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Canadian Science Advisory Secretariat
Science Advisory Report 2011/052

PRE-SEASON RUN SIZE FORECASTS FOR FRASER RIVER SOCKEYE & PINK SALMON IN 2011

Sockeye adult spawning phase (source: DFO website) and Fraser watershed distribution (DFO GIS Division).

Pink adult spawning phase (source: DFO website) and Fraser watershed distribution (DFO GIS Division).

Context

Pre-season abundance forecasts of returning Fraser River adult Sockeye and Pink Salmon in 2011 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 increasing reliance on in-season run size estimates. Forecasts are produced by DFO as agreed under the Canada-United States 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 was completed in 2010 (Grant et al. 2010). Further details associated with this year's 2011 forecast are presented in Grant & MacDonald (2011). This updated methodology forms the basis for this advice.

This Science Advisory Report has resulted from a Fisheries and Oceans Canada, Canadian Science Advisory Secretariat Regional Advisory Process. Additional publications resulting from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

SUMMARY

- Salmon forecasts remain highly uncertain due to both stochastic (random) variability in annual survival rates and uncertainty about changes to average survival (productivity) experienced by stocks from the egg stage to adult returns.

Fraser River Sockeye

- Fraser Sockeye survival has been particularly uncertain in recent years due to systematic declines in productivity exhibited by most stocks and the extremely variable productivity in the past two brood years (2005 and 2006 brood years corresponding, respectively, to 2009 and 2010 returns for most Sockeye).
- Alternative assumptions of Sockeye productivity are presented as separate forecasts: 'Long-Term Average Productivity' (Table 2) and 'Recent Productivity (brood years: 1997-2004)'(Table 4). The 'Recent Productivity' scenario is considered most plausible. The 'Long-Term Average Productivity' scenario is considered plausible, but less likely.
- Under the assumption of 'Recent Productivity', there is a one in ten chance (10% probability) the Fraser River Sockeye Salmon return will be at or below 1.0 million, and a nine in ten chance (90% probability) it will be at or below 12.1 million. The mid-point of this distribution (50% probability) is 3.2 million (there exists a one in two chance the return will be above or below this value assuming recent stock productivity). Under the assumption of 'Long-Term Average Productivity', there is a one in ten chance (10% probability) the return will be at or below 1.7 million, and a nine in ten chance (90% probability) it will be at or below 15.1 million. The mid-point of this distribution (50% probability level) is 4.6 million.
- The 2011 forecast has a higher age-5 proportion (35-50% of age-4 + age-5 returns) than average (~20%), given the generally higher brood year escapements for age-5 Sockeye and the use of average (in the case of 'Recent Productivity' forecasts) to above average (for 'Long-Term Average Productivity' forecasts) 2010 age-4 productivity, to forecast age-5 returns for some stocks.

Fraser River Pink:

- Based on the assumption of 'Long-Term Average Productivity', there is a one in ten chance (10% probability) the Pink return will be at or below 9.2 million and a nine in ten chance (90% probability) it will be at or below 37.5 million. The mid-point of this distribution (50% probability level) is 17.5 million. Recent productivity scenarios were not compared for Pink Salmon as they have not exhibited similar declines in productivity as Fraser Sockeye.
- The Fraser Pink forecast is highly uncertain because predictions are made outside the observed data range given the record high fry abundance in 2010.

INTRODUCTION

Overview of Past Adult Returns

To provide context for the 2011 Fraser River adult Sockeye Salmon return forecasts, the cycle average returns are presented in Tables 2 & 4 (column I). On the 2011 cycle, average annual Fraser Sockeye returns (1953-2009) for all 19 forecasted stocks combined were ~ 5.3 million. Chilko (Summer Run) and Late Shuswap (Late Run) have historically been the main drivers of return abundances on the 2011 cycle line, each accounting for ~30% of the average total return on the cycle. Stellako and Birkenhead also have contributed relatively high returns to the cycle

average, at ~11% and 7% respectively. Stocks that have each comprised greater than 2% of the 2011 average cycle return include Early Stuart, Seymour, Quesnel and Weaver.

Escapement in the 2006 and 2007 Brood Years

Since most Fraser Sockeye return as age-4 fish (Gilbert-Rich aging convention: 4_2), the greatest proportion of Sockeye that will return in 2011 are recruited from eggs spawned by adults in 2007 (brood year). For some stocks, data on the number of juveniles (fry or smolts) from the 2007 brood year are available and may be used as an alternative predictor variable in applicable forecast models.

For the 2007 brood year, the abundance of either effective female spawners (EFS) or smolts (Chilko & Cultus) for 10 of the 19 forecasted Fraser Sockeye stocks was close to or above their time series cycle average (1951-2003 for most stocks) and includes Fennell, Pitt, Raft, Scotch, Chilko, Late Stuart, Quesnel, Harrison, Weaver and Birkenhead. The greatest contributors to the 2007 brood year total EFS were Chilko (37% of the total EFS), Harrison (13%), Birkenhead (13%), Quesnel (8%), and Late Shuswap (8%), while several other stocks (Stellako, Pitt, Weaver) contributed ~4% each. The remaining 11 forecasted stocks each contributed less than 2% to the total 2007 brood year EFS. Nine stocks, in particular, had 2007 brood year EFS that were well below average (e.g. Early Stuart, Bowron, Gates, Nadina, Seymour, Stellako, Cultus, Late Shuswap and Portage).

Almost all Fraser Sockeye stocks have an age-5 (5_2) component (on average 20% of total recruits). For the majority of these stocks, the number of EFS contributing to age-5 returns in 2011 (2006 brood year) was close to, or above, their cycle average (most time series: 1948-2002), with the exception of three stocks (Bowron, Cultus and Weaver), which were below average.

