PRE-SEASON RUN SIZE FORECASTS FOR FRASER RIVER SOCKEYE SALMON IN 2010

Figure 1. Sockeye salmon adult spawning phase. DFO website.

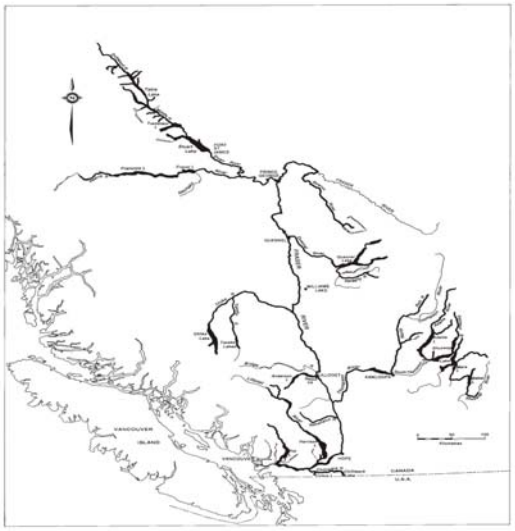

Figure 2: Sockeye spawning locations in South Western BC.

Context :
Pre-season abundance forecasts of returning Fraser River adult Sockeye Salmon in 2010 were requested by Fisheries and Oceans Canada (DFO) Fisheries Management. Forecasts are used for pre-season planning purposes and for in-season management. They are most useful early in the summer fishing season before reliance on in-season run size estimates. Forecasts are produced by DFO as agreed under the United States (U.S.)-Canada Pacific Salmon Treaty. As a result of changes in stock productivity in recent years, a detailed review of the 2010 Fraser River Sockeye forecast methodology, with consideration of productivity changes, was completed in 2010 and forms the basis for this advice (Grant et al. 2010).

SUMMARY

- Most Fraser River Sockeye stocks have exhibited declining trends in productivity beginning as early as 1960. Exceptions to this trend include Late Shuswap (a stock that has not exhibited long-term systematic trends in productivity), which is expected to be the largest component of the 2010 total return. The 2009 return of adult Sockeye salmon was at record low productivity for a number of important stocks, including Quesnel and Chilko.

- Salmon forecasts remain highly uncertain and vary depending on the assumptions underlying the chosen forecast models.

- Uncertainty that is attributed to stochastic (random) variability in annual survival rates is communicated in the 2010 forecast paper through a series of forecasted values that

correspond to standardized cumulative probabilities (10%, 25%, 50%, 75%, 90%). For example, there would be a one in four chance at the 25% probability level that the actual number of returning Sockeye will be at or below the forecasted value given the assumptions about future survival. This is different from previous years when the 25% probability level forecast indicated a one in four chance that the actual number of returning Sockeye would meet or exceed the forecasted value.

- Uncertainty that results from different assumptions about future survival (productivity), is assessed through the evaluation of three alternative scenarios that characterize the potential productivity of spawners in the 2006 brood year (returning as age 4 recruits in 2010): "Long-Term Average Productivity", "Recent Productivity (brood years: 1997-2003)", and "Productivity Equivalent to the 2005 Brood Year" (2009 return year).

- The forecast approach that assumes that recent productivity will persist through to 2010 ("Recent Productivity" forecast), is recommended to be the most appropriate for pre-season planning. Based on this assumption, there is a one in four chance (25% probability) that the return of Fraser River Sockeye Salmon will be at or below 7.0 million and a three in four chance (75% probability) that it will be at or below 18.3 million. The total return forecast is dominated by Late Shuswap Sockeye (63% of the total forecast at the 50% probability level) and this stock has not exhibited long-term systematic decreases in productivity similar to most other stocks.

- "Recent Productivity" forecasts for each of the four run timing groups from the 25% and 75% probability levels are as follows: Early Stuart Run: 26,000 to 66,000; Early Summer Run: 374,000 to 1,601,000; Summer Run: 1,605,000 to 4,343,000; and Late Run 5,023,000 to 12,305,000.

