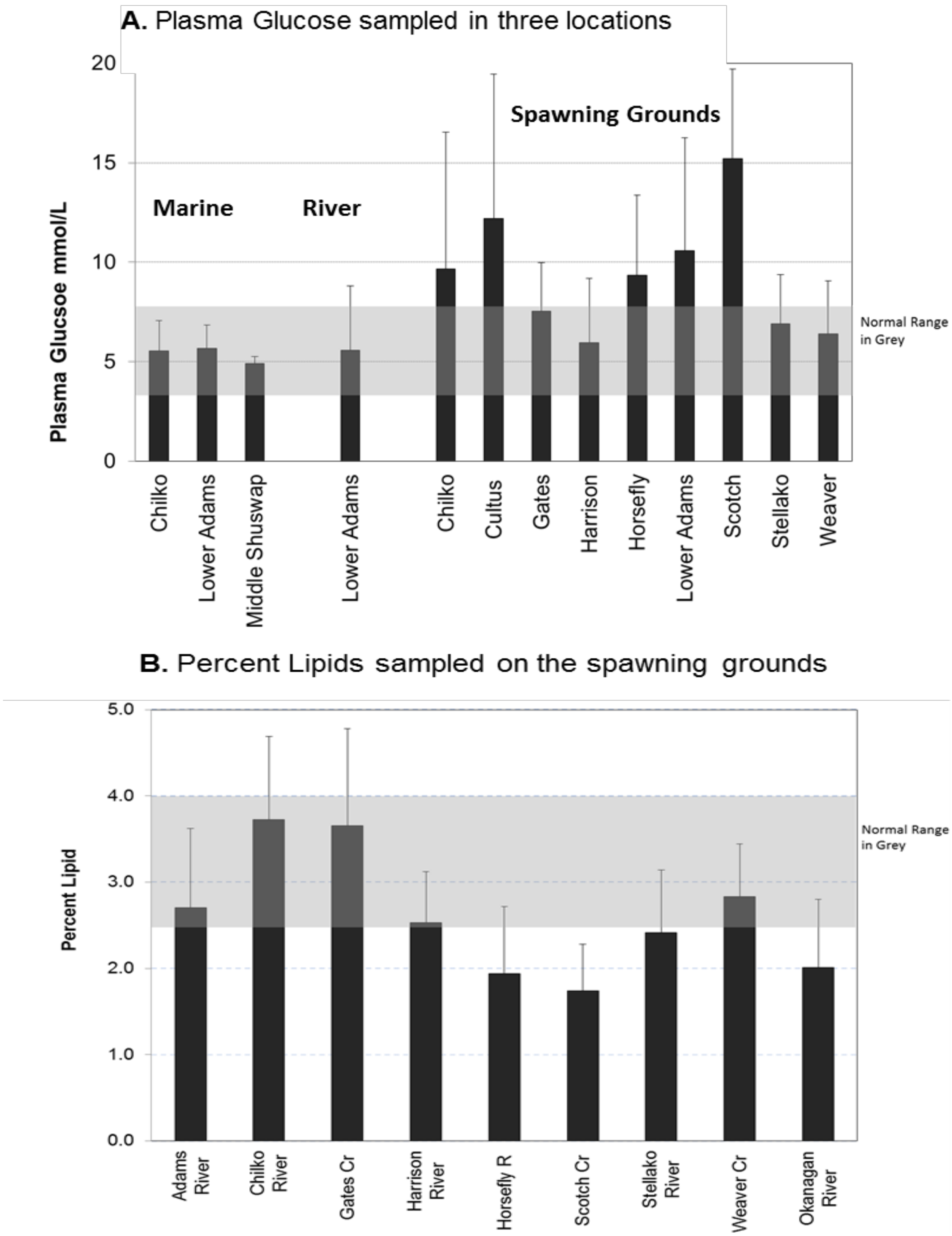


Figure 12. A. Plasma glucose (micromol-per-Litre) values of adult Fraser Sockeye returns sampled in the marine approach areas (Marine), upon entry into the Fraser River (River), and at their spawning grounds (normal range: 4-7 micromol-per-Litre). B. Percent lipids sampled in adult Fraser Sockeye on the spawning grounds (normal range: 2.5%-4.0%).

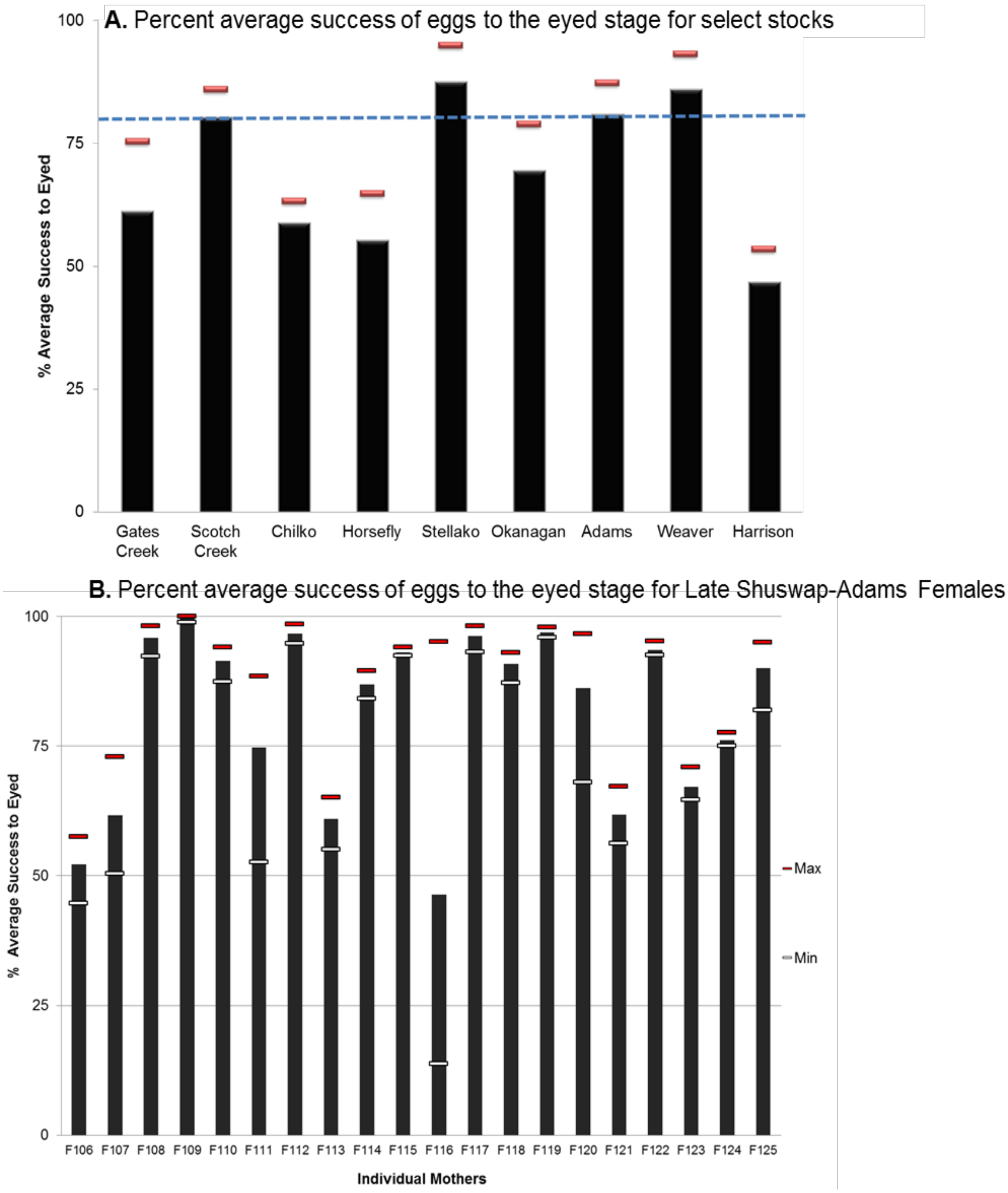


Figure 13. A. Percent average success of eggs to the eyed stage for select stocks (80% indicated by dotted line). B. Percent average success of eggs to the eyed stage for Late Shuswap-Adams Females.