Survival Rates (Productivity)

Amongst all Fraser Sockeye stocks there has been considerable variability in productivity trends (Grant et al. 2010). Specifically, productivity for seven stocks has systematically decreased starting in the 1960's-1970's (Early Stuart; Bowron; Fennell; Gates; Nadina; Seymour; Portage). Productivity for five stocks, including the four Summer Run stocks, has decreased starting in the 1980's-1990's (Chilko; Late Stuart; Quesnel; Stellako; Birkenhead). Pitt Sockeye have exhibited variable systematic productivity, decreasing in the late 1960's, increasing in the 1990's, and decreasing again post-2000. Raft, Late Shuswap and Weaver have not exhibited long-term systematic trends in productivity and Harrison Sockeye have increased in productivity (Grant et al. 2010). Productivity has been particularly low for a number of stocks in the last four to eight brood years (Tables 2 & 4, columns E & F; Tables 3 & 5, columns D & E).

Marine survival ($\log_e$ (R/smolt)) for Chilko and Cultus Sockeye has declined since the mid-1980's (Grant et al. 2010). Chilko and Cultus are the only two stocks with smolt data, which is used to partition freshwater and marine survival (note: marine survival includes the period of smolt downstream migration from their rearing lakes down to the Strait of Georgia)

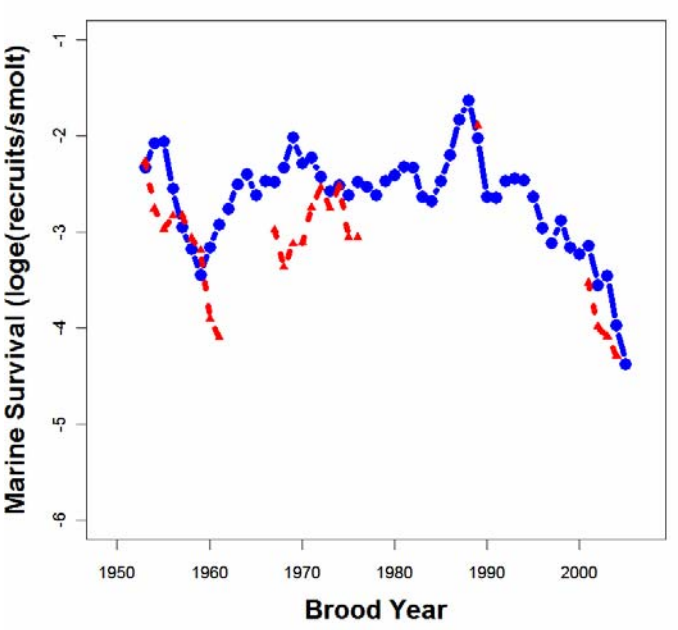


Figure 1. Chilko-ES/Chilko-S (blue solid line with circles) & Cultus-L (red dashed line with triangles) marine survival (log$_e$ recruits/smolt) from the 1951-2005 brood years. Note: the 2004 and 2005 brood year marine survival data include preliminary 2009 and 2010 age-4 and age-5 return data (these years are current in the process of being finalized). Re-printed from Grant et al. (2010).

Productivity in the last two brood years, in particular, has been extremely variable. The 2005 brood year productivities (2009 return year for most of these Sockeye) were amongst the lowest on record for most Fraser Sockeye stocks, including Harrison Sockeye, which are unique in both age (age-3 and age-4) and life-history (migrate to the ocean after gravel emergence with no lake rearing period). In contrast, 2006 brood year productivities (2010 return year for most of these Sockeye) were average for most stocks including Harrison, with the exceptions of Late Shuswap, Scotch and Seymour, which exhibited well above average productivities.

ANALYSIS

Forecast Methods

Details of the 2011 forecast methods are presented in a separate Research Document. Two separate forecast approaches were developed and evaluated for the 2011 Fraser River Sockeye Salmon forecast:

- 'Long-Term Average Productivity', which assumes the long term productivity trends (brood years 1948 to 2004 for most stocks) will persist through to 2011.
- 'Recent Productivity', which assumes recent productivity trends (brood years 1997 to 2004) will persist through to 2011; recent productivity ranges from below average for a number of stocks, to average (Late Shuswap, Raft, Weaver amongst others) and above average (Harrison).

Table 1. List of candidate models organized by their two broad categories (non-parametric and biological) with descriptions. Models are described in detail in Grant et al. (2010) Appendices 1 to 3. Where applicable, models use effective female spawner data (EFS) as predictor variables unless otherwise indicated by '(juv)' or '(smolt)' next to the model, where juvenile fry data or smolt data are used instead of EFS data.

MODEL CATEGORY	DESCRIPTION
A. Non-Parametric Models	
R1C[1]	Return from 4 years previous
R2C[1]	Average return from 4 & 8 years previous
RAC	Average return on the cycle line on the time series
TSA	Average return across all cycles lines on the time series
RS1[1]	Product of average productivity from 4 years previous and EFS (or juv/smolt)
RS2[1]	Product of average productivity from 4 & 8 years previous and EFS (or juv/smolt)
RS4yr[1]	Product of average productivity from the last 4 years and EFS (or juv/smolt)
RS8yr[1]	Product of average productivity from the last 4 & 8 years and EFS (or juv/smolt)
RS	Product of average productivity on time series for specified stocks and EFS (or juv/smolt) (used for miscellaneous stocks)
B. Biological Models	
Power	Bayesian
Power-cyc	Bayesian (cycle line data only)
Ricker	Bayesian
Ricker-cyc	Bayesian (cycle line data only)
Larkin	Bayesian
KF Ricker[1]	Bayesian
Covariates for Biological Models	(e.g. Power (FrD-mean))
FrD-mean	Mean Fraser discharge (April - June)
Ei	Entrance Island sea-surface temperature (April – June)
Pi	Pine Island sea-surface temperature (April – July)
FrD-peak	Peak Fraser Discharge
PDO	Pacific Decadal Oscillation