- The two other forecast scenarios "Long-Term Average Productivity", and "Productivity Equivalent to the 2005 Brood Year" (2009 return year), are considered to be within the range of possible outcomes but are given less weight in the current assessment.

INTRODUCTION

Overview of Past Adult Returns

To provide context for the 2010 Fraser River adult Sockeye Salmon return forecasts, the cycle average returns are presented in Table 1. On the 2010 cycle, average annual returns (1980-2006) for all 19 forecasted stocks combined were ~15 million. Late Shuswap (Late Run) has been the main driver of the average return abundances on the 2010 cycle line, accounting for 50% of the total return. The 2010 cycle is the dominant cycle for Late Shuswap, and most adult Sockeye produced in this system occur in the Adams River. Quesnel and Chilko (Summer Run) stocks are also forecasted to contribute relatively high proportions (~15%) to the 2010 cycle average returns. Although the 2010 Quesnel cycle has not been historically a strong cycle (pre-1980 average returns: 10,000), returns on the 2010 subdominant cycle began to increase in the 1980's to a maximum of 5 million in 2002. Quesnel returns on this cycle have subsequently declined to 700,000 in 2006. Other stocks that make up more than 1% each of the 2010 average cycle returns include the following: Early Summers: Scotch (dominant in 2010) and Seymour (dominant in 2010); Summer Run: Late Stuart and Stellako; Late Run: Weaver and Birkenhead.

Escapement in the 2005 and 2006 Brood Years

The abundance of adult returns in any given year is influenced by three main factors: the age-proportions of returning fish, the abundance of their parental spawners (brood year escapement), and their survival rate from the egg to adult return stages. Since most Fraser Sockeye are comprised of predominantly age-4 fish (Gilbert-Rich aging convention: 4_2), most Sockeye that return in 2010 are recruited from eggs spawned by adults in 2006 (brood year). For some of the stocks, data on the number of juveniles (fry or smolts) produced by the spawners are available and can be used as an alternative variable within the forecast models.

For the 2006 brood year, either the number of effective female spawners (EFS) or smolts (Chilko & Cultus) for 15 of the 19 forecasted Fraser Sockeye stocks were close to or above the time series average (1980-2005). The four stocks with below average EFS abundance for the 2006 brood year were Bowron, Late Stuart, Quesnel, and Weaver. The greatest contributors to the 2006 brood year EFS (77% of the total) were Late Shuswap (57%), Chilko (13%), Birkenhead (7%), and several stocks (Scotch, Seymour, Quesnel, Stellako, and Harrison) that contributed ~4% each to the total. The remaining 11 forecasted stocks contributed less than 1% to the total 2006 brood year escapement.

Most Fraser Sockeye stocks also have a small age-5 (5_2) component. For most of these stocks, the numbers of EFS contributing to age-5 returns in 2010 (2005 brood year) were close to average or above average (time series: 1980-2005), with the exception of Early Stuart, Bowron, Seymour, Late Stuart, Quesnel, and Birkenhead.

Survival Rates (Productivity)

Total productivity for all Fraser Sockeye stocks combined has been declining since the 1990's (Figure 1 B). This decline in productivity coincides with variability in total escapement (Figure 1 A). Most Fraser Sockeye stocks have experienced lower total productivity in $\log_e$ (recruits-per-effective female spawners (R/EFS)) in the past four (2000- 2003) to eight (1996-2003) brood years relative to a 1980-2003 reference period.

Most Fraser River Sockeye Salmon stocks have experienced a general decreasing trend in productivity based on the Kalman filtered (KF) Ricker a productivity parameter values which show smoothed, long term trends in productivity (Grant et al. 2010 using Dorner et al. 2008 methodology). Seven stocks have experienced systematic decreasing trends in the KF Ricker a parameter starting in the 1960's-1970's (Early Stuart; Bowron; Fennell; Gates; Nadina; Seymour; Portage). Six populations including the four Summer Run stocks have experienced decreasing trends starting in the 1980's-1990's (Pitt; Chilko; Late Stuart; Quesnel; Stellako; Birkenhead). Raft, Late Shuswap and Weaver have not exhibited long-term systematic trends in productivity.

