Evaluation of Uncertainty in Fraser Sockeye (*Oncorhynchus nerka*) Wild Salmon Policy Status using Abundance and Trends in Abundance Metrics

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ABSTRACT

The Department of Fisheries and Oceans (DFO) Wild Salmon Policy (WSP) goal is "to restore and maintain healthy salmon populations and their habitats for the benefit and enjoyment of the people of Canada in perpetuity" (Fisheries and Oceans Canada 2005). In order to achieve this goal, the WSP outlines a number of strategies, including '*Strategy 1: standardized monitoring of wild salmon statuses*, which is the subject of this paper. Convervation Units (CUs) identified through 'WSP *Action Step 1.1: the identification of conservation units (CUs)'* are used to update '*Action Step 1.2: the development of criteria to assess CUs and identify benchmarks to represent biological statuses*, and to partially address '*Action Step 1.3: CU status assessment'*, for 26 out of 37 CUs (the remaining 11 CUs are tentative CUs pending further research.) Using a previously developed toolkit for CU status assessment (Holt et al. 2009; Holt 2009), *abundance* benchmarks were estimated for each CU with stock-recruitment data (each CU has unique benchmarks), and *trends in abundance* upper and lower benchmarks (identical benchmarks for all CUs) were modified for Fraser Sockeye. These benchmarks were used to delineate the three WSP biological status zones (red, amber, and green). *Abundance* benchmarks were estimated across a range of Ricker models, including model forms that emphasize recent lower CU productivity observed for most CUs. *Abundance* metric benchmarks were also estimated across a range of probability levels to reflect uncertainty in the estimation process. In the evaluation of status using the *abundance* metric, both geometric and arithmetic recent mean CU abundances were compared against benchmarks. Since multiple metrics (one *abundance* and three *trends in abundance* metrics, depending on the CU*)* and uncertainty in *abundance* benchmarks are presented in the current paper, statuses for each CU can comprise all three WSP status zones. **The purpose of the current paper is not to develop a final single status for each CU, but instead present the uncertainty in statuses for each metric by CU. The development of a final single stock status for each CU, required to complete WSP Action Step 1.3, will be addressed in subsequent processes and publications.**

> **Comment:** Update after July meeting with Holtby, Benner, Whitehouse, Cone & Grant

RÉSUMÉ

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INTRODUCTION

The Department of Fisheries and Oceans (DFO) Wild Salmon Policy (WSP) goal is "to restore and maintain healthy salmon populations and their habitats for the benefit and enjoyment of the people of Canada in perpetuity"(2005). In order to achieve this goal, the WSP outlines a number of strategies, including '*Strategy 1: standardized monitoring of wild salmon statuses*, which is the subject of this paper. This paper uses convervation units (CUs) identified through 'WSP *Action Step 1.1: the identification of conservation units (CUs)'* to update '*Action Step 1.2: the development of criteria to assess CUs and identify benchmarks to represent biological statuses*, and to partially address '*Action Step 1.3: CU status assessment'*, for 26 out of 37 CUs (the remaining 11 CUs are tentative CUs pending further research). Since several metrics are used to assess status for each CU and uncertainty in *abundance* benchmarks is considered in the current assessment, the resulting statuses for each CU can include a combination of the three WSP biological status zones (red, amber, and green)(Figure 1). Aggregation of divergent statuses for a CU into a final single status, required to complete WSP Action Step 1.3, is not the subject of the current paper and instead will be addressed in a subsequent process.

Methodology for the identification of CUs and a consequent list of draft CUs for salmon stocks in the Pacific Region (WSP Action Step 1.1) was presented in Holtby and Ciruna (2007) (recently updated by Holtby in 2011). This represents a 'living' CU list, subject to change as new analysis and data become available. The current paper presents the 2011 revised list of 32 'current' Fraser Sockeye CUs (Table 1). In addition to these 32 current CUs, five are 'proposed' CUs pending new information, six are considered 'extirpated' CUs, and two CUs have been deleted from the original list. Out of the 32 'current' CUs, two CUs (McKinley-S & Chilko-ES) cannot be assessed independently, since data for these CUs are aggregated with their adjacent larger CUs (respectively, Quesnel-S & Chilko-S). Five of the 'current' CUs do not have sufficient data for status assessments. Therefore, assessment of status can be completed for 27 of the 32 'current' Fraser Sockeye CUs (including the Quesnel-S/McKinley-S and Chilko-ES/Chilko-S aggregates) (Table 1; Appendix 1).

Coincidental to the identification of CUs, methodology for the identification of salmon CU status (WSP Action Step 1.2) was presented in two recent papers (Holt 2009; Holt et al. 2009). Classes of indicators recommended for the assessment of Pacific salmon status include *abundance*, *trends in abundance*, *fishing mortality*, and *distribution* (Figure 2). Within each class of indicator, more than one metric can be used to assess status (Figure 2). For each metric, lower and upper benchmarks delineate the three WSP status zones (red, amber and green) (Figure 1). To meet the definition specified in the WSP, the lower benchmark is set at a level that ensures there is a substantial buffer between the benchmark and the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) classification of 'endangered'. Although changes in status are intended to inform management decision making, on their own they are not prescriptive.

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Table 1. The ==32 CUs with sufficient data to evaluate status (assessable CUs), 5 proposed CUs pending further information, 6 extirpated CUs and 2 deleted CUs (deleted from previous CU list).==

--- Insert updated list after meeting with group ---

Since a relatively complete time series of escapement and recruitment data exists for a large number of Fraser Sockeye CUs, the classes of indicators explored in this assessment of status include *abundance* and *trends in abundance* (WSP Action Step 1.2). The *fishing mortality* class of indicator differs from the remaining three (Figure 2), as it reflects a threat to the CU rather than an intrinsic property of the CU, and is typically used only when abundance data are not available (Holt et al. 2009). Further, a recent DFO workshop concluded that further research on *fishing mortality* benchmarks and their usefulness in status evaluation is required prior to their

application. For Fraser Sockeye, the *fishing mortality* class of indicator is not used to assess CU status, since abundance data are available. The *distribution* class of indicator is also not assessed, because escapement enumeration methods generally do not provide the flexibility to assess distributional changes through time. Additional work is also required to determine how distribution affects a CUs extirpation risk and status. Therefore, only the *abundance* and *trends in abundance* metrics are considered for Fraser Sockeye status assessment.

Figure 1. Wild Salmon Policy status zones (red, amber and green) delieated by lower and upper benchmarks. Increasing spawner abundance and distribution is inversely related to to the extent of management intervention. Reprinted from Fisheries and Oceans Canada (2005).
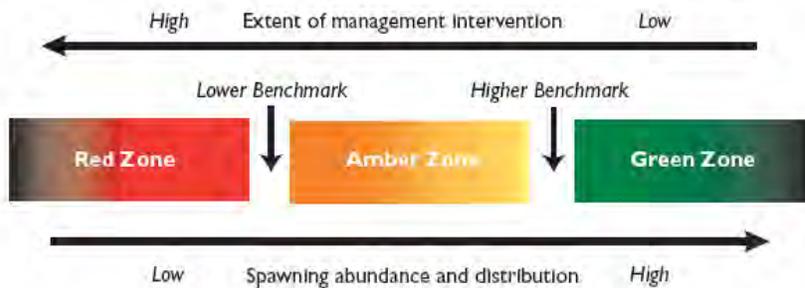
Figure 2. Hierarchy for the assessment of biological status of Conservation Units, including four classes of indicators, quantifiable metrics within classes, and benchmarks on each metric. Reprinted from Holt et al. (2009).
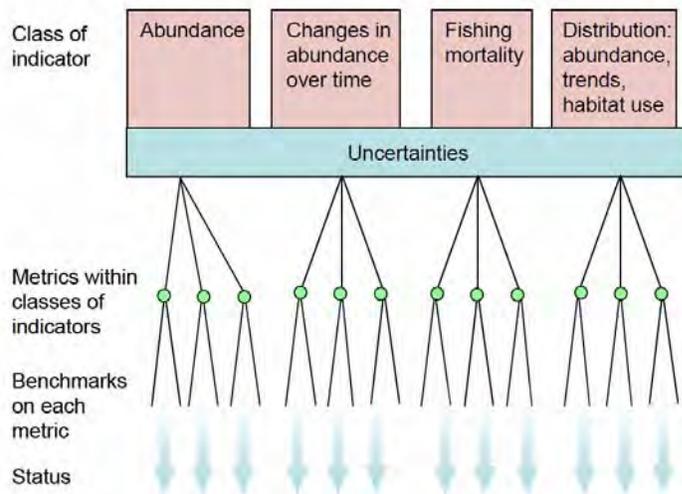
Holt et al. (2009) and Holt (2009) have identified benchmarks for *trends in abundance* indicators

(common across all CUs) and have developed a framework for estimating benchmarks for *abundance* indicators (unique to each CU). For *abundance* lower and upper benchmarks, Holt (2009) recommended using, respectively, S_{gen} (the spawner abundance that would result in recovery to maximum sustained yield (S_{MSY}) in one generation) and 80% S_{MSY}. Simulation modelling results indicated that, compared to other benchmarks, using S_{gen} (estimated using a Ricker model) as a lower benchmark was associated with a relatively low probability (<25%) of extirpation over 100 years for populations under equilibrium abundances (>15,000 spawners), and a relatively high probability (>75%) of recovery to the spawning abundance necessary to provide maximum sustained yield (S_{MSY}) in three generations (Holt 2009). The S_{gen} lower benchmark was also more robust to uncertainties in productivity than other benchmarks evaluated. Although the Larkin model that considers persistent delayed-density effects on abundance within the four-year cycles was recommended as a model form to explore by the CSAP Subcommittee (November 15/16 2011), this model was excluded from the current assessment. The Larkin model was excluded since model assumptions of constant abundances on a cycle through time are violated and the Ricker model benchmarks are relatively robust to extirpation risk and recovery. Therefore, only Ricker model forms were considered. Different forms of the Ricker model were included that consider recent decreases in productivity observed for many Fraser Sockeye CUs. Inclusion of the recent productivity specifically in benchmark estimation was important, given previous simulation modelling indicated that the risk of extinction at higher spawner abundances increased significantly in the case of linear declines in productivity, relative to all other productivity scenarios (stable, cyclic, linear increase) (Holt 2009).

The objectives of the current paper are to present the following information:

   A) background on Fraser Sockeye life-history, population trends, and threats;

   B) an updated list of Fraser Sockeye CUs, including 32 current CUs, 11 tentative CUs and 4 CUS proposed for deletion from the CU list (WSP Strategy 1, Action Step 1.1);

   C) history, escapement time series, trends in abundance, productivity, and abundance for all 26 assessible CUs; background provided for remaining 15 CUs.

   D) updated lake rearing maximum spawning capacity estimates used as prior values of carrying capacity in the estimation of *abundance* benchmarks in a Bayesian framework;

   E) evaluation of uncertainty in *abundance* benchmarks for each CU with stock-recruitment data and modified Holt et al. (2009) *trends in abundance* benchmarks (WSP Strategy 1, Action Step 1.2);

   F) for each CU, evaluation of status for each metric, including over a range of *abundance* benchmarks that reflect both structural and stochastic uncertainty (partially addresses WSP Strategy 1, Action Step 1.3).

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FRASER SOCKEYE BACKGROUND

SPECIES CLASSIFICATION AND DESCRIPTION

Sockeye salmon are one of the seven species of Pacific salmon. Sockeye salmon develop secondary sexual characteristics as they return to the spawning grounds, similar to other Pacific Salmon. Adult Sockeye spawning characteristics include bright red body coloration, olive green heads and tails, and an elongated snout. Spawning Sockeye are sexually dimorphic; males are distinguished from females by a fleshy back hump located between their head and dorsal fin, and a curved upper jaw with protruding canine-like teeth. The juvenile smolt stage is characterized by oval parr marks of irregular heights that largely occur above the lateral line (Pollard et al. 1997). In their ocean phase, Sockeye are silver-blue in coloration, have no spots on their back or tail, are slim and tubular, and can range in weight from 2.2 to 3.1 kg (maximum: 6.3 kg). More detailed descriptions of Fraser Sockeye are available (Foerster 1968; Hart 1973; Burgner 1991).

FRASER WATERSHED

The Fraser River supports the largest abundance of Sockeye salmon in the world for a single river (Northcote and Larkin 1989), due to its length (1,600 km), watershed size (223,000 km^2), and lake nursery area (2,500 km²) (Figure 3). Over fifty percent of all salmon production in British Columbia (over sixty-five percent for Sockeye) occurs in the Fraser watershed. From it's headwaters in the Rocky Mountains, the Fraser River follows the Rocky Mountain Trench to the Interior Plateau. It continues south to the Coast Mountains and drains from a broad floodplain into the Strait of Georgia. The Lower Fraser watershed and the Upper Fraser watershed are divided by the narrow Hells Gate canyon. Within the Fraser watershed there are hundreds of tributaries, steams, marshes, bogs, swamps, sloughs, and lakes. As a result of this large system, Fraser Sockeye spawning migration can range from tens to thousands of kilometres (Figure 3).

FRASER SOCKEYE LIFE HISTORY

Overview

The dependence of Sockeye salmon on specific lakes for juvenile habitat has resulted in a greater variety of life history patterns, relative to other species of Pacific salmon . Two key life-history types of Sockeye salmon include anadromous Sockeye (characterized by having both freshwater and marine phases), and kokanee (*O. nerka* that spend their entire life-cycle in freshwater). These two forms of *O. nerka* have diverged genetically (Taylor et al. 1996; Taylor et al. 1997; Foote et al. 1999; Craig and Foote 2001), and ecologically (Foote et al. 1999; Wood et al. 1999), and likely do not interbreed, due to differences in spawning times and anadromous female Sockeye mate selection, which favours the larger anadromous males (over the smaller non-anadromous males). The current paper focuses on the anadromous form of Sockeye Salmon, that spawn (and subsequently die) as adults in freshwater, incubate as eggs in gravel in the freshwater environment, and either migrate to the ocean shortly after gravel emergence as fry, or migrate to the ocean as smolts after rearing in freshwater lakes for one to three years. Anadromous Sockeye spend an additional one to three years rearing in the ocean as juveniles before they return to spawn.

Figure 3. Sockeye salmon freshwater distribution in the Fraser River watershed with key CU lakes identified (blue text). Heavy black indicates locations of Sockeye spawning.

Age Structure

Fraser Sockeye recruits can range in age from three to six years, spending from one (as eggs in gravel) to three winters in freshwater depending on the population. Most Fraser Sockeye, however, return to spawn as four-year-old fish (~80% of the total adult recruitment age composition), after spending two winters in the freshwater followed by two winters in the marine environment (age 4_2 based on the Gilbert Rich ageing convention). A smaller proportion (~20% of the total adult age composition) of five-year-old fish spend one extra winter in the marine environment (5_2). Fraser Sockeye are also comprised of a small component of three-year-old fish (typically called jacks/precocious males or jills/precocious females, although jills are far less common) that return to spawn after only one year in the ocean (age 3_2). One exception to this age composition occurs in Pitt River Sockeye (Pitt-ES CU), which predominantly return as five-year-old fish (~65% 5_2 out of the total 4_2 + 5_2's). For all CUs, there can be a very small proportion (1.6% out of the total recruitment) of fish that spend three winters in freshwater and varying lengths of time in the marine environment (ages: $4_3,5_3,6_3$). In recent years (1980 to present), maturation appears to have delayed, as returns are comprised of increasing proportions of four year olds relative to three year olds and five year olds relative to four year olds (Holt and Peterman 2004; Grant et al. 2010). Overall, however, four-year-olds continue to dominate recruitment for most stocks.

A major life-history variant occurs in the Harrison River (Lower Fraser River (River-Type) CU) and Widgeon Slough (Widgeon (River-Type) CU). Sockeye in these CUs are comprised of age-3 (3_1) and age-4 (4_1) fish that do not rear in freshwater lakes as juveniles. For the Lower Fraser River (River-Type) CU, the proportion of recruits that return as three or four year olds is highly variable, with higher percentages of age-4 fish (~65%) returning during odd years when pink salmon are also spawning in this system (Grant et al. 2010).

Adult Return Migration, Spawning, and Freshwater Residence

Fraser Sockeye return from the North Pacific to the Strait of Georgia via the northern Johnstone Strait or the southern Juan de Fuca Strait route. The proportion travelling through Johnstone Strait varies from 2 to 80% (Groot and Cooke 1987), and is affected by El Niño events, during which warmer water flows from the south cause higher diversion rates through Johnstone Strait (Groot and Quinn 1987).

The natural homing of Sockeye to their spawning areas is precise in both timing and location, more so than in other species of Pacific Salmon (Burgner 1991). Return migration timing is related to temperature regimes in the egg incubation areas, to ensure appropriate development and emergence timing of eggs and fry (Miller and Brannon 1982). The spawning period for Fraser Sockeye can range from July to October, and adults typically cease feeding as they enter the freshwater system (Burgner 1991; COSEWIC 2003b).

Adult Sockeye usually spawn in rivers, streams and along lake foreshores. Typical of the genus *Oncorhynchus*, eggs are deposited in nests constructed by the female, fertilized by a male or an opportunistic precocious male, and then subsequently covered with gravel by the female. Nests are dug in gravel that ranges in size from coarse sand to large angular rubble and boulders. Water depth ranges from 0.1 meters in small streams to over 30 m in lakes; water temperature ranges from 2 to $8°$ C. Eggs incubate in the gravel through the winter, with incubation duration and the timing of emergence mediated by ambient temperatures from mid-April to mid-May (Burgner 1991). Following emergence, the progeny of river spawners migrate in schools to the lake, where they move along the shoreline in shallow water before progressively moving offshore (Morton and Williams 1990). In Cultus Lake, the progeny of shore spawners immediately migrate into deep water (Brannon 1965). Juveniles rear in the lake for one to two

winters after gravel emergence. In most cases, fry rear in lakes immediately adjacent to their natal spawning streams, but exceptions have been documented. For example, fry from Gates Creek (and channel) initially enter Anderson Lake to rear; however, a variable and often substantial proportion of fry continue their migration through this lake to rear futher downstream, in Seton Lake (Geen and Andrew 1961). Similarly, an occasionally large proportion of fry from the Birkenhead River initially enter Lillooet Lake, then migrate through the lake to rear in Harrison Lake (Cave 1988). In both cases, the growth of fry in the second lake appears to be higher than in the original nursery lake (J. Hume, data on file).

Smolt Outmigration and Marine Residence
In the spring (April to June), Fraser Sockeye smolts move quickly downstream from their rearing lake, through the Fraser River and Fraser estuary and into the Strait of Georgia (Healey 1980; Tucker et al. 2009; Welch et al. 2009). Upon entry into the Strait of Georgia, most Sockeye migrate northward through Johnstone Strait and along the continental shelf before entering the North Pacific sometime between the fall and winter period (Tucker et al. 2009; Welch et al. 2009) (Figure 4). Stellako (Fraser-S CU) and Stuart (Stuart-S, Takla-Trembelur-S, Takla-Trembleur-Estu) Sockeye appear to leave the continental shelf somewhat earlier (in the fall) than all other stocks (Tucker et al. 2009). Based on a historical review of North American Sockeye stocks, juvenile Fraser Sockeye salmon in the North Pacific high seas (after they leave the continental shelf) are widely distributed in the Gulf of Alaska, between 48°N and 60°N and 125°E to 170°E (Forrester 1987) (Figure 4).

Lower Fraser River (River-Type) (i.e. Harrison River) Sockeye have unique ocean migration timing and migration routes. After emergence from the spawning gravel, Harrison Sockeye rear in sloughs for a few months prior to their downstream migration, and, as a result, enter the Strait of Georgia a few months after all other Fraser Sockeye (Birtwell et al. 1987). Also, unlike all other Fraser Sockeye, Harrison Sockeye rear in the Strait of Georgia for up to six months prior to migrating through the Southern Juan de Fuca Strait to the Gulf of Alaska (Taylor et al. 1997; Tucker et al. 2009).
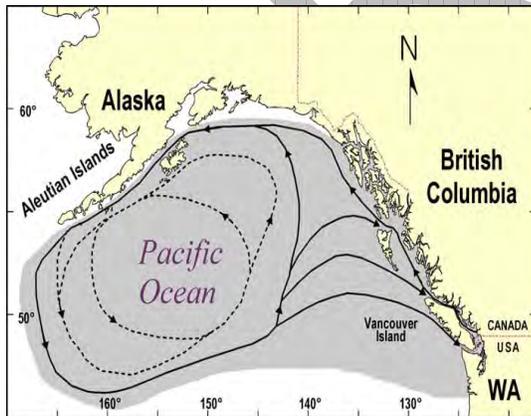
Figure 4. The open ocean migration pattern of Fraser River Sockeye salmon. Grey area is overall distribution, black lines are main routes and dashed lines indicate other areas covered (Migration patterns modified from French et al. (1976) & Healy (2002); reprinted from Johannessen and Ross (2002)).

POPULATION SIZE AND TRENDS
Cycles and Escapement, Catch and Return Trends

Fraser Sockeye predominantly return to spawn as four-year–olds, and for some of the large lakes in the Fraser River watershed persistent 4-year cycles of Sockeye abundance occur. Hypotheses on the presence of cyclic dominance include depensation due to overfishing (Collie and Walters 1987; Walters and Staley 1987; Walters and Woodey 1992); increased predation on the smaller subdominant cycles (Ward and Larkin 1964; Larkin 1971); or alternatively, reduction in spawning abundance, juvenile rearing habitat, or food availability on the off-cycles, due to high spawner or juvenile Sockeye abundances on the dominant cycles. A review of hypotheses is presented in Levy & Wood (1992).

Cyclic fluctuations in abundance have changed over time for Fraser Sockeye populations (Cass and Wood 1994; Ricker 1997; Myers et al. 1998). From 1892 to 1912, most Fraser Sockeye populations cycled synchronously, with one dominant cycle line occurring every four years, followed by three weaker cycle lines (Figure 5). The dominant cycle occurred on the 1901 cycle line (for reference this would have been the 2009 cycle), and appears to have persisted from as far back as the first reference to Fraser River Sockeye in 1793 (Fisheries and Oceans Canada 1998). During this early period of synchronous cyclic dominance (up to the 1913 Hells Gate slide), the Fraser was often considered to be the greatest Sockeye producer globally (Aro and Shepard 1967). Average returns from 1893 to 1913, on the 1901 dominant cycle, were 30.6 million Sockeye (Figure 5). Catch during dominant cycle years averaged 21.7 million, and escapement averaged 8.9 million (Figure 5). On the remaining three weaker cycles, during this period, returns (average: 5.3 million annually), catch (average: 4.6 million annually) and escapement (average: 0.7 million) were considerably lower than on the dominant (1901) cycle.

In 1913, construction work on the Canadian Pacific Railway line in the Fraser Canyon caused a major landslide at Hells Gate. The landslide created an almost complete barrier to the large Fraser Sockeye populations that migrate into the upper watershed (Figure 5). The slide was particularly devastating because it occurred on the synchronous dominant cycle year for all Fraser Sockeye populations. As a result, the original dominant cycle (1901) was lost (Figure 5). After the 1913 landslide, considerable restoration work was conducted at Hells Gate to permit upstream fish passage, and management actions were implemented to reduce overfishing and permit stocks to rebuild. Despite initial efforts, the run remained particularly low from 1914 to 1929 (average return: 2.4 million), while catch remained relatively high (2.1 million). After 1929, the run started to re-build slightly, with a dominant cycle occurring in 1930; however, the pattern of cycle line dominance was not as distinct as in earlier years (Figure 5).

Starting in the 1980's, the total Sockeye run built to a maximum return of 23.6 million (1993), and subsequently declined. Highly cyclic stocks, during this recent period, included the Shuswap early summer and late runs (dominant cycle year: 2010), Quesnel, Early & Late Stuart (dominant cycle year: 2009) and Nadina & Gates (dominant cycle year: 2008). In the most recent years of available data, returns have been particularly small (from 2007 to 2009 average return: 1.3 million; average escapement: 0.9 million; average catch: 0.4 million). In 2009, extremely low returns corresponded with the lowest productivity on record for most Fraser Sockeye stocks (Grant et al. 2010). In contrast, preliminary returns in 2010 were relatively high (~30 million preliminary returns as of October 11, 2010), and corresponded with above average productivity. The mechanisms that produced the anomalously low returns of 2009 and the extremely high returns of 2010 remain uncertain, and are the subject of on-going scientific research.

Figure 5. Escapement (white bars), catch (black or grey bars), and difference between estimates (DB Sockeye. The 1901 (corresponding to 2009 in recent years) dominant cycle is represented by the g each annual bar represents the total return. The DBE is the difference between the in-season hydroa BC and the spawning ground escapements plus in-river catches, and represents en-route loss and as vertical line represents the division between early time series data (1982-1944), constructed by Gilho harvest data, and post-1944 data from the PSC and DFO records. Preliminary 2010 returns are indica of the time series. This time series data was provided by I. Guthrie & M. Lapointe from the PSC.

Productivity and Survival

Overall productivity (recruits-per-effective total spawner) for Fraser Sockeye was generally high up to the mid-1980's, and has subsequently declined (Figure 6 A), in some years falling below replacement for certain stocks. The overall productivity trend is driven by the most abundant CUs, which are largely Summer Run CUs (Chilko-ES/Chilko-S, Quesnel-S/McKinley-S, Fraser-S (Stellako) and Takla-Trembleur-S/Stuart-S (Late Stuart)) that coincide with increases in escapement (Figure 6B). Amongst the remaining individual CUs, however, there is considerable variability in productivity trends (Grant et al. 2010).

Most CUs have experienced a general decreasing trend in productivity; however, the timing of when this trend began differs amongst stocks. Seven CUs have experienced decreasing trends since the 1960's-1970's (Takla-Trembleur-Early Stuart, Bowron-ES, Kamloops-ES, Anderson-ES, Francois-ES, Shuswap-ES and Seton-L). Six CUs, including the four Summer Run CUs, have experienced decreasing trends starting in the 1980's-1990's (Pitt-ES, Chilko-ES/Chilko-S, Takla-Trembleur-S/Stuart-S, Quesnel-S/McKinley-S, Fraser-S and Lilooet-L). Raft (a population in the Kamloops-ES CU), Shuswap-L and Harrison (U/S)-L (Weaver Creek & Channel) have not exhibited any persistent trends, while Lower Fraser River (River-Type) is the one exception that has exhibited an increasing trend (with the exception of the 2005 brood year, which exhibited the lowest productivity on record) (Grant et al. 2010).

To understand which broad ecosystem is driving changes in CU productivity, total survival can be partitioned into freshwater and marine survival, when both outmigrating smolt and adult return data are available. For Fraser Sockeye, only Chilko-ES/Chilko-S and Cultus-L Sockeye CUs have both smolt and adult return data. Most mortality in Fraser Sockeye occurs in the freshwater environment between the egg to smolt stage. On average, 4 billion ($\pm$ 3 billion) eggs are laid per year, based on the total annual number of Fraser Sockeye effective female spawners (EFS) multiplied by their average fecundity (3,500 eggs/EFS). Freshwater survival (egg to smolt), as indicated by Chilko River Sockeye, has been 3% on average, which is one third the average marine survival (smolt to returning adult) of 9%. It is important to also note that marine survival estimates generally include some freshwater mortality, encountered in the Fraser River between the time smolts are counted exiting their rearing lakes and when they enter the marine environment.

Chilko-ES/Chilko-S freshwater production has been exceptional in recent years; numbers of outmigrating smolts in the 2005 (77 million age-1 smolts) and 2006 (71 million age-1 smolts) brood years were well above average (1980-2006 brood years: 24 million age-1 smolts) (Figure 7 A). For Cultus-L, although the number of effective female spawners (EFS) has been particularly low in recent years, hatchery supplementation of both fry into Cultus Lake and smolts into Sweltzer Creek (downstream of Cultus Lake) has increased the number of outmigrating smolts to above average in the recent time series. However, both Chilko ES/Chilko-S and Cultus-L have experienced particularly low marine survival (below their cycle average) in the past four to eight brood years (Figure 7 B).
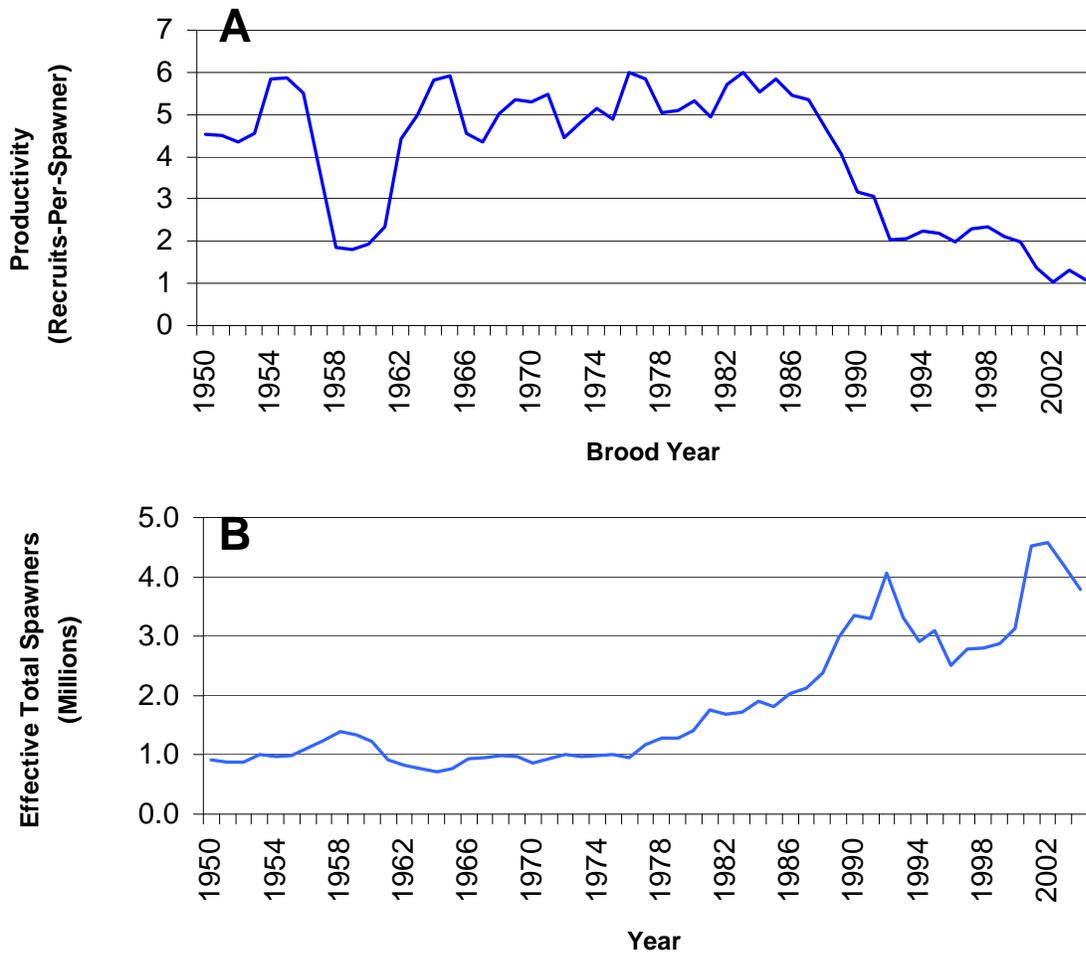
Figure 6. A) Four-year running average productivity in recruits (age-4_2 plus age 5_2)-per-effective-total-spawner, and B) Escapement (effective total spawners) for Fraser Sockeye CUs. These trends are driven by CUs that dominate total abundance (Quesnel-S/McKinley-S, Chilko-ES/Chilko-S, Takla-Trembleur-S/Stuart-S, and Fraser-S). Other CUs exhibit variables productivity trends {Grant, 2010 309 /id}.
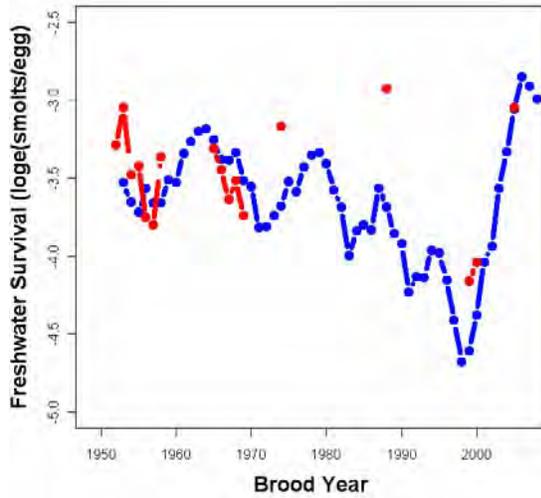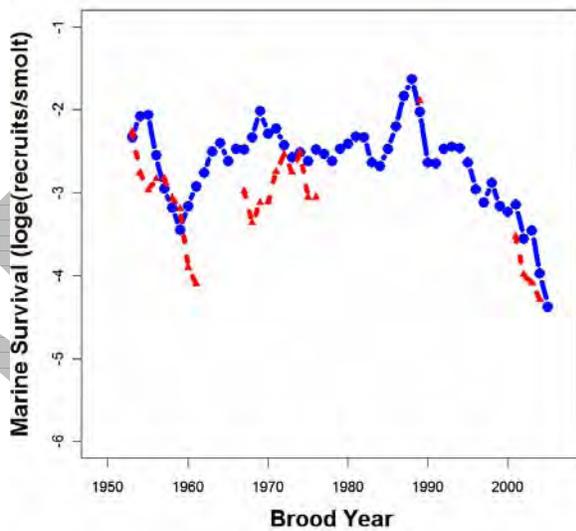
Figure 7. A) Chilko-ES/Chilko-S freshwater survival (log$_e$ smolt-per-eggs; eggs; effective female spawners X average fecundity of 3,000 eggs/female). B) Chilko-ES/Chilko-S (blue solid line with circles) & Cultus-L (red dashed line with triangles) marine survival (log$_e$ recruits-per-smolt) from the 1951-2005 brood years. Note: the 2004 and 2005 brood year marine survival data include preliminary 2009 and 2010 age-4 and age-5 return data (these years are current in the process of being finalized). Cultus-L freshwater production includes wild production only. Re-printed from Grant et al. (2010)

FRASER SOCKEYE POPULATION STRUCTURE

Genetics

The last glacial period is likely a major factor in the structure of current Fraser Sockeye populations overall. Two major glacial refugia influenced the current Fraser Sockeye population structure: the Cascadia refugia, and the Beringia refugia (Wood et al. 1994; Withler et al. 2000; Beacham et al. 2005). Post-glaciation, the lower Fraser River was likely colonized by Sockeye moving in from the coastal North-Eastern Pacific (Beringia refugia), while the upper Fraser was likely colonized by Sockeye from the Columbia and Skeena Rivers (Cascadia refugia)(Wood et al. 1994). Recent genetic evidence has confirmed these two lineages for Fraser Sockeye (Beacham et al. 2005).

The next major event to affect Fraser populations (particularly upper Fraser), since the last glacial period, was the 1913 Hells Gate landslide, which blocked Fraser Sockeye passage, and dramatically reduced upper Fraser populations. This event, in combination with relatively large fisheries, nearly extirpated Upper Fraser populations (Ricker 1950). Since this period, despite both reduced population sizes and hatchery enhancement work in the Upper Fraser, there is little evidence that genetic bottlenecks (lower genetic variation) have occurred in Upper Fraser populations. Generally, transplants contributed little to the genetic variation of Fraser populations, with the exception of the upper Adams River, Fennell Creek and Portage Creek Sockeye (Withler et al. 2000). The main factor contributing to the current genetic structure of Fraser populations is post-glacial colonization, and limited straying from nursery lakes (Withler et al. 2000).

Run-Timing

==Barry's comment is structure changed over time:==The run timing groups of Fraser Sockeye were established for fishery management purposes, and therefore consist of populations with similar migratory timing during their return from the ocean to the spawning grounds. The earliest timed run is the Early Stuart Run, which is comprised of one Fraser Sockeye stock (Early Stuart) that spawns in the Stuart-Takla watershed, and arrives in the lower Fraser River from late-June to late-July. The Early Summer Run, comprised of eight key stocks (Bowron, Fennell, Gates, Nadina, Pitt, Raft, Scotch, Seymour) and a number of smaller stocks rolled up into an early summer miscellaneous group, spawn throughout the Fraser system, and arrive in the river from mid-July to mid-August. The Summer Run consists of four stocks (Chilko, Late Stuart, Quesnel and Stellako) that arrive in the river from mid-July to mid-September. The last run timing group to enter the Fraser watershed is the Late Run, which is comprised of six key stocks (Cultus, Harrison, Late Shuswap, Portage, Weaver, Birkenhead) and a number of smaller stocks rolled up into a miscellaneous late run group, all of which enter the Fraser from August to mid October. From 2002-2009, the Birkenhead population was separated from the Late Run group because their timing was more similar to Summer Run stocks, and because they did not exhibit pre-spawn mortality shown by other Late Run stocks. However, starting in 2010, Birkenhead sockeye were re-integrated into the Late Run group because their timing had shifted to later than most Late Run stocks. The Summer-Run timing group typically dominates return abundances (Fisheries and Oceans Canada 2006;Fisheries and Oceans Canada 2008;Fisheries and Oceans Canada 2009), with the exception of the 2006 cycle, which is the dominant cycle for the Adams River Sockeye run (Shuswap-L CU) (Grant et al. 2010). However, these two groups (Summer Run and Adams River Sockeye) overlap considerably in their timing.

Conservation Units

Methodology for the identification of conservation units for Canada's salmon stocks in British

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Columbia (DFO's Pacific Region) is detailed in Holtby & Ciruna (2007). Generally, Fraser Sockeye were first partitioned into two major life-history types: lake-type (rear in freshwater as juveniles for one to three years) and ocean-type (migrate to the ocean after gravel emergence). Run-timing (for lake-type Sockeye), genetics, and freshwater-marine joint adaptive zones (for river-type Sockeye) were further used to identify and name individual CUs.

Lake-type CUs are comprised of Sockeye populations that meet a number of criteria. Specifically, lake-type CUs include Sockeye populations observed in or above a lake (lakes were larger than ~0.5 km^2) or at a lake outlet where there were no barriers to fish passage into the lake. There are cases where clusters of hydrologically connected lakes (<1 km^2) are combined into a single CU unless evidence existed to indicate these populations were genetically or ecologically distinct. For example, Shuswap Lake, Adams Lake and Momich Lake Early Summer timed Sockeye populations are combined into a single CU, due to genetic similarities between these populations, largely attributed to the use of Shuswap Lake hatchery transplants to rebuild the Adams and Momich Lake populations. Run timing is also used to distinguish between lake-type Sockeye CUs, particularly where there is no temporal and/or spatial overlap between different run timing groups. Where data are available, lake-type Sockeye CUs are further partitioned into upstream (e.g. Weaver Creek and Channel populations that migrate upstream as fry to rear in Harrison Lake) and downstream lake migrants (e.g. the Big Silver population that migrates downstream as fry to rear in Harrison Lake as juveniles). Lake-type CUs are named after their juvenile rearing lake, followed by their adult return run timing to the Fraser River (Early Stuart: EStu, Early Summer: ES, Summer: S; Late:L). For example, Sockeye that rear in the Stuart River complex and comprise the Early Stuart Run timing group are named Takla-Trembluer-EStu (Holtby and Ciruna 2007).

River-type CUs do not meet the criteria outlined above for lake-type CUs, as these Sockeye do not rear in Lakes after emergence from gravel. Instead, river-type Sockeye migrate to the ocean shortly after emergence from the gravel. These CUs are named according to the freshwater adaptive zone they occupy, and their life-history type. For example, river-type Sockeye that spawn in the Harrison River and migrate to the ocean after they emerge from the gravel are named Lower Fraser River (River-Type) (Holtby and Ciruna 2007).

THREATS
The number of salmon that return to the Fraser River in any given year is determined by the number of effective spawners in the parental generation (specifically the number of eggs deposited in spawning gravel), their age of maturity when they return, and survival from the egg stage through to adult returns. Considerable mortality occurs in both the freshwater and marine environment during the egg stage (egg incubation in lake or stream gravel), fry stage (lake rearing), smolt, and juvenile stages (downstream migration in the Fraser, Strait of Georgia ocean entry, and rapid northward migration through the Johnstone Strait, along the continental shelf to the North Pacific). Mortality can also occur in the adult stage prior to spawning, either en-route to the spawning grounds in the Fraser River, or on the spawning grounds (pre-spawn mortality). In addition, direct removal of adults through fisheries reduces the number of fish that reach their natal streams and rivers to spawn. A number of threats to salmon stocks in general, and to Fraser Sockeye populations in particular, have been identified and include the following: fisheries, environmental conditions in the freshwater and marine environments, en-route and pre-spawn mortality, habitat alteration, exotic species, and pathogens and disease.

Fisheries

Management: past & present

From 1946-1984 the International Pacific Salmon Fishery Commission (IPSFC) was responsible for management of Canadian (British Columbia) and United States (Washington State) fisheries in an area known as the Convention Area. The total allowable catch (TAC) of salmon in this area was shared equally between Canada and the United States. Since 1985, following the Pacific Salmon Treaty, the Fraser River Panel (FRP) of the Pacific Salmon Commission (PSC) has regulated management of Fraser Sockeye fisheries in Panel Area waters (updated January 27, 2009: **http://www.psc.org/pubs/Treaty.pdf**) (Figure 8). The Fraser River Panel is comprised of Canadian and U.S. representatives, and its purpose is to ensure that spawning escapement targets for each major stock or stock group, set by Canada as well as international and domestic allocation goals, are met **(Fisheries and Oceans Canada 1998)**. Under the Treaty, the U.S. share of the Fraser Sockeye harvest has gradually decreased; under the current annex it is 16.5% of international TAC. DFO is responsible for management of the Canadian fisheries outside the Panel area, but must coordinate actions with the Fraser Panel (FRP) to ensure that escapement and allocation objectives are met (Figure 8). Annually, DFO produces a Southern B.C. Salmon Integrated Fisheries Management Plan (IFMP) for all salmon fisheries in BC waters, which incorporates the results of consultations, and input from First Nations, commercial and recreational sectors, as well as environmental NGOs. The IFMP provides specific decision rules for a number of salmon fisheries, including those directed at Fraser River Sockeye (see IFMP's on the following DFO Website: **http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/MPLANS/MPlans.htm**).

Management of Fraser River Sockeye is highly complex, since there are a number of stocks (~19 major groups), with inter-annual differences occurring in stock composition, abundance, and migration timing. Under the terms of the Treaty, fisheries are managed using information on four run-timing aggregates: Early Stuart, Early Summer, Summer and Late. Typically, several stocks will co-occur in the primary fishing areas because of similarities in the marine arrival and upstream migration timings of different stocks. In addition, the diversion rate (proportion of Fraser Sockeye stocks approaching the Fraser River via the northern route through Johnstone Strait) varies considerably both within and between years. For these reasons, and because of the different escapement objectives for each stock, Fraser Sockeye management decisions frequently involve trade-offs between harvest and meeting the escapement objectives of the various stock-groups. For example, it is not uncommon for some fraction of the harvest of more abundant stocks to be foregone to protect less abundant stocks with similar migration timing.

Fishing plans for Sockeye are based initially on pre-season forecasts of stock abundance, diversion rates (through Johnstone Strait versus Juan de Fuca Strait), and migration timing. Typically, contingency plans are developed on a range of forecast values, including potential forecasts that are both lower and higher than the median predictions. Pre-season plans are later refined by in-season estimates of return abundance, derived from relative abundance indices in test fisheries, estimates of lower river escapements from the PSC hydro-acoustic facility at Mission (BC), data from other sources of harvest, as well as stock composition analysis. Fishery openings and closures in Panel waters are managed by the FRP to achieve target escapement levels for the four run timing groups. Canada co-ordinates its Fraser Sockeye fisheries outside Panel waters to ensure they are consistent with international and domestic objectives. Both Canada and the U.S. adjust fisheries directed at Fraser Sockeye to minimize interceptions of non-target species such as Pink, Chum, Chinook, Coho and Steelhead salmon, and to limit catches of stocks of concern, such as interior Fraser Coho, Steelhead, Sakinaw and Cultus Sockeye. Throughout the fishing season (June to late September), estimates of Sockeye run size and stock composition are constantly revised, and management responds with adjustments

to fisheries decisions (based on changes in run estimates, spawning escapement objectives, gross escapement objectives, and available TAC). Gross escapement objectives include the spawning escapement targets plus any in-river catch requirements, and an additional factor called a management adjustment. Management adjustments are additions to the spawning escapements targets that ensure that the number of fish reaching spawning areas will reach desired levels. Management adjustments account for both systematic differences between upper and lower river escapement estimates, as well as in-river migration conditions. River migration conditions are monitored daily, and management adjustments are updated frequently during the in-season period based on the combination of observed and forecasted river conditions.

Information on in-season changes are provided on the PSC website: www.psc.org/news_frpnews.htm and through DFO Fisheries Notices: http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/fns/index.cfm?pg=search_options&lang=en&id=recreational.
After each fishing season, Panel management decisions and strategies are assessed to determine if goals were met, and to look at options for improving management, data collection, and analysis techniques.

Catch History
The first cannery was built on the Fraser River in 1866, spurring rapid development of the commercial gillnet fishery. Relative to total returns, this fishery was particularly intense on the subdominant cycles, as compared to the 1901 (2009 if this persisted to present) dominant cycle (Figure 5). It is likely that fisheries exaggerated the cyclical pattern of return abundances, due to depensatory exploitation rates. Prior to 1913, catches ranged from 1.8 to 32.3 million (Figure 5). After the Hells Gate landslide, upstream passage was greatly restricted several years, and subsequent overfishing further constricted Sockeye abundances. As a result, catches declined to an average of 1.9 million fish from 1915-1930 on all cycles (Figure 5) (Fisheries and Oceans Canada 1998). Exploitation rates (catch/total return) were again high from 1950 to the mid-1990s (average: 75%), and have subsequently declined (average: 34%). The highest catch since 1958 occurred in 1993 (17.8 million Fraser Sockeye caught), with 95% of this occurring in marine areas. In very recent years (2007-2009), catches have been the lowest on the time series (average: 2.5 million), due to extremely low returns in these years. During these years the majority of harvests in Canada were allocated to meet First Nation's FSC (food, social and ceremonial) needs. However, on larger return years, most catch still occurs in the marine areas; the majority of the Canadian commercial harvest is caught in the troll fisheries, the purse seine and gillnet fisheries in Johnstone and Juan de Fuca Straits, and the gillnet fishery in the Fraser River. Additional commercial catch occurs in smaller commercial fisheries in northern and central B.C. that occasionally intercept Fraser River Sockeye, and in a few directed fisheries in the Strait of Georgia that primarily target late-run Fraser stocks. Other Fraser Sockeye catch occurs in the native food fisheries that operate throughout the Fraser River watershed, and in the recreational fishery, which has increased its catches since the mid-1990's, with the development of the in-river fishery upstream of Mission. U.S. catches mainly occur in net fisheries in the southern approaches to the Fraser River, specifically the US waters in the Juan de Fuca Strait, near the San Juan Islands, and south of Point Roberts. Some Fraser Sockeye are also taken incidentally in southeastern Alaska. US catches are generally small, averaging at 18% of total catch since 1993.
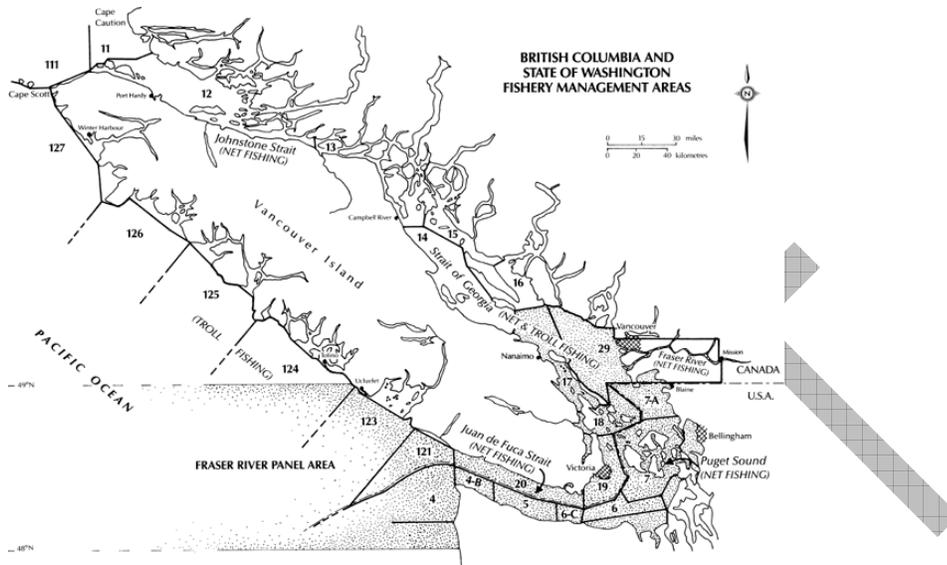
Figure 8. British Columbia and Washington fishery management areas http://www.psc.org/ including Fraser River Panel Area waters (shaded grey).

Environmental Conditions (Freshwater Author: M. Hague, Science, DFO)

Freshwater Environment

Freshwater life history stages account for a significant portion of overall mortality, and variation in total mortality (>40%), in Sockeye salmon species, with average survival from the egg to smolt stage estimated at only 2% (Bradford 1995). The transition and migration between habitats at critical life stages expose Sockeye salmon to high levels of mortality; mortality estimates for egg to fry in Takla River ranges from 60% to 90% (Patterson and Hague 2008); estimates of mortality during smolt outmigration have been estimated at >50% for Cultus and Chilko Sockeye smolts (Welch et al. 2008)(Hinch, UBC, pers. Comm.); and premature mortality during freshwater migration and spawning routinely exceed 20% (Gilhousen 1990; Peterman et al. 2010). The combined effects of mortality in different freshwater life history stages have ultimately been linked to overall changes in productivity and abundance of salmon populations. Rates of population decline and variability in total survival have sometimes been attributed, in part, to indices of freshwater habitat condition (Bradford and Irvine 2000; Mueter et al. 2005).

In contrast to the marine environment, specific freshwater processes controlling survival are generally well identified. During the egg development stage, survival has been directly linked to water quality issues, such as temperature, sedimentation, metals, and dissolved oxygen in the spawning environment {Levasseur, 2006 388 /id;Greig, 2007 383 /id}. Scouring by high winter flows (Steen and Quinn 1999) or dewatering due to low water levels (Neitzel and Becker 1985) are also a concern. Estimates of productive capacity for Fraser Sockeye lakes have been forecasted from photosynthetic rate models (Shortreed et al. 2001), and can be used as an index of lake rearing suitability. Recent studies show that density-dependent growth rates of fry are also mediated by interactions with lake temperature (Crozier et al. 2010). There is no direct data linking smolt survival with environmental conditions for Fraser Sockeye, but other studies have shown positive relationships between spring flows and smolt outmigration survival (Kjelson

and Brandes 1989). Adult spawning migration survival is a function of both acute and cumulative impacts largely mediated by exposure to extreme temperatures and flows (Gilhousen 1990; Wagner et al. 2005; Crossin et al. 2008; Macdonald et al. 2010; Mathes et al. 2010).

There are a multitude of factors influencing salmonid freshwater survival, but temperature indices are often used to summarise the overall quality of freshwater habitat (Nelitz et al. 2007) since many physiological and phenological processes are related to thermal conditions (Brett 1971). Furthermore, significant trends in warming freshwater temperatures (Quinn and Adams 1996; Foreman et al. 2001; Patterson and Hague 2007; Patterson et al. 2007a; Patterson et al. 2007b) and changes in hydrology (Rodenhuis et al. 2007; Pike et al. 2008) are consistent with changes in river entry timing and behaviour for salmon populations in the Columbia River system (Quinn et al. 1997; Goniea et al. 2006), as well as an increased frequency of high en route loss events for Fraser River Sockeye salmon (Hague and Patterson 2009; Macdonald et al. 2010). Despite basin-wide temperature increases, and the role of temperature in mediating growth and survival at juvenile life stages, the limited data available shows no consistent trends across populations. Similarly, the increase in water temperatures and the expected changes in the timing of migration for fry (e.g. Stuart/Takla DFO data), smolts (Mission timing DFO data), and adults (Late run) have not occurred.

There is a general consensus that the Fraser River will continue to warm throughout the 21st century and will likely shift from a predominantly snowmelt to a rainfall driven system (Morrison et al. 2002; Ferrari et al. 2007; Nelitz et al. 2009). These changes could alternatively be exacerbated (pine beetle, forest harvest, groundwater) or potentially mitigated by anthropogenic activities occurring during the same time period (Nelitz et al. 2009; McDaniels et al. 2010). Climate change has the potential to impact all salmon freshwater life history stages, however, experts have identified the fresh water egg-to-fry and adult spawning migration as being the most susceptible (McDaniels et al. 2010). If warming trends continue as anticipated, the majority of Fraser River Sockeye salmon populations are generally expected to suffer from increases in the frequency and magnitude of en route loss events (Hague et al. 2010; Martins et al. 2010), and we may also anticipate basin-wide declines in egg and fry survival (McDaniels et al. 2010).

Marine Environment
In addition to freshwater conditions, ocean environmental conditions are believed to contribute to both large interannual variations in productivity (recruits-per-spawner) of salmon as well as decade-long persistent changes in average productivity (Mantua et al. 1997; Beamish et al. 1997; Beamish et al. 1999; Beamish et al. 2004b). The mechanisms that link changes in climate to changes in salmon productivity are poorly understood. However, it is generally thought that salmon are most vulnerable in the first six months of ocean entry (early ocean entry to over-winter mortality) when they are their smallest size and, therefore, most vulnerable to the two major mortality mechanisms, predation and starvation (Beamish and Mahnken 2001). In particular, it is hypothesized that during the early ocean entry period salmon are particularly vulnerable to predation due to their small size, and that during their first ocean over-winter period they are most vulnerable to starvation and that reaching a critical size is the key to over-winter survival (Beamish and Mahnken 2001). For Fraser Sockeye, given that almost all populations appear to enter the Strait of Georgia as smolts and then rapidly migrate northward through the Johnstone Strait, along the continental shelf and out into the North Pacific (Tucker et al. 2009; Welch et al. 2009), there is a broad area over which these fish will be particularly vulnerable to early marine mortality.