1. Models Used Exclusively In Recent Productivity Forecasts

The 'Long-Term Average Productivity' forecast approach uses methods similar to those described in previous forecasts (Cass et al. 2006; DFO 2006; DFO 2007; DFO 2009; Grant et al. 2010). Retrospective analysis is used in the model selection process to rank all candidate models relative to one another. Candidate models are described in Table 1 and non-parametric models that consider recent productivity (RS1, RS2, R1C, R2C, RS4yr, RS8yr and KF) were not included in the suite of models for this 'Long-Term Average' productivity scenario. Retrospective analysis for the 'Long-Term Average Productivity' forecast approach seeds each model with the first half of the stock-recruitment time series by stock and then iteratively generates a forecast for the second half of the time series (updating the recruitment data only up to the previous forecast brood year). Performance measures (see Grant et al. 2010 for more details) are then

calculated using these retrospective forecasts and actual returns. 'Long-Term Average Productivity' forecasts use the well above long-term average productivity associated with the 2006 brood year (2010 returns for most Sockeye) for Scotch, Seymour and Late Shuswap to estimate 2011 age-5 recruits for these stocks. Miscellaneous stocks were forecast using the product of their brood year escapements and the average productivity for spatially and temporally similar stocks that have stock recruitment data as identified in Table 1 (footnotes e, f, g, h, i, m).

In contrast, the 'Recent Productivity' forecast methods vary from those used prior to the 2010 forecast. Specifically, this forecast scenario includes three new models (RS4yr, RS8yr, KF) that consider the recent decrease in productivity experienced by many Fraser Sockeye stocks, in addition to the full suite of candidate models. For the 'Recent Productivity' retrospective analysis, only the last eight brood years' (brood years 1997 to 2004) of the retrospective forecasts and actual returns are used to calculate performance measures and rank models. Therefore, model selection for the 'Recent Productivity' forecasts focused on models that performed best in the recent productivity period. In cases where recent productivity models outperformed full time series models (Early Stuart, Bowron, Gates, Scotch, Seymour, Chilko, Late Stuart, Quesnel, Late Shuswap and Portage), productivity from the 2006 brood year (2010 returns for most Sockeye) that was average to above average was used to estimate age-5 recruits for these stocks. Miscellaneous stocks were forecast using the product of their brood year escapements and the average recent (brood years 1997 to 2004) productivity for spatially and temporally similar stocks that have stock recruitment data as identified in Table 1 (footnotes e, f, g, h, i, m).

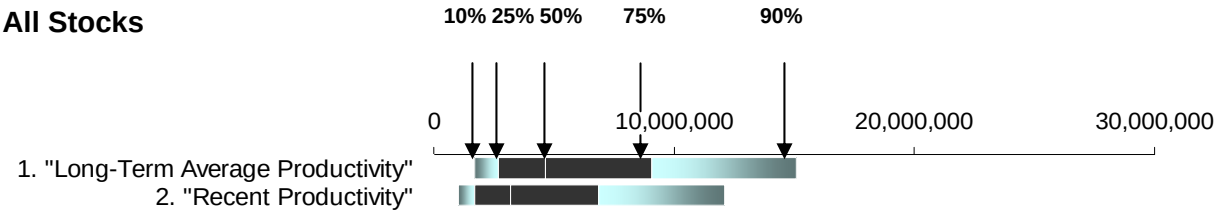
Data used in this assessment are identical to the 2010 forecast, with the inclusion of one additional brood year (2004) of stock-recruitment and environmental data. The time series does not include the 2005 brood year (age-4 recruits in 2009 and age-5 recruits in 2010), as these data were not finalized at the time of this publication. Candidate models are described in Table 1 below and details are also provided in Appendices 1 to 3 in Grant et al. (2010). Retrospective performance measures are described in Appendix 4 in Grant et al. (2010).

Fraser River Pink salmon are forecast using methods and retrospective analysis model ranking as described in DFO (2007).

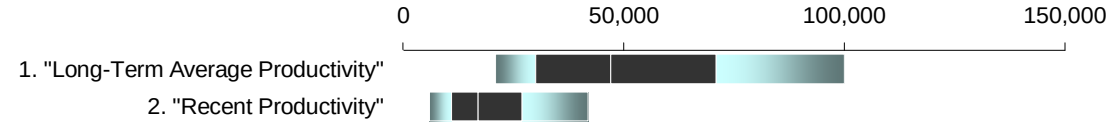
2011 Fraser Sockeye Forecasts

Alternative assumptions of Sockeye productivity are presented as separate forecasts: 'Long-Term Average Productivity' and 'Recent Productivity (brood years: 1997-2004)' (Figure 2).

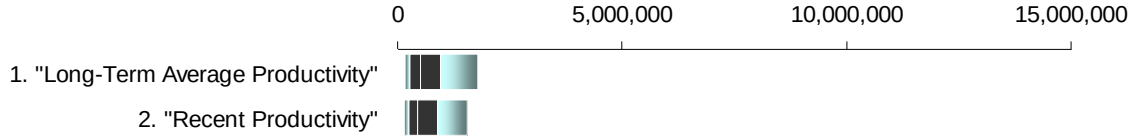
A. All Stocks



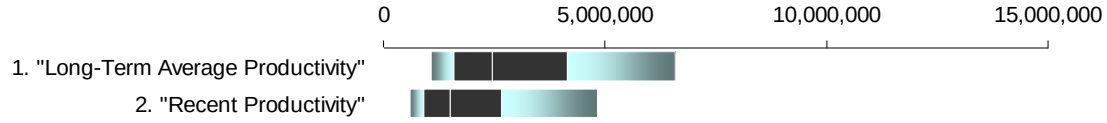
B. Early Stuart (note different scale compared to following four run timing groups)



C. Early Summer



D. Summer



E. Late Run

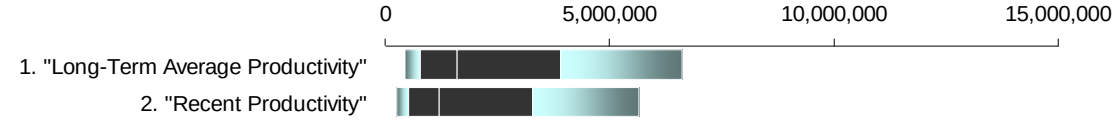


*Figure 2. Fraser Sockeye 2011 forecast probability distributions for **A. All Stocks**; **B. Early Stuart; C. Early Summer; D. Summer and E. Late Run timing groups** for the two forecast scenarios: **1. 'Long-Term Average Productivity'; 2. 'Recent Productivity'.** These figures describe both the stochastic (random) uncertainty in forecasts (probability distributions) and the uncertainty associated with future Fraser Sockeye survival (represented by the two different survival scenarios). Colors on horizontal bars represent the 10% to 90% probability levels (see first example that links, using arrows, the probability level to the bar color as a key for all subsequent figures).*