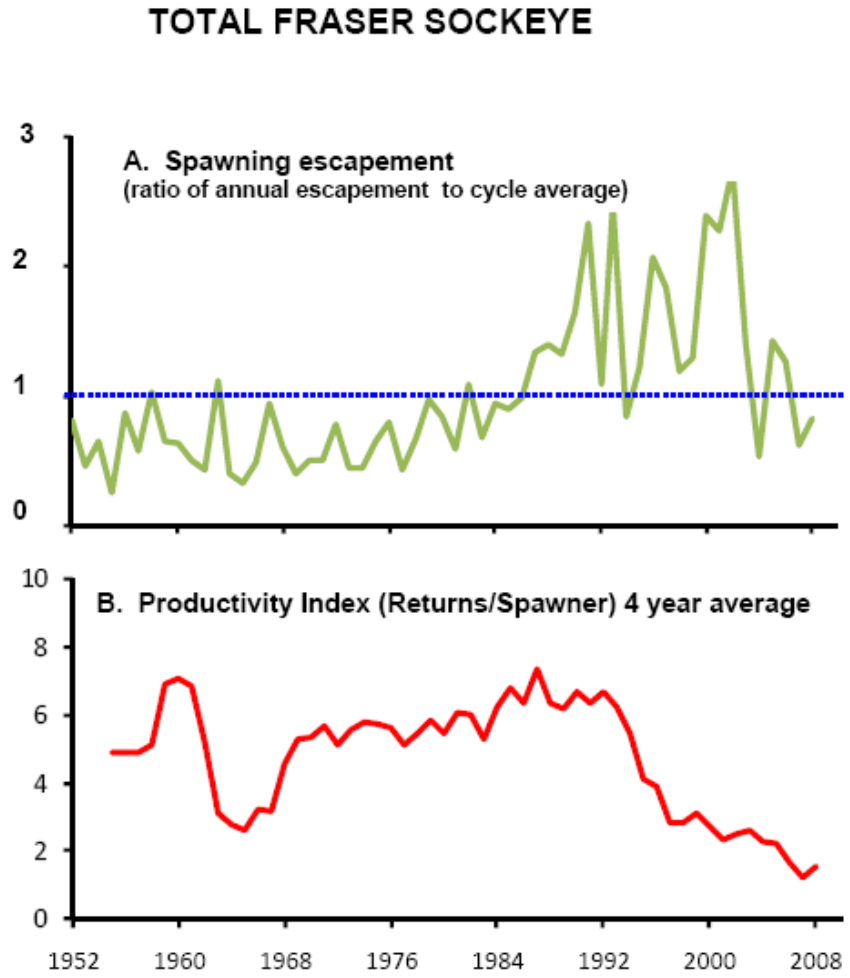

Figure 1. Time series of A. total spawning escapement (ratio of annual escapement to cycle average escapement) and B. productivity index (returns/spawner) smoothed using a running four year average. Note: In plot A, ratios above the blue dashed line are years when annual total escapements are greater than the cycle average and ratios below the blue dashed line are years when annual escapements are below the cycle average.

Marine productivity ($\log_e$ (R/smolt)) for Chilko & Cultus Sockeye also exhibit similar decreasing trends (Grant et al. 2010). Measures of marine productivity require smolt outmigration counts which have been assessed only for Chilko & Cultus Sockeye stocks.

For the 2005 brood year (2009 returns), productivity was amongst the lowest on record for most Fraser Sockeye stocks. At the time of this forecast, preliminary 2009 age-4 return data were available for only a select number of stocks. In particular, Summer Run stocks that were expected to return at high abundances experienced the lowest productivity on record for the 2005 brood year (2009 returns). As a result of these low productivities, 2009 returns fell below the 2009 forecast distribution's 10% probability level (Figure 2). The 2009 forecast assumed long-term average productivities would persist through to 2009 given indicators of ocean productivity suggested that conditions for salmon survival had improved. Chilko marine survival had exhibited coincidental increases in the 2004 brood year (2006 ocean entry and 2008 returns) from the previous brood year (DFO 2009).

