Fraser Sockeye (*Oncorhynchus nerka*) Wild Salmon Policy Evaluation of Stock Status: State and Rate

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Correct citation for this publication:
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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). The current paper updates WSP Strategy 1, Action Step 1.1 (the identification of Conservation Units (CUs)) and Action Step 1.2 (identification of benchmarks) and Action Step 1.3 (CU status assessment) for Fraser River Sockeye Salmon (*Oncorhynchus nerka*). Stock status is evaluated for 26 out of the existing 36 Fraser Sockeye CUs; the remaining 10 CUs are tentative given data are currently insufficient to confirm the validity of these CUs. Background is provided for all 36 CUs and rationale is provided for the five CUs removed from the original Fraser Sockeye CU list. Using a previously developed toolkit (Holt et al. 2009; Holt 2009), *abundance* benchmarks (unique benchmarks for each CU with stock-recruitment data) were estimated and *trends in abundance* upper and lower benchmarks (identical benchmarks for all CUs) were modified for Fraser Sockeye. These benchmarks delineate three biological status zones (Green, Amber, Red). Although changes in stock status inform management decision making, on their own they are not prescriptive for fisheries management. For each metric, the current state of each Fraser Sockeye CU was compared to the associated benchmark and status was assigned. For *abundance* benchmarks, in addition to the standard Ricker model recommended by the WSP toolkit, benchmarks were also estimated using a Ricker model fit to only recent stock-recruitment data and a Kalman filter (KF) Ricker model to account for recent productivity trends, and a Larkin model to account for delayed-density (cyclic dominance) effects observed for many CUs. The delta Akaike criterion (AIC) supported the Larkin model for most CUs stock-recruitment data. Of these models, the KF Ricker model generally produced the largest benchmarks and the Larkin model produced the smallest. Of all 26 assessible CUs, seven were poor in status (in the red zone) across most metrics, 13 were intermediate in status (range of status' from red to amber to green across all metrics) and five were good in status (green zone); one CU of these 26 assessable CUs could not be quantitatively evaluated for stock status.

RÉSUMÉ

OBLIGATOIRE (page iii)

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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"(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 status", which is the subject of this paper. Three action steps recommended under this strategy include Action Steps 1.1: the identification of conservation units (CUs); 1.2: the development of criteria to assess CUs and identify benchmarks to represent biological status; and 1.3: monitoring and assessment of CU status (2005; Fisheries and Oceans Canada 2005; Fisheries and Oceans Canada 2005). The current paper updates WSP Action Step 1.1 (the identification of CUs) and completes the WSP Action Step 1.2 (identification of benchmarks) and WSP Action Step 1.3 (CU status assessment) for Fraser Sockeye (*Oncorhynchus nerka*).

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 by Holtby and Ciruna (2007) (recently updated by Holtby in 2010). This list is subject to change as new data and information become available. The current paper presents a revised list of 36 Fraser Sockeye CUs (Table 1). Of these 36 CUs, 10 are considered in this paper as tentative and require further research to confirm whether or not they are valid CU's, and two CU's (McKinley-S & Chilko-ES) cannot be assessed independently since data for these CU's are aggregated with their adjacent larger CUs (respectively, Quesnel-S & Chilko-S). Five CUs were removed from the original list as they were not considered CUs by the authors after further evaluation. Therefore, assessment of stock status can be completed for 26 Fraser Sockeye CUs (including the Quesnel-S/McKinley-S and Chilko-ES/Chilko-S aggregates) (Table 1). All CU's and associated escapement sites are reported in Appendix 1.

Coincidental to the identification of CUs, methodology for the identification of salmon stock 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 stock status include *abundance*, *trends in abundance*, *fishing mortality*, and *distribution* (Figure 1). For each class of indicator more than one metric could be used to assess stock status (Figure 1). For each metric, lower and upper benchmarks delineate, respectively, the red to amber stock status and the amber to green stock status zones (Figure 2). 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'.

For each CU there could be more than one indicator of status depending on the number of classes of indicators and the number of associated metrics in each class of indicators used (Figure 1). Although changes in stock status are intended to inform management decision making, on their own they are not prescriptive.

Table 1. The 26 CUs with sufficient data to evaluate stock status (assessable CUs), 10 tentative CUs that require additional research to confirm they are valid and 5 CUs that have been removed from the original CU list due to errors in the escapement database.

Assessable CU's	Tentative CU's (Additional Research Required)	Removed from original CU list
1 Anderson-ES	1 Alouette-ES	1 Hayward Lake
2 Bowron-ES	2 Boundary Bay (River-Type)	2 Indian/Kruger
3 Chilko-ES[1]	3 Cariboo-S (River-Type)	3 Kawkawa-L
4 Chilko-S[1]	4 Coquitlam-ES	4 Francois-L
5 Chilliwack-ES	5 Fraser Canyon (River-Type)	5 Stuart-Estu
6 Cultus-L	6 Fraser-ES	
7 Francois-ES	7 Mid-Fraser River (River-Type)	
8 Fraser-S	8 Nadina-ES	
9 Harrison (D/S)-L	9 Thompson (River-Type)	
10 Harrison (U/S)-L	10 Upper Fraser (River-Type)	
11 Kamloops-ES		
12 Kamloops-L		
13 Lilloet-L		
14 Lower Fraser River (River-Type)		
15 McKinley-S[2]		
16 Nahatlach-ES		
17 Pitt-ES		
18 Quesnel-S[2]		
19 Seton-L		
20 Shuswap-ES		
21 Shuswap-L		
22 Stuart-S		
23 Takla Trembleur-Early Stuart		
24 Takla Trembleur-S		
25 Taseko-ES		
26 Widgeon (River-Type)		

1. Chilko-S/Chilko-ES and **2. Quesnel-S/McKinley-S** are aggregated for status evaluation.

Since a relatively complete time series of escapement and recruitment exists for a large number of Fraser Sockeye CUs, the classes of indicators explored in this assessment include *abundance* and *trends in abundance* (WSP Action Step 1.2). The *fishing mortality* class of indicator differs from the remaining three (Figure 1) 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 discussion on *fishing mortality* benchmarks and their usefulness in stock status evaluation is required prior to their use. For Fraser Sockeye, the *fishing mortality* class of indicator will not be 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. Future evaluation of *distribution* CU status is recommended where data exist and would require the inclusion of information on habitat status (WSP Strategy 2). Therefore, for the purpose of Fraser Sockeye stock status assessment, only the *abundance* and *trends in abundance* indicator classes are considered.

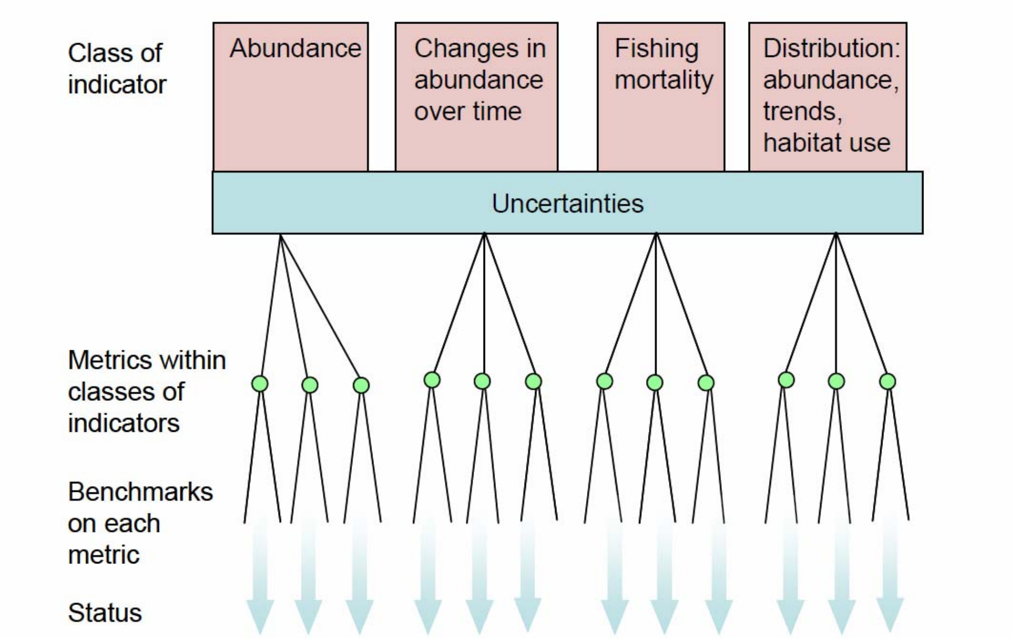


Figure 1. Hierarchy for the assessment of biological status of Conservation Units, including four classes of indicators, quantifiable metrics within classes and benchmarks on each metric. Reprinted from Holt et al. (2009).

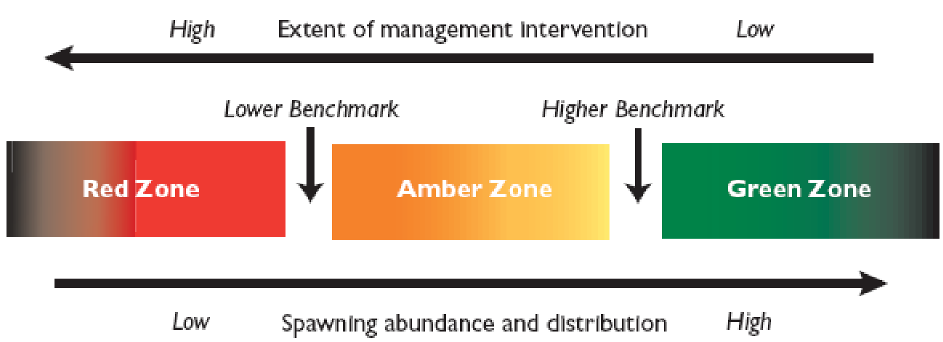


Figure 2. Classification of stock status using the current state of the stock and upper and lower benchmarks to categorize a stock into red, amber or green zones delineated by increasing spawner abundance and distribution and decreasing extent of management intervention. Reprinted from Fisheries and Oceans Canada (2005).

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 calculating benchmarks for *abundance* indicators (unique to each CU). 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 specifically was associated with the lowest probability (<25%) of extirpation over 100 years for populations under equilibrium abundances (>15,000 spawners) and high probability (>75%) of recovery to S_{MSY} in three generations when fishery uncertainties were accounted for (Holt 2009). Further, simulation modelling indicated that in the case of linear declines in productivity (such is the case in Fraser Sockeye), the risk of extinction increased significantly at higher spawner abundances relative to all other productivity scenarios (stable, cyclic, linear increase) (Holt 2009). Therefore, in cases of persistent declines in productivity, with the exception of Harrison (U/S) (largely comprised of Weaver Creek/Channel Sockeye), Shuswap-L, and one population within the Kamloops-ES CU (Raft creek) (Grant *et al.* 2010), alternative methods were used to establish Fraser Sockeye abundance benchmarks to compare with the recommended Ricker model (using the full stock-recruitment time series). These included using the Ricker model with a truncated stock-recruitment time series to include only the more recent (lower productivity) time periods, and also using the Kalman filter Ricker model (KF Ricker). Both additional methods take into account the recent period of lower productivity exhibited by most CUs. In addition, since Fraser Sockeye CUs, particularly those that occupy the large rearing lakes, exhibit persistent delayed-density effects on abundance within the four-year population cycle, benchmarks were also calculated using the Larkin model to account for this pattern of abundance.

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

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

B) a revised list of Fraser Sockeye CUs (WSP Strategy 1, Action Step 1.1);

C) history, escapement time series, trends in abundance, productivity, and abundance for the 26 assessable CUs;

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

E) *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) the status for each metric of the 26 assessable Fraser Sockeye CUs including the two CU aggregates (Quesnel-S/McKinley-S & Chilko-ES/Chilko-S) (WSP Strategy 1, Action Step 1.3);

G) background information including history, data quality and quantity for the 11 tentative CUs and rationale for the removal of five CUs removed from the original list.

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 km^2) (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 (Burgner 1991). 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 1995; 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.

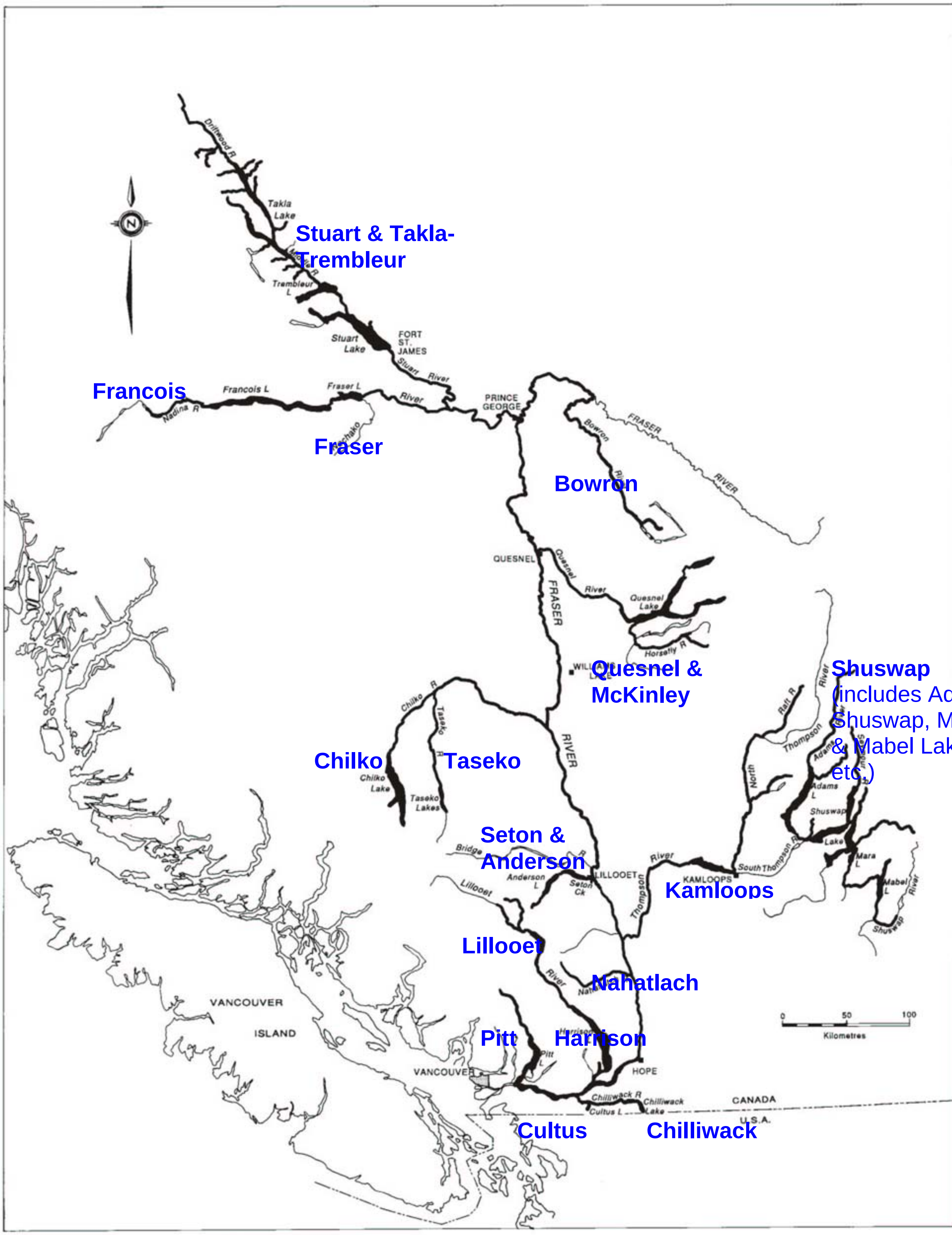


Figure 3. Sockeye salmon freshwater distribution in the Fraser River watershed with key conservation unit lakes identified (blue text). Heavy black indicates locations of Sockeye spawning.

Age Structure

Fraser Sockeye 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 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). There is a smaller proportion (~20% of the total adult age composition) of five year old fish that spend one extra winter in the marine environment (5_2). Fraser Sockeye also have 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 these age proportions 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 these 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 returns 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)). These CUs are comprised of age-3 (3_1) and age-4 (4_1) fish that do not spend time as juveniles rearing in freshwater lakes. 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 that result in warmer water flows from the south and, consequently, higher diversion rates through Johnstone Strait in these years (Groot and Quinn 1987).

Sockeye homing to the spawning areas is precise both in 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 2003a).

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. The 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 school and migrate to the lake and 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). They both rear in the lake for one to two winters after gravel emergence. In most cases, fry rear in the lakes immediately adjacent to the spawning streams but exceptions have been documented. For example, fry from Gates Creek (and channel) initially enter Anderson Lake but a variable and often substantial proportion migrate through the lake and rear in Seton Lake (Geen and Andrew 1961). Similarly an occasionally large proportion of the fry from the Birkenhead River initially enter Lillooet Lake and then migrate through the lake to rear in Harrison Lake (Cave 1988). In both cases the growth of the 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 the 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 distributed largely 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 (Taylor *et al.* 1996; Tucker *et al.* 2009).

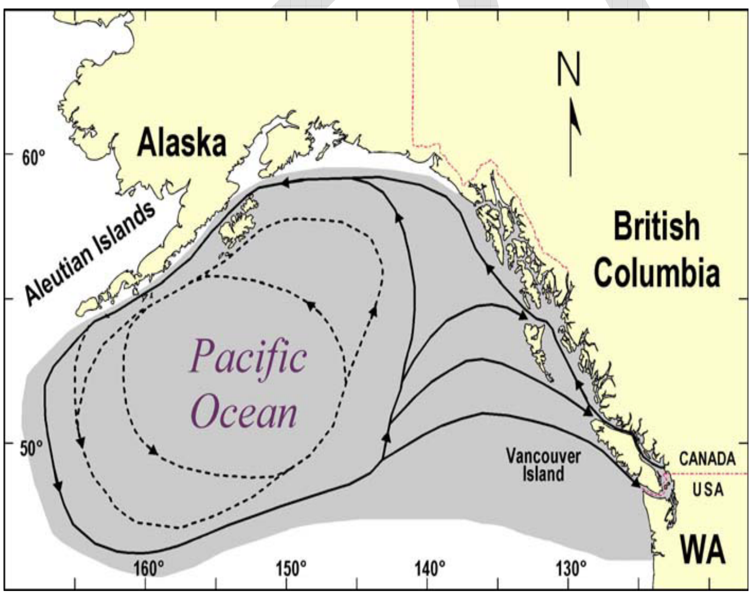


Figure 4. The open ocean migration pattern of Fraser River Sockeye salmon. Grey area is overall distribution, black lines are main routes and dashed lines indicate other area covered (Migration patterns modified from French et al. (1976) & Healy (2002); reprinted from (Johannessen and Ross 2002)).

POPULATION SIZE AND TRENDS

Cycles and Escapement, Catch and Return Trends

Fraser Sockeye predominantly return as four year olds. The large lakes in the watershed produce persistent 4-year cycles in abundance. Hypotheses of why cyclic dominance occurs include depensation due to overfishing (Collie and Walters 1987; Walters and Staley 1987; Walters and Woodey 1992), increased predation on the smaller subdominant cycles (Larkin 1971; Ward and Larkin 1964), 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 (Ricker 1997; Myers *et al.* 1998; Cass and Wood 1994).

From 1892 to 1912, most of the Fraser Sockeye abundance cycled synchronously amongst populations with one dominant cycle line occurring every four years followed by three weaker cycle lines (Figure 5). The dominant cycle line existed on the 1901 year (for reference this would have been the 2009 cycle if it persisted) and appears to have occurred as far back as the first reference of Fraser River Sockeye in 1793 (Fisheries and Oceans Canada 1998). The 1901 cycle dominated up to the 1913 Hells Gate Slide and during this early period the Fraser was often considered to be the greatest Sockeye producer globally (Aro and Shepard 1967). Average returns from the late 1800’s to 1913 on the 1901 dominant cycle were 52 million Sockeye (Figure 5). Catch during this period on the dominant cycle averaged 21 million and escapement averaged 31 million (Figure 5). On the remaining three weaker cycles during this period, returns (average: 9.9 million annually), catch (average: 4.6 million annually) and escapement (average: 5.3 million) were considerably lower than on the dominant (1901) cycle.

The 1913 landslide occurred in the Fraser Canyon at Hells Gate and was caused by the construction of the Canadian Pacific Railway lines. 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 in the Fraser Canyon at Hells Gate to permit upstream fish passage and management actions were implemented to reduce overfishing and permit stocks to rebuild. Fraser Sockeye abundance started to build and there were less distinct differences in the cycle lines (Figure 5). Although the run remained particularly low from 1914 to 1929 (average return: 4.5 million), catch remained relatively high (2.1 million). After 1929, the run started to build slightly with a dominant cycle occurring in 1930.

Starting in the 1980’s, the total Sockeye run built to a maximum return of 41 million (mid-1990) 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). Returns were particularly small from 2007 to 2009 (average return: 2.4 million; average escapement: 1.6 million; average catch: 0.4 million). In 2009, returns were particularly low and corresponded to the lowest productivity on record for most Fraser Sockeye stocks (Grant *et al.* 2010). In contrast, preliminary returns for 2010 were relatively high (~35 million preliminary returns as of October 11, 2010) and corresponded to above average productivity. The mechanisms that produced the anomalously low returns in 2009 and the extremely high returns in 2010 remain uncertain and are the subject of on-going scientific research.

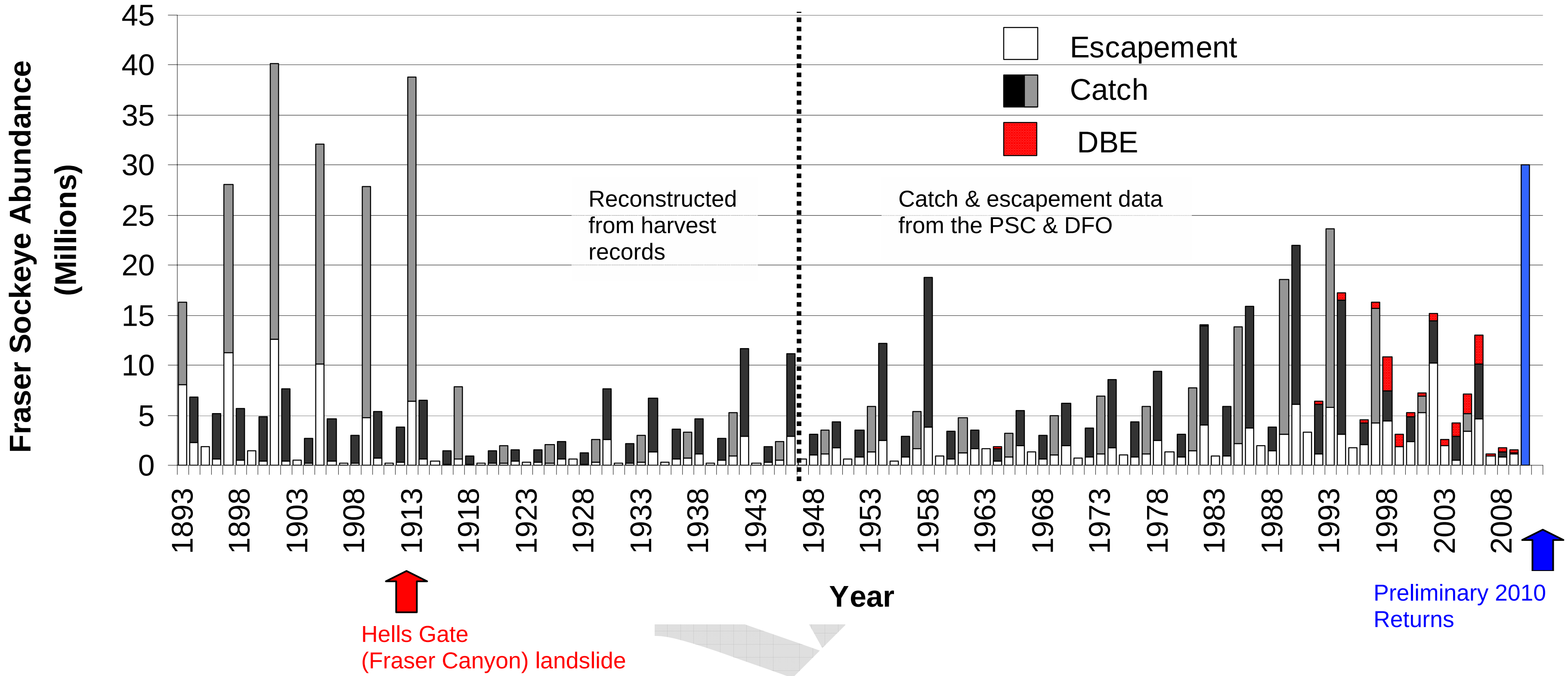


Figure 5. Escapement (white bars), catch (black or grey bars) and difference between estimates (DBE: red dotted bars) for Fraser Sockeye. The 1901 (corresponding to 2009 in current years) dominant cycle is represented by the grey bars. Maximum height of each annual bar represents the total return. The DBE is the difference between the in-season hydroacoustic estimates at Mission BC and the spawning ground escapements and represents en-route loss and assessment error. The dashed vertical line represents the division between early time series data (1892-1944) that was reconstructed by Gilhousen (1992) from commercial harvest data and post-1944 data from the PSC and DFO data records. Preliminary 2010 returns are indicated by blue bar at the end 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) was generally high up to the mid-1980's and has subsequently declined (Figure 6 A). This overall productivity trend is driven by the most abundant stocks, which are largely Summer Run stocks (Chilko-ES/Chilko-S, Quesnel-S/McKinley-S, Fraser-S (Stellako) and Takla-Trembleur-S/Stuart-S (Late Stuart)). During the recent period in which productivity has declined, escapement (effective total spawner) has coincidently declined, suggesting that this lower productivity is not driven by density-dependent mortality (Figure 6 B). Despite these overall trends, however, its important to recognize that there exists considerable variability in productivity trends amongst individual stocks (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 starting in the 1960's-1970's (Takla-Trembelur-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 Shuswap-ES CU), Shuswap-L and Harrison (U/S)-L (Weaver Creek & Channel) have not exhibited declining trends. Lower Fraser River (River-Type) is the one exception that exhibits 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 stock productivity, total survival can be partitioned into freshwater and marine survival if both outmigrating smolt and adult return data are available. For Fraser Sockeye, only Chilko-ES/Chilko-S and Cultus-L Sockeye stocks have both smolt and adult return data. It is important to note that marine survival estimates generally include some freshwater mortality in the Fraser River between the time smolts are counted exiting their rearing lakes and when they enter the marine environment. Most of the mortality in Fraser Sockeye occurs in the freshwater environment between the egg to smolt stage. On average 4 billion (± 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%.

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. 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).

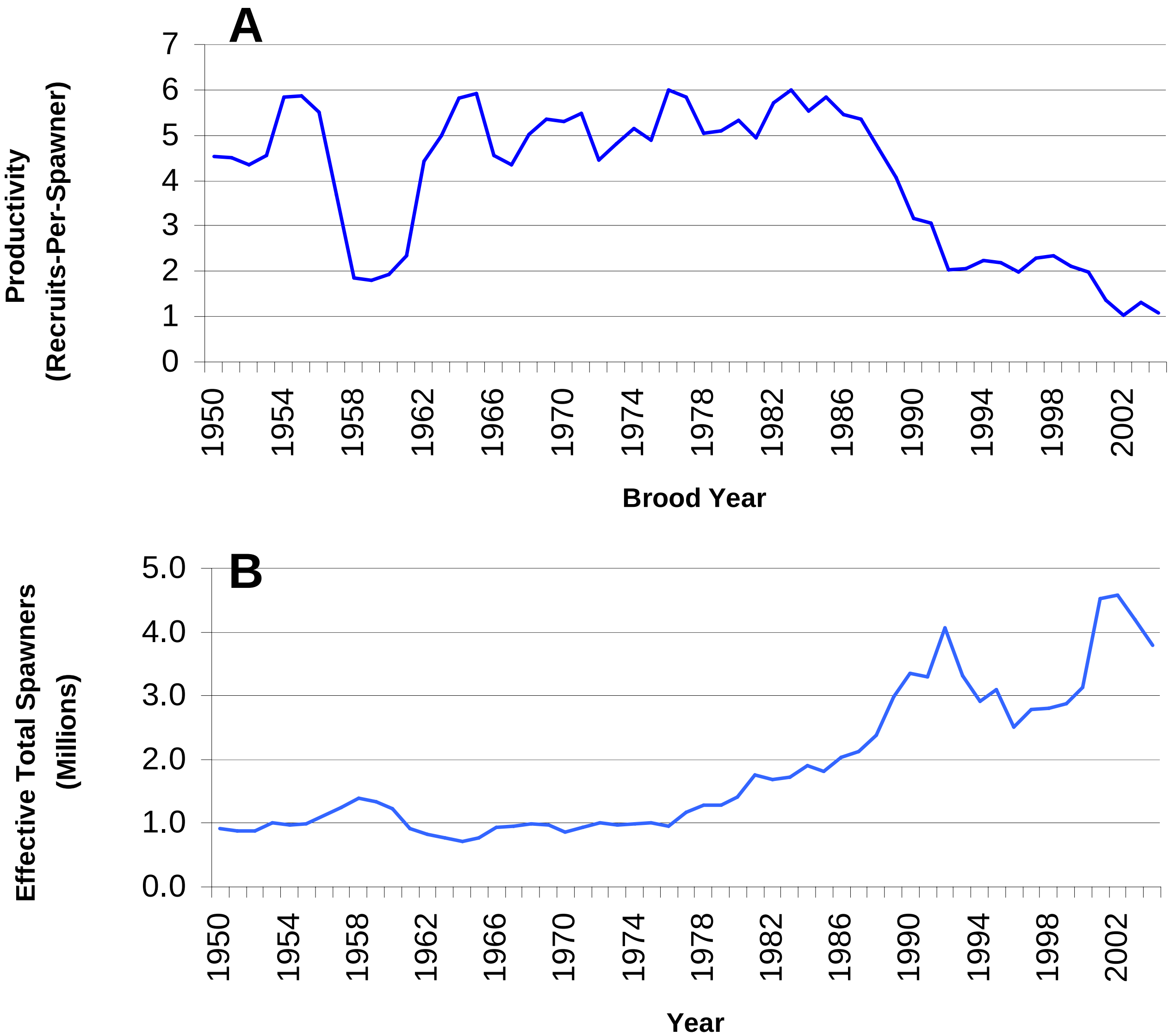
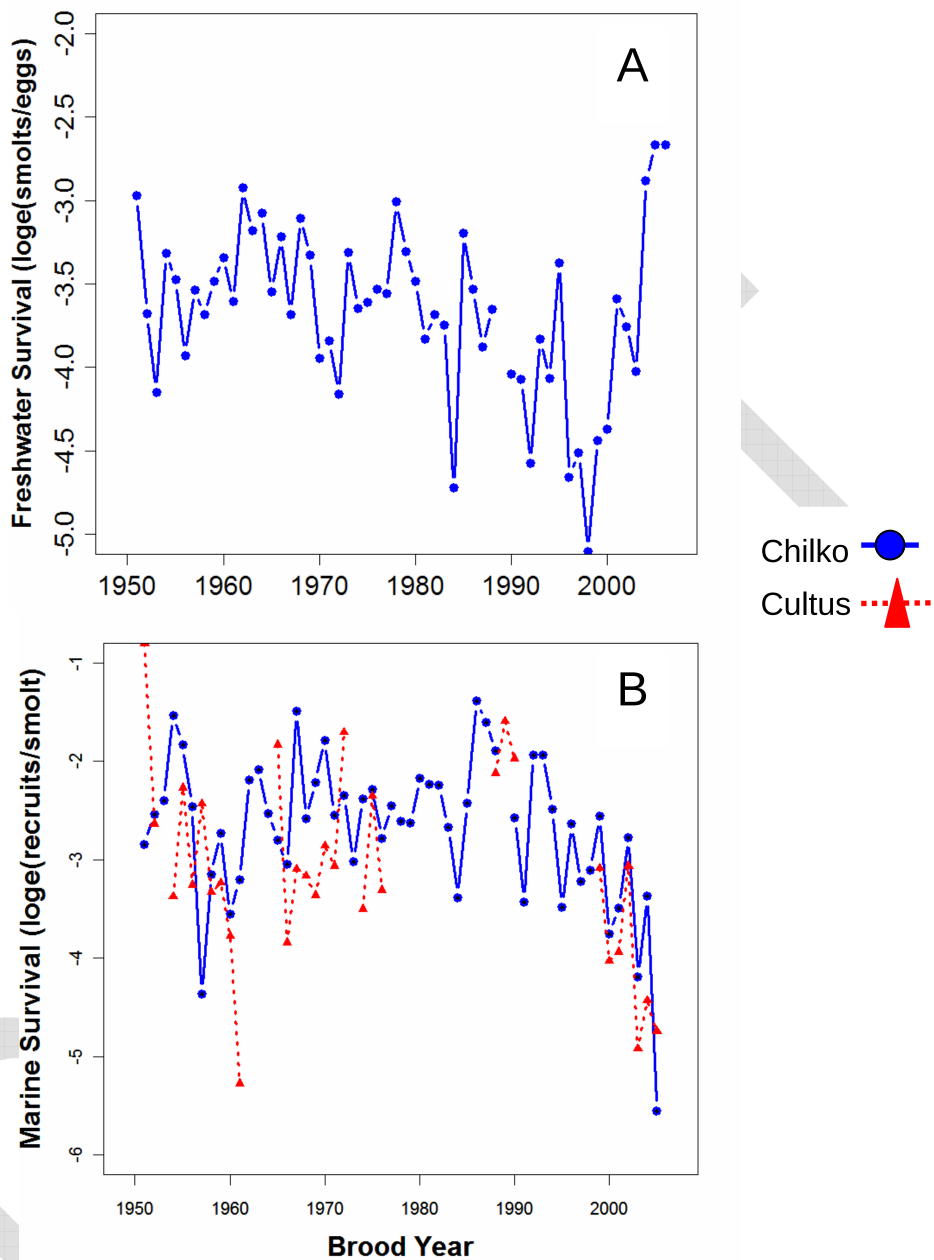


Figure 6. **A.** Four-year running average productivity in recruits (age-4_2 plus age-5_2)-per-effective total spawner and **B.** escapement (effective total spawners) for Fraser Sockeye populations. These trends are driven by CUs that dominate total abundance (Quesnel-S/McKinley-S, Chilko-ES/Chilko-S, Takla-Tremleur-S/Stuart-S and Fraser-S).



Figures 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 to 2005 brood years. Note: the 2004 and 2005 brood year marine survivals are preliminary pending final results for 2009 age-4 and age-5 returns. Cultus-L freshwater production is not plotted because freshwater production in recent years includes hatchery enhancement. Reprinted from Grant *et al*. (2010).

FRASER SOCKEYE POPULATION STRUCTURE

Genetics

The last glacial period is likely a major factor that structured current Fraser Sockeye populations overall. There were two major glacial refugia that influenced current Fraser Sockeye population structure: the Cascadia refugia and the Beringia refugia (Beacham *et al.* 2005; Withler *et al.* 2000; Wood *et al.* 1994). Post-glaciation, the lower Fraser was likely colonized by Sockeye moving in from the coastal North-Eastern Pacific (Beringia refugia) and the upper Fraser was likely colonized 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).

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

Run-Timing

The run timing groups of Fraser Sockeye were established for fishery management purposes and consist of populations with similar migratory timing during their return from the ocean to the spawning grounds. The earliest time 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) and arrives 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 that enters the Fraser from August to mid October. From 2002-2009, Birkenhead was separated from the Late Run group given their timing was more similar to Summer Run stocks and they did not exhibit pre-spawn mortality similar to other Late Run Stocks. However, starting in 2010 they were re-integrated into the Late Run group because their timing 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 year for the Adams River Sockeye run (Shuswap-L CU) (Grant *et al.* 2010). However, there is considerable overlap in timing of these groups.

Conservation Units

Methodology for the identification of conservation units for Canada's salmon stocks in British 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 met 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, Sockeye lake-type 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 using 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 are named Takla-Trembluer-EStu (Holtby and Ciruna 2007).

River-type CUs did 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 combination of effective spawners in the parental generation (specifically the number of eggs deposited in spawning gravel) and survival (freshwater and marine) determines the number of salmon that return (escapement, catch & en-route loss) to the Fraser River in any given year. Considerable mortality occurs in both the freshwater and marine environment from 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 have been identified to salmon stocks generally and some to Fraser Sockeye populations in particular, including fisheries, environmental conditions in the freshwater and marine environments, en-route and pre-spawn mortality, habitat alteration particularly in the freshwater, exotic species, and pathogens and disease.

Fisheries

Management: past & present

From 1937-1984 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) was shared equally between Canada and the United States. After 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 with its purpose to ensure 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 harvest has gradually decreased and 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 and this plan incorporates 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 the 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 based on information for 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 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 abundance stocks with similar migration timings.

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 some 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, and estimates of lower river escapements from the PSC hydro-acoustic facility at Mission (BC), data from other 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-targets 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 to address domestic concerns. 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 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 increases to the spawning escapements targets to ensure that the numbers of fish reaching spawning areas reach desired levels. Management adjustments account for systematic differences between upper and lower river escapement estimates and 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 forecast 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, the Panel management decisions and strategies are assessed to determine if the goals were met and to look at options for improving management and data collection and analyses techniques.

Catch History

The first cannery was built on the Fraser River in 1866 and subsequently the commercial gillnet fishery developed rapidly. Relative to total returns, this fishery was particularly intense on the subdominant cycles compared to the 1901 (2009 if this persisted to present) dominant cycle (Figure 5). It is likely that these fisheries exaggerated cyclical pattern in return abundances due to depensatory exploitation rates. Prior to 1913, catches ranged from 35-50 million (Figure 5). After the Hells Gate landslide greatly restricted upstream passage for several years and subsequent overfishing, 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 higher from 1950 to mid-1990s (average: 75%) and subsequently have 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 were 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 needs. However, on larger return years, most catches still occur in the marine areas with Canadian commercial catches mainly occurring in the troll fisheries, purse seine and gillnet fisheries in Johnstone and Juan de Fuca Straits and the gillnet fishery in the Fraser River. There are smaller commercial fisheries in northern and central B.C. that may occasionally intercept Fraser River Sockeye and a few directed fisheries primarily for late-run stock in the Strait of Georgia. Sockeye are harvested in native food fisheries throughout the Fraser River watershed. Recreational catches have increased since the development of the in-river fishery upstream of Mission in the mid 1990s. U.S. fisheries mainly occur in the net fisheries in Juan de Fuca Strait, near the San Juan Islands and south of Point Roberts in the southern approaches to the Fraser river located in US waters. Some Fraser Sockeye are also taken incidentally in southeastern Alaska. US catches generally are generally small; an average of 18% of total catch since 1993.

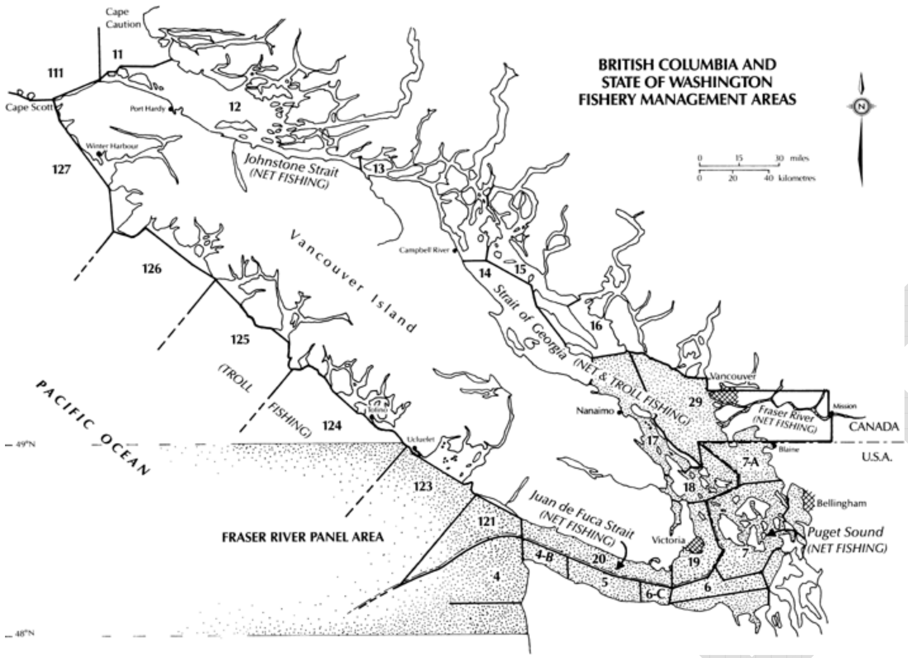


Figure 8. British Columbia and Washington fishery management areas http://www.psc.org/ including Fraser River Panel Area waters (shaded grey).

<u>Environmental Conditions (Freshwater Author: M. Hague, Science, DFO)</u>

<u>Freshwater Environment</u>

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 rivers range 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)(S. 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 *et al.* 2006; Greig *et al.* 2007). 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 migration survival has is a function of both acute and cumulative impacts largely mediated by exposure to extreme temperatures and flows (Gilhousen 1980; 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 *et al.* 2007a) 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) has not occurred.

There is a general consensus that the Fraser River will continue to warm throughout the 21st century and 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 (McDaniels *et al.* 2010; Nelitz *et al.* 2009). 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).

<u>Marine Environment</u>

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 (Beamish *et al.* 1997; Mantua *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 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 (Grant *et al.* 2010; Haeseker *et al.* 2008). 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 an annual mean estimates for Early Stuart, Early Summer, Summer, and Lates average 50%, 50%, 20%, and 40%, respectively, from 1992 to 2009 (PSC data). This en route loss is an interaction of physical (water temperature, discharge, sediment, harvest) (Macdonald 2000; Macdonald *et al.* 2000; Macdonald *et al.* 2010; Crossin *et al.* 2008; Mathes *et al.* 2010) and biological factors (energy status, disease condition, pathogens, predators, and cumulative stress) (Wagner *et al.* 2005; Cooke *et al.* 2006; Young *et al.* 2006; Farrell *et al.* 2008; Bradford *et al.* 2010b; Bradford *et al.* 2010c). The relative contribution and interaction among these factors varies on an annual basis, and are mediated by the over-arching influence of water temperature. The current increasing trends in warming 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; Bradford *et al.* 2010b; Bradford *et al.* 2010c; Crossin *et al.* 2008). 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 in 2008 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 approximate 3-6 weeks earlier 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 both 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 and will likely continue.

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, 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 forecast. The change in forest coverage due to both the MPB killed trees and resultant salvage logging is predicted to have 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. 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 (Bradford *et al.* 2008a; Bradford *et al.* 2008b; Tovey *et al.* 2008). Non-native fish species have largely expanded their distribution outside of their natural range 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*)

(Bradford *et al.* 2008a; Bradford *et al.* 2008b; Tovey *et al.* 2008). 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 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 have 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

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 (Schaefer 1951; Atkinson 1944; Howard 1948) 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 stock was based on the number 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 studies were used. In 2004, this threshold was raised to >75,000 spawners due to funding limitations. Starting in the mid-1990's the number of sites assessed increased across a number of larger CU's due to improvements to equipment (e.g. boats) and funding that permitted increased spatial assessment coverage of smaller Sockeye spawning streams.

Escapement enumeration assessment methods for Fraser River Sockeye salmon are documented in a number of technical reports (Houtman and Cone 1995; Schubert and Fanos 1997a; Schubert and Fanos 1997b; Schubert and Tadey 1997; 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 using known fence counts 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 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, since additional data on the spawning success of female fish are also available, this information is used in the current paper to estimate status for *trends in abundance* and *abundance* metrics. Specifically, 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). For *abundance* metrics, effective total spawner (ETS) data are used (product of the number of adult male and female spawners and spawner success).

For most CUs, 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 the 1950's 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 site in the escapement record. Sites were included in the calculation of total EFS for a CU only if they were assessed for >70% of the historical time series. An annual EFS record was only included if the field assessment period for that year coincided with peak escapement on the historical record and 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 in the later time series (increased resolution) rolled up into one site in the early time series (lower resolution). Examining how the resolution of data included in individual 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 site in a given year (for CUs with multiple sites) or no abundance estimates for the single 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 cycles which, if missing, could significantly reduce the generational mean (i.e., smoothed four year running average) for segments of the time series including that year. Specifically, abundance estimates for any missing year (e.g. 1942) were interpolated by inserting the mean of the same cycle year from the immediately previous (e.g. 1938) and subsequent generation (e.g. 1946). If the corresponding cycle year of either of the closest two generations was missing (e.g., 4 years previous or subsequent to missing point), the corresponding cycle year no more than two generations away (e.g. 1934 & 1950) was used to calculate the mean used in the interpolation. Interpolation was conducted prior to log transformation and smoothing with the generational mean. or, if these data were missing then two cycles previous were used in the average (Appendix 4).

For missing data in CUs with multiple sites, sites that were spatially proximate and correlated in terms of abundance were grouped together. Gaps in these site groupings were filled using a modified English et al. (2007) approach (Appendix 4). This approach gap fills based on the proportion each site's abundance contributes to the total system when averaged only across years with data available for all populations, rather than across the entire time period as described in English et al. (2007). In addition, for highly cyclic stocks gap filling was done separately for dominant versus 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 4).

Recruitment Data

Recruitment data are organized by the PSC and combine escapement (see previous section) and catch data and, in recent years, estimates of Sockeye en-route loss all organized by stock and age. 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 on only data starting in 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 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).

Other CU's that have been influenced by hatchery enhancement were also truncated to eliminate enhancement years. For the Shuswap-ES CU, a key site in this CU (Scotch Creek) was strongly influenced by hatchery production prior to 1980 and, 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 and, therefore, only stock recruitment data from the 1965-2004 brood years were included. The Cultus-L CU was significantly enhanced in recent years and, 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 was negligible therefore this year's stock-recruitment data 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 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.

Carrying Capacity Data

A system's total capacity for numbers of Sockeye could be limited by the available adult spawning habitat or juvenile food availability in the rearing lake. In the current paper, Bayesian priors on spawning capacity or lake-rearing capacity are used where available and appropriate when calculating abundance benchmarks using the Ricker model and Kalman filtered Ricker (KF Ricker) models (see proceeding Spawner Abundance section). Although Bodtker et al. (2007) developed a Bayesian PR method that explicity take into consideration uncertainty associated with using lake productivity to estimate the spawner abundance that maximize smolt production (S_{max}), these methods have not been updated for this current paper's PR model results. Instead where rearing capacity data were available and used in models, the current paper uses a sigma that encompassed the spawning capacity data available and these informative priors were lognormally distributed. 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).