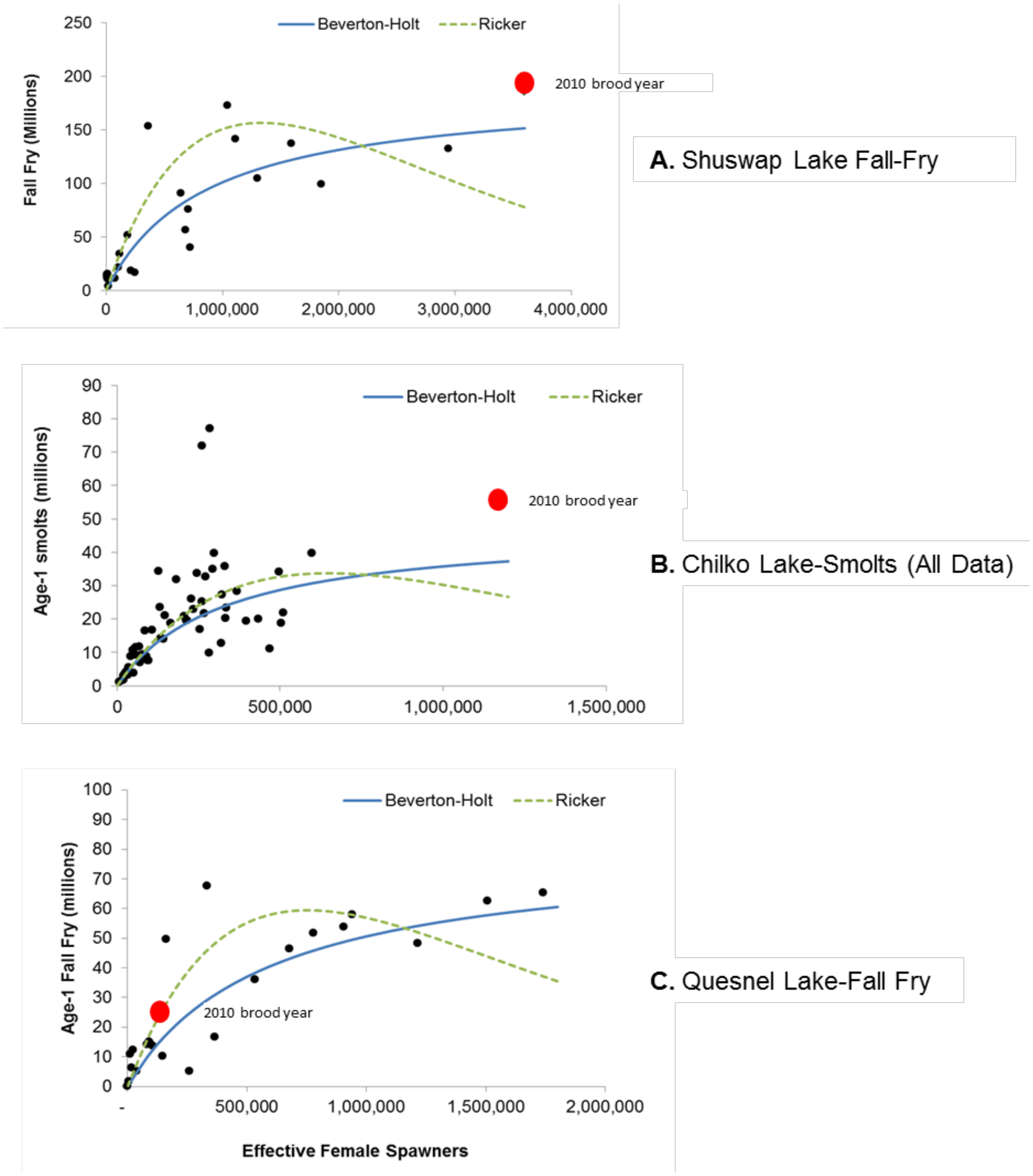
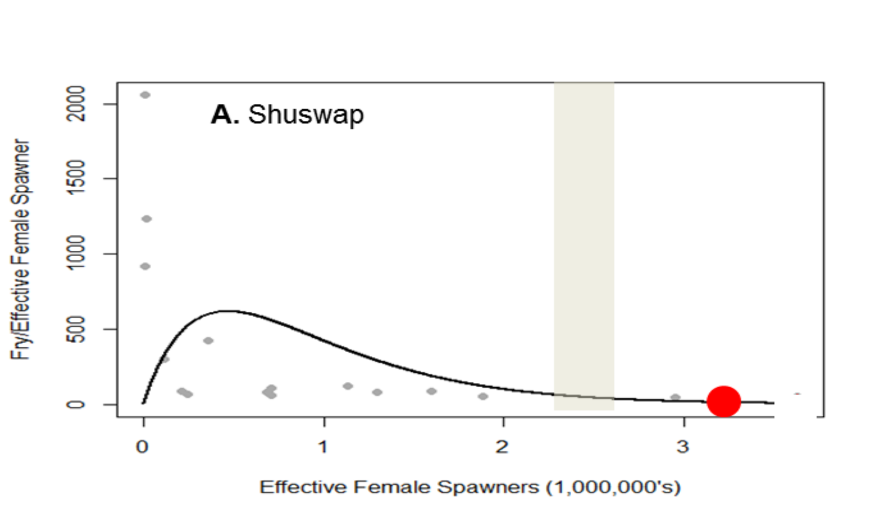


Figure 14. A. Fall fry-per-effective female spawners in Shuswap Lake (brood years 1974 to 2011). B. Smolt-per-effective female spawners in Chilko Lake for all years (brood years 1949-2010, excluding 1989). C. Fall fry-per-effective female spawner in Quesnel Lake (brood years 1974 to 2011 non-inclusive). In each figure the 2010 brood year value is indicated by a red filled circle and text.