Longer-term fluctuations in salmon population have been linked to broad changes in ocean climate that start with changes in major pressure systems over the Pacific, affecting ocean temperatures and productivity. Two key indices of the climate-ocean system include the Aleutian Low Pressure Index (ALPI) (Beamish et al. 1997) and the Pacific Decadal oscillation (PDO) (Mantua et al. 1997). Positive ALPI (a measure of the intensity of the Aleutian Low pressure system in the North Pacific) indicate large Aleutian Lows and decreased upwelling along coastal North America; negative values indicate the opposite. Positive PDO (an index of sea surface temperatures in the Pacific) indicate warmer temperatures along the west coast of North America and cooling in the central Pacific; negative PDO's indicate the opposite. In summary, positive ALPI and negative PDO's represent improved ocean conditions for salmon. There has been evidence of major shifts in these indices in 1925, 1947, 1977, 1989 (ALPI only), and 1998 (Beamish et al. 1997; Beamish et al. 1999; Beamish et al. 2004a; Beamish et al. 2004b; Beamish et al. 2004c). Specifically, 1977 to 1988 was a productive period for Sockeye Salmon (Beamish et al. 2004b) followed by a period of decreased productivity in the 1990's. This coincides with a period of increasing numbers of returning Fraser Sockeye up to the mid-1990's and a subsequent decrease in abundance (Figure 5). In addition to broader changes in ocean conditions, regional-scale factors such as sea-surface-temperature have also been used to predict survival rates in salmon (Mueter et al. 2002; Mueter et al. 2005).

Despite these linkages to broad scale and regional climate patterns in the ocean, predicting future survival of Fraser Sockeye salmon remains a challenge (Haeseker et al. 2008; Grant et al. 2010). There is likely a complex set of conditions in both the freshwater and marine environment (temperature, food availability, and predation) covering a broad temporal and spatial scale, that determines survival and total recruitment for Fraser Sockeye stocks. These conditions likely vary interannually, and therefore, no one factor such as food availability in their natal rearing lake or sea-surface-temperature in the Strait of Georgia is sufficient to explain variability in Fraser Sockeye recruitment.

Early Migration and Pre-Spawn Mortality (Author: D. Patterson, Science, DFO)
En Route Mortality
Each year a variable portion of Sockeye salmon perish during their upstream migration. Mortality estimates for Fraser Sockeye salmon, based on discrepancies between lower river and spawning ground escapement estimates (adjusted for catch), range from 0% to 90%, with annual mean estimates for Early Stuart, Early Summer, Summer, and Lates averaging 50%, 50%, 20%, and 40%, respectively, from 1992 to 2009 (PSC data). This en route loss the result of an interaction of physical (water temperature, discharge, sediment, harvest) (Macdonald 2000; Macdonald et al. 2000; Crossin et al. 2008; Macdonald et al. 2010; Mathes et al. 2010) and biological factors (energy status, disease condition, pathogens, predators, and cumulative stress) (Wagner et al. 2005; Young et al. 2006; Cooke et al. 2006; Farrell et al. 2008; Bradford et al. 2010a). The relative contribution and interaction among these factors varies on an annual basis, and is mediated by the over-arching influence of water temperature. The current increasing trends in Fraser River temperatures (Patterson et al. 2007a), and the predicted rise in water temperatures and changes in hydrology anticipated from climate change (Morrison et al. 2002; Ferrari et al. 2007) are linked to recent increases in en route mortality (Farrell et al. 2008) and are forecasted to have a continued impact on a population specific basis (e.g. (Hague et al. 2010; Martins et al. 2010).

Pre-Spawn Mortality
The historic pre-spawn mortality (PSM), quantified as population estimates of the percentage of egg retention in female carcasses recovered from the spawning grounds, for Fraser Sockeye

salmon populations averages ==from 10 to 15% across populations==, with extreme events (>40%) being episodic and highly variable among stocks. The causes and associations of PSM are complex and multi-factorial (Gilhousen 1990) and include pathogens, high stress and low energy, and longevity on spawning grounds (Macdonald et al. 2000; Macdonald et al. 2007; Crossin et al. 2008; Bradford et al. 2010b; Bradford et al. 2010c). Again, most of these factors are accentuated by increasing temperatures and increased time spent in freshwater. Therefore, it is not surprising that within-stock trends in PSM are correlated with migration timing and/or migration and spawning ground temperatures (Gilhousen 1990). Correlations with temperature also improve with proximity to spawning ground (Macdonald et al. 2007). While there are no consistent trends across stocks, there is some evidence that PSM has been higher and more variable in recent years for Late run stocks (Hinch 2009), and in 2008 a system-wide PSM event resulted in overall poor egg retention of 64% (DFO data).

Late Run

An extreme example of a threat to Sockeye salmon from both en route and pre-spawn mortality comes from a closer examination of Late-run Sockeye populations over the past 16 years. During this time period, Late-run Sockeye have on average entered the Fraser River approximately 3-6 weeks earlier than normal without a change in spawning dates (Lapointe *et al.* 2003; Cooke *et al.* 2004). The early entry is a result of a reduced holding period in the Strait of Georgia, as marine approach times have not changed. This has resulted in Late-run Sockeye being exposed to higher en route migration temperatures, associated with late August/early September arrivals, for longer periods of time. The combination has contributed to high en route loss estimates (especially for the early entrants (English *et al.* 2005)) and high PSM values in recent years. While the causes for the shift in early entry behaviour have proved elusive (Hinch 2009), the consequences have been well documented. In 2009 and 2010, however, Late-run Sockeye reverted to more normal entry timing.

Habitat Alteration (Authors: J. Hwang & B. Fanos, OHEB, DFO)

Fraser Sockeye have specific habitat requirements during their freshwater life-history stages, which span from their entry into freshwater and upstream migration to spawning grounds as adults, incubation in lake or river gravel as eggs, and rearing in lakes as juveniles, to their downstream outmigration as smolts enroute to the Pacific Ocean. In fact, considerable mortality throughout the entire life history occurs in the freshwater environment. On average 4 billion (± 3 billion) eggs are laid each year (assuming an average fecundity of 3,500 eggs multiplied by effective female spawners). For Chilko Sockeye, the only Fraser Sockeye indicator system where total survival can be partitioned into freshwater and marine survival, freshwater survival (egg to smolt) has been on average 3% and marine survival (smolt to returning adult) has been on average 9%. Habitat alteration in the freshwater may impact freshwater survival and, therefore, total recruitment for Fraser Sockeye.

Overall, the Fraser Watershed (223,000 km^2) is covered by 5,100 km^2 of urban area (concentrated in the Lower Mainland) and 1,510 km^2 of agricultural area (Gray and Tuominen 1999). The greatest concentration of human development within the Fraser watershed occurs in the Lower Mainland near the outlet of the Fraser River (83% of total development in the Fraser watershed) (Schreier *et al.* 1991). Throughout the watershed, however, urban development, transportation corridors, agricultural and forestry land-use, recreational land and water-use, water extraction, etc. represent risks to Fraser Sockeye during their freshwater residence.

Water quality issues have not been identified as a watershed-wide concern for Fraser Sockeye. However, there are localized water quality issues that could be of concern to Fraser Sockeye in the freshwater. In particular, all Fraser Sockeye populations must migrate through the highly

urbanized Lower Fraser River area during both their upstream migration as adults and their downstream outmigration as juveniles. In this area, they may be exposed to contaminant inputs from point sources (e.g. waste-water treatment plants) and non-point sources (e.g. urban run-off) that can result in fish mortality or may interfere with migration timing, homing behaviours, and physiological transitions into the marine or freshwater environment. Sources and contaminants in the Strait of Georgia are presented in detail in Grant and Ross (2002) and those in the Fraser watershed are found in Johannessen and Ross (2002). Details on specific risks and impacts to Fraser Sockeye are also documented (Johannessen and Ross 2002). Other localized impacts also occur, particularly in lake environments with foreshore human development such as Cultus Lake and Shuswap Lake (Main Arm), where agricultural runoff, foreshore septic systems, houseboats and other lake recreation can input deleterious substances into the lake environment. Recent studies in Shuswap Lake, for example, have detected notable declines in water quality.

Gravel removal for flood control, which has occurred in recent years in the Lower Fraser River (downstream of the Fraser Canyon) between Hope and Mission, has been flagged by stakeholders as a concern to Fraser Sockeye. However, currently there is no indication that gravel removal impacts Fraser Sockeye during their upstream migration as adults or downstream migration as smolts.

In the Upper Watershed (above the Fraser Canyon), forestry is the single largest land use activity. Observed land-use issues related to forestry have included stream crossings impairing fish migration, sediment input, riparian vegetation impacts etc. Generally, however, habitat issues related to forestry have not been regarded as significant issues to Fraser Sockeye. More recently, the Mountain Pine Beatle (MPB) (*Dendroctonus ponderosae)* has represented a major issue related to forests and forestry in the upper watershed as it expands its range due to milder winters. The MPB has affected a significant portion of the Fraser watershed by killing huge areas of forest. The change in forest coverage due to both the MPB killed trees and resultant salvage logging is predicted to cause significant hydrological changes in the watershed, changing the nature and timing of peak flows, low flows and temperature regimes, and has the potential to change riparian communities and sedimentation.

Water use and withdrawal for human use, occurring particularly in the Upper Fraser Watershed, has been identified as a concern for certain waters that support Sockeye. Due to increasing demands for water, reduced supply due to climactic variability, and the existence of long-standing historical water rights, the availability of water for fish may be significantly reduced in the near future. As an example, in southern and interior BC the natural period of low water levels (flow) during the summer often coincides with peak irrigation demand, as well as the migration and spawning period for salmon. A combination of these factors can significantly impair the ability of salmon to successfully migrate and spawn, as has been observed in the Thompson-Shuswap and Chilcotin areas.

Exotic Species
Exotic (non-native) fish species represent threats to salmonid populations in British Columbia (Tovey et al. 2008; Bradford et al. 2008a; Bradford et al. 2008b). Non-native fish species have largely expanded their distribution outside of their natural ranges through stocking programs that occurred as early as the 1800's (Rahel 2002). Due to the recognition of the risks to native biota and ecosystems, stocking of non-native fish species has been more conservative in the last two decades (Rahel 2002). However, non-native species continue to be introduced into aquatic ecosystems through both unauthorized introductions by the public or through continued expansions of their ranges from their initial point of introduction. Six exotic fish species, in

particular, present a risk to Fraser Sockeye, and include the Yellow Perch (*Perca flavescens*), Pumpkinseed (*Lepomis gibbosus*), Northern Pike (*Esox lucius*), Walleye (*Sander vitreus*), Smallmouth bass (*Micropterus dolomieu*), and Largemouth bass (*Micropterus salmoides*) (Tovey et al. 2008; Bradford et al. 2008a; Bradford et al. 2008b). For Perch, Smallmouth and Largemouth Bass, the probability of becoming widely established once it has arrived in BC is considered high (Bradford et al. 2008a; Bradford et al. 2008b). Other species such as Pike, Walleye, Pumpkinseed present high risks to native biota if they spread further in BC (Tovey et al. 2008). Depending on the invasive fish species, they can either compete for food resources (i.e. Perch and Pumpkinseed) or are predators of (i.e. Pike, Walleye, Smallmouth and Largemouth Bass) juvenile Fraser Sockeye in their rearing lakes.

Pathogens and Disease (Author: K. Garver, Science, DFO)
A diverse range of pathogens including viruses, bacteria, fungi and parasites can infect Sockeye Salmon. However, it is important to note that the presence of a pathogen in a Sockeye Salmon does not necessarily result in disease or compromised heath conditions. Whether or not a Sockeye Salmon becomes diseased when exposed to a pathogen depends upon complex interactions between the host, the pathogen and the environment in which these interactions take place. Disease can present itself in Fraser Sockeye Salmon lethally or sublethally (e.g. changes in swimming ability, growth, osmocompetence and reproduction). However, quantification of these disease impacts in wild fish can be difficult. Due to the overall complexity of disease it is extremely difficult to predict the occurrence and severity of disease and what, if any, role disease plays in structuring Fraser River Sockeye populations.

Three pathogens that have been directly observed in Fraser Sockeye include infectious hematopoietic necrosis (IHNN) virus, *Ichthyophthirius mutifiliis* and *Parvicapsula minibircornis*.
Infectious hematopoietic necrosis virus (IHNV) is an aquatic rhabdovirus that is enzootic (constantly present) in Sockeye salmon populations in the Pacific Northwest of North America. The virus infects all life stages of Sockeye salmon, however IHN disease is predominantly observed in fry, while adult spawning Sockeye, although carriers of virus, remain asymptomatic. Mass mortality events due to IHNV disease have been reported in two Fraser River Sockeye stocks. The first IHNV mortality event occurred in the spring of 1973 at Chilko Lake, and resulted in an estimated loss of 23.7 million fry. Subsequently, in 1987 an IHNV epizootic event occurred at Weaver Creek spawning channel resulting in nearly 50% mortality (8.3 million fry died out of a total 16.8 million) of all migrating fry within days of leaving the spawning channel. Despite these significant impacts incurred in Fraser Sockeye fry due to IHN disease, long-term monitoring of Nadina River and Weaver Creek spawning channels has revealed that over a 24-year period (1986-2009), IHNV prevalence varies annually within the same Sockeye stock and is inconsistent between stocks. There is no correlation with IHNV prevalence in adults and the occurrence in fry. Additionally, the data set illustrates that the occurrence of IHN disease outbreaks in fry have not increased over the 24 year monitoring period for either Weaver Creek or Nadina River stocks. Our inability to detect IHNV in Sockeye salmon fry from Weaver Creek and Nadina River over the past 10 (1998-2007) and 16 (1992-2007) years; respectively, suggests that IHNV is not a major contributor to the long-term decline of these two stocks.

Ichthyophthirius multifiliis (ICH) is a naturally occurring freshwater ciliate protozoan that causes a disease commonly referred to as "ich" or "white spot disease". The pathogen typically does not cause disease in Sockeye salmon. However, if conditions such as warm water, reduced flows, and adult crowding exist then disease can occur due the development of high numbers of this pathogen. Such disease events have been documented in Fraser and Skeena River Sockeye salmon and have resulted in severe pre-spawn mortalities of up to 80%. However, as with IHN disease, ICH disease prevalence has been inconsistent and varies between stocks.

Additionally, the frequency of ICH epizootic disease events at Weaver Creek and Nadina River has not increased since 1990, suggesting that ICH disease is not a major factor contributing to the long term decline of these two stocks.

Parvicapsula minibicornis is a myxozoan parasite that is enzootic in Fraser River Sockeye stocks. Surveys for the parasite have revealed that transmission occurs at or near the river estuary and that adults and juvenile salmon become infected with the parasite as they migrate through this area. In adult salmon, the prevalence and severity of infection is affected by time and temperature, such that migrating Sockeye holding in the river under elevated river temperatures are at higher risk of more severe infections. Severe *P. minibicornis* infections may interfere with renal osmoregulatory function and increase the probability of pre-spawning mortality. However, assigning a clear negative impact due to this parasite is difficult, as severe *P. minibicornis* infections are also evident in successfully spawning fish. There are no data on the severity of infection of juvenile Sockeye in marine waters with *Parvicapsula*. In the absence of information regarding the relationship between *Parvicapsula* infection and disease in Sockeye salmon, its contribution to migratory behaviour and/or high mortality remains unknown. In summary, pathogens are a natural component of all ecosystems and not all infections lead to disease. Often enzootic pathogens are 'well-adapted' in that they do little to harm their host, however, the incidence and severity of disease from such pathogens may increase if abnormal conditions and/or adverse factors ("stressors") occur.

DATA
Escapement Data

In the early 1900's, spawner abundance was estimated by the Government of Canada's Fisheries Agency using visual techniques that were often opportunistic and not specifically designed for the systems being assessed. In 1938, additional resources became available for the development of improved estimation techniques, and concurrently the International Pacific Salmon Fisheries Commission (IPSFC) assumed responsibility for the management and assessment of Fraser River Sockeye resources. The IPSFC's early work (Atkinson 1944; Howard 1948; Schaefer 1951) resulted in a two-tiered escapement approach, with higher precision assessment methods applied to stocks that were predicted to return at higher abundances and lower precision methods applied to stocks predicted to return at lower abundances (Woodey 1984; Andrew and Webb 1987).

With the signing of the Pacific Salmon Treaty in 1985, Fisheries and Oceans Canada (DFO) assumed responsibility from the IPSFC for the assessment of Fraser River Sockeye, and adopted the two-tiered escapement estimation system developed by the IPSFC, whereby the method of estimation for each CU was based on the number of spawners expected to return in a given year. Historically, low precision visual surveys have been used to enumerate stocks with expected low escapements (<25,000 spawners). For stocks with large expected returns (>25,000), higher precision methods, such as enumeration fences and mark-recapture programs, were used. In 2004, this threshold was raised to >75,000 spawners due reduce the number of stock assessed with high precision methods due to funding limitations. Starting in the mid-1990's, the number of assessed sites increased across a number of larger stocks, due to improvements in equipment (e.g. boats), and funding that permitted increased spatial assessment coverage of smaller Sockeye spawning streams.

Escapement enumeration methods for Fraser River Sockeye salmon are documented in a number of technical reports (Houtman and Cone 1995; Schubert and Tadey 1997; Schubert and Fanos 1997a; Schubert and Fanos 1997b; Schubert 1998; Cone 1999; Houtman et al. 2000; Schubert 2000; Schubert 2007; Schubert and Houtman 2007). Annual escapement plans are also available on-line: http://www.pac.dfo-mpo.gc.ca/fraserriver/escapeupdate.htm. Fence and tower counts are considered the most accurate methods of estimating spawner abundance, with almost all fish being counted as they migrate past, barring operational or environmental constraints. Fence counts are typically used to calibrate less accurate visual surveys and to estimate bias in mark recapture programs. Visual surveys are conducted by air (helicopter) or ground (boat or foot) and are considered the least accurate and precise methods to assess salmon abundance. Visual counts are expanded based on calibration work, in which fence counts were conducted simultaneously with visual surveys on smaller creeks with generally good visibility. Although a factor of 1.8 is applied to expand escapement counts from visual surveys to estimate total escapement (Andrew and Webb 1987), recent calibration work on different types of systems (e.g. larger rivers) report that this factor typically underestimates actual escapement (estimates are negatively biased) (Benner, DFO, pers. comm.). Mark recapture estimates fall somewhere between fence/tower counts and visual surveys for accuracy and precision. Bias in mark recaptures is generally identified and corrected in the analyses.

Escapement data (total number of adults that 'escaped' fisheries and were enumerated on the spawning grounds) are recommended by Holt et al. (2009) to evaluate trends in abundance for Pacific Salmon. For Fraser Sockeye however, additional data on the spawning success of female fish are also available, and are therefore used in the current paper to estimate status for *trends in abundance* and *abundance* metrics. Spawner success is calculated as the proportion

of eggs (0%, 50%, or 100%) successfully spawned, based on spawning ground carcass surveys. For *trends in abundance* metrics, effective female spawner (EFS) data are used (product of the number of female spawners and spawner success) as egg production is limited specifically by the number of females that have successfully spawned. For *abundance* metrics, effective total spawner (ETS) data are used (product of the number of adult male and female spawners and female spawner success). Both males and females (instead of just females in the case of the *trends in abundance* metrics) are used for *abundance* metrics since total abundance benchmarks are more readily transferrable to fisheries management applications and to other status assessments such as those conducted by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Effective total spawners, however, similar to effective female spawners includes female spawner success in its calculation to more closely reflect successful spawners.

For most CU data, the start of the escapement (EFS & ETS) time series was truncated to 1950, since earlier assessments were often conducted opportunistically using visual survey methods not specifically designed for the system being assessed. There are some CUs for which the escapement time series starts later than 1950, and these are documented in the proceeding individual CU sections. At the time of this report, the most recent escapement data available was 2009. Therefore, the escapement time series for each CU generally ran from 1950 to 2009.

For *trends in abundance* metrics, each assessable CU (and the two CU aggregates) had at least one assessed stream site in the escapement record. Sites were included in the calculation of total EFS for a CU if they were assessed for >70% of the historical time series (Appendix 1 & Appendix 2). An annual EFS record was only included if the field assessment period for that year coincided with peak escapement on the historical record, and if there was a minimum of one site visit. The resolution of the escapement record for a number of CUs changes through time, with many sites that are seen in the later time series (increased resolution) rolled up into one site in the early time series (lower resolution). Examining how the resolution of sites changed over time was a critical step in deciding whether a site should be included in the escapement time series for a CU. For example, McNomee Creek (Shuswap-ES) was historically rolled into the Seymour River site records, and was only recently recorded independently from Seymour as its own site. Therefore, in the escapement record there was no data recorded separately for the McNomee site until 1992. If this site was excluded in error, due to a lack of expert knowledge on how the escapement resolution changed over time, this would have introduced a negative bias in the recent time series.

For CUs with either no abundance estimates for any included site in a given year (for CUs with multiple sites), or no abundance estimates for the single included site in a given year (for CUs with only one site), missing data points were gap filled using cycle averages. Gap filling is particularly important for dominant cycle years, which, if missing, could significantly reduce the generational mean (i.e., smoothed four year running average) for segments of the time series that include that missing estimate. Using the cycle average method, abundance estimates for any missing year (e.g. 1942) were interpolated by inserting the mean of the same cycle year (4-year cycle) from the immediately previous (e.g. 1938) and subsequent generation (e.g. 1946). If the cycle year of either of the closest two generations was missing (i.e., 4 years previous or subsequent to the missing point), the corresponding cycle year no more than two generations away (e.g. 1934 & 1950) was used to calculate the mean. Interpolation was conducted prior to log transformation and smoothing (with the generational mean) (Appendix 2 & Appendix 5).

For missing data points in CUs with multiple sites, those sites that were spatially proximate and correlated in terms of abundance were grouped together. Gaps within these site groupings were then filled using a mean proportion approach (Appendix 2 & Appendix 5). This approach gap fills based on the proportion each site contributes to the total group abundance, when averaged

across years for which data is available for all populations. In addition, for highly cyclic stocks, the gap filling approach seperated dominant and subdominant years (and in some cases additionally weak cycle years), since site proportions varied by cycle year (e.g. Shuswap-L and Takla-Trembleur-EStu, where Takla-Trembleur-EStu was separated for all cycles, and for Shuswap-L just the dominant and subdominant cycles were filled) (Appendix 2 & Appendix 5).

Appropriate methods for gap filling are currently being investigated (Carrie Holt, DFO Science) through simulations (note to Sue: compare Carrie's gap filling paper to our approaches described above).

Recruitment Data

Recruitment data, organized by stock and age by the PSC, combine escapement (see previous section) and catch data, and, in recent years, estimates of Sockeye en-route loss. For most CUs that have stock-recruitment data, the time series includes the brood years 1950-2004. Although for most CUs the time series begins prior to 1950, to be consistent with the *trends in abundance* metric only data as far back as 1950 were used. Exceptions to this time period include CU's where the stock-recruitment time series was influenced strongly by the introduction of spawning channels, dam blockage, and differences in population dynamics due to hatchery enhancement or poor data. To ensure that the entire stock-recruitment time series is comparable, only brood years that occur after the construction of spawning channels are included in the time series for the Anderson-ES (brood years 1968-2004), Francois-ES (brood years 1973-2004), and Harrison (U/S)-L (brood years 1966-2004) CUs. For the Kamloops-ES CU, only years after the removal of a dam blocking Sockeye access to Fennel Creek were included (brood years 1967-2004).

CU's that have been influenced by hatchery enhancement were also truncated to eliminate enhancement years. In the Shuswap-ES CU, a key site (Scotch Creek) was strongly influenced by hatchery production prior to 1980, therefore, only stock-recruitment data from the 1980-2004 brood years were used. The Seton-L CU similarly had early hatchery influences and considerable gaps in the early time series, therefore, only stock recruitment data from the 1965-2004 brood years were included. The Cultus-L CU was significantly enhanced in recent years, therefore, the 2001 to 2004 brood years were not included. Although the hatchery program for Cultus-L Sockeye started in 2000, the number of fry produced in this initial year was negligible, therefore stock-recruitment data from the 2000 BY was included in the time series. Pitt-ES Sockeye stock-recruitment data include adults that were removed for hatchery enhancement, since these fish contribute to subsequent recruitment in this system. Quesnel-S and McKinley-S stock-recruitment data are combined into one aggregate, given that production data and escapement data cannot be partitioned into these individual CUs. Similarly, Chilko-ES and Chilko-S stock-recruitment data are also combined into a single aggregate.

Note: incorporate info from email from Mike Lapointe

Carrying Capacity Data

The capacity of a Sockeye production can be limited in the freshwater environment by the amount of available spawning ground habitat for egg incubation and/or by the lake fry rearing habitat (food availability, competitor population size, etc.). For Fraser Sockeye, currently no reliable (peer reviewed) estimates of spawning ground capacity exist. Since only lake rearing capacity data are available for Fraser Sockeye, this information was used to set prior information ('b' parameter priors) on maximum spawner capacity for the evaluation of CU status for abundance metrics. In the current paper, to update maximum spawner capacity estimates, lakes were placed into one of three groups depending on the extent of their capacity is influenced by competitor populations. Where rearing capacity data were available and applied in

models, the current paper used a standard deviation that encompassed the available spawning capacity data in formulating lognormally distributed informative priors. The paper updates estimates of juvenile Sockeye rearing capacity using data on photosynthetic rate (PR) and juvenile Sockeye competitors in the lake. Photosynthetic rate is positively correlated with fish yield in freshwater lakes (Fee et al. 1985; Downing et al. 1990) and, in fact, is more closely correlated with fish yield than any other variable (e.g. chlorophyll and total phosphorus) (Downing et al. 1990). A Sockeye-specific PR model that predicts the abundance and biomass of Sockeye smolts produced at lake rearing capacity, and the number of spawners required to produce those smolts was developed (Hume *et al.* 1996) through combining PR analysis and the euphotic zone model of Koenings and Burkett (1987). This PR model was recently further revised to explicitly use PR (Shortreed *et al.* 2000) and adjust for the presence of competitors and age-2 smolts (Cox-Rogers *et al.* 2010).

Bodtker et al. (2007) developed a Bayesian PR (Photosynthetic Rate) method that explicity takes into consideration uncertainty associated with using lake productivity to estimate the spawner abundance that maximizes smolt production (S_{max}). However, these methods have not been updated for this current paper's PR model results. Bodtker et al. (2007) suggested that if prior information from sources such as PR models and likelihood stock-recruitment data are relatively informative and contradictory, then caution should be applied when combining these sources. Therefore, in cases where S_{max} spawning habitat or lake rearing prior distributions were considerably different from the likelihood distributions, or alternative carrying capacity data did not exist, then uninformative priors were used. These uninformative priors were uniformly distributed from 0 to a maximum for the CU (typically 0-1 million).

In the current paper, the presence of competitors was expanded to consider all common competitors of juvenile Sockeye that are similarly planktivorous (feed on zooplankton). In the Fraser study lakes, the most common competitors were often kokanee (*Oncorhynchus nerka*) and may also include redside shiner (*Richardsonius balteatus*), threespine stickleback (*Gasterosteus aculeatus*), longfin smelt (*Spirinchus thaleichthys*), Chinook salmon (*O. tshawytscha*), and various whitefish species (*Coregonus* spp.). Based on reports in the literature (Roberge et al. 2001; McPhail 2007), and limited stomach analysis (data on file), we assumed that the diet of the competitors was the same as age-0 Sockeye, and that competitor biomass used the same proportion of available food as an equivalent amount of Sockeye biomass. This is a conservative approach, as we know from sampling that these species occupy the lake's limnetic zone and are planktivorous, though we have little data on competitor population variability or diet. Many competitor species may have a wider dietary range than Sockeye, therefore we may be overestimating their competitive overlap for zooplankton prey.

Although data on the abundance, biomass, diet, and temporal variability of juvenile Sockeye competitors are limited, we have made preliminary estimates competitor biomass based on pelagic surveys. Abundance estimates were derived from hydroacoustic surveys and community composition, and fish size data were obtained from midwater trawling (Table 1) (MacLellan and Hume 2010). In some instances, we were able to distinguish between age-0 Sockeye and kokanee using either genetic or otolith sampling, but these data were not always available. The presence and abundance of age-1 kokanee was inferred from the trawl catch and from the proportion of age-2 smolts in the adult return data. A considerable amount of work is required to improve these estimates, as sampling was often limited (e.g. 'n/a' in Table 2), and little is known about the seasonal abundance, distribution, or niche overlap of Sockeye competitors in most of these lakes.

In many nursery lakes, a proportion of Sockeye fry from each brood year resides in the lake for more than one year, leaving as age-2 smolts. While in the lake these older fish compete directly with age-0 Sockeye, but they also contribute to smolt production and cannot be treated as

simple competitors. While the presence of older smolts will not affect the predicted maximum smolt biomass a lake may produce, they can have a substantial effect on the number of smolts that comprise this biomass. We accounted for the presence of older smolts in our models by using the estimated weighted mean smolt size, based on the proportion of each age class in the smolt run of each brood year (Cox-Rogers et al. 2010).

For lakes in the Fraser watershed, the limnological data used in applying the PR model was collected for one to ten years on a monthly basis over most of the growing season (May to October). An exception was Pitt Lake, which was sampled only 3 times over two years (Shortreed et al. 2001). A detailed description of the methods used is available in Shortreed et al. (1998). Details of the PR model and the adjustments described are presented in Cox-Rogers et al. (2010).

Data Quality

Overall data quality can vary amongst sites and between years. For the purpose of this paper both escapement and recruitment data are assigned one of the following five codes, depending on data quality. More detailed assessments of data quality could be summarized by year and site and across the different data types used, but was not within the scope of the current paper. In general, most Fraser Sockeye escapement data are assessed with methods rated three or above in the following scoring system.

1) Poor: An estimate with poor accuracy due to poor counting conditions, few surveys (one or two in a given year), incomplete time series, etc.
2) Fair: An estimate using two or more visual inspections that occur during peak spawning where fish visibility is reasonable; methodology and data quality varies across the time series in terms of good to poor quality.
3) Good: four or more visual inspections with good visibility.
4) Very Good: An estimate of high reliability using mark recapture methods, DIDSON methods, or near-complete fence counts that have relatively high accuracy and precision. Visual surveys that have been calibrated with local fence programs.
5) Excellent: an unbreached fence estimate with extremely high accuracy given an almost complete census of counts.

CLASS OF INDICATORS, METRICS AND BENCHMARKS
Spawner Abundance (State)

Holt et al. (2009) and Holt (2009) recommend using the Ricker model with a Bayesian approach (with prior information on the carrying capacity parameter where available) to estimate *abundance* benchmarks for Pacific Salmon CUs. For *abundance* lower and upper benchmarks, Holt (2009) recommended, respectively, S_{gen} (the spawner abundance that would result in recovery to S_{MSY} in one generation) and 80% S_{MSY}. Simulation modelling results indicated that S_{gen} as a lower benchmark was associated with a relatively low probability (<25%) of extirpation over 100 years for populations under equilibrium abundances (>15,000 spawners) and relatively high probability (>75%) of recovery to S_{MSY} in three generations when fishery uncertainties were accounted for (Holt 2009). Details of the Ricker model used to estimate benchmarks for Fraser Sockeye are documented in Holt et al. (2009) and Holt (2009).

To address temporal trends in productivity, stock-recruitment models that incorporate changes in intrinsic productivity (the Ricker *a* parameter) over time were also used in the current paper.

Estimates of intrinsic productivity in the current year were then used to calculate benchmarks on spawner abundances. Several approaches were used to incorporate changes in intrinsic productivity that included models using truncated (more recent) time series, a model-smoothed approach, and a recursive Bayesian method (similar to a Kalman filtered approach). These estimates of productivity better reflect existing conditions than estimates derived from models that assume stationary productivity.

The first approach was using truncated (more recent) stock-recruitment time series to estimate benchmarks using the standard Ricker models. Most CUs have exhibited lower productivities in recent time periods, relative to the earlier periods, and therefore parameters and benchmarks are estimated using the lower productivity stock-recruitment time series. For most CUs with a complete (1950-2004 brood years) time series, in addition to estimating benchmarks using the full time series, data sets were truncated to two additional (more recent) periods that included 1970-2004 and 1990-2004. For CUs with shorter time series, in addition to their full time series, data sets were truncated to one additional (more recent) period that included 1990-2004.

The second approach used to incorporate changes in a CUs intrinsic productivity is the Ricker-smoothed approach that uses the standard Ricker model but estimates the Ricker a parameter from a running-average of the last (most recent) four years in the stock-recruitment time series ($a_t = \ln(R_t/S_t)+bS_t$).

The final (third) approach is the recursive Bayesian estimation method. Similar to the Kalman filter (KF) approach, sometimes used for salmon stock assessment (Dorner et al. 2008), the recursive Bayesian approach estimates trends in productivity due to underlying processes, independent of interannual variability that are at least in part due to observation errors. The true dynamics are unknown, and are represented by a hidden Markov process. Although the KF is numerically less demanding than recursive Bayesian estimation, prior information on model parameters can be easily included into the recursive Bayesian approach. Including prior information on population capacity (Ricker b parameter) is especially critical when the time-series of spawner and recruitment data is short or uninformative (most cases). Priors can reduce biases in parameter estimates that are due to observation errors in spawner abundances ("errors-in-variables") and recruitment anomalies at low spawner abundances ("time-series bias") (Walters and Martell 2004). Here, we build on previous use of recursive Bayesian estimation for estimating time-varying productivity for Sockeye salmon in the Fraser River (Grant et al. 2010), by including informative priors on capacity. In preliminary testing, we found that when priors are uninformative, parameter estimates from recursive Bayesian estimation converge with the smoothed estimates from a Kalman filter.

Priors on the carrying capacity parameters were incorporated into Ricker and KF Ricker models (see previous section on Carrying Capacity Data). Bayesian posterior parameter distributions for the biological models were estimated using WinBUGS (Bayesian software Using Gibbs Sampling) (WinBUGS is available at, http://www.mrc-bsu.cam.ac.uk/bugs/welcome.shtml). Bayesian diagnostics were examined for all models and CUs. We used Gelman & Rubin diagnostics and the Geweke Statistic, G (if G>2 or < -2 then estimates derived from the first 10% of the chain differed from the last 50% and convergence has not occurred) to determine if MCMC chain convergence had occurred. If convergence was not achieved, the number of MCMC trials and/or the burn-in length was increased. Chains were examined for autocorrelation, and thinned if it was present. One example (Takla-Trembleur-Early Stuart) of diagnostic results is presented in Appendix 6. A separate Appendix can be provided upon request, containing all model diagnostics for all assessable CUs; however, due to its length (70 pages), it was excluded from the current report.

A Larkin model that accounts for the effects of biological interactions among cycle lines, due to, for example, competition for food or predation (Walters and Staley 1987; Cass and Grout 2006;

Martell et al. 2008), was not included in the current evaluation of uncertainty in *abundance* metric benchmarks. Our current methods for estimating benchmarks for the Larkin model assume that each cycle has equal abundances throughout the time series, which does not capture the temporal variability observed for most CUs and which is fundamental to the Larkin model. The assumption of constant abundances across cycle lines for Larkin benchmarks results in very strong density dependence, low recruitment, and often extremely small S_{MSY} and S_{gen} values. Alternatively, it may be possible to impose a more realistic (though arguablely arbritatry) sequence of spawner abundances or to estimate cycle-line specific benchmarks. However, estimating cycle-line specifc benchmarks is challenging due to multiple local optimal values, the choice of which depends on the starting values in the optimization algorithm (Al Cass, pers. comm.). While cycle-line specific target escapements or harvest rates may be appropriate for management in order to optimize harvest across cycle lines, uncertainty in the biological mechanisms underlying cyclic patterns (and corresponding uncertainty in probability of extirpation and recovery associated with various cyclic patterns on benchmarks) makes it difficult to justify benchmarks on biological status by cycle line. Instead, a longer term perspective (e.g., aggregating over cycle lines) may be more appropriate for identifying biological benchmarks and assessing status.

Holt (2009) and Holt and Bradford (*2011*) found that the probability of extirpation and recovery to S_{MSY} from the lower benchmark S_{gen} calculated from the Ricker model, were relatively robust to uncertainty in underlying spawner-recruitment model. The performance of lower benchmark derived from the Ricker model did not vary considerably when the underlying "true" stock-recruitment model was actually a Larkin model with highly cyclic dynamics compared to when it followed a Ricker model. In contrast, Holt (2009) and Holt and Bradford (in press) found that uncertainty in productivity had a relatively large effect on probability of extirpation and recovery to S_{MSY} from the lower benchmark, S_{gen}.

Given the current challenges with estimating the Larkin model benchmarks and given that the Ricker model form of the lower benchmark is relatively robust to probability of extirpation and recovery to S_{MSY}, only Ricker models are included in the current paper.

Holt et al. (2009) recommended evaluating *abundance* status by comparing the current (brood years 2006-2009) effective total spawners (ETS) geometric mean to the *abundance* benchmarks. Most Fraser Sockeye exhibit highly cyclic annual abundances (four year cycles), often having persistent dominant (large) abundance cycles, followed by weaker (lower) abundance cycles. Using a geometric mean on such cyclic, lognormally distributed abundance data is appropriate in representing the average value of the time series, because unlike the arithmetic mean, the geometric metric is not inflated by the less frequent, higher abundance years. This results in a more accurate measure of where the majority of values lie. When geometric means were estimated for CUs, for most CUs they were similar to arithmetic means. However, for highly cyclic stocks such as Late Shuswap, they resulted in considerably lower average abundances compared to the arithmetic means. Due to the two-tiered enumeration program in place for Fraser Sockeye, higher abundance cycles (dominant cycle lines) are generally enumerated with higher precision methods than lower abundance cycles (off-cycle lines). These more precise estimates are downweighted in the geometric mean approach, giving more relative weight to the less precise, lower estimates. Therefore, the geometric may provide a less accurate measure of the centre of data than the arithmetic mean. In this paper, we used both the geometric and the arithmetic mean of the recent generation to evaluate status to reflect uncertainty in the most appropriate choice of the mean. Status evaluations using the geometric and arithmetic means are presented in Table 3. Holt et al. (2009) also recommended also comparing the current year's abundance to provide another metric for *abundance* CU status. This was not used in the current paper as status would be highly confounded by cyclic

dominance, with evaluations performed on dominant years generally indicating a better status than those performed during weak cycle years.

Trends in Abundance (Rate)

There are a number of possible metrics within the *trends in abundance* class of indicator, including metrics that compare current abundances (last generation) to a range of historical baselines (e.g. historical average, a historical maximum, first generation in the time series) and metrics that measure trends (e.g. rate of change in the last three generations). A recent study evaluated the effectiveness of different metrics in correctly categorizing the status of Fraser Sockeye abundance data for 18 CUs, using a Receiver Operating Characteristic (ROC) approach and retrospective analysis (Porszt 2009). The Porszt (2009) study has been updated to include two additional metrics: the ratio of the geometric mean spawner abundance of the current generation to the historical mean, and to the mean of the first three generations. These analyses concluded that metrics that generally ranked highly in identifying true status were those that compared the last generation abundance to historical baselines (e.g. time series average). Metrics that categorized status by comparing the last generation abundance to the historical maximum consistently ranked low, and metrics that evaluated trends over the last three generations to categorize status performed intermediate to these metrics.

Three metrics were chosen to assess *trends in abundance* for each CU, based on the toolkit of metrics presented by Holt et al. (2009), results from Porszt (2009), and the recent evaluation of several additional metrics (described above). The first *trends in abundance* metric examines changes in abundance over the long term, using the ratio of the current generational geometric mean to the long-term geometric mean. The next two *trends in abundance* metrics evaluate trends over the short term, measuring the changes in abundance over the most recent three generations (using both a deterministic and probabilistic approach, as described in Holt et al. (2009)). The ratio of the current generation geometric mean to the highest generational mean, described in Holt et al. (2009), was excluded as a potential metric, since it ranked low relative to all other trend metrics assessed by Porszt (2009).

For the long-term *trends in abundance* metric (ratio of the current generational geometric mean to the long-term geometric mean), benchmarks for this metric described by Holt et al. (2009) were 0.25 and 0.5 as, respectively, lower and upper benchmarks. However, in a previous publication, Pestal and Cass (2009) considered ratios of less than 0.5 as low in status, and those above 0.5 as ranging from below average to above average in status (Petal and Cass 2009). Therefore, in the current paper we used 0.5 as the lower benchmark (ratios below this value are considered low to very low: red status), and 0.75 as the upper benchmark (ratios above this value are considered near or above average: green status) for the ratio metric, to provide greater resolution in assessing status. Ratios between 0.5 and 0.75 are considered average (amber status). The ratio of the current generation to historical average was estimated on $\log_e$ transformed EFS time series that were smoothed using a four-year running average. The running mean starts on the second year of data in a time series, and includes the one year before and two years after this second year. The purpose of this transformation is to minimize the influence of cyclic abundance, and of observation and assessment errors.

For short-term *trends in abundance,* the linear rate of change in the last three generations was estimated both deterministically and probabilistically (two metrics). The Committee on the Status of Endangered Wildlife in Canada (COSEWIC), and the International Union for the Conservation of Nature (IUCN) both use the change in abundance over the last three generations (or 10 years, whichever is longer) as their *trends in abundance* metric (COSEWIC 2003a; COSEWIC 2003b; Rand 2008) to assess wildlife status. The upper and lower benchmarks for this metric, as used by Holt et al. (2009), are respectively, a 15% decline and a 25% decline in abundance.

This lower benchmark represents a smaller reduction in abundance (more biologically conservative) than the COSEWIC/IUCN guideline (30% reduction) that classifies a species as "threatened". To apply these changes in abundance as benchmarks, we used the linear rates of change that are associated with a reduction of 25% (lower benchmark) and 15% (upper benchmark) over three generations (i.e. the slope of a line of best fit that relates to a decline of this size). These rates of decline (25% and 15%) convert to slopes (in $\log_e$ space) of, respectively, -0.015 (upper benchmark) and -0.026 (lower benchmark). These $\log_e$ slopes deviate slightly from Holt et al. (2009), due to a modification in the slope calculation. Specifically, the slope calculation used by Holt et al. (2009) examined the rate of change over 12 years, while the current paper used 11 years, relating to the change (in years) from year 1 (e.g. 1998) to year 12 (e.g. 2009). The second recent *trends in abundance* metric explores uncertainty in the linear rate of change in the last three generations ($\log_e$ slope as described above) by comparing the probability that the slope is below the lower benchmark of 25% (slope: -0.026). This metric is not independent of the previously described recent *trends in abundance* metric, but rather is complementary and adds weight of evidence towards the first deterministic status.

To calculate the last three generation trend, the abundance time series' were first converted to $\log_e$ space, then smoothed into a running average over complete generations (i.e. 4 years for Fraser River Sockeye salmon) to remove the annual "noise" that obscures underlying trends in population abundance (COSEWIC 2003b). Regression analyses were conducted on the last three generations (1998-2009) of the transformed abundance data to calculate the linear rate of change. The slope, calculated in $\log_e$ space, was then compared to the upper and lower benchmarks presented in the previous paragraph to assess status by CU for this metric.

Productivity

Productivity indices combine the freshwater and marine mortality presented in Grant et al. (2010), and have been updated to reflect the current CU level of organization. The three indices include $\log_e$(R/EFS), Ricker model residuals, calculated as deviations between the model's annual predictions and observations (Ricker 1975), and Ricker model *a*-parameter values, estimated annually using a Kalman filter procedure (KF Ricker *a*-parameter) (Peterman et al. 2000; Peterman et al. 2003; Dorner et al. 2008). The $\log_e$(R/EFS) productivity index describes total stock productivity. The remaining two indices remove the density dependent effects of spawner abundance in the total $\log_e$(R/EFS) variability. The KF Ricker *a*-parameter values further remove short term variability in $\log_e$(R/EFS) productivity.

RESULTS: WILD SALMON POLICY STATUS EVALUATION

CONSERVATION UNIT BIOLOGICAL STATUS

A*bundance* and *trends in abundance* metrics were used to evaluate status for 26 assessable Fraser Sockeye CUs. An overview of results is presented in the immediately proceeding section. Detailed descriptions of analyses and results for each CU, including data used, historical backgournd, and status assessments, follow the overview section.

Carrying Capacity

In the current paper, to update maximum spawner capacity estimates, lakes were placed into one of three groups depending on the extent of their capacity is influenced by competitor populations. In some lakes (Bowron, Chilko, Francois, Kamloops, and Lillooet, Lake), the extent

and the lack of non-Sockeye catch, indicated that productive capacity was not measurably reduced by competitors. In a second group of lakes (Cultus, Adams, Fraser, Mabel, Trembleur, Shuswap, and Quesnel Lake), while variance was high, productive capacity was estimated to be reduced by a moderate amount (1-10%; mean ~6%) by competitor foraging. A third group of lakes (Anderson, Chilliwack, Harrison, Seton, Pitt, Stuart, and Takla Lakes) had a high variance associated with a large reduction in productive capacity by competitors (15-90%; mean ~37%). Maximum spawner capacity for lakes within each of these three groups were estimated by applying a mean competitor adjustment within groups (Appendix 4, Table C)

Given the limitations inherent in the available competitor data, and the assumptions that were necessary in order to develop biomass estimates, we cannot assign a high degree of confidence to the estimates of competitor biomass. Therefore, the estimates should be used with caution and with the full understanding of how they were derived. For lakes in the Fraser watershed included in the PR model for which we were unable to develop an estimate of competitor biomass, it may be appropriate to assign a value derived for other lakes with similar ecologies and species compositions. For example, smelt are known to be abundant in the pelagic zone of Pitt Lake in a similar fashion to Harrison Lake (Henderson *et al.* 1991). Thus, we thought it reasonable to assign Pitt Lake to same group as Harrison Lake.

For the analysis of benchmarks using a Bayesian approach, carrying capacity *b* parameter priors were explored using maximum spawners estimated from lake rearing capacity (updated in current paper). Priors using this data were informative (lognormally distributed), while those not based on this data were uninformative (uniformly distributed with a range from 0 – 1,000,000) (Table 2). For the uninformative priors, a comparison of applying different large upper bounds indicated that this does not significantly affect benchmark estimates.

Table 2. Spawning capacity (Total adults spawners S_{max}) carrying capacity ('b' parameter) priors used to estimate benchmarks for abundance metrics using a Bayesian approach. All CU's Smax (resize when finalizing)

CONSERVATION UNIT	SR Time Series (Brood Years)	Spawning (S_{max}) Capacity Used in SR Models		
		Prior Distribution	Average	Log Sigma
Anderson-ES	1968-2004	Uniform	0-1,000,000	Uniform
Bowron-ES	1950-2004	Lake Rearing	40,000	0.30
Chilko-S & Chilko-ES	1950-2004	Lake Rearing	400,000	0.50
Cultus-L	1950-2000	Lake Rearing	80,000	0.20
Francois-ES	1973-2004	Uniform	0-1,000,000	Uniform
Fraser-S	1950-2004	Lake Rearing	550,000	0.30
Harrison (U/S)-L	1966-2004	Uniform	0-1,000,000	Uniform
Kamloops-ES	1967-2004	Uniform	0-500,000	Uniform
Lillooet-L	1950-2004	Lake Rearing	164,000	0.30
LFR (River-Type) (immediate migrants)	1950-2004	Uniform	0-800,000	Uniform
Pitt-ES	1950-2004	Uniform	1-1,500,000	Uniform
Quesnel-S & McKinley-S	1950-2004	Lake Rearing	1,000,000	0.20
Seton-L	1965-2004	Uniform	0-300,000	Uniform
Shuswap-ES	1980-2004	Uniform	0-2,000,000	Uniform
Shuswap-L	1950-2004	Lake Rearing	1,500,000	0.40
Takla-Trembleur-Stuart-S	1950-2004	Lake Rearing	1,400,000	0.50
Takla-Trembleur-Estu[2]	1950-2004	Lake Rearing	600,000	0.40

1. Source: J. Hume & L. Pon, Salmon Aquatic Freshwater Ecosystem Program, DFO; Appendix 3.
2. Early Stuart rear in Takla Lake

Benchmarks for Spawner Abundance (State)

For each CU with stock-recruitment data, benchmarks for abundance metrics were estimated using the Ricker model and, in addition, three approaches were used to incorporate recent productivity in the intrinsic productivity parameter estimation process into this model. Specifically, truncated (more recent) stock-recruitment time series were used to estimate benchmarks for both model forms, smoothed (recent four year running averages on the intrinsic productivity parameter) models and recursive Bayesian approaches that incorporate priors on the carrying capacity parameter were used. For all model forms, benchmarks were presented across six probability levels (10%, 25%, 50%, 75% and 90%) to reflect the stochastic

uncertainty in the model fitting to stock-recruitment data. To assess status for each model and probability level combination by CU, recent mean CU abundances (arithmetic and geometric means) were compared to each of the paired lower and upper benchmarks that delineate, respectively, the red to amber and the amber to green WSP biological status zones (Table 3).

Across all Ricker model forms explored, generally the recursive Bayesian Ricker model, smoothed Ricker, and the most truncated stock-recruitment time series (brood years 1990-2004) Ricker models produced the highest (most biologically conservative) benchmarks. As most Fraser Sockeye CUs have exhibited systematic declines in productivity (Appendix 2, Figures 1 e & f), these models incorporate the recent productivity declines in their estimation of lower and upper benchmarks. Ricker models that considered all or most of the stock-recruitment time series generally produced lower (less biologically conservative) benchmarks, since the earlier, highest productivity period, in most CU's time series were included in the parameter estimation process. One major exception is the Lower Fraser River (River-Type) CU that has exhibited the highest productivity on its stock-recruitment time series in recent years, and therefore, produced lower benchmarks when using models that consider this recent, higher, productivity.

Benchmarks were compared across five probability levels (10%, 25%, 50%, 75%, and 90%), with lower benchmarks occuring at lower probability levels (less biologically conservative values) and higher benchmarks at higher probability levels (more biologically conservative values). Comparisons of status across these probability levels provides an indication of how sensitive statuses are by model and probability level. For example, for eight CUs (Pitt-ES, Lower Fraser River (River-Type), Takla-Trembleur-EStu, Bowron-ES, Stuart-S/TAkla-Trembleur-S, Quesnel-S/McKinley-S and Cultus-L), status was relatively insensitive (constant) to the model used or probability level. For most CUs, however, status was sensitive (varied) depending on the model form and the probability level.

Arithmetic versus geometric mean recent generation (brood years 2006-2009) estimates for each CU were generally less than 30% different for most CUs. Major exceptions included Shuswap-ES, Chilliwack-ES, Shuswap-L, and Seton-L that produced large differences (>60%) in the estimate of recent abundances using the arithmetic versus geometric mean approaches. Since these stocks exhibit cyclic dominance specifically in the last generation, the geometric mean downweights the dominant, large cycle, and, therefore, produces a much lower recent abundance estimate relative to the arithmetic mean. As a result, *abundance* metric status for these four CU's is quite different depending on whether the arithmetic versus geometric mean is used; the geometric mean results in poorer statuses across models and probability levels relative to the arithmetic mean for these CUs. For most other CUs, the difference in *abundance* metric status across models and probability levels is not significantly different when arithmetic versus geometric means are compared.

It is important to note that these statuses are specific to *abundance* metrics and to not reflect the final overall status of these CUs which will be a part of a subsequent process that will combine status across all metrics into an overall single status for each CU.

Benchmarks for Trends in Spawner Abundance (Rate)

Status for three trends in abundance metrics were evaluated for each CU. One metric considered long-term trends in abundance (ratio of the current generation to the long-term average) and two metrics considered recent trends in abundance (linear rate of change in the last three generations and the probability that this rate of change is below the lower benchmark).

Of the 26 CUs with EFS data, one CU (Chilliwack-ES) could not be assessed for trends in abundance given the time series was too short to conduct this analyses. In addition, four CUs were aggregated into two CUs for *trends in abundance* analyses since their time series could not be separated into their invidual CUs (Chilko-ES/Chilko-S and Quesnel-S/McKinley-S). So in total, there were 23 CUs where *trends in abundance* status assessments could be conducted across metrics.

Of these 23 CUs where *trends in abundance* metric assessments were conducted, 50% (12 out of 23 CUs) exhibited long-term *trends in abundance* statuses that were in the WSP green (or one yellow) zone and recent *trends in abundance* statuses that were in the WSP red zone. These general status trends are related to the high abundance exhibited by these CUs in the 1990's relative to the previous time series and subsequent declines from these maximums to average abundances in recent years. Therefore, relative to the long-term abundance, recent abundances are close to average (green status on the ratio of the current generation to the long-term average metric), and in recent years abundance has declined as CUs return to average abundances after a period of high production (red status on the linear rate of change in the last three generation metric).

Divergences from this general *trends in abundance* status across metrics include the following: five CUs (Pitt-ES, Lower Fraser River-River-Type, Shuswap-L, Harrison (D/S)-L and Lillooet-L) were in the green zone for both recent and long-term trend in abundance metrics; three CUs (Bowron-ES, Taseko-ES, and Cultus-L) that were red zone for *trends in abundance* metrics; two CUs (Widgeon-River-Type and Kamloops-L) were in the red zone for the long-term trends in abundance metric and green or yellow for the recent trends in abundance metrics; and one CU (Kamloops-ES) that was in the green zone for long-term trends and in the yellow zone for recent trends in abundance.

It is important to note that these statuses are specific to *trends in abundance* metrics and do not reflect the final overall status of these CUs which will be a part of a subsequent process that will combine status across all metrics into an overall single status for each CU.

