PRE-SEASON RUN SIZE FORECASTS FOR FRASER RIVER SOCKEYE AND PINK SALMON IN 2013

Figure 1. Sockeye adult spawning phase (source: DFO website) and their distribution in the Fraser watershed (DFO GIS Division).

Figure 2. Pink adult spawning phase (source: DFO website) and their distribution in the Fraser watershed (DFO GIS Division).

Context

Pre-season abundance forecasts of returning Fraser River adult Sockeye and Pink salmon in 2013 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 in-season test fisheries provide adjustments to the run size estimates. Forecasts are produced by DFO as agreed under the Canada-United States Pacific Salmon Treaty. The details associated with the 2013 forecast are presented in an associated Canadian Science Advisory Secretariat (CSAS) Research Document (Grant and MacDonald 2013).

This Science Advisory Report has resulted from a DFO Canadian Science Advisory Secretariat (CSAS) Regional Peer Review (RPR) meeting November 13-15, 2012 on Pre-season abundance forecasts for Fraser River Sockeye and Pink Salmon returns in 2013; and Assessment of mark selective fisheries strategies for Strait of Georgia Coho Salmon . Additional publications from this process will be posted as they become available on the Fisheries and Oceans Canada Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

SUMMARY

Fraser River Sockeye

- For Fraser Sockeye, quantitative and qualitative indicators of stock productivity (recruits-per-spawner) explored to-date have not reduced forecast uncertainty and remain an active area of research.
- Fraser Sockeye forecasts have been particularly uncertain in recent years due to the systematic declines in productivity exhibited by most stocks, which culminated in some of the lowest productivities on record in the 2005 brood year (2009 four year old and 2010 five year old returns). Subsequently, total stock productivity has improved.
- For the 2013 forecast, models were selected for each stock based on their relative ability to predict true returns over the full stock-recruitment time series. The performance of each model was compared to a suite of forecast models, which excluded the recent productivity models introduced in 2010.
- A sensitivity analysis was also conducted to compare the 2013 forecasts with forecasts produced using top ranked models evaluated over the low productivity period (brood years 1997 to 2005), which include recent low productivity models introduced in 2010.
- To capture inter-annual random variability in Fraser Sockeye productivity, forecasts are presented as standardized cumulative probabilities (10%, 25%, 50%, 75%, and 90%).
- The 2013 forecast indicates a one in ten chance (10% probability) the total Fraser Sockeye return will be at or below 1,554,000 (lowest observed on this cycle) and a nine in ten chance (90% probability) it will be at or below 15,608,000, assuming productivity is similar to past observations. The mid-point of this distribution (50% probability) is 4,765,000 (there exists a one in two chance the return will be at or below this value). The four year old percentage of the total forecast is 90%, and ranges from 13% to 100%, depending on the stock. The 2013 forecast is larger than the 2012 forecast, attributed to higher escapements in the 2009 versus 2008 brood year.
- Consistent with management changes made in 2012 by the Fraser River Panel, Raft, Harrison, and North Thompson miscellaneous stocks were included with the Summer Run timing group, due to changes in their migration timing.
- Summer Run stocks, particularly Chilko and Quesnel, contribute 78% to the total return forecast, whereas Late Run (12%), Early Summer (5%) and Early Stuart Run stocks (4%) each contribute considerably less. The Harrison 2013 forecast is particularly uncertain, and returns have a higher likelihood of falling outside the forecast distribution.
- The total forecasted 2013 Fraser Sockeye return largely falls (up to a three in four chance, based on past observations) below the cycle average (8,579,000), due to the below average 2009 and 2008 brood year escapements for most stocks. Conversely, there is a one in four chance the return will be above the cycle average, if Fraser Sockeye productivity falls at the high end of past observations. If low productivity conditions resume, returns could be considerably lower, based on a sensitivity analysis forecast that ranges from 523,000 to 5,419,000 at the 10% to 90% probability level.

Fraser River Pink

- For Fraser Pink Salmon, the forecast ranges from 4,794,000 to 17,111,000 fish at the 10% to 90% probability levels. The median (50% probability) forecast of 8,926,000 Pink Salmon is below the long-term (1959-2011) average return (12,580,000). The Fraser Pink forecast originally presented to CSAS was generated by the power model without the sea-surface salinity environmental covariate, due to the unavailability of salinity data

at the time of the review. The original forecast was higher than the forecast presented in the current paper, and ranged from 6,881,000 to 27,687,000 returns at the 10% to 90% probability levels, with a median (50% probability) forecast of 14,010,000 returns. Fraser Pink forecasts are highly uncertain given the changes to the return estimation methods through time.

INTRODUCTION

Fraser Sockeye

Overview of Past Adult Returns

Fraser Sockeye returns have varied tremendously over time, with some of the most extreme variations observed in recent years (Figure 3A). The 2013 cycle has the second largest average return of the four cycles of Fraser River Sockeye, with an average annual Fraser Sockeye return (1953-2009) of 8.6 million for all 19 forecasted stocks combined (see Table 1, column G for the average cycle line return for each stock). Quesnel (Summer Run) has historically been the main driver of returns on this cycle line, accounting for 46% of the total run on average. Late Stuart, Chilko, and Early Stuart have also contributed relatively high proportions to the 2013 cycle average, at 19%, 9% and 9% respectively. Stocks that have each comprised greater than 2% (~3% each) of the average return on the 2013 cycle include Stellako, Weaver and Birkenhead. All remaining stocks have contributed less than 2% to the average return for this cycle.

Escapement in the 2008 and 2009 Brood Years

Since most Fraser Sockeye return as four year old fish after spending two winters in freshwater and two winters in the marine environment, the majority of Sockeye returning in 2013 will be recruits from eggs spawned by adults in 2009 (i.e., the brood year). Since this brood year was associated with one of the lowest returns on record, escapements, as a result, were low for most stocks in 2009.

Overall, the number of effective female spawners (EFS) in the 2009 brood year (511,000 EFS) was by far the lowest on the 2013 cycle since 1977 (2009 cycle average: 1.1 million). For approximately half of the stocks (9 out of 19), 2009 brood year EFS or smolt (Chilko and Cultus) abundances were well below their cycle averages (1949-2005 time series for most stocks) (Table 1, column C). Three stocks (Chilko, Quesnel and Harrison) together contributed 62% (25%, 17% and 20%, respectively) of the total 2009 brood year EFS. Most Fraser Sockeye stocks also have a five year old component that contributes, on average, 15% to their total recruitment (Table 1, column D). The 2008 brood year EFS for five year olds returning in 2013 was also amongst the lowest (300,000 EFS) on the 2012 cycle, and was lower than the 2009 EFS.