Estimates of spawning habitat capacity are available for some Sockeye populations in the Fraser watershed (Fisheries and Oceans Canada 1995). Optimal spawning capacity was estimated for index streams representing different bio-geoclimatic zones in the Fraser watershed and these estimates were applied to spawning habitat for different Sockeye populations. No recent estimates are available for all Fraser Sockeye CU's.

In addition to spawning habitat capacity, the current paper updates estimates of juvenile Sockeye lake rearing capacity using data on photosynthetic rate (PR) and juvenile Sockeye competitors in the lake. Photosynthetic rate data are positively correlated to fish yield in freshwater lakes (Fee *et al.* 1985; Downing *et al.* 1990) and, in fact, are more closely correlated to 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 the combination of the 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 to adjust for the presence of competitors and age-2 smolts (Cox-Rogers *et al.* 2010). 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 that they are planktivorous although we have little data on competitor population variability or diet. Many competitor species may have a wider dietary range than do Sockeye and 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 of the biomass of competitors 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 this data were not always available. The presence of age-1 kokanee and their abundance 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 reside 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, so they 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 numbers 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 from most lakes 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 in the following paragraphs are presented in Cox-Rogers et al. (2010).

CLASS OF INDICATORS, METRICS AND BENCHMARKS

<u>Spawner Abundance (State)</u>

The Ricker model using a Bayesian approach (with prior information on the carrying capacity parameter where available) was recommended by Holt et al. (2009) and Holt (2009) 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 the lowest probability (<25%) of extirpation over 100 years for populations under equilibrium abundances (>15,000 spawners) and 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 incorporated changes in intrinsic productivity (the Ricker *a* parameter) over time were also considered. Estimates of intrinsic productivity in the current year were then used to calculate benchmarks on spawner abundances. These estimates of productivity reflect existing conditions better than estimates derived from models that assume stationary productivity. Time-varying productivities were estimated using recursive Bayesian estimation. Similar to the Kalman filter (KF) approach sometimes used for salmon stock assessment (Dorner et al. 2008), recursive Bayesian estimation also estimates the true values recursively over time using observed values, assuming an underlying process model (the Ricker model in this case) (as in Grant et al. 2010). 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 Bayesian approach. Including prior information on population capacity (Ricker *b* parameter) is especially critical when time-series of spawner and recruitment data are short or uninformative (most cases), in order to reduce biases in parameter estimates due to observation errors in spawner abundances ("errors-in-variables") and time-series that are contain recruitment anomalies at low spawner abundances only ("time-series bias") (Walters and Martell 2004). Here, we build on previous use of recursive Bayesians estimation for estimating time-varying productivity for Sockeye salmon in the Fraser River (Grant et al. 2010) by including information priors on capacity. Bayes 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). In preliminary testing, we found that when priors are uninformative, parameter estimate 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, first pararaph).

In addition, since some Fraser Sockeye CUs exhibit persistent cyclic dominance in abundance (e.g. Shuswap-ES, Shuswap-L, Stuart-S & Quesnel-S), benchmarks calculated using the Larkin model that accounts for cyclic dominance were also considered (Walters and Staley 1987; Cass and Grout 2006; Martell *et al.* 2008) when setting escapement goals for those stocks. The

Larkin model includes the effects of biological interactions among cycle lines due to, for example, competition for food or predators. Methods used by Martell et al. 2009 for the Larkin model were replicated in the current paper. The model form is as follows: $\ln(R/S) = a - b_0S_1 - b_1S_{t-1} - b_2S_{t-2} - b_3S_{t-3} + w_{t.}$ (Martell *et al.* 2008).

Bayesian diagnostics were examined for all models and CUs. Both Gelman & Rubin diagnostics and Gewke Statistics (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) were used to determine if MCMC chain convergence had occurred. Burn-in length was increased if convergence did not occur. Autocorrelation of chains was also examine and if chains were autocorrelated chains were thinned.

The best fit model to the escapement and recruitment data for each CU or CU aggregate was assessed using Akaike's Information Criteria (AIC). AIC uses the maximum likelihood value obtained in model fitting, and the complexity of each model (number of parameters) to weight models against one another. The AIC value of each model represents a tradeoff between its goodness of fit and its complexity. AIC values themselves have no meaning; to determine which model best fit Fraser Sockeye CU data we calculated the delta AIC for each model (AIC - AIC_{min}), thus determining the relative fit of each model. A larger delta AIC value indicates less plausible models, while those with AIC values closer to zero are better fit (Martell *et al.* 2008). The "rules of thumb" state that if the delta AIC values is less than 2 there is substantial empirical support for the model, while those greater than 10 show no support for the model (Martell *et al.* 2008).

Holt et al. (2009) recommended evaluating *abundance* stock status by comparing the current (brood years 2006-2009) effective total spawners (ETS) geometric mean to the *abundance* benchmarks. However, since most Fraser Sockeye exhibit highly cyclic annual abundance (four year cycles) with often persistent dominant (large) abundance cycles followed by weaker (lower) abundance cycles, and since these higher abundance cycles are generally enumerated with higher precision methods, it would be inappropriate to use a geometric mean that downweights the higher abundance years. When geometric means were estimated for CUs they resulted in considerably lower average abundances compared to arithmetic means. Therefore, in the current paper, the arithmetic mean of the recent generation was used to evaluate status. 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, again, stock status would be confounded by cyclic dominance, with dominant years generally having a better stock status compared to weak cycles.

<u>Trends in Abundance (Rate)</u>

There are a number of possible metrics within the *trends in abundance* class of indicator, including metrics that measure trends (e.g. rate of change in the last three generations) and metrics that compare current recent abundances (last generation) to a range of historical baselines (e.g. historical average, a historical maximum, first generation in the time series). A recent study evaluated the effectiveness of different metrics in correctly categorizing the stock 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 the metrics that generally ranked near the top for 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 to the historical maximum ranked consistently lower and metrics that evaluated trends over the last three generations to categorize status performed intermediate to these metrics.

Two 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 metric evaluates trends over the short term, measuring the rate of change over the most recent three generations (using both a deterministic and probabilistic approach, as described in Holt et al. (2009)). The other metric examines the extent of change over the long term, according to the ratio of the current generational geometric mean to the long-term geometric mean. The ratio of the current generation geometric mean to the highest generational mean metric described in Holt et al. (2009) was excluded since it does not accurately reflect the true status of the CU.

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and the International Union for the Conservation of Nature (IUCN) both use the rate of change over the last three generations as their *trends in abundance* metric (COSEWIC 2003a; COSEWIC 2003b; Rand 2008) to assess wildlife status. The upper and lower benchmarks for this metric used by Holt et al. (2009) are respectively, a 15% rate of decline and a 25% rate of decline. These percentages convert to slopes (in $\log_e$ space) of -0.015 (upper benchmark) and -0.026 (lower benchmark); which 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).

To calculate the last three generation trend, abundance time series' were first converted to $\log_e$ space and 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). The purpose of this transformation is to minimize the influence of observation and assessment error and cyclic abundance. Regression analyses were conducted on the last three generations (1998-2009) of the transformed abundance data to calculate the degree of change over time. The slope calculated in $\log_e$ space is then compared to the upper and lower benchmarks presented in the previous paragraph.

The smoothed (four year running average) $\log_e$-transformed spawner abundances were also used when calculating the geometric mean over the most recent generation and the long-term average baseline. Holt et al. (2009) used 0.25 and 0.5 as, respectively, upper and lower benchmarks to delineate stock status according to the ratio of the current generation to the long-term average metric. In the original paper, however, Pestal and Cass (2009) considered ratios less than 0.5 low and those above 0.5 ranging from below average to above average (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). Ratios between 0.5 and 0.75 are considered below average (amber status). Therefore, for Fraser Sockeye a lower benchmark of 0.5 and an upper benchmark of 0.75 were used to provide greater resolution in assessing stock status.

Productivity

These 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.* 1998; Peterman *et al.* 2003; Dorner *et al.* 2008). The $\log_e$(R/EFS) productivity index describes total stock productivity. The remaining two indices remove 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 STOCK STATUS EVALUATION

STOCK STATUS

A*bundance* and *trends in abundance* metrics were used to evaluate stock status of 26 assessable Fraser Sockeye CUs. Overview of these results are presented in the immediately proceeding sections. Detailed results for each CU, including data used, historical backgournd, and status follow the overview results section.

Carrying Capacity

Maximum spawners based on the capacity of juvenile rearing lakes were updated for use as *b* carrying capacity priors for Ricker and KF Ricker models in the evaluation of *abundance* benchmarks. Analysis of the juvenile Sockeye competitor data set found considerable variance between years in lakes where suitable data existed; often two standard errors were in excess of 100% of the mean. Therefore, lakes were grouped as described below and a mean competitor adjustment was applied within groups (Appendix 3, Table 3). In some lakes, the extent of sampling conducted and the lack of non-Sockeye catch indicated that productive capacity was not measurably reduced by competitors. These lakes were Bowron, Chilko, Francois, Kamloops, and Lillooet, lakes. In a second group of lakes, while variance was high, productive capacity was estimated to be reduced by a moderate amount (1-10%; mean ~6%) by competitor foraging. These lakes were Cultus, Adams, Fraser, Mabel, Trembleur, Shuswap, and Quesnel lakes. A third group of lakes had a high variance associated with a large reduction in productive capacity by competitors (15-90%; mean ~37%). These lakes were Anderson, Chilliwack, Harrison, Seton, Pitt, Stuart, and Takla lakes. Rather than use the individual reduction estimates, we applied the mean for each group to arrive at an adjusted productive capacity for each lake.

Given the limitations inherent to the available competitor data and the assumptions that were necessary in order to develop biomass estimates, we can not assign a high degree of confidence to the estimate of competitor biomass. Therefore, the estimates should be used with caution and with the full understanding of how they were derived. For Fraser lakes 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 the Ricker or KF Ricker in a Bayesian statistics approach, carrying capacity '*b*' parameter priors were explored using either lake rearing capacity (updated in current paper) or spawning ground capacity (DFO 1995) data where available. Priors using this data were informative (lognormally distributed) and, what these data were not used, uninformative (uniformally distributed with a range from 0 – 1,000,000) (Table 2). For the uninformative priors, the comparison of different large upper bounds indicated they did not significantly affect benchmark estimates. Generally, the lowest maximum spawning capacity (either lake rearing capacity or spawning ground capacity) was used for priors.

Table 2. CU spawning capacity (Total adults spawners S_{max}) parameter priors used to estimate benchmarks for Ricker and Kalman Filtered Ricker models in a Bayesian framework (green highlighted columns). Summary spawning capacity based on lake rearing photosynthetic rate estimates and spawning ground habitat estimates are also presented.

CONSERVATION UNIT	SR Time Series (Brood Years)	Spawning (S_{max}) Capacity Used in SR Models			S_{max}: Lake Rearing[1]			S_{max}: Spawning Ground[2]
		Prior Distribution	Average	Log Sigma	Average	SD	*N*	
Anderson-ES	1968-2004	**Uniform**	**0-1,000,000**	**Uniform**	286,000	54,000	4	18,000 (channel only)
Bowron-ES	1950-2004	**Lake Rearing**	**40,000**	**0.30**	40,000	NA	1	45,000
Chilko-S & Chilko-ES	1950-2004	**Lake Rearing**	**400,000**	**0.50**	483,000	161,000	6	593,000
Cultus-L	1950-2000	**Lake Rearing**	**80,000**	**0.20**	85,000	17,000	3	56,000
Francois-ES	1973-2004	**Uniform**	**0-1,000,000**	**Uniform**	1,350,000	453,000	2	24,000 (channel only)
Fraser-S	1950-2004	**Lake Rearing**	**550,000**	**0.30**	600,000	201,000	2	434,000
Harrison (U/S)-L	1966-2004	**Uniform**	**0-1,000,000**	**Uniform**	811,000	316,000	2	34,000 (channel only)
Kamloops-ES	1967-2004	**Uniform**	**0-500,000**	**Uniform**	445,000	NA	1	237,000
Lillooet-L	1950-2004	**Lake Rearing**	**164,000**	**0.30**	164,000	NA	1	NA
LFR (River-Type) (immediate migrants)	1950-2004	**Spawning Ground**	**430,000**	**0.50**	NA	NA		428,000
Pitt-ES	1950-2004	**Spawning Ground**	**70,000**	**0.30**	115,000	NA	1	70,000
Quesnel-S & McKinley-S	1950-2004	**Lake Rearing**	**1,000,000**	**0.20**	1,115,000	315,000	10	2,410,000
Seton-L	1965-2004	**Uniform**	**0-300,000**	**Uniform**	188,000	31,000	4	NA
Shuswap-ES	1980-2004	**Uniform**	**0-2,000,000**	**Uniform**	1,900,000	319,000	6	NA
Shuswap-L	1950-2004	**Lake Rearing**	**1,500,000**	**0.40**	1,900,000	319,000	6	1,550,000
Takla-Trembleur-Stuart-S	1950-2004	**Lake Rearing**	**1,400,000**	**0.50**	2,458,000	281,000	3	1,420,000
Takla-Trembleur-Estu	1950-2004	**Lake Rearing**	**600,000**	**0.40**	794,000	170,000	3	589,000

1. Source: J. Hume & L. Pon, Salmon Aquatic Freshwater Ecosystem Program, DFO; Appendix 3.
2. Source: DFO (1995). Fraser River Sockeye Salmon. DFO Publication.

Benchmarks for Spawner Abundance (State)

For all models used, Bayesian MCMC chains burn-in lengths were increased and thinning was conducted if, respectively, chains did not converge or were autocorrelated. One example (Takla-Trembleur-Early Stuart) of the diagnostic results are presented in Appendix 5. A separate Appendix will be provided, however, with all CUs and all models diagnostics, however, due to the length (70 pages) it was excluded from the current report. For the KF Ricker model there were three CUs where estimates of the sigma parameters are not very reliable because the chains were autocorrelated. However, for one CU (Bowron), MCMC iterations for 10 000 samples (i.e., much longer), and then again for 1000 iterations but thinning every 1000 iterations (i.e., thinning at a larger interval) and autocorrelation was removed and in these cases had a minimal effect on the benchmark estimates.

The recommended benchmarks for Pacific Salmon *abundance* benchmarks are the median (50% probability level) lower (S_{gen}) and upper (80%S_{msy}) benchmarks estimated with a Ricker model in a Bayesian framework using priors on the '*b*' carrying capacity parameter (Holt et al. 2009; Holt 2009). However, given most CUs have exhibited persistent declines in productivity (Appendix 2, Figures 1 c & d), Ricker models with truncated (more recent stock-recruitment data only) and KF Ricker models that account for recent productivity were also used to estimate benchmarks. In addition, since many Fraser Sockeye CUs exhibit cyclic dominance, benchmarks were also estimated using a model that includes delayed-density interactions between cycle lines (Larkin model). Therefore, for *abundance* metrics, benchmarks were estimated separately for each CU using three different models (Ricker, KF Ricker, and Larkin) in a Bayesian statistical approach with priors incorporated on the carrying capacity '*b*' parameter for only the Ricker and KF Ricker models. For each CU, benchmarks are presented for all models across six probability levels (10%, 25%, 50%, 75% and 90%) and corresponding status are also presented for each model/probability level relative to the last generation abundance (average ETS from 2006-2009) (Table 4). For each CU, status estimated from Ricker (full time series), KF Ricker, and Larkin model median benchmarks are summarized in Table 3; truncated versions of the Ricker model were not included in Table 3 as they resulted in identical status' to the Ricker model using the full stock-recruitment time series.

Generally, the KF Ricker model and the most truncated Ricker model (brood years 1990-2004) produced the highest benchmarks and the Larkin model produced the lowest; the untruncated Ricker model results were generally inbetween these extremes (Table 4). Although the median probability level is recommended, benchmarks were compared across five probability levels and resulted in lower benchmarks at lower probability levels (less conservative values) and higher benchmarks at higher probability levels (more conservative values). Depending on the CU, status would vary by probability level (Table 4).

For the 18 CUs (including the following aggregated CUs: Chilko-ES/Chilko-S; Quesnel-S/McKinley-S; Takla-Trembelur-S/Stuart-S) with stock-recruitment data, the most truncated Ricker models (brood years 1990-2004) and the KF Ricker models produced the highest upper and lower *abundance* benchmarks since they account for recent lower CU productivity. These two models either produced similar benchmarks (Bowron-ES, Kamloops-ES, Pitt-ES, Chilko-ES/Chilko-S, Quesnel-S/McKinley-S, Fraser-S, Cultus-L, and Lillooet-L) or the KF benchmarks were considerably higher (Anderson-ES, Francois-ES, Shuswap-ES, Stuart-S/Takla-Trembelur-S, LFR-River-Type, Seton-L, Harrison (U/S)-L). The KF Ricker model resulted in a poorer stock status relative to untruncated Ricker models for four CUs (Anderson-ES, LFR-(River-Type), Seton L, and Harrison (U/S)-L). In contrast Larkin models produced benchmarks that were considerably lower than all other model's benchmarks. The Larkin model benchmarks resulted in a better stock status relative to the untruncated Ricker models for nine CUs (Stuart-Early Stuart, Bowron-ES, Francois-ES, Shuswap-ES, Chilko-S/Chilko-ES, Stuart-S/Takla-Trembelur-S, Quesnel-S/McKinley-S, Fraser-S, and Shuswap-L). Based on AIC results, the Larkin model is strongly supported by the stock-recruitment data for all CUs, although the Ricker model with priors on the 'b' parameter (AIC < 2) were also supported for Bowron-ES, Francois-ES and Cultus-L (Table 5).

The abundance status was consistent across all models for only four CUs, Cultus-L (red status), Pitt-ES (green status), LFR (River-Type) (green status) and Kamloops-ES (amber status). For the first three CUs, this consistency is attributed to their extremely low (Cultus-L) or high (Pitt-ES, LFR (River-Type)) current abundance that places the CU below the lower benchmark or above the upper benchmark for all models despite their wide range in benchmark values across models. Seven CU's had similar status for the Ricker and KF Ricker models and a better status for the Larkin model. Specifically, Takla-Trembleur-EStu, Bowron-ES, Francois-ES, Quesnel-S/McKinley-S and Shuswap-ES were red for Ricker models and amber or green (Shuswap-ES only) for the Larkin model. Shuswap-L was amber for Ricker models and green for the Larkin model. For five CUs, status was consistent between the Ricker (untruncated) and the Larkin and different for the KF Ricker model; with the KF Ricker model status' always being poorer.

One Fraser-S had different status for each model (amber: Ricker untruncated; red: KF Ricker; green: Larkin).

Benchmarks for Trends in Spawner Abundance (Rate)

Trends in abundance metrics provide an indication of the current status of the CU (metric 1: ratio of the current generation to the historical average) and the future status (metric 2: linear rate of change in the last three generations). Out of the total 26 assessable CUs (these included the four CUs in the two aggregates: Chilko-S & Chilko-ES and Quesnel-S & McKinley-S), the ratio of the current generation average (2006-2009) to the historical average (abundance ratio) for 18 of these CUs were above the upper benchmarks for this metric (ratio >75%: green status) (Table 3). Most of these CUs have exhibited above average abundance in the mid-1990's (most striking for Summer Run timed CUs) and have subsequently declined and returned to abundances closer to average (Table 3; Appendix 2, Figures 1 a & b). As a result, 13 of these CUs have exhibited decreasing trends in the last three generations that fall between the upper (>15% decline) and lower benchmarks (>25% decline) for this metric (one CU: amber status) or below the lower benchmark (12 CUs: red status). However these recent trends, alone, are not a concern given abundances for these CUs are returning to average. If these trends persist, however, they can affect the future status of this CU. These decreasing trends are coincidental with decreasing productivity trends observed for most Fraser Sockeye CUs.

Five of the 18 CUs that are above the abundance ratio upper benchmark have been exhibiting stable or increasing trends over the past three generations and include Pitt-ES, Harrison (D/S)-L, Lillooet-L, and Lower Fraser River (LFR)(River-Type). The LFR (River-Type) CU comprised of Harrison River Sockeye, in particular, has been exhibited exceptional increases in abundance in recent years. Harrison Sockeye are unique from a number of perspectives including their age, life-history (immediate migrants), and ocean distribution. All these CUs are in the Lower Fraser watershed in adjacent or overlapping rearing lakes (Pitt L, Lillooet-Harrison L). Shuswap-L, in addition has exhibited recent above average abundance and has also not exhibited changes in abundance over the past three generations. Shuswap-L has also not exhibited any persistent trends in productivity.

For five CUs, abundance ratios are below the lower benchmark for this metric (< 50% of the long term average: red status) and includes Bowron-ES, Taseko-ES, Cultus-L, Widgeon (River-Type) and Kamloops Late (red status). For all these CUs, except Widgeon (River-Type) and Kamloops-L, they have also exhibited decreasing trends in the last three generation that are below the lower benchmark for this metric (red status). Of these, Widgeon (River-Type) has been increasing in abundance over the last three generations (green status) and Kamloops Lake has decreased but at a rate between the lower and upper benchmark for this metric (amber status). All these CUs are currently very small in size and, therefore, for all these factors are at high risk of extirpation. For the final two CUs, ratios of the current generation to the time series average are between the lower (ratio: 0.5) and upper (ratio: 0.75) benchmarks for this metric (amber status) and include Takla-Trembleur-EStu and Nahatlach-ES. These three CUs have also been experiencing decreases in productivity and, particularly, for Nahatlach-Es have currently a very small population size. So over all, in total, seven CUs are of particular concern from a stock status perspective for trends in abundance metrics. Only Chilliwack-ES could not be quantitatively evaluated for stock status. Details on these metrics by CU will be presented in individual detailed CU sections below.

Overview of Stock Status for Twenty-Six Assessible CUs

Seven CUs were consistently poor in status (red) across the metrics evaluated and include Takla-Trembelur-EStu, Bowron-ES, Nahatlach-ES, Taseko-ES, Cultus-L, Widgeon (River-Type), and Kamloops-L (Table 3). All these CUs except Takla-Trembluer-EStu have extremely low (<2,000 ETS) recent average abundances (brood years 2006-2009). Takla-Trembleur-EStu was one of these seven CUs that had stock-recruitment data (the other being Cultus-L) and its current average ETS was below the lower benchmarks for all Ricker models and their associated probability levels and was only amber for the Larkin model (Table 4). For Cultus-L, its current average ETS was below the lower benchmark for all models and probability levels (red status) (Table 4). For these seven CUs, almost all metrics were red in status including the ratio of the current generation to the historical average and the linear rate of change in the last three generations with the exception of Takla-Trembelur-EStu and Nahatlach-ES (both amber status for the ratio of the current abundance to the historical average) and Widgeon (River-Type) (green status for the metric that evaluates trends over the last three generations) (Table 3).

Thirteen CUs were intermediate in terms of status and include Kamloops-ES, Anderson-ES, Francois-ES, Shuswap-ES, Chilko-S/Chilko-ES, Stuart-S, Takla-Trembelur-S, Quesnel-S/McKinley-S, Fraser-S, Seton-L, Harrison (U/)-L (Table 3). Although these CUs were all below the lower benchmark for the linear rate of change in the last three generations (red status) (with the exception of Kamloops-ES that was between the lower and upper benchmark for this metric: amber status), most of these CUs were decreasing from a period of above average abundance. For the ratio of the current generation to the historical average metric, all these CUs were close to or above their long term average abundances and, therefore, above the upper benchmark for this metric (green status). For *abundance* metrics, these CU's were generally all between the median lower and upper benchmarks (amber status) with the exception of Shuswap-ES and Fraser-S that were above their median upper benchmarks (green status). For the KF Ricker models and Ricker, CU status' were either similar or poorer to those of the Larkin model (Table 4).

Five CUs were consistently very good in status (green) across the metrics evaluated and include Pitt-ES, LFR (River-Type), Shuswap-L, Harrison (D/S)-L, and Lillooet-L. Interestingly, all these CUs (except Shuswap-L) occur in the Lower Fraser watershed in adjacent lake systems (Harrison Lake, Lillooet-L and Pitt-L). All these CUs are well above their long-term average abundances, have exhibited increasing trends in the last three generations, and had abundances that were largely above the upper benchmarks across all models and probability levels (Tables 3 & 4). The recent abundance for Shuswap-L was only above the upper benchmark (green status) for the Larkin model at the median and lower probability levels and was amber for all other models.

One CU, Chilliwack-ES, could not be quantitatively assessed for stock status due to its relatively short time series, although it has exhibited declines in abundance in recent years and has a very low current spawner abundance (average ETS: 900) (Table 3).

Stock Status: Twenty-Six Assessable Conservation Units

Twenty-six CUs have sufficient information to be assessed for stock status. Of these twenty-six, two (McKinley-S and Chilko-ES) cannot be independently assessed as their data is 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 (Roos 1991; Geen and Andrew 1961), and, therefore, a change in the CU name to Seton-ES might be appropriate.

History: Between 1919 to 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. One additional transfer of fry occurred in 1950 from the Adams River to Anderson Lake (Aro 1979). The 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 was constructed on this system and was operational starting in 1956 (Roos 1991). This facility is comprised of the Seton Dam 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 the 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 they 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 at the tailrace. Success of fish departing the tailrace and entering the Seton River and reaching the dam depends on Seton water quality; 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). Impacts to the downstream migrating smolt stage include ~10% mortality of the smolts as they move through the dam turbines, which 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 the 1980's, the creek was assessed by 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. The Gates Creek and Channel sites were combined to evaluate stock 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).

Trends in Abundance: The early time series, prior to channel construction, is characterized by lower spawner abundance (average EFS from 1954 to 1974: 1,300) (Appendix 2, 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) (Table 3; Appendix 2, 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 from 1995 to 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 2, Anderson-ES, Figure 1 b).

The ratio of the recent average generation abundance relative to the long-term average for Anderson-ES (ratio: 1.98) is almost double the time series average and greater than the upper benchmark for this metric (ratio: 0.75) (green status) (Table 3; 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% rate of decline) and there is an 80% probability this recent trend is below this lower benchmark (red status) (Table 3, Appendix 2, Anderson-ES, Figures 2 a & b).

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 2, Anderson-ES, Figure 1 c). Productivity (R/S) has been particularly low recently from 1998 to 2005 brood years, with four of these years below replacement (Appendix 2, 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 subsequently increased (Appendix 2, Anderson-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 (brood years 1968-2004) to ensure a consistent production time series and spawning area throughout the time series. For Ricker model benchmark estimates (recommended model by Holt et al. 2009), a uniformly distributed prior on the '*b*' parameter that ranged from 0 to 1,000,000 was used (Table 2; Appendix 2, Anderson-ES, Figure 2 d). Using the full time series (brood years 1968-2004), the median lower and upper benchmarks were, respectively, 3,000 and 20,000 ETS (Table 4; Appendix 2, Anderson-ES, Figure 2 e). The recent generational ETS average (4,100) for this CU falls between the Ricker model's lower benchmark and upper benchmarks (amber status) (Tables 3 & 4).

Given Anderson-ES has experienced consistent declines in productivity, benchmarks were also estimated using both a Ricker model with a truncated time series (brood years 1990-2004) and a KF Ricker model. The KF Ricker model produced the largest median lower (70,000) and upper (199,000) benchmarks of all models and the truncated Ricker model produced lower benchmarks (7,000) and upper benchmarks (26,000) that were higher than the Ricker model using the full time series but considerably lower than the KF Ricker model (Table 4). For these models (truncated Ricker and KF Ricker), the recent generational ETS average (4,100) falls below their respective lower benchmarks (red status) (Tables 3 & 4).

The Larkin model was most supported based on statistical theory by the delta AIC results (delta AIC = 0) for Anderson-ES relative to Ricker models that either included or excluded prior information on the '*b*' parameter (Table 5). The Larkin model produced the lowest median lower benchmark (1,000) and upper benchmark (6,000) of all models used and the recent generational ETS average falls between these two benchmarks (amber status) (Tables 3 & 4).

Status Summary: Anderson-ES increased in abundance in the 1970's in part due to the installation of the spawning channel. As a result, the current generation EFS relative to the historical average has almost doubled (green status). The current generation ETS is between the upper and lower benchmarks estimated using the Ricker or Larkin models (amber status). Although the overall status of this CU ranges from red to 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 25% rate of decline (red status), although this CU has been returning to average following a period of above average abundance. Also, since this CU has been experiencing consistent decreases in productivity, the current generation ETS is below the lower benchmark estimated using the KF Ricker model to incorporate this recent lower productivity in the calculation of abundance benchmarks (red status). Therefore, if these trends in abundance and productivity persist into the future they will negatively affect the status of this CU.

<u>Bowron-ES</u>

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) during a period from 1924 - 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. 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 fry from these Sockeye spawners would have to travel upstream through fast flow conditions to reach the lake; these Sockeye may be river-type. Recently, Sockeye have been observed in upper Bowron River and similarly, these also may be a river-type population.

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 2, Bowron-ES, Figures 1 a & b). This CU has recently declined from an average EFS three generations prior to the end of the time series (3,900) to the current generation average EFS (800) (Table 3; Appendix 2, 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 2, 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 3; Appendix 2, Bowron-ES, Figure 2 c). In recent years (last three generations), Bowron-ES EFS has 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) (Table 3; Appendix 2, Bowron-ES, Figures 2 a & b). This trend is likely more pronounced given that the early observed abundance time series is quite possibly biased low (see *Escapement time series* section above).

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 2, Bowron-ES, Figure 1 c). Productivity (R/S) has been particularly low recently from 1994 to 2005 brood years, with six of these years close to or below replacement (Appendix 2, Bowron-ES, Figure 1 d). There are no freshwater or marine survival data available for this CU.

Abundance: The full stock-recruitment time series available 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 2, Bowron-ES,

Figure 2 d). Using the full time series (1950-2004), the median lower and upper benchmarks were, respectively, 4,000 and 17,000 ETS (Table 4; Appendix 2, Bowron-ES, Figure 2 e). The recent generational ETS average (1,600) for this CU falls below the lower benchmark using the Ricker model (red status) (Tables 3 & 4).

Given Bowron-ES has experienced consistent declines in productivity, benchmarks were also estimated using both a Ricker model with truncated time series (brood years 1970-2004 & 1990-2004) and a KF Ricker model. The Ricker model with the most truncated time series (brood years 1990-2004) and KF Ricker model produced the largest median lower (~6,000) benchmarks of all models with similar median upper benchmarks to all other models (~12,000) (Table 4). For these models, the recent generational ETS average (1,600) also falls below their respective lower benchmarks (red status) (Tables 3 & 4).

Although the Ricker model with priors on the '*b*' parameter was most supported by delta AIC results (delta AIC = 0) for Bowron-ES relative to Ricker models without priors and the Larkin model, the Larkin model was still plausible (delta AIC: 1.78) (Table 5). This model produced the lowest median lower benchmark (1,000) and similar upper benchmark (10,000) to all models used and, as a result, the recent generational ETS average falls between these two benchmarks for the Larkin model (amber status) (Tables 3 & 4).

Status Summary: Bowron-ES has reached particularly low abundances in recent years. As a result, the current generation EFS is only 27% of the historical average (red status). The current generation ETS is below the lower benchmarks estimated using the Ricker or KF Ricker models (red status) and between the lower and upper benchmarks for the Larkin model (amber status). The linear rate of change in the last three generations is greater than a 50% rate of decline (red status) and this CU has been experiencing consistent decreases in productivity. Therefore, if these trends in abundance and productivity persist into the future they will further negatively affect the status of this CU. Currently, the abundance is quite low (ETS: 1,600) and declining at rates greater then 50%, therefore, this CU would be categorized at risk by COSEWIC.

<u>Chilko-ES and Chilko-S (CUs combined for stock status assessment)</u>

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 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 to Chilko Sockeye relative to other Sockeye stocks was hypothesized to be linked to their greater energy reserves and ability to therefore withstand a delay in migration (Roos 1991). Based on recent studies, Chilko Sockeye (relative to other similar timed Fraser Sockeye CUs) have been identified as superoptimal migrants (they have greater stride lengths: higher ground speed per tailbeat and use less energy than would be predicted) (Hinch and Rand 2000). Chilko Sockeye are more torpedo shaped 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 2, Chilko-ES & Chilko-S, Figures 1 a-f) (Bradford *et al.* 2000). Limnological surveys in 2009, conducted in response to recent increases in smolt production, found that PR 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). This system was estimated 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.

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) (Table 3; Appendix 2, 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 2, Chilko-ES & Chilko-S, Figures 1 a & b). After 1990, cyclic dominance disappeared (Appendix 2, 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 2, 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) (Table 3; Appendix 2, 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) (Table 3; Appendix 2, Chilko-ES & Chilko-S, Figures 2 a & b).

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 years (Appendix 2, Chilko-ES & Chilko-S, Figure 1 c). Productivity (R/S) has been particularly low recently from the 1994 to 2005 brood years, with six of these years close to or below replacement (Appendix 2, 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 2, Chilko-ES & Chilko-S, Figure 1 e). Marine survival has decreased consistently from the 1990 to 2005 brood years (Appendix 2, Chilko-ES & Chilko-S, Figure 1 f).

Abundance: The full stock-recruitment time series available 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 394,000 and sigma of 5,000 was used, based on calculations of lake rearing capacity (Table 2; Appendix 2, Chilko-ES & Chilko-S, Figure 2 d). Using the full time series (1950-2004), the median lower and upper benchmarks were, respectively, 40,000 and 275,000 ETS (Table 4; Appendix 2, Chilko-ES & Chilko-S, Figure 2 e). The recent generational ETS average (275,100) for this CU falls above the upper benchmark estimated using the Ricker model (green status) (Tables 3 & 4).

Given the Chilko-ES & Chilko-S aggregate has experienced consistent declines in productivity, benchmarks were also estimated using both a Ricker model with truncated time series (brood years 1970-2004 & 1990-2004) and a KF Ricker model. The KF Ricker model produced the largest median lower benchmark (63,000) and a similar upper benchmark to all other Ricker models with full or truncated time series (average: 261,000). For these models, the recent generational ETS average (275,000) also falls above all their respective median upper benchmarks (green status) (Tables 3 & 4).

The Larkin model was most supported by delta AIC results (delta AIC = 0) for the Chilko-ES & Chilko-S aggregate relative to Ricker models that either included or excluded prior information on the '*b*' parameter (Table 5). The Larkin model produced the lowest median lower benchmark (26,000) and a slightly higher upper benchmark (291,000) than all models used and the recent generational ETS average falls between these two benchmarks (amber status) (Tables 3 & 4).

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 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 productivity (attributed to declines in both freshwater and marine survival) 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.

<u>Chilliwack-ES</u>

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 populations 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 that decrease 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 the standard lake survey methods, and both estimates from standard methods and tower counts did not deviate significantly from one another.

Trends in Abundance: Chilliwack Lake exhibits variable escapement throughout the time series and was particularly low in the last generation (average EFS: 500) relative to the long-term average (average EFS: 1,100) (Table 3; Appendix 2, Chilliwack-ES, Figure 1 b (Chilliwack Lake only)). Dolly Varden Creek can only be compared to Chilliwack Lake post-2000 and during these years exhibited a considerably shallower declining trend compared to Chilliwack Lake. Dolly Varden Creek has 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 2, Chilliwack-ES, Figure 1 a). In years when the Dolly Varden Creek population is large (2001, 2004 & 2008), it comprises 94% of the total escapement to this CU. On all weaker abundance years for Dolly Varden Creek, the creek comprises 54% of the total escapement for this CU. Given Dolly Varden Creek comprises a greater average proportion of EFS relative to the total (Dolly Varden Creek plus Chilliwack Lake post-2001) and given the trends appear to be considerably different 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.

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.

Status Summary: Chilliwack-ES trends in abundance could not be quantitatively evaluated as the combined time series of the creek and lake is too short (2001-2009). The lake has been exhibiting declining trends in recent years, however, a considerably less pronounced trend was observed for the creek that makes up the largest proportion of total abundance in this CU. Overall, the recent generation average ETS for this CU is small (900) and, this alone, would place this CU in a risk category by COSEWIC. Status will be evaluated in future years as more data becomes available.

<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 starting in the 1960's. 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 lower 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 stock 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 stock 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 the 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 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 (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, given 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 (Bradford et al 2010; Schubert et al. 2002; Cultus Recovery Team 2009), only wild unmarked fish (no adipose-fin clip) were included in the escapement time series.

Trends in Abundance: Cultus-L has experienced three distinct periods of abundance (Appendix 2, Cultus-L, Figures 1 a & b). The earliest years in the time series (1934 to 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 2, 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) (Table 3; Appendix 2, 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 this metric (-0.026) and there is a 100% probability the recent trend is below the lower benchmark for this metric (red status) (Table 3; Appendix 2, Cultus-L, Figures 2 a & b).

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 2, 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 2, 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 2, 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 that 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, and therefore stock-recruitment data for this year can be included in the time series. For Ricker model benchmark estimates (recommended model by Holt et al. 2009), a lognormally distributed prior on the '*b*' parameter with a mean of 80,000 and sigma of 2,000 was used, based on calculations of lake rearing capacity (Table 2; Appendix 2, Cultus-L, Figure 2 d). Using the full time series

(1950-2000), the median lower and upper benchmarks were, respectively, 12,000 and 32,000 ETS (Table 4; Appendix 2, Cultus-L, Figure 2 e). The recent generational ETS average (900) for this CU falls below the median lower benchmark estimated using the Ricker model (red status) (Table 4).

Given Cultus-L has experienced consistent declines in productivity, benchmarks were also estimated using both a Ricker model with truncated time series (brood years 1970-2000 & 1990-2000) and a KF Ricker model. All models produced similar median lower benchmarks (average: 13,000) and upper benchmarks (26,000) including the Ricker model full time series (Table 4). For these models, the recent generational ETS average (900) also falls below the median lower benchmark estimated using the Ricker model (red status) (Tables 3 & 4).

The Ricker model with priors was more statistically supported relative to Ricker models excluding prior information on the '*b*' parameter and the Larkin model, when using delta AIC results (delta AIC = 0) for Cultus-L. However, this model selection tool also gives support to the Larkin model (delta AIC: 0.82) (Table 5). The Larkin model produced the lowest median lower benchmark (1,000) and upper benchmark (9,000) of all models used, though the recent generational ETS average still falls below this lower benchmark (red status) (Tables 3 & 4).

Status Summary: Cultus Lake started to decrease in abundance in the late 1960's and has reached particularly low abundances in recent years. As a result, the current generation EFS is only 7% of the historical average (red status). The current generation ETS is below the lower benchmarks estimated using the Ricker, KF Ricker or Larkin models (red status). The linear rate of change in the last three generations is greater than a 50% rate of decline (red status) and this CU has been experiencing consistent decreases in productivity. Currently, the wild Sockeye abundance is quite low (ETS: 900). This CU is classified by COSEWIC as 'endangered' and recovery efforts for this CU are on-going.

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.

Within the Nadina Channel there have been 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). Given that the early timed Nadina River population merged with the late population after channel construction and the number of Sockeye distributed between the channel and the river is controlled, all three sites must be included to evaluate stock 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.

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 2, Francois-ES, Figure 1 a). This CU has declined from an above average EFS three generations prior to the end of the time series (22,600) to the current generation average EFS (4,900) (Table 3; Appendix 2, 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 2, 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) (Table 3; Appendix 2, 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 69% probability this recent trend is below the lower benchmark for this metric (red status) (Table 3; Appendix 2, Francois-ES, Figures 2 a & b).

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 2, 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 2, 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 2, 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. For Ricker model benchmark estimates (recommended model by Holt et al. 2009), a uniformly distributed prior (0-1,000,000) was used for the '*b*' parameter (Table 2; Appendix 2, Francois-ES, Figure 2 d). Using the full time series (1973-2005), the median lower and upper benchmarks were, respectively, 18,000 and 60,000 (Table 3; Appendix 2, Francois-ES, Figure 2 e). The recent generational ETS average (9,400) for this CU falls below the lower benchmark estimated using the Ricker model (red status) (Tables 3 & 4).

Given Francois-ES has experienced consistent declines in productivity, benchmarks were also estimated using both a Ricker model with truncated time series (brood years 1990-2004) and a KF Ricker model. The KF Ricker model produced the largest median lower benchmark (90,000) and upper benchmark (average: 203,000) of all other Ricker models with full or truncated time series. The truncated Ricker model produced similar median lower and upper benchmarks to the Ricker model using the full time series (Table 4). For these models, the recent generational ETS average (15,400) also falls below all their respective median lower benchmarks (red status) (Tables 3 & 4).

The Larkin model was most supported by delta AIC results (delta AIC = 0) for Francois-ES relative to Ricker models that either included or excluded prior information on the '*b*' parameter (Table 5). The Larkin model produced the lowest median lower benchmark (2,000) and upper benchmark (18,000) compared to all models used and the recent generational ETS average falls between these two benchmarks (amber status) (Tables 3 & 4).

Status Summary: Francois-ES has experienced relatively high escapements starting in the mid-1990's. As a result, the current generation EFS is 1.35 times greater than the historical average (green status). The current generation ETS, however, is below the lower benchmark for the Ricker and KF Ricker models (red status) and between the lower and upper benchmarks for the Larkin model (amber). Although the overall status of this CU ranges from red to 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 25% 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 productivity (attributed to both freshwater and marine survival decreases) starting in the 1980'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.

<u>Fraser-S</u>

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 this log driving period (Schubert 2000).

There is a significant hydro-electric infrastructure on the Nechako River; 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 affected Sockeye historically, 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). 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 the sampling biases that occurred in the mark recapture program were bi-directional and, as a result, cumulatively small (Schubert 2007).

Trends in Abundance: The average abundance 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 was 53,000 (Table 3). 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) (Table 3; Appendix 2, 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 2, Fraser-S, Figures 1 a & b). After this period, abundance fluctuated, with no persistence of cyclic dominance and large inter-annual variability in abundance. Throughout the time series spawner success has remained high (~90%) and has not exhibited any persistent trends (Appendix 2, 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) (Table 3; Appendix 2, 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) (Table 3; Appendix 2, Fraser-S, Figures 2 a & b).

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 2, 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 2, 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, although the time series is short (1990 to 2002 brood years) (Appendix 2, 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. For Ricker model estimates (recommended model by Holt et al. 2009), a lognormally distributed prior on the '*b*' parameter with a mean of 56,700 and sigma of 3,000 was used based on calculations of lake rearing capacity (Table 2; Appendix 2, Fraser-S, Figure 2 d). Using the full time series (brood years 1950-2004), the median lower and upper benchmarks were respectively, 44,000 and 204,000 (Table 4; Appendix 2, Fraser-S, Figure 2 e). The recent generational ETS average (87,500) for this CU falls between the median lower and upper benchmark estimated using the Ricker model (amber status) (Tables 3 & 4).

Given Fraser-S has experienced consistent declines in productivity, benchmarks were also estimated using both a Ricker model with truncated time series (brood years 1970-2004 & 1990-2004) and a KF Ricker model. The KF Ricker model produced the largest lower median benchmark (96,000) and similar upper benchmarks (164,000) to all other Ricker models with full or truncated time series. The recent generational ETS average for this CU falls below the KF Ricker model lower median benchmark (red status) (Tables 3 & 4). The most truncated time series (1990-2004) Ricker model median benchmarks were similar to the KF model benchmarks and the least truncated (1970-2004) were similar to the untruncated Ricker model benchmarks. For these models, the recent generational ETS average (87,500) falls between their respective median lower and upper benchmarks (amber status) (Tables 3 & 4).

The Larkin model was most supported by delta AIC results (delta AIC = 0) for the Fraser-S aggregate relative to Ricker models that either included or excluded prior information on the '*b*' parameter (Table 5). The Larkin model produced the lowest median lower (6,000) and upper (78,000) benchmarks of all models used and the recent generational ETS average falls above the upper benchmark (green status) (Tables 3 & 4).

Status Summary: Fraser-S has experienced relatively high escapements starting in the mid-1970's. As a result, the current generation EFS is 1.31 times greater than the historical average (green status). The current generation ETS, however, is between the lower and upper benchmarks for the Ricker model (amber status), below the lower benchmark for the KF Ricker model (red status) and above the upper benchmark for the Larkin model (green). Although the overall status of this CU ranges from red to 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 25% 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 productivity (attributed to both freshwater and marine survival decreases) starting in the 1980'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.

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.

Trends in Abundance: Harrison (D/S)-L is a small CU with an average EFS of 1,500 (Appendix 2, Harrison (D/S)-L, Figure 1 a). From 1964 to 1998, the population abundance was relatively low (average EFS: 580), and has subsequently increased from 1999 to 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 lower spawner success (1953: 30%; 1981: 67%; 1983: 54% and 2008: 63%) (Appendix 2, 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) (Table 3; Appendix 2, 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) (Table 3; Appendix 2, Fraser-S, Figures 2 a & b). There may be some data quality issues in the time series that could result in this period under-estimating total abundance. Therefore, it is possible that these increasing trends are somewhat biased high.

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.

Status Summary: Harrison (D/S)-L has experienced much higher escapements starting in the mid-1990's relative to the early time series. As a result, the current generation EFS is 13.1 times greater than the historical average (green status). In addition, the linear rate of change in the last three generations shows an increasing trend (green status). Productivity and abundance data are not available for this CU. Overall, the data available indicate that status for this CU is good.

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 (International Pacific Salmon Fisheries Commission 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 (International Pacific Salmon Fisheries Commission 1972). 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). East Creek has independent data early in the time series and was included in the Weaver Creek estimate after 1951. Steelhead Creek, not included separately in the escapement records, has also been rolled up into the totals for Weaver Creek. The 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.

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). . Average EFS across the entire time series was 19,200 (Table 3). Harrison (U/S)-L has not exhibited cyclic dominance throughout the time series (Appendix 2, 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 2, 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) (Table 3; Appendix 2, 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) benchmark (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 2, Harrison (U/S)-L, Figures 2 a & b).

Productivity: In contrast with other Early Summer Run and Early Stuart CUs, Harrison (U/S)-L has not exhibited any persistent trends in productivity throughout the time series (based on Kalman filter Ricker *a* parameter values)(Appendix 2, 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 2, 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 2, 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. For Ricker model benchmark estimates (recommended model by Holt et al. 2009), a uniformly distributed (0-1,000,000) prior on the '*b*' parameter was used (Table 2; Appendix 2, Harrison (U/S)-L, Figure 2 d). Using the full time series (1966-2005), the median lower and upper benchmarks were, respectively, 9,000 and 78,000 (Table 3; Appendix 2, Harrison (U/S)-L, Figure 2 e). The recent generational ETS average (20,400) for this CU falls between the median lower and upper benchmark estimated using the Ricker model (amber status) (Tables 3 & 4).