*Table 2. The **'Long-Term Average Productivity'** 2011 forecasts (from the 10% to 90% probability levels) are presented by stock and timing group (columns A and J to N). The selected models by stock for these forecasts are presented in column B. Average run sizes are presented across all cycles (H) and for the 2011 cycle (I). Brood year escapements (smolts for Chilko and Cultus) for age-4 (2007) and age-5 (2006) recruits returning in 2011 (columns C & D) are presented and colour coded relative to their 1950-2009 cycle average. Forecasted returns (column G), that correspond to their 50% probability level (column L), and productivity in the last eight brood years (column E) and last four brood years (column F) are also colour coded relative to their cycle average. Color codes represent the following: Red (< average), yellow (average) and green (> average).*

A	B	C	D	E	F	G	H	I	J	K	L	M	N
Run timing group		BY (07)	BY (06)	Prod.	Prod.	Ret	Mean Run Size		Probability that Return will be at/or Below Specified Run Size [a]				
Stocks	Forecast Model [b]	(EFS)	(EFS)	(-8yr)	(-4yr)	2011	all cycles [c]	2011 cycle [d]	10%	25%	50%	75%	90%
Early Stuart	*Ricker-Pi*	2,400	15,900	2.5	2.4		311,000	172,000	**21,000**	**30,000**	**47,000**	**71,000**	**100,000**
Early Summer							**510,000**	**497,000**	**164,000**	**284,000**	**518,000**	**958,000**	**1,785,000**
(total excluding miscellaneous)							***510,000***	***497,000***	**115,000**	**194,000**	**354,000**	**650,000**	**1,201,000**
Bowron	*Ricker-PDO*	1,100	600	2.4	2.1		39,000	79,000	5,000	7,000	12,000	20,000	33,000
Fennell	*TSA*	6,800	8,000	4.0	4.3		25,000	33,000	7,000	13,000	25,000	47,000	84,000
Gates	*Power*	1,100	1,500	5.3	4.9		53,000	24,000	7,000	10,000	17,000	28,000	47,000
Nadina	*Power(juv)-Ei*	1,000	4,500	3.9	4.6		80,000	87,000	6,000	9,000	15,000	25,000	42,000
Pitt	*Ricker-Pi*	19,900	21,300	0.4	0.1		72,000	71,000	41,000	67,000	118,000	197,000	372,000
Raft	*Power*	8,100	3,400	3.7	2.9		32,000	21,000	19,000	28,000	44,000	69,000	104,000
Scotch	*Ricker-PDO*	4,800	72,700	6.3	5.3		78,000	19,000	13,000	26,000	57,000	128,000	274,000
Seymour	*Power*	5,900	57,300	5.2	3.8		131,000	163,000	17,000	34,000	66,000	136,000	245,000
Misc [e]	*RS (Sc/Se)*	4,000	20,000				--	--	11,000	19,000	41,000	64,000	93,000
Misc [f]	*RS (Ra/Fe)*	1,000	3,000				--	--	4,000	6,000	11,000	23,000	46,000
Misc [g]	*RS (Ra/Fe)*	10,000	12,000				--	--	28,000	51,000	87,000	178,000	362,000
Misc [h]	*RS (Esum)*	1,000	1,000				--	--	2,000	5,000	9,000	15,000	29,000
Misc [i]	*RS (Esum)*	2,000	1,000				--	--	4,000	9,000	16,000	28,000	54,000
Summer							**3,730,000**	**2,389,000**	**1,067,000**	**1,598,000**	**2,464,000**	**4,138,000**	**6,579,000**
Chilko [j]	*Power(juv)*	27.5M	71M	0.03	0.03		1,350,000	1,556,000	809,000	1,170,000	1,733,000	2,854,000	4,296,000
Late Stuart	*Power*	4,100	14,300	2.7	2.9		560,000	86,000	24,000	46,000	82,000	161,000	312,000
Quesnel	*Ricker-cyc*	33,800	90,400	1.8	0.8		1,358,000	153,000	121,000	182,000	299,000	552,000	980,000
Stellako	*Ricker-PDO*	19,600	79,800	2.5	1.9		462,000	594,000	113,000	200,000	350,000	571,000	991,000
Late							**3,020,000**	**2,196,000**	**448,000**	**781,000**	**1,598,000**	**3,907,000**	**6,622,000**
(total exlcuding miscellaneous)							***3,020,000***	***2,196,000***	***437,000***	***760,000***	***1,561,000***	***3,842,000***	***6,509,000***
Cultus [j & k]	*Power(juv)-FrD-peak*	341,000	389,200	0.02	0.02		39,000	86,000	5,000	8,000	15,000	31,000	60,000
Harrison [l]	*RS*	57,400	4,400	16.1	19.7		60,000	71,000	37,000	99,000	380,000	1,660,000	2,637,000
Late Shuswap	*Larkin*	32,300	1.2M	4.1	1.4		2,152,000	1,427,000	43,000	109,000	251,000	587,000	1,192,000
Portage	*Power*	800	11,000	5.3	5.1		40,000	27,000	4,000	9,000	19,000	37,000	68,000
Weaver	*Power(juv)-PDO*	15,800	13,600	11.8	6.9		363,000	209,000	185,000	281,000	440,000	717,000	1,142,000
Birkenhead	*Ricker-PDO*	54,300	137,400	1.5	1.2		366,000	376,000	163,000	254,000	456,000	810,000	1,410,000
Misc. non-Shuswap [m]	*RS (Birkenhead)*	3,000	11,000				--	--	11,000	21,000	37,000	65,000	113,000
TOTAL SOCKEYE SALMON							-	-	**1,700,000**	**2,693,000**	**4,627,000**	**9,074,000**	**15,086,000**
(TOTAL excluding miscellaneous)							***(7,571,000)***	***(5,254,000)***	***(1,640,000)***	***(2,582,000)***	***(4,426,000)***	***(8,701,000)***	***(14,389,000)***
PINK SALMON	*Power-SSS*	2009 Brood Year Fry 1 billion					**11,800,000**	**11,800,000**	**9,156,000**	**12,648,000**	**17,495,000**	**25,125,000**	**37,496,000**