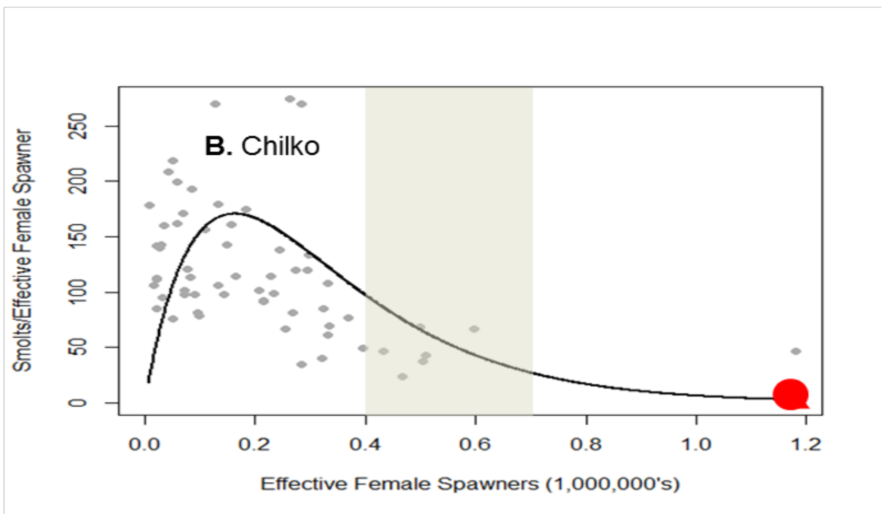


Figure 15. Early freshwater survival (fall-fry-per-effective female spawners or smolt-per-effective female spawners) versus effective female spawners, with a Ricker model fit through the data set. The range of spawners at maximum production (Smax) estimated from photosynthetic rate models and stock-recruitment data are represented by the shaded grey areas on each plot. Large red filled circles represent the 2010 brood year escapements and associated freshwater survivals for A. Shuswap (early and late run stocks) and B. Chilko.

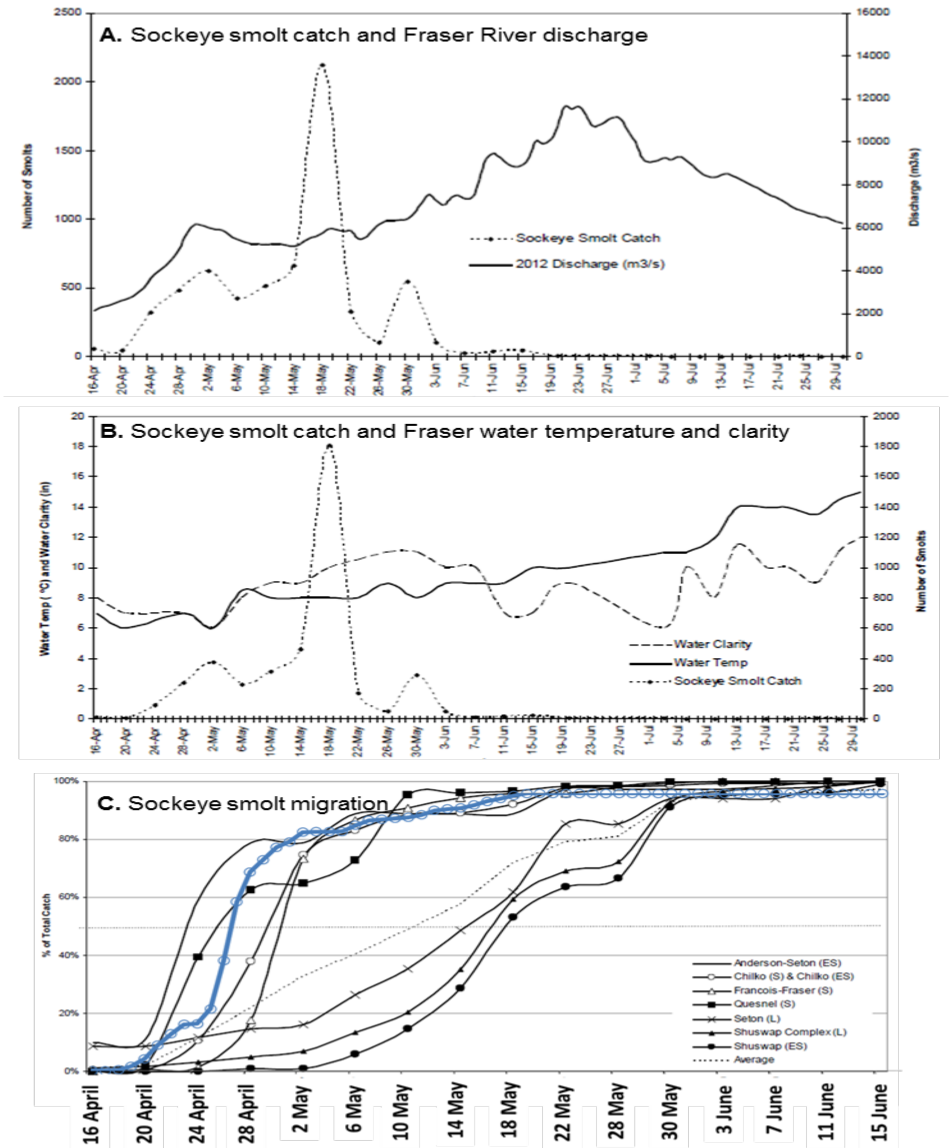


Figure 16. Fraser Sockeye smolt survey (inclined plane trap and rotary screw trap) at Mission, B.C. in 2012. A. Daily Sockeye Salmon catch and average Fraser River discharge. B. Average daily Fraser River water temperature (°C) and water clarity (Secchi Disc depth in inches). C. Cumulative run timing of out-migrating Sockeye salmon by CU in the lower Fraser River juvenile Sockeye salmon assessment project 2012 (n=2,307). Re-printed from Mahoney et al. (2013). Blue line represents Chilko smolt outmigration at Chilko Lake in 2012. Red bars represent the 50% migration dates for both groups of outmigrating smolts.

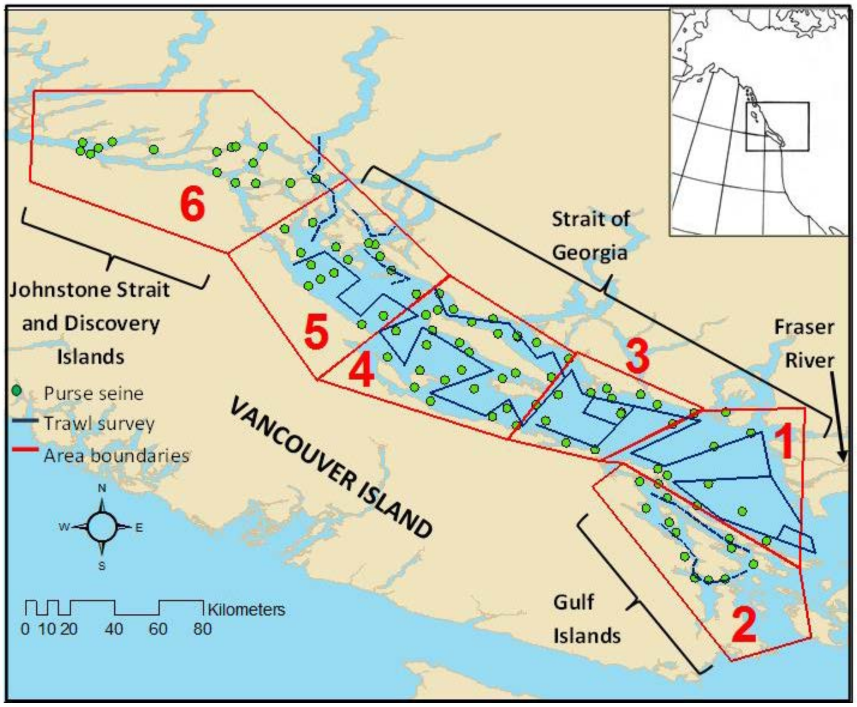


Figure 17. Location of trawl survey standard track line (blue line) and purse seine surveys (green dots) in the SOG and Discovery Islands. Dotted blue lines are sampled during the trawl survey but are not part of the standard track line for interannual comparisons.