Harrison (U/S)-L has not experienced persistent declines in productivity, although this CU has declined in productivity in the last generation. In order to evaluate the effect of this recent decrease in productivity on *abundance* stock status, benchmarks were also estimated using both a Ricker model with truncated time series (brood years 1990-2004) and a KF Ricker model. The KF Ricker model produced the largest median lower benchmark (38,000) and upper benchmark (219,000) of all other Ricker models with full or truncated time series. The recent generational ETS average for this CU falls below the KF Ricker model median lower benchmark (red status) (Tables 3 & 4). The truncated time series (1990-2004) Ricker model median benchmarks were lower than the full time series but the recent generational ETS average still falls between the lower and upper benchmarks (amber status)(Tables 3 & 4).

The Larkin model was most supported by delta AIC results (delta AIC = 0) for the Harrison (U/S)-L aggregate relative to Ricker models that either included or excluded prior information on the '*b*' parameter (Table 5). The Larkin model produced the lowest median lower benchmark (3,000) and slightly higher upper benchmarks (median: 51,000) compared to all models used and the recent generational ETS average falls between the lower and upper benchmark (amber status) (Tables 3 & 4).

Status Summary: Harrison (U/S)-L increased in abundance in the 1970's in part due to the installation of the spawning channel. As a result, the current generation EFS is close to (80% of) the historical average (green status). The current generation ETS is between upper and lower benchmarks estimated using the Ricker or Larkin models (amber status). Although the overall status of this CU ranges from red to 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 25% rate of decline (red status). Also, since this CU has been experiencing consistent decreases in productivity, the current generation ETS is below the lower benchmark estimated using the KF Ricker model to incorporate this recent lower productivity in the calculation of abundance benchmarks (red status). Therefore, if these trends in abundance and productivity persist into the future they will negatively affect the status of this CU.

<u>Kamloops-ES</u>

Sites: Populations that rear in Kamloops Lake include Clearwater, 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). 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 Fennel 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 a historical average of 400 EFS (prior to 2000) to a recent average of 164,000 EFS (2000-2009). The shifts 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 some observations of larger 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.

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 2, Kamloops-ES, Figure 1 a). Much of the early increases in abundance are attributed to Fennell, which increased in abundance starting in the mid-1970's after the Barriere dam removal. Raft 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 and Fennel has shown significant declines (in the last two years of the time series the population was only 500 EFS). Over the time series, average EFS was 6,900. This CU has declined from an above average EFS period three generations prior to the end of the time series (16,800) to the current generation average EFS (9,200) (Table 3; Appendix 2, Kamloops-ES, Figure 1 b). Spawner success was generally high throughout the time series (average: 88%) with the exception of 2008 for Fennell (20%) and Raft (70%) (Appendix 2, 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) (Table 3; Appendix 2, 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 (Table 3; Appendix 2, Kamloops-ES, Figures 2 a & b).

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 1970 to 1990 brood years and productivity has subsequently remained consistently lower than the early time period (Appendix 2, Kamloops-ES, Figure 1 c). Productivity (R/S) has been particularly low recently from 2003 to 2005 brood years, with two of these years close to or below replacement (Appendix 2, 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. For Ricker model benchmark estimates, a uniformly distributed prior (0-500,000) on the '*b*' parameter was used (Table 2; Appendix 2, Kamloops-ES, Figure 1 d). Using the full time series (brood years 1967-2005), the median lower and upper benchmarks, respectively, are 5,000 and 23,000 (Table 3; Appendix 2, Kamloops-ES, Figure 1 e). The recent generational ETS average (15,400) for this CU falls between the median lower and upper benchmark estimated using the Ricker model (amber status) (Tables 3 & 4).

Given Kamloops-ES has experienced consistent declines in productivity, benchmarks were also estimated using both a Ricker model with truncated time series (brood years 1990-2004) and a KF Ricker model. The KF Ricker model produced the largest median lower benchmark (15,000) and upper benchmark (average: 42,000) compared to all other Ricker models with full or truncated time series. The truncated Ricker model produced median lower and upper benchmarks intermediate to the Ricker model using the full time series and the KF Ricker model (Table 4). For the truncated Ricker model and the KF Ricker model, the recent generational ETS average (15,400) also falls between their respective median lower and upper benchmarks (amber status) (Tables 3 & 4).

The Larkin model was most supported by delta AIC results (delta AIC = 0) for Kamloops-ES relative to Ricker models that either included or excluded prior information on the '*b*' parameter (Table 5). The Larkin model produced the lowest median lower benchmark (2,000) and upper benchmark (18,000) compared to all models used and the recent generational ETS average falls between these two benchmarks (amber status) (Tables 3 & 4).

Status Summary: Kamloops-ES increased in abundance in the 1970's in part due to increases in the Fennell Creek population, attributed to the removal of the Barriere dam. Raft did not exhibit a building trend until later in the time series (starting in 1995). As a result of these increases, the current generation EFS is double the historical average (green status). The current generation ETS is between upper and lower benchmarks estimated using the Ricker, KF Ricker or Larkin models (amber status). Although the overall status of this CU ranges from amber to 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 between a 15% and 25% rate of decline (amber status), although this CU has been returning to average following a period of above average abundance. Productivity trends for this CU have also been consistently decreasing on the time series. Therefore, if these trends in abundance and productivity persist into the future they will negatively affect the status of this CU.

<u>Kamloops-L</u>

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). 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 generally 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.

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 2, 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 2, 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) (Table 3; Appendix 2, 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 (Table 3; Appendix 2, Kamloops-L, Figures 2 a & b).

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.

Status Summary: Kamloops-L has been decreasing in abundance starting in the mid-1970's. As a result of these decreases, the current generation EFS is only 30% of the historical average (red status). The linear rate of change in the last three generations has been less than a 25% rate of decline but greater than a 15% decline (amber status). There are no stock-recruitment data available to estimate abundance benchmarks for this CU, however, overall abundance is extremely low (average ETS from 2006-2009 brood years is 300). This low abundance alone, would place this CU in a risk category by COSEWIC.

<u>Lillooet-L</u>

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 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). 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.

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 2, 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 success has remained high (~91%) and has not exhibited any persistent trends (Appendix 2, Lillooet-L, Figure 1 b).

The ratio of the recent generation average abundance to the long-term average (ratio: 1.48) is greater than the upper benchmark for this metric (ratio: 0.75) (green status) (Table 3; Appendix 2, Lillooet-L, Figure 2 c). This CU has increased in abundance in the last three generations with a positive slope (0.02) that is greater than the upper benchmark for this metric (-0.015); there is only a 2% probability that this recent trend falls below the lower benchmark for this metric (green status) (Table 3; Appendix 2, Lillooet-L, Figures 1 a & b).

Productivity: Similar to Summer Run CUs, Lillooet-L has exhibited systematic declines in productivity (Kalman filter Ricker *a* parameter values) from the mid-1980's (Appendix 2, 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 2, 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. For Ricker model benchmark estimates (recommended by Holt et al. 2009), a lognormally distributed prior on the '*b*' parameter with a mean of 164,000 and sigma of 3,000 was used based on calculations of lake rearing capacity (Table 2; Appendix 2, Lillooet-L, Figure 2 d). Using the full time series (brood years 1950-2004), the median lower and upper benchmarks were respectively, 12,000 and 79,000 (Table 4; Appendix 2, Lillooet-L, Figure 2 e). The recent generational ETS average (104,900) for this CU falls above the upper benchmark estimated using the Ricker model (green status) (Tables 3 & 4).

Given Lillooet-L has experienced consistent declines in productivity, benchmarks were also estimated using both a Ricker model with truncated time series (brood years 1970-2004 & 1990-2004) and a KF Ricker model. The KF Ricker model and the most truncated Ricker model (1990-2004) similarly produced the largest lower median benchmarks (average 27,000) and similar upper benchmarks (59,000) to all other Ricker models with full or truncated time series. The recent generational ETS average for this CU falls above these median upper benchmarks (green status) (Tables 3 & 4). The least truncated time series (1970-2004) Ricker model benchmarks were similar to full time series Ricker model (green status) (Tables 3 & 4).

The Larkin model was most supported by delta AIC results (delta AIC = 0) for the Lillooet-L aggregate relative to Ricker models that either included or excluded prior information on the '*b*' parameter (Table 5). The Larkin model produced the lowest median lower benchmark (6,000) and slightly higher upper benchmarks (73,000) to all models used and the recent generational ETS average falls above the upper benchmark (green status) (Tables 3 & 4).

Status Summary: Lillooet-L has experienced relatively high escapements starting in the mid-1970's and increasing further since the mid-1980's. As a result, the current generation EFS is 1.48 times greater than the historical average (green status). The current generation ETS is above the upper benchmarks using the Ricker, KF Ricker, or Lakin models (green status). In addition, the linear rate of change in the last three generations has been increasing (green status). Despite all these metrics, this CU has been experiencing consistent decreases in productivity starting in the 1990's with the lowest productivity on record occurring in recent years. Therefore, although the overall status of this CU is green, if this productivity trend persists into the future it may negatively affect the status of this CU.

<u>Lower Fraser River (River-Type)</u>

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, 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 Harrison 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 provide an important control on water levels at low discharge (Rood and Hamilton 1995). As a result, 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)(International Pacific Salmon Fisheries Commission 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). 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 have 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)

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 2, 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 2, 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)(Table 3; Appendix 2, 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) and there is a 0% probability this trend is below the lower benchmark (Table 3; Appendix 2, 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.

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 2, 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 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). For Ricker model benchmark estimates (recommended model by Holt et al. 2009), a lognormally distributed prior on the '*b*' parameter with a mean of 430,000 and sigma of 5,000 was used, based on calculations of lake spawning capacity (Table 2, Lower Fraser River (River-Type), Figure 2 d). Using the full time series (brood years 1950-2005), the median lower and upper benchmarks were respectively, 14,000 and 46,000 (Table 4; Appendix 2, Lower Fraser River (River-Type), Figure 2 e). The recent generational ETS average (147,700) for this CU falls above the median upper benchmark estimated using the Ricker model (green status) (Tables 3 & 4).

Given the Lower Fraser (River-Type) CU experienced a recent year of low productivity, benchmarks were also estimated using both a Ricker model with truncated time series (brood years 1970-2004 & 1990-2004) and a KF Ricker model. The KF Ricker model produced the largest median lower benchmarks (35,000) and upper benchmarks (194,000) to all other Ricker models with full or truncated time series. The recent generational ETS average for this CU falls between this model's median upper and lower benchmarks (amber status) (Tables 3 & 4). All truncated Ricker model time series produced similar upper and lower benchmarks to the full time series (green status) (Tables 3 & 4).

The Larkin model was most supported by delta AIC results (delta AIC = 0) for the Lower Fraser River (River-Type) CU relative to Ricker models that either included or excluded prior information on the '*b*' parameter (Table 5). The Larkin model produced the lowest median lower benchmark (1,000) and upper benchmark (10,000) of all models used and the recent generational ETS average falls above the upper benchmark (green status) (Tables 3 & 4).

Status Summary: Lower Fraser River (River-Type) is comprised only of Harrison River Sockeye, which have experienced exceptionally high escapements in recent years. As a result, the current generation EFS is 6.98 times greater than the historical average (green status). The current generation ETS is above the upper benchmarks using the Ricker and Larkin models (green status) and between the lower and upper benchmarks using the KF Ricker model (amber status). In addition, the linear rate of change in the last three generations has been increasing (green status). This CU has been experiencing consistent increases in productivity, in contrast to most other CUs, which have been decreasing. Therefore, the overall status of this CU is largely green, and the amber status indicated by the KF Ricker model might be attributed to the one recent year of well below average productivity for this CU.

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). The river assessments began in 1975 using visual surveys (peak live cumulative dead methods). Lake assessments consistently started 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 revised Karl English method (calculating filled values according to the proportional contribution of the lake to the river, 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.

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 2, 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 2, 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 the 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) (Table 3; Appendix 2, 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) (Table 3; Appendix 2, Nahatlach-ES, Figures 2 a & b).

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.

Status Summary: Nahatlatch-ES increased in abundance in the mid-1980's and decreased starting in the mid-1990's. As a result, the current generation EFS is only 55% of the historical average (amber status). The linear rate of change in the last three generations has been greater than a 50% rate of decline (red status). In addition, the recent generation average ETS for this CU is small (1,700) and, this alone, would place this CU in a risk category by COSEWIC. Therefore, overall the status of this CU ranges from red to amber.

Pitt-ES

Sites: The only site for Pitt-ES Sockeye is 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 that cut off half of this creek from Sockeye Spawning and flushed 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). This site was assessed using mark recapture methods. The escapement time series includes Sockeye removed for hatchery enhancement.

Trends in Abundance: From 1950 to 1995, the Pitt-ES Sockeye escapement was relatively small (average EFS: 8,600) (Appendix 2, 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 2, 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) (Table 3; Appendix 2, Pitt-ES, Figure 2 c). Overall, this CU has not changed in abundance over the last three generations with 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) (Table 3; Appendix 2, Pitt-ES, Figures 2 a & b).

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 from the 1960 to 1970 brood years, low productivity from the 1975 to 1990 brood years and high productivity again from the 1990 to 1995 brood years and subsequently decreased (Appendix 2, Pitt-ES, Figure 1 c). Productivity (R/S) has been particularly low recently from the 2000 to 2005 brood years, with productivity in all these years falling below replacement (Appendix 2, Pitt-ES, Figure 1 d). There are no freshwater or marine survival data available for this CU.

Abundance: The stock-recruitment time series includes the years 1950-2004. The Pitt escapement and recruitment time series includes fish removed for Pitt River hatchery enhancement. For Ricker model estimates of benchmarks (recommended model by Holt et al. 2009), a lognormally distributed prior with a mean of 73,000 and sigma of 5,000 was used on the '*b*' parameter based on calculations of lake spawning capacity (Table 2; Appendix 2, Pitt-ES, Figure 2 d). Using the full time series (brood years 1950-2004), the median lower and upper benchmarks were respectively, 8,000 and 24,000 (Table 4; Appendix 2, Pitt-ES, Figure 2 e). The recent generational ETS average (32,200) for this CU falls above the upper benchmark estimated using the Ricker model (green status) (Tables 3 & 4).

Given Pitt-ES has experienced declines in productivity in recent years, benchmarks were also estimated using both a Ricker model with truncated time series (brood years 1970-2004 & 1990-2004) and a KF Ricker model. All these models produced similar lower benchmarks (average: 9,000) and upper benchmarks (average: 25,000) to the Ricker model with the full time series, therefore, the recent generational ETS average for this CU falls above the upper benchmarks (green status) (Tables 3 & 4).

The Larkin model was most supported by delta AIC results (delta AIC = 0) for the Pitt-ES CU relative to Ricker models that either included or excluded prior information on the '*b*' parameter (Table 5). The Larkin model produced the lowest lower benchmark (3,000) and slightly lower upper benchmarks (20,000) to all models used and the recent generational ETS average falls above the upper benchmark (green status) (Tables 3 & 4).

Status Summary: Pitt-ES experienced high escapements from the mid-1990's to 2000, and although abundances have declined post-2000 they remain high relative to the early time series. As a result, the current generation EFS is 2.17 times greater than the historical average (green status). The current generation ETS is above the upper benchmarks using the Ricker, KF Ricker and Larkin models (green status). In addition, the linear rate of change in the last three generations has not changed (green status). This CU has been experiencing decreases in productivity in recent years. The overall status of this CU is green.

<u>Quesnel-S and McKinley-S (CUs combined for stock status assessment)</u>

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 on the Horsefly 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 and no fish were able 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, and covered 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 populations (Roos 1991). The 1913 Hells Gate landslide presented a barrier to migration particularly for later timed Quesnel-CU Sockeye; later timed Sockeye made it into the system because of higher water levels. The Quesnel Sockeye were more greatly affected than other populations by the landslide because they have smaller energy reserves and because of their spawn timing. Horsefly Sockeye spawn shortly after arrival at their spawning ground versus other populations that have later spawning timing (Roos 1991). Droughts that de-water smaller streams and Beaver dams that present a barrier to fish migration into smaller streams have both impacted available spawning habitat throughout the time series.

Historically (1950's to 1970's) there also has been high pre-spawn mortality in the Horsefly due to their earlier timing and migration through warmer Lower Fraser and spawning ground water temperatures. There was a particularly large mortality event on the Horsefly in 1961 attributed to a *Chondrococcus columnaris* outbreak caused by warmer waters. In 1966 cold water was siphoned from McKinley Lake to cool McKinley Creek to 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 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 carrying capacity; the channel component is small relative to the natural Horsefly stock. The Quesnel/Horsefly project also includes the operation of a temperature control/dam structure on McKinley Creek. The McKinley Creek structure provides lower water temperatures in McKinley Creek to reduce pre-spawn mortality on dominant and subdominant cycle years.

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 relationships from 1980 to 2009 given gaps occurred during these later years when Quesnel-ES abundance was significantly higher than the early time series.

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 and abundance only starts to increase in the mid-1990's.

Trends in Abundance: From 1950 to 1980, the Quesnel-S & McKinley-S aggregate escapement was relatively small (average EFS: 23,000) (Appendix 2, Quesnel-S & McKinley-S, Figure 1 b). Escapement increased starting in 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). Spawner success has been consistently high for this CU throughout the time series with the exception of 2008 (~60% spawner success) (Appendix 2, Quesnel-S & McKinley-S, Figure 1 b).

The ratio of the recent generation average abundance to the long-term average (ratio: 7.70) is considerably higher than the upper benchmark for this metric (ratio: 0.75) (green status) (Table 3; Appendix 2, Quesnel-S & McKinley-S, Figure 2 c). In recent years (last three generations), the Quesnel-S & McKinley-S aggregate has declined following a period of above average EFS (see previous paragraph). The slope of this recent trend (-0.17) 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) (Table 3; Appendix 2, Quesnel-S & McKinley-S, Figures 2 a & b).

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 years (Appendix 2, 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 2, 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 2, Quesnel-S & McKinley-S, Figure 1 e). Marine survival data are not available for this CU.

Abundance: The stock-recruitment time series includes the years 1950-2004. For Ricker model benchmarks estimates (recommended model of Holt et al. 2009), a lognormally distributed prior with a mean of 73,000 and sigma of 5,000 on the '*b*' parameter was used based on calculations of lake rearing capacity (Table 3; Appendix 2, Quesnel-S & McKinley S, Figure 2 d). Using the full time series (brood years 1950-2004), the median lower benchmark and upper benchmarks were, respectively, 126,000 and 717,000 (Table 3; Appendix 2, Quesnel-S & McKinley-S, Figure 2 e). The recent generational ETS average (95,800) for this CU falls below the lower benchmark estimated using the Ricker model (red status) (Tables 3 & 4).

Given Quesnel-S & McKinley-S has experienced consistent declines in productivity, benchmarks were also estimated using both a Ricker model with truncated time series (brood years 1970-2004 & 1990-2004) and a KF Ricker model. The KF Ricker model and the most truncated time series Ricker model (1990-2004) produced similarly the largest median lower benchmark (~240,000) and similar upper benchmarks (average: 500,000) to all other Ricker models with full or truncated time series. The least truncated Ricker model (1970-2004) produced similar median lower and upper benchmarks to the Ricker model using the full time series (Table 4). For all these models, the recent generational ETS average (95,800) also falls below all their respective median lower benchmarks (red status) (Tables 3 & 4).

The Larkin model was most supported by delta AIC results (delta AIC = 0) for Quesnel-S & McKinley-S relative to Ricker models that either included or excluded prior information on the '*b*' parameter (Table 5). The Larkin model produced the lowest median lower benchmarks (38,000) and similar upper benchmarks (427,000) compared to all models used and the recent generational ETS average falls between these two benchmarks (amber status) (Tables 3 & 4).

Status Summary: The Quesnel-S & McKinley-S aggregate increased in abundance starting in the mid-1990's and has decreased from this period of high abundance in recent years. As a result, the current generation EFS is 7.7 times greater than the historical average (green status). The current generation ETS is below the lower benchmarks using the Ricker or KF Ricker models (red status) and between the lower and upper benchmarks for the Larkin model (amber). The overall status of this CU ranges from red to green and other metrics also 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 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.

<u>Seton-L</u>

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, however, the current Seton-L population is similar to the Lower Adams River, indicating that transplants from this area in the 1950's were most successful (Withler *et al.* 2000). Despite the proximity of Seton-L to Anderson-ES Sockeye during spawning and overlap in 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).

The Seton Creek hydro facility on this system includes the Seton Dam 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, in particular, presents a barrier to Sockeye migration, a fishway was constructed in concert with the dam (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, as they are either attracted to the home-stream water or they use it as a 'cold-water' refuge. Fish are then injured in the tailrace directly (Fretwell 1980) or this delay can lead to premature senescence and subsequent enroute mortality. Success of fish departing the tailrace, entering the Seton River and reaching the dam depends on Seton water quality, with higher Cayoosh Creek dilution resulting in higher migration failure (10-30% migration failure during IPFSC studies). Once fish enter the Seton River they must travel 5 km upriver, ascent the Seton Dam fishway, then migrate through Seton Lake to the spawning grounds. Locating the fishway presents an additional challenge; when Gates fish were experimentally transplanted downstream 25% could not re-locate the fishway entrance (Roscoe and Hinch 2008). Identified impacts from the hydropower facility also include the mortality of smolts (~10%) as they migrate downstream through the dam turbines (Andrew and Geen 1958), which has yet to be resolved (Roos 1991). There has been a significant improvement in Seton-L Sockeye since 1970 (to 1982) (Roos 1991).

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

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 2, Seton-L, Figure 1 a). Spawner success has remained high (~96%) and has not exhibited any persistent trends (Appendix 2, 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) (Table 3; Appendix 2, Seton-L, Figure 2 c). This CU has decreased in abundance in the last three generations and 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) (Table 3; Appendix 2, Seton-L, Figures 1 a & b).

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 2, Seton-L, Figure 1 c). Productivity (R/S) has been particularly low recently (1999 to 2005 brood years), with three of these years below or close to replacement (Appendix 2, Seton-L, Figure 1 d). Freshwater and marine survival data are not available for this CU.

Abundance: The stock-recruitment time series includes the years 1965-2004. There are considerable gaps in the early time series and this system was only consistently assessed starting in 1965. For Ricker estimates of benchmarks (recommended model by Holt et al. 2009), a uniformly distributed prior (0-300,000) was used on the '*b*' parameter (Table 3; Appendix 2, Seton-L, Figure 2 d). Using the full time series (brood years 1965-2004), the median lower and upper benchmarks were respectively, 1,000 and 9,000 (Table 4; Appendix 2, Seton-L, Figure 2 e). The recent generational ETS average (5,300) for this CU falls between the lower and upper above the upper benchmark estimated using the Ricker model (amber status) (Tables 3 & 4).

Given Seton-L has experienced declines in productivity in recent years, benchmarks were also estimated using both a Ricker model with truncated time series (brood years 1990-2004) and a KF Ricker model. The KF Ricker model produced the largest median lower benchmark (10,000) and upper benchmarks (27,000) to all other Ricker models with full or truncated time series. For this model, the recent generational ETS average (5,300) falls below its median lower benchmark (red status) (Tables 3 & 4). The truncated Ricker model benchmarks were similar to the full time series resulting in a similar status (amber status) (Tables 3 & 4).

The Larkin model was most supported by delta AIC results (delta AIC = 0) for the Seton-L CU relative to Ricker models that either included or excluded prior information on the '*b*' parameter (Table 5). The Larkin model produced a similar lower benchmark (1,000) and upper benchmarks (6,000) to the Ricker model and the recent generational ETS average falls similarly between the lower and upper benchmark (amber status) (Tables 3 & 4).

Status Summary: Seton-L has experienced relatively stable escapements throughout the time series. As a result, the current generation EFS is close (90%) to the historical average (green status). The current generation ETS is between the lower and upper benchmarks for the Ricker and Larkin models (amber status) and below the lower benchmark for the KF Ricker model (red status). The overall status ranges from red to green and 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). This CU has also been experiencing consistent decreases in productivity, 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.

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, respectively. Hatchery enhancement of Upper Adams River from 1948-1980 using largely Seymour River (and to a lesser extent Taseko and Cayenne) Sockeye (Withler *et al.* 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 (Beacham *et al.* 2004; Withler *et al.* 2000).

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 obstruction by the Hells Gate landslide and the Adams splash dam. The Momich Sockeye may have originated as strays from egg transplants in 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 populations, 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/Creek(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). 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 starting in 1994; therefore a large number of these systems were excluded from the assessment of stock status.

Seymour was the most consistently assessed system, with no gaps in the time series. Mark recapture surveys were used on larger escapement years and peak live cumulative dead visual surveys on smaller escapement years. Scotch 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 abundances 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 cycles (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.

For Adams Lake and Momich Lake populations, Momich, Momich/Cayenne and Upper Adams River were included in the assessment of stock 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.

Eagle and Anstey were excluded from the assessment of stock 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 stock status. Anstey was also excluded because of significant gaps in the time series prior to 1990, and uncertainty in the estimates, 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.

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 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 2, Shuswap-ES, Figures 1 a & b). Cyclic dominance is not synchronous for populations in the Shuswap-ES CU, particularly between Shuswap Lake rearing populations and Adams/Momich Lake rearing populations (Appendix 2, 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) (Table 3; Appendix 2, 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) (Table 3; Appendix 2, Shuswap-ES, Figures 2 a & b).

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 has decreased from the 1980 to 1990 brood year and has subsequently increased (Appendix 2, 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 2, 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. For Ricker model estimates of benchmarks (recommended model by Holt et al. 2009), a uniformly distributed prior (0-2,000,000) was used for the '*b*' parameter (Table 2; Appendix 2, Shuswap-ES, Figure 2 d). Using the full time series (brood years 1980-2004), the median lower and upper benchmarks were respectively on average, 98,000 and 219,000 (Table 4; Appendix 2, Shuswap-ES, Figure 2 e). The recent generational ETS average (64,600) for this CU falls below the lower benchmark estimated using the Ricker model (red status) (Tables 3 & 4).

Given Shuswap-ES has experienced declines in productivity particularly in recent years, benchmarks were also estimated using both a Ricker model with truncated time series (brood years 1990-2004) and a KF Ricker model. The KF Ricker model produced the largest median lower benchmark (199,000) and upper benchmarks (387,000) to all other Ricker models with full or truncated time series. For this model, the recent generational ETS average (64,600) also falls below its median lower benchmark (red status) (Tables 3 & 4). The truncated Ricker model benchmarks were similar to the full time series resulting in a similar status (red status) (Tables 3 & 4).

The Larkin model was most supported by delta AIC results (delta AIC = 0) for the Shuswap-ES CU relative to Ricker models that either included or excluded prior information on the '*b*' parameter (Table 5). The Larkin model produced the smallest lower benchmark (6,000) and upper benchmarks (46,000) to the Ricker model and the recent generational ETS average falls above the upper benchmark (green status) (Tables 3 & 4).

Status Summary: Shuswap-ES has increased in abundance starting in the mid-1980's. As a result, the current generation EFS is close (90%) to historical average (green status). The current generation ETS is below the lower benchmarks for the Ricker and KF Ricker models (red status) and above the upper benchmark for the Larkin models (green status). The overall status ranges from red to green and 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 25% rate of decline (red status). Therefore, if these trends in abundance persist into the future they will negatively affect the status of this CU.

<u>Shuswap Complex-L</u>

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 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 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).

Adams River dominates the total abundance for this CU (80% 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 10% 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 also 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 moved to the Shuswap Lake-Main Arm site and no more records occurred in the Shuswap Lake site. 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 there were no more records of the Shuswap Lake-Main Arm site. Therefore, these nine sites, 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 were small 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 only 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.

Trends in Abundance: Cyclic dominance is synchronous in the Shuswap-L complex, with the large dominant cycle (2006), followed by a much smaller subdominant cycle (2007) and two very weak cycles (2008 & 2009) (Appendix 2, Shuswap-L, Figure 1 a). Abundance has been relatively consistent on the dominant cycle for 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%); Momich River in 1999 (58%) and 2006 (46%), Little River in 1999 (35%), 2001 (65%) 2006 (64%) and 2007 (69%); Lower Shuswap River in 1997 (67%) and 2001 (29%) and Pass Creek in 2003 (20%) and 2006 (40%) (Appendix 2, Shuswap-L, Figure 1 b).

The ratio of the recent generation average abundance to the long-term average (ratio: 0.95) is higher than the upper benchmark for this metric (ratio: 0.75) (green status) (Table 3; Appendix 2, Shuswap-L, Figure 2 c). This CU has increased in abundance over the last three generations with a positive slope (0.03) that is greater than the upper benchmark for this metric (-0.015) and there is only a 12% probability that this recent trend is below the lower benchmark for this metric (green) (Table 3; Appendix 2, Shuswap-L, Figures 2 a & b).

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 2, 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 2, 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 2, 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. For Ricker model benchmark estimates (recommended model of Holt et al. 2009), a lognormally distributed prior with a mean of 178,400,000 and sigma of 4,000 was used on the '*b*' parameter based on calculations of lake rearing capacity (Table 2; Appendix 2, Shuswap-L, Figures 2 d). Using the full time series (brood years 1950-2004). Using the full time series (brood years 1950-2004), the median lower benchmark and upper benchmarks were, respectively, 374,000 and 1,343,000 (Table 3; Appendix 2, Shuswap-L, Figure 2 e). The recent generational ETS average (578,400) for this CU falls between the lower and upper benchmark estimated using the Ricker model (amber status) (Tables 3 & 4).

Given Shuswap-L has experienced consistent declines in productivity, benchmarks were also estimated using both a Ricker model with truncated time series (brood years 1970-2004 & 1990-2004) and a KF Ricker model. The KF Ricker model produced the largest median lower benchmark (519,000) and similar upper benchmarks (1,166,000) to all other Ricker models with full or truncated time series. The truncated Ricker models produced similar median lower and upper benchmarks to the Ricker model using the full time series (Table 4). For all these models, the recent generational ETS average (578,400) also falls between their respective median lower and upper benchmarks (amber) (Tables 3 & 4).

The Larkin model was most supported by delta AIC results (delta AIC = 0) for Shuswap-L relative to Ricker models that either included or excluded prior information on the '*b*' parameter (Table 5). The Larkin model produced the lowest median lower benchmarks (51,000) and similar upper benchmarks (537,000) compared to all models used and the recent generational ETS average falls above the upper benchmark (green status) (Tables 3 & 4).

Status Summary: Shuswap-L has experienced relatively consistent high abundances throughout the time series. As a result, the current generation EFS is close (95%) to the historical average (green status). The current generation ETS is between the lower and upper benchmarks for the Ricker and KF Ricker models (amber status) and above the upper benchmark for the Larkin models (green status). The linear rate of change in the last three generations has largely not changed (green status). Productivity has also been relatively consistent throughout the time series, with a decrease only in recent years. Overall, however, the status of this CU ranges from amber to green.

<u>Stuart-S</u>

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 Stuart-S CU experienced 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), although it is expected to be less severe than in the Stellako River due to different physical characteristics in this system compared to Fraser-S (Roos 1991).

Late Stuart may be limited in terms of available spawning grounds and the Lake has a greater capacity to rear fry than that supported by spawning sizes (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). These two sites were consistently assessed, have a relatively complete time series and 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 on 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 (modified English 2007 method).

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

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 was 49,400. This CU has declined from an above average EFS period three generations prior to the end of the time series (92,700) to the current generation average EFS (22,700) (Table 3; Appendix 2, 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 Kuzchwa 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) (Table 3; Appendix 2, Stuart-S, Figure 2 c). In recent years (last three generations), 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) (Table 3; Appendix 2, Stuart-S, Figures 2 a & b).

Productivity (data combined with Takla-Trembleur-S CU): Similar to other Summer Run CU's, the Stuart-S & Takla-Trembleur aggregate has exhibited systematic declines in productivity (Kalman filter Ricker *a* parameter values) since the 1990 brood year (Appendix 2, 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 2, 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/Trembluer-S). For Ricker model benchmark estimates (recommended model of Holt et al. 2009), a lognormally distributed prior with a mean of 135,800,000 and sigma of 5,000 on the '*b*' parameter was used based on calculations of lake rearing capacity (Table 2; Appendix 2, Stuart-S, Figure 2 d). Using the full time series (brood years 1950-2004), the median lower benchmark and upper benchmarks were, respectively, 107,000 and 508,000 (Table 3; Appendix 2, Stuart-S, Figure 2 e). The recent generational ETS average (59,100) for this CU falls below the lower benchmark estimated using the Ricker model (red status) (Tables 3 & 4).

Given Stuart-S (aggregated with Takla-Trembelur-S) has experienced consistent declines in productivity, benchmarks were also estimated using both a Ricker model with truncated time series (brood years 1970-2004 & 1990-2004) and a KF Ricker model (pending analysis). The most truncated Ricker model produced higher median lower benchmarks (226,000) and the least truncated (1970-2009) produced a similar median lower benchmark to the Ricker model using the full time series (Table 4). Upper benchmarks were similar across all models. For all these models, the recent generational ETS average (59,100) also falls below all their respective median lower benchmarks (red status) (Tables 3 & 4).

The Larkin model was most supported by delta AIC results (delta AIC = 0) for Stuart-S relative to Ricker models that either included or excluded prior information on the '*b*' parameter (Table 5). The Larkin model produced the lowest median lower benchmarks (26,000) and similar upper benchmarks (216,000) compared to all models used and the recent generational ETS average falls between these lower and upper benchmarks (amber status) (Tables 3 & 4).

Status Summary: Stuart-S increased in abundance in the early 1990's, and in recent years has somewhat declined relative to the early time series. As a result, the current generation EFS is double the historical average (green status). The current generation ETS (Stuart-S & Takla-Trembleur-S aggregate) is below the lower benchmark for the Ricker model and between the lower and upper benchmark for the Larkin model (amber status). Although the overall status of this CU ranges from red to 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 shows a greater than 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 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.

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: These summer-timed SK spawn at the outlet streams of the large lakes in this system (Middle, Sakeniche, Kazchek) in the same locations as the Takla-Trembelur-Early Stuart timed SK (Holtby and Ciruna 2007). Most of the available spawning capacity for this CU occurs in the Middle River. Availability of good spawning ground in Middle River is the main limiting factor of the size of the Takla-Trembelur-S population (International Pacific Salmon Fisheries Commission 1972). Historically, construction occurred within the watershed (pulpwood and sawlog harvesting and the extenstion of the Pacific Great Eastern Railway) that resulted in some disturbance to spawning beds in Middle River (International Pacific Salmon Fisheries Commission 1972).

Middle River was enhanced with eggs from Birkenhead River in 1923 and the Kazcheck in 1924 to 1928 from the Birkenhead, Skeena, Stuart to Kazchek (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). 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 modified English et al. (2007) method. Sakeniche River was also assessed using 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.

Trends in Abundance: Abundance was relatively low up to 1988 (average EFS: 19,800) and was relatively high post-1988 (average EFS: 38,600). Across the entire time series, average EFS was 26,400. This CU has declined from an above average EFS period three generations prior to the end of the time series (29,600) to the current generation average EFS (5,400) (Table 3; Appendix 2, Takla-Trembleur-S, Figure 1 b). The Takla-Trembleur-S CU exhibits strong cyclic dominance, with one dominant cycle (average EFS: 97,000) and three subdominant cycles (average EFS: 4,700). Throughout the time series spawner success has remained high (~93%) and generally consistent, 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 Middle River and Kazchek exhibit similar trends throughout the time series.

The ratio of the recent generation average abundance to the long-term average (ratio: 0.95) is higher than the upper benchmark for this metric (ratio: 0.75) (green status) (Table 3; Appendix 2, Takla-Trembleur-S, Figure 2 c). In recent years (last three generations), Takla-Trembleur-S has declined following a period of above average EFS (see previous paragraph). The negative slope of this recent trend (-0.18) is steeper than the lower benchmark for this metric (-0.026 or 25% rate of decline) and there is a 99% probability that this recent decreasing trend is below the lower benchmark for this metric (red status) (Table 3; Appendix 2, Takla-Trembleur-S, Figures 2 a & b).

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 2, 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 2, 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). For Ricker model benchmark estimates (recommended model of Holt et al. 2009), a lognormally distributed prior with a mean of 135,800,000 and sigma of 5,000 on the '*b*' parameter was used based on calculations of lake rearing capacity (Table 2; Appendix 2, Takla-Trembleur-S, Figure 2 d). Using the full time series (brood years 1950-2004), the median lower benchmark and upper benchmarks were, respectively, 107,000 and 508,000 (Table 3; Appendix 2, Takla-Trembleur-S, Figure 2 e). The recent generational ETS average (59,100) for this CU falls below the lower benchmark estimated using the Ricker model (red status) (Tables 3 & 4).

Given Takla-Trembleur-S (aggregated with Stuart-S) has experienced consistent declines in productivity, benchmarks were also estimated using both a Ricker model with truncated time series (brood years 1970-2004 & 1990-2004) and a KF Ricker model (pending analysis). The most truncated Ricker model produced higher median lower benchmarks (226,000) and the least truncated (1970-2009) produced a similar median lower benchmark to the Ricker model using the full time series (Table 4). Upper benchmarks were similar across all models. For all these models, the recent generational ETS average (59,100) also falls below all their respective median lower benchmarks (red status) (Tables 3 & 4).

The Larkin model was most supported by delta AIC results (delta AIC = 0) for the Takla-Trembleur-S & Stuart-S aggregate relative to Ricker models that either included or excluded prior information on the '*b*' parameter (Table 5). The Larkin model produced the lowest median lower benchmarks (26,000) and similar upper benchmarks (216,000) compared to all models used and the recent generational ETS average falls between these lower and upper benchmarks (amber status) (Tables 3 & 4).

Status Summary: Takla-Trembleur-S abundance has been relatively high through the time series with decreases in the 1960's and 1970's and in recent years. As a result, the current generation EFS is close to historical average (green status). The current generation ETS (Stuart-S & Takla-Trembleur-S aggregate) is below the lower benchmark for the Ricker model and between the lower and upper benchark for the Larkin model (amber status). Although the overall status of this CU ranges from red to 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 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.

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. For the Early Stuart Run timing (Stuart-EStu) there are 50 enumeration sites in the escapement database, including: 5 Mile Creek, 10 Mile Creek, 15 Mile Creek, 25 Mile Creek, Ankwill Creek, Babptiste 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 Babtiste and Butterfield), Tildesley Creek, Unnamed Creek (placeholder for unknown names) (Appendix 1).

History: Historical evidence as far back as 1920 indicates that the Early Stuart Run has never been large (Cooper and Henry 1962). 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 consistently occurred 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'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 through the Fraser Canyon, they have experienced delayed migration in some years. 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, Takla-Trembleur-EStu Sockeye were blocked downstream of Hells Gate for 15 days in 1955 due to a later than normal freshet, resulting in very low escapement and fish in poor condition (escapement: 2,000). In 1960 this CU was 15 days late arriving on the spawning grounds and, as a result, a large number did not reach the grounds (Holtby and Ciruna 2007). 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).

The many 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 the Middle River near the outlet of Takla Lake (with the possible exception of Rosette) (International Pacific Salmon Fisheries Commission 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 (International Pacific Salmon Fisheries Commission 1972).

Escapement time series: Four key sites in the Takla/Trembleur-Estu CU have been enumerated consistently, Forfar, Gluske, Kynoch and Rossette Creeks (Appendix 1). Earlier in 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 consistently assessed using peak live cumulative dead methods include 15 Mile, 25 Mile, 5 Mile, Ankwill, Dust (also assessed in several years with methods other than peak live cumulative dead, mark recapture in 1981 and enumeration fences in 1997 and 2000-2006), Frypan, Shale, and Narrows Creeks. The twelve sites (Forfar, Gluske, Kynoch, Rosette, 15 Mile, 25 Mile, 5 Mile, Ankwill, Dust, Frypan, Shale, and Narrows) required negligible gap filling. 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, which were gap-filled using the revised English method for aggregates of sites that had correlated abundance trends (Driftwood: Blackwater, Consolidated, Driftwood, Kastberg, Kotsine, Lion, Porter; Takla North East Arm: 5 Mile, 15 Mile, 25 Mile, Shale, Forsythe, Ankwill, Frypan, Takla North West Arm: Crow; Point; Takla South Arm: Sandpoint, Narrows, Sakeniche, Bivouac Trembleur:, Felix, Paula).

A total of twenty-two sites were excluded from the escapement time series. Sixteen sites were not included because they were only assessed one or two times annually, 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), French (many gaps and small abundances) Creeks.

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 these escapements have subsequently declined (Appendix 2, 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 was 40,900. This CU has declined from an above average EFS period three generations prior to the end of the time series (31,000) to the current generation average EFS (13,300) (Table 3; Appendix 2, 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 2, 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) (Table 3; Appendix 2, Takla-Trembleur-EStu, Figure 2 c). In recent years (last three generations), Takla-Trembelur-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) (Table 3; Appendix 2, Takla-Trembleur-EStu, Figures 2 a & b).

Productivity: Similar to Early Summer Run CUs, Takla-Tremleur-EStu has exhibited systematic declines in productivity (Kalman filter Ricker *a* parameter values) since the mid-1960 brood years (Appendix 2, Takla-Trembleur-EStu, Figure 1 c). Productivity (R/S) has been particularly low recently from 1995 to 2005 brood years, with eight of these years below replacement (Appendix 2, Takla-Trembleur-EStu Figure 1 d). Early freshwater survival (fry to EFS) has been variable, increasing and decreasing throughout the time series (Appendix 2, Takla-Trembleur-EStu, Figure 1 e). Marine survival data are not available for this CU.

Abundance: The stock-recruitment time series includes the years 1950-2004. For Ricker model benchmark estimates (recommended model of Holt et al. 2009), a lognormally distributed prior with a mean of 600,000 and sigma of 4,000 on the '*b*' parameter was used based on calculations of lake rearing capacity (Table 2; Appendix 2, Takla-Trembleur-EStu, Figure 2 d). Using the full time series (brood years 1950-2004), the median lower benchmark and upper benchmarks were, respectively, 77,000 and 244,000 (Table 3; Appendix 2, Takla-Trembleur-EStu, Figure 2 e). The recent generational ETS average (26,500) for this CU falls below the lower benchmark estimated using the Ricker model (red status) (Tables 3 & 4).

Given Takla-Trembleur-EStu has experienced consistent declines in productivity, benchmarks were also estimated using both a Ricker model with truncated time series (brood years 1970-2004 & 1990-2004) and a KF Ricker model (pending analysis). The most truncated Ricker model produced higher median lower benchmarks (129,000) and the least truncated (1970-2009) produced a median lower benchmark in-between the Ricker model using the full time series and the most truncated Ricker model (1990-2004)(Table 4). Upper benchmarks were similar across all models. For all these models, the recent generational ETS average (26,500) also falls below all their respective median lower benchmarks (red status) (Tables 3 & 4).

The Larkin model was most supported by delta AIC results (delta AIC = 0) for Takla-Trembleur-EStu relative to Ricker models that either included or excluded prior information on the '*b*' parameter (Table 5). The Larkin model produced the lowest median lower benchmark (12,000) upper benchmark (94,000) compared to all models used, and the recent generational ETS average falls between these lower and upper benchmarks (amber status) (Tables 3 & 4).

Status Summary: Takla-Trembleur-EStu experienced higher abundances in the mid-1980's to mid-1990's and subsequently declined. As a result, the current generation EFS is 58% of the historical average (amber status). The current generation ETS is below the lower benchmark for the Ricker and KF Ricker model (red status) and between the lower and upper benchmark for the Larkin model (amber status). Although the overall status of this CU ranges from red to amber, 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 shown a greater than 50% decline (red status). This CU has also been experiencing consistent decreases in productivity starting in the 1960'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.

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).

Trends in Abundance: Taseko Lake Sockeye are small in abundance (average EFS: 1,300) (Appendix 2, 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 2, 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) (Table 3; Appendix 2, 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) (Table 3; Appendix 2, Taseko-ES, Figures 2 a & b). The average size of this CU is small (average ETS: 2,300).

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.

Status Summary: Taseko-ES abundance has been relatively low since the 1960's and particularly low in recent years. As a result, the current generation EFS is only 32% of the historical average (red status). The linear rate of change in the last three generations has been greater than a 50% rate of decline (red status). Although the lake surveys likely underestimate true abundance, the current low abundance (ETS: 600) would place this CU in a category of risk by COSEWIC.

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 in 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 where they migrate, that facilitates 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 (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 (Appendix 1).

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 2, 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) (Table 3; Appendix 2, 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 (Table 3; Appendix 2, 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.

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.

Status Summary: Widgeon (River-Type) abundance has been relatively low starting in the mid-1980's. As a result, the current generation EFS is only 35% of the historical average (red status). The linear rate of change in the last three generations has increased (green status). The current low abundance (ETS: 500) and extremely small spatial distribution would place this CU in a category of risk by COSEWIC.

<u>Stock Status: Ten Tentative Conservation Units (Additional Research Required)</u>

<u>Alouette-ES</u>

An Early Summer timed run (April-July migration) of anadromous Sockeye salmon spawned (September-November) on the mainstem of the Alouette River and reared in Alouette Lake prior to the construction of a hydroelectric dam (1925-1928) on this system (Gaboury and Bocking 2004). After its construction, the dam blocked fish passage and eliminated this run of anadromous 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, 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 stock 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).

<u>Boundary Bay (River-Type)</u>

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.

<u>Cariboo-S (River-Type)</u>

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.

<u>Coquitlam-ES</u>

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 analysis 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 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 stock 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).

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 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 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 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. This CU is also a placeholder until more data can be collected to confirm the persistence of this CU.

Stock Status: Five Conservation Units Removed 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 occur in this lake.

Francois (later-timed)-ES/S (was erroneously labelled Francois-L)

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 difference in spawning location and timing that spatially and temporally isolated them from one another. After channel construction in 1973, this 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 of higher abundance Fraser-S (Stellako River) abundances. These populations are not persistent and are likely not genetically distinct from the Fraser-S CU populations and, therefore, also should not be considered a separate CU.

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

For Abundance metrics, both the structural (different models) and stochastic (probability distribution) uncertainty was presented in Tables 3 and 4 to encompass a range of uncertainty in these benchmarks. Figures for each CU in Appendix 2 further contribute to understanding the details behind each CUs status for each metric. For *trends in abundance* metrics, the current paper attempts to address the complexity of the red, amber, green zones for WSP stock 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 3). This approach provides more information on the actual CU values, rather than simply presenting one of three colors for each metric. We have not combined the status from each metric into an overall, single measure of status for each CU. This would require information on the status of other indicators (distribution and fishing mortality) that are not yet assessed. In any event, developing a method to combine the status based on each individual metrics into a single status zone (red, amber or green), if deemed important, needs careful consideration so as not to oversimplify the information content of each metric.