Harrison River Sockeye salmon also experienced the lowest productivity on record in the 2005 brood year, despite having a different ocean entry year (2006 ocean entry and 2008/2009 returns) from other Fraser Sockeye stocks from the same brood year. The 2006 brood year productivity for Harrison Sockeye, with the same ocean entry year (2007) as all other Fraser Sockeye that returned in 2009, were below average but improved relative to the 2005 brood year. Harrison Sockeye salmon have an unusual age structure and life history. They are age-3 (3_1) and 4 (4_1), migrating to sea shortly after emergence.

ANALYSIS

2010 Forecast Methods

Three separate forecast approaches were developed and evaluated for the 2010 Fraser River Sockeye Salmon forecast:

- "Long Term Average Productivity" - assumes that the long term productivity trends (1948 to present for most stocks) will persist through to 2010;
- "Recent Productivity" - incorporates recent declining trends (1997 to present) in stock productivity into the methods; and
- "Productivity Equivalent to the 2005 Brood Year" (2009 return year) - assumes that productivity will be similar to that of the 2009 return (lowest on record for a number of stocks).

The "Long-Term Average Productivity" forecast approach used methods identical to those described in the 2009 Fraser Sockeye forecast paper (DFO 2009). Specifically, model ranks for the 2010 "Long-Term Average" forecast uses the first ranked model from the retrospective analysis conducted for the 2009 forecast that uses the entire retrospective time series to calculate performance measures. In contrast, the "Recent Productivity" forecasts vary in methodology from the 2009 methods. Specifically, this forecast incorporates three new models that take into account the recent decrease in productivity experienced by most Fraser Sockeye stocks. In addition, retrospective analysis calculates performance measures across all models for a truncated time period (1997-2004 brood years), as opposed to half the time series for forecasts conducted in previous years (DFO 2009). Therefore, model selection for the "Recent Productivity" forecasts focused on which models performed best in the recent low productivity period. In addition, given productivity from the 2005 brood year was extremely poor (low numbers of age-4 recruits in 2009), the "Recent Productivity" forecast approach incorporates this preliminary productivity data to forecast age-5 recruits in 2010. The "Productivity Equivalent to the 2005 Brood Year" forecasts use preliminary data on productivity (R/EFS or R/smolt) associated with the 2005 brood year (that resulted in 2009 poor returns).

2010 Forecast Results

Fraser Sockeye forecasts are highly uncertain (Cass et al. 2006; Haeseker et al. 2008) and vary depending on the assumptions underlying the chosen forecast models. For example the 2009 forecasted Fraser Sockeye returns fell below the 10% probability forecast (Figure 2). Returns in 2009 were associated with the lowest productivity on record for most stocks. At the time of the release of the 2009 forecast, improvements to stock productivity were assumed given ocean indicators suggested that ocean conditions had improved and increases in stock productivity (Chilko marine survival) were observed in the previous brood year.