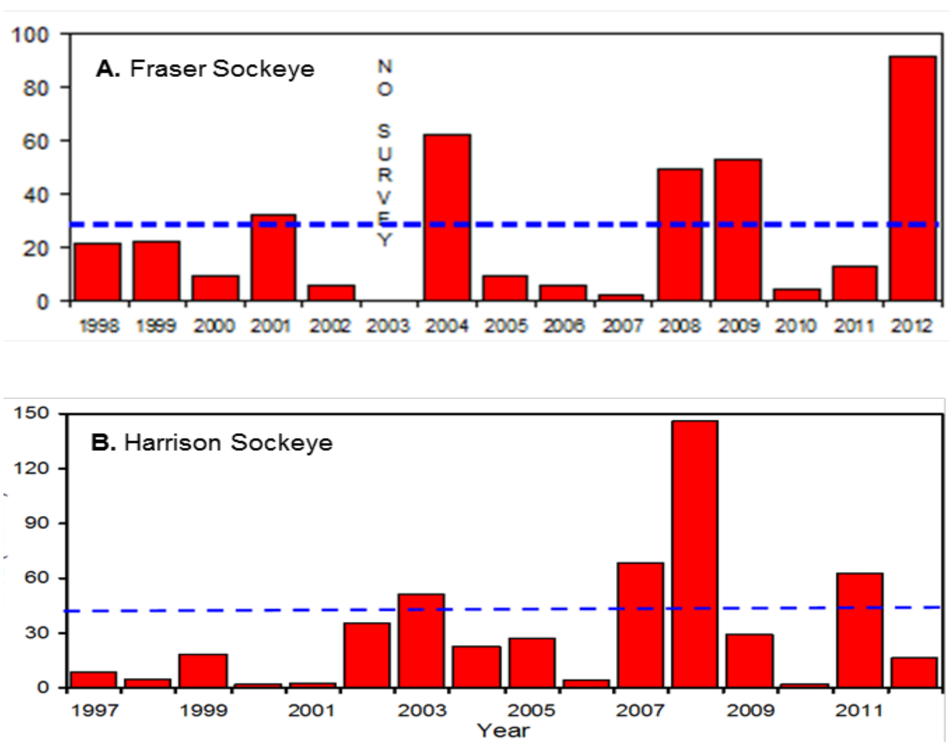
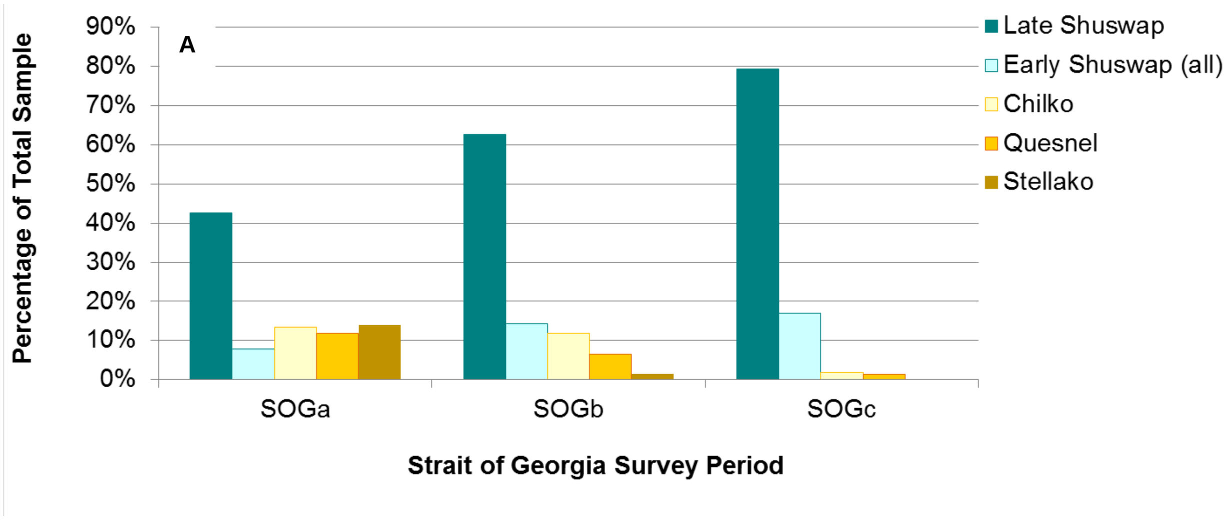


Figure 18. CPUE (catch-per-unit-effort) from 1998 to 2012 of A. Sockeye Salmon in standard late-June/early-July SOG trawl surveys; and B. surveys in September largely comprised of Harrison Sockeye.



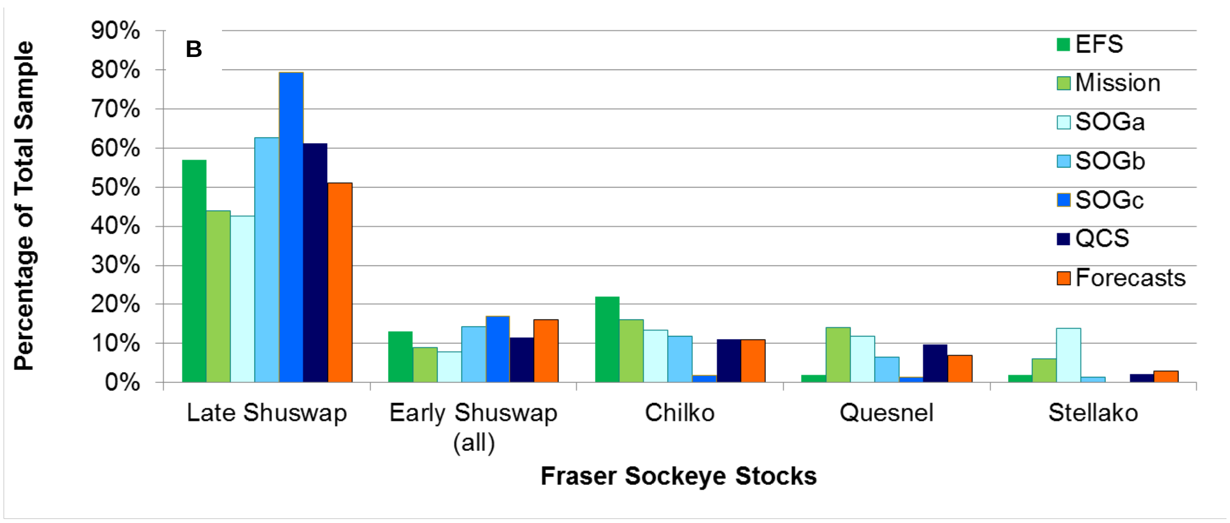


Figure 19. A. Percentage of each stock in the Strait of Georgia surveys during three different sampling periods (see subsequent B. figure descriptions). B. Percentage of each stock in the following: total effective females estimated on the spawning grounds (EFS) in 2010, total sampled smolts in the Mission program in 2012 (Mission), total sampled juveniles in the Strait of Georgia Purse Seine surveys from May 19 to June 1 (SOGa) and from June11-25 (SOGb), total sampled juveniles in the Strait of Georgia trawl surveys (June 20-July 2) (SOGc), Queen Charlotte Sound (QCS) trawl surveys, and the official 2014 Fraser Sockeye 50% probability level return forecast (Forecasts: DFO 2014).