a. Probability that return will be at, or below, specified projection.
b. See Table 1 for model descriptions
c. Sockeye: 1953-2009 (depending on start of time series)
d. Sockeye: 1955-2007 (depending on start of time series)
e. Unforecasted miscellaneous Early Summer Stocks (Early Shuswap stocks: S.Thompson; used Scotch/Seymour R/EFS)
f. Unforecasted miscellaneous Early Summer stocks (N. Thomson tributaries; used Raft/Fennell R/EFS).
g. North Thompson River (used Raft/Fennell R/EFS)
h. Chilliwack Lake and Dolly Varden Creek (used Early Summer R/EFS)
i. Nahatlach River & Lake (used Early Summer R/EFS)
j. Brood year smolts in columns C & D (not effective females)
k. For Cultus, this 'Long-Term Average Productivity' smolt-jack forecast uses the full marine survival time series.
l. Harrison are age-4 (column C) and age-3 (column D).
m. Unforecasted miscellaneous Late Run stocks (Harrison Lake down stream migrants including Big Silver, Cogburn, etc.); used Birkenhead R/EFS & Weaver age proportions.

Definitions: BY: Brood year; BY07: brood year 2007; BY06: brood year 2006; EFS: effective female spawners; Prod. (8yr), Prod. (4yr): Productivity in recruits-per-effective female spawners in the last 8 yrs or last 4 yrs; Pi (Pine Island sea-surface-temperature covariate); PDO (Pacific Decadal Oscillation covariate); TSA (time series average model); Ei (Entrance Island sea-surface-temperature covariate); R/S (used for stocks with no recruit data--product of R/S for stocks indicated and EFS), cyc (cycle line data only used); FrD-peak (peak Fraser discharge covariate); SSS (sea surface salinity covariate)

*Table 3. For each of the 19 forecasted stocks (column A), average age-4 productivities (recruits-per-effective female spawner: R/EFS) are presented for the first part of the time series (up to and including 1979) (column B), the last eight brood years (1996-2004) (column D), and the last four brood years (2000-2004) (column E) relative to the average over the 1980-2004 brood years (column C). The **'Long-Term Average Productivity'** 2011 forecast from the 10% to 90% probability levels (**based on Table 2 forecasts and escapements)** are presented in columns (F) to (J). Log_e (R/EFS) was used to determine colour codes for columns (B) to (E) (see methods in Grant et al. 2010), however, productivities in the below table are presented in R/EFS. Color codes represent the following: Red (< average), yellow (average) and green (> average).*

A	B	C	D	E	F	G	H	I	J
Run timing group	**Early Time Series**	**Reference Period**	**Last 8 yrs**	**Last 4 yrs**	**"Long-Term Average" 2011 forecast productivities (R/EFS) for each probability level in Table 3 by stock**				
Stocks	**Avg R/EFS (up to 1979)**	**Avg R/EFS (1980-2004)**	**Avg R/EFS (1997-2004)**	**Avg R/EFS (2001-2004)**	**10%**	**25%**	**50%**	**75%**	**90%**
Early Stuart	9.5	3.9	2.5	2.4	**3.8**	**5.4**	**9.2**	**15.0**	**23.8**
Early Summer									
Bowron	9.0	4.8	2.4	2.1	2.7	4.5	9.1	16.4	28.2
Fennell	20.0	4.2	4.0	4.3	0.6	1.2	2.6	5.4	10.3
Gates	17.0	7.3	5.3	4.9	3.6	7.3	12.7	22.7	38.2
Nadina	10.1	5.3	3.0	4.6	2.0	3.0	6.0	11.0	21.0
Pitt	2.6	0.6	0.4	0.1	0.9	1.2	1.7	2.1	2.9
Raft	7.9	4.5	3.7	2.9	1.1	2.0	3.6	6.5	11.4
Scotch	NA	6.7	6.3	5.3	1.7	2.9	5.4	10.0	18.3
Seymour	10.9	5.1	5.2	3.8	2.2	4.2	7.8	15.3	24.7
Summer									
Chilko[a]	0.08	0.06	0.03	0.03	0.02	0.03	0.05	0.09	0.14
Late Stuart	11.3	7.3	2.7	2.9	3.2	6.3	14.6	31.5	65.6
Quesnel[b]	15.1	5.1	1.8	0.8	2.3	4.0	7.6	15.0	27.6
Stellako	10.1	4.5	2.5	1.9	1.5	3.8	8.0	16.8	29.4
Late									
Cultus[a]	0.05	0.04	0.02	0.02	0.01	0.02	0.04	0.08	0.15
Harrison[c]	2.3	4.9	16.1	19.7	NA	NA	NA	NA	NA
Late Shuswap[b]	8.1	5.2	4.1	1.4	0.7	2.0	4.4	9.8	17.9
Portage	20.9	8.8	5.3	5.1	3.8	6.3	16.3	35.0	66.3
Weaver	15.2	10.2	11.8	6.9	7.7	12.5	21.0	36.9	66.8
Birkenhead	9.4	3.0	1.5	1.2	0.9	1.8	3.7	8.0	14.6

a. Chilko and Cultus are marine survival (recruits per smolt)
b. Quesnel and Late Shuswap are cycle averages
c. Harrison forecasts cannot be assessed for productivity due to their variable age proportions; making comparisons to columns B to E productivities not valid.