For most CUs (13 out of the 26 assessible CUs), status for their suite of metrics were a blend of both status (red, amber and green) and severity of status' (on how far below or above the upper or lower benchmarks their metric values fell) (Table 3). There were seven CUs that were consistently in the status red zone across most, if not all metrics, including Takla-Trembelur-EStu, Bowron-ES, Nahatlatch-ES, Taseko-ES, Cultus-L, Widgeon (River-Type) and Kamloops-L (Table 3). Two of these CUs are very small in size over the long term time series (Taseko-ES (2,300), Widgeon (River-Type) (600)) and four are moderately small (Bowron-ES (8,000), Nahatlach-ES (4,200), Cultus-L (9,600) and Kamloops-L (7,000)). Only Takla-Trembelur-EStu (78,500) was a much larger CU historically and currently remains at much higher abundances than other CUs with consistently red zone status across most metrics. For the smaller CUs, given their low abundances and decreasing trends they are at a high risk of extirpation. One of these CUs is currently listed by COSEWIC as 'endangered'(Cultus-L) with recovery efforts on-going.

There were five CUs that were consistently in the status green zone across most, if not all metrics, including Pitt-ES, LFR (River-Type), Shuswap-L, Harrison (D/S)-L, and Lillooet-L. Interestingly, all of these CUs (except Shuswap-L) occur in the Lower Fraser watershed in adjacent lake systems (Harrison Lake, Lillooet-L and Pitt-L). These CUs are well above their long-term average abundances, have exhibited increasing trends in the last three generations, and had abundances that were largely above the upper benchmarks across all models and probability levels (Tables 3 & 4). The recent abundance for Shuswap-L was only above the upper benchmark (green zone) for the Larkin model at the median and lower probability levels and was in the amber zone for all other models. Lower Fraser (River-Type) Sockeye and Harrison (D/S)-L, both in the Harrison Lake system, have been exhibiting significant increases in abundance over their long-term averages, although it is possible that some of Harrison (D/S)-L trends may be attributed to poorer quality data earlier in the time series. Lower Fraser (River-Type) Sockeye, comprised of Harrison River Sockeye, have been exhibiting persistent increasing trends in productivity (with the exception of the 2005 brood year) and have a unique age composition (3_1 and 4_1), life-history (migrate to the ocean sometime after gravel emergence and later ocean entry than other Fraser Sockeye CUs) and ocean distribution (remain in the Strait of Georgia for several months after ocean entry in contrast to all other CUs that migrate rapidly north out of the Strait).

There was considerable variability in the *abundance* benchmarks and associated CU status depending on the structure of the population dynamics models applied. Given most CUs have been exhibiting long-term decreases in productivity, models and the resulting benchmarks that consider these trends might be appropriate. They imply, of course, that the recent levels are representative of the future. It is important to note that future projections/forecasts of productivity are highly uncertain. Simulations by Holt (2009) indicated that the probability of extirpation increased at higher abundances for simulated salmon populations that exhibit linear decreases in productivity relative to trendless, linear increase and cyclic productivity patterns. The KF Ricker model generally produced the highest benchmarks given they consider only the most recent year's instrinsic productivity and, typically, most CUs have experienced low productivity in the last four to eight brood years in their time series (Grant et al. 2009). Even the Lower Fraser (River-Type) CU, comprised of Harrison River Sockeye, had a higher KF Ricker benchmark than all other models since, although it has generally been increasing in productivity, one recent year's productivity was particularly low. The higher benchmark was attributed to the 2005 brood year productivity, which was amongst the lowest productivites on record for this CU. For all CUs, the highly truncated Ricker models (brood years 1990-2004) produced benchmarks that were either similar to the KF Ricker model benchmarks or lower, depending on whether the recent intrinsic productivity was similar to the intrinsic productivity experienced by a CU from 1990-2004.

For both the Ricker and KF Ricker model, 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.

We used an arithmetic mean of the recent generation (2006-2009) ETS instead of the geometric mean or abundance in the last year of the time series recommended by Holt et al. (2009). This was done so that, in the first case of the last generation mean, the dominant cycles were not downweighted by a geometric means since they are generally assessed with higher accuracy and precision than the lower abundance cycles. In the second case, using the single last year in the time series would confound the interpretation of stock status for highly cyclic stocks since dominant cycles would always have a better stock status than subdominant or weak cycles. Given the persistence of cyclic dominance for Fraser Sockeye, it might be inappropriate to use a generation abundance average for these Ricker models.

Instead, the Larkin model, which considers the delayed effect of spawner abundance from previous broods on recruitment (i.e. cycle line interactions), might be more appropriate when comparing the recent generation average to benchmarks. Larkin model benchmarks were consistently much lower than all other model benchmarks and, as a result, CU status using this model was generally better. With this model, comparing the mean in the recent generation to the Larkin benchmarks is more appropriate than with the Ricker models, as they account for delayed-density effects across cycle lines. The one caveat is that with decreasing productivity observed in most CU's since as early as the 1950's, the Larkin model benchmarks that do not consider recent productivity might underestimate benchmarks if low productivity persists into the future, and results in a greater risk of extinction.

For a large number of CUs (15 of the 26 assessible 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 above average abundance in the 1990s. This metric is consistently used by the World Conservation Union (IUCN) and the COSEWIC to determine stock status. However, the case of Fraser Sockeye emphasizes the importance of placing this metric in the context of the historical time series. In and of themselves they do not indicate a stock of concern, depending on the historical time series, but instead are metrics that should be tracked, since if they persist into the future these trends will affect stock status.

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 course scale for most systems. If these indicators of stock 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.

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. Consideraby more work can be done in talking to experts on Fraser Sockeye to pull together more information on these CUs that includes both traditional knowledge of the data, the animal, and its habitat.

ACKNOWLEDGMENTS

This work benefited from discussions with Timber Whitehouse, Keri Benner, Mike Lapointe and Ann-Marie Huang. We also greatfully acknowledge individuals who contributed text and edits to the threats section including David Patterson, Merran Hague, Jason Hwang, Brad Fanos, Kyle Garver, Ann-Marie Huang, and Mike Lapointe. Finally, this paper would not be possible without the dedicated field crews working on Fraser Sockeye in the field, laboratory and office who provide the data and detailed understanding of this animal.

Table 3. Stock Status for each metric and each of the 26 Assessible CUs. All status' are color coded red if they are below the lower benchmark (LB), green if they are above the upper benchmark (UB) and amber if they are between the LB and UB for each metric. To interpret *Trends in Abundance* status', the time series average effective female spawners (EFS)(Avg.), the average EFS the third generation from the end of the time series, and the last generation average EFS (Last Gen.) are provided for each CU. For *Trends in Abundance* metric 1, the ratio of the current generation to the historical average, UB and LB are the same across all CUs and are, respectively 0.5 for the LB and 0.75 for the UB. Ratios are presented for each CU and colour coded to correspond with status. For *trends in abundance* metric 2, linear rate of change in the last three generations, for all CU's the LB is a 25% rate of decline (slope: -0.026) and the UB is a 15% rate of decline (slope: -0.015). Log slopes are presented for each CU and colour coded to correspond with status. To interpret *Abundance* status', time series average effective total spawners (ETS) and the recent generation (2006-2009) average ETS are provided for each CU. Ricker (full time series), Kalman Filter Ricker (Kalman) and Larkin model stock status by CU are provided relative to the estimated median lower and upper benchmarks (benchmarks are unique to each CU and are presented in Table 4). For CUs with no stock-recruitment data, recent generation average ETS is coloured red or amber depending on whether they would be considered at risk by COSEWIC criteria.

	Escapement: (EFS)			Trends (EFS) (Metric 1)	Trends (EFS) (Metrics 2 & 3)		Escapement: (ETS)		Abundance (Metric 1)		
Run Timing Group / Conservation Unit	Avg.	Gen. 3rd from Last	Last Gen.	Ratio of Current Generation to Historical Average	Linear Rate of Change Change in Last 3 Gens.	Prob. Decline <LB	Long-Term Avg.	2006-2009 Avg.	Ricker	Kalman	Larkin
				0.25 0.50 0.63 0.75 1.0	percent: -50% -25% -15% +% / slope: -0.063 -0.026 -0.015 +%						
	(EFS)	(EFS)	(EFS)				(ETS)	(ETS)			
Early Stuart											
Takla-Trembleur-Estu	40,900	31,000	13,300	0.58	-0.1	0.999	78,500	26,500			
Early Summer											
Bowron-ES	4,300	3,900	800	0.27	-0.19	0.99	8,000	1,600			
Kamloops-ES	6,900	16,800	9,200	2.14	-0.02	0.381	12,500	15,400			
Anderson-ES	3,600	6,200	2,400	1.98	-0.04	0.804	7,600	4,100			
Francois-ES	7,500	22,600	4,900	1.35	-0.04	0.687	16,500	9,400			
Pitt-ES	13,200	38,900	15,800	2.17	0	0.271	28,300	32,200			
Shuswap-ES	21,200	23,700	37,000	0.9	-0.06	0.891	39,900	64,600			
Nahatlach-ES	2,200	2,300	1,000	0.55	-0.14	1	4,200	1,700	NA	NA	NA
Chilliwack-ES[2]	1,100	1,400	500	NA NA NA NA NA NA	NA NA NA NA NA	NA	2,000	900	NA	NA	NA
Taseko-ES	1,300	800	400	0.32	-0.12	0.974	2,300	600	NA	NA	NA

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

Table 3. Continued (see previous pages description).

Run Timing Group / Conservation Unit	Escapement: (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 in Last 3 Gens. (percent: -50%, -25%, -15%, +%; slope: -0.063, -0.026, -0.015, +%)	Prob. Decline <LB	Escapement: (ETS) Long-Term Avg. (ETS)	2006-2009 Avg. (ETS)	Abundance (Metric 1) Ricker	Kalman	Larkin
Summer											
Chilko-S & Chilko-ES	191,600	406,800	153,600	1.22	-0.13	1	333,300	275,100			
Stuart-S	49,400	92,700	22,700	2.35	-0.14	0.99	129,300	59,100		NA	
Takla-Trembleur-S	26,400	29,600	5,400	0.95	-0.18	0.99	(combined above)				
Quesnel-S & McKinley-	188,700	585,600	50,700	7.7	-0.17	0.995	339,000	95,800			
Fraser-S	53,000	105,000	47,300	1.31	-0.04	0.784	96,300	87,500			
Late											
Cultus-L [1]	11,800	1,100	800	0.07	-0.11	0.997	9,600	900			
LFR-(River Type)	13,600	4,700	63,400	6.98	0.27	0	27,400	147,700			
Shuswap-L	312,300	204,300	303,700	0.95	0.03	0.115	608,200	578,400			
Seton-L	3,800	3,200	4,100	0.91	-0.08	0.949	6,900	5,300			
Harrison (U/S)-L	19,200	13,400	10,700	0.8	-0.03	0.603	42,700	20,400			
Harrison (D/S)-L	1,500	3,200	4,300	13.3	0.11	0.008	2,900	8,300	NA	NA	NA
Lillooet-L	44,200	59,000	58,200	1.48	0.02	0.022	76,000	104,900			
Widgeon (River-Type)	300	30	200	0.35	0.14	0	600	500	NA	NA	NA
Kamloops-L	4,300	300	200	0.3	-0.02	0.374	7000	300	NA	NA	NA

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

Table 4. Stochastic uncertainty (probability distributions from 10% to 90%) and structural uncertainty (different model forms: Ricker with differing time series lengths, Kalman Filtered Ricker model: Kalman, and Larkin models) in the evaluation of benchmarks for Fraser Sockeye with stock status evaluated for last generation ETS by probability level and model form benchmarks. Status is red if last generation ETS is below the lower benchmark, green if above the upper benchmark and amber if between the lower and upper benchmark calculated for each CU and model and probability level.

		Abundance (Effective Total Spawner) Lower Benchmark					**Abundance** (Effective Total Spawner) Upper Benchmark					**Last Gen.**	**Abundance** (Effective Total Spawner) **Stock Status**				
Run Timing Group Conservation Unit	model (time series)	10%	25%	50%	75%	90%	10%	25%	50%	75%	90%	**(ETS) 2006-2009**	**Probability Level** 10%	25%	50%	75%	90%
Early Stuart	Ricker (1950-2004)	50,000	62,000	77,000	101,000	130,000	190,000	212,000	244,000	291,000	343,000	26,500	Red	Red	Red	Red	Red
Stuart-Estu	Ricker (1970-2004)	71,000	86,000	114,000	144,000	181,000	191,000	212,000	254,000	296,000	345,000		Red	Red	Red	Red	Red
	Ricker (1990-2004)	92,000	108,000	129,000	145,000	150,000	146,000	155,000	164,000	166,000	154,000		Red	Red	Red	Red	Red
	Kalman (1950-2004)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		NA	NA	Red	NA	NA
	Larkin (1950-2004)	8,000	10,000	12,000	14,000	17,000	78,000	85,000	94,000	106,000	119,000		Amber	Amber	Amber	Amber	Amber
Early Summer																	
Bowron-ES	Ricker (1950-2004)	3,000	3,000	4,000	5,000	7,000	23,000	20,000	17,000	15,000	14,000	1,600	Red	Red	Red	Red	Red
	Ricker (1970-2004)	3,000	3,000	4,000	5,000	7,000	20,000	17,000	15,000	13,000	11,000		Red	Red	Red	Red	Red
	Ricker (1990-2004)	3,000	4,000	6,000	7,000	9,000	14,000	14,000	13,000	12,000	10,000		Red	Red	Red	Red	Red
	Kalman (1950-2004)	4,000	5,000	6,000	7,230	8,520	6,000	8,000	11,000	13,000	16,000		Red	Red	Red	Red	Red
	Larkin (1950-2004)	1,000	1,000	1,000	2,000	2,000	7,000	8,000	10,000	12,000	15,000		Amber	Amber	Amber	Red	Red
Kamloops-ES	Ricker (1967-2004)	3,000	4,000	5,000	7,000	9,000	17,000	20,000	23,000	28,000	36,000	15,400	Amber	Amber	Amber	Amber	Amber
	Ricker (1990-2004)	4,000	7,000	10,000	18,000	34,000	81,000	48,000	33,000	26,000	21,000		Amber	Amber	Amber	Red	Red
	Kalman (1967-2004)	NA	NA	15,000	NA	NA	NA	NA	42,000	NA	NA		NA	NA	Amber	NA	NA
	Larkin (1967-2004)	1,000	2,000	2,000	3,000	3,000	15,000	16,000	18,000	21,000	24,000		Green	Amber	Amber	Amber	Amber
Anderson-ES	Ricker (1968-2004)	1,000	2,000	3,000	4,000	10,000	12,000	15,000	20,000	27,000	55,000	4,100	Amber	Amber	Amber	Amber	Red
	Ricker (1990-2004)	2,000	4,000	7,000	14,000	30,000	13,000	17,000	26,000	44,000	80,000		Amber	Amber	Red	Red	Red
	Kalman (1950-2004)	15,000	34,000	70,000	112,000	143,000	45,000	94,000	199,000	325,000	416,000		Red	Red	Red	Red	Red
	Larkin (1950-2004)	0	0	1,000	1,000	1,000	5,000	6,000	6,000	7,000	8,000		Amber	Amber	Amber	Amber	Amber
Francois-ES	Ricker (1973-2004)	8,000	12,000	18,000	31,000	56,000	36,000	45,000	60,000	92,000	149,000	9,400	Amber	Red	Red	Red	Red
	Ricker (1990-2004)	7,000	11,000	20,000	42,000	77,000	28,000	36,000	54,000	86,000	131,000		Amber	Red	Red	Red	Red
	Kalman (1950-2004)	29,000	50,000	90,000	131,000	156,000	71,000	119,000	203,000	305,000	382,000		Red	Red	Red	Red	Red
	Larkin (1950-2004)	1,000	2,000	2,000	3,000	4,000	14,000	16,000	18,000	22,000	25,000		Amber	Amber	Amber	Amber	Amber
Pitt-ES	Ricker (1950-2004)	6,000	6,000	8,000	9,000	1,000	21,000	23,000	24,000	26,000	28,000	32,200	Green	Green	Green	Green	Green
	Ricker (1970-2004)	6,000	7,000	9,000	11,000	12,000	21,000	22,000	25,000	26,000	27,000		Green	Green	Green	Green	Green
	Ricker (1990-2004)	5,000	6,000	8,000	11,000	13,000	22,000	23,000	25,000	27,000	28,000		Green	Green	Green	Green	Green
	Kalman (1950-2004)	5,470	7,500	10,040	12,610	15,140	20,450	23,850	27,130	31,060	35,070		Green	Green	Green	Green	Amber
	Larkin (1950-2004)	2,000	3,000	3,000	4,000	4,000	17,000	19,000	20,000	22,000	24,000		Green	Green	Green	Green	Green
Shuswap Complex-ES	Ricker (1980-2004)	37,000	56,000	98,000	183,000	274,000	111,000	145,000	219,000	358,000	467,000	64,600	Amber	Amber	Red	Red	Red
	Ricker (1990-2004)	35,000	52,000	86,000	152,000	227,000	96,000	116,000	158,000	227,000	298,000		Amber	Amber	Red	Red	Red
	Kalman (1950-2004)	75,370	123,480	199,000	280,380	331,340	164,280	256,840	387,000	571,210	713,730		Red	Red	Red	Red	Red
	Larkin (1950-2004)	3,000	4,000	6,000	8,000	9,000	36,000	40,000	46,000	52,000	60,000		Green	Green	Green	Green	Green

Table 4. Continued (see previous page description)

Run Timing Group / Conservation Unit	model (time series)	Abundance (Effective Total Spawner) Lower Benchmark 10%	25%	50%	75%	90%	Abundance (Effective Total Spawner) Upper Benchmark 10%	25%	50%	75%	90%	Abundance (Effective Total Spawner) Last Gen. 2006-2009	Stock Status Probability Level 10%	25%	50%	75%	90%
Summer																	
Chilko-S	Ricker (1950-2004)	27,000	33,000	40,000	49,000	58,000	239,000	253,000	275,000	301,000	325,000	275,000					
	Ricker (1970-2004)	21,000	25,000	31,000	40,000	50,000	221,000	237,000	256,000	277,000	308,000						
	Ricker (1990-2004)	19,000	30,000	43,000	70,000	98,000	213,000	240,000	263,000	286,000	320,000						
	Kalman (1950-2004)	36,680	45,820	63,000	80,600	99,410	197,430	222,600	250,000	278,320	308,590						
	Larkin (1950-2004)	18,000	22,000	26,000	32,000	36,000	252,000	271,000	291,000	317,000	335,000						
Stuart-S	Ricker (1950-2004)	54,000	76,000	107,000	148,000	205,000	336,000	405,000	508,000	636,000	787,000	59,100					
Takla-Trembleur-S	Ricker (1970-2004)	69,000	90,000	129,000	177,000	248,000	373,000	414,000	508,000	607,000	734,000						
	Ricker (1990-2004)	133,000	169,000	226,000	300,000	378,000	347,000	383,000	442,000	491,000	526,000						
	Kalman (1950-2004)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		NA	NA	NA	NA	NA
	Larkin (1950-2004)	16,000	20,000	26,000	35,000	45,000	160,000	185,000	216,000	268,000	328,000						
Quesnel-S	Ricker (1950-2004)	87,000	104,000	126,000	150,000	174,000	624,000	671,000	717,000	760,000	799,000	95,800					
	Ricker (1970-2004)	81,000	98,000	118,000	147,000	171,000	635,000	671,000	720,000	773,000	815,000						
	Ricker (1990-2004)	139,000	175,000	216,000	266,000	301,000	551,000	552,000	553,000	544,000	514,000						
	Kalman (1950-2004)	157,960	212,530	255,000	294,000	330,880	184,980	322,470	464,000	1,589,620	693,260						
	Larkin (1950-2004)	27,000	32,000	38,000	45,000	52,000	373,000	390,000	427,000	465,000	514,000						
Fraser-S	Ricker (1950-2004)	28,000	36,000	44,000	58,000	71,000	156,000	178,000	204,000	241,000	271,000	87,500					
	Ricker (1970-2004)	28,000	35,000	47,000	62,000	84,000	151,000	170,000	208,000	245,000	299,000						
	Ricker (1990-2004)	47,000	64,000	84,000	109,000	136,000	159,000	187,000	209,000	228,000	242,000						
	Kalman (1950-2004)	64,780	78,540	96,000	116,650	140,290	99,260	128,560	164,000	205,090	248,890						
	Larkin (1950-2004)	4,000	5,000	6,000	7,000	8,000	68,000	74,000	78,000	84,000	91,000						

Table 4. Continued (see previous page description)

Run Timing Group / Conservation Unit	model (time series)	Abundance (Effective Total Spawner) Lower Benchmark 10%	25%	50%	75%	90%	Abundance (Effective Total Spawner) Upper Benchmark 10%	25%	50%	75%	90%	Abundance (Effective Total Spawner) Last Gen. 2006-2009	Stock Status Probability Level 10%	25%	50%	75%	90%
Cultus-L	Ricker (1950-2005)	17,000	15,000	12,000	10,000	9,000	36,000	34,000	32,000	29,000	28,000	900					
	Ricker (1970-2005)	18,000	15,000	12,000	10,000	8,000	36,000	34,000	32,000	29,000	27,000						
	Ricker (1990-2005)	8,000	13,000	13,000	12,000	11,000	7,000	14,000	16,000	18,000	20,000						
	Kalman (1950-2004)	7,760	10,820	13,000	15,590	17,980	7,400	14,590	22,000	29,930	36,050						
	Larkin (1950-2004)	1,000	1,000	1,000	1,000	2,000	7,000	8,000	9,000	10,000	12,000						
LFR-River Type	Ricker (1950-2005)	9,000	10,000	14,000	20,000	27,000	37,000	40,000	46,000	58,000	69,000	147,700					
	Ricker (1970-2005)	8,000	10,000	14,000	19,000	28,000	43,000	50,000	56,000	67,000	83,000						
	Ricker (1990-2005)	5,000	8,000	14,000	24,000	38,000	53,000	59,000	79,000	101,000	132,000						
	Kalman (1950-2004)	11,430	20,060	35,000	54,260	78,500	87,960	129,530	194,000	284,070	395,600						
	Larkin (1950-2004)	1,000	1,000	1,000	2,000	2,000	9,000	10,000	10,000	11,000	13,000						
Shuswap Complex-L	Ricker (1950-2005)	249,000	295,000	374,000	457,000	249,000	1,108,000	1,181,000	1,343,000	1,493,000	1,691,000	578,400					
	Ricker (1970-2005)	234,000	290,000	362,000	468,000	575,000	1,045,000	1,175,000	1,292,000	1,441,000	1,578,000						
	Ricker (1990-2005)	213,000	285,000	383,000	531,000	644,000	807,000	879,000	929,000	960,000	963,000						
	Kalman (1950-2004)	329,790	417,130	519,000	632,130	767,570	525,560	869,840	1,166,000	1,431,930	1,727,900						
	Larkin (1950-2004)	29,000	38,000	51,000	70,000	85,000	426,000	472,000	537,000	621,000	660,000						
Seton-L	Ricker (1965-2004)	0	1,000	1,000	1,000	2,000	6,000	7,000	9,000	11,000	14,000	5,300					
	Ricker (1990-2004)	1,000	1,000	2,000	4,000	9,000	6,000	7,000	10,000	16,000	27,000						
	Kalman (1950-2004)	NA	NA	10,000	NA	NA	NA	NA	27,000	NA	NA		NA	NA		NA	NA
	Larkin (1950-2004)	0	1,000	1,000	1,000	1,000	5,000	5,000	6,000	7,000	8,000						
Harrison (U/S)-L	Ricker (1966-2004)	4,000	6,000	9,000	14,000	26,000	52,000	62,000	78,000	106,000	167,000	20,400					
	Ricker (1990-2004)	1,000	2,000	4,000	7,000	19,000	26,000	36,000	45,000	70,000	137,000						
	Kalman (1950-2004)	10,770	18,630	38,000	69,130	95,180	76,980	119,610	219,000	368,410	487,840						
	Larkin (1950-2004)	2,000	2,000	3,000	5,000	6,000	39,000	44,000	51,000	65,000	78,000						
Lillooet-L	Ricker (1950-2004)	8,000	9,000	12,000	14,000	17,000	69,000	72,000	79,000	86,000	96,000	104,900					
	Ricker (1970-2004)	7,000	10,000	13,000	17,000	22,000	67,000	74,000	80,000	88,000	95,000						
	Ricker (1990-2004)	16,000	21,000	27,000	34,000	40,000	59,000	60,000	62,000	60,000	60,000						
	Kalman (1950-2004)	17,210	21,740	26,570	30,960	35,890	27,700	40,440	55,270	67,520	79,060						
	Larkin (1950-2004)	4,000	5,000	6,000	7,000	10,000	61,000	65,000	73,000	79,000	89,000						

Table 4. Log_e Likelihoods (Likelihood), Akaike's Information Criterion (AIC) and delta AIC values for Ricker models without priors, Ricker models with priors and Larkin mdoesl for each CU with stock-recruitmnet data (Table approach replicated from Martel et al. 2008 and updated with current stock recruitment data organized by CU).

	Ricker				Larkin		Delta AIC (AIC-AIC_{min})		
Conservation Unit	**No 'b' Prior**		**b' Prior**		**No Prior**		**Ricker**	**Ricker**	**Larkin**
(with stock-recruitment data)	**Likelihood**	**AIC**	**Likelihood**	**AIC**	**Likelihood**	**AIC**	**No 'b' Prior**	**b' Prior**	
Early Stuart									
Takla-Trembleur-EStu	-66.5	139	-66.50	137.01	-56.76	125.52	13.48	11.49	**0.00**
Early Summer									
Bowron-ES	-65.36	136.72	-65.53	135.06	-62.42	136.84	**1.66**	**0.00**	1.78
Kamloops-ES	-40.05	86.1	-40.05	84.10	-33.54	79.09	7.01	5.01	**0.00**
Anderson-ES	-48.65	103.3	-48.65	101.30	-37.96	87.92	15.38	13.38	**0.00**
Francois-ES	-39.81	85.62	-39.81	83.62	-35.26	82.52	3.10	**1.10**	**0.00**
Pitt-ES	-61.19	128.37	-61.88	127.77	-54.37	120.74	7.63	7.03	**0.00**
Shuswap-ES	-32.47	70.94	-32.47	68.94	-23.3	58.59	12.35	10.35	**0.00**
Summer									
Chilko-S/Chilko-ES	-58.76	123.51	-59.02	122.05	-51.36	114.73	8.78	7.32	**0.00**
Takla-Trembleur/Stuart-S Aggregate	-91.5	188.99	-91.96	187.92	-81.7	175.41	13.58	12.51	**0.00**
Quesnel/McKinley-S	-78.42	162.84	-78.52	161.04	-61.38	134.75	28.09	26.29	**0.00**
Fraser-S	-55.07	116.14	-56.88	117.76	-42.1	96.2	19.94	21.56	**0.00**
Late									
Cultus-L	-71.22	148.44	-70.59	145.18	-67	146	3.26	**0.00**	0.82
Lower Fraser River (River-type)	-79.57	165.14	-92.04	188.07	-75.7	163.4	1.74	24.67	**0.00**
Shuswap-L	-76.24	158.49	-77.54	159.07	-66.17	144.33	14.16	14.74	**0.00**
Seton-L	-55.36	116.72	-55.36	114.72	-45.55	103.1	13.62	11.62	**0.00**
Harrison (U/S)-L	-49.91	105.83	-49.91	103.83	-44.01	100.01	5.82	3.82	**0.00**
Lillooet-L	-74.5	155.01	-74.66	153.32	-68.32	148.64	6.37	4.68	**0.00**

APPENDIX 1: For each conservation unit, the sites available in the escapement database are indicated and a checkmark beside the site name indicates it was used in the escapement time series to evaluate stock status for *Trends in Abundance* metrics.

Anderson-ES

Sites	IN
Gates Channel	√
Gates Creek	√

Bowron-ES

Sites	IN
Antler Creek	
Bowron River	√
Pomeroy Creek	√
Huckey Creek	√
Sus Creek	√

Chilko-S & Chilko-ES

Sites	IN
Chilko River	√
Chilko Channel	√
Chilko Lake North	
Chilko Lake South	√

Chilliwack-ES

Sites	IN
Chilliwack Lake	√
Dolly Varden Creek	√

Cultus-L

Sites	IN
Cultus	√

Francois-ES

Sites	IN
Early Nadina River	√
Late Nadina River	√
Nadina Channel	√
Tagetochlain Creek	
Uncha Creek	

Fraser-S

Sites	IN
Stellako River	√

Harrison (D/S)-L

Sites	IN
Bear Creek	
Big Silver Creek	√
Cogburn Creek	
Crazy Creek	
Douglas Creek	
Hatchery Creek	
Sloquet Creek	
Tipella Creek	
Tipella Slough	

Harrison (U/S)-L

Sites	IN
East Creek	√
Weaver Channel	√
Weaver Creek	√

Kamloops-ES

Sites	IN
Barriere River	
Clearwater River	
Dunn Creek	
Fennell Creek	√
Finn Creek	
Grouse Creek	
Harper Creek	
Hemp Creek	
Lemieux Creek	
Lion Creek	
Mann Creek	
Moul Creek	
North Thompson River	
Raft River	√

Kamloops-L

Sites	IN
South Thompson River	√

Lilloet-L

Sites	IN
25 Mile Creek	
Birkenhead River	√
Green River	
Lillooet Slough	
Miller Creek	
Poole Creek	
Railroad Creek	
Ryan Creek	
Sampson Creek	
JohnSandy not in database	

Lower Fraser River (River-Type)

Sites	IN
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	

Nahatlach-ES

Sites	IN
Nahatlach Lake	√
Nahatlach River	√

Appendix 1. Continued (see previous page 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 description).

Shuswap-ES

Sites	IN
Adams Channel	
Adams River	
Anstey River	
Bear Creek	
Burton Creek	
Bush Creek	
Cayenne Creek	√
Celista Creek	
Craigellachie Creek	
Crazy Creek	
Eagle River	
Gold Creek	
Hunakwa Creek	
Loftus Creek	
McNomee Creek	√
Middle Shuswap River	
Momich/Cayenne	√
Onyx Creek	
Pass Creek	
Perry River	
Ross Creek	
Salmon River	
Scotch Creek	√
Seymour River	√
Upper Adams	√
Yard Creek	

Shuswap-L

Sites	IN	Sites	IN
5 Mile Creek		Pass Creek - shore	
Adams Channel		Perry River	
Adams Lake		Queest Creek - shore	
Adams Lake - East		Reinecker Creek	
Adams Lake - North		Reinecker Creek - shore	
Adams Lake - South		Ross Creek	
Adams River	√	Ross Creek - shore	√
Adams River - shore	√	Salmon River	
Anstey River	√	Scotch Creek	√
Anstey River - shore	√	Scotch Creek - shore	√
Bear Creek		Seymour River	
Bessette Creek		Shuswap Lake	√
Bush Creek		Shuswap Lake - Anstey Arm	√
Bush Creek - shore		Shuswap Lake - Main Arm	√
Canoe Creek		Shuswap Lake - Main Arm North	√
Celista Creek		Shuswap Lake - Main Arm South	√
Cook Creek		Shuswap Lake - Salmon Arm	√
Crazy Creek		Shuswap Lake - Salmon Arm East	√
Cruikshank Pt.W.-shore	√	Shuswap Lake - Salmon Arm North	√
Eagle River	√	Shuswap Lake - Salmon Arm South	√
Four Mile Creek- shore		Shuswap Lake - Seymour Arm	√
Gold Creek		Tappen Creek	
Hlina Creek - shore	√	Trinity Creek	
Hunakwa Creek		Tsikwustum Creek	
Kingfisher Creek		Tsuius Creek	
Knight Creek - shore		Upper Adams River	
Lee Creek - shore	√	Vanishing Creek - shore	
Little River	√	Wap Creek	
Loftus Creek		Yard Creek	
Lower Shuswap River	√		
Mara Lake - shore			
McNomee Creek			
Middle Shuswap River	√		
Momich River	√		
Momich River - shore			
Noisy Creek			
Onyx Creek			
Onyx Creek - shore	√		
Pass Creek	√		

Stuart-S

Sites	IN
Kuzkwa Creek	√
Pinchi Creek	
Sowchea Creek	
Stuart Lake	
Stuart River	
Tachie River	√

Takla-Trembleur-Estu

Sites	IN	Sites	IN
5 Mile Creek	√	Sakeniche River	√
10 Mile Creek		Sandpoint Creek	√
15 Mile Creek	√	Shale Creek	√
25 Mile Creek	√	Sinta Creek	√
Ankwill Creek	√	Sowchea Creek	
Baptiste Creek		Takla Lake - shore	
Bates Creek		Takla Lake - unnamed	
Bivouac Creek	√	Tarnezell Creek	
Blackwater Creek	√	Tildesley Creek	
Blanchette Creek		Tliti Creek	
Casamir Creek		Unnamed 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 Creek	√		
Kynock Creek	√		
Leo Creek			
Lion Creek	√		
McDougall Creek			
Middle River (Rosette)			
Nahounli Creek			
Nancut Creek			
Narrows Creek	√		
Paula Creek	√		
Point Creek	√		
Porter Creek	√		
Rosette Creek	√		

Appendix 1. Continued (see previous page 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: 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).

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 abundance over the last three generations*. The deterministic regression rate of change of smoothed 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 to the long-term average geometric mean. Historical time-series of EFS (smoothed, log scale) 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

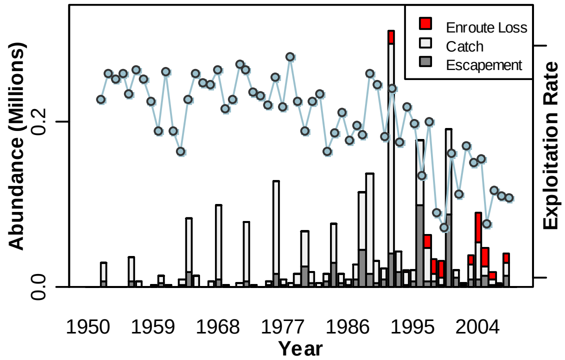
2d. Prior (blue line) and posterior (bars) distribution for spawners at maximum recruitment for CU's where stock and recruitment data are available. The median posterior value is indicated with dashed vertical black line. Uniform or lognormal distribution inputs are reported in figure title.

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.

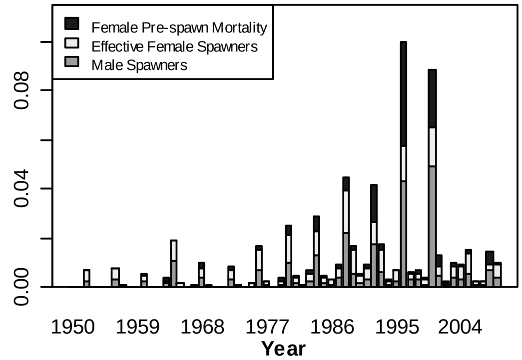
LIST OF 26 ASSESSIBLE (DATA AVAILABLE) CONSERVATION UNITS WITH FIGURES.

Anderson-ES

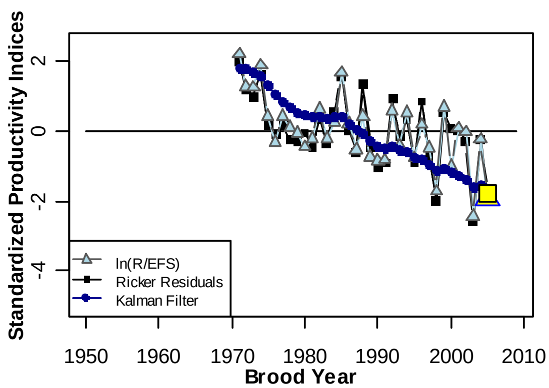
1a.



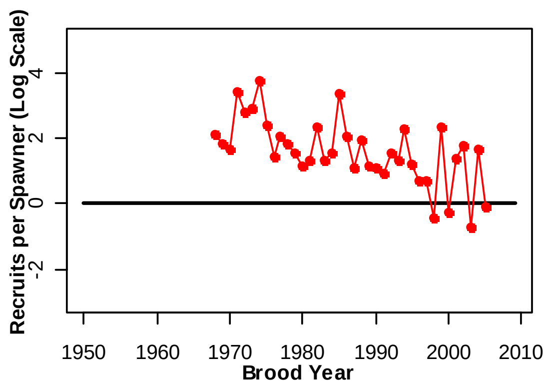
b.



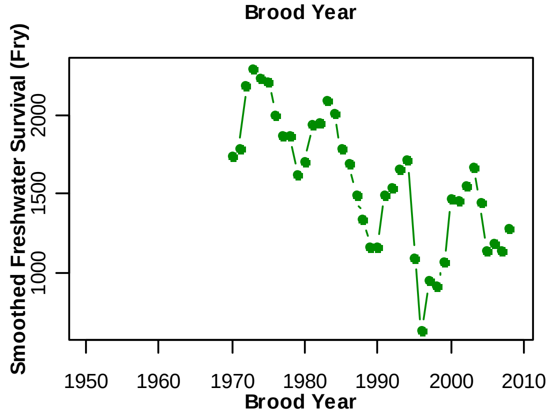
c.



d.



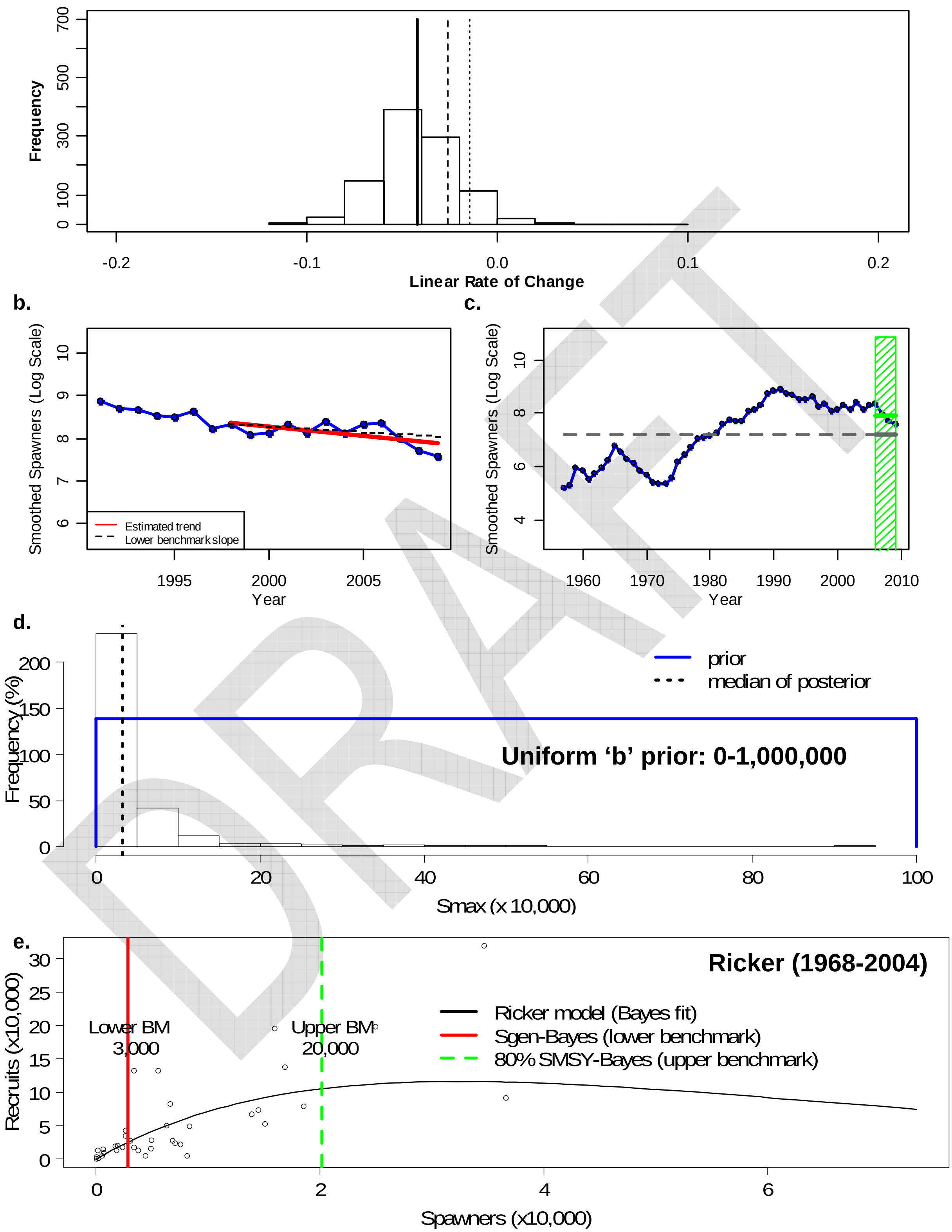
e.



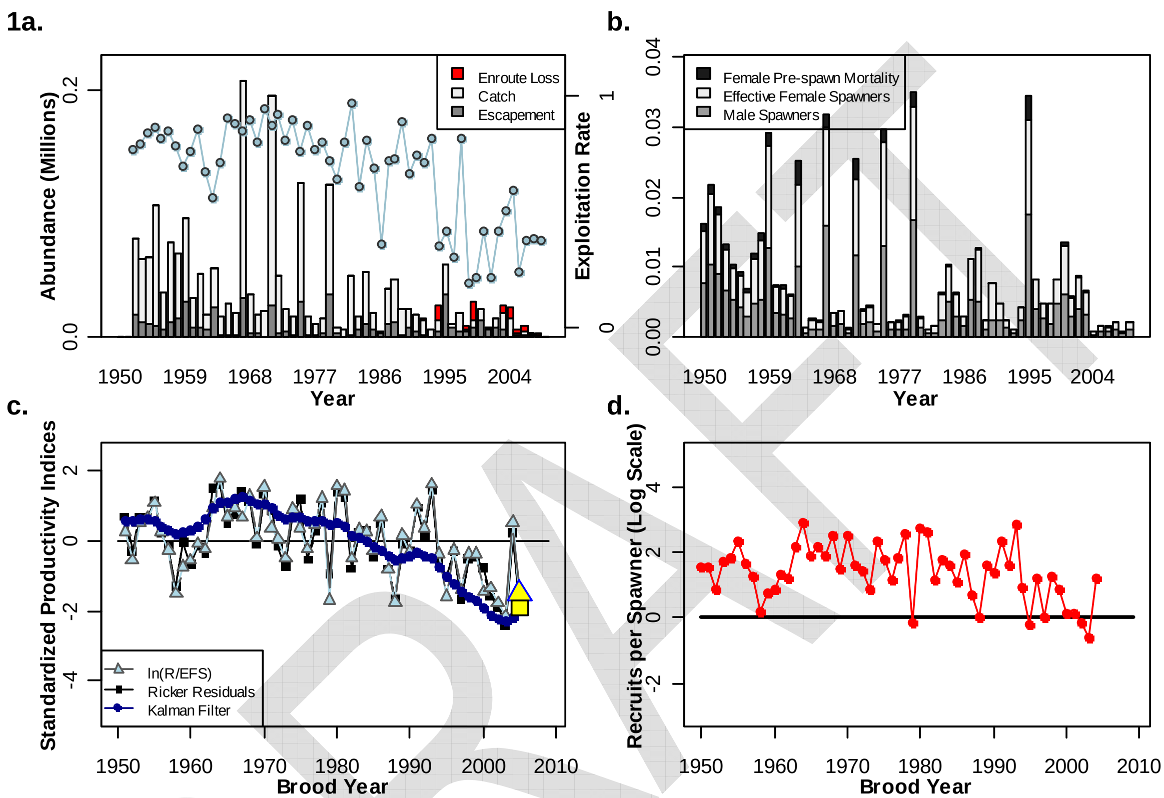
f.

No marine survival data available

2a.


Frequency
Linear Rate of Change
b.
Smoothed Spawners (Log Scale)
Estimated trend
Lower benchmark slope
Year
c.
Smoothed Spawners (Log Scale)
Year
d.
Frequency (%)
prior
median of posterior
Uniform 'b' prior: 0-1,000,000
Smax (x 10,000)
e.
Recruits (x10,000)
Ricker (1968-2004)
Ricker model (Bayes fit)
Sgen-Bayes (lower benchmark)
80% SMSY-Bayes (upper benchmark)
Lower BM
3,000
Upper BM
20,000
Spawners (x10,000)

Bowron-ES

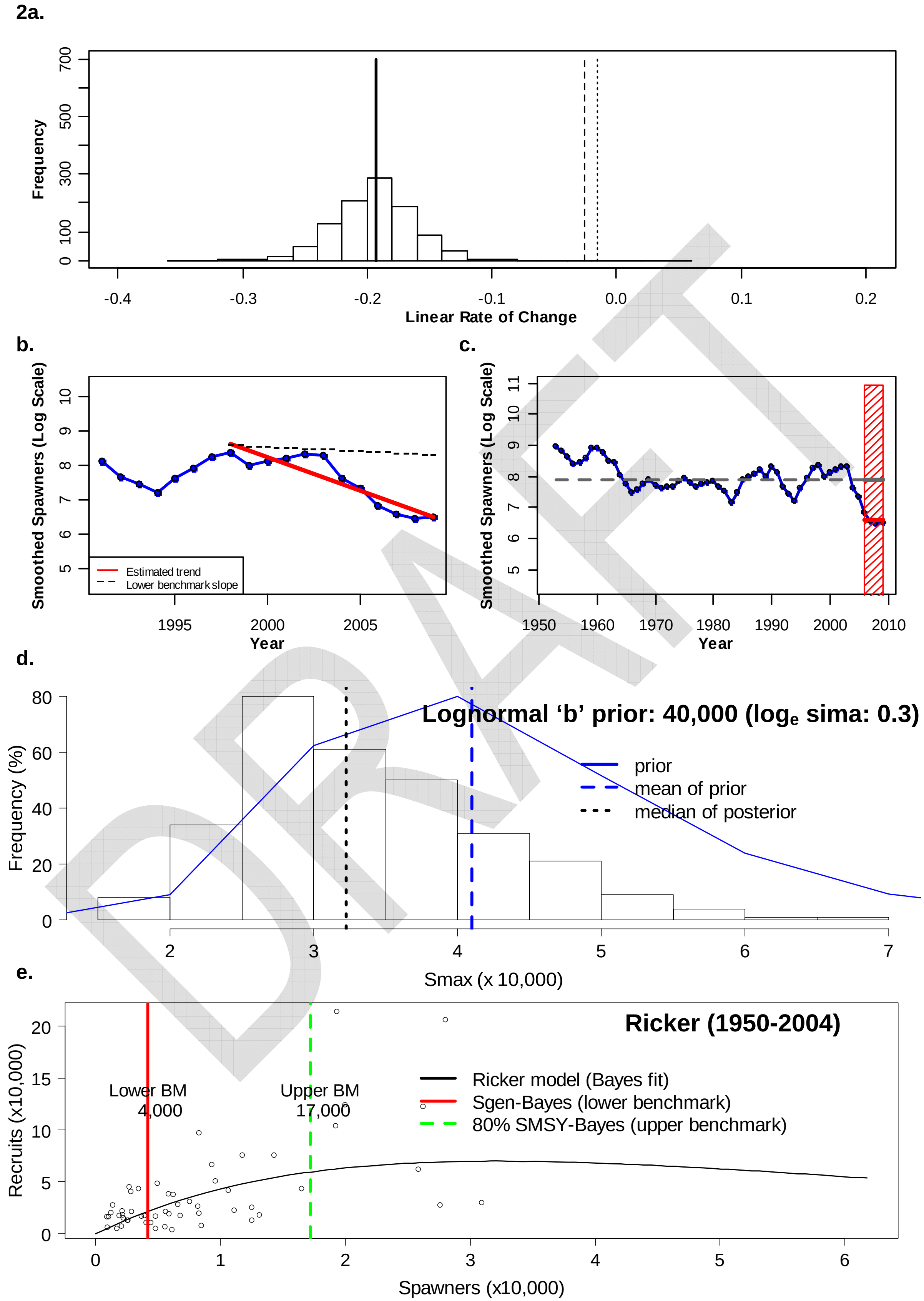


e.