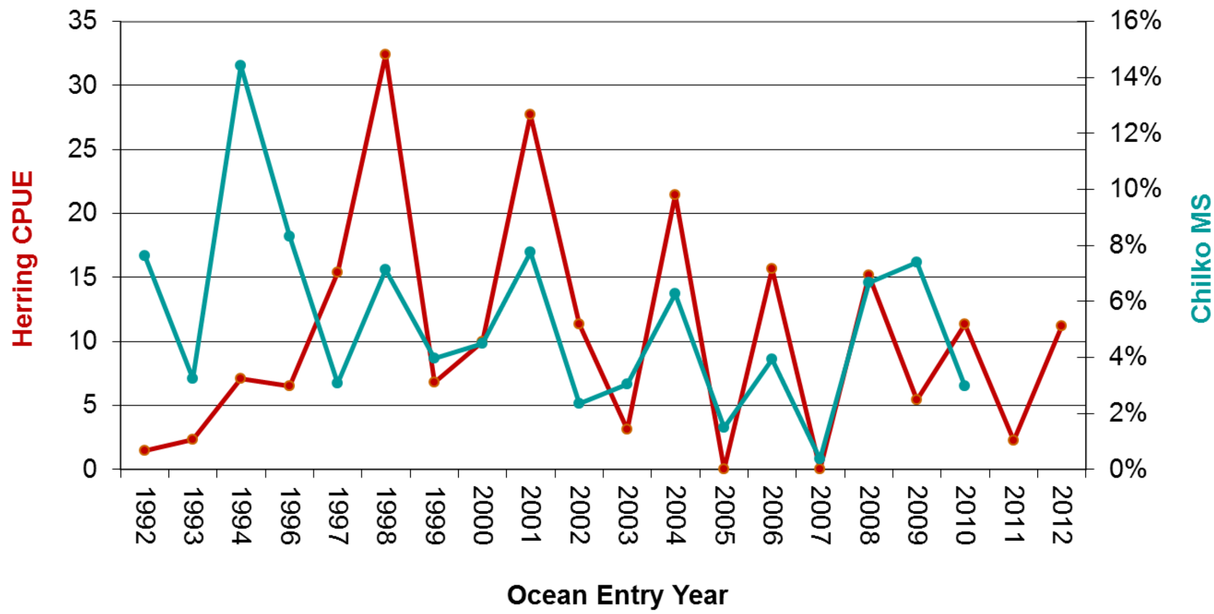


Figure 20. Herring catch-per-unit-effort (CPUE) is represented by the red line and Chilko marine survival is indicated by the blue line. This relationship was first published in Resnel et al. (2010). Updated Herring CPUE data were provided by Jake Schweigert (DFO).

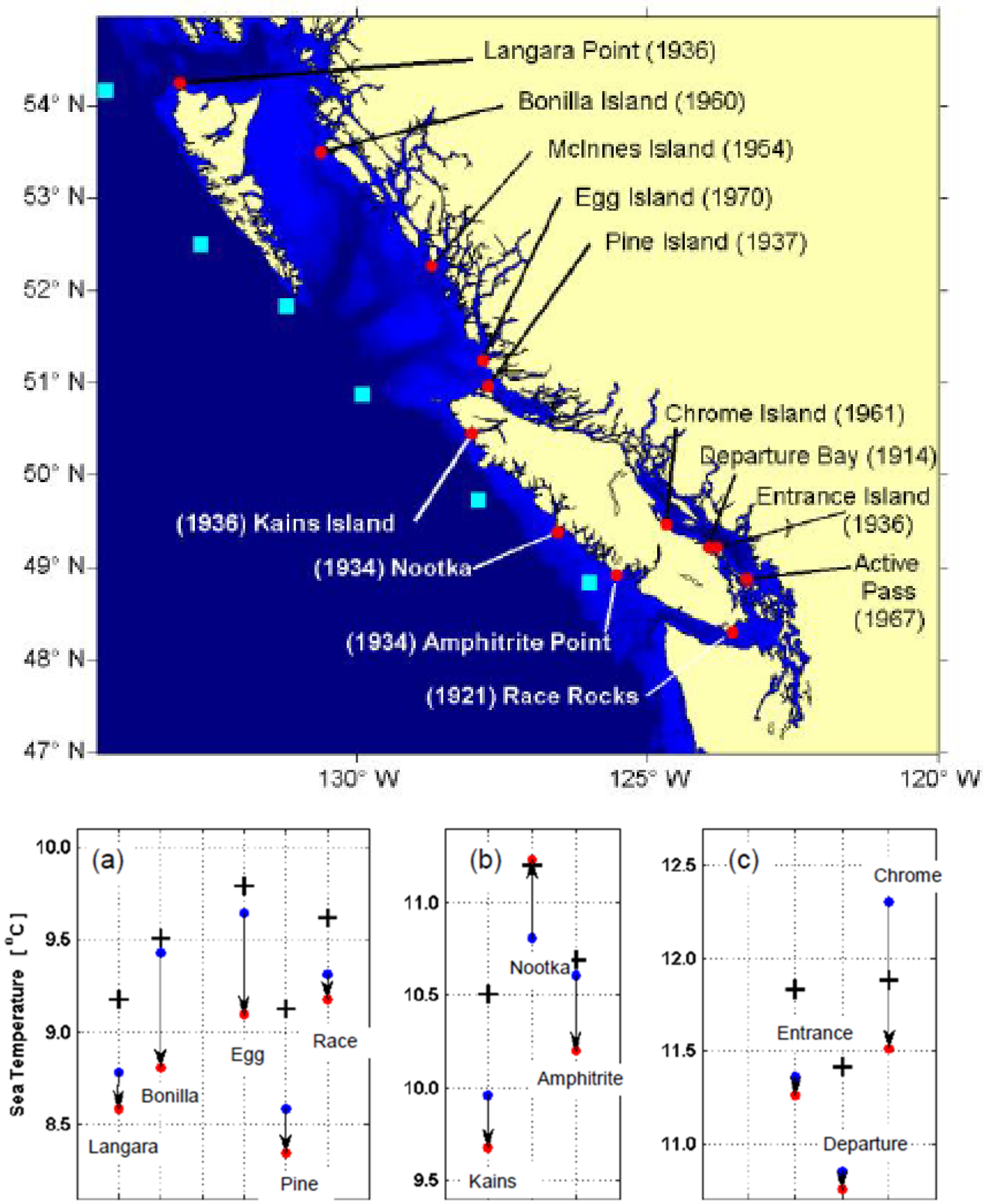


Figure 21. Map of lighthouse stations where sea-surface temperatures have been recorded. The three figures represent the average daily sea surface temperature in 2011 (blue dots) and 2012 (red dots) for stations in three regions a) North and Central Coast; b) West coast of Vancouver Island; and c) the Strait of Georgia; note that Race Rocks is included in WCVI for convenience. The crosses represent the mean annual temperatures based on 30 years of data (1981-2010). Reprinted from Irvine & Crawford (2013).