*Table 4. The **'Recent Productivity'** 2011 forecasts (from the 10% to 90% probability levels) are presented by stock and timing group (columns A and J to N). The selected models by stock for these forecasts are presented in column B. Average run sizes are presented across all cycles (H) and for the 2011 cycle (I). Brood year escapements (smolts for Chilko and Cultus) for age-4 (2007) and age-5 (2006) recruits returning in 2011 (columns C & D) are presented and colour coded relative to their 1950-2009 cycle average. Forecasted returns (column G), that correspond to their 50% probability level (column L), and productivity in the last eight brood years (column E) and last four brood years (column F) are also colour coded relative to their cycle average. Color codes represent the following: Red (< average), yellow (average) and green (> average).*

A	B	C	D	E	F	G	H	I	J	K	L	M	N
Run timing group		**BY (07)**	**BY (06)**	**Prod.**	**Prod.**	**Ret**	**Mean Run Size**		**Probability that Return will be at/or Below Specified Run Size [a]**				
Stocks	**Forecast Model [b]**	**(EFS)**	**(EFS)**	**(-8yr)**	**(-4yr)**	**2011**	**all cycles[c]**	**2011 cycle[d]**	**10%**	**25%**	**50%**	**75%**	**90%**
Early Stuart	*RS4yr*	2,400	15,900	2.5	2.4		311,000	172,000	**6,000**	**11,000**	**17,000**	**27,000**	**42,000**
Early Summer							**510,000**	**497,000**	**153,000**	**257,000**	**453,000**	**894,000**	**1,558,000**
(total excluding miscellaneous)							***510,000***	***497,000***	**107,000**	**181,000**	**332,000**	**648,000**	**1,232,000**
Bowron	*RS4yr*	1,100	600	2.4	2.1		39,000	79,000	2,000	2,000	5,000	12,000	22,000
Fennell	*Power*	6,800	8,000	4.0	4.3		25,000	33,000	14,000	21,000	35,000	60,000	93,000
Gates	*KF*	1,100	1,500	5.3	4.9		53,000	24,000	2,000	4,000	8,000	16,000	30,000
Nadina	*Ricker-FrD (mean)*	1,000	4,500	3.0	4.6		80,000	87,000	4,000	7,000	12,000	21,000	37,000
Pitt	*Ricker*	19,900	21,300	0.4	0.1		72,000	71,000	32,000	51,000	82,000	140,000	236,000
Raft	*Ricker-PDO*	8,100	3,400	3.7	2.9		32,000	21,000	29,000	44,000	68,000	108,000	171,000
Scotch	*KF*	4,800	72,700	6.3	5.3		78,000	19,000	14,000	32,000	80,000	201,000	465,000
Seymour	*RS4yr*	5,900	57,300	5.2	3.8		131,000	163,000	10,000	20,000	42,000	90,000	178,000
Misc [e]	*RS (Sc/Se)*	4,000	20,000			--	--	--	11,000	23,000	40,000	54,000	77,000
Misc [f]	*RS (Ra/Fe)*	1,000	3,000			--	--	--	3,000	5,000	7,000	17,000	23,000
Misc [g]	*RS (Ra/Fe)*	10,000	12,000			--	--	--	27,000	40,000	57,000	138,000	180,000
Misc [h]	*RS (Esum)*	1,000	1,000			--	--	--	2,000	3,000	6,000	13,000	16,000
Misc [i]	*RS (Esum)*	2,000	1,000			--	--	--	3,000	5,000	11,000	24,000	30,000
Summer							**3,730,000**	**2,389,000**	**590,000**	**903,000**	**1,500,000**	**2,657,000**	**4,835,000**
Chilko [j]	*RJ4yr (smolt)*	27.5M	71M	0.03	0.03		1,350,000	1,556,000	513,000	749,000	1,141,000	1,740,000	2,548,000
Late Stuart	*RS8yr*	4,100	14,300	2.7	2.9		560,000	86,000	5,000	14,000	41,000	123,000	331,000
Quesnel	*RAC*	33,800	90,400	1.8	0.8		1,358,000	153,000	50,000	99,000	239,000	639,000	1,673,000
Stellako	*RS4yr*	19,600	79,800	2.5	1.9		462,000	594,000	22,000	41,000	79,000	155,000	283,000
Late							**3,020,000**	**2,196,000**	**257,000**	**516,000**	**1,207,000**	**3,288,000**	**5,648,000**
(total exlcuding miscellaneous)							***3,020,000***	***2,196,000***	***254,000***	***502,000***	***1,188,000***	***3,261,000***	***5,612,000***
Cultus [j & k]	*Smolt-Jack*	341,000	389,200	0.02	0.02		39,000	86,000	4,000	6,000	9,000	13,000	17,000
Harrison[l]	*RS*	57,400	4,400	16.1	19.7		60,000	71,000	37,000	96,000	372,000	1,656,000	2,630,000
Late Shuswap	*Ricker-Pi*	32,300	1.2M	4.1	1.4		2,152,000	1,427,000	60,000	152,000	355,000	780,000	1,555,000
Portage	*KF*	800	11,000	5.3	5.1		40,000	27,000	4,000	9,000	21,000	47,000	98,000
Weaver	*Ricker-FrD (peak)*	15,800	13,600	11.8	6.9		363,000	209,000	90,000	143,000	253,000	444,000	761,000
Birkenhead	*KF*	54,300	137,400	1.5	1.2		366,000	376,000	59,000	96,000	178,000	321,000	551,000
Misc. non-Shuswap[m]	*RS (Birkenhead)*	3,000	11,000	--	--	--	--	--	3,000	14,000	19,000	27,000	36,000
TOTAL							-	-	**1,006,000**	**1,687,000**	**3,177,000**	**6,866,000**	**12,083,000**
(TOTAL excluding miscellaneous)							***(7,571,000)***	***(5,254,000)***	***(957,000)***	***(1,597,000)***	***(3,037,000)***	***(6,593,000)***	***(11,721,000)***