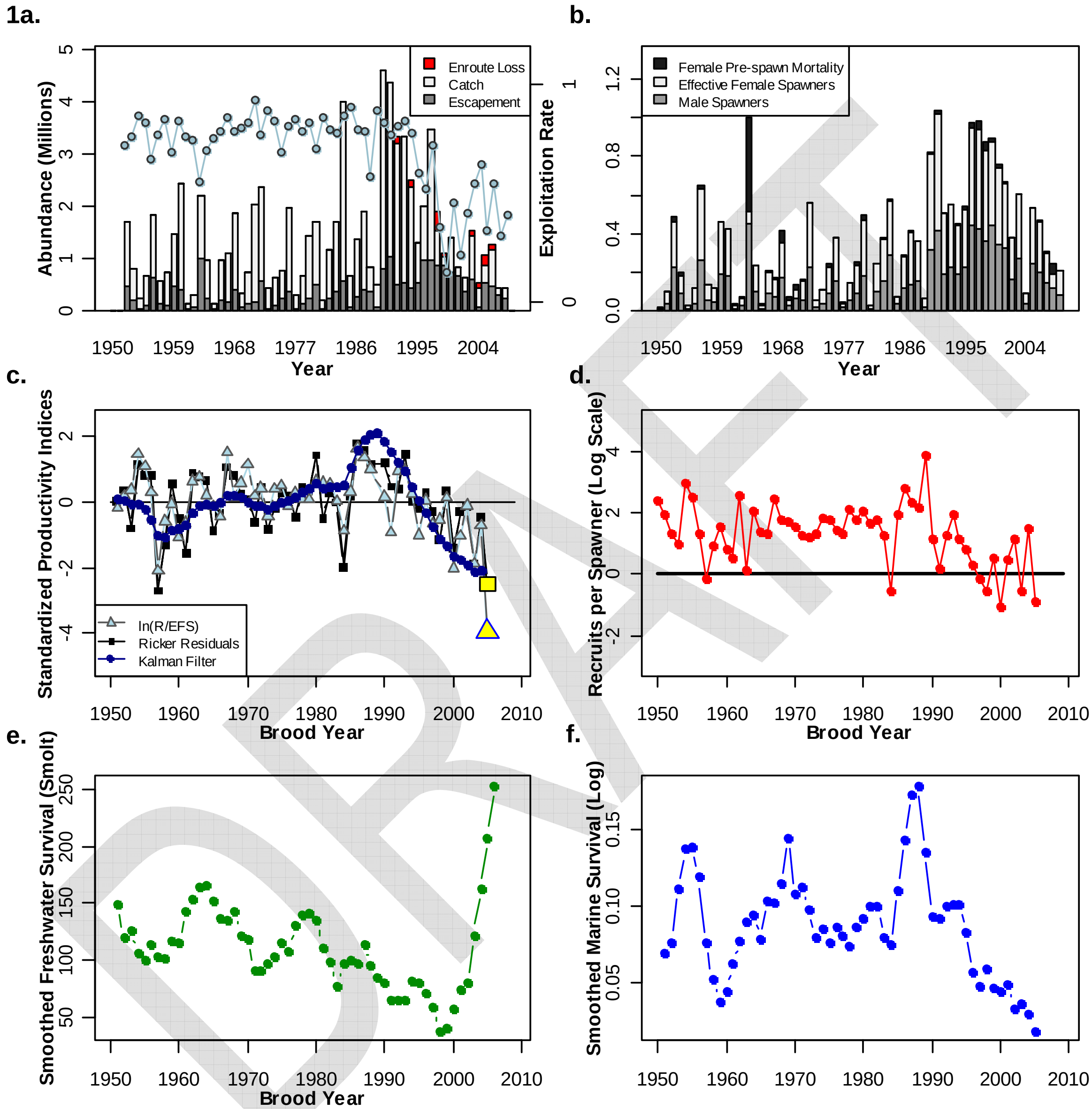
No freshwater survival data available

f.

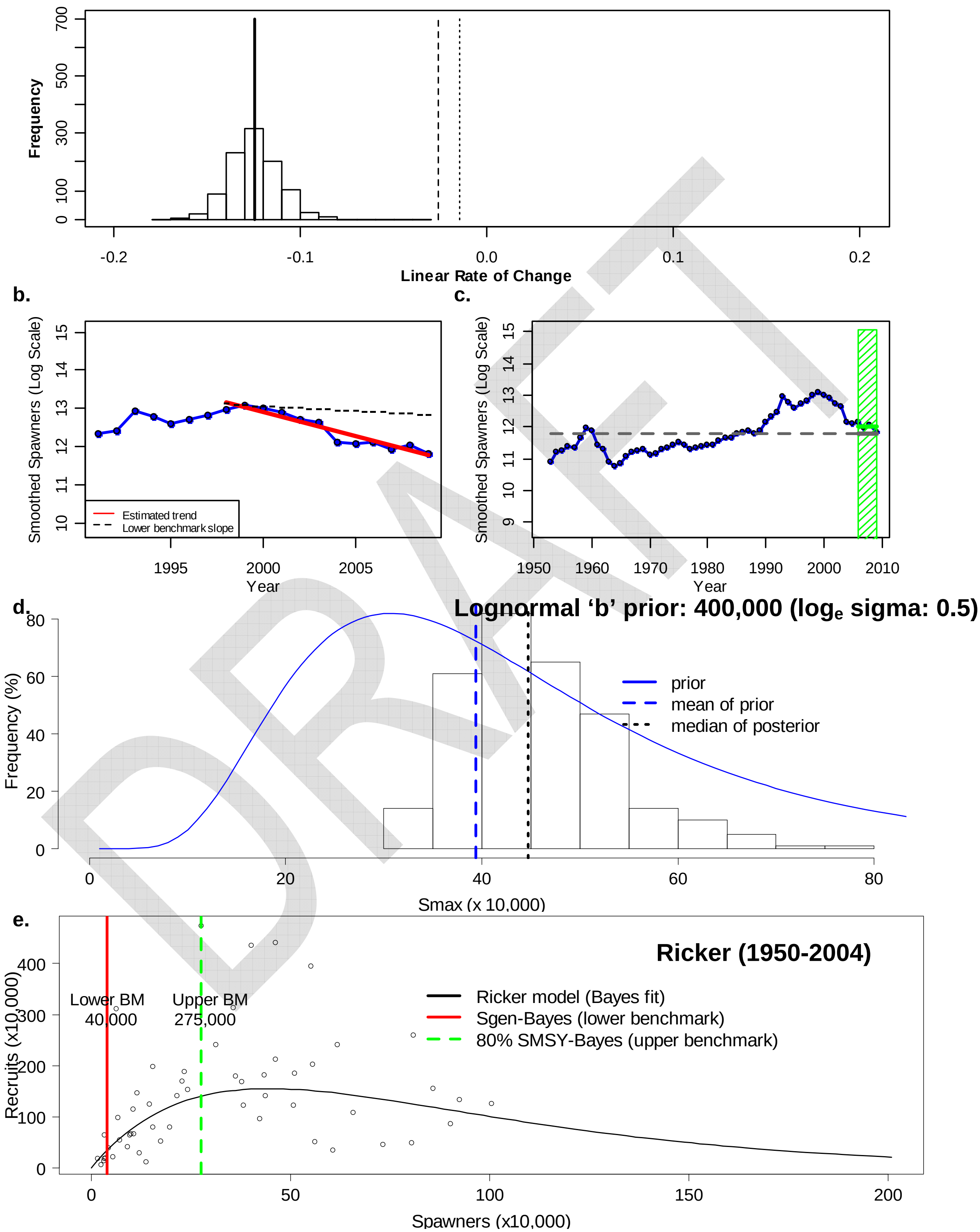
No marine survival data available


2a.
Frequency
0
100
300
500
700
-0.4
-0.3
-0.2
-0.1
0.0
0.1
0.2
Linear Rate of Change
b.
Smoothed Spawners (Log Scale)
5
6
7
8
9
10
Estimated trend
Lower benchmark slope
1995
2000
2005
Year
c.
Smoothed Spawners (Log Scale)
5
6
7
8
9
10
11
1950
1960
1970
1980
1990
2000
2010
Year
d.
Frequency (%)
0
20
40
60
80
Lognormal 'b' prior: 40,000 (loge sima: 0.3)
prior
mean of prior
median of posterior
2
3
4
5
6
7
Smax (x 10,000)
e.
Recruits (x10,000)
0
5
10
15
20
Ricker (1950-2004)
Lower BM
4,000
Upper BM
17,000
Ricker model (Bayes fit)
Sgen-Bayes (lower benchmark)
80% SMSY-Bayes (upper benchmark)
0
1
2
3
4
5
6
Spawners (x10,000)

Chilko-ES & Chilko-S



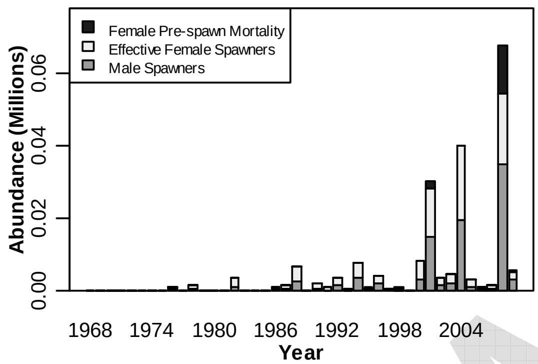
2a.



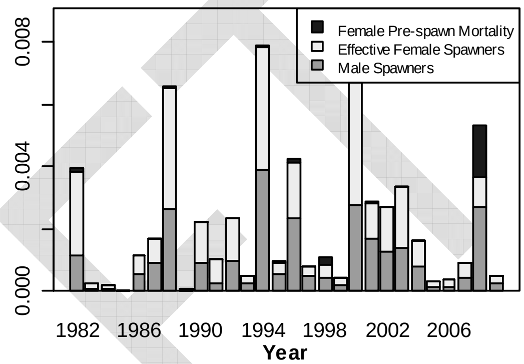
Frequency
Linear Rate of Change
b.
c.
Smoothed Spawners (Log Scale)
Estimated trend
Lower benchmark slope
Year
d.
Lognormal 'b' prior: 400,000 (loge sigma: 0.5)
Frequency (%)
prior
mean of prior
median of posterior
Smax (x 10,000)
e.
Ricker (1950-2004)
Lower BM
40,000
Upper BM
275,000
Ricker model (Bayes fit)
Sgen-Bayes (lower benchmark)
80% SMSY-Bayes (upper benchmark)
Recruits (x10,000)
Spawners (x10,000)
DRAFT

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.

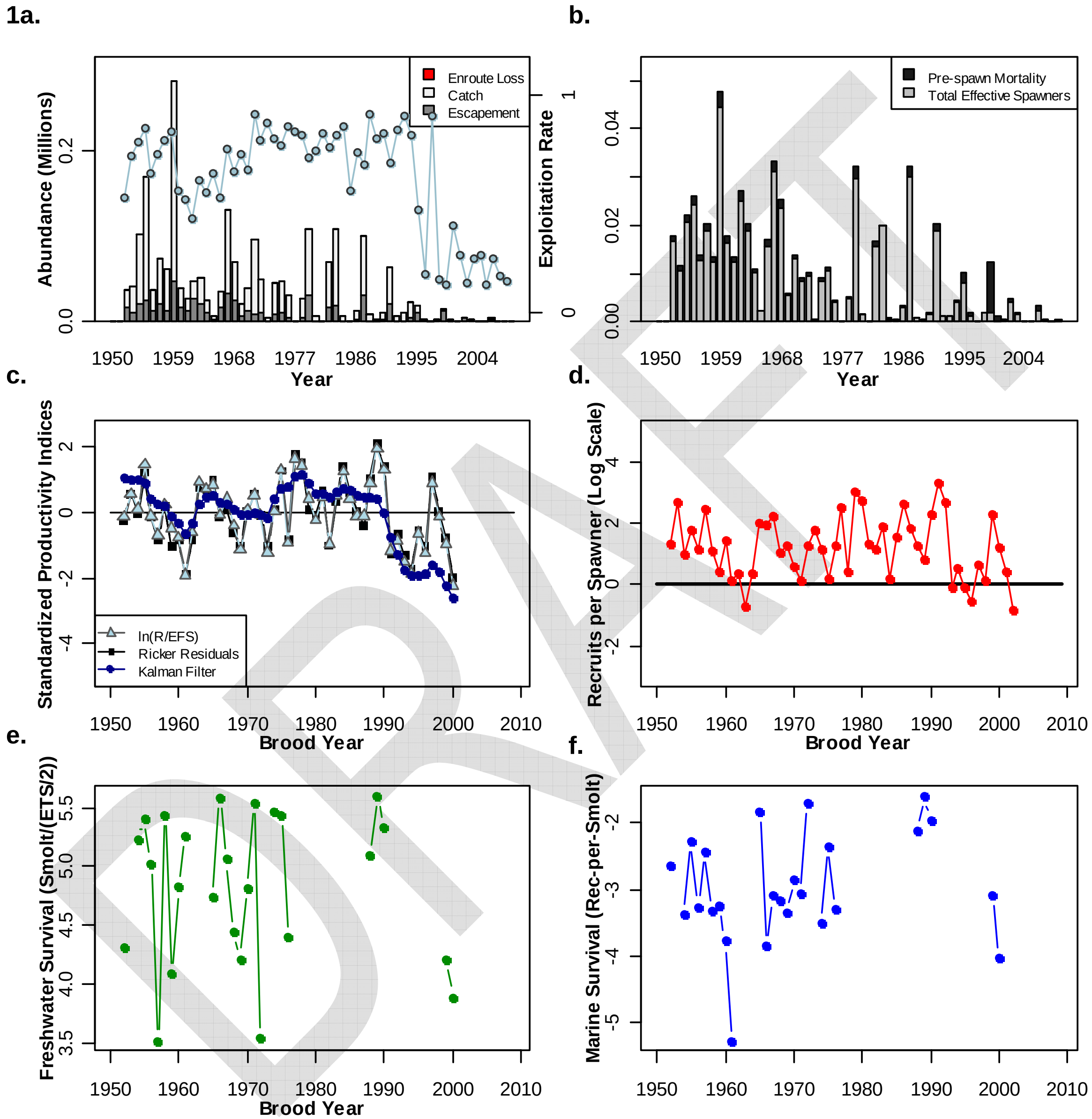
2a.

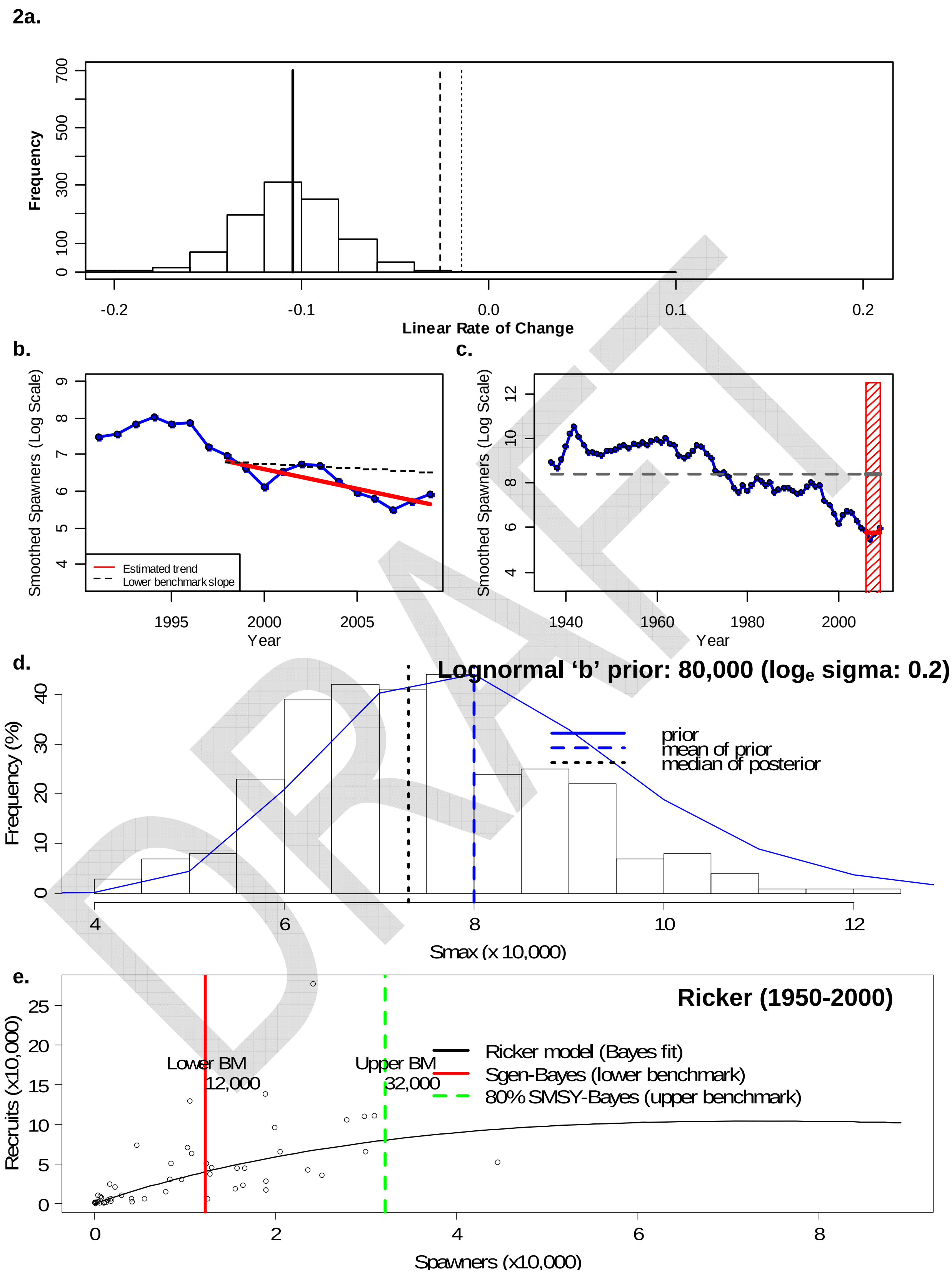
Chilliwack-ES could not be quantitatively assessed in terms of stock status.

b.

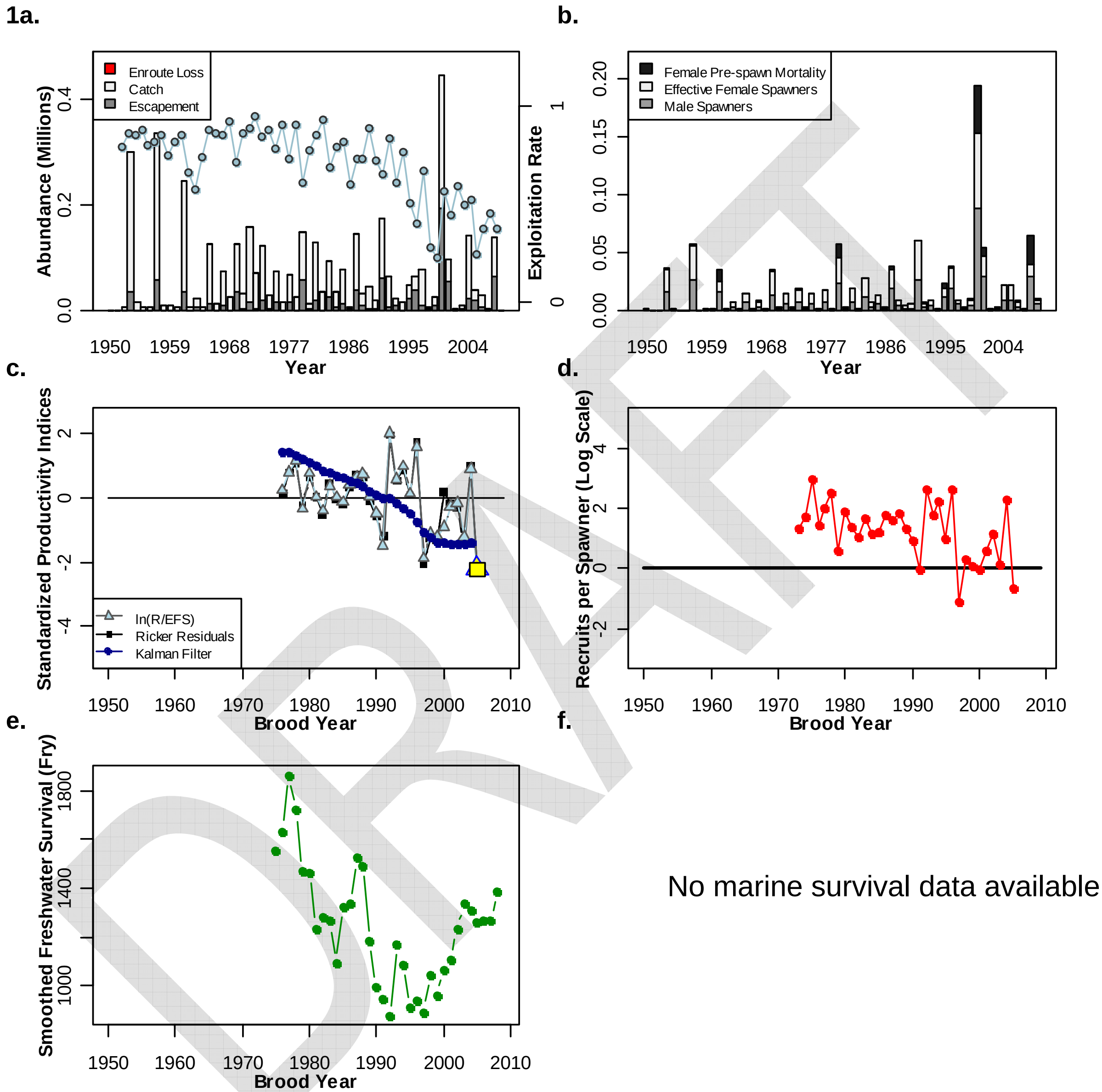
c.

Cultus-L

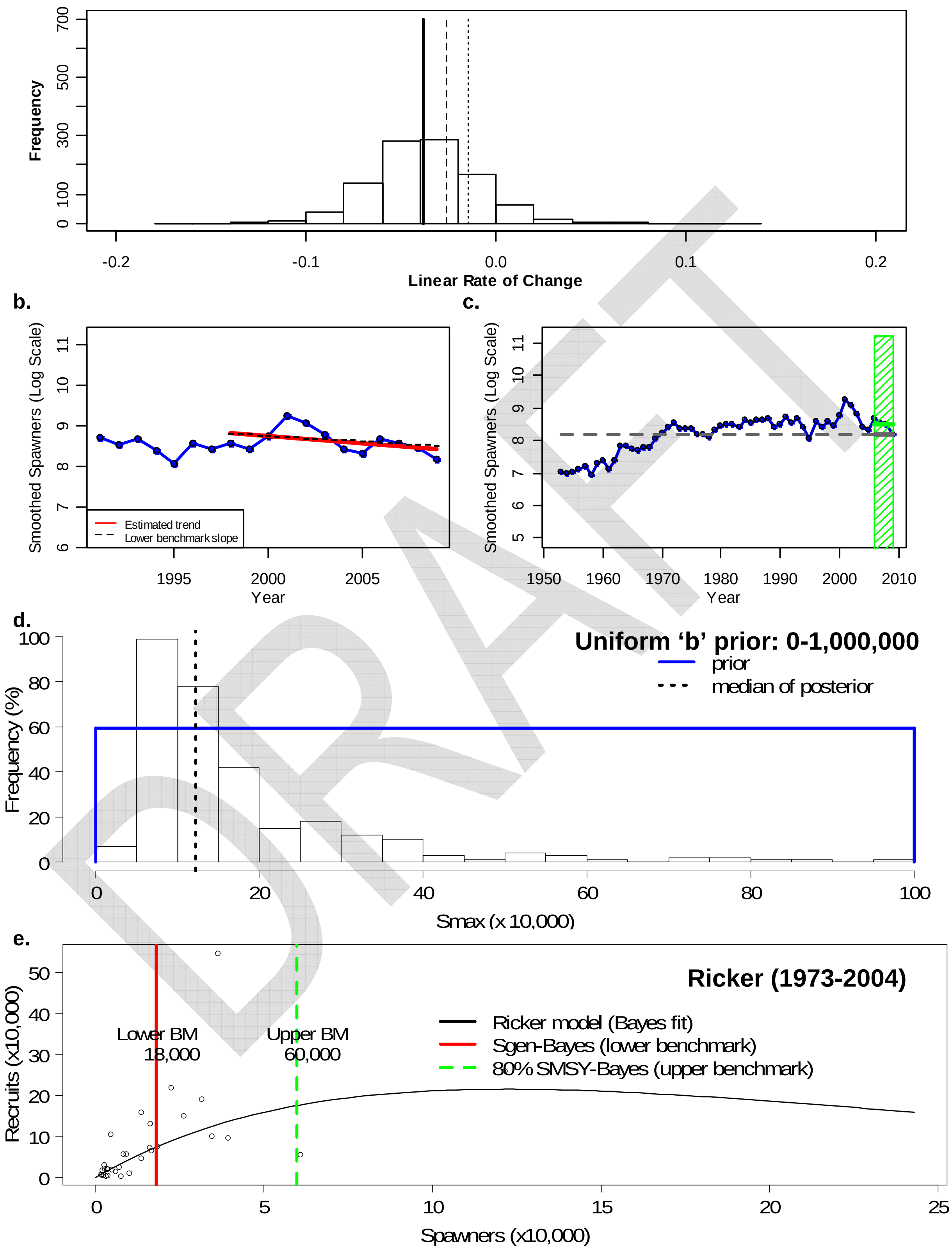

1a.
b.
Enroute Loss
Catch
Escapement
Abundance (Millions)
Exploitation Rate
0.0
0.2
0
1
1950 1959 1968 1977 1986 1995 2004
Year
Pre-spawn Mortality
Total Effective Spawners
0.00
0.02
0.04
1950 1959 1968 1977 1986 1995 2004
Year
c.
d.
Standardized Productivity Indices
-4
-2
0
2
ln(R/EFS)
Ricker Residuals
Kalman Filter
1950 1960 1970 1980 1990 2000 2010
Brood Year
Recruits per Spawner (Log Scale)
-2
0
2
4
1950 1960 1970 1980 1990 2000 2010
Brood Year
e.
f.
Freshwater Survival (Smolt/(ETS/2))
3.5
4.0
4.5
5.0
5.5
1950 1960 1970 1980 1990 2000 2010
Brood Year
Marine Survival (Rec-per-Smolt)
-5
-4
-3
-2
1950 1960 1970 1980 1990 2000 2010


2a.
Frequency
Linear Rate of Change
b.
Smoothed Spawners (Log Scale)
Estimated trend
Lower benchmark slope
Year
c.
Smoothed Spawners (Log Scale)
Year
d.
Lognormal 'b' prior: 80,000 (log_e sigma: 0.2)
Frequency (%)
prior
mean of prior
median of posterior
Smax (x 10,000)
e.
Ricker (1950-2000)
Recruits (x10,000)
Lower BM
12,000
Upper BM
32,000
Ricker model (Bayes fit)
Sgen-Bayes (lower benchmark)
80% SMSY-Bayes (upper benchmark)
Spawners (x10,000)

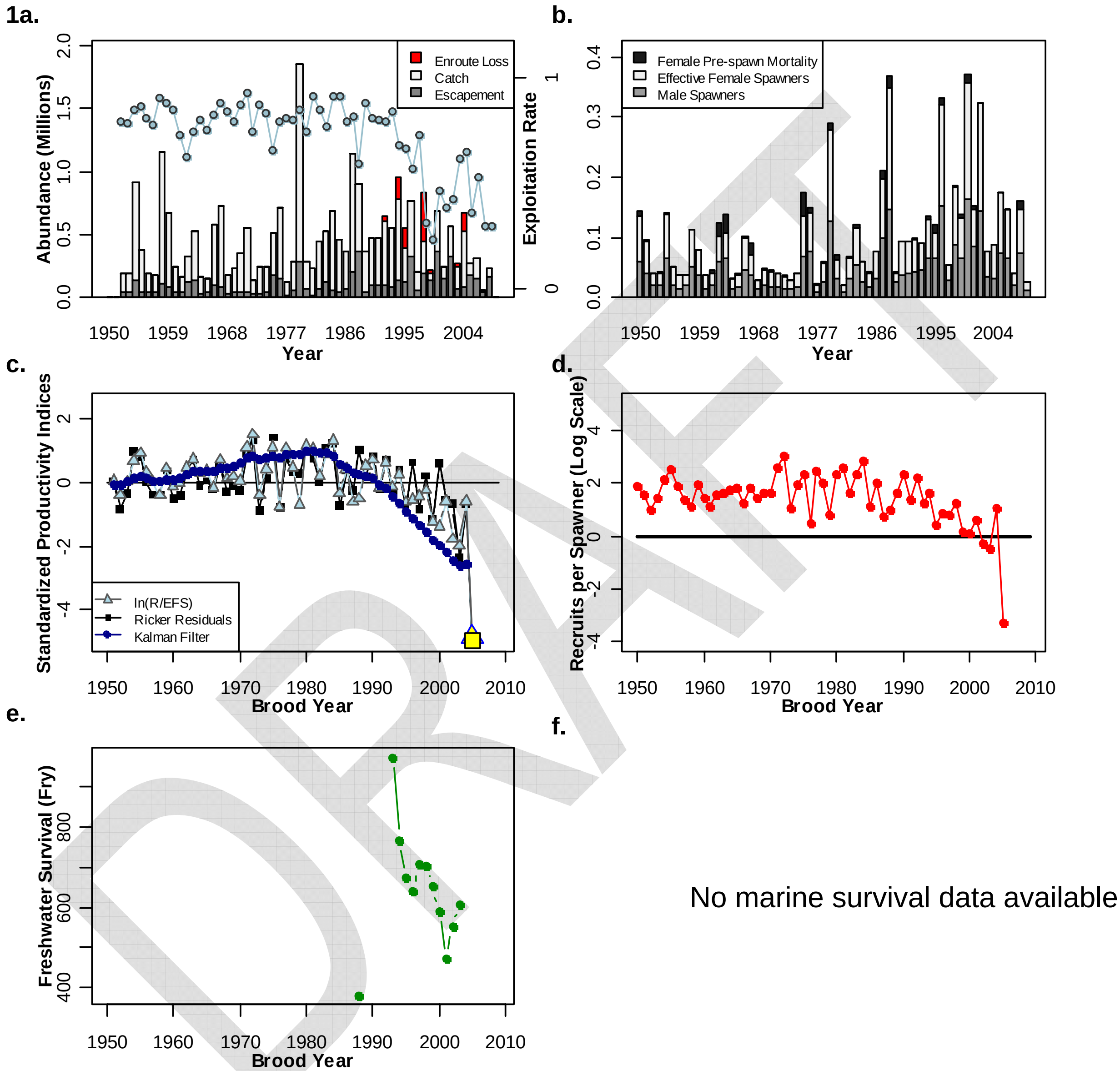
Francois-ES


1a.
Enroute Loss
Catch
Escapement
Abundance (Millions)
Exploitation Rate
Year
b.
Female Pre-spawn Mortality
Effective Female Spawners
Male Spawners
Year
c.
Standardized Productivity Indices
ln(R/EFS)
Ricker Residuals
Kalman Filter
Brood Year
d.
Recruits per Spawner (Log Scale)
Brood Year
e.
Smoothed Freshwater Survival (Fry)
Brood Year
f.
No marine survival data available

2a.

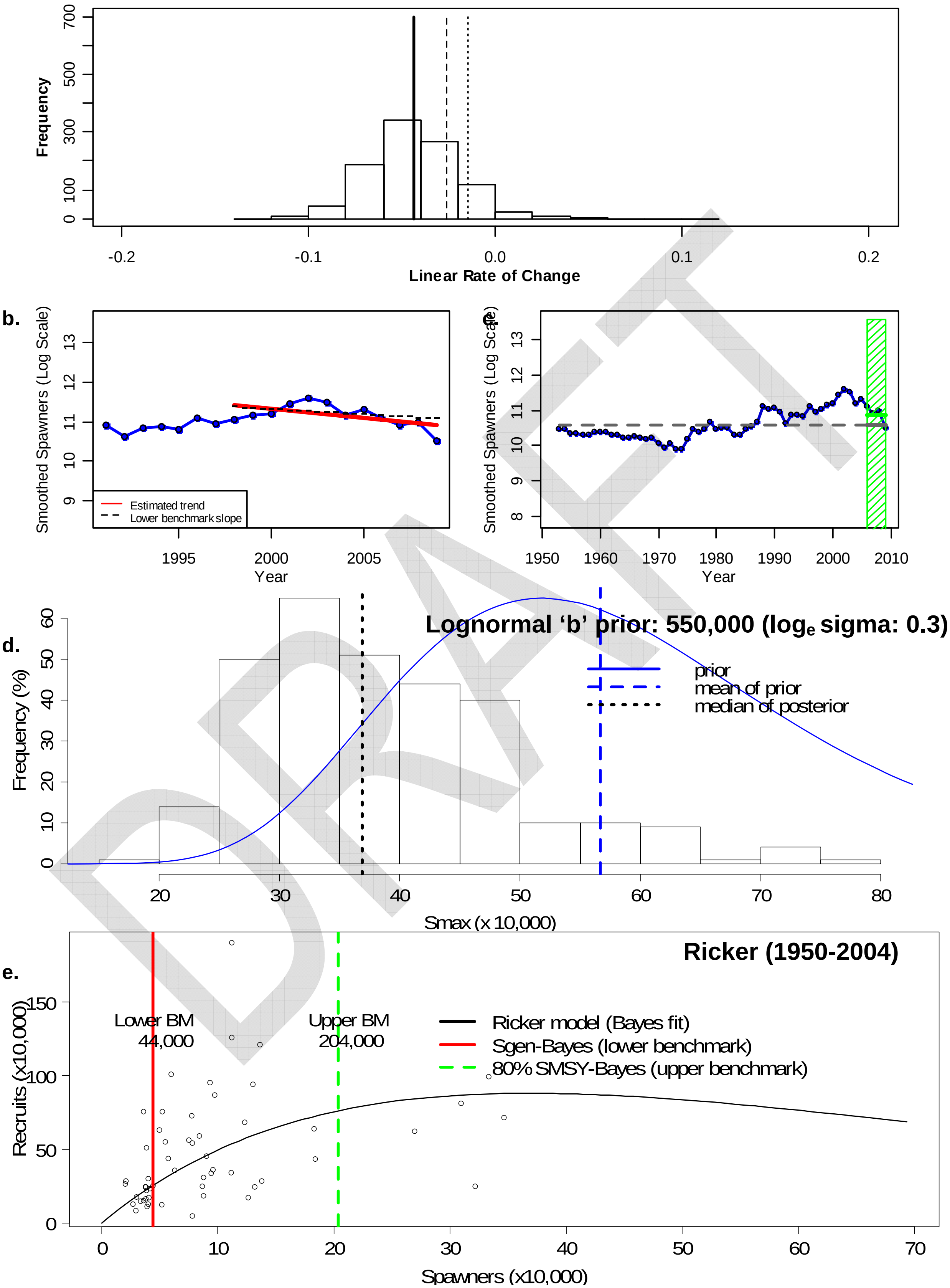

Frequency
Linear Rate of Change
b.
c.
Smoothed Spawners (Log Scale)
Estimated trend
Lower benchmark slope
Year
d.
Uniform 'b' prior: 0-1,000,000
prior
median of posterior
Frequency (%)
Smax (x 10,000)
e.
Ricker (1973-2004)
Ricker model (Bayes fit)
Sgen-Bayes (lower benchmark)
80% SMSY-Bayes (upper benchmark)
Lower BM
18,000
Upper BM
60,000
Recruits (x10,000)
Spawners (x10,000)

Fraser-S



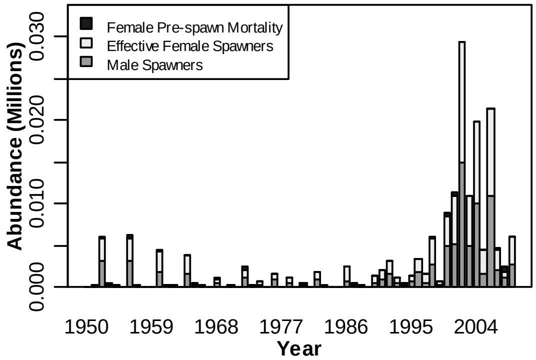
1a.
Enroute Loss
Catch
Escapement
Abundance (Millions)
Exploitation Rate
Year
b.
Female Pre-spawn Mortality
Effective Female Spawners
Male Spawners
Year
c.
ln(R/EFS)
Ricker Residuals
Kalman Filter
Standardized Productivity Indices
Brood Year
d.
Recruits per Spawner (Log Scale)
Brood Year
e.
Freshwater Survival (Fry)
Brood Year
f.
No marine survival data available

2a.


Frequency
0
100
300
500
700
-0.2
-0.1
0.0
0.1
0.2
Linear Rate of Change
b.
Smoothed Spawners (Log Scale)
9
10
11
12
13
Estimated trend
Lower benchmark slope
1995
2000
2005
Year
c.
Smoothed Spawners (Log Scale)
8
9
10
11
12
13
1950
1960
1970
1980
1990
2000
2010
Year
d.
Lognormal 'b' prior: 550,000 (log$_e$ sigma: 0.3)
Frequency (%)
0
10
20
30
40
50
60
prior
mean of prior
median of posterior
20
30
40
50
60
70
80
Smax (x 10,000)
e.
Ricker (1950-2004)
Recruits (x10,000)
0
50
100
150
Lower BM
44,000
Upper BM
204,000
Ricker model (Bayes fit)
Sgen-Bayes (lower benchmark)
80% SMSY-Bayes (upper benchmark)
0
10
20
30
40
50
60
70
Spawners (x10,000)

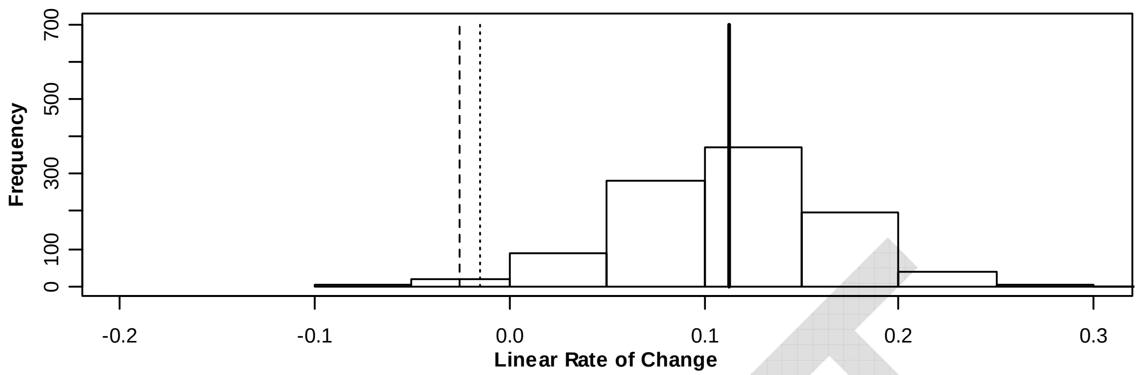
Harrison (D/S)-L

1b.

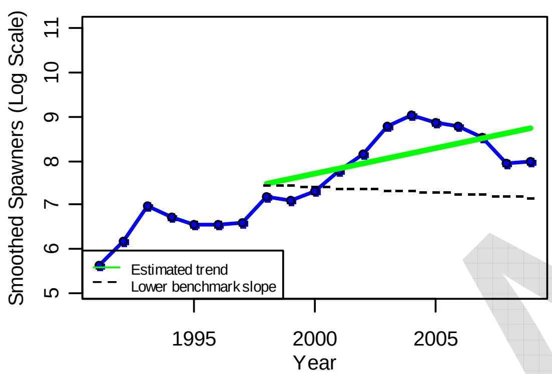


Only escapement data is available for Harrison (D/S)-L.

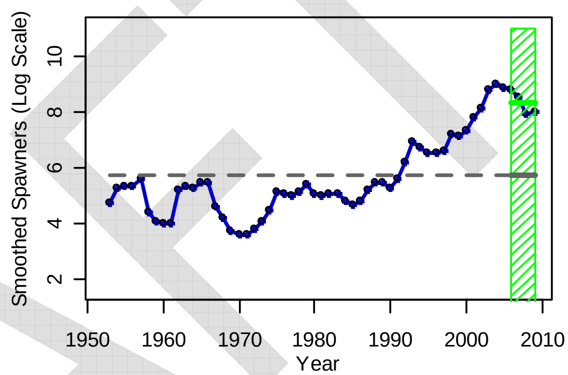
2a.



b.



c.



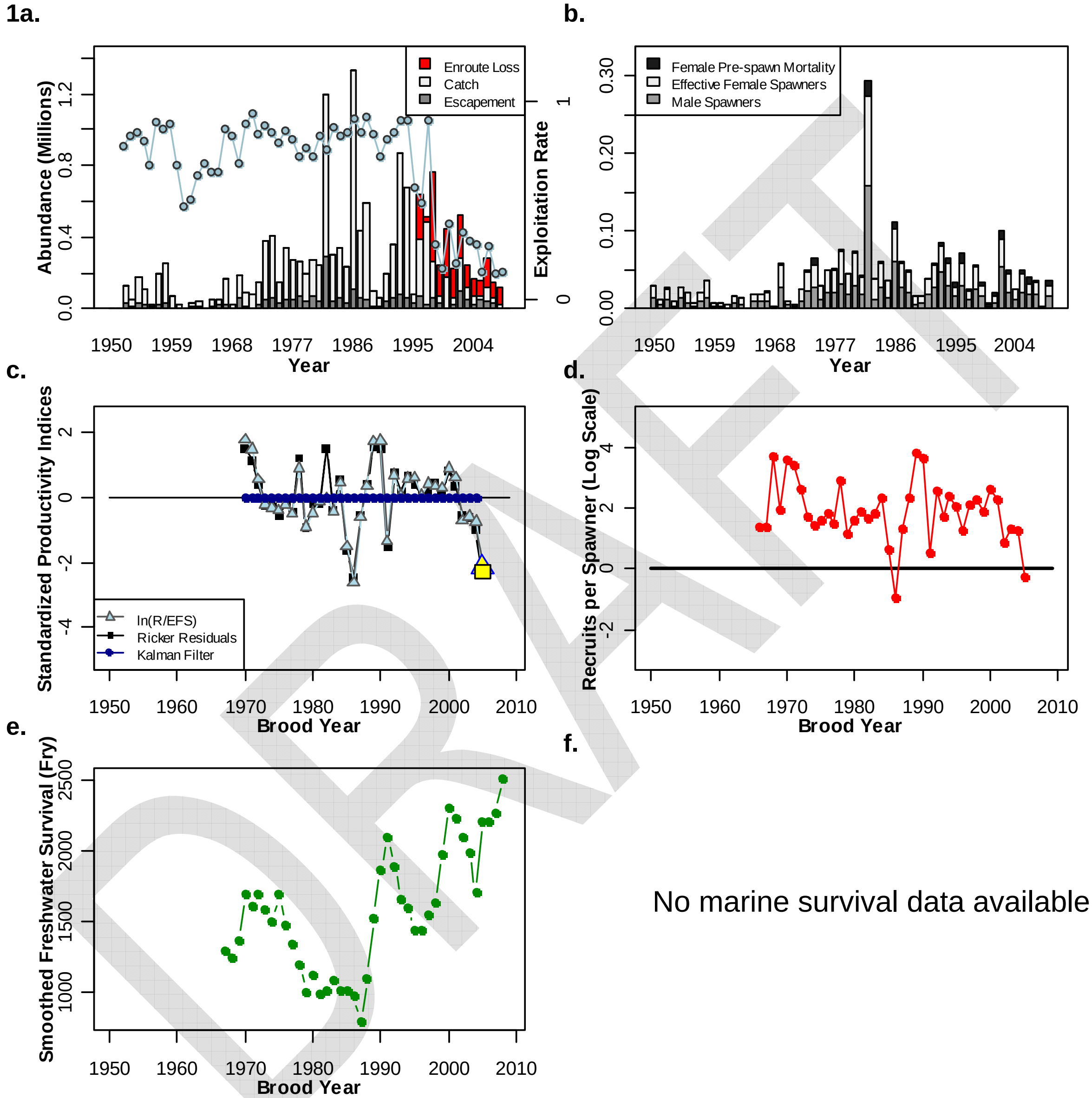
d.