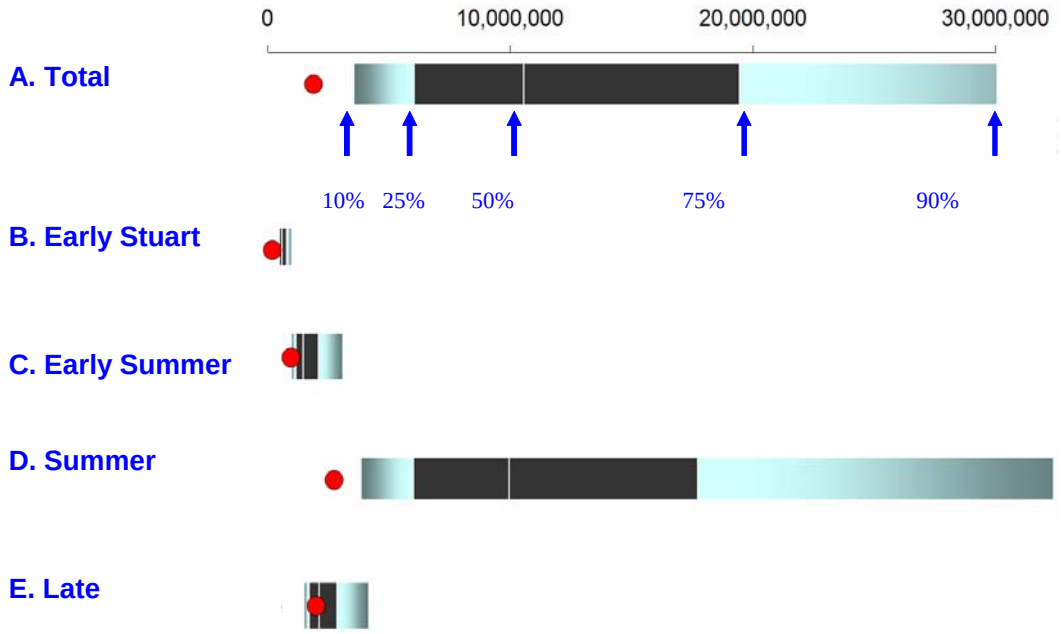

*Figure 2. Probability distributions for the 2009 return for **A.** All Stocks total; **B.** Early Stuart; **C.** Early Summer; **D.** Summer; **E.** Late Run timing groups for the forecasts and 2009 preliminary returns (red circles).*

For the 2010 forecast, in order to characterize uncertainty about Fraser Sockeye productivity for the 2006 brood year (2010 age-4 recruits), three alternative scenarios are presented: "Long-Term Average Productivity", "Recent Productivity", "Productivity Equivalent to the 2005 Brood Year (2009 Returns)" (Figure 3; Tables 1-3). The "Recent Productivity Forecast", which assumes that recent productivity will persist through to 2010, is recommended to be the most appropriate for pre-season planning given the recent decreases in productivity observed for most stocks. Based on this assumption, there is a one in four chance (25% probability) that the return of Fraser River Sockeye Salmon will be at or below 7.0 million and a three in four chance (75% probability) that it will be at or below 18.3 million (Table 1). The same probability range (25% to 75% probability levels) for each of the four run timing groups are as follows: Early Stuart Run: 26,000 to 66,000; Early Summer Run: 374,000 to 1,601,000; Summer Run: 1,605,000 to 4,343,000; and Late Run 5,023,000 to 12,305,000. The total return forecast is dominated by Late Shuswap Sockeye (63% of the total forecast at the 50% probability level).

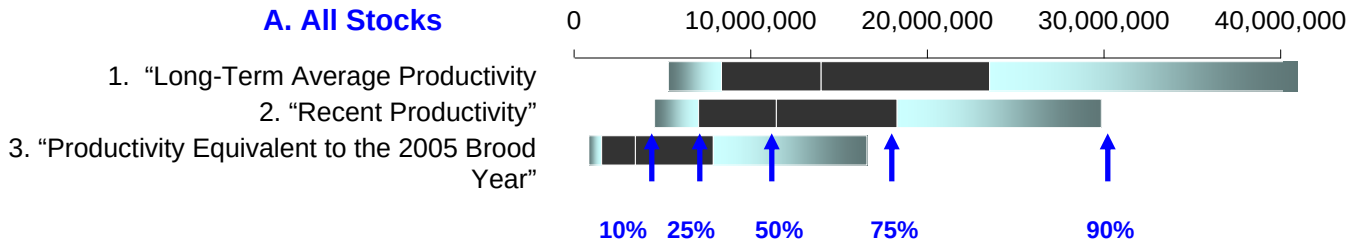

Figure 3. 2010 Forecast probability distributions for Fraser Sockeye for three forecast methods that vary based on their assumptions regarding productivity associated with 2006 brood year (2010 returns): 1. "Long-Term Average Productivity"; 2. "Recent Productivity" (incorporates recent declining productivity into the forecast methods); 3. "Productivity Equivalent to the 2005 Brood Year (2009 return year)".