Harrison Sockeye have a unique age structure compared to other Fraser Sockeye stocks. This stock is comprised of three and four year old fish with varying inter-annual proportions. Higher proportions of four year olds occur in odd (Fraser Pink salmon) years (Grant et al. 2011). The brood years contributing to Harrison returns in 2013 include 2009 and 2010, which were both well above previously observed escapements for this stock (Table 1, columns C and D).

Trends in Productivity and Survival Rates

In recent decades, productivity (i.e., adult returns per EFS) across all Fraser Sockeye stocks has generally declined (Figure 3B), though individual trends vary amongst stocks (Grant et al. 2010, 2011; Peterman and Dorner 2011, 2012). One notable exception is Harrison Sockeye, which have increased in productivity in recent years (Grant et al. 2010, 2011; Peterman and Dorner 2011, 2012). Harrison Sockeye have a unique age-structure and life-history compared to all other stocks. This stock migrates to the ocean shortly after gravel emergence (most other Sockeye rear in lakes for one to two years prior to ocean migration) and returns as three and

four year old fish (most other Sockeye return as four and five year olds). For most stocks, declining productivity trends reached the lowest level yet observed in the 2005 brood year (2009 return year for most Sockeye) (Figure 3B). Subsequently, productivity appears to have improved for most stocks in the 2006 to 2008 brood years (2010 to 2012 return years for most Sockeye).

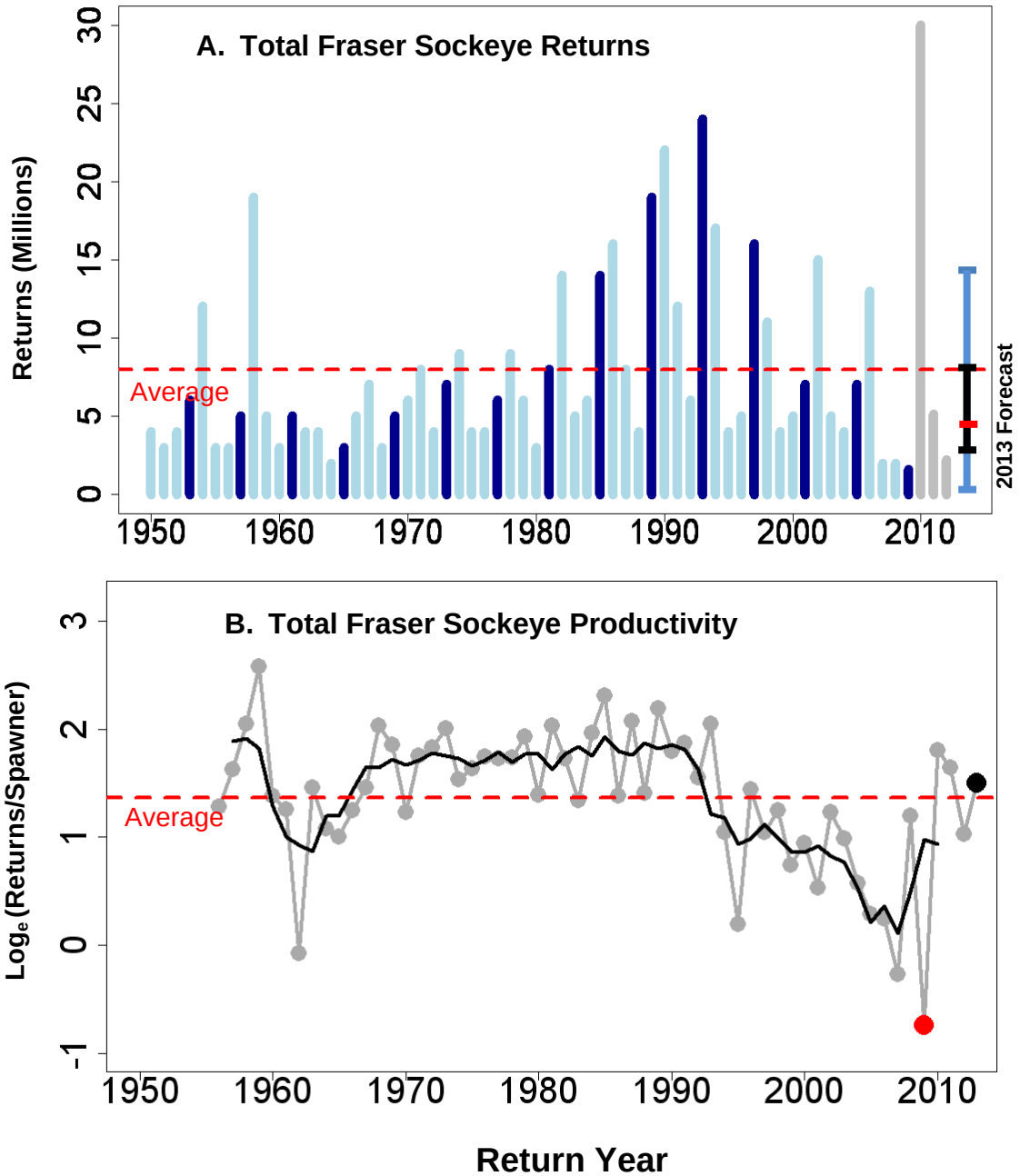


Figure 3. A. Total Fraser Sockeye annual returns (dark blue bars for the 2009/2013 cycle and light blue bars for the three other cycles)*. Grey bars in 2010 are preliminary return data and 2011 and 2012 are in-season return data, which are all subject to change. The vertical bar aligned with 2013 on the x-axis represents the 2013 forecast (length of the blue bar represents the 10% to 90% p-level, length of the black bar represents the 25% to 75% p-level, and the red horizontal bar represents the 50% p-level).* ***B. Total Fraser Sockeye productivity (log$_e$ (returns/total spawner)) up to the 2013 return year****. The light grey filled circles and line presents annual productivity and the black line presents the smoothed four year running average. Returns for 2009 (red filled circle) and 2010 are preliminary, for 2011 and 2012 are in-season estimates only, and for 2013 (black filled circle) presents the 50% p-level forecast.* **(Escapement**

data are provided by DFO and return data are provided by the Pacific Salmon Commission. Red dashed line in both plots is the time series average.)