Twenty-Six Assessable Conservation Units

Twenty-six CUs have sufficient information to be assessed for status. Of these twenty-six, two (McKinley-S and Chilko-ES) cannot be independently assessed, as their data are rolled up with other CUs (respectively Quesnel-S and Chilko-S).

Anderson-ES

(Note: A substantial number of these Sockeye move into Seton Lake and, therefore, a more appropriate name for this CU would be Seton-ES)

Sites: Populations that rear in Anderson Lake include Gates Creek and Gates Channel (Appendix 1). There is evidence that many Gates Creek and Channel fry migrate directly into Seton Lake, and don't use Anderson Lake for rearing (Geen and Andrew 1961; Roos 1991), therefore, a change in the CU name to Seton-ES might be appropriate.

History: Between 1919 and 1930, over 15 million Sockeye eggs and juveniles were transplanted to Gates Creek, Gates Lake and Anderson Lake from the Birkenhead River and Sweltzer Creek. An additional transfer of fry occurred in 1950 from the Adams River to Anderson Lake (Aro 1979). The resulting current Anderson-ES population is considered genetically distinct (Withler

et al. 2000), and its low genetic diversity and unusual allele frequencies reflect founder effects and/or genetic drift at small population sizes (Withler et al. 2000).

The natural spawning area of Gates Creek historically supported an estimated 150,000 Sockeye. However, forest harvesting and the encroachment of human activities are believed to have deteriorated habitat quality, and restricted Sockeye production to the point where only 10,000 Sockeye could be accommodated by the late 1960's (Doug Lofthouse, Oceans, Habitat & Enhancement Branch, DFO, unpublished report). As a result, between 1967 and 1968, the Gates Creek Sockeye spawning channel was constructed at the west end of Anderson Lake, to compensate for lost production from Gates Creek and Anderson and Seton Lakes. The channel is estimated to account for a high proportion of the CU's production. Gates Channel has an available spawning area of 11,300 m^2, and was designed to accommodate 18,000 Sockeye (Doug Lofthouse, Oceans, Habitat & Enhancement Branch, DFO, pers. comm.).

A hydro facility on this system has been operational since 1956 (Roos 1991). This facility is comprised of the Seton Dam, located below the outlet of Seton Lake, and the Cayoosh Dam on Cayoosh Creek. Water is diverted by canal from Seton Lake to a powerhouse on the Fraser River, where it is released through a tailrace located 500 m downstream of the outlet of Seton River. Since the Seton Dam presents a barrier to Sockeye migration, a fishway was constructed in concert with dam construction (Roos 1991). It has been suggested that both the tailrace and fishway may slow or impede Sockeye migration and cause physiological stress to the fish (Roscoe and Hinch 2008). Due to the downstream tailrace location, migrating adult Sockeye have been shown to stop at the outlet of the tailrace, where that are either attracted to the home-stream water or they use it as a 'cold-water' refuge. Fish may either be directly injured in the tailrace (Fretwell 1980) or indirectly suffer pre-spawn mortality due to the delay in migration from stalling at the tailrace. Success of fish departing the tailrace, entering the Seton River, and reaching the dam depends on Seton water quality, whereby higher Cayoosh Creek dilution results in higher migration failure (10-30% migration failure during IPFSC studies). Once fish enter the Seton River they must travel five kilometers upriver, ascend the Seton Dam fishway, and then migrate through Seton Lake and Anderson Lake (~50km) to the spawning grounds. One study indicated that locating the fishway entrance presents a challenge to migrating Sockeye (during experimental downstream transplants 25% of these Sockeye could not re-locate the fishway entrance) (Roscoe and Hinch 2008). Further impacts of the hydro facility include mortality (~10%) of downstream migrating smolts as they move through the dam turbines. This issue has yet to be resolved (Roos 1991).

Escapement time series: Two sites are included in the escapement time series: Gates Creek and Gates Channel (Appendix 1). Gates Creek was consistently assessed starting in 1954, using peak live cumulative dead visual survey methods up to 1979, with the exception of 1964 when a mark recapture assessment was conducted. Starting in 1980, the creek was assessed using counts of Sockeye diverted into the creek at the diversion weir. Given the public location of the diversion weir, vandalism has compromised the escapement time series of Gates Creek and, therefore, post-1980 these are likely minimum escapement estimates. Gates Channel (operations commenced in 1968) was assessed throughout the time period using a census of carcasses recovered in the channel (Appendix 2). The Gates Creek and Channel sites were combined to evaluate status. They cannot be evaluated independently, since numbers of Sockeye distributed between the channel and creek are a consequence of loading regimes at the outlet of this system (Roberta Cook, Ocean Habitat Enhancement Branch, DFO).

Productivity: Similar to other Early Summer Run and Early Stuart CUs, Anderson-ES has exhibited systematic declines in productivity (Kalman filter Ricker *a* parameter values) since the late-1960 brood years (Appendix 3, Anderson-ES, Figure 1 c). Productivity (R/S) has been

particularly low during the most recent brood years (1998 to 2005), with four of these years having productivities that are below replacement (Appendix 3, Anderson-ES, Figure 1 d). Similar to other CUs with freshwater survival data, Anderson-ES early freshwater survival (fry to EFS) decreased consistently from the start of the time series in 1968 to the mid-1990 brood years, and has subsequently increased (Appendix 3, Anderson-ES, Figure 1 e). Post-fry survival (Appendix 3, Anderson-ES, Figure 1 f) that includes a period of freshwater survival, in addition to marine survival, exhibited decreases since channel construction (1969).

Abundance: The stock-recruitment time series for Anderson-ES was truncated to only include years after the construction of the spawning channel (brood years 1968-2004). This ensures consistency in the production time series and spawning area.

Trends in Abundance: The early time series, prior to channel construction, is characterized by lower spawner abundance (arithmetic average EFS from 1954 to 1974: 1,300) (Appendix 3, Anderson-ES, Figures 1 a & b). Escapements (EFS) increased starting in the 1970's (EFS 1970-2009 average: 4,500), coinciding with channel construction. This CU has recently declined from a period of above average EFS three generations prior to the end of the time series (6,200), to the current generation average EFS (2,400) (Tables 4 & 6; Appendix 3, Anderson-ES, Figure 1 b). This CU exhibits strong cyclic dominance throughout the time series (one dominant cycle average EFS: 8,300; three weak cycles average EFS: 2,100). Generally, spawner success on the time series has been high (70%), with the exception of more recent years. Spawner success dropped between 1995 and 2002, to an average of 56%. Years when spawner success was particularly low include 1992 (channel: 37% & creek: 50%), 1996 (channel & creek: 25%), 2000 (channel: 32% & creek: 47%), 2001 (creek only: 49%), and 2008 (channel and creek: 23%) (Appendix 3, Anderson-ES, Figure 1 b).

The ratio of the recent generation geometric average relative to the long-term average for Anderson-ES EFS (ratio: 1.98) is almost double,. and is therefore greater than the upper benchmark for this metric (ratio: 0.75) (green status) (Tables 4 & 6; Appendix 2, Anderson-ES, Figure 2 c). For comparison, if only data after the installation of Gates channel (1968-2009) are used to estimate the trend in abundance, the ratio of the recent generation abundance to the long-term average would still be greater (green status) (ratio: 1.37) than the upper benchmark for this metric (ratio: 0.75). In recent years (last three generations), Anderson-ES EFS has declined following a period of higher EFS (see previous paragraph). The slope of this recent trend (-0.04) is steeper than the lower benchmark for this metric (-0.026 or 25% decline), and there is an 80% probability that this recent trend is below this lower benchmark (red status) (Tables 4 & 6, Appendix 3, Anderson-ES, Figures 2 a & b).

Bowron-ES

Sites: The populations that rear in Bowron Lake (Early Summer timing) include Bowron River, Pomeroy, Huckey, and Sus Creeks, and may also include Antler Creek (see Escapement time series section below) (Appendix 1).

History: Hatchery transplants were introduced into the Bowron system from Lakelse Lake (Skeena River hatchery) between 1924 and 1926 (Aro 1979). Since these transplants were not successful, population expansion within this CU after the Hells Gate landslide is likely attributed to remnant Bowron-ES Sockeye (Withler 1982). There was a significant Mountain Pine Beatle outbreak in the 1980's in the Bowron watershed that resulted in significant forest harvesting in this area (K. Peters, pers. comm.).

Escapement time series: Four sites were included in the Bowron-ES escapement time series: Bowron River, Huckey, Pomeroy and Sus Creeks (Appendix 1). For early years in the escapement records, the Bowron River time series includes Pomeroy, Sus and Huckey Creek estimates; whereas in recent years there are a few independent assessments for these smaller creeks (Appendix 2). In years when Huckey, Pomeroy and Sus were assessed independently, their contribution to total production of the CU was 0 (Pomeroy & Sus) to negligible (Huckey); Bowron River dominates total production. Escapement enumeration methods varied from largely fence counts in the earlier time series (1950-1963) to largely visual surveys (helicopter) from 1964 to present, with no gaps in the time series. In 1995, a fence was installed to re-evaluate the expansion factor used to calibrate the visual surveys in this system. It was found that the expansion factor appropriate for this system (2.9) is much higher than that typically used for Fraser Sockeye (1.8). Therefore, previous surveys (1985-1994) may underestimate true escapement (Schubert 2007).

Antler Creek was excluded from the time series given the limited numbers of years it was assessed (only from 1950-1961) during opportunistic surveys from a fence program, and its small contribution to overall abundance in this CU (~1% of total escapement). Although unconfirmed, Antler Creek Sockeye may not rear in Bowron Lake. Given that fry from these Sockeye spawners would have to travel upstream through fast flowing conditions to reach the lake; these Sockeye may actually be river-type. Recently, Sockeye have been observed in the upper Bowron River, and similarly, these also may be a river-type population.

Productivity: Similar to other Early Summer Run and Early Stuart CUs, Bowron-ES has exhibited systematic declines in productivity (Kalman filter Ricker *a* parameter values) since the mid-1960 brood years (Appendix 3, Bowron-ES, Figure 1 c). Productivity (R/S) has been particularly low recently (1994 to 2005 brood years), with six of these years close to or below replacement (Appendix 3, Bowron-ES, Figure 1 d). There are no freshwater or marine survival data available for this CU.

Abundance: The full stock-recruitment time series for Bowron-ES includes the brood years 1950-2004. For Ricker model benchmark estimates (recommended model by Holt et al. 2009), a lognormally distributed prior on the '*b*' parameter, with a mean of 41,000 and sigma of 30,000, was used, based on calculations of lake rearing capacity (Table 2; Appendix 3, Bowron-ES, Figure 2 d).

Trends in Abundance: Bowron-ES exhibited relatively high escapements (EFS) early in the time series (1950-1959 EFS average: 7,400) relative to the time series average (4,300) (Appendix 3, Bowron-ES, Figures 1 a & b). This CU has declined in abundance, from an average of 3,900 EFS three generations prior to the end of the time series, to the current generation average of 800 EFS (Tables 4 & 6; Appendix 3, Bowron-ES, Figure 1 b). From 1959 to 1979, the CU started to exhibit strong cyclic dominance (one dominant cycle average EFS: 13,600; three weak cycles average EFS: 1,600). Cyclic dominance subsequently disappeared (1983-2009 average EFS: 3,200). Spawner success has remained high throughout the time series (~91%) and has not exhibited any persistent trends (Appendix 3, Bowron-ES, Figure 1 b).

The ratio of the recent generation average abundance relative to the long-term average for Bowron-ES (ratio: 0.27) is below the lower benchmark for this metric (ratio: 0.5) (red status) (Table 4; Appendix 2, Bowron-ES, Figure 2 c). In recent years (last three generations), Bowron-ES EFS have declined at a rate (-0.19) that is steeper than the lower benchmark for this metric (-0.026 or 25% rate of decline), and there is a 99% per cent probability this recent trend is below this lower benchmark (red status) (Tables 4 & 6; Appendix 3, Bowron-ES, Figures 2 a & b). This

Chilko-ES and Chilko-S (CUs combined for status assessment)

Sites: Chilko River, South End of Chilko Lake, North End of Chilko Lake and Chilko River Channel (Appendix 1).

History: Chilko Lake is a large oligotrophic lake far from any significant human development in the Fraser River watershed. The south end of the lake is surrounded by glaciated mountains, and the northern portion extends onto the edge of the interior plateau of BC. Due to its glacial influence, this lake has historically experienced cooler temperatures. Several glacially turbid rivers enter the southern half of the lake, causing water clarity to decrease from north to south during the summer months. The lake's orientation and proximity to the Coast Mountains result in frequent strong southerly winds. As a result, the lake has a cool epilimnion and an unstable thermal regime.

Amongst populations with similar run timing that spawn upstream of Hells Gate, Chilko Sockeye were the least impacted by the 1913 Hells Gate landslide, despite the fact that Chilko Sockeye migration has almost double the grade (twice as steep) of any other Fraser River CUs. The limited impact of the Hells Gate landslide on Chilko Sockeye, relative to other Sockeye stocks, is hypothesized to be linked to their greater energy reserves and their ability to therefore withstand delays in migration (Roos 1991). In recent studies, Chilko Sockeye (relative to other similar timed Fraser Sockeye CUs) have been identified as superoptimal migrants, having greater stride lengths, higher ground speed per tailbeat, and lower energy usage than would be predicted (Hinch and Rand 2000). Chilko Sockeye are more torpedo shaped than other stocks, which would enhance water flow over the body and decrease drag. As a result, Chilko Sockeye have migration advantages over other similar timed Fraser Sockeye CUs.

Chilko Lake was fertilized in 1988, and again during 1990-1993. Bradford et al. (2000) reported that the size of smolts increased during these periods of fertilization. They also found a positive correlation between the larger smolt body sizes and smolt-to-adult (marine) survival. Fertilization also appeared to have increased abundance on the weaker 1989 cycle, and improved survival during the early 1990's, when productivity for most other CUs decreased (Appendix 3, Chilko-ES & Chilko-S, Figures 1 a-f) (Bradford *et al.* 2000). Limnological surveys, conducted in 2009, in response to recent increases in smolt production, found that the Photosynthetic Rate had increased to rates similar to those seen during fertilization (D. Selbie, pers. comm.). In addition to fertilization, a small artificial side channel was operated from 1988 to 2004 on Chilko River, to enhance the productive capacity of Chilko; although spawning habitat did not appear to be limiting to Sockeye at that time. Post-2004 this channel was decommissioned, and, therefore, became inaccessible to Chilko-S Sockeye.

Escapement time series: All sites were included in the escapement time series since they represent one complete time series with the North and South End of Chilko Lake assessed separately in some years and in other years included in the Chilko River site in the escapement database (Appendix 1 & 2). This system was enumerated using mark recapture methods up to 2008, with the exception of 1967, which was estimated based on the expansion of counts at Henry's Bridge. In 2009, DIDSON methods were used to estimate abundance. Chilko River (including the North End of Chilko Lake) comprises 98% of the total abundance in years when the South End (of the lake) spawners and channel were estimated separately.

Productivity: Similar to other Summer Run CUs, the Chilko-ES & Chilko-S CU aggregate has exhibited systematic declines in productivity (Kalman filter Ricker *a* parameter values) since the 1990 brood year (Appendix 3, Chilko-ES & Chilko-S, Figure 1 c). Productivity (R/S) has been particularly low recently (1994 to 2005 brood years), with six years close to or below replacement (Appendix 3, Chilko-ES & Chilko-S, Figure 1 d). Similar to other CUs with freshwater survival data, the Chilko-ES and Chilko-S aggregate survival decreased consistently from the mid-1960 to 2000 brood years, and has subsequently increased (Appendix 3, Chilko-ES & Chilko-S, Figure 1 e). Marine survival has decreased consistently from the 1990 to 2005 brood years (Appendix 3, Chilko-ES & Chilko-S, Figure 1 f).

Abundance: The full stock-recruitment time series available includes the brood years 1950-2004.

> **Comment:** has not been revised; needs revised table updating etc.

Trends in Abundance: The Chilko-ES & Chilko-S CU exhibited a period of particularly high escapement (EFS) from 1990 to 2000 (average EFS: 400,000), relative to the time series average (192,000). Subsequently, this CU has declined from an above average EFS period three generations prior to the end of the time series (407,000) to the current generation average EFS (154,000) (Tables 4 & 6; Appendix 3, Chilko-ES & Chilko-S, Figure 1 b). This CU exhibited strong cyclic dominance from 1950 to 1990 (dominant cycle average escapement: 250,000; one weak cycle average EFS: 39,000; and two subdominant cycles average EFS: 117,000;) (Appendix 3, Chilko-ES & Chilko-S, Figures 1 a & b). After 1990, cyclic dominance disappeared (Appendix 3, Chilko-ES & Chilko-S, Figures 1 a & b). Spawner success has remained generally high throughout the time series (~92%) and has not exhibited any persistent trends; with the exception of 2008 where spawner success was low (53%) (Appendix 3, Chilko-ES & Chilko-S, Figure 1 b).

The ratio of the recent generation average abundance to the long-term average (ratio: 1.22) is greater than the upper benchmark for this metric (ratio: 0.75) (green status) (Tables 4 & 6; Appendix 3, Chilko-ES & Chilko-S, Figure 2 c). In recent years (last three generations), the Chilko-ES & Chilko-S aggregate has declined following a period of above average EFS (see previous paragraph). The slope of this recent trend (-0.13) is steeper than the lower benchmark for this metric (-0.026 or 25% rate of decline), and there is a 100% probability this recent trend is below this lower benchmark (red status) (Tables 4 & 6; Appendix 3, Chilko-ES & Chilko-S, Figures 2 a & b).

Metric Status Summary: The Chilko-ES & Chilko-S aggregate has experienced relatively high escapements, starting in the 1990's. As a result, the current generation EFS is 1.22 times greater than the historical average (green status). The current generation ETS geometric average is between the upper and lower benchmarks for all models. Conversely, the current generation ETS arithmetic average is above the upper benchmarks using the Ricker or KF Ricker models (green status), and between the lower and upper benchmarks for the Larkin model (amber). Although the overall status of this CU is largely green, other metrics indicate that it will be important to track on-going status. Specifically, the linear rate of change in the last three generations has been greater than a 50% rate of decline (red status), although this CU has been returning to average following a period of above average abundance. This CU has also been experiencing consistent decreases in total productivity starting in the 1990's, with the lowest productivity on record occurring in recent years. Therefore, if these trends in abundance and productivity persist into the future they will negatively affect the status of this CU.

Chilliwack-ES

Sites: Populations that rear in Chilliwack Lake include Chilliwack Lake and Dolly Varden Creek (also known as Upper Chilliwack River) (Appendix 1).

History: Chilliwack Lake is a relatively isolated lake surrounded by glaciated mountains. This lake is influenced by glacial melt and, therefore, given increasing temperatures and associated decreases in glacial mass, it has been warming. The Chilliwack-ES CU is amongst the first population of Sockeye to enter the Fraser River, with an entry-timing more closely associated with the Early Stuart Sockeye than other Early Summer Runs. Chilliwack-ES Sockeye spawn in the lake and in Dolly Varden Creek from late August to early September.

Escapement time series: Chilliwack Lake assessments began in the 1970's but were only consistently assessed starting in 1982, with generally two or more visual (boat) surveys conducted annually. Carcass counts are expanded based on survey effort, using methods established during studies on the Taseko Lake population. The estimates are likely biased low given limitations in the number of carcasses that reach the lake surface after becoming moribund (Patterson et al. 2007b). Lake counts may be further compromised on survey days with heavy rain or winds, which decrease the visibility of carcasses on the lake surface.

Dolly Varden Creek has only been consistently assessed in more recent years, starting in 2001, and represents the bulk of the spawning (>70% of the total lake plus creek EFS) in the CU. Dolly Varden Creek is assessed using peak live and cumulative dead (helicopter) surveys. In 2001, a tower count was used to assess the total escapement to the lake and river combined, and a visual (helicopter) survey was conducted on Dolly Varden Creek; the Lake was then estimated by subtracting the tower count from the creek estimate. The lake was also coincidentally assessed in 2001 using standard lake survey methods; both estimates from standard methods and tower counts did not deviate significantly from one another.

Productivity: Productivity and survival could not be estimated for this CU as there are no associated recruitment data available for this CU.

Abundance: Abundance benchmarks were estimated for this CU using alternative approaches given that although there are no stock-recruitment data for this CU, there are lake rearing capacity data available

Trends in Abundance: Chilliwack Lake has exhibited variable escapement throughout the time series, and was particularly low in abundance in the last generation (average EFS: 500) relative to the long-term average (average EFS: 1,100) (Table 4 & 6; Appendix 3, Chilliwack-ES, Figure 1 b (Chilliwack Lake only)). Dolly Varden Creek can only be compared to Chilliwack Lake post-2000, and during these years has exhibited a considerably shallower declining trend compared to Chilliwack Lake. Dolly Varden Creek exhibited high EFS in three years (2001, 2004 & 2008 average EFS: 34,000) and weaker EFS in all other years assessed (average EFS: 2,000) (Appendix 3, Chilliwack-ES, Figure 1 a). In years when the Dolly Varden Creek population was large (2001, 2004 & 2008), it comprised 94% of the total escapement to this CU. On all weaker abundance years for Dolly Varden Creek, the creek comprised 54% of the total escapement for this CU. Given that the sparsely-enumerated Dolly Varden Creek comprises a greater average proportion of the total EFS (Dolly Varden Creek plus Chilliwack Lake post-2001), and given that the trends in the EFS time series considerably differ between the two assessed sites, *trends in abundance* metrics could not be quantitatively assessed for this CU; it would be misleading to present the status for Chilliwack Lake alone given these differences.

> **Comment:** has not been revised; needs revised table updating etc.

<u>Cultus-L</u>

Sites: The only population that rears in Cultus Lake is Cultus Lake (all spawners spawn in Cultus Lake) (Appendix 1).

History: Cultus-L has been the most intensively studied salmon stock in British Columbia. Studies on spawner abundance, lake characteristics and juvenile production began with the work of the Pacific Biological Station in the 1920's, and have continued into the present with the work of the International Pacific Salmon Fisheries Commission and the Department of Fisheries and Oceans (Schubert *et al.* 2003). Cultus-L Sockeye spawner abundance was low and variable during large scale hatchery experimentation in the 1920's and 1930's, very high in 1939-1942 following removal of predators, strong but variable in the early 1940's to late 1960's, and has subsequently declined. Exploitation rates were high from 1952 to 2002 (average: 67%), since this population co-migrates with more abundant and productive CUs (Harrison (U/S)-L, Shuswap-L). Beginning in 1995, ER's decreased to an average of 33%. In 2001 and 2002, the Fraser Panel and DFO limited fisheries on Late Run populations to ER's of ~20% (Fisheries and Oceans Canada 2010; Bradford et al. 2010a). Three main causes for the decline of Cultus-L Sockeye include high exploitation rates between 1952 and 1995, high pre-spawn mortality (coincides with early migration of Late Run Sockeye starting in 1995), and low marine survival, particularly in recent years. Other causes may include heavy recreational, residential and agriculture land use around the lake, the loss of spawning habitat attributed to water milfoil invasion, and predation threats (Schubert et al. 2003; COSEWIC 2003a; Cultus Sockeye Recovery Team 2009).

As a result of significant population declines in this CU, Cultus-L is listed as *Endangered* by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC)(25 October 2002)(COSEWIC 2003a). Consequently, a Cultus Lake Sockeye Recovery Planning Team was formed in 2002, with both internal-DFO and non-DFO representation, to document status and develop a recovery plan (COSEWIC 2003a; Cultus Sockeye Recovery Team 2009). This team was disbanded after the publication of the Cultus Recovery Strategy (Cultus Sockeye Recovery Team 2009), which outlined an overall conservation goal and four key objectives.

Subsequently, a Cultus Conservation team (similar DFO membership to the Recovery Team) was formed to continue with recovery work, and track recovery efforts and status. A recent publication (Research Document and corresponding Science Advisory Report), as part of the Canadian Science Advisory Secretariat (CSAS) process, has been peer-reviewed and is near publication (Fisheries and Oceans Canada 2010; Bradford et al. 2010a). In summary, this publication concludes that although the decline in Cultus-L Sockeye has been halted, the population has not yet met any of the recovery objectives set by the Cultus Sockeye Recovery Team. The prospects for Cultus-L Sockeye are highly uncertain, and are tied to future trends in smolt-to-recruit survival. Recovery actions in recent years have included reductions in harvest (~20% ER), predator control in Cultus Lake (which has coincided with an increase in in-lake survival of juvenile Sockeye salmon), and a captive broodstock/supplementation program (majority of adults returning in 2008 & 2009 were of hatchery origin).

Escapement time series: Only Cultus Lake was included in the escapement time series (Appendix 1). Cultus Lake Sockeye have been assessed since 1925 using an enumeration fence in Sweltzer Creek, located approximately 200 m downstream from the lake outlet. The fence is installed at the start of the migration period (normally mid/late September), and is removed at its completion in early/mid December. As this CU population started to migrate earlier in the mid-1990's, fence installation has occurred at progressively earlier dates, with installation in recent years occurring in August.

For the escapement time series, effective total adult escapement (total adult escapement multiplied by female spawner success) was used instead of effective female escapement, due to uncertainty in sex identification at the fence. Cultus Sockeye do not have well developed secondary sexual characteristics when assessed at the Cultus fence because they migrate through the fence early, and move into the deeper and cooler lake where they hold for months before spawning in December to January. Calculation of spawner success is typically based on the assessment of carcasses on the spawning grounds. However, given low abundances of Cultus-L Sockeye in recent years, recovery of female carcasses has been negligible. Therefore, a combination of spawner success data from the enhancement program (Cultus Sockeye captured at the fence and retained in holding ponds for hatchery purposes), Weaver Creek & Channel data, and data on Cultus-L Sockeye recruits-per-juveniles, was used to assess spawner success for Cultus Sockeye. Post-2000, due to hatchery enhancement of this system (Schubert et al. 2003; Cultus Sockeye Recovery Team 2009; Bradford et al. 2010a), only wild unmarked fish (no adipose-fin clip) were included in the escapement time series.

Productivity: Similar to other CUs, Cultus-L has exhibited systematic declines in productivity (Kalman filter Ricker *a* parameter values) since the 1990 brood year (Appendix 3, Cultus-L, Figure 1 c). Productivity (R/S) has been particularly low recently (1993 - 2005 brood years), with seven of these years close to or below replacement (Appendix 3, Cultus-L, Figure 1 d). Freshwater and marine survival trends are a challenge to interpret, due to considerable gaps in the smolt, and therefore, survival time series (Appendix 3, Cultus-L, Figures 1 e & f). In years where it exists, the marine survival time series tends to correspond to the Chilko survival time series (Figure 6).

Abundance: For Cultus-L Sockeye, only the brood years from 1950-2000 were used to estimate abundance benchmarks. Although brood years 2001 - 2003 have full recruitment data (age-4 plus age-5 recruits), these years were not included, due to the confounding influence of the enhancement program, which has contributed fry and smolts to Cultus Lake production, and is unaccounted for in the spawner-recruit relationship. Although the hatchery program started in 2000, the number of fry produced in the first year of operation was negligible, therefore stock-recruitment data for this year can be included in the time series.

Trends in Abundance: Cultus-L has experienced three distinct periods of abundance (Appendix 3, Cultus-L, Figures 1 a & b). The earliest years in the time series (1934 - 1968) exhibited the highest average effective total spawners (ETS) at 19,400, with peak escapements occurring from 1939 to 1942 (average ETS: 45,500), following predator removal from Cultus Lake. This early period of abundance was strong but variable with no cyclic dominance, attributed to the operation of the Sweltzer hatchery and periodic control of predators feeding on fry in the lake (Cultus Sockeye Recovery Team 2009). Abundance subsequently declined during the period from 1960 to 1991 (average ETS was 8,200). During this period, cyclic dominance occurred with three stronger cycles and one weaker cycle. In recent years (1992 to 2009), average ETS has declined further to 1,600, and cyclic dominance has again disappeared. Female spawner success was relatively high (92%) in the historical time series from 1934 to 1992. In recent years, spawner success has decreased (74%) with some years as low as 15% (e.g. 1999 and 2000) (Appendix 3, Cultus-L, Figure 1 b).

The ratio of the recent generation average wild Sockeye abundance to the long-term average (ratio: 0.07) is well below the lower benchmark for this metric (ratio: 0.5) (red status) (Tables 4 & 6; Appendix 3, Cultus-L, Figures 2 c). In the last three generations, this CU has declined in wild Sockeye abundance with a negative slope (-0.11) that is steeper than the lower benchmark for

Francois-ES

Sites: Populations that rear in Francois Lake include Nadina River (sites include: Early and Late Nadina River), Nadina Channel, Tagetochlain and Uncha Creeks (Appendix 1).

History: The Nadina Sockeye spawning channel is located south of the city of Houston, next to the Nadina River at the outlet of Nadina Lake. The channel was built to augment the Nadina Sockeye stock and increase utilization of the Francois Lake rearing area by juveniles. Historically, the Nadina River stock was divided into an early and a later timed run, both of which migrated into the system in the early summer. The earlier timed Sockeye would migrate up the Nadina River into Nadina Lake where they would hold, then later drop down to spawn in the Nadina River downstream of the current channel. The later run timing Sockeye would migrate in after the earlier timed population and would spawn at the current spawning channel location. After construction of the Nadina channel, the early timed Sockeye were restricted from leaving the channel to perform their historical holding and spawning patterns. As a result, the early and later timed Nadina River Sockeye mixed and inter-bred in the channel, eliminating the distinct timing components of this Early Summer run.

The Nadina Channel Sockeye have experienced several years of elevated pre-spawn mortality associated with *Ichthyophthirius multifiliis,* particularly in 1978, 1987 and 1995. Although this pathogen typically does not cause disease in Sockeye Salmon, "ich" or "white spot disease" can occur if numbers of this pathogen are high due to conditions such as warm water, reduced flows and adult crowding.

Escapement time series: Three sites are included in the escapement time series: Nadina River Early, Nadina River Late, and Nadina Channel (Appendix 1 & 2). Given that the early timed Nadina River population has merged with the late population, and the number of Sockeye distributed between the channel and the river is controlled at the channel, all three sites must be included to evaluate status. No gap filling was required for these three sites. Tagetochlain and Uncha Creeks were excluded from the time series because they were inconsistently assessed in the 1950's & early 1960's.

Productivity: Similar to other Early Summer Run and Early Stuart CUs, Francois-ES has exhibited systematic declines in productivity (Kalman filter Ricker *a* parameter values) since the mid-1960 brood years (Appendix 3, Francois-ES, Figure 1 c). Productivity (R/S) has been particularly low recently, from the 1997 to 2005 brood years, with six of these years close to or below replacement (Appendix 3, Francois-ES, Figure 1 d). Similar to other CUs with freshwater survival data, Francois-ES early freshwater survival (fry to EFS) decreased consistently from the start of the time series in 1973 to the mid-1990's, and has subsequently increased (Appendix 3, Francois-ES, Figure 1 e). Marine survival data are not available for this CU.

Abundance: The stock-recruitment time series only included years after the construction of the spawning channel in this system (brood years 1973-2004), to ensure consistency in the spawning area throughout the time series
Trends in Abundance: Francois-ES has exhibited relatively consistent escapement throughout the time series (average EFS: 5,700), often oscillating between higher abundances on odd years (average EFS: 9,800) and lower abundances on even years (average EFS: 5,100) (Appendix 3, Francois-ES, Figure 1 a). This CU has declined from an above average EFS three

Comment: has not been revised; needs revised table updating etc.

generations prior to the end of the time series (22,600), to the current generation arithmetic average EFS (4,900) (Tables 4 & 6; Appendix 3, Francois-ES, Figure 1 b). Throughout the time series, spawner success has remained high (~93%) in the river and channel (90%) with the exception of 2008 when the channel had only 1% spawner success (Appendix 3, Francois-ES, Figure 1 b).

The ratio of the recent generation average abundance to the long-term average (ratio: 1.35) is above the upper benchmark for this metric (ratio: 0.75) (green status) (Tables 4 & 6; Appendix 3, Francois-ES, Figure 2 c). For comparison, if only data after the installation of Nadina channel (1973-2009) are used to estimate the trend in abundance, the ratio of the recent generation abundance to the long-term average would still be greater (ratio: 0.97) than the upper benchmark for this metric (ratio: 0.75) (green status). In the last three generations, this CU has declined in abundance with a negative slope (-0.04) that is steeper than the lower benchmark for this metric (-0.026 or 25% rate of decline), and there is a 69% probability this recent trend is below the lower benchmark for this metric (red status) (Tables 4 & 6; Appendix 3, Francois-ES, Figures 2 a & b).

Fraser-S

Sites: The only population that rears in Fraser Lake (Summer Run timing) is the Stellako River Sockeye (Appendix 1).

History: After the 1913 Hells Gate landslide, the Fraser-S population began to build and exhibit cyclic dominance. In 1964, log driving commenced on the Stellako River, to transport logs downstream from upriver forestry operations. This practice moved logs by releasing large volumes of water from splash dams during the spring freshets. Log driving degraded the river system, leaving bark and wood fibre deposits on the river bottom and spawning grounds, and eroding river banks through scouring and log jams (Roos 1991). After 1968, log driving was discontinued. This CU has not exhibited cyclic dominance since the log driving period (Schubert 2000).

Significant hydro-electric infrastructure exists on the Nechako River, which is connected to the Stellako system. However, Fraser-S Sockeye habitat has not been affected, as the dam was constructed upstream of Sockeye accessible areas. Although flow management associated with this facility has likely historically affected Sockeye, current flows are managed to meet temperature targets for this species.

Escapement time series: Only the Stellako River was included in the escapement time series (Appendix 1 & 2). Escapement enumeration included mark recapture programs from 1950 to 1993 and from 2007 to 2009, and a fence program from 1994 to 2006. In 1994 and 1995, both mark recapture and fence counts were conducted to evaluate mark recapture biases (Schubert 2007); fence data were used as the escapement time series for these years. The comparison study concluded that sampling biases in the mark recapture program were bi-directional, and, as a result, were cumulatively small (Schubert 2007).

Productivity: Similar to other Summer Run CUs, Fraser-S has exhibited systematic declines in productivity (Kalman filter Ricker *a* parameter values) since the 1990 brood year (Appendix 3, Fraser-S, Figure 1 c). Productivity (R/S) has been particularly low recently (1998 - 2005 brood years), with six of these years close to or below replacement (Appendix 3, Fraser-S, Figure 1 d). Similar to other CUs with freshwater survival data, Fraser-S early freshwater survival decreased from the 1990's to the 2000 brood year, and has subsequently increased, though the time

series for comparison is short (1990 to 2002 brood years) (Appendix 3, Fraser-S, Figure 1 e). Marine survival data are not available for this CU.

Abundance: The stock-recruitment time series includes brood years 1950-2004.

Trends in Abundance: The average abundance in the Fraser-S CU was low in the first half (1950-1974) of the time series (average: 32,300 EFS) and increased from 1975 to 2002 (average EFS: 70,800), with increasing frequency of high abundance years (exceeding 150,000 EFS). Average EFS across the entire time series is 53,000 (Tables 4 & 6). This CU has declined from an above average EFS period three generations prior to the end of the time series (105,000) to the current generation average EFS (47,300) (Tables 4 & 6; Appendix 3, Fraser-S, Figure 1 b). From 1950 to 1968, Fraser-S exhibited cyclic dominance, with one dominant cycle (average EFS: 61,500), one subdominant cycle (average EFS: 41,200) and two off cycles (average EFS: 19,700) (Appendix 3, Fraser-S, Figures 1 a & b). After this period, abundance fluctuated, with no persistence of cyclic dominance but large inter-annual variability in abundance. Throughout the time series, spawner success has remained high (~90%) and has not exhibited any persistent trends (Appendix 3, Fraser-S, Figure 1 b).

The ratio of the recent generation average abundance to the long-term average (ratio: 1.31) is above the upper benchmark (green status) (ratio: 0.75) (Tables 4 & 6; Appendix 3, Fraser-S, Figure 2 c). In recent years (last three generations), Fraser-S has declined following a period of above average EFS (see previous paragraph). The negative slope of this recent trend (-0.04) is steeper than the lower benchmark for this metric (-0.026 or 25% rate of decline) and there is a 78% probability that this recent decreasing trend is below the lower benchmark for this metric (red status) (Tables 4 & 6; Appendix 3, Fraser-S, Figures 2 a & b).

Harrison (D/S)-L

Sites: Populations that migrate downstream to rear in Harrison Lake, after emerging from the gravel as fry, include Bear Creek, Big Silver Creek, Cogburn Creek, Crazy Creek, Douglas Creek, Hatchery Creek, Sloquet Creek, Tipella Creek and Tipella Slough (Appendix 1).

History: Big Silver Creek, the most consistently assessed stream in this CU, originates in the Lillooet Range of the Coast Mountains east of Harrison Lake, and flows predominantly west to the lake. River flows are maintained throughout the summer via snowfields in the headwaters. Although the total length of the Big Silver mainstem, from headwaters to mouth, is approximately 40 km, a waterfall 6 km from the mouth prevents fish passage further upstream. The lower 15 km of the mainstem channel is very stable and contains only a single major bifurcation 2 km up from the mouth. Big Silver contains numerous narrow bedrock canyons spread sporadically through the length of the mainstem. Stream banks are stable and serve to confine the river during periods of high flow (Wilson et al. 1999). Big Silver was historically affected by logging activities, which may have changed flow regimes, sediment deposition, and caused erosion (Fisheries and Oceans Canada 1999). Restoration and enhancement projects have been conducted on Big Silver Creek, aimed specifically at enhancing flows and Sockeye usage of the north fork of this creek where high quality spawning habitat (classic spawning gravel), relative to the south fork (large cobbles), occurs (K. Peters, DFO Stock Assessment pers. comm.).

Escapement time series: Big Silver creek is the only creek consistently assessed in this CU, likely due to ease of surveyor accessibility (Appendix 1). Douglas, Hatchery and Bear Creeks

were assessed in 1950-1953 (in these year's Big Silver comprised 50% of the total escapement) and Cogburn, Crazy, Sloquet and Tippella Creeks were assessed only after 2000 (in these year's Big Silver comprises 92% of the total escapement that includes these streams). Therefore, only Big Silver Creek is included in the escapement time series (Appendix 2).

Productivity: Productivity and survival could not be estimated for this CU as there are no associated recruitment data available for this CU.

Abundance: Abundance benchmarks could not be estimated for this CU as there are no associated recruitment data available for this CU.

Trends in Abundance: Harrison (D/S)-L is a small CU with an average EFS of 1,500 (Appendix 3, Harrison (D/S)-L, Figure 1 a). From 1964 to 1998, the population abundance was relatively low (average EFS: 580), and subsequently increased between 1999 and 2009 (average EFS: 5,400). From 1950 to 1964, Harrison (D/S)-L Sockeye exhibited cyclic dominance, with one dominant (average EFS: 2,500) and three subdominant cycles (average EFS: 100). Since 1964, this CU has not exhibited cyclic dominance. Throughout the time series, spawner success has remained high (~85%), with a few intermittent years of low spawner success (1953: 30%; 1981: 67%; 1983: 54% and 2008: 63%) (Appendix 3, Fraser-S, Figure 1 b).

The ratio of the recent generation average abundance to the long-term average (ratio: 13.3) is well above the upper benchmark for this metric (ratio: 0.75) (green status) (Tables 4 & 6; Appendix 3, Fraser-S, Figure 2 c). This CU has increased in abundance in the last three generations with a positive slope (0.11) that is greater than the upper benchmark for this metric (-0.015 or 15% rate of decline) and there is an extremely small probability (1%) that this recent increasing trend is below the lower benchmark for this metric (green status) (Tables 4 & 6; Appendix 3, Fraser-S, Figures 2 a & b). However, there may be data quality issues in this time period that would result in the under-estimation of total abundance. Therefore, it is possible that the increasing trend is somewhat biased high.

Harrison (U/S)-L

Sites: Populations that migrate upstream to rear in Harrison Lake, after emerging from the gravel as fry, include East Creek (rolled up into Weaver Creek after 1951 and may alternatively be named Sakwi Creek), Steelhead Creek (rolled up into Weaver Creek throughout the time series), Weaver Creek and Weaver Channel (Appendix 1).

History: Until 1965, Weaver Creek was the key producer of Sockeye in this CU (average EFS: 9,200), with negligible contributions from Steelhead Creek (small creek on the west side of Weaver Creek near a swampy area) and East Creek (located on the east side of Weaver Creek). Towards the end of this early period (1961-1964), extensive logging within the watershed caused considerable flooding and scouring of Sockeye spawning habitat, and abundance declined to near extinction (Roos 1991). Substantial erosion and sediment input into Sakwi and Weaver Creeks occurred as a result of logging (1963), and road and trail clearing associated with the development of a ski resort (1970's) (Rood and Hamilton 1995). In the 1972 brood year, a decline in egg-to-fry survival in Weaver Creek was attributed to the accumulation of sediment and organic debris in the gravel. Gravel cleaning returned survival to normal by the 1973 brood year, but it declined again in 1974-1975 for the same reason (IPSFC 1972).

The Weaver Creek diversion weir and spawning channel (located on Weaver Creek, upstream of Harrison River), the first of its kind for Sockeye in BC, was built in the mid-1960's, and started operating in the fall of 1965. Weaver channel was constructed to re-build production from the Weaver stock, and subsequently allow for increased harvest opportunities on the aggregate

Late Run stock (which includes the large Adams River run). The channel also serves to protect the Weaver run from periodic flooding events. A flow control structure is operated at the outlet of Weaver Lake, to manage the water supply for channel operations. Sakwi Creek, a tributary of Weaver Creek, upstream of the channel, also has an intake that provides water for the channel as required.

The channel operated at 25% of capacity until 1969, when there were sufficient spawners to fill it to near capacity INSERT REFERENCE (IPSFC). Subsequently, Sockeye were preferentially diverted into the channel over the creek, since their presence in the creek is thought to affect oxygen concentrations in the channel's source water. The channel has approximately eight times higher egg-to-fry survival compared to the creek (natural spawning grounds), based on data available from 1965-1988. Losses in the last four years can be attributed to *Parvicapsula*, a parasite that causes pre-spawn mortality. The cause of *Parvicapsula* outbreaks is not yet clear, although it is postulated to be associated with changes in river entry timing and water temperatures (Roberta Cook, Ocean Habitat Enhancement Branch, DFO, pers. comm.). There has also been one year (1995) of elevated pre-spawn mortality associated with *Ichthyophthirius multifiliis.* Although this pathogen typically does not cause disease in Sockeye Salmon, "ich" or "white spot disease" can occur if numbers of this pathogen are high due to conditions such as warm water, reduced flows, and adult crowding.

Weaver has historically had low flow levels and was essentially dry during the 1952 drought (Rood and Hamilton 1995). Channel excavation is conducted annually in lower Weaver Creek to maintain a low flow channel and holding pools, to improve conditions for salmon migration during low flow conditions. Weaver has also been dredged a number of times to maintain access to the spawning channel (Rood and Hamilton 1995).

Escapement time series: Three sites are included in the escapement time series: Weaver Creek, Weaver Channel and East Creek (Appendix 1 & 2). East Creek has independent data early in the time series but was included in the Weaver Creek estimate after 1951. Steelhead Creek is not included separately in the escapement records, and has also been rolled up into the totals for Weaver Creek. Weaver Creek and Channel cannot be evaluated independently, since numbers of Sockeye in each is a consequence of loading regimes at the outlet of this system. Data for the channel begins in 1965 after its construction. From 1950 to 1988 mark recapture surveys were primarily used to assess escapement into Weaver Creek (with the exceptions of 1951, 1966-1968, which were assessed with peak live cumulative dead methods). From 1989 to 2009, peak live cumulative dead visual surveys were conducted (with the exceptions of 1994, 1996 and 1998, which were assessed using mark recapture methods, and from 1999-2000 and 2002-2003, which were assessed using an enumeration fence). Weaver Channel was exclusively assessed at the channel diversion fence, using counts of live Sockeye migrating above the diversion weir to the spawning channel, the upper creek, and into the ESSR holding channel. Fish removed for ESSR were not counted in escapements. Visual surveys were conducted in lower Weaver Creek downstream of the diversion fence, and carcass surveys were conducted upstream and downstream of the diversion fence.

Productivity: In contrast to Early Summer Run and Early Stuart CUs, Harrison (U/S)-L has not exhibited any persistent trends in productivity (based on Kalman filter Ricker *a* parameter values)(Appendix 3, Harrison (U/S)-L, Figure 1 c). However, productivity (R/S) has been particularly low in recent years (2000 to 2005 brood years), with one of these years falling below replacement (Appendix 3, Harrison (U/S)-L, Figure 1 d). Similar to other CUs with freshwater survival data, Harrison (U/S)-L early freshwater survival (fry to EFS) decreased consistently from the start of the time series in 1966 up to 1990, and has subsequently increased (Appendix 3, Harrison (U/S)-L, Figure 1 e). Marine survival data are not available for this CU.

Abundance: The stock-recruitment time series only included years after the construction of the Weaver spawning channel (brood years 1966-2004), to ensure consistency in the spawning area through the time series.

Trends in Abundance: Abundance was particularly low at the start of the time series, prior to channel construction (1950-1974 average EFS: 11,000), increased from 1975 to 1990 (average EFS: 32,500) and has decreased again in recent years (1990-2009 average EFS: 18,700). The average EFS for the entire time series is 19,200 (Tables 4 & 6). Harrison (U/S)-L has not exhibited cyclic dominance throughout the time series (Appendix 3, Harrison (U/S)-L, Figure 1 a). Spawner success was consistently high from 1964 to 1994 (channel: 96%; creek: 95%) and lower from 1995 to 2009 (channel: 83%; creek: 57%). In the channel, the lowest spawner success years were 1995, 2006 and 2008 (~70% in each year). The creek had a large number of years with extremely low spawner success (2001: 8%; 2006: 14% and 2008: 7%, and many years after 1994 where success was 40-50% i.e. 1995-1997; 1999; 2009) (Appendix 3, Harrison (U/S)-L, Figure 1 b).

The ratio of the recent generation average abundance to the long-term average (ratio: 0.8) is above the upper benchmark (ratio: 0.75) (green status) (Tables 4 & 6; Appendix 3, Harrison (U/S)-L, Figure 2 c). When only using the period of channel operation (1965-2009), the ratio of the recent generation average abundance to the long-term average (ratio: 0.62) was between the lower (0.5) and upper (ratio: 0.75) benchmarks (amber status). This CU has declined in abundance in the last three generations with a negative slope (-0.03) that is steeper than the lower benchmark for this metric (-0.026 or 25% rate of decline), and there is a 60% probability that this recent decreasing trend is below the lower benchmark for this metric (red status) (Appendix 3, Harrison (U/S)-L, Figures 2 a & b).

Kamloops-ES

Sites: Populations that rear in Kamloops Lake include Clearwater River, Dunn Creek, Fennell Creek, Finn Creek, Grouse Creek, Harper Creek, Hemp Creek, Lemieux Creek, Lion Creek, Mann Creek, Moul Creek, North Thompson and Raft Rivers (Appendix 1). Although the Barriere River (Upper Barriere River) population rears in a separate lake (Barriere Lake), this population was included in the Kamloops-ES CU because it was transplanted from the Raft River (located upstream of the Barriere-Thompson Confluence) (Holtby and Ciruna 2007).

History: A dam on the Barriere River downstream of Fennell Creek obstructed Sockeye migration into this system until 1952, when it was decommissioned (Roos 1991). From the 1950's to 1960's, Sockeye were transplanted into the Barriere River and Fennell Creek from the Raft River (Aro 1979). Transplants to Fennell were likely successful due to genetic relatedness between this and the donor population (Raft) (Beacham *et al.* 2004). These transplants were successful without loss of genetic diversity (Withler et al. 2000). There is also some evidence of straying from nearby populations into Fennell Creek (Withler et al. 2000).

Escapement time series: Only two sites were included in the escapement time series: Raft River and Fennell Creek (Appendix 1 & 2). Raft River has been consistently assessed since 1950 since this system is relatively small and easy to access. Raft has been assessed using a combination of mark recapture and visual survey methods, with mark recaptures generally conducted during years of larger abundance. Fennell was consistently assessed starting in 1962, using peak live cumulative dead visual survey methods. There were no assessments on this system prior to this period, because fish migration had historically been restricted by the

Barriere dam. All other streams were assessed starting in 1994 (peak live cumulative dead visual survey methods), therefore, data were insufficient to include these systems in the escapement time series. The time series for Barriere also has considerable gaps, negligible spawner abundance, and potentially poor quality data, due to the structure of the spawning substrate (big boulders), which makes visual ground surveys problematic. It is unclear whether these counts represent actual Barriere spawners or fish migrating through to Fennell and Harper Creeks. Therefore, Barriere was also not included in the escapement time series.

For most of the time series up to 2002, Raft and Fennell make up >80% of the total escapement for years in which other systems were also assessed. From 2000 to 2007, the North Thompson River began to contribute larger escapements to the CU (roughly 40%), and the relative contribution of Raft and Fennell dropped to 60%. However, assessment methods used on the North Thompson have changed recently. Historically, the North Thompson was assessed using visual (ground) survey methods (peak live cumulative dead). This assessment method is particularly challenging for the North Thompson River because it is a large, extremely turbid system. Also, surveys generally occurred in the 1st week of September and, therefore, likely missed the peak of spawning. Starting in 2000, surveys were conducted by air during the 3rd week of September. These more recent surveys likely better reflect true abundance in the system compared to previous assessments. During the methodology switch, abundance increased from an historical average of 400 EFS (prior to 2000) to a recent average of 164,000 EFS (2000-2009). The shift in assessment methods, as well as the size and turbidity of the system, confounds the ability to determine if the increase in abundance in the North Thompson River reflects actual trends, or is an artefact of methodology. It is likely that the change in abundance indicates a true increase, given that observations of large numbers of carcasses were not previously reported by DFO field assessment staff. Trends in the North Thompson also somewhat align with those of Raft, increasing in abundance starting in the late 1990's with a peak in escapement in 2005. Therefore, due to uncertainty in the North Thompson time series prior to 2000, and given similarities to Raft, North Thompson was not included in the trend analysis.

Productivity: Similar to other Early Summer Run and Early Stuart CUs, Kamloops-ES exhibited systematic declines in productivity (Kalman filter Ricker *a* parameter values) from the 1970 to 1990 brood years, and has subsequently remained consistently lower than in the early time period (Appendix 3, Kamloops-ES, Figure 1 c). Productivity (R/S) has been particularly low recently, from the 2003 to 2005 brood years, with two of these years close to or below replacement (Appendix 3, Kamloops-ES, Figure 1 d). There are no freshwater or marine survival data available for this CU.

Abundance: The stock-recruitment time series for Kamloops-ES includes the years 1967-2004. The time series begins later than most to account for the removal of the Barriere dam in 1967, and ensure consistency in the spawning area throughout the time series.

Trends in Abundance: Abundance in this CU was relatively low at the start of the time series (1950-1977 average EFS: 3,200), and subsequently started to build (1978-2009 average EFS: 10,100) (Appendix 3, Kamloops-ES, Figure 1 a). Much of the early increases in abundance are attributed to the Fennell Creek population, which increased in abundance starting in the mid-1970's, after the Barriere dam removal. Raft River did not exhibit a building trend until later in the time series, starting in 1995. Since this period, Raft has exhibited stable abundances, with only slight declines in recent years, while Fennell has shown significant declines (in the last two years of the time series the population was only 500 EFS). Over the time series, the average EFS was 6,900. This CU has declined from a period of above average EFS three generations

prior to the end of the time series (16,800), to the current generation average EFS (9,200) (Tables 4 & 6; Appendix 3, Kamloops-ES, Figure 1 b). Spawner success was generally high throughout the time series (average: 88%), with the exception of 2008 (Fennell: 20% and Raft: 70%) (Appendix 3, Kamloops-ES, Figure 1 b).

The ratio of the recent generation average abundance to the long-term average (ratio: 2.14) is greater than the upper benchmark for this metric (ratio: 0.75) (green status) (Tables 4 & 6; Appendix 3, Kamloops-ES, Figure 2 c). In recent years (last three generations), Kamloops-ES has declined following a period of above average EFS (see previous paragraph). The negative slope of this recent trend (-0.02) is less steep than the lower benchmark (-0.026 or 25% rate of decline), but steeper than the upper benchmark (-0.015 or 15% rate of decline) (amber status). There is a 38% probability that this recent trend is below the lower benchmark for this metric (Tables 4 & 6; Appendix 3, Kamloops-ES, Figures 2 a & b).

Kamloops-L

Sites: The only site in the Kamloops-L CU is the South Thomson River, located east of Kamloops Lake (Appendix 1).

History: The South Thompson population may have initially consisted of overflow from the dominant Adams run in the Shuswap system. It now appears to be a persistent population.

Escapement time series: The Kamloops-L time series includes the South Thompson River (Appendix 1 & 2). This population has been assessed using peak live cumulative dead visual survey methods. Gap filling of several weak cycle years was required to complete the time series. The average of one cycle before and after each gap was used for gap filling. However, for two years with gaps, the average was calculated using data two generations removed, due to multiple consecutive gaps occurring on one cycle (Appendix 2).

Productivity: Productivity and survival could not be estimated for this CU as there are no associated recruitment data available for this CU.

Abundance: Abundance benchmarks could not be estimated for this CU as there are no associated recruitment data available for this CU.

Trends in Abundance: This CU has exhibited variable abundance throughout the time series, with relatively high abundances from 1950-1961 (average EFS: 10,000) and 1982-1997 (average EFS: 6,000), lower abundances from 1962-1981 (average EFS: 1,400), and a recent decline to the lowest period on record (1998-2009 average EFS: 400) (Appendix 3, Kamloops-L, Figure 1 a). This CU is highly cyclic, with one dominant cycle (average EFS: 17,000), and three weak cycles with negligible abundances (average EFS: 40). Spawner success was high throughout the time series (average: 96%)(Appendix 3, Kamloops-ES, Figure 1 a).