Although there is considerable uncertainty (widest probability distributions of all forecasts) associated with sibling (jack) forecasts, the 50% probability level forecasts for sibling (jack) models are similar to the 50% probability level forecasts for the "Recent Productivity" forecasts. This is particularly important for Late Shuswap that dominates return abundances in the "Recent Productivity" forecasts for 2010. The sibling model forecast was similar for Late Shuswap (age-4 recruits: 6.3 million) relative to the "Recent Productivity" forecast (age-4 recruits: 7.3 million). Similarly for Chilko that is also contributing a relatively large number of returns to the total forecast (age-4 recruits: 1.9 million), the sibling model also produced a relatively close forecast (age-4 recruits: 1.2 million) (Grant et al. 2010).

In addition to "Recent Productivity" forecast table (Table 1), two additional forecast tables were produced that include the "Long-Term Average Productivity" (Table 2) and "Productivity Equivalent to the 2005 Brood Year (2009 Returns)" (Table 3) forecasts (Figure 3). The "Long-Term Average Productivity" forecast does not deviate significantly from the "Recent Productivity" forecast because "Recent Productivity" forecast abundance is dominated by Late Shuswap (Late Run) that has not exhibited systematic declines in productivity compared to other stocks (Figure 3). The biggest differences between the "Recent Productivity" and "Long-Term Productivity" forecasts were in the Early Stuart, Early Summer and Summer Run timing groups, which comprise a considerably smaller fraction of the total forecast and have experienced decreases in productivity in recent years.

The "Productivity Equivalent to the 2005 Brood Year" forecast is considerably lower than the "Long-Term Productivity" forecast given productivity in the 2005 brood year (2009) return year was amongst the lowest on record for many stocks (Figure 3). The biggest differences in the forecast distributions are for the Summer Run stocks that experienced, in particular, the lowest productivity in the 2005 brood year on record.

Table 1. "Recent Productivity" 2010 forecast table (at various probability levels) by stock and timing group (condensed from Table 2; Grant et al. 2010). The "Recent Productivity" forecast incorporates new models that take into account recent productivities. Model performance of old and new models were evaluated only for more recent brood years (1997-2004). Methods and results for the "Recent Productivity" 2010 forecast are described in detail in Grant et al. 2010.