No stock-recruitment data to calculate abundance based benchmarks

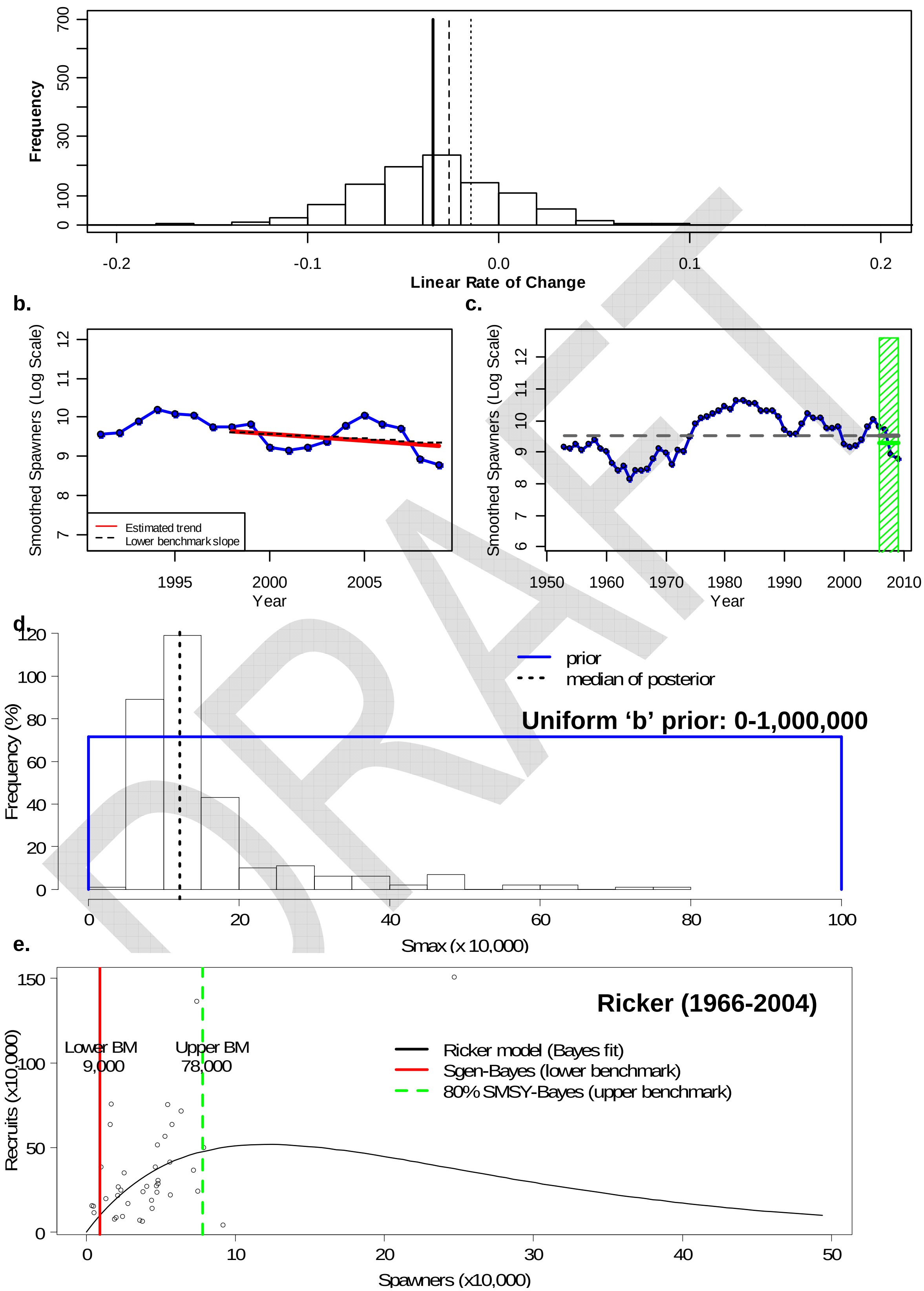
e.

No stock-recruitment data to calculate abundance based benchmarks

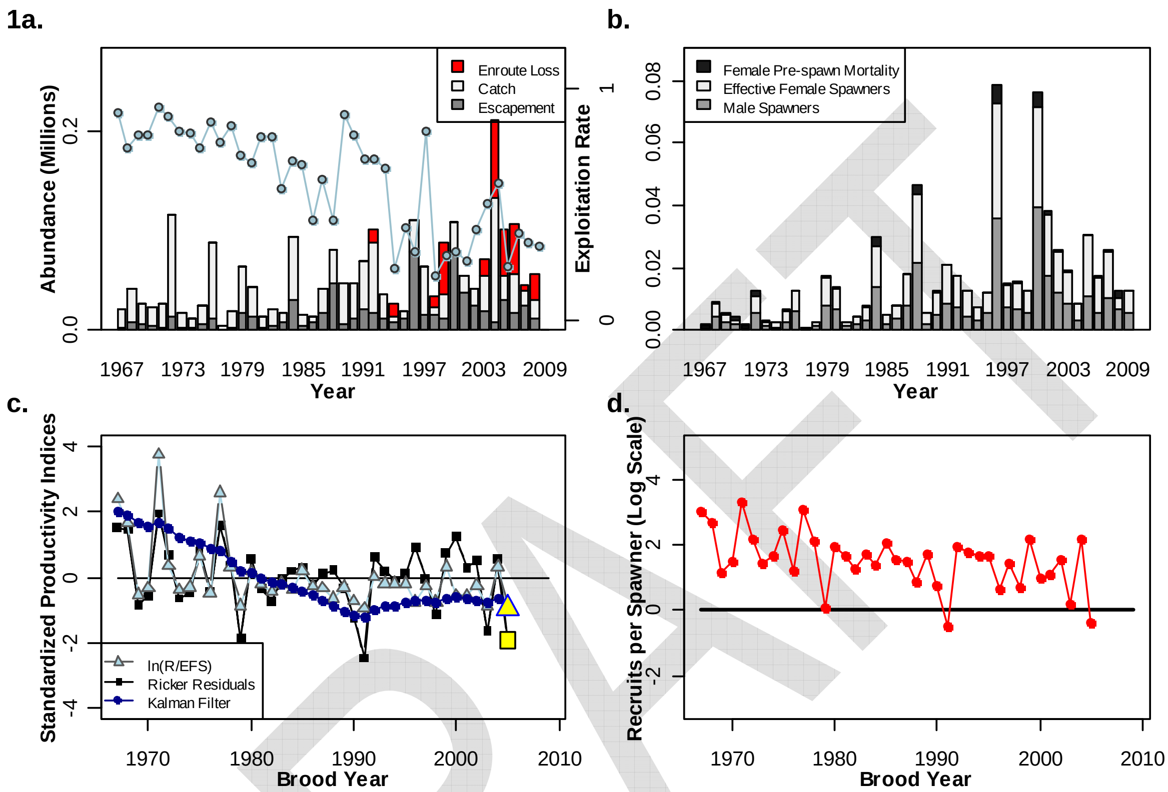
Harrison (U/S)-L



2a.


Frequency
0
100
300
500
700
-0.2
-0.1
0.0
0.1
0.2
Linear Rate of Change
b.
c.
Smoothed Spawners (Log Scale)
Estimated trend
Lower benchmark slope
1995
2000
2005
Year
1950
1960
1970
1980
1990
2000
2010
d.
Frequency (%)
prior
median of posterior
Uniform 'b' prior: 0-1,000,000
Smax (x 10,000)
e.
Ricker (1966-2004)
Lower BM
9,000
Upper BM
78,000
Ricker model (Bayes fit)
Sgen-Bayes (lower benchmark)
80% SMSY-Bayes (upper benchmark)
Recruits (x10,000)
Spawners (x10,000)

Kamloops-ES

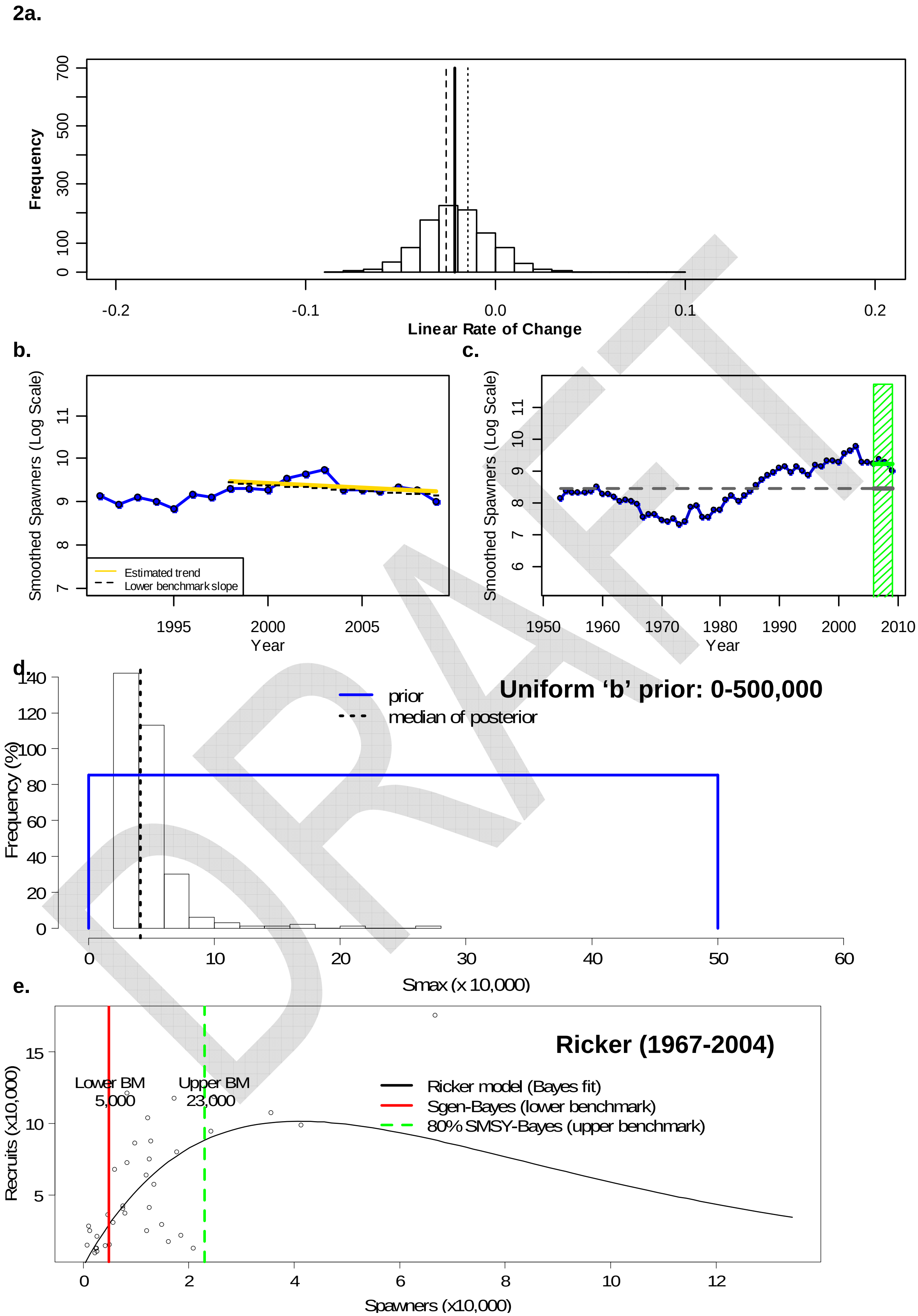


e.

f.

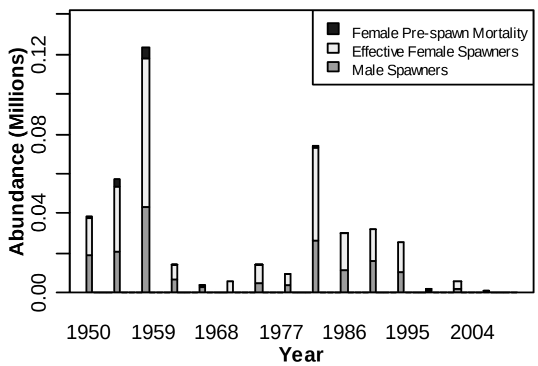
No freshwater survival data available

No marine survival data available


2a.
Frequency
Linear Rate of Change
b.
Smoothed Spawners (Log Scale)
Estimated trend
Lower benchmark slope
Year
c.
Smoothed Spawners (Log Scale)
Year
d.
prior
median of posterior
Uniform 'b' prior: 0-500,000
Frequency (%)
Smax (x 10,000)
e.
Ricker (1967-2004)
Lower BM
5,000
Upper BM
23,000
Ricker model (Bayes fit)
Sgen-Bayes (lower benchmark)
80% SMSY-Bayes (upper benchmark)
Recruits (x10,000)
Spawners (x10,000)

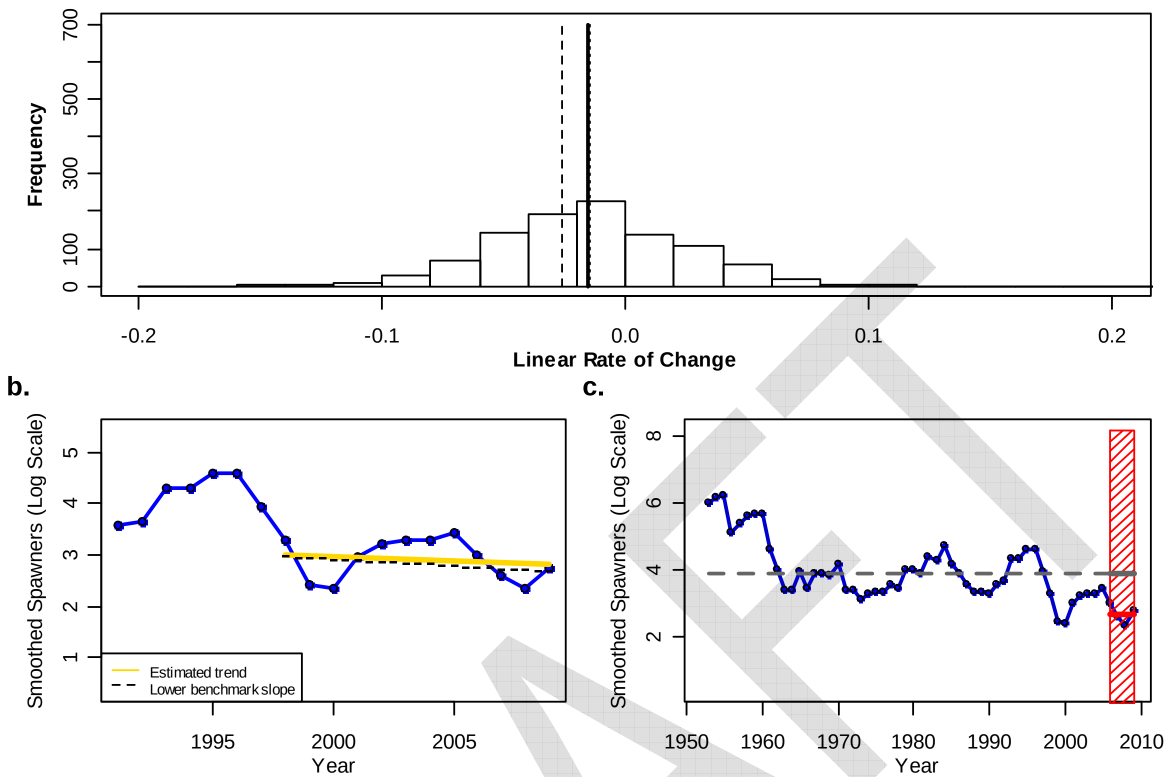
Kamloops-L

1b.



Only escapement data is available for Kamloops-L.

2a.



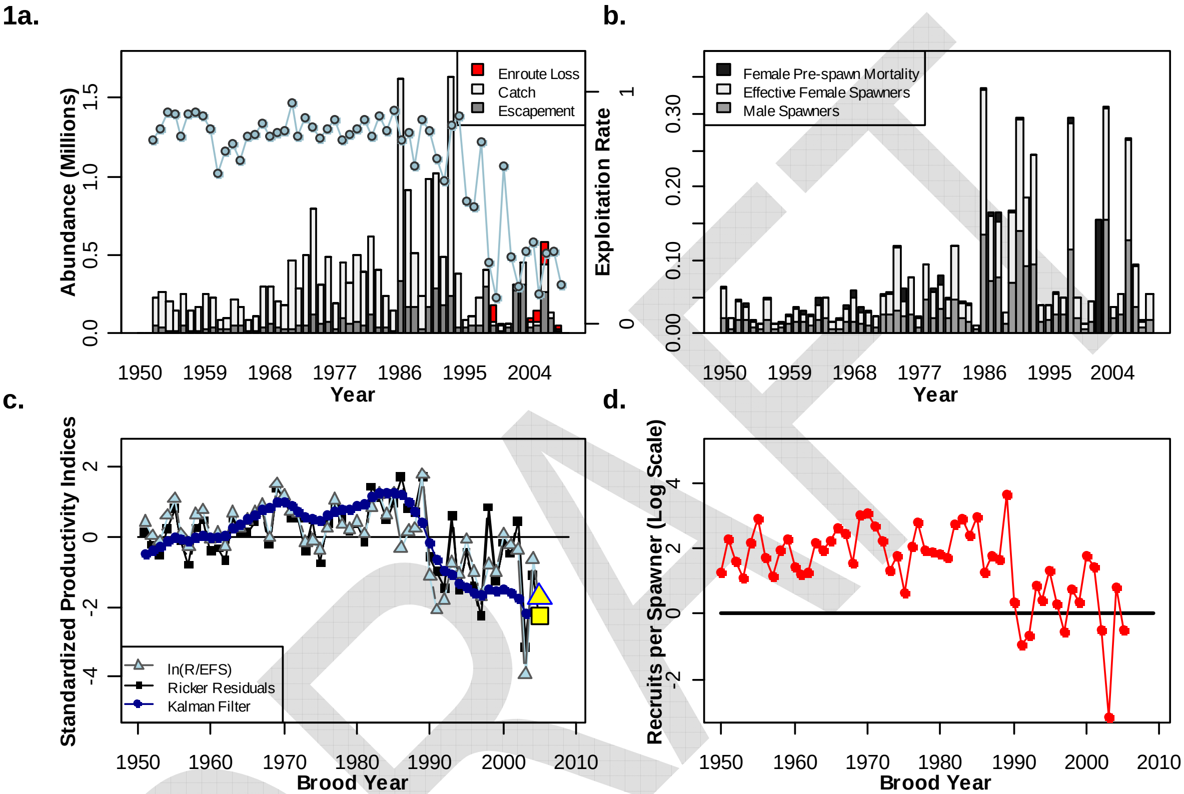
d.

No stock-recruitment data to calculate abundance based benchmarks

e.

No stock-recruitment data to calculate abundance based benchmarks

Lillooet-L

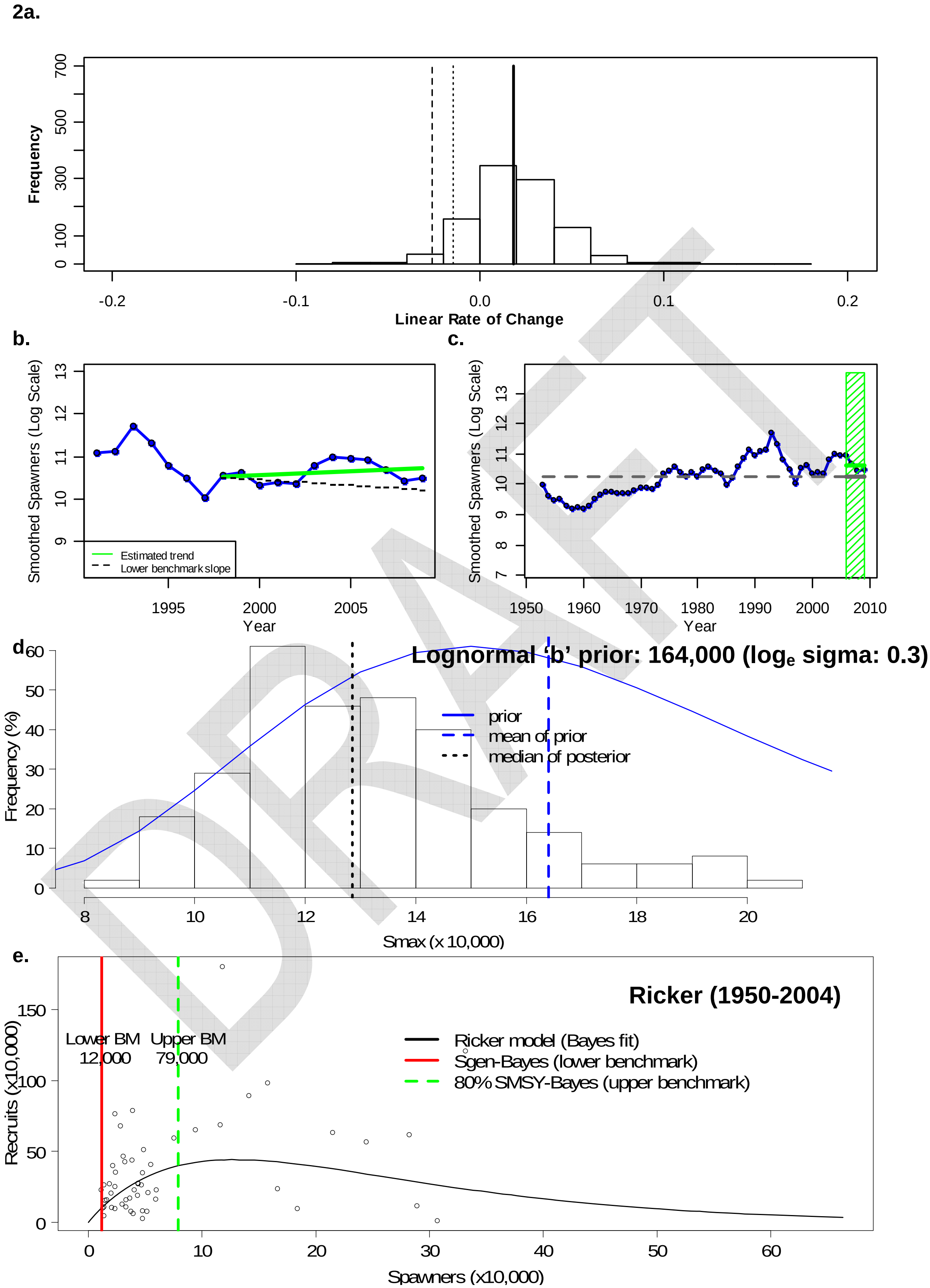


e.

f.

No freshwater survival data available

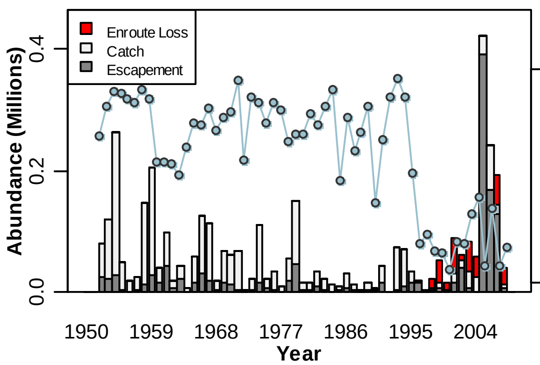
No marine survival data available



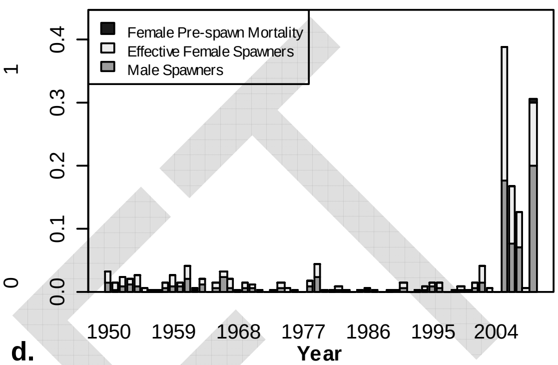
2a.
Frequency
Linear Rate of Change
-0.2
-0.1
0.0
0.1
0.2
b.
Smoothed Spawners (Log Scale)
Estimated trend
Lower benchmark slope
Year
c.
Smoothed Spawners (Log Scale)
Year
d
Lognormal 'b' prior: 164,000 (log$_e$ sigma: 0.3)
Frequency (%)
prior
mean of prior
median of posterior
Smax (x 10,000)
e.
Ricker (1950-2004)
Recruits (x10,000)
Lower BM 12,000
Upper BM 79,000
Ricker model (Bayes fit)
Sgen-Bayes (lower benchmark)
80% SMSY-Bayes (upper benchmark)
Spawners (x10,000)

Lower Fraser River (River-Type)

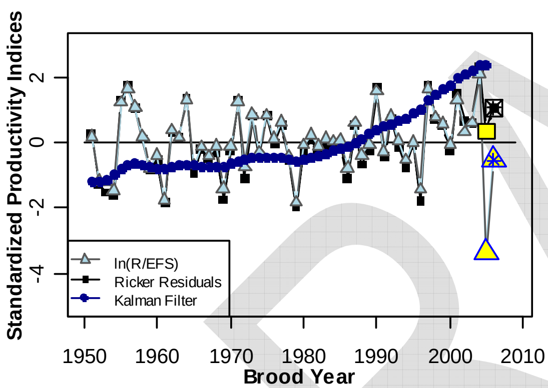
1a.



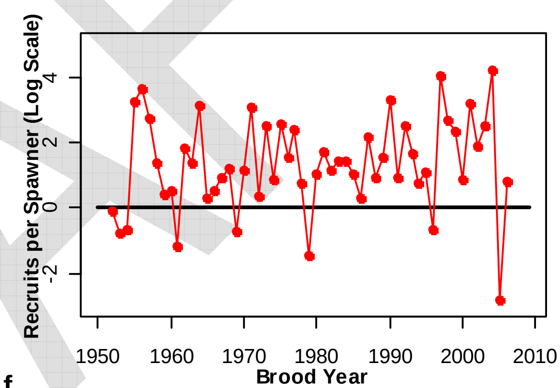
b.



c.



d.

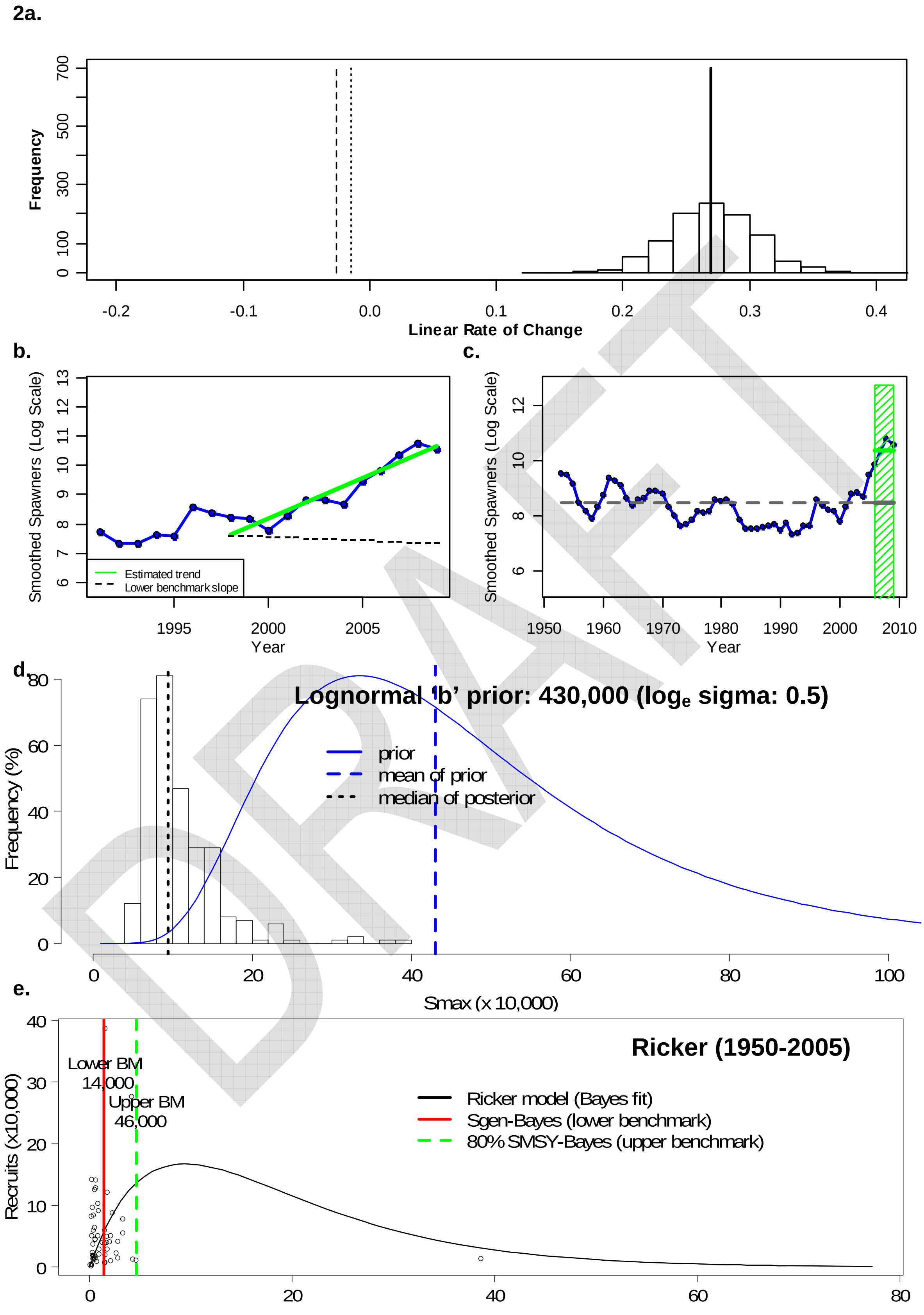


e.

No freshwater survival data available

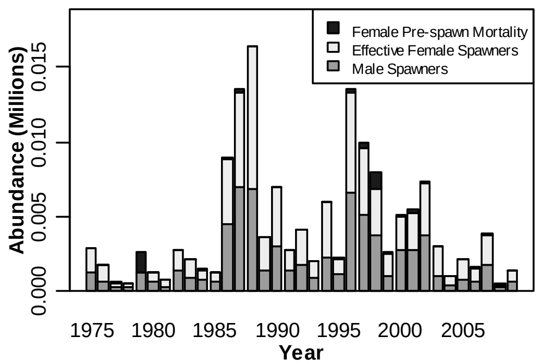
f.

No marine survival data available


2a.
Frequency
0
100
300
500
700
-0.2
-0.1
0.0
0.1
0.2
0.3
0.4
Linear Rate of Change
b.
Smoothed Spawners (Log Scale)
Estimated trend
Lower benchmark slope
1995
2000
2005
Year
c.
Smoothed Spawners (Log Scale)
1950
1960
1970
1980
1990
2000
2010
Year
d.
Lognormal 'b' prior: 430,000 (loge sigma: 0.5)
prior
mean of prior
median of posterior
Frequency (%)
Smax (x 10,000)
e.
Ricker (1950-2005)
Lower BM
14,000
Upper BM
46,000
Ricker model (Bayes fit)
Sgen-Bayes (lower benchmark)
80% SMSY-Bayes (upper benchmark)
Recruits (x10,000)
Spawners (x10,000)

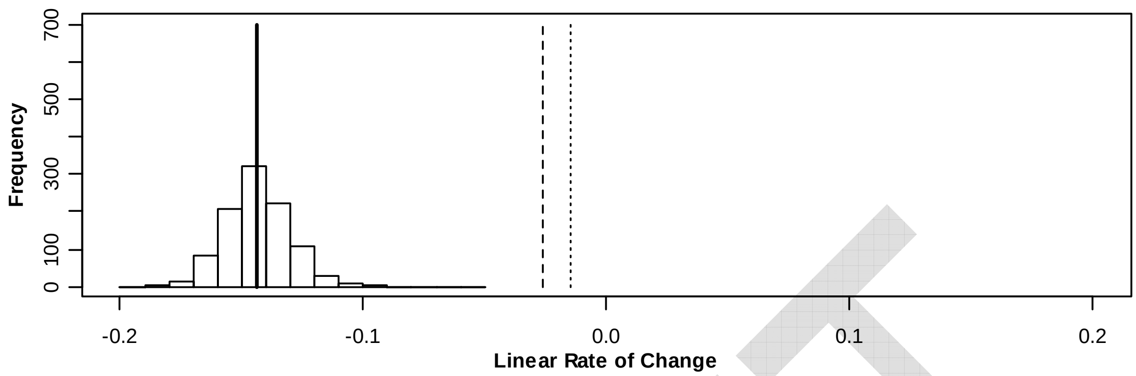
Nahatlatch-ES

1b.

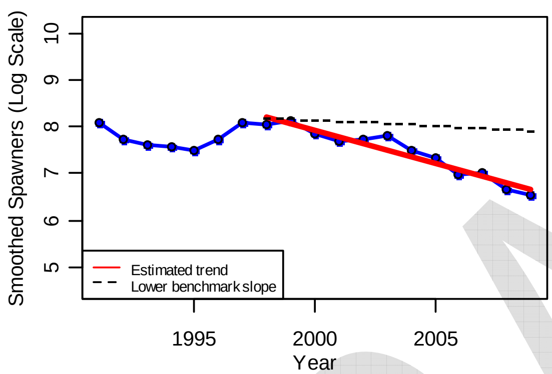


Only escapement data is available for Nahatlach-ES.

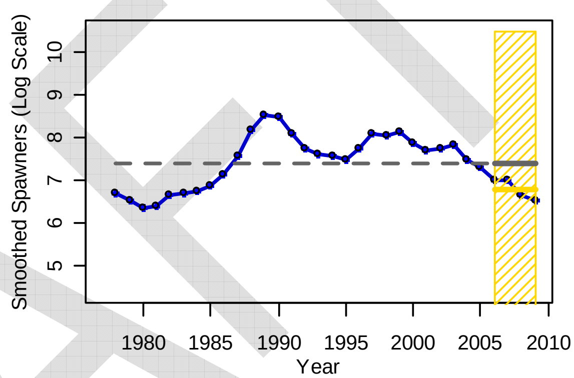
2a.



b.



c.



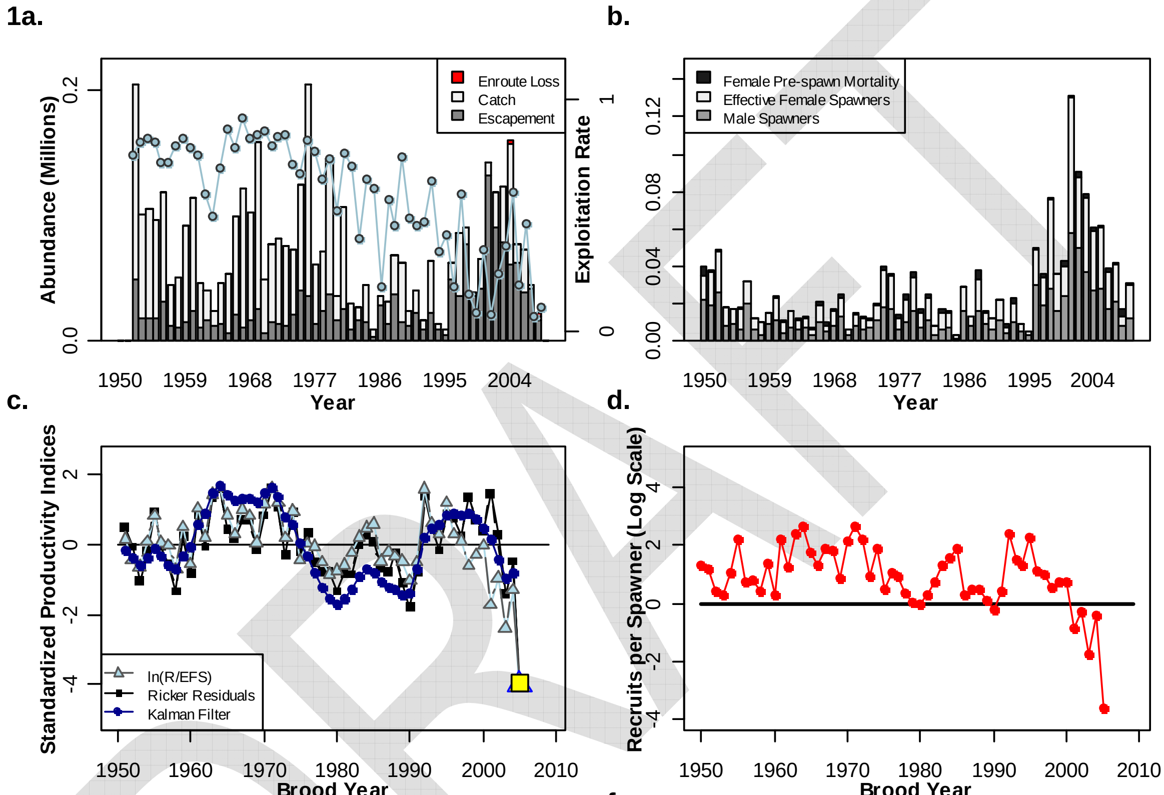
d.

No stock-recruitment data to calculate abundance based benchmarks

e.

No stock-recruitment data to calculate abundance based benchmarks

Pitt-ES



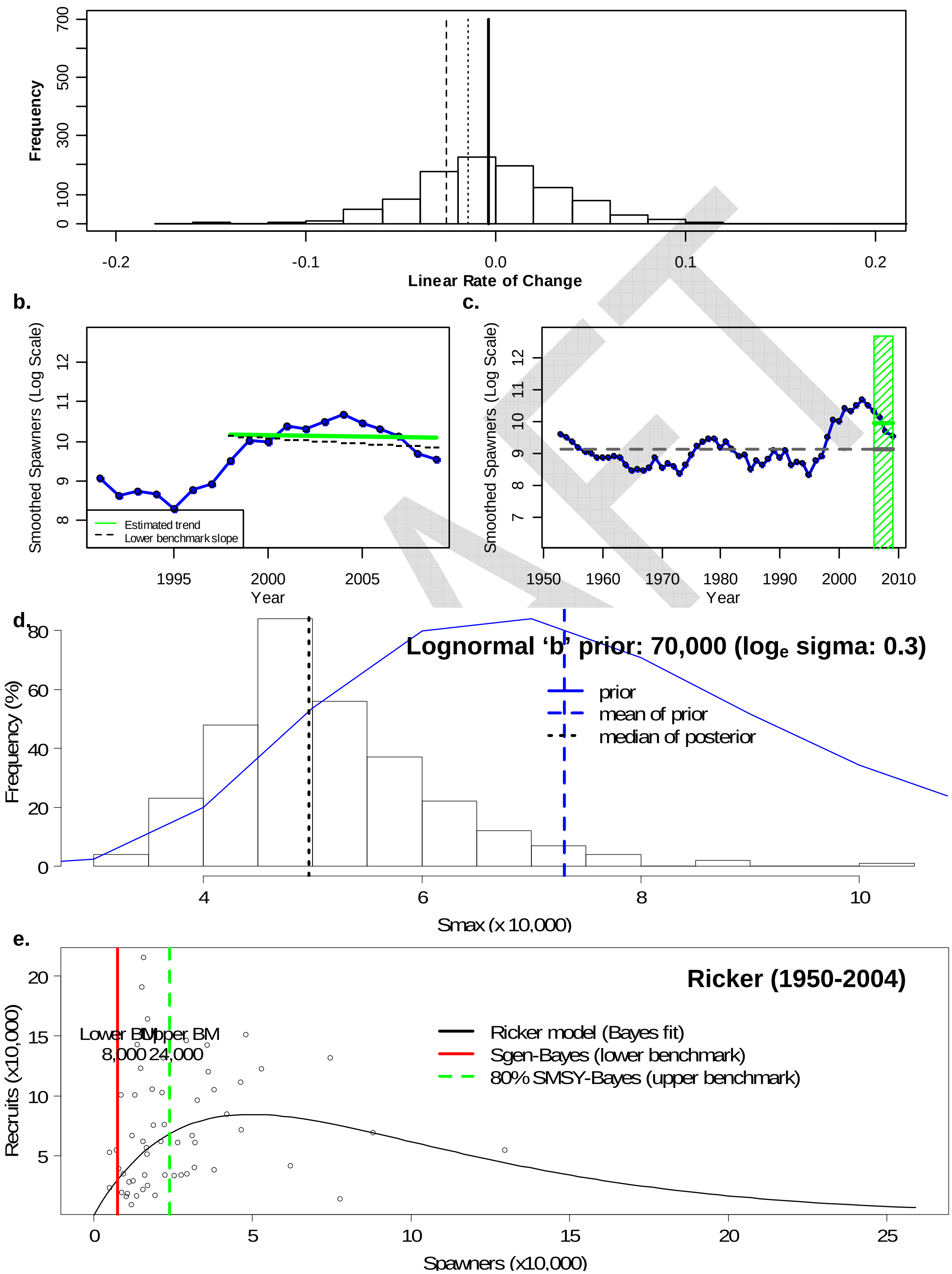
e.

f.

No freshwater survival data available

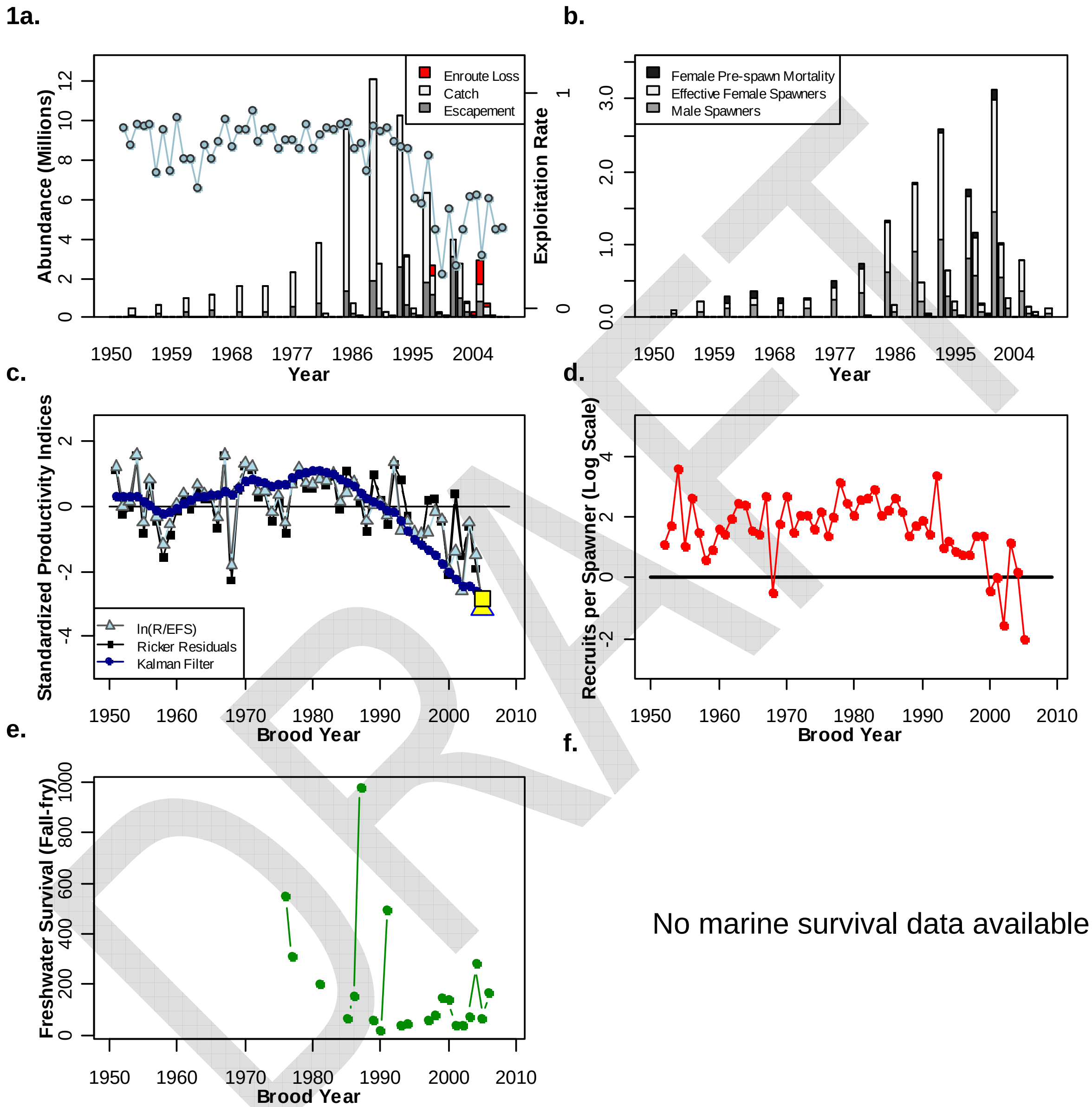
No marine survival data available

2a.