a. Probability that return will be at, or below, specified projection.
b. See Table 1 for model descriptions
c. Sockeye: 1953-2009 (depending on start of time series)
d. Sockeye: 1955-2007 (depending on start of time series)
e. Unforecasted miscellaneous Early Summer Stocks (Early Shuwap stocks: S.Thompson; used Scotch/Seymour R/EFS)
f. Unforecasted miscellaneous Early Summer stocks (N. Thomson tributaries; used Raft/Fennell R/EFS).
g. North Thompson River (used Raft/Fennell R/EFS)
h. Chilliwack Lake and Dolly Varden Creek (used Early Summer R/EFS)
i. Nahatlach River & Lake (used Early Summer R/EFS)
j. Brood year smolts in columns C & D (not effective females)
k. For Cultus, this 'Recent Productivity' smolt-jack forecast uses a truncated (brood years 1997-2004) marine survival time series.
l. Harrison are age-4 (column C) and age-3 (column D).
m. Unforecasted miscellaneous Late Run stocks (Harrison Lake down stream migrants including Big Silver, Cogburn, etc.); used Birkenhead R/EFS & Weaver age proporitons

Definitions: BY: Brood year; BY07: brood year 2007; BY06: brood year 2006; EFS: effective female spawners; Prod. (8yr), Prod. (4yr): Productivity in recruits-per-effective female spawners in the last 8 yrs or last 4 yrs; Pi (Pine Island sea-surface-temperature covariate); PDO (Pacific Decadal Oscillation covariate); TSA (time series average model); Ei (Entrance Island sea-surface-temperature covariate); R/S (used for stocks with no recruit data--product of R/S for stocks indicated and EFS), cyc (cycle line data only used); FrD-peak (peak Fraser discharge covariate); SSS (sea surface salinity covariate)

*Table 5. For each of the 19 forecasted stocks (column A), average age-4 productivities (recruits-per-effective female spawner: R/EFS) are presented for the first part of the time series (up to and including 1979) (column B), the last eight brood years (1996-2004) (column D), and the last four brood years (2000-2004) (column E) relative to the average over the 1980-2004 brood years (column C). The **'Recent Productivity'** 2011 forecast from the 10% to 90% probability levels (**based on Table 4 forecasts and escapements)** are presented in columns (F) to (J). Log_e (R/EFS) was used to determine colour codes for columns (B) to (E) (see methods in Grant et al. 2010), however, productivities in the below table are presented in R/EFS. Color codes represent the following: Red (< average), yellow (average) and green (> average).*

A	B	C	D	E	F	G	H	I	J
Run timing group Stocks	Early Time Series Avg R/EFS (up to 1979)	Ref. Period Avg R/EFS (1980-2004)	Last 8 yrs Avg R/EFS (1997-2004)	Last 4 yrs Avg R/EFS (2001-2004)	"Recent Productivity" 2011 forecast productivities (R/EFS) for each probability level in Table 3 by stock				
					10%	25%	50%	75%	90%
Early Stuart	9.5	3.9	2.5	2.4	**0.8**	**1.7**	**2.5**	**4.2**	**6.3**
Early Summer									
Bowron	9.0	4.8	2.4	2.1	0.9	0.9	1.8	4.5	7.3
Fennell	20.0	4.2	4.0	4.3	1.0	1.9	3.2	6.5	11.5
Gates	17.0	7.3	5.3	4.9	1.8	2.7	5.5	10.9	18.2
Nadina	10.1	5.3	3.0	4.6	2.0	3.0	6.0	11.0	22.0
Pitt	2.6	0.6	0.4	0.1	0.7	1.0	1.2	1.3	1.3
Raft	7.9	4.5	3.7	2.9	2.0	3.7	6.5	11.6	19.9
Scotch	NA	6.7	6.3	5.3	1.0	2.5	5.6	13.3	29.0
Seymour	10.9	5.1	5.2	3.8	1.0	1.9	3.7	7.5	13.4
Summer									
Chilko[a]	0.08	0.06	0.03	0.03	0.01	0.02	0.03	0.04	0.06
Late Stuart	11.3	7.3	2.7	2.9	0.5	1.0	2.7	7.3	18.3
Quesnel[b]	15.1	5.1	1.8	0.8	0.3	1.0	3.9	13.5	40.9
Stellako	10.1	4.5	2.5	1.9	0.5	0.9	1.8	3.6	6.5
Late									
Cultus[a]	0.05	0.04	0.02	0.02	0.01	0.02	0.02	0.03	0.04
Harrison[c]	2.3	4.9	16.1	19.7	NA	NA	NA	NA	NA
Late Shuswap[b]	8.1	5.2	4.1	1.4	1.3	3.4	7.6	15.8	29.2
Portage	20.9	8.8	5.3	5.1	2.5	5.0	12.5	28.8	60.0
Weaver	15.2	10.2	11.8	6.9	2.8	5.4	11.4	22.4	42.4
Birkenhead	9.4	3.0	1.5	1.2	0.7	1.0	1.7	2.6	3.9

a. Chilko and Cultus are marine survival (recruits per smolt)
b. Quesnel and Late Shuswap are cycle averages
c. Harrison forecasts cannot be assessed for productivity due to their variable age proportions; making comparisons to columns B to E productivities not valid.

The 'Recent Productivity' scenario is considered most plausible (CSAP Salmon Sub-Committee). The 'Long-Term Average Productivity' scenario is considered plausible but less likely. Based on the assumption of 'Recent Productivity', there is a one in ten chance (10% probability) the return will be at or below 1.0 million, and a nine in ten chance (90% probability) it will be at or below 12.1 million (Table 4). The mid-point of this distribution (50% probability level) is 3.2 million (one in two chance the return will be above or below this value assuming recent stock productivity). Productivities associated with these forecasts are presented in Table 5. Based on the assumption of 'Long-Term Average Productivity', there is a one in ten chance (10% probability) the return will be at or below 1.7 million, and a nine in ten chance (90% probability) it will be at or below 15.1 million (Table 2). The mid-point of this distribution (50% probability level) is 4.6 million (one in two chance the return will be above or below this value assuming long-term average stock productivity). Productivities associated with these forecasts are presented in Table 3.