Run Timing Group	Mean Run Size		Probability that Return will be at/or Below Specified Run Size [a]				
Stocks	all cycles[b]	2010 cycle[c]	10%	25%	50%	75%	90%
Early Stuart	304,000	113,000	**17,000**	**26,000**	**41,000**	**66,000**	**101,000**
Early Summer	--	--	**174,000**	**374,000**	**783,000**	**1,601,000**	**3,047,000**
(total exlcuding miscellaneous)	***(504,000)***	***(797,000)***	***(129,000)***	***(269,000)***	***(581,000)***	***(1,251,000)***	***(2,543,000)***
Bowron	21,000	20,000	400	700	1,300	2,500	4,600
Fennell	29,000	26,000	9,000	16,000	31,000	56,000	90,000
Gates	59,000	17,000	2,000	4,000	9,000	17,000	33,000
Nadina	79,000	22,000	9,000	16,000	30,000	60,000	107,000
Pitt	60,000	55,000	7,000	12,000	26,000	53,000	96,000
Raft	33,000	16,000	7,000	13,000	24,000	42,000	71,000
Scotch	73,000	248,000	40,000	106,000	265,000	640,000	1,450,000
Seymour	150,000	393,000	55,000	101,000	195,000	380,000	691,000
Misc [d]	--	--	13,000	58,000	134,000	242,000	302,000
Misc [e]	--	--	7,000	10,000	14,000	22,000	42,000
Misc [f]	--	--	24,000	35,000	48,000	76,000	144,000
Misc [g]	--	--	1,000	1,000	4,000	6,000	10,000
Misc [h]	--	--	0	1,000	2,000	4,000	6,000
Summer	**5,332,000**	**5,059,000**	**1,045,000**	**1,605,000**	**2,612,000**	**4,343,000**	**6,984,000**
Chilko	1,740,000	1,900,000	864,000	1,273,000	1,958,000	3,011,000	4,435,000
Late Stuart	750,000	396,000	8,000	21,000	60,000	169,000	429,000
Quesnel	2,350,000	2,200,000	111,000	215,000	438,000	909,000	1,727,000
Stellako	492,000	563,000	62,000	96,000	156,000	254,000	393,000
Late	**3,193,000**	**9,126,000**	**3,331,000**	**5,023,000**	**8,003,000**	**12,305,000**	**19,695,000**
(total exlcuding miscellaneous)	***(3,193,000)***	***(9,126,000)***	***(3,264,000)***	***(4,951,000)***	***(7,871,000)***	***(12,035,000)***	***(19,352,000)***
Cultus	17,000	18,000	5,000	6,000	9,000	14,000	19,000
Harrison	58,000	NA	53,000	97,000	195,000	429,000	1,167,000
Late Shuswap	2,210,000	7,640,000	3,101,000	4,652,000	7,252,000	10,791,000	16,702,000
Portage	55,000	90,000	8,000	18,000	42,000	99,000	221,000
Weaver	406,000	690,000	71,000	126,000	264,000	472,000	799,000
Birkenhead	447,000	688,000	26,000	52,000	109,000	230,000	444,000
Misc. non-Shuswap [i]			67,000	72,000	132,000	270,000	343,000
TOTAL	-	-	**4,567,000**	**7,028,000**	**11,439,000**	**18,315,000**	**29,827,000**
(TOTAL excluding miscellaneous)	***(9,333,000)***	***(15,095,000)***	***(4,455,000)***	***(6,851,000)***	***(11,105,000)***	***(17,695,000)***	***(28,980,000)***

a. probability that return will be at/or below specified projection.
b. sockeye: 1980-2006 (excluding miscellaneous stocks)
c. sockeye: 1980-2008 (excluding miscellaneous stocks)
d. unforecasted mis. Early Summer Stocks (Early Shuwap stocks: S.Thompson); return timing most similar to Scotch/Seymour
e. unforecasted misc. Early Summer stocks (N. Thomson tributaries; return timing most similar to Fennell/Bowron/Nadina).
f. North Thompson River
g. Nahatlach River & Lake
h. Chilliwack Lake and Dolly Varden Creek
i. unforcasted miscellaneous Late Run stocks (Harrison)

Table 2. The "Long-Term Average Productivity" 2010 forecast table (at various probability levels) by stock and timing group. These forecasts were produced using methodology described in the 2009 Fraser Sockeye forecast paper (DFO 2009). Specifically, model forecasts use the first ranked model based on retrospective analysis conducted for the 2009 forecasts (using the entire retrospective time series to calculate performance measures). The three new models used in the "Recent Productivity" forecast (Table 1) are not used in this table. In addition, age-5 recruits were forecasted using the 2009 forecast methodology (DFO 2009).

Probability of Return at/or Below Specified Run Size

Run Timing Group	10%	25%	50%	75%	90%
Early Stuart	55,000	85,000	135,000	213,000	315,000
Early Summer	387,000	723,000	1,518,000	3,544,000	7,993,000
Summer	1,434,000	2,304,000	3,972,000	6,981,000	11,875,000
Late	3,484,000	5,239,000	8,364,000	12,803,000	20,741,000
TOTAL	5,360,000	8,351,000	13,989,000	23,541,000	40,924,000

Table 3. The "Productivity Equivalent to the 2005 Brood Year" 2010 forecast table (at various probability levels) by stock and timing group. For a number of stocks, particularly Summer Run stocks that were predicted to return at high abundances, productivity for the 2005 brood year was amongst the lowest on record. These forecasts were produced by using preliminary productivity data (R/EFS or R/smolt) associated with the 2005 brood year (that resulted in 2009 poor returns)(Grant et al. 2009). At the time of this paper, 2009 returns data were preliminary and not available by each of the 19 forecasted stocks.