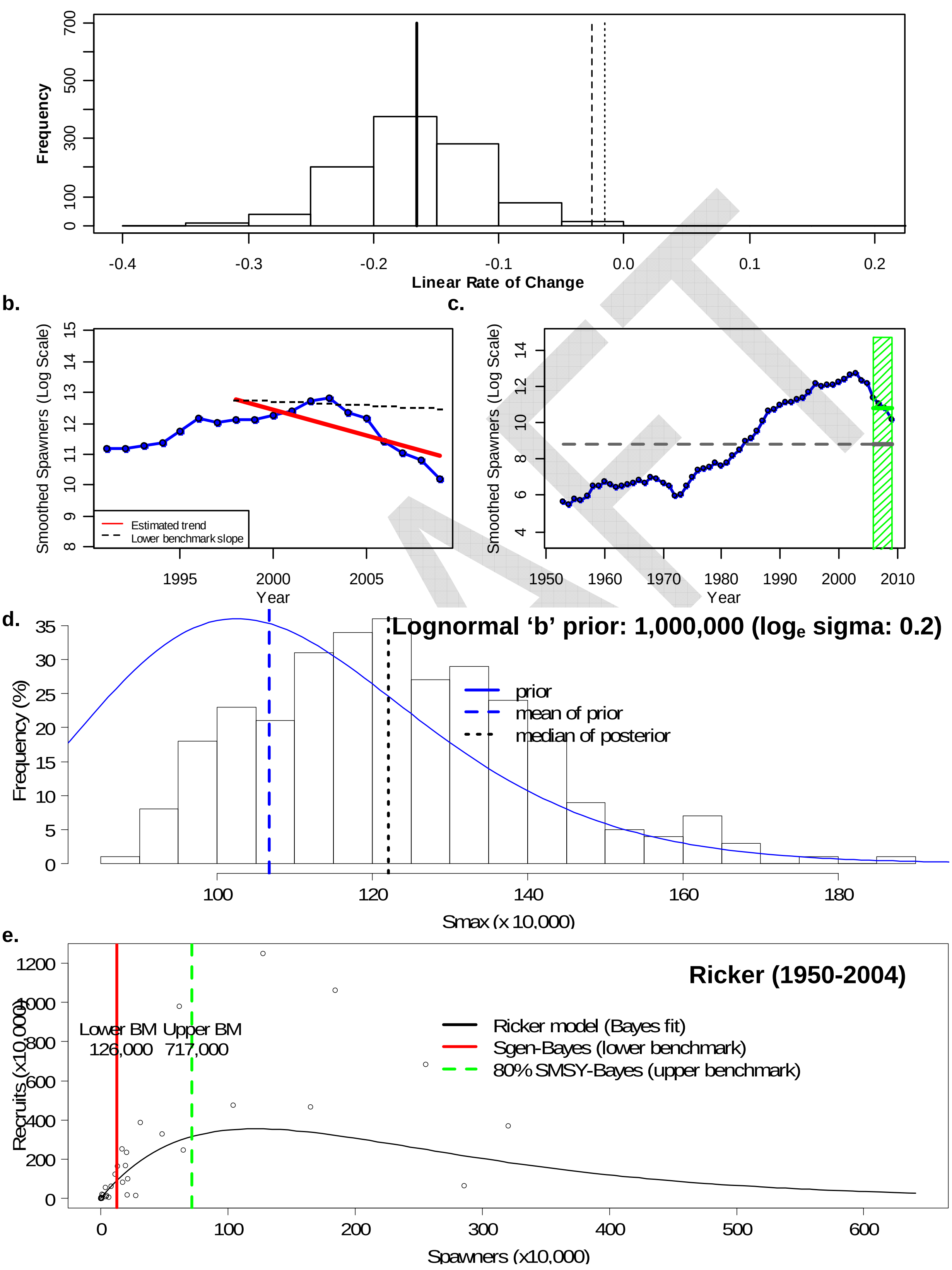


Frequency
Linear Rate of Change
b.
Smoothed Spawners (Log Scale)
Estimated trend
Lower benchmark slope
Year
c.
Smoothed Spawners (Log Scale)
Year
d.
Lognormal ‘b’ prior: 70,000 (log$_e$ sigma: 0.3)
prior
mean of prior
median of posterior
Frequency (%)
Smax (x 10,000)
e.
Ricker (1950-2004)
Lower BM
Upper BM
8,000
24,000
Ricker model (Bayes fit)
Sgen-Bayes (lower benchmark)
80% SMSY-Bayes (upper benchmark)
Recruits (x10,000)
Spawners (x10,000)

Quesnel-S and McKinley-S Aggregate

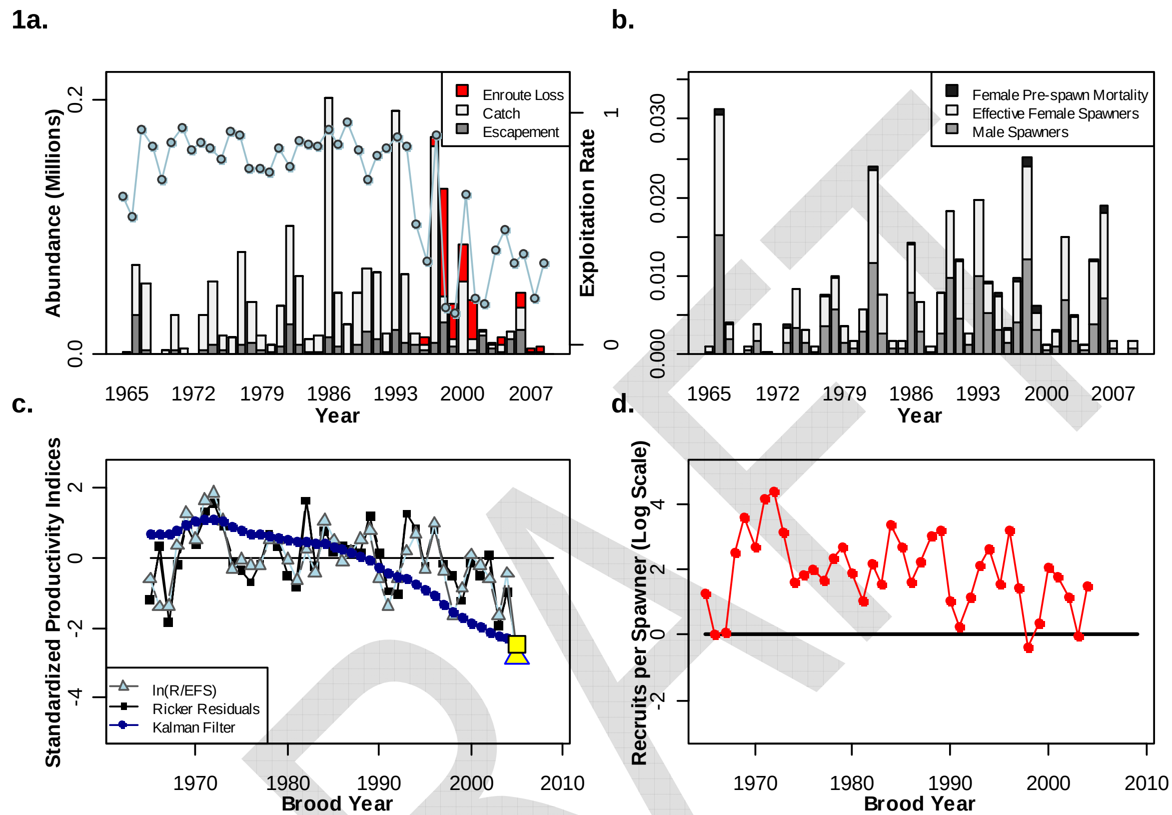


2a.



Frequency
0
100
300
500
700
-0.4
-0.3
-0.2
-0.1
0.0
0.1
0.2
Linear Rate of Change
b.
c.
Smoothed Spawners (Log Scale)
Estimated trend
Lower benchmark slope
1995
2000
2005
Year
1950
1960
1970
1980
1990
2000
2010
Year
d.
Lognormal 'b' prior: 1,000,000 (log_e sigma: 0.2)
Frequency (%)
prior
mean of prior
median of posterior
Smax (x 10,000)
e.
Ricker (1950-2004)
Recruits (x10,000)
Lower BM Upper BM
126,000 717,000
Ricker model (Bayes fit)
Sgen-Bayes (lower benchmark)
80% SMSY-Bayes (upper benchmark)
Spawners (x10,000)

Seton-L

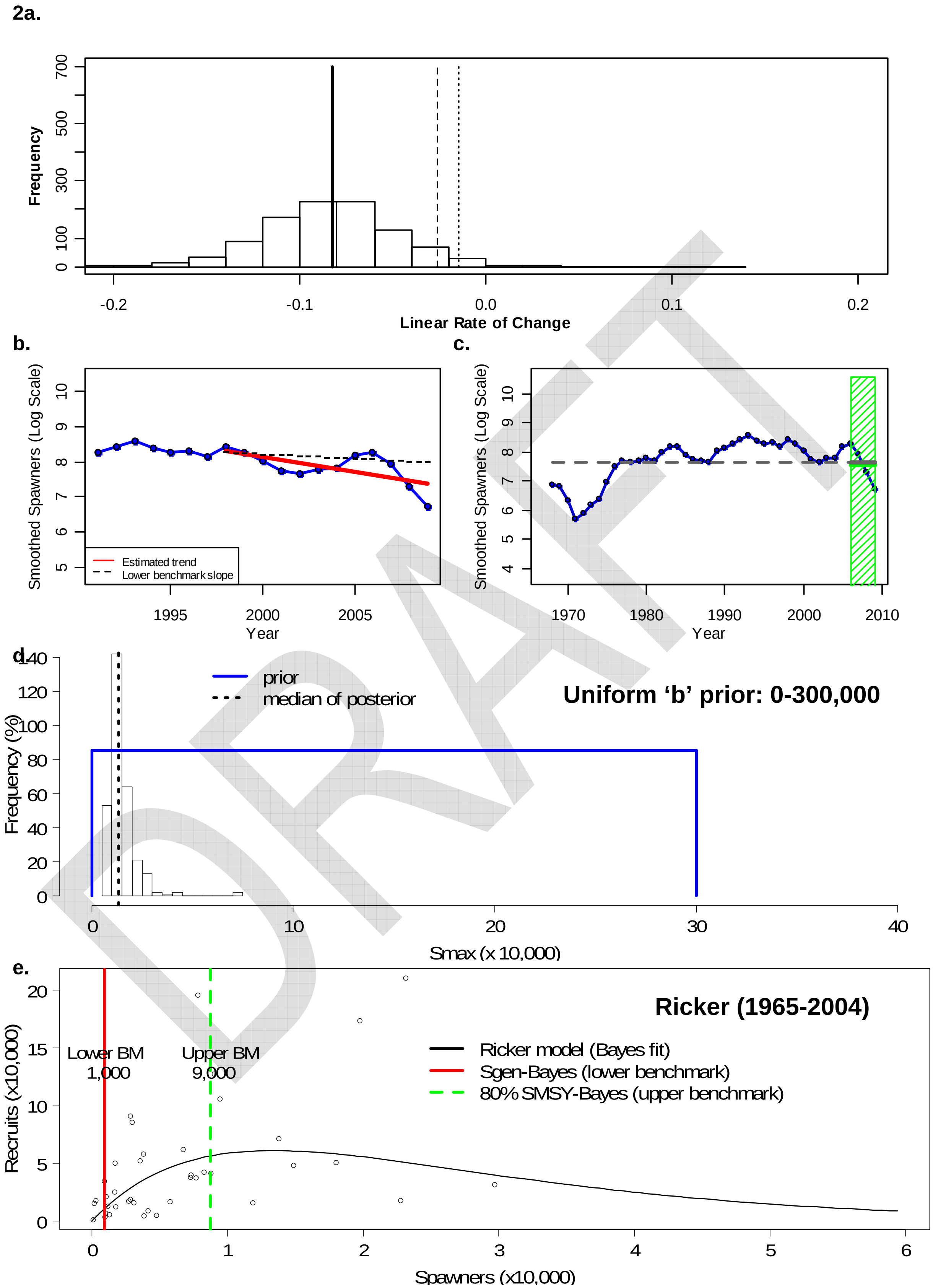


e.

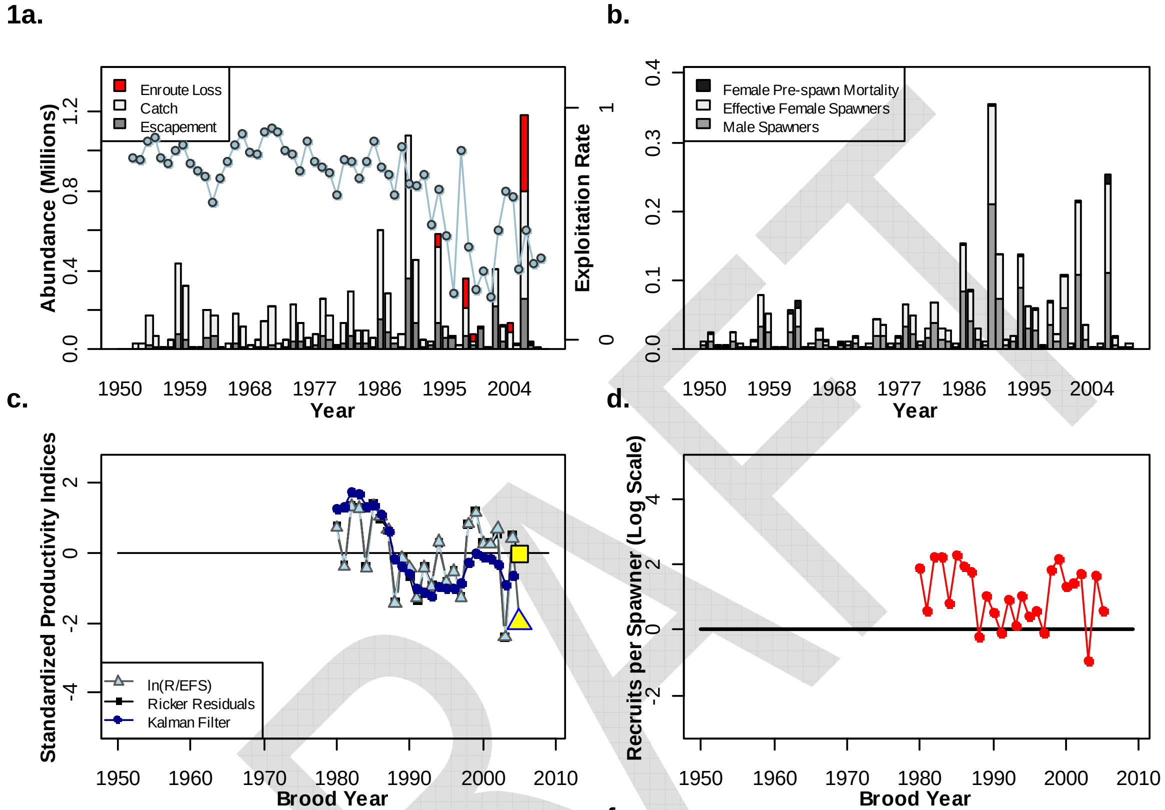
No freshwater survival data available

f.

No marine survival data available


2a.
Frequency
Linear Rate of Change
b.
Smoothed Spawners (Log Scale)
Year
Estimated trend
Lower benchmark slope
c.
Smoothed Spawners (Log Scale)
Year
d.
Frequency (%)
prior
median of posterior
Uniform 'b' prior: 0-300,000
Smax (x 10,000)
e.
Recruits (x10,000)
Ricker (1965-2004)
Lower BM
1,000
Upper BM
9,000
Ricker model (Bayes fit)
Sgen-Bayes (lower benchmark)
80% SMSY-Bayes (upper benchmark)
Spawners (x10,000)

Shuswap-ES



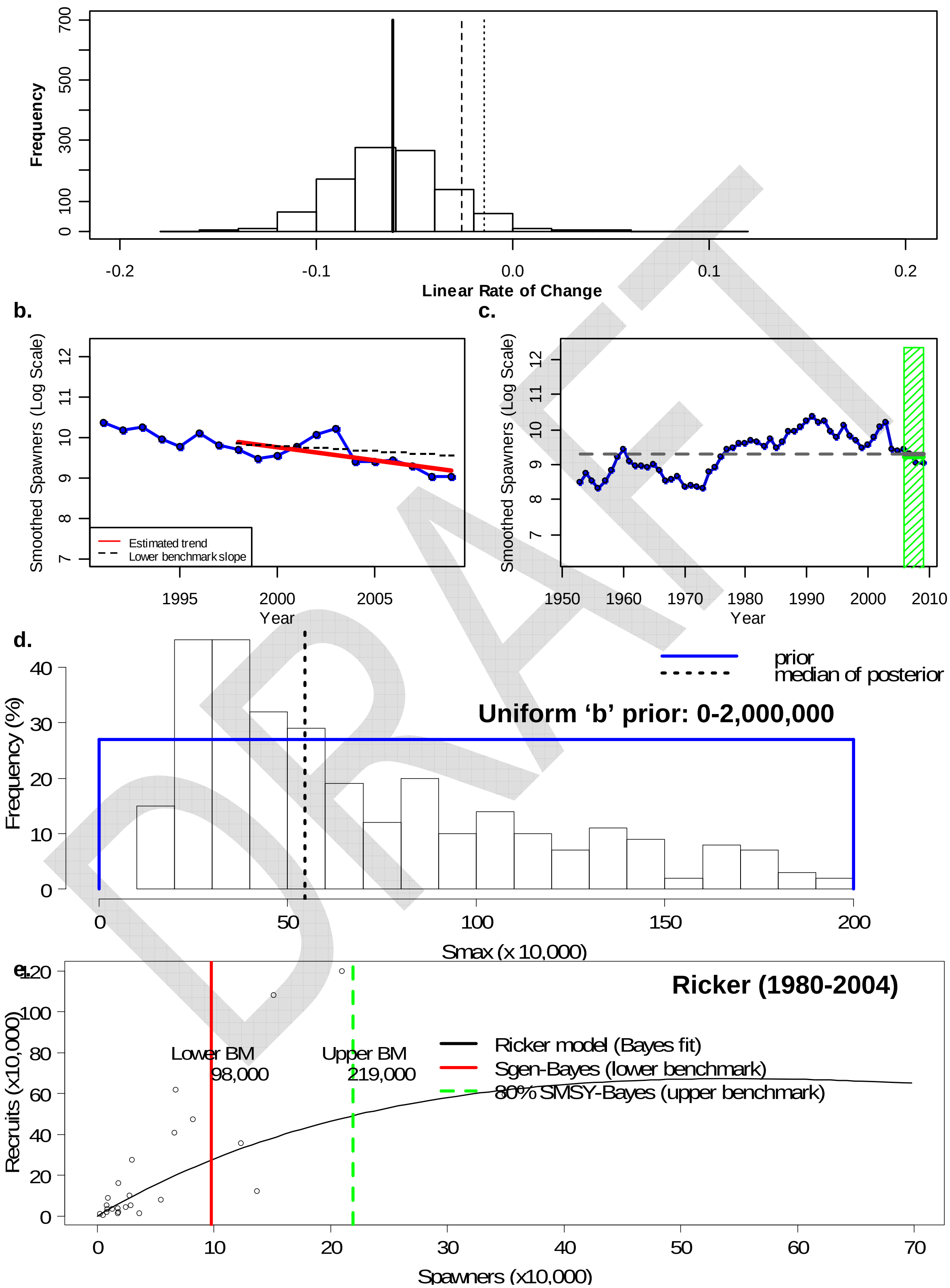
e.

f.

No freshwater survival data available

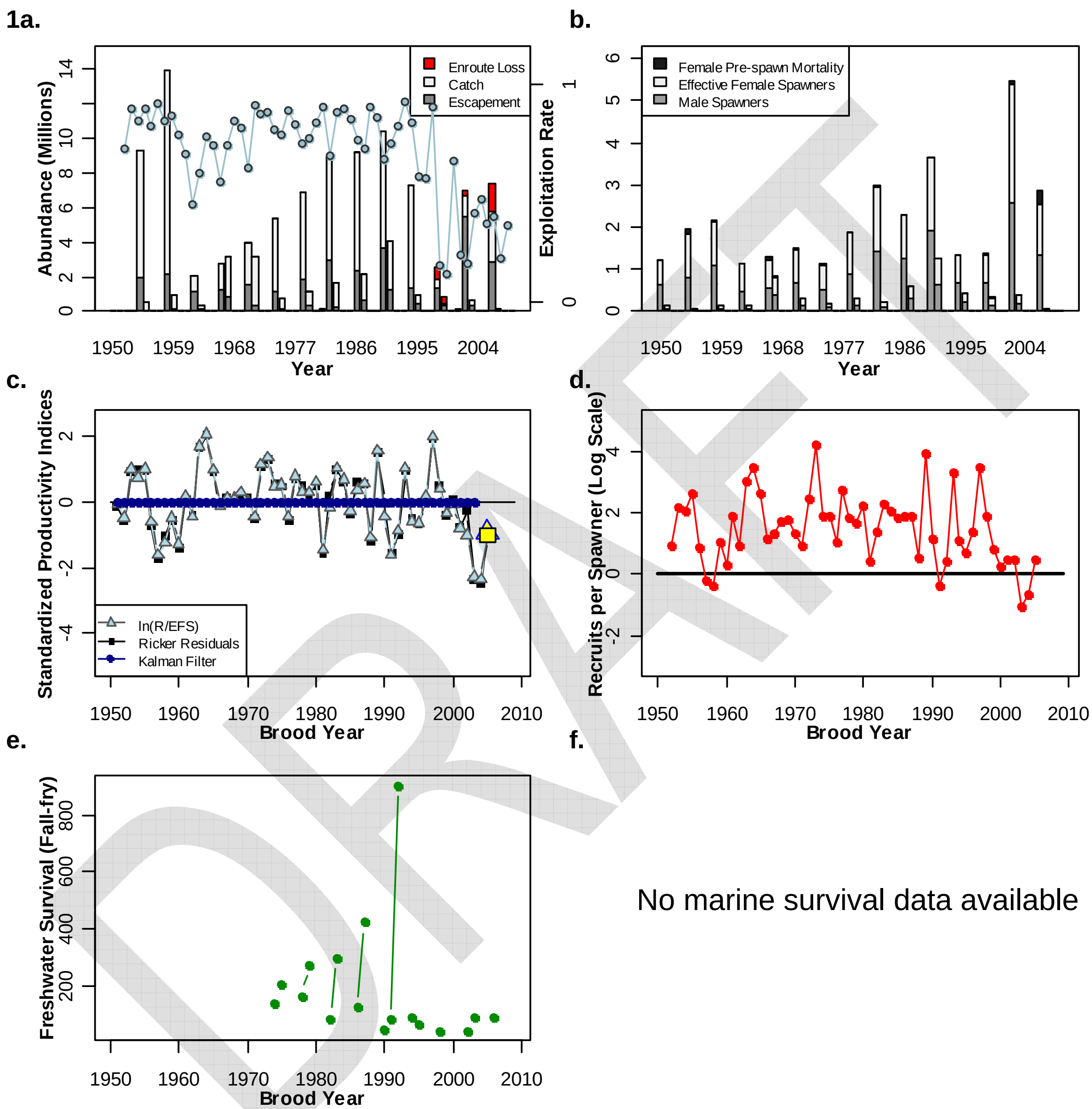
No marine survival data available

2a.



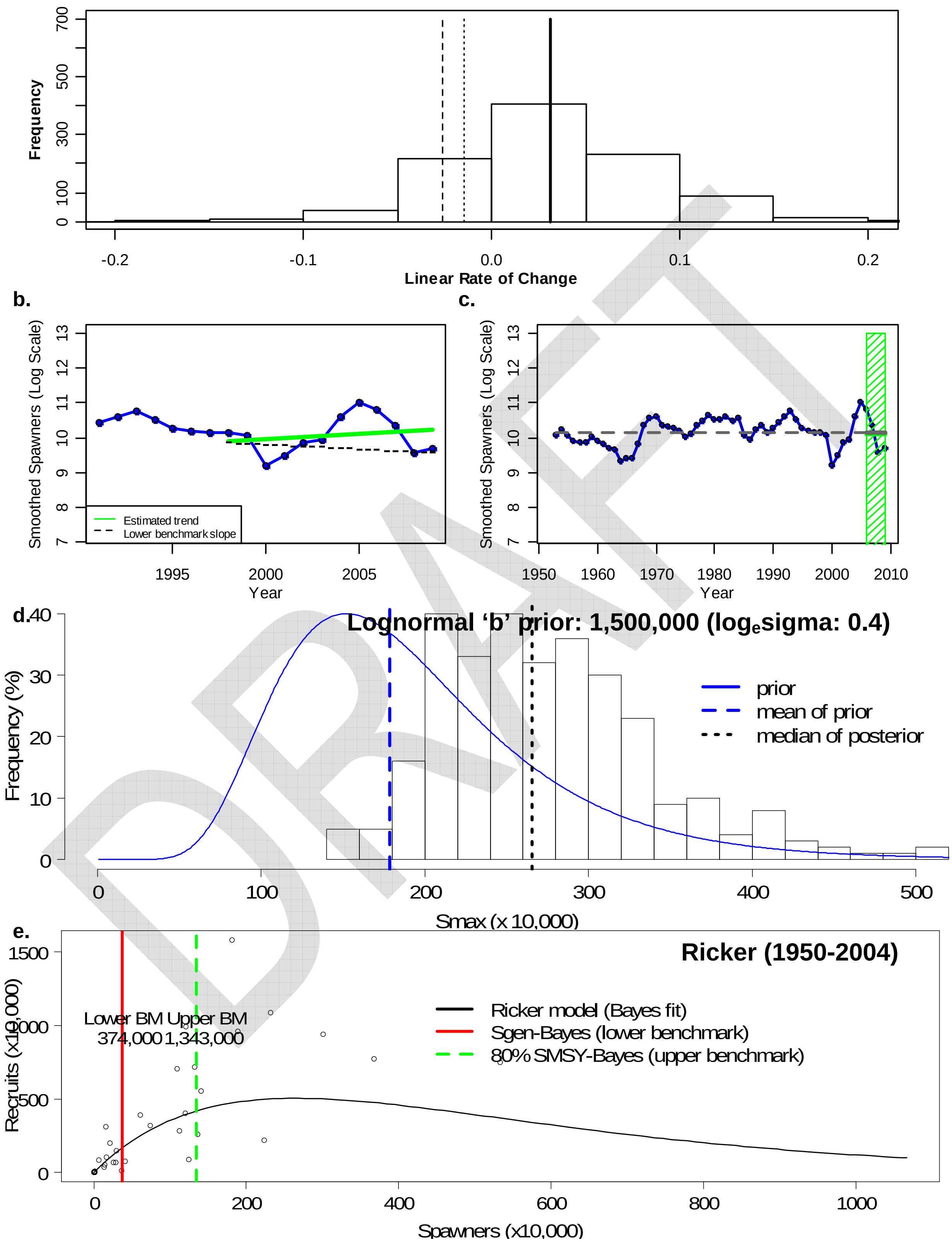
Frequency
Linear Rate of Change
b.
c.
Smoothed Spawners (Log Scale)
Estimated trend
Lower benchmark slope
Year
d.
prior
median of posterior
Uniform 'b' prior: 0-2,000,000
Frequency (%)
Smax (x 10,000)
e.
Ricker (1980-2004)
Lower BM
98,000
Upper BM
219,000
Ricker model (Bayes fit)
Sgen-Bayes (lower benchmark)
80% SMSY-Bayes (upper benchmark)
Recruits (x10,000)
Spawners (x10,000)

Shuswap-L



1a.
Abundance (Millions)
Exploitation Rate
Enroute Loss
Catch
Escapement
Year
b.
Female Pre-spawn Mortality
Effective Female Spawners
Male Spawners
Year
c.
Standardized Productivity Indices
ln(R/EFS)
Ricker Residuals
Kalman Filter
Brood Year
d.
Recruits per Spawner (Log Scale)
Brood Year
e.
Freshwater Survival (Fall-fry)
Brood Year
f.
No marine survival data available
DRAFT

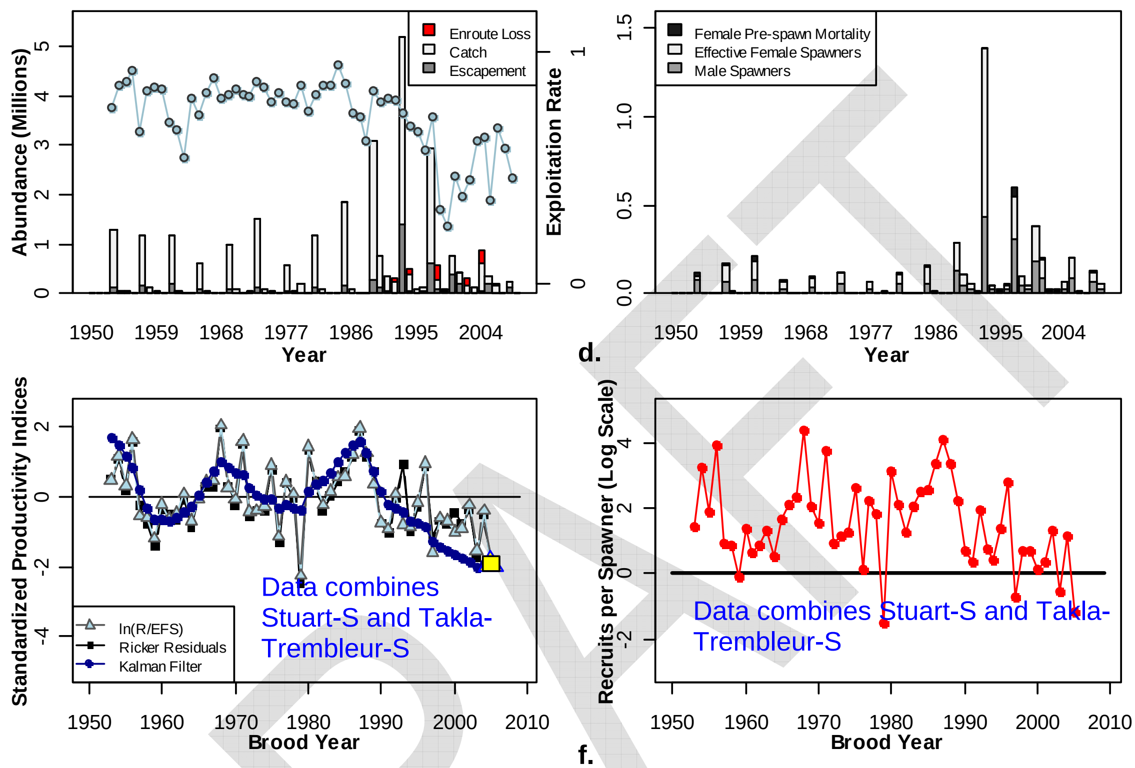
2a.



Frequency
0
100
300
500
700
-0.2
-0.1
0.0
0.1
0.2
Linear Rate of Change
b.
Smoothed Spawners (Log Scale)
Estimated trend
Lower benchmark slope
1995
2000
2005
Year
c.
1950
1960
1970
1980
1990
2000
2010
Year
d.
Lognormal 'b' prior: 1,500,000 (log$_e$sigma: 0.4)
Frequency (%)
prior
mean of prior
median of posterior
Smax (x 10,000)
e.
Ricker (1950-2004)
Recruits (x10,000)
Lower BM Upper BM
374,000 1,343,000
Ricker model (Bayes fit)
Sgen-Bayes (lower benchmark)
80% SMSY-Bayes (upper benchmark)
Spawners (x10,000)

Stuart-S

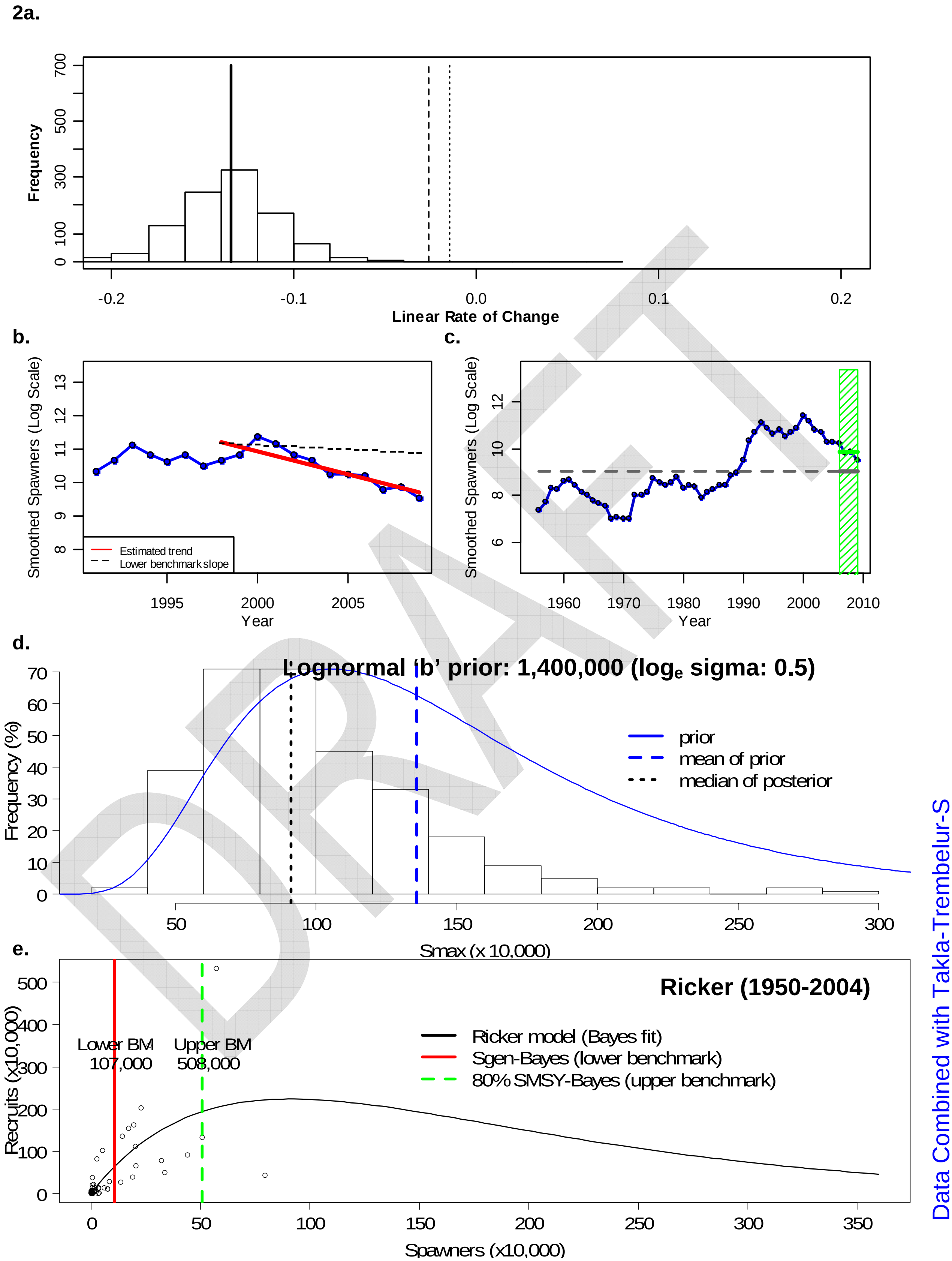
1a. **b.**



e. **f.**

No freshwater survival data available

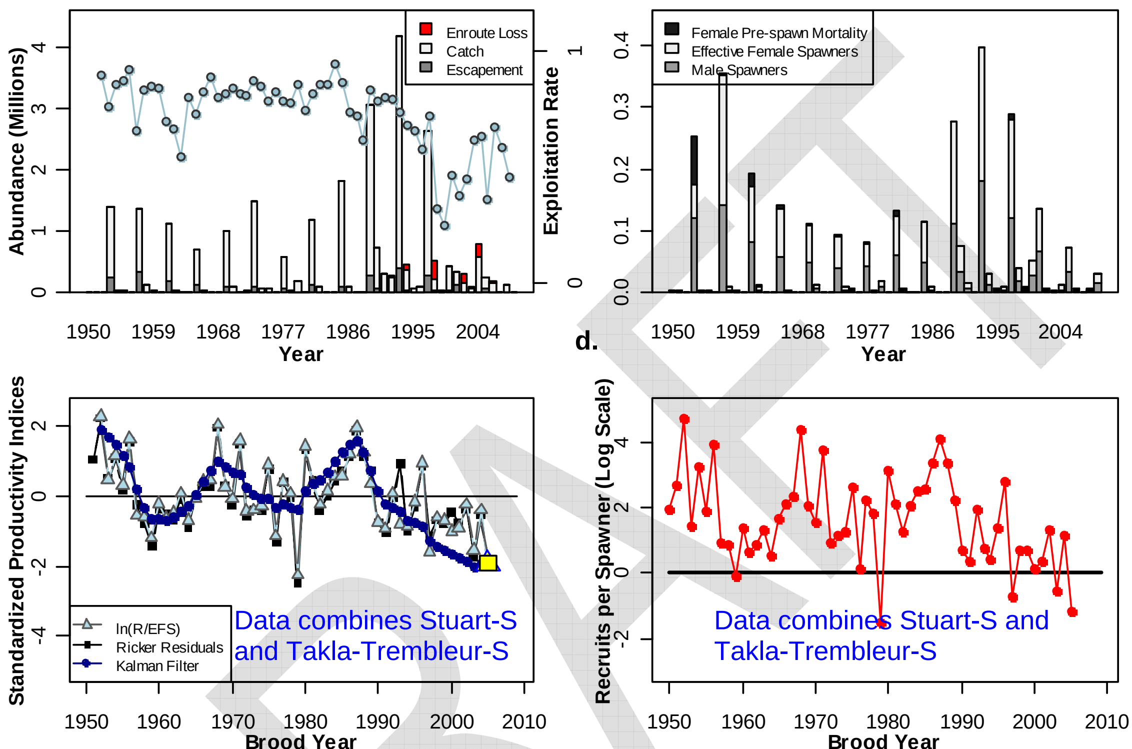
No marine survival data available



2a.
Frequency
Linear Rate of Change
b.
Smoothed Spawners (Log Scale)
Estimated trend
Lower benchmark slope
Year
c.
Smoothed Spawners (Log Scale)
Year
d.
Lognormal 'b' prior: 1,400,000 (log$_e$ sigma: 0.5)
Frequency (%)
prior
mean of prior
median of posterior
Smax (x 10,000)
e.
Ricker (1950-2004)
Recruits (x10,000)
Lower BM
107,000
Upper BM
508,000
Ricker model (Bayes fit)
Sgen-Bayes (lower benchmark)
80% SMSY-Bayes (upper benchmark)
Spawners (x10,000)
Data Combined with Takla-Trembelur-S

Takla-Trembleur-S

1a. b. c. d.

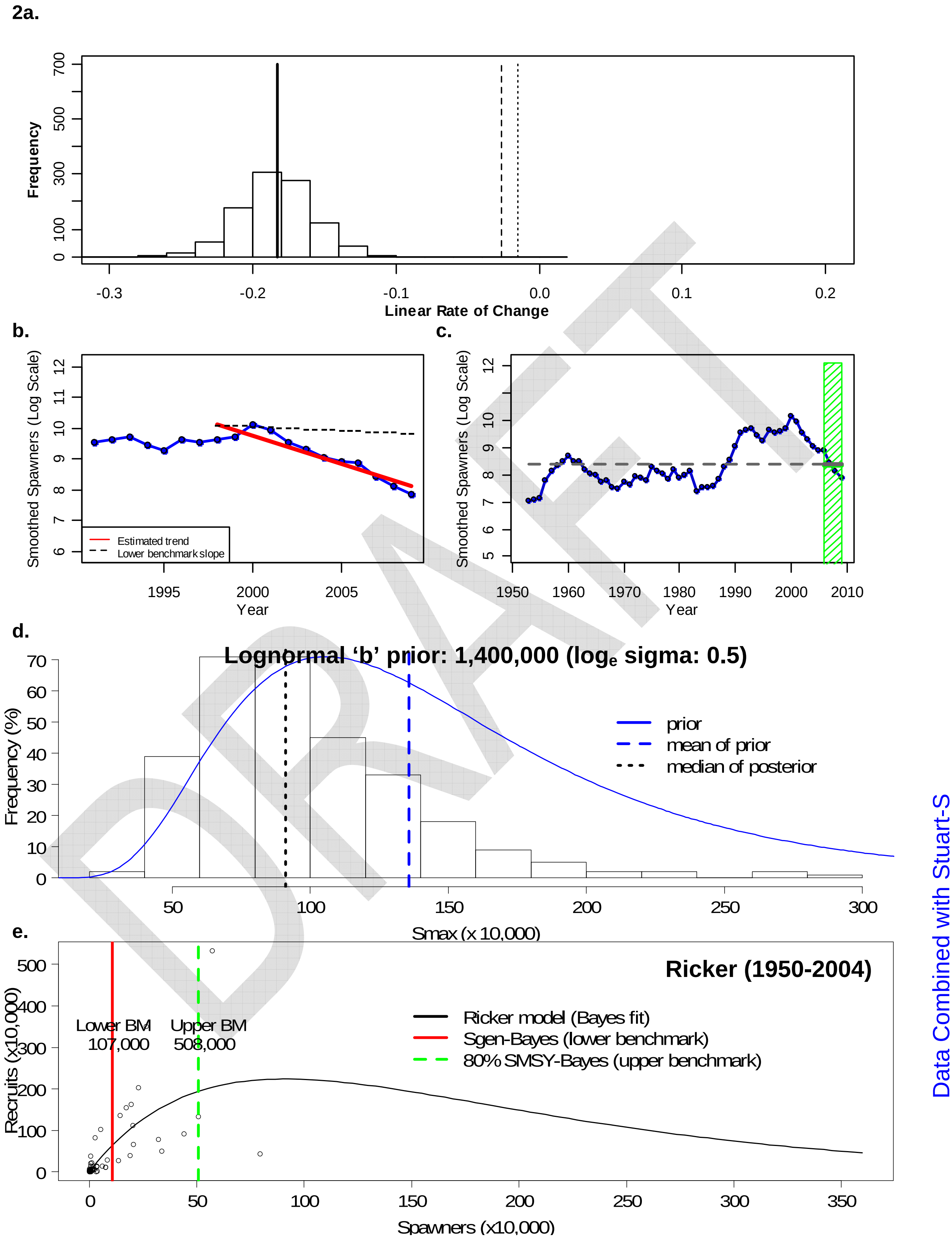


e.

No freshwater survival data available

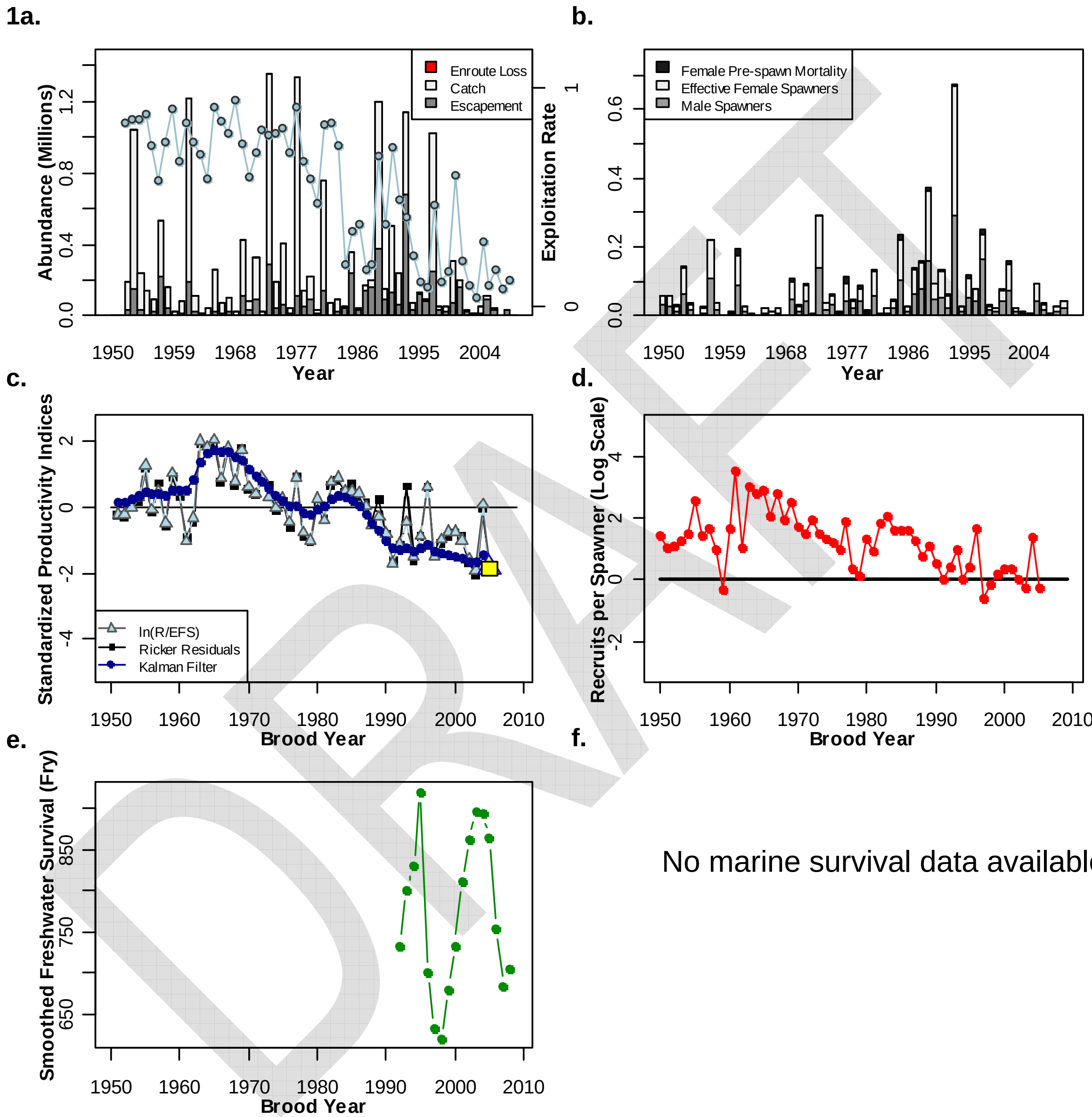
f.