Patterns in survival of Chilko Sockeye smolts, the only stock with a long-term smolt time series that can be used to partition total survival into freshwater and marine components, indicate that changes in both the freshwater and marine environments influence Chilko total survival in any given year (Figure 4A and B). Chilko marine survival, in particular is likely an indicator of marine survival of other stocks, as most Fraser Sockeye stocks occupy similar marine systems in time and space. Although there have been improvements in marine survival in recent years, in the absence of leading indicators of survival, it is unclear whether the recent improvements will persist through to the 2013 returns.

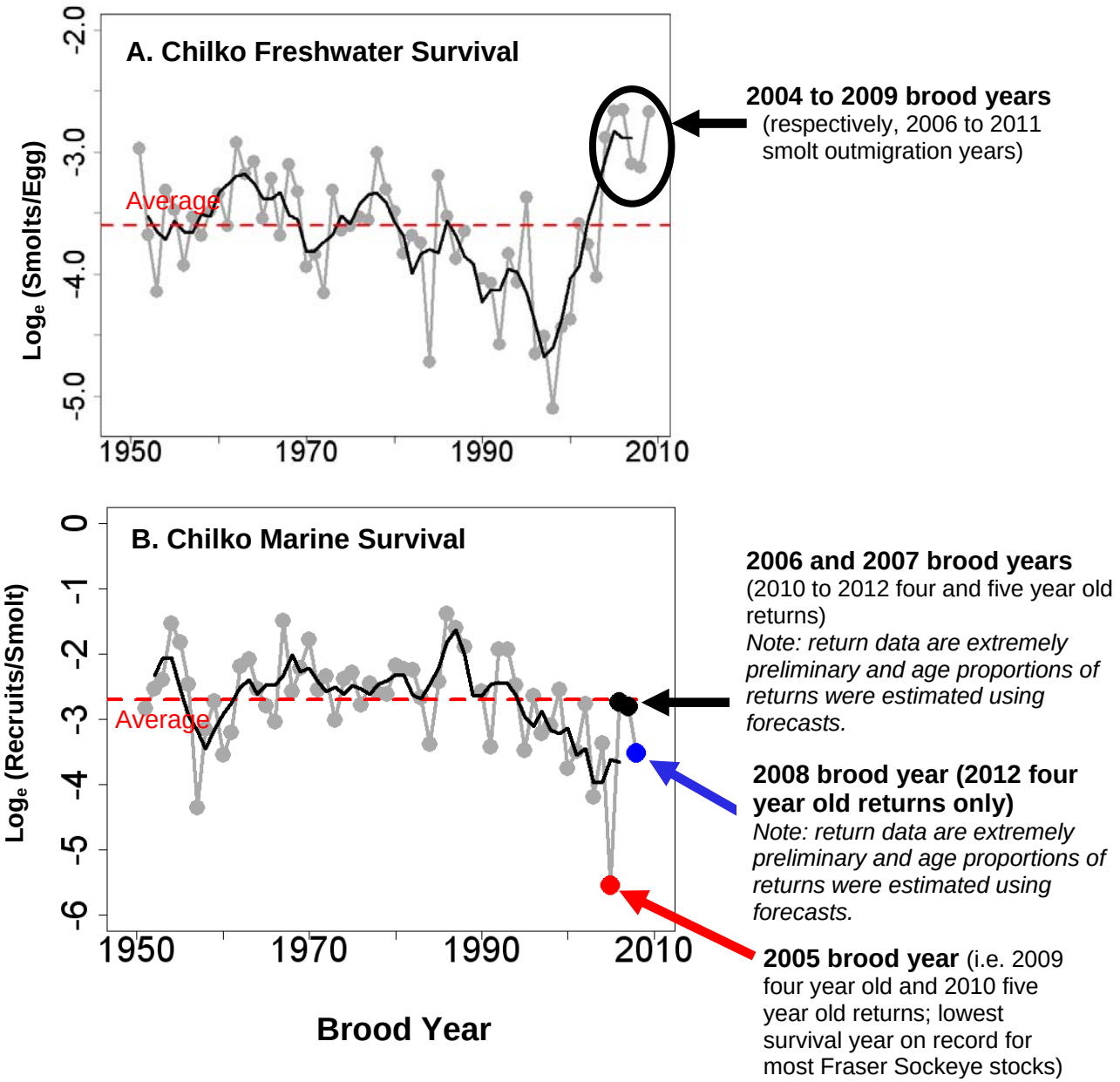


Figure 4. Chilko River Sockeye A. freshwater (log_e smolts per egg) and B. marine (log_e recruits per smolt) annual survival (filled grey circles and lines) and smoothed four-year running average survival (black lines). Red dashed lines in both plots indicate long-term average survival.

Fraser Pinks

From 1957 to 1981 Pink returns (catch plus escapement) increased. The earlier time-series of Fraser Pink returns was relatively low (10.7 million on average from 1959 to 1997) compared to the later time-series (15.2 million on average from 1999 to 2009) (Figure 5). Increases in returns later in the time series are likely attributed to Fraser Pink expansion into the upper Fraser watershed above Hells Gate (Pess et al. 2012).

Average Pink escapements similarly increased from a low of 4.0 million in the early time series (average from 1959 to 1997), to 13.1 million in the later time series (average from 1999 to 2011) (Figure 5). In recent years (2003 to 2011), escapement estimates have not been measured directly on the spawning grounds, but are estimated using test fishery return estimates minus catch. During this period, escapements have been particularly high (average escapement: 14.7 million Pinks). In 2011 (brood year for 2013 returns), the Fraser Pink escapement was 10.4 million, which is greater than the time-series average (6.3 million from 1959 to 2011).

The more recent increase in Pink escapement is in part due to declines in catch (Figure 5). Fraser Pink catch was particularly high early in the time series (1959 to 1997) at 6.7 million on average, and dropped to 1.7 million in the later time series (1999 to 2009) (Figure 5). Smaller catches of Fraser Pink salmon in the later time series are attributed to a decline in the commercial interest in this species. There has been, however, a growing interest in Pink harvest since 2009.

Fraser Pink fry abundances are estimated at Mission during their downstream migration, consistent with methods developed in 1962 (Vernon 1966). Given the high uncertainty in Pink escapement estimates in recent years, fry abundance is used as a predictor variable in the forecast process. Similar to the escapement time-series, Pink fry abundances were low (average: 270 million) early in the time-series (1961 to 1977) (Figure 6) and subsequently increased (400 million from 1979 to 2001). Pink fry abundances have been particularly high in recent years (632 million from 2003 to 2011). The Pink fry abundance from the 2011 brood year (returning in 2013) was 519 million, which was below the recent average of 632 million, but above the time series average of 400 million.