Probability of Return at/or Below Specified Run Size [a]

Run Timing Group	10%	25%	50%	75%	90%
Early Stuart	12,000	19,000	29,000	46,000	70,000
Early Summer	68,700	141,400	314,000	698,000	1,430,000
Summer	94,000	159,000	290,000	548,000	1,029,000
Late	645,000	1,243,000	2,842,000	6,586,000	14,068,000
TOTAL	819,700	1,562,400	3,475,000	7,878,000	16,597,000

Sources of Uncertainty

- Salmon forecasts remain highly uncertain and vary depending on the assumptions underlying the chosen forecast models.
- Uncertainty that is attributed to stochastic (random) variability in annual survival rates is communicated in the 2010 forecast paper through a series of forecasted values that correspond to standardized cumulative probabilities (10%, 25%, 50%, 75%, 90%). For example, there would be a one in four chance at the 25% probability level that the actual number of returning Sockeye will be at or below the forecasted value given the assumptions about future survival.
- Uncertainty that results from different assumptions about future survival (productivity), is assessed through the evaluation of three alternative scenarios that characterize the potential productivity of spawners in the 2006 brood year (returning as age 4 recruits in 2010): "Long-Term Average Productivity", "Recent Productivity (brood years: 1997-2003)", and "Productivity Equivalent to the 2005 Brood Year" (2009 return year).
- At the time of this publication, stock productivity calculations for 2009 used to calculate age-4 recruits for the "Recent Productivity" and age-4 and age-5 recruits for the "Productivity Equivalent to the 2009 Return Year" are considered preliminary and incomplete.

CONCLUSIONS AND ADVICE

- The productivity of most Fraser River Sockeye stocks has decreased in recent years compared to their long-term time series. The productivity associated with 2005 brood year (2009 return year) is the lowest on record for many stocks based on data available. The Late Shuswap stock has not experienced long-term systematic trends in productivity, in contrast to most other stocks.
- The 2010 forecast analysis evaluates three forecast approaches with differing assumptions regarding productivity of the 2006 brood year (2010 returns) and include the following: "Long-Term Average Productivity", "Recent Productivity (brood years: 1997-2003)" and "Productivity Equivalent to the 2005 Brood Year".
- The forecast approach that assumes that recent productivity will persist through to 2010 ("Recent Productivity Forecast") is recommended to be the most appropriate for pre-season planning. Based on this assumption, there is a one in four chance (25% probability) that the return of Fraser River Sockeye Salmon will be at or below 7.0 million and a three in four chance (75% probability) that it will be at or below 18.3 million.
- Individual stock and stock groupings forecasts, for the 25% and 75% probability range, are: Early Stuart Run: 26,000 to 66,000; Early Summer Run: 374,000 to 1,601,000; Summer Run: 1,605,000 to 4,343,000; and Late Run 5,023,000 to 12,305,000. The total return forecast is dominated by Late Shuswap Sockeye (63% of the total forecast at the 50% probability level).

OTHER CONSIDERATIONS

- Regardless of the inclusion of the new modeling approaches, there remains a high degree of uncertainty in the annual Fraser River Sockeye salmon forecasts. While recommendations were presented to improve the forecasting performance, significant improvements are unlikely to reduce uncertainty.
- Further, while it was agreed that information to predict changes in ocean productivity may help decrease the uncertainty in future forecasts, environmental indicators that have been explored for Fraser River Sockeye to date typically have not improved forecast performance. It is likely that a different set of environmental indicators are needed for Fraser Sockeye than those evaluated thus far.

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