The ratio of the recent generation average abundance to the long-term average is lower (ratio: 0.3) than the lower benchmark for this metric (ratio: 0.5) (red status) (Tables 4 & 6; Appendix 3, Kamloops-L, Figure 2 c). This CU has decreased in abundance over the last three generations, with a negative slope (-0.02) that is less steep than the lower benchmark for this metric (-0.026 or 25% rate of decline), but steeper than the upper benchmark (-0.015 or 15% rate of decline) (amber status). There is a 37% probability this recent trend is below the lower benchmark for this metric (Tables 4 & 6; Appendix 3, Kamloops-L, Figures 2 a & b).

Comment: has not been revised; needs revised table updating etc.

Lillooet-L

Sites: Populations that rear in Lillooet-L include the Birkenhead River, Green River, John Sandy Creek, Lillooet River, Miller Creek, Poole Creek, Railroad Creek, Ryan River, Sampson Creek and Twenty-Five Mile Creek (Appendix 1).

History: The Lillooet-L CU is situated below the Fraser Canyon, and was not directly impacted by the 1913 Hells Gate landslide. Between 1946 and 1951, the course of the Birkenhead River was manually changed to flow directly into Lillooet Lake (instead of via the Lillooet River) for the purpose of flood control (Hamilton 1994). This alteration likely reduced the potential spawning area (Schubert and Tadey 1997). Sections of the Birkenhead River and much of the lower 40 km of the upper Lillooet River have been dyked, and much of the floodplain has been ditched or filled, which has degraded salmon habitat. Changes to the system include wider shallower river channels with steeper gradients, channel degradation in the lower 13 km of Lillooet River, the isolation of cut-off meanders, a loss of wetlands, and a rapid increase in the rate of advance of the river delta (Schubert and Tadey 1997). In August 2010, a major landslide, caused by the Capricorn Mountain and Glacier giving way, resulted in rock and debris flows that blocked Meager Creek, located north of Pemberton. In 2010, returns of Sockeye will have to swim through a 1.5 km long suspended sediment wedge, as they enter the Birkenhead River. Although the remaining component of the Birkenhead River is not turbid, it is uncertain what impacts the suspended sediments will have on this population, and for how many years this will persist.

Escapement time series: Only the Birkenhead River was included in the escapement time series (Appendix 1 & 2). The Birkenhead River has been consistently assessed throughout the time period, and makes up over 99% of the escapement in years when other populations were also assessed. All other populations comprise only a minor component of total production for the Lillooet-L CU, and these populations have only been opportunistically assessed with lower precision methods (visual ground surveys). Birkenhead River was assessed with a mark recapture program up to 1999. Biases in the mark recapture methods were identified in 1994, and methods were modified in 1995. Conclusions of a 1995 study indicated that the pooled Petersen population estimates were no longer seriously biased (Schubert and Tadey 1997; Houtman et al. 2000). In 2000, an overflight visual survey was conducted, in 2001 a counting tower was used, and subsequently, an enumeration fence has been used to assess escapement. One year in the Birkenhead time series was not assessed (2002) and this was gap filled with average of the previous and subsequent generation (Appendix 2).

Productivity: Similar to Summer Run CUs, Lillooet-L has exhibited systematic declines in productivity (Kalman filter Ricker *a* parameter values) since the mid-1980's (Appendix 3, Lillooet-L, Figure 1 c). Productivity (R/S) has been particularly low recently, from the 1989 to 2005 brood years, with twelve of these years close to or below replacement (Appendix 3, Lillooet-L, Figure 1 d). There are no freshwater or marine survival data available for this CU.

Abundance: The stock-recruitment time series includes the brood years 1950-2004.

Trends in Abundance: Escapements were relatively low from 1950 to 1973 (average EFS: 18,000), slightly higher from 1973 to 1985 (average EFS: 36,100), and reached a period of maximum abundance from 1986 to 2009 (average EFS: 74,400) (Appendix 3, Lillooet-L, Figure 1 a). In many years during this most recent time period, abundances have reached as high as 200,000 EFS. Lillooet-L has not exhibited cyclic dominance throughout the time series. Spawner

Comment: has not been revised; needs revised table updating etc.

Lower Fraser River (River-Type)

Sites: This CU includes fourteen river-type populations: Alouette River, Chehalis River, Chilliwack River, Coquihalla River, Gallagher Creek, Harrison River, Johnson Slough, Maria Slough, Ruby Creek, Silver Hope Creek, Steelhead Creek, Vedder River, Wahleach Creek, Harrison River, and the Chehalis River (Appendix 1).

History: Almost all sites for this CU, with the exception of the Harrison River, were identified based on a small number of sporadic Sockeye observations throughout the time series. These sites were opportunistically assessed during enumeration programs for other salmon species. It is unclear whether observations at sites other than the Harrison River represent unique river-type populations (generally when Sockeye are observed, numbers are less than 10). More data are required, such as scale analysis, to confirm that these are river-type Sockeye (absence of a freshwater check on the scale) that migrated to the ocean shortly after gravel emergence. There are numerous comments in the escapement data that suggest that many of these observations are strays from nearby lake-type Sockeye populations. The only site with a consistent time series and a confirmed established river-type population in the Lower Fraser Area is the Harrison River river-type Sockeye.

The Harrison River system originates in the Coast Mounts and drains Harrison Lake. The mouth of the Harrison River forms a floodplain marsh approximately 0.05 km^2 in size. The Harrison Rapids at the outlet of the Chehalis River provide an important control on water levels at low discharge (Rood and Hamilton 1995). As a result, the Harrison River is very stable with coarse substrate. During the spring the rapids are backwatered and inundated by the freshet flows of the Fraser River (Fisheries and Oceans Canada 1999). The rapids and lower portion of the river, which are used by Sockeye for spawning habitat, have been dredged to maintain a navigation channel (Rood and Hamilton 1995). At higher discharges the river spreads to cover the main channel as well as three others where fish spawn (primarily pink spawning ground)(IPSFC 1972).

Harrison Sockeye are unique compared to other Fraser Sockeye stocks in terms of their freshwater residence, age structure, ocean migration timing, and migration routes. After Harrison Sockeye emerge from the gravel they are thought to rear in sloughs for a few months prior to their downstream migration, and, as a result, enter the Strait of Georgia a few months after all other Fraser Sockeye (Birtwell et al. 1987). Unlike other Fraser Sockeye, they do not rear in freshwater lakes as juveniles for one to two years. Also unlike all other Fraser Sockeye, Harrison Sockeye rear in the Strait of Georgia for up to six months, prior to migrating through the Southern Juan de Fuca Strait (Taylor et al. 1996; Tucker et al. 2009). All other Fraser Sockeye immediately migrate north through the Johnstone Strait once they reach the Strait of Georgia.

Escapement time series: The only site in the Lower Fraser River (River-Type) CU where consistent assessments have been conducted is the Harrison River (Appendix 1 & 2). Mark recapture programs were conducted on this system until 1971, and in 1978-1979. After 1971, peak live cumulative dead visual survey methods were typically used, largely via boat, and then via helicopter starting in 1994. Escapements increased dramatically beginning in 2005 (400,000 total adults), though it was not until 2009 that a mark recapture program was re-instituted. Escapement estimates between 2005 and 2008 underestimate true abundance, due to the assessment challenges of visually counting large numbers of Sockeye. Visual assessments were compromised in four additional years (1986, 1989, 1991 and 1993), due to poor visibility in the lake. Overall, the use of visual surveys on the Harrison introduces large negative biases, because observations are confounded by the size and depth of the river, and the large coincident spawning populations of Chinook and Chum (Schubert 2007)

Productivity: Lower Fraser (River-Type) Sockeye, unlike most other CUs, have increased in productivity in recent years, with the exception of the 2005 brood year, which had the lowest productivity on record for this CU (Appendix 3, Lower Fraser River (River-Type), Figures 1 c & d). Mechanisms explaining the recent dramatic increase in productivity and abundance are poorly understood.

Abundance: The stock-recruitment time series for Lower Fraser (River-type) includes the years 1950-2004. Since this CU is dominated by Harrison Sockeye, which return as three and four year old fish (rather than four and five year olds for all other Sockeye CUs), total recruitment data are available up to 2005 (only available to 2004 for all other Fraser Sockeye CUs).

Trends in Abundance: From 1950 to 2004, the Lower Fraser River (River-Type) Sockeye CU was relatively small in terms of abundance (average EFS: 6,400) (Table 2; Appendix 3, Lower Fraser River (River-Type), Figure 1 a). After 1994, abundance dramatically increased to a maximum of 200,000 EFS in 2005 (average EFS: 93,000). With the exception of one brood year in the recent time period, which experienced the lowest productivity on record for this CU (2005 brood year), this CU has been extremely productive and abundant. This CU has not exhibited cyclic dominance. Spawner success has also been consistently high throughout the time series (average: 98%) (Table 2; Appendix 3, Lower Fraser River (River-Type), Figure 1 b).

The ratio of the recent generation average abundance to the long-term average (ratio: 6.98) is considerably higher than the upper benchmark for this metric (ratio: 0.75) (green status)(Tables 4 & 6; Appendix 3, Lower Fraser River (River-Type), Figure 2 c). This CU has increased in abundance over the last three generations, and this positive slope (0.27) is greater than the upper benchmark (-0.015 or 15% rate of decline) for this metric (green status). There is a 0% probability this trend is below the lower benchmark (Tables 4 & 6; Appendix 3, Lower Fraser River (River-Type), Figures 2 a & b). Given that escapement estimates for recent years are likely negatively biased (underestimate) and imprecise (highly uncertain), this increasing trend is likely larger than the current trend analysis indicates.

Nahatlatch-ES

Sites: The populations that rear in Nahatlatch Lake include Nahatlatch River and a Nahatlatch Lake spawning population; the River makes up 80% of the total on average (Appendix 1).

History: Nahatlatch-ES is relatively remote, and is located in a protected BC park. No known transplants or major human activities have occurred in this system.

Escapement time series: Two sites were included in the escapement time series: Nahatlatch Lake and Nahatlatch River (Appendix 1 & 2). The river assessments began in 1975 using visual surveys (peak live cumulative dead methods). Consistent lake assessments began in 1980, using standard visual survey (lake expansion) methods; there are a few years of sporadic data prior to 1980, but assessments are less reliable and did not use systematic methods. The Nahatlatch Lake estimates were gap filled for the years 1975, 1976, and 1978 using the Mean Proportion Method (calculating filled values according to the proportional contribution of the lake to the system, estimated from years for which there are assessments for both populations). In 1979 the lake estimate is included in the river abundance estimate and, therefore, gap filling for this year was not required.

Productivity: Productivity and survival could not be estimated for this CU as there are no associated recruitment data available for this CU.

Abundance: Abundance benchmarks could not be estimated for this CU as there are no associated recruitment data available for this CU.

> **Comment:** has not been revised; needs revised table updating etc.

Trends in Abundance: Abundance was lowest at the start of the time series (1975-1985 average EFS: 900), highest in the middle of the time series (1986-2002 average EFS: 3,500), and dropped again in recent years (2003-2009 average EFS: 1,100) (Appendix 3, Nahatlatch-ES, Figure 1 a). Nahatlatch-ES has not exhibited cyclic dominance within the time series. During the beginning (1975 to 1985) and end (1995 to 2009) of the time series for the Nahatlatch River site, spawner success was slightly lower and more variable (average: 94%; range: 78% to 100%) compared to the middle (1986 to 1994) component of the time series (average: 99%; range: 98% to 100%) (Appendix 3, Nahatlach-ES, Figure 1 a). The Nahatlatch Lake site showed similar trends in spawner success, but they are not used for comparison purposes due to lower quality data from this site.

The ratio of the recent generation average abundance to the long-term average (ratio: 0.55) is only slightly greater than the lower benchmark for this metric (ratio: 0.50), and is below the upper benchmark (ratio: 0.75) (amber status) (Tables 4 & 6; Appendix 3, Nahatlatch-ES, Figure 2 c). This CU has decreased in abundance over the last three generations, and this negative slope (-0.14) is steeper than the lower benchmark (-0.026 or 25% rate of decline). There is a 100% probability that this recent trend is below the lower benchmark for this metric (red status) (Tables 4 & 6; Appendix 3, Nahatlach-ES, Figures 2 a & b).

Pitt-ES

Sites: The only site for Pitt-ES Sockeye is the Pitt River (Appendix 1).

History: The upper Pitt River is a glacially fed system originating near Isosceles Peak at an elevation of 1710 m. The river flows in a braided shifting channel across a wide, flat-bottomed valley, confined by steep mountains, and is characterized by rapids, riffles and deep pools. The river flows into Pitt Lake, which is the largest (length: 52 m) freshwater tidal lake in North America. Sockeye distribution in the upper Pitt River extends from the mouth of the river at Pitt Lake, to an area of impassable rapids 40 km upstream. Forestry is quite active in the watershed (10% of it has been logged)(Fisheries and Oceans Canada 1999).

The Pitt-ES system is extremely flashy, which can create major changes in the river channel. For example, North Boyse Creek was historically a high quality spawning location for Sockeye, until a flood event in the early 1980's changed the course of the Pitt mainstem, cutting off half of this creek from Sockeye Spawning, and flushing out most of the good spawning gravel from the

remainder of this Creek (K. Peters, pers. comm.). The flashy nature of this system also creates considerable scouring action when flooding occurs. As a result, in years when high water events coincide with egg incubation, substantial egg losses can affect Sockeye production. To mitigate the effects of flooding, and associated production impacts, this CU is hatchery enhanced.

Escapement time series: The Pitt River site is the only site for this CU (Appendix 1 & 2). This site was assessed using mark recapture methods. The escapement time series includes Sockeye removed for hatchery enhancement.

Productivity: In contrast to other Early Summer Run and Early Stuart CUs, Pitt-ES has exhibited variable productivity (Kalman filter Ricker *a* parameter values), with high productivity between the 1960 to 1970 brood years, low productivity between the 1975 to 1990 brood years, high productivity again from the 1990 to 1995 brood years, and a subsequent decline (Appendix 3, Pitt-ES, Figure 1 c). Productivity (R/S) has been particularly low recently, from the 2000 to 2005 brood years, with productivity in all of these years falling below replacement (Appendix 3, Pitt-ES, Figure 1 d). There are no freshwater or marine survival data available for this CU.

Abundance: The stock-recruitment time series for Pitt-ES includes the years 1950-2004. The Pitt escapement and recruitment time series includes fish removed for Pitt River hatchery enhancement.

> **Comment:** has not been revised; needs revised table updating etc.

Trends in Abundance: From 1950 to 1995, the Pitt-ES Sockeye escapement was relatively small (average EFS: 8,600) (Appendix 3, Pitt-ES, Figure 1 b). After 1995, escapement increased to an average of 28,000 EFS. This CU has not exhibited cyclic dominance. Spawner success has been consistently high for this CU throughout the time series (average: 96%), with the exception of 2008 (71% spawner success) (Appendix 3, Pitt-ES, Figure 1 b).

The ratio of the recent generation average abundance to the long-term average (ratio: 2.17) is higher than the upper benchmark for this metric (ratio: 0.75) (green status) (Tables 4 & 6; Appendix 3, Pitt-ES, Figure 2 c). Overall, this CU has not changed in abundance over the last three generations, and has a slope (0.0) that is greater than the upper benchmark (-0.015 or rate of decline of 15%) for this metric. There is a 27% probability this recent trend is below the lower benchmark for this metric (green status) (Tables 4 & 6; Appendix 3, Pitt-ES, Figures 2 a & b).

Quesnel-S and McKinley-S (CUs combined for status assessment)

Sites: (Creeks) Abbott Creek, Amos Creek, Archie Creek, Bill Miner Creek, Blue Lead Creek, Bouldery Creek, Buckingham Creek, Cameron Creek, Clearbrook Creek, Devoe Creek, East Arm - unnamed creek 1, Franks Creek, Goose Creek, Grain Creek, Hazeltine Creek, Horsefly Channel, Horsefly River, Horsefly River - Above Falls, Horsefly River – Lower, Horsefly River - Upper Isaiah Creek, Junction Creek, Killdog Creek, Limestone Creek, Little Horsefly River, Long Creek, Lynx Creek, Marten Creek, McKinley Creek, McKinley Creek – Lower, McKinley Creek – Upper, Mitchell River, Moffat Creek, Niagara Creek, Penfold Creek, Raft Creek, Roaring River, Rock Slide, Service Creek, Spusks Creek, Sue Creek, Summit Creek, Taku Creek, Tasse Creek, Tisdall Creek, Trickle Creek, Wasko Creek, Watt Creek, Whiffle Creek, Winkley Creek. (Lake) Bear Beach - Shore Baxter, Beach, Betty Frank's – Shore, Big Slide – Shore, Big Slide, 1 km, West – shore, Bill Miner Cr. – Shore, Bill Miner Cr. - Shore 3 km west, Blue Lead Cr. – Shore, Bouldery Cr. – Shore, Bouldery Cr. - Shore 2 km east, Bowling Point, Deception Point, Devoe Creek – Shore, Double T – Shore, East Arm - Rock Slide to Peninsula Pt. Shore, East Arm - unnamed creek 2 – shore, East Arm - unnamed point, Elysia – Shore,

Elysia shore - 1 km west, Franks Creek – shore, Goose Point – Shore, Goose Pt., .8 km south – shore, Goose Pt., 5 km south – shore, Grain Cr. – Shore, Horsefly Lake, Hurricane Point, Junction Shore, Killdog Creek – Shore, Lester Shore, Limestone Point – Shore, Limestone Pt, .5 km south – shore, Logger Landing, Long Cr. – Shore, Lynx Cr. – Shore, Marten Cr. – Shore, North Arm - shore, Bowling to Goose Pt., North Arm - shore, Roaring to Deception Pt., North Arm - unnamed cove, Opa Beach, Penfold Camp Shore, Quartz Point, Quesnel Lake, Roaring Point, Roaring R. – Shore, Slate Bay, Slate Bay, 1 km east, Tasse Creek – shore, Wasko Creek – shore, Watt Cr. – Shore.

History: Historically, Quesnel runs were likely in excess of 10,000,000 Sockeye on the dominant cycle years in the 1800's; escapement in 1909 was 4,000,000 (Babcock 1904). The Quesnel populations were likely the largest amongst the all Summer Run timed populations until they started to decline in the late 1800's (Roos 1991). Several key factors contributed to low abundances in the Horsefly system early in the time series (prior to 1980), and included dam construction at the outlet of Quesnel Lake, placer mining, the Hells Gate landslide (1913), and droughts. Dams were constructed to hold back high water freshets for mining operations, allowing no fish to migrate past the dam into Quesnel Lake or the Horsefly River from 1898 to 1903. A fishway was in operation starting in 1905 until 1921, when the dam was removed. Gold placer mining occurred in the South fork of Quesnel Lake and the Horsefly River from 1871 to 1945, and tailings from these operations were dumped into the river, covering significant areas of spawning gravel, which fish subsequently avoided during spawning. During this period of damming and mining, there was a coincidental sharp decline in the Sockeye population (Roos 1991). The 1913 Hells Gate landslide presented a further barrier to migration, particularly for later timed Quesnel-CU Sockeye. The Quesnel Sockeye were more highly affected by the landslide than other populations because they have smaller energy reserves, and because of their spawn timing. Horsefly Sockeye spawn shortly after arriving at their spawning grounds, whereas other populations have later spawning timing (Roos 1991). Throughout the time series, droughts that de-water smaller streams, and Beaver dams that present a barrier to fish migration , have both impacted the available spawning habitat in the Quesnel system.

Historically (1950's to 1970's), there has also been high pre-spawn mortality in Horsefly Sockeye, due to their earlier timing, which causes them to migrate through warmer Lower Fraser and spawning ground water temperatures. A particularly large mortality event occurred on the Horsefly in 1961, and can be attributed to a *Chondrococcus columnaris* outbreak, caused by warmer waters. In 1966, cold water was siphoned from McKinley Lake to cool McKinley Creek and control this disease, although a virulent bacterial gill disease still caused high pre-span mortality in 1969 (Roos 1991).

Quesnel started to build in abundance in the 1980's, particularly on the dominant and sub-dominant cycles, reaching a peak abundance between 1992 and 2001. Increased abundance has been attributed to natural expansion and the re-invasion of remnant stocks, despite transplants (Withler et al. 2000) of eggs from various systems (Stellako, Bowron, Stellako, Adams, Seymour to Horsefly) to the Horsefly from the 1920's to the 1970's (Aro 1979).

A Sockeye spawning channel exists beside the Horsefly River. The channel provides an available spawning area of 15,200 m^2 and has a capacity of 12,200 females (Roberta Cook, Ocean Habitat Enhancement Branch, DFO). The initial objectives of installing the channel were to rebuild the Horsefly River Sockeye population to historic levels in the subdominant and off-years, and to supplement the dominant cycle to test Quesnel Lake's juvenile carrying capacity during "Cyclic Dominance" studies. The facility is currently operated in subdominant and off-years to rebuild the Horsefly population and increase fishing opportunities. Operation in dominant years was discontinued, since returns from natural spawning areas were sufficient to

test Quesnel Lake`s carrying capacity; the channel component is small relative to the natural Horsefly stock.

Escapement time series: The Mitchell, Horsefly, McKinley and Little Horsefly River sites were all included in the escapement time series. The Mitchell was consistently assessed throughout the time series using peak live cumulative dead visual methods, and starting in 1989 was assessed on the dominant and subdominant cycles with mark recapture methods. In 2009, the Mitchell was assessed using DIDSON methods. Two other sites included in the Mitchell time series include Cameron and Penfold Creeks, which were rolled up into the Mitchell estimate in the early time series, and broken out into their individual sites in later years. The Horsefly River, Horsefly River-Above Falls, Horsefly River-Lower, and Horsefly River-Upper were consistently assessed using peak live cumulative dead visual methods, and, in recent years (post-1980), were largely assessed with mark recapture methods. Throughout the time series, the escapement records were either rolled up into a total Horsefly River-Upper (1950-1967) or into the Horsefly River site (1993-2009), or broken down into the individual enumeration sites (1968-1992). McKinley Creek was also consistently assessed and either rolled up into McKinley Creek (1950-1969) or broken down into the individual enumeration sites (1969-2009). In addition, there are years when McKinley estimates were rolled up into the Horsefly sites (1964, 1965 and 1981). All sites were assessed largely using peak live cumulative dead visual methods. Enumeration fences were used on the Lower McKinley and McKinley sites in recent years (sporadically post-1989). Little Horsefly River was also consistently assessed using peak live cumulative dead visual survey methods. Major gaps for all these sites occurred in 1992 (weak cycle) and 2006 (dominant cycle) for Mitchell River, and 2002 (subdominant cycle) for all other sites except Cameron Creek. Gaps were filled based on relationships between all these sites using either the two weak cycles, the dominant cycle or subdominant cycle years from 1980 to 2009, given gaps occurred during these later years when Quesnel-ES abundance was significantly higher than in the early time series (Mean Proportion Method - Cyclic) (Appendix 2).

Quesnel Lake was consistently assessed throughout the time series using peak live cumulative dead methods. Early in the time series, surveys were conducted and very few to no spawners were observed in the lake; abundance only starts to increase in the mid-1990's.

Productivity: Similar to other Summer Run CUs, the Quesnel-S & McKinley-S CU aggregate has exhibited systematic declines in productivity (Kalman filter Ricker *a* parameter values) since the 1990 brood year (Appendix 3, Quesnel-S & McKinley S, Figure 1 c). Productivity (R/S) has been particularly low recently (1999 to 2005 brood years), with most of these years close to or below replacement (Appendix 3, Quesnel-S & McKinley-S, Figure 1 d). Similar to other CUs with freshwater survival data, Quesnel-S & McKinley-S early freshwater survival (fall fry to EFS) decreased from the 1970 brood years, and has subsequently increased (Appendix 3, Quesnel-S & McKinley-S, Figure 1 e). Marine survival data are not available for this CU.

Abundance: The stock-recruitment time series for Quesnel-S & McKinley-S includes the years 1950-2004.

Trends in Abundance: From 1950 to 1980, the Quesnel-S & McKinley-S aggregate escapement was relatively small (average EFS: 23,000) (Appendix 3, Quesnel-S & McKinley-S, Figure 1 b). Escapement increased from the 1980's to 2001 (average EFS: 430,000). Average EFS across the entire time series was 189,000. Subsequently, this CU has declined from an above average EFS period three generations prior to the end of the time series (586,000), to the current generation average EFS (51,000). This CU has exhibited cyclic dominance throughout the time series, with one dominant cycle (average EFS: 500,000), one subdominant cycle that starting building in the 1980's (average EFS: 230,000) and two weak cycles (average EFS: 18,500).

Comment: has not been revised; needs revised table updating etc.

Seton-L

Sites: The major population that rears in Seton-L is Portage Creek (Appendix 1). Some portion of the Gates Creek and channel fish also rear in Seton Lake (Geen and Andrew 1961).

History: In 1903, the first hatchery in BC began operating on Portage Creek (Babcock 1904) near the present location of the Seton Dam. At this time, poor husbandry techniques were implicated for the declining abundance of Portage Sockeye (Geen and Andrew 1961). In 1913, the Hells Gate landslide decimated this population. In addition, water diverted from the Bridge River into Seton Lake in 1934 decreased primary productivity in this lake (Roos 1991). The residual Portage stock was small, particularly in the 1950's. In the first half of the century, various transplants were attempted in Portage Creek from multiple Fraser systems, such as Birkenhead and the Lower Adams River (Aro 1979). Genetically, the current Seton-L population is similar to the Lower Adams River, indicating that transplants from this area were most successful (Withler et al. 2000). Despite the proximity of Seton-L to Anderson-ES Sockeye during spawning, and the overlap in their rearing lakes, Seton-L is relatively genetically unique. There is also no evidence of genetic bottlenecks for Seton-L despite its genetic variability being less than the donor population (Withler et al. 2000).

A hydro facility on this system has been operational since 1956 (Roos 1991). This facility is comprised of the Seton Dam, located below the outlet of Seton Lake, and the Cayoosh Dam on Cayoosh Creek. Water is diverted by canal from Seton Lake to a powerhouse on the Fraser River, where it is released through a tailrace located 500 m downstream of the outlet of Seton River. Since the Seton Dam presents a barrier to Sockeye migration, a fishway was constructed in concert with dam construction (Roos 1991). It has been suggested that both the tailrace and fishway may slow or impede Sockeye migration and cause physiological stress to the fish (Roscoe and Hinch 2008). Due to the downstream tailrace location, migrating adult Sockeye have been shown to stop at the outlet of the tailrace, where that are either attracted to the home-stream water or they use it as a 'cold-water' refuge. Fish may either be directly injured in the tailrace (Fretwell 1980) or indirectly suffer pre-spawn mortality due to the delay in migration from stalling at the tailrace. Success of fish departing the tailrace, entering the Seton River, and reaching the dam depends on Seton water quality, whereby higher Cayoosh Creek dilution results in higher migration failure (10-30% migration failure during IPFSC studies). Once fish enter the Seton River they must travel five kilometers upriver, ascend the Seton Dam fishway, and then migrate through Seton Lake and Anderson Lake (~50km) to the spawning grounds. One study indicated that locating the fishway entrance presents a challenge to migrating Sockeye (during experimental downstream transplants 25% of these Sockeye could not re-locate the fishway entrance) (Roscoe and Hinch 2008)**.** Further impacts of the hydro facility include mortality (~10%) of downstream migrating smolts as they move through the dam turbines. This issue has yet to be resolved (Roos 1991).

Escapement time series: Only Portage Creek was included in the escapement time series (Appendix 1 & 2). This system was assessed using visual survey methods (peak live-cumulative dead) throughout the time series. Data prior to 1954 is quite sporadic, therefore, only the time series from 1965 to present was used in the assessment of status.

Productivity: Similar to Early Summer Run and Early Stuart CUs, Seton-L has exhibited persistent decreases in productivity since the 1970 brood year (based on Kalman filter Ricker *a* parameter values) (Appendix 3, Seton-L, Figure 1 c). Productivity (R/S) has been particularly low recently (1999 to 2005 brood years), with three years below or close to replacement (Appendix 3, Seton-L, Figure 1 d). Freshwater and marine survival data are not available for this CU.

Abundance: The stock-recruitment time series for Seton-L includes the years 1965-2004. There are considerable gaps in the early time series, and this system was only consistently assessed starting in 1965.

Trends in Abundance: Abundance is relatively stable across the time series (average EFS: 3,800). Seton-L has exhibited cyclic dominance with one dominant cycle (average EFS: 7,900), two subdominant cycles (average EFS: 3,300), and one off cycle (average EFS: 800) (Appendix 3, Seton-L, Figure 1 a). Spawner success has remained high (~96%) and has not exhibited any persistent trends (Appendix 3, Seton-L, Figure 1 b).

The ratio of the recent generation average abundance to the long-term average (ratio: 0.91), is greater than the upper benchmark for this metric (ratio: 0.75) (green status) (Tables 4 & 6; Appendix 3, Seton-L, Figure 2 c). This CU has decreased in abundance in the last three generations. This negative slope (-0.08) is steeper than the lower benchmark for this metric (-0.026 or 25% rate of decline), and there is a 95% probability this recent trend is below the lower benchmark for this metric (red status) (Tables 4 & 6; Appendix 3, Seton-L, Figures 1 a & b).

Shuswap-ES

Site: The Shuswap Lake Complex-ES is comprised of three lakes: Adams Lake, Momich Lake (exclusively used by ES timing), and Shuswap Lake. Populations that rear in Adams Lake include Burton and Pass (Sinmax) Creeks and Upper Adams River. Populations that rear in Momich Lake include Cayenne Creek and the Momich and Upper Momich River (Mueller and Enzenhofer 1991). Populations that rear in Shuswap Lake include Adams Channel, Adams River, Anstey River, Celista Creek, Craigellachie Creek, Crazy Creek, Eagle River, Hiuhill (Bear) Creek, Hunakwa Creek, Loftus Creek, McNomee Creek, Middle Shuswap River, Nikwikwaia (Gold) Creek, Onyx Creek, Perry River, Ross Creek, Salmon River, Seymour River, Scotch Creek and Yard Creek (Appendix 1).

History: Both Early Summer and Late Run timing populations inhabit the rearing lakes of this CU, though due to significant differences in ecology and run timing, spawning populations have been separated into two groups, respectively the Shuswap-ES and Shuswap-L CUs (Holtby and Ciruna 2007). The Adams-Momich Lake Early Summer timed populations (Upper Adams River, Momich River, and Cayenne Creek) were thought to have been extirpated by the combined effects of the Fraser Canyon's Hells Gate landslide in 1913, and splash damming on the lower Adams River (1908-1940), which severely obstructed Sockeye access through the Fraser Canyon and into Adams and Momich Lakes. Hatchery enhancement of the Upper Adams River from 1948-1980, using largely Seymour River (and to a lesser extent Taseko and Cayenne)

Comment: has not been revised; needs revised table updating etc.

Sockeye (Withler, Le, Nelson, Miller, and Beacham 2000;Roos 1991), contributed to the re-establishment of this population in 1954 (Williams 1987). The resulting Upper Adams River population is highly genetically related to the donor (Seymour River) population, although some genetic differences exist. There has also not been any loss of genetic diversity within the Upper Adams population, despite enhancement (Withler et al. 2000; Beacham et al. 2004).

The Momich River Sockeye population was discovered in 1960. The origin of this population is not well known. No transplants were made to this system, and it is unlikely that this small population survived the obstruction caused by the combination of the Hells Gate landslide and the Adams splash dam. The Momich Sockeye population may have originated as strays from egg transplants to the Adams River (from Seymour) (Roos 1991). Momich River Sockeye appear genetically distinct from the rest of the Shuswap-ES CU (Holtby and Ciruna 2007). Similarly, the nearby Cayenne Creek population was first observed in 1960, and also likely established from earlier transplants of Seymour and/or Taseko eggs and juveniles into Adams Lake (cited from Williams 1987) (Withler et al. 2000). Adams-Momich Lake populations are now genetically distinct, as a result of genetic drift or founder effects (Withler et al. 2000). Despite this, however, Holtby and Ciruna (2007) placed the Adams-Momich Lake early summer timed populations in the Shuswap-ES CU, because of their likely hatchery origin. In response to low returns of Adams-Momich populations in 1992, restoration efforts have enhanced the offspring of this cycle year, through a combination of reduced fishing, hatchery releases and nutrient enrichment of the lake nursery area (Hume *et al.* 2003). Adams Lake was fertilized (nitrogen & phosphorus) in 1997 (18 weeks) to promote lake growth and Sockeye survival (Hume et al. 2003). The Momich Sockeye population has rapidly increased on its dominant cycle years (2008 cycle).

Within the Shuswap Lake system, no Scotch Creek-ES Sockeye historically existed on the dominant Adams River cycle (2010 cycle). In 1962, 1,023,000 eyed eggs from Seymour Creek were transplanted into Scotch Creek, producing a dominant run that coincided with the dominant Adams Late run (2010 cycle) (Roos 1991). Anstey, Eagle and Salmon River populations were large prior to 1913, but disappeared after the Hells Gate landslide. Anstey was not enhanced by hatcheries; building of this population appears to have occurred naturally from the first Sockeye observed in this system in 1949 (Roos 1991). In that year, Sockeye were also first observed in the Eagle River (11 fish). This population was subsequently enhanced by transplants from Seymour in 1958 and 1962, which likely contributed to increased escapements by 1982. There is generally a delay in the success of transplants as they adapt to their local environment (Roos 1991). Within this system, hatchery transplants were also attempted in the Salmon, Tappen, Silver, and Silk-atwa Rivers/Creeks (1902-1931) from donor populations in Harrison, Birkenhead, Pitt, Sweltzer, and the Adams River (Aro 1979). The Salmon River population changed its dominant cycle during the 1922-42 period, and remains that way today (Roos 1991).

Escapement time series: Six sites were included in the escapement time series for the Shuswap Complex-ES CU: Seymour River, Scotch Creek, McNomee Creek, Momich - Momich/Cayenne and Upper Adams River (Appendix 1 & 2). Seymour and Scotch make up 70% of the total escapement in this system from 1994-2009, when other creeks/rivers were consistently assessed. Other systems consistently assessed include Momich, Cayenne, Upper Adams River, Eagle, and Anstey, and these five, combined with Scotch and Seyour, make up 90% of total adult escapement in years when other systems were consistently assessed (1994-2009). All other systems had small populations, and were generally only consistently assessed from 1994 on; therefore a large number of these systems were excluded from the assessment of status.

Seymour was the most consistently assessed system, containing no gaps in the time series. Mark recapture surveys were used on large escapement years, and peak live cumulative dead visual surveys on smaller escapement years. The Scotch time series has some missing values, particularly prior to 1980. Until 1993, Scotch Creek was assessed with peak live cumulative dead methods (except 1990, which was a mark recapture), and as the abundance started to increase, enumeration methods switched to a fence (1994 to 2009). Gaps in the Scotch Creek escapement time series in 1951 and 1959 were filled with zeros. In these years, no surveys were conducted, as the expected abundance was negligible, as seen in other off cycle years (see history of abundance in history section above). McNomee population estimates were historically rolled into Seymour, so this time series was included with no gap filling (Appendix 2).

For Adams Lake and Momich Lake populations, Momich, Momich/Cayenne and Upper Adams River were included in the assessment of status. In early years, since Momich and Cayenne creeks are connected, assessments were conducted on a Momich/Cayenne Creek aggregate. In recent years, starting in 1994, these were recorded as separate sites (Momich and Cayenne). Both of these sites were included in the assessment of trend status. The Upper Adams River had a negligible population up to the 1980's, when hatchery rebuilding programs became effective, increasing abundances from under 300 total adults, prior to the 1950's, to a maximum of 70,000 in 2000. This population has subsequently declined. All of the populations that rear in Momich Lake or Adams Lake are dominant on cycle 2 (2008), differing from both the Seymour and Scotch dominant cycles. Off-cycle data was negligible at the beginning of the time series in 1960, and in many cases no Sockeye were observed, or the site was not visited given the negligible numbers. This system, as a result was not gap-filled prior to 1960, and was likely negligible (Appendix 2).

Eagle and Anstey were excluded from the assessment of status. The survey area for Eagle was expanded in 1990 to include an area where substantial spawning occurred. As a result, the Eagle escapement increased from an average of 700 total adults prior to 1990 to an average of 4,000 total adults after 1990. Due to this inconsistent methodology, its relatively small contribution to total escapement (~16%) for stocks consistently assessed post-1990 (Scotch, Seymour, McNomee, Eagle, and Anstey), and its similarities to trends in the Seymour River time series, Eagle was not included in the assessment of trends in status. Anstey was also excluded because of significant gaps in the time series prior to 1990 and uncertainty in the estimates, which were due to challenges in assessing this system. Anstey makes up, on average, only 6% of the total Scotch-Seymour-McNomee escapement, and would not have an impact on the assessment of trends if included.

Productivity: The productivity time series is relatively short for Shuswap-ES (brood years 1980-2005). Productivity (Kalman filter Ricker *a* parameter values) for this CU decreased from the 1980 to 1990 brood year, and has subsequently increased (Appendix 3, Shuswap-ES, Figure 1 c). Productivity (R/S) was particularly low from the mid-1980 to mid-1990 brood years, with four years below or close to replacement (Appendix 3, Shuswap-ES, Figure 1 d). There are no freshwater or marine survival data available for this CU.

Abundance: The stock-recruitment time series for Shuswap-ES includes the years 1980-2004. Prior to 1980, Scotch Creek was significantly enhanced on the dominant cycle of the Adams Lake run. Therefore, to ensure consistency in the time series, years prior to 1980 were not used in the stock-recruitment time series.

Trends in Abundance: Shuswap-ES Abundance was relatively small in the early time series (1950-1985 average EFS: 11,900). Abundance later increased (1986-2009: 35,200), particularly on the dominant cycle, in which abundance exceeded 100,000 EFS for three years. The overall

> **Comment:** has not been revised; needs revised table updating etc.

CU trend is driven by the Shuswap Lake rearing populations. In particular, early in the time series (prior to the 1980's) the Seymour River dominates the trends, then in later years (post-1980's) Scotch Creek increased in abundance, equally contributing to the Shuswap-ES trend. Populations that rear in Adams and Momich Lakes have exhibited different trends, building in abundance from 1980's (Adams) and 1960's (Momich), and significantly declining in recent years (post-2001) (Appendix 3, Shuswap-ES, Figures 1 a & b). Cyclic dominance is not synchronous across populations in the Shuswap-ES CU, particularly between Shuswap Lake rearing populations and Adams/Momich Lake rearing populations (Appendix 3, Shuswap-ES, Figure 1 a). The Adams Lake-Momich Lake rearing populations are dominant on the 2008 cycle. In contrast, most Shuswap Lake rearing populations are dominant on the 2006 cycle. Seymour has consistently exhibited one dominant cycle (2006), followed by one subdominant cycle (2007) and two weak cycles (2008 & 2009). As mentioned, Scotch Creek had a different dominant cycle early in the time series (cycle 3: 2009), until hatchery transplants from Seymour River(1949-1975) (Aro 1979) built up the subdominant cycle, creating dominance in the same year as Seymour (2006). All other small creeks in the Shuswap Lake system exhibit similar cyclic dominance to Seymour.

The ratio of the recent generation average abundance to the long-term average (ratio: 0.90) is higher than the upper benchmark for this metric (ratio: 0.75) (green status) (Tables 4 & 6; Appendix 3, Shuswap-ES, Figure 2 c). In recent years (last three generations), Shuswap-ES has declined, following a period of above average EFS (see previous paragraph). The slope of this recent trend (-0.06) is steeper than the lower benchmark for this metric (-0.026 or 25% rate of decline), and there is an 89% probability this recent trend is below this lower benchmark (red status) (Tables 4 & 6; Appendix 3, Shuswap-ES, Figures 2 a & b).

Shuswap Complex-L

Sites: **The Shuswap Lake Complex** is comprised of five lakes: Adams Lake, Shuswap Lake, Little Shuswap Lake, Mara Lake, and Mable Lake; although Momich Lake does have Shuswap Complex-ES rearing fish, it does not have a Late Run timing component. Populations that rear in **Adams Lake** include Adams Lake-Shore, Bush Creek-Shore, Misc. East Side-Shore, Misc. North End-Shore, Misc. South End-shore, Bush Creek, Momich River, Pass Creek, and Upper Adams River. **Shuswap Lake** is a large lake that can be divided into the Anstey Arm, Main Arm, Salmon Arm and Seymour Arm. Populations that rear in **Shuswap Lake-Anstey Arm** (North-East Arm) include Anstey Arm-Shore, Anstey River, Four Mile Creek-Shore, Queest Creek-shore, Vanishing Creek, Hunakwa Creek. Populations that spawn in **Shuswap Lake-Main Arm (South-West)** include Adams River, Adams River-Shore, Cruikshank Pt West-Shore, Hlina Creek-Shore, Lee Creek-Shore, Misc. North Side-Shore, Misc. South Side-Shore, Onyx Creek-Shore, Ross Creek-Shore, Scotch Creek-Shore, Adams Channel, Adams River, Hiuhill (Bear) Creek, Nikwikwaia (Gold) Creek, Onyx Creek, Ross Creek, Scotch Creek. Populations that rear in **Shuswap Lake-Salmon Arm** (South-East) include Salmon Arm-shore, Knight Creek-Shore, Misc. East Side-Shore, Misc. North Side-Shore, Misc. South Side-Shore, Reinecker Creek Shore, Canoe Creek, Crazy Creek, Eagle River, Loftus Creek, Perry River, Salmon River, Tappen Creek and Yard Creek. Populations that rear in Shuswap Lake-Seymour Arm (North West) include miscellaneous Seymour Arm-Shore, Celista Creek, McNomee Creek, Seymour River. The only population that rears in **Little Shuswap Lake** is Little River. Populations that rear in **Mara Lake** include Mara Lake Shore, Lower Shuswap River, Cooke Creek, Kingfisher Creek and Trinity Creek. The populations that rear in **Mabel Lake** include Middle Shuswap River, Bessette Creek, Noisy Creek, Tsiuis Creek and Wap Creek (Appendix 1).

History: Both Early Summer and Late Run timing populations inhabit the rearing lakes of this CU, though due to significant differences in ecology and run timing, spawning populations have been separated into two groups, respectively the Shuswap-ES and Shuswap-L CUs (Holtby and Ciruna 2007).

Similar to the Shuswap-ES CU, the splash dam on the Adams River and the 1913 Hells Gate landslide played a large role in the extirpation of Late run populations that rear in Adams Lake. Current Adams Lake Late Run populations likely came from Shuswap Lake strays. The late component of the Adams Lake population is small in terms of abundance (Hume et al. 1996).

Within Shuswap Lake, the two north arms (Seymour and Anstey) are largely undeveloped, while the two south arms (Main and Salmon) are developed for recreational and residential use. There are concerns that septic tanks in the area could leach potentially deleterious contaminants into the waterways in this southern part of the lake.

In terms of hydrological separation between lakes, both Mabel and Adams Lakes are quite different from Shuswap Lake, particularly regarding productivity and fish abundance. It has been proposed that these three lakes be separated into three separate CUs (J.Hume, DFO, pers. comm.).

Escapement time series: Twenty sites were included in the escapement time series: Adams River, Anstey River, Eagle River, Little River, Lower Shuswap River, Middle Shuswap River, Momich River, Pass Creek, Scotch Creek, Shuswap Lake, Shuswap Lake-Main Arm, Shuswap Lake-Main Arm North and Shuswap Lake-Main Arm South, Adams River-Shore, Cruikshank Point West-Shore, Hlina Creek-Shore, Lee Creek-Shore, Onyx Creek-Shore, Ross Creek-Shore, Scotch Creek-Shore. All other sites were excluded from the escapement time series because they were only assessed as far back as the 1990's or later 2000's, and they represent negligible spawning (Appendix 1 & 2).

Adams River dominates the total abundance for this CU (70% of total EFS). The Adams River time series is complete and required no gap filling. From 1950-1963, mark recapture methods were generally used to assess total abundance. From 1963-1984, the one off cycle year (cycle 3) was assessed using peak live cumulative dead visual methods (all other cycles (1,2 & 4) were assessed with mark recapture methods). From 1985 to 2009, the two off cycles (cycle 3 and cycle 4) were both assessed using peak live cumulative dead visual methods (cycle 1 and 2 were assessed using mark recapture methods). The Adams channel was excluded from the escapement time series due to sparse data (1990-2009) and negligible abundances, since this channel was designed as rearing habitat for Coho, and entry was often barricaded by beaver dams. Little River also represents a relatively high proportion of the total EFS in this CU (10% of total EFS). Little River was consistently assessed (no gaps in the time series), generally using peak live cumulative dead surveys or recovery expansions. Starting in 1998, due to higher abundances (>70,000) in Little River, mark recapture methods were used for the dominant cycle, and peak live cumulative dead surveys for all other cycles. The remaining stream/river sites used to assess *trends in abundance* (Anstey, Eagle, Momich, Lower Shuswap, and Middle Shuswap Rivers, Pass and Scotch Creeks) comprised 13% of the total EFS for Shuswap-L. These sites were consistently assessed on the dominant and subdominant cycles using varied assessment methods. Anstey was assessed using peak live cumulative dead visual survey methods. The number of surveys performed in this system was generally low (1 visit per year) until 1994, when the number of visits increased (and ranged from one to six). Eagle was also generally assessed with peak live cumulative dead surveys, with the exception of a number of years (1983-1988, 1990-1992, 1994, 1998, 1999-2004 and 2006-2009) when an enumeration fence was used. Assessment methods in the Eagle River were not compromised for the Late run populations like they were for the Early Summer, given the fish spawn in different locations.

The Lower Shuswap River was also consistently assessed using peak live cumulative dead counts until the 1970's, when mark recaptures were conducted on dominant, and occasionally on subdominant, cycles. The Middle Shuswap River, Scotch Creek, Momich River and Pass Creek were all assessed using peak live cumulative dead methods.

In early years (1950-1973) on Shuswap Lake, only Main Arm spawners were recorded, since this area between the Adams River and Little River attracts the bulk of the spawners in this CU. Crews were, therefore, consistently in this area of the lake, and could easily assess shore spawners. Site resolution (number of sites recorded) increased throughout the time series for Shuswap Lake Main Arm spawners. From 1974-2001, Shuswap Lake Main Arm data were recorded as the Shuswap Lake-Main Arm site, and Shuswap Lake was no longer used as a site name. From 2002-2009 the Shuswap Lake-Main Arm site data were divided into the following nine sites: Shuswap Lake-Main Arm North, Shuswap Lake-Main Arm South, Adams River-Shore, Cruikshank Point West-Shore, Hlina Creek-Shore, Lee Creek-Shore, Onyx Creek-Shore, Ross Creek-Shore, Scotch Creek-Shore sites, and records were no longer placed in the Shuswap Lake-Main Arm site. Therefore, these nine sites, as well as the Shuswap Lake, Shuswap Lake-Main Arm and Shuswap Lake-Main Arm North and South sites were combined into the escapement time series. All Adams Lake sites had small abundances on the dominant cycle (< 4,000 total adult spawners) and had many gaps in the time series.

Gaps in river and stream data were filled on the dominant and subdominant cycles using separate calculations for each cycle, given that individual sites varied in their proportional contribution to the total EFS depending on the cycle (dominant or subdominant). Gaps were not filled on the two weak cycles because escapement was negligible on these cycles in years when sites were assessed (frequently close to or equal to zero). No gaps were filled in the lake site data (Appendix 2).

Productivity: In contrast with other Early Summer Run and Early Stuart CUs, Shuswap-L has not exhibited any persistent trends in productivity through time (based on Kalman filter Ricker *a* parameter values)(Appendix 3, Shuswap-L, Figure 1 c). However, productivity (R/S) has been particularly low recently, from the 1998 to 2005 brood years, with five of these years below or close to replacement (Appendix 3, Harrison (U/S)-L, Figure 1 d). Shuswap-L early freshwater survival (fry to EFS) was relatively high from the start of the time series in 1970 up to 1990, and subsequently decreased (Appendix 3, Shuswap-L, Figure 1 e). Marine survival data are not available for this CU.

Abundance: The stock-recruitment time series includes the years 1950-2004.

Trends in Abundance: Cyclic dominance is synchronous in the Shuswap-L complex, and consists of a large dominant cycle (2006), followed by a much smaller subdominant cycle (2007) and two very weak cycles (2008 & 2009) (Appendix 3, Shuswap-L, Figure 1 a). Abundance has been relatively consistent in dominant cycle years for the Adams River (average: 750,000), with generally all dominant cycles above or close to 500,000 EFS. Relatively low abundances occurred in the Adams River from 1993 to 2001 (average: 140,000 EFS), peaking in 2002 (2.0 million). Exceptions to this Adams River trend include relatively high abundances post-1980 in the following Shuswap-L populations: Anstey, Eagle, Pass, Middle Shuswap, Lower Shuswap and Scotch. These populations generally had two peaks in escapement, in 1990 and 2002. Similarly to the Adams River, Shuswap Lake showed higher abundances starting in the 1980's, with the population declining during 1993-2001 and 2005- 2009; the lake made up less than 1% of total EFS for Shuswap L on average. Momich had consistently low escapement throughout the time series (maximum: 412 EFS). Spawner success has remained high (>95%) and was generally consistent, with the following exceptions: Adams River in 2000 (52%) and 2001 (90%);

Stuart-S

Sites: There are two Sockeye run-timing groups (two different CUs) that rear in Stuart Lake: Summer Run and Early Stuart. The Summer Run timing (Stuart-S) populations that rear in Stuart Lake include Kuzkwa River, Pinchi Creek, Sowchea Creek, Tachie River, Stuart River and a population that spawns in Stuart Lake (Appendix 1).

History: Similar to Fraser-S, the history of the Stuart-S CU includes log driving on the Tachie River, starting in the 1960's (Roos 1991). However, although this practice was discontinued on the Stellako River (Fraser-S) in 1968, it was not discontinued on the Tachie River at this time. The extent of damage to spawning grounds is unknown (Roos 1991), though it is expected to be less severe than in the Stellako River system, due to differences in the physical characteristics of this system (Roos 1991).

Stuart Lake has a greater capacity to rear fry than that supported by spawning sizes, indicating that the Late Stuart population may be limited in terms of available spawning grounds (Roos 1991). Hatchery transfers occurred early in this system (1907-1928), with transfers to Stuart, Pinchi, Sowchea, and Tachie from Pierre, Pinkut, Birkenhead, and the Skeena River (Aro 1979).

Escapement time series: Two sites were included in the escapement time series for Stuart-S: Tachie River and Kuzkwa River (Appendix 1 & 2). These two sites were consistently assessed, each has a relatively complete time series, and together they represent >96% of total escapement in years when all systems were assessed. Tachie was consistently assessed starting in 1953. Until 1992, a mark recapture was conducted on dominant cycles, and peak live cumulative dead (air) surveys were conducted on the remaining three cycles. After 1992, mark recaptures were conducted more frequently on roughly two out of the four cycle years. Kuzkwa was assessed using peak live cumulative dead survey methods (rafting surveys or, starting in the 1960's, helicopter surveys). Kuzkwa is a larger system that generally requires two days to assess. Usually only one survey was conducted in the early time series, coinciding with peak spawn. Up to three surveys were conducted in larger abundance years, starting in 1997. Generally, Kuzkwa has negligible abundances during the three off cycles, with larger abundances occurring only on dominant cycle years. The time series used to assess trends in abundance covers 1953 to 2009. No gap filling was required for Tachie estimates. For Kuzkwa, only 1956 was gap-filled using its proportional relationship with Tachie (Mean Proportion Method) (Appendix 2).

The remaining four systems (Sowchea, Pinchi, Stuart River, and Stuart Lake) were excluded from the escapement time series. Sowchea Creek has not been consistently assessed because this site is not as readily accessible as other sites, and it also has negligible spawning (< 400 fish). Sowchea has been opportunistically assessed only. Pinchi has a slightly more complete time series than Sowchea and Stuart Lake, however, most assessments were conducted

inconsistently through fishery officer surveys, and data were not comparable between years until the late 1970's. Stuart Lake was assessed only once in 1958, and had a total escapement of 293; lake spawning is typically challenging to assess given that spawning can occur at depths not visible during visual surveys.

Productivity (data combined with Takla-Trembleur-S CU): Similar to other Summer Run CU's, the Stuart-S & Takla-Trembleur-S aggregate has exhibited systematic declines in productivity (Kalman filter Ricker *a* parameter values) since the 1990 brood year (Appendix 3, Stuart-S, Figure 1 c). Productivity (R/S) has been particularly low recently, from the 1997 to 2005 brood years, with five of these years close to or below replacement (Appendix 3, Stuart-S, Figure 1 d). Freshwater and marine survival data are not available for this CU.

Abundance (data combined with Takla-Trembleur-S CU): The stock-recruitment time series includes the years 1950-2004 (combined with Takla-Trembleur-S).

<comment>Comment: has not been revised; needs revised table updating etc.

Trends in Abundance: Escapement to this CU was relatively low up to 1992 (average EFS: 22,300), after which it increased dramatically to 957,000 EFS in 1993, and maintained a higher average abundance from 1993 to 2009 (average EFS: 111,800). Across the entire time series, average EFS is 49,400. This CU has declined from a period of above average EFS three generations prior to the end of the time series (92,700), to the current generation average EFS (22,700) (Tables 4 & 6; Appendix 3, Stuart-S, Figure 1 b). The Stuart-S CU exhibits strong cyclic dominance, with one dominant cycle (average EFS: 144,700) and three subdominant cycles (average EFS: 15,700). Throughout the time series, spawner success has generally remained consistently high (~90%), with the exception of 1949-1951, which exhibited the lowest spawner success on record (average: 65%), due to high water temperatures and earlier run timing during this period. Both Pinchi Creek and Kuzkwa River have exhibited similar trends throughout the time series.