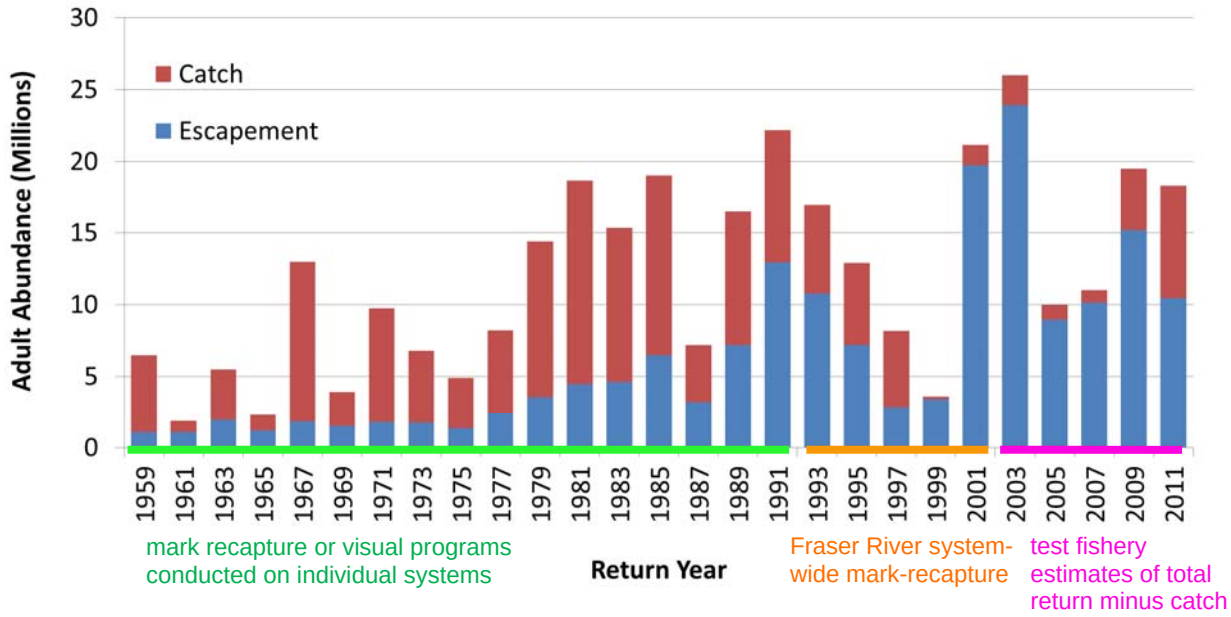


Figure 5. Fraser River Pink Salmon abundance from 1959 to 2011. Escapement enumeration methods have changed considerably over time (see coloured x-axis and coloured labels). For the first part of the time series (1959 to 1991), individual mark recaptures or visual survey escapement programs were conducted on separate systems (e.g. Lower Fraser, Fraser Canyon, Upper Fraser, Seton-Anderson, Thompson, Harrison, Vedder-Chilliwack). From 1993 to 2001, a system-wide Fraser River mark recapture escapement program was conducted. Post-2001, no escapement enumeration programs were conducted. Instead, escapement is estimated using total return estimates from test fisheries minus catch estimates.

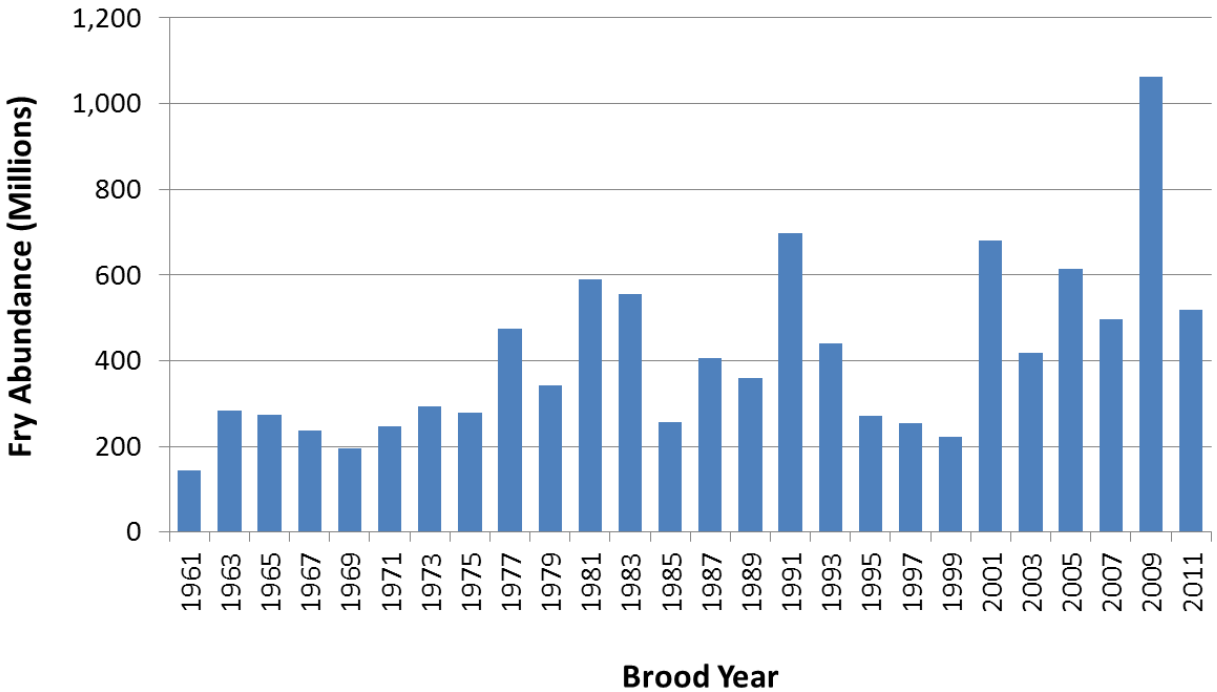


Figure 6. Fraser River Pink Salmon fry abundance from 1961 to 2011, estimated at Mission during their downstream migration.

ANALYSIS

Fraser Sockeye

Forecast Methods

The 2013 forecast approach is consistent with 2012 forecast methods (DFO 2012b; MacDonald and Grant 2012). The 2013 forecast model ranks are based on the 2012 analysis of model performance, with the exception of the exclusion of three model forms (RS4yr, RS8yr and KF). These models were excluded due to changes in productivity in recent years and the lack of available productivity data for these years. The final model choice for each stock in 2013 (presented in Tables 1 to 3) is based on a combination of model ranks and selection criteria (see Table 4 for model descriptions).