The total forecast for the 'Recent Productivity' scenario is smaller than the 'Long-Term Average Productivity' scenario. However, at the individual stock level, only 47% (9 out of 19) of the stocks in the 'Recent Productivity' scenario used models that specifically consider their lower recent productivity (e.g. RS4yr, RS8yr, KF or truncated marine survival time series in the case of the Cultus smolt-jack model). For these stocks, differences between the two forecast scenarios were attributed to differences between recent (below average) and long-term stock productivities. For the remaining 53% (10 out of 19) of the stocks, either their top ranked 'Recent Productivity' models were those that either used the full stock-recruitment time series instead of one of these three new recent productivity models (8 stocks) or, despite their use of recent productivity models, these stocks had similar recent and long-term average productivities (2 stocks). Therefore, for these stocks, differences between the two forecast scenarios were attributed to differences in model form as opposed to differences in productivity.

In the 2011 forecast, age-5 return proportions (~35% to 50% of age-4's plus age-5's) are above average (long-term age-5 proportion average: ~20%) for two reasons. First, the generally higher brood year EFS in the 2006 brood year (age-5 returns in 2011) relative to the 2007 brood year (age-4 returns in 2011) contributed to increased age-5 proportions in 2011. Second, above average 2006 age-4 productivity was used to forecast 2011 age-5 returns for a number of stocks, also contributing to increased age-5 proportions.

2011 Fraser Pink Forecasts

The first ranked Power model with an environmental covariate (specifically, average sea-surface salinity from July to September at the Race Rocks and Amphitrite Point lighthouse stations) was used to generate the 2011 Fraser Pink return forecast (DFO 2006). The 2011 Pink forecast ranges from 9.2 million fish to 37.5 million fish at the 10% to 90% probability levels (Table 2). The median (50% probability) forecast of 17.5 million Pink Salmon is 1.5 times greater than the long-term (1959-2007) cycle average return (11.8 million) (Table 2). This forecast was 34% smaller than the Power model excluding an environmental covariate (median probability forecast of 26.9 million).

The 2011 Pink forecast is highly uncertain for a number of reasons. First, the estimated brood year (2010) Fraser Pink fry abundance (1 billion) was the largest abundance of outmigrating fry recorded (the second highest occurred in 1997 at 697 million fry) and is more than double the long-term (brood years 1961-2007) average of 376 million fry. As a result, the Pink forecast model is extrapolating beyond the range of observed stock-recruitment data when using this record fry abundance as a predictor variable. In addition, it is important to note that the 2010 fry estimate was interpolated between the dates of April 23 to May 1 (the interpolation comprised 30% or 296 million of the total estimated abundance), a period during which the survey vessel was out of commission and four surveys were missed (J. Tadey, DFO, pers. comm.). The gap in the time series occurred during the historical peak migration period and coincided with the 2010 peak observed abundance. The un-interpolated (the period during normal vessel operation) fry abundance was 766 million fry, which alone represents the largest Pink fry abundance on the time series. Finally, estimation methods for Pink recruitment have changed significantly over the years, and in recent year's, recruitment is estimated with lower precision methods (test fisheries) due to the absence of spawning ground enumerations for Pink salmon.

Sources of Uncertainties

Considerable Sockeye mortality occurs in both the freshwater and marine environment throughout their life-history (from the egg stage to when the adults return to the Fraser watershed to spawn). Currently Fraser Sockeye forecasts are associated with large uncertainty (wide probability distributions). In attempts to improve the predictability of inter-annual variation

in recruitment, Fraser Sockeye return forecasts have incorporated environmental variables, both quantitatively into forecast models (Grant et al. 2010), and qualitatively into the forecast advice (DFO 2009). However, to date, inclusion of environmental variables has not significantly decreased forecast uncertainty. On-going research and upcoming workshops continue to explore environmental variables that could be used to explain inter-annual variability in Fraser Sockeye recruitment.

CONCLUSIONS

- The 'Recent Productivity' scenario is considered most plausible for forecasting Fraser River Sockeye Salmon Returns in 2012. The 'Long-Term Average Productivity' scenario is considered plausible but less likely.
- The total Fraser Sockeye forecast for the 'Recent Productivity' scenario is smaller than the 'Long Term Average Productivity' scenario. However, in the 'Recent Productivity' scenario, only 47% (9 out of 19) of the individual stocks used models that specifically consider their lower recent productivity, and therefore, produced smaller forecasts. For the remaining 53% (10 out of 19) of the stocks, differences between the forecasts under the two productivity scenarios can be attributed to differences in model form rather than differences in productivity.
- The 2011 Fraser Sockeye forecasts have higher age-5 proportions (35-50% of total age-4 + age-5 returns) than average (~20%), given the generally higher brood year escapements for age-5 Sockeye (compared to age-4 Sockeye) and the use of above average 2010 age-4 productivity to forecast age-5 returns for some stocks.
- Fraser Pink Salmon have not exhibited similar declines in productivity to Fraser Sockeye. Therefore, only one forecast scenario based on 'Long-Term Average Productivity' was considered.
- Based on the assumption of 'Long-Term Average Productivity', there is a one in four chance (25% probability) the Pink return will be at or below 12.6 million and a three in four chance (75% probability) it will be at or below 25.1 million. The mid-point of this distribution (50% probability level) is 17.5 million. Recent productivity scenarios were not compared for Pink Salmon as they have not exhibited similar declines in productivity as Fraser Sockeye.
- The Fraser Pink forecast is highly uncertain because predictions are made outside the observed data range given the record high fry abundance in 2010. Other factors also contribute to the increased forecast uncertainty (e.g. absence of spawning ground enumerations for Pink salmon in recent years).

SOURCES OF INFORMATION

This Science Advisory Report has resulted from a Fisheries and Oceans Canada, Canadian Science Advisory Secretariat, Regional Advisory Meeting of February 4, 2011 on *2011 Fraser River Sockeye and Pink Salmon forecasts*. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

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