The ratio of the recent generation average abundance to the long-term average (ratio: 2.35) is higher than the upper benchmark for this metric (ratio: 0.75) (Tables 4 & 6; Appendix 3, Stuart-S, Figure 2 c). In recent years (last three generations), abundance in Stuart-S has declined following a period of above average EFS (see previous paragraph). The negative slope of this recent trend (-0.14) is steeper than the lower benchmark for this metric (-0.026 or 25% rate of decline), and there is a 78% probability that this recent decreasing trend is below the lower benchmark for this metric (red status) (Tables 4 & 6; Appendix 3, Stuart-S, Figures 2 a & b).

Takla/Trembleur-S

Sites: Two Sockeye run-timing groups (two different CU's) rear in Takla and Trembleur Lakes: Summer Run and Early Stuart. The Takla-Trembleur-S CU is made up of three sites: Kazchek Creek, Middle River, and Sakeniche River (Appendix 1).

History: The summer-timed Sockeye in the Takla-Trembleur system spawn at the outlet streams of its large lakes (Middle, Sakeniche, Kazchek), in the same locations as the Takla-Trembleur-Early Stuart timed Sockeye (Holtby and Ciruna 2007). Most of the available spawning capacity in this CU occurs in the Middle River. Historically, pulpwood and sawlog harvesting, and the extenstion of the Pacific Great Eastern Railway caused disturbance to spawning beds in Middle River (IPSFC 1972). Currently, availability of good spawning grounds in Middle River is the main factor limiting the Takla-Trembleur-S Sockeye abundance INSERT REFERENCE-(ipsfc).

Middle River was enhanced with eggs from the Birkenhead River in 1923, and Kazchek Creek received eggs from the Birkenhead, Skeena and Stuart Rivers between 1924 and 1928 (Aro 1979).

Escapement time series: Two systems were included in the escapement time series for Takla/Trembleur-S: Middle River and Kazchek Creek (Appendix 1 & 2). Both sites have nearly complete abundance time series starting in the 1950's, and together they make up almost 100% of the total abundance in this system for years in which Sakeniche River was also assessed. Middle River was generally assessed using mark recapture methods on dominant years and peak live cumulative dead surveys on the other three cycle lines. Kazchek Creek was assessed using peak live cumulative dead methods (visual surveys). The Kazchek Creek time series was gap filled in 1984 using its relationship with Middle River, according to the Mean Proportion Method (Appendix 2). Sakeniche River was also assessed using the peak live cumulative dead methodology, however, there are considerable gaps in the time series' of this population. In years when Sakeniche was assessed, surveys were limited to one site visit only.

Productivity (data combined with Stuart-S CU): Similar to other Summer Run CU's, the Takla-Trembleur-S & Stuart-S aggregate has exhibited systematic declines in productivity (Kalman filter Ricker *a* parameter values) since the 1990 brood year (Appendix 3, Takla-Trembleur-S, Figure 1 c). Productivity (R/S) has been particularly low recently, from the 1997 to 2005 brood years, with five of these years close to or below replacement (Appendix 3, Takla-Trembleur-S, Figure 1 d). Freshwater and marine survival data are not available for this CU.

Abundance (data combined with Stuart-S CU): The stock-recruitment time series includes the years 1950-2004 (combined with Stuart-S).

Takla-Trembleur-EStu

Sites: There are two Sockeye timing groups (two different CU's) that rear in Takla and Trembleur Lakes: the Early Stuart and Summer Run. There are 50 enumeration sites in the escapement database that have Early Stuart Run timing (Stuart-EStu), including: 5 Mile Creek, 10 Mile Creek, 15 Mile Creek, 25 Mile Creek, Ankwill Creek, Baptiste Creek, Bates Creek, Bivouac Creek, Blackwater Creek, Blanchette Creek, Casamir Creek, Consolidated Creek, Crow Creek, Driftwood River, Dust Creek, Felix Creek, Fleming Creek, Forfar Creek, Forsythe Creek, French Creek, Frypan Creek, Gluske Creek, Hooker Creek, Hudson Bay Creek, Kastberg Creek, Kazchek Creek, Kotesine River, Kynoch Creek, Leo Creek, Lion Creek, McDougall Creek, Middle River (Rossette Bar), Nahounli Creek, Nancut Creek, Narrows Creek, Paula Creek, Point Creek, Porter Creek, Rossette Creek, Sakeniche River, Sandpoint Creek, Shale Creek, Sinta Creek, Sowchea Creek, Takla Lake-shore, Takla Lake-unnamed creek, Tarnezell Creek (same as Baptiste and Butterfield), Tildesley Creek, Unnamed Creek (placeholder for unknown names) (Appendix 1).

History: Evidence dating as far back as 1920 indicates that the Early Stuart Run was not been large historically (Cooper and Henry 1962). This CU may not have existed prior to x (Barry indicated HBL records). Abundance was particularly low from 1962-1968 (average EFS: 7,000), increased to a peak of approximately 400,000 EFS in 1992, and subsequently decreased. Recent declines have occurred consistently across most streams in the CU. Studies into the decline of the Early Stuart Sockeye, conducted through the Stuart-Takla Fisheries Interaction Project, found no evidence that the spawning and incubation environment was responsible for declines in Early Stuart populations (D. Patterson, DFO, pers. comm.). Land-use changes, road densities, and stream crossings have not been proven to have negative effects on Sockeye abundance at the sub-watershed level (Macdonald *et al.* 1992). Declines have largely been

attributed to the Early Stuart population's long migration route (greatest upstream migration of all Fraser Sockeye CU's), their spring (during freshet) upstream migration timing, and the increased (more extreme) water temperatures in the Fraser River post-1990. As a result, Takla-Trembleur-EStu Sockeye have the highest accumulation of thermal units of any Fraser Sockeye CU, which results in fewer Takla-Trembleur-EStu Sockeye reaching the spawning grounds, due to en-route mortality, and lower spawner success in those that survive (a.k.a. higher pre-spawn mortality). A decrease in marine productivity has also contributed to recent declines in the abundance of this CU.

Since the Takla-Trembleur-EStu Sockeye migrate during the spring freshet high water flows, particularly in the Fraser Canyon, they have experienced delayed migration in some years. Takla-Trembleur-EStu Sockeye were blocked downstream of Hells Gate for 15 days in 1955, due to a later than normal freshet, which resulted in very low escapement, while those that made it to the spawning grounds were in poor condition (escapement: 2,000). In 1960, this population was again 15 days late arriving on the spawning grounds, and, as a result, a large number did not reach the grounds (Holtby and Ciruna 2007). Fishways were constructed in the Fraser Canyon between 1945 and the mid-1960's, improving the ability of early timed migrants to ascend areas of difficult passage (Levy et al. 2008). However, further periods of low abundance occurred from 1962–1968, due to en-route loss, and from 1997-1999, due to weather conditions (Levy et al. 2008).

Beaver dams in this system are an on-going problem in terms of limiting spawning habitat. Although Sockeye in this system are capable of leaping over smaller dams, larger dams have presented barriers to fish passage. Most Takla-Trembleur-EStu Sockeye are thought to rear in Takla Lake, including those that spawn in the tributaries of the upper part of Middle River, near the outlet of Takla Lake (with the possible exception of Rosette) (IPSFC 1972). When there are more than 65,000 females, the fish are forced into marginal areas of the watershed, or they dig out already used areas INSERT REFERENCE (IPSFC).Insert 2004 loss due to high water with early stuart spawning in Fraser canyon?BArry

> **Comment:** Is this middle river only

Escapement time series: Four key sites in the Takla/Trembleur-Estu CU have been enumerated consistently, Forfar, Gluske, Kynoch and Rossette Creeks (Appendix 1 & 2). For the first portion of the time series (1930's to late 1980's), these sites were assessed largely using peak live cumulative dead visual surveys and some mark recapture surveys, particularly in Forfar Creek (1950, 1954, 1960, 1961, 1965, 1973, 1977 and 1978); Gluske was assessed using a mark recapture in 1978, and Kynoch in 1960-1961 and 1978. Forfar, Gluske and Kynoch have been enumerated using a fence program in recent years (Gluske: 1988-2009 excluding 1993; Forfar: 1989-2009 excluding 1993 and 2007; Kynoch: 1991-2006 excluding 1993 and 1997). Data from these fenced sites, in concert with peak live cumulative dead visual surveys, have been used to develop expansion factors for all other streams assessed using peak live cumulative dead visual methods. Eight other sites that were consistently assessed using peak live cumulative dead methods include 15 Mile, 25 Mile, 5 Mile, Ankwill, Dust (mark recapture in 1981 and enumeration fences in 1997 and 2000-2006), Frypan, Shale, and Narrows Creeks. These twelve sites (Forfar, Gluske, Kynoch, Rosette, 15 Mile, 25 Mile, 5 Mile, Ankwill, Dust, Frypan, Shale, and Narrows) required negligible gap filling (Appendix 2). During the three subdominant cycles, these sites comprise, on average, 82% of the total escapement in this CU; escapement is negligible in most other sites on these cycles. On dominant years, however, these twelve sites only comprise 50% of the total escapement.

The additional sixteen sites included in the escapement time series were assessed exclusively with peak live cumulative dead methods, including: Bivouac Creek, Blackwater Creek, Consolidated Creek, Crow Creek, Driftwood River, Felix Creek, Forsythe Creek, Kastberg Creek, Kotsine River, Lion Creek, Paula Creek, Point Creek, Porter Creek, Sakeniche River,

Sandpoint Creek, and Sinta Creek. These sites had numerous gaps. Gaps in all streams were filled using the Mean Proportion Method - Cyclic across aggregates of sites that had correlated abundance trends (Driftwood: Blackwater, Consolidated, Driftwood, Kastberg, Kotsine, Lion, Porter, Dust, Sinta; Takla North East Arm: 5 Mile, 15 Mile, 25 Mile, Shale, Crow; Upper Trembleur: Forsythe, Ankwill, Frypan; Takla South Arm: Sandpoint, Narrows, Sakeniche, Bivouac; Trembleur:Felix, Paula, Point).

A total of twenty-two sites were excluded from the escapement time series. Sixteen sites were not included because they were only assessed sporadically, or they were only assessed starting in 1997 (generally). These include the following: 10 Mile Creek, Baptiste Creek, Bates Creek, Casamir Creek, Hooker Creek, Kazchek Creek, Middle River (Rossette Bar), Nahounli Creek, Nancut Creek, Sowchea Creek, Takla Lake-shore, Takla Lake-unnamed creek, Tarnezell Creek, Tildesly Creek, Tlitli Creek, and Unnamed Creek. An additional six sites were excluded for various reasons: Fleming (methodology changed during the time series), Hudson Bay (inconsistent access), MacDougall (beaver dams blocked fish assess), Leo (beaver dams), Blanchette (many gaps and limited data), and French (many gaps and small abundances) Creeks.

Productivity: Similar to Early Summer Run CUs, Takla-Trembleur-EStu has exhibited systematic declines in productivity (Kalman filter Ricker *a* parameter values) since the mid-1960 brood years (Appendix 3, Takla-Trembleur-EStu, Figure 1 c). Productivity (R/S) has been particularly low recently, from the 1995 to 2005 brood years, with eight of these years below replacement (Appendix 3, Takla-Trembleur-EStu Figure 1 d). Early freshwater survival (fry to EFS) has been variable, increasing and decreasing throughout the time series (Appendix 3, Takla-Trembleur-EStu, Figure 1 e). Marine survival data are not available for this CU.

Abundance: The stock-recruitment time series for Takla-Trembleur-EStu includes the years 1950-2004.

Trends in Abundance: Takla-Trembleur-EStu had relatively low escapements up to 1981 (average EFS: 30,000), increased to a peak of ~400,000 in 1992, and has subsequently declined in abundance (Appendix 3, Takla-Trembleur-EStu, Figure 1 a). A particularly low period of abundance occurred from 1962 to 1968 (average EFS: 7,000). Across the entire time series, average EFS is 40,900. This CU has declined from a period of above average EFS three generations prior to the end of the time series (31,000), to the current generation average EFS (13,300) (Tables 4 & 6; Appendix 3, Takla-Trembleur-EStu, Figure 1 b). This CU has exhibited strong cyclic dominance throughout the time series, with the dominant cycle occurring on the 2009 cycle (one dominant cycle average EFS: 100,000 and three weaker cycles average EFS: 20,000). Spawner success has been relatively high throughout the time series (Forfar average: 90%; Gluske average: 88%; Kynoch average: 90%; Rossette average: 88%), with notably low spawner success in 1998 (range from 40-60%) and from 1978-1980 (range from 72-74%) for the four key streams in this system (Appendix 3, Takla-Trembleur-EStu, Figure 1 b).

The ratio of the recent generation average abundance to the long-term average (ratio: 0.58) is between the lower (ratio: 0.5) and upper benchmark (ratio: 0.75) for this metric (amber status) (Tables 4 & 6; Appendix 3, Takla-Trembleur-EStu, Figure 2 c). In recent years (last three generations), abundance in Takla-Trembleur-EStu has declined, following a period of above average EFS (see previous paragraph). The negative slope of this recent trend (-0.10) is steeper than the lower benchmark for this metric (-0.026 or 25% rate of decline), and there is a 100% probability that this recent decreasing trend is below the lower benchmark for this metric (red status) (Tables 4 & 6; Appendix 3, Takla-Trembleur-EStu, Figures 2 a & b).

Comment: has not been revised; needs revised table updating etc.

Taseko-ES

Sites: The only population to rear in Taseko Lake is the population that also spawns in Taseko Lake (Appendix 1).

History: Taseko Lake is a glacially influenced lake that has, as a result, poor fish visibility. Carcass counts are expanded based on survey effort, using methods established from studies historically conducted on Taseko Lake. Estimates are likely biased low given limitations in the number of carcasses that reach the lake surface after becoming moribund (Patterson et al. 2007b). Lake counts can be further compromised on survey days with heavy rain or winds that decrease the visibility of carcasses on the lake surface.

Escapement time series: This site has been assessed since 1949, however there are considerable gaps in the time series (Appendix 1 & 2).

Productivity: Productivity and survival could not be estimated for this CU as there are no associated recruitment data available for this CU.

Abundance: Abundance benchmarks could not be estimated for this CU as there are no associated recruitment data available for this CU.

Trends in Abundance: The Taseko Lake Sockeye population is small in abundance (average EFS: 1,300) (Appendix 3, Taseko-ES, Figure 1 b). This population has decreased in abundance from a peak period of 2,900 EFS (1950-1964) to an average of 376 EFS (1990-2009). This CU has not exhibited cyclic dominance, and throughout the time series spawner success has remained high (~93%)(Appendix 3, Taseko-ES, Figure 1 b).

For all calculations, the time series of this CU was limited to include only surveyed years. There are considerable gaps in the middle of the time series that cannot be gap filled; therefore, only the early time series (1950-1968) and the recent period (1993-2009) were used. The ratio of the recent generation average abundance to the long-term average (ratio: 0.28) is below the lower benchmark for this metric (ratio: 0.5) (red status) (Tables 4 & 6; Appendix 3, Taseko-ES, Figure 2 c). The last three generation trend metric has a negative slope (-0.12) that is steeper than the lower benchmark for this metric (-0.026 or 25% rate of decline), and there is a 97% probability that this recent trend is below the lower benchmark for this metric (red status) (Tables 4 & 6; Appendix 3, Taseko-ES, Figures 2 a & b). The average size of this CU is small (average ETS: 2,300).

Widgeon (River-Type)

Sites: The Widgeon CU is a river-type population and includes only one population: Widgeon Creek (Appendix 1).

History: Widgeon (River-Type) Sockeye are possibly the most unique CU in the Fraser Watershed. This population is adapted to the tidal conditions of Widgeon Slough. The fish move back and forth between Pitt Lake and Widgeon Slough with the tides, moving into the slough to spawn on high tides and moving into Pitt Lake on low tides. Due to consistent Sockeye movement into the slough, a channel has developed through which they migrate, facilitating the counting of fish. Sockeye also move into areas in Widgeon Slough where eel grass covers the spawning gravel, though it is unclear whether they do this for protection from predators

> **Comment:** has not been revised; needs revised table updating etc.

(defence) or for spawning. Water levels are very low during low tide (de-watered) with only sufficient cover for egg incubation, therefore, atypical of the Sockeye species, females cannot remain with their nests until they die. Overall, the spawning area is very small (~100 m in length) and visibility of Sockeye is good. Widgeon Sockeye are similar to Harrison (River-Type) Sockeye in that they migrate to the ocean after gravel emergence and do not rear in lakes as juveniles. Widgeon (River-Type) Sockeye are also the smallest adults in the watershed.

Escapement time series: Widgeon Slough has been assessed consistently using peak live cumulative dead visual (foot) surveys. There are three gaps in the time series where incomplete surveys were conducted. These gaps were filled using the cycle-line average (Appendix 1 & 2).

Productivity: Productivity and survival could not be estimated for this CU as there are no associated recruitment data available for this CU.

Abundance: Abundance benchmarks could not be estimated for this CU as there are no associated recruitment data available for this CU.

Trends in Abundance: Widgeon has an extremely small population (average EFS: 300). This population has decreased in abundance from a peak period of 400 EFS (1950-1989) to a more recent average of 120 EFS (1990-2009). In 2009, the abundance increased to 800 EFS (Appendix 3, Widgeon (River-Type), Figure 1 b). Throughout the time series spawner success has remained high (~96%).

The ratio of the recent generation abundance to the long-term average (ratio: 0.35) is below the lower benchmark for this metric (ratio: 0.5) (red status) (Tables 4 & 6; Appendix 3, Widgeon (River-Type), Figure 2 c). Given that the decrease in abundance occurred prior to the last three generations, and that the 2009 escapement increased six-fold from the last four generations average, the last three generation trend metric has a positive slope (0.14) that is greater than both the lower (-0.026) and upper (-0.015) benchmarks for this metric. There is a 0% probability that this recent trend is below the lower benchmark for this metric (Tables 4 & 6; Appendix 3, Widgeon (River-Type), Figures 2 a & b) (green status). The average size of this CU is extremely small (average ETS: 625). Given their extremely small abundance (average ETS: 625) (COSEWIC population size threshold for 'threatened' status is <1,000) and constricted geographic location, the Widgeon population is extremely vulnerable to extirpation.

Status: Ten Tentative Conservation Units (Additional Research Required)

Alouette-ES

An Early Summer timed run (April-July migration) of anadromous Sockeye salmon spawned (September-November) in the mainstem of the Alouette River and reared in Alouette Lake prior to the construction of the hydroelectric dam (1925-1928) on this system (Gaboury and Bocking 2004). After its construction, the dam blocked fish passage and eliminated this run of Sockeye salmon; this population was considered extirpated and unrecoverable. A spillway was constructed in 1985, and, as a result of recent experimentation in flow regimes (2005-2009) over the dam (spillway releases), some Sockeye smolts (from reservoir kokanee) emigrated from the Alouette reservoir. These fish were observed below the dam at the outlet of the Alouette reservoir years later as adults (confirmed to have originated from emigrating Alouette smolts), after a period of ocean residence (Mathews and Bocking 2007). Recovery of Alouette-ES Sockeye requires the continuation of spill regimes that permit outmigration of Sockeye smolts (currently occurs each spring as part of the Alouette water use plan) and the manual trucking (Trap & Truck Program) of returning adult fish back into the reservoir (Balcke 2009), or,

Comment: has not been revised; needs revised table updating etc.

alternatively, the construction of a fishway for adult migration (Gaboury and Bocking 2004). The Alouette-ES CU is currently not a self-sustaining anadromous Sockeye Run, and therefore, is only considered a placeholder CU. No status analysis can be completed for this CU at this time. The restoration of anadromous fish runs, where practical, is a key objective of the Bridge-Coastal Fish and Wildlife Restoration Program (BCRP).

Boundary Bay (River-Type)

There is only one recent observation of Sockeye for this CU. Currently, this observation has not been verified or confirmed and, therefore, it is unclear if this is a valid CU.

Cariboo-S (River-Type)

There is only one recent observation of Sockeye for this CU obtained opportunistically from the Chinook-Coho Program. Therefore, it is unclear if this is a valid CU.

Coquitlam-ES

An Early Summer timed run of anadromous Sockeye salmon reared in Coquitlam Lake prior to the construction of a hydroelectric dam (1914) on this system. The Coquitlam Reservoir is now one of three lakes that contributes to the Vancouver Water District municipal water supply (Fisheries and Oceans Canada 1999). After its construction, the dam blocked fish passage and, as a result, eliminated this run of anadromous Sockeye salmon; this population was considered extirpated and unrecoverable. In recent years (2005-2009) due to some experimentation in flow regimes over the dam (spillway releases), some Sockeye smolts (from reservoir kokanee) emigrated from the Coquitlam reservoir. These fish returned to the dam at the outlet of the Coquitlam reservoir years later as adults, after a period of ocean residence (Lyse Godbout, pers. comm.). Both genetic and gill raker analyses of kokanee and volitional (fish spilled over the dam) Sockeye smolts in the Coquitlam reservoir indicate that these fish are similar, and that the kokanee have been recently derived from anadromous Sockeye. This suggests that kokanee currently residing in the reservoir have the potential to return to an anadromous life-history (Nelson and Wood 2007). Coquitlam Sockeye are closely related to nearby Pitt River Sockeye, suggesting a common colonizing population, and straying between these populations prior to dam construction (Nelson and Wood 2007). Recovery of Coquitlam-ES Sockeye would require spill regimes that would permit outmigration of Sockeye smolts, and the manual trucking of returning adult fish back into the reservoir on the other side of the dam. The Coquitlam-ES CU is currently not a self-sustaining anadromous Sockeye Run and, therefore, is only considered a placeholder CU. No status analysis can be completed for this CU at this time. The restoration of anadromous fish runs, where practical, is a key objective of the Bridge-Coastal Fish and Wildlife Restoration Program (BCRP).

Francois (later-timed)-ES/S (was erroneously labelled Francois-L in Holtby & Ciruna (2009))

Populations that were included in the original CU list include Nadina River and Uncha and Sweetnam Creeks. Historically, Nadina River had both an earlier and later timed run (both were early summer run timing). The early run would migrate up into Nadina Lake and then drop downstream (below the current channel location) to spawn. A later run timing group would migrate up to the location of the current channel to spawn. These populations were distinct due to differences in spawning location and timing, which spatially and temporally isolated them from one another. After channel construction in 1973, the earlier timed run could no longer enter the lake or drop back below the channel; once they entered the channel they remained in the channel. Therefore, both the earlier timed run and later timed run spawned together in the spawning channel. As a result, these two populations have merged into one, and are included in the Francois-ES CU, since they now spawn concurrently in the same location. The Uncha and

Sweetnam Creek populations are Summer Run timed, and Sockeye are observed in these creeks only during years when the abundance of Fraser-S (Stellako River) Sockeye is high. These populations are not persistent and are likely not genetically distinct from the Fraser-S CU populations, therefore, they also should not be considered a separate CU.

Fraser-ES

This CU includes two sites: Endako River and Ormond Creek. These populations are likely extirpated and were never large since the substrate is of poor quality for salmon and there is much better gravel for Sockeye spawning in other locations. Field Crews sporadically survey this system, therefore, data are negligible and the status of this CU cannot be assessed.

Fraser Canyon (River-Type)

This CU includes several sites: American, Emory, Silverhop, Spuzzum and Yale Creeks, and the Bridge and Coquihalla Rivers. This is a placeholder CU, as more data, such as scale analysis, is required to confirm that these populations are river-type Sockeye (absence of a freshwater check on the scale) that migrated to the ocean shortly after gravel emergence. It is likely that this CU consists of upstream Sockeye populations that drop out of the Fraser River into these Fraser Canyon streams when migration conditions are poor (high temperatures and extreme high or low flows). The only Sockeye population that appears to be somewhat persistent is in the Bridge River. There is limited data for populations in this CU, as these sites were only assessed during Pink years that coincided with the dominant cycle Adams River Sockeye run.

Mid-Fraser River (River-Type)

This CU includes the following sites: Nechako River (persistent TC), Quesnel, Bridge (persistent TC), Williams L Creek and Hawks Creek. The source population of this proposed CU likely changes depending on migration conditions. It is persistent, but reporting has been irregular and more sampling is required to confirm that this CU is genetically distinct.

Nadina-ES

This CU consists of Glacier Creek, above Nadina Lake. This system was initially flown because a large population was observed going up the falls into the lake. The system is very difficult to assess and has only been opportunistically surveyed in the last 10 to 15 years. The Glacier Creek population does not appear to be genetically distinct from the Nadina River and Channel population (Francois-ES CU).

Thompson (River-Type)

The sites in this CU include the mainstem of the Thompson River and Deadman Creek. These sites were only assessed only in Pink (odd) years.

Upper Fraser (River-Type)

There has only been one observation of Sockeye in Tete Jaune Creek in the Upper Fraser, and this was observed opportunistically during a Chinook survey. Chinook are consistantly assessed in this system, therefore, indicating that Sockeye have not likely been present in other years. This CU is a placeholder until more data can be collected to confirm the persistence of the CU.

Status: Four Conservation Units Proposed For Removal From The CU List

Hayward Lake

This CU should be removed from the CU list as it is associated with an error in the escapement database. Steelhead Creek, the population associated with this CU, does not occur in the Hayward Lake system but rather the Harrison Lake system. Therefore, this is not a valid CU.

Indian/Kruger

This is not a persistent population and only opportunistic surveys have been conducted.

Kawkawa-L

Kawkawa Lake was dammed and, as a result, has not been accessible to spawning Sockeye since its construction. There may have been anadromous Sockeye in this system prior to damming, although this has not been confirmed. Currently, Kokanee do occupy the lake.

Stuart-EStu

There are two sites in the Stuart-EStu CU, both of which have only one year of data (Nahounli Creek) or negligible escapement data (Sowchea Creek). The population in Nahounli Creek is not persistent, and was only surveyed in 1951. There are sixteen escapement records for Sowchea Creek, occurring in 1941, 1951, 1955, 1956, 1960, 1970, 1974, 2001, and during 2003-2009. Sockeye are observed in these creeks only when spawner abundance in the Takla-Trembleur CU is high or migration conditions have been stressful (e.g. warmer water conditions). These populations are not genetically distinct from the Takla-Trembleur-EStu CU and are not persistent. Therefore, this CU should be removed from the Fraser Sockeye CU list.

CONCLUSIONS

The purpose of this paper was not to provide a final single stock status for each Fraser Sockeye CU, but instead to explore uncertainty in status across a range of metrics and benchmarks. Final single stock status for each CU is the subject of an on-going process (initiated June 10th 2011 at an internal DFO workshop) and final results will be presented in subsequent papers.

For Abundance metrics, both the structural (different models) and stochastic (probability distribution) uncertainty in benchmarks were presented in Table 3. *Abundance* metric status for most CUs was sensitive to the model choice, benchmark probability level, and the methods used to estimate the recent (last generation) abundance (arithmetic versus geometric means).

Although a recommendation in the CSAP process was to include Larkin models, these models were excluded from the current analysis given assumptions of constant abundances on a cycle through time are violated and the Ricker model benchmarks are relatively robust to extirpation risk and recovery. Therefore, only Ricker model forms were considered.

Since most CUs have exhibited recent declines in productivity, Ricker model forms that take this lower recent productivity into consideration (truncated stock-recruitment time series Ricker models, Smoothed Ricker models and Recursive Bayesian models), generally produced larger (more biologically conservative) benchmarks relative to models that used the full (or close to the full) stock-recruitment time series. For CUs that have not exhibited systematic declines in productivity, benchmarks were not significantly different between model forms. Model forms that consider recent systemmatic productivity declines in the estimation of benchmarks were

important to consider given previous simulation modelling indicated that the risk of extinction at higher spawner abundances increased significantly in the case of linear declines in productivity, relative to all other productivity scenarios (stable, cyclic, linear increase) (Holt 2009).

Finally, in the case of *abundance* metrics, recent abunadances estimated using arithmetic versus geometric means generally did not have a significant affect on *abundance* statuses except in the case of CUs that have exhibited high cyclicity in the last generation (e.g. Shuswap-ES, Chilliwack-ES, Shuswap-L, and Seton-L). For these exceptions, the geometric mean generally produced much lower recent abundance averages since the high abundance cycle line was downweighted considerably in the mean calculation producing much lower statuses for this metric relative to the arithmetic mean that equally weights all four recent years.

For all models, prior information on the carrying capacity parameter was used if available and appropriate. The current paper updates PR model S_{max} calculations by considering competitors to Fraser Sockeye juveniles. There are numerous caveats to this data as presented in the results section. Although for some CUs this paper uses the mean of these results, the precision expressed by the standard deviation (sigma) only encompasses a range of S_{max} observed. More appropriately, Bodtker et al. (2007) methods should be updated and used for estimating the uncertainty in the S_{max} ('*b*' parameter) priors. Further, spawning habitat capacity data was found only in one past report, and this data should be updated for all CUs in a peer review process.

For *trends in abundance* metrics, the current paper attempts to address the complexity of the red, amber, green zones for WSP status by presenting the actual metric values and shades of these zones (depending on how close or far to the benchmarks CU values fell) (Table 4). This approach provides more information on the actual CU values, rather than simply presenting one of three colors for each metric. For a large number of CUs, the *trends in abundance* indicators based on the three generational decline metric were in the red zone. For most of these CUs exhibiting a declining trend, this was largely attributed to the fact that many CUs were returning to average after a period of high abundance in the 1990s. This metric is consistently used by the World Conservation Union (IUCN) and the COSEWIC to determine status. However, the case of Fraser Sockeye emphasizes the importance of placing this metric in the context of the historical time series.

This paper only estimated *abundance and trends in abundance* indicators. Although d*istribution* metrics are important to evaluate for changes in distribution over time, these metrics will be a challenge to assess for Fraser Sockeye and other Pacific Salmon. Artifacts of data collection methods often preclude the ability to track true distributional trends, other than on a coarse scale for most systems. If these indicators of status are to be used in the future they will require considerable input from the programs currently monitoring and evaluating Fraser Sockeye abundance in the Fraser watershed and will also require linkages with habitat indicators. *Fishing mortality* benchmarks, since they are not instrinsic properties of the CU, may not be specifically required in evaluating CU status, even when consensus on benchmarks for this class of indicator is reached. This *class of indicator*, however, might be appropriate for characterizing a threat to CUs rather than status.

The current paper attempts to frame out uncertainties in statuses across metrics as a starting point for the final step in the development of a single status for each CU. In the current paper, most CU's have a number of statuses across all metrics and across the range of benchmarks explored. The process of combining all these statuses into a final single status for each CU is part of an on-going process that uses expert knowledge and will be the subject of subsequent papers.

NEXT STEPS

o The development of a single status for each CU using information on status uncertainty across benchmarks and metrics presented in the current paper is the key next step. To start this work, DFO recently held an internal workshop on June 10, 2011 to explore methods for aggregating status specific to Fraser Sockeye. Future workshops and publications are expected as outcomes of this next step.

o Future work is recommended for the development and implementation of *distribution* class of indicators. This would require the modification of existing escapement enumeration study designs to meet the additional objective of assessing Fraser Sockeye distributional changes through time. Development of appropriate benchmarks for *distribution* metrics will concurrently be required.

o For *trends in abundance* metrics considerable efforts for this paper were placed in organizing the data, determining which sites to include or exclude, and gap filling. Similar efforts went into the production database. This type of work required considerable input from the experts on the Fraser Sockeye enumeration programs through time and cannot be done independent of this type of input. This paper attempts to provide the first steps in documenting the current CU escapement data. A process for providing these time series in the publically available NuSeds escapement database was recommended during the November 15/16 2011 review of this paper. This revised time series would not replace the existing escapement time series, but would be additional, for those without the expert knowledge but that require this level of data treatment for analysis.

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Table 3. Uncertainty in *abundance* metric status for each Fraser Sockeye Conservation Unit (CU). Ben... function of (1) the model used to estimate benchmarks (Ricker, Kalman Filtered Ricker, Smoothed Ric... included in the analysis, and (3) the cumulative probability distributions of lower and upper benchmark... reflect, respectively, stochastic and structural uncertainty in benchmarks. *Abundance* metric status is e... arithmetic or geometric mean of the last generation ETS (2006-2009) in relation to each combination o... level. Status is red if the last generation ETS is below the lower benchmark, green if it is above the up... it is between the lower and upper benchmarks. <mark>(insert picture; not working right now and insert absolu...</mark> <mark>CUs with no data)</mark>

Conservation Unit	model (time series)	Abundance (Effective Total Spawner) Lower Benchmark					Abundance (Effective Total Spawner) Upper Benchmark					Arithmetic Last Gen. 2006-2009
		10%	25%	50%	75%	90%	10%	25%	50%	75%	90%	
Early Stuart Run												
Takla-Trembleur-Estu	Ricker (1950-2004)	46,000	55,000	68,000	88,000	111,000	174,000	192,000	218,000	259,000	302,000	26,500
	Ricker (1970-2004)	63,000	76,000	97,000	127,000	154,000	177,000	198,000	225,000	263,000	298,000	
	Ricker (1990-2004)	85,000	95,000	111,000	126,000	130,000	130,000	138,000	143,000	147,000	147,000	
	Ricker-smoothed (1950-2004)	62,000	72,000	85,000	104,000	126,000	74,000	84,000	97,000	117,000	139,000	
	Recursive Bayes (1950-2004)	82,000	107,000	138,000	176,000	218,000	83,000	131,000	187,000	261,000	332,000	
Early Summer Run												
Bowron-ES	Ricker (1950-2004)	3,000	3,000	4,000	5,000	6,000	13,000	15,000	17,000	19,000	22,000	1,600
	Ricker (1970-2004)	3,000	3,000	4,000	5,000	7,000	11,000	13,000	14,000	17,000	18,000	
	Ricker (1990-2004)	3,000	4,000	5,000	7,000	9,000	10,000	11,000	12,000	14,000	15,000	
	Ricker (1950-2004)(smoothed)	4,000	5,000	5,000	6,000	7,000	5,000	6,000	6,000	7,000	8,000	
	Recursive Bayes (1950-2004)	4,000	5,000	6,000	7,000	9,000	6,000	8,000	11,000	13,000	16,000	
Kamloops-ES	Ricker (1967-2004)	3,000	4,000	5,000	6,000	9,000	17,000	19,000	23,000	27,000	33,000	15,400
	Ricker (1990-2004)	4,000	6,000	10,000	17,000	32,000	20,000	25,000	32,000	45,000	74,000	
	Ricker (1967-2004)(smoothed)	3,000	4,000	5,000	7,000	9,000	16,000	18,000	21,000	26,000	32,000	
	Recursive Bayes (1967-2004)	5,000	8,000	15,000	35,000	58,000	23,000	30,000	49,000	101,000	161,000	
Anderson-ES	Ricker (1968-2004)	1,000	2,000	3,000	4,000	9,000	12,000	14,000	19,000	27,000	48,000	4,100
	Ricker (1990-2004)	2,000	3,000	6,000	14,000	30,000	12,000	16,000	24,000	46,000	98,000	
	Ricker (1968-2004)(smoothed)	2,000	3,000	5,000	7,000	11,000	9,000	11,000	14,000	20,000	31,000	
	Recursive Bayes (1968-2004)[1]	16,000	34,000	70,000	112,000	145,000	45,000	94,000	199,000	326,000	416,000	
Francors-ES	Ricker (1973-2004)	8,000	11,000	17,000	33,000	59,000	35,000	42,000	58,000	100,000	158,000	9,400
	Ricker (1990-2004)	7,000	11,000	18,000	40,000	76,000	29,000	36,000	48,000	84,000	121,000	
	Ricker (1973-2004)(smoothed)	10,000	13,000	20,000	33,000	61,000	27,000	34,000	48,000	75,000	132,000	
	Recursive Bayes (1973-2004)[1]	29,000	50,000	90,000	131,000	169,000	71,000	119,000	203,000	305,000	382,000	

Table 3. Continued (see previous page for description)

Run Timing Group / Conservation Unit	model (time series)	Abundance (Effective Total Spawner) Lower Benchmark					Abundance (Effective Total Spawner) Upper Benchmark					Arithmetic Last Gen. 2006-2009	Stock Status Probability L
		10%	25%	50%	75%	90%	10%	25%	50%	75%	90%		10% 25% 50% 7...
Early Summer Run Continued													
Pitt-ES (switched to uniform)	Ricker (1950-2004)	4,000	5,000	6,000	8,000	9,000	18,000	20,000	22,000	24,000	26,000	32,200	
	Ricker (1970-2004)	5,000	6,000	7,000	9,000	12,000	19,000	20,000	22,000	24,000	27,000		
	Ricker (1990-2004)	3,000	4,000	6,000	8,000	12,000	19,000	20,000	20,000	24,000	27,000		
	Ricker (1950-2004)(smoothed)	6,000	8,000	9,000	11,000	11,000	14,000	16,000	17,000	18,000	18,000		
	Recursive Bayes (1950-2004)	5,000	8,000	10,000	13,000	15,000	20,000	24,000	27,000	31,000	35,000		
Shuswap-ES	Ricker (1980-2004)	37,000	58,000	89,000	156,000	253,000	113,000	144,000	198,000	304,000	497,000	64,600	
	Ricker (1990-2004)	34,000	54,000	87,000	161,000	238,000	91,000	119,000	155,000	241,000	308,000		
	Ricker (1980-2004)(smoothed)	27,000	36,000	51,000	79,000	130,000	71,000	87,000	113,000	161,000	248,000		
	Recursive Bayes (1980-2004)[1]	75,000	123,000	200,000	280,000	331,000	164,000	257,000	387,000	571,000	714,000		
Chilliwack-ES	Carrying Capacity of system (deterministic, not probabilistic)	–	-	8,000	-	–	–	-	16,000	–	-	12,000	
Summer Run													
Chilko-S / Chilko-ES	Ricker (1950-2004)	28,000	33,000	39,000	47,000	54,000	238,000	252,000	273,000	294,000	311,000	275,000	
	Ricker (1970-2004)	20,000	25,000	31,000	39,000	60,000	215,000	235,000	252,000	274,000	304,000		
	Ricker (1990-2004)	21,000	28,000	43,000	66,000	92,000	216,000	239,000	258,000	285,000	310,000		
	Ricker (1950-2004)(smoothed)	44,000	51,000	61,000	72,000	85,000	200,000	209,000	222,000	236,000	253,000		
	Recursive Bayes (1950-2004)	37,000	46,000	63,000	81,000	99,000	197,000	223,000	250,000	278,000	309,000		
Stuart-S / Takla-Trembleur-S	Ricker (1950-2004)	55,000	73,000	104,000	146,000	197,000	343,000	400,000	499,000	608,000	741,000	59,100	
	Ricker (1970-2004)	64,000	87,000	125,000	188,000	267,000	365,000	414,000	500,000	622,000	763,000		
	Ricker (1990-2004)	129,000	170,000	234,000	309,000	392,000	349,000	380,000	444,000	499,000	549,000		
	Ricker (1950-2004)(smoothed)	105,370	150,000	209,000	284,000	392,000	216,000	336,000	482,000	703,000	958,000		
	Recursive Bayes (1950-2004)	110,000	134,000	166,000	210,000	272,000	164,000	192,000	231,000	284,000	358,000		
Quesnel-S / McKinley-S	Ricker (1950-2004)	84,000	100,000	121,000	140,000	168,000	600,000	637,000	701,000	742,000	805,000	95,800	
	Ricker (1970-2004)	76,000	91,000	112,000	139,000	164,000	615,000	647,000	694,000	736,000	775,000		
	Ricker (1990-2004)	126,000	160,000	202,000	253,000	291,000	518,000	529,000	536,000	539,000	521,000		
	Ricker (1950-2004)(smoothed)	187,000	209,000	234,000	253,000	268,000	344,000	358,000	369,000	378,000	384,000		
	Recursive Bayes (1950-2004)	158,000	213,000	256,000	294,000	331,000	185,000	322,000	464,000	580,000	693,000		
Fraser-S	Ricker (1950-2004)	27,000	33,000	42,000	53,000	68,000	151,000	168,000	195,000	225,000	264,000	87,500	
	Ricker (1970-2004)	28,000	34,000	43,000	59,000	76,000	152,000	170,000	192,000	238,000	274,000		
	Ricker (1990-2004)	44,000	67,000	79,000	102,000	130,000	155,000	172,000	197,000	219,000	246,000		
	Ricker (1950-2004)(smoothed)	49,000	58,000	67,000	79,000	90,000	78,000	84,000	90,000	98,000	107,000		
	Recursive Bayes (1950-2004)	66,000	79,000	96,000	117,000	140,000	99,000	129,000	164,000	205,000	249,000		

Table 3. Continued (see previous page for description)

Run Timing Group / Conservation Unit	model (time series)	Abundance (Effective Total Spawner) Lower Benchmark					Abundance (Effective Total Spawner) Upper Benchmark					Abundance Arithmetic Last Gen. 2006-2009
		10%	25%	50%	75%	90%	10%	25%	50%	75%	90%	
Late Run												
Cultus-L	Ricker (1950-2005)	9,000	10,000	12,000	15,000	17,000	28,000	29,000	32,000	34,000	36,000	900
	Ricker (1970-2005)	8,000	10,000	12,000	15,000	18,000	27,000	29,000	32,000	34,000	36,000	
	Ricker (1990-2005)	11,000	12,000	13,000	13,000	8,000	19,000	18,000	16,000	14,000	7,000	
	Ricker (1950-2004)(smoothed)	11,000	12,000	14,000	16,000	18,000	16,000	18,000	21,000	24,000	26,000	
	Recursive Bayes (1950-2004)	8,000	11,000	13,000	16,000	18,000	7,000	15,000	22,000	30,000	36,000	
LFR-River Type	Ricker (1950-2005)	6,000	7,000	9,000	11,000	14,000	28,000	30,000	32,000	36,000	40,000	147,700
	Ricker (1970-2005)	6,000	7,000	9,000	11,000	14,000	33,000	36,000	39,000	44,000	48,000	
	Ricker (1990-2005)	3,000	4,000	6,000	9,000	13,000	34,000	38,000	43,000	49,000	58,000	
	Ricker (1950-2004)(smoothed)	100	100	200	300	300	7,000	8,000	10,000	11,000	13,000	
	Recursive Bayes (1950-2004)[1]	2,000	2,000	2,000	2,000	2,000	5,000	6,000	7,000	9,000	11,000	
Shuswap Complex-L	Ricker (1950-2005)	234,000	283,000	365,000	434,000	546,000	1,070,000	1,162,000	1,288,000	1,415,000	1,633,000	578,400
	Ricker (1970-2005)	201,000	268,000	337,000	447,000	558,000	984,000	1,090,000	1,194,000	1,384,000	1,503,000	
	Ricker (1990-2005)	171,000	238,000	339,000	469,000	576,000	757,000	836,000	879,000	902,000	915,000	
	Ricker (1950-2004)(smoothed)	345,000	364,000	376,000	383,000	384,000	347,000	373,000	394,000	409,000	418,000	
	Recursive Bayes (1950-2004)	330,000	417,000	519,000	632,000	768,000	526,000	870,000	1,166,000	1,432,000	1,728,000	
Seton-L	Ricker (1965-2004)	0	1,000	1,000	1,000	2,000	6,000	7,000	8,000	10,000	12,000	5,300
	Ricker (1990-2004)	1,000	1,000	2,000	4,000	7,000	6,000	7,000	10,000	14,000	23,000	
	Ricker (1965-2004)(smoothed)	1,000	1,000	2,000	2,000	3,000	5,000	5,000	6,000	7,000	9,000	
	Recursive Bayes (1965-2004)	1,000	1,000	2,000	2,000	3,000	5,000	6,000	6,000	7,000	9,000	
Harrison (U/S)-L	Ricker (1966-2004)	4,000	6,000	9,000	14,000	23,000	52,000	61,000	76,000	103,000	147,000	20,400
	Ricker (1990-2004)	1,000	2,000	4,000	7,000	13,000	25,000	32,000	43,000	63,000	99,000	
	Ricker (1966-2004)(smoothed)	7,000	9,000	13,000	19,000	30,000	45,000	54,000	67,000	90,000	133,000	
	Recursive Bayes (1966-2004)	11,000	19,000	38,000	69,000	95,000	77,000	120,000	219,000	368,000	488,000	
Lillooet-L	Ricker (1950-2004)	8,000	9,000	11,000	14,000	17,000	67,000	72,000	77,000	85,000	93,000	104,900
	Ricker (1970-2004)	7,000	9,000	13,000	17,000	21,000	67,000	73,000	80,000	88,000	94,000	
	Ricker (1990-2004)	15,000	20,000	26,000	33,000	39,000	27,000	59,000	61,000	59,000	55,000	
	Ricker (1950-2004)(smoothed)	15,000	18,000	22,000	26,000	30,000	48,000	50,000	51,000	52,000	54,000	
	Recursive Bayes (1950-2004)	17,000	22,000	27,000	31,000	36,000	29,000	40,000	55,000	68,000	79,000	

1. For these models the Smax estimated is unrealistically high relative to those estimated with all other models; therefore these models are not recommended for benchmark considerations
2. Simulation testing indicates high time-series bias in Sgd and Sgen that increases with reduced series length, therefore, truncated Larkin models are not recommended

Table 4. Trends in Abundance status for each of the 26 assessible CUs for short-term and long-term t[...] *trends in abundance* statuses, average effective female spawners (EFS)(Avg.), the average EFS in the[...] end of the time series, and the last generation average EFS (Last Gen.) are provided for each CU to s[...] reference only, diiferent (transformed) values are used in the actual assessments). For the long-term t[...] the ratio of the current generation to the historical average UB (0.75) and LB (0.5) are the same across[...] presented for each CU and colour coded to correspond with status. For the short-term trends in abund[...] of change in the last three generations LB is a 25% rate of decline (slope: -0.026) and the UB is a 15%[...] 0.015) for all CUs. Log$_e$ slopes are presented for each CU and colour coded to correspond with status[...] *in abundance* metric is the probability that this recent decline is below the lower benchmark of 25% an[...] first deterministic *recent trends in abundance* metric. All statuses are color coded red if they are below[...] green if they are above the upper benchmark (UB) and amber if they are between the LB and UB for e[...]

Run Timing Group Conservation Unit	Escapement: Trend Indicators (EFS) Avg. (EFS)	Gen. 3rd from Last (EFS)	Last Gen. (EFS)	Trends (EFS) (Metric 1) Ratio of Current Generation to Historical Average 0.25 0.50 0.63 0.75 1.0	Trends (EFS) (Metrics 2 & 3) Linear Rate of Change Change in Last 3 Gens. -50% -25% -15% +% slope: -0.063 -0.026 -0.015 +
Early Stuart					
Takla-Trembleur-Estu	40,900	31,000	13,300	0.58	-0.10
Early Summer					
Bowron-ES	4,300	3,900	800	0.27	-0.19
Kamloops-ES	6,900	16,800	9,200	2.14	-0.02
Anderson-ES	3,600	6,200	2,400	1.98	-0.04
Francois-ES	7,500	22,600	4,900	1.35	-0.04
Pitt-ES	13,200	38,900	15,800	2.17	0.00
Shuswap-ES	21,200	23,700	37,000	0.9	-0.06
Nahatlach-ES	2,200	2,300	1,000	0.55	-0.14
Chilliwack-ES[1]	1,100	1,400	500	NA	NA
Taseko-ES	1,300	800	400	0.32	-0.12

1. Chilliwack-ES cannot be assessed quantiatively due to its short time series.

Table 4. Continued (see previous pages for description).

Run Timing Group / Conservation Unit	Escapement: Trend Indicators (EFS) Avg. (EFS)	Gen. 3rd from Last (EFS)	Last Gen. (EFS)	Trends (EFS) (Metric 1) Ratio of Current Generation to Historical Average	Trends (EFS) (Metrics 2 & 3) Linear Rate of Change Change in Last 3 Gens.
Summer					
Chilko-S & Chilko-ES	191,600	406,800	153,600	1.22	-0.13
Stuart-S	49,400	92,700	22,700	2.35	-0.14
Takla-Trembleur-S	26,400	29,600	5,400	0.95	-0.18
Quesnel-S & McKinley-S	188,700	585,600	50,700	7.7	-0.17
Fraser-S	53,000	105,000	47,300	1.31	-0.04
Late					
Cultus-L [2]	11,800	1,100	800	0.07	-0.11
LFR-(River Type)	13,600	4,700	63,400	6.98	
Shuswap-L	312,300	204,300	303,700	0.95	
Seton-L	3,800	3,200	4,100	0.91	-0.08
Harrison (U/S)-L	19,200	13,400	10,700	0.8	-0.03
Harrison (D/S)-L	1,500	3,200	4,300	13.3	
Lillooet-L	44,200	59,000	58,200	1.48	
Widgeon (River-Type)	300	30	200	0.35	
Kamloops-L	4,300	300	200	0.3	-0.02

Metric 1 scale: 0.25 0.50 0.63 0.75 1.0

Metrics 2 & 3 scale: -50% -25% -15% (slope: -0.063 -0.026 -0.015)

2. Cultus is effective total wild spawners since sex identification at the fence during enumeration is a challenge

APPENDIX 1: For each conservation unit, the sites available in the escapement database are in beside the site name indicates it was used in the escapement time series to evaluate stock stat *Abundance* metrics.

Anderson-ES		Bowron-ES		Chilko-S & Chilko-ES		Chilliwack-ES		Cultus-L		Francois
Sites	IN	Sites	IN	Sites	IN	Sites	IN	Sites	IN	Sites
Gates Channel	√	Antler Creek		Chilko River	√	Chilliwack Lake	√	Cultus	√	Early Nad
Gates Creek	√	Bowron River	√	Chilko Channel	√	Dolly Varden Creek	√			Late Nad
		Pomeroy Creek	√	Chilko Lake North						Nadina C
		Huckey Creek	√	Chilko Lake South	√					Tagetoch
		Sus Creek	√							Uncha C

Harrison (D/S)-L		Harrison (U/S)-L		Kamloops-ES		Kamloops-L		Lilloet-L		Lower F River (R
Sites	IN	Sites	IN	Sites	IN	Sites	IN	Sites	IN	Sites
Bear Creek		East Creek	√	Barriere River		South Thompson River	√	25 Mile Creek		Alouette
Big Silver Creek	√	Weaver Channel	√	Clearwater River				Birkenhead River	√	Chehalis
Cogburn Creek		Weaver Creek	√	Dunn Creek				Green River		Chilliwacl
Crazy Creek				Fennell Creek	√			Lillooet Slough		Coquihal
Douglas Creek				Finn Creek				Miller Creek		Gallaghe
Hatchery Creek				Grouse Creek				Poole Creek		Harrison
Sloquet Creek				Harper Creek				Railroad Creek		Johnson
Tipella Creek				Hemp Creek				Ryan Creek		Maria Slc
Tipella Slough				Lemieux Creek				Sampson Creek		Ruby Cre
				Lion Creek				JohnSandy not in database		Silver Ho
				Mann Creek						Steelhea
				Moul Creek						Vedder R
				North Thompson River						Wahleac
				Raft River	√					

APPENDIX 1. Continued (see previous page for description).

Pitt-ES		Quesnel-S & McKinley-S						Seton-L	
Sites	IN	Sites	IN	Sites	IN	Sites	IN	Sites	IN
Upper Pitt River	√	Abbott Creek		Isaiah Creek		Tisdall Creek		Portage Creek	√
		Amos Creek		Junction Creek		Trickle Creek			
		Archie Creek		Junction Creek - shore		Wasko Creek			
		Baxter Beach		Killdog Creek		Wasko Creek - shore			
		Bear Beach - shore		Killdog Creek - shore		Watt Creek			
		Betty Frank's - shore		Lester Shore		Watt Creek - shore			
		Big Slide - shore		Limestone Creek		Whiffle Creek			
		Big Slide - shore 1km West		Limestone Point - shore		Winkley Creek			
		Bill Miner Creek		Limestone Point - shore 5km South	√				
		Bill Miner Creek - shore		Little Horsefly River					
		Bill Miner Creek - shore 3km West		Logger Landing					
		Blue Lead Creek		Long Creek					
		Blue Lead Creek - shore		Long Creek - shore					
		Bouldery Creek		Lynx Creek					
		Bouldery Creek - shore		Lynx Creek - shore					
		Bouldery Creek - shore 2km East		Marten Creek					
		Bowling Point		Marten Creek - shore					
		Buckingham Creek		McKinley Creek	√				
		Cameron Creek	√	McKinley Creek - Lower	√				
		Clearbrook Creek		McKinley Creek - Upper	√				
		Deception Point		Mitchell River	√				
		Devoe Creek		Moffat Creek					
		Devoe Creek - shore		Niagara Creek					
		Double T - shore		North Arm - shore (Bowling-Goose Pt.)					
		East Arm - shore (Rock Slide-Penninsula Pt)		North Arm - shore (Roaring-Deception Pt.)					
		East Arm - unnamed creek 1		North Arm - unnamed cove					
		East Arm - unnamed creek 2 - shore		Opa Beach					
		East Arm - unnamed point		Penfold Camp Shore					
		Elysia - shore		Penfold Creek	√				
		Elysia - shore 1km West		Quartz Point					
		Franks Creek		Quesnel Lake					
		Franks Creek - shore		Raft Creek					
		Goose Creek		Roaring Point					
		Goose Point - shore		Roaring River					
		Goose Point - shore 8km South		Roaring River - shore					
		Grain Creek		Rock Slide					
		Grain Creek - shore		Service Creek					
		Hazeltine Creek		Slate Bay					
		Horsefly Channel	√	Slate Bay 1km East					
		Horsefly Lake		Spusks Creek					
		Horsefly River	√	Sue Creek					
		Horsefly River - Above Falls	√	Summit Creek					
		Horsefly River - Lower	√	Taku Creek					
		Horsefly River - Upper	√	Tasse Creek					
		Hurricane Point		Tasse Creek - shore					

APPENDIX 1. Continued (see previous page for description).