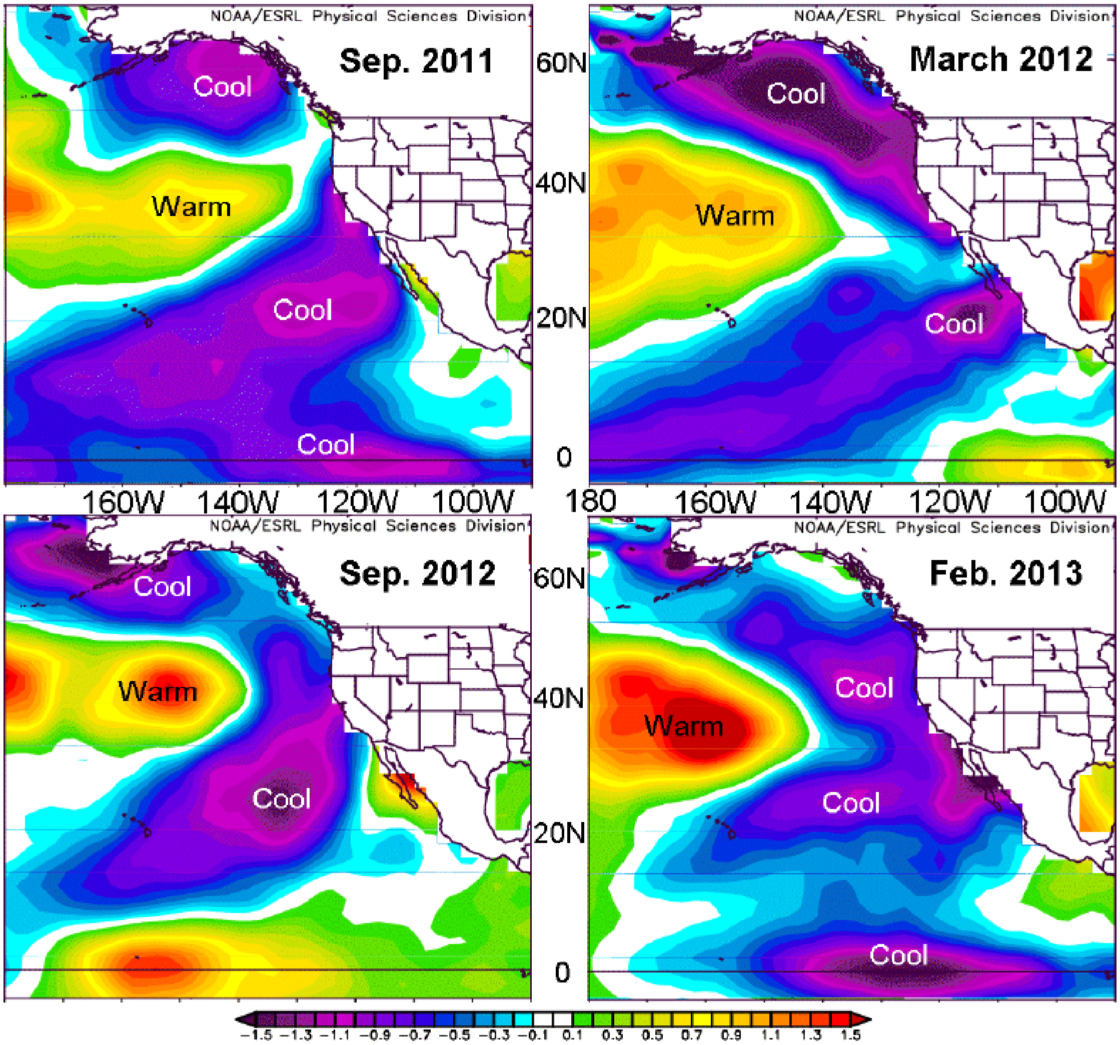


Figure 22. Sea surface temperature anomalies in the eastern Pacific Ocean for September 2011 to February 2013. The maps extend from North America west to 180°, and from 5° South to 65° North. The equator is marked by the horizonal black line near the bottom of each panel. The temperature anomaly scale in °C is at bottom. Positive and negative temperature anomalies are labelled warm and cool, respectively, in each panel. Reference years for temperature anomalies are 1981 to 2010. Images provided by NOAA:. Reprinted from Irvine & Crawford (2013).