No marine survival data available

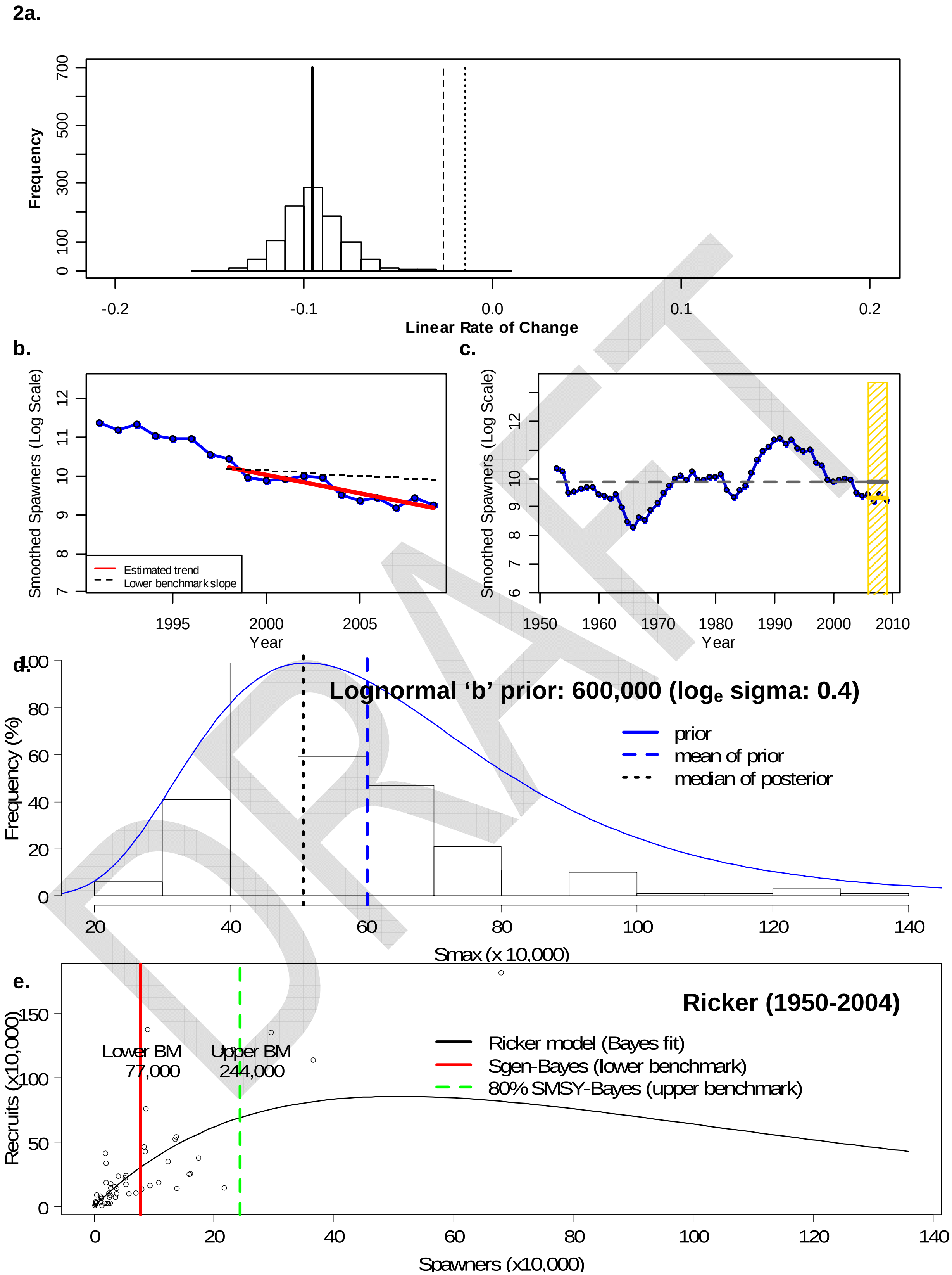


2a.
Frequency
0
100
300
500
700
-0.3
-0.2
-0.1
0.0
0.1
0.2
Linear Rate of Change
b.
Smoothed Spawners (Log Scale)
6
7
8
9
10
11
12
1995
2000
2005
Year
Estimated trend
Lower benchmark slope
c.
Smoothed Spawners (Log Scale)
5
6
7
8
9
10
12
1950
1960
1970
1980
1990
2000
2010
Year
d.
Lognormal 'b' prior: 1,400,000 (log$_e$ sigma: 0.5)
Frequency (%)
0
10
20
30
40
50
60
70
50
100
150
200
250
300
Smax (x 10,000)
prior
mean of prior
median of posterior
e.
Ricker (1950-2004)
Recruits (x10,000)
0
100
200
300
400
500
Lower BM
107,000
Upper BM
508,000
Ricker model (Bayes fit)
Sgen-Bayes (lower benchmark)
80% SMSY-Bayes (upper benchmark)
0
50
100
150
200
250
300
350
Spawners (x10,000)
Data Combined with Stuart-S

Takla-Trembleur-Early Stuart (EStu)

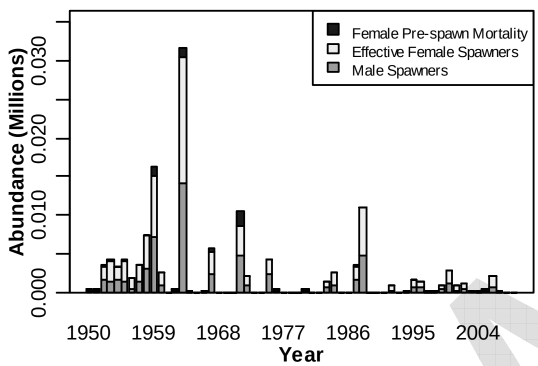


No marine survival data available


2a.
Frequency
0
100
300
500
700
-0.2
-0.1
0.0
0.1
0.2
Linear Rate of Change
b.
Smoothed Spawners (Log Scale)
7
8
9
10
11
12
Estimated trend
Lower benchmark slope
1995
2000
2005
Year
c.
Smoothed Spawners (Log Scale)
6
7
8
9
10
12
1950
1960
1970
1980
1990
2000
2010
Year
d.
Lognormal ‘b’ prior: 600,000 (log$_e$ sigma: 0.4)
prior
mean of prior
median of posterior
Frequency (%)
0
20
40
60
80
100
20
40
60
80
100
120
140
Smax (x 10,000)
e.
Ricker (1950-2004)
Ricker model (Bayes fit)
Sgen-Bayes (lower benchmark)
80% SMSY-Bayes (upper benchmark)
Lower BM
77,000
Upper BM
244,000
Recruits (x10,000)
0
50
100
150
0
20
40
60
80
100
120
140
Spawners (x10,000)

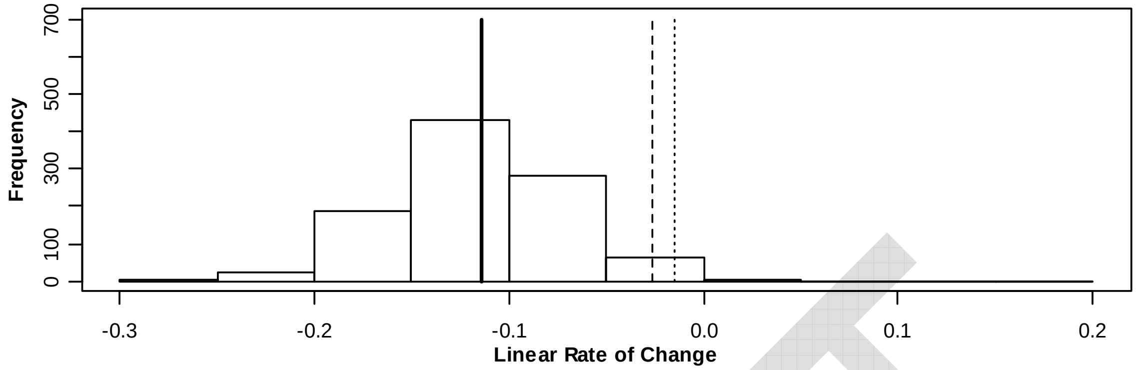
Taseko-ES

1b.

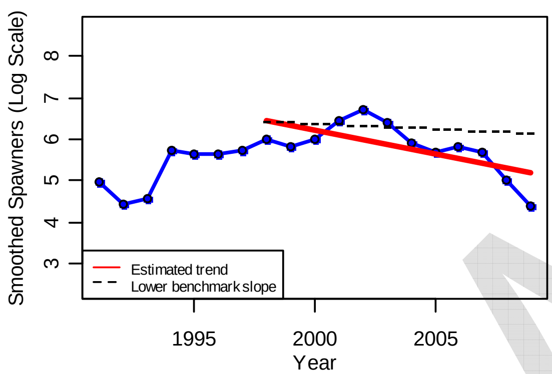


Only escapement data is available for Taseko-ES.

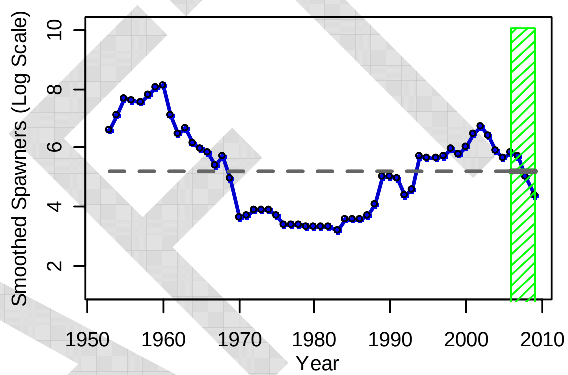
2a.



b.



c.



d.

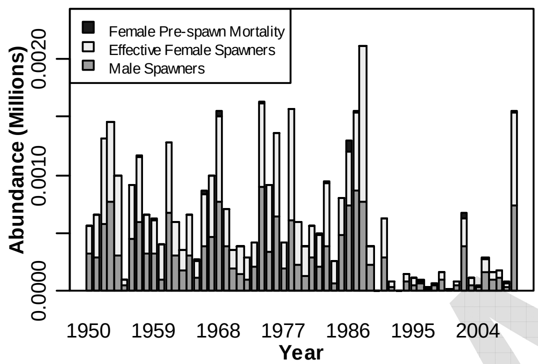
No stock-recruitment data to calculate abundance based benchmarks

e.

No stock-recruitment data to calculate abundance based benchmarks

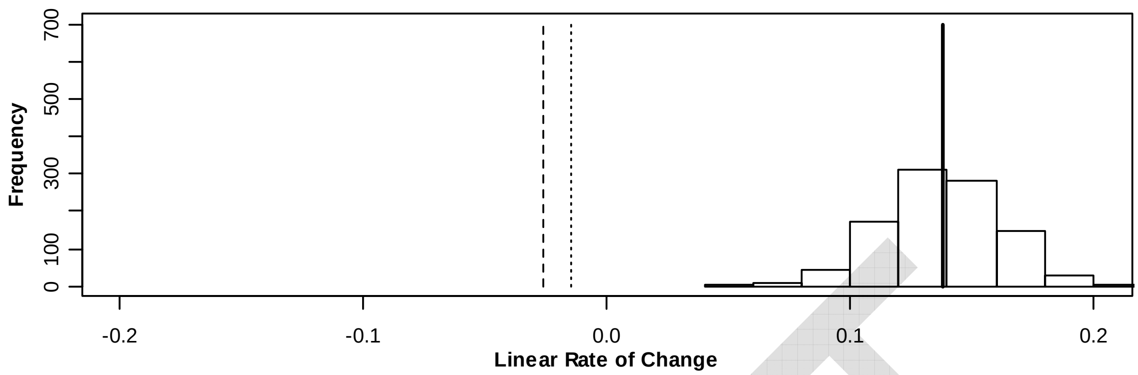
Widgeon-(River-Type)

1b.

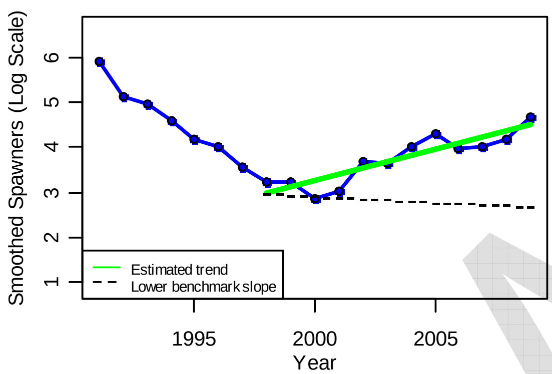


Only escapement data is available for Widgeon (River-Type).

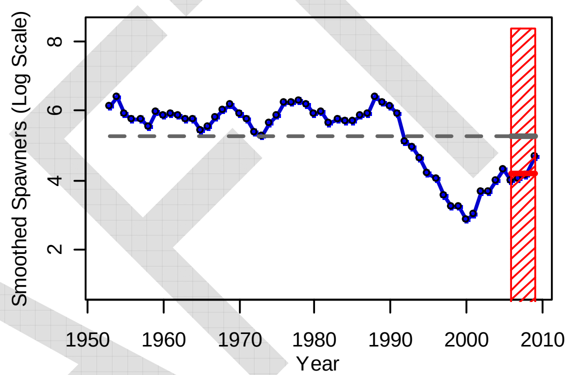
2a.



b.



c.



d.

No stock-recruitment data to calculate abundance based benchmarks

e.

No stock-recruitment data to calculate abundance based benchmarks

APPENDIX 3: 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 rearing lakes. PR data based on monthly sampling of May-October growing season for 1 or more years, with the exception of Pitt lake. The presence of age-2 smolts has been accounted for in Chilko and Cultus lakes only. (*) indicates lakes for which competitor biomass was extrapolated from similar lakes. Escapement is in total adult spawners.

				Unadjusted PR model predictions				Adjusted PR model predictions		
Lake	Comment	Mean seasonal PR (mg C /m²)	PR_{total} (t C/lake)	Smolt biomass (kg) (R_{max})	Smolt #'s	Escapement (S_{max})	Prop. of PR_{total} used by competitor biomass	Smolt biomass (kg) (R_{max})	Smolt #'s	Escapement (S_{max})
Adams	Probably affected by fertilization	115	2659	120,970	26,882,310	497,175	6%	113,712	25,269,371	466,934
Anderson	Mean all years	303	1527	69,484	15,440,880	285,571	37%	43,775	9,727,754	179,752
Bowron	2004 only	131	219	9,947	2,210,536	40,883	0%	9,947	2,210,536	40,847
Chilko*	Fertilized Mean	103	3396	154,539	34,341,944	635,137	0%	154,539	29,556,995	546,162
Chilko*	Natural mean ?1995	69	2295	104,432	23,207,184	429,205	0%	104,432	21,335,362	394,240
Chilko*	2009 natural	121	4020	182,922	40,649,286	751,788	0%	182,922	37,370,636	690,544
Chilliwack	3 year mean	101	218	9,926	2,205,840	40,796	37%	6,254	1,389,679	25,679
Cultus	3 year mean	404	457	20,779	4,617,558	85,399	6%	19,532	4,316,524	79,762
Francois*	2 year mean	163	7247	329,738	73,275,020	1,355,185	0%	329,738	73,275,020	1,353,995
Fraser	2 year mean	332	3227	146,830	32,628,960	603,456	6%	138,021	30,671,222	566,751
Harrison	2 year mean	109	4336	197,289	43,841,980	810,836	37%	124,292	27,620,447	510,378
Kamloops*	2007	257	2378	108,188	24,041,836	444,642	0%	108,188	24,041,836	444,251
Lillooet	2000	163	880	40,022	8,893,783	164,486	0%	40,022	8,893,783	164,342
Mabel*	2 year mean	203	2160	98,285	21,841,092	403,940	6%	92,388	20,530,626	379,370
Pitt*	Jul, Oct 1989 & Mar 1990	72	617	28,056	6,234,608	115,306	37%	17,675	3,927,803	72,579
Quesnel	Mean all 10 years	125	6075	276,413	61,425,000	1,136,025	6%	259,828	57,739,500	1,066,926
Quesnel	Pre- 1995 mean (5 yrs)	104	5054	229,975	51,105,600	945,173	6%	216,177	48,039,264	887,682
Quesnel	Post 2003 mean (5 yrs)	130	6318	287,469	63,882,000	1,181,466	6%	270,221	60,049,080	1,109,603
Seton	4 year mean	233	1007	45,798	10,177,440	188,227	37%	28,853	6,411,787	118,479
Shuswap	6 year mean	171	10159	462,252	102,722,620	1,899,804	6%	434,517	96,559,263	1,784,247
Stuart	3 year mean	137	8899	404,914	89,980,800	1,664,150	37%	255,096	56,687,904	1,047,494
Takla	3 year mean	56	2475	112,624	25,027,475	462,871	37%	70,953	15,767,309	291,352
Trembleur	3 year mean	84	1769	80,491	17,886,960	330,810	6%	75,662	16,813,742	310,689

APPENDIX 4: Methodology used for gap filling CU time series data where required.

Cycle 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

Revised English Method

Application: CU's with multiple streams

Original English Method: English *et al*. (2007) developed a method of gap filling based on the assumption of spatial correlation between sites. This 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 of each stream across the years of available data,

$\bar{E}_s = \frac{\sum_{y=1}^{Y} E_{sy}}{Y_s}$, where $\bar{E}_s$ is the mean escapement for stock *s*, E_{sy} is recorded escapement for each stock (*s*), *y* = years with escapement data, Y_s = total number of years with escapement data for stock *s*. The proportion that each stock contributes to the aggregate over the course of the time series is calculated as: $P_s = \frac{\bar{E}_s}{\sum_{s=1}^{S} \bar{E}_s}$, 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, $F_y = \frac{1}{\sum_{s=1}^{S} P_{sy}}$, 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: $E_y^{'} = F_y * \sum_{s=1}^{S} E_{sy}$, where $E_y^{'}$ is the expanded aggregate, and E_{sy} is the recorded escapement of each stream in that year.

Revised English Method: When calculating the average escapement of each stream we included 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.

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

Cycle Separation Method (Dominant/Sub-dominant or all cycles): 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, we found that the proportional contribution of individual sites also tends to differ between cycle years. Therefore, we calculated the average escapement and the proportions individually for each cycle, in order to be more representative when gap-filling. This revision was further to the previously mentioned revision to the English Method.

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 5: Bayesian Diagnostics using the Larkin model output for Takla-Trembleur-Early Stuart

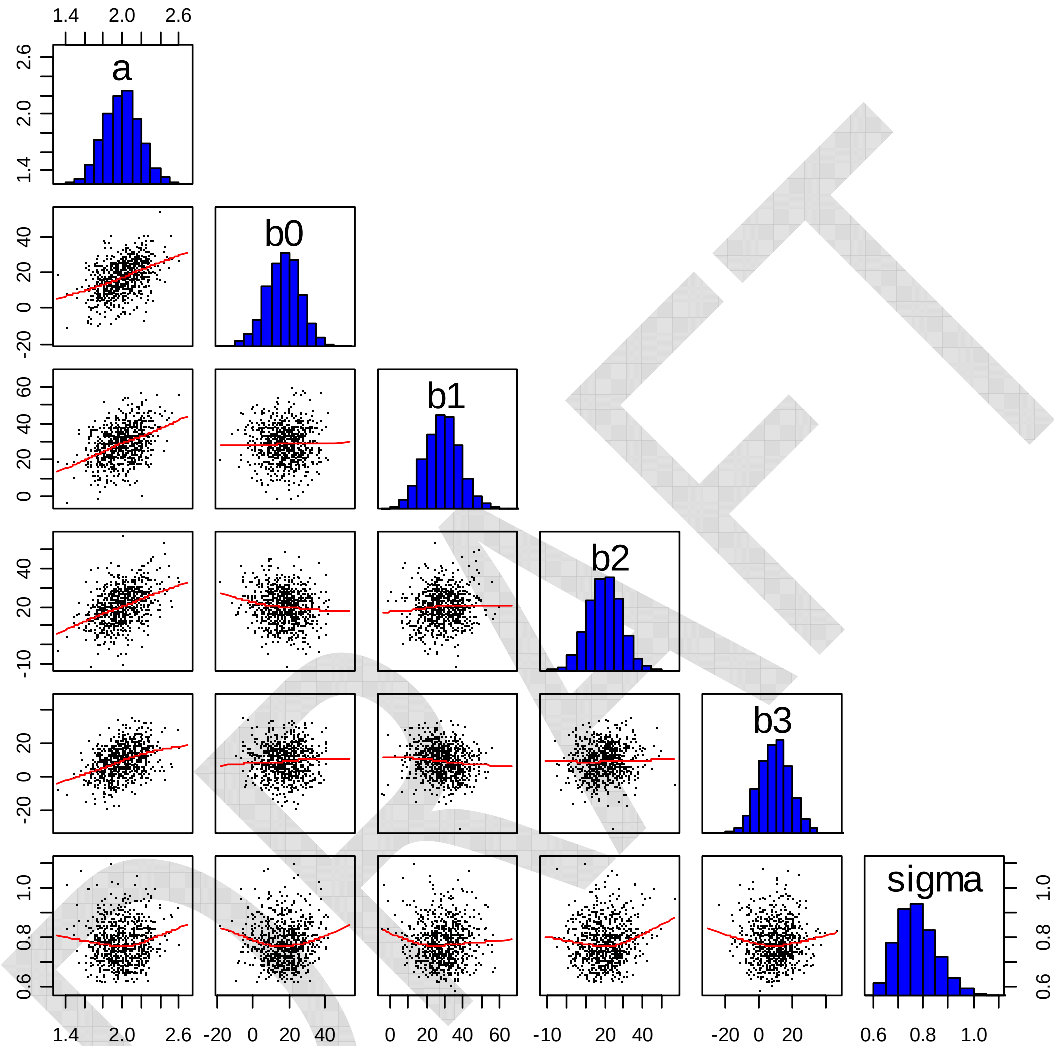


Figure A1. Pairs plot of 2000 estimates (b0, b1, b2, b3, sigma) taken from an MCMC sample of length 100,000 and burn-in length of 10,000 for the Takla-Trembleur-Early Stuart CU.

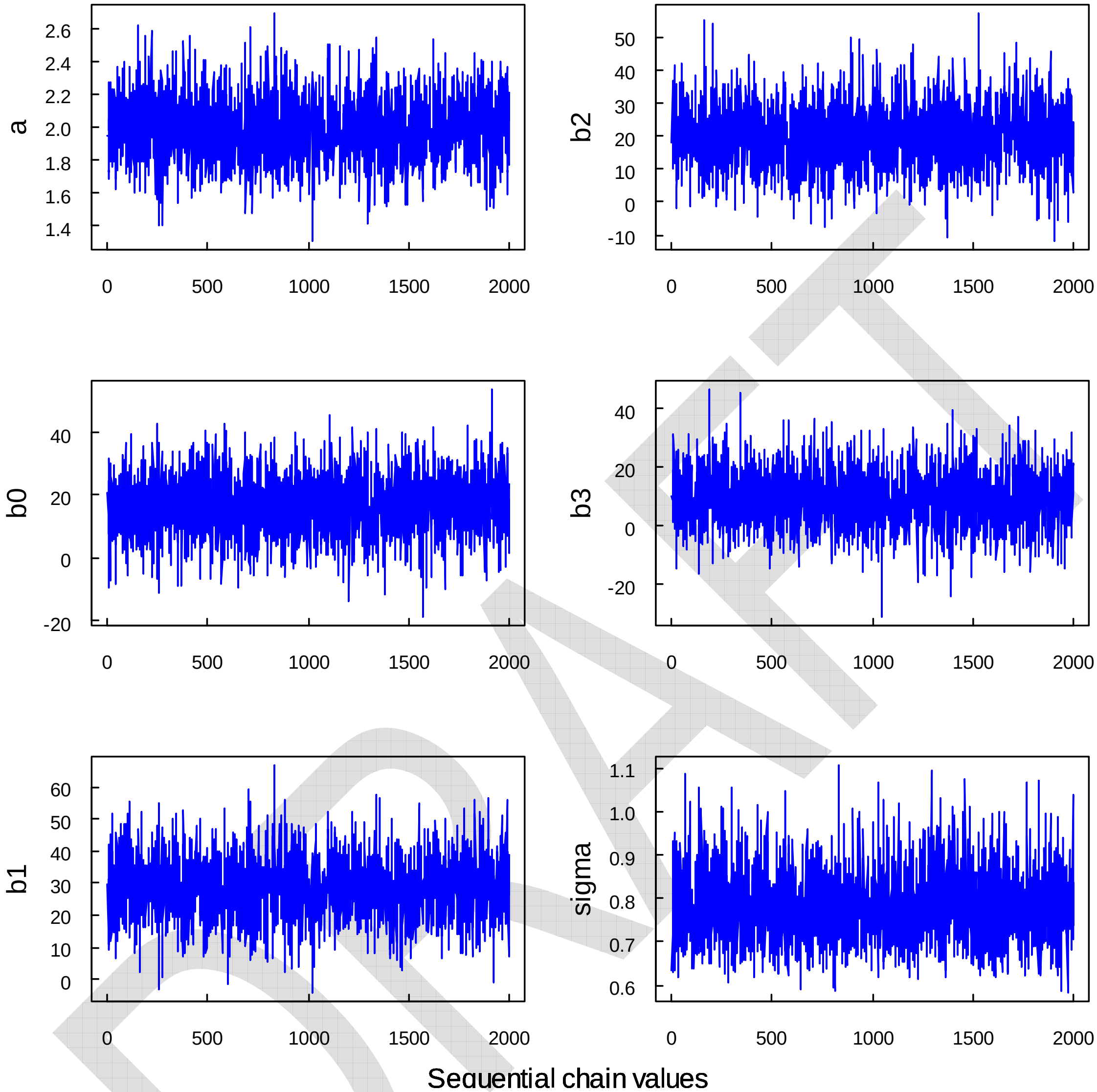


Figure A2. Trace plots of 2000 estimates (b0, b1, b2, b3, sigma) taken from an MCMC sample of length 100,000 after burn-in of length 10,000 for the Takla-Trembleur-Early Stuart CU.

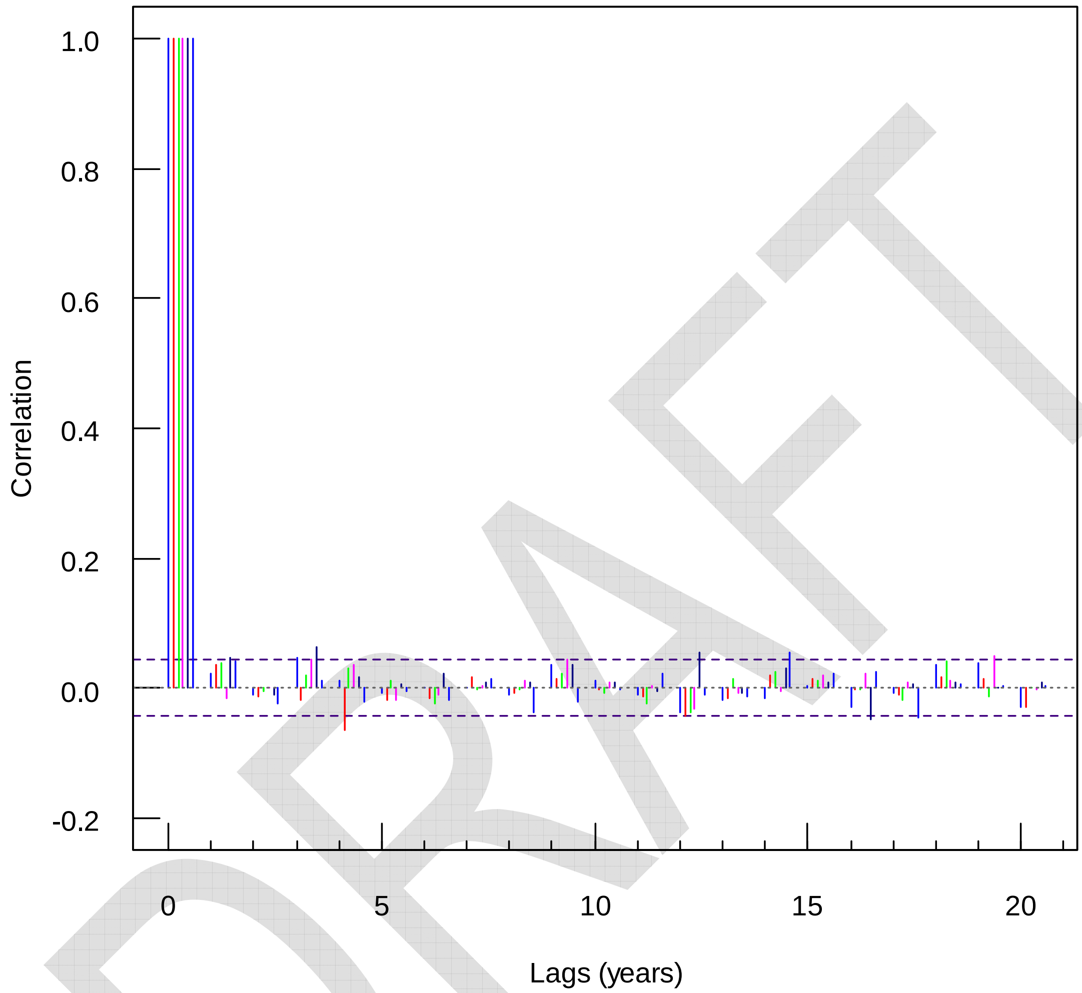


Figure A3. Autocorrelation plot for 20 years lags of 2000 estimates (b0, b1, b2, b3, sigma) taken from an MCMC sample of length 100,000 and burn-in length of 10,000 for the Takla-Trembleur-Early Stuart CU.

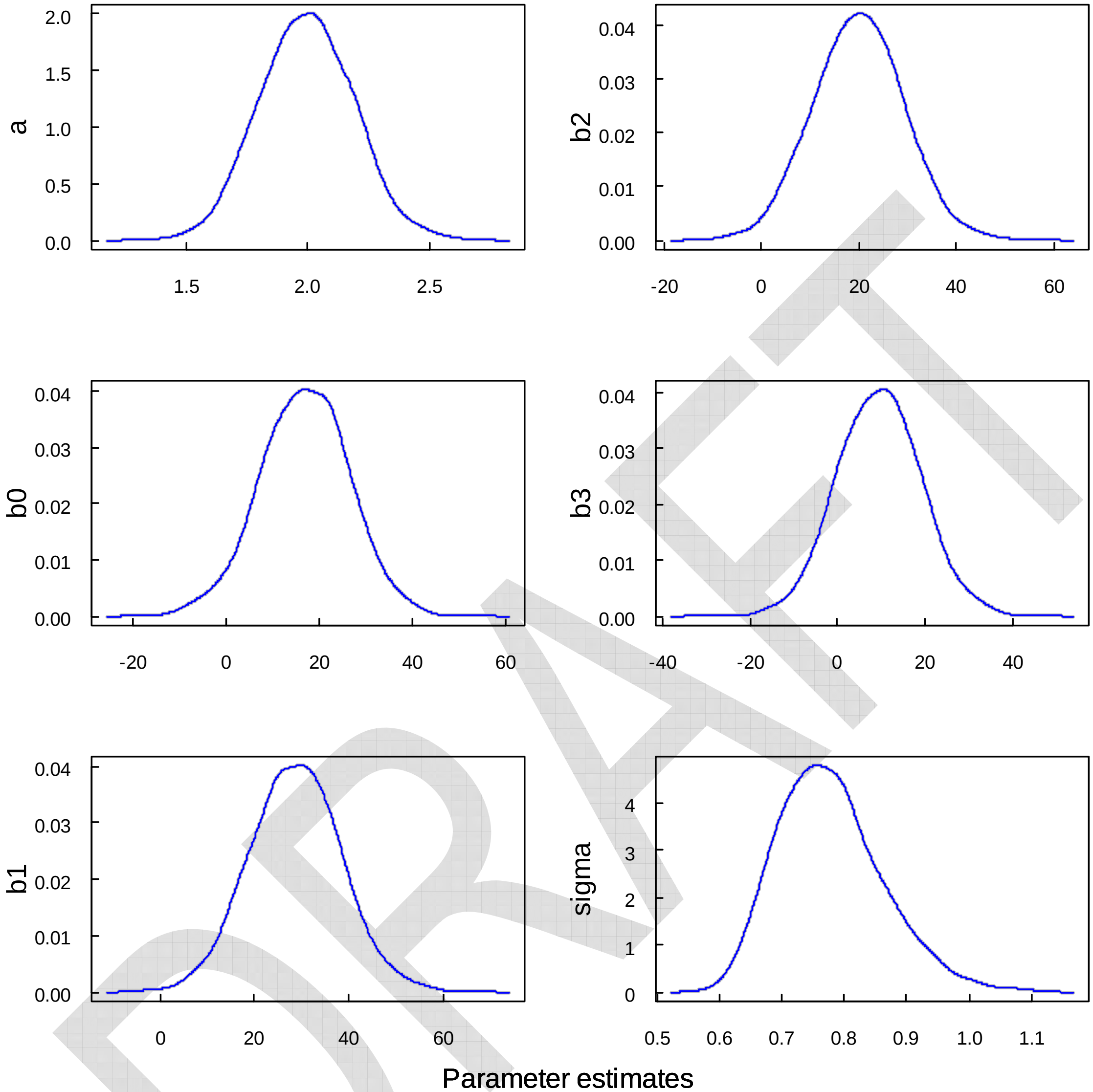


Figure A4. Kernel density plots of 2000 estimates (b0, b1, b2, b3, sigma) taken from an MCMC sample of length 100,000 and burn-in length of 10,000 for the Takla-Trembleur-Early Stuart CU.

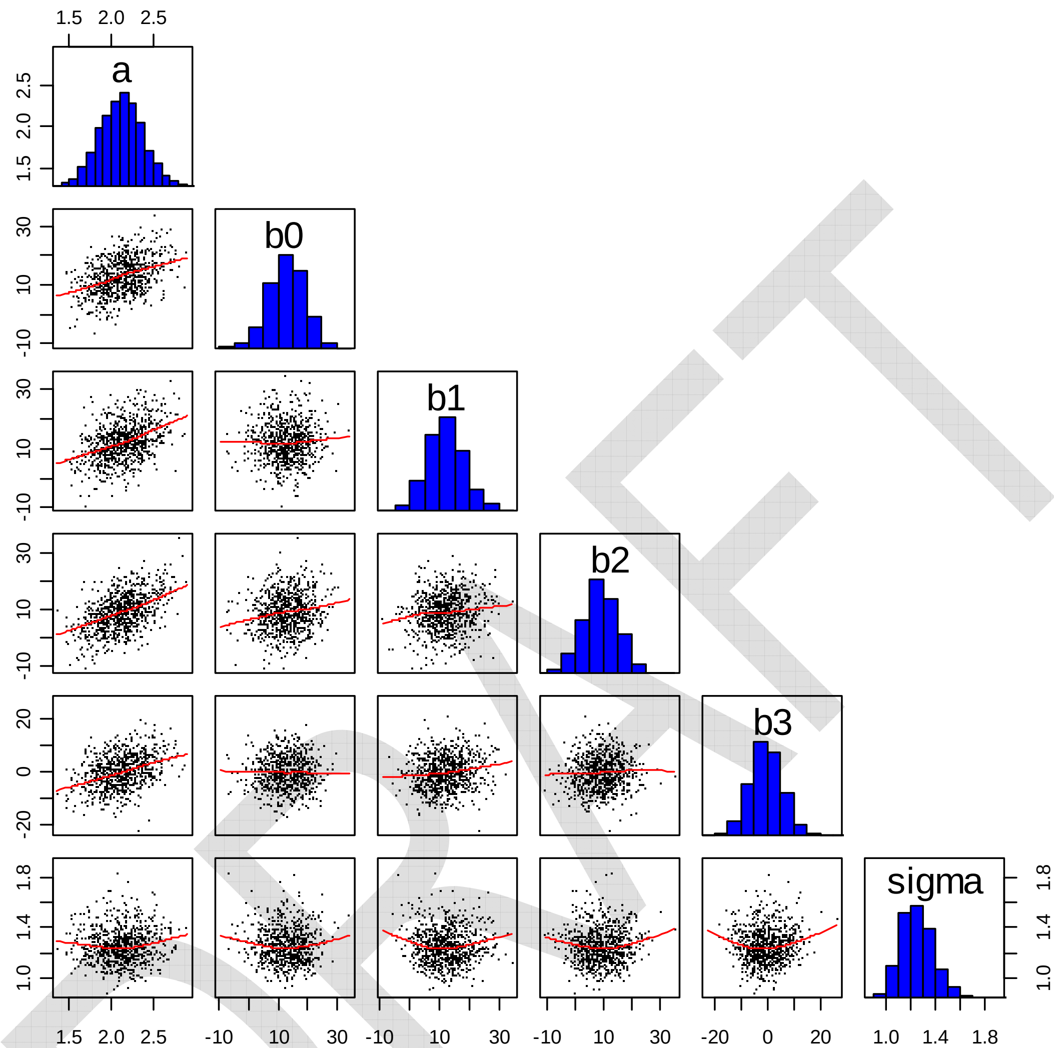


Figure A5. Pairs plot of 2000 estimates (b0, b1, b2, b3, sigma) taken from an MCMC sample of length 100,000 and burn-in length of 10,000 for the Takla-Trembleur-S/Stuart-S CU.

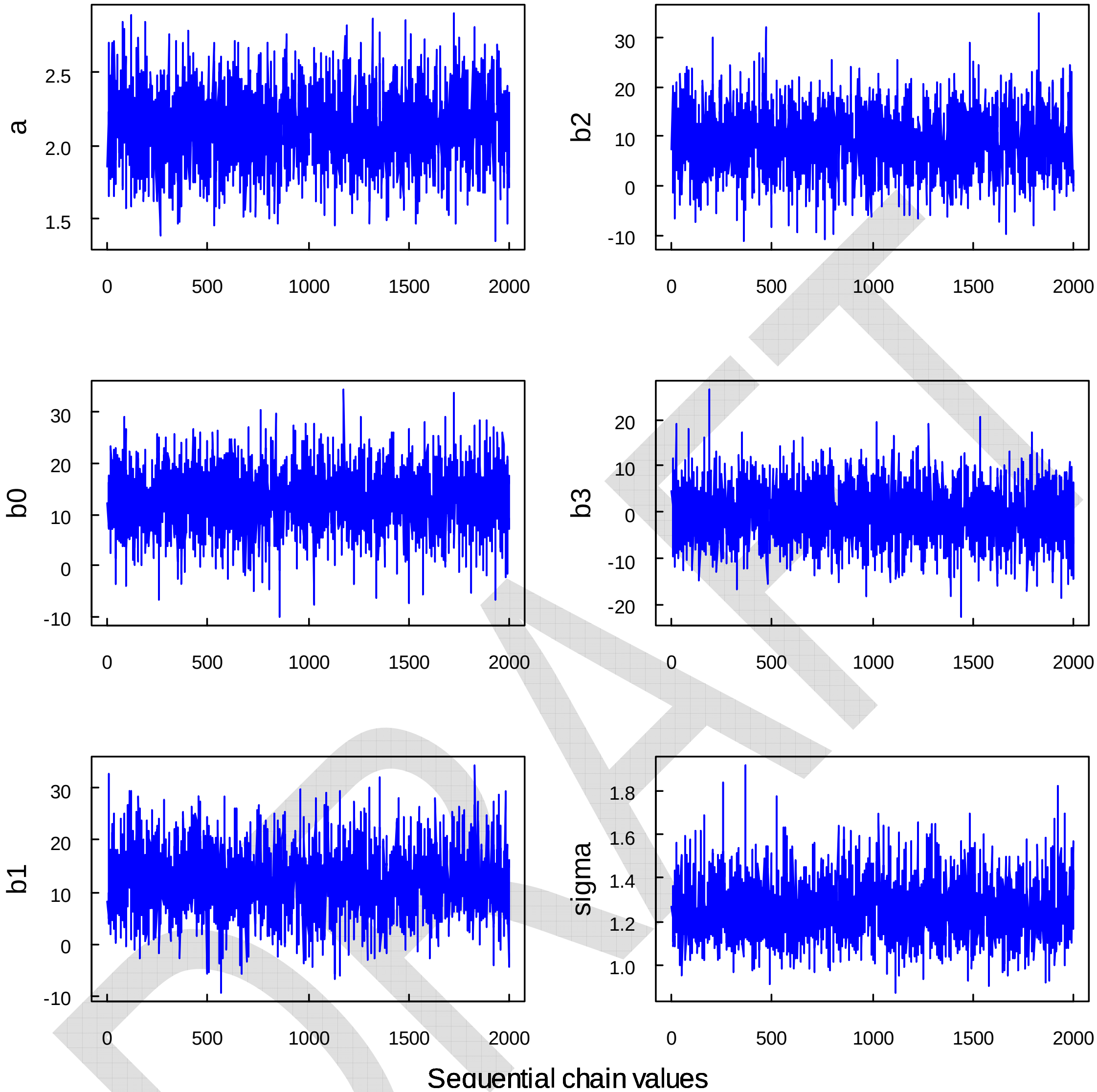


Figure A6. Trace plots of 2000 estimates (b0, b1, b2, b3, sigma) taken from an MCMC sample of length 100,000 after burn-in of length 10,000 for the Takla-Trembleur-S/Stuart-S CU.

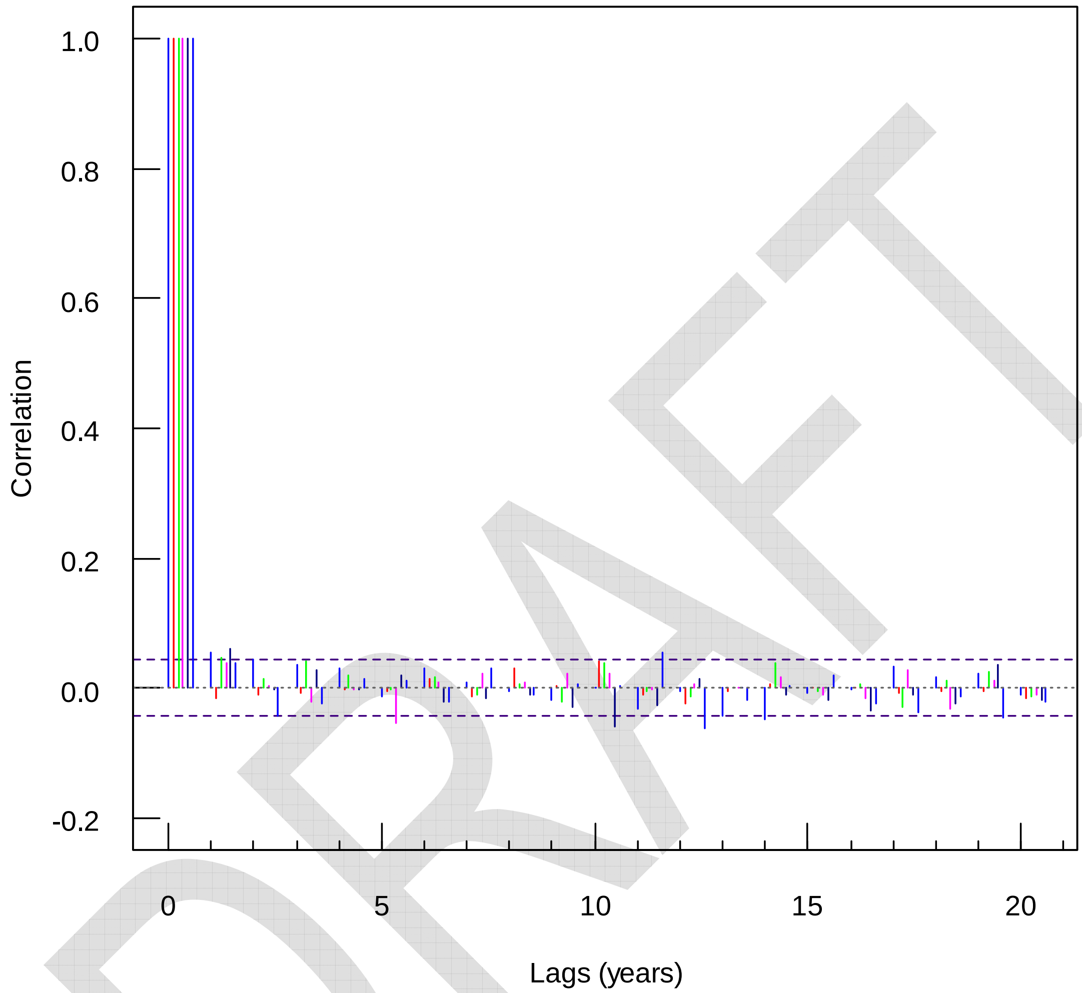


Figure A7. Autocorrelation plot for 20 years lags of 2000 estimates (b0, b1, b2, b3, sigma) taken from an MCMC sample of length 100,000 and burn-in length of 10,000 for the Takla-Trembleur-S/Stuart-S CU.

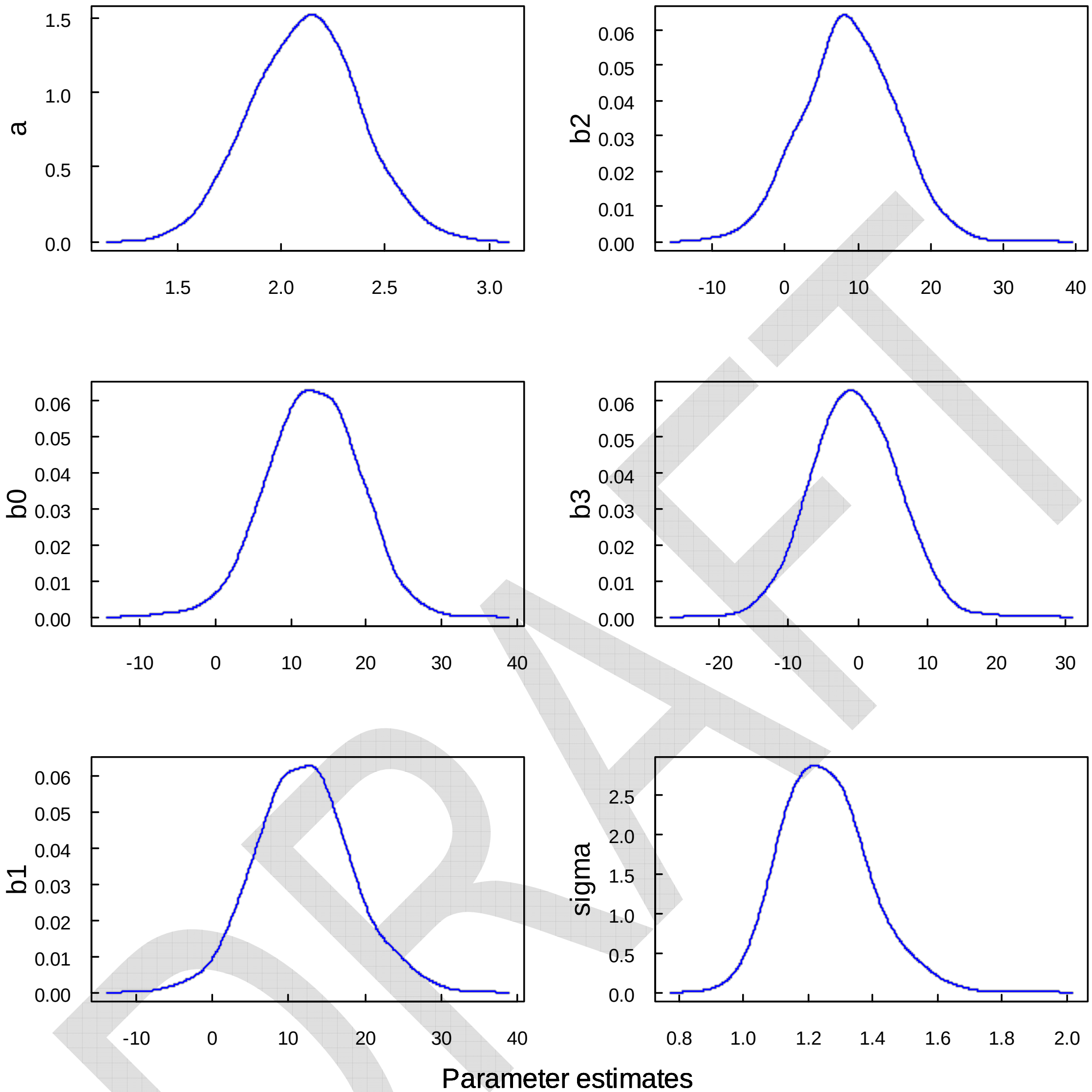


Figure A8 Kernel density plots of 2000 estimates (b0, b1, b2, b3, sigma) taken from an MCMC sample of length 100,000 and burn-in length of 10,000 for the Takla-Trembleur-S/Stuart-S CU.

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: <u>DESCRIPTION OF THE REQUEST – TO BE FILLED BY THE CLIENT REQUESTING THE INFORMATION/ADVICE</u>

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	Category of Request
☒ Fisheries and Aquaculture Management	☒ Stock Assessment
☐ Oceans & Habitat Management and SARA	☐ Species at Risk
☐ Policy	☐ Human impacts on Fish Habitat/ Ecosystem components
☒ Science	☐ Aquaculture
☐ Other (please specify):	☐ 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: <u>PLANNING OF THE ADVISORY PROCESS</u>

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:

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