Shuswap-ES		Shuswap-L				Stuart-S		Takla-Trembleur-Estu		
Sites	IN	Sites	IN	Sites	IN	Sites	IN	Sites	IN	Sites
Adams Channel		5 Mile Creek		Pass Creek - shore		Kuzkwa Creek	√	5 Mile Creek	√	Saker
Adams River		Adams Channel		Perry River		Pinchi Creek		10 Mile Creek		Sand
Anstey River		Adams Lake		Queest Creek - shore		Sowchea Creek		15 Mile Creek	√	Shale
Bear Creek		Adams Lake - East		Reinecker Creek		Stuart Lake		25 Mile Creek	√	Sinta
Burton Creek		Adams Lake - North		Reinecker Creek - shore		Stuart River		Ankwill Creek	√	Sowc
Bush Creek		Adams Lake - South		Ross Creek		Tachie River	√	Baptiste Creek		Takla
Cayenne Creek	√	Adams River	√	Ross Creek - shore	√			Bates Creek		Takla
Celista Creek		Adams River - shore	√	Salmon River				Bivouac Creek	√	Tarne
Craigellachie Creek		Anstey River	√	Scotch Creek	√			Blackwater Creek	√	Tildes
Crazy Creek		Anstey River - shore	√	Scotch Creek - shore	√			Blanchette Creek		Tliti C
Eagle River		Bear Creek		Seymour River				Casamir Creek		Unna
Gold Creek		Bessette Creek		Shuswap Lake	√			Consolidated Creek	√	
Hunakwa Creek		Bush Creek		Shuswap Lake - Anstey Arm	√			Crow Creek	√	
Loftus Creek		Bush Creek - shore		Shuswap Lake - Main Arm	√			Driftwood River	√	
McNomee Creek	√	Canoe Creek		Shuswap Lake - Main Arm North	√			Dust Creek	√	
Middle Shuswap River		Celista Creek		Shuswap Lake - Main Arm South	√			Felix Creek	√	
Momich/Cayenne	√	Cook Creek		Shuswap Lake - Salmon Arm	√			Fleming Creek		
Onyx Creek		Crazy Creek		Shuswap Lake - Salmon Arm East	√			Forfar Creek	√	
Pass Creek		Cruikshank Pt.W.-shore	√	Shuswap Lake - Salmon Arm North	√			Forsythe Creek	√	
Perry River		Eagle River	√	Shuswap Lake - Salmon Arm South	√			French Creek		
Ross Creek		Four Mile Creek- shore		Shuswap Lake - Seymour Arm	√			Frypan Creek	√	
Salmon River		Gold Creek		Tappen Creek				Gluske Creek	√	
Scotch Creek	√	Hlina Creek - shore	√	Trinity Creek				Hooker Creek		
Seymour River	√	Hunakwa Creek		Tsikwustum Creek				Hudson Bay Creek		
Upper Adams	√	Kingfisher Creek		Tsuius Creek				Kastberg Creek	√	
Yard Creek		Knight Creek - shore		Upper Adams River				Kazchek Creek		
		Lee Creek - shore	√	Vanishing Creek - shore				Kotesine Creek	√	
		Little River		Wap Creek				Kynock Creek	√	
		Loftus Creek		Yard Creek				Leo Creek		
		Lower Shuswap River	√					Lion Creek	√	
		Mara Lake - shore						McDougall Creek		
		McNomee Creek						Middle River (Rosette)		
		Middle Shuswap River	√					Nahounli Creek		
		Momich River	√					Nancut Creek		
		Momich River - shore						Narrows Creek	√	
		Noisy Creek						Paula Creek	√	
		Onyx Creek						Point Creek	√	
		Onyx Creek - shore	√					Porter Creek	√	
		Pass Creek	√					Rosette Creek	√	

APPENDIX 1. Continued (see previous page for description).

Takla Trembleur-S		Taseko-ES		Widgeon (River-Type)	
Sites	IN	Sites	IN	Sites	IN
Dust Creek		Taseko Lake	√	Widgeon Creek	√
Kazchek Creek	√				
Middle River	√				
Sakeniche River					

APPENDIX 2. Escapement Data (EFS) Gap Filling. NuSEDs escapement data for years between shown for each stream used in *trends in abundance* analyses for the 26 assessible CUs. The av (across all years of data) of the CU abundance contibuted by each stream is shown to indicate years, their corresponding cycles, and gap filling methods are indicated for each stream.

CU Stream	Avg. Prop.	Escapement Time Series 1950 — 1980 — 2009	Ga
Anderson-ES			
Gates Channel	0.72		NA
Gates Creek	0.28		NA
Bowron-ES			
Bowron River	0.99		NA
Huckey Creek	0.01		NA
Pomeroy Creek	0.00		NA
Sus Creek	0.00		NA
Chilko-ES & Chilko-S			
Chilko River	0.93		NA
Chilko Channel	0.02		NA
Chilko Lake South	0.05		NA
Chilliwack-ES			
Chilliwack Lake	0.12		NA
Dolly Varden Creek	0.88		NA
Cultus-L			
Cultus Lake	1.00		NA
Francois-ES			
Early Nadina River	0.12		NA
Late Nadina River	0.34		NA
Nadina Channel	0.54		NA
Fraser-S			
Stellako River	1.00		NA
Harrison (D/S)-L			
Big Silver Creek	1.00		NA

CU Stream	Avg. Prop.	Escapement Time Series 1950 – 1980 – 2009	Gap
Harrison (U/S)-L			
East Creek	0.00		NA
Weaver Creek	0.46		NA
Weaver Channel	0.54		NA
Kamloops-ES			
Fennell Creek	0.40		NA
Raft River	0.60		NA
Kamloops-L			
South Thompson River	1.00		Cycl
Lillooet-L			
Birkenhead River	1.00		Cycl
LFR - River Type			
Harrison River	1.00		NA
Nahatlatch-ES			
Nahatlatch River	0.75		NA
Nahatlatch Lake	0.25		Mear
Pitt-ES			
Upper Pitt River	1.00		NA
Quesnel-S & McKinley-S			
Cameron Creek	0.03		Mear
Horsefly Channel	0.05		Mear
Horsefly River	0.56		Mear
Horsefly River-Above Falls			Mear
Horsefly River-Lower			Mear
Horsefly River-Upper			Mear
Little Horsefly River	0.01		Mear
McKinley Creek	0.07		Mear
McKinley Creek-Lower			Mear
McKinley Creek-Upper			Mear
Mitchell River	0.27		Mear
Penfold Creek	0.01		Mear

APPENDIX 2. Continued (see previous page for description).

CU Stream	Avg. Prop.	Escapement Time Series 1950 — 1980 — 2009	Gap
Seton-L			
Portage Creek	1.00		NA
Shuswap-ES			
Cayenne Creek	0.02		NA
McNomee Creek	0.03		NA
Momich/Cayenne Creek	0.01		NA
Scotch Creek	0.22		Gap
Seymour River	0.68		NA
Upper Adams River	0.04		Mean
Shuswap-L			
Adams River	0.71		NA
Adams River-shore	0.00		NA
Anstey River	0.00		Mean
Anstey River-shore	0.00		NA
Cruikshank Pt West	0.00		NA
Eagle River	0.01		Mean
Hlina Creek-shore	0.00		NA
Lee Creek-shore	0.00		NA
Little River	0.10		NA
Lower Shuswap River	0.11		Mean
Middle Shuswap River	0.01		NA
Momich River	0.00		Mean
Onyx Creek-shore	0.00		NA
Pass Creek	0.00		Mean
Ross Creek-shore	0.00		NA
Scotch Creek	0.00		Mean
Scotch Creek-shore	0.00		NA
Shuswap Lake	0.01		NA
Anstey Arm	0.01		NA
Main Arm	0.02		NA
Main Arm N.	0.00		NA
Main Arm S.	0.00		NA
Salmon Arm	0.01		NA
Salmon Arm E.	0.00		NA
Salmon Arm N.	0.00		NA
Salmon Arm S.	0.00		NA
Seymour Arm	0.00		NA

APPENDIX 2. Continued (see previous page for description).

CU Stream	Avg. Prop.	Escapement Time Series 1950 — 1980 — 2009	Gap
Stuart-S			
Kuzkwa Creek	0.09		Mean
Tachie River	0.91		Mean
Takla-Trembleur-Estu			
5 Mile Creek	0.00		Mean
15 Mile Creek	0.00		Mean
25 Mile Creek	0.00		NA
Ankwill Creek	0.03		NA
Bivouac Creek	0.02		Mean
Blackwater Creek	0.00		Mean
Consolidated Creek	0.00		Mean
Crow Creek	0.01		Mean
Driftwood Creek	0.26		Mean
Dust Creek	0.06		NA
Felix Creek	0.06		Mean
Forfar Creek	0.09		NA
Forsythe Creek	0.01		Mean
Frypan Creek	0.01		NA
Gluske Creek	0.08		NA
Kastberg Creek	0.00		Mean
Kotesine Creek	0.00		Mean
Kynock Creek	0.15		NA
Lion Creek	0.01		Mean
Narrows Creek	0.04		NA
Paula Creek	0.03		Mean
Point Creek	0.01		Mean
Porter Creek	0.02		Mean
Rosette Creek	0.07		NA
Sakeniche River	0.00		Mean
Sandpoint Creek	0.02		Mean
Shale Creek	0.01		NA
Sinta Creek	0.00		Mean
Takla-Trembleur-S			
Kazchek Creek	0.03		Mean
Middle River	0.97		NA

CU Stream	Avg. Prop.	Escapement Time Series 1950 ··· 1980 ··· 2009	Ga
Taseko-ES Taseko Lake	1.00		Cyc
Widgeon-River Type Widgeon Creek	1.00		Cyc

1. Pre- and post-1980 time series separated when calculating proportions)
2. Streams grouped according to correlation of trends prior to gap filling
3. Dominant and Sub-dominant cycles only

APPENDIX 3: Historical trends and results of status assessments are illustrated for each assessable CU according to the availability of data. Available figures are organized per CU according to the following structure.

Figure 1: Historical time-series of returns, exploitation, escapement, productivity, and survival plotted for each CU or in some cases an indicator system within the CU. Figures not available for a CU due to data gaps are noted in individual CU sections. Abundance time-series are not gap-filled in figures.

> 1a. Total CU returns are broken into total escapement (dark grey-bars), catch (light grey-bars), and en-route loss (red-bars). Exploitation rates are also presented (blue-line).

> 1b. Total escapement is broken into male (dark grey-bar), female (lighter grey-bar) and female pre-spawn mortality (black-bar) components.

> 1c. Three standardized (z-score) and smoothed (4 yr running average) indices of productivity time-series: ln(R/EFS)(light blue triangles-lines), Ricker model residuals (dark blue squares-lines), and Kalman filter a-parameter (dark blue circles-lines) values (the latter index provided by C. Michielsens from the PSC). Large yellow triangles (ln(R/EFS)) and squares (Ricker residuals) indicate 2005 brood year productivity indices. The Lower Fraser River-River Type CU also has data for the 2006 brood year, shown as large blue trianges (ln(R/EFS)) and squares (Ricker residuals).

> 1d. Productivity (log$_e$ recruits-per-spawner) (red circles-lines) in relation to replacement (e.g. 1 recruit per 1 spawner) (horizontal black line).

> 1e. Smoothed (4 yr running average) freshwater survival index-fry or smolt per EFS (green circles-lines).

> 1f. Smoothed (4 yr running average) marine survival index-recruits/smolt (blue circles-lines).

Figure 2: Results of rate of change and abundance-based status assessments.

> 2a. Frequency distribution of the posterior distribution of the linear rate of change of smoothed log-transformed EFS abundances. The posterior distribution (bars) and it's median value (black solid line) are plotted in relation to the lower (dashed line) and upper (dotted line) benchmarks.

> 2b. Change in EFS abundance over the last three generations. The deterministic regression rate of change of smoothed (year labels indicate the last year of the 4-year running average) log-transformed EFS over the past three generations (solid line coloured according to status on this metric: red, amber or green). The lower benchmark rate of decline (25%) is indicated for comparison (black dashed line).

2c. Ratio of the current generational geometric mean EFS abundance to the long-term average geometric mean. Smoothed, log scale historical time-series of EFS (year labels indicate the last year of the 4-year running average) used to calculate the long-term geometric mean (dashed line) is shown. The current generation (hatched box) and the geometric mean of the current generation (solid coloured line) are indicated and coloured according to the status obtained on this metric

2d. Prior (blue line) and posterior (bars) distribution for spawners at maximum recruitment for CU's where stock and recruitment data are available. The median posterior value is indicated with dashed vertical black line. Uniform or lognormal distribution inputs are reported in figure title.

2e. Conservation Unit stock (ETS)-recruitment relationship (model fit: black solid line) with lower (red vertical solid line) and upper (green vertical dashed line) benchmarks indicated.

LIST OF 26 ASSESSIBLE (DATA AVAILABLE) CONSERVATION UNITS WITH FIGURES.

2a.

b.

c.

d.

Uniform 'b' prior: 0-1,000,000

e.

Ricker (1968-2004)

# Bowron-ES

1a.

b.

c.

d.

e.

No freshwater survival data available

**f.**

No marine survival data available

**2a.**


b.

c.

d.

Lognormal 'b' prior: 40,000 (log$_e$ sima: 0.3)

e.

Ricker (1950-2004)

2a.

b.

c.
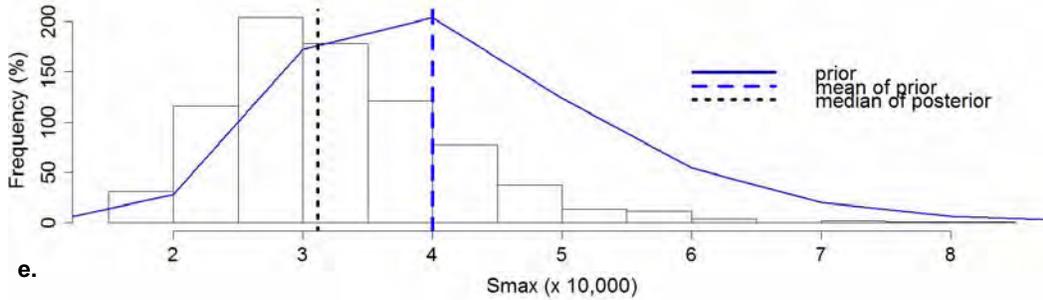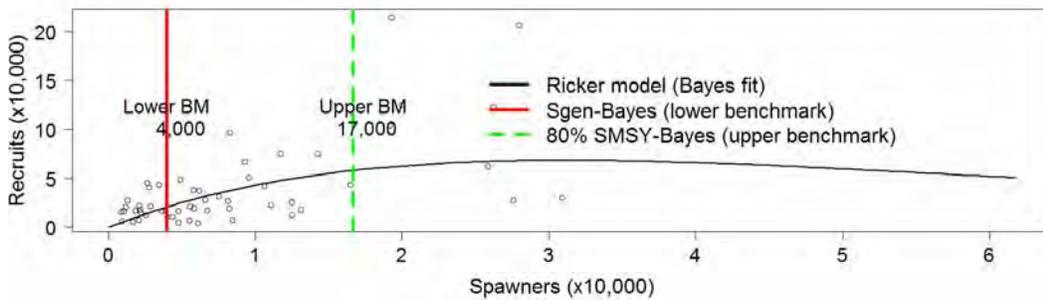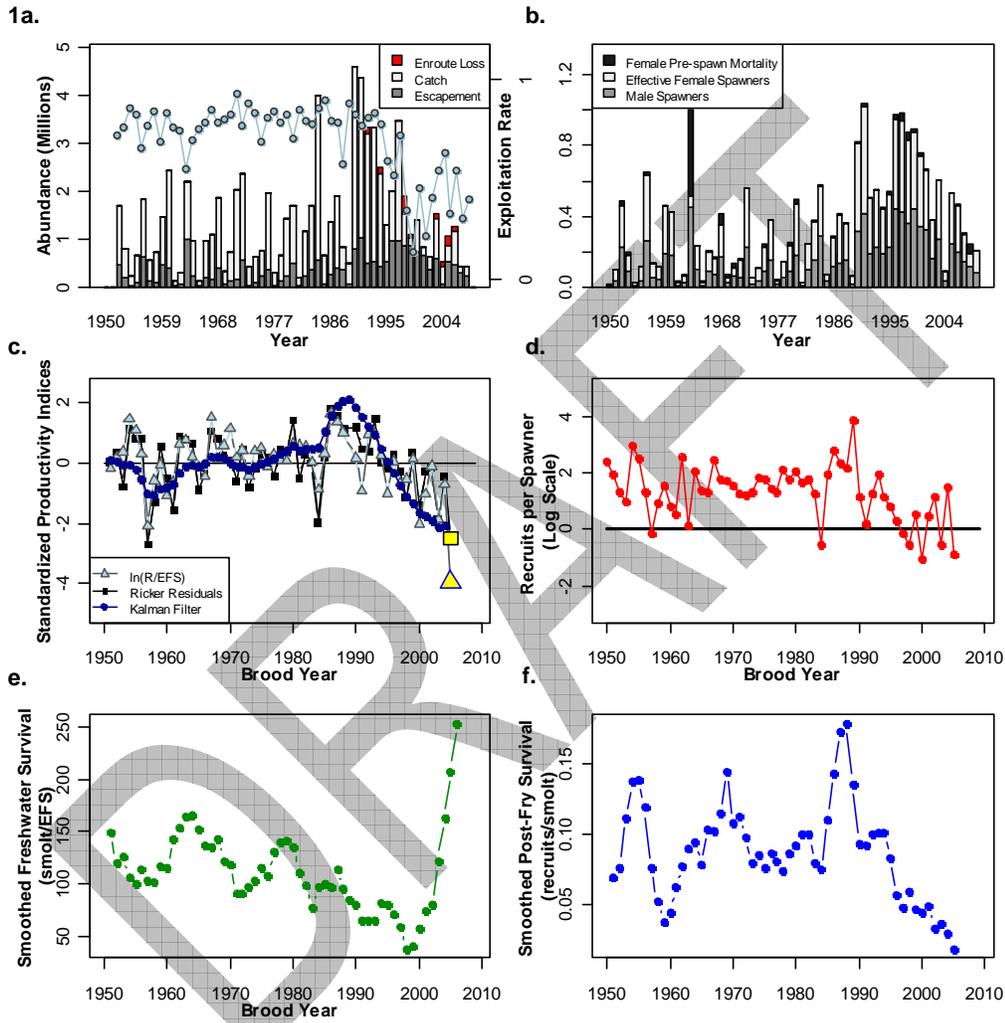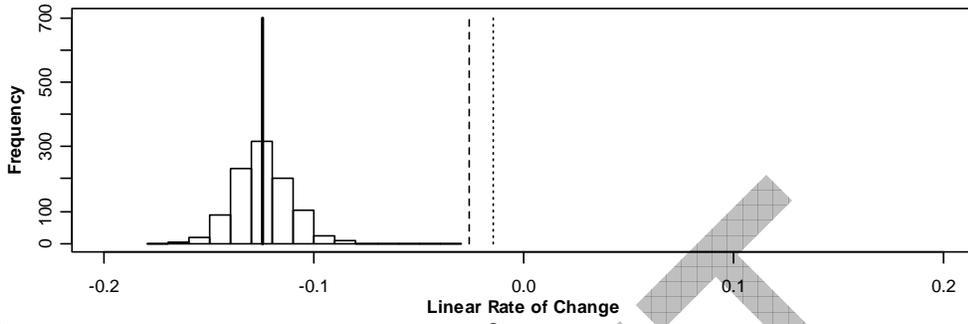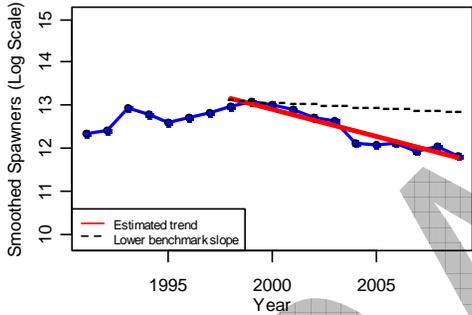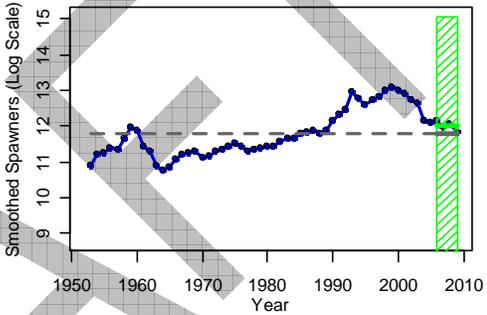
d.   **Lognormal 'b' prior: 400,000 (log$_e$ sigma: 0.5)**
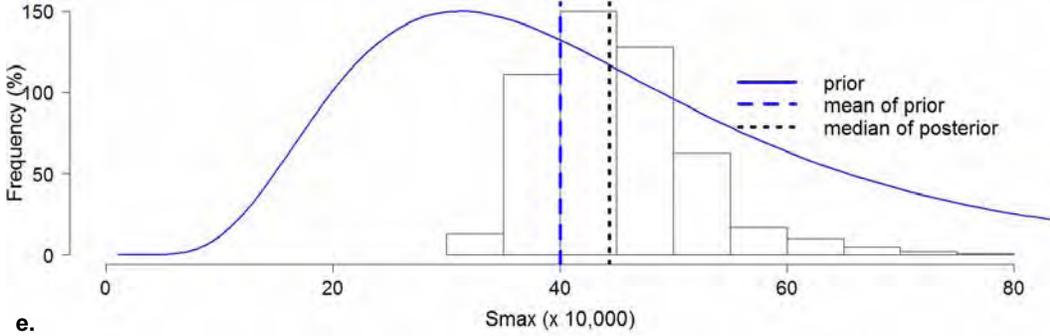
e.   **Ricker (1950-2004)**
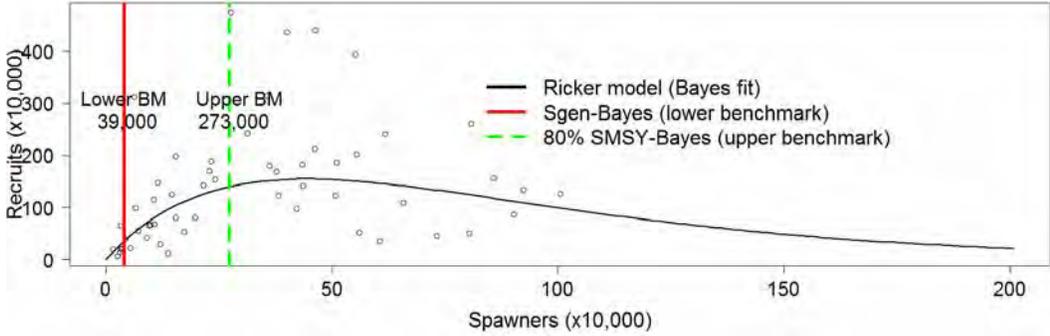
Chilliwack-ES

1b.
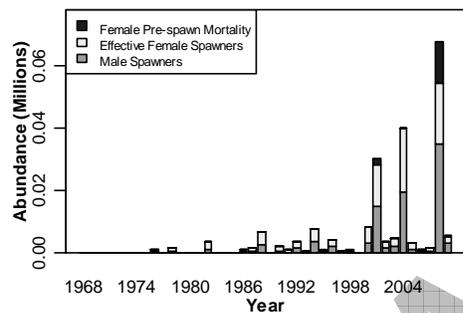
1b (Chilliwack Lake Only).
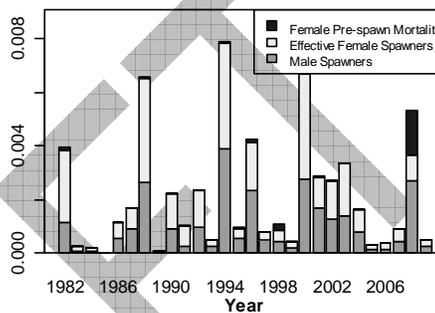
Only Escapement data is available for Chilliwack ES.
Prior to 2000, only Chilliwack Lake data is available.   From 2000
to 2004 Chilliwack River (Dolly Varden) Creek data is also
included in the escapement time series.

2a.

Chilliwack-ES could not be quantitatively assessed in terms of stock status.

b.   **c.**

Cultus-L

1a.

b.

c.

d.

e.

f.

2a.

b.

c.

d.
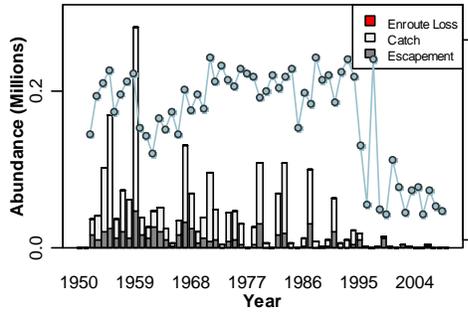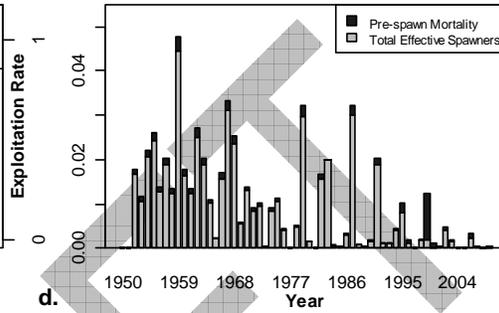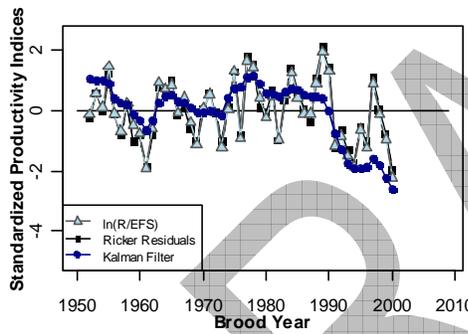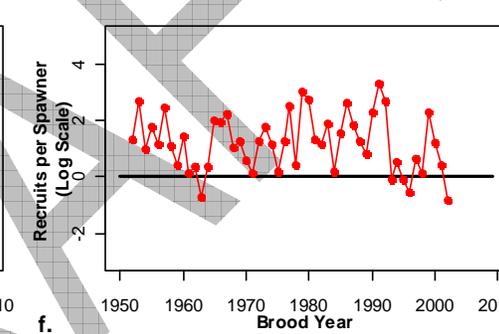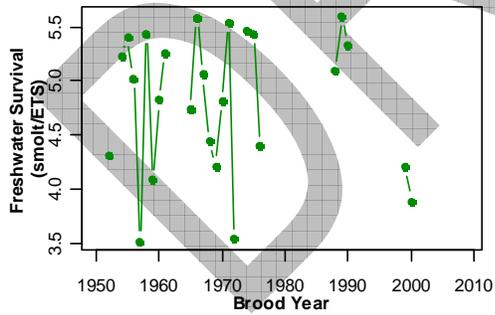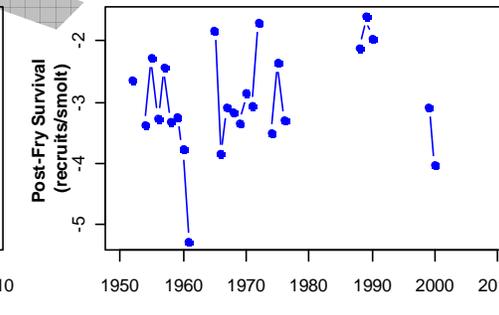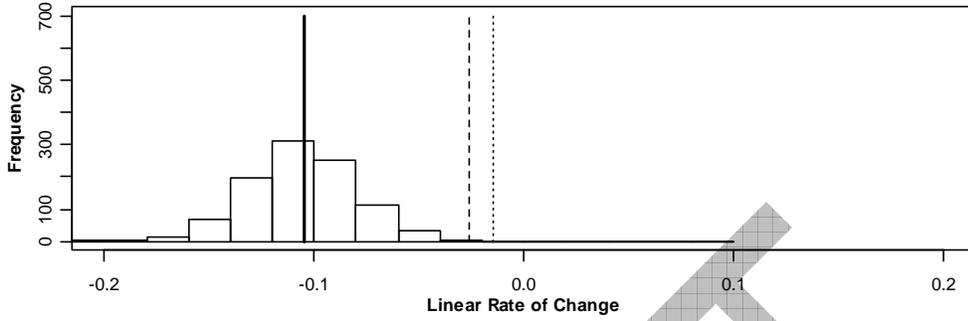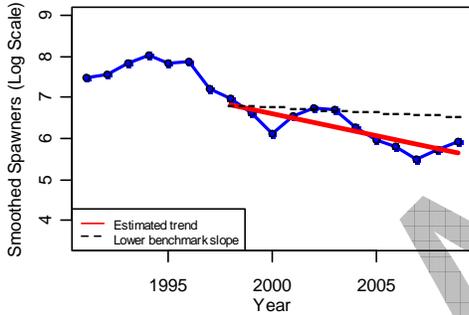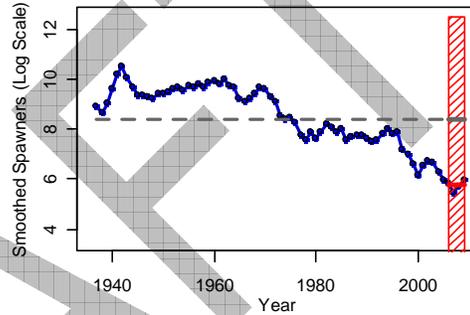
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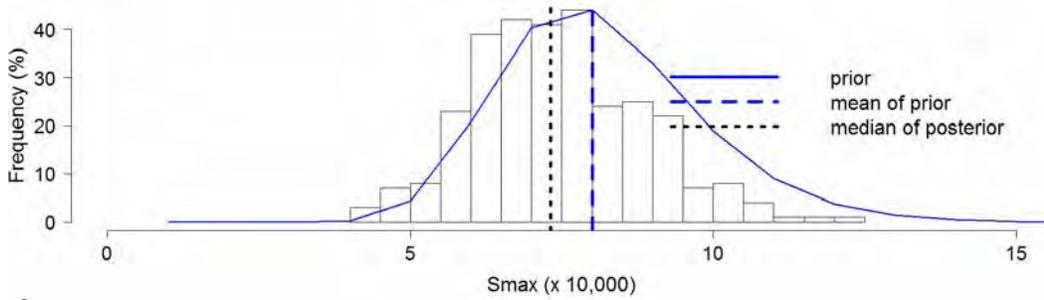
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Ricker (1950-2000)
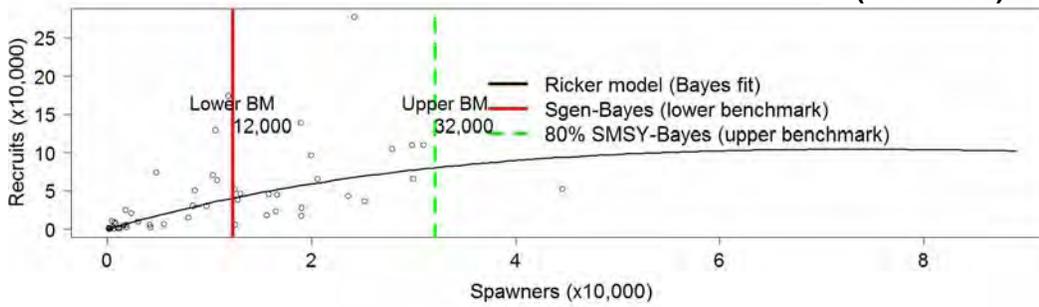
Francois-ES

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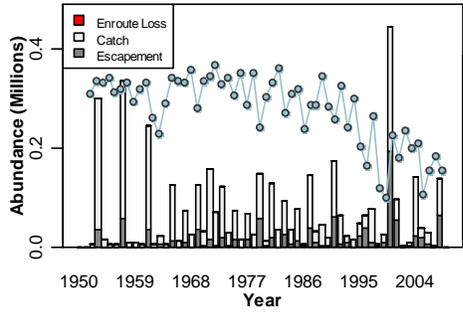
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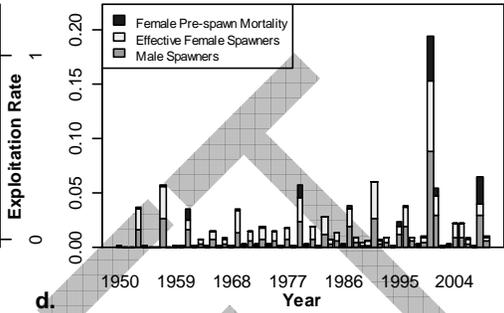
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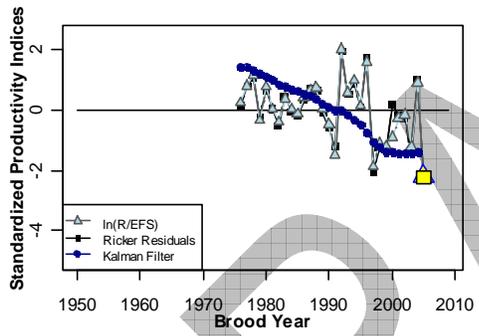
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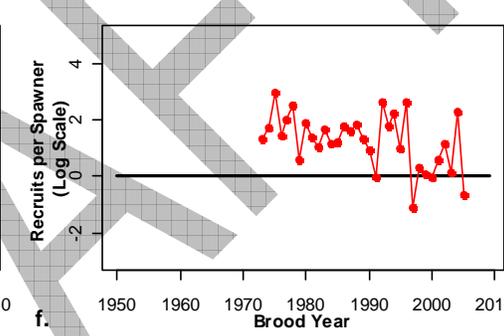
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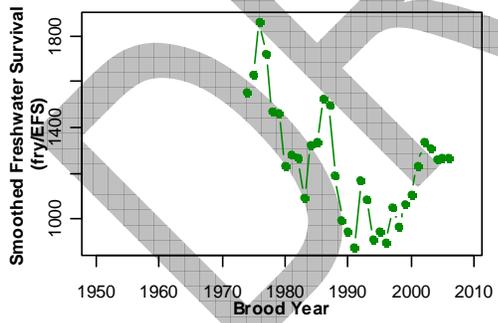
f.

2a.

b.

c.

d.
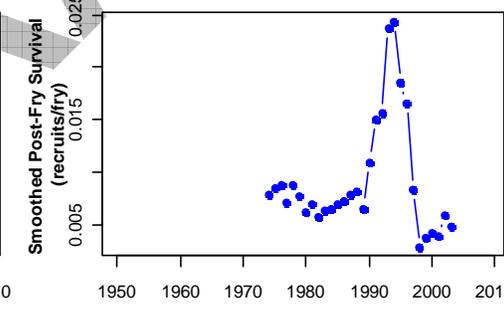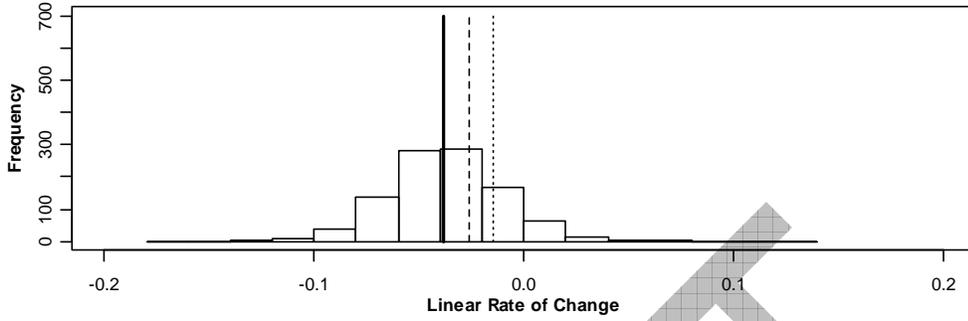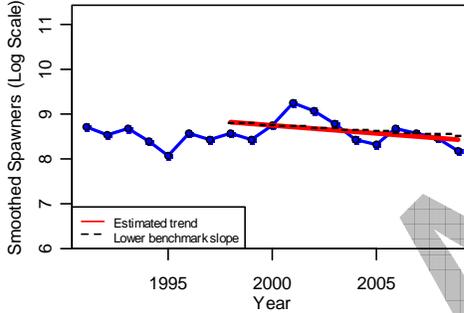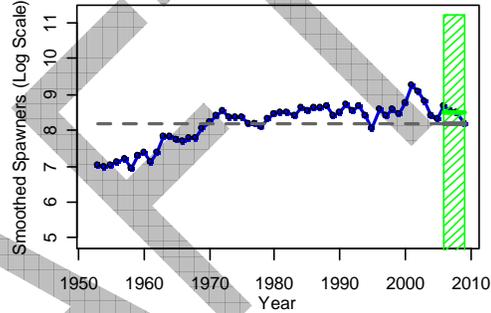
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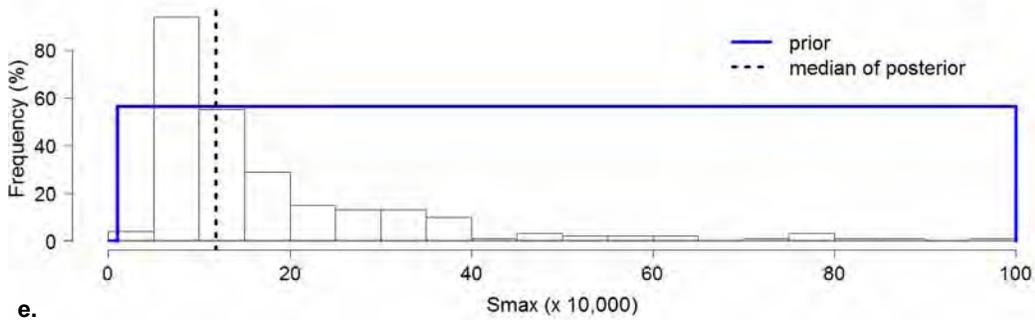
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Ricker (1973-2004)
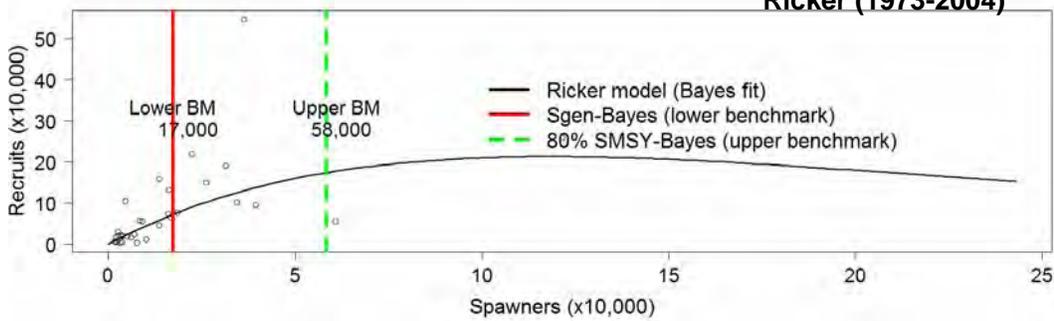
Fraser-S
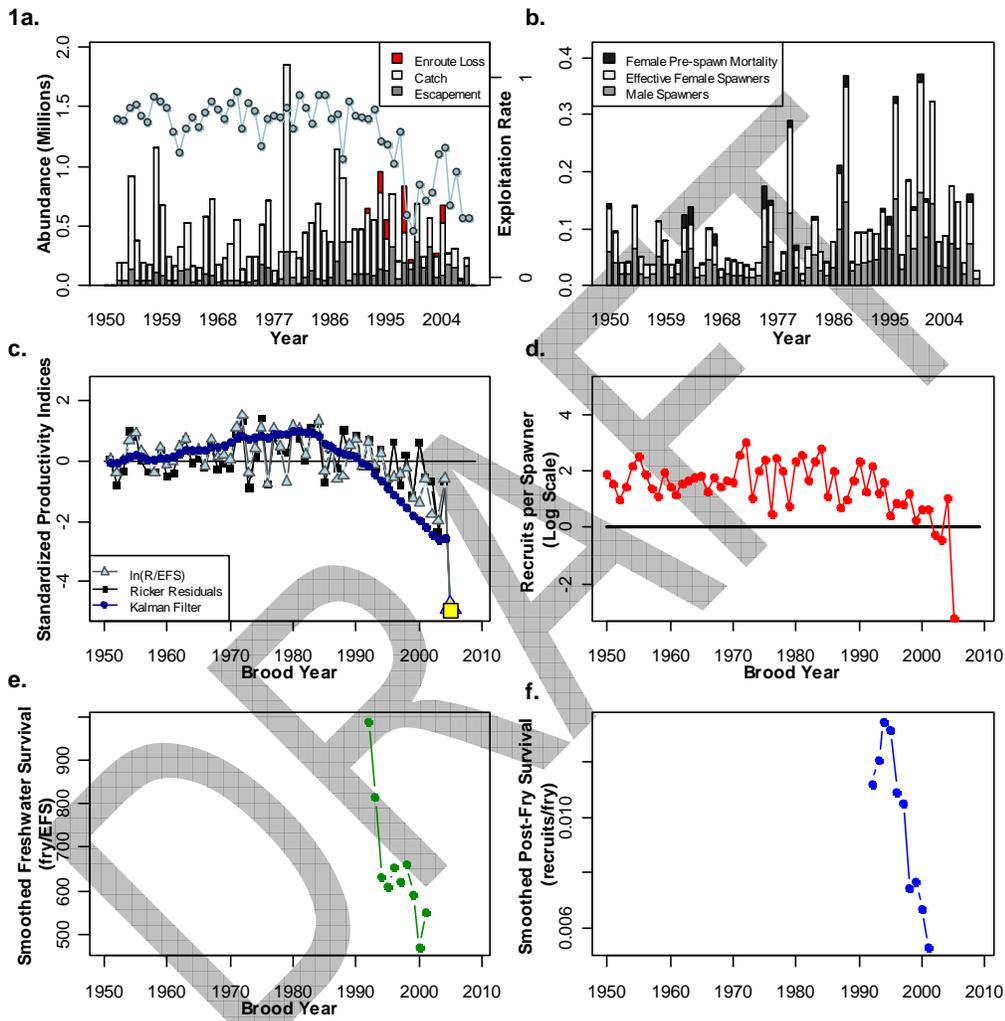
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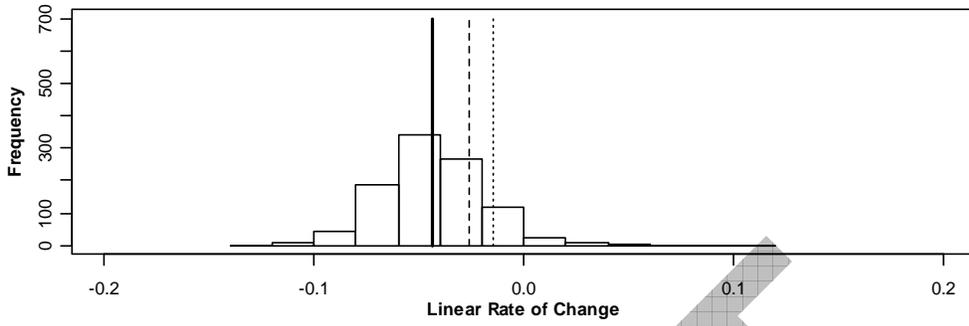
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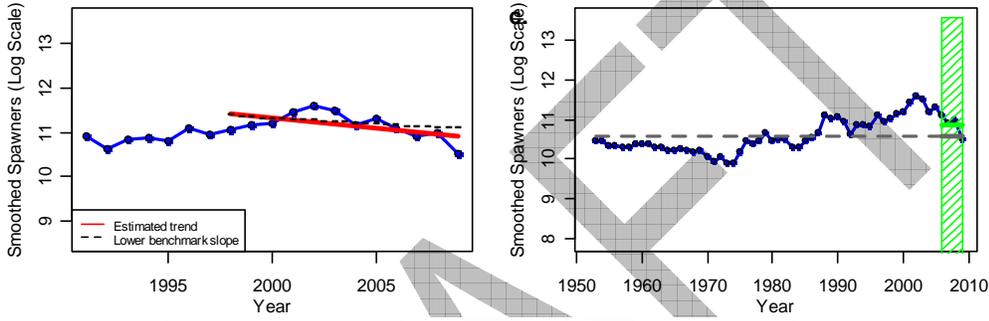
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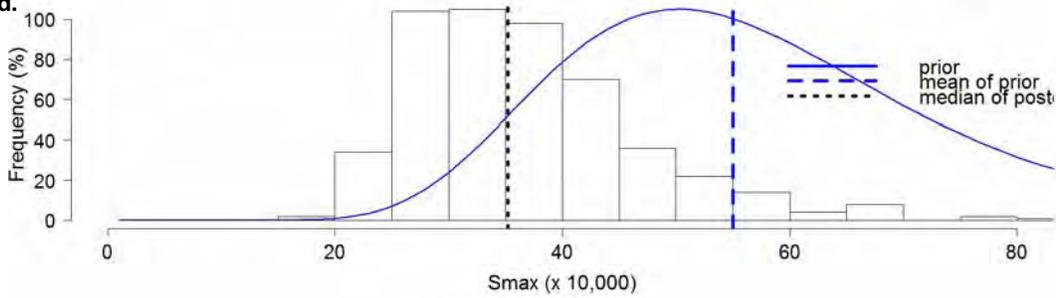
Ricker (1950-2004)

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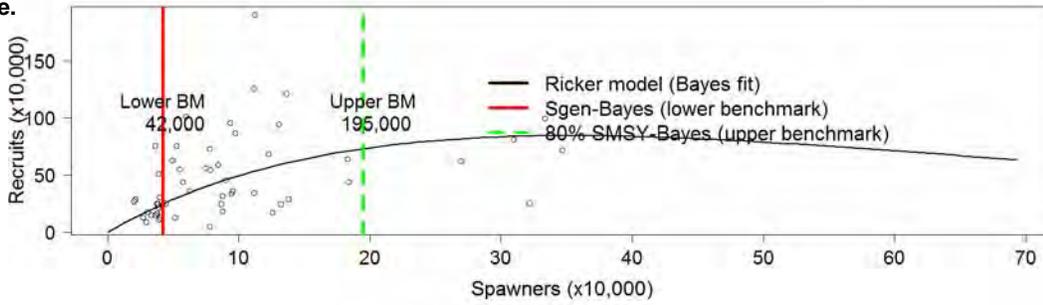
Harrison (D/S)-L

1b.
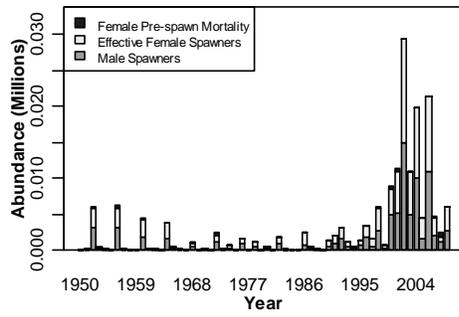
Only escapement data is available for Harrison (D/S)-L.

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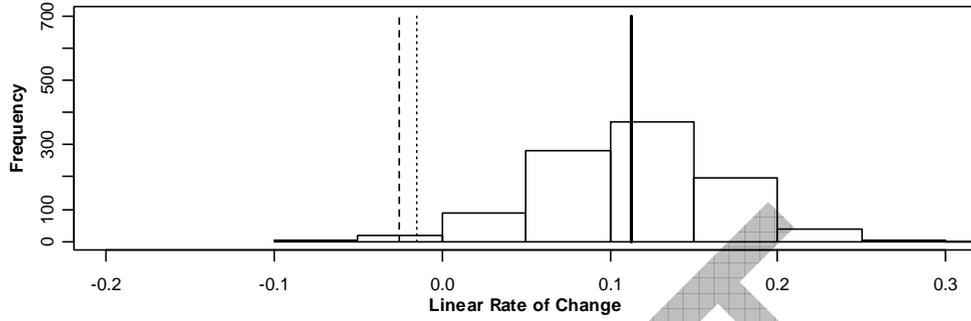
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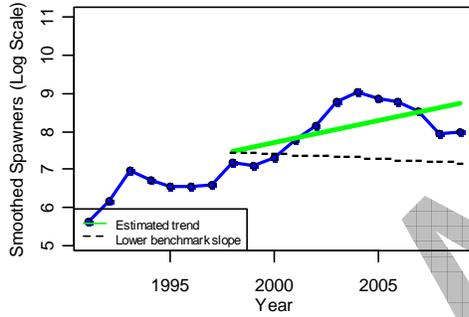
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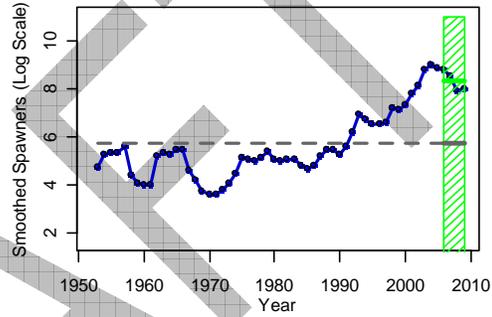
d.

No stock-recruitment data to calculate abundance based benchmarks

e.

No stock-recruitment data to calculate abundance based benchmarks

Harrison (U/S)-L

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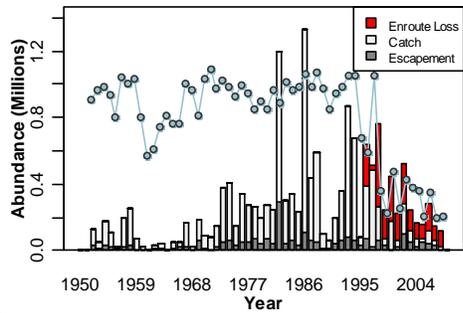
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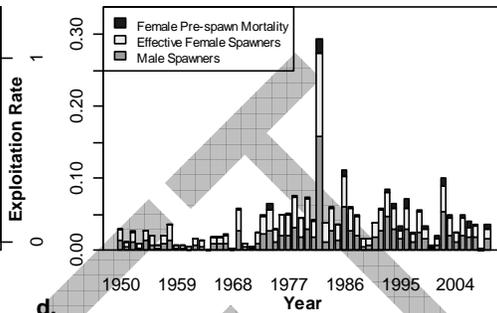
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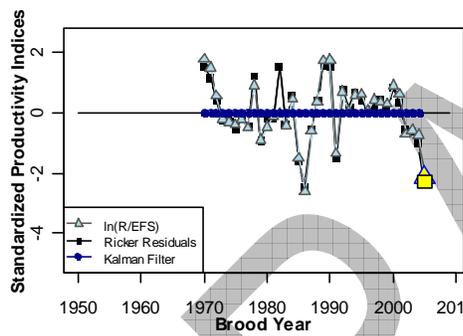
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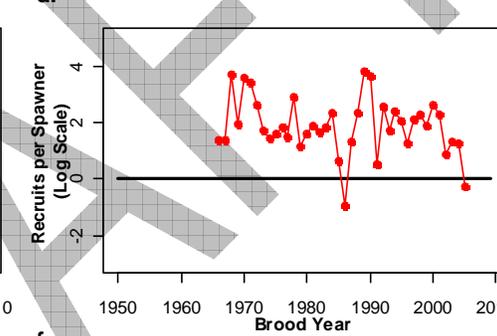
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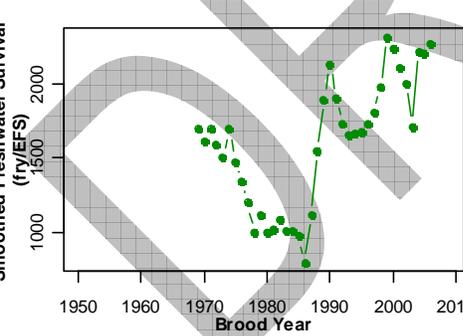
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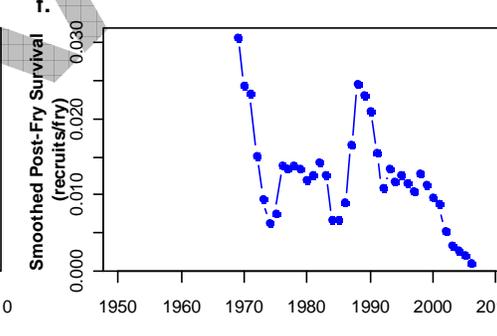
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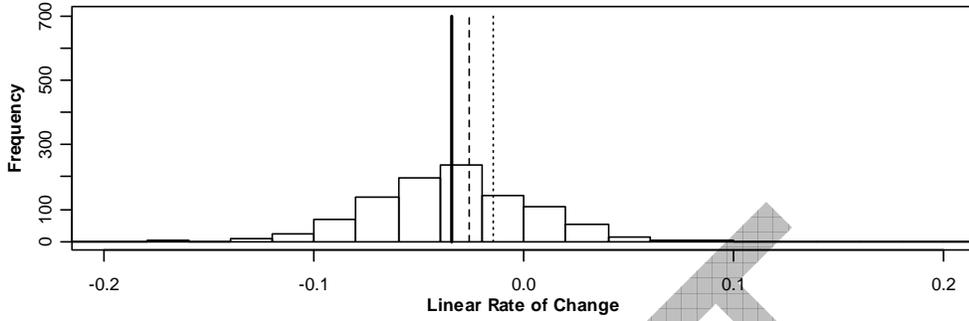
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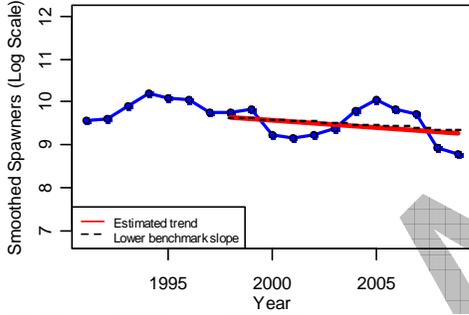
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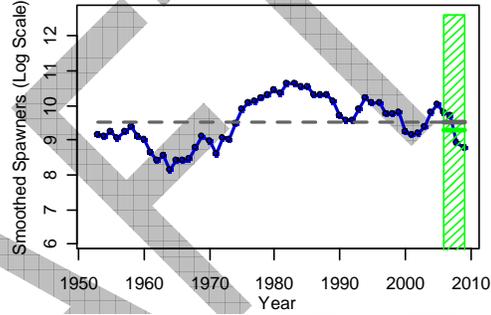
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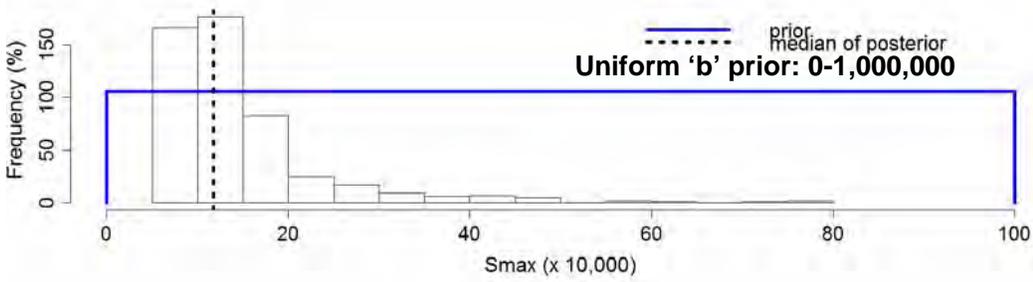
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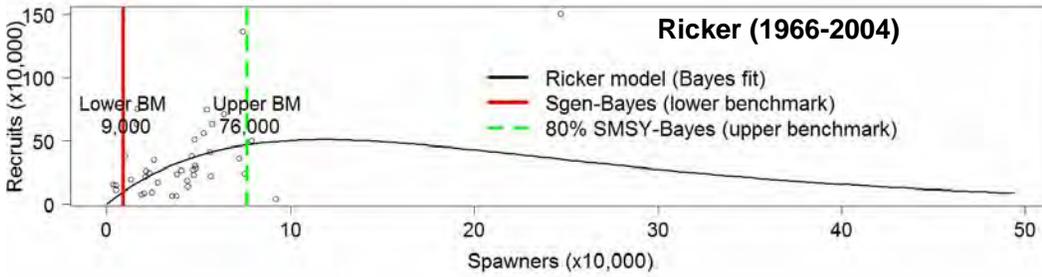
Kamloops-ES

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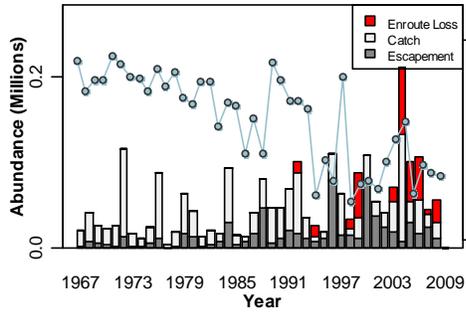
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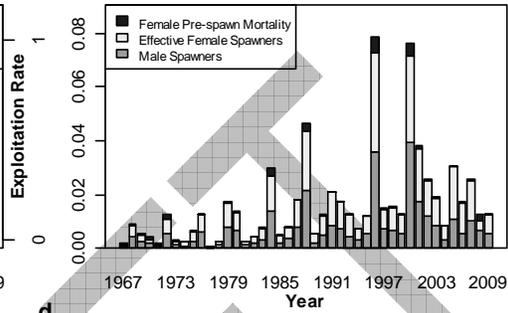
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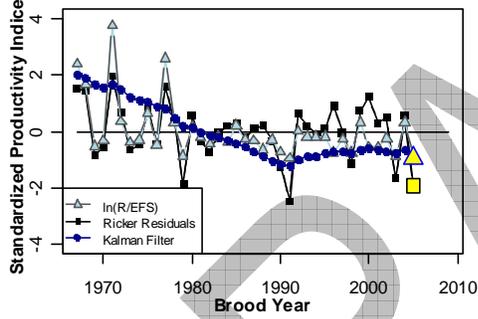
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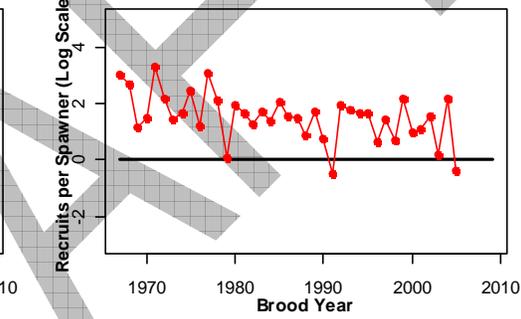
e.