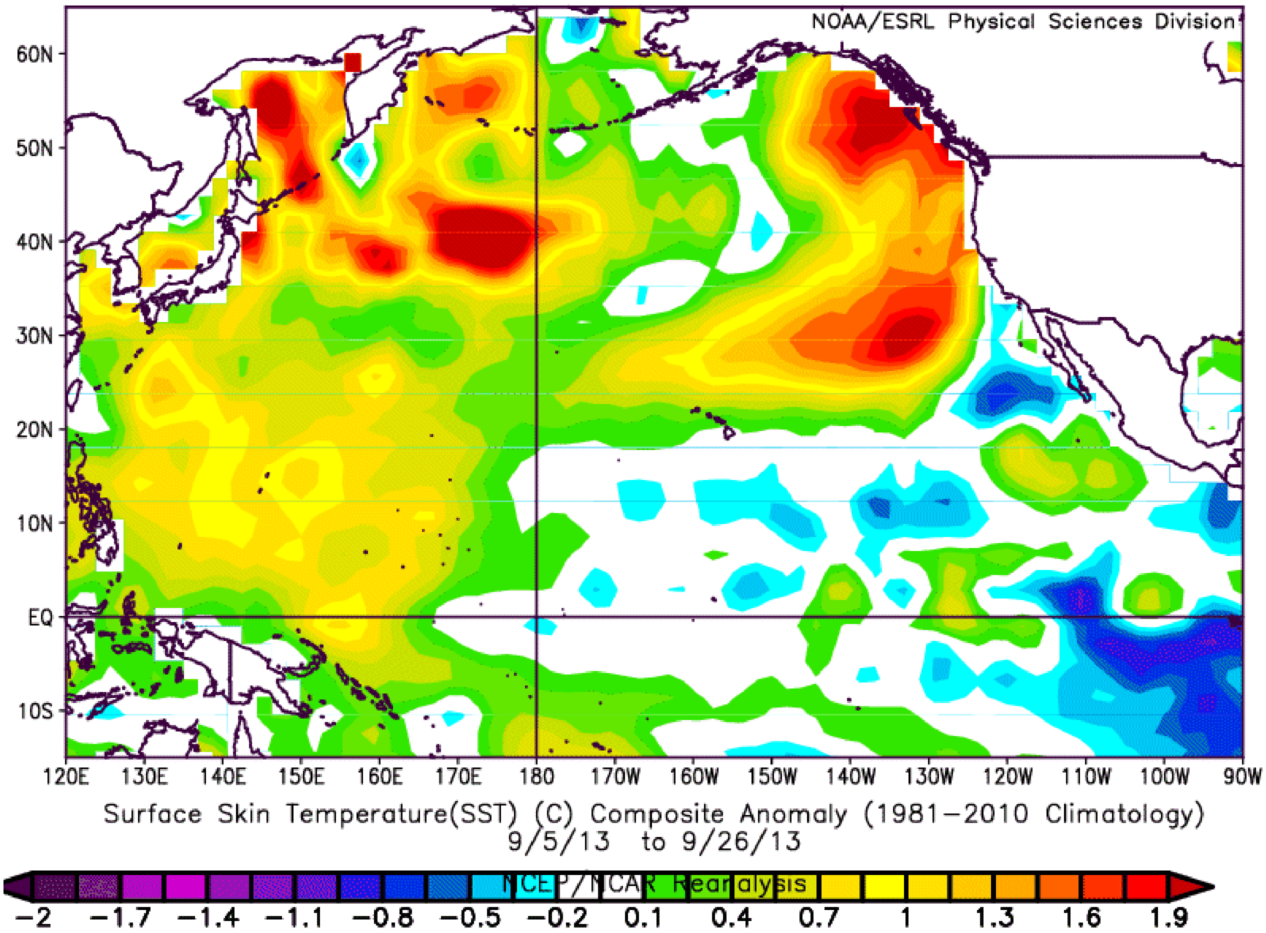


Figure 23. Sea surface temperature anomalies in the eastern Pacific Ocean for September 2013. The maps extend from North America west to 180°, and from 5° South to 65° North. The equator is marked by the horizonal black line near the bottom of each panel. The temperature anomaly scale in °C is at bottom. Positive and negative temperature anomalies are labelled warm and cool, respectively, in each panel. Reference years for temperature anomaly are 1981 to 2010. Images provided by NOAA: Courtesy of B. Crawford, DFO.

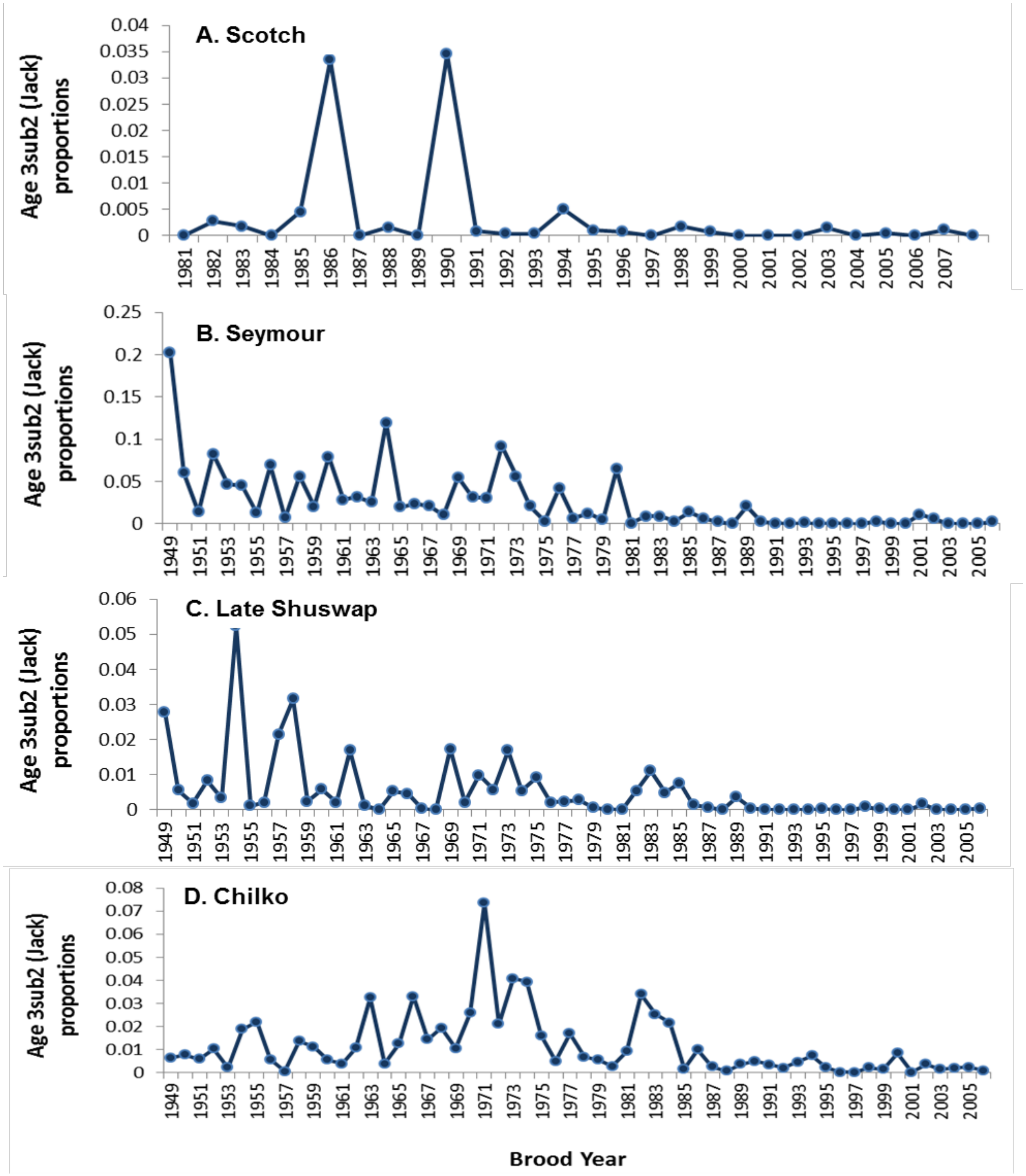


Figure 24. Jack (age 32) proportions (relative to 42 and 52 aged fish) for A. Scotch, B. Seymour, C. Late Shuswap, and D. Chilko have generally declined post-1980; age of maturity across most Fraser Sockeye stocks has increased post-1980.

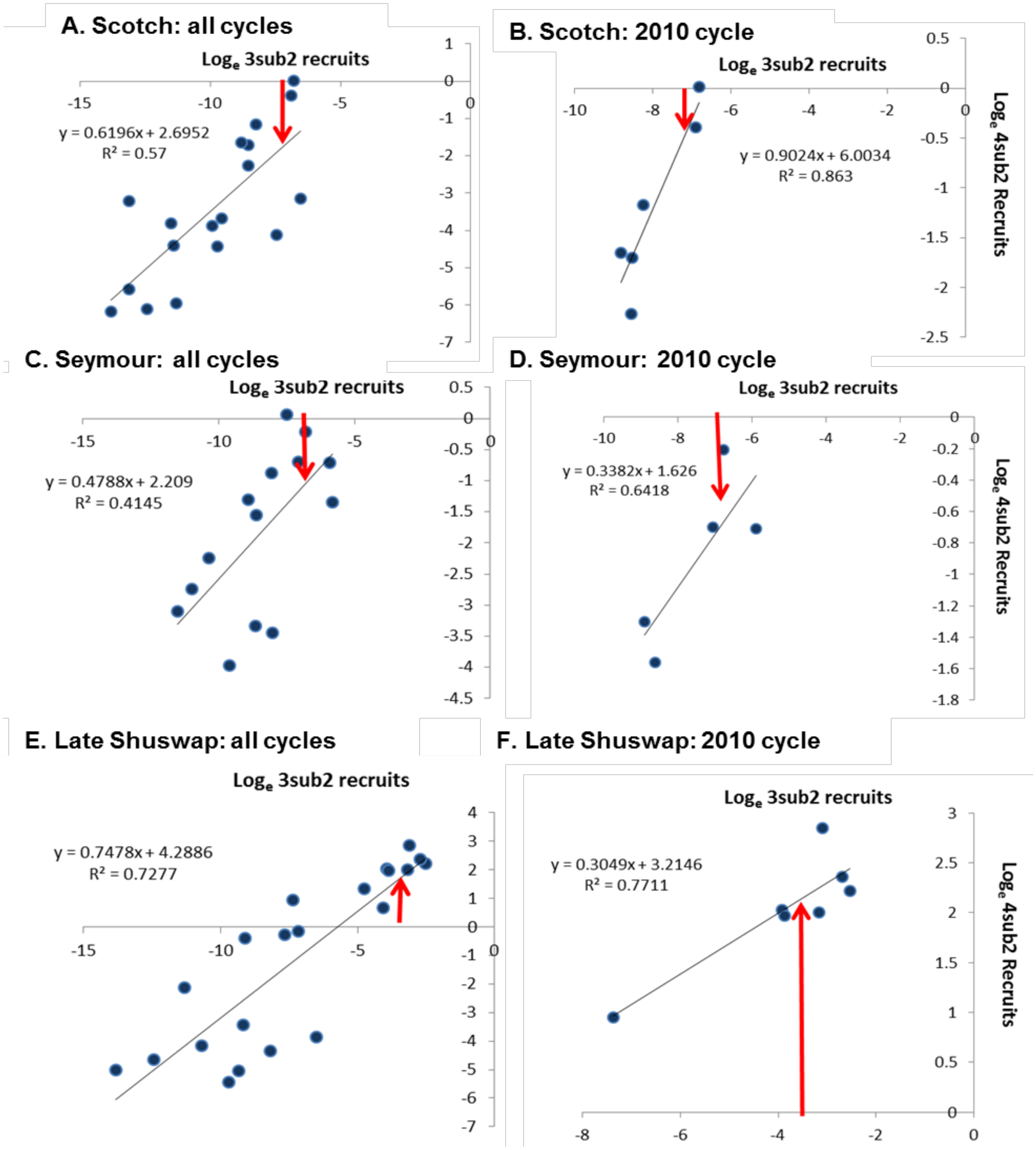


Figure 25. 4sub2 to jack relationships (3sub2 versus 4sub2) post-1980 for Scotch, Seymour and Late Shuswap on all cycles (A,C,E) and for Scotch, Seymour and Late Shuswap on the dominant 2014 cycle only (B,D,F). Red arrows indicate the 2010 brood year jack (3sub2) escapement in 2013 (recruitment data were not available at the time of this publication).

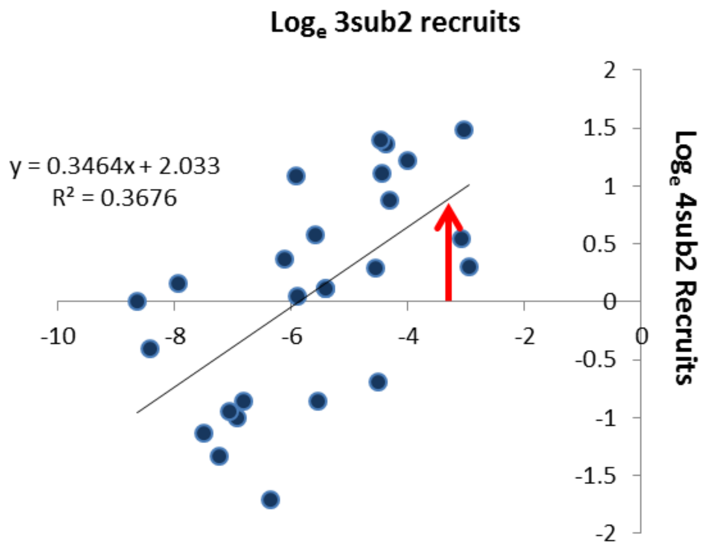


Figure 26. 4sub2 to jack relationships (3sub2 versus 4sub2) post-1980 for Chilko on all cycles; there is no cyclic dominance for this stock. Red line indicates the 2010 brood year jack (3sub2) escapement in 2013 (recruitment data were not available at the time of this publication).

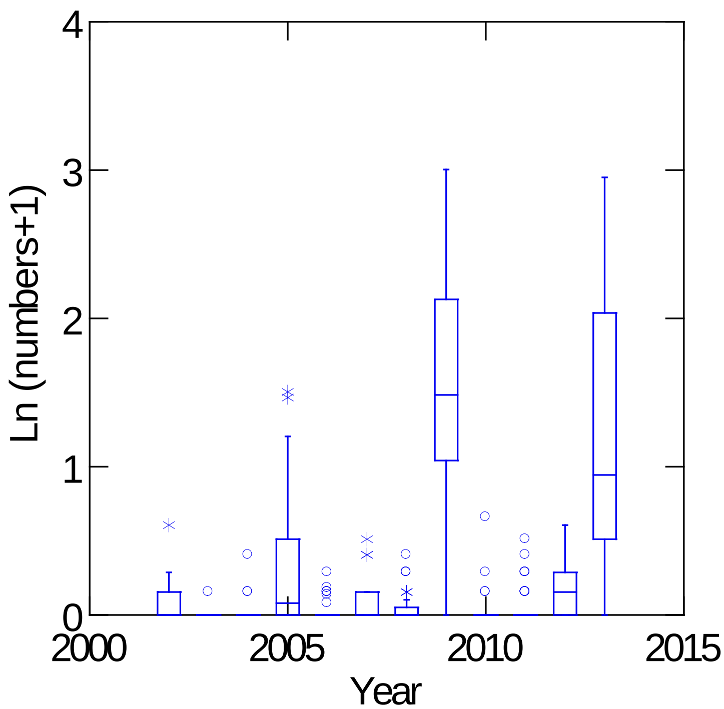


Figure 27. Total loge (ln) catch-per-unit effort of jack (3sub2) Fraser Sockeye caught in Area 20 (Juan de Fuca Strait) plus Area 12 (Johnstone Strait). The 2013 jack abundance (from the 2010 brood year) is represented by the final bar (McKinnell et al. 2012).

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Approved by

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Nanaimo, British Columbia
March 13, 2014

Sources of information

This Science Response Report results from the Science Special Response Process of Janaury 2014 to summarize data on fish condition and/or survival from the 2010 spawners and their offspring.as a supplement to pre-season run size forecasts for Fraser River Sockeye (*Oncorhynchus nerka*) salmon in 2014.

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