2013 Fraser Sockeye Forecasts

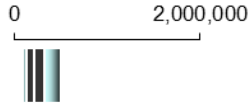
Fraser Sockeye forecasts for 2013 are associated with relatively high uncertainty, due to wide variability in annual salmon productivity (recruits-per-spawner), and observation error in the stock-recruitment data. High forecast uncertainty is consistent with previous Fraser Sockeye forecasts (Cass et al. 2006; DFO 2006; DFO 2007; DFO 2009; Grant et al. 2010; DFO 2012a; DFO 2012b; Grant and MacDonald 2012; MacDonald and Grant 2012) and recent research conducted on coast-wide salmon stocks (Haeseker et al. 2007 and 2008). Fraser Sockeye forecasts have been particularly uncertain in recent years, due to the systematic declines in productivity exhibited by most stocks, which culminated in one of the lowest productivities on record in the 2005 brood year (2009 four year old and 2010 five year old returns) (Figures 3 B and 4 B). Subsequently (2010 to 2012 return years), productivity appears to have improved (Figures 3 B and 4 B). Given the absence of leading quantitative or qualitative indicators of Fraser Sockeye productivity, stochastic (random) uncertainties associated with the 2013 Fraser Sockeye forecasts are presented as a series of forecasted values that correspond to standardized cumulative probabilities (10%, 25%, 50%, 75%, and 90%). The 50% (median) probability level is the mid-point of the forecast distribution, which indicates a one in two chance that Fraser Sockeye returns will be at or below these values, assuming stock productivity is similar to past observations.

The 2013 forecast indicates a one in ten chance (10% probability) the total Fraser Sockeye return will be at or below 1,554,000 and a nine in ten chance (90% probability) it will be at or below 15,608,000, assuming productivity is similar to past observations (Tables 1 and 2; Figure 7; Table 4 for model descriptions). The mid-point of this distribution (50% probability) is 4,765,000 (there exists a one in two chance the return will be at or below this value). The four year old percentage of the total forecast is 90% (ranges from 13% to 100%, depending on the stock) (Table 2). The 2013 forecast is larger than the 2012 forecast (DFO 2012b; MacDonald and Grant 2012), attributed to higher four year old brood year escapements in the 2009 brood year than in 2008. For the 2013 forecast, Raft, Harrison, and North Thompson miscellaneous stocks were included in the Summer Run timing group, due to changes in the migration timing of these stocks. These changes are consistent with a recent decision by the Fraser River Panel of the Pacific Salmon Treaty (PST) process.

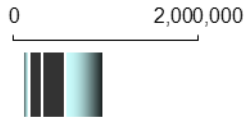
Summer Run stocks, particularly Chilko and Quesnel, contribute 78% to the total return forecast, whereas Late Run (12%), Early Summer (5%) and Early Stuart Run stocks (4%) each contribute considerably less (Figure 7). The Harrison forecast (Summer Run timed) is particularly uncertain, as the 2009 and 2010 brood year escapements for this stock were well above the observed range. Additionally, Harrison Sockeye exhibit high variability in their age proportions from year to year. Therefore, the Harrison return has a higher likelihood of falling outside the forecast range. The total forecasted 2013 Fraser Sockeye return largely falls (up to

a three in four chance, based on past observations) below the cycle average (8,579,000), due to the below average 2009 and 2008 brood year escapements for most stocks. Conversely, there is a one in four chance the return will be above the cycle average if Fraser Sockeye productivity falls at the high end of past observations. If low productivity resumes, based on the sensitivity analysis forecast, returns could range from 523,000 to 5,419,000 at the 10% to 90% probability level (Table 3). In this scenario, the entire distribution falls below the cycle average.

A. Early Stuart



B. Early Summer



C. Summer

D. Late

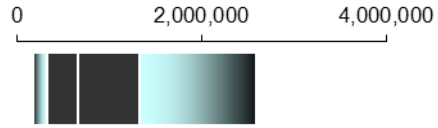


*Figure 7. Fraser Sockeye 2013 forecast probability distributions for **A**. Early Stuart; **B**. Early Summer; **C**. Summer and **D**. Late Run timing groups. These figures describe the stochastic (random) uncertainty in Fraser Sockeye forecasts as probability distributions. The width of the blue (or grey) bars represents the 10% and 90% probability levels, the width of the black bars represents the 25% to 75% probability levels, and the white line in the centre of the black bars represents the 50% probability level.*

Table 1. Fraser Sockeye forecasts for 2013 are presented by stock and timing group from the 10% to 90% probability levels (columns A and H to L). The selected models for each stock are presented in column B. Average run sizes are presented across all cycles (F) and for the 2013 cycle (G). Brood year escapements (smolts for Chilko and Cultus) for four (2009) and five year old (2008) recruits returning in 2013 (columns C and D) are presented and colour coded relative to their cycle average from 1949-2005 (brood year). Forecasted returns (column E), corresponding to the 50% probability level (column J) 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
Run timing group		BY (09)	BY (08)	Ret	**Mean Run Size**		**Probability that Return will be at/or Below Specified Run Size [a]**				
Stocks	**Forecast Model [b]**	(EFS)	(EFS)	2013	**all cycles [c]**	**2013 cycle [d]**	**10%**	**25%**	**50%**	**75%**	**90%**
Early Stuart	*Ricker (Ei)*	21,900	14,400		**311,000**	**792,000**	**92,000**	**137,000**	**211,000**	**331,000**	**507,000**
Early Summer					**478,000**	**274,000**	**73,000**	**130,000**	**253,000**	**468,000**	**844,000**
(total excluding miscellaneous)					***478,000***	***274,000***	**55,000**	**94,000**	**180,000**	**342,000**	**621,000**
Bowron	*MRS*	1,000	300		39,000	24,000	2,000	3,000	7,000	14,000	26,000
Fennell	*Power*	700	200		25,000	12,000	3,000	5,000	9,000	15,000	25,000
Gates	*Larkin*	5,300	1,800		53,000	40,000	24,000	37,000	67,000	115,000	191,000
Nadina	*MRJ*	3,700	10,200		80,000	72,000	10,000	20,000	44,000	95,000	189,000
Pitt	*Larkin*	18,100	5,400		72,000	74,000	5,000	9,000	15,000	28,000	50,000
Scotch	*Ricker*	2,700	100		78,000	25,000	4,000	8,000	17,000	39,000	82,000
Seymour	*Ricker-cyc*	3,100	300		131,000	27,000	7,000	12,000	21,000	36,000	58,000
Misc (EShu & Taseko) [e]	*RS (Sc/Se)+RS(Chilko)*	1,500	500		NA	NA	2,000	4,000	13,000	18,000	20,000
Misc (Chilliwack) [f]	*RS (Esum)*	2,400	19,700		NA	NA	15,000	31,000	57,000	103,000	194,000
Misc (Nahatlatch) [f]	*RS (Esum)*	400	150		NA	NA	1,000	1,000	3,000	5,000	9,000
Summer					**3,822,000**	**6,791,000**	**1,222,000**	**2,095,000**	**3,718,000**	**6,663,000**	**12,131,000**
(total excluding miscellaneous)					***3,822,000***	***6,791,000***	**1,218,000**	**2,088,000**	**3,705,000**	**6,637,000**	**12,079,000**
Chilko [g]	*Power (juv) (Pi)*	35 M	11.8 M		1,350,000	824,000	736,000	1,147,000	1,829,000	2,929,000	4,482,000
Late Stuart	*Power*	43,300	57,900		560,000	1,654,000	80,000	151,000	333,000	686,000	1,393,000
Quesnel	*Ricker-cyc*	82,800	2,500		1,358,000	3,956,000	277,000	596,000	1,218,000	2,445,000	5,188,000
Stellako	*Larkin*	15,800	73,800		462,000	245,000	91,000	131,000	192,000	291,000	423,000
Raft [h]	*Ricker (PDO)*	6,000	3,600		32,000	28,000	22,000	32,000	51,000	81,000	124,000
Harrison [h & i]	*Ricker (Ei)*	100,600	399,661		60,000	84,000	**12,000	**31,000	**82,000	**205,000	**469,000
Misc (N. Thomp. Tribs) [h & j]	*R/S (Ra/Fe)*	70	200		NA	NA	100	300	1,000	1,000	2,000
Misc (N. Thomp River) [h & j]	*R/S (Ra/Fe)*	1,700	1,000		NA	NA	4,000	7,000	12,000	25,000	50,000
Late					**2,960,000**	**834,000**	**167,000**	**293,000**	**583,000**	**1,133,000**	**2,126,000**
(total exlcuding miscellaneous)					***2,960,000***	***834,000***	***160,000***	***280,000***	***559,000***	***1,091,000***	***2,053,000***
Cultus [g]	*MRJ*	174,000	145,300		39,000	14,000	2,000	3,000	7,000	16,000	33,000
Late Shuswap	*Ricker-cyc*	20,200	80		2,152,000	182,000	14,000	36,000	111,000	274,000	574,000
Portage	*Larkin*	800	60		40,000	47,000	2,000	5,000	12,000	28,000	61,000
Weaver	*MRS*	12,900	600		363,000	281,000	42,000	76,000	147,000	281,000	506,000
Birkenhead	*Ricker (Ei)*	34,500	6,800		366,000	310,000	100,000	160,000	282,000	492,000	879,000
Misc. non-Shuswap [k]	*R/S (Lillooet-Harrison)*	3,700	900		NA	NA	7,000	13,000	24,000	42,000	73,000
TOTAL SOCKEYE SALMON					-	-	**1,554,000**	**2,655,000**	**4,765,000**	**8,595,000**	**15,608,000**
(TOTAL excluding miscellaneous)					***(7,571,000)***	***(8,579,000)***	***(1,529,000)***	***(2,606,000)***	***(4,668,000)***	***(8,427,000)***	***(15,312,000)***
		2011 Brood Year Fry									
TOTAL PINK SALMON	*Power (SSS)*	520 M			**12,580,000**	**12,580,000**	**4,794,000**	**6,401,000**	**8,926,000**	**12,473,000**	**17,111,000**

a. Probability that return will be at, or below, specified projection.
b. See Table 5 for model descriptions
c. Sockeye: 1953-2009 (depending on start of time series)
d. Sockeye: 1953-2009 (depending on start of time series)
e. Misc. Early Shuswap stocks use Scotch and Seymour R/EFS in forecast; Misc. Taseko uses Chilko R/EFS in forecast
f. Misc. Chilliwack & Nahatlach use Early Summer Run stocks R/EFS in forecast
g. Brood year smolts in columns C & D (not effective females)
h. Raft, Harrison, Miscellaneous North Thompson stocks moved in current forecast to Summer Run timing group due to changes in run timing of these stocks
i. Harrison are age-4 (column C) and age-3 (column D).
j. Misc. North Thompson stocks use Raft & Fennel R/EFS in forecast
k. Misc. Late Run stocks (Harrison Lake down stream migrants including Big Silver, Cogburn, etc.) use Birkenhead R/EFS in forecast

** Harrison forecasts are extremely uncertain due to age-proportion variations and brood year escapements (2009/2010) that are out of the historical data range

Definitions: BY: Brood year; BY09: brood year 2009; BY08: brood year 2008; EFS: effective female spawners; Ei (Entrance Island sea-surface-temperature); PDO (Pacific Decadal Oscillation), Pi (Pine Island sea-surface temperature).

Table 2. Four and five year old age composition (three and four year olds for Harrison) of forecasted returns for each stock at the 50% probability level. Model descriptions are presented in Table 4.

	2013 Fraser Sockeye Forecasts				
Sockeye stock/timing group	Model	FOUR YEAR OLDS 50%[a]	FIVE YEAR OLDS 50%[a]	TOTAL 50%[a]	Four Year Old Proportion
Early Stuart	*Ricker (Ei)*	**195,000**	**16,000**	**211,000**	**92%**
Early Summer		**185,000**	**68,000**	**253,000**	**73%**
Bowron	*MRS*	6,000	1,000	7,000	86%
Fennell	*Power*	7,000	2,000	9,000	78%
Gates	*Larkin*	64,000	3,000	67,000	96%
Nadina	*MRJ*	29,000	15,000	44,000	66%
Pitt	*Larkin*	13,000	2,000	15,000	87%
Scotch	*Ricker*	17,000	0	17,000	100%
Seymour	*Ricker -cyc*	20,000	1,000	21,000	95%
Misc (EShu & Taseko)	*RS*	13,000	0	13,000	100%
Misc (Chilliwack)	*RS*	14,000	43,000	57,000	25%
Misc (Nahatlatch)	*RS*	2,000	1,000	3,000	67%
Summer		**3,402,500**	**315,500**	**3,718,000**	**92%**
Chilko	*Power (juv) (Pi)*	1,695,000	134,000	1,829,000	93%
Late Stuart	*Power*	272,000	61,000	333,000	82%
Quesnel	*Ricker-cyc*	1,217,000	1,000	1,218,000	100%
Stellako	*Larkin*	90,000	102,000	192,000	47%
Raft	*Ricker (PDO)*	36,000	15,000	51,000	71%
Harrison[b]	*Ricker (Ei)*	82,000	0	82,000	100%
Misc (N. Thomp. Tribs)	*RS*	500	500	1,000	50%
Misc (N. Thomp River)	*RS*	10,000	2,000	12,000	83%
Late		**516,900**	**66,400**	**583,000**	**89%**
Cultus	*MRJ*	6,900	400	7,300	95%
Late Shuswap	*Ricker-cyc*	111,000	0	111,000	100%
Portage	*Larkin*	11,000	1,000	12,000	92%
Weaver	*MRS*	145,000	2,000	147,000	99%
Birkenhead	*Ricker (Ei)*	223,000	59,000	282,000	79%
Misc. non-Shuswap	*RS*	20,000	4,000	24,000	83%
Total		**4,299,400**	**465,900**	**4,765,000**	**90%**

a. Probability that actual return will be at or below specified run size

b. Harrison are four (in four year old columns) and three (in five year old columns) year old forecasts (although the Harrison three year old forecast is 240 fish, due to rounding 0 fish are reported here)

Table 3. Sensitivity analysis 2013 forecast, which could occur if past low stock productivities (1997-2004 brood years) have resumed. Fraser Sockeye "Recent Model Performance" forecasts for 2013 are presented by stock and timing group from the 10% to 90% probability levels (columns J to N). The selected models for each stock, as determined by assessing the jack-knife results for 1997-2004 as reported in MacDonald and Grant 2012, are presented in column B.

A	B	J	K	L	M	N
Run timing group		**Probability that Return will be at/or Below Specified Run Size [a]**				
Stocks	**Forecast Model [b]**	**10%**	**25%**	**50%**	**75%**	**90%**
Early Stuart	*KF*	**24,000**	**34,000**	**57,000**	**92,000**	**144,000**
Early Summer		**40,000**	**65,000**	**119,000**	**223,000**	**420,000**
(total excluding miscellaneous)		**31,000**	**56,000**	**110,000**	**214,000**	**411,000**
Bowron	*KF*	1,000	2,000	4,000	6,000	10,000
Fennell	*Power*	3,000	5,000	9,000	15,000	25,000
Gates	*KF*	8,000	15,000	27,000	50,000	96,000
Nadina	*MRJ*	10,000	20,000	44,000	95,000	189,000
Pitt	*KF*	1,000	1,000	3,000	7,000	15,000
Scotch	*Ricker*	500	900	2,000	4,000	9,000
Seymour	*Larkin*	7,000	12,000	21,000	37,000	67,000
Misc (Eshu & Taseko)	*RS (Sc/Se)+RS(Chilko)*	2,000	2,000	2,000	2,000	**2,000**
Misc (Chilliwack)	*RS (Esum)*	7,000	7,000	7,000	7,000	**7,000**
Misc (Nahatlatch)	*RS (Esum)*	300	300	300	300	**300**
Summer		**386,000**	**636,000**	**1,095,000**	**2,043,000**	**3,605,000**
(total excluding miscellaneous)		**384,000**	**632,000**	**1,087,000**	**2,022,000**	**3,578,000**
Chilko	*KF(juv)*	233,000	375,000	609,000	1,024,000	1,502,000
Late Stuart	*RS4yr*	15,000	39,000	114,000	333,000	873,000
Quesnel	*KF*	18,000	35,000	72,000	147,000	306,000
Stellako	*Larkin*	91,000	131,000	192,000	291,000	423,000
Raft	*Power*	15,000	24,000	37,000	57,000	89,000
Harrison	*Ricker (Ei)*	12,000	28,000	63,000	170,000	385,000
Misc (N. Thomp. Tribs)	*R/S (Ra/Fe)*	100	300	500	1,400	1,800
Misc (N. Thomp River)	*R/S (Ra/Fe)*	2,000	4,000	7,000	20,000	25,000
Late		**73,000**	**162,000**	**343,000**	**671,000**	**1,250,000**
(total exlcuding miscellaneous)		***71,000***	***154,000***	***334,000***	***656,000***	***1,231,000***
Cultus[c]	*Smolt-Jack (trunc)*	1,000	2,000	3,000	4,000	6,000
Late Shuswap	*Ricker (Pi)*	19,000	57,000	139,000	263,000	478,000
Portage	*KF*	1,000	3,000	6,000	16,000	42,000
Weaver	*MRS*	42,000	76,000	147,000	281,000	506,000
Birkenhead	*RS4yr*	8,000	16,000	39,000	92,000	199,000
Misc. non-Shuswap	*R/S (Lillooet-Harrison)*	2,000	8,000	9,000	15,000	19,000
TOTAL SOCKEYE SALMON		**523,000**	**897,000**	**1,614,000**	**3,029,000**	**5,419,000**
(TOTAL excluding miscellaneous)		***(510,000)***	***(876,000)***	***(1,588,000)***	***(2,984,000)***	***(5,364,000)***

a. Probability that return will be at, or below, specified projection.
b. See Table 5 for model descriptions
c. Cultus smolt-jack model uses a truncated post-1991 marine survival time series

Table 4. List of candidate models organized by their two broad categories (non-parametric and biological) with descriptions. Models that emphasize recent stock productivity are indicated. Models are described in detail in Appendices 1 to 3 of Grant et al. (2010). Where applicable, models use effective female spawner data (EFS) as a predictor variable unless otherwise indicated by '(juv)' or '(smolt)' next to the model (in Tables 1 to 3), where fry data or smolt data are used instead.

MODEL CATEGORY		DESCRIPTION
A. Non-Parametric Models		
R1C	(recent productivity)	Return from 4 years previous
R2C	(recent productivity)	Average return from 4 and 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	(recent productivity)	Product of average productivity from 4 years previous and brood year EFS (or juv/smolt)
RS2	(recent productivity)	Product of average productivity from 4 and 8 years previous and brood year EFS (or juv/smolt)
RS4yr	(recent productivity: *introduced in 2010*	Product of average productivity from the last 4 years and brood year EFS (or juv/smolt)
RS8yr	(recent productivity) *introduced in 2010*	Product of average productivity from the last 4 and 8 years and brood year EFS (or juv/smolt)
MRS		Product of average productivity from entire time series and brood year EFS (or juv/smolt)
RSC		Product of average cycle-line productivity (entire time-series) and brood year EFS (or juv/smolt)
RS (used for miscellaneous stocks)		Product of average productivity on time series for specified stocks and brood year EFS (or juv/smolt)
B. Biological Models		
power		Bayesian
power-cyc		Bayesian (cycle line data only)
Ricker		Bayesian
Ricker-cyc		Bayesian (cycle line data only)
Larkin		Bayesian
Kalman Filter Ricker (KF)	(recent productivity) *introduced in 2010*	Bayesian
Smolt-jack		Bayesian
C. Biological Models Covariates		(e.g. Power (FrD-mean))
FrD-mean		Mean Fraser discharge
Ei		Entrance Island spring sea-surface temperature
Pi		Pine Island spring sea-surface temperature
FrD-peak		Peak Fraser Discharge
PDO		Pacific Decadal Oscillation
SSS		Sea Surface Salinity (Race Rocks and Amphitrite Point light house stations)

Fraser Pinks

The power model with an environmental covariate (specifically, average sea-surface salinity from July to September at the Race Rocks and Amphitrite Point lighthouse stations) ranked first in a previously-run retrospective analysis of potential Fraser Pink models (DFO 2006). The 2013 Pink forecast ranges from 4,794,000 to 17,111,000 fish at the 10% to 90% probability levels (Table 1). The median (50% probability) forecast of 8,926,000 Pink Salmon is below the long-term (1959-2011) average return (12,580,000) (Table 1).

The Fraser Pink forecast originally presented at the November 2012 CSAS meeting was generated by the power model without the sea-surface salinity environmental covariate, due to the unavailability of salinity data at the time of the review. The original forecast was higher than the forecast presented in the current paper, and ranged from 6,881,000 to 27,687,000 returns at

the 10% to 90% probability levels, with a median (50% probability) forecast of 14,010,000 returns.

The 2013 Pink forecast is highly uncertain, as estimation methods for Pink recruitment have changed significantly over time. Specifically, in recent years (post-2001), recruitment is estimated using test fishery indices of abundance, rather than direct measures of escapement and catch, as was used in previous years.

Sources of Uncertainty

Considerable Sockeye mortality occurs in both the freshwater and marine environments throughout their life history from the egg stage to when the adults return to the Fraser watershed to spawn. In order to improve the predictability of Fraser Sockeye productivity (recruits-per-spawner), return forecasts have incorporated environmental variables, both quantitatively into forecast models (Grant et al. 2010; Grant and MacDonald 2012), and qualitatively into forecast advice (DFO 2009). However, to-date, the inclusion of environmental variables has not explained a significant portion of the variability in annual productivity or significantly decreased forecast uncertainty. To capture inter-annual random (stochastic) variability in Fraser Sockeye productivity, forecasts are presented as probability distributions from the 10% to 90% probability levels. Structural uncertainty in the forecast models is also explored through the comparison of stock forecasts using different top ranked models (MacDonald and Grant 2012). Despite the communication of uncertainty in the forecast process, if environmental conditions and resultant stock productivities fall outside the range of past observations, returns could fall outside the 2013 forecast distribution.

The two key stocks that account for the largest percentage of the total 2013 run size forecast are Quesnel and Chilko (at 78% of the total forecast). For Quesnel, in particular, reductions in productivity up to the 2005 brood year were possibly linked to delayed-density interactions between cycle lines (Peterman and Dorner 2012). Improvements in freshwater productivity were observed in the 2009 brood year for this stock, and the Larkin model, which considers cycle-line interactions, produced a similar forecast to the Ricker-cyc model used in the current forecast. Other model forms, such as the standard Ricker model produced lower forecasts than the model used for the current forecast.

The forecasted Harrison returns represent a small proportion of the aggregate total. However, there is considerable uncertainty in the Harrison forecast due to the exceptionally high brood escapements that fall outside the range of the historical time series. Therefore, Harrison returns have a higher likelihood of falling outside the 2013 forecast distribution, relative to other stocks.

The Pink escapement programs have progressively changed over the last two decades. Therefore, the forecast distribution for Pinks in 2013, likely underrepresents the uncertainty in this forecast.

CONCLUSIONS

- The average return on the 2013 cycle is the second largest of the four cycles of Fraser River Sockeye. However, the brood year escapement for 2013 returns was the lowest on this cycle since 1977, contributing to a largely below average Fraser Sockeye forecast.
- For the 2013 forecast there is a one in 10 chance (10% probability) that the total Fraser Sockeye return will be at or below 1,554,000, and a nine in 10 chance (90% probability) it will be at or below 15,608,000, assuming stock productivity is similar to past observations. The mid-point of this distribution (50% probability) is 4,765,000 (there exists a one in two chance the return will be above or below this value). The 2013 forecast is larger than the 2012 forecast, attributed to higher escapements in the 2009 brood year than in 2008.

- Given the below average brood year escapements for a large number of stocks, there is a three in four chance the 2013 return will fall below the cycle average, assuming stock productivity is similar to past observations. There is only a one in four chance returns will be above the cycle average. If low productivity resumes, the return could be particularly small.
- The brood escapement for Harrison Sockeye was substantially greater than those experienced historically. Therefore, forecast models are extrapolating well beyond the observed forecast range and are subject to particularly high uncertainty. For this stock in particular, returns have a higher likelihood of falling outside the 2013 forecast distribution.
- The total four year old proportion of the 2013 forecast (~90% of the total four plus five year old forecast at the 50% probability level) ranges from 13% to 100% depending on the stock.
- While it varies by stock, productivity has improved for the aggregate. Information on individual stock productivity for recent years is currently unavailable. Given the lack of leading indicators of Fraser Sockeye productivity, future stock productivities are highly uncertain.
- For Fraser Pink Salmon, the forecast ranges from 4,794,000 to 17,111,000 fish at the 10% to 90% probability levels (Table 1). The median (50% probability) forecast of 8,926,000 Pink Salmon is below the long-term (1959-2011) average return (12,580,000). Fraser Pink forecasts are highly uncertain given the temporal changes to the adult estimation methods.

SOURCES OF INFORMATION

This Science Advisory Report has resulted from a Fisheries and Oceans Canada, Canadian Science Advisory Secretariat, Regional Peer Review Meeting on Nov. 13-15, 2012 on the Pre-season abundance forecast for Fraser River Sockeye and Pink Salmon returns in 2013; and Assessment of mark selective fisheries and enhancement strategies for Strait of Georgia Coho Salmon. Additional publications from this process will be posted as they become available on the Fisheries and Oceans Canada Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

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