No freshwater survival data available

f.

No marine survival data available

2a.

b.

c.
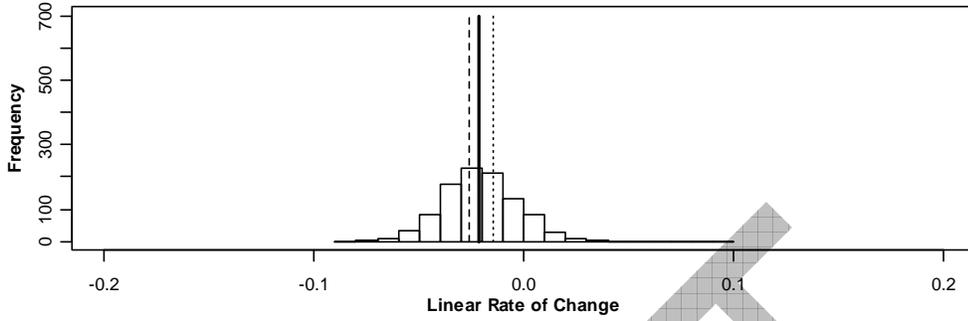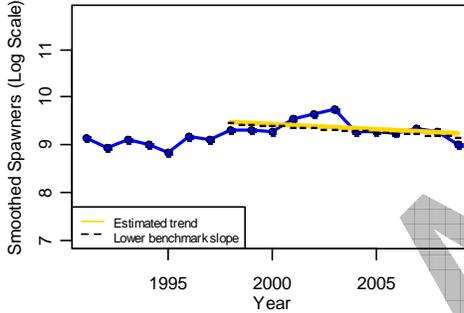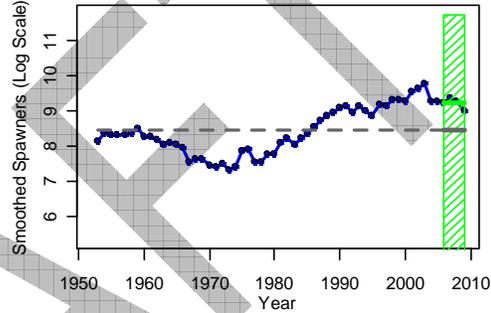
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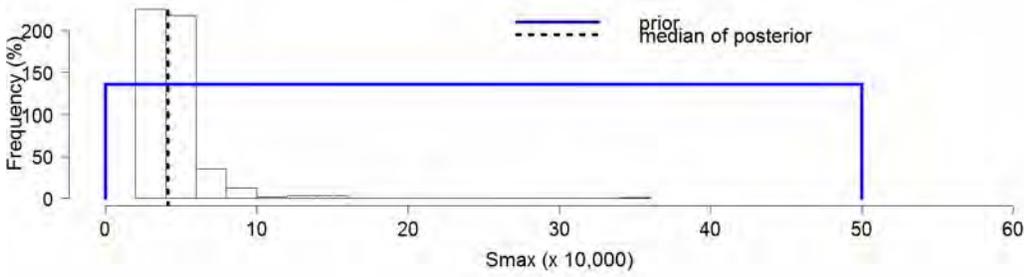
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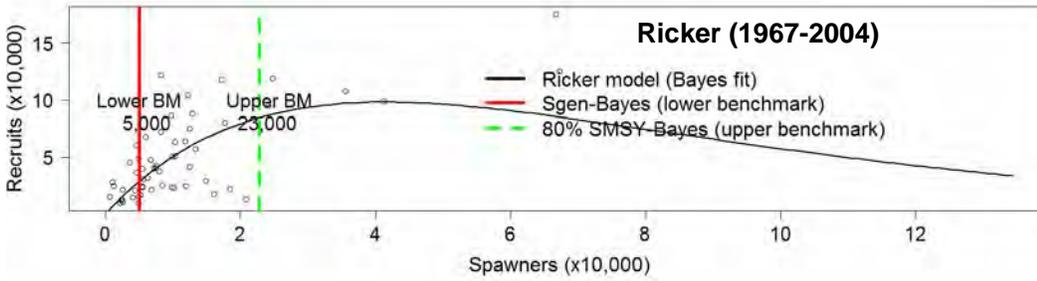
Kamloops-L

1b.
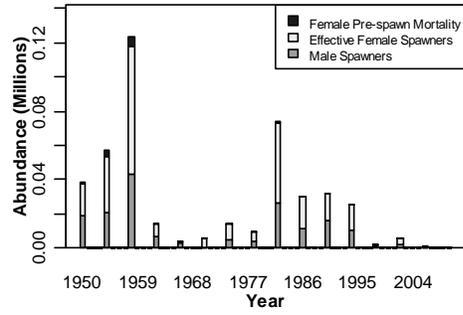
Only escapement data is available for Kamloops-L.

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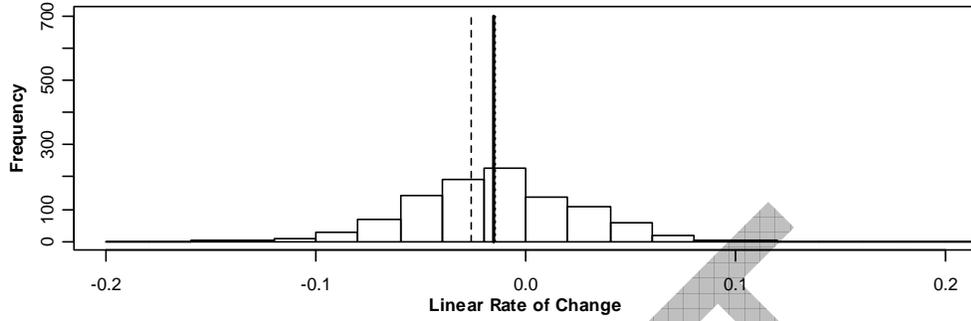
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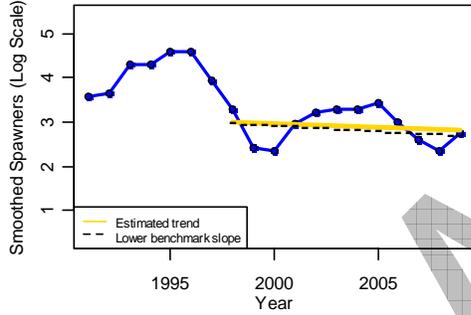
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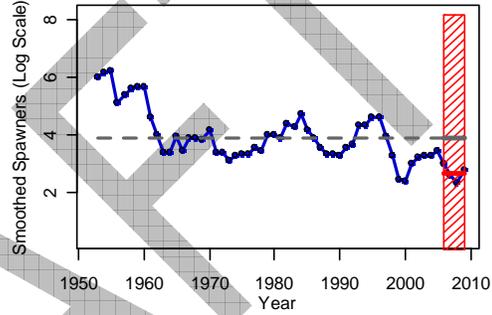
d.

No stock-recruitment data to calculate abundance based benchmarks

e.

No stock-recruitment data to calculate abundance based benchmarks

Lillooet-L

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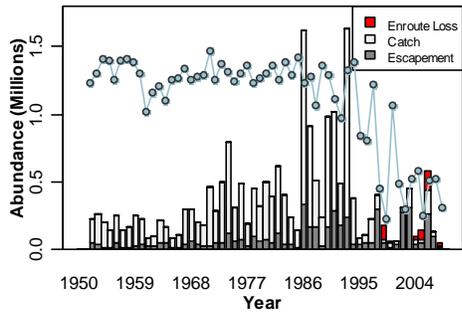
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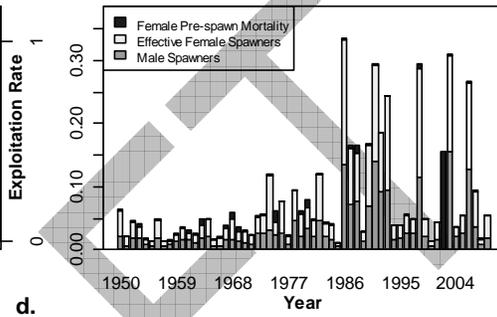
c.
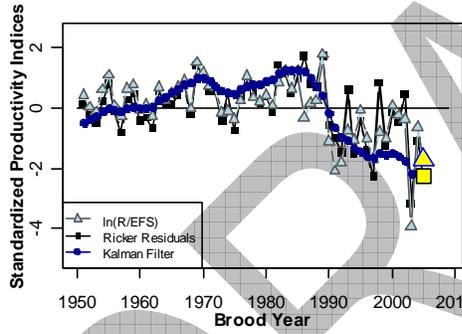
d.
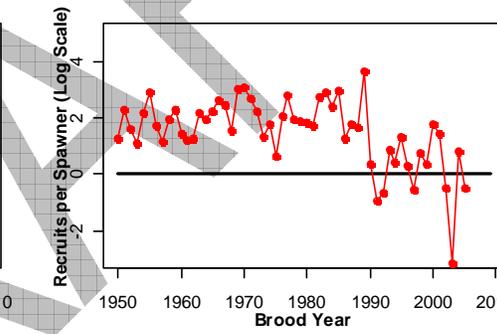
e.

No freshwater survival data available

f.

No marine survival data available

2a.

b.

c.
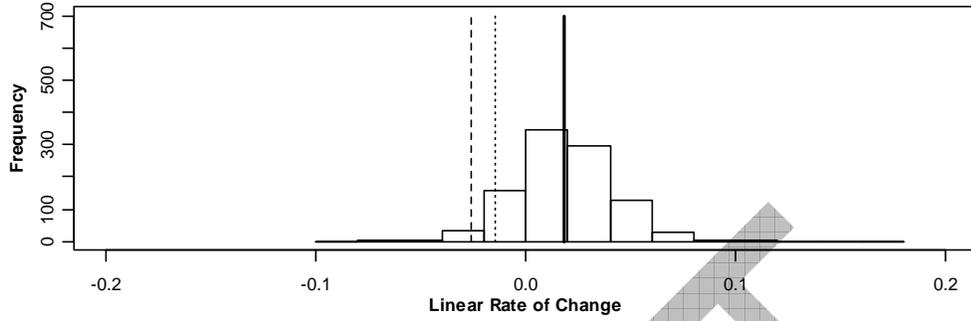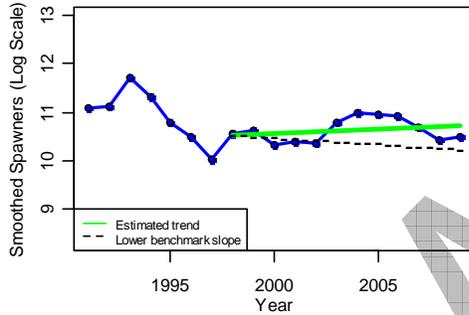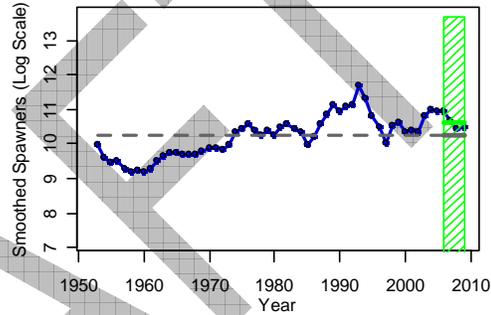
Lognormal 'b' prior: 164,000 (log$_e$ sigma: 0.3)

d.
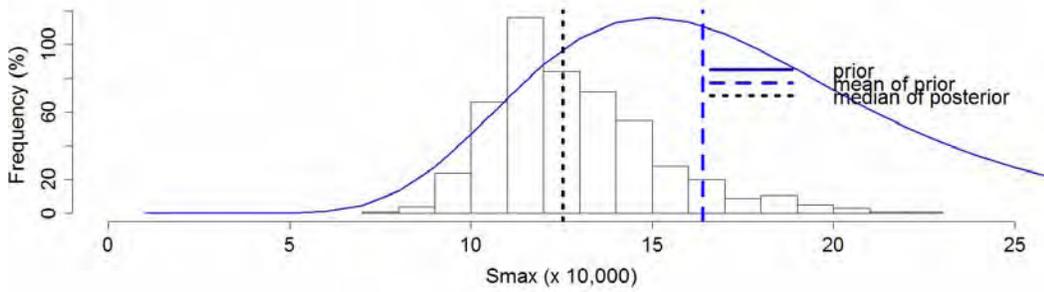
e.
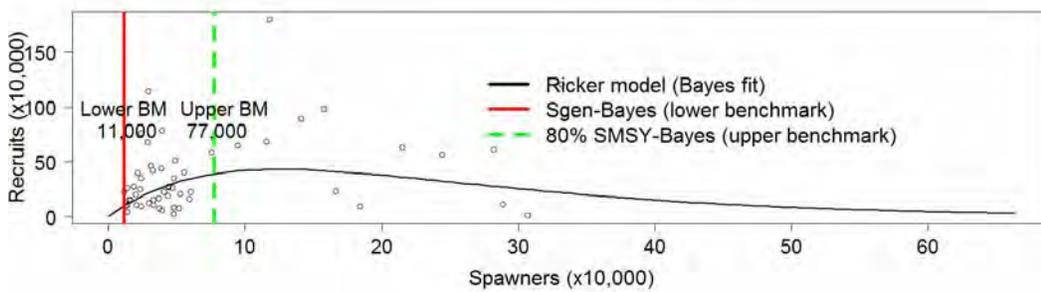
Ricker (1950-2004)

Lower Fraser River (River-Type)

1a.
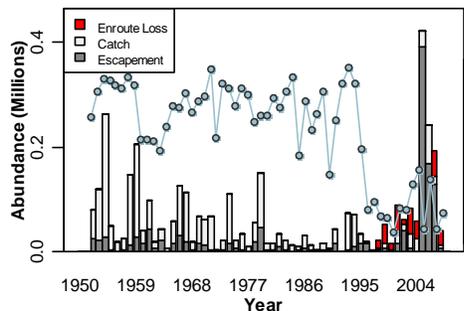
b.
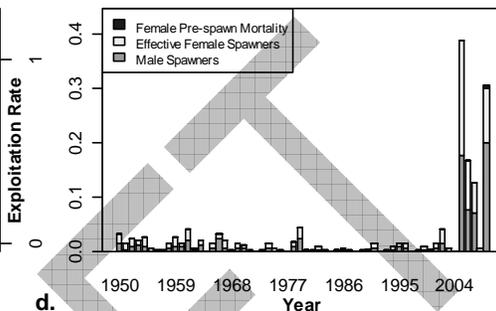
c.
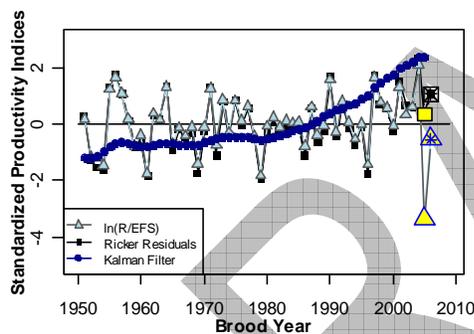
d.
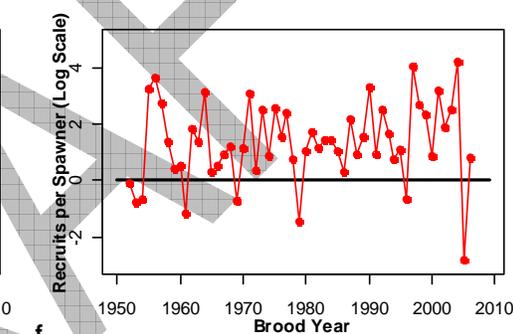
e.

No freshwater survival data available

f.

No marine survival data available

2a.

b.

c.
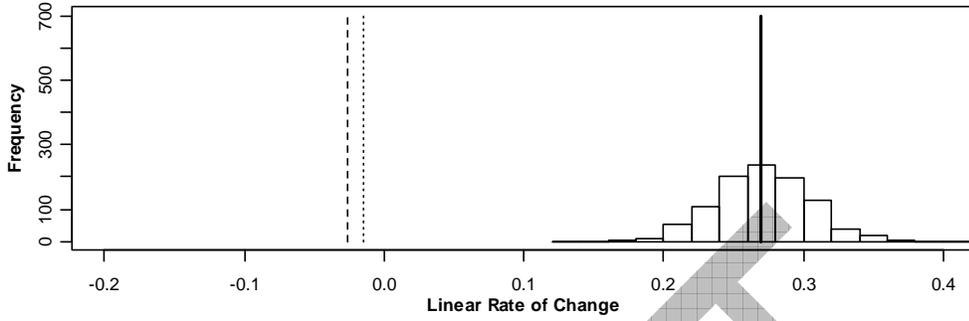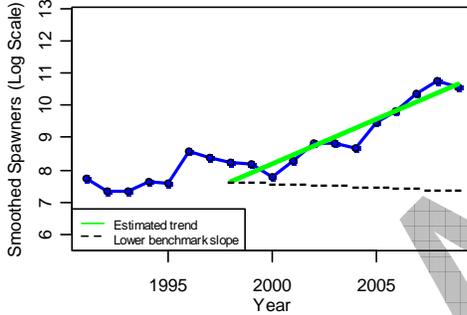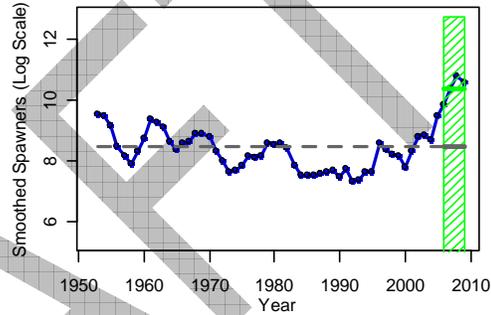
d.

Uniform 'b' prior: 0-800,000
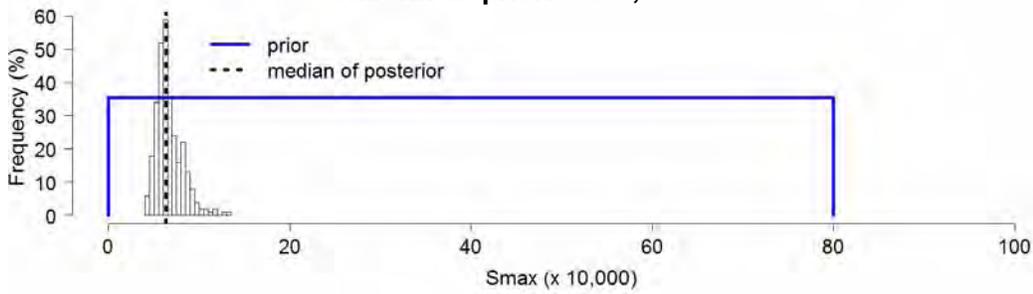
e.

Ricker (1950-2005)
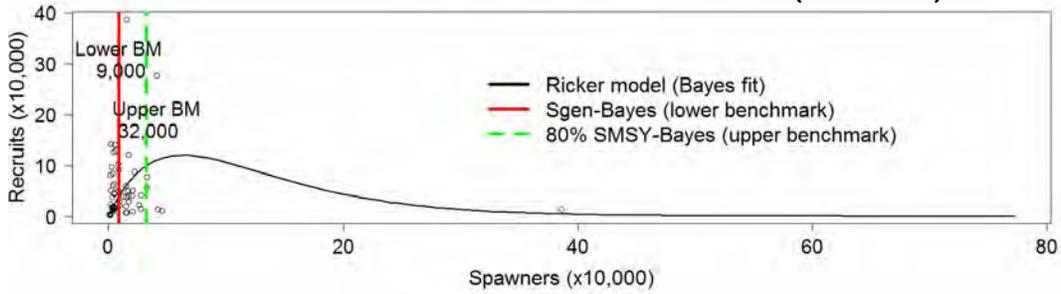
Nahatlatch-ES

1b.
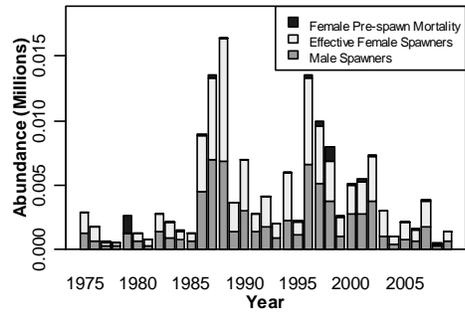
Only escapement data is available for Nahatlach-ES.

2a.
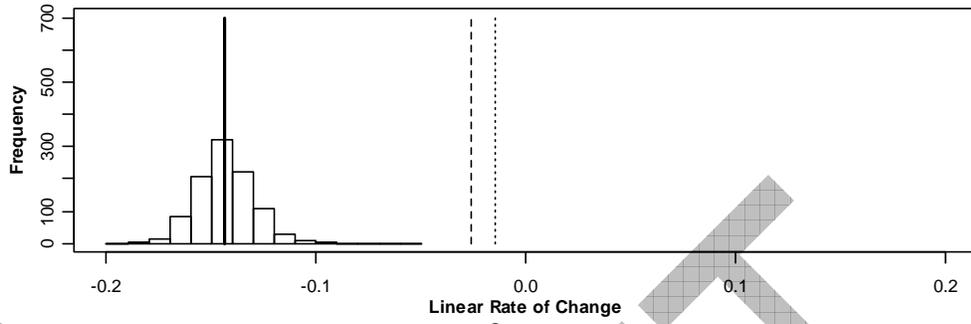
b.
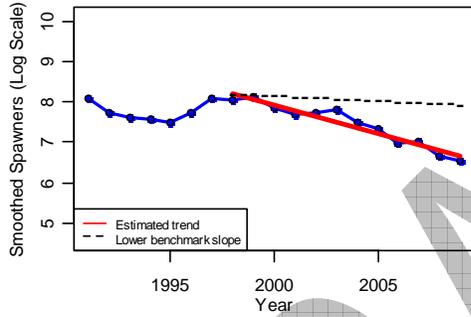
c.
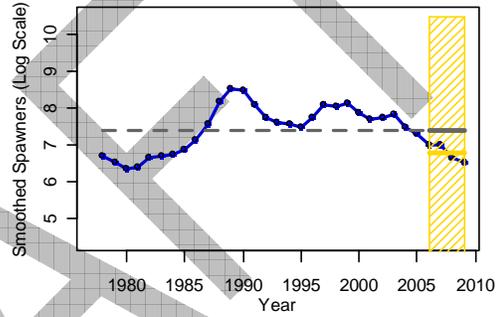
d.

No stock-recruitment data to calculate abundance based benchmarks

e.

No stock-recruitment data to calculate abundance based benchmarks

Pitt-ES
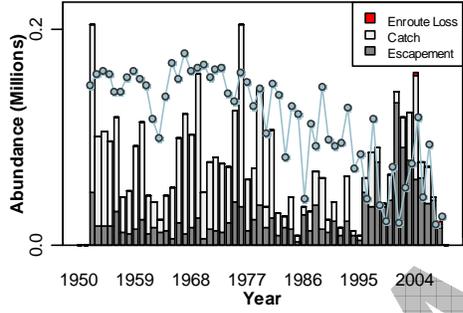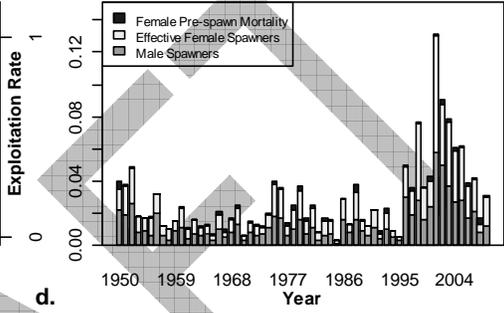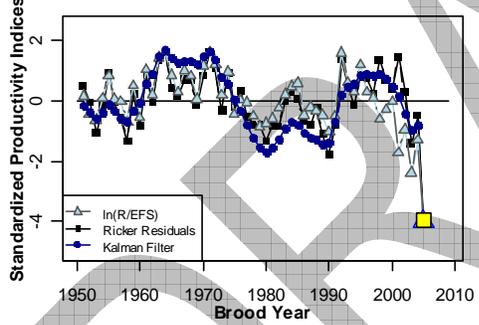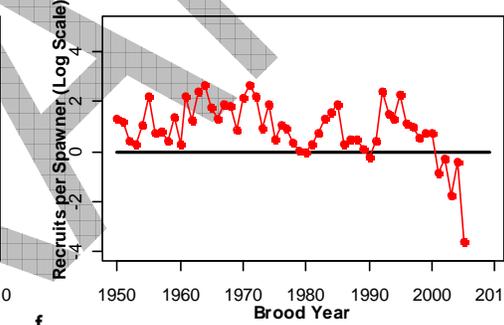
No freshwater survival data available   No marine survival data available

2a.
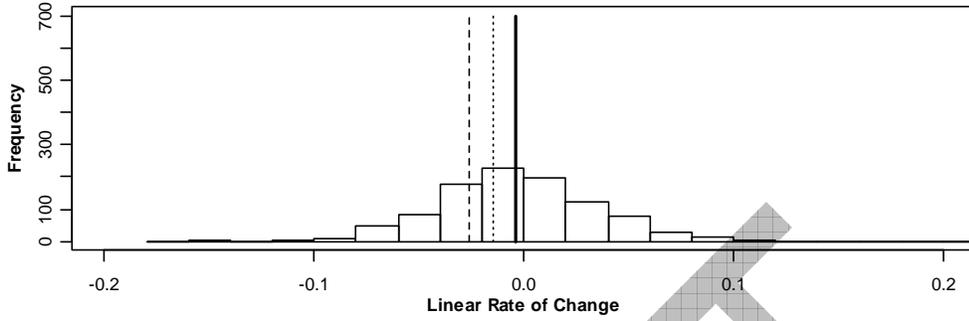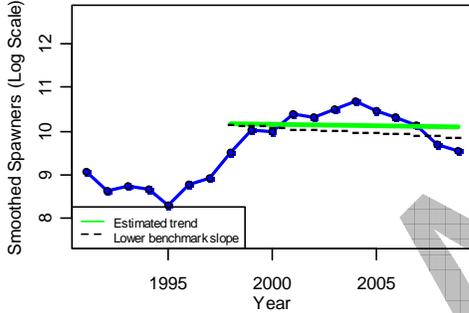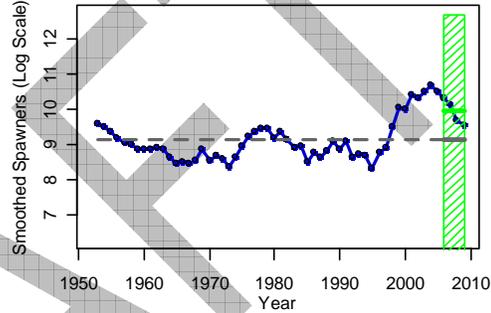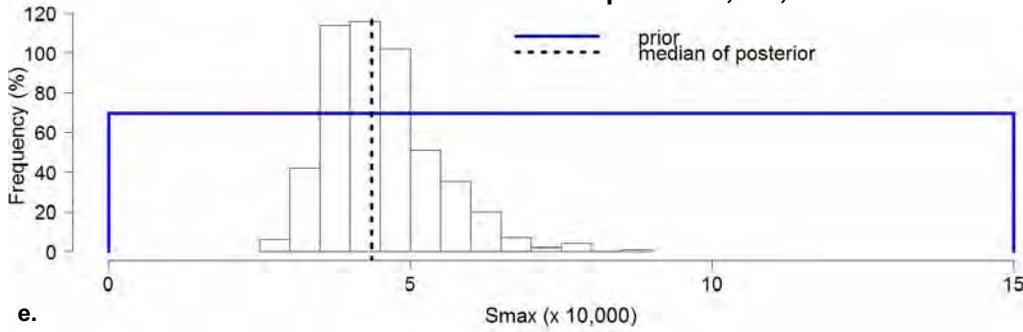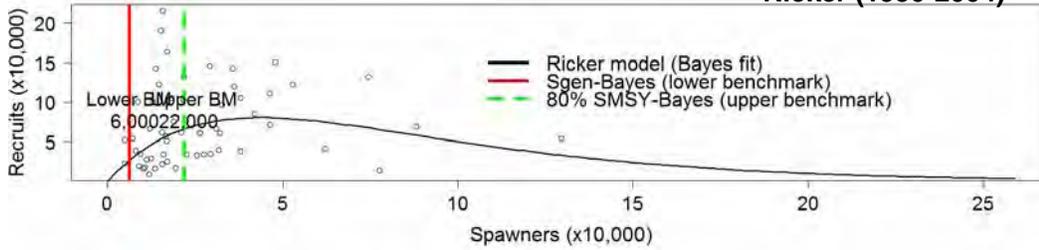
Quesnel-S and McKinley-S Aggregate

2a.

b.

c.
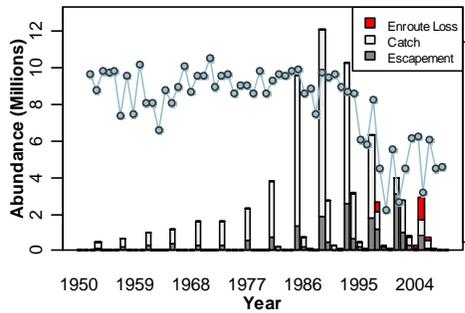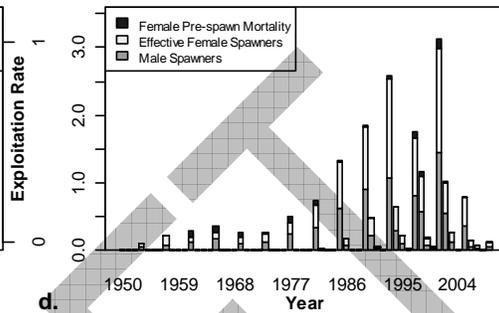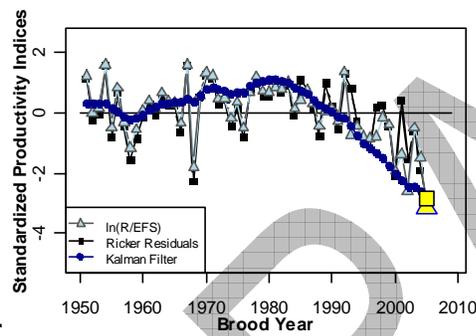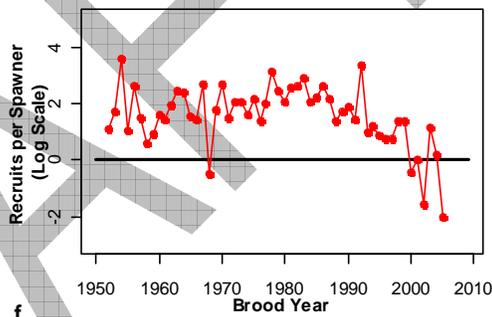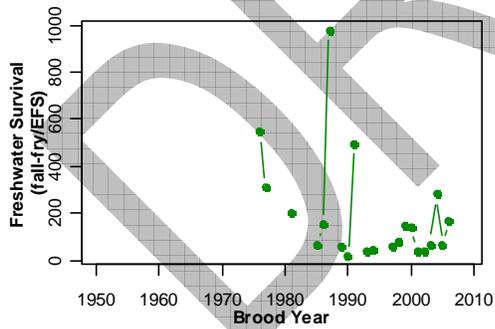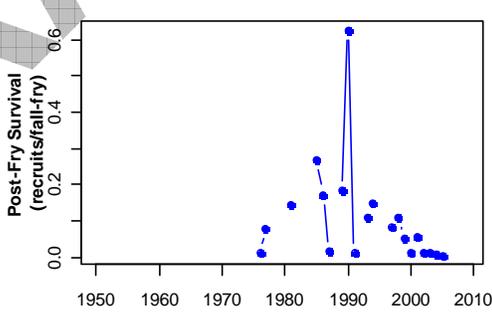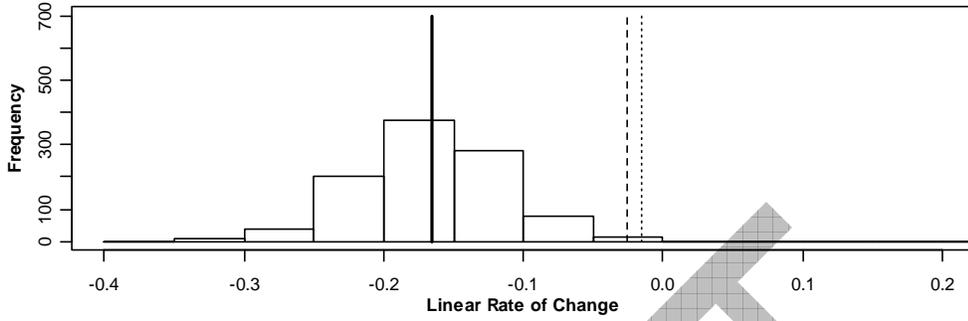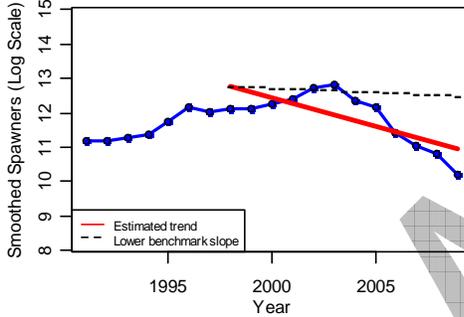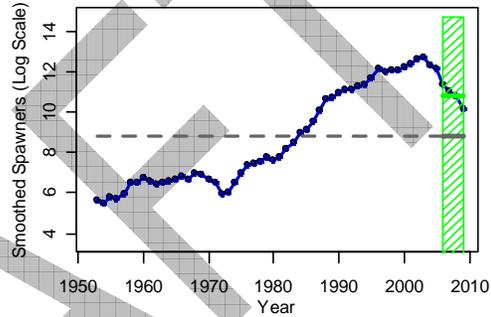
d. **Lognormal 'b' prior: 1,000,000 (log$_e$ sigma: 0.2)**
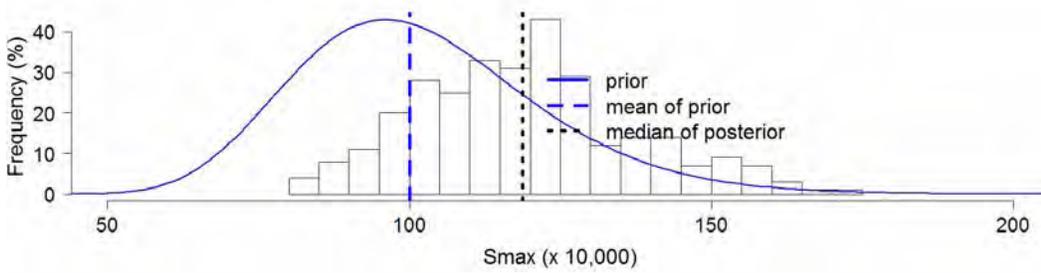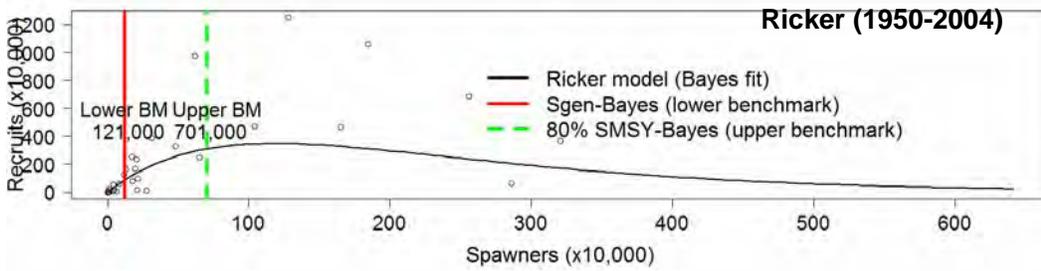
e.

Seton-L

1a.
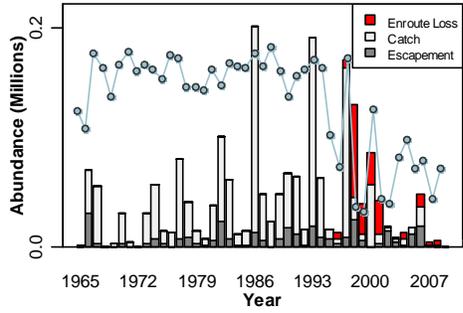
b.
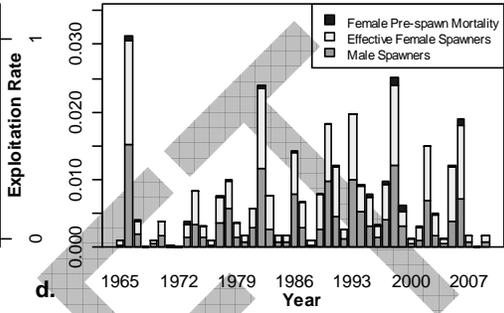
c.
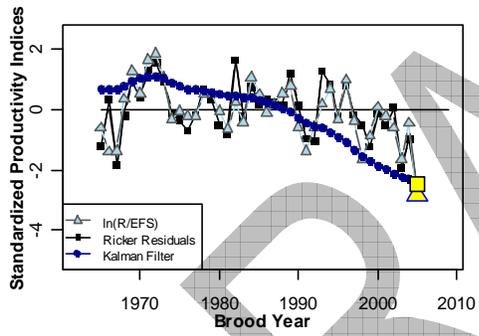
d.
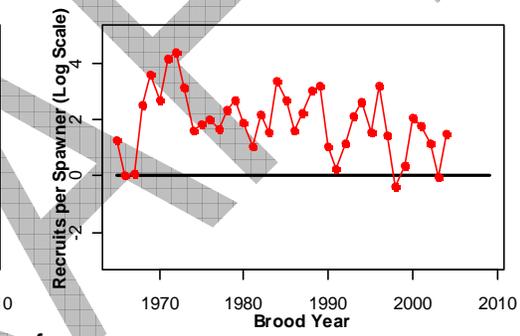
e.

No freshwater survival data available

f.

No marine survival data available

2a.

b.

c.

d.

Uniform 'b' prior: 0-300,000

e.

Ricker (1965-2004)
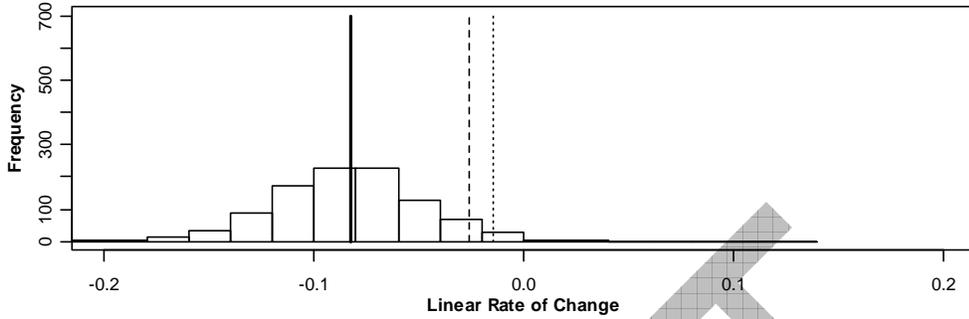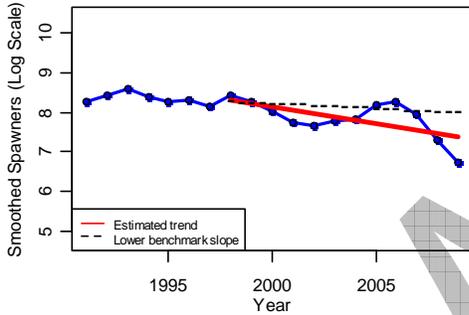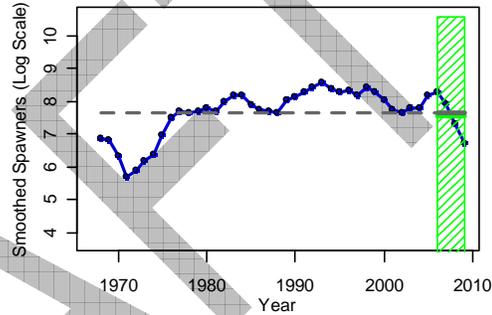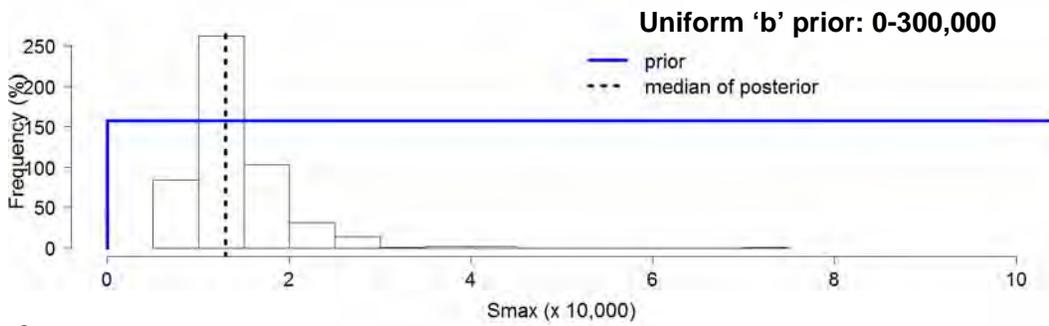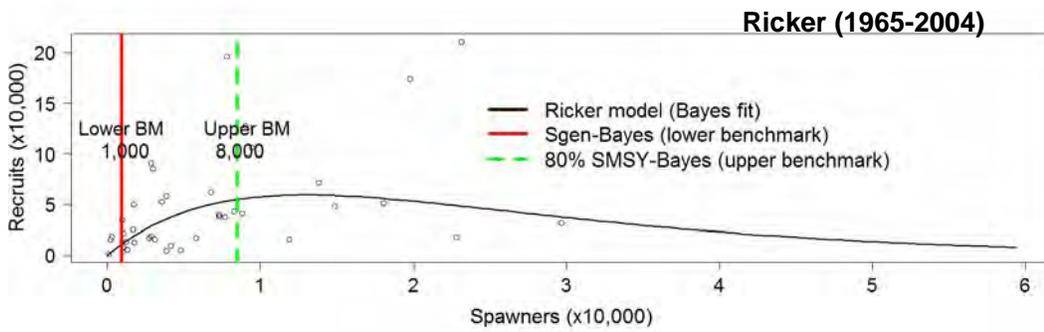
Shuswap-ES

1a.

b.

c.

d.

e.

No freshwater survival data available

f.

No marine survival data available

2a.

b.

c.

d.

Uniform 'b' prior: 0-2,000,000

e.

Ricker (1980-2004)

Shuswap-L

1a.

b.

c.

d.

e.

f.

2a.

b.

c.

d.
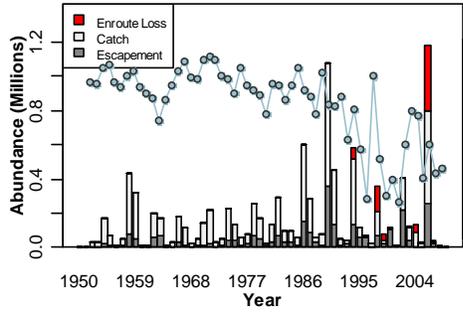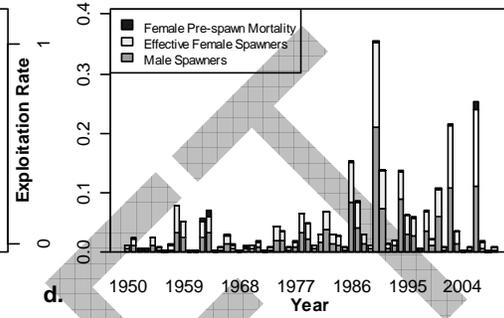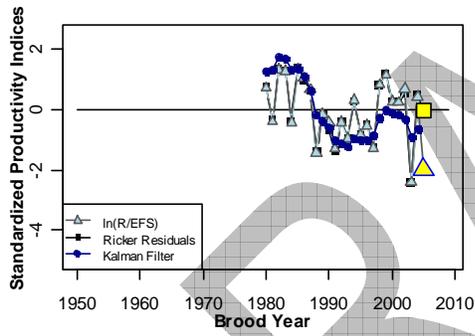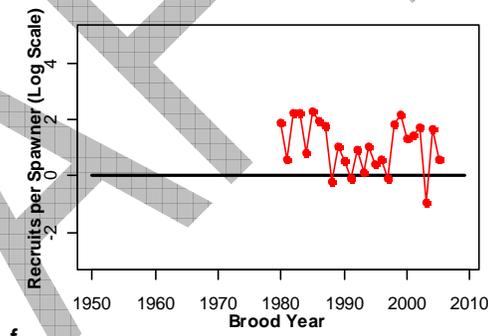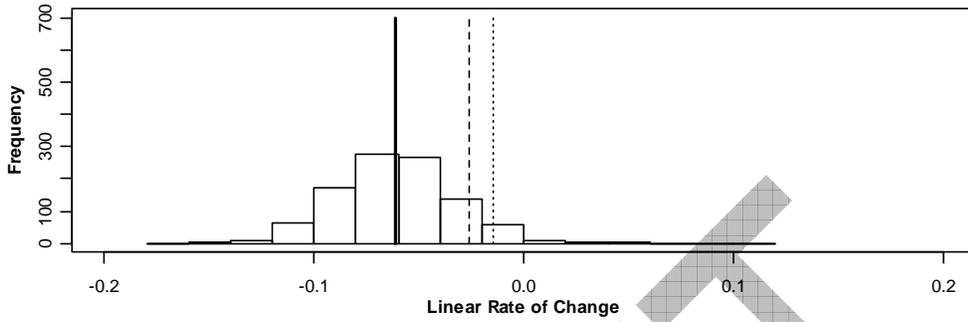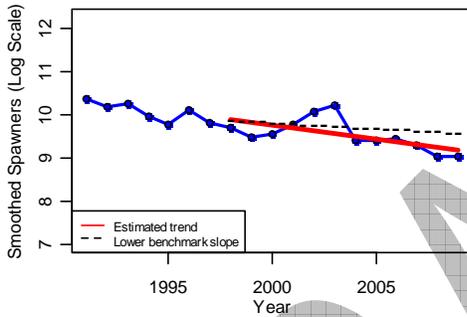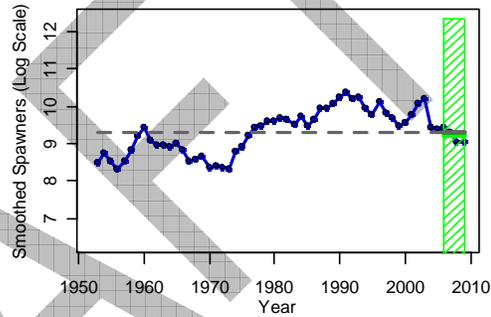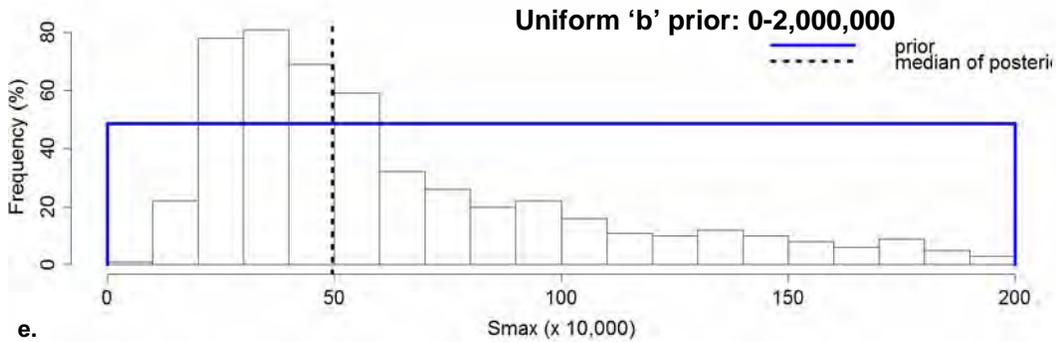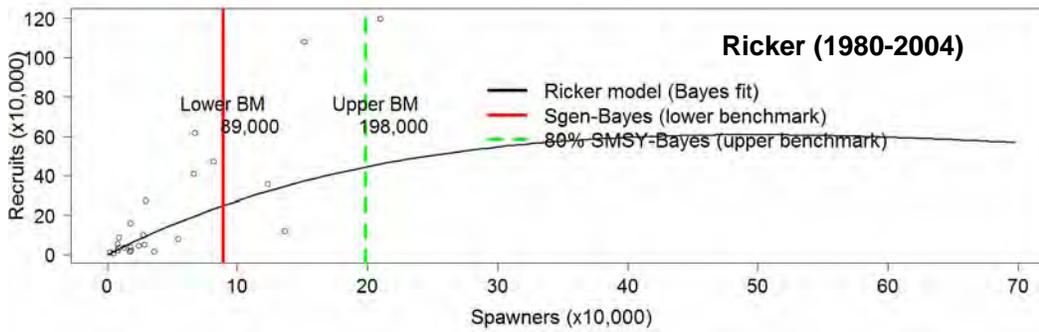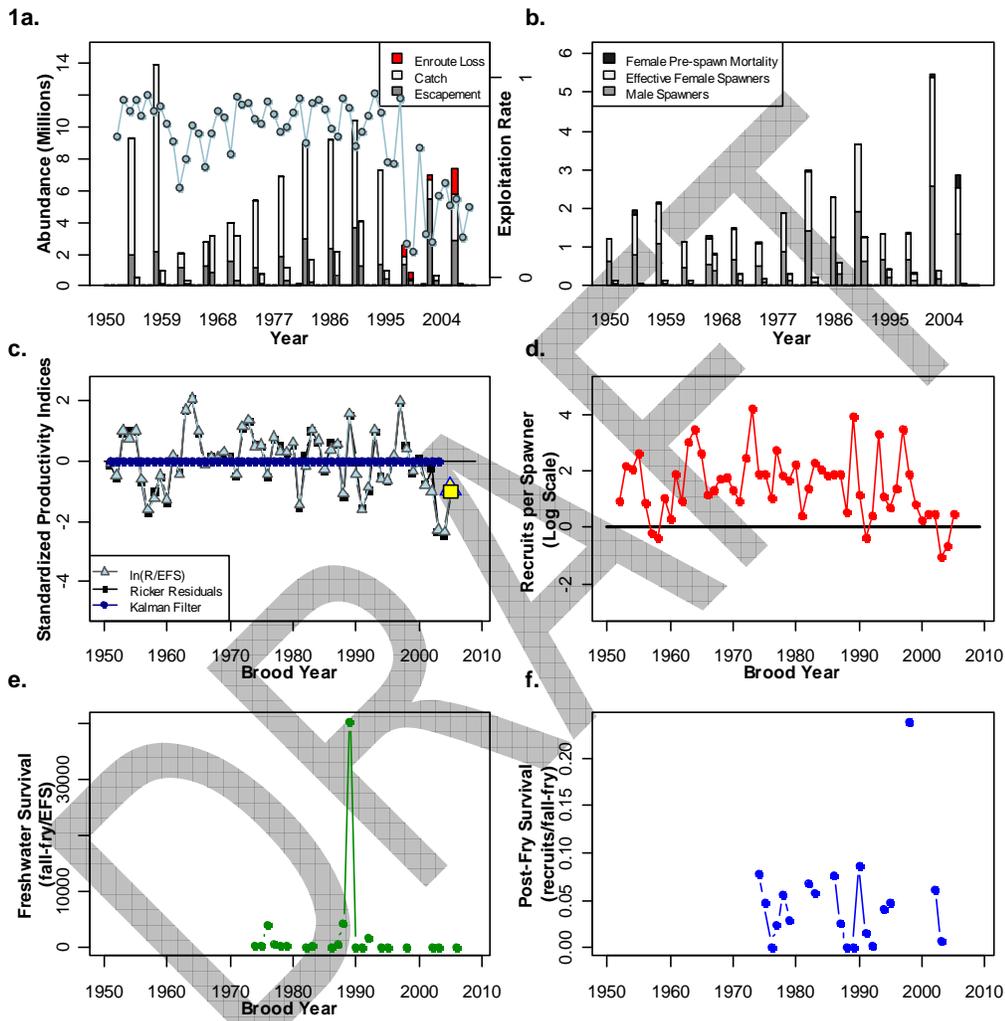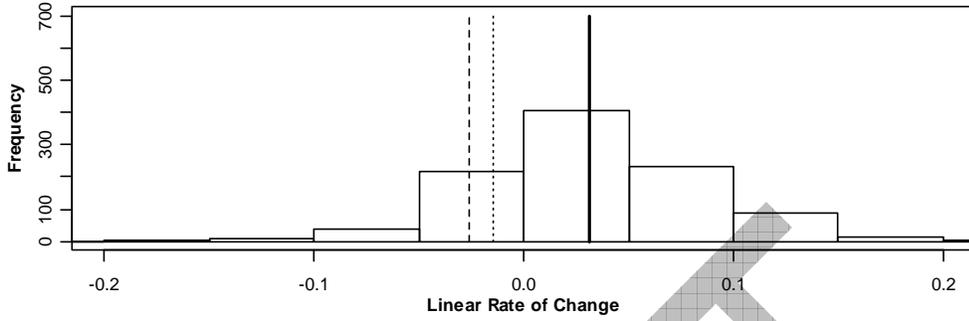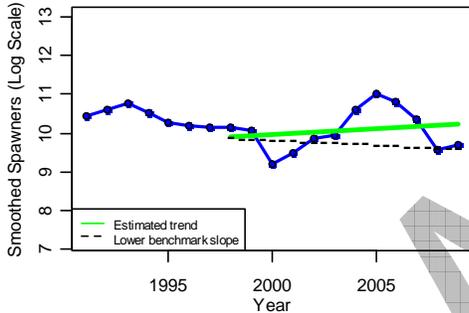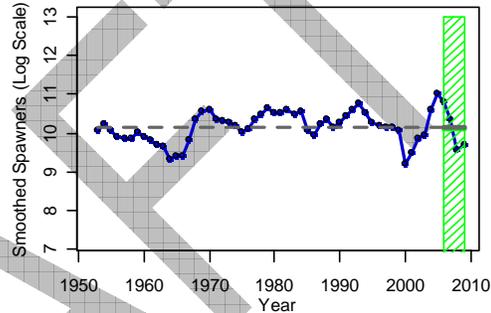
Lognormal 'b' prior: 1,500,000 (log$_e$sigma: 0.4)
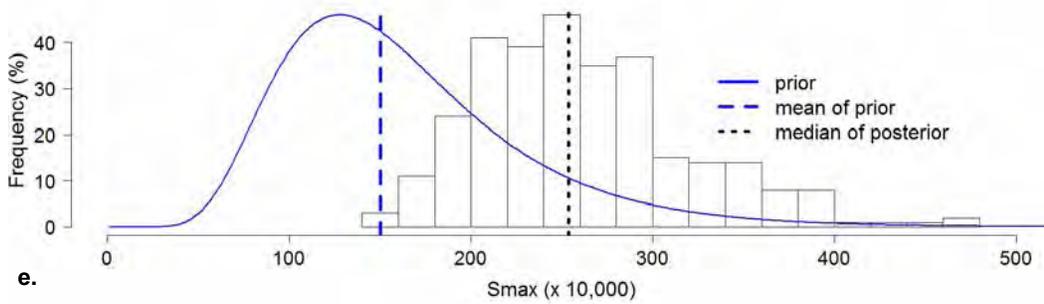
e.
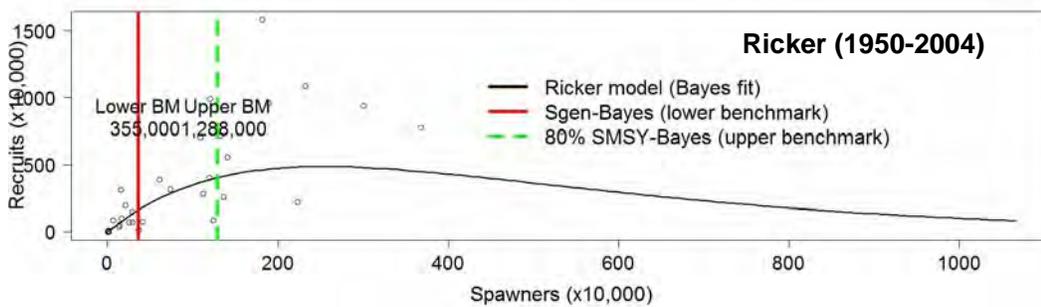
Stuart-S

1a.
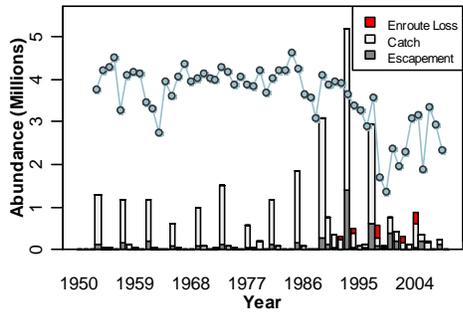
b.
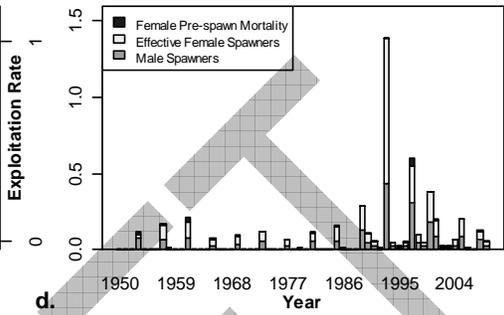
c.
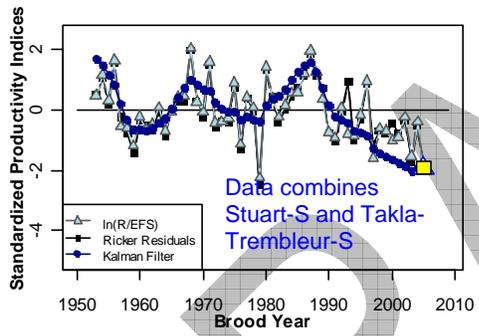
Data combines Stuart-S and Takla-Trembleur-S
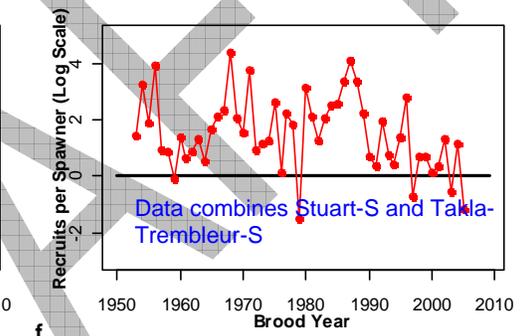
d.

Data combines Stuart-S and Takla-Trembleur-S

e.

No freshwater survival data available

f.

No marine survival data available

2a.

b.

c.

d.

Lognormal 'b' prior: 1,400,000 ($\log_e$ sigma: 0.5)

e.
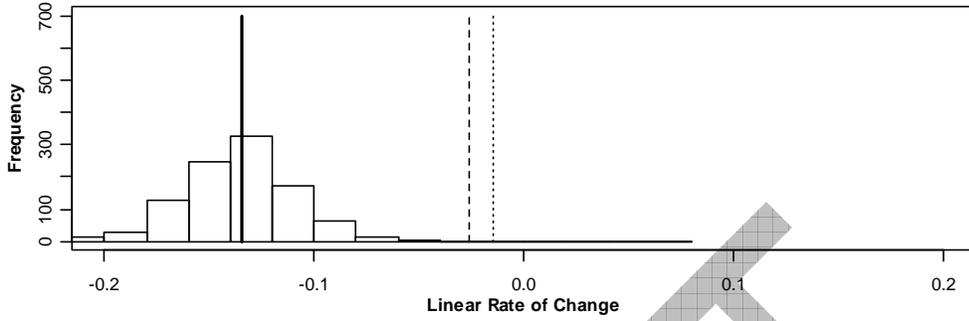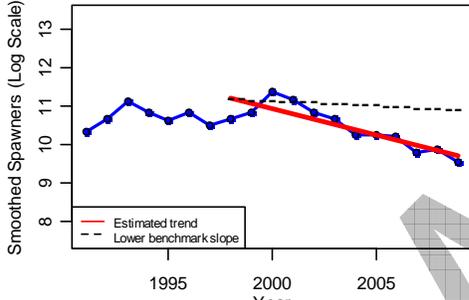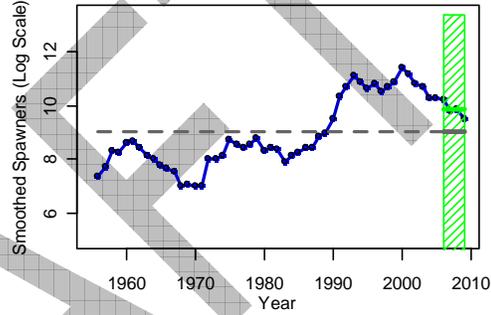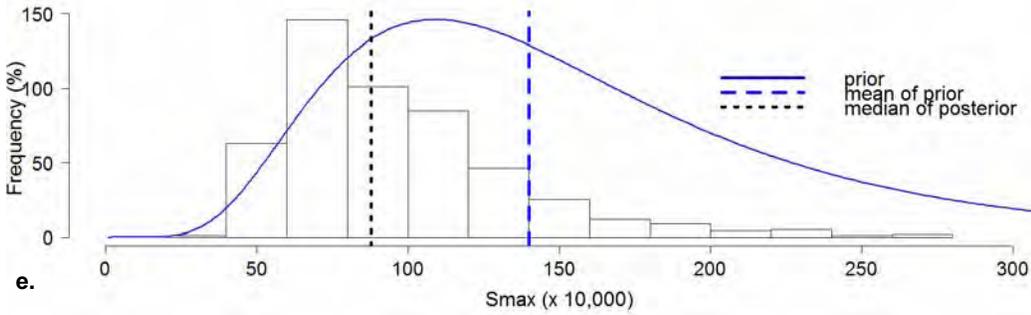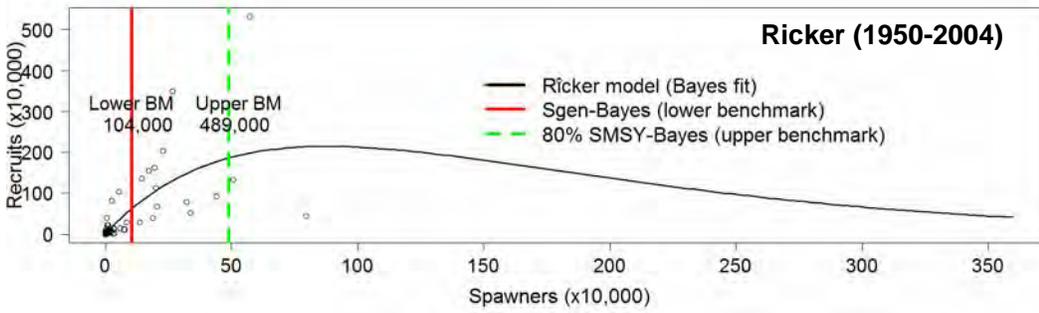
Data Combined with Takla-Trembelur-S

Takla-Trembleur-S

1a.
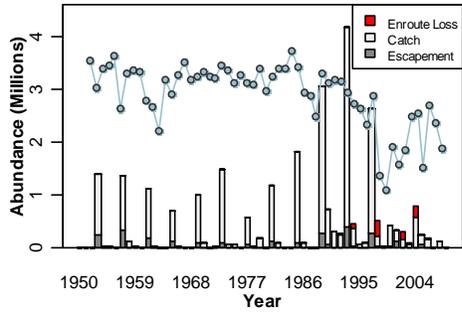
b.
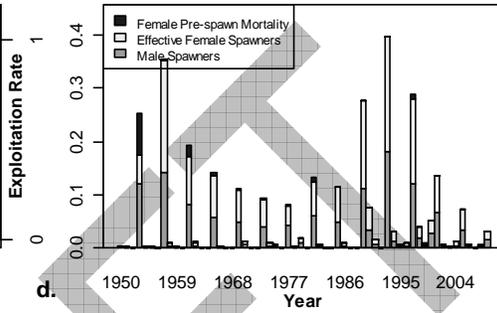
c.
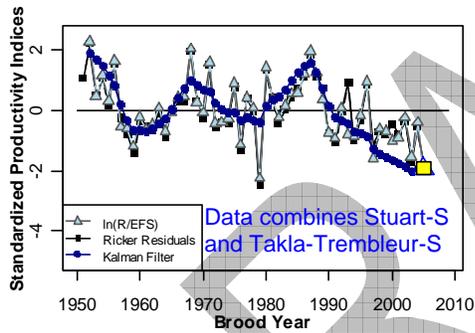
Data combines Stuart-S and Takla-Trembleur-S
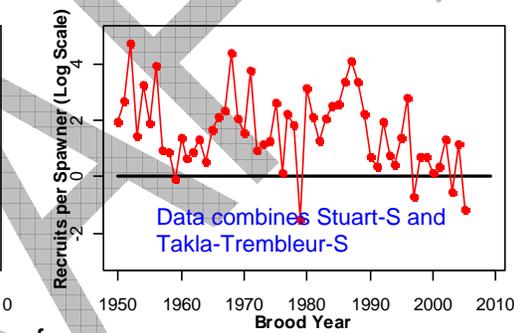
d.

Data combines Stuart-S and Takla-Trembleur-S

e.

No freshwater survival data available

f.

No marine survival data available

2a.

d.

Lognormal 'b' prior: 1,400,000 ($\log_e$ sigma: 0.5)

e.
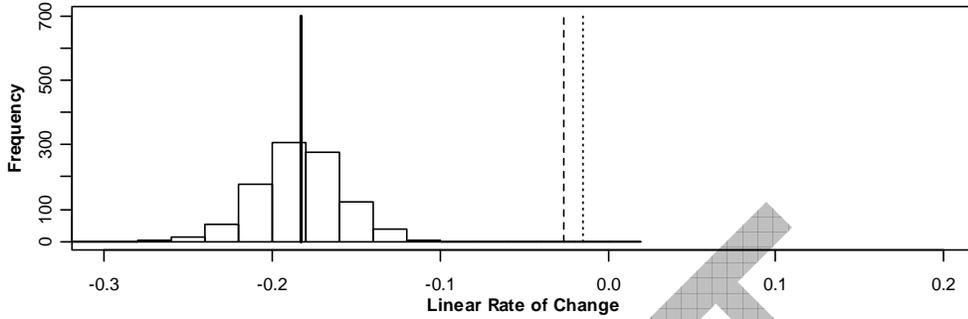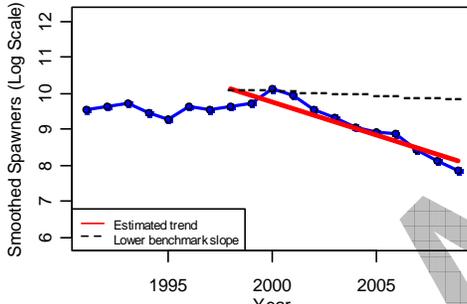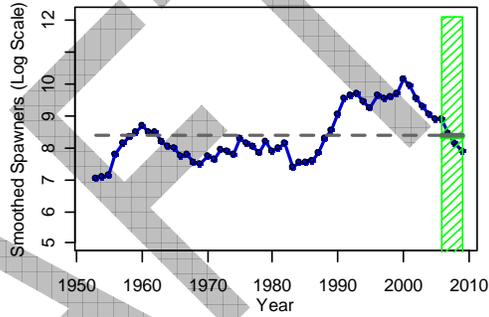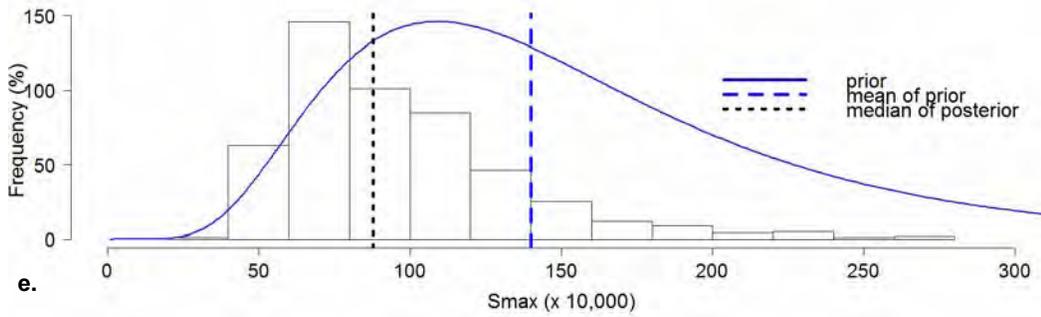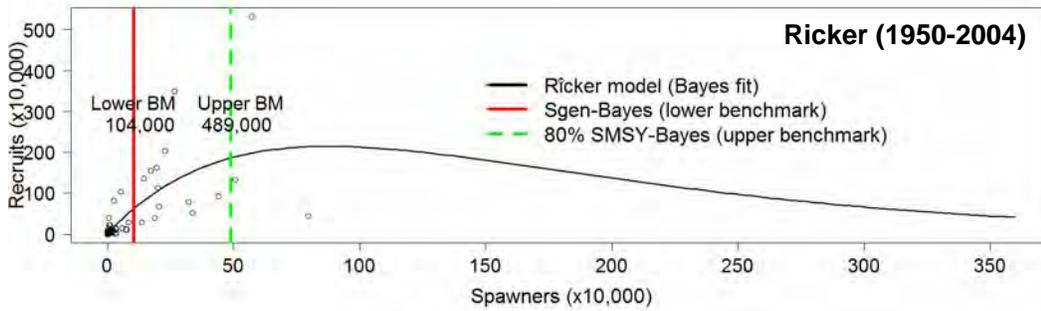
Data Combined with Stuart-S

Takla-Trembleur-Early Stuart (EStu)

2a.


b.

c.

d.
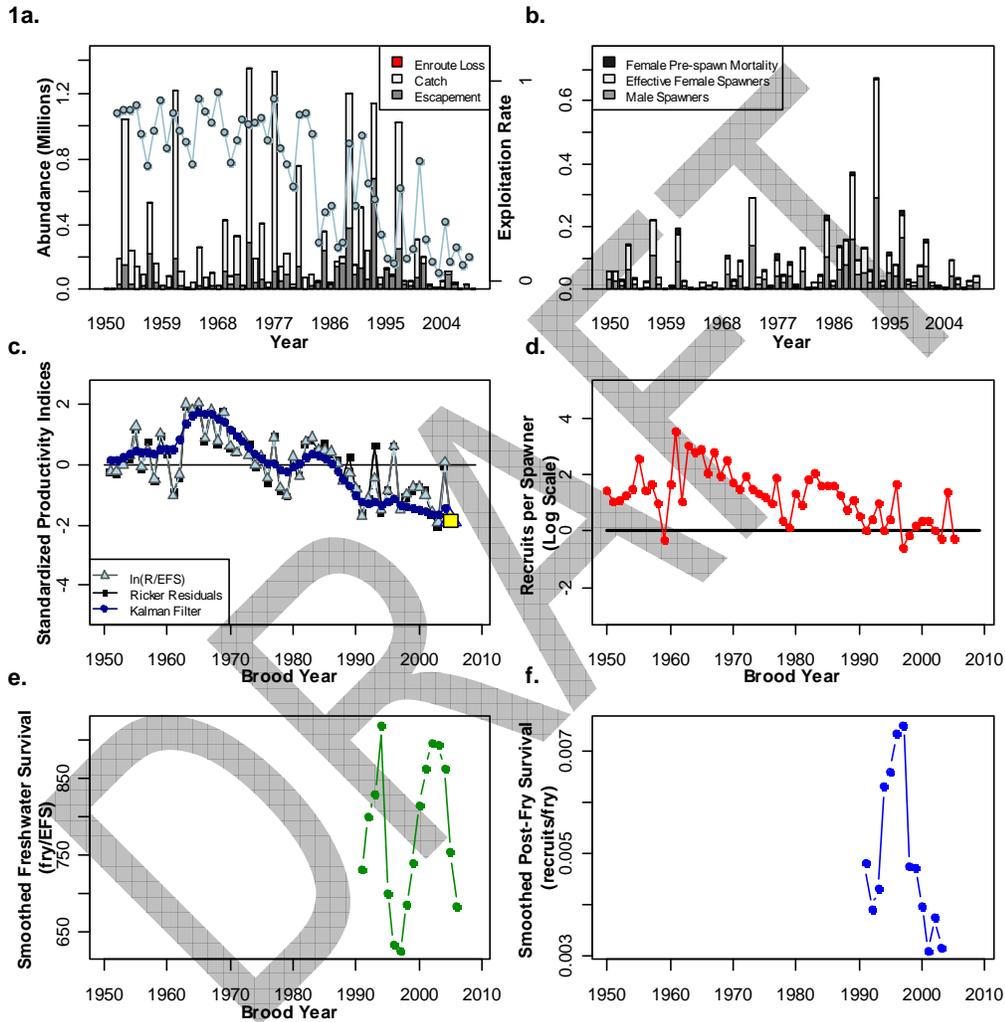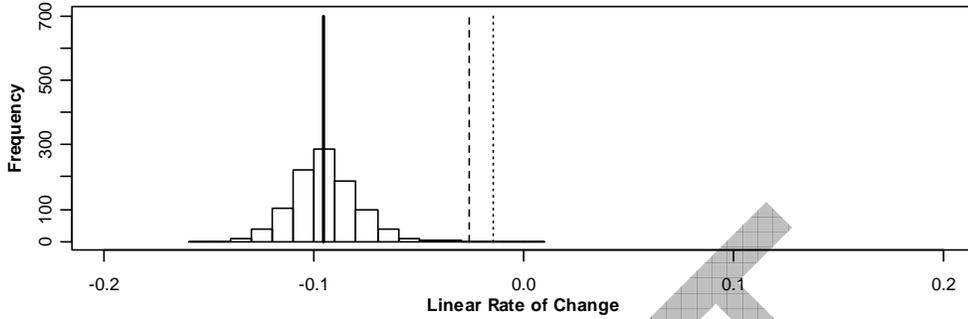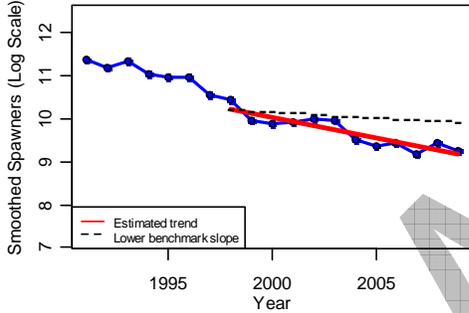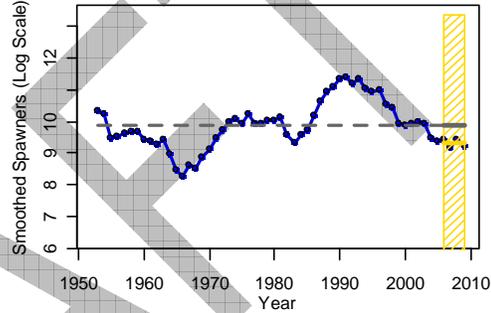
Lognormal 'b' prior: 600,000 ($\log_e$ sigma: 0.4)
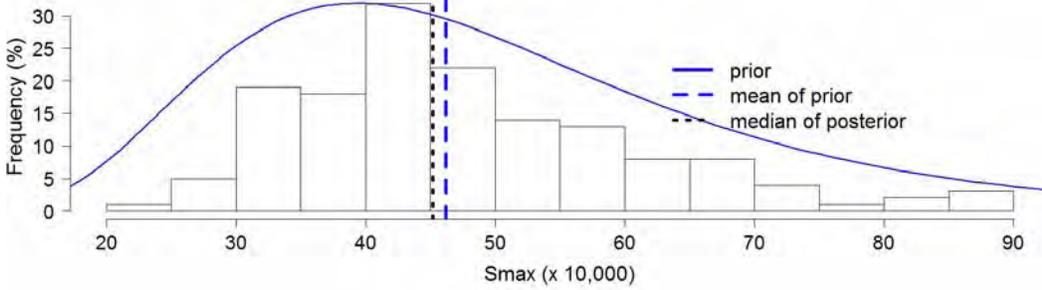
e.

Ricker (1950-2004)
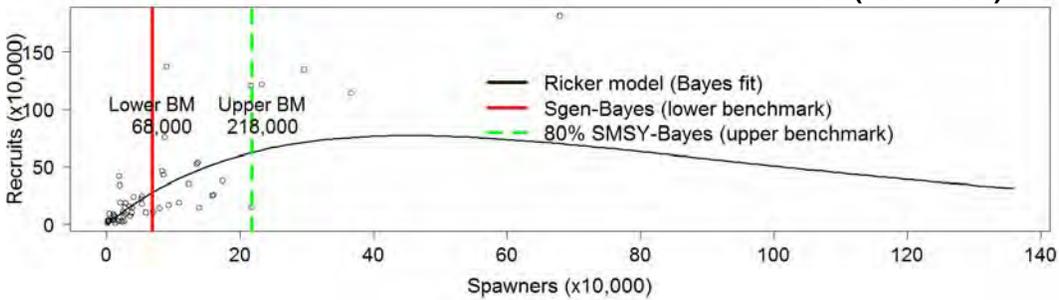
Taseko-ES

1b.
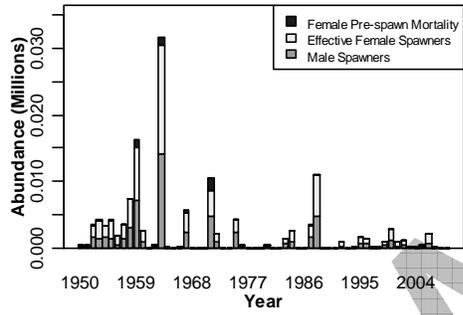
Only escapement data is available for Taseko-ES.

2a.
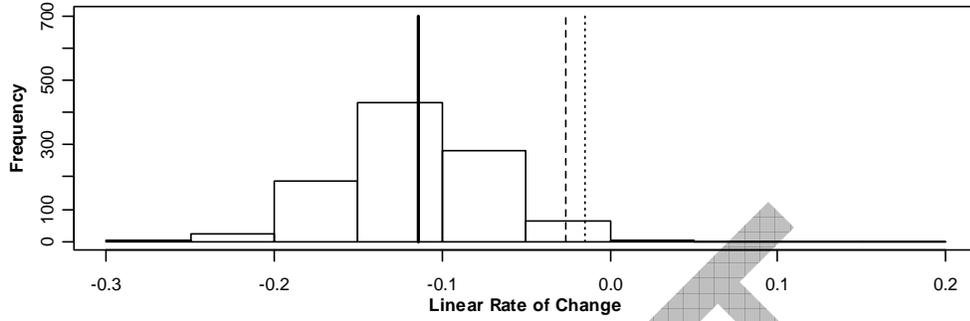
b.
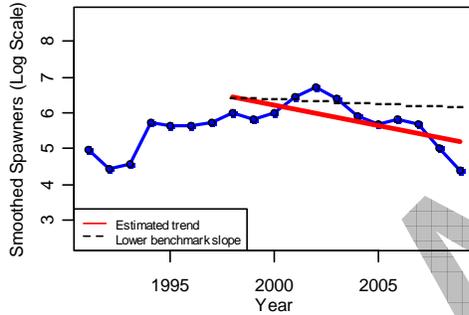
c.
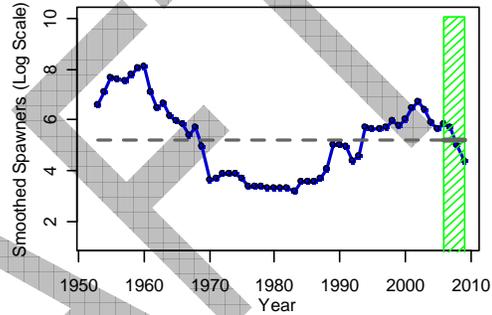
d.

No stock-recruitment data to calculate abundance based benchmarks

e.

No stock-recruitment data to calculate abundance based benchmarks

Widgeon-(River-Type)

1b.
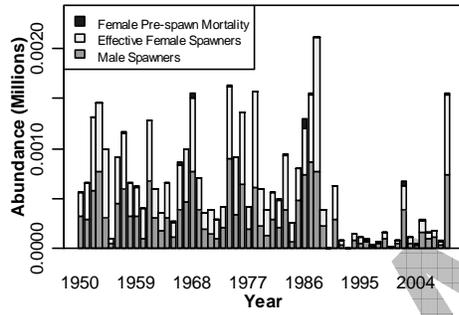
Only escapement data is available for Widgeon (River-Type).

2a.
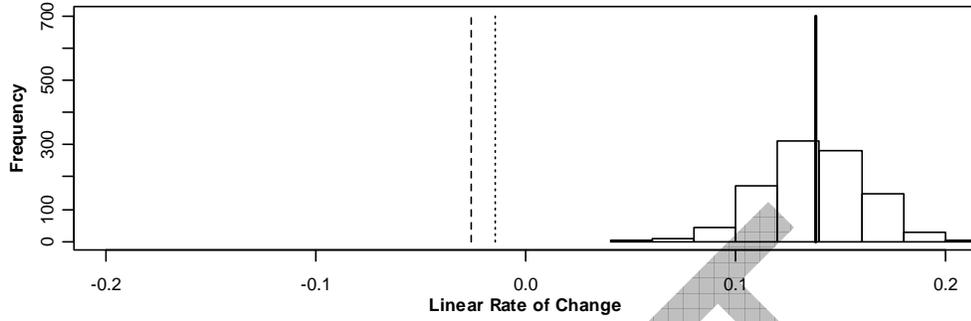
b.
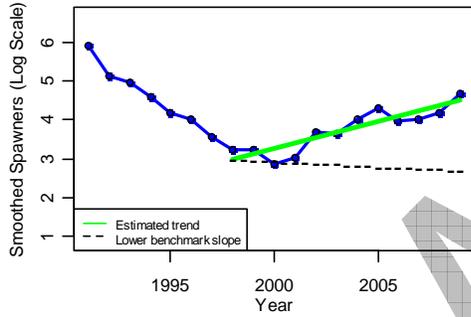
c.
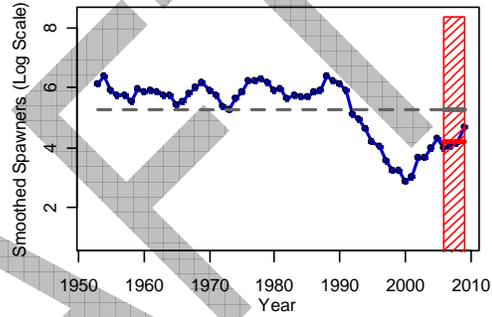
d.

No stock-recruitment data to calculate abundance based benchmarks

e.

No stock-recruitment data to calculate abundance based benchmarks

APPENDIX 4: Update spawning capacity based on lake rearing…

Table A. Summary of trawl catch for each survey used to estimate competitor biomass for the PR model. Empty cells indicate that the competitor was not caught in the trawl survey.

| Lake	Year	Survey	DNA/ otolith	Age-0 nerka	Age-1 nerka	Age-2+ nerka	Age-0 other	Other large fish
Adams	1997	199714	y	160				
Adams	1998	199811	y	275				
Anderson	2000	200010	y	496	27	1	1	1
Anderson	2001	200107	n	337	24			
Anderson	2002	200209	n	95	9	1		1
Anderson	2003	200308	n	150	34	8		
Bowron	2004	200406	n	134		1	2	
Chilliwack	2001	200110	n	509	5	3		
Chilliwack	2002	200212	y	10	3	1		
Chilliwack	2009	200905	y	94	2			
Cultus	2001	200109	n	2		1	7	
Cultus	2002	200211	n				6	
Cultus	2009	200901	n		56	1	53	1
Fraser	1992	199205	n	152	1		4	
Harrison	1999	199910	n	324			2,737	1
Lillooet	2000	200011	n	60	1		7	1
Quesnel	1987	198703	n	323	13	3		
Quesnel	1988	198808	n	17	2	3		
Quesnel	1994	199404	n	684		2		
Quesnel	2003	200306	n	1,252	7	1		
Quesnel	2004	200407	n	637	1			
Seton	2000	200008	y	40	3	60		
Seton	2001	200108	n	146	1	2	1	
Seton	2002	200208	n	230	18			
Shuswap	1987	198702	n	2,780	1		1	1
Shuswap	1988	198814	n	1,124	56	14	1	
Shuswap	1989	198914	n	160		2		
Shuswap	1990	199019	n	1,111	16	6	5	
Shuswap	1991	199117	n			1		
Stuart	1996	199607	y	489		22		
Stuart	1997	199709	y	443			8	
Stuart	1998	199808	y	189		11	6	
Takla	1996	199605	y	292	16	19		1
Takla	1997	199710	y	230	21	2		
Takla	1998	199809	y	657	5	1	4	
Trembleur	1996	199606	y	226		2	2	
Trembleur	1997	199712	y	238			2	
Trembleur	1998	199805	y	861				

Table B. Biomass estimates (kg/lake) by competitor category for each survey used to estimate competitor biomass for the PR model. Note that n/a indicates some unknown quantity of competitor biomass that we were unable to estimate from the trawl and acoustic data.

Lake	Year	Survey	Age-0 kokanee	Age-1 kokanee	Age-2+ kokanee	Other age-0	Total biomass
Adams	1997	199714	3,235	0	0	0	3,235
Adams	1998	199811	694	0	0	0	694
Anderson	2000	200010	1,421	416	9,543	0	11,381
Anderson	2001	200107	n/a	431	0	0	431
Anderson	2002	200209	n/a	653	6,248	0	6,901
Anderson	2003	200308	n/a	1,120	45,536	0	46,656
Bowron	2004	200406	n/a	n/a	n/a	9	9
Chilliwack	2001	200110	n/a	n/a	10,402	n/a	10,402
Chilliwack	2002	200212	730	n/a	1,048	n/a	1,777
Chilliwack	2009	200905	1,502	n/a	n/a	0	1,502
Cultus	2001	200109	n/a	0	n/a	113	113
Cultus	2002	200211	n/a	0	0	562	562
Cultus	2009	200901	n/a	n/a	0	190	190
Fraser	1992	199205	n/a	3,829	0	n/a	3,829
Harrison	1999	199910	n/a	0	0	30,376	30,376
Lillooet	2000	200011	n/a	34	0	0	34
Quesnel	1987	198703	n/a	39,592	n/a	0	39,592
Quesnel	1988	198808	n/a	26,144	n/a	0	26,144
Quesnel	1994	199404	n/a	0	n/a	n/a	0
Quesnel	2003	200306	n/a	n/a	45,931	0	45,931
Quesnel	2004	200407	n/a	188	0	0	188
Seton	2000	200008	675	1,288	12,113	0	14,075
Seton	2001	200108	n/a	n/a	27,611	0	27,611
Seton	2002	200208	n/a	3,854	0	0	3,854
Shuswap	1987	198702	n/a	4,448	0	0	4,448
Shuswap	1988	198814	n/a	82,527	n/a	0	82,527
Shuswap	1989	198914	n/a	9,558	n/a	n/a	9,558
Shuswap	1990	199019	n/a	n/a	n/a	0	0
Shuswap	1991	199117	n/a	0	n/a	0	0
Stuart	1996	199607	24,307	0	90,419	0	114,726
Stuart	1997	199709	42,288	0	0	907	43,195
Stuart	1998	199808	19,086	0	n/a	808	19,894
Takla	1996	199605	6,723	5,582	52,177	0	64,483
Takla	1997	199710	5,771	13,436	81,814	0	101,022
Takla	1998	199809	6,178	1,441	134,714	23	142,357
Trembleur	1996	199606	11,926	0	n/a	31	11,957
Trembleur	1997	199712	3,830	0	0	8	3,838
Trembleur	1998	199805	202	0	0	0	202

Table C. Preliminary mean PR model estimates of the productive capacity of Fraser River Sockeye re... based on monthly sampling of May-October growing season for 1 or more years, with the exception of ... presence of age-2 smolts has been accounted for in Chilko and Cultus lakes only. (*) indicates lakes f... biomass was extrapolated from similar lakes. Escapement is in total adult spawners.

Lake	Comment	Mean seasonal PR (mg C /m²)	PR_{total} (t C/lake)	Unadjusted PR model predictions Smolt biomass (kg) (R_{max})	Smolt #'s	Escapement (S_{max})	Prop. of PR_{total} used by competitor biomass	Adjuste Smolt biomass (kg) (R_{max})
Adams	Probably affected by fertilization	115	2659	120,970	26,882,310	497,175	6%	113,712
Anderson	Mean all years	303	1527	69,484	15,440,880	285,571	37%	43,775
Bowron	2004 only	131	219	9,947	2,210,536	40,883	0%	9,947
Chilko*	Fertilized Mean	103	3396	154,539	34,341,944	635,137	0%	154,539
Chilko*	Natural mean ?1995	69	2295	104,432	23,207,184	429,205	0%	104,432
Chilko*	2009 natural	121	4020	182,922	40,649,286	751,788	0%	182,922
Chilliwack	3 year mean	101	218	9,926	2,205,840	40,796	37%	6,254
Cultus	3 year mean	404	457	20,779	4,617,558	85,399	6%	19,532
Francois*	2 year mean	163	7247	329,738	73,275,020	1,355,185	0%	329,738
Fraser	2 year mean	332	3227	146,830	32,628,960	603,456	6%	138,021
Harrison	2 year mean	109	4336	197,289	43,841,980	810,836	37%	124,292
Kamloops*	2007	257	2378	108,188	24,041,836	444,642	0%	108,188
Lillooet	2000	163	880	40,022	8,893,783	164,486	0%	40,022
Mabel*	2 year mean	203	2160	98,285	21,841,092	403,940	6%	92,388
Pitt*	Jul, Oct 1989 & Mar 1990	72	617	28,056	6,234,608	115,306	37%	17,675
Quesnel	Mean all 10 years	125	6075	276,413	61,425,000	1,136,025	6%	259,828
Quesnel	Pre- 1995 mean (5 yrs)	104	5054	229,975	51,105,600	945,173	6%	216,177
Quesnel	Post 2003 mean (5 yrs)	130	6318	287,469	63,882,000	1,181,466	6%	270,221
Seton	4 year mean	233	1007	45,798	10,177,440	188,227	37%	28,853
Shuswap	6 year mean	171	10159	462,252	102,722,620	1,899,804	6%	434,517
Stuart	3 year mean	137	8899	404,914	89,980,800	1,664,150	37%	255,096
Takla	3 year mean	56	2475	112,624	25,027,475	462,871	37%	70,953
Trembleur	3 year mean	84	1769	80,491	17,886,960	330,810	6%	75,662

APPENDIX 5: Methodology used for gap filling CU time series data where required.

Cycle-Line Average Method

Application: CU's with only one site or with no abundance estimates for any sites in a given year.

Method: Missing values were interpolated using the average of the escapement estimates for the previous and subsequent generation on that cycle. Where the previous and subsequent estimates are not available, the average of up to two generations away from the gap is used; if no data are available within two generations the gap is assumed to equal zero (usually systems are not assessed when abundance is assumed negligible) or the years are not included in the time series (in most cases large gaps occur in the early time series). Interpolation was conducted prior to log transformation and smoothing with the generational mean.

Example: **Lillooet-L**
Birkenhead was gap filled for the 2002 estimate. No other sites were used in the analysis, therefore the cycle average had to be used. The gap was filled using the average of the previous generation (1998 EFS estimate: 172,997) and the subsequent generation (2006 EFS estimate: 137,365), giving a gap-filled estimate of 155,181 EFS.

Usage: Kamloops-L, Lillooet-L, Taseko-ES, Widgeon Stream Type

Mean Proportion Method

Application: CU's with multiple streams

Method: This method of gap filling is based on the assumption of spatial correlation between sites. The method uses trends in the escapement time series' of spatially related stream aggregates to interpolate missing values for individual streams within that aggregate. We used each CU as an aggregate, assuming that trends in escapement were consistent across streams in a CU. One exception to this was the very large Takla-Trembleur-EStu CU, in which individual sites and groups of sites showed very different trends. For this CU we grouped sites into six separate aggregates based on location and correlation in abundance trends.
This method calculates the mean abundance of each stream across the years of available data, including only years for which all streams in the aggregate had recorded data. This was to account for possible changes in the escapement trend in years in which streams had missing data, ensuring that the proportion calculations were representative.

$$\overline{E}_s = \frac{\sum_{y=1}^{Y} E_{sy}}{Y_s}$$, where $\overline{E}_s$ is the mean escapement for stock *s, E_{sy}* is recorded escapement for

each stock (*s*), *y* = years with escapement data for all streams, Y_s = total number of years with escapement data for all stocks. The proportion that each stock contributes to the aggregate

over the course of the time series is calculated as: $P_s = \frac{\overline{E}_s}{\sum_{s=1}^{S} \overline{E}_s}$, where P_s is the portion of the

stock aggregate that is contributed by stock *s* and *S* = the total number of stocks in aggregate *a*. Expansion factors are then calculated for each year of aggregate data in order to expand the

aggregate to account for missing stocks in each year, $F_y = \dfrac{1}{\sum\limits_{s=1}^{S} P_{sy}}$, where F_y is the expansion

factor for each year in an aggregate and P_{sy} is the proportion contributed for each stream in that year (missing values will = 0). Finally, the new aggregate sum for each year is calculated as the product of the expansion factor and the sum of the recorded escapement data across streams:

$E_y^{'} = F_y * \sum\limits_{s=1}^{S} E_{sy}$, where $E_y^{'}$ is the expanded aggregate, and E_{sy} is the recorded escapement

of each stream in that year.

Example: Nahatlatch-ES had missing data for the Nahatlatch Lake site in 1975, 1976, and 1978. The average escapements for both Nahatlatch Lake and River were calculated excluding these years from the dataset, resulting in proportional contributions of 0.25 and 0.75, respectively, to the Nahatlatch CU. [When the entire dataset is used, the proportions are 0.26 and 0.74, because the low escapements to Nahatlatch River in 1975, 1976 and 1978 are included in the average, while the Nahatlatch Lake average is not being pulled down by these low years.]

Usage: Nahatlatch-ES, Shuswap-ES, Stuart-S, Takla-Trembleur-S

Mean Proportion Method- Cyclic (Dominant/Sub-dominant or all cycles)

Application: In highly cyclical CU's, where the dominant and (in some cases) sub-dominant cycles are highly different from both each other and the off-cycle years in term of abundance.

Method: We found that in highly cyclic stocks, the proportional contribution of individual sites tends to differ between cycle years. Therefore, we calculated the average escapement and the site proportions individually for each cycle, in order to be representative of actual patterns when gap-filling.

Example: In the Shuswap-L CU, the Adams River site contributes 71% of the spawning escapement, on average, in dominant cycle years, whereas in subdominant years this site represents 95% of Shuswap-L escapement.

Usage: Shuswap-L, Takla-Trembleur-Estu, Quesnel_S

APPENDIX 6: Pacific Science Advisory Review Committee (PSARC) Request for Wild Salmon Policy Stock Status Evaluation for Fraser Sockeye

REQUEST FOR SCIENCE INFORMATION AND/OR ADVICE

PART 1: **DESCRIPTION OF THE REQUEST – TO BE FILLED BY THE CLIENT REQUESTING THE INFORMATION/ADVICE**

Date *(when initial client's submission is sent to Science) (dd/mm/yyyy)***:**

Directorate, Branch or group initiating the request and category of request

Directorate/Branch/Group
- ☒ Fisheries and Aquaculture Management
- ☐ Oceans & Habitat Management and SARA
- ☐ Policy
- ☒ Science
- ☐ Other (please specify):

Category of Request
- ☒ Stock Assessment
- ☐ Species at Risk
- ☐ Human impacts on Fish Habitat/ Ecosystem components
- ☐ Aquaculture
- ☐ Ocean issues
- ☐ Invasive Species
- ☐ Other (please specify):

Initiating Branch Contact:	
Name: Paul Ryall (Lead, Salmon Team)	Telephone Number: 604-666-0115
Email: Paul.Ryall@dfo-mpo.gc.ca	Fax Number: 604-666-9136

Issue Requiring Science Advice (i.e., "the question"):
Issue posed as a question for Science response.

1. Develop Wild Salmon Policy (WSP) lower benchmarks for up to 36 Fraser Sockeye WSP Conservation Units (CUs) where data availability permits; several of these 36 CUs have been flagged by Fisheries and Oceans Canada (DFO) Stock Assessment as being opportunistic spawning sites only rather than CUs. For each CU, up to four broad criteria (abundance, temporal trends in abundance, distribution of spawners, and fishing mortality) may be used for benchmark development depending on data quality and availability. The total number of lower benchmarks for each CU will vary depending on the criteria and associated benchmarks used; each criteria used could have more than one benchmark. The first step before identifying lower benchmarks on spawner abundances specifically will require the compilation/estimation of the recruitment time series by CU and subsequently the estimation of stock-recruitment parameters.

2. Provide a preliminary assessment of stock status for all Fraser Sockeye CUs using the WSP lower benchmarks. This step will be an iterative process as it is amongst the first salmon group in the Pacific Region where WSP lower benchmarks are being developed; not all methodology has been finalized including the use of multiple benchmarks to assess status.

Rationale for Advice Request:
What is the issue, what will it address, importance, scope and breadth of interest, etc.?

The development of Wild Salmon Policy (WSP) benchmarks is required for all salmon CUs in the Pacific Region of DFO. The Pacific Region identifies "Pacific Fisheries Reform' as a key priority in its '2006-2010 Pacific Region Implementation Plan' and lists as the first action, implementation of the WSP. Fraser Sockeye have been identified as one of the priorities for WSP CU benchmark development by the WSP

Strategy 1 Steering Committee. Fraser Sockeye are a high profile species among British Columbia salmon stocks and, as such, have greater pressure to comply with the WSP to evaluate stock status. In addition, formal WSP stock status evaluations are conditions of certification for the Marine Stewardship Council (MSC) for Fraser Sockeye Salmon identified in their 'Action Plan to Address Conditions for MSC Certification for British Columbia Sockeye Fisheries'. The deadline for lower benchmark development outlined in the MSC Action Plan is 'through December 2011'. Finally, WSP lower benchmarks for Fraser Sockeye will be used in the Fraser River Sockeye Spawning Initiative (FRSSI) to be used in simulation modelling to evaluate the performance of different management actions (escapement strategies) in relation to stock status prescribed by WSP benchmarks.

A WSP lower benchmark methodology paper has been recently approved through PSARC and published by the Canadian Science Advisory Secretariat (CSAS) (Holt et al. 2009). This paper evaluates four broad criteria for assessing stock status that includes recent abundances, recent temporal trends in abundance, distribution of spawners, and fishing mortality relative to stock productivity. Using multiple criteria to assess stock status is required, particularly in light of declining productivity observed for Fraser Sockeye stocks in recent years.

Subsequent to the development of these benchmarks, this request also includes the completion of a preliminary review of the stock status for each Fraser Sockeye CU. As described in the previous section, this will be an iterative process given all methods have not been fully assessed including evaluating stock status when multiple benchmarks are available.

Possibility of integrating this request with other requests in your sector or other sector's needs?

WSP lower benchmark priorities also include Barkley Sound Sockeye and Fraser River Chinook CUs. This request will be linked with work conducted by Science teams working on these other CUs. All three groups will provide leadership and guidance to the development of WSP lower benchmarks for the remaining CUs in the Region through the WSP Strategy 1 Steering Committee and Working Group. This work is being conducted by Regional and Area Science.

Intended Uses of the Advice, Potential Impacts of Advice within DFO, and on the Public:
Who will be the end user of the advice (e.g. DFO, another government agency or Industry?). What impact could the advice have on other sectors? Who from the Public will be impacted by the advice and to what extent?
Required directly by Stock Assessment and DFO Science to identify stock status for Fraser Sockeye stocks for provision of advice to internal and external groups.

Fraser Sockeye are a high profile species among British Columbia salmon stocks and, as such, have greater pressure to comply with the relatively new WSP to evaluate stock status. Formal WSP stock status evaluations are conditions of certification (for marketing Fraser Sockeye internationally) by the Marine Stewardship Council (MSC) for Fraser Sockeye Salmon; lower benchmark deadline as a condition of MSC certification is 'through December 2011.'

Information completed on Fraser Sockeye conservation unit stock status is also required to feed into the multi-stakeholder FRSSI process to evaluate performance of different management actions in relation to stock status prescribed by WSP lower benchmarks.

Date Advice Required:

Latest possible date to receive Science advice (dd/mm/yyyy): 05/01/2010

Rationale justifying this date: to have benchmarks in place to input into the FRISSI process and fishing season for 2011.

Funding:
Specific funds may already have been identified to cover a given issue (e.g. SARCEP, Ocean Action Plan, etc.)

Source of funding:

Expected amount:

Initiating Branch's Approval:

Approved by Initiating Director: ☐   Date (dd/mm/yyyy):

Name of initiating Director:

Send form via email attachment following instructions below:

Regional request: Depending on the region, the coordinator of the Regional Centre for Science Advice or the Regional Director of Science will be the first contact person. Please contact the coordinator in your region to confirm the approach.

National request: At HQ, the Director of the Canadian Science Advisory Secretariat (Denis.Rivard@dfo-mpo.gc.ca) AND the Director General of the Ecosystem Science Directorate (Sylvain.Paradis@dfo-mpo.gc.ca) will be the first contact persons.

PART 2: **RESPONSE FROM SCIENCE**

In the regions: to be filled by the Regional Centre for Science Advice.
At HQ: to be filled by the Canadian Science Advisory Secretariat in collaboration with the Directors of the Science program(s) of concern.

Criteria characterising the request:	Constraints regarding the planning of a standard peer review/Workshop:	Other criteria that could affect the choice of the process, the timelines, or the scale of the meeting:
☐ Science advice is requested (rather than just information) ☐ A sound basis of peer-reviewed information and advisory precedent already exists. ☐ Inclusiveness is an issue ☐ Advice on this specific issue has been provided in the past. ☐ Urgent request. ☐ DFO is not the final advisory body. ☐ CEAA process ☐ COSEWIC process ☐ Other:	☐ External expertise required ☐ This is a scientifically controversial issue, i.e., consensus does *not* currently exist within DFO science. ☐ Extensive preparatory work is required. ☐ Determination of information availability is required (prior to provision of advice). ☐ Resources supporting this process are not available. ☐ Expected time needed for the preparatory work: ☐ Other (please specify):	☐ The response provided could be considered as a precedent that will affect other regions. ☐ The response corresponds to a new framework or will affect the framework currently in place. ☐ Expertise from other DFO regions is necessary. ☐ Other (please specify):

Recommendation regarding the advisory process and the timelines:

☐ Science Special Response Process (SSRP)   ☐ Workshop   ☐ Peer Review Meeting

Rationale justifying the choice of process:

Types of publications expected and if already known, number of report for each series:

☐ Science Advisory Report ( )   ☐ Research Document ( )

☐ Proceeding ( )   ☐ Science Response Report ( )

☐ Other:

Date Advice to be Provided:

☐ Date specified can be met.
☐ Date specified can NOT be met.

Alternate date, as agreed to by client Branch lead and Science lead (dd/mm/yyyy):

OR

☐ No Formal Response to be Provided by Science

Rationale:
☐ DFO Science Region does not have the expertise required.
☐ DFO Science Region does not have resources available at this time.
☐ The deadline can not be met.
☐ Not a natural science issue (e.g. socio-economic)
☐ Response to a similar question has been provided elsewhere:
  Reference:

  Additional explanation:

Science Branch Lead:

Name: Telephone Number:
Email:

* Please contact Science Branch lead for additional details on this request.

Science Branch Approval:

Approved by Regional Director, Science (or their delegate authority):
☐   Date (dd/mm/yyyy):

Name of the person who approved the request:

Once part 2 completed, the form is sent via email attachment to the initiating Branch contact person.

PART 3:   PLANNING OF THE ADVISORY PROCESS

Science Branch Approval:

Coordinator of the event:

Potential chair(s):

Suggested date (dd/mm/yyyy) / period for the meeting:

Need a preparatory meeting:

Leader of the Steering Committee: