The Cohen Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River

February 2011

TECHNICAL REPORT 7

Fraser River Sockeye Fisheries and Fisheries Management and Comparison with Bristol Bay Sockeye Fisheries

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Preface

Fraser River sockeye salmon are vitally important for Canadians. Aboriginal and non-Aboriginal communities depend on sockeye for their food, social, and ceremonial purposes; recreational pursuits; and livelihood needs. They are key components of freshwater and marine aquatic ecosystems. Events over the past century have shown that the Fraser sockeye resource is fragile and vulnerable to human impacts such as rock slides, industrial activities, climatic change, fisheries policies and fishing. Fraser sockeye are also subject to natural environmental variations and population cycles that strongly influence survival and production.

In 2009, the decline of sockeye salmon stocks in the Fraser River in British Columbia led to the closure of the fishery for the third consecutive year, despite favourable pre-season estimates of the number of sockeye salmon expected to return to the river. The 2009 return marked a steady decline that could be traced back two decades. In November 2009, the Governor General in Council appointed Justice Bruce Cohen as a Commissioner under Part I of the *Inquiries Act* to investigate this decline of sockeye salmon in the Fraser River. Although the two-decade decline in Fraser sockeye stocks has been steady and profound, in 2010 Fraser sockeye experienced an extraordinary rebound, demonstrating their capacity to produce at historic levels. The extreme year-to-year variability in Fraser sockeye returns bears directly on the scientific work of the Commission.

The scientific research work of the inquiry will inform the Commissioner of the role of relevant fisheries and ecosystem factors in the Fraser sockeye decline. Twelve scientific projects were undertaken, including:

Project	
1	Diseases and parasites
2	Effects of contaminants on Fraser River sockeye salmon
3	Fraser River freshwater ecology and status of sockeye Conservation Units
4	Marine ecology
5	Impacts of salmon farms on Fraser River sockeye salmon
6	Data synthesis and cumulative impact analysis
7	Fraser River sockeye fisheries harvesting and fisheries management
8	Effects of predators on Fraser River sockeye salmon
9	Effects of climate change on Fraser River sockeye salmon
10	Fraser River sockeye production dynamics
11	Fraser River sockeye salmon – status of DFO science and management
12	Sockeye habitat analysis in the Lower Fraser River and the Strait of Georgia

Experts were engaged to undertake the projects and to analyse the contribution of their topic area to the decline in Fraser sockeye production. The researchers' draft reports were peer-reviewed and were finalized in early 2011. Reviewer comments are appended to the present report, one of the reports in the Cohen Commission Technical Report Series.

EXECUTIVE SUMMARY

1. **Catch Monitoring Programs –** The overall ratings for Fraser sockeye catch estimates were: “Good” for accuracy, “Unknown” for precision and “Medium” for reliability since 2001. The catch estimates prior to 2001 are likely to be biased low due to under-reporting of commercial catches in the sale slip system and deficiencies in catch monitoring efforts for First Nation fisheries. The limited documentation for DFO catch monitoring program, few estimates of precision and minimal verification at landing sites for most Canadian commercial fisheries (42% of the harvest) leaves substantial room for improvement in the catch monitoring programs.

2. **Non-Retention Fisheries –** Two types of non-retention fishing affect Fraser sockeye: 1) releases from freshwater recreational and selective beach seine fisheries and 2) net fallout from gillnet fisheries. Recent radio-telemetry studies have shown that survival from releases in the lower Fraser River to spawning areas were 57.0%, 52.2 % and 36.3% for releases of sockeye caught using fishwheels, beach seines and angling, respectively. The data compiled from 2005-09 provide compelling evidence that the largest en-route losses occur at times and locations where upstream-migrating sockeye are stressed by a combination of elevated water temperature, in-river gillnet fisheries, and difficult passage points. While there is little that can be done about annual water temperatures or difficult passage points, it is possible to minimize cumulative environmental effects and fishery related factors by dissociating the timing and location of in-river fisheries from these other stressors.

3. **Pre-season Forecasts –** Fraser River forecasts explained 44% of the year-to-year variation in returns between 1980 and 2009 (i.e., 56% left unexplained), and we can expect total returns in any given year to vary from total forecasts by about 25%. However, the relationship between forecasts and returns was not reliable for seven of the 18 Fraser sockeye indicator stocks. Forecasts for Bowron, Pitt, Chilko, and Stellako have been particularly poor, having explained only 8.7%, 0.4%, 9.1%, and 9.3% of return variation in the past 30 years. This is especially alarming for Chilko because this group contributes (on average) about 24% of the total Fraser return. The recognized challenges with forecasting salmon returns have led most managers to rely on in-season information to manage sockeye fisheries.

4. **In-season Forecasts –** The accuracy and precision of in-season run size estimates varies through the season and between the different run-timing groups. The bias and error rapidly improves for Early Stuart and Summer-run stocks as the run approaches the typical 50% point. The in-season forecasts for Early Summer and Late-run groups tend to be more accurate throughout their respective migration periods and precision remains at about 10-25% for most of the run. In general, in-season forecasts have been sufficiently accurate, precise, and timely to make the necessary management decisions to achieve harvest rate goals defined for each of the four run-timing groups.

5. **Escapement Enumeration –** The reliability of in-season estimates has been questioned on a number of occasions when spawning-ground surveys have estimated substantially fewer or greater numbers of sockeye than the number estimated to have passed Mission. These major discrepancies have undermined confidence in the in-season escapement estimates and have recently led to the development of alternative in-season monitoring systems such as using DIDSON hydroacoustic techniques at Mission and Qualark for fish counts and using fishwheels in the lower Fraser River to estimate species composition. Post-season escapement estimates are much more reliable than in-season estimates for Fraser sockeye. Virtually every type of enumeration method used to estimate escapement for salmon has been used or tested in the Fraser watershed for Fraser sockeye. The methods currently used are appropriate and the best of the available alternatives for Fraser sockeye.

6. **Escapement Targets –** The methods used to define escapement targets for Fraser sockeye were relatively simple from 1987-2002, more complex from 2004-2010, and are destined to become more complex in the future as Wild Salmon Policy benchmarks are identified for each sockeye Conservation Unit. The large year-to-year variability in escapement targets makes it difficult to regulate fisheries and evaluate management performance. The trend towards increasing complexity in the definition of escapement goals may have become an impediment to achieving these goals. From 2003-2006, observed escapements were substantially less than the escapement targets for three of the four run-timing groups (-42% to -54%). A detailed comparison of observed escapement with the escapement targets for each of the 19 indicator stocks was not possible because the annual targets have not been documented for each of these stocks. A clearly defined set of escapement goals for each run-timing group and indicator stock would be much easier to communicate to fishers than the current complex "Total Allowable Mortality" (TAM) rules. These escapement goals would still offer managers the latitude to

implement harvest rate ceilings to protect less productive stocks when returns of the target stocks are large.

7. **Escapements versus Minimum Escapement Goals –** Low Escapement Benchmarks (LEBs) have been defined for each Fraser sockeye indicator stock and run-timing group. These LEBs have been used in the Fraser River Sockeye Spawning Initiative and Marine Stewardship Council certification process to evaluate management options and stock status for Fraser sockeye. For most stocks, the LEBs were set equal to 40% of the 4-year average escapement that maximizes recruitment. Historical escapements for each indicator stock and run-timing group were compared with these LEBs to assess stock status and trends. For three of the four run-timing groups, escapements to spawnng areas have been consistently above the LEBs. Escapements for the fourth run-timing group (Early Stuart) fell below its LEB goal from 2005-09 but no commercial fisheries have been permitted to target early run-timing group in these years. Some harvesting of Early Stuart sockeye has been permitted in middle and upper Fraser First Nations FSC fisheries. Escapement of all summer-run stocks declined rapidly from 2003 to 2009 and most sockeye fisheries were closed from 2007-09 to maximize escapements for these stocks. Within the Early Summer and Late-run timing groups, two stocks (Bowron and Cultus) have been consistently below their LEBs in recent years.

8. **Abundance Estimates –** For most salmon stocks, total abundance is estimated by summing catch and escapement. For Fraser sockeye, en-route losses (fish not accounted for in the catch and escapement estimates) can exceed 90% of fish having entered the Fraser River. The location, timing, and magnitude of these en-route losses are critical for estimating total abundance and exploitation rates. No estimates of en-route loss are available for years prior to 1992 and this may have contributed to a negative bias in abundance and positive bias in exploitation rates (prior to 1992), if substantial en-route losses occurred but were not detected.

9. **Extent of Overharvesting –** Based on available estimates of abundance and exploitation rate, it is likely that overharvesting occurred for Early Stuart sockeye in the period 1984-2000 and for Early Summer sockeye in the period 1960-89. No evidence of overharvesting was detected for the other two run-timing groups as a whole but there is clear evidence that at least one component of the Late-run group (Cultus Lake sockeye) was overharvested during the late 1980’s and early 1990’s.

10. **Status of Cultus Sockeye –** Progress has been made on reducing the abundance of sockeye predators in Cultus Lake, reducing harvest rates on Cultus adults, and increasing smolt production through hatchery supplementation efforts, yet such efforts have not resulted in meeting any of the defined conservation objectives for the population. Given the current uncertainty associated with the outcomes of various conservation actions for Cultus sockeye, past and present recovery efforts should be considered "experimental" and thus require ongoing and rigorous monitoring programs.

11. **Bristol Bay –** There are substantial differences between the Fraser River and Bristol Bay fisheries that make many of the approaches used in Bristol Bay inappropriate for Fraser sockeye stocks and fisheries. One aspect of the Bristol Bay fisheries that should be considered seriously for application to the Fraser is the clarity and priority associated with their escapement goals. A clearly defined set of escapement goals for Fraser sockeye would not guarantee success but is one way that the management of stocks could be made simpler and increase the potential for achieving these escapement goals.

12. **State of the Science –** The scientific methods used to prepare pre-season forecasts, monitor catch and escapement, estimate returning abundance during the fishing season and determine the annual returns for each of the major sockeye stocks are consistent with the best practices for salmon fisheries. DFO and PSC have maintained a time series of abundance estimates available for these 19 indicator stocks dating back to 1952. These estimates are widely considered to be some of the best available for sockeye salmon stocks. However, the future of this valuable time series and the conversion of historical and future data into catch, escapement and total abundance estimates for each CU will depend heavily on the resources available to support critical monitoring programs, capture these data in structured databases and complete the necessary analyses.

13. **Recommendations –** The final section of our report provides recommendations which address important data gaps and known deficiencies in the fisheries management system.

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INTRODUCTION

Background

The Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River (www.cohencommission.ca) was established to investigate and report on the reasons for the decline and the long term prospects for Fraser River sockeye stocks and to determine whether changes need to be made to fisheries management policies, practices, and procedures.

In September 2010, LGL Limited was contracted to investigate sockeye fisheries harvesting and fisheries management with a view towards informing the Commission about their role in the reduction in Fraser sockeye productivity, and particularly the collapse of the 2009 sockeye return.

In October 2010, our contract was amended to include the compilation of information related to the Bristol Bay, Alaska sockeye fishery and a comparison of the sockeye harvesting practices and fisheries management in the Fraser River and Bristol Bay fisheries.

Objectives

The combined objectives for Fraser and Bristol Bay components of the project were:

- To prepare a review of fisheries for Fraser sockeye including First Nations, commercial, and recreational fisheries.
- To undertake a functional description of fisheries management for Fraser River sockeye.
- To discuss and develop conclusions about the differences and similarities in sockeye fisheries management practices in the Fraser River and Bristol Bay sockeye fisheries.

The "Scope of Work" defined 17 tasks for the Fraser component of the project and 8 additional tasks for the Bristol Bay component (Appendix A). As part of our review, we were asked to describe and evaluate the accuracy, precision, and reliability of methods used to (1) estimate catch for each fishery sector, (2) derive pre-season forecasts of abundance, (3) assess in-season abundance, and (4) estimate escapement.

How we define accuracy, precision and reliability

Here we define accuracy and precision in the context of quantitative assessments (e.g., pre-season and in-season forecast estimates, some catch and escapement estimates) and for distinguishing between evaluations of methods and evaluations of estimates. When someone asks if a catch estimate is accurate they usually want to know whether the estimate is close to the "actual" number of fish caught. In most instances, the "actual" catch is unknown, so it is not possible to determine the accuracy of the estimate. However, we can evaluate the methodology to determine if estimates should logically be close to the "actual" value or if these estimates are likely to be biased low (i.e., underestimate catch) or biased high (i.e., overestimate catch). A similar conundrum exists for evaluating the accuracy and precision of pre-season forecasts and total returns because accuracy and precision both assume we can compare our estimates to the actual number of sockeye that returned in a given year (i.e., the total number of fish returning to the Fraser River watershed, including all those lost to various fisheries, without sampling error or bias). For the purpose of this report:

Accuracy of the methods will be assessed by examining the type of data collected, survey design, estimation procedures, and whether the survey effort is adequate to derive an unbiased estimate.

Accuracy of the estimate (for individual years) will only be assessed for the pre-season and in-season forecasts of run size because we can use the final post-season run size estimate as the "actual" value for these evaluations.

The term "precision" is typically used by statisticians to describe the amount of variability or uncertainty associated with an estimate. Many surveys report precision as the 95% confidence intervals associated with the estimate. Although categorizing error as either precise or imprecise is somewhat arbitrary, we can make generalizations such as imprecise surveys have wide confidence intervals (e.g., ± 70% of the estimate) and precise surveys have narrow confidence intervals (e.g., ± 10% of the estimate). We use 95% confidence intervals to describe precision associated with catch and escapement estimates (where precision values are percentages of the mean); different measures of precision are used to describe precision associated with run-size forecast estimates, as described later in the report. A 95% confidence interval means that if you conducted the survey 20 times, 19 of the survey results would be within this confidence interval. In other words, there is a 1 in 20 (5%) chance that the survey result will be outside the 95% confidence interval (e.g., the 2010 sockeye return was above the upper limit of the 95% confidence interval).

For the purpose of this report:

Precision of the methods and estimates will be assessed within years by examining the size of confidence intervals associated with the resulting estimates. Where possible, we provide the 95% confidence intervals expressed as a percentage of the estimate (e.g. ± 10%).

The term “reliability” is often used to combine both precision and accuracy. In some instances, we may not be able to quantify accuracy or precision but there may be sufficient information to indicate whether or not an estimate is reliable. For example, the catch estimates that are based on mandatory reporting in log books or at landing sites can be evaluated in terms of compliance with these mandatory reporting requirements. If most fishers report their catch and the portion of active fishers reporting is known, the estimates would be highly reliable. With regard to escapement, where the “actual” number of spawners is never known, reliability is typically used as a relative term. The most reliable estimates are those derived from counting fences or rigorous mark-recapture programs whereas unreliable estimates are derived from visual surveys where water clarity is poor or effort is insufficient to cover the spawning grounds or spawning period. For the purpose of this report:

Reliability of the methods will be qualitatively assessed on a relative basis (e.g., Method A is more reliable than Method B).

Reliability of the estimates will also be qualitatively assessed on a relative basis using available information on the application of method (e.g., we assess whether the survey effort was sufficiently large in scope to produce a reliable estimate).

Our evaluations of the pre-season and in-season run size forecasting methods used for Fraser and Bristol Bay sockeye stocks included more quantitative assessments of the accuracy, precision, and reliability of the forecasts. Additional clarification of these terms are found under the relevant headings.

FISHERIES HARVESTING

Overview of Fisheries

Fraser sockeye are harvested at numerous points along their return migration path between Alaska and spawning areas in the upper Fraser watershed (Figure 1, Figure 2). Given the diversity of Fraser sockeye stocks, virtually all of the harvests are classified as "mixed-stock" fisheries.

Table 1 provides the annual estimates of the number of Fraser sockeye harvested by each of the three major fishing sectors in Canada (First Nations, commercial, and recreational) and two distinct fishing areas in the US (Washington and Alaska). These catch estimates were extracted from PSC annual reports because these reports are the only published source of catch estimates for Fraser sockeye. Table 2 provides a summary of our qualitative ratings for accuracy, precision, and reliability of the data used to generate the catch estimates for the majority of the sockeye harvested in each fishery. For example, if catch estimates for seines were rated "Good" and seines catch the majority of the sockeye, the overall rating will be "Good" for that fishery. A quantitative assessment of accuracy was not possible because the true catch values are not known. Similarly, there was insufficient information to quantitatively assess the precision of catch estimates. For Table 2 and other similar summary tables in the report, we used the following qualitative-rating scales for our evaluations of data quality:

- Accuracy = the degree managers can be confident that the reported catch reflects the actual harvest ("Fair" = likely biased low in some or most years; "Good" = any bias is likely to be small; "Very Good" = complete enumeration of the catch).
- Precision = generally unknown for most fisheries, estimates of precision are provided where available and where catch estimates are a complete count, the precision rating was "High").
- Reliability = the degree managers can rely on the catch estimates for in-season and post-season assessments. These ratings are similar to the ratings for accuracy except biased estimates that received a "Fair" rating for accuracy could receive a "Medium" rating for reliability if the direction of the bias is known.

Since 2001, the overall ratings for Fraser sockeye catch estimates were: "Good" for accuracy, "Unknown" for precision, and "Medium" for reliability (Table 2). The catch estimates prior to 2001 are likely to be biased low due to under-reporting of commercial catches in the sale slip system and deficiencies in catch monitoring efforts for First Nation fisheries. The limited documentation for DFO catch monitoring program, few estimates of precision, and minimal verification at landing sites for most Canadian commercial fisheries (42% of the harvest) combine to leave substantial room for improvement in the catch monitoring programs. Details regarding each of these fisheries and the rationale for our evaluations of catch estimation methods are presented in the following sections.

Table 1 Annual estimates of the harvest of Fraser sockeye by Canadian and US fisheries, 1986-2009 (extracted from PSC annual reports).

	Canadian Fisheries					US Fisheries			Test	
Year	Commercial	First Nation	Recreational	Other	Total	Alaska	Wash.	Total	Fisheries	Total
1986	8,795,000	555,000	0	14,000	9,364,000	12,000	2,733,000	2,745,000	72,000	12,181,000
1987	3,232,000	508,000	8,000	5,000	3,753,000	5,000	1,936,000	1,941,000	53,000	5,747,000
1988	1,176,000	423,000	16,000	0	1,615,000	0	679,000	679,000	50,000	2,344,000
1989	12,152,000	611,000	13,000	4,000	12,780,000	133,000	2,249,000	2,382,000	67,000	15,229,000
1990	12,458,000	923,000	31,000	26,000	13,438,000	251,000	2,157,100	2,408,100	79,000	15,925,100
1991	6,282,000	697,000	24,000	47,000	7,050,000	64,000	1,818,000	1,882,000	105,000	9,037,000
1992	3,528,000	420,000	7,000	4,000	3,959,000	83,000	609,000	692,000	20,000	4,671,000
1993	13,747,000	1,033,000	21,000	3,000	14,804,000	182,000	2,692,000	2,874,000	90,000	17,768,000
1994	10,035,000	1,111,000	14,000	24,000	11,184,000	256,000	1,828,000	2,084,000	54,000	13,322,000
1995	799,000	924,000	12,000	0	1,735,000	23,000	410,000	433,000	87,000	2,255,000
1996	955,000	754,000	15,000	78,000	1,802,000	36,000	270,000	306,000	79,000	2,187,000
1997	8,435,000	1,196,000	75,000	18,000	9,724,000	222,000	1,337,000	1,559,000	142,000	11,425,000
1998	1,278,000	844,000	18,000	99,000	2,239,000	186,000	522,000	708,000	107,000	3,054,000
1999	49,000	347,000	16,000	9,000	421,000	21,000	20,000	41,000	99,000	561,000
2000	955,000	877,000	30,000	10,000	1,872,000	2,000	494,000	496,000	95,000	2,463,000
2001	297,000	848,000	37,000	15,000	1,197,000	43,000	241,000	284,000	123,000	1,604,000
2002	2,218,000	1,155,000	128,000	116,000	3,617,000	1,000	449,000	450,000	156,000	4,223,000
2003	1,036,100	804,400	77,100	10,600	1,928,200	67,700	243,800	311,500	107,200	2,346,900
2004	1,057,700	890,500	55,100	3,500	2,006,800	63,300	195,600	258,900	73,500	2,339,200
2005	129,379	956,238	49,669	7,315	1,142,601	294,256	201,036	495,292	117,543	1,755,437
2006	3,247,000	1,145,000	171,000	8,000	4,571,000	20,000	702,000	722,000	134,000	5,427,000
2007	0	196,866	189	2,147	199,202	139,000	3,541	142,541	33,877	375,620
2008	16,215	447,277	16,469	1,171	481,132	1,552	49,587	51,139	41,324	573,595
2009	0	71,800	58	1,958	73,816	14,085	4,301	18,386	32,139	124,341
Averages										
1986-91	7,349,167	619,500	15,333	16,000	8,000,000	77,500	1,928,683	2,006,183	71,000	10,077,183
1992-00	4,420,111	834,000	23,111	27,222	5,304,444	112,333	909,111	1,021,444	85,889	6,411,778
2001-09	889,044	723,898	59,398	18,410	1,690,750	71,544	232,207	303,751	90,954	2,085,455
Percentages										
1986-91	73%	6%	0%	0%	79%	1%	19%	20%	1%	100%
1992-00	69%	13%	0%	0%	83%	2%	14%	16%	1%	100%
2001-09	42%	35%	3%	1%	81%	3%	11%	15%	4%	100%

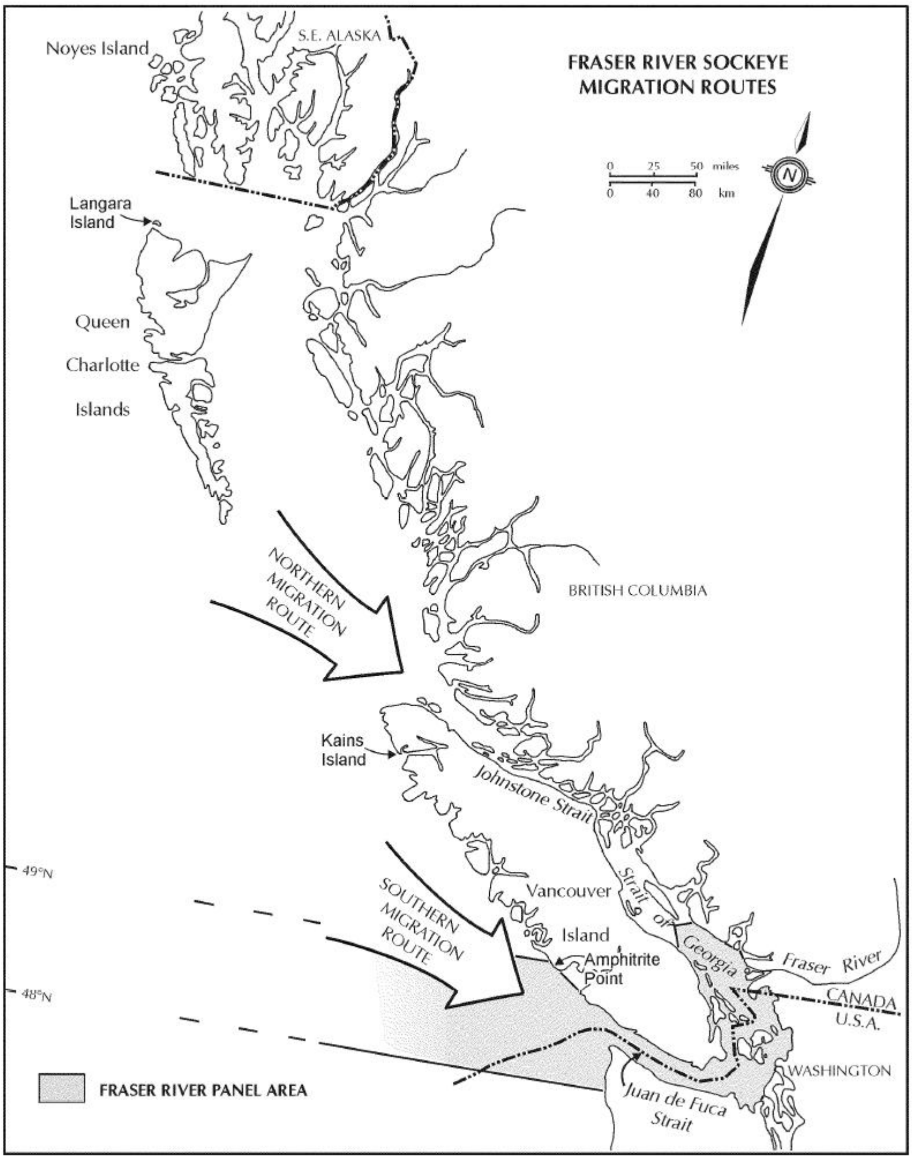


Figure 1 Fraser sockeye marine migration routes and the location of Fraser River Panel Area waters (from PSC 2008).

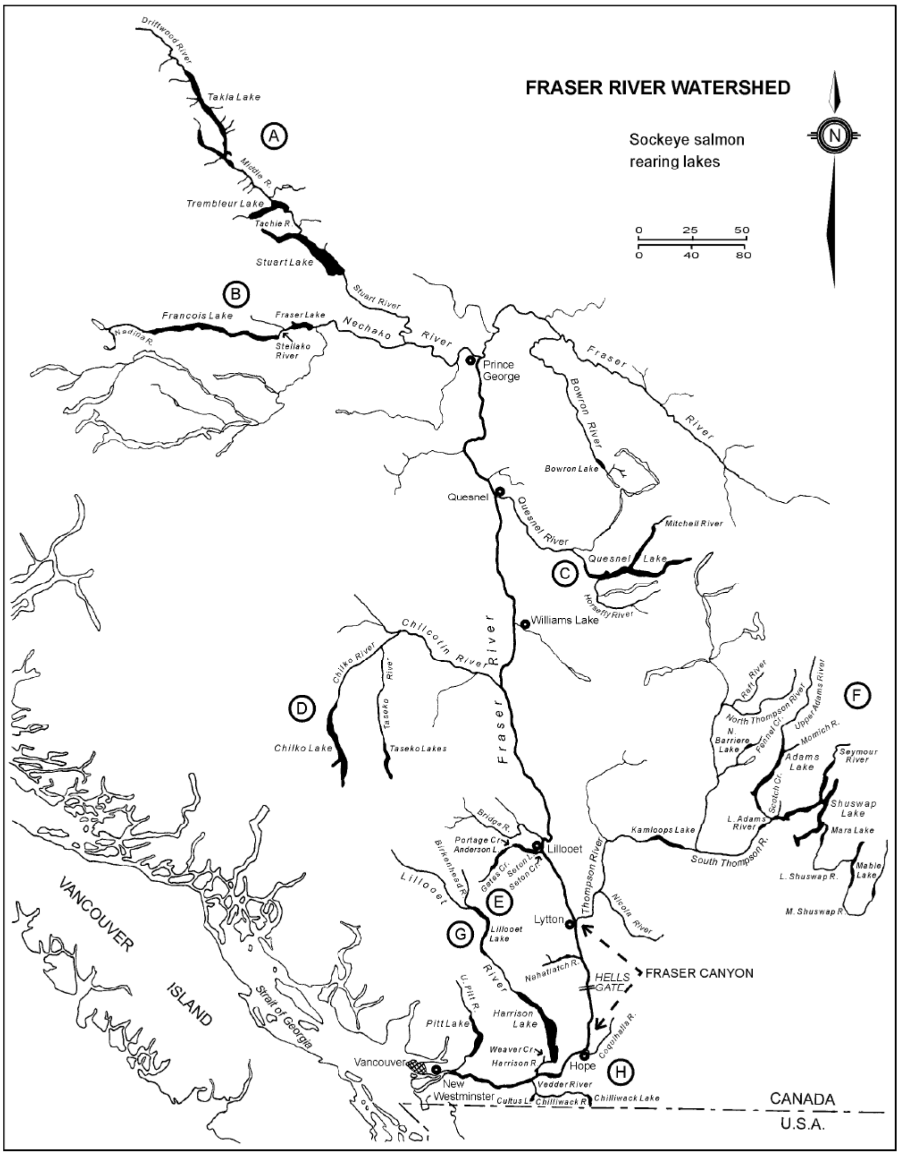


Figure 2 Sockeye spawning areas and rearing lakes in the Fraser River watershed (from PSC 2008).

Table 2 Summary of available information on accuracy, precision and reliability of the catch monitoring programs used to produce estimates of the harvest of Fraser sockeye (2001-2009).

	% of	Quality of Catch Estimates		
Location	Catch	Accuracy	Precision	Reliability
Canadian First Nations				
Food, Social, Ceremonial	29%	Good	Unknown	Medium
Economic Opportunity	6%	Good	High	Good
Canadian Commercial	42%	Fair	Unknown	Medium
Canadian Recreational	3%	Fair	NA	Medium
Canadian Selective	1%	Very Good	High	High
US (Alaska + Wash.)	15%	Very Good	High	High
Test Fisheries	4%	Very Good	High	High
Total	100%	Good	Unknown	Medium

Overview of First Nation Fisheries

Our evaluations related to commercial fisheries management address the following two tasks as defined in the Statement of Work (Appendix A):

> *3.1 The Contractor will summarize the food, social, ceremonial and commercial harvest levels of Fraser River sockeye allocated to First Nations (through treaty, fisheries agreement, communal fishing licence or other program or agreement), and the actual harvest levels achieved, according to fishing location and method, for the period 1980 - 2009. The formal and informal structure of the First Nations fishery will be characterized.*
>
> *3.2 The Contractor will describe and evaluate the accuracy, precision and reliability of methods for making catch estimates.*

The management of First Nation fisheries that target Fraser sockeye is a challenging process involving more than 72 First Nations (Figure 3). In 2009, AFS Agreements were signed with 39 groups representing most of these First Nations. In addition to these AFS Agreements, communal licences that define fishing times, locations, methods and target species are issued to each First Nation or First Nation group. On 3 April 2009, the Tsawwassen First Nation became the first group with a modern day Treaty to include a defined allocation for Fraser sockeye. Through these agreements, licences, and annual consultations with First Nations, DFO has identified sockeye "allocations" for FSC fisheries which totaled 1,029,650 in 2009. Within any given year, the number of sockeye available for harvest by Canadian First Nations depends on the abundance of Fraser sockeye and conservation concerns regarding other species.

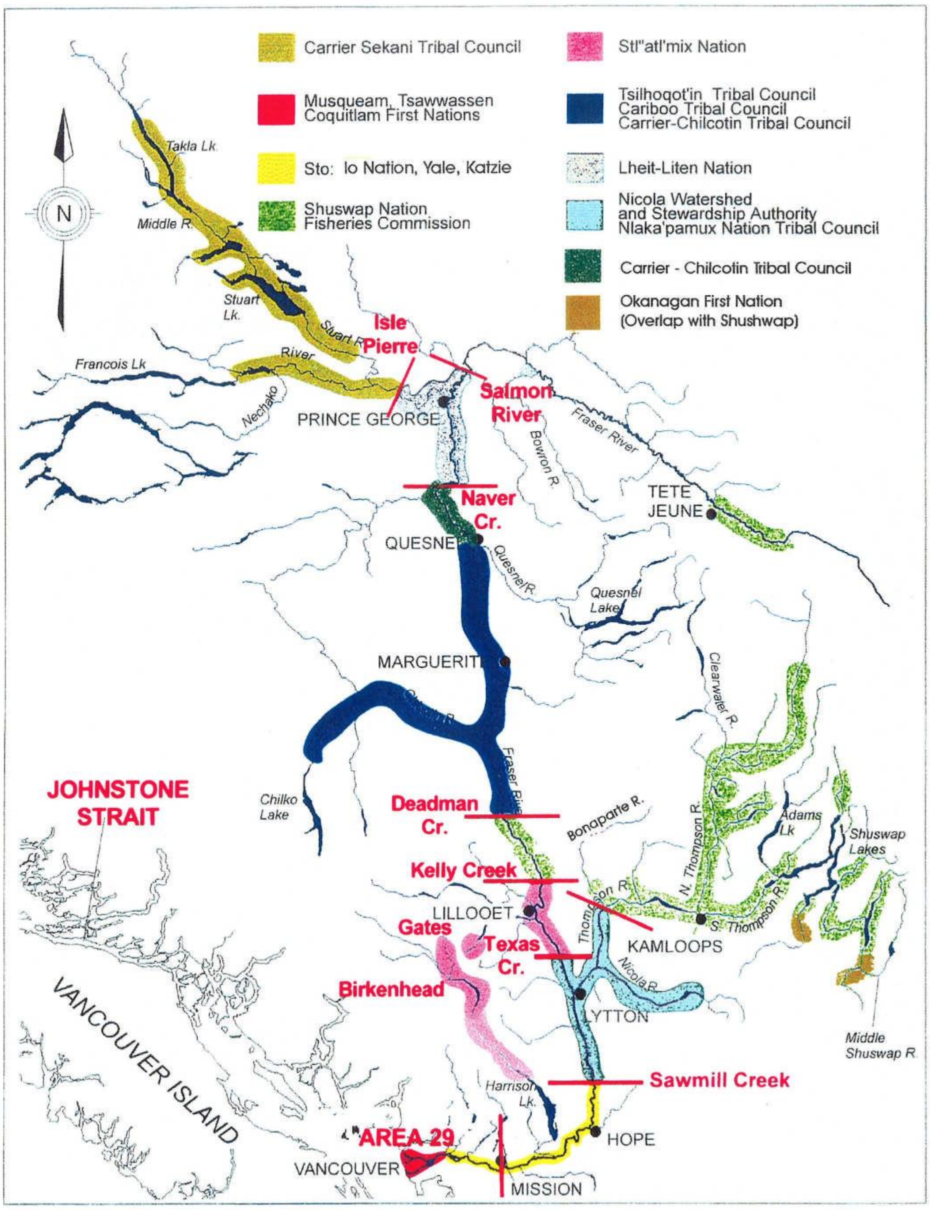


Figure 3 Geographic location and boundaries of the major Firsts Nation fisheries within the Fraser River watershed (from English et al. 2007).

Table 3 provides the annual estimates of the number of Fraser sockeye harvested in Canadian First Nation fisheries. The official estimate of the total harvest of Fraser sockeye in First Nation fisheries was extracted from PSC annual reports (e.g., PSC 2008). Additional information from DFO was used to parse the total harvest into each of the major fishery components (Ionson 2009; Bert Ionson, retired DFO Aboriginal Fisheries Program Manager, Vancouver, B.C., pers. comm.). The overall ratings for sockeye catch estimates for First Nation fisheries were: “Good” for accuracy, “Unknown” for precision and “Medium” for reliability (Table 4). Catch monitoring for First Nation fisheries was rated having higher quality than commercial fisheries because of the extensive efforts to verify effort and catch rates using independent surveys instead of reports from fishers (Alexander 2002). Regulations for mandatory landing sites for “Pilot Sales” and Economic Opportunity (EO) fisheries since 1993, and separation of FSC and EO fisheries since 2004, have substantially improved the reliability of catch estimates for EO fisheries. Details regarding each of these fisheries and the rationale for our evaluations of catch estimation methods are presented in the following sections.

Table 3 Annual estimates of the harvest of Fraser sockeye in First Nations fisheries in Canadian marine waters and the upper and lower Fraser River, 1986-2009 (extracted from PSC annual reports and DFO records).

	First Nation FSC Fisheries				First Nation EO Fisheries			
Year	Marine[1]	Fraser below Sawmill[2]	Fraser above Sawmill[3]	FSC Total[4]	Marine	Fraser below Sawmill[2]	Fraser above Sawmill	First Nation Total[1]
1986	21,000			555,000				555,000
1987	40,000			508,000				508,000
1988	7,000			423,000				423,000
1989	39,000			611,000				611,000
1990	114,000			923,000				923,000
1991	91,000			697,000				697,000
1992	52,000	5,763	53,656	111,419		308,581		420,000
1993	185,000	67,596	158,526	411,122		621,878		1,033,000
1994	183,000	30,896	328,137	542,033		568,967		1,111,000
1995	32,000	120,336	313,955	466,291		457,709		924,000
1996	76,000	12,158	218,035	306,193		447,807		754,000
1997	121,000	5,660	282,153	408,813		787,187		1,196,000
1998	200,000	366,015	204,883	770,898		73,102		844,000
1999	95,000	137,205	114,795	347,000		0		347,000
2000	91,000	422,850	340,436	854,286		22,714		877,000
2001	184,000	182,659	286,746	653,405		194,595		848,000
2002	265,000	532,013	238,716	1,035,729		119,271		1,155,000
2003	217,500	407,651	179,249	804,400		0		804,400
2004	256,200	223,912	142,573	622,685		267,815		890,500
2005	266,554	452,573	231,587	950,714		5,524		956,238
2006	298,000	166,222	224,675	688,897		456,103		1,145,000
2007	42,898	72,919	81,003	196,820		46		196,866
2008	31,861	270,817	144,599	447,277		0		447,277
2009	9,918	21,633	40,202	71,753		47		71,800
Averages								
1986-91	52,000			619,500				619,500
1992-00	115,000	129,831	223,842	468,673		365,327		834,000
2001-09	174,659	258,933	174,372	607,964		115,933		723,898
Percentages								
1986-91	8%			100%	0%	0%	0%	100%
1992-00	14%	16%	27%	56%	0%	44%	0%	100%
2001-09	24%	36%	24%	84%	0%	16%	0%	100%

[1] Estimates from annual PSC Fraser Panel Reports or databases.

[2] Estimates from DFO records (Bert Ionson, pers. comm.)

[3] Estimates derived by subtraction (FSC Total - Marine - Fraser below Sawmill)

[4] Estimates derived by subtraction (First Nation Total - First Nation Commercial)

Table 4 Summary of available information on accuracy, precision and reliability of the catch monitoring programs used to produce estimates of the harvest of Fraser sockeye for First Nations fisheries (2001-09).

Location	% of Catch	Quality of Catch Estimates		
		Accuracy	Precision	Reliability
FSC Fisheries				
Marine Fisheries	24%	Good	Unknown	Medium
Fraser - below Sawmill	36%	Good	Unknown	Medium
Fraser - above Sawmill	24%	Fair	Unknown	Medium
Economic Opportunity Fisheries[1]	16%	Good	High	Good
Total	100%	Good	Unknown	Medium

[1] ratings for 2004-09, ratings for 2001-03 would be lower for EO fisheries

First Nation FSC Fisheries

Management Structure

Since the late 1800's, when Canada asserted management control of Pacific coast fisheries, the ability of First Nations to harvest for 'food' purposes has been integral to the overall fisheries management system (Ionson 2009). The Government of Canada's current legal and policy framework identifies a special obligation to provide First Nations the opportunity to harvest fish for food, social, and ceremonial purposes. In 1992, the Aboriginal Fisheries Strategy (AFS) was implemented to address several objectives related to First Nations and their access to the resource in response to the Supreme Court of Canada decision in *R. v. Sparrow*. These included:

- improving relations with First Nations;
- providing a framework for the management of the First Nations fishery in a manner that was consistent with the 1990 Supreme Court of Canada Sparrow decision;
- greater involvement of First Nations in the management of fisheries; and
- increased participation in commercial fisheries (Allocation Transfer Program or ATP).

AFS increased resources for First Nations to pursue capacity building in areas such as stock assessment, habitat assessment and rehabilitation, catch monitoring, and enforcement. Currently, most First Nation groups in British Columbia have AFS agreements with Canada. A communal 'XSFC' license is also issued to the First Nation group to authorize fishing for domestic purposes (otherwise termed Food, Social, and Ceremonial or FSC purposes). Table 5 provides a list of those First Nation groups with signed AFS agreements, XSFC licences, and sockeye FSC allocations for 2009 (AFS agreements are identified by number in Table 5 and can be found online in the DFO WAVES library, http://inter01.dfo-mpo.gc.ca/waves2/index.html). In some cases, the AFS agreements are with a collective of First Nation groups (e.g. Nuu-Chah-Nulth Tribal Council) and others are with individual First Nations or Bands.

Collective affiliations among member nations have not always been in place since 1992. For example, in the lower Fraser River, the number of bands comprising the St:olo Nations has changed over the years. Similarly, in the marine waters, the First Nation collectives have changed over the years. Table 5 reflects the state of the First Nation organizational structure for the purposes of AFS agreements in 2009 only. DFO views these First Nation collectives as essential for practical management of the salmon fishery to avoid large numbers of in-season meetings and to have a single management regime for large areas (e.g. the lower Fraser) (Ionson 2009). Many First Nations, on the other hand, value their independent identities and have resisted joining collectives for that reason.

AFS agreements are not intended to define or extinguish Aboriginal or treaty rights and are not evidence of the nature or extent of any Aboriginal or treaty rights. AFS agreements typically include agreements with respect to cooperative fishery management, funding, catch accounting, and sometimes economic fishery opportunities. They include a detailed fishing plan that outlines the species and quantity to be fished for FSC purposes, gear to be used and areas to be fished, the disposition of the fish, licensing, designation of fishers and vessels, and the management responsibilities of the Aboriginal organization. They may or may not include agreements with respect to fishery monitoring and compliance and dispute resolution. AFS agreements often include a description of the general conditions of the communal XSFC license which is issued as a separate document to the First Nation group. Agreements also set out funding arrangements.

First Nation fishing for FSC purposes is generally permitted 365 days of the year. However, time and area closures are still used by DFO for the orderly management of the Fraser River sockeye fishery to meet escapement goals, and to meet sector and First Nation allocations. These closures are done in-season by fishery notice to the public and fishing sectors. As well, First Nation groups are invited to participate in the regular in-season update teleconference meetings held by DFO and the Pacific Salmon Commission throughout the season.

First Nations harvest Fraser sockeye for FSC purposes at numerous points along the migration path for returning adults. These include the follow major areas of fisheries:

1. Marine fisheries;
2. Fraser River fisheries below Sawmill; and
3. Fraser River fisheries above Sawmill.

The following sections describe the methods used to derive catch estimates for First Nation fisheries in each of these areas.

Table 5 AFS agreements, communal licence holders, and sockeye allocations for the B.C. South Coast and Fraser First Nations in 2009.

Area	Sub Area	AFS Agreement	Communal Licence	Licence Holder	Sockeye Allocation
BC Interior	Fraser River - Above Sawmill	CFA2009-1902	XFSC 65 2010	Carrier Sekani Tribal Council	17,500
BC Interior	Fraser River - Above Sawmill	CFA2009-1911	XFSC 66 2010	Esketemc Northern Shuswap And	75,000
BC Interior	Fraser River - Above Sawmill		XFSC 67 2010	Kluskus First Nation	1,500
BC Interior	Fraser River - Above Sawmill	CFA2009-1934	XFSC 68 2010	Lheidli T'Enneh Indian Band	7,000
BC Interior	Fraser River - Above Sawmill		XFSC 69 2010	Nadleh Whut'En Band	5,000
BC Interior	Fraser River - Above Sawmill		XFSC 70 2010	Nazko Indian Band	1,500
BC Interior	Fraser River - Above Sawmill	CFA2009-1960	XFSC 71 2010	Lhtako Dene Nation	1,500
BC Interior	Fraser River - Above Sawmill		XFSC 72 2010	Stellat'En First Nation	2,500
BC Interior	Fraser River - Above Sawmill	CFA2009-1976	XFSC 73 2010	Tl'Azt'En Nation	10,000
BC Interior	Fraser River - Above Sawmill		XFSC 74 2010	Toosey Indian Band	5,000
BC Interior	Fraser River - Above Sawmill		XFSC 75 2010	High Bar First Nation	8,000
BC Interior	Fraser River - Above Sawmill		XFSC 76 2010	Lower Nicola Indian Band	130,000
BC Interior	Fraser River - Above Sawmill		XFSC 77 2010	Nicomen Indian Band	
BC Interior	Fraser River - Above Sawmill		XFSC 78 2010	Nlaka'Pamux First Nation	
BC Interior	Fraser River - Above Sawmill	CFA2009-1945	XFSC 79 2010	Nicola Tribal Association	
BC Interior	Fraser River - Above Sawmill		XFSC 80 2010	St'At'Imc Nation	65,000
BC Interior	Fraser River - Above Sawmill		XFSC 81 2010	Whispering Pines Band	2,000
BC Interior	Fraser River - Above Sawmill	CFA2009-1987	XFSC 82 2010	Xaxli'P Band	
BC Interior	Fraser River - Above Sawmill	CFA2009-1948		Northern Shuswap TC	
BC Interior	Fraser River - Above Sawmill	CFA2009-1963		Secwepemc Nation Fisheries Commission	
BC Interior	Fraser River - Above Sawmill			Adams Lake Band	170
BC Interior	Fraser River - Above Sawmill			Bonaparte Band	115
BC Interior	Fraser River - Above Sawmill			Kamloops Band	100
BC Interior	Fraser River - Above Sawmill			Little Shuswap Band	75
BC Interior	Fraser River - Above Sawmill			Neskonnlith Band	40
BC Interior	Fraser River - Above Sawmill			Simpcw FN	230
BC Interior	Fraser River - Above Sawmill			Skeetestchen Band	330
BC Interior	Fraser River - Above Sawmill			Splatsin FN	40
Lower Fraser	Fraser River - Port Mann and Sawmill		XFSC 87 2010	Kwikwetlem First Nation	3,500
Lower Fraser	Fraser River - Port Mann and Sawmill		XFSC 92 2010	Lower Fraser River First Nation Group	300,000
Lower Fraser	Fraser River - Port Mann and Sawmill	CFA2009-1912		St:olo Nations	
Lower Fraser	Fraser River - Port Mann and Sawmill			Mount Currie	10,000
Lower Fraser	Fraser River - Port Mann and Sawmill	CFA2009-1988		Yale Band	
Lower Fraser	Fraser River - Below Port Mann		XFSC 83 2010	Tsawwassen First Nation	13,000
Lower Fraser	Fraser River - Below Port Mann	CFA2009-1978	XFSC 86 2010	Musqueam First Nation	75,000
Lower Fraser	Fraser Mouth	CFA2009-1966		Squamish	20,000
Lower Fraser	Fraser Mouth	CFA2009-1982		Tsleil-Waututh	7,000
Lower Fraser	Fraser Mouth			Hwlitsum	5,000
Lower Fraser	Fraser Mouth			Semiahmoo	3,500
South Coast	Georgia Strait Mainland	CFA2009-1930	XFSC 11 2010	Klahoose First Nation	4,000
South Coast	Georgia Strait Mainland	CFA2009-1962	XFSC 32 2010	Sechelt Indian Band	15,000
South Coast	Georgia Strait Mainland	CFA2009-1964	XFSC 33 2010	Sliammon First Nation	10,000
South Coast	Johnstone Strait		XFSC 12 2010	Johnstone Strait First Nations	80,000
South Coast	Johnstone Strait	CFA2009-1942	XFSC 14 2010	Namgis First Nation	
South Coast	Johnstone Strait	CFA2009-1959	XFSC 9 2010	Quatsino Indian Band	4,000
South Coast	Johnstone Strait	CFA2009-1900		A'Tlegay	
South Coast	Johnstone Strait	CFA2009-1909		DMT	
South Coast	Johnstone Strait	CFA2009-1917		Gwa' Sala 'Nakwaxda'xw	
South Coast	Johnstone Strait	CFA2009-1931		Kwakiutl First Nation	
South Coast	Johnstone Strait	CFA2009-1940		Musgamagwa Territorial Marine	
South Coast	South Vancouver Island	CFA2009-1921	XFSC 13 2010	Homalco Indian Band	4,000
South Coast	South Vancouver Island	CFA2009-1955	XFSC 16 2010	Pacheedaht First Nation	6,500
South Coast	South Vancouver Island	CFA2009-1972	XFSC 17 2010	T'Souke Indian Band	3,000
South Coast	South Vancouver Island		XFSC 18 2010	Beecher Bay	1,050
South Coast	South Vancouver Island		XFSC 19 2010	Esquimalt Nation	1,000
South Coast	South Vancouver Island		XFSC 20 2010	Songhees First Nation	2,100
South Coast	South Vancouver Island	CFA2009-1980	XFSC 21 2010	Tseycum First Nation	1,050
South Coast	South Vancouver Island	CFA2009-1937	XFSC 22 2010	Malahat First Nation	1,200
South Coast	South Vancouver Island	CFA2009-1908	XFSC 23 2010	Cowichan Tribes	30,000
South Coast	South Vancouver Island	CFA2009-1918	XFSC 25 2010	Halalt First Nation	3,500
South Coast	South Vancouver Island	CFA2009-1906	XFSC 26 2010	Chemainus First Nation	15,000
South Coast	South Vancouver Island	CFA2009-1957	XFSC 27 2010	Penelakut First Nation	12,000
South Coast	South Vancouver Island	CFA2009-1936	XFSC 28 2010	Lyackson First Nation	4,000
South Coast	South Vancouver Island	CFA2009-1965	XFSC 29 2010	Snuneymuxw First Nation	17,000
South Coast	South Vancouver Island	CFA2009-1943	XFSC 30 2010	Nanoose First Nation	4,500
South Coast	South Vancouver Island	CFA2009-1958	XFSC 31 2010	Qualicum First Nation	1,000
South Coast	South Vancouver Island	CFA2009-1933	XFSC 34 2010	Lake Cowichan First Nation	250
South Coast	South Vancouver Island	CFA2009-1977	XFSC 35 2010	Tsawout First Nation	4,000
South Coast	South Vancouver Island		XFSC 36 2010	Tsartlip First Nation	7,500
South Coast	South Vancouver Island		XFSC 37 2010	Pauquachin First Nation	2,000
South Coast	South Vancouver Island		XFSC 40 2010	Nuchatlaht Indian Band	
South Coast	West Coast Vancouver Island-A			Nuu-chah-nulth TC	26,400
Total					1,029,650

Catch Estimation Methods

The procedures used to monitor and estimate sockeye harvests varies among the three FSC fisheries (marine, below Sawmill and above Sawmill), and among the gear types used in each fishery. Appendix C provides a list of the First Nation Groups that conduct catch monitoring programs in each fishing area and summary information related to each fishery and catch monitoring program. Table 6 provides a summary of the data quality ratings for the catch monitoring programs and the relative magnitude of each fishery expressed as a proportion of the total First Nations' sockeye harvest during the period 1992-2000. The proportion of the First Nation catch that is not included in this table is the catch taken in "pilot sales" or "economic opportunity" fisheries conducted in the Fraser River below Sawmill Creek. Table 7 provides a similar summary for the catch monitoring programs conducted during the period 2001-2009, when FSC fisheries accounted for 84% of the sockeye harvested in First Nation fisheries.

Table 6 Summary of available information on accuracy, precision and reliability of the catch monitoring programs used to estimate the FSC harvest of Fraser sockeye, 1992-2000.

	% of	Quality of Catch Estimates		
Location	FN Catch	Accuracy	Precision	Reliability
Marine Fisheries	14%	Fair	Unknown	Low
Fraser - below Sawmill	16%	Variable[1]	Unknown	Variable[1]
Fraser - above Sawmill	27%	Fair	Unknown	Low
Total	57%	Variable[1]	Unknown	Variable[1]

[1] separation of FSC and commercial harvest not available for several years

Table 7 Summary of available information on accuracy, precision and reliability of the catch monitoring programs used to produce estimates of the FSC harvest of Fraser sockeye, 2001-09.

	% of	Quality of Catch Estimates		
Location	FN Catch	Accuracy	Precision	Reliability
Marine Fisheries	24%	Good	Unknown	Medium
Fraser - below Sawmill	36%	Good	$\pm$18% in 2001[1]	Medium
Fraser - above Sawmill	24%	Fair	$\pm$17% in 2002[1]	Medium
Total	84%	Good	Unknown	Medium

[1] likely highest precision achieved

Marine Fisheries.

The majority of the harvest of Fraser sockeye in marine FSC fisheries is taken by purse seine gear in Areas 12 and 13. DFO reports that most of the seine catch is validated by certified observers on board the fishing vessels or by monitors at the landing sites. The general approach for estimating FSC sockeye catch by seine vessels is to sum up the observed catches and report the total catch on a daily basis. Catch estimates for FSC gillnet and troll fishers are seldom verified and are thus less reliable than estimates for seine vessels. Reports of sockeye caught by gillnet and troll vessels are submitted by the First Nation Bands either weekly or monthly.

Overall, we rated the accuracy of catch estimates for marine FSC fisheries to be “Good” for seine fisheries and “Fair” for gillnet fisheries. No estimates of precision are available for any of the marine FSC catch estimates, thus the rating of “Unknown”. The overall rating for reliability was “Medium”, which reflects the combination of highly reliable catch estimates for seine harvests and the uncertainty associated with catch estimates for gillnet vessels.

Fraser River Fisheries below Sawmill.

Virtually all of the sockeye harvested in Fraser River FSC fisheries below Sawmill Creek are caught using gillnets and catch estimates are reported after each opening. Below the Mission Railway Bridge, most fishers use drift gillnets. Above Mission, fishers use both drift and set gillnets but the majority of the catch is taken using set gillnets. The quality of the catch monitoring programs in the lower Fraser River improved substantially through the 1990’s, in part because of funding through AFS programs. The implementation of the Tsawwassen First Nation Treaty in 2009 resulted in further improvements in the coverage, accuracy and reliability of the Tsawwassen catch estimates. Catch estimates for drift net fisheries conducted above Port Mann rely on reports obtained from a fixed set of landing sites. These landing sites probably capture the majority of the catch but not the entire harvest.

Detailed reviews of the methods used to estimate sockeye catch for set-net fisheries conducted between Mission and Sawmill Creek were conducted from 1998-2001 (Alexander 1998; 2000a; 2001a; 2002a). Alexander (2002a) concluded that the methods used in 2001 (a combination of net counts from aerial surveys and interviews at landing sites) were valid for estimating sockeye catches for these set net fisheries. The precision of the 2001 sockeye catch estimates was ±18% and a small to medium positive bias in the catch estimates was detected using simulation analyses. The reliability of the annual sockeye catch estimate depends on survey effort and coverage during the periods when fishers target sockeye. Table 8 summarizes the proportions of observed fishing effort (set nets counted during aerial surveys) covered by interviews at landing sites. For most week-area strata, interviews account for 30-50% of the total number of set gillnets observations.

Table 8 Interview coverage of the Mission-Sawmill set net fishery expressed as a percentage of the total set nets counted during aerial surveys in each fishing area in each week, 2007-2010 (Matthew Parslow, DFO Annacis, pers. comm.).

Year	Week	Mission to Harrison River	Harrison River to Laidlaw	Laidlaw to Hope bridge	Hope bridge to Yale beach	Yale Beach to Sawmill Creek
2007	30	32%	40%	49%	33%	41%
	31	69%	6%	22%	44%	17%
	32	52%	11%	42%	53%	53%
	34	50%	13%	46%	41%	45%
2008	29	58%	31%	36%	42%	39%
	30	64%	23%	44%	49%	45%
	31	56%	15%	38%	54%	49%
	32	68%	32%	43%	53%	59%
	33	57%	19%	48%	26%	36%
	34	53%	24%	50%	42%	42%
	35	33%	13%	36%	36%	23%
2009	29	43%	27%	43%	54%	30%
2010	26	15%	26%	27%	31%	40%
	31	37%	20%	31%	56%	40%
	32	32%	23%	46%	57%	28%
	33	40%	21%	34%	39%	53%
Average		47%	22%	40%	44%	40%

Overall, we rated the accuracy of catch estimates for Fraser River FSC fisheries below Sawmill to be “Good”. Estimates of precision are limited to a few years but those that are available indicate an adequate level of precision. The overall rating for reliability was “Medium” because of the intensive monitoring of the Mission-Sawmill set gillnet fishery, which accounts for the majority of the harvest, offset by the uncertainty associated with growing drift gillnet effort in the fishing areas between Mission and Hope.

Fraser River Fisheries above Sawmill.

Sockeye harvested in Fraser River FSC fisheries above Sawmill Creek are caught using a wide variety of gear types and are reported weekly. Appendix C summarizes information on the fisheries and catch monitoring programs conducted by each of the six First Nation Groups for FSC fisheries above Sawmill Creek. The standard method for monitoring Fraser River mainstem fisheries between Sawmill and Deadman Creek is to count set gillnet and dip net fishers using helicopter surveys and obtain catch rate information from interviews at landing sites.

Detailed reviews of the methods used to estimate sockeye catch for set net fisheries conducted above Sawmill Creek were conducted from 1998-2002 (Alexander 1999; 2000b; 2001b; 2002b; 2003). Alexander (2003) concluded that the methods used in 2002 (a combination of net counts from vehicle, boat and aerial surveys and interviews conducted at landing sites) were valid for estimating sockeye catches for these fisheries. The precision of the 2002 sockeye catch estimate was ±17%, but this value likely underestimates the true level of uncertainty associated with these catch estimates. Alexander (2003) identified concerns related to reductions in survey effort that affected the precision and reliability of the weekly catch estimates. The following minimum sample sizes were recommended for each sub-region by week, assuming 7-day openings:

- 30 catch interviews;
- 4 effort counts using aerial- or boat-based surveys; and
- 6 samples of 24-hour effort profiles.

The reliability of the annual sockeye catch estimates depend on survey effort and coverage during the periods when fishers target sockeye. In general, survey effort has been extensive and provided complete coverage of the sockeye fishing periods each year. Table 9 summarizes the DFO and First Nation annual catch monitoring effort for First Nation fisheries above Sawmill Creek (1996-2009). Further details on weekly survey efforts in 2005 and 2006 are in Appendix C. 2005 and 2006 were selected because they represent the two most recent years with substantial sockeye fisheries prior to 2010. For most week-area strata, survey effort has exceeded the minimum target levels identified in Alexander (2002).

Overall, we rated the accuracy of catch estimates for Fraser River FSC fisheries above Sawmill to be “Good” due to the substantial amount of effort in most years. Estimates of precision are limited to a few years but those that are available indicate an adequate level of precision. The overall rating for reliability was “Medium” because of the generally complete coverage of the sockeye fishery and the magnitude of the underestimation biases in the catch estimates is likely to be small.

Table 9 Annual catch monitoring effort for First Nation FSC fisheries above Sawmill Creek, 1996-2010 (Jamie Scroggie, DFO Kamloops, pers. comm.).

Year	Helicopter Overflight	Boat Patrol[1]	24-Hour Effort Surveys	16-Hour Effort Surveys	Interviews	Vehicle Patrols[1]	Foot Patrols
1996	39	43	53	0	1350	120	90
1997	37	37	97	0	2412	6	11
1998	35	14	56	0	1819	1	13
1999	na	1	30	0	769	57	51
2000	80	25	92	0	1690	138	0
2001	41	42	107	0	1558	104	140
2002	7	28	78	0	1345	45	105
2003	0	31	69	0	1203	93	50
2004	0	33	0	78	1483	64	62
2005	28	35	51	102	2022	101	268
2006	27	23	110	88	2713	196	140
2007	21	20	48	39	1152	191	122
2008	26	30	63	123	1799	195	148
2009	21	20	37	37	611	195	114
2010	30	43	90	68	1855	142	155
Average							
1996-00	48	24	66	0	1608	64	33
2001-10	20	31	65	53	1574	133	130

[1] Boat and vehicle patrols include those conducted by DFO and local First Nations

First Nations Economic Opportunity Fisheries

Management Structure

Ionson (2009) compiled a brief history of the “Pilot Sales” and “Economic Opportunity” fisheries that have been negotiated with lower Fraser River First Nations since 1992. The following timeline, extracted from Ionson (2009), provides the sequence of events associated with the definition of commercial allocations and catch monitoring procedures related to these fisheries:

1992 – DFO and Lower Fraser First Nations negotiate the first AFS agreements, which include provisions for Pilot Sales fisheries. The opportunity to sell harvested fish resulted in a significant increase in fishing effort. In the area from Port Mann Bridge to Sawmill Creek, the weekly gear count increased from 391 to 724.

1993 – Mandatory landing sites are established to improve catch estimates for Pilot Sales fisheries.

1994 – Two agreements are negotiated that included Pilot Sales; one for the mouth to Port Mann area (Musqueam, Tsawwassen, Burrard and Coquitlam) and one for the area from Port Mann to Sawmill Creek.

1995 – "Musqueam, Tsawwassen and Burrard Bands enter a 3-year agreement with provisions made to negotiate changes as necessary to the schedules to the agreements (i.e., allocations, funding arrangements). Negotiations with Sto:lo resulted in an agreement to that of the previous year except provisions were made to increase the sockeye allocation by 30,000 pieces in the event the run size exceeded 13.5 million."

1996 – "The approach to allocation was changed. In order to avoid concerns related to a run size greater than forecast (like in 1993) or less than forecast (like 1995), the idea of a "Base plus percent" was introduced with the idea that at very low run sizes (and subject to conservation requirements), a base amount would be available for food, social and ceremonial purposes but if run sizes increased and commercial fisheries were permitted, the allocation would be increased and sales would be permitted. In 1996, agreements provided for sales on the condition that a directed Canadian commercial fishery is conducted for that species of Fraser River salmon."

1997 – Agreements are reached with some groups but not others. However, Bands that did not sign agreements were licenced to fish in the same times and areas as "agreement" groups and catch estimates were aggregated for both agreement and non-agreement groups. "It should be noted that it is felt that most of the catches were accounted for as many of the members of communities who did not sign the agreement continued to use designation cards issued in previous years and sold fish at established landing sites."

1998-00 – No agreements with Sto:lo groups because the threshold number of signatories was not achieved. Annual funding was provided to support participation in consultations and catch monitoring activities.

2001-02 – Separate agreements were established with Musqueam and Tsawwassen, which defined a single sockeye allocation where sale was authorized "once a commercial TAC was identified and a commercial fishery was held on that stock of Fraser salmon." A sufficient number of Sto:lo communities were willing to engage in an agreement that provided for sale of sockeye in 2001 but not in 2002.

2003 – Provincial Court Justice Kitchen ruled the Minister did not have the authority to limit commercial sales to First Nations and deemed the Pilot Sales arrangements to be invalid (*R. v. Kapp*. 2003). Consequently, only FSC fisheries were permitted in 2003.

2004 – The Provincial Court decision in *R. v. Kapp* was overturned in 2004 by the Appeal Court of B.C. and Economic Opportunity fisheries were restarted with modifications to address some of the criticisms. There was a requirement for clear separation of the FSC allocation from the commercial portion of the allocation. There was some year-to-year, pre-season flexibility for the FSC/Commercial split, usually ranging from 50/50 to 25/75; however, once the split was set, there was no flexibility to further modify it in-season. As in previous years, Economic Opportunities for First Nations were tied to a commercial fishery being conducted on that stock.

2004-07 – Separate agreements, including sockeye allocations, were negotiated with Musqueam, Tsawwassen and Sto:lo groups in 2004, 2005 and 2006. Sockeye allocations were defined for Musqueam and Tsawwassen in 2007 but not for Sto:lo.

2008 – No agreements were negotiated with any lower Fraser First Nations regarding sockeye allocations.

Most recently, as part of the reform of Pacific fisheries and the implementation of the Pacific Integrated Commercial Fisheries Initiative (PICFI), which was announced in 2007, DFO has been seeking to increase First Nation participation in economic fisheries through an interest-driven business planning process. This process includes the potential for providing First Nations with access to additional commercial licences for a wide variety of species.

Catch Estimation Methods

The catch monitoring system for lower Fraser Pilot Sales or Economic Opportunity fisheries has included "mandatory landing sites" since 1993. Under this requirement, all fish landed for sale must be enumerated at one of the designated landing sites. Prior to the separation of FSC and commercial fishing days in 2004, there was greater potential for missing a portion of the First Nation commercial catch because there were no requirements for enumeration of FSC fish at landing sites. The separation of the FSC and sale fisheries has made it easier to monitor catch and enforce landing requirements for sale fisheries. Consequently, our ratings for the accuracy, precision and reliability of the catch estimates for First Nation commercial sockeye fisheries are substantially higher for recent years (2004-2009) than earlier years (Table 10).

Table 10 Summary of available information on accuracy, precision and reliability of the catch monitoring programs used to estimate the harvest of Fraser sockeye in First Nation Pilot Sales and Economic Opportunity fisheries during three periods.

	% of	Quality of Catch Estimates		
Location	FN Catch	Accuracy	Precision	Reliability
Pre-AFS (1980-91)	?	Unknown	Unknown	Low
Early AFS (1992-03)	35%	Variable[1]	Unknown	Variable[1]
Recent AFS (2004-09)	20%	Good	High	Good

[1] separation of FSC and commercial harvest not available for several years

First Nation Harvests and Allocations for Fraser Sockeye

Comparisons of annual catch estimates with First Nation allocations were only possible for Fraser River fisheries below Sawmill Creek using the information provided by DFO (Ionson 2009). These comparisons were further limited to years when there were negotiated agreements with lower Fraser First Nations and thus defined allocations for these Fraser sockeye fisheries. Table 11 provides the available information on sockeye allocations and harvests for Musqueam and Tsawwassen First Nations, and Table 12 provides similar information of the First Nations included in the Sto:lo Group from the initiation of the AFS Agreements in 1992 through 2008. Total sockeye catches have been close to or less than the defined allocations for these lower Fraser First Nations in most years. The only notable exception is the 2006 Sto:lo harvest that exceeded the defined allocation by approximately 72,000 sockeye. The primary reason for the differences between allocations and final catch estimates is uncertainty in the in-season estimates of the total allowable catch.

Table 11 and Table 12 also provide several examples of the uncertainty associated with the split between FSC and Pilot Sales fisheries for years before 1998. For example, the very low FSC catches for Tsawwassen and Musqueam in 1993, 1994, 1996 and 1997, and the low FSC reports for the Sto:lo Group in 1995-1997, are not realistic. In each of these years, some of the sockeye caught in sales fisheries were likely used for FSC purposes. In all years with Sto:lo Agreements after 1992, the defined sockeye allocations (averaging 497,000) were substantially higher than the reported catches for most years without Agreements (averaging 246,000). However, the reported FSC harvests for years without Sto:lo Agreements tend to be larger than the reported FSC harvests for years with Agreements. If we exclude the years prior to 1998 when FSC catch was likely under-reported, the average FSC catch in years without Agreements (246,000) was 1.3-fold larger than the average of the reported FSC catches for years with Agreements (188,000).

Table 11 Comparison of annual sockeye allocations and catch estimates for Musqueam and Tsawwassen First Nations, 1992-2008.

		Allocation			Catch			Difference
Year	Groups	FSC	Sales	Total	FSC	Sales	Total	(Catch-Alloc)
1992	Musqueam/Tsawwassen			70,000			64,101	-5,899
1993	Musqueam/Tsawwassen			109,873	3,249	136,062	139,311	29,438
1994	Musqueam/Tsawwassen			140,000	915	140,284	141,199	1,199
1995	Musqueam/Tsawwassen			140,000	115,673	16,041	131,714	-8,286
1996	Musqueam/Tsawwassen			107,718	480	93,611	94,091	-13,627
1997	Musqueam/Tsawwassen			185,000		197,680	197,680	12,680
1998	Musqueam/ Tsawwassen			70,000	28,512	73,102	101,614	31,614
1999	Musqueam/ Tsawwassen			70,000	26,189		26,189	-43,811
2000	Musqueam/ Tsawwassen[1]		19,558		77,666	22,714	100,380	
Average				111,574	36,098	97,071	110,698	414
2001	Musqueam			73,959	26,595	43,072	69,667	-4,292
2002	Musqueam			87,802	2,117	89,026	91,143	3,341
2003	Musqueam	No agreement						
2004	Musqueam	37,500	90,891	128,391	35,854	45,138	80,992	-47,399
2005	Musqueam	22,500	110,473	132,973	61,858	0	61,858	-71,115
2006	Musqueam	18,750	81,829	100,579	18,754	86,666	105,420	4,841
2007	Musqueam	60,000		60,000	8,786	0	8,786	-51,214
2008	Musqueam	No agreement			31,304	0	31,304	
Average				97,284	26,467	37,700	64,167	-27,640
2001	Tsawwassen			24,653	2,436	27,121	29,557	4,904
2002	Tsawwassen			29,267	1,268	30,245	31,513	2,246
2003	Tsawwassen	No agreement						
2004	Tsawwassen	12,500	30,732	43,232	13,573	15,396	28,969	-14,263
2005	Tsawwassen	7,500	30,297	37,797	28,081	0	28,081	-9,716
2006	Tsawwassen	6,281	27,276	33,557	6,281	27,769	34,050	493
2007	Tsawwassen	20,000		20,000	4,948	0	4,948	-15,052
2008	Tsawwassen	No agreement			16,673	0	16,673	
Average				31,418	10,466	14,362	24,827	-5,231

[1] FSC Allocation defined based on fishing time in 2000.

Table 12 Comparison of annual sockeye allocations and catch estimates for First Nations included in agreements with the Sto:lo Group, 1992-2008.

Year	Groups	Allocation FSC	Allocation Sales	Allocation Total	Catch FSC	Catch Sales	Catch Total	Difference (Catch-Alloc)
1992	Sto:lo Group			325,000			244,480	-80,520
1993	Sto:lo Group			618,500	64,347	485,816	550,163	-68,337
1994	Sto:lo Group			500,000	29,981	428,683	458,664	-41,336
1995	Sto:lo Group			500,000	4,663	441,668	446,331	-53,669
1996	Sto:lo Group			390,782	11,678	354,196	365,874	-24,908
1997	Sto:lo Group			631,401	5,660	589,507	595,167	-36,234
1998	Sto:lo Group		No agreement		337,503	0	337,503	
1999	Sto:lo Group		No agreement		111,016	0	111,016	
2000	Sto:lo Group		No agreement		345,184	0	345,184	
2001	Sto:lo Group			378,610	120,655	124,402	245,057	-133,553
2002	Sto:lo Group		No agreement		410,102	0	410,102	
2003	Sto:lo Group		No agreement					
2004	Sto:lo Group	150,000	364,023	514,023	174,485	207,281	381,766	-132,257
2005	Sto:lo Group	90,000	442,920	532,920	322,464	5,520	327,984	-204,936
2006	Sto:lo Group	75,000	328,056	403,056	134,003	341,668	475,671	72,615
2007	Sto:lo Group		No agreement		59,185	46	59,231	
2008	Sto:lo Group		No agreement		215,158	0	215,158	
Average (1993-08)				496,588	156,406	198,586	354,991	-70,314
Agreement Years (1998-08)				457,152	187,902	169,718	357,620	-72,907
No Agreement Years (1998-08)					246,358	8	246,366	

Overview of Commercial Fisheries

Our evaluations related to commercial fisheries management address the following two tasks as defined in the Statement of Work:

> *3.3 The Contractor will summarize the target and achieved allocations of Fraser River sockeye to the commercial sector, according to fishing method (troll, seine, and gillnet), for the last 30 years.*
>
> *3.4 The Contractor will describe and evaluate the accuracy, precision and reliability of methods for making catch estimates.*

Table 13 summarizes the annual number of Fraser sockeye harvested in Canadian fisheries inside and outside of the Fraser Panel Area waters for the period 1986-2009.

Annual harvest estimates in U.S. fisheries are in Table 1. The geographic distribution of Canadian harvests of Fraser sockeye has changed substantially over the past 30 years. Harvests in Area 20 represented 24% of the Canadian catch from 1986-1991 compared to only 4% since 2001. Harvests of Fraser sockeye in Areas 11-16 have increased from 32% to over 60% from pre- to post-1991 periods. The overall ratings for commercial fishery catch estimates were "Fair" for accuracy, "Unknown" for precision and "Medium" for reliability (Table 14). Bijsterveld et al. (2002) and DFO (2009) have documented inaccuracies associated with the estimates of sockeye catch from sale slip data prior to 2004. One of the products from the detailed review of the 1996-2004 catch estimates (DFO 2009) was the replacement of catch estimates for these years with those derived from non-sale slip systems. Consequently, sale slip data has not been the primary source of catch estimates for Fraser sockeye since 1995. As indicated above, the limited documentation of catch monitoring methods, few estimates of precision and minimal verification at landing sites leaves substantial room for improvement in most of the catch monitoring programs for Fraser sockeye fisheries. This is especially true for Canadian commercial fisheries. Catch estimates for U.S. fisheries are derived from a "Fish Ticket" system that is believed to provide a complete census of the salmon harvested in Alaskan and Washington State commercial fisheries. Details regarding each of these fisheries and the rationale for our evaluations of catch estimation methods are presented in the following sections.

Table 13 Annual estimates of the harvest of Fraser sockeye by Canadian fisheries inside and outside of the Fraser Panel Area waters, 1986-2009 (extracted from PSC annual reports).

	Fraser River Panel Area					Non-Panel Areas					
Year	Areas 121-124 Troll	Area 20 Net	Areas 17-18 and 29 Troll	Area 29 Net	Total	Areas 1-10 Troll and Net	Areas 11-16 Troll and Net	Areas 124-127 Troll[1]	Total	Selective Fisheries	Total
1986	206,000	2,003,000	209,000	2,535,000	4,953,000	37,000	2,195,000	1,610,000	3,842,000	0	8,795,000
1987	208,000	463,000	33,000	600,000	1,304,000	79,000	1,572,000	277,000	1,928,000	0	3,232,000
1988	16,000	219,000	77,000	682,000	994,000	2,000	148,000	32,000	182,000	0	1,176,000
1989	463,000	3,286,000	65,000	2,420,000	6,234,000	350,000	4,984,000	584,000	5,918,000	0	12,152,000
1990	312,000	3,379,000	324,000	3,032,000	7,047,000	1,079,000	2,738,000	1,594,000	5,411,000	0	12,458,000
1991	275,000	1,278,000	124,000	811,000	2,488,000	257,000	2,420,000	1,117,000	3,794,000	0	6,282,000
1992	103,000	880,000	4,000	257,000	1,244,000	169,000	2,049,000	66,000	2,284,000	0	3,528,000
1993	148,000	460,000	137,000	2,630,000	3,375,000	1,211,000	8,684,000	477,000	10,372,000	0	13,747,000
1994	233,000	846,000	352,000	1,298,000	2,729,000	1,145,000	6,042,000	119,000	7,306,000	0	10,035,000
1995	9,000	61,000	1,000	186,000	257,000	43,000	476,000	23,000	542,000	0	799,000
1996	1,000	69,000	4,000	708,000	782,000	0	173,000	0	173,000	0	955,000
1997	0	259,000	19,000	1,315,000	1,593,000	434,000	6,408,000	0	6,842,000	0	8,435,000
1998	0	0	15,000	268,000	283,000	93,000	902,000	0	995,000	0	1,278,000
1999	0	0	0	1,000	1,000		47,000	1,000	48,000	0	49,000
2000	0	0	4,000	418,000	422,000	0	532,000	1,000	533,000	0	955,000
2001	16,000	46,000	25,000	12,000	99,000	0	163,000	0	163,000	35,000	297,000
2002	111,000	226,000	17,000	950,000	1,304,000	0	796,000	43,000	839,000	75,000	2,218,000
2003	0	0	0	249,000	249,000	0	737,200	0	737,200	49,900	1,036,100
2004	0	10,600	0	246,300	256,900	0	787,700	0	787,700	13,100	1,057,700
2005	0	0	0	3,375	3,375	0	126,004	0	126,004	0	129,379
2006	83,000	54,000	0	775,000	912,000	0	2,162,000	13,000	2,175,000	160,000	3,247,000
2007	0	0	0	0	0	0	0	0	0	0	0
2008	0	11,240	331	0	11,571	0	4,644	0	4,644	0	16,215
2009	0	0	0	0	0	0	0	0	0	0	0
Averages											
1986-91	246,667	1,771,333	138,667	1,680,000	3,836,667	300,667	2,342,833	869,000	3,512,500	0	7,349,167
1992-00	54,889	286,111	59,556	786,778	1,187,333	386,875	2,812,556	76,333	3,232,778	0	4,420,111
2001-09	23,333	38,649	4,703	248,408	315,094	0	530,728	6,222	536,950	37,000	889,044
Percentages											
1986-91	3%	24%	2%	23%	52%	4%	32%	12%	48%	0%	100%
1992-00	1%	6%	1%	18%	27%	9%	64%	2%	73%	0%	100%
2001-09	3%	4%	1%	28%	35%	0%	60%	1%	60%	4%	100%

Table 14 Summary of available information on accuracy, precision and reliability of the catch monitoring programs used to produce estimates of the commercial harvest of Fraser sockeye in Canadian waters (2001-2009).

Location	% of Catch	Quality of Catch Estimates		
		Accuracy	Precision	Reliability
Fraser Panel Areas				
Troll	3%	Good	Unknown	High
Seine (Area 20)	4%	Fair	Unknown	Medium
Gillnet (Area 29)	28%	Fair	Unknown	Medium
Non-Panel Area				
Troll	9%	Good	Unknown	High
Net (Area 11-16)	52%	Fair	Unknown	Medium
Selective Fisheries	4%	Very Good	High	High
Total	100%	Fair	Unknown	Medium

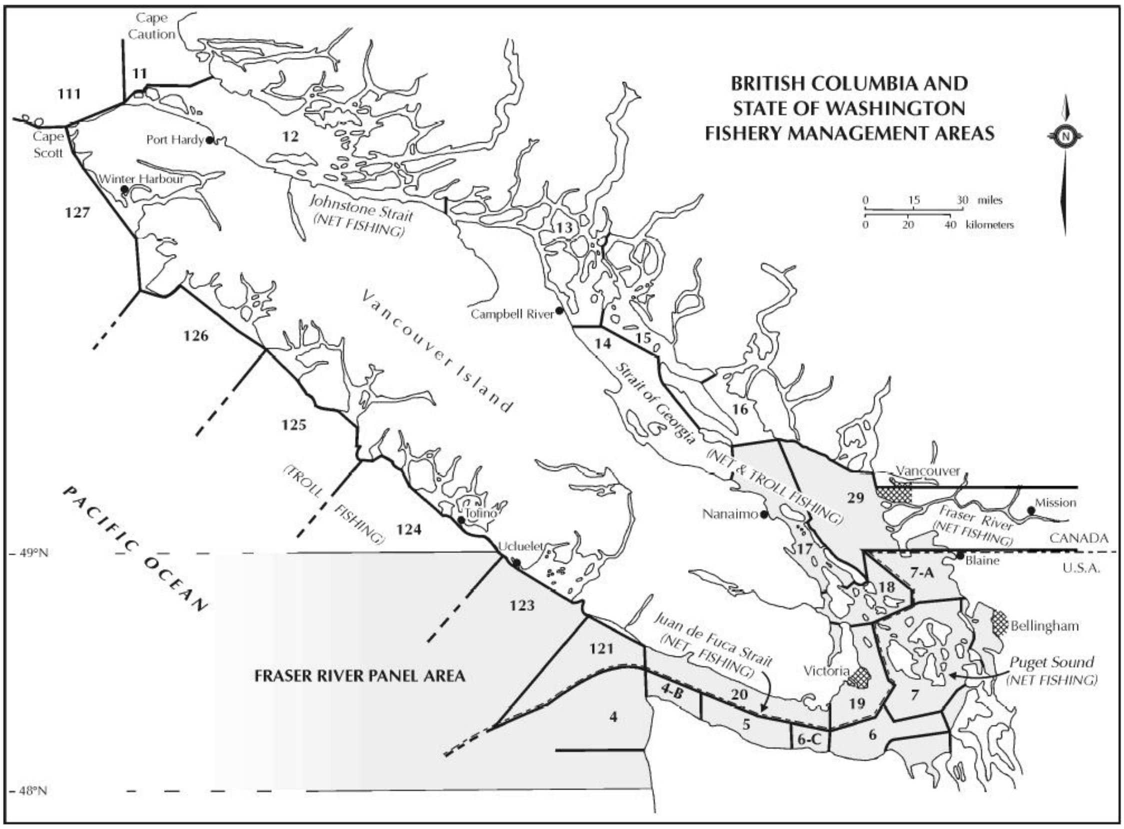


Figure 4 Fishery management areas and commercial gear types used in the Fraser River Panel Area and Canadian south coast waters (from PSC 2008).

Canadian Commercial Fisheries

The procedures used to derive in-season and post-season catch estimates have evolved considerably over the past 30 years and vary by gear type. Prior to 1998, in-season catch estimates were derived for most commercial fisheries using fishery guardian gear counts and catch per effort estimates from hail data. Since 1998, most in-season catch estimates have been derived by combining catch per effort estimates from hails and fisher's phone-in or electronic log book reports with estimates of effort from on-water or aerial gear counts. Historically, all post-season catch estimates were derived from sale slip data, but since 1998, the final catch estimates have been derived from the FOS system, which captures information from in-season monitoring programs and reports from individual fishers. These changes resulted from concerns regarding incomplete catch reporting through the sale slip system for several fisheries. Bijsterveld et al. (2002) provides the following description of the three major catch reporting programs that have been used to derive catch estimates for Canadian commercial salmon fisheries in the Pacific region since 1951:

> ***Sales Slip Program.*** *The sales slip program was initiated in the Pacific region in 1951, and historically has been the principal official means for capturing information on commercial fish landings. Sales slips are generally completed and submitted on behalf of commercial fishermen, by commercial buyers or offloaders at the time when fish are sold. However, fishermen are responsible for ensuring that their records are complete. Current licensing conditions make it mandatory for sales slips to be completed for all fish caught, even if the fish landed are used for bait, personal consumption, public or private sale, or disposed of otherwise. In general, sales slips document the quantity (accurate weight and estimated numbers), value and species of the retained catch. Information about the sale includes: commercial buyer, purchase date, catching vessel, statistical area of catch, number of days fished, gear type, catch in numbers and weight by species and size grade, as well as the price per pound and value of the catch. The completed sales slips are forwarded to DFO regional headquarters for processing. Sales slips are a federal and provincial requirement for all commercial landings, and are to be completed and submitted to DFO within 7 days of landing the catch. Sales slip books are purchased or printed by buyers, offloaders and fishermen.*

> ***Logbook Program.*** *The logbook program was initiated by DFO in 1998 in order to improve catch reporting and address the by-catch concerns, especially for coho salmon. The program consists of collecting detailed catch and release information from all individual fishermen in the South Coast commercial salmon fisheries.*

Fishermen are required to report by phone their logbook catch summary on a weekly and sometimes daily basis, and to mail the completed logbooks to DFO by the end of the season. The phone-in data are used by fisheries managers to guide their in-season decisions. This program is mandatory to all commercial fishermen, and provides a large and cost-effective database encompassing the entire fleet. A portion of this program is funded by the fishermen through the purchase of logbooks.

Observer Program. *Unlike the logbook program which involves the total fleet, the observer program samples only a portion of the salmon fleet. The observer program is the responsibility of DFO and was initiated in 1998 to operate in conjunction with the logbook program. Trained/DFO-certified observers are deployed on-board the commercial fishing vessels, with the aim of providing accurate and detailed catch information on a representative sample of the fleet. On-board observers monitor catch and release by species, gather biological samples (fish weight, length, scales, DNA, etc.) and conduct coho/chinook condition experiments. Data standards for catch reporting are upheld through a rigorous training course and certification examination, developed by DFO in conjunction with Malaspina University College. Currently, DFO funds the majority of the observer program, which is about four times the cost of the logbook program. The combined information from the observer and the logbook programs provides fisheries managers with timely and accurate catch and effort data. Managers utilize the daily information to track and minimize incidental catches while maintaining a harvest on target species.*

In 2010, implementation of 100% dockside monitoring for seine and troll Individual Transferable Quota (ITQ) fisheries improved the reliability of their final catch estimates. Appendix D provides a tabular summary of the relative size of each commercial fishery, methods used to estimate sockeye catch, the degree of compliance with the current phone-in reporting system, validation at landing sites, and qualitative ratings for the accuracy, precision and reliability of the catch estimates.

The Area B Seine fishery includes all marine fishing using purse seine gear on the B.C. South Coast (Areas 11-29). In 2010, an ITQ system was used to set catch limits for the 145 active purse seine licences. The designated skipper for each of these vessels is required to provide a report for the previous days catch by 08:00 on the day following the fishing. These daily catch reports are typically delivered by phone to a contractor (Archipelago Marine Research Ltd.) who then enters these data into the FOS database. Some skippers upload daily catch data directly into the FOS system using electronic logbook systems. In addition to the FOS reporting, the 2010 ITQ fisheries required 100% catch verification by dockside monitors. The dockside monitors interview each skipper to verify fishing locations and times and observe the offloading of the catch to verify total harvest estimates. These data are usually complete within four to five days of each fishery and are provided to the regional management biologist to verify the FOS estimates and to make necessary adjustments. The catch estimate for this fishery was rated as “Fair” for accuracy because the relative low (10-25%) compliance with the phone-in reporting requirement and the lack of catch validation at landing sites (Appendix D). The precision of the catch estimates are unknown but reliability was rated “Medium” because the current catch monitoring methods probably account for the vast majority of the sockeye harvested in these fisheries.

The Area D gillnet fishery includes all marine fishing using gillnet gear in Areas 11-15 and 23-27 on the B.C. South Coast. This fishery has been managed as a limited entry “derby” fishery since 1980. As for seiners, gillnet skippers are required to report the each day’s catch by 08:00 on the following day. However, reporting delays are common for the Area D gillnet fleet such that additional data from aerial-survey boat counts and charter patrol hails are frequently needed to derive the in-season catch estimates. All phone-in catch and fishing effort data is entered into the FOS database by a contractor. The data from aerial survey boat counts and charter patrol hails are entered in to the FOS database by the regional management biologist. No dockside validation is required for gillnet vessels. In-season catch estimates are checked for data entry errors after the fishing season prior to posting as the final post-season estimates. The catch reporting requirements and monitoring methods for the Area D fishery are similar to those described for the other south coast net fisheries and thus received the same ratings for accuracy, precision and reliability.

Area E gillnet includes commercial gillnet fisheries conducted in Areas 16-22, 28 and 29. Virtually all of the harvest of Fraser sockeye by Area E gillnet vessels occurs in Area 29 between the Fraser estuary and the Mission Railway Bridge. The catch reporting requirements and monitoring methods for the Area E fishery prior to 2010 are similar to those described for the other south coast net fisheries and thus received the same ratings for accuracy, precision and reliability. Additional monitoring activities implemented in 2010 included a Dockside Monitoring Program (DMP) and renewed in-season reporting requirements. The goal of the DMP was to have shore-based monitors enumerate 35% of the catch.

The new in-season reporting system required the vessel master to:

1. File a Start-Fishing report prior to beginning fishing on a fishing trip;
2. File an End-Fishing Report no later than 24 hours following the end of a fishing trip and prior to commencing a subsequent fishing trip; and
3. Provide a daily catch report for each day fished before 08:00 of the following day.

These additional requirements were intended to address previously documented delays in catch reporting, the lack of catch validation at landing sites, and inconsistencies between logbooks, phone-in reports and sale slips (Bijsterveld et al. 2002).

Area G troll includes all harvesting by troll vessels in Areas 121-127 on West Coast Vancouver Island (WCVI) and Area H troll includes troll fisheries in Areas 11-18 and 29. The methods used to estimate catch for these fisheries is similar to that for the Area D gillnet fishery. A big difference between these two fisheries is that troll fisheries often open for many more days than gillnet fisheries but the aerial vessel counts used to estimate fishing effort are usually limited to the days with net fishery openings. Therefore, effort estimates for days without vessel counts must rely upon phone-in data and estimates from the portion of vessels that provide phone-in data on a daily basis. Fortunately, the daily phone-in reporting rate for troll fishers is substantially better (>80% in recent years) than that for gillnet fishers (often <25%). The higher reporting rate for trollers increases the sample size for catch per effort estimates but there are fewer opportunities to verify catch rates from on-water hails during charter patrols. The catch estimate for this fishery was rated as “Good” for accuracy because of the relatively high compliance (>80%) with the phone-in reporting requirement. The precision of the catch estimates are unknown and reliability was rated “Medium” because the current catch monitoring methods probably account for the vast majority of the sockeye harvested in these fisheries.

Canadian Allocations by Sector

Information on Fraser sockeye allocations by commercial gear type was not available prior to 2000. For 2001-2006, where the catch of Fraser sockeye was greater than 100,000 pieces per year, the total catch by each gear type has been fairly close to target allocations (Table 15). Fraser sockeye catches during the period 2007-2009 were too low for any meaningful comparison of allocations with actual harvest shares.

Table 15 Fraser River sockeye salmon commercial allocations and harvest by gear type (troll, seine, gillnet) in the South Coast fishery. Percentage values in regular font show allocations per gear type relative to the total commercial allocation; percentage values in brackets and italics show proportion of actual harvest.

		Allocation = % of Potential Harvest, *(% of Actual Harvested)*		
Year	**Actual Harvest**	**Seine (B)**	**Gillnet (D &E)**	**Troll (G & H)**
2001	297,000	44% *(29%)*	35% *(41%)*	21% *(30%)*
2002	2,218,000	37% *(33%)*	43% *(54%)*	20% *(13%)*
2003	1,036,100	41% *(47%)*	45% *(41%)*	15% *(12%)*
2004	1,057,700	54% *(48%)*	36% *(39%)*	11% *(13%)*
2005	129,379	48% *(43%)*	41% *(41%)*	11% *(16%)*
2006	3,247,000	48% *(49%)*	41% *(39%)*	12% *(12%)*
2007	--	--	--	--
2008	16,215	48% *(73%)*	41% *(24%)*	12% *(3%)*
2009	--	--	--	--
Average	**1,143,056**	**46%** ***(46%)***	**40%** ***(40%)***	**15%** ***(14%)***

U.S. Commercial Fisheries

Fraser sockeye are harvested as by-catch in Alaskan fisheries near Noyes Island and as the target species in the US portion of Panel Area waters (Figure 1). The average US harvest of Fraser sockeye during the 2001-09 period has been 300,000 pieces with 24% of the catch taken in Alaska, 7% taken in Juan de Fuca Strait and 69% taken in the US Gulf Islands. The typical numbers and types of fishing gear used in these fisheries include: 7 Treaty Indian gillnet vessels operating in Juan de Fuca Strait; 200 gillnet and 11 seine Treaty Indian vessels that have separate openings from the non-Treaty fisheries in the U.S. Gulf Islands, which can include 75 gillnet vessels, 25 seine vessels and <20 reef nets operations.

"Fish Ticket" systems are used in Alaska and Washington State to produce the final catch estimates for all commercial fisheries. Stock composition estimates for the southeast Alaskan fisheries are derived from fish-scale analyses, which are important because the presence of Fraser sockeye is highly variable in these Alaskan fisheries (Table 1). Fraser sockeye represent the vast majority of the sockeye harvested in Washington State commercial fisheries where scale and DNA samples are used to distinguish between

Fraser and non-Fraser stocks. U.S. management agencies believe these systems produce highly accurate and reliable catch estimates despite having little or no dockside validation (Amy Seiders, Northwest Indian Fisheries Commission, pers. comm.). Based on the information provided by U.S. agencies, U.S. catch estimates of Fraser sockeye were rated "Good" for accuracy, "Unknown" for precision and "High" for reliability.

Overview of Recreational Fisheries

Our evaluations related to recreational fisheries management address the following two tasks as defined in the initial Statement of Work:

> *3.5 The Contractor will describe and summarize the daily and annual catch limits for recreational fishers of Fraser sockeye set for the last 30 years.*
>
> *3.6 The Contractor will describe and evaluate the accuracy, precision and reliability of methods for making catch estimates, including consideration of the creel survey.*

Historically, recreational fisheries in B.C. did not target Fraser River sockeye but rather Chinook and coho. However, primarily through the late 1980s and throughout the 1990s, sockeye were harvested incidentally in DFO Statistical Areas 11 and 12 of Johnstone Straits and Statistical Areas 13-20, 28 and 29 of the Strait of Georgia (Salish Sea) (Figure 4). Prior to the mid-1980s, DFO did not count sockeye harvested in recreational fisheries as it was considered inconsequential (Kristianson and Strongitharm 2006).

Unlike the commercial fishery, recreational fisheries in B.C. are open unless closed by Variation Order. Information outlined in Variation Orders, including changes to annual fishing plans, are communicated via Fishery Notices, media reports, telephone information lines and/or postings on the Pacific Region DFO website.

Commencing in 1999, DFO implemented a policy that, between 1999 and 2005, the recreational harvest of sockeye would not exceed 5% of the combined recreational and commercial harvest of sockeye. This limit has not been exceeded in any year of monitoring.

Table 16 provides the annual estimates of the number of Fraser sockeye harvested in Canadian recreational fisheries (1991-2009) and the total Fraser sockeye harvest.

Available catch estimates for the recreational fishery accounted for less than 3.3% of the annual harvest of Fraser sockeye.

The geographic distribution of Canadian harvests of Fraser sockeye has changed substantially over the past 20 years. Harvests in tidal waters accounted for 52% of the reported catch of from 1992-2000, compared to 7% from 2001-2009. The vast majority of the recreational catch of Fraser sockeye has occurred within the Fraser River since 2001. The overall ratings for recreational fishery catch estimates were “Fair” for accuracy, “Unknown” for precision and “Medium” for reliability (Table 17). These ratings reflect the uncertainty associated with the catch estimates for the lower Fraser recreational fishery, which represents 93% of the estimated recreational sockeye catch in recent years. In contrast to the creel surveys used to monitor recreational fisheries in Georgia Strait, the documentation of catch monitoring efforts and estimates of precision was notably lacking for the lower Fraser recreational fishery. Details regarding each of these recreational fisheries and the rationale for our evaluations of catch estimation methods are presented in the following sections.

Table 16 Estimates of Fraser sockeye harvested in Canadian recreational fisheries by year and by region, 1986-2009.

Year	Strait of Georgia	Johnstone Strait	West Coast Vancouver Island	Fraser River	Total Recreational	Total Catch	Percent Recreational
1991	23,521	2344	1056	*0*	26,921	9,037,000	0.30%
1992	6,745	2014	1360	*0*	10,119	4,671,000	0.22%
1993	23,600		1420	*0*	25,020	17,768,000	0.14%
1994	14,054		359	*0*	14,413	13,322,000	0.11%
1995	5,897		4	6,376	12,277	2,255,000	0.54%
1996	2,365		9	9,371	11,745	2,187,000	0.54%
1997	16,887		197	30,458	47,542	11,425,000	0.42%
1998	4,474		878	9,655	15,007	3,054,000	0.49%
1999	492	1538	51	1,913	3,994	561,000	0.71%
2000	6,367	744	0	24,075	31,186	2,463,000	1.27%
2001	3,219	0	182	41,773	45,174	1,604,000	2.82%
2002	5,133	62	216	125,040	130,451	4,223,000	3.09%
2003	2,918	384	310	73,393	77,005	2,346,900	3.28%
2004	3,340	1352	257	50,388	55,337	2,339,200	2.37%
2005	7,035	767	268	42,629	50,699	1,755,437	2.89%
2006	2,035	5445	794	134,292	142,566	5,427,000	2.63%
2007	192	76	58	11	337	375,620	0.09%
2008	79	10	26	16,344	16,459	573,595	2.87%
2009	0	48	304	0	352	124,341	0.28%
Average							
1992-00	8,987	1,432	475	9,094	19,034	6,411,778	0.49%
2001-09	2,661	905	268	53,763	57,598	2,085,455	2.26%
Percentages							
1992-00	47%	na	2%	48%	100%		
2001-09	5%	2%	0%	93%	100%		

Table 17 Summary of available information on accuracy, precision and reliability of the catch monitoring programs used to produce estimates of the harvest of Fraser sockeye for recreational fisheries, 2001-2009.

Location	% of Catch	Quality of Catch Estimates		
		Accuracy	**Precision**	**Reliability**
Tidal Waters				
Georgia Strait	5%	Fair	±24-90%	Medium
Johnstone Strait	2%	Unknown	NA	Low
WCVI	0%	Unknown	Unknown	Low
Non-Tidal Waters				
Mission-Hope	93%	Fair	Unknown	Medium
Total	**100%**	Fair	Unknown	Medium

Tidal Recreational Fisheries

Most of the recreational fishing for Fraser sockeye in tidal waters occurs in Johnstone Strait, Strait of Georgia and Juan de Fuca Strait (Figure 1). There are also recreational fisheries that harvest sockeye on the West Coast of Vancouver Island (WCVI) and in the tidal waters of Washington State. Recreational fisheries in each of these areas are monitored and accounted for separately and usually by creel survey methods.

Sockeye catches in each of tidal recreational fisheries are not accounted for by stock. It is assumed that all sockeye caught in the Strait of Georgia and Johnstone Strait recreational fisheries are of Fraser River origin. Most of the WCVI recreational fishery for sockeye occurs in Alberni Inlet and targets local stocks returning to the Somass River. Some portion of the sockeye harvested by anglers in the outer areas of Barkley Sound and other WCVI fisheries are likely Fraser sockeye; however, there are no stock-composition estimates for the WCVI recreational fishery. The methods used to derive the annual catch estimates for each of these fisheries are provided below.

Catch Limits

In most years when sockeye retention has been permitted in the south coast tidal fisheries, anglers have been permitted to retain four sockeye per day (daily limit). An exception was 2001, when tidal sport fishers were permitted to retain sockeye subject only to a total possession limit of 8 salmon per angler per day (DFO 2001). After 2004, the daily bag limit for sockeye in tidal sport fisheries has been set at either two or four per day in (years when sockeye retention has been permitted). The historical record of daily catch limits for sockeye was requested from DFO but not delivered (Appendix B). No annual catch limits have been defined for sockeye but the possession limit for all salmon species is twice the daily bag limit.

<u>Strait of Georgia Recreational Fishery</u>

The Strait of Georgia Creel Survey (GSCS) has provided monthly catch and fishing effort estimates for recreational fishing in Strait of Georgia (Areas 13-19, 28, 29) and Juan de Fuca Strait (Area 19 – East of Sheringham Point) since July 1980 (Figure 4) (Shardlow et al. 1989). Commencing in 2002, estimates were also derived for Area 20SG. The 1980-1985 surveys were primarily focused on estimating the catch of Chinook and coho and the catch of other salmon species was combined. Annual estimates of sockeye caught in the Strait of Georgia and Juan de Fuca Strait fisheries between 1986 and 1999 were reported in English et al. (2002). Comparable estimates for 2000-2009 were obtained from subsequent DFO reports (Zetterberg and Carter 2010, Carter and Zetterberg 2010, Zetterberg et al. 2009, Hardie et al. 2002; Hardie et al. 2003; see Figure 16 for annual sockeye catch estimates derived from these reports).

Since the actual harvest of sockeye in Strait of Georgia recreational fisheries is unknown, the accuracy of the GSCS estimates cannot be determined. However, the methods used in the GSCS are believed to produce accurate estimates because of the rigorous survey design and extensive survey effort conducted throughout the fishing period when sockeye are vulnerable to this fishery (English et al 1986; English et al. 2002). Creel surveys combined with aerial boat counts are considered to be the most reliable method for estimating catch and effort for marine recreational fisheries (Pollock et al. 1994). Catch rates tend to be highly variable between fishers and areas in recreational fisheries so it is essential that the survey is stratified by time and area and sufficient effort is allocated to obtain an unbiased estimate of the catch rate and fishing activity pattern for each stratum.

Because of the large geographical extent of the Strait of Georgia fishery, aerial survey boat counts are essential to ensure that all fishing areas are surveyed and there is an unbiased estimate of the number of boats fishing at a particular point in time (English et al. 1986). Appendix D provides summaries of the survey effort (angler interviews and aerial boat counts), catch and effort estimates, and estimates of precision related to the sockeye catches for 1986-2009. These data show that the percent of the fishing effort sampled by the GSCS has fluctuated within the 3-8% range with no apparent trend from 1986-2009. Over this period, the annual tidal recreational catch of Fraser sockeye has ranged from less than 100 to over 30,000 and precision has ranged from ±12% to ±90%. The precision and reliability of these estimates is generally better in years when fishing effort is higher than 200,000 boat trips and is highly variable when fishing effort is less than 200,000 boat trips. It is evident that the precision of the sockeye catch estimates has declined since 1998; the mean precision level prior to 1999 was 22% and for 1999 to 2009 it was 48% (Appendix D).

The accuracy of the GSCS catch estimates is primarily determined by the coverage of the survey, the timing of aerial survey flights, and the extent of cooperation from anglers. In general, the survey has covered the bulk of the Strait of Georgia sport fishery when sockeye are caught and most anglers allow the surveyors to observe their catch and provide accurate information on fishing effort.

Although the catch estimates are relatively precise for the entire Strait of Georgia fishery, the estimates for most Statistical Areas are very imprecise because of low sockeye catch and the high variability in sockeye catch rates between anglers. A relatively small portion of tidal water anglers target sockeye effectively while most target other species and only catch sockeye when they are very abundant.

The GSCS methods were initially reviewed in 1981 (English et al. 1986) and the results from the 1983 to 1999 creel surveys were reviewed in 2000 (English et al. 2002). Both of these reviews found the estimates to be highly reliable for summer months when large numbers of angler interviews could be conducted to derive catch per effort estimates and fishing activity patterns for each of the fishing areas. Recommendations regarding improvements to the analytical methods for estimating catch and effort were provided in English et al. (2002), as follows:

1. Maintain the interview survey effort at or above current levels to ensure that activity patterns are derived from more than 50 interviews per stratum;
2. Do not use activity patterns derived from less than 15 interviews per stratum to compute effort estimates for a specific sub-area;
3. Use the "new" effort estimation analysis approach to compute estimates for fishing effort by sub-area;
4. Use the "new" sub-area CPE analysis approach to compute catch estimates for each sub-area;
5. Ensure that the detailed monthly catch and effort estimates are reviewed by the field program manager and at least one senior analyst familiar with the study design; and

6. Maintain sufficient coverage of total catch to meet biosampling requirements for fishery assessment purposes.

It is unknown if all of these recommendations were implemented but, as mentioned previously, the precision of the estimates of sockeye salmon for GSCS has declined since 1999.

Johnstone Strait Recreational Fishery

Table 16 provides estimates of the recreational fishery harvest of sockeye in Johnstone Strait (Area 12) for the years 1991, 1992, and 1999-2009 when creel surveys were conducted (Hardie et al. 1999, http://www.pac.dfo-mpo.gc.ca/stats/rec/index-eng.htm). The annual recreational catch of sockeye in Johnstone Strait has ranged from zero to 5,445 during this period. Although not available to this report, the precision and reliability of these estimates are believed to be generally lower than those for the Strait of Georgia Creel Survey because of lower survey effort and fewer anglers in Johnstone Strait.

West Coast Vancouver Island Recreational Fishery

Chinook and coho are the primary target species for the WCVI sport fishery except for June-July fisheries in Alberni Inlet that target sockeye returning to the Somass River. Consequently, most of the WCVI sockeye catch are not Fraser sockeye. The creel survey methods used to estimate catch for this fishery are described in Lewis (2004) and are comprised of angler interviews over the broad geographic region and aerial overflights. The methods used to calculate catch and effort statistics are similar to the methods used in the SGCS.

Table 16 provides annual estimates of the catch of Fraser River sockeye in WCVI recreational fisheries. The assumptions used to estimate the proportion of total WCVI recreational catch that were Fraser-origin sockeye are provided in Appendix D. In general, the catch of Fraser sockeye in WCVI recreational fisheries is very low and primarily incidental when anglers are targeting coho and Chinook.

Washington State Recreational Fishery

Very few Fraser sockeye are harvested by recreational anglers in Washington State. Most of the sockeye harvested by anglers in Washington State are caught in terminal areas for the Lake Washington sockeye stock. Consequently, the PSC's annual catch tables for Fraser sockeye do not include estimates for recreational fisheries in Washington State.

Non-Tidal Recreational Fisheries

Commencing in 1991, DFO opened a directed fishery on Fraser sockeye in the lower Fraser River (Roscoe and Pollen 2010). In 1995, DFO estimated fewer than 10,000 sockeye were caught (estimated harvested + released) on the Fraser River by sports fishermen, but by 2002 the fishery's popularity grew rapidly and recreational catch was estimated to be more than 100,000.

Catch Limits

In years when sockeye returns to the Fraser River are sufficient to meet First Nations needs and support a significant commercial fishery, daily catch limits have been set at four salmon per angler per day in waters upstream from Mission on the Fraser River (IFMP 2001). In years when sockeye returns are low (e.g., 2007 and 2009), lower Fraser anglers are not permitted to retain sockeye. In some years (e.g., 2008), the daily bag limit was reduced to two sockeye and for specific areas of the Fraser River, the daily limit has been reduced to one sockeye for specific periods.

Lower Fraser River Recreational Fishery

With the exception of 1991-1994, the lower Fraser River recreational fishery has been assessed annually since 1984 using a creel survey method. The methods are described in Bratty et al. (1998) and include estimates of effort, catch and precision. However, sockeye were not a target species for lower Fraser anglers during the period 1984-1990, so catch estimates were very low (Appendix D).

Table 16 provides estimates of the sockeye harvested by anglers in lower Fraser River fisheries from 1995 to 2009. Sockeye harvests have increased substantially since the mid-1990s and have ranged from 1,900 to 134,000 in years when sockeye retention was permitted. Estimates of precision were not made available by DFO for this report.

Non-Retention Fisheries

Our evaluations related to commercial fisheries management address the following task as defined in the Statement of Work:

> *3.7 The Contractor will describe and summarize the consequences of non-retention fisheries (First Nations, commercial, recreational) on sockeye physiology, survival and abundance.*

For this section, we have defined non-retention to include those fish captured and released and those fish that encounter fishing gear but escape capture. An example of the first category are sockeye released during sport fisheries because anglers are not permitted to retain sockeye during a specific period or the angler continues to fish for sockeye after their daily bag limit has been reached. Estimates of the number of sockeye released by lower Fraser anglers are provided in Appendix E and have exceeded 65,000 fish in several years. Examples of the second category are fish that swim into a gill net, struggle for seconds or several minutes and escape from the net (sometimes referred to as net fall-out). It is very difficult to quantify net fall-out but everyone who has operated a gillnet has observed fish hitting the net, struggling and escaping capture. Most of this section focuses on the first category of non-retention but the potential impact of the second type of non-retention is discussed at the end of this section.

Recent high profile declines in the abundance of some iconic salmon populations (e.g., Interior Coho and Cultus sockeye) coupled with declines in productivity for most Fraser River sockeye stocks has raised awareness that accurate estimates of mortality for fish released from mixed stock/species fisheries is crucial for developing sustainable fisheries management strategies. Although salmon fisheries are typically managed to harvest a specific species or stock it is often impossible not to intercept other co-migrating salmon, including some that are threatened. Fisheries management has three options; (1) continue to harvest abundant stocks with an increased risk of extinction to threatened ones, (2) shut down lucrative fisheries to protect threatened ones, or (3) apply restrictions in the form of release requirements for non-target species or stocks (e.g., release non-target species, particular sizes, or those without external hatchery markings). Release requirements have been applied to several gear types (e.g., gillnetting, seine nets, fish wheels, dip nets, angling). Releasing fish (a.k.a. "discarding" in some literature) has become used increasingly in management but is predicated on the assumption that true release mortality estimates are known. Unfortunately, there is almost no scientifically defensible information on post-release mortality associated with any freshwater gear type and across all three fishing sectors for Pacific salmon. That stress and injury associated with capture can cause mortality after release (both short-term and delayed) in salmon and has been well recognized for over 50 years and therefore efforts have already been made to develop effective recovery methods for ocean commercial fisheries (Farrell et al. 2001). However, there has been little research to quantify levels of mortality or to understand the mechanism underlying mortality in order to better mitigate or prevent mortality. Without this type of information, especially in an era of warming rivers wherein we expect higher stress-related mortality (Dempson et al. 2002), it is difficult to ensure sustainability of salmon fisheries and conservation of stocks.

In virtually all types of fisheries, some proportion of individuals die shortly after release as a result of acute physical injury (e.g., hooked in the heart, gills tangled in a net). Fitness (i.e., the ability to survive or reproduce) of escapees can also be reduced because of minor injury, physiological disturbance, or behavioural alterations (Cooke and Wilde 2007). Most research that examines mortality of released fish does so holding them in pens, tanks, or cages (reviewed in Davis 2002, and Cooke and Schramm 2007). Biotelemetry is being used increasingly to study mortality of released fish, eliminating issues associated with holding fish in captivity (crowding, water quality, abrasion, lack of predators) (reviewed in Donaldson et al. 2008). When fish are captured by angling, release mortality can range from <1% to >90% depending on specific gear, species, fisher's skill/intentions, and many environmental factors (reviewed in Arlinghaus et al. 2007).

A fish's response to capture is physiologically similar to burst swimming and results in a suite of hormonal, energetic and ionic changes (Wood 1991; Farrell et al. 2000; Kieffer 2000). Specifically, it causes anaerobic consumption of endogenous fuels, lactic acid accumulation, changes in cellular structure and enzyme function, and shifts of water out of the plasma into muscle, ultimately disrupting ionic/osmotic balance (Wood 1991; Kieffer 2000). Capture also causes production of 'stress hormones' such as cortisol (Barton et al. 2002), which help fish maintain biochemical homeostasis during stressful events but results in the shift of energy from anabolic processes (i.e., growth and reproduction) to catabolic ones (i.e., energy mobilization and restoration of homeostasis) (Wendelaar Bonga 1997). Hypoxia can be associated with capture and release depending on how fish are captured (e.g., a gill net that restricts ventilation in a fish) and handled (e.g., extent of air exposure). Hypoxia causes production of stress hormones and heat shock proteins (Ferguson and Tufts 1992; Furimsky et al. 2003; Iwama et al. 2004) and further burdens muscle glycogen stores as well as adenylates; many of which have already been depleted while the fish struggled in capture gear. Significant levels of oxidative stress may also occur during recovery. Despite such physiological changes, some fish can recover quickly, but recovery is species- and context-dependent and poorly understood.

Stress of capture and release can also change behaviour by either increasing (e.g., Mäkinen et al. 2000) or decreasing activity (Holland et al. 1993) during the first hours and days after release. Yet there is little information on behavioural consequences of capture on released fish, and no data on Pacific salmon. Large departures from behavioural norms may indicate physiological stress and impaired ability to forage, avoid predators, migrate and reproduce (Schreck et al. 1997). Considering salmon are harvested en-route to spawning grounds, behavioural impairments (fallback or delay) could have significant consequences on migration success through exhaustion of energetic resources. Despite physiological and behavioural changes that accompany fish capture and handling, some fish do indeed recover quickly with no fitness consequences; again, such recovery is species- and context- dependent (Cooke and Suski 2005) and generally not known for Pacific salmon in freshwater.

Research initiated in 2009 was designed to address some of the important knowledge gaps related to post-release survival for Pacific salmon caught in freshwater fisheries. This research has largely been conducted in a collaborative manner involving researchers from Carleton University, DFO, Pacific Salmon Foundation, UBC, J.O. Thomas and Associates, and LGL Limited. Most of the research focuses on the three main capture techniques used in freshwater salmon fisheries; rod and reel (recreational and First Nations), beach seine (First Nations), and gillnet (commercial and First Nations). In the Fraser River, sockeye are captured and released (or they escape and are thus are released unintentionally) via all these gear types. The research has focused on assessing mortality rates of released fish following various forms of capture or stressor (both in field and laboratory settings), developing predictive physiological and behavioural indices of post-release mortality under different thermal experiences, and the development and testing of recovery approaches in order to reduce post-release mortality.

In a recent study (Donaldson et al. 2011), physiological condition, post-release behaviour and survival of river migrating Fraser River sockeye were examined. Fish were captured by either beach seine or angling and released immediately, or they were captured by angling and released following a 24-hour recovery period in a net pen. Before release, all salmon were biopsied or tagged with radio telemetry transmitters. Capture by either angling or beach seine with immediate release resulted in >95 % survival 24 hours after release, whereas net pen recovery after angling resulted in ~ 80 % survival over the same time period (Table 18). This differential in survival was similarly expressed in the percentage of released fish reaching natal sub-watersheds, with 52.2% and 36.3% of fish immediately released by beach seine and angling reaching natal sub-watersheds, respectively, compared with 2.9 % of fish released after angling and net pen recovery. The survival from release to spawning areas for radio-tagged sockeye released from lower Fraser fishwheels during the same period in 2009 was 57% (Robichaud et al. 2010). In a different study, where sockeye were caught in the ocean and tagged, freshwater survival was estimated to be in the order of 60-80% (English et al. 2005; Robichaud et al 2007; Martins et al 2010), thus providing a reference point to compare survival for the different freshwater handling approaches. Collectively, these results suggest that assessments of post-release survival need to extend beyond the first 24 hours to detect differences between different capture and handling techniques. Short-term survival (<24 h) was very similar for sockeye released from beach seine and recreational fisheries and notably lower for angler caught sockeye for each of the longer tracking intervals. The impact of multiple stresses on sockeye survival was clearly evident for sockeye released after 24 hours of "recovery" in net pens. The differences between the held and immediately released fish were evident within 24 hours of release and expanded with each additional interval. The suspected higher stress levels for the net pen releases were confirmed from blood samples obtained just prior to the release. Plasma stress indices reflected the 10-fold difference in survival, with ~4-fold higher plasma cortisol, ~2-fold higher plasma glucose and significantly depressed plasma ions and osmolality relative to fish sampled upon capture.

Table 18 Survival[1] of sockeye salmon captured by beach seine or angling and released either immediately or following 24 hours of recovery in a net pen (from Donaldson et al., 2011).

Capture method	Survived >24 h	Survived >48 h	Survived >96 h	Reached natal sub-watershed
Beach seine (immediate release)	21 of 22 (95.5 %)	20 of 22 (90.9 %)	16 of 22 (72.7 %)	12 of 23 (52.2 %)
Angling (immediate release)	31 of 32 (96.9 %)	25 of 32 (78.1 %)	19 of 32 (59.4 %)	12 of 33 (36.3 %)
Net pen recovery (holding for 24 h)	29 of 36 (80.6 %)	22 of 36 (61.1 %)	12 of 36 (33.3 %)	1 of 35 (2.9 %)

[1] *Survival to reach natal sub-watersheds represents only individuals that were detected by fixed station receivers at terminal areas. Total numbers do not include unreported fisheries harvest.*

In another study (M. Donaldson, unpub. data), physiological condition, migration behaviour, and survival of river-migrating sockeye were examined following experimental stressors. A field experimental approach with four treatments was used. Treatments included: (1) rapid beach seine (removal from beach seine <3 min); (2) prolonged beach seine (removal from beach seine 10-15 min; (3) tangle net simulation (3 min net entanglement and 1 min air exposure); and (4) gill net simulation (3 min net entanglement and 1 min air exposure). The treatments induced severe physiological disturbances for fish exposed to the gill net and tangle net simulations, including increases in plasma cortisol, lactate, glucose, osmolality and ions (Na+ and Cl-) relative to the rapid beach seine group, which emerged as the least stressful treatment. Tracking individuals using a comprehensive 20 receiver acoustic telemetry array and manual tracking receiver revealed striking differences in migration behaviour, where individuals exposed to the most stressful treatment, the gill net simulation, moved away from the release site almost three-fold faster than those exposed to the least stressful treatment, the rapid beach seine capture and release. The beach seine treatments did not cause immediate mortality, unlike the tangle net and gillnet simulations that caused 6.7% and 6.9% immediate mortality, respectively.

Martins et al. (2010) analysed data from telemetry studies conducted in 2002-2007 to assess the effect of freshwater thermal stress, experienced in the lower Fraser River, on migration survival and the ability to reach natal watersheds of different Fraser sockeye stocks. This study used tracking data for 1,474 sockeye (400 Chilko, 331 Quesnel, 212

Stellako-Late Stuart and 531 Adams) that were known to have passed a detection station located near Mission, B.C. Some fish used in this study were captured and tagged in the ocean using purse seine gear and others were captured in the lower Fraser River using tangle nets or fishwheels. Survival rates relative to post-handling thermal experience was estimated using capture–recapture models. They found that post-release survival of all stocks was greatest at 15 °C but diminished as temperatures warmed. Stock-specific effects were strongly evident. Chilko sockeye were the most resilient to increasing temperatures following capture and release, whereas Adams sockeye were the least resilient, suffering 80-90% post-release mortality at temperatures >18 °C. The most likely reason for increased mortality at higher water temperatures is the significant reduction in aerobic scope for sockeye between 16 and 20 °C (Farrell et al. 2008). Aerobic scope limits the fish's ability to allocate energy to essential tissues, which restricts whole-animal tolerance to extreme temperatures (Portner 2002; Farrell et al. 2008; Portner and Farrell 2008; Farrell 2009). Stress is enhanced as aerobic scope is reduced, and with further increase in temperature there is insufficient scope to sustain aerobic swimming, leading to anaerobic activity, exhaustion and death by lactic acidosis or cardiac collapse (Portner 2001, 2002; Farrell 2002, 2009; Farrell et al. 2008). These temperature related effects on survival are likely magnified by disease, parasite loads and fishery related stress experienced by the migrating fish.

The 2002-2009 sockeye telemetry studies have also provided information on the general geographic locations for major en-route losses. In each study, where Summer-run sockeye were tagged the portion of the Fraser River between Seton and Kelly Creek has accounted for the highest portion of en-route losses above Sawmill. The data compiled from 2005-2009 provide compelling evidence that the largest en-route losses occur at times and locations where upstream migrating sockeye are stressed by a combination of elevated water temperature, in-river fisheries and difficult passage points (Robichaud et al. 2010). While there is little that can be done about annual water temperatures or difficult passage points, it is possible to minimize cumulative effects environmental and fishery related factors by dissociating the timing and location of in-river fisheries from these other stressors.

Stress on migrating sockeye could also be reduced through changes to fishing methods. The sockeye telemetry studies have provided extensive data on tagged fish moving downstream (dropping back) after encountering areas with intensive fisheries (Robichaud et al. 2006; 2007; 2010). Fish tracked moving downstream in the mid Fraser River are clearly not harvested but likely impacted by the combination of in-river fisheries and environment stressors. As water temperatures increase in the Fraser River, it will become increasingly important to assess and minimize the impact of fishing methods, times and locations on in-river survival of sockeye and other salmon species.

FISHERIES MANAGEMENT

Overview of Pre-season Forecasting

Our evaluations related to pre-season forecasts address the following two tasks as defined in the Statement of Work:

> *3.8 The Contractor will describe and evaluate the accuracy, precision and reliability of pre-season forecasting methods. This work will include a description of the application of pre-season forecasting in harvest management.*
>
> *3.9 The Contractor will also describe and evaluate the accuracy, precision and reliability of other methods, if any, that are available for pre-season forecasting not historically or currently used by DFO and the Pacific Salmon Commission.*

DFO produces annual pre-season forecasts of the returning adult sockeye abundance for 19 indicator stocks (CSAS 2009). These forecasts are used by resource managers for pre-season planning and in-season management until there is sufficient information from test fisheries to produce an in-season forecast. The Fraser River Sockeye Spawning Initiative (FRSSI) process uses forecasts of adult returns for each of the four run-timing groups (a.k.a. timing groups) to define the target harvest rates for each group. These target harvest rates are used by the PSC Fraser Panel to determine the pre-season harvest allocation for Canadian and U.S. fisheries and to develop their respective domestic fishing plans. The in-season estimates usually replace the pre-season forecasts in this fisheries management process as each timing group approaches its projected mid-point.

We defined forecast reliability to include instances where the linear relationship between forecast and actual return was statistically significant for the period 1980 – 2009, and used regression parameters and MAPE in combination to describe relative accuracy and precision of the pre-season forecasts for run-timing groups and indicator stocks.

Fraser River forecasts explained 44% of the year-to-year variation in returns between 1980 and 2009 (i.e., 56% left unexplained), and we can expect total returns in any given year to vary from total forecasts by about 25%. However, the relationship between forecasts and returns was not reliable for seven of the 18 Fraser sockeye indicator stocks.

Forecasts for Bowron, Pitt, Chilko, and Stellako have been particularly poor, having explained only 8.7%, 0.4%, 9.1%, and 9.3% of return variation in the past 30 years. This is especially alarming for Chilko because this group contributes (on average) about 24% of the total Fraser return.

The recent error in Fraser sockeye forecasts and recognized challenges with forecasting salmon returns have led most managers to rely on in-season information to manage sockeye fisheries. Fishermen and processors want reliable forecasts so they can make better business decisions, but most recognize that they should not make major investments based on annual run size forecasts.

Review of Pre-season Forecasting Methods

The data sources and alternative methods (models) used to derive pre-season forecasts for each of the 19 indicator stocks are fairly complex and described in detail in Cass et al. (2006). The suite of alternative models tested for each indicator stock depends on the types of data available for that group.

Table 19 provides a list of the various models from Cass et al. (2006) that have been used in the pre-season forecasting process from 2007 to 2010 (CSAS, 2006; 2007; 2009; 2010). Most of the models use estimates of total returns, brood year spawners, or returns per spawner available for each of the 19 indicator stocks; however, some models require data on fry or smolt abundance that are only available for a few stocks (e.g., Chilko, Cultus, Nadina, Weaver).

The models range in complexity from simple, such as naïve models (i.e., simple time series models without explicitly modeled mechanisms), to the more complex, such as Ricker stock-recruitment models that include environmental factors in their calculations. Cass et al. (2006) provides details on data sources, model equations, the retrospective analysis approach, and measures used to assess the performance of the 14 models used prior to 2008. Brief descriptions of the five additional models tested in 2009-2010 are provided in (CSAS 2009, 2010). Most of the data required for these models are from PSC databases.

Four of the five models added in recent years use estimates of stock productivity, defined in terms of recruits per spawner (R/S), where recruits are the number of adults returning (catch plus escapement and “en-route losses”) for a specific stock and spawners are the number of “effective female spawners” in the brood year for that stock (i.e., female parents of the recruits). Effective female spawners are the female sockeye that contribute to the eggs deposited in the gravel, which is a necessary distinction from female recruits since not all females that return to the Fraser River successfully deposit eggs at their spawning site. Spawning ground surveys provide the sex ratios, egg retention and pre-spawn mortality estimates needed to estimate the number of effective female spawners. The primary reason for adding these R/S models into the 2010 forecasting process was the long-term trend of declining productivity for several Fraser sockeye stocks and the exceptionally low returns per spawner observed in 2009.

The typical approach used in recent years has been to test the performance of the various models for each of the 19 indicator stocks in retrospective analyses and use the results from the best performing model for the annual pre-season forecasts (Cass et al. 2006). Table 20 shows the best performing model for each of the 19 indicator stocks in each of the past four years (CSAS 2006; 2007; 2009; 2010). There are several stocks where the same model has been the selected for multiple years but no instances where a single model has been considered to be the best available in each of the past four years.

Model descriptions

For some stocks, 14 possible models were parameterized as candidates for forecasting. DFO separates the models into three groups—Naïve, Biological, and Biological-Environmental. For most Fraser stocks, current returns tend to be correlated with returns from four years earlier due to spending one year in freshwater and three years in the ocean, thus creating a four year life cycle. Naïve models simply average the previous cycle line returns (returns that occurred 4, 8, 12 years, etc. ago) and vary only by how many cycles they include in the average.

Biological models are further separated into escapement, juvenile, and sibling models. Returns are related to broodyear escapements by way of Ricker and power curves—Biological Escapement models. Juvenile data (fry and/or smolts) are available for eight of the 19 stocks and are used to predict returns in a power model—Biological Juvenile models. Smolt and jack (number returning as small three year olds) data are used in combination with survival and age composition estimates to forecast age-4 and age-5 returns—Biological Sibling models.

Biological-Environmental models use Fraser River discharge measured at Hope and spring sea surface temperature (SST) measured in the year of smoltification as covariates (extra explanatory variables) in the Ricker and power Escapement models mentioned above.

Model selection methods

Retrospective analysis is based on metrics that measure a model's past performance. This procedure involves comparing the forecasted returns to the observed returns in previous years and indexing their difference in several ways. These metrics include mean absolute percent error (MAPE) and root mean square error (RMSE) (Cass et al. 2006). For a given stock, models are ranked by each of these metrics and the two rankings are averaged; the model with the highest average rank is selected. Not all stocks have juvenile data and those that do usually have additional years of returns; thus, only years having both juvenile and return data are used when comparing Biological Juvenile and Biological Escapement models for these stocks.

Pre-season estimates of forecast accuracy

The models described above were parameterized using Bayesian statistical techniques programmed into Bayesian Software Using Gibbs Sampling (BUGS). This approach allows prior information about parameter estimates (such as historical averages of these parameters) to be updated with new data to generate posterior distributions of parameters and their predicted output (in this case the forecasts). Aside from making it convenient for combining information from different sources, the resulting posterior distributions can be used to characterize uncertainty and speak about the chances that various events (returns) will occur. Developing distributions of uncertainty is very different than developing a single-value estimate for returns; the former gives a range of possible values centered around that most like to occur (akin to an hypothetical average centered in a bell curve, with the probability of achieving a given result will decrease as we move away from the center), the latter gives a single point estimate without capturing the surrounding uncertainty.

In Figure 5 to Figure 8, we report the expected accuracy of forecasts (i.e., range of returns that should be contained by the lower 25th percentile and upper 75th percentile confidence limits) based on forecasting models used in those years and the actual returns. Still, assessing the uncertainty in this way relies on the assumption that the future will resemble the past, and if conditions change since past data were collected (such as a decline in stream productivity or marine survival) then actual returns are less likely to fall within the confidence limits. For example, in 2009 (Figure 6), none of the actual returns for the 19 indicator stocks and the four run timing groups fell within the bounds for the middle 50% of the forecast estimates. This is in contrast to the 2003 (Figure 7) and 1998 (Figure 8) forecasts where the actual returns for 13 of the 18 indicator stocks fell within the middle 50% bounds for the forecasts each year.

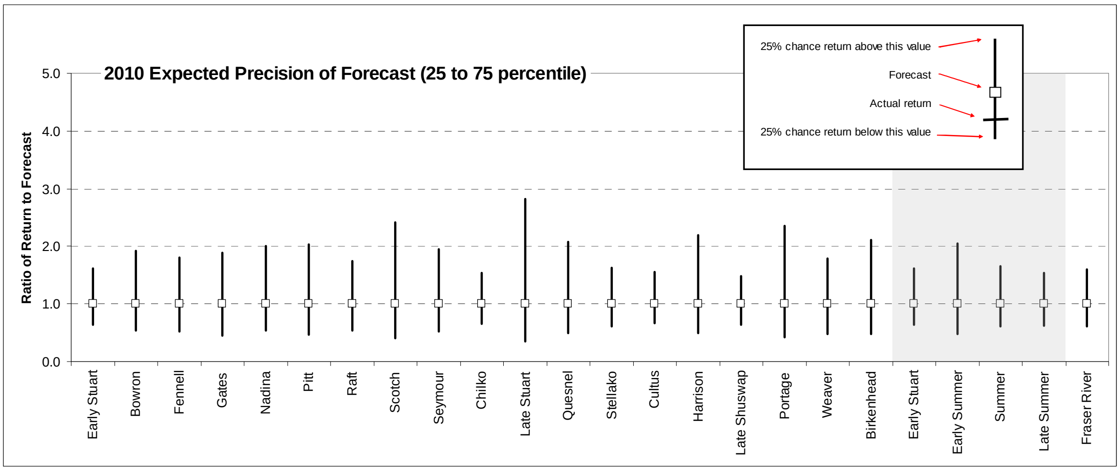


Figure 5 The 2010 forecasted point estimate (squares). The vertical black lines depict the upper and lower confidence limits for the forecast predictions (upper 75th and lower 25th percentiles). Indicator stocks, beginning at left from Early Stuart to Birkenhead, are pooled into four run timing groups to their right (shaded area) followed by all Fraser River stocks combined. Official return values for the 2010 run were unavailable at time of reporting.

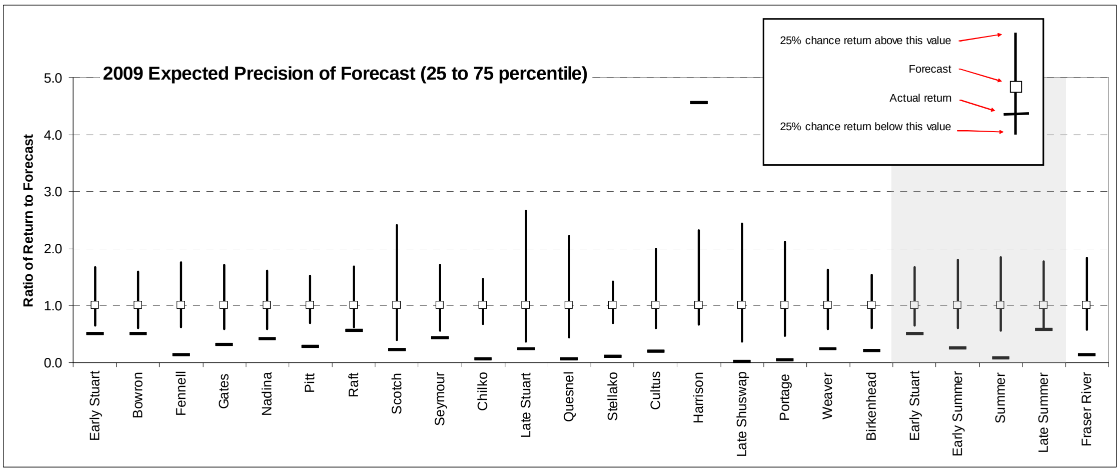


Figure 6 The 2009 forecasted point estimate (squares) and actual returns (horizontal bars). The vertical black lines depict the upper and lower confidence limits for the forecast predictions (upper 75th and lower 25th percentiles). Indicator stocks, beginning at left from Early Stuart to Birkenhead, are pooled into four run timing groups to their right (shaded area) followed by all Fraser River stocks combined. This figures shows that forecasts for all stocks in 2009 were higher than returns, except for the Harrison indicator stock that was forecasted well below the actual return.

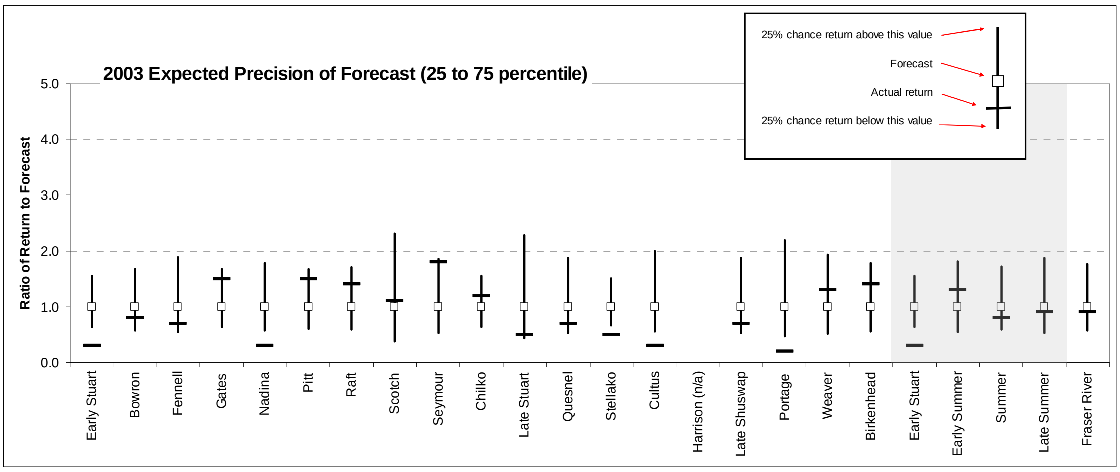


Figure 7 The 2003 forecasted point estimate (squares) and actual returns (horizontal bars). The vertical black lines depict the upper and lower confidence limits for the forecast predictions (upper 75th and lower 25th percentiles). Indicator stocks, beginning at left from Early Stuart to Birkenhead, are pooled into four run timing groups to their right (shaded area) followed by all Fraser River stocks combined. Forecasts were accurate when horizontal bar-markers approach squares, for example Fraser River, Late Summer, Scotch.

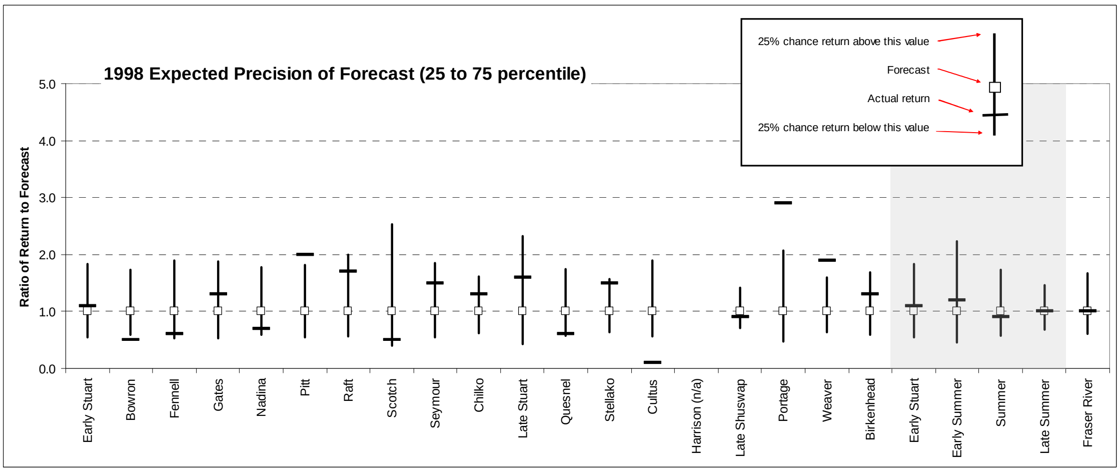


Figure 8 The 1998 forecasted point estimate (squares) and actual returns (horizontal bars). The vertical black lines depict the upper and lower confidence limits for the forecast predictions (upper 75th and lower 25th percentiles). Indicator stocks, beginning at left from Early Stuart to Birkenhead, are pooled into four run timing groups to their right (shaded area) followed by all Fraser River stocks combined.

Table 19 List of candidate models and data requirements for Fraser sockeye pre-season forecasts (2006-2010) (adapted from Cass et al. 2006).

				Data Applied			
No.	*Model Name*	*Model Type*	*Model Method*	*Returns*	*Escapement & Adult Recruitment*	*Juvenile Estimates*	*Environment*
1	R1C	Naïve	Same returns as 4 years previous	X			
2	R2C	Naïve	Average of returns 4 & 8 years previous	X			
3	RAC	Naïve	Average returns on cycle line	X			
4	TAC	Naïve	Time Series Average Return	X			
5	Power	Biological	Power function combining all cycles		X		
6	Power-cyc	Biological	Power function based on 1 cycle line		X		
7	Ricker	Biological	Ricker function combining all cycles		X		
8	Ricker-cyc	Biological	Ricker function based on 1 cycle line		X		
9	Power-fry	Biological				X	
10	Smolt-Jack	Biological	Bayesian			X	
11	Ricker-disc	Biological & Environmental	Multiple regression				Average spring Fraser Discharge
12	Ricker-peak	Biological & Environmental	Multiple regression				Peak spring Fraser Discharge
13	Ricker-ei Ricker-pi	Biological & Environmental	Multiple regression				Average spring-summer Lighthouse SST
14	Ricker-PDO	Biological & Environmental	Multiple regression				Winter Pacific Decadal Oscillation Index
15	Ricker-KF	Biological & Environmental					Kalman filter used to est. Ricker 'a'
16	RS1	Recruits per spawner	R/S from last generation and effective females in brood year		X		
17	RS4yr	Recruits per spawner	R/S from last 4 generations and effective females in brood year		X		
18	RS8yr	Recruits per spawner	R/S from last 8 generations and effective females in brood year		X		
19	RJ4yr	Recruits per spawner	R/S from last 4 generations and smolts in brood year		X		

Table 20 Pre-season forecast models used from 2007 to 2010 for the 19 sockeye indicator stocks (from CSAS 2006; 2007; 2009; 2010).

Stock/Timing Group	2007	2008	2009*	2010
Early Stuart	Fry	Fry	Power+RS2	RS4yr
Early Summer				
Bowron	Ricker-pi	Ricker-pi	Ricker-pi	RS4yr
Fennell	RAC	Power	Ricker	Power
Gates	Power	Power	Ricker-cyc	Ricker-KF
Nadina	Fry	Fry	Ricker-peak	Ricker-FRD-mean
Pitt	TSA	Power	Power	Ricker
Raft	Power	Power	Power	Ricker-PDO
Scotch	R1C	Power	RS1	Ricker-KF
Seymour	Ricker-cyc	Ricker-cyc	Ricker-cyc	RS4yr
Summer				
Chilko	Smolt	Smolt	Pawer (Smolt)	RJ4yr
Late Stuart	R1C	Power	RIC	RS8yr
Quesnel	Ricker-fry + R1C	Power	Pooled	Ricker-KF
Stellako	R1C	Ricker	Larkin	RS4yr
Late				
Cultus	Smolt-jack	Smolt-jack	Power Smolt-jack	Smolt-jack
Late Shuswap	Larkin+RAC	Larkin	Ricker-PDO	Ricker-cyc
Portage	Power	Power	Ricker-cyc	Ricker-KF
Weaver	Fry	Fry	Larkin	Ricker-FRD-peak
Birkenhead	Power	Power	Power	Ricker-KF
Harrison	Ricker-PDO	T/S	Ricker-PDO	Ricker-FRD-mean

* effective females used for brood year escapements estimates

Results of Pre-season Forecasts versus Estimated Returns Assessment

We used MAPE and regression analysis to assess the reliability, precision and accuracy of forecasts for the 19 indicator stocks, 4 run-timing groups, and the total Fraser River for the period 1980-2009 (Table 21); the same approach is used for the Bristol Bay stocks. Appendix F provides an overview of how analytical results are used to judge accuracy, precision, and reliability for the pre-season forecasts. Detailed analyses for each management group are reported in Appendix G.

Our objective was to determine whether there was a statistical relationship between forecasted values and actual returns. If there was no such relationship (i.e., returns varied at random with respect to forecasts) we deemed the forecast to be unreliable. If, however, the relationship was statistically significant (i.e., large returns arrived in years with large forecasts, and small returns arrived in years with small forecasts), we deemed the forecast to reliably track the general rises and falls of the actual returns. If the forecasting was reliable, we took further steps to describe, in terms relative to other stocks, "how good" the forecast was based on regression and MAPE statistics. This iterative approach to assessing forecast performance was adapted from methods used in Haesaker et al. 2008.

We base our interpretations of forecast precision and accuracy on a few simple facts: a perfect relationship between forecast and return will have a regression slope= 1, intercept= 0, and R^2= 1.0. As any of these values depart from optimal, either precision or accuracy erodes. MAPE becomes useful when slope depart substantially from 1 (an instance where R^2 would be very low), because MAPE describes dispersion around the fit line independently of slope. For example, if there was no relationship between forecast and return, the regression slope would be flat (i.e., zero slope) and R^2 would be very small; in other words, the forecasts failed to track the rises and falls of the returns and so the forecasting for that hypothetical stock is unreliable.

Figure 9 shows MAPE to be relatively consistent across all stocks, which at first glance appears at odds with

Figure 10 that shows forecasting in some stocks to be significantly better than others. For example, Seymour and Chilko have near identical MAPE yet regression analysis says forecasting for Seymour is reliable and Chilko is not. Quite simply, these contrasting results between MAPE and regression tell us that the forecasts for these two groups have deviated from the regression line to a similar extent (i.e., forecasts are about 45 to 50%

different from the straight line), even though the regression line for Seymour has a positive slope (forecast predicts return to some extent) and the regression line for Chilko is flat (forecast does not predict return). Moreover, the significant regression for Seymour tells us that above and beyond the 50% year-to-year error, forecasts for this indicator stock have reliably tracked large and small returns. The non-significant regression for Chilko tells us that the 50% annual flux in returns occurs at random with respect to the forecast value. To summarize, MAPE and R^2 values do not always agree: MAPE can remain constant (e.g., 50%), even if R^2 decreases rapidly with decreasing regression slope.

Based on the aforementioned criteria, the relationship between forecasts and returns was not considered reliable for seven of the 18 indicator stocks (note: 18 instead of 19 indicator stocks because forecasts for Harrison were not available). Forecasts for Bowron, Pitt, Chilko, and Stellako were particularly poor, having explained only 8.7%, 0.4%, 9.1%, and 9.3% of inter-annual return variation in the past 30 years. This is especially alarming for Chilko because this group contributes (on average) to about 24% of the total Fraser return. The other 11 indicator stocks had a statistically significant relationship between forecast and return, accuracy in all except three was good (i.e., regression slope close to 1.0), and precision of forecast varied from 47 to 72% from the actual return in all but the Cultus Lake stock (i.e., MAPE= 92% for Cultus forecasts).

For Late Stuart, Quesnel, and Late Shuswap, forecasts have explained 76%, 74%, and 81% of the annual return variation since 1980. The highly cyclic nature of these stocks has probably contributed (at least in part) to the apparently higher predictive power of their forecasts, as signified by the significant forecast-return relationship in regression analysis. In other words, the combination of large forecasts issued in dominant years with small forecasts issued in years with small returns (off cycle years) could drive positive results in a regression analysis if the forecasters were knowledgeable about such large-scale and cyclic changes in run size. For example, the difference between dominant and off-cycle years for the Chilko, Bowron, Pitt and Stellako runs (all with non-significant regression slopes) are 1-2 orders of magnitude (e.g., Chilko was ~225,000 in 1981 to ~4.6M in 1990); unlike Quesnel, Late Stuart and Late Shuswap runs (significant regression slopes) that differ between dominant and off-cycle years by 3-4 orders of magnitude (e.g., Quesnel was ~6,000 in 1984 and ~10M in 1993). For our purposes, the regression analysis approach gives us a general glimpse of whether the forecasts for individual stocks are successfully tracking the rises and falls in their returns, but caution is needed before using the statistical estimates presented here to make direct comparisons in forecasting success between a stock with strong cyclic dominance versus ones without. Figure 9 and

Figure 10 summarizes data for all of the 18 indicator stock groups, including the amount of error that can be expected in any given forecast year and the amount of annual variation in returns that has been explained by forecasts for the period 1980 to 2009.

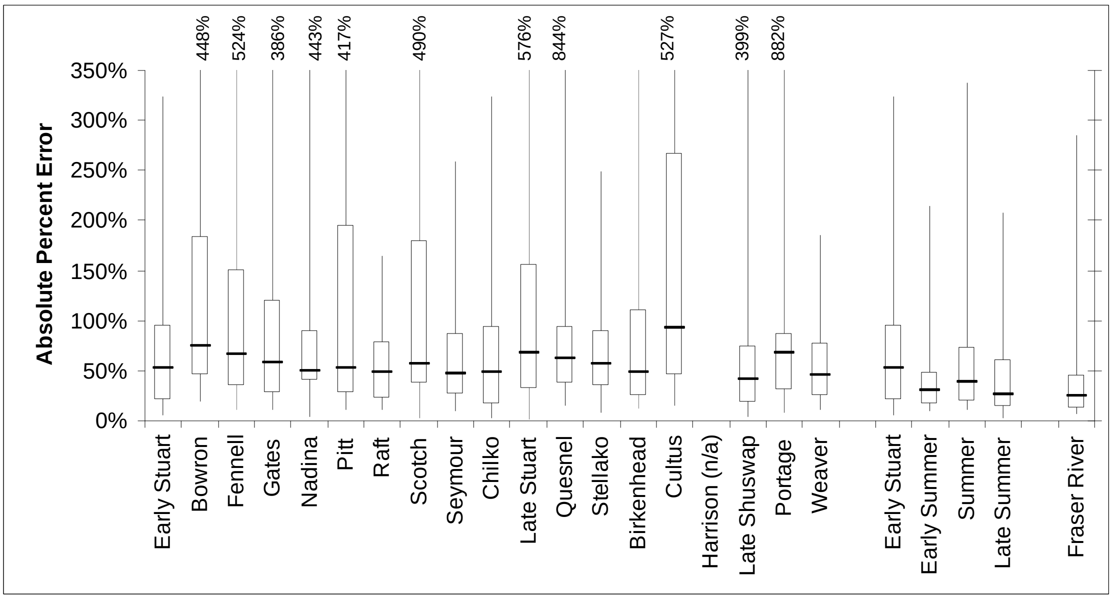


Figure 9 Absolute Percent Error in forecasts relative to actual returns for the period 1980-2009. Median absolute percent error (MAPE) is shown by the horizontal bars for each stock; boxes represent the upper 75th and lower 25th percentiles of the annual data, and whiskers extend to the upper 95th and lower 5th percentiles, respectively. MAPE can be interpreted as the expected % error in forecast (relative to observed return) for any given year, but does not tell us whether the error is an underestimate or overestimate of the actual return. However, the APE for an under-forecast can never exceed 100%, therefore, APEs greater than 100% indicate that the forecast was greater than the return.

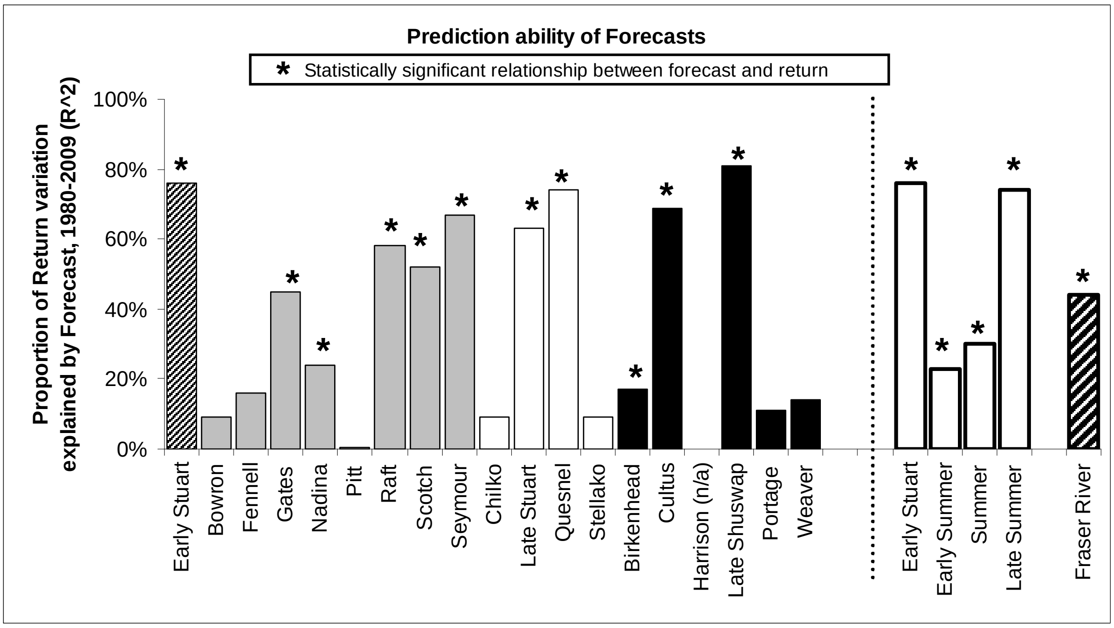


Figure 10 Proportion of year-to-year variation in sockeye returns explained by forecasts (R^2) for 19 indicator stocks, four timing groups, and total Fraser River (1980-2009). Asterisks denote Forecast versus Return relationships that were statistically significant (re: regression analysis). Bars for indicator stocks are coloured by timing group: hatched = Early Stuart; grey = Early Summer; white = Summer-run; black = Late-run. Data for the Harrison group was not available (n/a).

The long-term reliability, precision, and accuracy of forecasts varied widely across run-timing groups (Table 21). For example, the amount of inter-annual fluctuation in returns explained by forecasts (R^2) ranged from 23% (Early Summer) to 76% (Early Stuart). Nevertheless, forecasts for all run timing groups were deemed to be statistically significant since they tracked the patterns of rise and fall in the actual returns for the period 1980 to 2009. The relationship between forecasts and returns for the entire Fraser River run was also significant (44% of inter-annual variance explained by forecasts). The Early Summer and Summer runs tended to lose accuracy with increasing forecast size (i.e., regression intercepts were close to zero but slopes deviated from 1). Therefore, despite deviation in accuracy and precision among the major run-timing groups and total Fraser River groups, these historical forecasts are to be considered reliable.

Table 21 Summary of MAPE and Regression Analyses, testing the relationship between pre-season forecasts and actual returns for the four run-timing groups and the entire Fraser River forecast. How to interpret statistical outcomes is described in the text above. Proportional size of CU relative to total Fraser return is the average annual value for the period 1980-2009. Similar analyses for the 19 indicator stocks are reported in Appendix H**.**

Stock	MAPE	Return Explained by Forecast (R^2)	Regression Slope	Regression Intercept (# fish)	Run size relative to total Fraser	Interpretation
Fraser River	25%	44%	0.84 (significant)	not significant	100%	• **Reliability**: Relationship between forecast and return is statistically significant, thus forecast is reliable. Expect forecast to overestimate or underestimate return by 25% in any given year. • **Precision**: Moderate amount of inter-annual variation explained by forecasts (R^2= 0.44). • **Accuracy**: Slope is close to one and intercept is not significantly different from zero, thus long-term accuracy is good.
Early Stuart	53%	76%	0.99 (significant)	not significant	3.3%	• **Reliability**: Relationship between forecast and return is statistically significant, thus forecast is reliable. Expect forecast to overestimate or underestimate return by 53% in any given year. • **Precision**: Moderate/Large amount of inter-annual variation explained by forecasts (R^2= 0.76). • **Accuracy**: Slope is close to one and intercept is not significantly different from zero, thus long-term accuracy is good.
Early Summer	31%	23%	0.60 (significant)	not significant	9.2%	• **Reliability**: Relationship between forecast and return is statistically significant, thus forecast is reliable. Expect forecast to overestimate or underestimate return by 31% in any given year. • **Precision**: Moderate/Small amount of inter-annual variation explained by forecasts (R^2= 0.23). • **Accuracy**: Slope is close to one and intercept is not significantly different from zero, thus long-term accuracy is good.

Stock	MAPE	Return Explained by Forecast (R^2)	Regression Slope	Regression Intercept (# fish)	Run size relative to total Fraser	Interpretation
Summer	39%	30%	0.64 (significant)	not significant	56.6%	• **Reliability**: Relationship between forecast and return is statistically significant, thus forecast is reliable. Expect forecast to overestimate or underestimate return by 39% in any given year. • **Precision**: Moderate/Small amount of inter-annual variation explained by forecasts (R^2= 0.30). • **Accuracy**: Slope departs mildly from one and intercept is not significantly different from zero, thus long-term accuracy is good but large forecasts tend to underestimate returns.
Late Summer	27%	74%	0. 87 (significant)	not significant	31.1%	• **Reliability**: Relationship between forecast and return is statistically significant, thus forecast is reliable. Expect forecast to overestimate or underestimate return by 27% in any given year. • **Precision**: Large amount of inter-annual variation explained by forecasts (R^2= 0.74). • **Accuracy**: Slope is close to one and intercept is not significantly different from zero, thus long-term accuracy is good.

Despite the significant predictive power of forecasts for the four run-timing groups, there remains substantial unexplained error in actual return sizes. As noted above, Fraser River forecasts explained 44% of the year-to-year variation in returns between 1980 and 2009 (i.e., leaving 56% unexplained), and we can expect returns in any given year to vary from forecasts by about 25%. Forecasts seem to be best for the Early Stuart and Late-run timing groups with 76% and 74% of the annual variation explained, respectively; whereas forecasts have been weaker for Early Summer and Summer-run groups where forecasts have accounted for 23% and 30% percent of the annual fluctuation.

The recent large errors in Fraser sockeye forecasts and recognized challenges with forecasting salmon returns have led most managers to rely on in-season information to manage sockeye fisheries. Fishermen and processors want reliable forecasts so they can make better business decisions, but most recognize that they should not make major investments based on annual run size forecasts. Importantly, our trend analysis is based on historical data and may have limited ability to predict the future reliability of forecasts for a particular stock, especially if changing environmental conditions undermine the utility of even the best performing pre-season forecasts based on historical data; yet another reason why pre-season forecasts are of little use in the management of Fraser sockeye and many southern B.C. salmon stocks.

Overview of In-season Run-size Abundance Estimation

Our evaluations related to escapement enumeration address the following task as defined in the initial Statement of Work:

> *3.10 The Contractor will describe and evaluate the accuracy, precision and reliability of in-season run-size abundance estimation methods. This work will include a description of the application of in-season and post-season run-size abundance estimation in harvest management.*

In-season assessments of returning run size are conducted by the PSC using a variety of models. These models integrate historical information on run timing with data from the four primary in-season data collection programs: (1) catch estimation, (2) test fishing, (3) stock identification, and (4) escapement estimation. The catch monitoring programs described earlier in this report provide in-season catch estimates for each of the major fisheries. Seine and gillnet test fisheries are conducted on both potential approach route (Johnstone Strait and Juan de Fuca Strait) to obtain indices of abundance and biological samples (scales and DNA) for racial analysis. Biological samples from commercial and test fisheries are analyzed in-season to determine the stock composition of harvest and escapements. Daily escapements of sockeye from marine fisheries are estimated in the Fraser River at Mission using hydroacoustic techniques.

The historical record (1997-2009) of the daily run size estimates for each run-timing group, as approved by the Fraser Panel, were evaluated for reliability and timeliness of in-season reporting. These in-season estimates are compared to the final post-season estimates for each run-timing group. The methods used to derive the final post-season run size estimate are described later in the report. We used daily plots of median percent error (MPE) as a measure of accuracy, median absolute percent error (MAPE) to quantify precision, and R^2 as an indicator of reliability. The accuracy of in-season run size estimates tend to be biased high (i.e., forecasts larger than runs) with low precision (25-78% error) early in the migration period for Early Stuart and Summer-run sockeye but the bias and error is rapidly reduced to less than 20% as the run-timing approaches their typical halfway points and less than 7% as the runs near their end. The in-season forecasts for Early Summer and Late-run groups tend to be more accurate throughout their respective migration periods and precision remains in the range of 10-25% for most of the run. In general, these statistics suggest that the in-season forecasts have been sufficiently accurate, precise and timely to make the management decisions needed to achieve the harvest rate goals defined for each of the four run-timing groups.

In-season Monitoring Methods

The following contains brief descriptions of the in-season run size estimation models used prior to 1995, adapted from PSC (1995):

Commercial Purse Seine Models

Prior to 1995, weekly catch and CPUE for purse seine fisheries in Juan de Fuca and Johnstone Straits was the major source of in-season run size information for Fraser sockeye. These weekly catch and CPUE estimates were compared to total post-season returns (using regression analysis) to define relationships that could be used in-season to forecast abundance. In these fishing areas, especially Johnstone Strait, sockeye are confined to relatively narrow migration routes and are highly vulnerable to purse seine fisheries. Travel time between these fishing areas and the Fraser River at Mission is typically 5-7 days for Summer-run sockeye. Catch information from fisheries early in the week are generally used by the Fraser Panel to formulate plans for the following week.

This type of model requires accurate estimates of total purse seine catch and gear count by area, and information on the duration of each fishery and area restrictions.

Cumulative Passage Model

These models use the historic relationship between run size of Summer-run stocks and the daily-reconstructed, cumulative abundances of those stocks in the Fraser River at Mission. Daily catches in all Panel and non-Panel Area fisheries and daily Mission hydroacoustic estimates of escapement for individual stocks are adjusted to common dates of migration and summed by day for the period of migration. The daily totals are then summed to give cumulative totals for each date and year. Regression analysis of annual run sizes on cumulative abundances to a particular date can then provide a means of assessing the current run size at any date by using cumulative catch and escapement data from that year. These models are not used for Late-run stocks because of the potential migration delay of 3-6 weeks in Georgia Strait before entering the Fraser River.

Cumulative-Normal Models

These models are based on the assumption that the migration of each returning stock approximates a normal distribution. In-season catches and escapements are adjusted to a common migration point and provide an estimate of the daily un-fished abundance at that point. The cumulative daily abundance estimates for each date are then compared (using regression analysis) to expected values obtained from a set of normal curves with varying run size, timing and duration parameters. The abundance and timing parameters of the normal distribution scenario that give the best fit (highest R^2 value) to the observed data become the "best" estimates for the run size. The model is updated as additional days of catch and escapement data become available. The method relies on high quality catch and escapement data and the assumption that the speed of fish movement between areas is consistent between years. Particularly important is the determination of whether Summer-run sockeye are delaying off the mouth of the Fraser River.

The cumulative-normal model will provide an estimate of run size at any stage of the run, but the estimates stabilize only after the peak of the run passes Mission. Cumulative-normal models, in theory, provide a valid method to estimate run sizes beyond the range of previous experience as long as the basic assumptions of the model are met. However, simulation studies have shown that the model is sensitive to deviations from normality (e.g., skewness or bimodality of the run).

Inputs to the cumulative-normal model for Late-run sockeye cannot be estimated in the same manner as for Summer-run sockeye because the Late-run escapements cannot be measured directly. However, an extension of the model was developed wherein harvest rates for Late-run stocks, obtained from past years' data, are applied to in-season catches in Juan de Fuca and Johnstone Straits' fisheries to estimate the daily abundance (i.e., catch plus escapement). These estimated daily abundances are summed day by day during the season and the accumulated total is compared (using regression analysis) to a range of cumulative-normal curves as for Summer-run stock. The escapement of Late-run sockeye to the Strait of Georgia can be estimated at any point in the season by subtraction of the catch from the estimate of abundance to date.

In-season Summer-run Exploitation Rate Model

This model was primarily developed to derive in-season abundance estimates for Late-run stocks. Daily and weekly exploitation rates for all marine fisheries are estimated for the most abundant Summer-run stocks from in-season catch and escapement estimates. Catches of co-migrating, Late-run stocks in these same fisheries are divided by the Summer-run exploitation rates to obtain estimates of abundance.

Bayesian Models

Limited commercial fishing in recent years has reduced the availability of the major source of data needed for the historical in-season run size estimation models. Catch and CPUE data from test fishing are now used more extensively in assessing sockeye and pink salmon abundances than in previous years. From 1998-2007, a Bayesian "Box-Car" or reconstruction-based model, developed by Bill Gazey, was employed. This model incorporated features of the cumulative-normal and cumulative-passage-to-date models, and implemented an objective method for combining the estimates from its component models based on the relative uncertainty of these models. This model was replaced in 2008 by a Bayesian time and density model using Winbugs software, similar in concept to the Cumulative Normal model. This model incorporates historical information on run-size, timing, spread of the migration and test fishing expansion line (inverse of catchability, see below) in the form of prior probability distributions or "Priors" as well as in-season reconstructions of daily abundance and test fishing CPUE. Further detail on the current Bayesian models are provided in Appendix I.

In-season *vs* Post-season Abundance Estimates, and Estimate Timeliness

Our evaluations related to the historical performance of in-season run-size forecasts address the following two tasks as defined in the initial Statement of Work:

> *3.14 The Contractor will analyze historical performance of the in-season assessment process, to include changes in estimates of in-season run sizes, with particular emphasis on how long it has taken within each season to correctly assess the final in-season run size. The key issue to be described is how quickly the in-season assessment process can respond, to meet escapement goals.*

In-season estimates were compared to the final post-season estimates for each run-timing group for each day in period 1 July to 10 September, and across years 1997 to 2009. The in-season estimates available on September 10th have been classified as the final in-season estimate because sockeye fisheries effectively end by this date. Post-season run size estimates are from the PSC Fraser sockeye production tables. The methods used to compute the final post-season estimates are described later in this report under the heading *Escapement Enumeration and Total Abundance Estimates*. We calculated daily median percent error (MPE) to assess changes of the in-season forecast accuracy over time, median absolute percent error (MAPE) to quantify changes in precision over time, and R^2 as an indicator of in-season forecast reliability.

The accuracy of in-season run size estimate tended to be biased high (i.e., forecasts larger than returns) with low precision (50-78% error) early in the migration period for Early Stuart and Summer-run sockeye but the bias and error was reduced rapidly to less than 20% as the runs approached the typical halfway point and less than 7% as the runs neared their ends (Figure 11). The in-season forecasts for Early Summer and Late runs tended to be biased low (i.e., forecasts smaller than returns) although more accurate than Early Stuart and Summer runs early in their respective migration periods. The precision of in-season forecasts for Early Summer and Late runs remained in the range of 10-25% for most of the fishing period for these stocks (Figure 12).

The reliability of in-season forecasts (where reliability was assessed by the forecasts' ability to estimate inter-annual variation in total returns) varied among run-timing groups (Figure 13). For Early Stuart, in-season estimates have predicted more than 90% of the inter-annual changes for the entire run period. In-season estimates for the Late-run group was also highly reliable, ranging from just over 80% of inter-annual variation predicted at the beginning of the run (late July) and over 90% of variation explained by the second week in August. Early Summer and Summer-run estimates have been less reliable at the beginning of the runs, but by mid-run the predictive power of in-season forecasts for both of these groups exceeded 80%.

Typically, fishing the Early Stuart group does not begin until about the second week of July (approximately halfway through the run timing) if fisheries are permitted to target these run-timing group. Modest fishing of the Early Summer and Summer-run groups typically begin in late July, with the Fraser Panel's delaying its decision to increase fishing efforts until about the halfway point of the runs, which usually occurs in the first or second week of August. If the Late-run stock is thought to be small in a given year, fishing effort will be typically scaled back in the third week of August to protect it. In general, the in-season forecasts have been sufficiently accurate, precise, reliable, and timely to make the management decisions needed to achieve the harvest rate goals defined for each of the four run-timing groups.

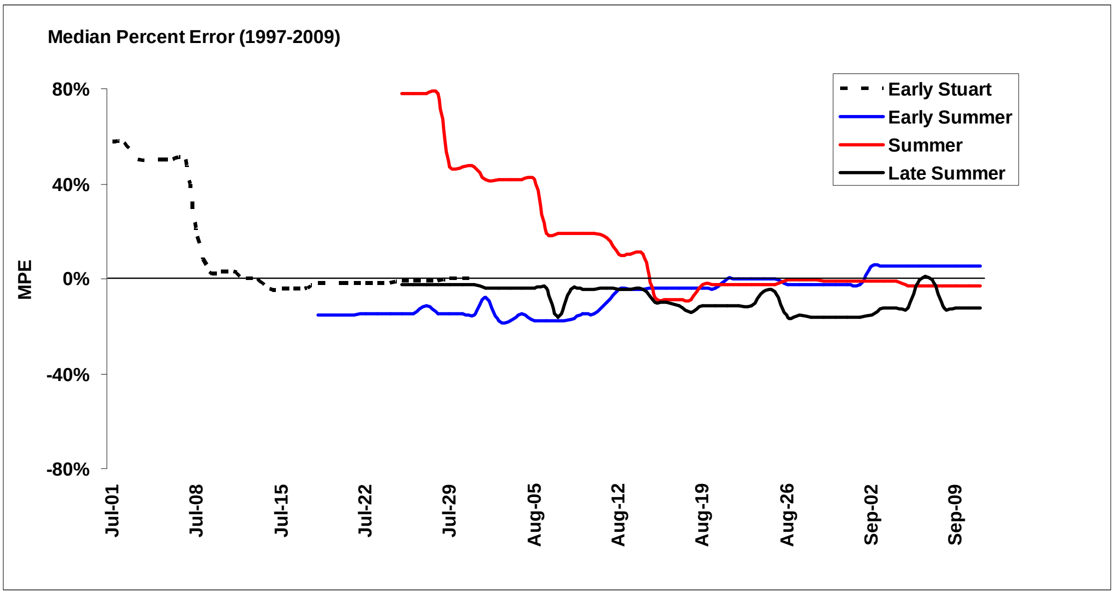


Figure 11 Median percent error (MPE) reflects forecast accuracy, calculated as the proportional difference of in-season run size forecast relative to final run size for each timing group. Positive values show final run sizes that are smaller than in-season forecasts (forecast over-estimate); negative values show final run sizes that are larger than in-season forecast (forecast under-estimate). Median percent error values derived from multiple years on the same date (between July 1st and September 9th and the final in-season estimate), for the period 1997-2009.

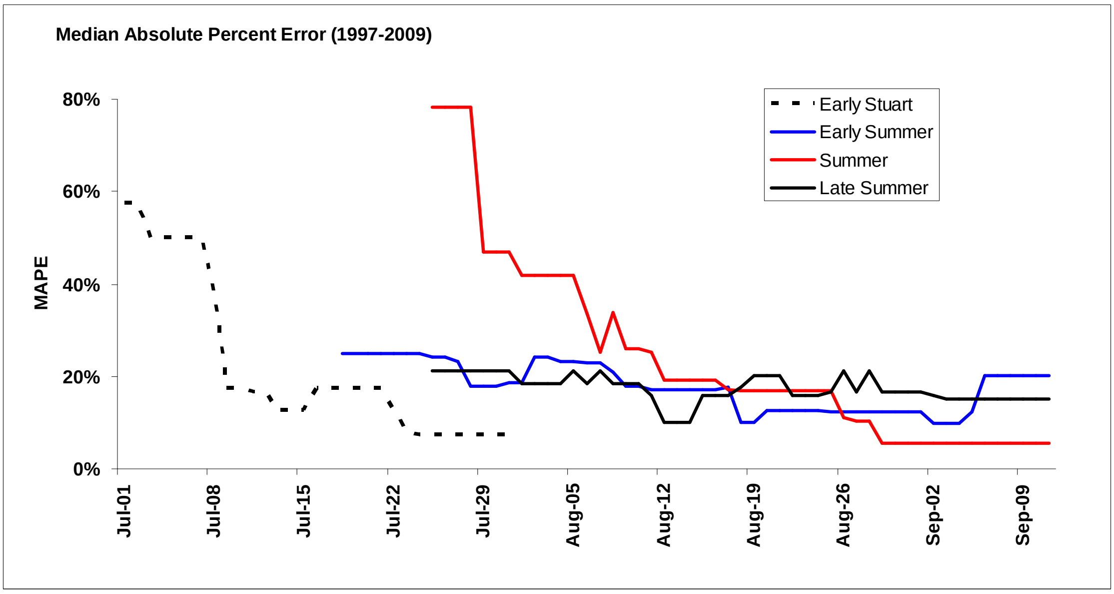


Figure 12 Median absolute percent error (MAPE) reflects forecast precision, calculated as the proportional difference of in-season run size forecast relative to final run size for each timing group. Median percent error values. MAPE values derived from multiple years on the same date (between July 1st and September 9th and the final in-season estimate), for the period 1997-2009.

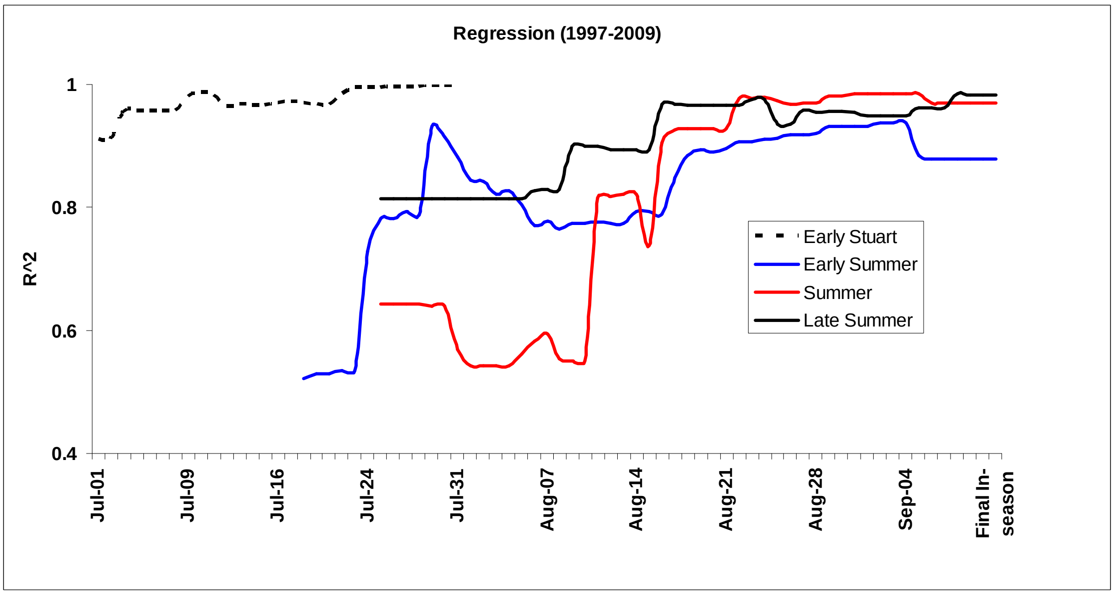


Figure 13 Coefficient of determination (R^2), calculated from regression analysis comparing in-season forecast to final return on each day in the period 1997 to 2009 (N=13 points per day).

Overview of Escapement Enumeration

Our evaluations related to escapement enumeration address the following tasks as defined in the initial Statement of Work:

3.12 The Contractor will describe and evaluate the accuracy, precision and reliability of in-season and post-season escapement enumeration methods used historically and currently by DFO and the PSC.

3.13 The Contractor will also describe and evaluate the accuracy, precision and reliability of other methods, if any, that are available for enumerating sockeye not historically or currently used by DFO and the PSC

The PSC has been responsible for providing in-season estimates of run size and escapement past Mission for Fraser sockeye. In-season indicators of run size are derived by combining marine test fishery catches with historical estimates of catch efficiencies (Appendix I). In-season estimates of escapement past Mission have been derived using a variety of hydroacoustic techniques and gillnet test fishery data to determine species composition of the hydroacoustic target counts. Since 1992, differences between Mission estimates and the sum of spawning escapement and catch above Mission have been attributed to "en-route loss". In 2006, the number of Late-run sockeye in spawning areas above Mission was estimated to be more than twice the Mission escapement estimate. Such major discrepancies have recently undermined the confidence in the in-season escapement estimates and have led to the development of alternative in-season monitoring systems using DIDSON hydroacoustic techniques at Mission and Qualark for fish counts and fishwheels to estimate near-shore species composition.

Post-season escapement estimates are believed to be much more reliable for Fraser sockeye because over 75% of the spawning sockeye have been enumerated using intensive mark-recapture techniques or counting fences (Table 22). The remainder is enumerated using visual survey techniques combined with expansion factors that typically underestimate the escapement for smaller stocks.

Table 22 Summary of the accuracy, precision and reliability of mark-recapture, fence count and visual survey methods used to obtain post-season estimates of spawning escapement for Fraser sockeye.

	% of	Quality of Escapement Estimates		
Methods	Total	Accuracy	Precision	Reliability
1980-2005[1]				
Mark-recapture	63%	Likely good	< ±25%	High
Fence Counts	14%	Very good	High	High
Visual	23%	Likely biased low	Unknown	Medium
2006-2009[2]				
Mark-recapture	64%	Good	±3-23%	High
Fence Counts	14%	Very good	High	High
Visual	22%	Biased low	Unknown	Medium
Total		Good	Medium	High

[1] Schubert and Houtman (2007)
[2] Preliminary Annual Fraser Sockeye Escapement Reports (Keri Benner, DFO Kamloops, pers. comm.)

Aside from a few streams that are enumerated using unbreached fence counts, the accuracy of the post-season escapement estimates is unknown. Precision can be estimated for all mark-recapture estimates and tend to be in the ±5 to 25% range (for 95% confidence intervals). The reliability of the escapement estimates vary substantially from stream to stream and between salmon species but Fraser sockeye escapement estimates tend to be among the most reliable escapement estimates derived for any B.C. salmon stock.

In-season Escapement Monitoring

A variety of monitoring systems are used in the lower Fraser River to assess the in-season abundance and stock composition of sockeye as they escape from the marine fisheries. These systems include: (1) Cottonwood drift gillnet test fishery; (2) Whonnock drift gillnet test fishery; (3) Mission hydroacoustic site; and (4) Qualark hydroacoustic site.

Whonnock and Cottonwood test fisheries are used occasionally to estimate the upstream passage of sockeye during (1) the Early Stuart time period if the salmon abundance in the river is too low and variable to justify the Mission Hydroacoustics program, and (2) the Pink migration in September in odd-years when sockeye are caught in low but disproportionate numbers to Pink salmon. Since the mid-1990s, test fishery catches have been impacted severely by salmon predators such as harbour seals. Some mitigation of the predation and interference by seals has been achieved through the use of an experimental pulsed, low-voltage DC electric gradient (Forrest et al. 2009).

The Cottonwood Test Fishery is conducted at a site in the south arm of the Fraser River that is approximately 20 km upstream from Steveston, B.C. An index of sockeye abundance entering the Fraser River is obtained from a single 5-9 minute drift gillnet set made during slack tide each day. Scale and DNA samples are obtained from a portion of the sockeye caught each day.

The Whonnock Test Fishery is conducted on the Fraser mainstem at a location 48 km upstream from Cottonwood and 18 km downstream from the Mission hydroacoustic site. This test fishery conducts two 5-10 minute sets per day using a variable-mesh non-selective gillnet. The primary purpose of this test fishery is to provide species and stock composition estimates that can be applied to the Mission hydroacoustic counts to derive stock specific estimates of the number of sockeye passing Mission each day.

Mission Hydroacoustic System

PSC has operated a hydroacoustic facility on the Fraser River near the Mission Bridge since 1977, for the purpose of providing timely in-season estimates of sockeye escapement from marine and lower river fisheries (Appendix J). This program has benefited from improved technologies and research in recent years (Xie et al. 2005, 2007, 2008).

Prior to 2004, the Mission estimates were derived using fixed and mobile single beam hydroacoustic systems. A fixed side-scan system was deployed on the south bank while the mobile downward-looking system was operated from a vessel during cross channel transects. Split-beam hydroacoustic systems were tested in 2002 and 2003 and have been the primary method for producing the official Mission estimates since the beginning of the 2004 sockeye season. 2006 was the first year that an independent side-scan split-beam system was fully operational on the north shore (i.e., “right bank”) for the entire sockeye escapement period and a DIDSON system was tested at the Mission site. DIDSON hydroacoustic systems have been tested at a variety of locations and proven to be a superior system for enumerating migrating salmon at Mission and Qualark during periods of peak abundance.

Qualark Hydroacoustic System

The Qualark Creek hydroacoustic monitoring site is located on the Fraser mainstem 15 km north of Hope, B.C. and 95 km upstream from Mission hydroacoustic site. The median travel time for adult sockeye migrating between Mission and Qualark is 2.9 days for Summer-run stocks and 3.5 days for Late-run stocks (Robichaud et al., in prep.). The Qualark site was initially developed using split-beam systems between 1993 and 1998. The site was not operated for 10 years due to funding constraints and the high personnel costs associated with operating the split-beam technology. In 2008, DIDSON sonar systems were tested at the site and proved to be a reliable method and that was easier to use and less costly to operate than the split-beam system (Enzenhofer et al. 2010). DIDSON systems were deployed on both banks of the Fraser River at Qualark in 2009 and 2010 and provided daily estimates of the numbers of salmon passing the site that were used in-season for comparison with the Mission estimates. Species composition at the Qualark site is determined using 30 m gillnet drifted from 150 m upstream of the site to 700 m downstream, six times each day. In 2009, the test fishery mesh sizes and methodology were modified based on advice from the PSC to ensure that the sample was representative of the salmon passing the Qualark site at the time of sampling. The mesh sizes used included 4, 4 ¾, 5 ¼, 5 ¾, 6 ¾ and 8 inch (stretched mesh). Further details on the Qualark hydroacoustic system and test fishing methods can be found in Enzenhofer et al. (2010).

Accuracy, Precision and Reliability

At best, the two gillnet test fisheries provide a relative index of the daily abundance of sockeye migrating past these site. However, no estimates of the accuracy of these estimates can be made because the number of sockeye migrating through these test fishery locations is not known. The precision of the daily catch per effort estimates can not be estimated for the gillnet test fisheries because there are only two sets made at Whonnock and one set at Cottonwood each day during the test fishing period. The reliability of these test fisheries for providing a relative index of abundance is severely compromised when sockeye abundances are low because harbour seals frequently remove fish from the nets before they can be enumerated by the test-fishery crews. These drift gillnet test fisheries are not effective at sampling near-shore waters so there is a potential for bias in the daily indices of abundance if the sockeye distribution across the river channel changes during the run. The recent operation of fishwheels near the Whonnock test fishery site has revealed substantial differences between the near-shore and off-shore species composition as measured using these two gear types, and these differences change throughout the run and are likely affected by the flow, water temperature and the relative abundance of the species (e.g., pink salmon abundance in odd-years) (Robichaud et al. 2010).

The accuracy of the Mission Hydroacoustic System has been assessed in recent years through comparisons of daily sockeye estimates with those derived from the Qualark Hydroacoustic System. While the true abundance of sockeye migrating past the Mission site is unknown, the Qualark site is believed to provide the most complete count for those stocks migrating upstream. After accounting for sockeye removed in fisheries between Mission and Qualark and stocks destined for spawning areas below Qualark, the resulting Mission estimates were similar to those from Qualark for periods in 2008 and 2009 when sockeye represented the vast majority of the species passing each site (Smith et al. 2009; Robichaud et al. 2010). The PSC generates daily estimates for the Mission site and DFO generates the daily estimates for the Qualark site; however, the precision of these estimates has not been computed for either site. The reliability of the Mission estimates has been questioned on a number of occasions when spawning ground surveys have estimated substantially fewer or greater numbers of sockeye than were estimated to have passed Mission. There have been several investigations into the potential reasons for inaccuracies in the Mission escapement estimates (Xie et al. 2002; 2008), the most likely being a significant underestimation of the Mission escapement of Late-run sockeye in 2006 because fish were thought to be avoiding the vessel-based sonar system (Xie et al. 2008).

Post-season estimates of Escapement

The final estimates of escapement for each sockeye stock are derived from the counting fences, mark-recapture techniques or visual surveys conducted on or near the spawning areas. The current rule for Fraser sockeye is to assess escapement using enumeration fences or mark-recapture techniques for all stocks where the escapement is likely to be greater than 75,000 adults. Stocks with abundances below 75,000 are assessed using visual survey techniques. The abundance level used to distinguish between small and large stocks was increased from 25,000 to 75,000 in 2001 as a result of increases in escapement levels and the number of stocks qualifying for the more costly escapement monitoring procedures.

Counting fences are generally accepted as the most reliable method of estimating escapement to spawning areas. While fences have been used to enumerate returns to 14 different sockeye spawning streams (Gluske, Forfar, Kynock, Dust, Nadina, Gates, Scotch, Stellako, Horsefly, McKinley, Kuzkwa, Birkenhead, Cultus and upper Eagle River), these streams usually represent less than 30% of the annual spawners for Fraser sockeye. Mark-recapture techniques are the next best assessment method and typically account for over 60% of the estimated sockeye spawning escapement. The remainder of the spawning ground escapement estimates is derived from visual surveys (Figure 14).

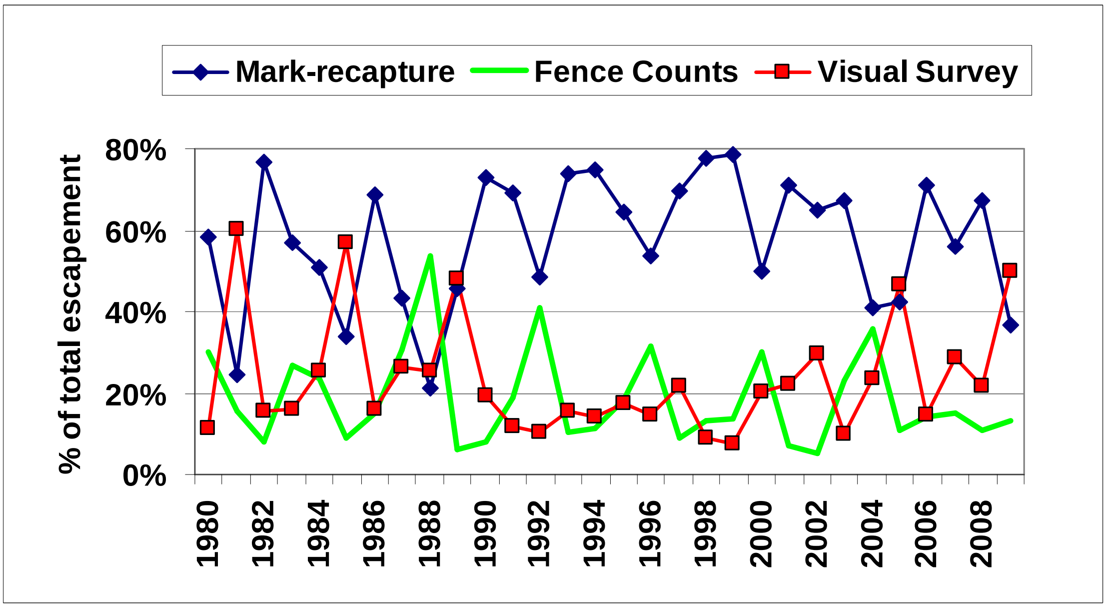


Figure 14 Portion of the total escapement of Fraser sockeye estimated using mark-recapture, fences and visual survey techniques, 1980-2009.

The field and analytical methods used to compute spawning ground escapement for Fraser sockeye have been fairly consistent since the 1950s despite the transfer of responsibilities from the International Pacific Salmon Fisheries Commission (IPSFC) to DFO in 1985. These methods were most recently described for the 1998 escapement monitoring efforts (Schubert and Houtman 2007) including several changes implemented in 1998 to address deficiencies in the mark-recapture study designs identified in 1994 (Anon. 1995). A brief description and summary evaluation of each escapement enumeration technique is provided below.

Fence counts

The objective of each enumeration fence program is to install the fence before the spawners arrive and maintain the fence and counting system throughout the run to provide a complete enumeration of the sockeye entering a spawning area. Visual surveys are conducted upstream of the fence immediately after installation to determine the number of sockeye already in the spawning area and, if spawners are observed, regular surveys are conducted downstream of the fence. The accuracy of escapement estimates derived for streams with enumeration fences depends on the portion of the run counted at the fence versus that estimated from other visual surveys. Fraser sockeye fences are typically installed before the runs arrive, they are usually fish-tight, and they are operated over the entire migration period. These fences do not tend to obstruct fish passage and fence operators are usually able to anticipate peak migration periods and implement procedures to ensure that the counts are accurate during these critical periods. Fence operations, fish abundance and counting conditions will vary from year to year but researchers believe that fence and channel estimates are likely estimated with a negative bias of less than 5% (Schubert and Houtman 2007).

Mark-recapture

The objective for each mark-recapture study is “to estimate the sex-specific escapement with a precision of within ±25%” (Schubert and Houtman 2007). The typical field goals are to apply tags to 1% of the anticipated escapement and to examine carcasses for tags in proportion to daily abundances. Tags are usually applied to fish captured as they enter the spawning area to ensure tagged fish are representative of all potential spawners. Carcass surveys are conducted throughout the spawning area over the entire die-off period. The results of mark-recapture studies conducted prior to 1998 indicate that the precision achieved was considerably better than the objective of ±25%, so sub-sampling of the spawning areas was implemented in 1998 as a cost savings measure (Schubert and Houtman 2007). Results for 2006-2009 indicated that the precision goal was achieved for all escapement estimates derived from mark-recapture data during these years (range ±5-23% Table 23). This level of precision is similar to that reported for the 1998 mark-recapture estimates (Schubert and Houtman 2007).

Visual surveys

The objectives for visual surveys are to conduct multiple surveys of the entire spawning area under optimal light conditions during the period of peak spawner abundance (Schubert and Houtman 2007). Escapement estimates are derived using IPSFC procedures described in Andrew and Webb (1987). For most streams where surveys count both live and dead fish, the total escapement is the sum of the maximum daily count of live spawners and the cumulative count of all carcasses through the date of the peak live count multiplied by an expansion factor. The expansion factor for the Early Stuart counts have been derived by comparing visual survey counts with total counts from up to three fences used to enumerate spawning escapement in local streams. A fixed expansion factor of 1.8 is typically used for most of the other sockeye stocks, monitored using visual survey techniques. The 1.8 expansion factor was based on historic comparisons of visual surveys and estimates derived from mark-recapture or fence enumeration techniques (Woodey 1984). Schubert and Houtman 2007 noted that "the source data for these comparisons, however, are not documented in published reports and are available to DFO only in unpublished form". No estimates of precision are available for Fraser sockeye escapement estimated using visual techniques. Cousens et al. (1982) found that visual survey techniques could produce estimates as precise as ±30% when observations are made by experienced surveyors under good conditions. The accuracy of estimates derived from visual survey data has been assessed for several stocks and expansion factors are almost always higher than the historical 1.8 factor. Given these results and the potential for visual surveys to miss fish when water clarity is poor or the fish are spawning in deep water (e.g., lakes or deep rivers), it is likely that escapement estimates from visual surveys are biased negatively (i.e., underestimate the true number of spawners). However, the effect of this negative bias on the total escapement estimate for Fraser sockeye would be relatively small because over 75% of the total escapement estimate is derived using the more reliable fence and mark-recapture techniques.

Alternative escapement estimation Methods

Virtually every type of enumeration method used to estimate escapement for salmon has been used in the Fraser watershed for Fraser sockeye. A wide variety of hydroacoustic systems and test fisheries have been tested and used in the lower Fraser River to estimate the escapement from marine fisheries (Appendix J). The advances in hydroacoustic technology in the 1990s led to substantial changes and significant improvements in the methods used at the Mission hydroacoustic site between 2004 and 2010. The PSC Southern Endowment Fund has supported studies to evaluate new hydroacoustic systems and other methods for estimating sockeye escapement to the lower Fraser River.

The 2007-2010 Fraser fishwheels and telemetry studies (Robichaud et al. 2008; 2010; Smith et al. 2009) tested several methods similar to those used successfully on the lower Nass River to enumerate escapements of sockeye, Chinook, coho and steelhead (Link and English 1996; Alexander et al. 2002). Fishwheels were tested at the two best sites downstream of Mission throughout the sockeye migration period under a widely varying river flow and abundances of other co-migrating salmon species. Conventional external tags (spaghetti tags) were applied to all sockeye and Chinook salmon caught by the fishwheels in 2007 and 2008 and upstream fisheries were sampled for mark-rate information. These assessments clearly indicated the portion of the run that could be captured by fishwheels and sampled for mark-rates by in-river fisheries was too low to provide reliable estimates of lower river escapement for Fraser sockeye (Robichaud et al. 2008; Smith et al. 2009). In 2009, the focus of the fishwheel studies shifted towards obtaining near-shore samples of species composition and providing sockeye for radio-telemetry studies designed to assess the magnitude and location of en-route losses. The PSC Mission hydroacoustic estimates were split into near-shore (within 50 m of each river bank) and off-shore strata (>50 meters from each river bank). The species composition of the Crescent Island fishwheels and the Whonnock gillnets were applied to the near-shore and off-shore counts, respectively, to derive daily estimates of the number of sockeye passing Mission; results were consistent with the PSC's 'best judgement' in-season sockeye abundance estimates. This method, combined with DIDSON hydroacoustic estimates for near-shore areas in September 2009, provided daily estimates of the number of Chinook and pink salmon passing Mission that were consistent with the pre-season expectations and post-season escapement estimates for these species (Robichaud et al. 2010).

Capture and assessment methods for other fish such as fences, traps and tower counts are not feasible or suitable for the lower Fraser River. The lower Fraser River is more than 500 m at the majority of sites below Mission and river discharges can exceed 10,000

m^3/sec during the sockeye run. Fish traps similar to those tested in the lower Skeena in 1983 (Griffiths and English 1984) or used in marine waters (e.g., Annette Island Alaska) are not practical for the lower Fraser River because of strong river currents and the abundance of harbour seals. The turbidity and depth of the lower Fraser rule out visual enumeration techniques like the tower count methods used in Alaska.

As indicated above, the primary methods used to estimate escapements to spawning areas have been mark-recapture, counting fences and visual surveys. Tower counts are used in some streams to guide mark-recapture estimates but are not used to generate the final escapement estimate. In recent years, mark-recapture programs for several of the larger Summer-run stocks (e.g., Horsefly and Chilko) have been replaced with partial weirs and DIDSON hydroacoustic systems (Cronkite et al. 2006). These DIDSON systems, while not suitable for all streams, are less costly than mark-recapture studies for large populations and have been demonstrated to provide counts as accurate as visual counts from clear water streams when the sonar beams cover the entire area occupied by migrating fish (Holmes et al. 2006). The methods used currently to estimate escapements to spawning areas are appropriate and the best of the available alternatives for Fraser sockeye.

Table 23 Spawning ground escapement estimates for Fraser sockeye derived using mark-recapture techniques, 2006-2009.

	Adult Males					Adult Females					Total Adult Escapement	
	Tags	Carcass Recovery		Escapement		Tags	Carcass Recovery		Escapement			
2006	Applied	Tagged	Total	**Estimate**	+/-	Applied	Tagged	Total	**Estimate**	+/-	Estimate	Precision
Seymour River	1,037	186	7,968	**45,670**	6,184	1,504	243	10,214	**61,517**	6,984	107,187	12%
Upper Pitt River	821	184	3,828	**17,276**	2,548	957	184	4,071	**21,540**	4,031	38,816	17%
Chilko River/Lake [a]	3,629	801	46,200	**199,987**	13,386	5,174	1,449	75,746	**268,960**	13,124	468,947	6%
Horsefly River [b]	1,382	246	4,763	**46,785**	9,150	1,650	304	7,119	**59,929**	9,685	106,714	18%
Adams River [c]	9,178	1,586	117,386	**713,344**	35,945	8,074	1,104	101,514	**748,017**	43,759	1,461,361	5%
Little River [d]	1,161	180	49,747	**200,095**	27,713	1,324	140	33,161	**216,695**	33,457	416,790	15%
Lower Shuswap [e] River	6,065	1,280	84,511	**400,006**	23,400	5,736	898	78,738	**505,546**	35,248	905,552	6%
2007												
Upper Pitt River	804	222	3,844	**20,849**	3,869	952	302	5,445	**19,483**	2,360	40,332	15%
Chilko River/Lake [a]	2,433	251	14,779	**145,669**	16,869	2,785	442	26,136	**159,940**	13,464	305,609	10%
Horsefly River [b]	528	97	4,493	**29,314**	7,169	551	92	5,106	**25,867**	5,535	55,181	23%
Stellako River	1,704	409	4,890	**20,419**	1,650	2,042	612	6,294	**20,873**	1,315	41,292	7%
Adams River [c]	714	71	2,358	**22,928**	5,139	759	93	3,778	**30,009**	5,621	52,937	20%
2008												
Upper Pitt River	742	229	1,646	**7,500**	1,536	932	265	2,014	**7,919**	1,244	15,419	18%
Chilko River/Lake [a]	2,143	74	3,674	**119,981**	26,833	2,890	88	4,301	**131,171**	26,680	251,152	21%
Stellako River	2,903	956	24,983	**74,205**	3,749	3,058	941	26,947	**85,366**	4,453	159,570	5%
Tachie River	1,017	196	11,852	**61,571**	7,655	1,325	256	12,154	**61,309**	6,625	122,880	12%
2009												
Pitt River, upper	1,126	268	2,651	**10,813**	1,935	1,038	206	4,199	**17,676**	2,771	28,489	17%
Harrison River	5,841	569	21,566	**198,234**	17,034	1,489	131	11,728	**f**	f		
Tachie River	398	56	3,296	**23,736**	5,673	686	140	4,990	**23,651**	3,407	47,387	19%

a. Study area includes Chilko River and Chilko Lake

b. Study area includes Horsefly River, Little Horsefly River, Moffat Creek, Lower McKinley Creek, Tisdall Creek, and Horsefly ASG

c. Study area includes Adams River, Adams River delta, and Cruickshank Point shore spawners

d. Study area includes Little River and Little Shuswap Lake

e. Study area includes Lower and Middle Shuswap Rivers, and Kingfisher, Trinity and Wap Creeks.

f. Mark-recapture estimate not computed for Harrison female spawners in 2009.

Escapement Targets

Our evaluations related to escapement targets address the following task as defined in the initial Statement of Work:

> *3.15 The Contractor will evaluate the scientific basis for determining escapement targets. The current and historical effectiveness of fisheries management, including reliance on the Fraser River Sockeye Spawning Initiative (FRSSI), to achieve sockeye escapement goals for individual CUs will be evaluated.*

Fraser sockeye fisheries are managed by an international panel to achieve year-specific harvest rates or escapement goals for each of the four run-timing groups. The Canada/U.S. Pacific Salmon Treaty (1999 Revised Annex 4, Chapter 4, Section 3b) defines the spawning escapement objective for Fraser sockeye as:

> *"…the target set by Canada including any extra requirements that may be determined by Canada and agreed to by the Fraser River Panel, for natural, environmental or stock assessment factors, to ensure the fish reach the spawning grounds at target levels. Any additional escapement amounts believed necessary by Canada for other than the foregoing will not affect the U.S. catch."*

From 1987 to 2002, escapement targets for Fraser sockeye were based on the "Rebuilding Plan" developed in 1985 following the signing of the Pacific Salmon Treaty. The rebuilding strategy was "to increase annual escapement incrementally from historic levels" (Staley 2010). The implementation plan for this rebuilding strategy defined:

- *Lower bounds for annual target escapement designed to maintain escapements above brood year levels for Early Summer, Summer-run and Late-run aggregates;*
- *Lower bound for annual target escapement on the Early Stuart aggregate fixed at 66,000 spawners and then revised to 75,000 spawners through consultations; and*
- *Upper bounds for annual target escapement for all aggregates were based on a 65-70% exploitation rate ceiling (Staley 2010), therefore, the upper bound varies with run size.*

Support for this approach was strong through the late 1980s and early 1990s as returning abundances increased with increasing escapement and higher marine survival. The declines in survival, total returns and catch in the late 1990s undermined support for the rebuilding plan in the early 2000's. In 2003, DFO conducted a review of the 1985 rebuilding strategy resulted in the initiation of a new process, the Fraser River Sockeye Spawning Initiative (FRSSI), for setting annual escapement goals and target exploitation rates for Fraser sockeye. A detailed description of the FRSSI process and models can be found in a number of DFO workshop reports (e.g., DFO 2009b) and one published report (Pestal et al. 2008). Staley (2010) provides a review of the FRSSI process and the methods used to set the interim conservation benchmarks and Fraser sockeye spawning targets for the 2007-2010 fishing seasons.

Current Escapement Goals

Two types of escapement goals or reference points for Fraser sockeye have been defined through the FRSSI process: (1) low escapement benchmark, and (2) fixed escapement target. The definition of these escapement goals is complicated by the historical pattern of cyclic dominance for several of the largest sockeye stocks. This cyclic dominance pattern can result in returns being more than 1500-fold larger on the dominant cycle line than off-cycle lines (e.g., Quesnel run size was estimated to be ~6,000 in 1984 and ~10M in 1993). Since most Fraser sockeye return at age four, the dominant, sub-dominant and off-cycle patterns have been maintained for these cyclic dominant stocks over many years. Consequently, DFO has defined the "reference points" for Fraser sockeye relative to the average of the 4-year sequence of escapements for each of the 19 indicator stocks (Table 24, DFO 2009b). The MSC certification process, recently completed for Fraser sockeye (Devitt et al. 2010), requires fisheries managers to define Limit Reference Points (LRPs) and Target Reference Points (TRPs) for each stock management unit. DFO has initiated a formal process under the WSP to define these reference points for Fraser sockeye (Holt et al. 2009). In the interim, DFO has been using their "low escapement benchmarks" as the operational equivalent of LRPs and their "fixed escapement target" as the operational equivalent of TRPs.

The low escapement benchmark (LEB) values have been defined through the FRSSI process as the highest value out of the following five alternatives, calculated for each of the indicator stocks:

- 20% of the average of the 4-year sequence of escapements that maximizes recruitment (Bayesian estimate, Larkin fit);
- 40% of the average of the 4-year sequence of escapements that maximizes recruitment;

- 20% of the average of the 4-year sequence of escapements that maximizes the log of recruitment;
- 40% of the average of the 4-year sequence of escapements that maximizes the log of recruitment; or
- Smallest observed 4-year average.

For most stocks, LEBs are set equal to 40% of the 4-year average escapement that maximizes recruitment. The low escapement benchmark for each of the four run-timing groups is the sum of the benchmarks for the identified indicator stocks within each run-timing group (Table 24).

The "Fixed Escapement Target" is the escapement target defined for all run sizes between the "no-fishing point" and the "Cut-Back Point" defined by the Total Allowable Mortality Rule (Figure 15). These target escapement levels have been defined for the four run-timing groups but not for individual stocks in Table 24. The approach of defining escapement goals based on a 4-year average is reasonable if none of the stocks are highly cyclic. These types of goals are not very informative or useful for the management of run-timing groups that contain highly cyclic stocks. The "true" target escapement levels for the dominant cycle of highly cyclic stocks like Quesnel and Late-Shuswap would be 3-4 times the 4-year average and those for off-cycle years would be 10-20% of the 4-year average. In addition, the target escapements defined for a specific year vary with run size and tend to be larger that the "Fixed Escapement Target" based on a 4-year average, as defined in Table 24. Table 25 provides examples of the escapement targets defined for each run-timing group for 2003-2006 as documented in the PSC Fraser Panel reports for these years (PSC 2007; 2008; 2009; 2010). For all Fraser sockeye combined, the annual targets based on post-season run-size estimates ranged from 2-6.2 million from 2003-2006 compared to the 1.2 million "Fixed Escapement Target"; and observed escapements were consistently less than the annual escapement targets (range -2 to -77%). For Early Stuart, the escapement targets, based on the post-season run size estimates, varied from 29,000 to 171,000 with an average of 86,000 for comparison with the 108,000 Fixed Escapement Target. For the Early Summer group, the escapement targets varied from 207,000 to 728,000 with an average of 423,000 for comparison with the 120,000 Fixed Escapement Target. For the Summer-run group, the escapement targets varied from 1,130,000 to 3,375,000 with an average of 1,969,000 for comparison with the 520,000 Fixed Escapement Target. For the Late-run group (Birkenhead+Late), the escapement targets varied from 321,000 to 3,328,000 with an average of 1,261,000 for comparison with the 500,000 Fixed Escapement Target.

The lack of clearly defined escapement targets for each indicator stock and the large year-to-year variability in escapement targets for each run-timing group makes it difficult to regulate fisheries and evaluate management performance. The trend towards increasing complexity in the definition of escapement goals may have become an impediment to achieving these goals. From 2003-2006, observed escapement was substantially less than the escapement targets for three of the four run-timing groups (-42% to -54%). Within the Late-run groups, the observed escapement to Birkenhead exceeded the escapement target in 2003 and 2006 and the average for the "True Late" stocks was only slightly less than the target (-9%). A detailed comparison of observed escapement with the escapement targets for each of the 19 indicator stocks was not possible because the annual targets have not been documented for each of these stocks. A clearly defined set of escapement targets for each indicator stock and run-timing group would be much easier to communicate to fishers than the current complex Total Allowable Mortality (TAM) rules and still allow managers the latitude to implement harvest rate ceilings to protect less productive stocks when returns of the target stocks are large.

The WSP has identified the need to define lower benchmarks (LBs) and upper benchmarks (UBs) for each Fraser sockeye stock. Holt et al. (2009) describe the methods that should be used to define these benchmarks and Grant et al. (2010) provided a range of estimates for each benchmark generated from alternative stock-recruitment models. However, the interim LBs and UBs defined through the FRSSI process and recent Canadian Science Advisory Secretariat (CSAS) working papers are fixed values intended to be compared with the 4-year average escapements for each stock or run-timing group (Staley 2010; Grant et al. 2010). These processes and CSAS papers have made substantive contributions to the definition of management goals and escapement targets but more work remains to be done. There should be at least two different LBs and two UBs for each cyclic stock. Since each run-timing group contains at least one cyclic stock, managers need cyclic-specific LBs and UBs for each run-timing group. These benchmarks or escapement goals would make it easier to assess stock status and trends for each cycle year relative to these defined goals and determine if fisheries should be permitted to target specific stocks in a specific year. For example, if the run size is below the LB for a stock, no fisheries should be permitted to target that stock. The stock-specific benchmarks should be used to define the LBs, UBs and total allowable mortality (harvest plus natural mortality) for each run-timing group. The LB and UB for a run-timing group could simply be the sum of the values for the component stocks. The total allowable mortality for each run-timing group should be based on the in-season assessment of the total return, environmental conditions and status of each stock relative to its LB and UB.

Table 24 Low escapement benchmarks for each indicator stock and fixed escapement targets by run-timing group as defined through the Fraser River Sockeye Spawning Initiative (DFO 2009b).

		Five Alternatives for Low Escapement Benchmark					**Low Esacpement Benchmark**	**Fixed Escapement Target**
		Production BM x% of average for optimal 4-year escapement sequence				**Potential Conservation Reference Point**	max. of five alternatives	"No Fishing Point"
Timing Group	Indicator Stocks	% of Smax 20%	% of Smax 40%	% of logarithm(Smax) 20%	% of logarithm(Smax) 40%	Smallest Observed 4yr average	(Max. LRP)	(Min. TRP)
Early Stuart								
	E. Stuart	25,200	50,300	24,100	48,300	10,200	50,300	108,000
Early Summer								
	Bowron	2,500	4,900	2,500	4,900	3,000	4,900	
	Fennell	1,100	2,200	1,100	2,200	500	2,200	
	Gates	1,700	3,500	1,100	2,300	1,500	3,500	
	Nadina	2,900	5,700	2,000	3,900	5,800	5,800	
	Pitt	3,400	6,800	3,400	6,800	11,200	11,200	
	Raft	2,600	5,200	2,500	4,900	2,600	5,200	
	Scotch	900	1,800	2,000	4,000	2,200	4,000	
	Seymour	9,500	19,000	9,500	19,000	9,100	19,000	
	total	24,600	49,100	24,100	48,000	35,900	55,800	120,000
Summer								
	Chilko	66,400	132,900	66,400	132,900	164,500	164,500	
	Late Stuart	39,100	78,300	39,100	78,300	29,500	78,300	
	Quesnel	77,300	154,500	41,100	82,200	7,800	154,500	
	Stellako	22,700	45,400	22,700	45,400	37,000	45,400	
	total	205,500	411,100	169,300	338,800	238,800	442,700	520,000
Lates								
	Birkenhead	19,700	39,300	19,700	39,300	23,200	39,300	
	Cultus	3,700	7,300	3,700	7,300	1,800	7,300	
	Harrison	2,000	4,100	2,000	4,100	3,600	4,100	
	Portage	100	300	600	1,200	1,300	1,300	
	Weaver	8,900	17,800	8,600	17,300	14,500	17,800	
	L. Shuswap	111,100	222,100	111,100	222,100	320,500	320,500	
	total	145,500	290,900	145,700	291,300	364,900	390,300	500,000
Total		400,800	801,400	363,200	726,400	649,800	939,100	1,248,000

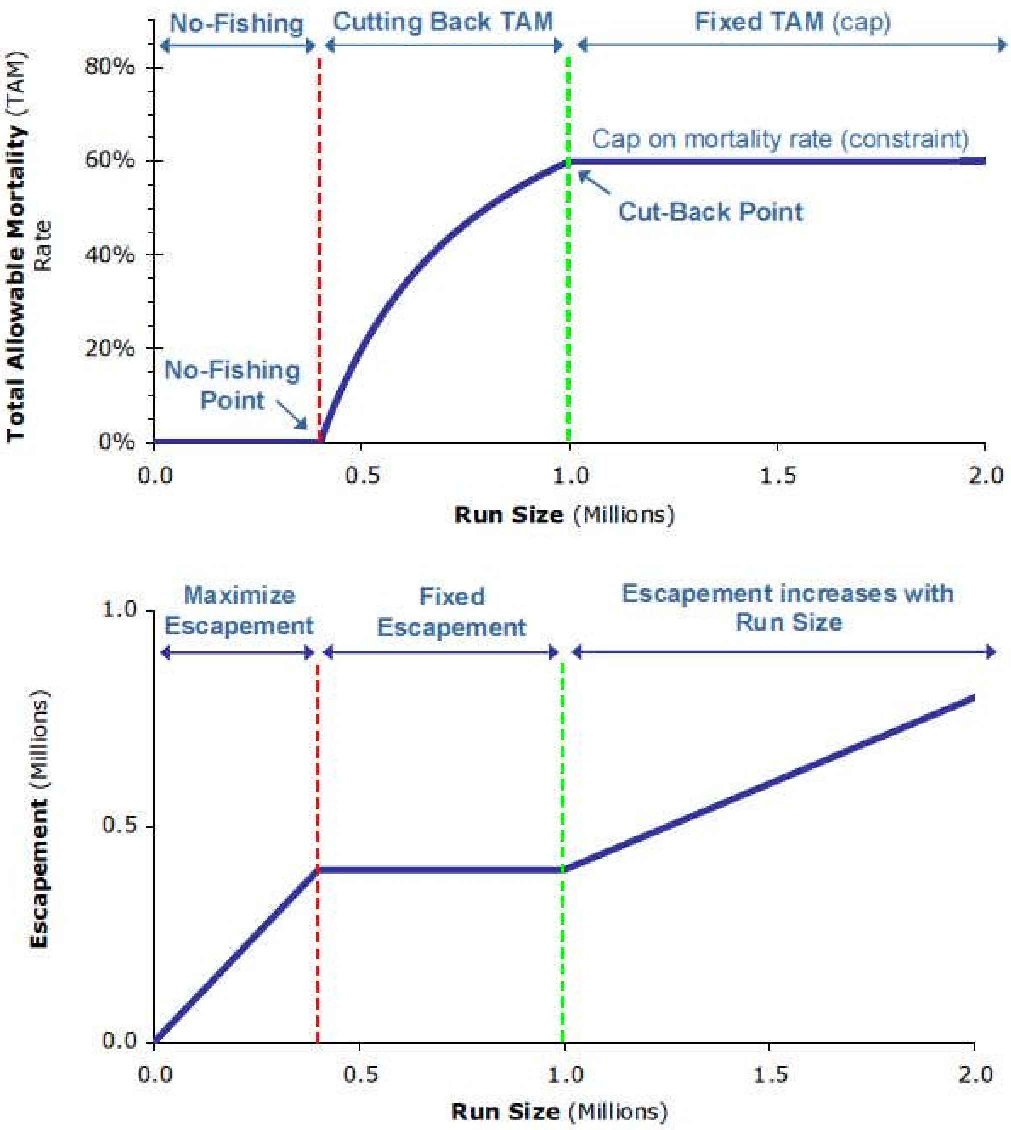


Figure 15 Illustration of Total Allowable Mortality (TAM) rule and corresponding escapement strategy (from DFO 2009b).

Table 25 Comparison of post-season escapement targets and observed spawning escapement for Fraser sockeye by run-timing group for 2003-2006. Counts are in 1000s of fish.

	Total	Escapement		Diff (Obs.-Target)	
	Run	Target[1]	Observed[2]	No.	%
2003 Post-season					
Early Stuart	30	29	13	-16	-55%
Early Summer	549	207	194	-13	-6%
Summer	2820	1130	1002	-128	-11%
Birkenhead	471	132	324	192	145%
Late	1018	525	446	-79	-15%
Total	4888	2023	1979	-44	-2%
2004 Post-season					
Early Stuart	137	90	9	-81	-90%
Early Summer	1240	434	150	-284	-65%
Summer	2381	1424	273	-1151	-81%
Birkenhead	157	94	63	-31	-33%
Late	267	227	28	-199	-88%
Total	4182	2269	523	-1746	-77%
2005 Post-season					
Early Stuart	220	171	99	-72	-42%
Early Summer	622	322	225	-97	-30%
Summer	5400	3375	2455	-920	-27%
Birkenhead	164	103	59	-44	-43%
Late	629	535	471	-64	-12%
Total	7035	4506	3309	-1197	-27%
2006 Post-season					
Early Stuart	56	54	36	-18	-33%
Early Summer	1820	728	392	-336	-46%
Summer	2522	1948	815	-1133	-58%
Birkenhead	635	254	290	36	14%
Late	7934	3174	3129	-45	-1%
Total	12967	6158	4662	-1496	-24%
4-year Average					
Early Stuart	111	86	39	-47	-54%
Early Summer	1058	423	240	-183	-43%
Summer	3281	1969	1136	-833	-42%
Birkenhead	357	146	184	38	26%
Late	2462	1115	1019	-97	-9%
Total	7268	3739	2618	-1121	-30%

[1] Target escapements calculated by applying DFO's escepement plan to the post-season run-size estimate

[2] DFO's spawning escapement estimate.

Escapements versus Minimum Escapement Goals

In this section, we compare the 4-year running average of observed escapements from 1960-2009 with the Low Escapement Benchmarks (LEBs) or “Interim LRPs” as defined in Table 24 for each run-timing group (Figures 16-19). The “Fixed Escapement Targets, or “Interim TRPs”, are also provided in these figures but not used to evaluate management performance because the annual escapement targets vary with run size and can be substantially different from the “Fixed Escapement Targets” derived from the TAM rule, as discussed above.

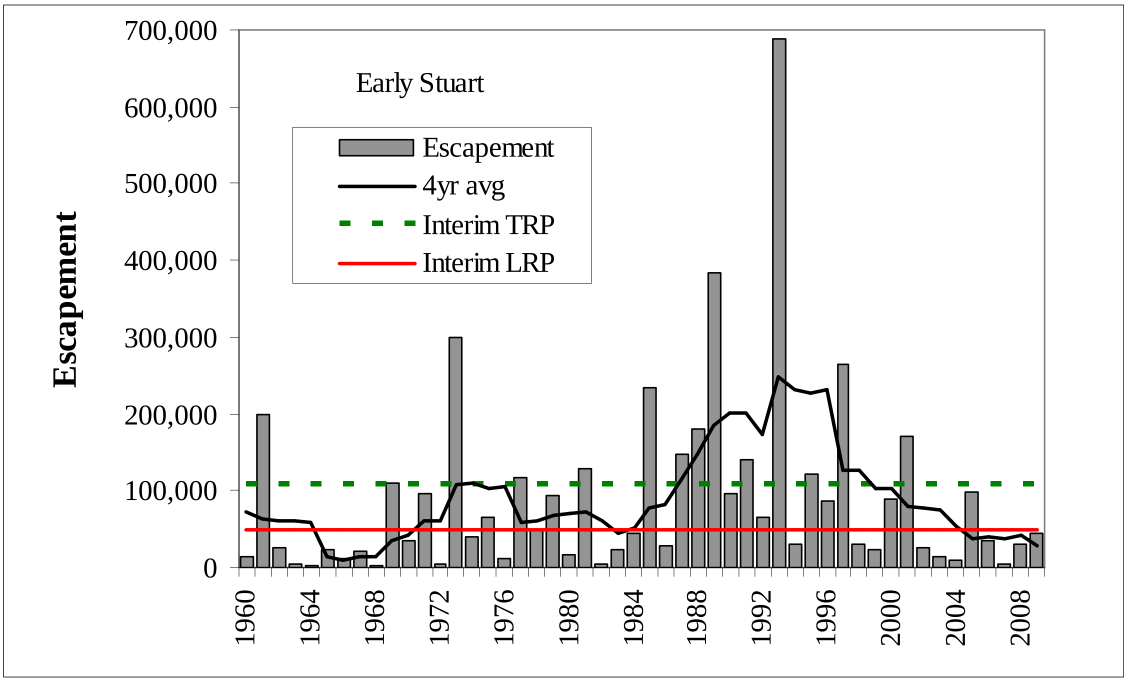


Figure 16 Escapement and operational reference points for Early Stuart sockeye.

The 4-year average escapement for Early Stuart sockeye has been above the Low Escapement Benchmark (LEB) for most of the years since 1970 but only five of the last 10 years (Figure 16). The two operational reference points were developed through the FRSSI process and implemented since 2006. The lower reference point (red line= 50,300) is the interim 4-year average escapement benchmark intended to delineate low escapement for this stock, and should be compared to the 4-year running average of escapement (black line in Figure 16). The 4-year average dropped below the LEB line from 2005-2009 because of the very low returns from 2002-2009. No commercial fisheries have been permitted to target Early Stuart sockeye stocks during this period and First Nation fisheries for FSC purposes have been very limited.

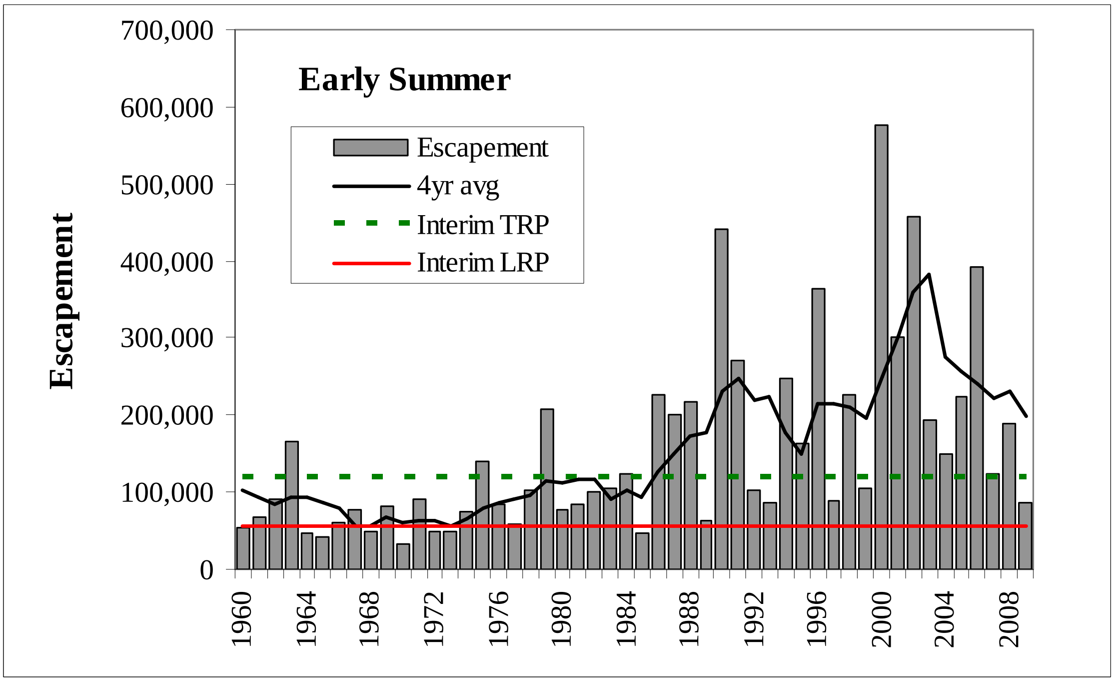


Figure 17 Escapement and operational reference points for Early Summer sockeye. The Early Summer run timing group includes eight stocks: Bowron, Fennel, Gates, Nadina, Upper Pitt, Raft, Scotch, and Seymour, as well as variable contributions from miscellaneous populations.

The 4-year average escapement for Early Summer sockeye has been consistently above the LEB since 1975 (Figure 17). There are no years since 1990 when the annual total escapement for this run-timing group has been less than the LEB. The Early Summer group includes eight indicator stocks with defined LEBs. We compared these LEBs with the historical escapement estimates for these stocks. Since the early 1980's, the 4-year moving averages of the annual escapement estimates have consistently exceeded the LEBs for each of the Early Summer indicator stocks, except Bowron sockeye. For Bowron, the 4-year moving average was consistently above the Bowron LEB prior to 2006 but lower than the LEB in 2007-2009. Fisheries were not permitted to target the Bowron stocks and other components of the Early Summer group in these years.

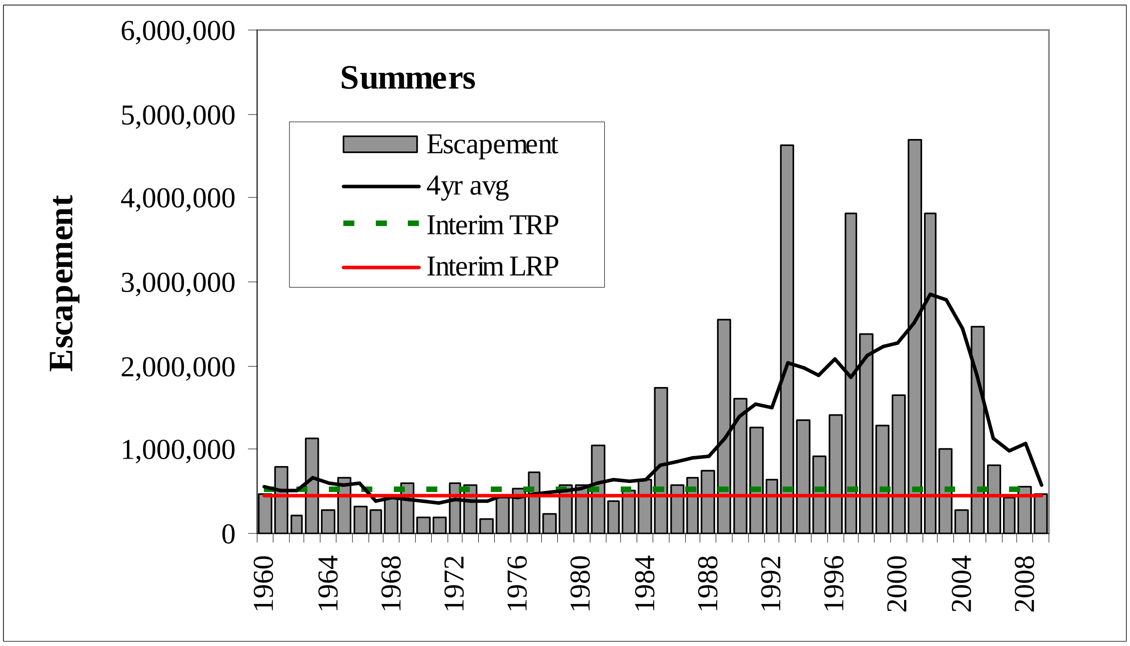


Figure 18 Escapement and operational reference points for Summer-run sockeye. The Summer-run timing group includes four stocks: Chilko, Quesnel, Late Stuart, and Stellako. Quesnel and Late Stuart follow a pronounced 4-year cyclic pattern.

The 4-year average escapement for Summer-run sockeye has been consistently above the LEB since 1980 (Figure 18). The annual total escapement for the Summer-run dropped below the LEB once in the past 10 years (2004), when in-river migratory conditions resulted in substantial mortalities between Mission and the spawning grounds. From 2007-2009, when escapements approached the LEB, commercial fisheries were not permitted and First Nation fisheries for FSC purposes were substantially reduced. The Summer-run sockeye includes four indicator stocks with defined LEBs. These LEBs were compared with the historical escapement estimates for these stocks and confirmed that the 4-year moving averages of the annual escapement estimates have consistently exceeded the LEBs for each of the Summer-run indicator stocks since the early 1980s.

The 4-year average escapement for Late-run sockeye has been consistently above the LEB since 1970 (Figure 19). The LEB and 4-year average values are heavily influenced by the dominant cycle line, where run size can be 4000-fold larger than those observed in off-cycle years (e.g., Adams River run was estimated to be ~1,700 in 1989 and ~7M in 1990). Consequently, the annual total escapement for this run-timing group is usually substantially above the LEB in dominant cycle years (e.g., 2002), close to the LEB in sub-dominant cycle years (e.g., 2003), and less than the LEB for the two off-cycle years (e.g., 2000 and 2001).

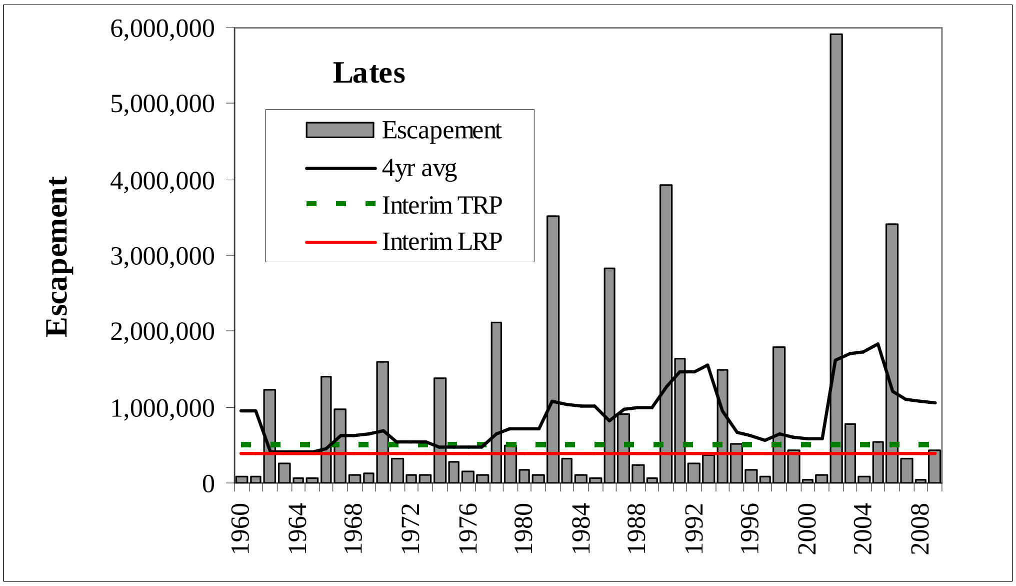


Figure 19 Escapement and operational reference points for Late-run sockeye. The Late-run timing group includes six stocks: Late Shuswap (includes Adams, Lower Shuswap), Birkenhead, Weaver, Cultus, Harrison, and Portage, as well as variable contributions from miscellaneous populations. Late Shuswap follow a pronounced 4-year cyclic pattern.

As for the other run-timing groups, commercial fisheries are closed or very limited in years when run sizes approach the LEB and most of the catch is taken in First Nation FSC fisheries. In recent years, fishing opportunities in dominant cycle years (e.g., 1998, 2002, 2006) have been greatly reduced from historical levels due to conservation concerns related to Cultus sockeye. The 4-year running average of the annual escapement estimates have been consistently below the LEB for Cultus sockeye since 1990 (Figure 20). Prior to 1996, fisheries harvested a substantial portion of the annual return for Cultus sockeye but fisheries restrictions implemented in 1998 have resulted in very limited harvests of Cultus sockeye over the past 10 years. In addition to Cultus, the Late-run timing group includes 5 indicator stocks. The LEBs for these other indicator stocks were compared with the historical escapement estimates and we confirmed that the 4-year moving averages of the annual escapement estimates have consistently exceeded the LEBs for each of these stocks since the early 1970s.

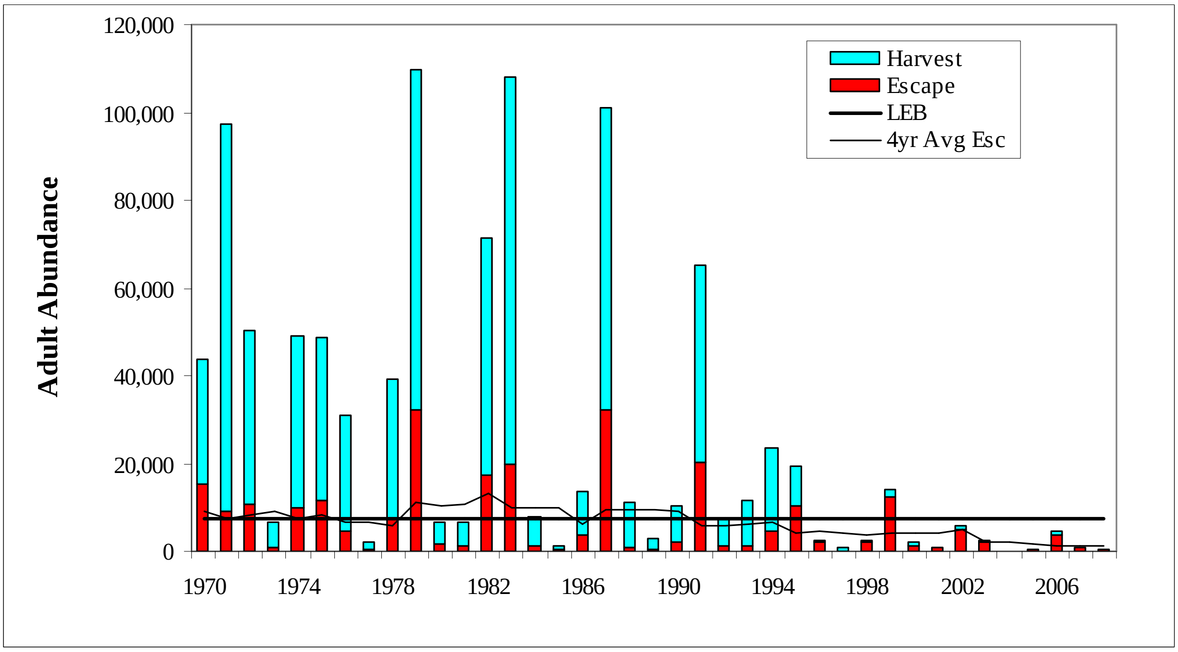


Figure 20 Annual escapement and harvest estimates for Cultus Lake sockeye along with the 4-year running average of escapement and Low Escapement Benchmark (LEB), 1970-2008.

Summary

Low Escapement Benchmarks (LEBs) have been defined for each Fraser sockeye indicator stock and run-timing group. These LEBs have been used in the Fraser River Sockeye Spawning Initiative and Marine Stewardship Council certification process to evaluate management options and stock status for Fraser sockeye. For most stocks, the LEBs were set equal to 40% of the 4-year average escapement that maximizes recruitment. Historical escapement for each indicator stock and run-timing group was compared with these LEBs to assess stock status and trends. For three of the four run-timing groups, escapements to spawnng areas have been consistently above the LEBs. The recent escapements for the fourth run-timing group (Early Stuart) have fallen below its LEB goal from 2005-09 but no commercial fisheries have been permitted to target early run-timing group in these years. Some harvesting of Early Stuart sockeye has been permitted in middle and upper Fraser First Nations FSC fisheries. Escapement of all summer-run stocks declined rapidly from 2003 to 2009 and most sockeye were closed from 2007-09 to maximize escapements for these stocks. Within the Early Summer and Late-run timing groups, two stocks (Bowron and Cultus) have been consistently below their LEBs in recent years.

Total Abundance Estimates and Extent of Overharvesting

Our evaluations related to overharvesting address the following task as defined in the initial Statement of Work:

> *3.16 The extent and impact of any overharvesting from 1985 to present will also be evaluated.*

We have included an examination of the reliability of the total abundance estimates in this section because exploitation rates require reliable estimates of total abundance. This section includes our assessment of the *extent* of overharvesting but does not address the potential *impact* of overharvesting that might have occurred. The task of evaluating impacts was removed from our assignment during our September 2010 scoping meeting because it was recognized that this would require substantially more time than was available for this project.

Total Abundance Estimates

The previous sections have provided evaluations of the accuracy, precision and reliability of the various catch and escapement monitoring programs. For many stocks, the estimated total abundance of returning adults is the sum of stock specific catch estimates and escapement estimates. For Fraser sockeye, another important component is "en-route loss" which is defined as the number of fish that die between river entry and the spawning area assessment sites that are not accounted in fishery harvest estimates (Figure **21**). Prior to 1992, en-route losses were not estimated for Fraser sockeye but pre-spawn mortality rates were reported to exceed 60% in some years (Wood 1965; Roos 1991). Pre-spawn mortality is defined as the number of fish that reached their spawning area but died before spawning.

Any potential relationship between en-route loss and pre-spawn mortality is difficult to assess with the available data because there is substantial uncertainty associated with many of the en-route loss estimates and both types of losses can vary substantially between stocks and over the upstream migration and spawning period. For example: the official PSC estimate of en-route loss was 0% for two Summer-run sockeye stocks (Stellako and late-Stuart) in 2005 and 26-46% for the other two major Summer-run stocks (Chilko and Quesnel). Telemetry studies of Late-run sockeye in 2002, 2003 and 2006 showed a consistent pattern of lower in-river survival (higher en-route loss) for fish that past Mission in early to mid August than fish that pass Mission in September (English et al. 2005; Robichaud and English 2007). Pre-spawn mortality is typically higher for late-run stocks early in the spawning period (Timber Whitehouse, DFO Kamloops, per. comm.); however, this pattern is not consistent in every year.

Given the magnitude of some en-route loss estimates (over 90% for Early Summer stocks in 2004), estimating en-route loss becomes critical for deriving reliable estimates of total abundance and exploitation rates. Figure 22 provides the annual abundance estimates (including en-route losses) and the associated exploitation rates per run-timing group. We have expanded the time period back to 1960 to provide a longer perspective on trends in abundance and exploitation rate. If significant en-route losses occurred prior to 1992 but were not detected or estimated, this would contribute to a positive bias in the exploitation rates estimates prior to 1992. However, en-route losses could be a recent phenomenon associated with the earlier river entry timing for many Late-run stocks and higher river water temperatures that likely affect the magnitude of en-route losses for all run-timing groups.

Extent of Overharvesting

The estimates of total abundance and exploitation rate show a number of clear trends for each of the run-timing groups (Figure 22). The total abundance for Early Stuart sockeye was highly variable with no clear trends from 1960-1997 and consistently low from 1998-2009. Exploitation rates (ERs) were relatively high (averaging 75%) from 1960-1983, highly variable from 1984-2000 (10-70%) and consistently low (averaging 13%) from 2001-2009. While 70-80% ERs are very high in recent context of low and declining productivity, the substantially higher productivity of Fraser sockeye from 1960-1980 appeared to support these higher ERs. With the declines in recruits per spawner starting in the mid-1980s (Peterman et al. 2010), it is likely that some degree of overharvesting occurred during the 1984-2000 period. Given recent trends in abundance it will be important to keep ERs for this stock at or below the 13% average level to allow for rebuilding of this stock if recruits per spawner improves. If recruits per spawner do not improve, ERs should be reduced to near zero for this stock.

The total abundance for the Early Summer group was fairly consistent during the 1960-1989 period and higher but more variable from 1990-2009. ERs were relatively high (averaging 77%) from 1960-1989, and show a declining trend since 1993. Given the increasing trend in abundances observed in the 1998-2006 period when ERs were in the 20-50% range, it is likely that many of the Early Summer stocks were overharvested during the 1960-1989 period. This overharvesting was likely the result of run-timing overlap with fisheries targeting the more abundant Summer-run stocks.

Summer-run stocks were fairly stable from 1960-1980, increased substantially on two of the cycle years from 1985-1993 and have subsequently declined to level below their historical average (Figure 22). As observed for Early Summer stocks, ER were consistently high (averaging 78%) from 1960-1989, and show a declining trend since 1993. Unlike Early Summer stocks, the abundance of Summer-run increased despite the high ERs and has declined during a period of reduced ERs. The increases and decreases observed for Summer-run groups on the 1985 and 1986 cycle years was largely due to trends in abundance for Quesnel sockeye, which had a clear period of higher than average productivity (recruits/spawner) for the 1981-1989 brood years and a clear trend of declining productivity to record low levels for the 2005 brood year (2009 returns). While there does not appear to be any evidence of overharvesting for Summer-run sockeye, the restriction of fisheries in 2001 and 2002 due to concerns for Late-run stocks resulted in an unusually high escapement for the Quesnel stock in two successive years (>3 million), which appeared to have affected the juvenile growth and fry-adult survival for the 2002 brood year. The average weight of fry sampled from Quesnel Lake in the fall of 2003 was <2 g (Woodey et al. 2005). Small fall fry generally result in small spring smolts and usually poor marine survival. The total return for the 2002 brood year for the Quesnel stock was 720,000 (0.2 recruits/spawner).

The Late-run group shows a much different pattern than the other timing groups, with a steady increase in abundance on the dominant cycle year from 1962-1986, a notable decline from 1990-1998 followed by larger returns in 2002 and 2006 (Figure 22). As observed for Early Summer and Summer-run stocks, ER was consistently high (averaging 76%) from 1960-1989, and had a declining trend since 1993. Like Summer-run stocks, the abundance trends for the Late-run group are driven by a single highly cyclic stock (Late Shuswap). This is one of the few Fraser sockeye stocks that has not shown a significant decline in recruits per spawner over the past 3-4 cycles (Peterman et al. 2010). The observed pattern of returns and ERs do not suggest that ERs have been excessive for the Late-run group as a whole; however, the high ERs for Late-run stocks prior to 1993 have been implicated in the decline of Cultus sockeye.

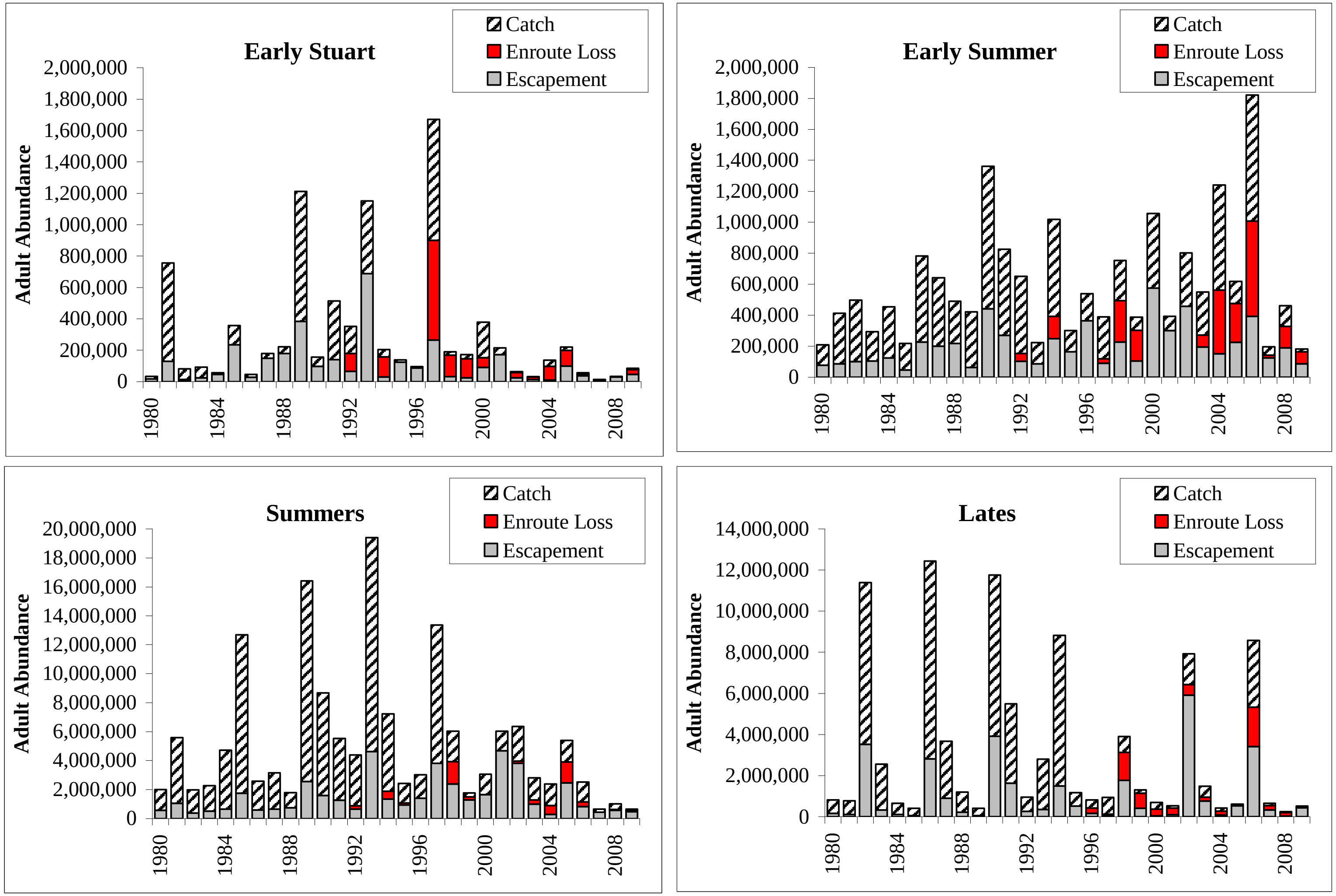


Figure 21 Estimates of total catch, escapement and en-route loss for Fraser sockeye by run-timing group, 1980-2009. En-route losses were not estimated prior to 1992.

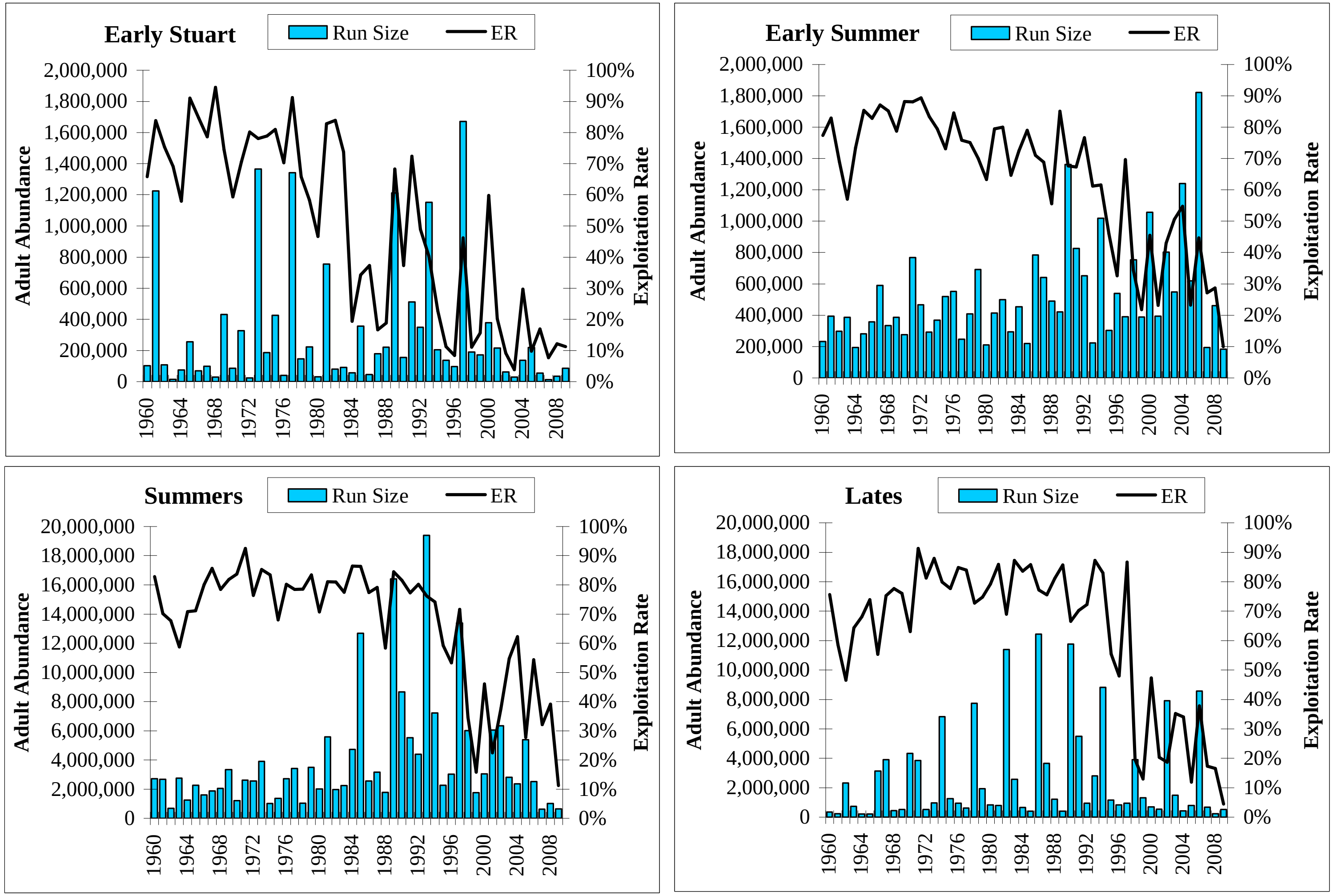


Figure 22 Estimates of total annual abundance and exploitation rates for Fraser sockeye by run-timing group for the period 1980-2009.

Cultus Lake Sockeye Recovery Efforts

Our evaluations related to Cultus Lake sockeye recovery efforst address the following task as defined in the Statement of Work (Appendix A):

> 3.17 *The Contractor will summarize the current conservation status of the Cultus Lake sockeye population, previously assessed by COSEWIC (Committee on the Status of Endangered Wildlife in Canada) to be endangered, and will evaluate whether DFO's recovery efforts have been effective in meeting stated recovery objectives. The Contractor will identify what recovery actions were available but not pursued by the Recovery Program.*

The Cultus Sockeye Recovery Team (CSRT) identified one over-arching conservation goal and four sequential conservation objectives:

> *Conservation Goal: To halt the decline of the Cultus sockeye population and to return it to the status of a viable, self-sustaining and genetically robust wild population that will contribute to its ecosystems and have the potential to support sustainable use.*
>
> *Objective 1: Ensure the genetic integrity of the population by exceeding a four-year arithmetic mean of 1,000 successful spawners with no fewer than 500 successful adult spawners on any one cycle.*
>
> *Objective 2: Ensure growth of the successful adult spawner population for each generation (that is, across four years relative to the previous four years), and on each cycle (relative to its brood year) for not less than three out of four consecutive years.*
>
> *Objective 3: Recover the population to the level of abundance at which it can be de-listed (i.e., designated Not at Risk) by COSEWIC.*
>
> *Objective 4: Over the long-term, recover the population to a level of abundance (beyond that of Objective 3) that will support ecosystem function and sustainable use.*

Progress has been made on a variety of Cultus sockeye conservation efforts, such as reducing predator abundance in Cultus Lake, reducing harvest rates on Cultus adults, maintaining genetic diversity in captive Cultus sockeye populations, and increasing the number of sockeye recruits (hatchery fish). Nevertheless, the CSRT Conservation Strategy objectives (listed above) have not been met. With regard to Objective 1, the mean number of successful spawners for the most recent four years (2006-2009) was 1,426 compared to the goal of 1,000; however, in 2008 the escapement estimate was 340 compared to the minimum target level of 500 in any year. Objective 2 calls for observed increase in escapement for at least three of four consecutive years; however, escapements in 2008 and 2009 were lower than those observed four years earlier in 2004 and 2005. Cultus sockeye have not recovered to a level of abundance sufficient for COSEWIC to consider de-listing this population (Objective 3) and therefore this stock is a long way from achieving Objective 4. Given the uncertainty associated with the outcomes of various conservation actions, ongoing efforts should be considered "experimental" and thus require ongoing and rigorous monitoring programs. Key knowledge gaps are identified.

Cultus Lake Sockeye Conservation Status

Escapement for the Cultus Lake sockeye stock has been monitored since 1921 (Figure **23**). Beyond the large fluctuations in the size of the dominant run cycle, which peaked in the 1920s and late 1930s, there has been a precipitous decline in the size of the Cultus stock since the 1970s. Causes of the population decline include: (i) overexploitation, (ii) early migration into Cultus Lake causing increased exposure to parasitic disease and high pre-spawn mortality, (iii) invasive species such as the aquatic plant Eurasian watermilfoil that destroys salmon habitat and improves salmon-predator habitat, (iv) in-lake predation on juveniles by Northern Pikeminnow, and (v) Cultus Lake habitat alteration and destruction (COSEWIC 2003). Early evidence suggests the population decline may have stopped over the past two cycle years (DFO 2010).

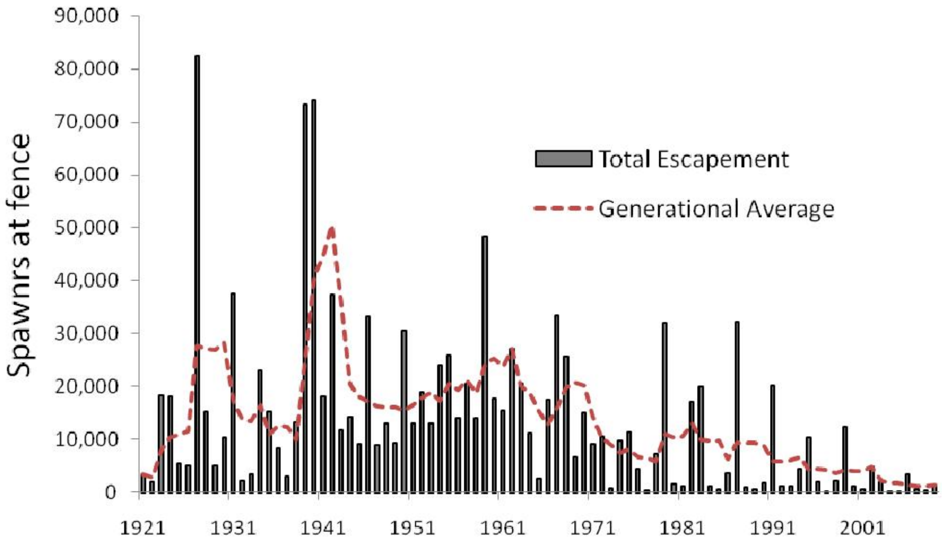


Figure 23 Number of adult sockeye entering Cultus Lake for the period 1921 to 2009. Figure from DFO 2010.

COSEWIC listed Cultus sockeye as endangered in an emergency assessment in October 2002; the listing was re-examined and confirmed in May 2003 (COSEWIC 2003). COSEWIC justifies the endangered status in this statement:

> *"The Cultus population has unique genetic and biological characteristics (migratory delay of adults at the Fraser estuary, protracted lake residency before spawning, exclusive lake spawning, late spawning date, deepwater life of fry). The lack of success with previous attempts to transplant sockeye to Cultus Lake and other lakes, suggests that Cultus sockeye are irreplaceable. The Cultus population has collapsed primarily due to overexploitation, including directed and incidental catches in mixed-stock fisheries at levels above those that can be sustained. An additional key source of impact on spawning adults since 1995 has been very high pre-spawn mortality, associated with unusually early migration into freshwater and with Parvicapsula parasite infestation. There are also ecological impacts to the lake habitat from colonization by Eurasian Watermilfoil, land development, stream channelization, nutrient input, and recreational use. Under present conditions, there is a high probability of extinction of the Cultus sockeye."* (COSEWIC 2003)

COSEWIC solicited the Minister of the Environment and Minister of Fisheries and Oceans for federal protection under the Species at Risk Act (SARA); a request that was eventually denied by the Governor in Council (GIC) in 2005:

> *"The Cultus and Sakinaw populations of Pacific sockeye salmon are not added to Schedule 1 [of SARA] because of the unacceptably high social and economic costs that the commercial fishing and recreational fishing sectors, some Aboriginal peoples, coastal communities and others would face if these species were added to Schedule 1. Although the overall health and resiliency of Pacific sockeye salmon is dependent on its overall genetic diversity, of which these two populations are a component, these two populations represent a small fraction of one percent of all B.C. sockeye salmon populations."* (Canada Gazette 2005)

Cultus Lake sockeye are currently listed as endangered by COSEWIC and DFO cites concerns about overexploitation, habitat degradation, and climate change in its most recent Cultus Lake Sockeye Salmon Status Report (DFO 2010). Given the relatively small population size (i.e., currently 5% of historical values) and poor understanding of factors limiting population recovery (e.g., spawning success of hatchery fish, factors causing low smolt-to-recruit survival), this population is vulnerable and at risk of extinction.

Recovery Objectives

In anticipation of a Schedule 1 listing under SARA, which would have given Cultus sockeye federal protection as an endangered species, DFO formed the Cultus sockeye Recovery Team (CSRT) in 2003. The CSRT published its National Recovery Strategy for Cultus Lake sockeye salmon the following year (CSRT 2004), identifying one over-arching recovery goal and four sequential recovery objectives.

> *Recovery Goal: To halt the decline of the Cultus sockeye population and to return it to the status of a viable, self-sustaining and genetically robust wild population that will contribute to its ecosystems and have the potential to support sustainable use.*
>
> *Objective 1: Ensure the genetic integrity of the population by exceeding a four-year arithmetic mean of 1,000 successful spawners with no fewer than 500 successful adult spawners on any one cycle.*
>
> *Objective 2: Ensure growth of the successful adult spawner population for each generation (that is, across four years relative to the previous four years), and on each cycle (relative to its brood year) for not less than three out of four consecutive years.*
>
> *Objective 3: Recover the population to the level of abundance at which it can be de-listed (i.e., designated Not at Risk) by COSEWIC.*
>
> *Objective 4: Over the long term, recover the population to a level of abundance (beyond that of Objective 3) that will support ecosystem function and sustainable use.*

After the GIC denied protection of Cultus sockeye under SARA (Canada Gazette 2005), DFO re-profiled the National Recovery Strategy into the National Conservation Strategy (CSRT 2009), which re-iterated the same recovery goal and recovery objectives as transcribed above but renamed them the conservation goal and conservation objectives, respectively.

The CSRT propose five general approaches to achieving the conservation goal and objectives:

1. Control exploitation by developing short and long-term harvest management plans that specify sustainable harvest rules and escapement policy for Cultus sockeye, especially with respect to mixed-stock fisheries.
2. Maximize freshwater survival by actions such as culling predators and predator habitat, and identifying factors causing early adult migrations into Cultus Lake, monitoring factors in the migratory corridor, controlling predation by marine mammals, and protecting against poachers.
3. Maintain assessments over the long term to adequately track population trends over time.
4. Fish culture to increase survival of all life stages, bolster population sizes in the wild, and maintain genetic diversity.
5. Community awareness to promote stewardship amongst residents, park visitors, farmers, businesses and resource industries in the Cultus Lake watershed.

The CSRT then divides these five approaches into a list of conservation action items: There are two relevant tables presented in Appendix K: the first table summarizes the action items that are either completed or under way to recover Cultus Lake Sockeye; the second table summarizes the actions identified by the CSRT as important but have yet to be implemented.

Progress has been made on a variety of Cultus sockeye conservation efforts, such as reducing predator abundance in Cultus Lake, reducing harvest rates on Cultus adults, maintaining genetic diversity in captive Cultus sockeye populations, and increasing the number of sockeye recruits (hatchery fish) (Bradford et al., report in preparation). For example, catches of Northern Pikeminnow (per unit effort) have declined dramatically in Cultus Lake since 2006. Freshwater survival of fry to smolts appears to have been increasing yearly since 2004 (although smolt to recruit survival appears unchanged over the same period). Fisheries management has reduced harvest rates to about 17% since 2003, down from about 67% in the period 1952-1972. Genetic diversity of released hatchery fish has increased since 2004. The captive breeding program has reduced the risk of a single catastrophic event driving low-abundance cycle years extinct by creating a parallel spawning population in captivity. Hatchery production in 2004 and 2005 generated over 90% of the 2008 return (340 fish), 67% of the 2009 escapement (889 fish), and about 60% of the 2008 smolt emigration that will return as adults in 2010.

Nevertheless, the CSRT (2009) Conservation Strategy objectives (listed below) have not been met. With regard to Objective 1, the mean number of successful spawners for the most recent four years (2006-2009) was 1,426 compared to the goal of 1,000; however, in

2008 the escapement estimate was 340 compared to the minimum target level of 500 in any year. Objective 2 calls for observed increase in escapement for at least three of four consecutive years; however, escapements in 2008 and 2009 were lower than those observed four years earlier in 2004 and 2005. Cultus sockeye have not recovered to a level of abundance sufficient for COSEWIC to consider de-listing this population (Objective 3) and therefore the stock is a long way from achieving Objective 4.

It is too early to know whether any of the various conservation efforts will translate into long-term population gains for the Cultus sockeye stock. For example, although hatchery releases are bolstering the number of returning adults, there are serious concerns about the viability of hatchery produced sockeye. The failed 2008 brood was from recruits comprising >90% hatchery fish. Smolt-to-recruit survival is also a genuine concern because current levels are substantially lower than historic levels: 5.8% average for the period 1952-1972, 2.6% average for the 1999-2005 broods, down to an average of 1.1% for the past 3 years. Some of the uncertainty associated with hatchery augmentation efforts will be reduced in the next few years, assuming the recovery and assessment programs continue. Given the current uncertainty associated with the outcomes of various recovery actions for Cultus sockeye, these actions need to be considered "experimental" (DFO 2010) and thus require ongoing and rigorous monitoring programs.

DFO is preparing a scientific review entitled "Status of Cultus Lake sockeye salmon", which reviews (Bradford et al., in preparation): (1) recent trends in the Cultus sockeye population, with focus on the last two generations, (2) the current status of the population relative to CSRT 2009 objectives 1 and 2 and proposed Wild Salmon Policy benchmarks, (3) the efficacy of the major recovery actions such as harvest reductions, captive broodstock, and predator control, and (4) results of a population viability analysis, which is a model that predicts possible future trajectories of the population as a function of various combinations of recovery actions and environmental conditions. Bradford et al. conclude their review of Cultus sockeye recovery by saying "future survival rates, short and long-term effects of the hatchery program, and the potential changes to the Cultus Lake food web from predator manipulation [are uncertain, thus] the prognosis for the Cultus Lake sockeye population remains highly uncertain." Finally, Bradford et al. finish by highlighting knowledge gaps and recommending direction for future population recovery actions, including:

1. A thorough monitoring program is necessary to carefully measure the benefits and possible risks of manipulating the Cultus sockeye population or the biological community of Cultus Lake.

2. The value of the captive breeding program needs to be reviewed. Long term supplementation may be a viable alternative to a captive program but this will depend on the relative reproductive success of hatchery fish in the wild.
3. In-lake predator control appears to be increasing juvenile sockeye survival; however, the potential negative ramifications of manipulating Cultus Lake's natural biological community is unknown and warrants further study.
4. To ensure the Cultus population persists despite poor smolt-recruit survival, all of the current recovery measures (harvest management, predator control, hatchery production) should be continued and managed adaptively.

BRISTOL BAY, ALASKA SOCKEYE FISHERY

Overview of Bristol Bay Sockeye Fisheries

Harvesting – Fish returning to nine river systems around Bristol Bay are targeted in five fishing districts with drift and set gillnets, which are the only commercial gear types allowed and account for virtually 100% of the total harvest. In 2009, there were 1,863 drift gillnet permits and 983 set net permits issued. The Bay sockeye salmon fishery is rather simple and straightforward with respect to allocation among user groups. The sport fishery is virtually nonexistent and subsistence fishing, while important from a cultural perspective and given the highest priority, is nominal in terms of relative magnitude (around 0.5% of the total run). Annual commercial harvest over the last 20 years has averaged 26 million fish and has ranged from 10 million to 45 million. Daily harvests at the peak of the annual fishery exceed 2 million fish on a regular basis and have been as high as 5.2 million fish on a single day (1993). The fishery occurs over about six weeks beginning early June and about 65% of the harvest occurs over a 2-week period centered on the 4th July. Harvest estimates are considered very accurate and precise as catches are tallied with a fish ticket system and are reported daily to the Alaska Department of Fish and Game (ADF&G). Furthermore, compared to other salmon fisheries there are few mixed species, mixed stock, or interception issues to contend with.

Escapement enumeration – The hallmark of the assessment system in Bristol Bay is its escapement monitoring projects operated by ADF&G. Counting towers are used for eight of the nine river systems (DIDSON sonar is used for the Nushagak River). When tower counts were compared to weir counts (assumed to be a complete census) on the Egegik River, relative error was -7.4%. Tower observer variability is negligible; even when experienced observers were compared to the inexperienced, percent errors ranged from -1.8% to +1.3%. No metrics of uncertainty around escapement counts are currently reported by ADF&G, but 95% confidence intervals were found to be <5% of the estimates in recent years for all systems.

Pre-season forecasting – Pre-season forecasts set the stage for the season but provide little influence on management decisions once the run has begun to arrive in the Bay—they are mostly done as a service to industry. ADF&G uses pre-season forecasts in two ways. First, they use it to help plan for orderly fisheries and ensure that adequate processing capacity will be available. Second, AMBs will use the pre-season forecast to identify conservation concerns associated with managing their districts and characterize, in a qualitative way, the degree of caution they will approach the early-season fishing in each district. A variety of methods have been tried/used for system-specific pre-season forecasting in Bristol Bay, but can be generalized into four types: (1) means models, (2) spawner-recruit models combined with assumed age composition, (3) sibling models, and (4) smolt models combined with assumed age composition. Beginning in 2001, all models were tried, but only the top performing model over the previous three years is used for the upcoming forecast. Forecasts are less reliable for individual stocks than all stocks combined. The high and low errors for individual stocks tend to cancel each other; as a result, total run forecasts for half of the years (i.e., the median) were within 15% of their corresponding observed returns and did not consistently over- or underestimate by an appreciable amount (MPE= -3%; 1990-2010).

In-season forecasting – In-season forecasts of returns to either the Bay as a whole or to specific fishing districts are not reported by ADF&G and done on an *ad hoc* basis by research staff and AMBs. Two sources of data are used for in-season forecasting: (1) the Port Moller test fishery, which intercepts the run 6-8 days prior to arrival in the Bay, and (2) catch and escapement (C+E) to date. The manager's use of the Port Moller information depends on how well the test fishery tracts the C+E estimates during the first part of the season. Given that subtle changes in run timing can affect the in-season forecasts, these forecasts are not particularly precise until later in the season when about 60% of the run has returned. The performance of both forecasts improves as the season progresses, and during the peak of the run (around July 4) MAPE for the C+E method is about 5% on average, but about 30% for the test fishery forecast.

Management – Ultimate management authority for salmon fisheries in Alaska rests with the Commissioner of the Alaska Department of Fish and Game (ADF&G). Regulations and regulatory management plans are established through a public process via the Alaska Board of Fisheries (BOF). Salmon fisheries in Alaska, including Bristol Bay, are somewhat unique compared to other jurisdictions in that the Commissioner of ADF&G delegates full management authority to open the fishery to local Area Management Biologists (AMBs). ADF&G's research biologists develop biological escapement goals for individual river systems based on sustained yield and/or maximum sustained yield (MSY) principles using relationships between escapement levels and subsequent returns (termed stock-recruit analyses). The primary duty of all AMBs is to hit these goals and distribute the escapements across the season based on historical run timing schedules. The tools available to AMBs in more or less chronological order are: (1) pre-season forecasts, (2) offshore test fishing at Port Moller, (3) district test fishing, (4) commercial fishery performance with catch and age sampling, (5) inside test fishing, (6) aerial surveys, (7) escapement monitoring. Historically, AMBs have been very adept at hitting escapement goal targets for several reasons: (1) catch and escapement estimates are very accurate, precise, and timely, (2) essentially no exploitation occurs up-river of the enumeration projects, (3) the nine systems are managed more or less individually with few interception/mixed stock fishery issues, (4) high exploitation rates (80-90%) can be turned on and off from tide to tide, and (5) managers are given immediate and direct authority.

Introduction

The purpose of this section is to provide an overview of sockeye fishery management in Bristol Bay, Alaska, and to characterize the pre-season and in-season forecasting methods used by fishery managers. We do not provide an exhaustive inventory of the nuances or history about Bristol Bay sockeye; rather, the chapter is a synopsis of the fisheries science tools used by the managers and of how the fishery is structured that will facilitate a comparison with the Fraser River sockeye fishery. From the description below, it will become clear that the two fisheries are quite different in many respects and that pre-season and in-season forecasts of abundance have disproportionate influences on management in each fishery. In Bristol Bay, pre-season forecasts of the total run and catch are largely done as a service to processors and harvesters for logistics planning. In-season forecasts are done in an *ad hoc* manner to assist managers who are focused on reaching escapement goals from day to day and tide to tide using daily and hourly escapement estimates, test fishing results, and levels of fishery performance. Individual river stocks or in some districts stock groups are managed separately to allow a target number of spawners past the commercial fishery. Four area management biologists manage escapements to nine river systems and are very adept at hitting escapement goal targets for several reasons: (1) catch and escapement estimates are very accurate, precise, and timely, (2) essentially no exploitation occurs up-river of the enumeration projects, (3) the nine systems are managed more or less individually with few interception/mixed stock fishery issues, (4) high exploitation rates (80-90%) can be turned on and off from tide to tide, and (5) managers are given immediate and direct authority.

The Bristol Bay Fishery

Since the Bristol Bay commercial fishery began in the 1880s, over 1.8 billion sockeye salmon have been harvested, and the fishery is in the midst of its most productive era. Annual harvests over the last 20 years have averaged 26 million fish and have ranged from 10 million to 45 million. Daily harvests at the peak of the annual fishery exceed 2 million fish on a regular basis and have been as high as 5.2 million fish on a single day

(1993). The landed value (to fishermen) of the 28.5 million fish caught in the Bay during 2010 was about $150 million. At the peak value of the fishery during the late 1980s, the annual catch was worth about $320 million to fishermen (in 2010 dollars).

Fish returning to nine river systems around Bristol Bay are targeted in five fishing districts (Figure 24). The fishery occurs over about six weeks beginning early June and about 65% of the harvest occurs over a 2-week period centered on the 4th July (Figure **25**). Historically, this Bay-wide run timing has been very consistent with peak abundance shifting by only one to three days from either side of this average. There is variation in run timing among the different districts with Egegik and Nushagak stocks being the earliest and Togiak and Ugashik stocks being the latest (Figure 25).

Although the Bristol Bay fishery is seen as a biological success story, from an economic standpoint the fishery has fallen on difficult times in the past, including the most recent decade (Link et al. 2003; Schelle et al. 2004; Hilborn 2006). Market competition from farmed salmon has lowered prices, thereby reducing the annual catch value by over half since its highs in the late 1980s (Link et al. 2003; Valderrama and Anderson 2010); in addition, increasing fuel prices have raised costs in this energy intensive fishery. Hilborn (2006) argued that the biological success story of Bristol Bay is due to clear biological objectives and clear lines of authority to meet these objectives, but optimizing economic performance is not explicitly pursued. Economic objectives often conflict with biological objectives in fishery management and the Bay is no exception (Bue et al. 2008). Despite recent interest in addressing economic objectives, sustained high catches and increased fish prices over the last few years (2008-2010) have reduced the urgency to improve the economic performance of the early 2000s when the value of the fishery was ~70% lower than its historic highs. We expect the focus on economic performance to return after a season or two of low catches.

The Bay commercial fishery is focused almost exclusively on sockeye salmon and conducted entirely by gillnets (Minard and Meacham 1987). Mixed-species issues are limited to a few districts and for limited periods during each season. Mixed- and weak-stock issues in the multi-river fishing districts (Naknek-Kvichak district and Nushagak district) have influenced management more than mixed-species issues. The two gear types, between which allocation plans are prescribed, are drift and set gillnets. Drift gillnet vessels are restricted to a maximum length of 32 feet, and setnets are fished from shore with permission for land tenure handled through a leasing program administered by the State.

The Bay is subjected to large tidal fluctuations twice a day (10 m or more) and fishing, tendering, access to shoreside plants, and other activities are synchronized with and around the tidal stages. Large numbers of fish can stage or mill inside (and outside) the fishing districts, surge with flooding tides, and dramatically change the catch and escapement situation for a stock in a single tide. Therefore, decisions and fishery announcements are made as frequently as every three hours during the peak of the total run. During these times managers can put the fishing fleet on "short notice" and warn the fleet to avoid harbours that go dry at low tide so that fishing periods can be initiated within hours or sometimes minutes of new catch and escapement information, including from aerial surveys of the fishing grounds and rivers.

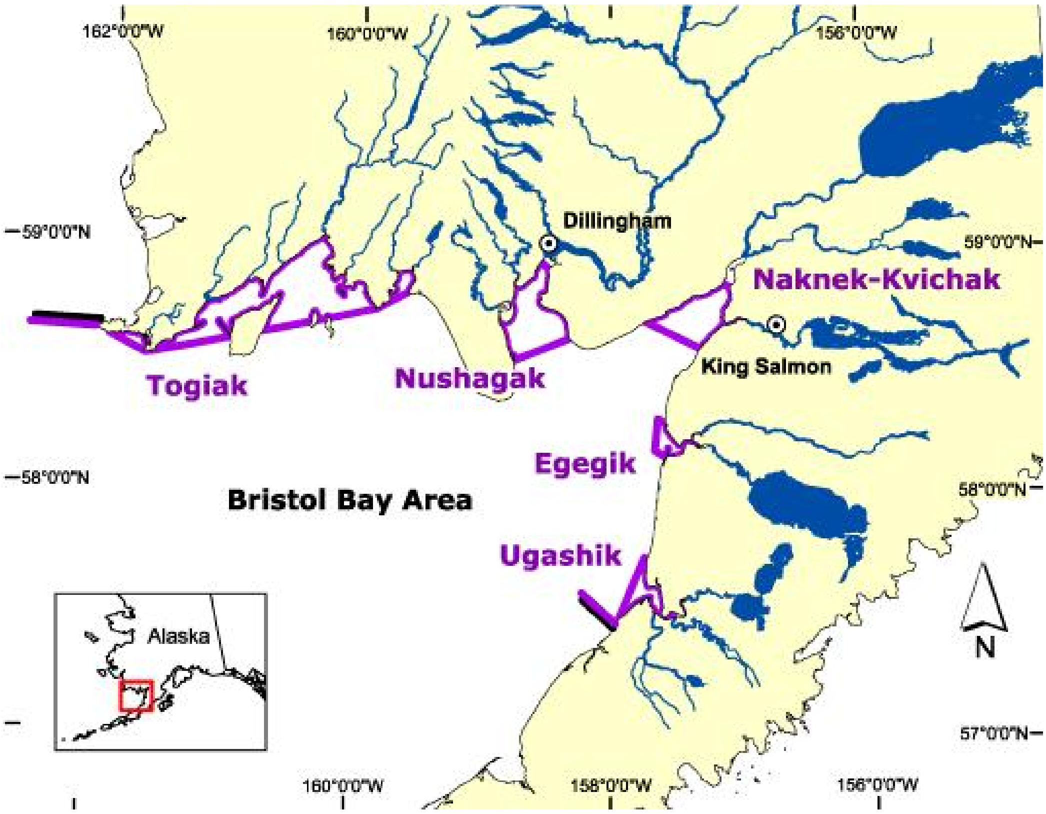


Figure 24 Map of Bristol Bay Alaska indicating the commercial fishing districts for sockeye salmon.

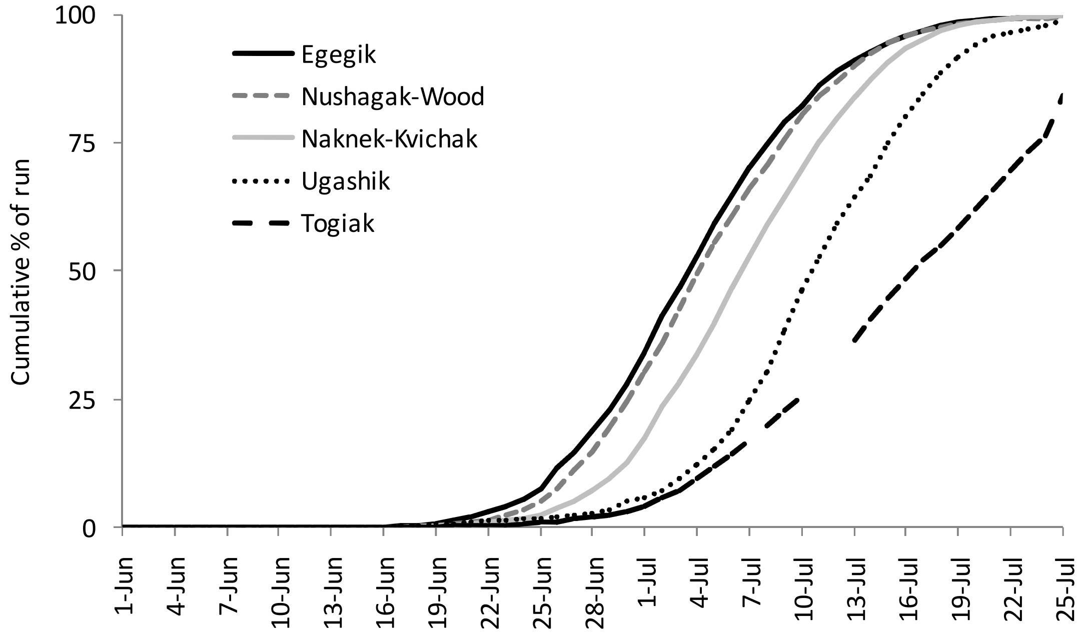


Figure 25 Cumulative percent of the Bristol Bay runs that occur by each day of the season. Curves represent the average run timings from 1991 - 2010.

Harvesting

Permitting

Eliminating exclusive access to salmon fisheries in Alaska was a major impetus for statehood and prohibition of exclusive rights to fish and wildlife was incorporated in the Alaska constitution and effective when Alaska became a state in 1959. Encouraged by a dwindling fishery, Alaska voters passed an amendment to the state's constitution in 1972 authorizing limited entry to the state's commercial fisheries. In 1973, the legislature enacted Alaska's Limited Entry Act (AS16.43) and created the Commercial Fisheries Entry Commission (CFEC) to administer a limited-entry program. The Bristol Bay salmon fishery is a standalone "area" (Area T) under the limited entry program and there are now 1,863 and 983 permits issued to drift and set gillnet gears, respectively (Table **26**; CFEC 2009). These permits are transferable and traded on an open market that is overseen by the CFEC, and ultimately, the judicial system of Alaska. Permit values vary among years depending on the financial returns expected from future year's fishing activity (Bocking and Peterman 1988) and in 2010 were traded for as much as $135,000 for driftnet permits and $35,000 for setnet permits. Participation level by permit holders in a given season is influenced by the expectations of price and the pre-season forecast of catch. Participation in recent years has ranged between 1,300 and 1,500 drift-netters of the possible 1,863.

Movement of commercial fishing permits among terminal fishing districts located at the river mouths is controlled with a registration regulation that slows movement among districts by imposing a 48-h waiting period for those wishing to change. This regulation protects the less mobile vessels (usually owned by local residents) from excessive competition that would arise from a fully mobile fleet. The Togiak District has the lowest available catch of all the districts and has a "one-way" district registration plan whereby permit holders who register or transfer to Togiak must remain there for the duration of the season. Impetus to improve the economic viability of the fishery in recent years has led to various regulation changes that allow increasing the amount of fishing gear above the 150 fathom limit placed on drift-netters when two permit holders are onboard the same vessel.

Table 26 Number and average value of commercial fishing permits issued during 2009 for the Bristol Bay sockeye salmon fishery. Values were obtained from the Alaska Commercial Fisheries Entry Commission website (CFEC 2009).

	Drift Gillnet	Set Gillnet	Across Gears
Resident	867	672	1539
Non-resident	996	311	1307
Total	1863	983	2846
No. multiple permit holders	12	52	64
Mean sale price	$78,300	$28,200	$53,250

Subsistence and Recreational Fisheries

This Bay sockeye salmon fishery is rather simple and straightforward with respect to allocation among sectors. The sport fishery is conducted entirely in freshwater and targets Chinook and coho salmon (Dye and Schwanke 2009). There has been no need to allocate sockeye harvest to the sport fishery because it is virtually nonexistent. Almost no sport harvest occurs (none reported in 2008; Morstad et al. 2010), but is estimated with mail in surveys (Clark 2005; Dye and Schwanke 2009).

Subsistence fishing, while important from a cultural perspective and given the highest priority, is nominal in terms of relative magnitude and is estimated with a permit system. The subsistence harvest relative to run strength has always been so small that satisfying subsistence needs is not usually an issue (P. Salomone, pers. comm., Area Management Biologist for Egegik and Ugashik, ADF&G). Regulations regarding subsistence include gear restriction to a 10 fathom gillnet of any mesh and a 200 sockeye per permit limit; the permits are for keeping tally of the take as another permit will be issued to anyone going over the limit. Subsistence harvest is always allowed during commercial openings, and many times subsistence remains open in between commercial closures. This constant opportunity to subsistence harvest throughout the season ensures that the 200 fish per person regulation is always achievable by those who pursue their limit. Minard and Meachum (1987) reported sockeye subsistence catch to average 144,000 (0.6% of the total run) between 1963 and 1985; Morstad et al. (2010) reported 104,000 (0.3% of the total run and 0.4% of harvest) for 2008.

Commercial Fisheries

Gear types and allocation

Prior to the 1980s, high-seas harvest by the offshore Japanese gillnet fisheries was substantial. Currently, state salmon fisheries in and around the South Alaska Peninsula intercept approximately 3% of the sockeye salmon returning to Bristol Bay (Figure 26). Only set and drift gillnets are permitted in the Bay; drift gillnets can be fished from vessel no greater than 32 feet in overall length. Set-net sites are maintained along beaches in the Bay and fished from skiffs with assistance from assorted wheeled and tracked vehicles. Beginning in 1998, the allocation between these two gear types was formalized into management plans, and allocations to drift-netters ranges among the districts from 72 to 90% of the catch (Table 27). Managers have been successful at meeting these apportionments in spite of allocation being secondary in priority to reaching escapement goals (Salomone 2006, 2009).

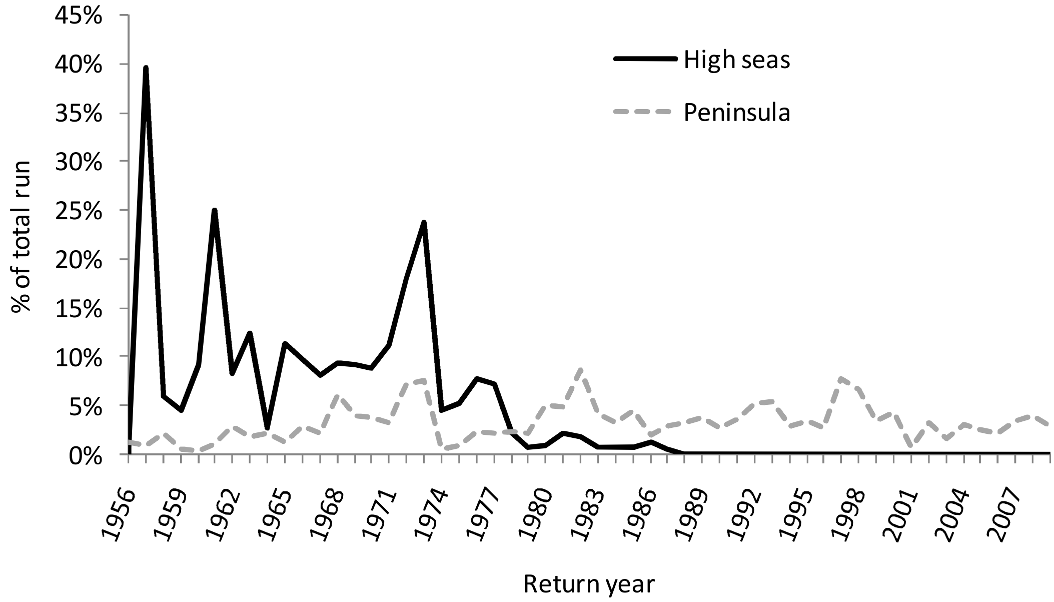


Figure 26 Interception harvest of sockeye salmon bound for Bristol Bay, Alaska from the high seas fishery (no longer in existence) south of the Alaska Peninsula and from the gillnet fisheries in and around the Peninsula.

Table 27 Allocation of commercial sockeye catch between gear groups in Bristol Bay, Alaska. Top values indicate negotiated catch allotments (%) within each fishing district while bottom values in parentheses reflect the 20 year (1990-2009) average of realized allotments.

District	Drift Gillnet	Set Gillnet
Naknek-Kvichak	84	16
	(85)	(12)
Egegik	86	14
	(87)	(13)
Ugashik	90	10
	(89)	(11)
Nushagak	74	26
	(72)	(28)
Togiak	na	na
	na	na

Processors

The number of companies in the processing sector has varied somewhat with the economic performance of the fishery and has ranged as high 39 in 1985 (Link et al. 2003). In 2009, 13 major processors operated in the Bay and accounted for 99.5% of the sockeye purchased (ADF&G 2009). Typically over half of the fish are processed in shoreside processing plants, with floating processing vessels accounting for about 20-25% of the catch in recent years. Products include headed and gutted, fillets, and canned. The shoreside processors are supplied fish via company-specific tendering fleets, and to a lesser extent, direct deliveries.

Tougher economic times in the fishery in recent years have contributed to occasional shortfalls in processing capacity, which has sometimes curbed harvest rates at the peak of the season. Processors face significant financial losses if they gear up with unused or underutilized processing capacity in the Bay. However, limits to capacity have contributed to daily catch limits for fishermen or suspended buying at times during high-catch periods. Oftentimes limits have the effect of simply altering the catch among individuals but at other times, limits or suspensions to buying have resulted in escapement exceeding escapement goals in some rivers. The latter has created the issue of “foregone harvest” and this has been source of considerable debate in the fishery in recent years (BB-RSDA 2008).

ADF&G surveys processors each year prior to the season to determine daily and seasonal capacity in an effort to identify and mitigate any significant shortfalls in processing capacity. For example, for the 2009 season ADF&G (2009) reported that the 13 processors were prepared to handle up to 1.8 million fish per day and around 31 million fish overall during the season. Even though the total season processing capacity is usually larger than the annual harvest, limits may still be imposed when daily catches exceed daily capacity, which is often due to the compressed nature of the run timing. Regardless of the contribution from the vagaries of the compressed run timing and weather, *all* fish above mid-point of the escapement goal range are considered by many as foregone harvest, which as defined, resulted in 4.3 to 7.5 million fish annually (average of 6.2) from 2003 to 2008 (BB-RSDA 2008). Limits to processing capacity contribute only a portion to this “excess” escapement. A substantial portion of the quoted foregone harvest can be attributed to the Naknek-Kvichak district where managers must manage three stocks in a common fishing area. For the years addressed by the RSDA study, weak-stock (Kvichak) management led to high escapements to the Naknek and Alagnak.

Harvest estimation methods

Total harvest in pounds from Bristol Bay fisheries is reasonably well accounted. Nearly 100% of the harvest is taken in commercial fisheries over a 6-week period and all sales are monitored by district via a "fish ticket" system administered by ADF&G. Individual permit holders record the sale of their catch at delivery using an ADF&G-issued plastic credit-card-like card, which is issued annually to each permit holder. The area is remote and the movement and sale of even modest numbers of fish outside of this catch tallying system is difficult at best. A small amount of uncertainty in catches stem from estimation procedures used to estimate numbers of fish from deliveries in weight, and from procedures to allocate catches from fishing districts to rivers of origin. Catches are estimated in-season for use by managers and on a post-season basis to build river-specific total run and brood tables.

During the season, district-specific catches are estimated each morning from processor reports of tender deliveries the preceding day. These daily catch estimates, along with the daily escapements are provided to the public in ADF&G's daily run summary, which is posted on the web by noon on the day following when they occurred (e.g., see http://csfish.adfg.state.ak.us/mariner/brbcatch/brbsummary.php). After the season is over and by November of each year, ADF&G research biologists develop estimates of the river-specific harvests and update brood tables to use for the following year's pre-season forecast.

Relative to most sockeye stocks, the river-specific catch and escapement estimates from Bristol Bay are some of the most accurate and precise in salmon biology today. There is some uncertainty surrounding catch, but precision is not estimated or reported and is believed to be modest. Uncertainty in catch stems from three sources: (1) how catch is estimated at the time of delivery to the processors, (2) how catch is assigned to natal stream systems, and (3) age composition estimation (T. Baker, pers. comm., Research Project Leader, Bristol Bay Salmon, ADF&G).

Fish are transported with tender vessels from the fishing districts to onshore and floating processing plants located throughout the Bay. Fish are offloaded from tenders into brailer bags, and the bags are weighed. Throughout each day, fish are sampled for individual weight; the average weight of a fish for that day and processor is divided into the total weight from the brailer bags to estimate the number of fish delivered to each processor. Of course, the average individual weight of fish changes, but these individual weights are updated daily and any bias introduced from inaccurate individual weights is considered negligible.

Catch from fishing districts with only one stream system are assigned to that stream (i.e., Togiak, Ugashik, and Egegik). For districts with more than one river system, catch has historically been apportioned post-season based on relative escapements by age (Bernard 1983). For instance, the catch of sockeye age-2.2 in the Kvichak-Naknek District is apportioned between the Kvichak and Naknek systems based on the relative proportion of age-2.2 fish that occurred in each escapement.

It has always been assumed that once sockeye enter the Bay, interception of fish in non-natal districts and streams was for the most part negligible, but assumptions create uncertainty. However, these assumptions have not been needed in recent years due to genetic stock identification (GSI) from catch samples. Dann et al. (2009) found the percent of the Kvichak run harvested in the Ugashik and Egegik districts was 4.7% in 2006, 4.9% in 2007, and 13.2% in 2008. An additional genetics study is underway that will estimate the stock compositions for the historical database based on scale samples taken in earlier years (T. Baker, pers. comm., ADF&G). Better estimates of river-specific harvest may change historical and future catch assignments enough to alter previously held conceptions of abundance trends and spawner-recruit relationships for some systems (Baker et al. 2009), but we doubt these changes will be substantial.

Harvest estimates

Historical harvest from Bristol Bay has been characterized by two features (Figure 27; Appendix L). First, there has been a decadal pattern in productivity and catch regimes attributed to the Pacific Decadal Oscillation, which has contributed to periodic and two- to three-fold shifts in catches across some decades. Second, the Bay-wide run followed a cycle of high catches for one and two years followed by “off-cycle” years of lower catches, driven by the dynamics of the Kvichak River system (Figure 27; Eggers and Rogers 1987; Fair 2003). Reasons for this cycle have not been definitive, and debate in the Bay and the scientific literature continues, but the data suggest it was influenced by marine and freshwater processes and largely reinforced by historical fishing patterns and a cyclic escapement goal policy (Ruggerone and Link 2006). Whatever the cause, the cycle began to break down during the mid-1990s and the Kvichak has failed to dominate the Bay-wide run since. Harvest has ranged from 9.9 to 44.2 million fish with an average of 25.5 million over the past 20 years (1991-2010; Appendix L). The Egegik stock has dominated this period with an average harvest of 8.7 million followed by the Kvichak and Naknek stocks with 4.3 and 3.5 million. Since 2004, harvest has been quite stable (average=28.0 million, range = 24.4-30.9).

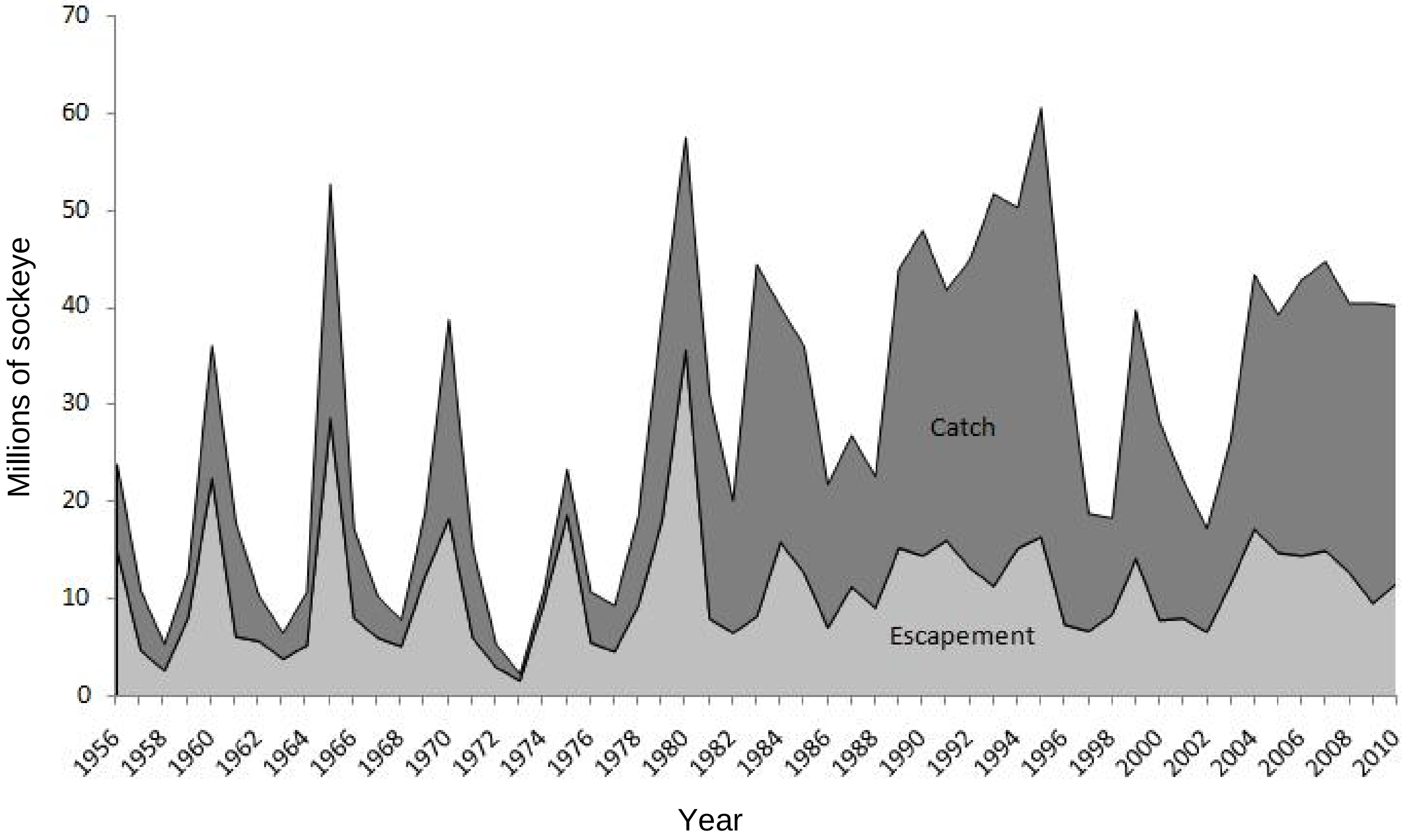


Figure 27 Historical depiction of catch and escapement for sockeye salmon summed across all stocks in Bristol Bay Alaska.

Management

Management Authority and Escapement Goal Management

Ultimate management authority for salmon fisheries in Alaska rests with the Commissioner of the Alaska Department of Fish and Game (ADF&G). ADF&G's management objectives include: managing for sustained yield (largely accomplished by adhering to escapement goals); maintaining genetic diversity and overall health of the escapement; providing for an orderly fishery; helping to ensure high quality fishery products; and harvesting fish consistent with regulatory management plans. (For the regulatory management plans, See 5 AAC 06.355: *Bristol Bay commercial set and drift gillnet sockeye salmon fisheries management and allocation plan.*) Regulations and regulatory management plans are established through a public process via the Alaska Board of Fisheries (BOF). The seven members comprising the BOF are appointed by Alaska's governor and serve staggered 3-year terms. The BOF addresses each region's fishery (e.g., Bristol Bay) once in a 3-year cycle, but has mechanisms to address emergency regulatory needs on an annual basis for all regions. Management plans are designed to promote conservation of fishery resources and specify allocations of fish to distinct groups of harvesters. When the BOF implements allocation regulations or policy, ADF&G has the responsibility to manage under these regulations, while attempting to achieve the other management objectives. However, the regulations specify that ADF&G's highest priority is to obtain escapement goals and maintain genetic diversity of the escapement (See 5 AAC 06.355 (c)(1)). When conservation concerns arise, management plans often set out how ADF&G should strive to address such concerns amid allocation issues.

Salmon fisheries in Alaska, including Bristol Bay, are somewhat unique compared to other jurisdictions in that the Commissioner of ADF&G delegates full management authority to open the fishery to local Area Management Biologists (AMBs). AMBs interact daily with stakeholders in the region while monitoring the performance of the fishery and developing run. AMBs issue "Emergency Orders" (EOs) to open fisheries for specified times and locations and must justify each EO in a written narrative. AMBs cannot regulate the number of participants in a given fishery or season as this access is regulated by a limited entry system, and ultimately, by the state's constitution. The BOF stipulates fishing gear and allocation plans and AMBs control time, area, and gear openings to reach management plan and escapement goal objectives. This decentralized management structure complements the escapement-goal system in that AMBs are well informed and have clear authority for meeting these goals.

Enforcement of regulations is the responsibility of the Department of Public Safety. A seasonally inflated team of Alaska State Troopers conduct the on-the-ground enforcement with a fleet of small and large vessels and several aircraft. Although ADF&G management biologists are deputized, management and enforcement activities are completely separate functions in Alaska; AMBs set time and area openings; Troopers ensure the fishery is prosecuted under the laws of Alaska.

Prioritizing escapement objectives over social (e.g., allocation among gear types) and economic objectives has contributed to managers' success in meeting river-specific escapement goals in most years (Figure 28, Figure 29, Figure 30). The downside of this success has been that it has provided little contrast in escapement levels for some stocks making it difficult for researchers to identify MSY-based "biological escapement goals" (BEGs). Today, all Bristol Bay sockeye escapement goals are characterized as sustainable escapement goals (SEGs) as opposed to the MSY-based BEGs (Baker et al. 2009). This SEG designation acknowledges that there are too few escapements at high levels for researchers to identify the escapement that will maximize yield.

The five Bristol Bay salmon fishing districts are regulated by four AMBs corresponding to (1) the Ugashik and Egegik districts, (2) the Naknek-Kvichak district (Kvichak, Naknek, and Alagnak rivers), (3) the Nushagak district (Nushagak, Wood and Igushik rivers), and (4) the Togiak district. Given the status of the fishery, the AMBs are usually mid- or late-career biologists who come to the positions with fishery management experience elsewhere in the state. Two senior regional management biologists often come to the Bay for periods during its short season to assist the AMBs with interpretation of information and to act as liaison with the harvesters and processors. The ADF&G commissioner and the Governor occasionally visit during the fishery. The four AMBs are supported by an administrative staff and three research biologists who prepare river-specific preseason forecasts and gather and interpret in-season information on the developing runs. A seasonal crew of about 50 people staff enumeration projects, test fisheries, and catch sampling programs. In total, a relatively small group of professionals from state government manages and provides research support to this fishery.

ADF&G's research biologists develop biological escapement goals for individual river systems based on sustained yield and/or maximum sustained yield (MSY) principles using relationships between escapement levels and subsequent returns (termed stock-recruit analyses). In 2000, the BOF and ADF&G adopted a "Policy for the Management of Sustainable Salmon Fisheries" (SSFP) (See 5 AAC 39.222: *Policy for the management of sustainable salmon fisheries*) that specifies guiding principles and protocols for the management of salmon fisheries to achieve maximum or optimum salmon production. Among other things, the SSFP sets out how and when a stock is deemed weak (conservation concern) and how the burden of conservation should be shared among users.

In Bristol Bay, research biologists have river-specific stock-recruit datasets spanning ~50 years of annual escapements and subsequent age-specific recruits (Baker et al. 2009). Once developed by ADF&G, escapement goals are presented to the BOF. At that stage, the BOF may accept the escapement goals (most commonly) or modify them to accommodate social, conservation, and allocation concerns by users and ADF&G. Conservation concerns in Bristol Bay can result in the BOF varying river-specific escapement goals (EGs) higher or lower from biological reference points (e.g., MSY) to protect weak stocks in mixed-stock fishing districts; in these cases optimum escapement goals (OEGs) are implemented by the BOF. An OEG for the more productive stock in a mixed-stock fishery is sometimes raised above the MSY escapement goal to permit managers to focus on meeting the weaker stock's EG and avoid criticism from exceeding the EG of the more productive stock (e.g., Naknek River OEG to help the manager meet Kvichak River EG). Less common is when an OEG is set lower than the MSY goal to reduce foregone harvest of the more productive stock because meeting the weaker stocks EG is seen as too hard an economic hardship on local communities (e.g., Nushagak River OEG to realize greater yield from the Wood River; Evans et al. 2000). In all cases, escapement goals established by the BOF must meet a "sustained yield" criterion based on historical catch and escapement data.

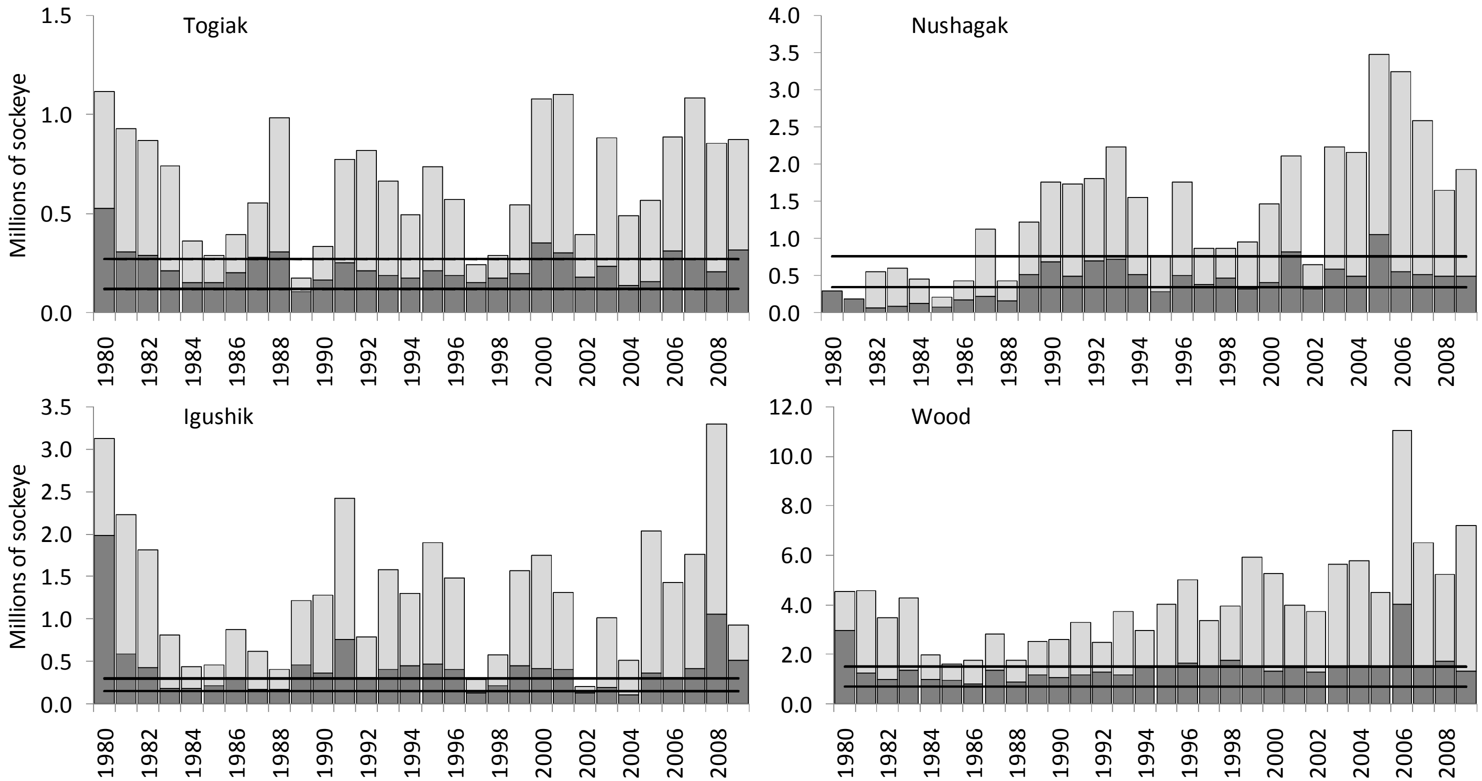
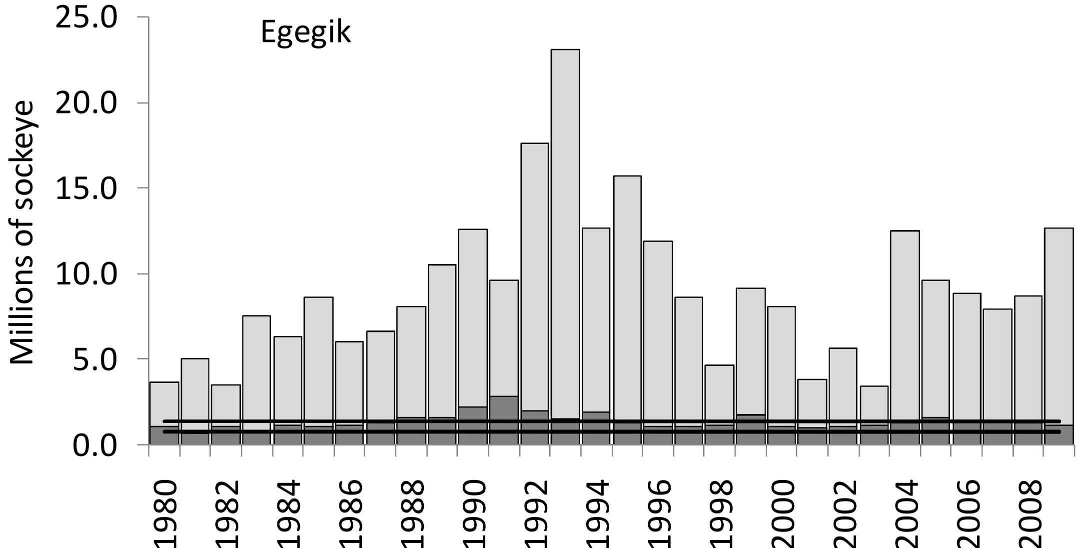


Figure 28 Catch and escapement of westside sockeye stocks in Bristol Bay Alaska. Light bars are catch, dark bars escapement, and black horizontal lines represent the upper and lower bounds of the current escapement goal range from Baker et al. (2009).



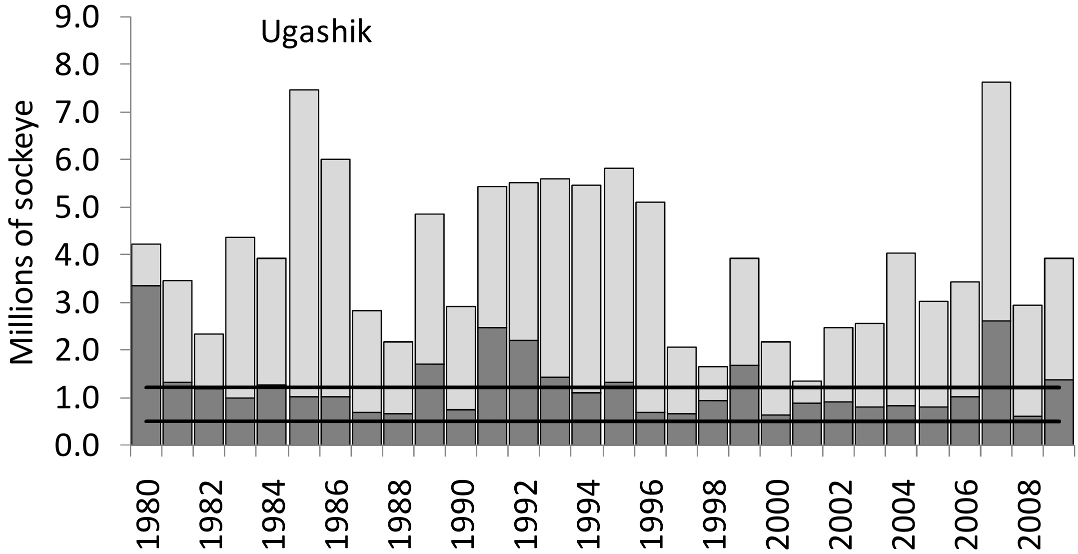


Figure 29 Catch and escapement of Egegik and Ugashik sockeye stocks in Bristol Bay, Alaska. Light bars are catch, dark bars escapement, and black horizontal lines represent the upper and lower bounds of the current escapement goal range from Baker et al. (2009).

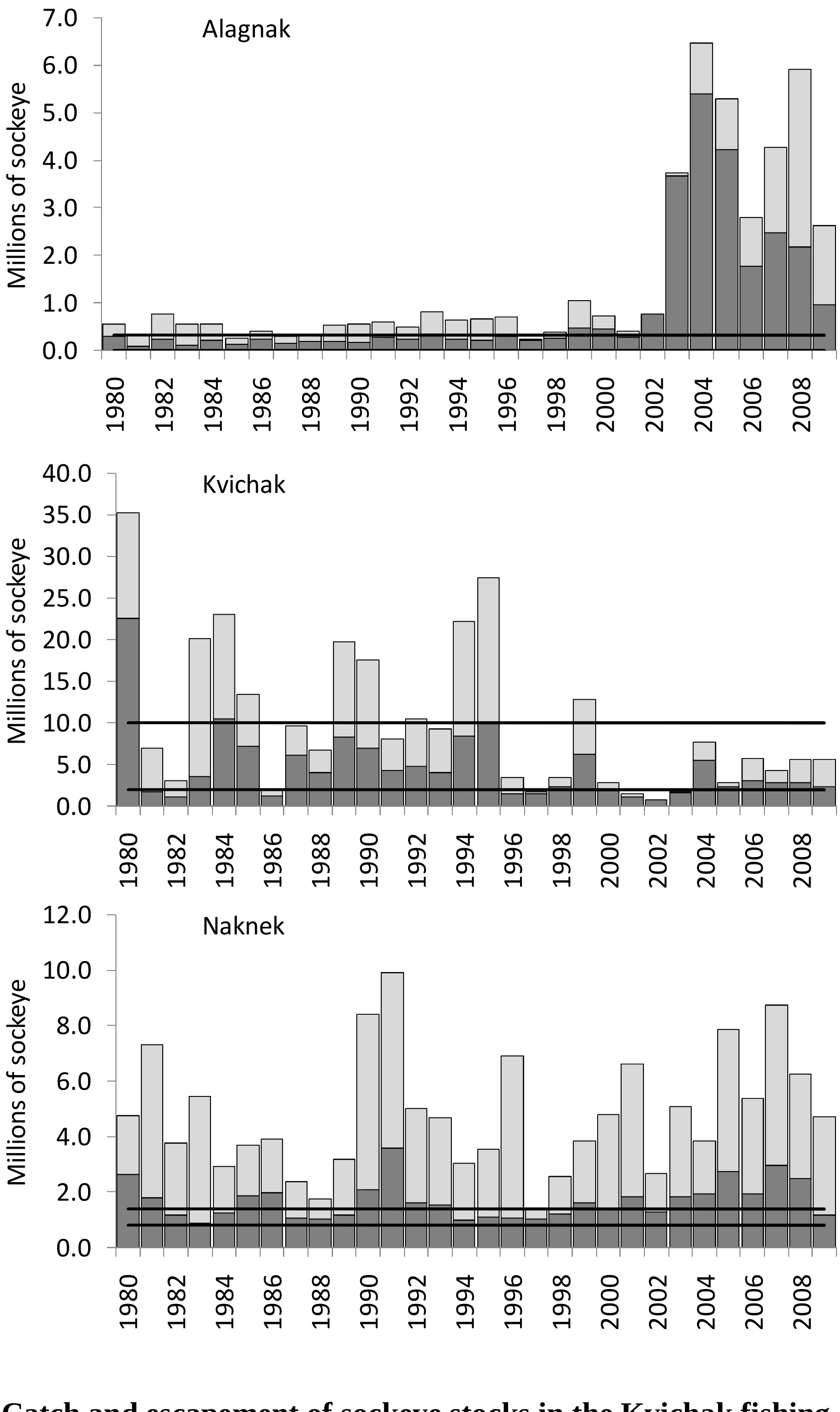


Figure 30 Catch and escapement of sockeye stocks in the Kvichak fishing district of Bristol Bay, Alaska. Light bars are catch, dark bars escapement, and black horizontal lines represent the upper and lower bounds of the current escapement goal range from Baker et al. (2009). There is no upper bound for the Alagnak stock.

The Role of Pre-season Forecasts

Pre-season forecasts of the stock-specific returns to Bristol Bay are issued in November of each year for the following year's season. These are largely done as a service to industry (J. Regnart, Regional Supervisor, Division of Commercial Fisheries, ADF&G). The remoteness of Bristol Bay and the compressed run timing of the fishery necessitate that processors and fishermen show up with sufficient gear and supplies to handle the season's catch. Bringing excess capacity to the Bay is very costly, and there is little opportunity to react to larger-than-expected catches. Pre-season forecasts can also influence the sales and marketing decisions of processors. Without a doubt, improving the accuracy of pre-season forecasts provides much greater economic benefit to the industry than any improvements in the in-season forecasts.

ADF&G uses pre-season forecasts in two ways. First, they use it to help plan for orderly fisheries and ensure that adequate processing capacity will be available. During the winter, AMBs survey licensed processors to assess the daily and seasonal capacity to process fish during the upcoming season (e.g., ADF&G 2009). Second, AMBs will use the pre-season forecast to identify conservation concerns associated with managing their districts and characterize, in a qualitative way, the degree of caution they will approach the early-season fishing in each district. In April of each year, AMBs release an "outlook" document (Note: the 2010 Outlook is available at: http://www.cf.adfg.state.ak.us/region2//finfish/salmon/bbay/brbout10.pdf) that provides the pre-season forecast, a summary of any regulatory changes from previous seasons, stock- and species-specific conservation concerns, and how they may approach early fishing in each of the five districts.

The Role of In-season Forecasts

In-season forecasts of returns to either the Bay as a whole or to specific fishing districts are not reported by ADF&G and done on an *ad hoc* basis by research staff and AMBs. Specific methods used for forecasting are outlined later. In-season forecasts of abundance are used secondarily for managing for escapement on a day-to-day and tide-to-tide basis. By "secondarily", we mean that AMBs focus their efforts on meeting escapement goals and spreading escapement throughout the course of the season by regulating day-to-day fishing time and area openings. AMBs do not attempt to predict how many fish in total may return and then use those forecasts to guide harvest objectives. This focus on managing escapement and not catch is understandable and logical given the dynamics of the runs in the Bay and the assessment methods available. Managing the fishery based on in-season forecasts of total abundance and available catch will always be less effective than managing the fishing fleet on a tide-to-tide basis to meet escapement goals. Despite relatively consistent run timing among years (e.g., usually 0-3 days either side of average), this is an area where 50% or more of the annual escapement goal can move above a fishing district and into the river on a single tide; thus, constant monitoring of the escapement counts and the number of in-river fish below the enumeration project is paramount.

There are two non-ADF&G entities that provide in-season interpretations of the developing run that are used to varying degrees by fishermen, processors, fish buyers, and to some extent AMBs. Supported by the Bristol Bay Science and Research Institute as a public service, we (Link and Raborn) manage the offshore Port Moller test fishery (described below) and provide daily interpretation of these test fish results, including the indices of abundance, run timing, and age and stock composition.

Supported by processors, researchers from the University of Washington (also known as FRI) prepare in-season forecasts of district-specific returns to help processors manage their tendering and fishing fleets and processing lines. These forecasts have a more limited distribution and are provided to processors, ADF&G, and selected researchers, including us (Link and Raborn). Processors are typically looking for predictions of large-effect circumstances, like an anticipated “drying up” or “swelling” of fish in a particular district so they can reposition fleets. A related use that processors have for in-season forecasts is for guiding decisions about haul-out or long-haul tenders. These decisions are influenced by forecasts of the total daily catch to expect over the coming week or so. Peak days can overwhelm processing capacity and necessitate suspensions in buying and daily limits on fishermen (i.e., very unpopular measures). As a “relief valve” to otherwise fixed daily processing capacity some processors will arrange large-volume (~300-500,000 lb or about 50-80,000 fish) tenders ahead of the season to move catch from peak days to processing facilities elsewhere in the Alaska and sometimes even as far as Prince Rupert, British Columbia. These tendering trips are costly (~$50,000-$100,000) and are “one-way” in nature—once sent out, the vessel cannot make a round trip in time for a second load. For these decisions, it is the anticipated daily catches in the near future that are germane and not the size of the entire run. Rough daily estimates of the run expected, a week into the future, can be developed with data from the offshore test fishery at Port Moller, which is described later.

Information Sources Used to Manage the Bristol Bay Fishery

The following is an overview of the assessment programs and data sources that are used by AMBs to assess run strength and guide fishing effort. Despite the short duration of the fishery a suite of effective assessment tools has evolved that are small in cost relative to the economic (and social) value of the fishery (Clark 2005; Appendix L). To the uninitiated, the list below may seem like a complicated array of assessment tools and the relative usefulness of each one is probably unclear. It is useful to keep in mind that the single most important information source used by AMBs is from the escapement monitoring programs. AMBs manage fishing effort to distribute the escapement across the season based on the historical run timing schedule. Typically, the lower and upper ends of the escapement goal range are multiplied by the average run timing for a given system to provide the AMB a year-to-date benchmark to follow throughout the season (Figure 31).

Escapement estimates are updated each day and plotted on this graph. Various run timing scenarios are used to slide the target trajectory back and forth and assess the consequences of the run being early or late. Depending on the observed escapement to date and the manager's belief about the current year's run timing, the fishery in each district is opened and closed. Fishing periods are usually at the beginning of a flood tide (the ebb tide is fished in the Nushagak District). Either the driftnet or set-net fishery may be lagged to achieve the correct allocation between gear groups, but hitting the escapement goal is paramount. In addition, the manager tries to spread the escapement across the entire season so as to promote genetic diversity and maintain the historic run timing (e.g., Figure 32).

All the additional information sources from other assessments influence the AMB's "comfort level" with whether the fishery can be opened on a given tide or day while maximizing the chances that the annual escapement goal will be met for a given river. Of course, choosing not to open comes with the risk of exceeding the escapement goal range. Combined with catch, the escapement monitoring projects provide a near immediate feedback to the AMB's view of the developing run. This real-time and iterative form of management to meet escapement goals makes only modest use of forecasted total run. Below we expound on the methods and reliability of the tools available to AMBs—in more or less chronological order these are: (1) pre-season forecasts, (2) offshore test fishing at Port Moller, (3) district test fishing, (4) commercial fishery performance with catch and age sampling, (5) inside test fishing, (6) aerial surveys, (7) escapement monitoring.

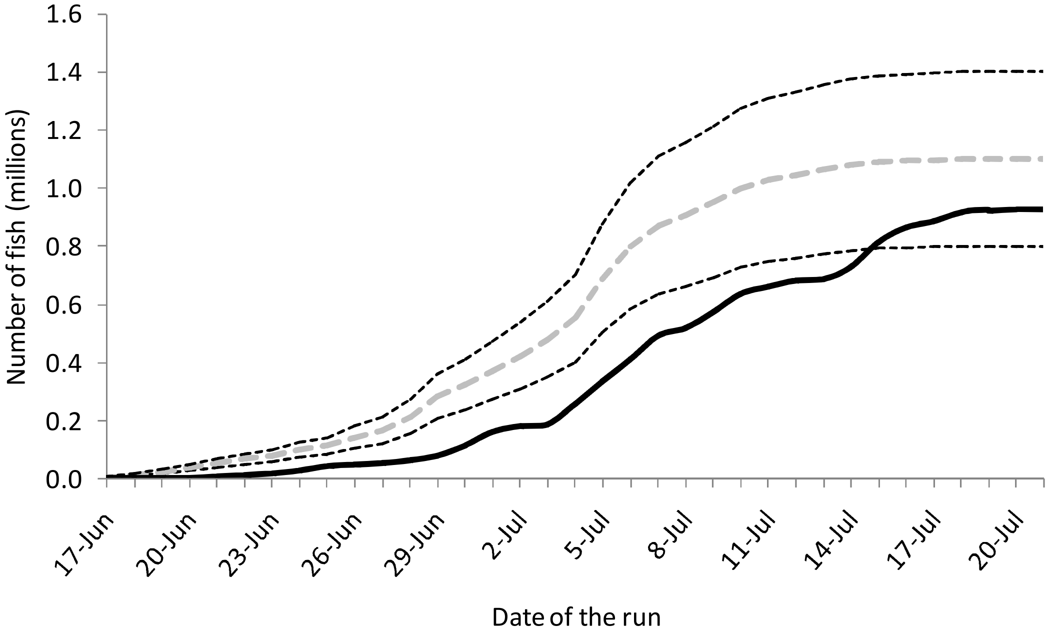


Figure 31 Cumulative escapement of sockeye throughout the 2010 fishing season in Egegik River, Alaska. The thin black dashed lines represent the upper and lower ends of the Escapement Goal multiplied by the historical run timing (the gray dashed line is the midpoint of the goal). The solid black line is the observed cumulative escapement. The dashed lines are sometimes slid back and forth along the x-axis if the manager feels the run is early or late.

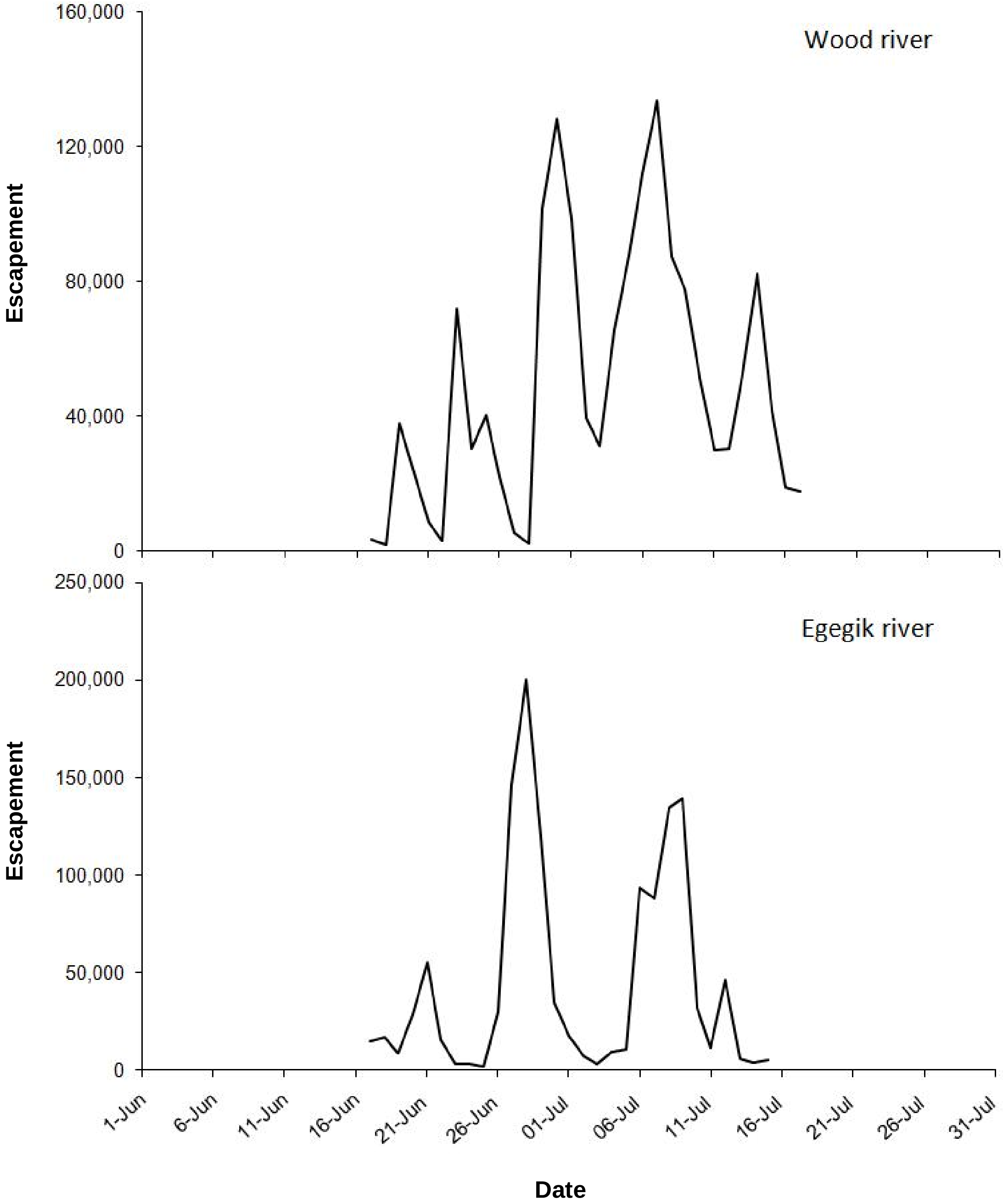


Figure 32 Observed escapement of sockeye past the counting towers on the Wood and Egegik Rivers, Alaska during 2003. Valleys in the graph indicate times when the commercial fishery was open 1-3 days earlier.

Pre-season forecasts

As noted above, these set the stage for the season but provide little influence on management decisions once the run has begun to arrive in the Bay. A variety of methods have been tried/used for system-specific pre-season forecasting in Bristol Bay, but can be generalized into four types: (1) means models, (2) spawner-recruit models combined with assumed age composition, (3) sibling models, and (4) smolt models combined with assumed age composition. Means models consist of simply assuming that a good prediction of future returns will equal the average of returns from the previous three, five, ten years and so on. Spawner-recruit models use a Ricker curve (Ricker 1954) to predict how many returns can be expected from a given year's spawning escapement and apportions these predicted returns across future years based on previously observed age compositions. Sibling models use simple regression to predict how many fish will return at older ages based on how many fish of the same brood year returned at younger ages. Finally, smolt models use the number of out-migrating smolts estimated for a given year and multiplied by previously observed age composition and marine survival estimates to project the number of returns in coming years. Detailed descriptions and comparisons of these methods are found in Fried and Yuen (1987), Henderson et al. (1987), Bocking and Peterman (1988), and Adkison and Peterman (1999). Up until 2000, ADF&G has used all four methods (although, smolt data was available for only some of the systems and years) and averaged their outputs giving each equal weight (T. Baker, pers. comm.; Eggers 2003; Fried and Yuen 1987; Bocking and Peterman 1988). Beginning in 2001, all models were tried, but only the top performing model over the previous three years has been used for the upcoming forecast (T. Baker, pers. comm.). In addition to the four models mentioned above, nonlinear forms of the sibling model as per Bocking and Peterman (1988) and time series processes (e.g., autoregressive 1, 2, etc.) in all models as per Adkison and Peterman (1999) are tried.

Given the number of published articles comparing forecasting methods, we have not included such comparisons in this report. Rather, we will describe the observed error for each system and year based on the forecasts reported by ADF&G. The type of model used for each system and year was not provided by ADF&G—only the forecasted return was available. For each system and year we estimated the median percent error (MPE) and the median absolute percent error (MAPE) between the forecasted and observed returns, as well as, R^2, and tests of intercept= 0 and slope= 0 when $\log_{10}$(observed run) was plotted against $\log_{10}$(forecasted run) (Figure 33, MPE not shown graphically; see Appendix F for detailed descriptions of these metrics). The $\log_{10}$ transformation was necessary to stabilize the variance and to achieve normality.

The Alagnak, Kvichak, and Nushagak systems have had the most reliable forecasts over the past 20 years (Appendix L; Figure 34). When all systems are combined, high and low errors across systems tend to cancel each other; as a result, annual forecasts for half of the years (i.e., the median) were within 15% of their corresponding observed returns and did not consistently over- or underestimate by an appreciable amount (MPE= -3%). When considered in absolute terms, the percent error of forecasts for all systems combined remains good at less than 15% different from actual returns (Figure 34). ADF&G substantially improved in their ability to consistently forecast beginning in 2001 (Figure **35**) when they switched their modeling protocol to choosing the model that performed best over the previous three years instead of averaging all models giving each equal weight; however, more consistent total returns in recent years no doubt facilitates forecasting ability.

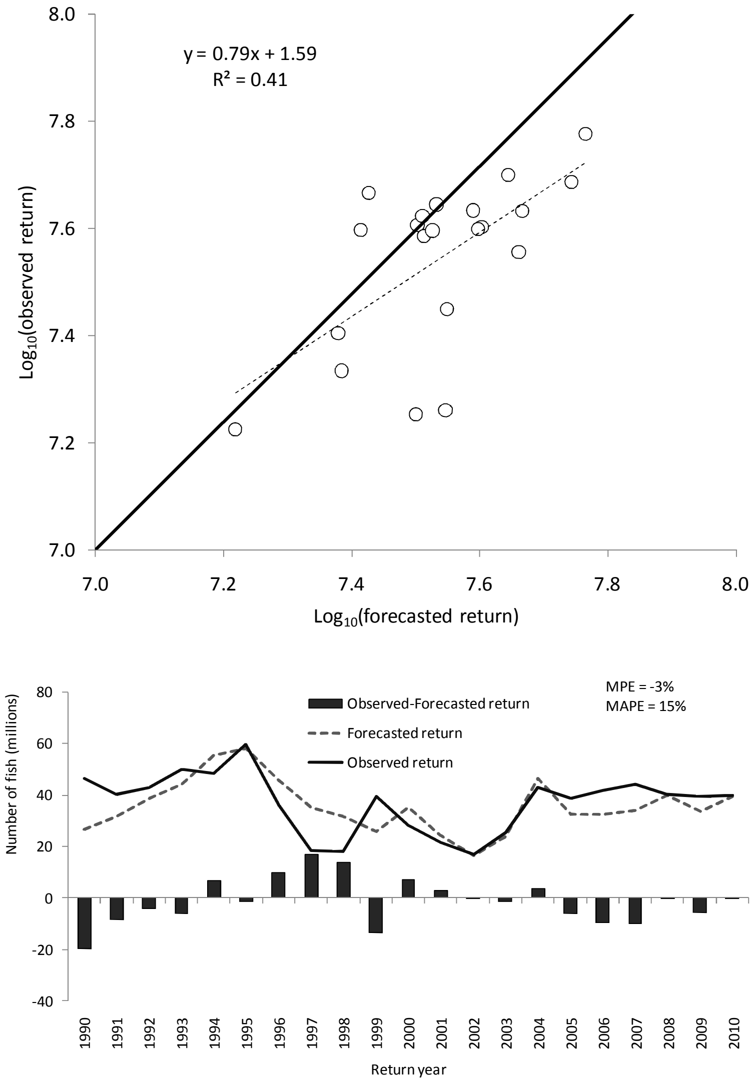


Figure 33 Pre-season forecast performance for all sockeye stocks in Bristol Bay, Alaska including years 1990-2010. For each year, stocks were pooled before comparing forecasted total return to observed total return. The black 45° line in the top graph represents the equilibrium line when $\log_{10}$(observed return)= $\log_{10}$(forecasted return); the dotted line is the best-fit linear regression line corresponding to the equation and R^2 value. The bottom graph depicts the forecasted return and observed return, as well as, their difference since 1990. MPE=median percent error across years since 1990; MAPE=median absolute percent error (see Appendix F **for a detailed explanation of statistical metrics).**

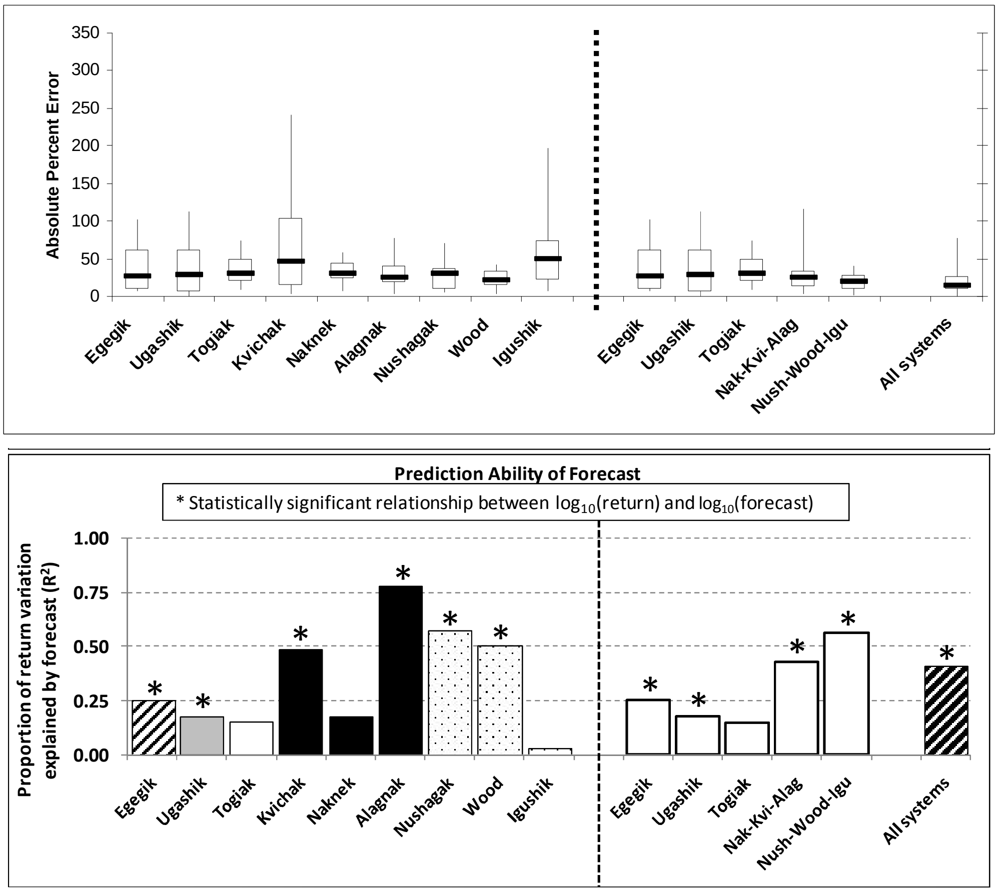


Figure 34 Pre-season forecast performance for all sockeye salmon stocks in Bristol Bay for the period 1990-2010. Top: Absolute percent error; median absolute percent error (MAPE) shown as horizontal bar; boxes represent upper and lower confidence limits for the 75th and 25th percentiles, respectively; whiskers extend to upper 95th and lower 5th percentiles. Bottom: R^2=the coefficient of determination; asterisks indicate $\log_{10}$(observed run) versus $\log_{10}$(forecasted) run relationships with slopes significantly differed from zero (α= 0.05). See Appendix F **for detailed explanation of metrics.**

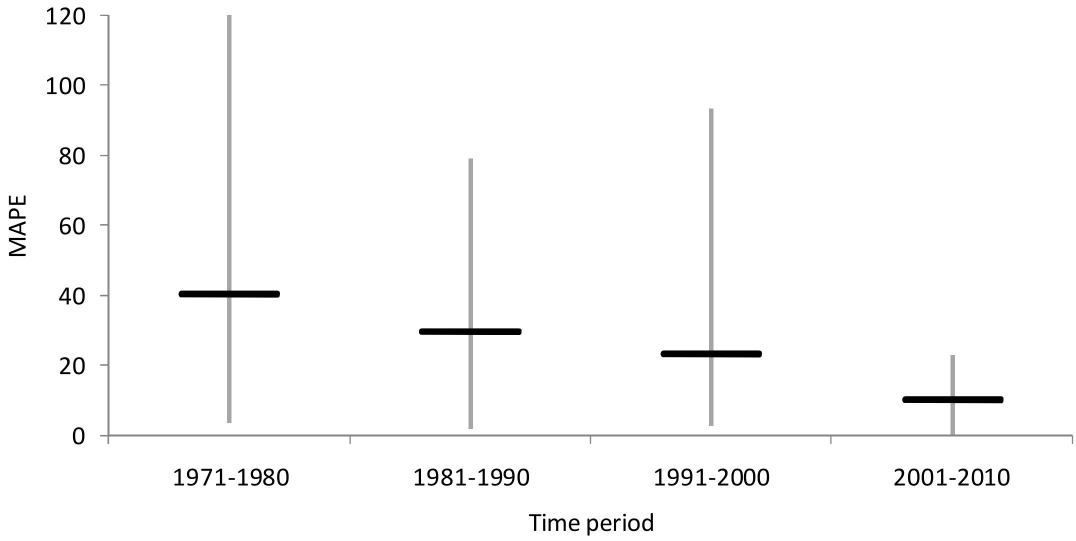


Figure 35 Pre-season forecast performance for all sockeye stocks in Bristol Bay Alaska compared across the four most recent decades. MAPE=median absolute percent error (see Appendix F **for detailed explanation) and is represented by the black horizontal lines; gray vertical lines indicate the range in MAPE observed for that decade.**

<u>Offshore test fishing (Port Moller)</u>

A test fishing program has been operating in the Bering Sea ~250 miles southwest of the inner areas of Bristol Bay since the 1970s. The test fishery is offshore of Port Moller, Alaska, and intercepts Bristol Bay bound sockeye about 6-8 days before they reach their stream of origin. Gillnets (200 fathoms—5 1/8 inch stretch mesh) are set at five stations located along a transect from Port Moller to Cape Newenham spaced 10 miles apart (Figure 24). Each year from June 10 to July 10, each station is sampled every day (weather permitting) and catches are converted to catch-per-unit-effort (CPUE) and summed to form an index of abundance (Flynn and Hilborn 2004). Scale and tissue samples from the catch provide age composition and genetic-based stock composition estimates within two to four days of when the fish are sampled at Port Moller; therefore a few days prior to when fish arrive in the fishing districts.

The usual forecasting method using Port Moller has been to test the regression (with a zero intercept) between the year-end total run (from the cumulative daily index observed in the current year based on a relationship built upon total runs) and the cumulative indexes observed in previous years on that date going back to 1987 (when the gillnet and sampling protocol was standardized) (Appendix L). The slope of this regression line then represents the average fish per index (FPI) across years for that day of the run. This relationship improves slightly as the season progresses (Figure 36), but the uncertainty around the test fishery forecast is still considered too high to have influence on management (T. Baker, pers. comm.). On average the forecast underestimates total run early in the season, becomes the least biased around June 30, then begins to underestimate again (Figure 36), indicating a time trend in the within-season FPI. One could have hopes of correcting the forecast based on this pattern, but it fluctuates significantly across years. The problems stem from measurement error in the index and from changes in the FPI both within season and annually.

Several attempts have been made to improve the accuracy of the forecast by reconfiguring how the index is calculated from the catches, accounting for temperature effects, and by *ad hoc* methods for removing size selectivity (e.g., Fried 1985; Flynn and Hilborn 2004), but none have proved convincing enough to sway managers. However, recent genetic sampling at the Port Moller test fishery allows stock composition estimates in-season and provides relative estimates of what is coming to each system in the coming days (T. Baker, pers. comm.). The addition of stock composition estimates has increased the “confidence” of the test fishery information. How much the information is used depends on how well Port Moller tracts the run during the first part of the season. For instance, if a spike in the Port Moller index is followed six days later by a spike in inshore catch, then more confidence is given to how well Port Moller is tracking the run for that year; likewise, researchers look to see if stock composition estimates at Port Moller tract what is observed inshore. However, no statistical rigor is currently applied to quantify these relationships.

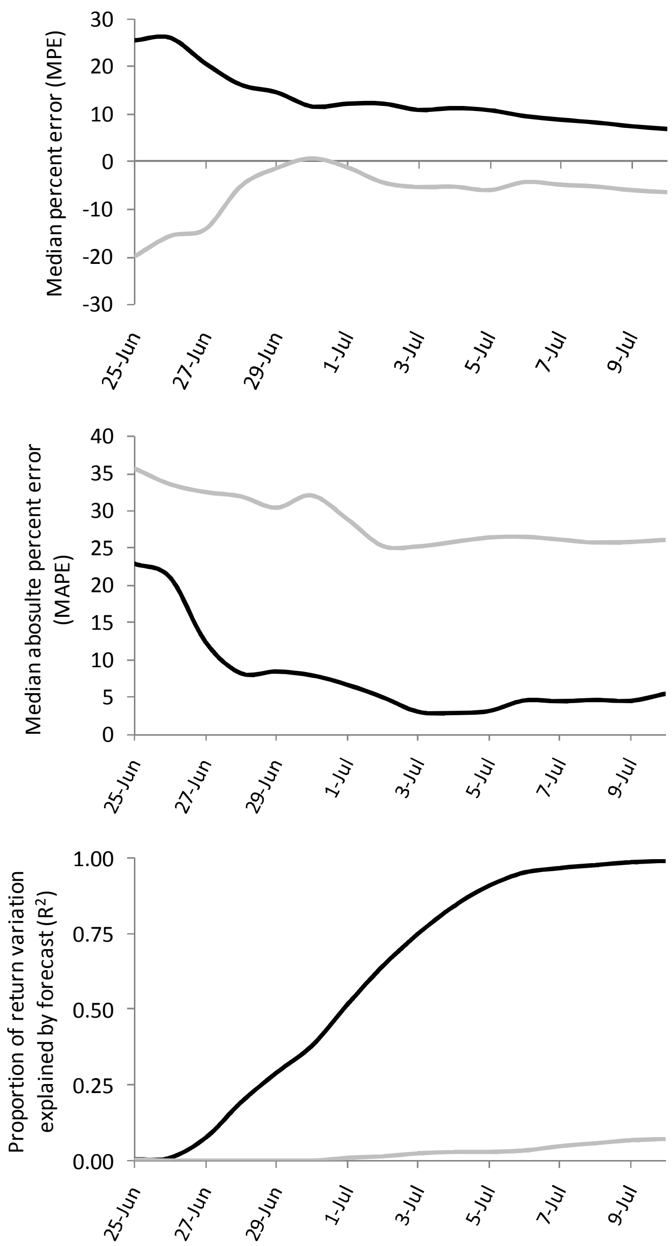


Figure 36 Average in-season forecasting performance of the sockeye total run in Bristol Bay, Alaska (2001-2010). The black line represents the cumulative catch+escapement model (all districts pooled) and the gray line the Port Moller model. MPE and MAPE represents the median percent error and median absolute error across years. The R^2 value was based on the best-fit linear regression line of $\log_{10}$(observed run) versus $\log_{10}$(forecasted run).

District test fishing

On an as-needed basis and typically early in the season, ADF&G managers will charter fishing vessels to conduct test fishing with commercial gillnets in and around the fishing districts. This is typically used in place of fishery performance when the fishery is closed and provides a crude index of abundance to detect the degree of “build up” of fish in the district. In large-run years when the fishery is happening daily there is little use for district test fishing. In a small-run year to a district, AMBs may deploy district test fishing frequently. District test fishing merely gauges substantially small or large groups of fish in the district and is generally inadequate for any sort of precise forecasting of abundance.

Commercial fishery performance with catch and age sampling

A fleet of several hundred fishing vessels usually provides a reliable picture of the number of fish in the district and AMBs are in regular contact with fleet managers to obtain catch rates early and throughout the fishing periods. Given relatively high harvest rates, particularly sophisticated or reliable forecasting models have not been needed (or developed) using fishery catch rates. The effects of weather, tides, and number of vessels would certainly be significant factors in such relationships.

ADF&G technicians sample the commercial catch from inshore fishing districts for age, sex, length, and weight information. Age composition is estimated with scales taken from harvested fish at processing plants throughout the Bay. Sample sizes are always high and afford minimum uncertainty due to sampling error. These data are used in-season to compare to the pre-season forecasted age composition (to look for anomalies that may indicate sources of error in the pre-season forecast). A comparison of the age composition from Port Moller and the district catch can provide some indication of the relative strength of the different stocks at Port Moller (to augment the genetic-based stock composition). These age data are also used on a post-season basis to build age-specific catch estimates for each district and subsequently all nine natal rivers. Stock-specific age compositions averaged over the past 20 years show how stocks differ with respect to how much time they each spend in freshwater versus the marine environment (Table 28). Catch numbers and trends were discussed in the Harvesting section above.

Table 28 Average age composition of sockeye stocks in Bristol Bay, Alaska from 1991-2010. Values represent the average percent of individuals that belong to each freshwater age (FA) and ocean age (OA) combination.

FA.OA	Alagnak	Egegik	Igushik	Kvichak	Naknek	Nushagak	Togiak	Ugashik	Wood	Average
1.3	47%	18%	71%	16%	53%	63%	66%	30%	43%	33%
2.2	9%	41%	3%	50%	11%	1%	5%	25%	3%	27%
1.2	38%	9%	21%	25%	16%	12%	19%	27%	50%	23%
2.3	5%	30%	4%	9%	18%	2%	8%	17%	2%	15%
0.3	0%	0%	0%	0%	0%	14%	1%	0%	0%	1%
1.4	1%	0%	0%	0%	1%	6%	1%	0%	0%	1%
2.1	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
3.2	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%
0.4	0%	0%	0%	0%	0%	2%	0%	0%	0%	0%
0.2	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%

Inside test fishing

ADF&G operates gillnet test fishing from skiffs above commercial fishing boundaries but below escapement enumeration projects on the Ugashik, Egegik, Kvichak, and Igushik rivers (Igushik has not operated since the early 2000s). These projects were developed because there is a two-day lag or better from the district fishing boundary to the enumeration projects (Minard and Meacham 1987). Somewhat more quantitative than district test fishing, inside test fishing provide managers with tide-by-tide indication of fish moving above the fishing district. The estimation method involves finding the travel time (measured discretely in days) by which to lag the daily test fish index to maximize the correlation with daily counts at the upstream enumeration project (counting tower). Once this is done, one can determine the fish per index (FPI) that each test fish index point represents and use this as a multiplier for the most recent days' test fish results to estimate the current "in-river fish" that are between the fishing district and escapement enumeration projects.

Aerial surveys

At key times during the season when uncertainty about the run strength is at its greatest, AMBs will fly aerial surveys of the rivers between their fishing districts and the tower sites to augment or verify the estimates obtained from inside test fishing. Surveying different stages of fishery openings can also provide the AMB with an indication of how hard fish are pushing into the district on a given tide, and the catch and subsequent escapement to expect.

Escapement monitoring

The hallmark of the assessment system in Bristol Bay is its escapement monitoring projects operated by ADF&G. Cumulative escapement counts are compared to historical data to provide managers an indication of whether they are ahead or behind the escapement that they would need to be to meet the escapement goal given their understanding of the current year's run timing. Set up prior to the arrival of the fish, counting towers are operated on banks of each side of the Ugashik, Egegik, Naknek, Alagnak, Kvichak, Wood, Igushik, and Togiak rivers. Beach seines are used to collect scale samples for estimating age composition. On the Nushagak River, ADF&G operates a sonar site to enumerate passing salmon. Chinook, chum salmon, and in some years pink salmon and coho salmon (when operated late in the season) are also sampled and enumerated in the Nushagak River, but sockeye comprise 90% of returning salmon. Species composition of the sonar counts is estimated from individuals collected in a gillnet test fishery that is operated adjacent to the sonar site.

In 1953, W. F. Thompson developed the tower counting system for Bristol Bay (Thompson 1962). The history and accuracy associated with these tower counts is described by Woody (2007), while methods for efficiently estimating sampling error (precision) can be found in Reynolds et al. (2007). Towers are constructed on clear streams at sites amenable to sampling, which is circumscribed by a set of guidelines (Woody 2007). When tower counts were compared to weir counts (assumed to be a complete census) on the Egegik River, relative error was -7.4% (Rietze 1957; Spangler and Rietze 1958). The sources of error include: (1) observer variability, (2) aspects of migration, (3) weather conditions, and (4) sampling error due to subsampling (Woody 2007). Observer variability is negligible; even when experienced observers were compared to the inexperienced, percent errors ranged from -1.8% to +1.3% (Anderson 2000). Species confusion is possible as several salmonids share natal streams, but Bay systems are dominated by sockeye and some species are easily distinguished (e.g., Chinook salmon) and/or have different run timings (e.g., coho salmon). High density passage of fish may bias observer counts, but using a replicated systematic sampling design with 20-minute counting intervals will reduce this bias (Siebel 1967; Reynolds et al. 2007). Bias from weather conditions are difficult to quantify, but Woody (2007) recommends careful site selection to reduce glare and wind, polarized glasses, riffle dampeners to reduce surface turbulence, and lighter colored substrates to provide contrast as salmon pass over.

Sampling error has been carefully examined and established protocols are statistically well vetted (Reynolds et al. 2007). Currently, ADF&G uses a non-replicated systematic sampling design whereby 10-minute counts are made every hour, 24 hours per day throughout the entire season with the same 10-minute interval being sampled for the duration (this interval is randomly chosen at the beginning of each season). Subsampling each hour creates uncertainty, which is best quantified with a modified variance estimator (the V5 estimator by Wolter [1984]) that accounts for patterns in the data (Reynolds et al. 2007). Sampling two 20-minute intervals every two hours (i.e., a replicated systematic sample design) is recommended when runs are compressed to cause high density passage. Replicated designs afford unbiased variance estimates that do not require modification. However, the use of 20-minute intervals approaches the maximum attention span for most observers (Woody 2007); consequently, ADF&G uses non-replicated 10-minute counts per hour with the modified V5 variance estimator. The Nushagak DIDSON sonar relies on the same sampling design as the tower counts with respect to hourly count intervals throughout the season.

These projects typically begin around early to mid June and end based on a decision rule when the counts represent <1% of the cumulative run to date for three days in a row. Because the Nushagak sonar site was continued to enumerate a coho salmon run up until 2005, it represents a convenient way to test this rule on the Nushagak sockeye run. On average, around 4% of the run would have been missed had the 3-day rule been applied to this system (Figure 37).

Escapements fluctuated drastically in Bristol Bay up through the mid 1980s owing to the Kvichak cycle repeating every 4-5 years, but the constant escapement policy has resulted in relatively stable escapements over the past 20 years and seems to have dissipated this cycle (Figure 27, Appendix L). No metrics of uncertainty are currently reported by ADF&G, but a 95% confidence interval was found to be <5% of the estimates in recent years for all systems (unpublished analysis of escapement counts using methods as per Reynolds et al. [2007]). In all, escapement estimates across systems in Bristol Bay are extremely accurate and precise relative to other salmon stocks and enumeration techniques.

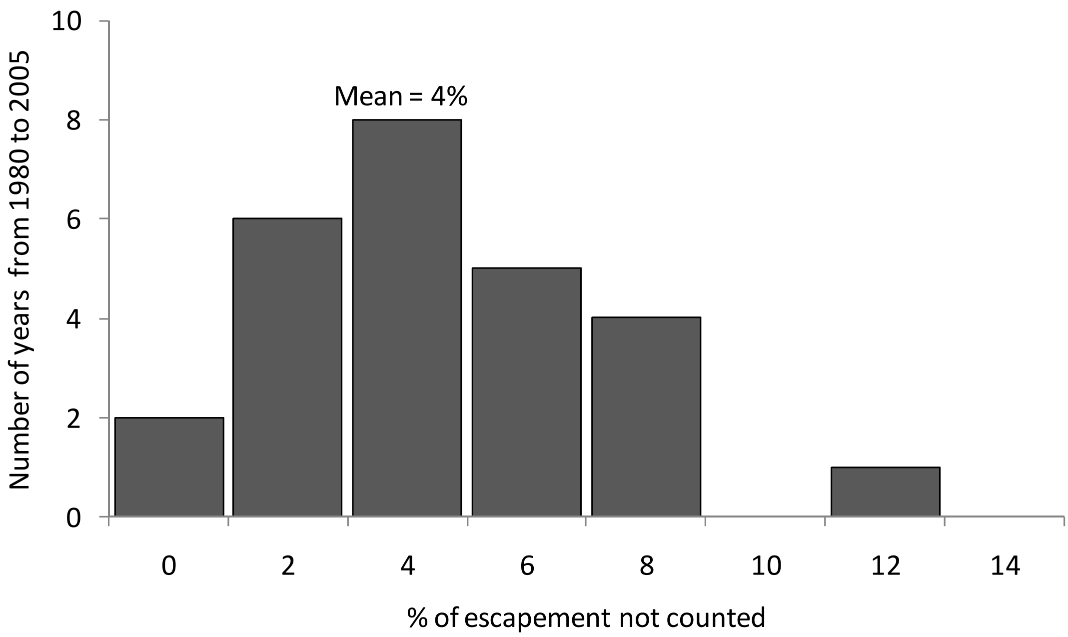


Figure 37 Projected percent of the sockeye escapement that would not have been counted if the 3-day-under-1% rule for ending enumeration projects had been used for the Nushagak River, Alaska.

<u>In-season forecasting of total run from catch and escapement</u>

Research staff uses the cumulative catch and escapement (C+E) to a given date to forecast total run to a district or river system. Given the effects of subtle changes in run timing can have on these forecasts, the estimates are not particularly precise until later in the season when about 60% of the run has returned. In-season forecasting methods and results are not made public by ADF&G nor are they consistent across managers in Bristol Bay. Some AMBs routinely liken the current year's cumulative C+E to a year in the past with a similar entry pattern and magnitude to give a guesstimate of what to expect for the year-end total (P. Salomone, pers. comm.). Others divide the current year's cumulative catch and escapement (C+E) by what proportion of the total run has historically returned on a given date. Forecasts can be made for each system separately, except where two systems empty into a common commercial fishing district in which case the forecast is just district specific. Some river systems are more amenable than others with respect to providing accurate forecasts. Further, river systems vary with respect to accuracy on a given date, due to minor differences in run timings. ADF&G begins to use this forecasting technique for a given system to some extent after they feel 50%-60% of the current year's run is accounted for inshore. We combined the forecasts and observed runs from all districts to facilitate comparison with the Port Moller model (Figure 36).

Instead of trying to forecast possible catches, AMBs use these total run forecasts to gauge how much room they might have to make up or get behind on escapement if they open or close a fishing period. The less certain that these forecasts project some remaining surplus production, the more conservative AMBs are with granting openings.

Other non-government organizations make C+E forecasts available to ADF&G. FRI uses the Port Moller test fishery and the cumulative C+E to update the pre-season forecast and predicts system specific total runs in a more formal statistical setting. Essentially, the pre-season, Port Moller, and C+E forecasts are averaged to provide a forecast every few days in-season with each method being weighted by the inverse of its variance (Ray Hilborn, Professor, University of Washington, pers. comm.). Of course, the pre-season forecast and its weight remain constant, but Port Moller and C+E change, with Port Moller reaching its maximum influence midway through the season and C+E dominating towards the end of the run. Similar to Bristol Bay, Henderson et al. (1987) found the pre-season forecast of sockeye for Smith Sound, B.C. to outperform in-season forecasts based on C+E until the very end of the season. Fried and Hilborn (1988) tried a Bayesian approach to combine forecasts and update them each day but this approach is not used. In-season forecasting uncertainty remains high, accuracy low (until it is too late in the season to be useful), and a magic bullet is yet to be found.

Post-season Evaluations

Following each fishing season ADF&G releases four publications as a service to the public and user groups via email and by posting them on ADF&G's Bristol Bay Home Page (See http://www.cf.adfg.state.ak.us/region2/finfish/salmon/bbayhome.php). First, catch and escapement estimates are finalized immediately following the end of the fishing season and reported in a Season Summary Report. These estimates are used to update brood tables and forecast the run for the following year; these Pre-season Forecasts (second publication) are always reported no later than November and in time for the annual Pacific Marine Expo, a fishing industry trade show hosted in Seattle. Third, Area Management Reports (AMRs) are issued sometime before the beginning of the next fishing season. These reports summarize the fishing season in much greater detail than the Season Summaries and offer the catch and escapement by stock, age, and return year for current year and previous 20 years. Fourth, the next season's Outlook

Report is released in March and gives an overview of the pre-season forecast, any regulatory changes that will be implemented, and the anticipated processing capacity.

On a 3-year cycle that coincides with the BOF meetings for the Bay, an additional report, the Escapement Goal Review, is issued that details the results of updated spawner-recruit analyses, makes recommendations for any escapement goal changes (Appendix L), and reviews management's success in achieving these goals for each stock. The consistency with which Bristol Bay escapement goals are met is illustrated in Figure 30 and Figure **28**. One exception was high escapement to the Wood River in 2006 during an abnormally large return of small-for-their-age 2-ocean fish when the fleet was incapable of exerting enough exploitation to stop the run with the gear they had available. Another appears to be the Alagnak River from 2003 to present. The Alagnak stock is passively managed with a risk-based escapement goal to give way for actively managing the Kvichak. Alagnak experienced a dramatic and substantial increase in run sizes beginning in 2003 and this coincided with an unproductive period for the Kvichak River. Note, however, that Figure 30 somewhat exaggerates the increase run size over earlier times because the enumeration method on the Alagnak River switched from one based on aerial surveys to tower counts in the early 2000s (J. Regnart, pers. comm.). These isolated exceptions notwithstanding, the consistency with which escapement goals are met for each stock across a wide range of run magnitudes is a testament to the quality and timeliness of in-season data, the level of fishing power available to the managers, and the authority with which they have to impose it.

COMPARISON OF FRASER & BRISTOL BAY SOCKEYE FISHERIES

The purpose of this section is to examine the key components of the Bristol Bay and Fraser River sockeye fisheries and provide the reader with the context for understanding the perceived and actual differences in the approaches used to manage and assess these fisheries.

Management Structure

The Bristol Bay and Fraser sockeye fisheries are substantially different in the structure and complexity of the management process. Many aspects of the management of Fraser sockeye stocks and fisheries are affected by the 1985 Canada/U.S. Pacific Salmon Treaty and 1999 Revised Annexes. This international treaty established a management body (Fraser River Panel) responsible for the management of fisheries conducted in Panel Area waters (Figure 1). Fisheries conducted outside Panel Area waters fall under the management authority of other agencies (e.g., DFO for other Canadian fisheries and ADF&G for Alaskan fisheries). The Fraser River Panel includes representatives from DFO, Washington Department of Fish and Wildlife, ADF&G, BC First Nations, U.S. Treaty Indian Tribes, National Marine Fisheries Service, along with representatives from the salmon processing industry and commercial fishing sectors on both sides of the boarder. Since decisions made by the Fraser River Panel affect fishing opportunities for Fraser sockeye both inside and outside Panel Area waters, it is not uncommon for weekly Fraser Panel conference calls to include more than thirty people, many of who are just observers. The Panel has 10 official members and 10 alternates. Decisions are typically made on a consensus basis but majority votes have been used for instances when consensus could not be achieved.

The Bristol Bay sockeye fishery and its management structure are considerably less complex than the Fraser River fishery. The Commissioner of ADF&G delegates full management authority to four Area Management Biologists and each AMB is responsible for a specific geographic areas defined as fishing districts. Despite the simpler process, ample opportunities are provided to users and the public for input into the management process. Management and allocation plans are set during the accessible and transparent Board of Fisheries process, which includes input from district-and-gear-specific advisory panels. Once management plans are established by the Board of Fisheries (during the off-season), individual AMBs are given authority to open and close this fishery to meet clear management objectives. AMBs consult users daily and hourly during the season and this helps to achieve management objectives, but there is no time or space in the process for broad-based and formal consultative processes during the fishing season.

Fisheries and Stocks

Fish returning to nine river systems around Bristol Bay are targeted in five fishing districts. These nine systems are managed in five fishing districts, which creates only a few interception/mixed stock fishery issues. Noted for very terminal nature of its harvesting, fishing districts in Bristol Bay extend no more than three miles offshore of the shoreline (i.e., state waters boundary) and generally no farther alongshore from river mouths. In recent years, management plans have been implemented to further increase the terminal nature with the introduction of “in-river” special harvest areas in the Naknek and Alagnak rivers (to protect Kvichak) and on the Wood River (to protect the Nushagak).

Allocation of catch among users in Bristol Bay, although a source of heated debated on many occasions, is simpler to administer than on the Fraser River. Allocation targets are established at Board of Fisheries meetings every three years in an open and transparent process where all affected parties are given time to speak to allocation plans. Commercial fisheries in the Bay are limited to just two gear types (set and drift gillnet), and catches in subsistence and recreational fisheries rarely exceed more than 1% of the annual sockeye harvest.

These features noted above are in stark contrast to Fraser sockeye where the entire run is destined for a single large river and management goals are set for four run-timing groups comprised of over 25 distinct indicator stocks (conservation units). Target harvest allocations are set for multiple First Nations, three commercial gear types in Canada, and several U.S. fisheries and gear types in Panel Area waters. The Fraser fishery is more of a gauntlet fishery than the Bristol Bay fishery, with harvesting occurring in places up to 200 km from the river mouth as well as along a good portion of the river. Travel times between major marine fishing areas and lower river assessment sites for Fraser sockeye range from 6-8 days for early run timing groups to 3-6 weeks for Late-run stocks.

The magnitude and duration of the two fisheries is substantially different. Daily harvests at the peak of the annual Bristol Bay fishery exceed 2 million fish on a regular basis and have been as high as 5.2 million fish on a single day. The Bay fishery occurs over about 6 weeks beginning early June and about 65% of the harvest occurs over a 2-week period centered on the July 4th. For Fraser sockeye, daily harvests rarely exceed 0.2 million fish and fisheries are typically initiated in marine waters in mid-July and continue in freshwater area into late September. Annual harvests over the last 20 years have averaged 26 million sockeye in Bristol Bay compared to 5 million for Fraser sockeye.

Finally, the harvesting sector (in the Bristol Bay fishery) benefits from a very diverse portfolio of rivers and stocks of fish. Recently ascribed as the “portfolio effect” by Schindler et al. (2010), the Bristol Bay fishery is made up of many large and productive rivers spread over a large geographic area; each river has a multitude of stocks and life history types (e.g., different freshwater ages, ages at maturity, and spawning eco-type [beach and river spawners]). As a result of diversified portfolio, fishing seasons with little or no harvesting are extremely rare in Bristol Bay; the last one occurring in 1973 when only 670,000 fish were caught. For Fraser sockeye, returns in 6 of the last 20 years have provided little or no commercial harvest. The recent most “disastrous” harvest in

Bristol Bay was in 1997 when there were 9.9 million fish caught. Fewer dramatically low harvests in the Bay likely translate into less controversy, fear, and politicizing of the fishery management regime than occurs on the Fraser River.

Variability in Returns and Escapement Goals

The two fisheries differ in how much their annual returns fluctuate from year to year. A convenient index of variability in annual returns across years is the coefficient of variation (CV), which is simply the standard deviation of the annual returns for a series of years divided by the mean for those years (and expressed as a percent). The CVs for Fraser and Bristol Bay returns from 1980 to 2009 reveal that Fraser sockeye returns have fluctuated about twice as much on an annual basis as the Bristol Bay returns during this time period (Fraser CV= 68% versus Bay CV= 32%; Appendix L).

The high variability in returns and uncertainty associated with optimum escapement goals for Fraser sockeye have resulted in managers and fishers selecting more complex abundance related harvest rules to set management goals for Fraser sockeye. These rules allow for more harvesting when run sizes are small, and more conservative harvest rates when run sizes are large, than would be permitted under a fixed escapement goal approach similar to that used for Bristol Bay sockeye. The more complex harvest rules and management goals come with added challenges, including the task of communicating fishing plans to the fishers.

The clarity and priority associated with the Bristol Bay escapement goals is very different from the Fraser harvest rate management approach and has provided Bristol Bay managers with greater ability to control fisheries and achieve the escapement goals. A clearly defined set of escapement goals for Fraser sockeye would not guarantee success but is one way that the management of Fraser sockeye stocks could be made simpler and increase the potential for achieving these escapement goals. If this approach was adopted for the Fraser it is unlikely that escapement goals would be constant across all cycle years for clearly cyclic stocks (e.g., late-Shuswap and Quesnel) but the goals would probably be similar across all years for non-cyclic stocks. These goals would be much easier the communicate to fishers than the current complex Total Allowable Mortality (TAM) rules and still allow managers the latitude to the implementation of harvest rate ceilings to protect less productive stocks when returns of the target stocks are large.

Pre-season Forecasts

One similarity between Bristol Bay and Fraser sockeye fisheries is the limited us of pre-season forecasts by fisheries managers. Pre-season forecasts are more important for processors and fishers than managers who rely on in-season information on catch and lower river escapements to manage marine fisheries. Nevertheless, we assessed the two fisheries with respect to the accuracy, precision and reliability of the pre-season forecasts. When all stocks are aggregated, median absolute percent error (MAPE; lower is better) appears slightly better for Bristol Bay than for the Fraser, but not by much. The difference (about 10% more in the Fraser) could have easily been caused by random noise. For both fisheries, MAPE for the total stock aggregate is less than that for any single stock or stock group. This result was expected because errors across stocks tend to cancel each other, rendering the aggregate forecast more precise. The aggregate Fraser forecast shows similar predictive ability (R^2= 0.44) as Bristol Bay forecasts (R^2= 0.44).

In-season Forecasts

In-season forecasting is of limited use to Bristol Bay managers who rely mostly on daily escapement counts and day-to-day movements of fish in the districts to manage the fishery. In-season forecasts come from two sources: (1) a test fishery in the marine waters of the Bering Sea that intercepts Bristol Bay bound sockeye about 6-8 days before they reach fishing districts adjacent to their stream of origin and it provides a Bay-wide forecast of total return, and (2) from cumulative daily catch and escapement estimates, which provide river-specific run forecasts. Overall, the test fishery performs poorly when used to predict total annual return. Even though total return predictions improve as the season progresses, these are not river-specific forecasts and are typically not reliable enough to justify one or more district-specific fishing periods (Figure 36). The usefulness of the test fishery is more qualitative, giving fishermen, processors, and managers about six days notice of when daily surges and lulls in run strength are coming. This six-day notice is of value and can affect fleet and processing operations and sometimes managers' openings and closings in anticipation of lulls or surges. In-season forecasts using cumulative catch and escapement combined with various run timing scenarios is reliable, but only after 50-60% of the run is accounted for inshore.

Fraser River in-season forecasts of total run by stock derived from marine and freshwater test fishery indices and the sonar-based Mission escapement estimates are directly relied upon by managers to determine when to permit fisheries. The reliability of the in-season forecasts varies across the different run-timing groups. The accuracy of in-season run size estimate tends to be biased high with low precision (40-80% error) for most of the first half of the migration period for Early Stuart and Summer-run sockeye but the bias and error is rapidly reduced to less than 10% as the run approaches the halfway point. The in-season forecasts for Early Summer and Late-run timing groups tend to be more accurate throughout their respective migration period and precision remains in the 15-25% range for most of the run. In general, in-season forecasts have been sufficiently accurate, precise and timely to make the management decisions needed to achieve the management goals defined for each of the four Fraser run-timing groups.

In-season and Post-season Escapement Enumeration

The hallmark of the assessment system in Bristol Bay is its escapement monitoring projects operated by ADF&G. Cumulative escapement counts are compared to historical data to provide managers an indication of whether they are ahead or behind the escapement that they would need to be to meet the escapement goal given their understanding of the current year's run timing. Hourly tower counts provide accurate estimates of the escapement for eight of the nine river systems. Towers count fish that left the terminal fishing districts 2-5 days earlier. For some rivers, in-river test fisheries provide estimates of the number of fish between the fishery and the tower for in-season management decisions only. These tower-based (or sonar-based) escapement estimates are assumed to be equivalent to spawning escapement since in-river harvests are almost non-existent.

These features of escapement monitoring in the Bay are major advantages over the Fraser sockeye situation where Mission escapement estimates are much less reliable than tower counts and a substantial portion of the fish passing Mission could be removed in upstream fisheries or lost due to "en-route" mortalities. The post-season estimates of escapement for Fraser sockeye provide substantially more information on the distribution of spawners than available for Bristol Bay but the costs associated with obtaining these estimates are substantial (in excess of $1 M per year). The combined cost for Bristol Bay escapement monitoring efforts, including the Nushagak sonar and eight counting towers in use today, is about $370,000 (Table 9 in Clark 2005).

Abundance Estimates

The earlier-in-the-year and shorter duration of Bristol Bay sockeye runs combined with essentially real time escapement monitoring make it possible for managers to generate reliable, post-season run size estimates by early September of each year and calculate pre-season run size forecasts for the following season by early November. This is substantially different from the situation on the Fraser where mark-recapture programs used to estimate spawning ground escapements for late-run stocks often continue through mid-November. Total run size estimates are not available until February or March of the year following the fishery and frequently not finalized before the beginning of the next fishing season.

An added feature of the Fraser River that complicates the development of final escapement estimates is the need to estimate those fish that were neither caught nor arrived at the spawning grounds. The combination of warmer river temperatures, in-river fisheries and much longer freshwater migration for some Fraser sockeye stocks (>1,000 km) create the potential for significant "en-route loss" (i.e., mortality) that has been verified in several years using radio-telemetry techniques. The uncertainty associated with the magnitude of these en-route losses makes the post-season abundance estimates for Fraser sockeye less reliable than those for Bristol Bay stocks.

STATE OF THE SCIENCE

Catch Monitoring

Current best practices regarding catch monitoring include (1) on-site interviews and periodic fishing effort counts for estimating catches for First Nation FSC and recreational fisheries, and (2) mandatory catch reporting combined with on-board observers and dock-side monitoring for commercial salmon fisheries. The methods used to monitor First Nation FSC and recreational harvests of Fraser sockeye are consistent with the best practices for these types of fisheries; however, there are on-going concerns regarding the level of monitoring effort and implementation of the survey designs. The catch monitoring programs for commercial fisheries include some of the elements of the best practices but fall well short of the scientific standards for a rigorous catch monitoring system because of deficiencies in fishers compliance with mandatory reporting requirements, insufficient verification of reported catches through on-board observers and dock-side monitoring prior to 2010, incomplete documentation of methods, and ineffective database management.

Non-Retention Fisheries

Best practices for selective or responsible fishing are well known for all sectors (Plate et al. 2008) but only a small fraction of the annual sockeye harvest is capture using selective fishing techniques. Commercial fisheries could be more selective by reducing the use of large mesh gillnets, mandatory brailing for all purse seine fisheries, and expansion of opportunities for trollers. The selectivity of First Nation fisheries and survival of non-retained species could be improved by reducing the use of set nets, requiring full-time monitoring of each set net, and increasing the use of more selective gear (e.g., dip nets, beach seines and fishwheels). The impact of both First Nation and recreational fisheries on non-retained species could be reduced by moving fisheries away from locations and times when migrating salmon are being severely stressed by high water temperature, river discharge and/or other environmental factors.

Pre-season and In-season Forecasts

The procedures used for pre-season forecasting of Fraser sockeye include the full range of stock-recruitment models used in the management and assessment of salmon fisheries. The deficiencies associated with reliability of pre-season forecasts are not due to the methods or models used but largely attributable to high year-to-year variability in marine survival. More extensive environmental monitoring data will likely been needed to improve our ability to predict changes in marine survival, but there are no guarantees that these additional investments will improve the reliability of pre-season forecasts.

In-season estimates of the abundance of sockeye returning to the Fraser River are derived by combining data from marine test fisheries, freshwater test fisheries and the Mission hydroacoustic site. Test fishery operations have been coordinated between the DFO and PSC and the methods are consistent with the state-of-the-art for salmon fisheries. The hydroacoustic monitoring techniques used at the Mission site include some of the most advanced technology used to monitor salmon in large river systems. However, PSC scientists have identified a number of deficiencies with these hydroacoustic techniques and continue to evaluate alternatives (Xie et al. 2002). Two promising alternatives that have been tested at the site in recent years are: (1) DIDSON hydroacoustic techniques, and (2) the use of side-scan fixed-station hydroacoustics in mid-channel locations. DIDSON technology has been proven superior to single beam or split-beam technology for counting upstream migrating salmon when abundances are high. The second alternative is a potential solution to concerns related to fish avoiding detection in the boat-based mobile hydroacoustic surveys conducted at the Mission site (Xie et al. 2008). The Bayesian models currently used to derive in-season forecasts from the available test fishery and Mission escapement data are as sophisticated as any used in the management of salmon fisheries. The in-season information on stock composition and abundance for Fraser sockeye is timely and readily available for fisheries management decisions.

Escapement monitoring

The primary methods used to estimate escapements to spawning areas for Fraser sockeye are mark-recapture, counting fences and visual surveys. Tower counts are used extensively in Alaska to estimate sockeye escapement but they are not used on the Fraser, except to guide mark-recapture programs. In recent years, partial weirs and DIDSON hydroacoustic systems have been used on the Horsefly and Chilko rivers (Cronkite et al.

2006) due to concerns regarding the rising costs of conducting mark-recapture programs for these large Summer-run stocks. These DIDSON systems, while not suitable for all streams, are less costly than mark-recapture studies for large populations and have been demonstrated to provide counts as accurate as visual counts from clear water streams when the sonar beams cover the entire area where the fish are migrating (Holmes et al. 2006). Although the portion of the sockeye escapement enumerated using the best available techniques varies from year to year, the methods used in recent years are appropriate and the best of the available alternatives for Fraser sockeye.

Escapement Goals

Currently, management goals for each run-timing group of Fraser sockeye are defined through the FRSSI process which has employed shared decision making techniques and a complex set of objectives and evaluation criteria. The key missing pieces from this process are (1) a clear definition of the escapement goals for each stock by cycle year, and (2) a method for integrating stock-specific goals into a management rule for each run-timing group. As demonstrated in the Bristol Bay fisheries, clearly defined escapement goals are critical for providing managers with the targets needed to make fisheries management decisions and assess stock status.

The WSP has identified the need to define lower benchmarks (LBs) and upper benchmarks (UBs) for each CU. Holt et al. (2009) describe the methods that should be used to define these benchmarks and Grant et al. (2010) provided a range of estimates for each benchmark generated from alternative stock-recruitment models. However, the interim LBs and UBs defined through the FRSSI process and recent CSAS working papers are fixed values intended to be compare with the 4-year average escapements for each stock or run-timing group (Staley 2010; Grant et al. 2010). As indicated earlier, these types of benchmarks are not very informative or useful for the management of cyclic stocks. There should be at least two different LBs and two UBs for each cyclic stock. Since each run-timing group contains at least one cyclic stock, managers need cyclic-specific LBs and UBs for each run-timing group. These benchmarks or escapement goals would make it easier to assess stock status and trends for each cycle year relative to these defined goals and determine if fisheries should be permitted to target specific stocks in a specific year. For example, if the run size is below the LB for a stock, no fisheries should be permitted to target that stock. The stock-specific benchmarks goals should be used to define the LBs, UBs and total allowable mortality (harvest plus natural mortality) for each run-timing group. The LB and UB for a run-timing group could be simply the sum of the values for the component stocks. The total allowable mortality for each run-timing group should be based on the in-season assessment of the total return, environmental conditions and status of each stock relative to its LB and UB.

Abundance estimates

The combination of mixed-stock fisheries, variable levels of en-route loss, and numerous spawning locations create major challenges for estimating the annual returns for each Fraser sockeye stock. As indicated earlier, there are a number of deficiencies with the catch monitoring systems and catch databases for Fraser sockeye. Catch estimates for each of the 19 Fraser indicator stocks are currently derived by PSC biologists by combining fishery specific stock composition estimates with DFO's catch estimates for all commercial and First Nation fisheries. Stock composition estimates for Fraser sockeye fisheries were based historically on analysis of scale patterns (Henry 1961; Gable and Cox-Rogers 1993) and currently based on state-of-the-art DNA micro-satellite analyses (Beacham et al. 2004). Scale and DNA samples are routinely obtained from all major commercial fishing areas and test fisheries located below Mission. Fisheries above Mission are not systematically sampled for stock composition so stock composition estimates from the Whonnock Test Fishery have been used to assign catches to specific stocks. Recently, detailed run reconstruction models have been developed to provide an estimates of catch by CU for all in-river fisheries using the best available catch and escapement estimates along with Mission run-timing, in-river migration speeds and en-route loss estimates from recent radio-telemetry studies (English et al 2005; Robichaud and English 2006; 2007; Robichaud et al. 2008; 2010). More work remains to be done on these analyses but these types of detailed run reconstruction models are likely to provide the best estimates of returning abundance by CU, especially for the smaller sockeye stocks that are poorly represented in the stock composition samples. Two key components of any abundance estimate for Fraser sockeye are the escapement estimates and run-timing for each stock. The marine test fisheries and Mission hydroacoustic site have been good sources for sockeye run timing information. DFO's spawning ground surveys, discussed earlier, provide reliable information on the escapements for the 19 indicator stocks. DFO and PSC have maintained a time series of abundance estimates available for these 19 indicator stocks dating back to 1952. These estimates are widely considered to be some of the best available for sockeye salmon stocks. However, the future of this valuable time series and the conversion of historical and future data into catch, escapement and total abundance estimates for each CU will depend heavily on the resources available to support critical monitoring programs, effort to capture these data in structured databases, and the work needed to complete the necessary analyses.

RECOMMENDATIONS

1. DFO needs to ensure that all catch monitoring programs (First Nations, commercial, and recreational) have complete documentation and information on catch and annual survey effort is maintained in easily accessible databases so managers and decision makers are aware of changes and trends in catch and monitoring efforts.

2. DFO should work with First Nation and recreational fishers to identify methods, times and locations that will allow for an effective harvest of sockeye while minimizing the impact of in-river fisheries on the non-retained portion of the sockeye catch (e.g., angler releases and net dropout).

3. The analytical resources currently allocated to preparing pre-season forecasts should be re-allocated to defining a clear set of escapement goals and in-season management models that will assist managers in fisheries planning and the achievement of these goals.

4. The current in-season escapement monitoring programs (including test fisheries, Mission and Qualark hydroacoustic systems) should be maintained and rigorously evaluated over the next four years to determine the most accurate and cost-effective system for providing in-season estimates of run size and escapement to the lower Fraser River.

5. Information on the annual survey effort associated with escapement monitoring programs should be documented and maintained in easily accessible databases so managers and decision makers are aware of changes and trends in escapement monitoring efforts.

6. Escapement goals for each indicator stock and run-timing group need to be clearly defined and communicated to fishers to facilitate the regulation of fisheries and evaluation of management performance. There should be at least two different Lower Benchmarks (LBs) and two Upper Benchmarks (UBs) for each cyclic stock. Since each run-timing group contains at least one cyclic stock, managers need cyclic-specific LBs and UBs for each run-timing group. These benchmarks or escapement goals would make it easier to assess stock status and trends for each cycle year relative to these defined goals and determine if fisheries should be permitted to target specific stocks in a specific year.

7. The location, timing and magnitude of en-route losses for major stocks and each run-timing group should be estimated each year and incorporated into run reconstruction models to maximize the reliability of annual abundance and exploitation rate estimates.

8. DFO needs to maintain its commitment to the recovery efforts for Cultus Lake sockeye and the monitoring programs needed to evaluate these efforts.

9. Management agencies should continue efforts to improve in-season estimates of abundance and annual estimates of en-route loss. This information is needed to manage in-river fisheries under changing environmental conditions (e.g. water temperature and flow) and meet commitments related to FN agreements and WSP.

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Appendix A Statement of Work.

Cohen Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River

"Fraser River Sockeye Fisheries and Fisheries Management"

SW1 Background

1.1 The Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River (www.cohencommission.ca) was established to investigate and report on the reasons for the decline and the long term prospects for Fraser River sockeye salmon stocks and to determine whether changes need to be made to fisheries management policies, practices and procedures.

1.2 The Contractor is to investigate sockeye fisheries harvesting and fisheries management with a view towards informing the Commission about their role in the reduction in Fraser sockeye productivity, and particularly the collapse of the 2009 return.

SW2 Objective

2.1 To prepare a review of fisheries for Fraser sockeye including First Nations, commercial and recreational fisheries.

2.2 To undertake a functional description of fisheries management for Fraser River sockeye salmon.

SW3 Scope of Work

Fisheries Harvesting

The Contractor will summarize the time series of Fraser sockeye fisheries openings in the 3 sectors, First Nations, Commercial, and Recreational, over the period 1980–2009. The interests and concerns of the different sectors will be characterized.

First Nations fishery

3.1 The Contractor will summarize the food, social, ceremonial and commercial harvest levels of Fraser River sockeye allocated to First Nations (through treaty, fisheries agreement, communal fishing licence or other program or agreement), and the actual harvest levels achieved, according to fishing location and method, for the period 1980-2009. The formal and informal structure of the First Nations fishery will be characterized.

3.2 The Contractor will describe and evaluate the accuracy, precision and reliability of methods for making catch estimates.

Commercial fishery

3.3 The Contractor will summarize the target and achieved allocations of Fraser River sockeye to the commercial sector, according to fishing method (troll, seine and gillnet), for the last 30 years.

3.4 The Contractor will describe and evaluate the accuracy, precision and reliability of methods for making catch estimates.

Recreational fishery

3.5 The Contractor will describe and summarize the daily and annual catch limits for recreational fishers of Fraser River sockeye set for the last 30 years.

3.6 The Contractor will describe and evaluate the accuracy, precision and reliability of methods for making catch estimates, including consideration of the creel survey.

All sectors

3.7 The Contractor will describe and summarize the consequences of non-retention fisheries (First Nations, commercial, recreational) on sockeye physiology, survival and abundance.

Fisheries Management

3.8 The Contractor will describe and evaluate the accuracy, precision and reliability of pre-season forecasting methods. This work will include a description of the application of pre-season forecasting in harvest management.

3.9 The Contractor will also describe and evaluate the accuracy, precision and reliability of other methods, if any, that are available for pre-season forecasting not historically or currently used by DFO and the Pacific Salmon Commission.

3.10 The Contractor will describe and evaluate the accuracy, precision and reliability of in-season run-size abundance estimation methods. This work will include a description of the application of in-season and post-season run-size abundance estimation in harvest management.

3.11 The Contractor will also describe and evaluate the accuracy, precision and reliability of other methods, if any, that are available for in-season and post-season run-size abundance estimation not historically or currently used by DFO and the PSC.

3.12 The Contractor will describe and evaluate the accuracy, precision and reliability of in-season and post-season escapement enumeration methods used historically and currently by DFO and the PSC.

3.13 The Contractor will also describe and evaluate the accuracy, precision and reliability of other methods, if any, that are available for enumerating sockeye not historically or currently used by DFO and the PSC.

3.14 The Contractor will analyze historical performance of the in-season assessment process, to include changes in estimates of in-season run sizes, with particular emphasis on how long it has taken within each season to correctly assess the final in-season run size. The key issue to be described is how quickly the in-season assessment process can respond, to meet escapement goals.

3.15 The Contractor will evaluate the scientific basis for determining escapement targets. The current and historical effectiveness of fisheries management, including reliance on the Fraser River Sockeye Spawning Initiative (FRSSI), to achieve sockeye escapement goals for individual CUs will be evaluated.

3.16 The extent and impact of any overharvesting from 1985 to present will also be evaluated.

3.17 The Contractor will summarize the current conservation status of the Cultus Lake sockeye population, previously assessed by COSEWIC (Committee on the Status of Endangered Wildlife in Canada) to be endangered, and will evaluate whether DFO's recovery efforts have been effective in meeting stated recovery objectives. The Contractor will identify what recovery actions were available but not pursued by the Recovery Program.

3.18 The Contractor will develop rebuilding strategies for Fraser River sockeye.

SW4 Deliverables

4.1 The Contractor will organize a Project Inception meeting to be held within 2 weeks of the contract date in the Commission office. The meeting agenda will be set by the Contractor and will include a work plan for project implementation.

4.2 The main deliverables of the contract are 2 reports evaluating Fraser River sockeye fisheries management investigations: (1) a progress report, and (2) a final report. The style for the Reports will be a hybrid between a scientific style and a policy document. An example of a document which follows this format is the B.C. Pacific Salmon Forum Final Report (www.pacificsalmonforum.ca).

4.3 A Progress Report (maximum 20 pages) will be provided to the Cohen Commission in pdf and Word formats by Nov. 1, 2010. Comments on the Progress Report will be returned to the contractor by Nov. 15, 2010.

4.4 A draft Final Report will be provided to the Cohen Commission in pdf and Word formats by Dec. 15, 2010. The draft Final Report should contain an expanded Executive Summary of 1-2 pages in length as well as a 1-page summary of the

"State of the Science". Comments on the draft Final Report will be returned to the contractor by Jan. 15, 2011 with revisions due by Jan. 31, 2011.

4.5 The Contractor will make himself available to Commission Counsel during hearing preparation and may be called as a witness.

4.6 The Contractor will participate in a 2-day scientific workshop on November 30 – December 1, 2010 with the Scientific Advisory Panel and other Contractors preparing Cohen Commission Technical Reports to address cumulative effects and to initiate discussions about the possible causes of the decline and of the 2009 run failure.

4.7 The Contractor will participate in a 2-day meeting presenting to and engaging with the Participants and the public on the results of the sockeye fisheries investigations on February 23-24, 2011.

Cohen Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River

"Comparison of Sockeye Fisheries Management in the Fraser River, BC and Bristol Bay, Alaska"

Amendment to LGL Ltd. Contract on "Fraser River Sockeye Fisheries and Fisheries Management"

SW1 Background

1.3 The Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River (www.cohencommission.ca) was established to investigate and report on the reasons for the decline and the long term prospects for Fraser River sockeye salmon stocks and to determine whether changes need to be made to fisheries management policies, practices and procedures.

1.4 The Commission wishes to engage a Contractor to investigate and compare sockeye harvesting practices and fisheries management in the Fraser River and Bristol Bay fisheries.

SW2 Objective

2.1 To discuss and develop conclusions about the differences and similarities in sockeye fisheries management practices in the Fraser River and Bristol Bay sockeye fisheries.

SW3 Scope of Work

Fisheries Harvesting

3.1 The Contractor will describe the sockeye salmon fishery in the Fraser River and Bristol Bay, both in freshwater and marine areas, broken down by commercial, First Nations and recreational fishing methods.

3.2 The Contractor will describe allocations, locations, methods, regulations including licensing in B.C. and Alaska and level of the harvest.

3.3 The Contractor will review and summarize fisheries policy documents and the mandate and structure of different fisheries organizations in B.C. and Alaska.

Fisheries Management

3.4 The Contractor will identify the critical information requirements for sockeye fisheries management in the Fraser River and in Bristol Bay.

3.5 The Contractor will describe and evaluate the accuracy and precision of pre-season forecasting methods in B.C. and Alaska. This work will include a description of the application of pre-season forecasting in harvest management.

3.6 The Contractor will describe and evaluate the accuracy and precision of in-season run-size abundance estimation methods in BC and Alaska. This work will include a description of the application of in-season run-size abundance estimation in harvest management.

3.7 For both B.C. and Alaska, the Contractor will analyze historical performance of the in-season assessment process, to include changes in estimates of run sizes with particular emphasis on how long it has taken within each season to correctly assess the final run size. The key issue to be described is how quickly the in-season assessment process can respond to errors in pre-season forecasts so as to meet escapement goals.

3.8 The Contractor will describe and evaluate the accuracy, precision and reliability of in-season and post-season escapement enumeration methods used in B.C. and Alaska.

SW4 Deliverables

4.1 The main deliverables of the contract are 2 word files addressing "Comparison of Commercial Sockeye Fisheries Management in the Fraser River, B.C. and Bristol Bay, Alaska": (1) a contribution to the LGL fisheries progress report, and (2) a contribution to the LGL final report. The style for these Reports will be a hybrid between a scientific style and a policy document. An example of a document which follows this format is the B.C. Pacific Salmon Forum Final Report (www.pacificsalmonforum.ca).

4.2 The Contractor will make themself available to Commission Counsel during hearing preparation and may be called as a witness.

Appendix B   List of requests to DFO by LGL Limited.

The following requests for information were submitted to DFO on 14 September 2010. Each request was directly related to one of the tasks outlined in the Statement of Work for the Fraser component of our review.

First Nations fishery

DFO Request 1: Information on annual FSC sockeye allocations for 1980-2009 for each First Nation that harvests Fraser sockeye. Note: it is expected that allocations will not be available for all FNs and few if any prior to 1993.

DFO Request 2: Sockeye harvest estimates by year for 1980-2009 for each First Nation that harvests Fraser sockeye.

DFO request 3: Copies of all communal licences issued to First Nations, First Nation Fishing Plans and fisheries agreements, prior to and including 2009, for First Nations that harvest Fraser sockeye.

DFO Request 3: Documents that describe the current (2005-2009) and historical (1980-2004) methods used to estimate First Nation catch of Fraser sockeye.

Commercial fishery

DFO Request 4: Dataset with the annual commercial sockeye catch of Fraser sockeye by gear type by statistical area for 1980-2009.

DFO Request 5: Documents that define the target Fraser sockeye commercial allocations (% by gear type) for each year in the 1980-2009 period (e.g., IFMP's for recent years).

DFO Request 6: Documents that describe the current (2005-2009) and historical (1980-2004) methods used to estimate commercial catch, including the role of sale slips, hail data, individual log books, on-board observers and other reporting systems in the catch estimation process.

Recreational fishery

DFO Request 7: Historical record of the daily and annual catch limits for sockeye in marine and freshwater areas for the periods when recreational fishers were permitted to retain sockeye each year from 1980 to 2009.

DFO Request 8: Annual sockeye catch estimates for marine and freshwater recreational fisheries that harvest Fraser sockeye and documents that describe how these estimates were derived in recent years (2005-2009) and historical years (1980-2004) for Fraser River fisheries. Note: we are familiar with the methods used to estimate sockeye catch for marine recreational fisheries from 1980-1999.

All sectors

DFO Request 9: List of all fisheries (locations, gear-type, times) when sockeye non-retention restrictions have been implemented for fisheries where Fraser sockeye could be harvested.

Fisheries Management

DFO Request 10: Documents that describe the pre-season forecasting methods used during the period 1980-1998. We have obtained the run size forecast documents prepared for more recent years.

DFO Request 11: Documents that describe the in-season and post-season run-size abundance estimation methods used in the 1980s, 1990s and 2000s.

DFO Request 12: Documents that describe the in-season and post-season escapement enumeration methods used in the 1980s, 1990s and 2000s.

DFO Request 13: Documents that provide the dates and magnitude for each in-season run-size estimates and the final in-season run size estimate for each run-timing group for Fraser sockeye for 4 cycle years in each of the past three decades (1980s, 1990s and 2000s).

DFO Request 14: The findings/recommendations from any internal or external reviews of the FRSSI process.

DFO Request 15: Recent CSAS documents prepared regarding the status and rebuilding efforts for Cultus Lake sockeye.

DFO Request 16: The up-to-date version of the Fraser sockeye production tables which contains the catch, escapement, exploitation rate and total run size for each sockeye indicator stock (including Cultus Lake sockeye). Note that we have a version of these tables dated October 2008.

DFO Request 17: Any documents describing rebuilding strategies for Fraser sockeye other than those for Cultus Lake sockeye.

Table B-1 Summary of information received related to each request submitted to DFO on 14 September 2010.

Item	Description	Date Requested	Request Sent To	Date Received	Comment	Status	Verifier (LGL)
Request #1	Annual FSC allocations to FN, 1980-2009	14-Sep-10	David Levy by email	14-Oct	2009 only	Incomplete	Bob
Request #2	Harvest estimates per FN, 1980-2009	14-Sep-10	David Levy by email	03-Nov	Total FN harvest from PSC annual reports and data files 1986-09	Complete	Karl
Request #3a	Communal licences issued to FN, FN fishing plans & fisheries agreements up to 2009	14-Sep-10	David Levy by email	14-Oct	2009 AFS Agreements provided on Oct. 14 - no licences	Incomplete	Bob
Request #3b	Description of current (05-09) and historic (1980-04) methods to est. FN catch	14-Sep-10	David Levy by email	19-26 Nov	Lower Fraser info provided by Mathew Parslow, Middle Fraser info provided by Jamie Scroggie	Complete	Karl
Request #4	Data, commercial catch by Gear Type and Area, 1980-2009	14-Sep-10	David Levy by email	03-Nov	Commercial harvest from PSC annual reports and data files 1986-09	Incomplete	Karl
Request #5	Target commercial allocations (% by gear type), 1980-2009	14-Sep-10	David Levy by email	09-Oct	Gear allocations for 2001-2009 from Counterpoint	Incomplete	Karl
Request #6	Current (2005-09) and historic (1980-04) methods to est. comm catch	14-Sep-10	David Levy by email	26-29 Nov	Two reports provided	Incomplete	Karl
Request #7	Daily and annual catch limits in marine/fresh, 1980-2009	14-Sep-10	David Levy by email		Several requests made but nothing provided by DFO	Incomplete	Bob

Item	Description	Date Requested	Request Sent To	Date Received	Comment	Status	Verifier (LGL)
Request #8	Rec. catch est., plus methods for recent (2004-09) and historic (1980-04) estimates	14-Sep-10	David Levy by email	14 Oct to 29 Nov	Reports provided on Oct. 14 but still waiting for digital file of catch estimates	Complete	Bob
Request #9	Fisheries where non-retention restrictions have been implemented	14-Sep-10	David Levy by email		Nothing provided by DFO	Incomplete	Bob
Request #10	Pre-season forecasting methods, 1980-1998	14-Sep-10	David Levy by email	12-Oct	Al Cass provided all data and reports requested	Complete	Karl & Tim
Request #11	In- & post-season run abundance est. methods, 1980s, 90s, 2000s.	14-Sep-10	David Levy by email	08-Dec	Nothing provided by DFO Details on in-season est. methods provided by PSC	Complete	Karl
Request #12	In- & post-season escapement enumeration methods, 1980s, 1990s, 2000s	14-Sep-10	David Levy by email	09-Nov	Reports on post-season methods provided by Al Cass, 2006-09 mark-recapture data and annual reports from Keri Benner.	Complete	Karl
Request #13	Dates/magnitudes for in-season run-size estimate, final in-season run est., each run-timing group	14-Sep-10	David Levy by email	02-Nov	Al Cass provided in-season run size estimates for 1986-2009	Complete	Karl
Request #14	Findings of internal-external reviews of FRSSI process	14-Sep-10	David Levy by email	21-Oct	Draft of Mike Staley's review of the FRSSI process was provided.	Complete	Karl
Request #15	Recent CSAS documents, rebuilding Cultus	14-Sep-10	David Levy by email	03-Nov	Documents received from Al Cass	Complete	Karl

Item	Description	Date Requested	Request Sent To	Date Received	Comment	Status	Verifier (LGL)
Request #16	Up-to-date production tables for each indicator stock	14-Sep-10	David Levy by email	20-Sep	Sockeye production tables provided by Al Cass	Complete	Karl
Request #17	Other rebuilding strategies other than Cultus	14-Sep-10	David Levy by email		Request dropped when task was removed from SOW	Deleted	

Appendix C   First Nation catch monitoring programs.

Table C-1 provides a list of the First Nation Groups that conduct catch monitoring programs in each fishing area and summary information related to each fishery and catch monitoring program. Most of information in this table was obtained from a DFO report on the methods used to estimate the catch of Fraser sockeye in 2004 entitled "Catch Monitoring – Southern B.C. Fisheries" (Ryall and Ionson 2005), submitted to the 2004 Southern Salmon Fishery Post-Season Review Committee chaired by the Honourable Bryan Williams. The details are provided under the following columns headings:

- First Nations = number of First Nations monitored by each group,
- Fishery Location = the geographic location of each sockeye fishery defined in terms of Pacific Fisheries Management Areas (PFMA);
- Relative Effort = the average number of permits issued to fishers or number of fishers active during a typical sockeye fishing season;
- Relative Catch = the rounded estimate of the 2004 sockeye catch for each fishery;
- Fishing Gear = types of fishing gear used to harvest sockeye;
- Catch Reporting = the frequency of reporting catch estimates to DFO;
- Catch Monitoring System = a brief summary of the methods used to obtain catch monitoring data from each fishery;
- Validation = the degree to which catch estimates are validated and any suspected biases associated with the catch estimates;
- Data Quality = qualitative ratings for accuracy, precision and reliability of the data used to generate the catch estimates for the majority of the sockeye harvested (i.e., if seines catch estimates are "Good" and seines catch the majority of the sockeye, the rating will be "Good");
- Accuracy = a qualitative rating of the degree managers can be confident that the reported catch reflects the actual harvest (fair = likely biased low in some or most years; good = any bias is likely to be small; very good = complete enumeration of the catch);
- Precision = generally unknown for most First Nation fisheries (estimates of precision are provided where available and where catch estimates are a complete count, the precision is very high); and
- Reliability = a qualitative rating of the degree managers can rely on the catch estimates for in-season and post-season assessments. These ratings are similar to the ratings for accuracy, except biased estimates that received a "fair" rating for

accuracy could receive a “medium” rating for reliability, where the direction of the bias is known.

Table C-2 provides a summary of the DFO and First Nation patrols (net counts), sockeye catch estimates, number of interview, and 16/24 hour effort profiles for 2005 and 2006. These years were selected because they represent the two most recent years with substantial sockeye fisheries prior to 2010. For most week-area strata, survey effort in these years exceeded the minimum target levels identified in Alexander (2002b).

Table C-1 Summary of information related to catch monitoring programs for each First Nation fisheries for Fraser sockeye.

Area/First Nation Groups	First Nations	Fishery Location	Relative Effort (permits/yr)	Relative Catch (2004)	Fishing Gear	Catch Reporting	Catch Monitoring System	Validation	Data Quality: Accuracy	Data Quality: Precision	Data Quality: Reliability
Johnstone Strait											
KTFC and other local First Nations	10	Area 11-12	40	40,000		Weekly reports	Total of report catch on permits. Electronic Data Reporting started in 2004	Limited validation	Fair	Unknown	Low
A'Tlegay Fisheries Society	5	Area 12-13	130	50,000	89% seine, 8% gillnet, 3% troll	Weekly reports	Guardians monitor fisheries on the fishing grounds.	90% of catch validated at landing site	Good	Unknown	High
First Nation Marine Society Coordinated Fishery	20	Area 12-13	na	109,000	100% seine	Daily reports	Certified observers on board each seine vessel and data used for in-season run size estimation.	100% of catch validated at landing site	Very Good	Unknown	High
West Coast Vancouver Island											
Nuu chah nulth		Area 121-126	na	500	Troll & gillnet	Monthly reports	Each fisher is required to provide a monthly report of catch by species and area?	Compliance variable	Fair	Unknown	Low
Juan de Fuca Strait											
Nuu chah nulth		Area 20		20,000	Seine & gillnet	Daily-weekly reports	Seine vessels must have fisheries guardian on board and report catch after offloading.	Seine vessel catches verified by audits	Good	Unknown	Seine - High Gillnet - low
Strait of Georgia											
South Island First Nations	4	Area 16 & 29	na	25,000	Seine & gillnet	Daily-weekly reports	Seine vessels must have fisheries guardian on board and report catch after offloading. Gillnet catch estimates based on hails and interviews, seldom verified.	Some seine landings verified by Fisheries Officers	Good	Unknown	Seine - High Gillnet - low
Fraser River - below Port Mann											
Musqueam & Tsawwassen (pre-Treaty)	2	Area 29 - Below Port Mann	65	49,000	Drift gillnet	Daily reports	On-water vessel count and average harvest per vessel obtained from interviews at landing sites.	Suspected under estimates	Fair	Unknown	Medium
Tsawwassen (post-Treaty)	1	Area 29 - Below Port Mann	25	na	Drift gillnet	Daily reports	Catch census based on landing site and telephone interviews.	50% of catch verified by monitors	Very Good	Very precise	High
Fraser River - Port Mann to Sawmill											
Sto:lo and Independent First Nations	17	Area 29 - Port Mann to Sawmill	400	250,000	Set gillnet	Daily reports	Overflight effort count every 24 hours and average catch rates from interviews at landing sites.	Small to medium positive bias	Good	$\pm$18% in 2001[1]	Medium
Sto:lo and Independent First Nations	17	Area 29 - Port Mann to Mission	50	50,000	Drift gillnet	Daily reports	Catch census based on landing site catch reports.	Suspected under estimates	Fair	Unknown	Medium

Table C-1 continued.

Area/First Nation Groups	First Nations	Fishery Location	Relative Effort (permits/yr)	Relative Catch (2004)	Fishing Gear	Catch Reporting	Catch Monitoring System	Validation	Data Quality: Accuracy	Data Quality: Precision	Data Quality: Reliability
Fraser River - Above Sawmill											
Nlaka'pamux Nation Tribal Council and Nicola Watershed and Stewardship Fisheries Authority	17	Fraser from Sawmill to Lytton and lower Thompson R.	80	76,000	Set gillnet & dipnets	Weekly reports	Helicopter or on-water effort counts and average catch rates from interviews at fishing sites.	Suspected under estimates in years with lower survey effort	Fair	±17% in 2002[2]	Medium
Stl'atl'imx Tribal Council	7	Faser River from Texas Creek to Kelly Creek	20	44,000	Set gillnet & dipnets	Weekly reports	Helicopter or on-water effort counts and average catch rates from interviews at fishing sites.	Suspected under estimates in years with lower survey effort	Fair	Unknown	Medium
Whispering Pines and High Bar Indian Band	2	Faser from Kelly Creek to Deadman Creek	5	1,200	Set gillnet	Weekly reports	Helicopter or on-water effort counts and average catch rates from interviews at fishing sites.	Suspected under estimates in years with lower survey effort	Fair	Unknown	Medium
Cariboo Tribal Council, Tsilhqot'in National Government & Alkali Lake Band	10	Faser from Deadman Creek to Marguerite & Chilcotin and Chilko rivers		15,000	Dip nets	Weekly reports	First Nation monitors interview fishers at major fishing sites. Observed catch expanded to account for areas and times not covered.	Suspected under estimates in years with lower survey effort	Fair	Unknown	Medium
Lheidli T'enneh, Carrier-Sekani Tribal Council, Tl'azt'en Nation	3	Faser from Naver Creek to Shelly & Nechako and Stuart rivers	85	6,500	Set gillnets (85) and Stellako River fence	Weekly reports	First Nation monitors interview fishers at major fishing sites. Observed catch expanded to account for areas and times not covered. Harvests from fence are fully enumerated.	Suspected under estimates in years with lower survey effort	Fair	Unknown	Medium
Secwepemc Nation Fisheries Commission	2	Thompson watershed upstream of Bonaparte	na	5,000	set nets, beach seines, drift nets, weirs, gaff	Annual reports	Catch census based on-site and telephone interviews. Very reliable data from large driftnet, weirs, beach seine operations.	Very good estimates for majority of the catch	Fair	Unknown	Medium
Summary											
Marine Fisheries	39	Area 11-29, Area 121-126	170	244,500	seine, gillnet, troll	Weekly reports	Guardians monitor fisheries on the fishing grounds.	90% of catch validated at landing site	Good	Unknown	Medium
Fraser Watershed - below Sawmill Creek	20	Area 29 - below Sawmill	490	299,000	Set gillnet	Daily reports	Overflight effort count every 24 hours and average catch rates from interviews at landing sites.	Small to medium positive bias	Good	±18% in 2001[1]	Medium
Fraser Watershed - Above Sawmill Creek	41	Area 29 - above Sawmill	190	147,700	Set gillnet & dipnets	Weekly reports	Helicopter or on-water effort counts and average catch rates from interviews at fishing sites.	Suspected under estimates in years with lower survey effort	Fair	±17% in 2002[2]	Medium
Total	100		850	691,200					Good	Unknown	Medium

[1]Alexander, C.A.D 2002. 2001 First Nation Catch Estimates on the Lower Fraser River and Recommended Improvements for Future Aerial-Access Creel Surveys. Prepared by ESSA Technologies Ltd., Vancouver, BC for The Canadian Department of Fisheries and Oceans, Fraser River/Interior Area Office, Delta BC. 46 pp.

[2]Alexander, C.A.D. 2003. First Nation sockeye catch estimates in the mid-Fraser River, 2002, with results of an impact analysis on the reduction of 24-hour effort surveys and aerial overflights. Prepared by ESSA Technologies Ltd., Vancouver, BC for the Canadian Department of Fisheries and Oceans, BC Interior Area Division, Kamloops, BC. 76 pp. + appendix.

Table C-2 Weekly catch monitoring effort and sockeye catch in a sample of four fisheries above Sawmill Creek, 2005 and 2006.

2005					Sockeye Catch				Interviews				Effort Counts	
Period (Week)	Open Days	DFO Patrols (Heli)	DFO Patrols (Boat)	FN Patrols Vehicle	Sawmill to Texas	Texas to Kelly	Kelly to Deadman	Thompson to Bonaparte	Sawmill to Texas	Texas to Kelly	Kelly to Deadman	Thompson to Bonaparte	16 hr	24 hr
32	7 days/week	4	5	14	10,384	2,430	299	0	116	178	5	8	12	8
33	7 days/week	4	4	11	22,945	6,367	317	39	168	221	4	17	17	9
34	7 days/week	4	5	7	9,396	7,438	293	1,080	116	249	13	13	15	9
35	7 days/week	4	5	9	26,304	11,105	247	818	76	223	6	19	13	9
36	7 days/week	4	0	7	19,514	16,380	305	3,009	64	277	6	10	16	10
37	7 days/week	3	0	7	10,541	15,295	373	1,609	27	155	2	19	14	3
38	7 days/week	3	2	2	1,577	2,629	133	97	9	43	1	4	14	1
39	1day / 7 days	2	0	0	487	377			1	7			1	2
Total		28	21	57	101,148	62,021	1,967	6,652	577	1,353	37	90	102	51

2006					Sockeye Catch				Interviews				Effort Counts	
Period (Week)	Open Days	DFO Patrols (Heli)	DFO Patrols (Boat)	FN Patrols Vehicle	Sawmill to Texas	Texas to Kelly	Kelly to Deadman	Thompson to Bonaparte	Sawmill to Texas	Texas to Kelly	Kelly to Deadman	Thompson to Bonaparte	16 hr	24 hr
31	3 days - GN, DN, RR	4	3	8	554	395	85	0	59	46	5	9	10	9
32	7 days - GN, DN, RR	3	4	26	5,494	1,932	7	99	66	77	3	19	14	9
33	7 days - GN, DN, RR	3	4	26	14,893	3,948	134	486	111	170	6	26	9	15
34	7 days - GN, DN, RR	3	7	30	12,860	8,429	488	2,653	105	480	13	65	12	12
35	7 days - GN, DN, RR	4	3	24	18,620	13,483	217	5,736	71	531	12	55	10	15
36	7 days - GN, DN, RR	3	0	17	15,989	5,992	324	10,924	21	305	11	18	10	16
37	7 days - GN, DN, RR	2	2	14	10,890	9,501	191	9,010	43	240	10	11	10	15
38	7 days - GN, DN, RR	2	0	6	3,690	1,721	181	6,596	19	137	2	10	9	17
39	4 GN/ 7 days DN, RR	2	0	7	308	206	0	9,075	11	3		4	4	2
40	7 days selective	1		12	0	276	0	1,772		1				
Total		22	20	150	82,744	45,212	1,542	44,579	447	1,943	57	208	78	101

Appendix D Commercial catch monitoring programs.

Table D-1 provides a list of the major Canadian commercial fisheries and the approach used to derive the sockeye catch estimates. Most of information in this table was obtained from Ryall and Ionson (2005). The details are provided under the following columns headings:

- Fishery Location = the geographic location of each sockeye fishery defined in terms of Pacific Fisheries Management Areas (PFMA);
- Fleet size = the average number of licenced vessels by gear type in 2004;
- Average Catch = average sockeye catch by fishery for 2001-2009;
- Fishing Gear = types of fishing gear used to harvest sockeye;
- % of Catch = portion of the total Canadian commercial catch harvested by each commercial fishery during the 2001-2009 period;
- Catch Reporting = reporting requirements for each fishery;
- Catch Monitoring System = a brief summary of the methods used to obtain catch monitoring data from each fishery;
- Validation = the degree to which catch estimates are validated and any suspected biases associated with the catch estimates;
- Data Quality = qualitative ratings for accuracy, precision and reliability of the data used to generate the catch estimates for the majority of the sockeye harvested (i.e., if seines catch estimates are “Good” and seines catch the majority of the sockeye, the rating will be “Good”);
- Accuracy = the degree managers can be confident that the reported catch reflects the actual harvest (“Fair” = likely biased low in some or most years; “Good” = any bias is likely to be small; “Very Good” = complete enumeration of the catch);
- Precision = generally unknown for most fisheries, estimates of precision are provided where available and where catch estimates are a complete count, the precision rating was “High”); and
- Reliability = the degree managers can rely on the catch estimates for in-season and post-season assessments. These ratings are similar to the ratings for accuracy, except biased estimates that received a “Fair” rating for accuracy could receive a “Medium” rating for reliability, where the direction of the bias is known.

Table D-1 Summary of information related to catch monitoring programs for Canadian commercial fisheries.

Country/Area	Fishery Location	Fleet Size (2004)	Average Catch (2001-09)	% of Catch (2001-09)	Catch Reporting	Catch Monitoring System	Validation	Data Quality: Accuracy	Data Quality: Precision	Data Quality: Reliability
Canada										
Fraser Panel Areas										
Areas 121-122 Troll	WCVI	142 troll in 2002	23,333	2.6%	Daily reports	Daily catch estimates from phone-in reports. Relies on complete catch reporting by fishers.	No validation at landing sites, >80% phone-in compliance	Good	Unknown	Medium
Area 17-18 and 29 Troll	Georgia Strait	3-30 troll	38,649	4.3%	Daily reports	Weekly overflight effort counts and average catch rates from fishers phone-in reports and charter patrol hails.	No validation at landing sites, >80% phone-in compliance	Good	Unknown	Medium
Area 20 Net	Juan de Fuca Strait	2-60 seine	4,703	0.5%	Daily reports	Overflight effort count every net fishery and average catch rates from fishers phone-in reports and charter patrol hails.	No validation at landing sites, 10-25% phone-in compliance	Fair	Unknown	Medium
Area 29 Net	Lower Georgia Strait &Fraser River below Mission	320 gillnet	248,408	27.9%	Daily reports	Overflight effort count every net fishery and average catch rates from fishers phone in reports, a few on-board observers and charter patrol hails. A dockside monitoring program was introduced in 2010 with the goal of sampling 35% of sockeye landings.	No validation at landing sites, 10-25% phone-in compliance	Fair	Unknown	Medium
Non-Panel Areas										
Area 1-10 Troll & Net	North Coast	250	0	0.0%	Daily Reports	Daily catch estimates from phone-in reports. Relies on complete catch reporting by fishers.	No validation at landing sites	Good	Unknown	Medium
Area 11-16 Net	Johnstone Str. & Georgia Str.	230 gillnet 130 seine	450,714	50.7%	Daily Phone In Reports	Overflight effort count every net fishery and average catch rates from fishers phone in reports and charter patrol hails.	No validation at landing sites, 10-25% phone-in compliance	Fair	Unknown	Medium
Area 11-16 Troll	Johnstone Str. & Georgia Str.	105 troll	80,014	9.0%	Daily Phone In Reports	Weekly overflight effort counts from net fishery days and average catch rates from fishers phone in reports and charter patrol hails.	No validation at landing sites, >80% phone-in compliance	Good	Unknown	Medium
Area 124-127 Troll	WCVI	142 troll in 2002	6,222	0.7%		Daily catch estimates from phone-in reports. Relies on complete catch reporting by fishers.	No validation at landing sites, >80% phone-in compliance	Likley Good	Unknown	Medium
Selective Fisheries			37,000	4.2%		Certified observers on board each vessel or at each fishing site.	100% of catch validated	High	High	High
Canadian Total			889,044	100.0%				Fair	Unknown	Medium

Appendix E Recreational catch monitoring programs.

Strait of Georgia Creel Estimates

Table E-1 provides a summary of the annual effort estimate and number of angler interviews as well as boat count surveys for the April – October period for the period 1986-2009 (Zetterberg and Carter 2010; Carter and Zetterberg 2010; Zetterberg et al. 2009; Hardie et al. 2003; Hardie et al. 2002; Hardie et al. 2001; English et al. 2002; Hardie et al. 1999; Collicutt and Shardlow 1993; Collicutt and Shardlow 1992; Collicutt and Shardlow 1990; Shardlow and Collicutt 1989a-e). Table E-1 shows the substantial decline in recreational fishing effort and the parallel decrease in the number of interviews conducted during the 1986-2009 period.

Table E-2 provides the annual GSCS estimates of the recreational fishery harvest of sockeye by Statistical Area for the period 1986-2009 and Table E-3 provides the precision associated with these sockeye catch estimates. Over this period, the annual tidal recreational catch of Fraser sockeye has ranged from less than 100 to over 30,000 and precision has ranged from ±12% to ±90%. Figure E-2 shows the relationship between fishing effort and the precision of the sockeye catch estimates. The precision and reliability of these estimates is generally better in years when fishing effort is higher than 200,000 boat trips and is highly variable when fishing effort is less than 200,000 boat trips.

Johnstone Strait Estimates

Table E-4 provides the estimates of the number of boat trips and recreational fishery harvest of sockeye in Johnstone Strait (Area 12) for the years 1991, 1992, and 1999-2009 when creel surveys were conducted (Hardie et al. 1999, http://www.pac.dfo-mpo.gc.ca/stats/rec/index-eng.htm).

West Coast Vancouver Island Estimates

Prior to 1984, sport catch estimates for the West Coast of Vancouver Island (WCVI) were limited to observations and estimates by Fishery Officers. Since then, structured creel surveys have been conducted in Alberni Inlet and Barkley Sound covering Statistical Area 23. In 1991, the WCVI sport fishery expanded to operate off the west coast of Vancouver Island from Carmannah Point, near Juan de Fuca Strait, to Quatsino Sound on the northwest of Vancouver Island. The recreational fishery in Area 20 centers near the community of Port Renfrew. The area east of Sheringham Point (Area 20-5) is covered by the Georgia Strait creel survey. Statistical Area 23 is further divided in 23A (Alberni Inlet) and 23B (Barkley Sound and Offshore).

The creel survey methods for this fishery are described in Lewis (2004) and are comprised of angler interviews over the broad geographic region and aerial overflights. In addition to catch estimates generated from creel survey, sport lodge catch and effort was also collected. The WCVI has a number of remote lodges where catch cannot be captured by the landing site creel survey method. Logbooks are distributed to lodges who voluntarily record their daily catch data by boat or group of boats. Logbooks are distributed in Statistical Areas 20 to 26 to lodge operators. Lodge operations that do not participate in the logbook program are monitored by the creel survey.

The WCVI tidal recreational fishery primarily focuses on Chinook and Coho except for Alberni Inlet in June and July when the target species is the terminal run of Somass sockeye. Catch and effort data has been collected separately for inshore and offshore areas since 1999 for Pacific Salmon Treaty (PST) Chinook catch accounting. Inshore (terminal) areas are defined as those waters inside the surf-line and offshore areas are those seaward of that line.

Table E-5 provides the estimated annual catch of Fraser River sockeye in WCVI recreational fisheries for 1985-2009. Fraser River sockeye catches in recreational fisheries on the WCVI were determined by proportioning the August and September catch estimates for Area 23 based on the ratio of Area 23B to Area 23A catches for August and September during 1995-91. For these years only, the creel estimates (http://www.pac.dfo-mpo.gc.ca/stats/rec/index-eng.htm) were separated for Area 23A and 23B. The average proportion of the Area 23 sockeye catch for August and September in these years was estimated to be 9.3%. The proportion was applied to the August and September sockeye catches for the years 1984-1995 and for 2001-2009. Monthly data were not available for the year 2000. The total estimated catch of sockeye in Area 23B for August and September was then halved to account for Barkley Sound sockeye stocks that might still be encountered in Barkley Sound in August and September. The additional sockeye catch estimates for the other Statistical Areas for August and September were added to the final annual estimate of Fraser sockeye catch.

Non-Tidal Sport Fisheries

Lower Fraser River Estimates

Table E-6 provides a summary of the number of angler hours, sockeye harvested and sockeye released by anglers in lower Fraser River fisheries from 1985 to 2009 with the exception of 1991-1994 when no creel surveys were conducted in the lower Fraser River. These estimates were derived from annual summary reports. The methods used to derive the 1995 catch estimates are reported in Bratty et al. (1998).

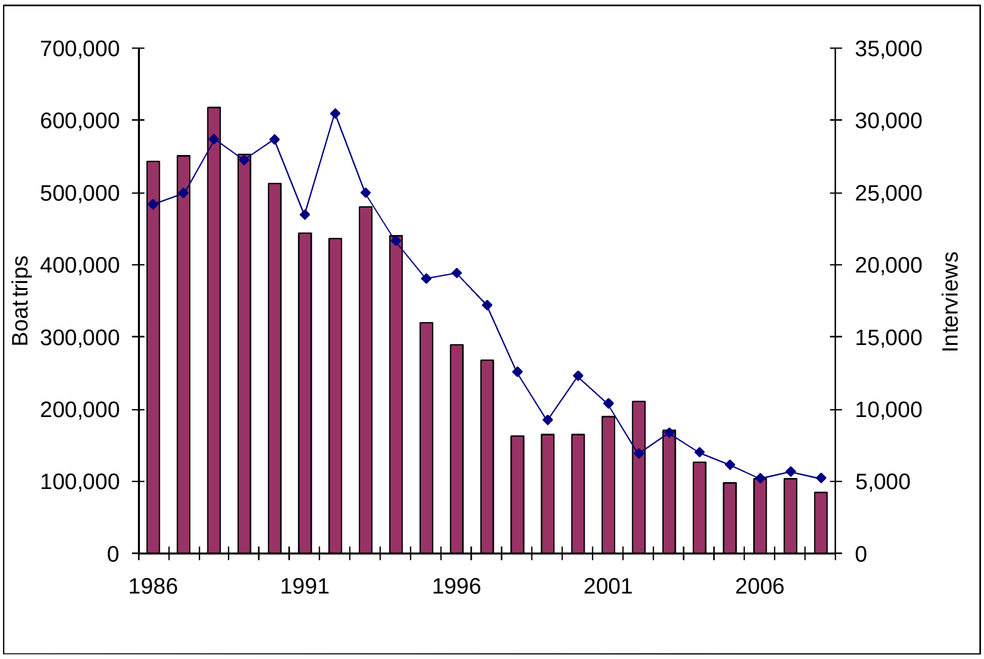


Figure E-1 Fishing effort (boat trips) and number of interviews conducted for the Strait of Georgia recreational fishery creel survey, 1986-2008.

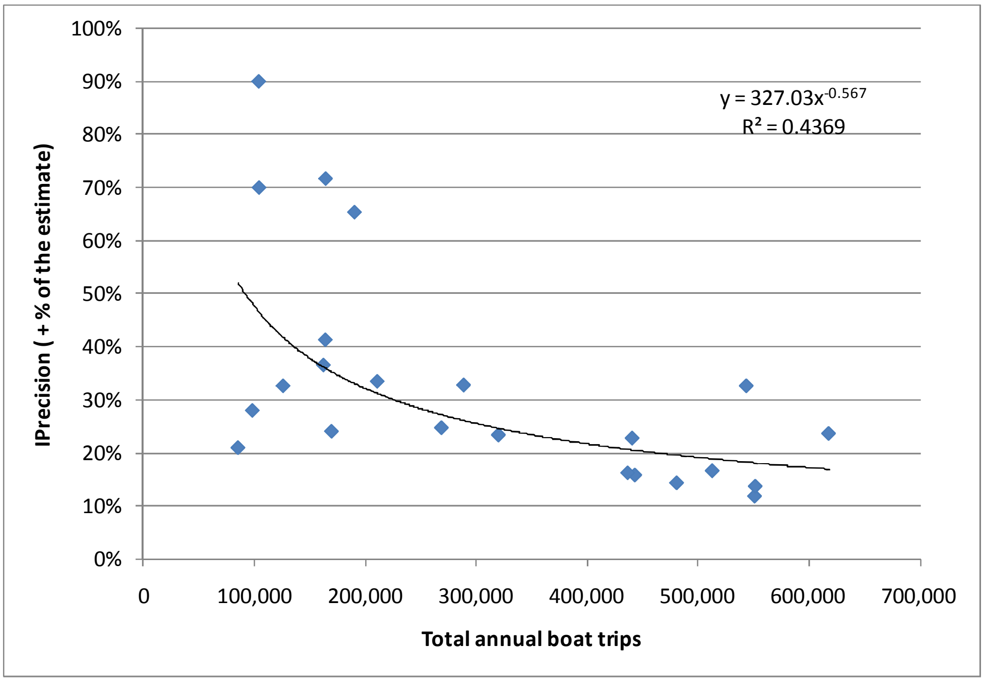


Figure E-2 Relationship between precision of the GSCS estimate of sockeye catch and number of boat trips, 1986-2008.

Table E-1 Number of interviews, aerial survey boat counts and total effort estimate in boat trips for the Strait of Georgia Creel Survey, 1986-2009.

Year	Shifts	Interviews	Overflights	Boat Trips	% Interviewed	Periods Monitored
1986	2,547	29,044	69	582,946	5.0%	Jan to Dec
1987	2,445	30,122	69	589,731	5.1%	Jan to Dec
1988	2,510	27,062	68	664,517	4.1%	Jan to Dec
1989	2,320	24,763	68	603,331	4.1%	Jan to Dec
1990	2,224	25,088	68	543,368	4.6%	Jan to Dec
1991	2,258	21,882	63	466,749	4.7%	Jan to Dec
1992	2,883	29,420	53	467,559	6.3%	Jan to Dec
1993	1,967	24,617	42	498,026	4.9%	Jan to Sep
1994	2,044	20,597	45	440,744	4.7%	Apr to Oct
1995	1,822	16,072	43	323,642	5.0%	Mar to Oct
1996	1,406	15,684	33	288,736	5.4%	Apr to Sep
1997	1,464	13,747	38	268,797	5.1%	Apr to Oct
1998	1,518	7,687	63	162,293	4.7%	Apr to Oct
1999	1,693	9,211	41	164,282	5.6%	Apr to Oct
2000	1,798	13,480	83	170,798	7.9%	Jan to Dec
2001	1,534	11,390	88	197,914	5.8%	Jan to Dec
2002	1,278	7,693	94	218,559	3.5%	Jan to Dec
2003	1,408	9,220	80	173,403	5.3%	Jan to Dec
2004	1,327	8,123	77	132,425	6.1%	Jan to Dec
2005	1,237	7,179	82	104,032	6.9%	Jan to Dec
2006	1,158	5,452	70	107,598	5.1%	Jan, Feb, Apr to Oct
2007	1,438	6,250	93	109,869	5.7%	Jan to Dec
2008	1,666	5,981	85	91,155	6.6%	Jan to Dec
2009	1,353	7,114	87	117,617	6.0%	Jan to Dec
Averages						
1986-99	2,079	21,071	55	433,194	5%	
2000-09	1,420	8,188	84	142,337	6%	

Table E-2 Annual Strait of Georgia Creel Survey estimates of the recreational fishery harvest of sockeye by Statistical Area for 1986-2009.

	Statistical Area										
Year	13	14	15	16	17	18	19	20(SG)	28	29	Total
1986	40	0	0	20	2	100	303		238	215	918
1987	1,154	91	0	48	22	56	5,332		767	1,397	8,867
1988	220	27	5	1	59	313	9,535		2,197	4,019	16,376
1989	493	63	7	1	8	335	9,131		1,063	2,255	13,356
1990	171	59	11	16	82	423	5,604		4,666	19,637	30,669
1991	4,108	36	6	27	1	330	7,996		2,332	8,685	23,521
1992	2,202	23	0	0	6	0	2,985		860	669	6,745
1993	7,592	125	13	32	85	54	15,675		8	16	23,600
1994	5,044	229	157	19	933	449	3,043		1,138	3,042	14,054
1995	1,648	16	4	1	171	75	2,706		310	966	5,897
1996	307	10	19	3	515	0	852		246	413	2,365
1997	7,542	717	301	3	843	91	6,648		289	453	16,887
1998	1,557	17	131	0	0	0	2,489		218	62	4,474
1999	142	4	0	0	11	2	333		0	0	492
2000	5,113	19	0	0	0	0	932		78	225	6,367
2001	1,196	0	0	0	0	57	1,216		0	750	3,219
2002	2,669	0	0	0	0	0	93	979	79	1,313	5,133
2003	928	24	0	0	0	246	74	1,461	53	132	2,918
2004	1,828	0	0	0	0	0	0	1,441	69	2	3,340
2005	4,712	0	0	0	0	0	65	2,168	89	1	7,035
2006	15,507	0	0	0	0	32	87	3,559	0	10,656	29,841
2007	3	0	0	0	0	0	7	185	0	0	195
2008	43	0	0	0	0	0	0	36	0	0	79
2009	0	0	0	0	0	0	0	197	0	0	197
Averages											
1986-99	2,301	101	47	12	196	159	5,188		1,024	2,988	12,016
2000-09	3,200	4	0	0	0	34	247	1,253	37	1,308	5,832

Table E-3 Estimates of precision for Strait of Georgia Creel Survey estimates of the recreational fishery harvest of sockeye by Statistical Area for 1986-2009.

	Statistical Area										
Year	13	14	15	16	17	18	19	20(SG)	28	29	Total
1986	172%			176%	392%	71%	64%		70%	50%	32%
1987	25%	71%		106%	98%	77%	16%		36%	34%	12%
1988	55%	73%	78%	392%	156%	42%	39%		24%	26%	24%
1989	53%	78%	112%	196%	123%	44%	18%		39%	26%	14%
1990	60%	103%	89%	86%	158%	66%	24%		25%	24%	17%
1991	17%	201%	229%	102%	392%	70%	22%		54%	33%	16%
1992	31%	119%			163%		24%		40%	46%	16%
1993	20%	131%	154%	66%	80%	184%	19%		155%	195%	14%
1994	27%	65%	57%	110%	67%	115%	31%		45%	52%	18%
1995	30%	179%	177%	196%	89%	80%	27%		47%	60%	18%
1996	42%	118%	85%	146%	64%		39%		59%	78%	25%
1997	26%	139%	66%	261%	131%	134%	22%		81%	82%	17%
1998	29%	185%	122%				55%		92%	152%	33%
1999	55%	196%			143%	196%	103%				72%
2000	35%	155%					38%		342%	110%	29%
2001	85%					131%	41%			128%	46%
2002	45%						140%	78%	83%	72%	33%
2003	22%	178%				142%	82%	35%	108%	187%	24%
2004	48%							44%	137%	98%	33%
2005	33%						61%	55%	155%	0%	28%
2006	32%					143%	156%	71%		50%	26%
2007	0%						161%	94%			89%
2008	156%							201%			125%
2009								79%			79%
Averages											
1986-99	46%	128%	117%	167%	158%	98%	36%		59%	66%	23%
2000-09	51%	166%				138%	97%	82%	165%	92%	51%

Table E-4 Annual Johnstone Strait estimates of the recreational fishery harvest of sockeye for 1991, 1992, and 1999-2009.

Year	Boat trips	Sockeye caught
1991		2344
1992		2014
1993		
1994		
1995		
1996		
1997		
1998		
1999	39151	1538
2000	17999	744
2001	6092	0
2002	5016	62
2003	13826	384
2004	16367	1352
2005	18461	767
2006	15721	5445
2007	16736	76
2008	12914	10
2009	15079	48
Average	16124	948

Table E-5 Annual WCVI estimates of the recreational fishery harvest of sockeye for 1985-2009. The catch of Fraser sockeye each year was estimated as 50% of the August and September catch for Area 23B plus all the sockeye catch from other WCVI Statistical Areas.

		WCVI Statistical Areas Reporting Sockeye Catch											August-September[1]		Estimated
Year	Period Monitored	23	123	24	124	25	125	26	126	27	127	Total Sockeye Caught	Area 23 Sockeye Catch	Area 23B Sockeye Catch	Fraser Sockeye Caught
1985	Aug - Sep	2,797										2,797	2,797	286	143
1986	Aug - Sep	21										21	21	2	1
1987	Jul-Sep	23,228										23,228	11,440	1,169	585
1988	Aug - Sep	374										374	374	38	19
1989	Jul-Sep	794										794	750	77	38
1990	Jul-Sep	14,430										14,430	9,353	956	478
1991	Jul-Sep	81,647										81,647	22,781	2,328	1,164
1992	Jul-Sep	112,638										112,638	29,339	2,998	1,499
1993	Jun - Sep	107,407										107,407	30,636	3,131	1,565
1994	Jun - Aug	31,299										31,299	7,733	790	395
1995	Jun - Aug	5,694										5,694	7	7	4
1996	Jun - Sep	33,464		7								33,471	1,366	18	16
1997	Jun - Sep	37,335		16								37,351	9,763	393	213
1998	Jun - Sep	57,952										57,952	11,079	1,756	878
1999	Jun - Sep	1,407										1,407	56	102	51
2000	Jun - Sep	24,314			1							24,315	na	na	na
2001	Jun - Sep	38,866	40		1							38,907	3,078	315	198
2002	Jun - Sep	55,575	142									55,717	1,656	169	227
2003	Jun - Sep	53,627	43	17	2	7						53,696	5,233	535	336
2004	Jun - Sep	79,244	7		23	6		6				79,286	4,677	478	281
2005	Jun - Sep	30,256	76	13	-	38	-					30,383	3,128	320	287
2006	Jun - Sep	26,863	366	15	358	23	24	5				27,654	1,645	168	875
2007	Jul - Aug	-	14		33		9				2	58	45	5	60
2008	Jul - Aug	16	18		4	4						42	21	2	27
2009	Jun - Sep	57,837	28			31	22			3		57,921	4,795	490	329
Averages															
1995-99		27,170		12								27,175	4,454	455	232
All Years		35,083	82	14	53	18	14	6		3	2	35,140	6,741	689	403

[1] the ratio of Area 23B:Area 23 estimates of sockeye catch for 1995-99 were used to derive Area 23B estimates for other years.

Table E-6 Lower Fraser River recreational angler effort and catch of sockeye salmon, 1984-2009.

Year	Angler hours	Sockeye harvested	Sockeye released	Total sockeye encounters
1984	380,900	NA	NA	-
1985	485,931	-	-	-
1986	771,595	-	31	31
1987	794,658	39	3	42
1988	722,590	204	50	254
1989	90,678	-	11	11
1990	60,152	-	32	32
1991				-
1992				-
1993				-
1994				-
1995	374,510	6,376	3,312	9,688
1996	212,205	9,371	8,369	17,740
1997	260,874	30,458	20,764	51,222
1998	360,449	9,655	6,219	15,874
1999	21,765	1,913	76	1,989
2000	372,341	24,075	25,965	50,040
2001	253,818	41,773	74,093	115,866
2002	391,511	125,040	66,789	191,829
2003	659,025	73,393	11,778	85,171
2004	524,886	50,388	9,619	60,007
2005	439,876	42,629	69,814	112,443
2006	747,058	134,292	23,643	157,935
2007	258,161	11	24,264	24,275
2008	228,682	16,344	17,131	33,475
2009	429,898	-	20,389	20,389
Mean	401,889	26,951	18,207	36,474

Appendix F Pre-season forecasts: Statistical methods for assessing run-size forecast precision, accuracy, and reliability, including definitions of median percent error (MPE), median absolute percent error (MAPE), regression models, and significance testing.

Statistical Analysis

Forecast accuracy, precision, and reliability were characterized by five metrics. MPE and MAPE describe the average errors in forecasts across years. These two statistics get at accuracy and precision, respectively, but can be misleading if interpreted alone. To facilitate interpretation we also constructed a best fit regression line between the observed run plotted against forecasted run (data were $\log_{10}$ transformed to meet model assumptions of normality and equal variance). The plot showing perfect forecasts in every year would reveal all points falling on a 45° line originating from zero. The regression analysis helps to determine quantitatively (as opposed to visual inspection) the closeness of a real relationship between two variables (i.e., here we consider forecast and return values) to the ideal/theoretical 45°relationship by producing intercept and slope parameter estimates, as well as, R^2. Below we describe each of these five metrics (MPE, MAPE, intercept, slope, and R^2) and how they are used to judge the reliability, precision, and accuracy of forecasts. We stress that no conclusion about reliability can be can be reached by looking at any one metric in a vacuum; all must be considered simultaneously.

What is MPE?

Median Percent Error (MPE) is a measure of central tendency with respect to the differences between observed and predicted values. It describes the percent difference that divides the data set equally—i.e., half the differences were greater than MPE and half were less. MPE is derived by first calculating the difference between forecasted and observed return values (forecast return - observed return = error or E) for each year; second, converting those values into a percent relative to the observed value ([E / observed return] ×100 = PE); and third, taking the median across years (MPE). If a forecast is accurate (i.e., not biased) then positive errors tend to cancel out negative errors across years indicating that errors are for the most part random. In other words, a MPE =

0 would mean that the forecast does not consistently over- or underestimate the return from year to year.

To find the central tendency in PEs across years, researchers routinely take the average and also use the acronym MPE (in this case it stands for Mean Percent Error).
We opted for using the median over the average (mean) PEs because the median avoids the undue influence of single aberrant years and still describes central tendency.

Graphing MPE for each consecutive year can illustrate changes in systematic forecast error though time. For example, forecasts may underestimate run strength during times when stream productivity and/or marine survival are increasing then switch to overestimating when these factors are decreasing. Furthermore, a MPE = 0 does not mean that the forecast is precise. There could still be substantial error in any one year; only, this error is cancelled by substantial error in the other direction for other years. For precision we must use another metric such as MAPE.

What is MAPE?

Median Absolute Percent Error (MAPE) is also a measure of central tendency with respect to the differences between observed and predicted values. MAPE is derived by first calculating the absolute difference between forecast and return values (|forecast return - observed return| = absolute error or AE) for each year; second converting those values into a percent relative to the observed value ([AE / observed return] ×100 = APE); and third taking the median across years (MAPE). For example, if we forecast 1.5 million sockeye and 1 million return, the error in our forecast would be 50% higher than the actual return (absolute percent error or APE=50%). If we forecast 1 million sockeye and 2 million return, our error in forecast would be 50% lower than the actual return (APE=50%). Thus, APE does not indicate direction of the difference (as does PE), but only the magnitude expressed as a percent. APE also renders errors proportional to actual sockeye return size, making errors in large forecasts directly comparable to errors in small forecasts. However, sometimes small absolute errors can result in large APE values, which can be misleading. For instance, if we forecast 30,000 for a run that is usually in the millions and 10,000 return then our APE will be (30,000-10,000)/10,000×100=200%. This value seems like a lot, but the forecast worked well in that it warned managers that a very small run was coming (thousands instead of millions). Conversely, a forecast of 30 million when 10 million return results in the same APE, but the consequences are much more dire (i.e., 20 million is a lot of lost fishing opportunity). For this reason we opted for using the median of APEs as we did for PEs to avoid the disproportionate influence of very small returns.

What is regression analysis?

Regression analysis describes the relationship between a predictor variable and a response variable by developing an equation with parameters that define the line best representing this relationship (e.g., Appendix G). For our purposes, the predictor variable is the forecasted returns, the response variable is the observed returns, and we assumed their relationship to be linear. This best-fit line and the scatter of points around that line tell us three aspects of the forecast-return relationship:

- R^2 is the fraction of year-to-year variation in return that is explained by the best-fit line. When data points are widely dispersed around the best-fit line, R^2 values move towards 0%; when data cluster closely to the best-fit line, R^2 values move towards 100%.

- Linear slope (i.e., rise over run) describes the rate of increase in observed return relative to forecast. When the slope equals 1, changes in the observed return are matched by corresponding changes in the forecast. Deviations from 1 mean that the forecast is wrong by a consistent percentage across the range of run sizes.

- Intercept, which essentially reflects where the best-fit line crosses the y-axis when the forecast = 0. Deviations from zero mean that the forecast is wrong by a consistent absolute amount across the range of run sizes.

Finally, the regression analysis calculates whether the linear slope is significantly different from zero. When slope is zero (i.e., when best-fit line through data is horizontal), we conclude forecast values have no relationship to return values (i.e., returns vary at random with respect to forecasts).

How does regression relate to reliability, precision, and accuracy of forecasts?

Reliability: If the regression slope is not statistically different from zero there is no relationship between forecast and return. In other words, when the slope is not significant, values of return vary randomly relative to values of forecast and thus forecasting is deemed unreliable. Conversely, forecasting would be reliable if the regression slope was significantly different from zero (i.e., there was a positive relationship between values of forecast and values of return) because a significant slope tells us the forecast values are predicting variation in return values. In other words, we consider forecasts to have been reliable over the period 1980 to 2009 if they have tracked the general ups and downs of the observed return values; thus reliability can be independent of accuracy and precision as long as, on average, large forecasts are met by large returns and relatively small forecasts are met by relatively small returns. Unreliable forecasts for the period 1980 to 2009 are those where there is no significant relationship between the size of the forecast and the size of the return. If the forecast is deemed reliable we can move forward with regression analysis and MAPE to describe forecasting precision and accuracy.

Precision: Regression estimates precision by the dispersion of data points around the regression line; in other words, the amount of variation in returns correlated by forecasts (R^2). For example, an R^2 value of 90% tells us that 90% of the year-to-year difference in returns is correlated with forecasts. Importantly, R^2 values are independent of location shifts. For example, forecasts may consistently over-estimate returns by 1 million fish, giving the forecaster high precision even if accuracy is low. Note: changes in R^2 can also signal changes in accuracy, when the regression slope departs from 1.

Accuracy: Regression estimates accuracy by the combination of intercept and slope of the regression line. A perfect forecast to return regression will have high accuracy (i.e., a slope of 1, intercept of zero) and high precision (i.e., all points would cluster closely to the regression line making R^2 close to 100%). A management group with highly accurate forecasts will therefore have a slope close to 1 (i.e., each 1000-fish increase in forecast is matched by a 1000-fish increase in return) and an elevation close to zero (i.e., intercept not statistically different from 0). If the regression slope is statistically significant but departs from 1, then accuracy will change as a function of forecast size (e.g., when observed returns are 50% different from forecasts across all levels of forecast, the regression slope will depart from 1). Accuracy also diminishes as regression elevations depart from 0; positive elevations reflect forecasts that have under-estimated the return whereas negative elevations reflect forecasts having over-estimated returns. If two management groups have similar regression slopes and elevations, that with the highest R^2 value or lowest MAPE will be the one with the most accurate forecasts.

Is statistical, biological, and social significance the same?

Not always. Statistical significance is an inference based on the magnitude of the difference in question relative to the noise in the data; biological significance refers to the functional relationship between organisms and their environment; social significance incorporates economic and cultural ramifications. We often calculate statistical significance by comparing the variance in data for a sub-group to total variance in the entire group. For example, a loss of a million fish may not be statistically significant relative to annual variations on the order of millions, or biologically significant in that it will substantially alter future recruits per spawner, yet losing one million fish will likely create economic and cultural issues. For the purpose of this section, the term "significant" refers only to a statistical significance.

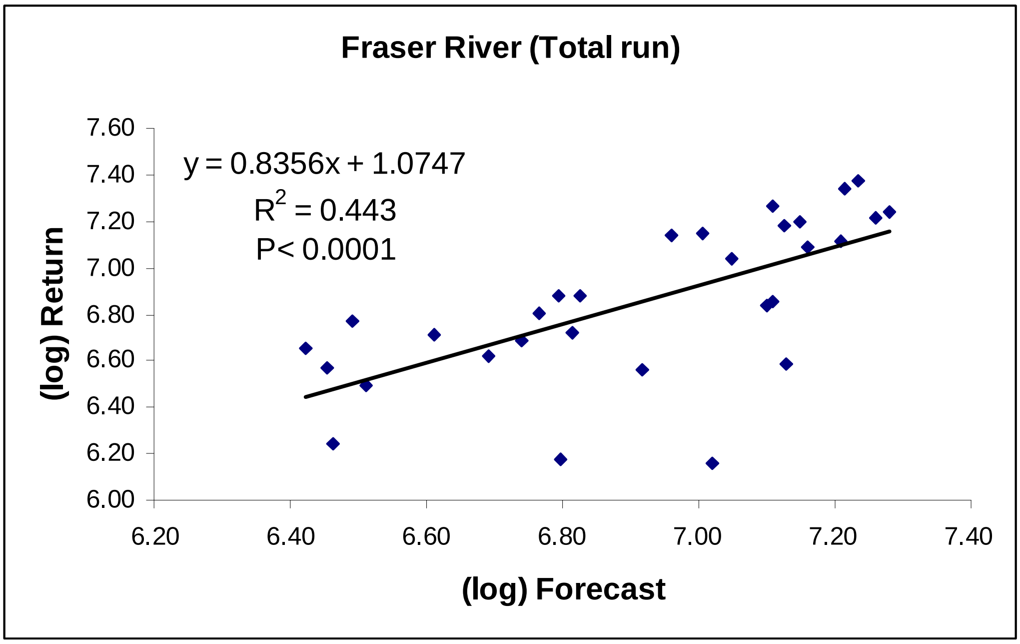
Appendix G Graphical representations of pre-season run size forecast error for the period 1980-2009. Results are shown individually for the total Fraser River, the four run timing management groups (Early Stuart, Early Summer, Summer-run, Late-run), and the 19 indicator stocks.

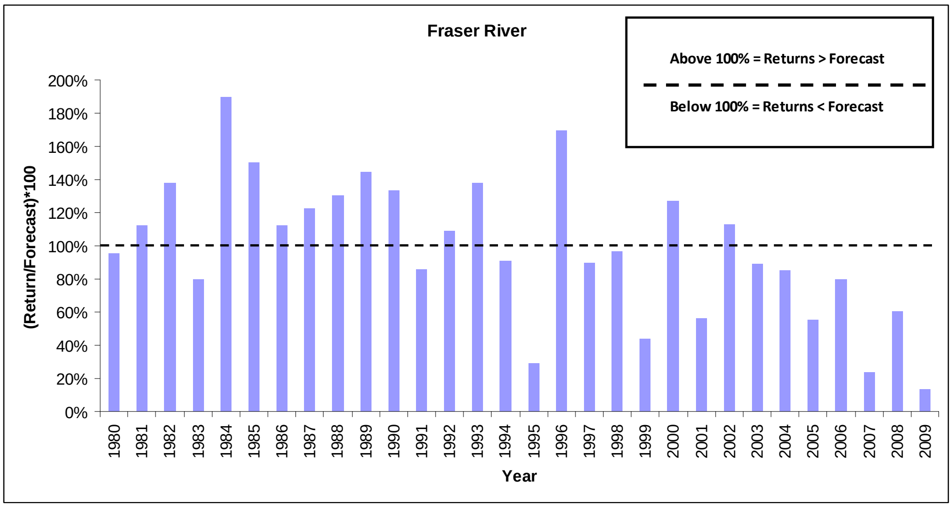
The following captions apply to each of the scatter plots and bar graphs shown below. Analyses for the total Fraser River sockeye run and the four run-timing groups (i.e., Early Stuart, Early Summer, Summer-run, and Late-run) appear first, followed by results for the 19 indicator stocks (listed in alphabetical order).

Scatter Plots: Regression analysis shows the strength of relationship between forecasts and returns of sockeye for management stocks in the Fraser River (1980-2009). Data were $\log_{10}$ transformed to conform to statistical assumptions of regression analysis. R^2 is the proportion of variation in Y (Return) correlated to variation in X (Forecast). P is the probability of the regression slope being equal to zero (i.e., no statistical relationship between forecast and return). Alpha has been adjusted for multiple comparisons (n= 18 CUs) from 0.05 to 0.0316 following Benjamini and Hochberg (1995); hence, P-values less than 0.0316 are evidence of a significant relationship between forecast and actual returns. Conversely, when $P > 0.0316$ there is no statistically significant relationship between forecasts and actual returns.

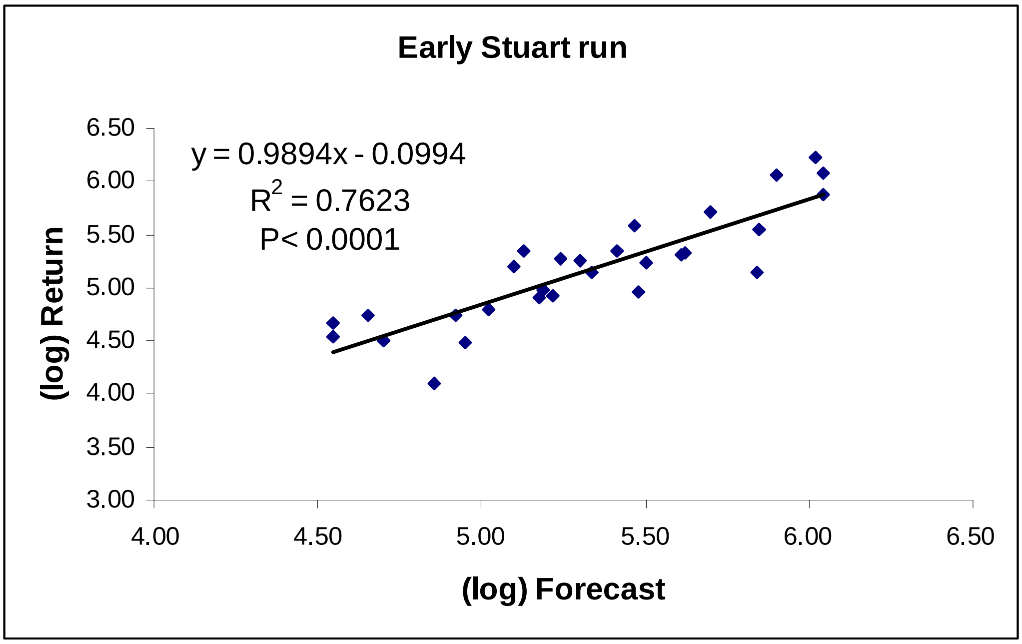
Bar Graphs: Ratio of Return to Forecast (expressed as %) for each year in the period 1980-2009 for each management stock of Fraser River sockeye. Ratios are a relative measure of return to forecast; therefore, values are independent of run size and directly comparable between years. A ratio of 100% denotes return = forecast. Ratios > 100% denote returns > forecasts; ratios < 100% denote returns < forecasts.

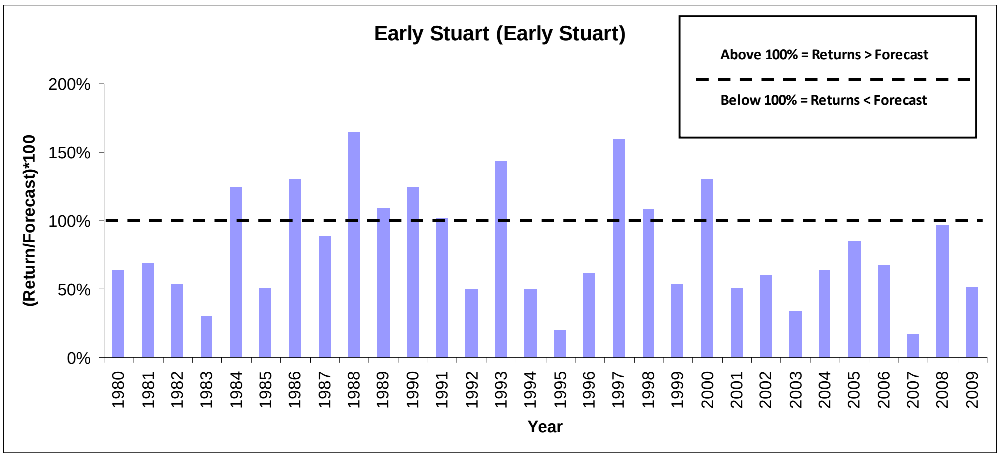
<u>**Total Fraser River Sockeye Run**</u>



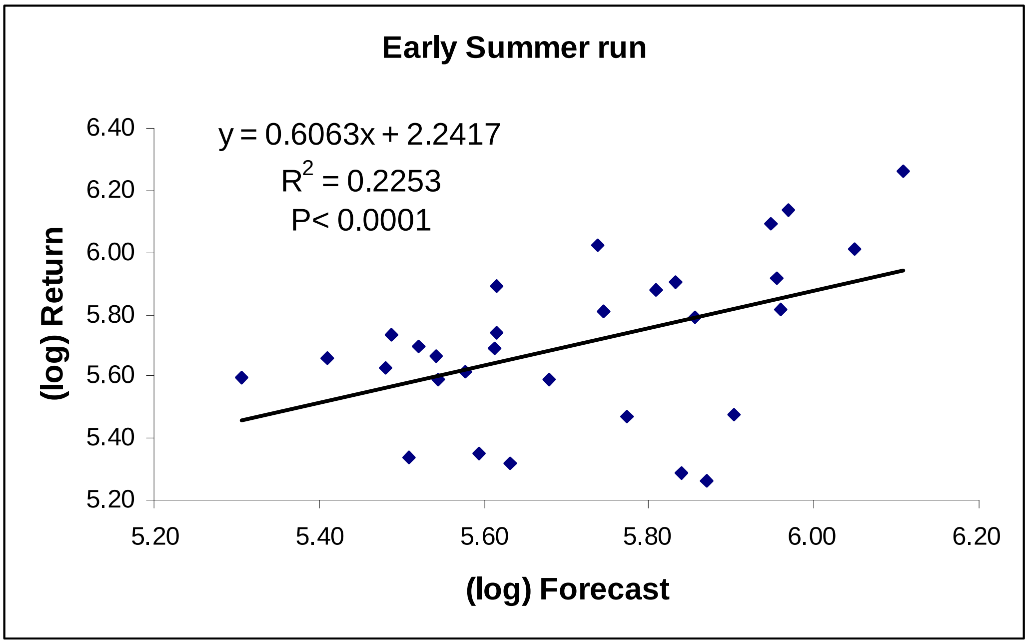


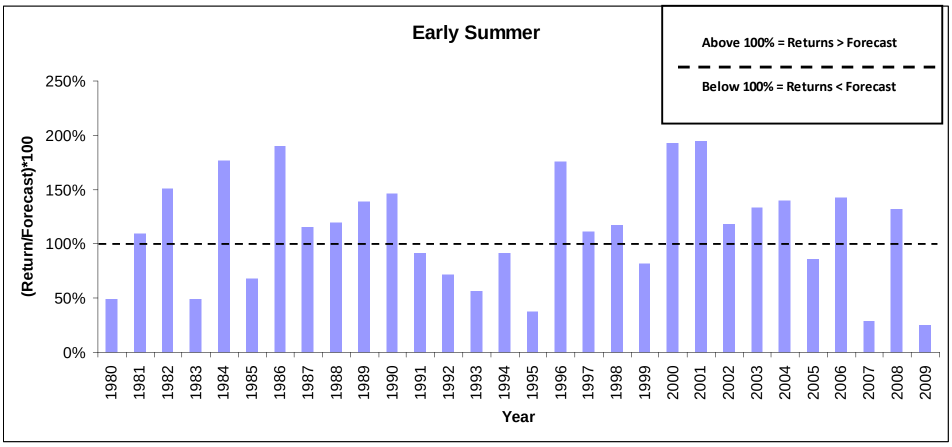
Early Stuart Timing Group



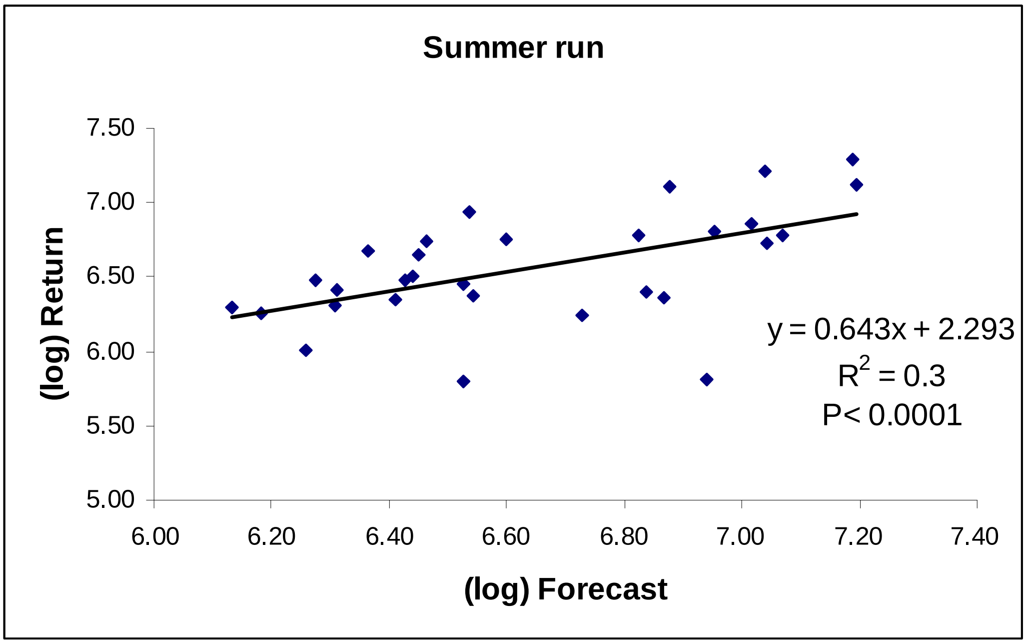


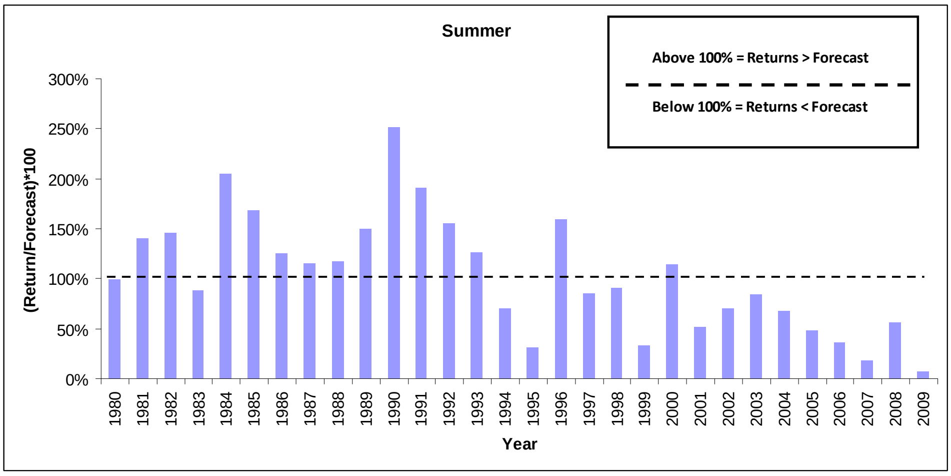
Early Summer-run Timing Group



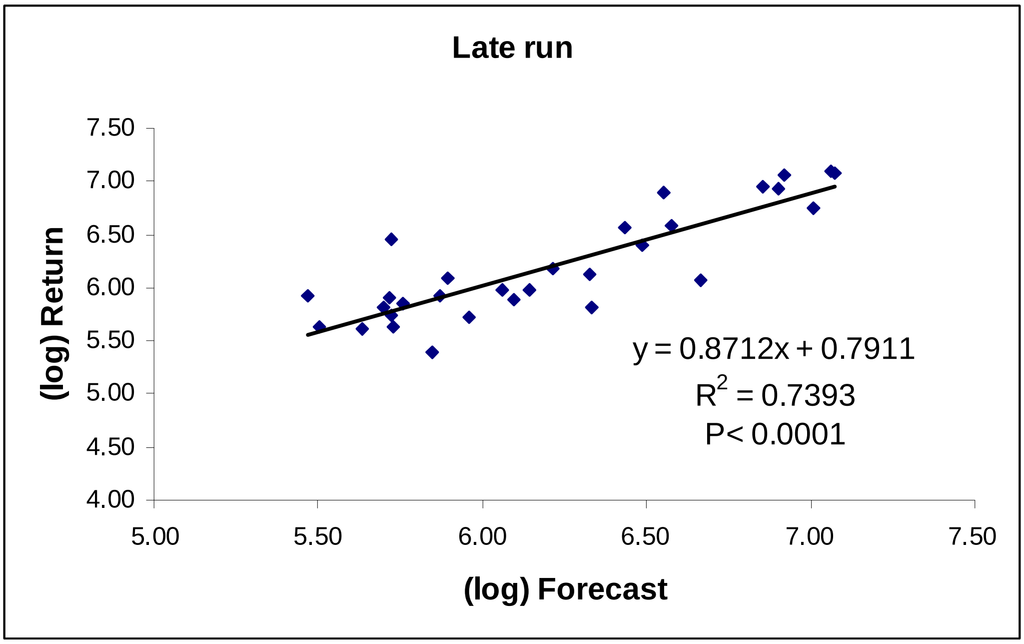


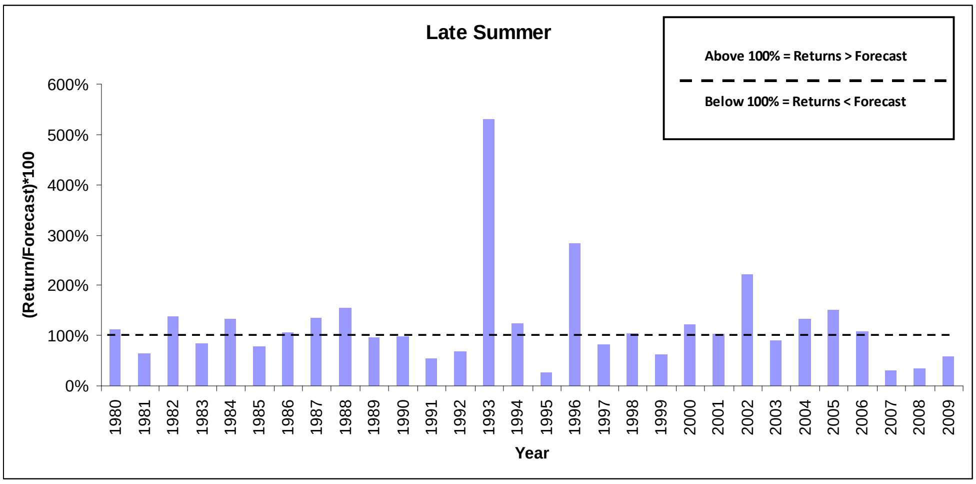
Summer-run Timing Group





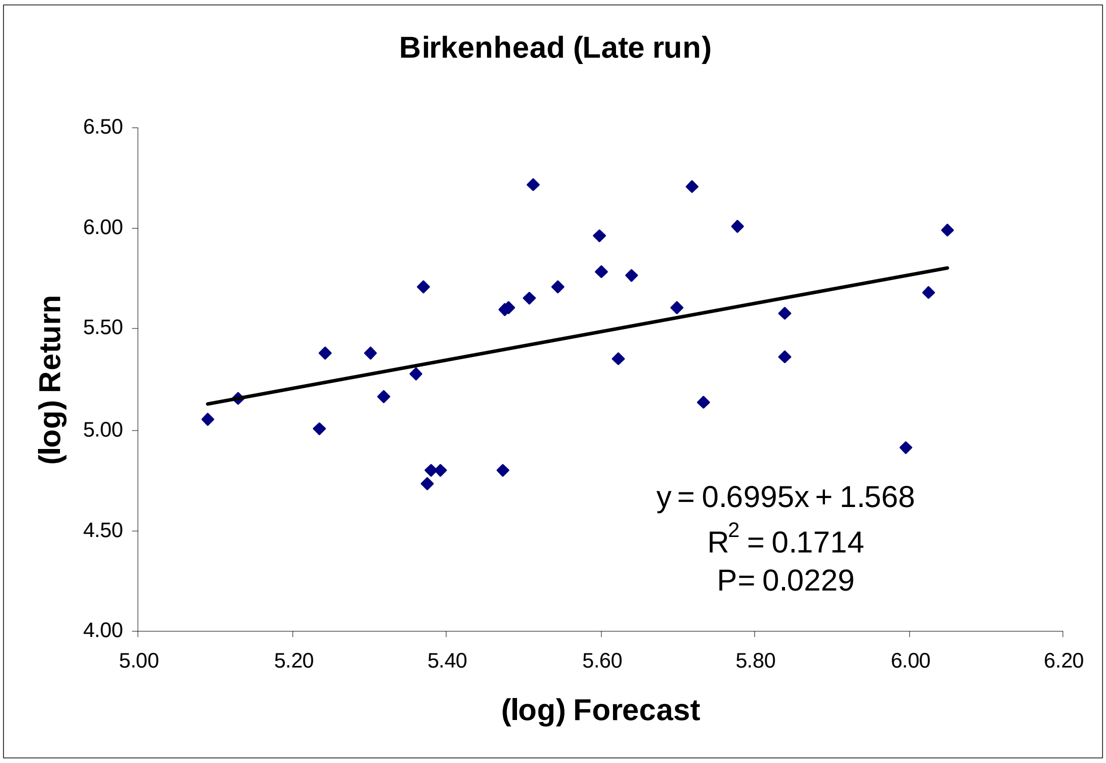
Late-run Timing Group

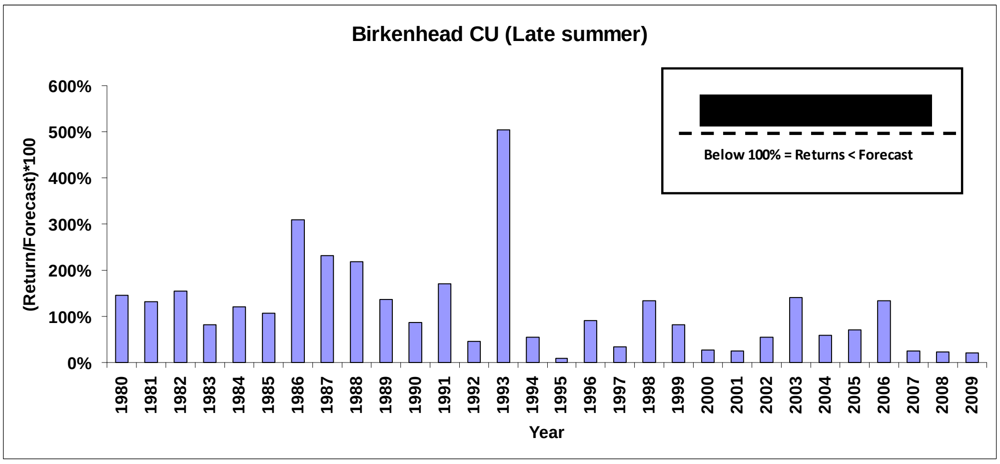




Fraser River Indicator Stocks (listed in alphabetical order)

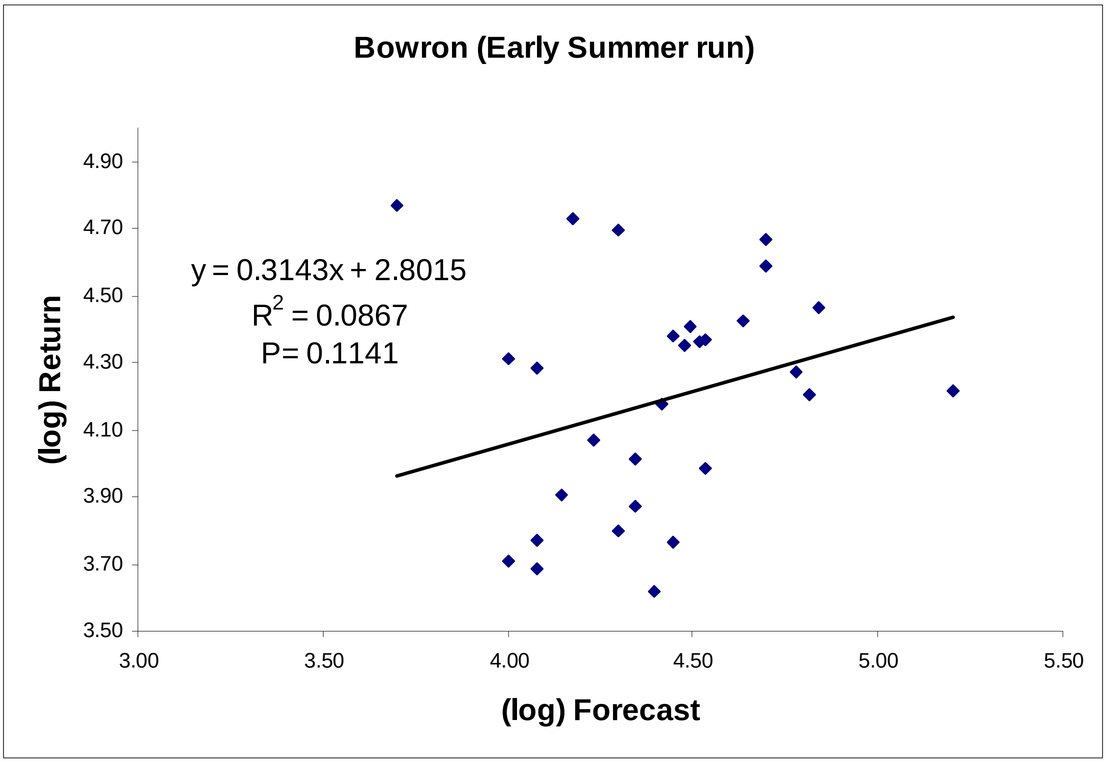
Birkenhead

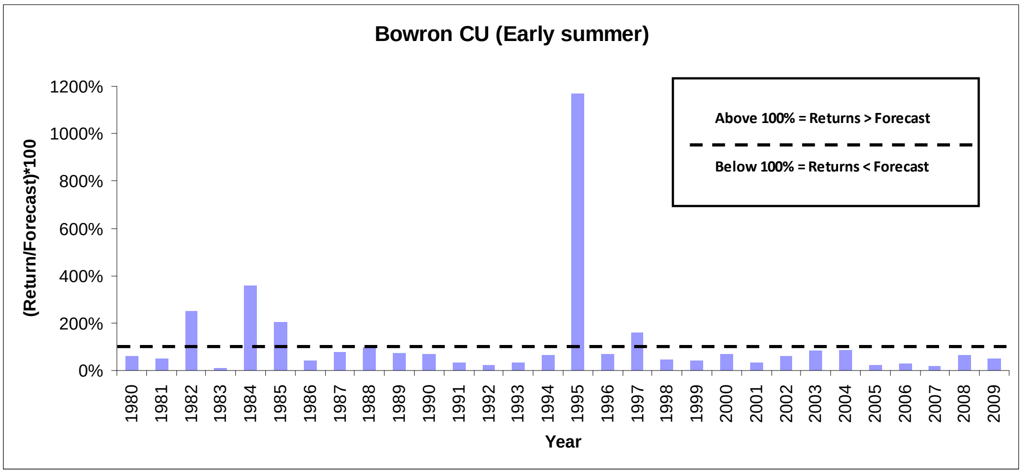




Fraser River Indicator Stocks (listed in alphabetical order)

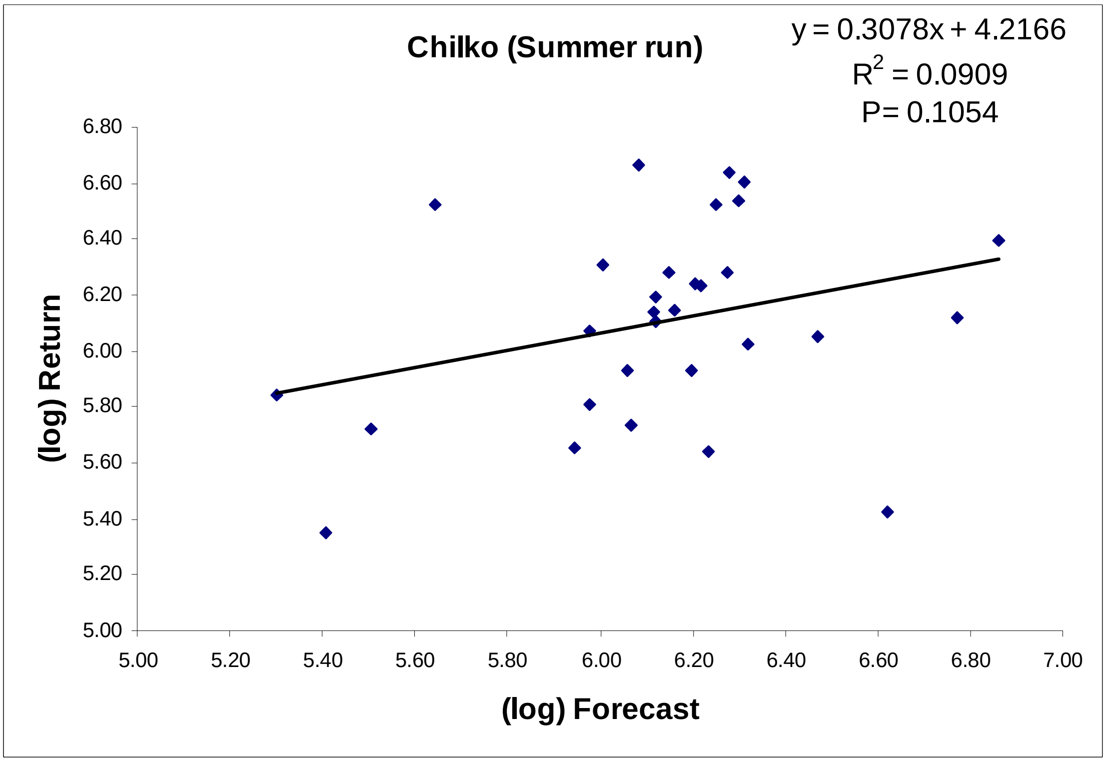
Bowron

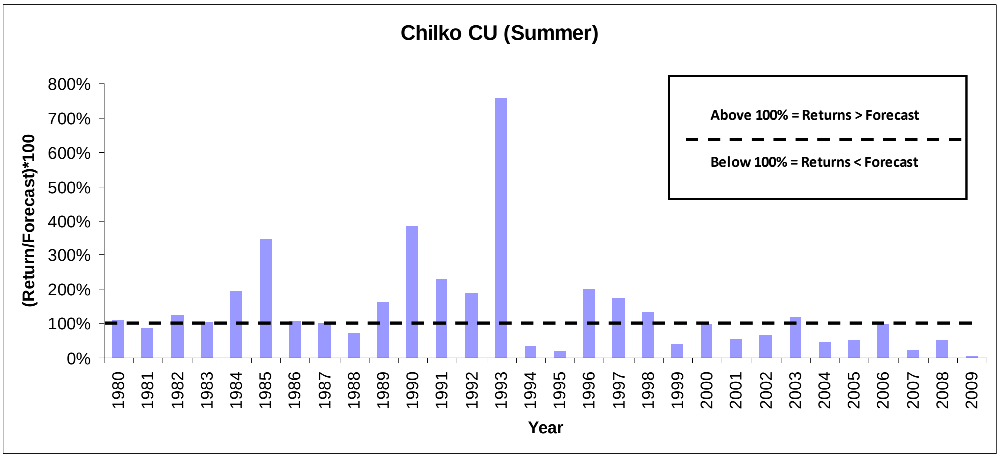




Fraser River Indicator Stocks (listed in alphabetical order)

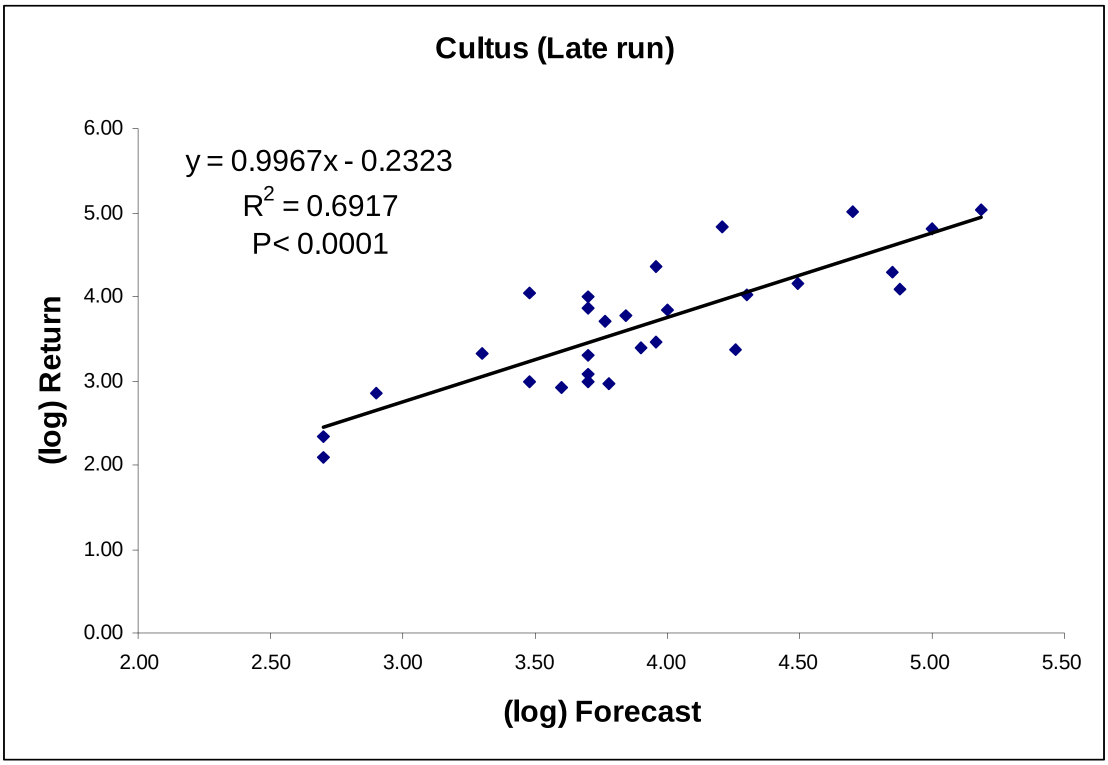
Chilko

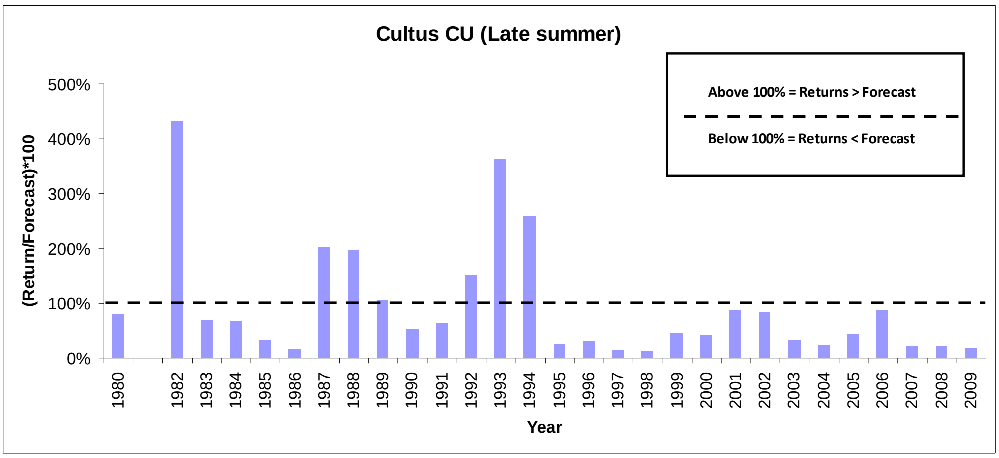




Fraser River Indicator Stocks (listed in alphabetical order)

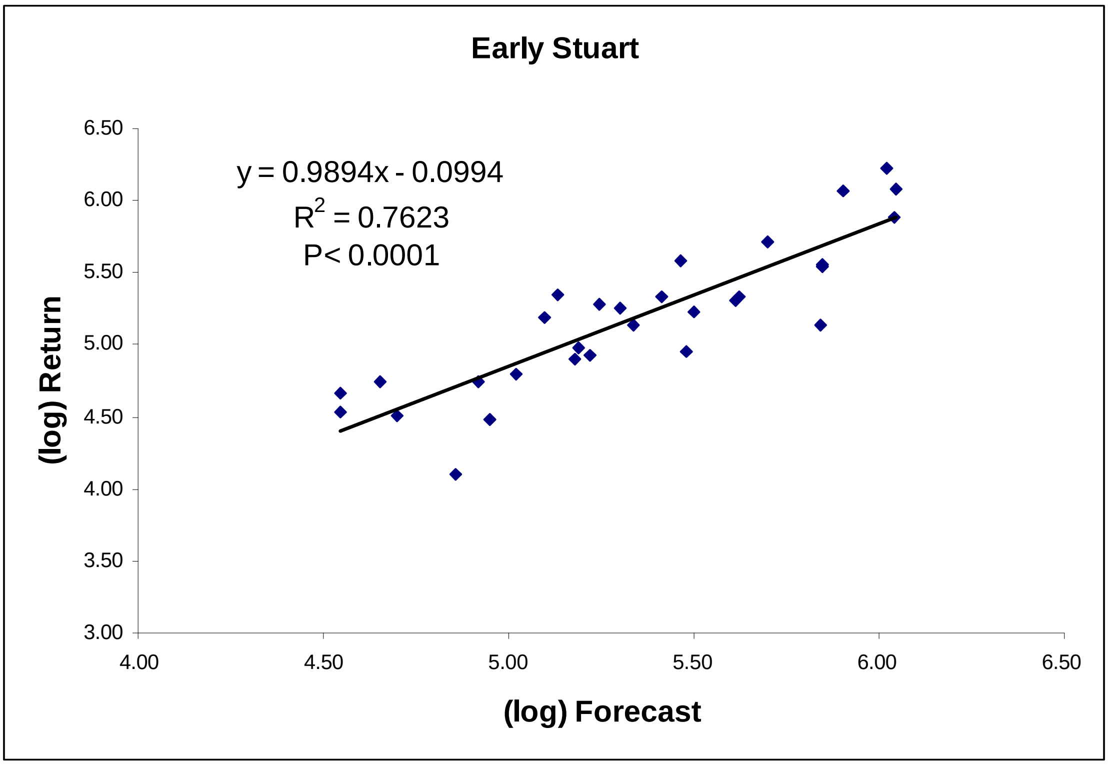
Cultus

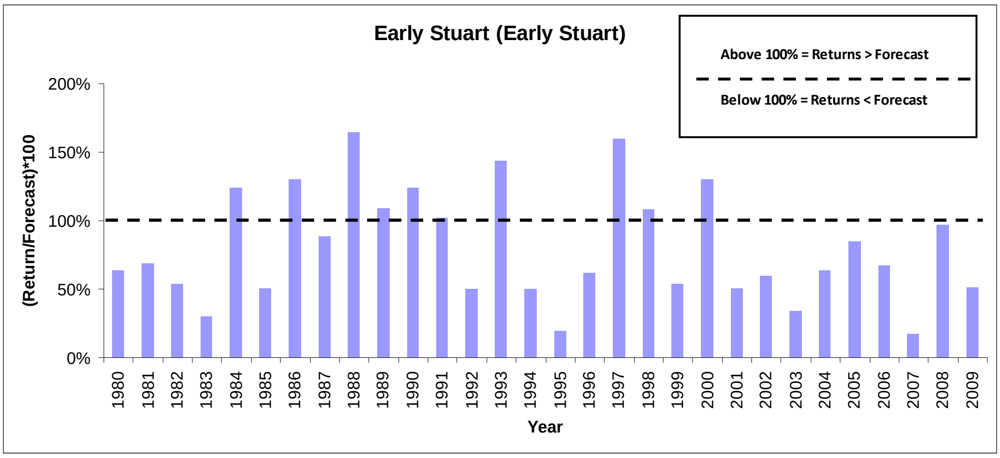




Fraser River Indicator Stocks (listed in alphabetical order)

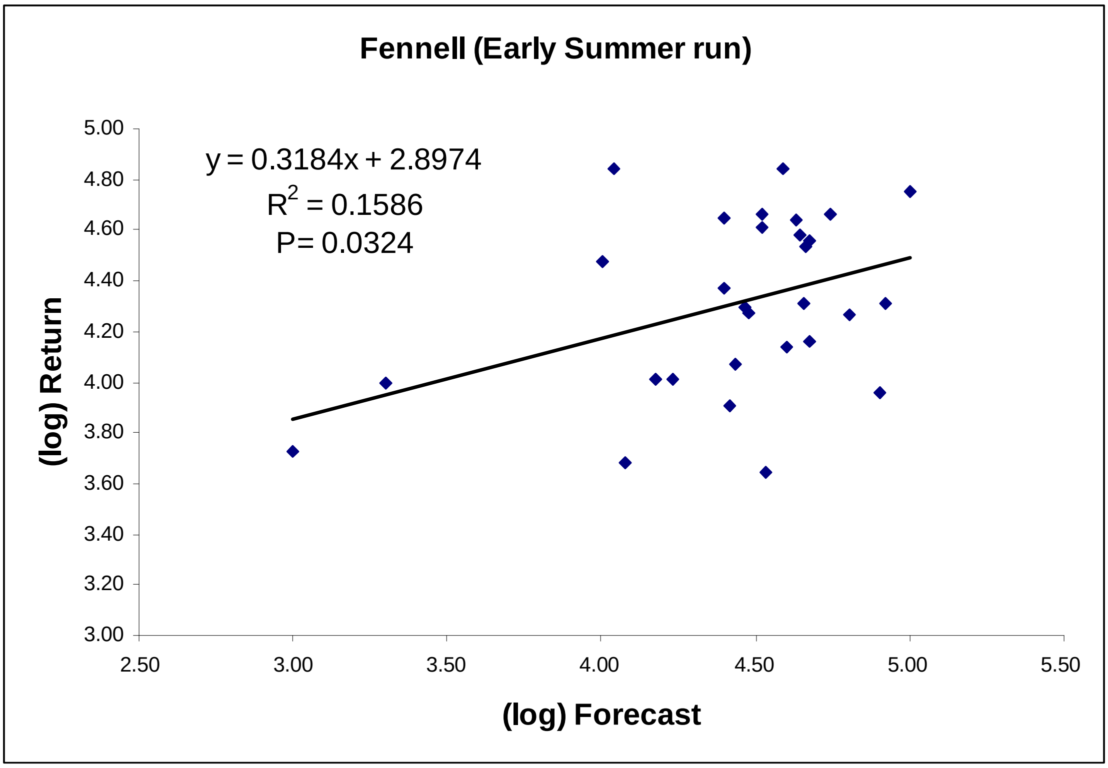
Early Stuart

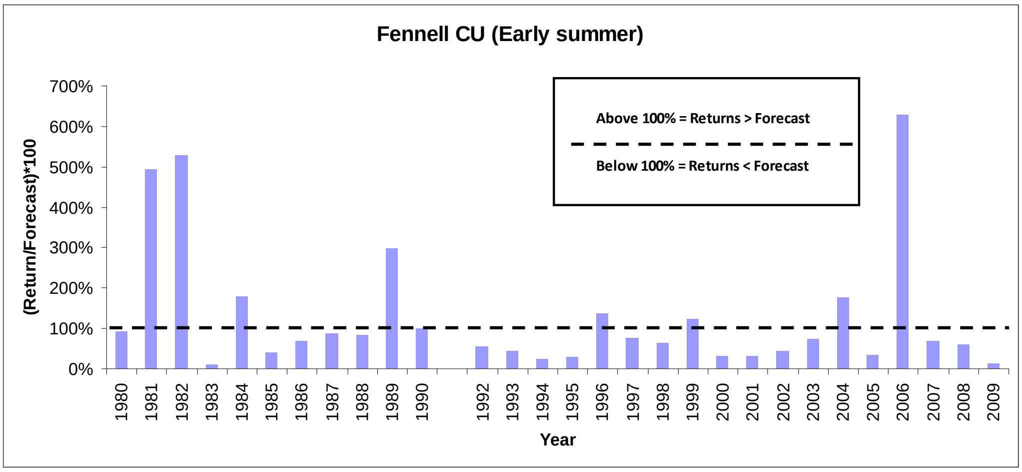




Fraser River Indicator Stocks (listed in alphabetical order)

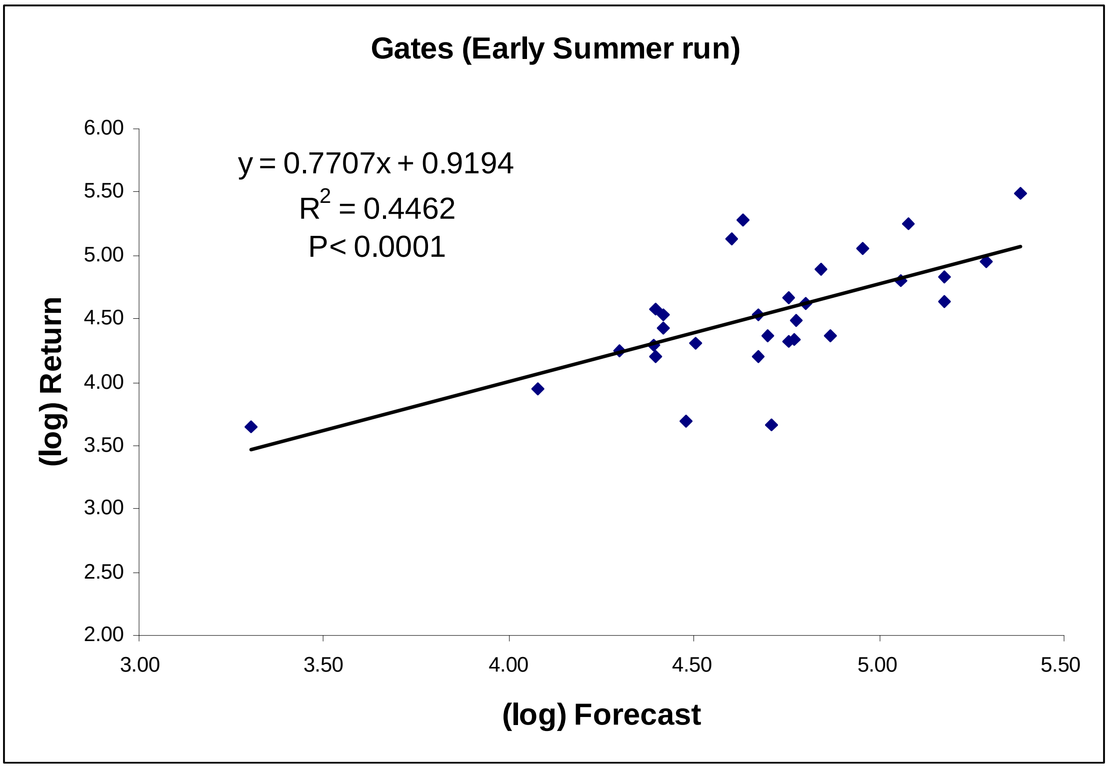
Fennell

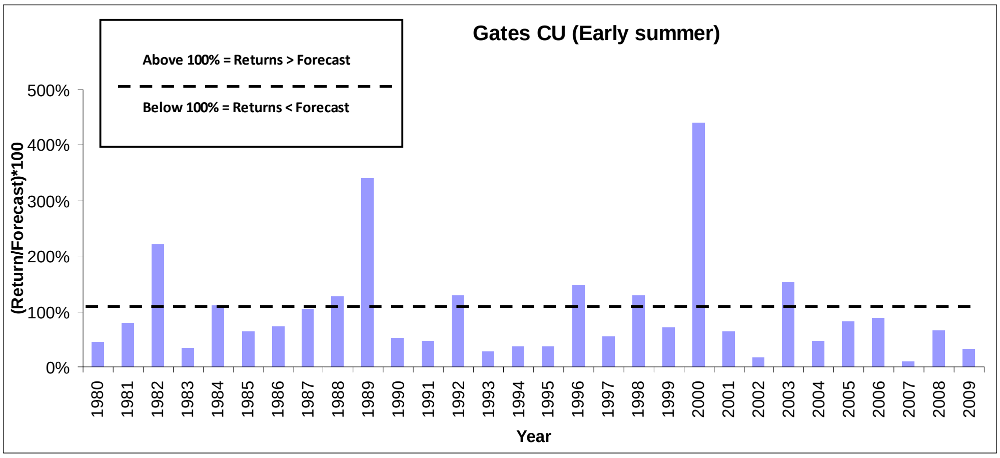




Fraser River Indicator Stocks (listed in alphabetical order)

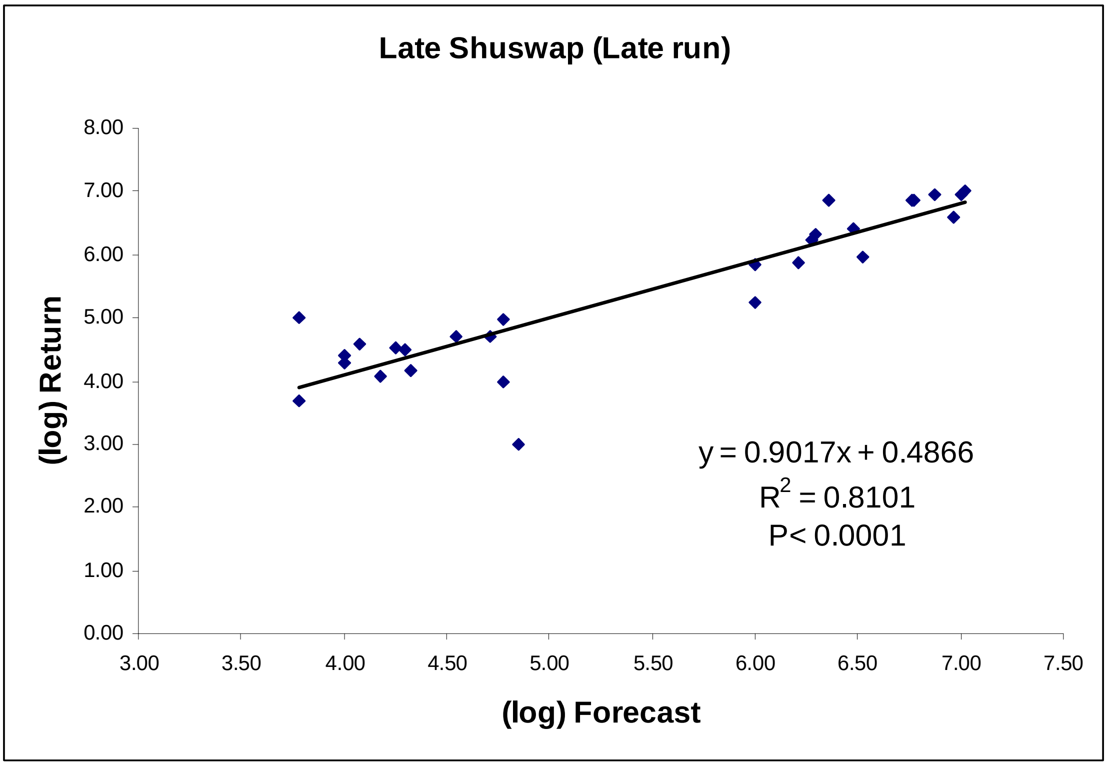
Gates

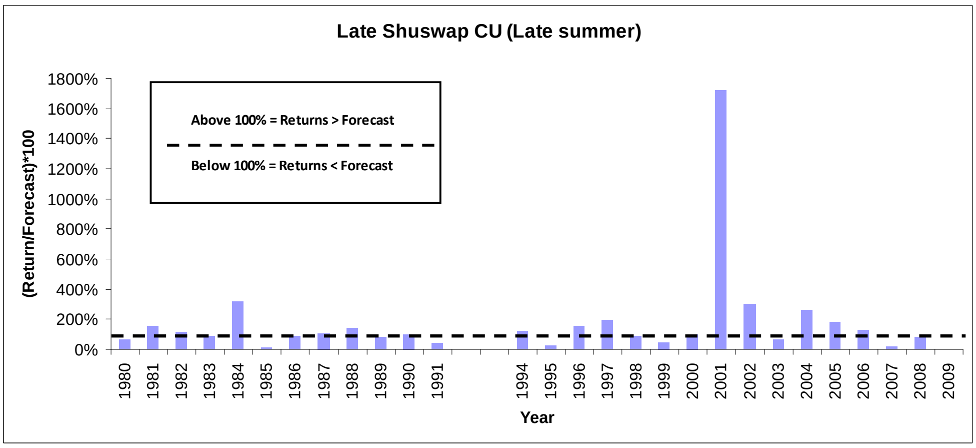




Fraser River Indicator Stocks (listed in alphabetical order)

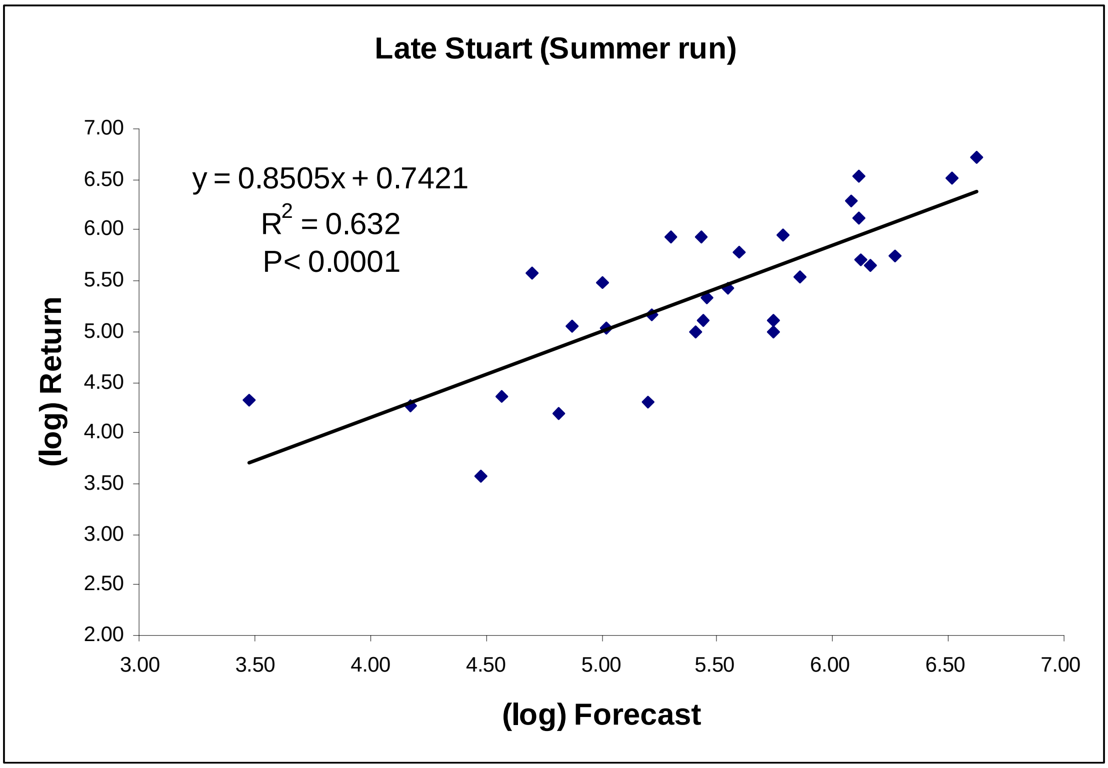
Late Shuswap

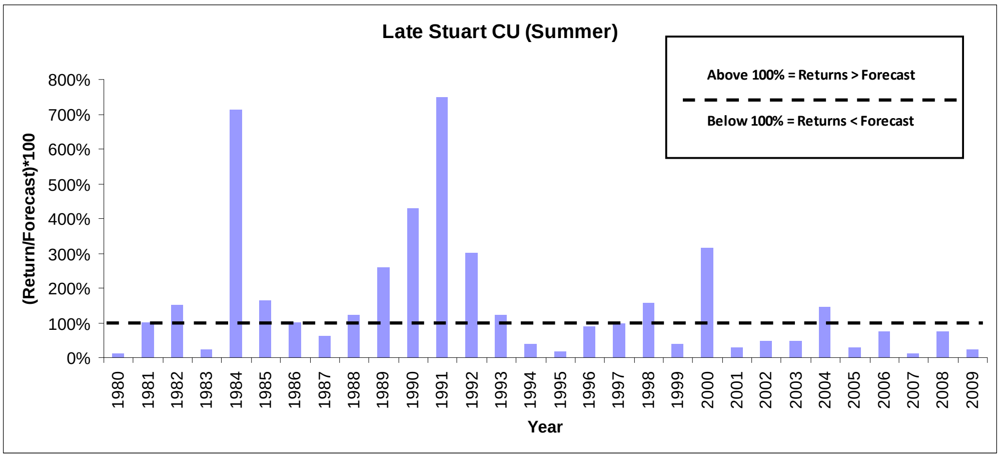




Fraser River Indicator Stocks (listed in alphabetical order)

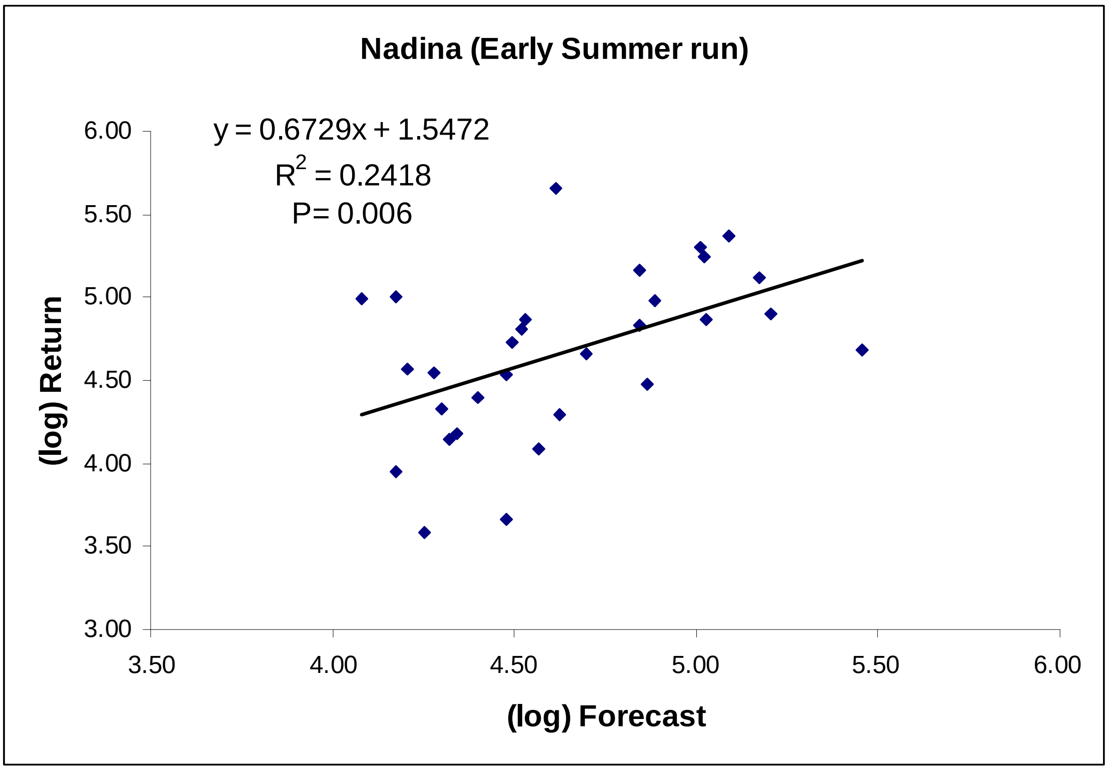
Late Stuart

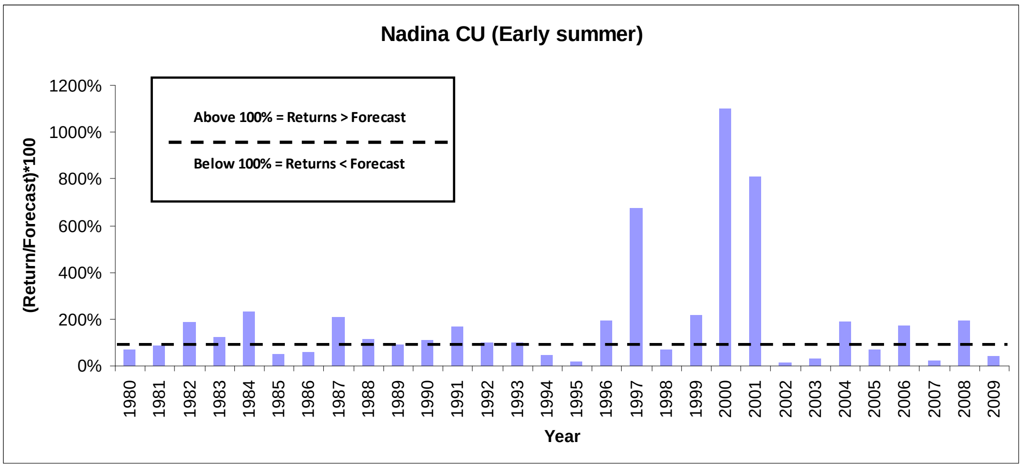




Fraser River Indicator Stocks (listed in alphabetical order)

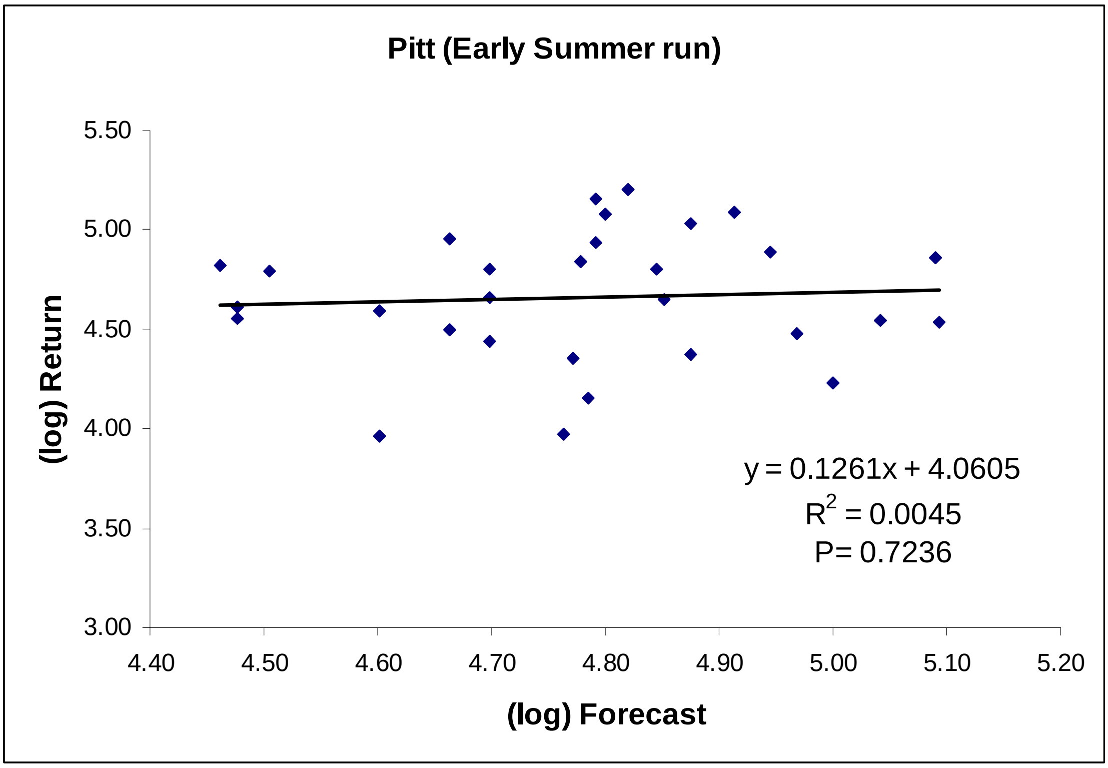
Nadina

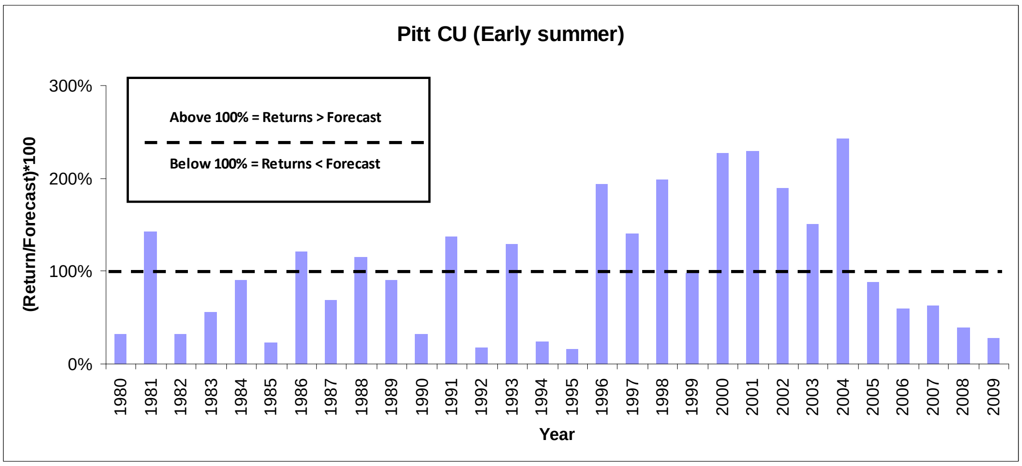




Fraser River Indicator Stocks (listed in alphabetical order)

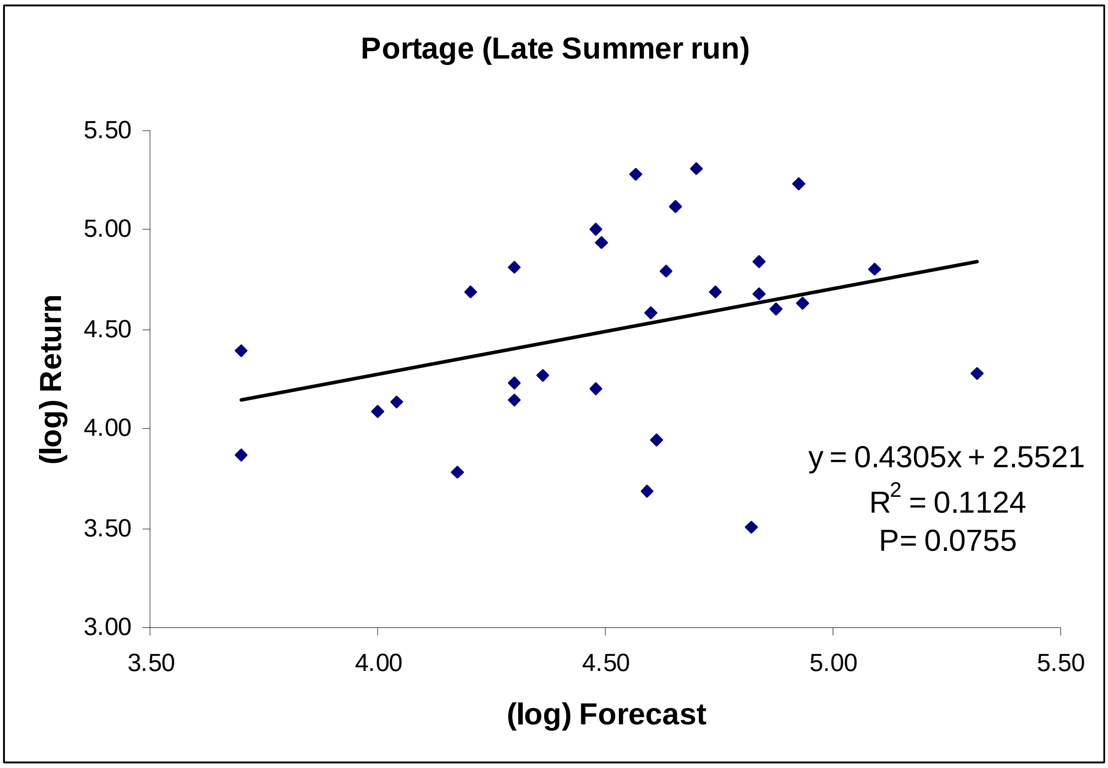
Pitt

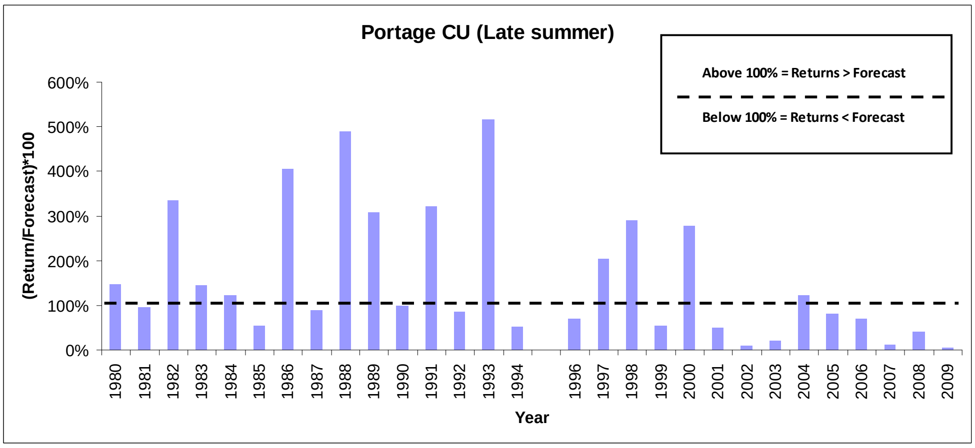




Fraser River Indicator Stocks (listed in alphabetical order)

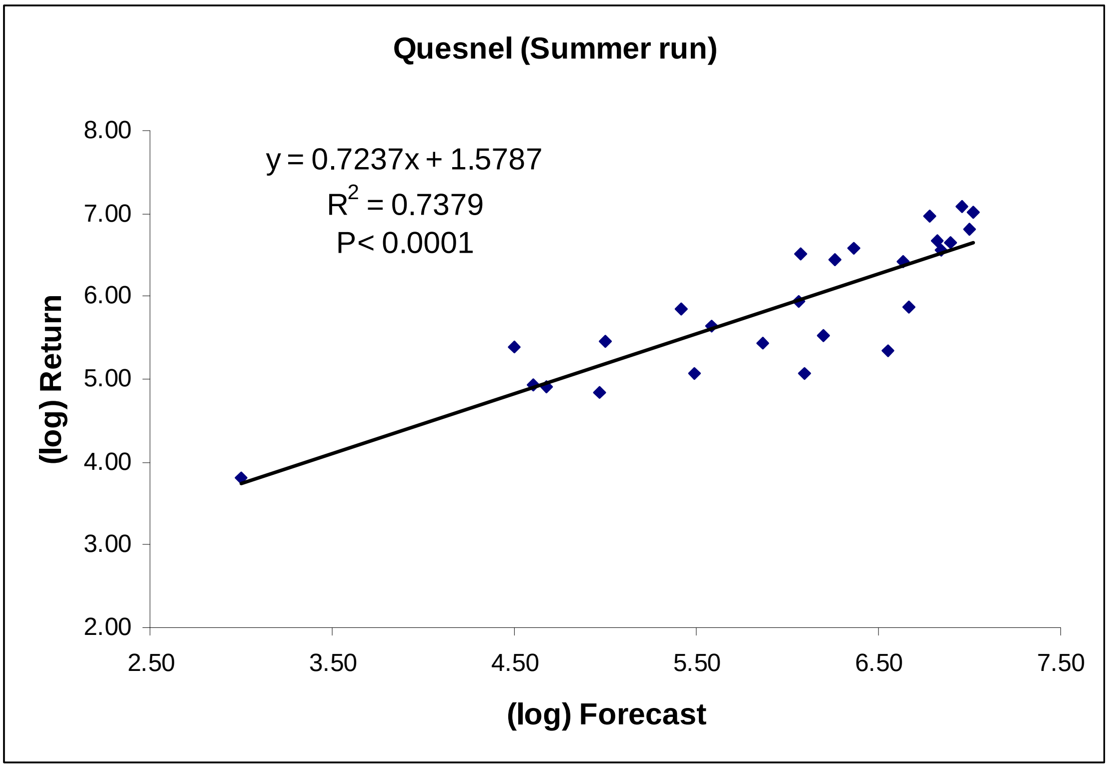
Portage

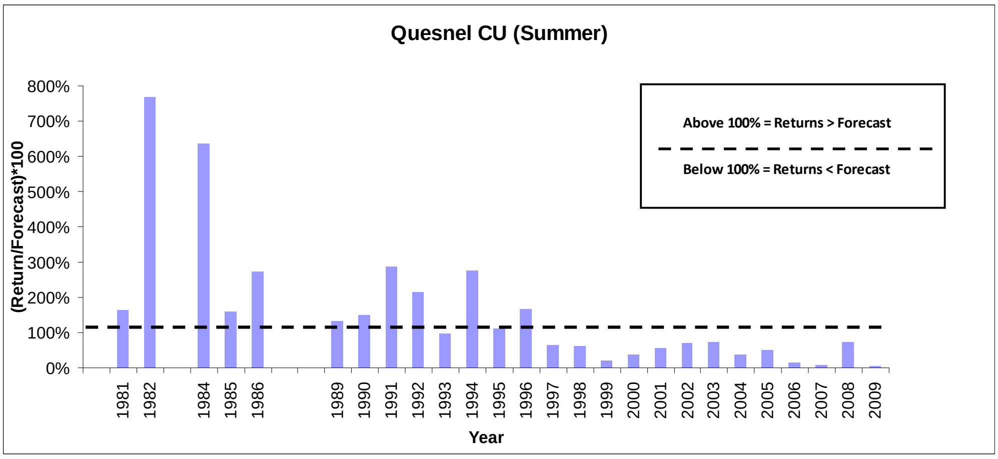




Fraser River Indicator Stocks (listed in alphabetical order)

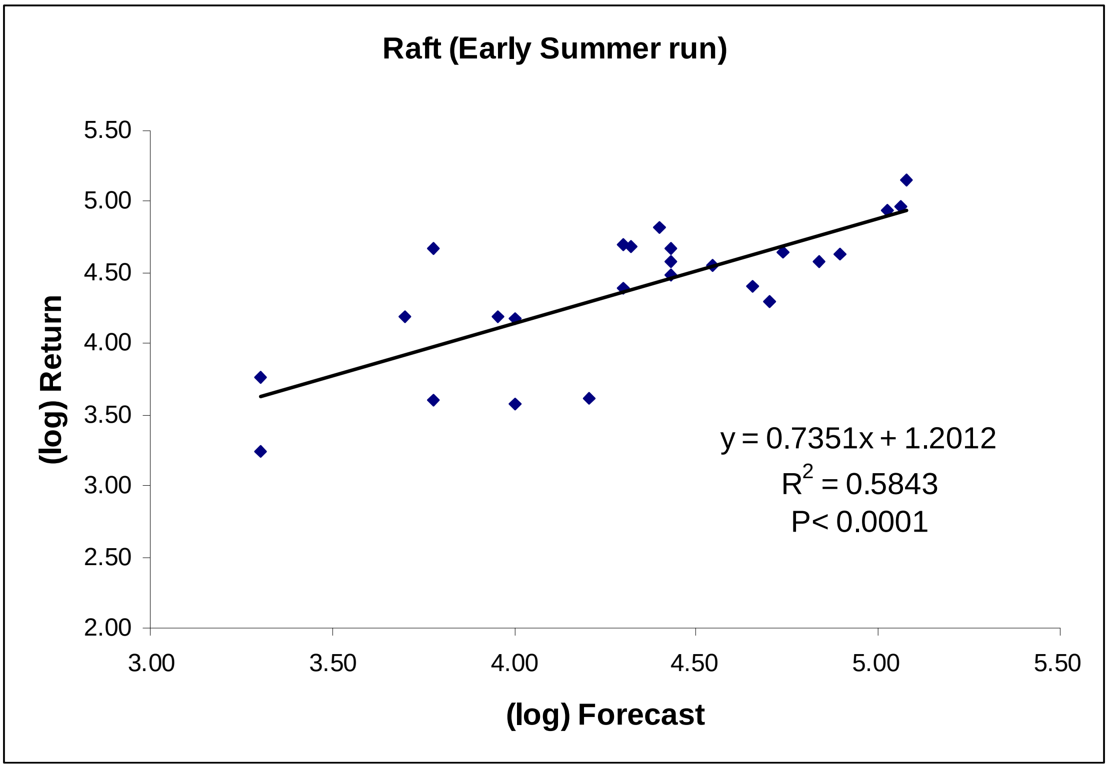
Quesnel

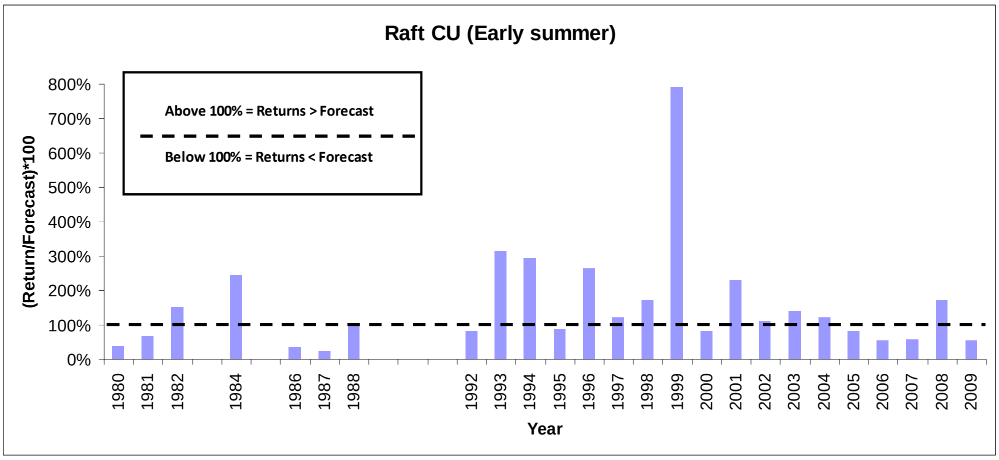




Fraser River Indicator Stocks (listed in alphabetical order)

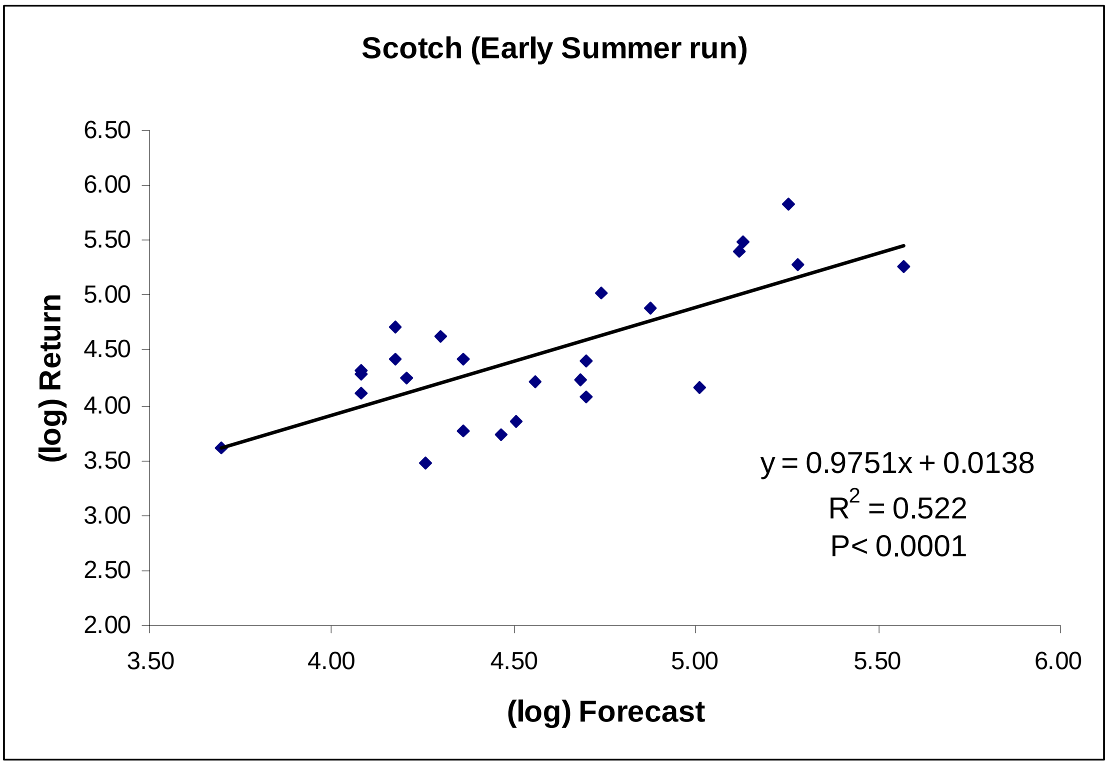
Raft

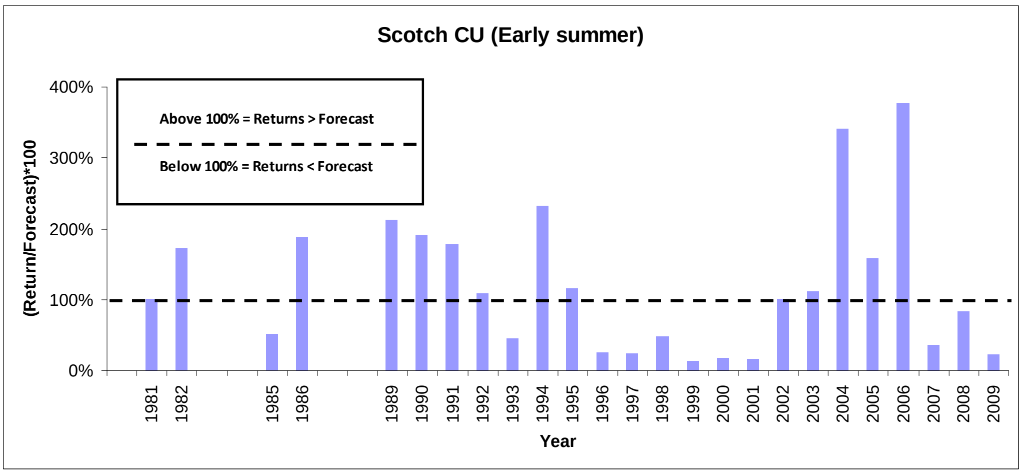




Fraser River Indicator Stocks (listed in alphabetical order)

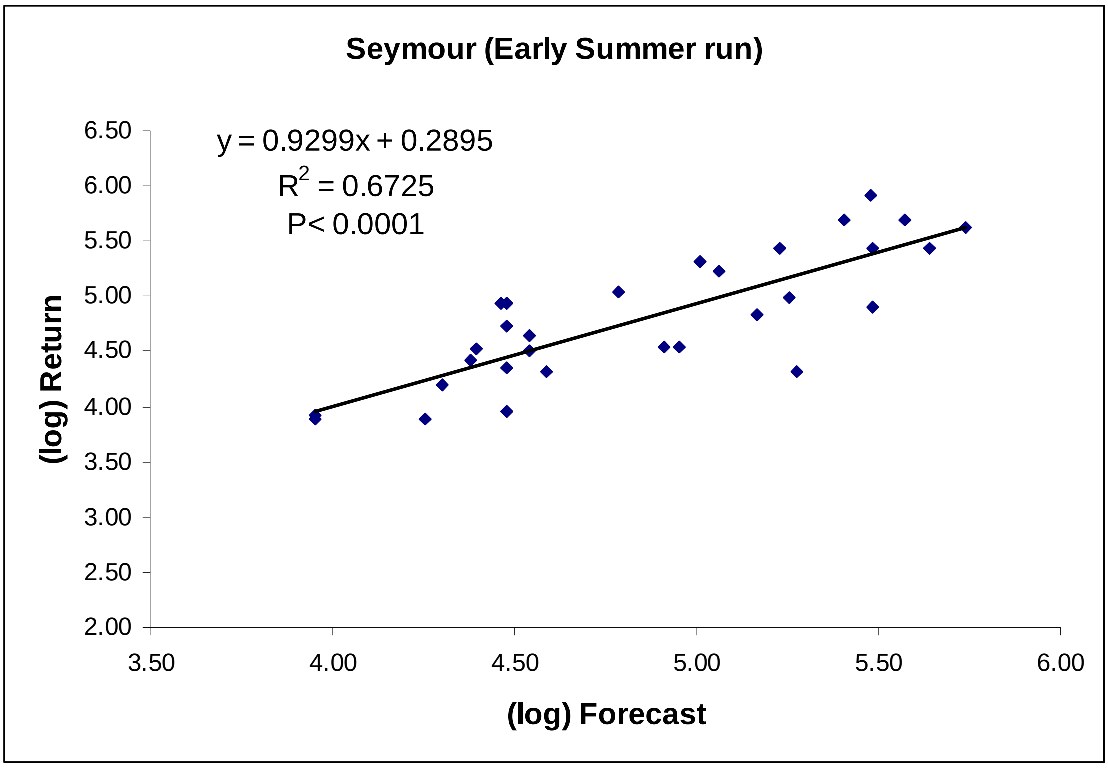
Scotch

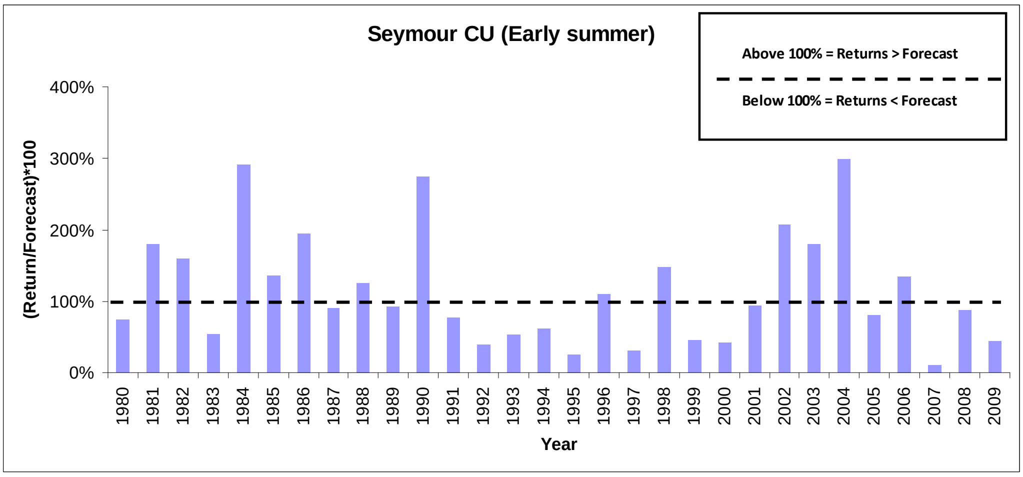




Fraser River Indicator Stocks (listed in alphabetical order)

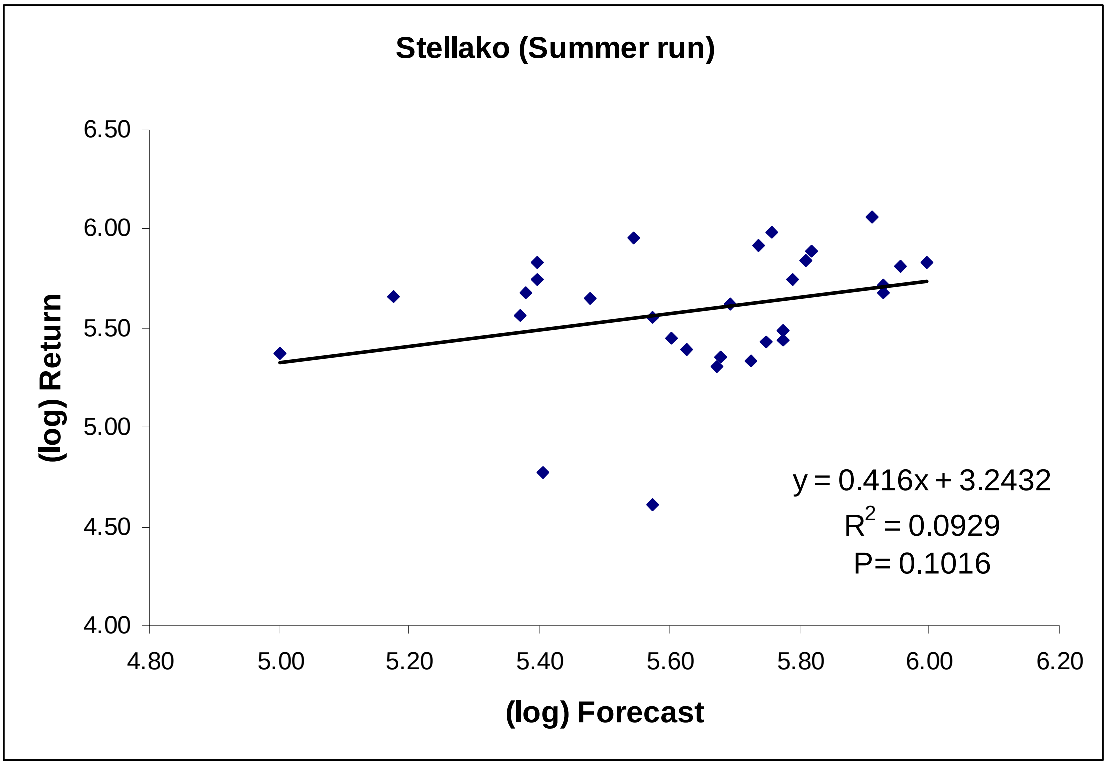
Seymour

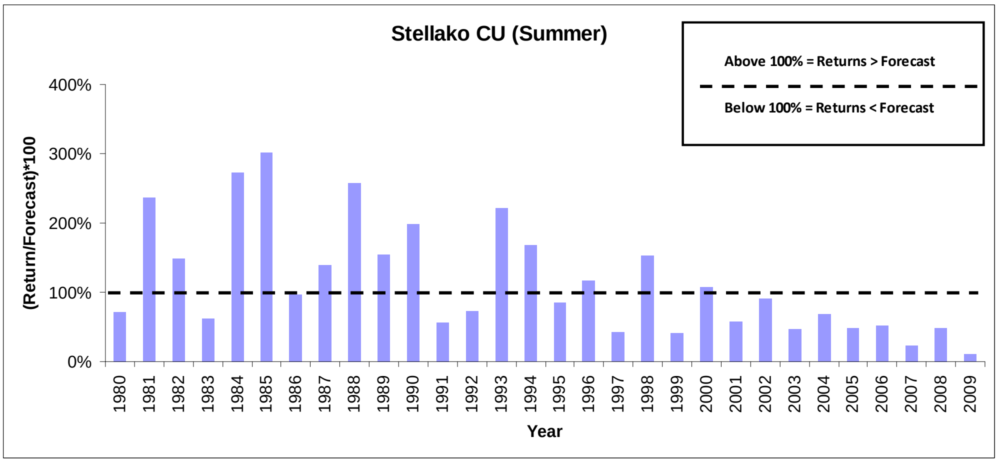




Fraser River Indicator Stocks (listed in alphabetical order)

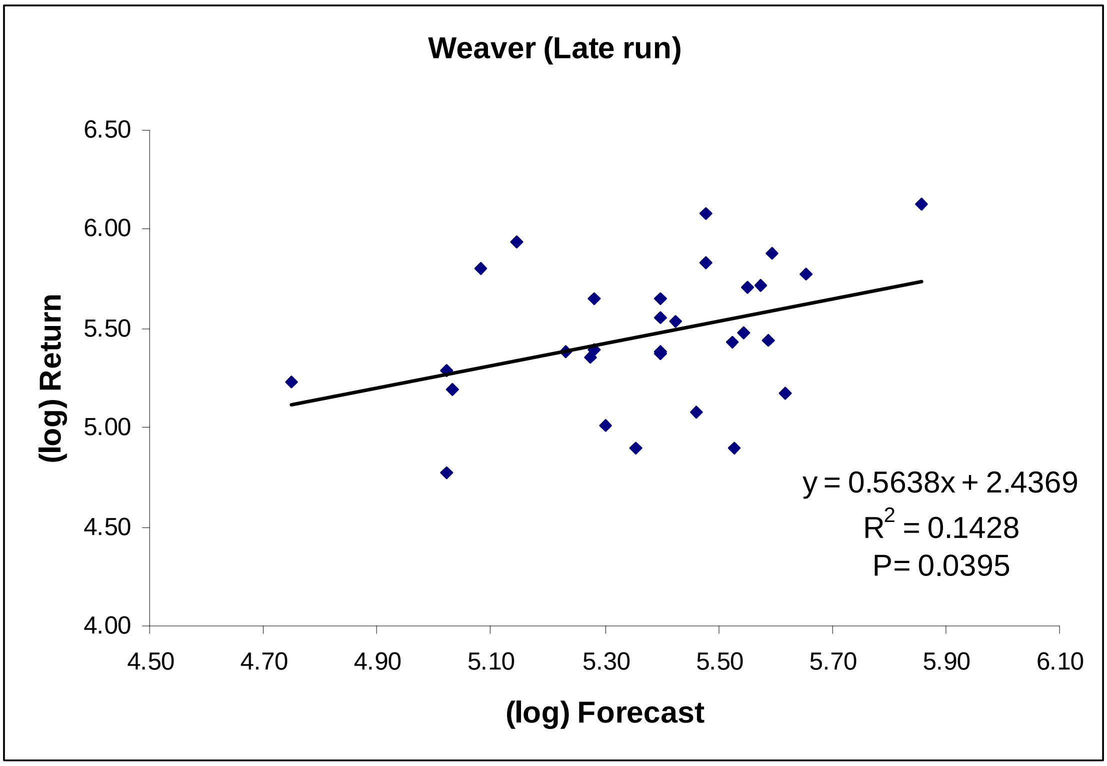
Stellako

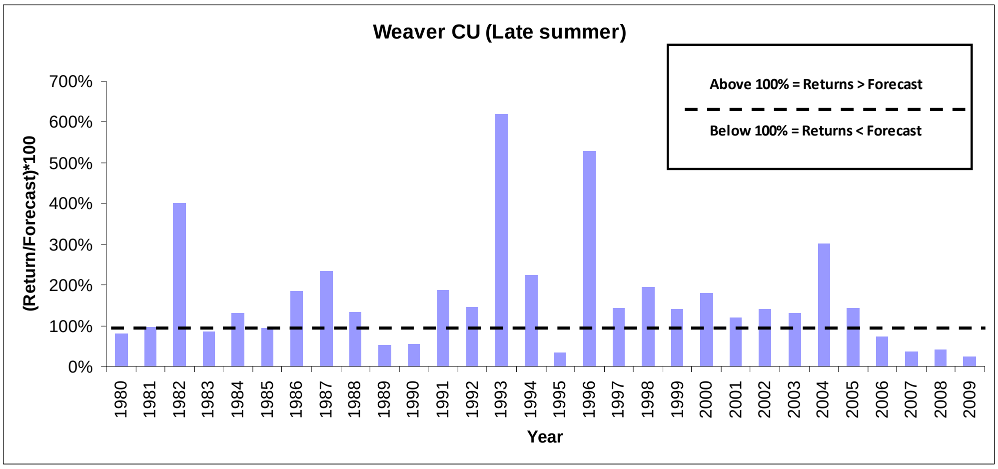




Fraser River Indicator Stocks (listed in alphabetical order)

Weaver





Appendix H Pre-season forecast: summary statistics and interpretations of precision, accuracy, and reliability for 19 indicator stocks in the Fraser River.

Management Group (Indicator Stock)	MAPE	Error in Return Explained by Forecast (R^2)	Regression Slope (Return : Forecast)	Regression Intercept	MG Size relative to total Fraser Return	Interpretation Regression analysis: inferences about reliability, precision, and accuracy relate to long-term trends (1980-2009). MAPE: expected error in any single year's forecast.
Early Stuart	53%	76%	0.99 (significant)	not significant	3.3%	• **Reliability**: Relationship between forecast and return is statistically significant, thus forecast is reliable. • **Precision**: Moderate/Large amount of inter-annual variation explained by forecasts (R^2= 0.76) • **Accuracy**: Slope is close to one and intercept is not significantly different from zero, thus long-term accuracy is good. • **Expected Error**: expect forecast to overestimate or underestimate return by 53% in any given year.
Early Summer						
Bowron	74%	8.7%	0.31 (not significant)	significant	0.3%	• **Reliability**: Relationship between forecast and return is not statistically significant, thus returns vary at random relative to forecasts, making forecasts unreliable. • **Expected Error**: expect forecast to overestimate or underestimate return by 74% in any given year.
Fennell	67%	16%	0.32 (not	significant	0.5%	• **Reliability**: Relationship between forecast and return is not statistically significant, thus returns vary at random relative to

Management Group (Indicator Stock)	MAPE	Error in Return Explained by Forecast (R^2)	Regression Slope (Return : Forecast)	Regression Intercept	MG Size relative to total Fraser Return	Interpretation Regression analysis: inferences about reliability, precision, and accuracy relate to long-term trends (1980-2009). MAPE: expected error in any single year's forecast.
			significant)			forecasts, making forecasts unreliable. • **Expected Error**: expect forecast to overestimate or underestimate return by 67% in any given year.
Gates	58%	45%	0.77 (significant)	not significant	1.1%	• **Reliability**: Relationship between forecast and return is statistically significant, thus forecast is reliable. • **Precision**: Moderate amount of inter-annual variation explained by forecasts (R^2= 0.45) • **Accuracy**: Slope departs from one and intercept is not significantly different from zero, thus long-term accuracy is good but large forecasts tend to underestimate returns. • **Expected Error**: expect forecast to overestimate or underestimate return by 58% in any given year.
Nadina	50%	24%	0.67 (not significant)	not significant	1.6%	• **Reliability**: Relationship between forecast and return is not statistically significant, thus returns vary at random relative to forecasts, making forecasts unreliable. • **Expected Error**: expect forecast to overestimate or underestimate return by 50% in any given year.
Pitt	53%	0.4%	0.13 (not significant)	significant	1.0%	• **Reliability**: Relationship between forecast and return is not statistically significant, thus returns vary at random relative to forecasts, making forecasts unreliable. • **Expected Error**: expect forecast to overestimate or underestimate return by 53% in any given year.
Raft	48%	58%	0.74	not	0.9%	• **Reliability**: Relationship between forecast and return is statistically

Management Group (Indicator Stock)	MAPE	Error in Return Explained by Forecast (R^2)	Regression Slope (Return : Forecast)	Regression Intercept	MG Size relative to total Fraser Return	Interpretation Regression analysis: inferences about reliability, precision, and accuracy relate to long-term trends (1980-2009). MAPE: expected error in any single year's forecast.
			(significant)	significant		significant, thus forecast is reliable. • **Precision**: Moderate amount of inter-annual variation explained by forecasts (R^2= 0.58) • **Accuracy**: Slope departs from one and intercept is not significantly different from zero, thus long-term accuracy is good but large forecasts tend to underestimate returns. • **Expected Error**: expect forecast to overestimate or underestimate return by 48% in any given year.
Scotch	57%	52%	0.98 (significant)	not significant	0.8%	• **Reliability**: Relationship between forecast and return is statistically significant, thus forecast is reliable. • **Precision**: Moderate amount of inter-annual variation explained by forecasts (R^2= 0.52) • **Accuracy**: Slope is close to one and intercept is not significantly different from zero, thus long-term accuracy is good. • **Expected Error**: expect forecast to overestimate or underestimate return by 57% in any given year.
Seymour	47%	67%	0.93 (significant)	not significant	1.5%	• **Reliability**: Relationship between forecast and return is statistically significant, thus forecast is reliable. • **Precision**: Moderate/Large amount of inter-annual variation explained by forecasts (R^2= 0.67) • **Accuracy**: Slope is close to one and intercept is not significantly different from zero, thus long-term accuracy is good. • **Expected Error**: expect forecast to overestimate or underestimate

Management Group (Indicator Stock)	MAPE	Error in Return Explained by Forecast (R^2)	Regression Slope (Return : Forecast)	Regression Intercept	MG Size relative to total Fraser Return	Interpretation Regression analysis: inferences about reliability, precision, and accuracy relate to long-term trends (1980-2009). MAPE: expected error in any single year's forecast.
						return by 47% in any given year.
Summer						
Chilko	48%	9.1%	0.31 (not significant)	significant	23.5%	• **Reliability**: Relationship between forecast and return is not statistically significant, thus returns vary at random relative to forecasts, making forecasts unreliable. • **Expected Error**: expect forecast to overestimate or underestimate return by 48% in any given year.
Late Stuart	68%	63%	0.85 (significant)	not significant	7.0%	• **Reliability**: Relationship between forecast and return is statistically significant, thus forecast is reliable. • **Precision**: Moderate/Large amount of inter-annual variation explained by forecasts (R^2= 0.63) • **Accuracy**: Slope is departs mildly from one and intercept is not significantly different from zero, thus long-term accuracy is good but large forecasts may underestimate return. • **Expected Error**: expect forecast to overestimate or underestimate return by 68% in any given year.
Quesnel	62%	74%	0.72 (significant)	significant	21.6%	• **Reliability**: Relationship between forecast and return is statistically significant, thus forecast is reliable. • **Precision**: Moderate/Large amount of inter-annual variation explained by forecasts (R^2= 0.74) • **Accuracy**: Slope departs from one and intercept is significantly different from zero, thus long-term accuracy is moderate and the tendency to over-estimate or underestimate returns will vary with

Management Group (Indicator Stock)	MAPE	Error in Return Explained by Forecast (R^2)	Regression Slope (Return : Forecast)	Regression Intercept	MG Size relative to total Fraser Return	Interpretation Regression analysis: inferences about reliability, precision, and accuracy relate to long-term trends (1980-2009). MAPE: expected error in any single year's forecast.
						forecast size. • **Expected Error**: expect forecast to overestimate or underestimate return by 62% in any given year.
Stellako	56%	9.3%	0.42 (not significant)	significant	7.3%	• **Reliability**: Relationship between forecast and return is not statistically significant, thus returns vary at random relative to forecasts, making forecasts unreliable. • **Expected Error**: expect forecast to overestimate or underestimate return by 56% in any given year.
Late Summer						
Birkenhead	48%	17%	0.70 (not significant)	not significant	5.3%	• **Reliability**: Relationship between forecast and return is not statistically significant, thus returns vary at random relative to forecasts, making forecasts unreliable. • **Expected Error**: expect forecast to overestimate or underestimate return by 48% in any given year.
Cultus	92%	69%	1.0 (significant)	not significant	0.2%	• **Reliability**: Relationship between forecast and return is statistically significant, thus forecast is reliable. • **Precision**: Moderate/Large amount of inter-annual variation explained by forecasts (R^2= 0.69) • **Accuracy**: Slope is approximately one and intercept is not significantly different from zero, thus long-term accuracy is good. • **Expected Error**: expect forecast to overestimate or underestimate return by 92% in any given year.

Management Group (Indicator Stock)	MAPE	Error in Return Explained by Forecast (R^2)	Regression Slope (Return : Forecast)	Regression Intercept	MG Size relative to total Fraser Return	Interpretation Regression analysis: inferences about reliability, precision, and accuracy relate to long-term trends (1980-2009). MAPE: expected error in any single year's forecast.
Harrison	n/a	n/a	n/a	n/a	1.9%	Insufficient data for analyses
Late Shuswap	41%	81%	0.90 (significant)	not significant	18.2%	• **Reliability**: Relationship between forecast and return is statistically significant, thus forecast is reliable. • **Precision**: Large amount of inter-annual variation explained by forecasts (R^2= 0.81) • **Accuracy**: Slope is close to one and intercept is not significantly different from zero, thus long-term accuracy is good. • **Expected Error**: expect forecast to overestimate or underestimate return by 41% in any given year.
Portage	68%	11%	0.43 (not significant)	significant	0.6%	• **Reliability**: Relationship between forecast and return is not statistically significant, thus returns vary at random relative to forecasts, making forecasts unreliable. • **Expected Error**: expect forecast to overestimate or underestimate return by 68% in any given year.
Weaver	45%	14%	0.56 (significant)	not significant	5.5%	• **Reliability**: Relationship between forecast and return is statistically significant, thus forecast is reliable. • **Precision**: Low amount of inter-annual variation explained by forecasts (R^2= 0.14) • **Accuracy**: Slope departs from one and intercept is not significantly different from zero, thus long-term accuracy is good but large forecasts tend to underestimate returns. • **Expected Error**: expect forecast to overestimate or underestimate return by 45% in any given year.

Appendix I Methods of In-season Stock Assessment by the Pacific Salmon Commission.

Pacific Salmon Commission

600 - 1155 Robson Street
Vancouver, B.C.
V6E 1B5
(604) 684-8081
(604) 666-8707 (fax)

To: Mike Lapointe
From: Jim Cave
Date: December 7, 2010
Re: Methods of In-season Stock Assessment: Test fishing CPUE and catchability.

As requested, I am summarizing the methods for In-season Stock Assessment. These include run-reconstruction and run-size estimation based on test fishery catch-per-unit-effort, (CPUE) data and estimates of catchability. Note that I am not including catch estimation, stock identification or hydroacoustics methods as these are the subject of discussion in other documents.

Overview

Run-size estimation for Fraser River sockeye (by stock group) and pink salmon historically was based primarily on catch, effort, escapement and racial composition. Traditionally, most of these data for Summer and Late-runs come from commercial fisheries. However, limited commercial fishing in recent years has reduced the availability of this source of data. Test fishing catch and CPUE data are now used more extensively in assessing sockeye and pink salmon abundances than in previous years. These data are analyzed using a cumulative-normal model, which is described in previously published reports (PSC 1995, 1998). Since 2001, a Bayesian “Box-Car” or reconstruction-based model developed by Bill Gazey was employed. This model incorporated features of the cumulative-normal and cumulative-passage-to-date models, and implemented an objective method for combining the estimates from its component models based on the relative uncertainty of these models. This model has since been replaced by a Bayesian time and density model using Winbugs software, similar in concept to the Cumulative Normal model. This model incorporates historical information on run-size, timing, spread of the migration and test fishing expansion line (inverse of catchability, see below) in the form of prior probability distributions or "Priors" as well as in-season reconstructions of daily abundance and test fishing CPUE. Previously, a Cumulative Passage model had also been employed but this model has been discontinued as priors on timing and historical distributions make its use redundant in the current model. The models described previously (PSC 1995) that used exclusively commercial catch and effort data have also been discontinued, due primarily to the major changes in fishing pattern, levels of effort and irregularity of the fisheries which provide the source data for these models.

The Pacific Salmon Commission conducts "Panel Approved Test Fisheries" in the marine areas "inside" Vancouver Island and in the Fraser River below Mission to collect CPUE data and biological information on stock identification and species composition. Daily CPUE data in combination with the stock composition information and historical estimates of catchability (q) are used to project stock abundances from the marine test fisheries. Catchability or "q" is defined as the proportion of a population removed by a defined unit of effort and the "Expansion line" is the inverse of catchability (1/q). Daily CPUE data are multiplied by expansion lines to generate estimates of abundance in marine areas from test fisheries. The CPUE-based estimates are used until the stocks pass the Mission Hydroacoustics site 6 days later in the case of Early Stuart, Early Summer-run and Summer-run sockeye. During some years, Late-run sockeye (Weaver Creek and Harrison River sockeye) pass directly upstream, a phenomenon known as "Early Upstream Migration" (http://www.psc.org/pubs/LateRun/R-69_LateRunSockeyeConf_2009_final.pdf). In these situations the projected abundances from marine test fisheries are replaced with estimates from the Mission Hydroacoustics program 6-8 days later. However on the 2010 and 2011 cycle years, Late-run sockeye are dominated by Late Shuswap sockeye, the majority of which continue to delay in the Strait of Georgia. Therefore the assessment of run-size, timing and escapement to the Strait of Georgia are derived from the marine test fisheries. During these years, most of the escapement of Late-run stocks passes Mission too late to be used in assessments for the management of most fisheries although these data still form the best estimate of potential spawning escapement.

Marine Gillnet Test Fisheries

The gillnet test fisheries in marine Areas 12 and 20 provide biological and CPUE data to assess the abundance of Early Stuart, Early Summer and Summer-run stocks of Fraser River sockeye. An important component this assessment is of the historical performance of these test fisheries to provide an indicator of abundance: the assessment of expansion line (inverse of catchability q). Gillnet test fisheries in Area 20 commence approximately June 20 or on a later date (July 14 in 2007) if there are conservations concerns on Early Stuart. Gillnet test fisheries in Area 12 typically commence July 12.

The restructuring of the in-season run-size estimation towards Bayesian methods has resulted in a reexamination of historical estimates of catchability in the context of uncertainty. These analyses incorporate both retrospective and Bayesian hierarchical analyses, to determine the extent of gains to management from marine test fisheries as indicated by decreased uncertainty in run-size assessments. Bayesian hierarchical analyses are used to estimate the historic values for the expansion lines and the associated uncertainty. The hierarchical model structure allows to simultaneous estimation the annual expansion lines as well as the mean and variance around the mean (Figure I-1). Hierarchical analyses allow informative years to carry more weight than years with less information. The mean and variance can be used to predict the expansion line for a new year (e.g. 2010). The resulting probability distribution for the expansion line for that year can then be used as an informative prior in run-size models. Patterns in time varying catchability can be expressed as:

$qt = \alpha Nt\beta$ (Wilburg et al. 2010),

and as such, analyses were structured to investigate both density dependence (Figure I-2) and time varying catchability (Figure I-3).

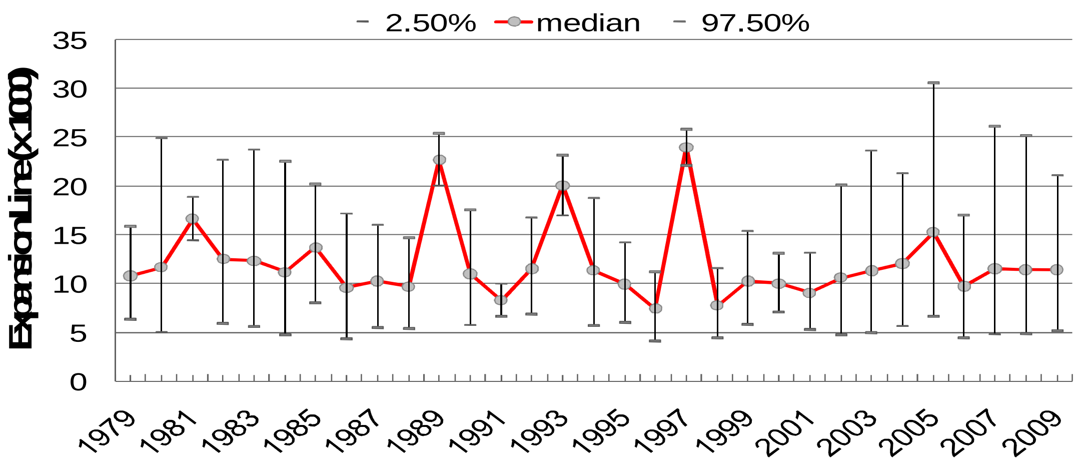


Figure I-1 Bayesian hierarchical analysis of the expansion line for Area 20 gillnet for the Early Stuart time period.

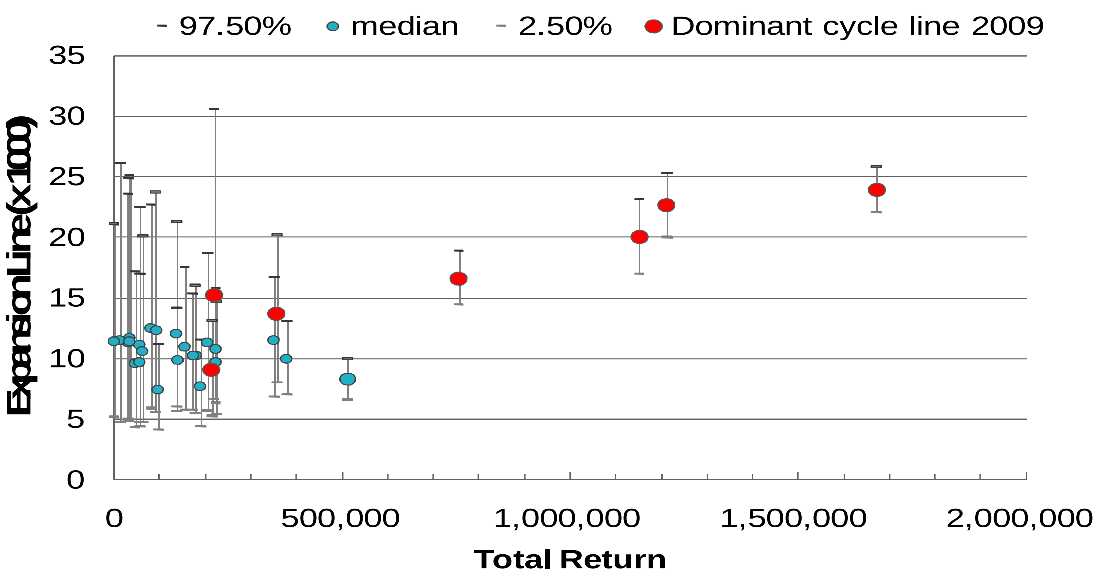


Figure I-2 Relationship between expansion line for Area 20 gillnet and total return for Early Stuart sockeye. The data indicate improved understanding of catchability by considering density dependent effects.

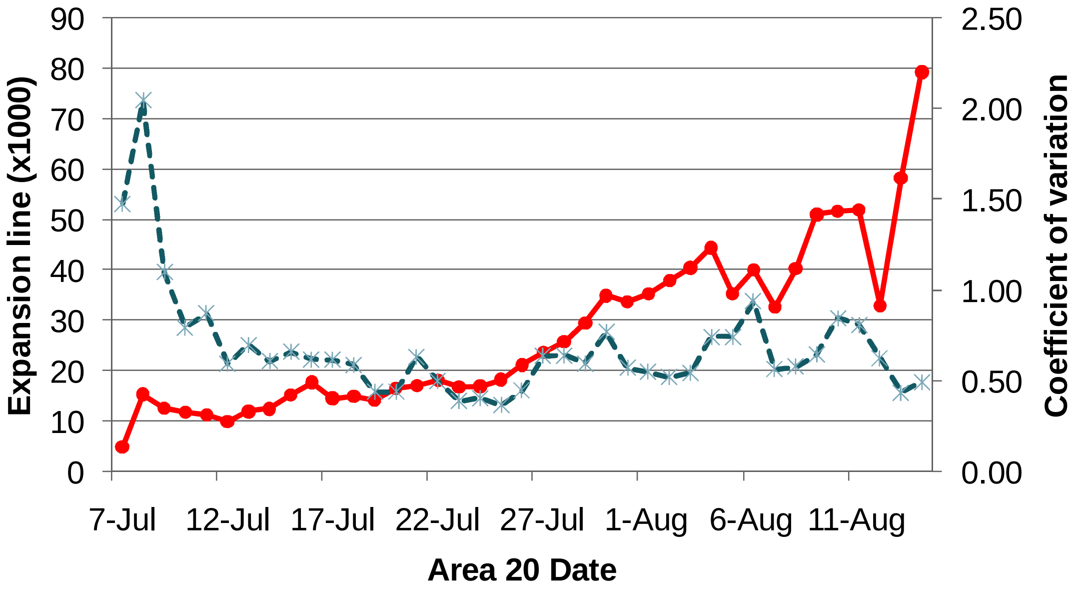


Figure I-3 Time series of mean expansion line for combined Area 12 and 20 gillnet (red circles) and coefficient of variation (blue dashed line) for the combined Early Stuart, Early Summer and Summer Run stock groups.

The predictive estimates of expansion lines for the marine gillnets are used to estimate abundance with uncertainty (Table I-1) for Early Stuart, Early Summer and Summer run sockeye. These projections of abundance are used in run-size models but are subsequently replaced at t+6 days with reconstructions of abundance from Mission hydroacoustic estimates and en-route catch. The predictive estimates are also used to project abundances entering the Fraser River, to assess potential catch and for the management of fisheries inside the assessment sites (Johnstone Strait, Juan de Fuca Strait, United States Panel Areas and in-river fisheries).

Table I-1 Mean and median values for gillnet expansion lines by period. The mean values were used in 2010. The upper and lower probability levels are estimated using Markov Chain Monte Carlo simulation in Winbugs.

	mean	median	sd	MC error	Lower 10% p Level	Upper 90% p Level
10-Jul	11.7	10	7.05	0.1	4.9	20.6
15-Jul	14.6	13	7.56	0.11	7.0	24.1
20-Jul	17.7	16	8.15	0.11	9.2	28.3
25-Jul	27.4	25	11.83	0.16	14.7	42.8
30-Jul	40.5	38	16.45	0.22	21.7	62.9
4-Aug	41.3	38	16.87	0.23	22.4	64.7
9-Aug	56.5	55	19.38	0.24	31.9	84.5

Marine Purse Seine Test Fisheries

The information from purse seine test fisheries became of increasing importance in the estimation of abundance beginning in 1995, with the restructuring and reduced frequency of the major commercial purse seine fisheries in Johnstone Straits and Area 20. These changes severely compromised the run-size models that utilized these data. As the seine test fisheries gained in importance, assessments were directed towards understanding the information gained from the data (Gazey 2001, 2002). [Seine test fisheries have been reviewed in 2003, (Cave: Analysis of the 2nd site purse seine test fishery at Sheringham Point; Cave 2003: Purse seine test fishing expansion factors; Tovey: Investigation of the Precision of CPUE and Catchability with Increased Purse Seine Test Fishing Effort in Area 20-1 in 2002).]

Gillnet test fisheries in Area 12 and 20 demonstrate similar catchability and are added together without adjustment to estimate the daily passage projected to reach Mission. However, the seine test fisheries show quite different efficiencies between Area 12 and 20, with catch-per-sets in Areas 12 and 13 being significantly greater for a given abundance than in Area 20. Because of this observation, historically catchability was assessed only for the approach for which the migration was dominant: either for the northern approach (through Area 12) on years of high diversion through Johnstone Strait or through for the southern approach (through Area 20) for years of low diversion through Johnstone Strait. The catchabilities derived in this manner would then be used to estimate the abundances through each approach uniquely. There still needed to be an assumption on what catchability to use for the “non-dominant” approach and circularity in the method is quite clear, as there would be an inherent calculation of annual diversion through Johnstone Strait (Diversion rate, D):

$$D_y = \frac{\sum CPUE_{12,y} / q_{12}}{\sum CPUE_{12,y} / q_{12} + \sum CPUE_{20,y} / q_{20}}$$

Where q12=0.005 and q20=0.002, as derived from other years when all the migration passed through one approach or the other. This method was used to estimate purse seine expansion lines through 2008 (Table I-2) although, the circularity is an obvious weakness.

Table I-2 Mean values for purse seine expansion lines by period. The expansion lines in use in 2009 are in red.

Year	J.S. Div	Area 20 Summer	Area 20 Late	Area 12 Summer	Area 12 Late	Area 13 Summer	Area 13 Late
1995	50%	612				245	
1997	77%			148	101	124	80
1998	78%	736	824	294	330	223	204
1999	50%	524	412	210	165	141	113
2000	36%	473	952	188	381	72	60
2001	20%	565	727	226	291	244	469
2002 SB	51%	602	647	241	259	203	216
2003 SB	65%	596	563	223	223	176	150
2004 SB	59%	754	318	262	161	262	161
Used '04	59%	587	587	219	252	179	184
2005 SB	70%	575	1367	245	560	162	261
Used '05	70%	596	563	223	223	176	150
2006 SB	61%	460	313	182	128	140	60
Used '06	61%	540	541	225	244	179	171
2007 SB	45%	396	498	149	194	166	170
Used '07		540	541	225	244	176	171
2008 SB	10%	442	527	138	210	363	87
Used '08		540	541	225	244	179	171
Mean		561	650	209	250	194	169
Subset of years:		477	496	182	198	188	180
Use '09		486		190		184	

As with gillnet information, the restructuring of the in-season run-size estimation towards Bayesian methods resulted in a reexamination of the historical assessment of purse seine catchability in the context of uncertainty, incorporating both retrospective and Bayesian hierarchical analyses (Michielsens 2010). To circumvent the circularity in the previous method, we considered using an approach that incorporated the geography of the test fishing locations:

$$N_{Tot} = N_{12} + N_{20}$$

$$N_{Tot} = \sum CPUE_{d,12} / q_{12} + \sum CPUE_{d,20} / q_{20}$$

Data

2 Estimated parameters

$q_{20} = x\, q_{12}$ Simplify the problem by relating the catchability of the two fisheries

The test fishing sites are in narrower locations in Area 12 (3.6 km or 9 inside seine net lengths Figure I-4), resulting in fish being more concentrated in those areas than in Area 20 (11.1 km or 20 west coast seine net lengths, Figure I-5). As such we used a ratio (20 net lengths/9 net lengths or 2.2) as an informed scalar to relate catchability to the area swept:

$$q_{20} \cdot Area\ Swept_{20} = q_{12} \cdot Area\ Swept_{12}$$

$$q_{20} = q_{12} \cdot \frac{Area\ Swept_{12}}{Area\ Swept_{20}} = \frac{9}{20.2} q_{12} = \frac{1}{2.2} q_{12}$$

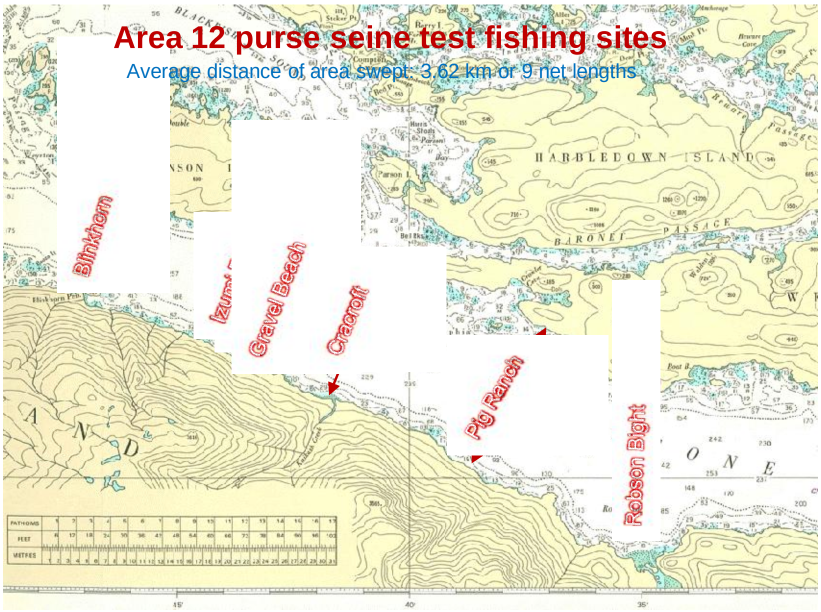


Figure I-4 Map of test fishing locations in Area 12. The average distance of the area swept is 3.6 km or 9 net lengths.

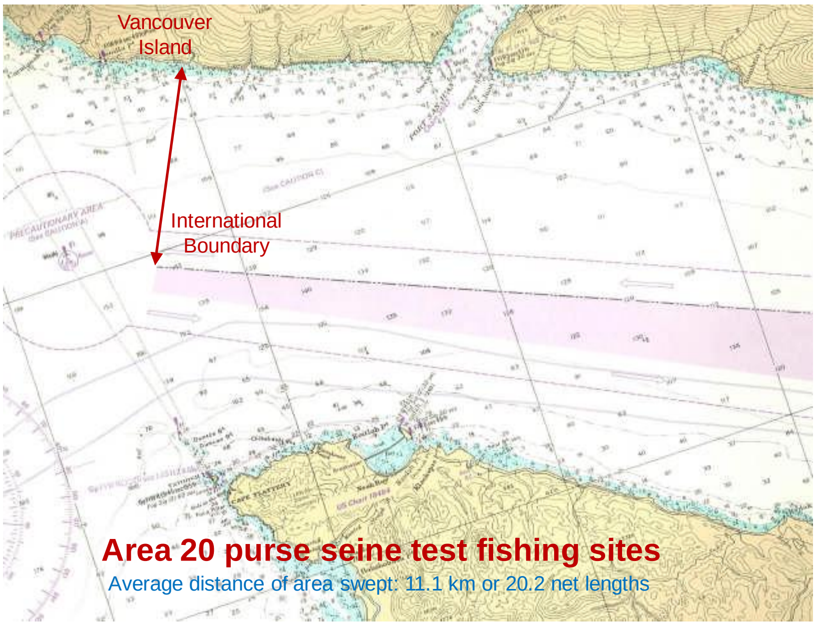


Figure I-5 Map of test fishing locations in Area 20. The average distance of the area swept is 11.1 km or 20 net lengths.

In the approach above, we accounted for observation error in the catch-per-set data and a Bayesian hierarchical model was used to simultaneously estimate the catchability for each year and the mean and the variance around the mean across the years. The posterior predictive distribution predicts the catchability in a new sampling year based on the mean and variance:

$$N_{Tot} = \sum CPUE_{d,12} / q_{12} + \sum CPUE_{d,20} / q_{20}$$
$$N_{Tot} = \sum CPUE_{d,12} / q_{12} + 2.2 \sum CPUE_{d,20} / q_{12}$$
$$q_{12} = \left(\sum CPUE_{d,12} + 2.2 \sum CPUE_{d,20} \right) / N_{Tot}$$

The mean Area 12 Expansion line was 180 with a coefficient of variation of 0.30. These served as priors to the Bayesian in-season run-size estimation model for summer run sockeye in 2010.

An extensive retrospective analysis was completed to evaluate the contribution of the purse seine test fishery data in the in-season Bayesian cumulative normal model. Specifically, we examined the extent of gains to management from marine test fisheries as indicated by decreased uncertainty in run-size assessments. We found that the use of seine test fishery data for in-season stock assessment improves the performance of models over those that use exclusively Mission-based reconstructions. The improvements in performance are even greater when the yearly variability in the catchability is accounted for instead of assuming a constant catchability across the years.

A reexamination of the historical Late-run expansion lines to be used for 2010 indicated an Area 12 line of 233 with a CV of 0.27 and an Area 20 line of 522 and a CV of 0.27. These served as priors to the Bayesian in-season run-size estimation model for Late-run sockeye in 2010 that includes covariation in catchability in Area 20 and Area 12.

Fraser River Gillnet Test Fishing

Gillnet test fisheries are operated in the Fraser River at Cottonwood, Whonnock and Mission. These test fisheries are primarily for the collection of biological information and catch by species for the assessment of species composition. Whonnock and Cottonwood are occasionally used to estimate the upstream passage of sockeye during 1) the Early Stuart time period if the salmon abundance in the river is too low and variable to justify the Mission Hydroacoustics program and 2) during the pink migration in September during odd-years in September when sockeye are caught in low but disproportionate numbers relative to pink salmon. Since the mid-1990's the test fisheries have been severely impacted by predation on catches by harbour seals. Some mitigation of the predation and interference by seals has been achieved through the use of an experimental pulsed, low-voltage DC electric gradient. (Forrest et al. 2009).

The multi-panel, variable-mesh net used at Whonnock is designed to be non-selective to catch all species of salmon and to provide estimates of the proportion of sockeye in the salmon migration. These sockeye proportions are multiplied by the estimates of total salmon obtained from the Mission hydroacoustics site to generate sockeye abundance estimates. Ideally only fish that gilled and girthed (as opposed to tangled) by the gillnet are used in the calculation. However if catches are quite low, or there are other concerns about possible bias, the total catch (not just gilled and girthed) might be used in the calculation. Of particular concern is the transition period during increasing dominance of pink salmon passing Mission. During this period, the proportion of sockeye based on the Whonnock test fishery demonstrate high bias and estimates from outside seine test fisheries may be applied to the daily passage at Mission with an 8 day lag. More recently we are examining data from a test gillnet and set net fishery at Mission using First Nations gear. Preliminary assessment of the data from this test fishery is showing promise.

Gulf Troll Test Fishing

Troll test fisheries are operated in the lower Strait of Georgia near the mouth of the Fraser River (Area 29, sub-areas 1-4 and 6) on Late-run sockeye when Late Shuswap sockeye predominate (cycle years 2010-2011). The study area for the survey is divided into 6 areas or quadrants. Two commercial troll vessels were chartered for the survey and each vessel fished one quadrant per day over 3 days to complete the survey. The summed, weighted CPUE data and historical estimates of catchability (q) are used to project Late-run abundance in the Gulf (*Memo to Jim Woodey from Jim Cave. November 7, 1997. Review of Area 29 Troll Test Fishing*). This model has since been refined with a Bayesian regression model using Winbugs software.

Appendix J The Hydroacoustics program of the Pacific Salmon Commission

Pacific Salmon Commission

600 - 1155 Robson Street
Vancouver, B.C.
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(604) 684-8081
(604) 666-8707 (fax)

To: Mike Lapointe
From: Jim Cave
Date: December 7, 2010
Re: The Hydroacoustics program of the Pacific Salmon Commission

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Hydroacoustic programs have been conducted on the Fraser River at Mission BC by the International Pacific Salmon Fisheries Commission (1977-1985) and the Pacific Salmon Commission (PSC; 1986 to the present) to assess the upstream passage of Fraser River sockeye salmon. The estimates of daily salmon passage provided by the hydroacoustics program, combined with information from test fishery, stock identification, and catch monitoring programs are used in models to provide estimates of stock size, timing, and escapement that are vital to the in-season management of Fraser River sockeye and pink salmon (Woodey 1987). Originally developed using single-beam hydroacoustics technology, the program continues to develop by using new split-beam and multi beam imaging sonar systems.

Following years of discrepancies between Mission estimates and arrivals at spawning areas, the hydroacoustics program has been the subject of several public reviews and inquiries (Pearce and Larkin 1992; Fraser River Sockeye Public Review Board (FRSPRB), 1995, Fraser River Panel Internal Review 1998; Williams Review 2005) as part of broader investigations to determine the causes of discrepancies. In response to recommendations by the Mission Hydroacoustic Facility Working Group (1994), PSC and DFO formed a joint research program to examine various assumptions about fish behaviour associated with the single-beam abundance-estimation model (Banneheka et al. 1995). The quantitative results from these studies answered key questions and resulted in the development of a new estimation model (Xie et al, 1997, and Xie et al, 2002, Xie 2002). From these findings, the PSC-DFO Hydroacoustic working group concluded that a split-beam sonar system would be a more reliable and robust estimator for estimating salmon passage at the Mission site.

From 1999-2002, a Phase 2 study demonstrated that the split-beam technology and estimation model could be implemented at the site. In 2003, the split-beam estimator was first put into operational phase during the field season to test the ability of the system to provide real-time information for in-season management. The results were satisfactory and, the Fraser River Panel approved the implementation of the split-beam system as the primary estimator of abundance for the in-season management of Fraser River sockeye in 2004. A major change to the sample methods was associated with the change in technology; in addition to a transecting vessel, a fixed shore based sampling platform was established on the south bank.

In 2004-2005, the Southern Boundary Restoration & Enhancement Fund (SEF) provided funding for a project to investigate the use of Dual-Frequency Identification Sonar (DIDSON) to examine fish behaviour in the Fraser River. This project verified many of the assumptions of, and estimates of daily salmon flux by the current split-beam estimator (described in detail in Xie et al 2005). It also indicated that DIDSON technologies could provide reliable estimates of daily salmon passage in near-shore areas of the river. Finally, since 2005, a stationary split-beam system similar to that on the south bank was developed and implemented on the north bank.

Due to the large sampling fractions, precision of estimates is already very high (Banneheka et al. 1995; Xie et al. 2005). However, two sources of potential bias remain in the estimation of sockeye daily abundance: (1) the mobile portion of the estimator, as it relies on the statistics of fish behaviour from the shore-based split beam systems and is also subject to possible negative bias as a result of salmon avoiding the transecting vessel; (2) Estimation of species composition of the salmon migration upstream.

In March 2006 the PSC sponsored a workshop on the application of hydroacoustics for salmon management (PSC 2007). This workshop was part of an initiative sponsored by the SEF Committee which had requested that a group be formed to develop a Stock Assessment Framework for Fraser River sockeye in 2006.

An SEF project was secured in 2007 to investigate a spatial sub-sampling method to survey offshore fish flux by using stationary acoustic systems. This feasibility study (2008-2010) was designed to assess a sampling approach to replace the current mobile survey approach. These systems were deployed in a stationary fashion at three locations across the river channel to monitor the upstream salmon migration, providing temporal and spatial measurements of offshore fish flux across the river. The direct measurements of fish migration in these locations were used as inputs to a spatial statistical model to estimate fish flux in offshore areas that are not sampled by the stationary system. In comparison with the current mobile estimator, the spatial sampling of fish flux across the entire river cross-section was sacrificed in order to achieve gains in direct measurements of fish flux in areas sampled by the stationary acoustic survey systems launched from these locations across the river. These measurements of flux are considered to be much more accurate and robust than obtained by the current mobile transect program. With this more robust spatial-statistical model, more accurate estimation of salmon flux for the entire offshore area would be achieved by extrapolating flux values from directly surveyed areas to the un-sampled areas, thus improving the accuracy of in-season estimates of daily abundance. Analyses of the data collected in the 2008 and 2009 seasons are completed with a detailed report to SEF (http://fund.psc.org/2008/Reports/SF_2008_I_30_Xie.pdf). The analysis of data collected in the 2010 season is on-going and a detailed report of findings is unavailable at this time.

Appendix K Cultus Lake Sockeye recovery actions that have and have not been implemented by the Cultus Sockeye Recovery Team (2009).

Table K-1 Summary of actions to recover the Cultus sockeye population that are already completed or under way (reproduced from CSRT 2009).

Conservation action	Comments	Partners
Captive brood stock program for 2000-07 brood years. Lake stocking using fry/smolts surplus to the captive broodstock program, 2003-09	Hatchery fry releases increased number of hatchery adults returning to spawn. Majority of adults returning in 2008 and 2009 were hatchery fish (DFO 2010). Knowledge gap. Reproductive success of hatchery fish given apparent brood failure in 2008 when >90% of adult spawners were hatchery fish.	DFO
Identify causes of early migration and high mortality	Competing hypotheses include (i) increasing abundance of Summer-run relative to Late-runs through the 1990's resulted in more Late-run sockeye entering the Fraser River with little or no delay during periods when Summer-run sockeye were abundant, and (ii) early entry is linked to changes in coastal waters (e.g. temperature or salinity) or fish physiology (e.g. maturity, osmoregulatory function, fish health). Accumulated exposure to elevated temperatures experience by early migration	DFO; UBC; PSC

Conservation action	Comments	Partners
	increases rate and severity of Parvicapsula infection, which increases en-route and pre-spawn mortality.	
Identify factors affecting salmon habitat. Improve freshwater survival of 2004 and 2005 broods by removing watermilfoil. Identify imminent risks from habitat destruction, pollution affecting each life stage. Identify the role and contribution of sockeye to the Cultus Lake ecosystem.	Study relating possible link between draw on Columbia Valley aquifer and spawning habitat. Littoral zone has been mapped to identify possible spawning habitat and areas needing watermilfoil control. Watermilfoil removal in 2006; similar efforts in 1990s were unsuccessful. Water quality and groundwater assessments.	DFO; Cultus Lake Park Board; B.C Parks; Lindell Beach Residents' Association
Improve freshwater survival of 2004 and 2005 broods by removing predators. Develop an integrated water milfoil, predator control project.	Northern Pikeminnow population assessment. Northern Pikeminnow removal programs include trapping, angling, derbies, seine net. Removal of predators from Lake coincides with in-lake survival of juvenile sockeye (DFO 2010). Since 2004, hatchery fry have been released into Cultus Lake away for the shore to avoid near-shore predators.	DFO; Fraser Valley Salmon Society
Determine the effects of Salmincola on marine survival.	Ongoing study: Although action has been taken to monitor infection rates in Cultus Lake and to treat	DFO; Vancouver Aquarium Marine

Conservation action	Comments	Partners
	hatchery fish, wild smolts are not being disinfected because (i) the disinfection process kills about 10% of treated fish, and (ii) action is postponed until the Salmincola parasite is proven to threaten marine survival and migration timing.	Science Centre
Control harvest to achieve 1,000/500 objective. Control fishery harvest to levels that permit generational growth. Develop sustainable harvest rules and escapement policies that are consistent with Team goals and objectives and explicitly address uncertainties.	2000-09 harvest rates reduced to an average of 20% for late-run complex of stocks (DFO 2010).	DFO; Pacific Salmon Commission
Eliminate activities that cause migratory delay in Sweltzer Creek. Promote stewardship and improve public awareness.	Sweltzer Creek is patrolled at least twice weekly identify and eliminate sources of migratory delay; adults migrate through Sweltzer Creek at a time of heavy recreational use. Brochures and notices have been disseminated. Permanent information kiosks erected around Cultus Lake.	DFO; Soowahlie Band

Table K-2 Summary of actions to recover the Cultus sockeye population that have been proposed but not pursued by the Cultus Sockeye Recovery Team (reproduced from CSRT 2009).

Conservation actions not taken	Anticipated outcome
Focused enforcement where the population most at risk.	Increased number of successful spawners.
Identify imminent risks from habitat destruction, pollution affecting each life stage.	Improved survival at all lifestages.
Identify and eliminate risk from marine mammal predation.	Increased number of adults through Sweltzer fence.
Develop an integrated watermilfoil, predator control project.	Maintain larger fry and smolt populations established by conservation actions such as watermilfoil and predator removal programs. Past efforts to remove water milfoil from Cultus Lake were unsuccessful.
Focused enforcement to reduce the threat of poaching.	Increased number of successful spawners.
Mitigate effects on habitat.	Improved survival at all life stages.
Identify the adult migration timing of Cultus relative to other Fraser Late-run sockeye.	Improved understanding of the stock-recruitment relationship may change approaches to recovery.
Identify the role and contribution of sockeye the Cultus Lake ecosystem.	Improved long-term population goal.

Appendix L Supplemental information for Bristol Bay sockeye fishery.

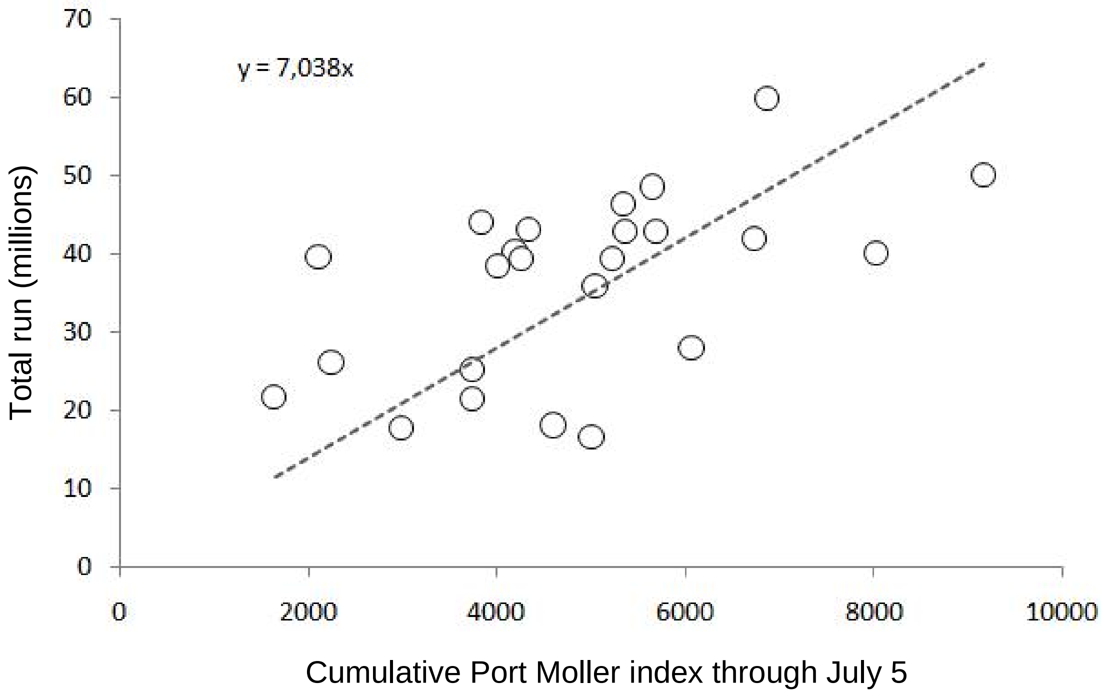

Figure L-1 Total run versus the cumulative Port Moller index through July 5 (accumulation begins on June 11) in each year (1987-2010). The dotted line depicts the best-fit regression line with zero intercept; the equation parameter, 7,038, represents the average fish per index (FPI) for this date across years.

Table L-1 Catch and escapement of sockeye for streams in Bristol Bay Alaska (1970-2010).

Year	Type	Alagnak	Egegik	Igushik	Kvichak	Naknek	Nushagak	Togiak	Ugashik	Wood	Total
1970	Catch	229,570	1,403,509	245,607	16,581,224	993,011		152,748	171,541	644,082	20,421,292
1970	Escapement	177,060	919,734	370,920	13,935,306	732,502		202,896	735,024	1,161,964	18,235,406
1970	Inshore Run	406,630	2,323,243	616,527	30,516,530	1,725,513		355,644	906,565	1,806,046	38,656,698
1971	Catch	321,781	1,306,682	227,835	3,764,861	1,770,736		200,507	954,068	755,300	9,301,770
1971	Escapement	187,302	634,014	210,960	2,387,392	935,754		200,242	529,752	851,202	5,936,618
1971	Inshore Run	509,083	1,940,696	438,795	6,152,253	2,706,490		400,749	1,483,820	1,606,502	15,238,388
1972	Catch	31,913	839,820	57,445	342,150	728,302		51,354	17,440	287,257	2,355,681
1972	Escapement	151,188	546,402	60,018	1,009,962	586,518		78,570	79,428	430,602	2,942,688
1972	Inshore Run	183,101	1,386,222	117,463	1,352,112	1,314,820		129,924	96,868	717,859	5,298,369
1973	Catch	2,096	221,337	28,030	21,791	144,362		75,694	3,920	148,161	645,391
1973	Escapement	35,280	328,842	59,508	226,554	356,676		106,930	38,988	330,474	1,483,252
1973	Inshore Run	37,376	550,179	87,538	248,345	501,038		182,624	42,908	478,635	2,128,643
1974	Catch	10,072	172,253	83,528	148,595	379,496		110,932	2,151	390,371	1,297,398
1974	Escapement	214,848	1,275,630	358,752	4,433,844	1,241,058		103,592	61,854	1,708,836	9,398,414
1974	Inshore Run	224,920	1,447,883	442,280	4,582,439	1,620,554		214,524	64,005	2,099,207	10,695,812
1975	Catch	13,279	964,024	78,060	1,605,407	1,466,730		184,856	14,558	369,456	4,696,370
1975	Escapement	100,480	1,173,840	241,086	13,140,450	2,026,686		180,562	429,336	1,270,116	18,562,556
1975	Inshore Run	113,759	2,137,864	319,146	14,745,857	3,493,416		365,418	443,894	1,639,572	23,258,926
1976	Catch	55,396	1,329,788	159,100	1,458,180	1,033,700		293,016	174,923	621,255	5,125,358
1976	Escapement	81,822	509,160	186,120	1,965,282	1,320,750		189,390	356,308	817,008	5,425,840
1976	Inshore Run	137,218	1,838,948	345,220	3,423,462	2,354,450		482,406	531,231	1,438,263	10,551,198
1977	Catch	50,134	1,780,567	50,529	739,464	1,377,616		201,004	92,623	272,383	4,564,320
1977	Escapement	100,000	692,514	95,970	1,341,144	1,085,856		162,534	201,520	561,828	4,241,366
1977	Inshore Run	150,134	2,473,081	146,499	2,080,608	2,463,472		363,538	294,143	834,211	8,805,686
1978	Catch	225,653	1,207,294	547,916	3,815,636	1,082,379		422,100	7,995	1,849,389	9,158,362
1978	Escapement	229,400	895,698	536,154	4,149,288	813,378		306,176	82,435	2,267,238	9,279,767
1978	Inshore Run	455,053	2,102,992	1,084,070	7,964,924	1,895,757		728,276	90,430	4,116,627	18,438,129
1979	Catch	278,934	2,257,332	982,573	13,418,829	1,294,063		393,337	391,118	1,931,200	20,947,386
1979	Escapement	294,200	1,032,042	859,560	11,218,434	925,362		198,238	1,706,904	1,706,352	17,941,092
1979	Inshore Run	573,134	3,289,374	1,842,133	24,637,263	2,219,425		591,575	2,098,022	3,637,552	38,888,478
1980	Catch	262,997	2,623,066	1,138,391	12,743,074	2,114,386		591,470	885,875	1,559,849	21,919,108
1980	Escapement	297,900	1,060,860	1,987,530	22,505,268	2,644,698		526,750	3,335,284	2,969,040	35,327,330
1980	Inshore Run	560,897	3,683,926	3,125,921	35,248,342	4,759,084		1,118,220	4,221,159	4,528,889	57,246,438
1981	Catch	228,411	4,361,406	1,637,749	5,234,733	5,529,665		620,288	2,116,066	3,334,348	23,062,666
1981	Escapement	82,210	694,680	591,144	1,754,358	1,796,220		307,130	1,327,699	1,233,318	7,786,759
1981	Inshore Run	310,621	5,056,086	2,228,893	6,989,091	7,325,885		927,418	3,443,765	4,567,666	30,849,425
1982	Catch	532,854	2,447,514	1,394,087	1,858,475	2,614,473	486,762	581,718	1,139,192	2,494,366	13,549,441
1982	Escapement	239,300	1,034,628	423,768	1,134,840	1,155,552	63,000	288,674	1,185,551	976,470	6,501,783
1982	Inshore Run	772,154	3,482,142	1,817,855	2,993,315	3,770,025	549,762	870,392	2,324,743	3,470,836	20,051,224
1983	Catch	461,075	6,755,256	632,333	16,534,901	4,563,396	515,546	529,776	3,349,451	2,911,291	36,253,025
1983	Escapement	96,220	792,282	180,438	3,569,982	888,294	85,400	212,640	1,001,364	1,360,968	8,187,588
1983	Inshore Run	557,295	7,547,538	812,771	20,104,883	5,451,690	600,946	742,416	4,350,815	4,272,259	44,440,613
1984	Catch	339,313	5,190,413	250,066	12,523,803	1,683,594	330,267	213,213	2,658,376	978,736	24,167,781
1984	Escapement	215,370	1,165,345	184,872	10,490,670	1,242,474	120,276	150,978	1,270,318	1,002,792	15,843,095
1984	Inshore Run	554,683	6,355,758	434,938	23,014,473	2,926,068	450,543	364,191	3,928,694	1,981,528	40,010,876
1985	Catch	146,469	7,537,273	247,531	6,183,103	1,849,521	138,591	133,263	6,468,862	654,232	23,358,845
1985	Escapement	118,030	1,095,192	212,454	7,211,046	1,849,938	69,300	153,482	1,006,407	939,000	12,654,849
1985	Inshore Run	264,499	8,632,465	459,985	13,394,149	3,699,459	207,891	286,745	7,475,269	1,593,232	36,013,694
1986	Catch	168,482	4,852,935	569,007	787,303	1,936,386	256,910	191,158	5,002,949	953,672	14,718,802
1986	Escapement	230,180	1,152,180	307,728	1,179,322	1,977,645	168,340	203,384	1,015,582	818,652	7,053,013
1986	Inshore Run	398,662	6,005,115	876,735	1,966,625	3,914,031	425,250	394,542	6,018,531	1,772,324	21,771,815
1987	Catch	142,591	5,356,669	447,382	3,526,824	1,316,587	891,184	274,613	2,128,652	1,490,457	15,574,959
1987	Escapement	154,210	1,273,553	169,236	6,065,880	1,061,806	225,034	278,276	686,894	1,337,172	11,252,061
1987	Inshore Run	296,801	6,630,222	616,618	9,592,704	2,378,393	1,116,218	552,889	2,815,546	2,827,629	26,827,020
1988	Catch	124,968	6,456,598	235,470	2,654,364	701,504	260,412	673,408	1,523,520	882,321	13,512,565
1988	Escapement	194,630	1,612,745	170,454	4,065,216	1,037,862	163,208	309,012	654,412	866,778	9,074,317
1988	Inshore Run	319,598	8,069,343	405,924	6,719,580	1,739,366	423,620	982,420	2,177,932	1,749,099	22,586,882
1989	Catch	336,918	8,901,994	752,320	11,456,509	2,016,529	703,109	68,375	3,146,239	1,332,756	28,714,749
1989	Escapement	196,760	1,611,566	461,610	8,317,500	1,161,984	513,421	104,240	1,713,287	1,186,410	15,266,778
1989	Inshore Run	533,678	10,513,560	1,213,930	19,774,009	3,178,513	1,216,530	172,615	4,859,526	2,519,166	43,981,527
1990	Catch	386,173	10,371,762	914,544	10,551,217	6,334,834	1,076,994	168,012	2,149,009	1,541,005	33,493,550
1990	Escapement	168,760	2,191,582	365,802	6,970,020	2,092,578	680,368	166,297	749,478	1,069,440	14,454,325
1990	Inshore Run	554,933	12,563,344	1,280,346	17,521,237	8,427,412	1,757,362	334,309	2,898,487	2,610,445	47,947,875

Table L-2 Current sockeye stock assessment activities and uses in Bristol Bay Alaska. Table was reproduced from Clark (2005).

Project/Activity	Pre-Season Forecasts	In-Season Management	Post-Season Assessment
Total Escapement Assessment (Ugashik, Egegik, Naknek, Branch, Kvichak, Igushik, Wood, Nuyakuk, and Togiak Towers and Nushagak Sonar projects)	Historic annual data used	Daily counts and cumulative counts used to estimate run timing and strength	Annual total data used
Escapement Age Composition (Ugashik, Egegik, Naknek, Branch, Kvichak, Igushik, Wood, Nuyakuk, and Togiak Tower and Nushagak Sonar projects)	Historic annual data used	Data used for assessment of pre-season forecast accuracy and for in-season assignment of catch to stock of origin	Data used for brood tables and for catch allocations
Inside Test Fishing and Aerial Surveys (Ugashik, Egegik, Naknek-Kvichak, and Igushik test fish projects)	Not used	Used to estimate number of fish above district but below tower	Not used
Outside Test Fishing (Port Moller)	Not used	Used to estimate number of fish that have not yet reached Bristol Bay	Not used
Catch Data (daily reports and yearend fish tickets) (Ugashik, Egegik, Naknek-Kvichak, Nushagak, and Togiak fishing districts)	Historic annual data used	Used to estimate run timing and strength by district	Annual total data used
Catch Age Composition (Ugashik, Egegik, Naknek-Kvichak, Nushagak, and Togiak fishing districts)	Historic annual data used	Data used for assessment of pre-season forecast accuracy and for in-season assignment of catch to stock of origin	Data used for brood tables and for catch allocations
Smolt Enumeration (Kvichak, Naknek, Egegik, Ugashik, Wood, and Nuyakuk)	Historic annual data used at times	Not used	Not used, but have potential for escapement goals

Table L-3 Performance criteria of pre-season forecasts by river system and year for sockeye stocks in Bristol Bay, Alaska from 1990 to 2010. Table values represent forecasted run minus observed run (return) expressed as a percent of observed run; thus, positive values reflect years and stocks when the run came in under forecast. MPE and MAPE represent the median percent error and median absolute error across years. The R^2, intercept, and slope values were based on the best-fit linear regression line of observed run versus forecasted run (data were $\log_{10}$ transformed). P-values for regression parameters are given in parentheses.

Year	Alagnak	Egegik	Igushik	Kvichak	Naknek	Nushagak	Togiak	Ugashik	Wood	All Systems
1990	109	-13	-7	86	119	31	-27	27	96	73
1991	8	45	94	-3	54	17	-42	49	291	27
1992	52	17	25	-20	3	-17	6	-11	8	11
1993	35	5	2	-27	27	68	41	40	46	14
1994	-39	-11	-16	17	-29	21	-27	16	-18	-12
1995	10	0	36	3	-37	25	-48	28	58	3
1996	-35	-24	-18	-63	39	2	31	51	10	-22
1997	-38	-50	-55	-77	-62	-61	-36	-1	-74	-48
1998	-51	-53	-43	-65	-31	3	-5	21	-49	-43
1999	140	160	74	6	30	166	9	71	107	52
2000	-6	-53	45	-71	-14	65	90	54	7	-21
2001	-51	-41	134	-51	136	-20	31	-25	3	-11
2002	22	5	24	-63	26	53	-8	-4	-66	1
2003	-54	-21	112	-36	30	360	51	28	21	6
2004	2	-2	-41	-42	-18	46	17	29	-54	-8
2005	-8	-17	43	19	107	7	119	-13	191	18
2006	-6	1	50	196	-26	-4	60	136	69	29
2007	-15	81	83	9	54	110	45	11	47	29
2008	7	-55	15	58	-21	78	-13	-26	140	0
2009	31	62	12	5	-6	23	8	42	-59	17
2010	-46	6	-17	140	-23	43	-8	23	-36	0
MPE	-6	-2	24	-3	3	25	8	27	10	3
MAPE	35	21	41	42	30	31	31	27	54	17
R2	0.32	0.19	0.14	0.69	0.13	0.82	0.53	0.34	0.00	0.44
Intercept	3476837 (0.155)	1765152 (0.101)	379916 (0.051)	-144981 (0.925)	2750987 (0.084)	201090 (0.467)	-205492 (0.586)	1473992 (0.214)	1259667 (0.01)	10047491 (0.18)
Slope	0.62 (0.008)	0.51 (0.046)	0.53 (0.101)	1 (0)	0.52 (0.104)	1 (0)	1 (0)	0.86 (0.005)	0.09 (0.807)	0.75 (0.001)

Table L-4 Summary of current escapement goals and recommended escapement goals for sockeye stocks in Bristol Bay, 2009. Reproduced from Baker et al. (2009).

	Current Escapement Goal				Recommended Escapement Goal		
System	Goal	Type	Year Adopted	Escapement Data	Action	Goal	Type
Sockeye Salmon							
Ugashik	500,000-1,200,000	SEG	1995; Changed to SEG in 2006	Tower	No Change		
Egegik	800,000-1,400,000	SEG	1995; Changed to SEG in 2006	Tower	No Change		
Naknek	800,000-1,400,000	SEG	1984; Changed to SEG in 2006	Tower	No Change		
Kvichak (off-cycle)	2,000,000-10,000,000	SEG	1997; Changed to SEG in 2006	Tower	Change to single goal	2,000,000-10,000,000	SEG
Kvichak (pre, peak)	6,000,000-10,000,000	SEG	1997; Changed to SEG in 2006	Tower	Change to single goal	2,000,000-10,000,000	SEG
Alagnak	320,000 minumim	SEG	2006	Tower	No Change		
Wood	700,000-1,500,000	SEG	2000; Changed to SEG in 2006	Tower	No Change		
Nushagak	340,000-760,000	SEG	1997; Changed to SEG in 2006	Sonar	No Change		
Igushik	150,000-300,000	SEG	2000; Changed to SEG in 2006	Tower	No Change		
Togiak	120,000-270,000	BEG	1997	Tower	Change to SEG	120,000-270,000	SEG
Kulukuk Bay	8,000 minimum	SEG	2006	Aerial	No Change		

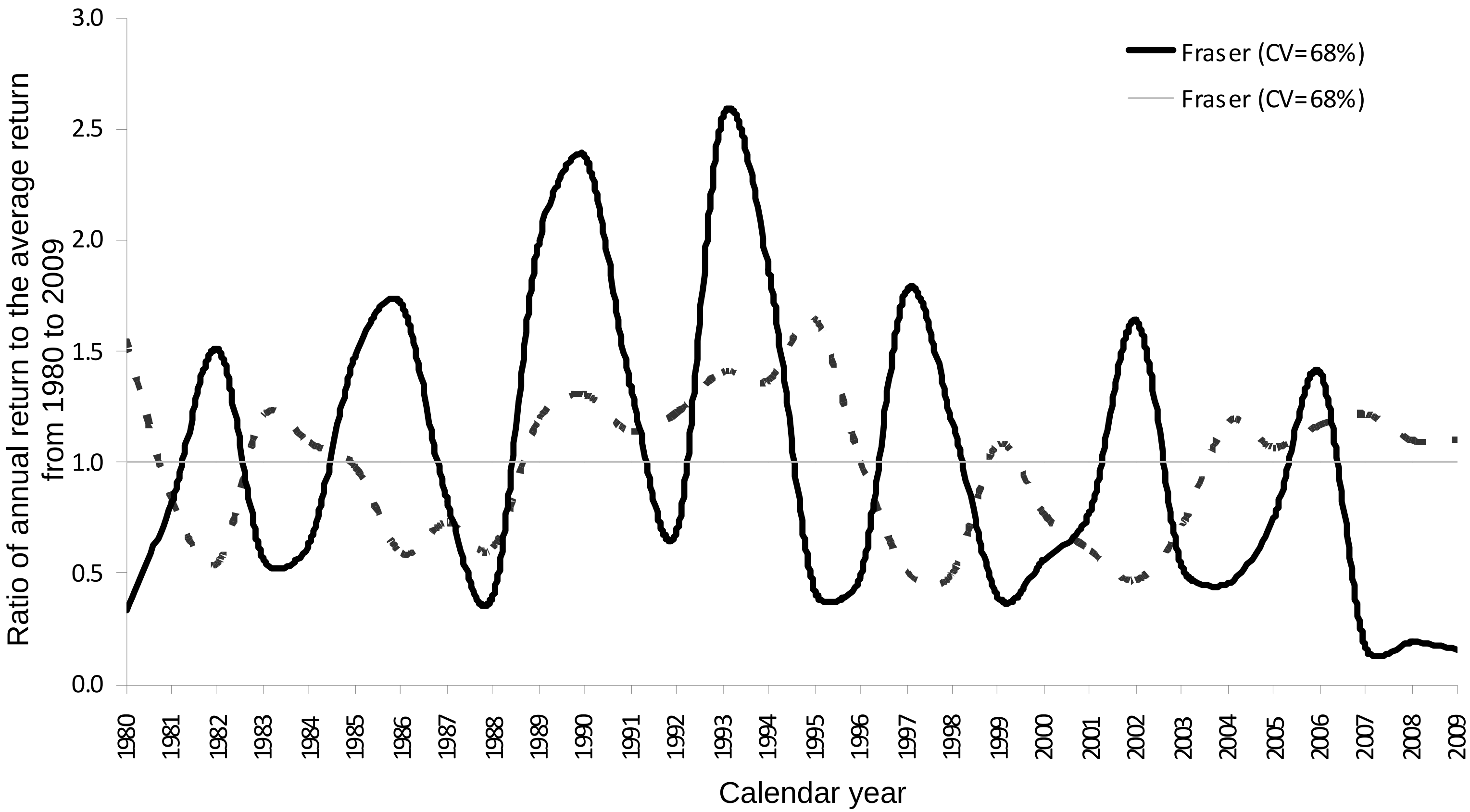

Figure L-2 Variability in annual returns for sockeye (all stocks combined) from the Fraser River, B.C. and Bristol Bay, Alaska. The coefficient of variation (CV) in annual returns observed for this time period is reported for each system.

Table L-5 Current sockeye stock assessment activities and uses in Bristol Bay, Alaska. Table was reproduced from Clark (2005).

Project/Activity	Pre-Season Forecasts	In-Season Management	Post-Season Assessment
Total Escapement Assessment (Ugashik, Egegik, Naknek, Branch, Kvichak, Igushik, Wood, Nuyakuk, and Togiak Towers and Nushagak Sonar projects)	Historic annual data used	Daily counts and cumulative counts used to estimate run timing and strength	Annual total data used
Escapement Age Composition (Ugashik, Egegik, Naknek, Branch, Kvichak, Igushik, Wood, Nuyakuk, and Togiak Tower and Nushagak Sonar projects)	Historic annual data used	Data used for assessment of pre-season forecast accuracy and for in-season assignment of catch to stock of origin	Data used for brood tables and for catch allocations
Inside Test Fishing and Aerial Surveys (Ugashik, Egegik, Naknek-Kvichak, and Igushik test fish projects)	Not used	Used to estimate number of fish above district but below tower	Not used
Outside Test Fishing (Port Moller)	Not used	Used to estimate number of fish that have not yet reached Bristol Bay	Not used
Catch Data (daily reports and yearend fish tickets) (Ugashik, Egegik, Naknek-Kvichak, Nushagak, and Togiak fishing districts)	Historic annual data used	Used to estimate run timing and strength by district	Annual total data used
Catch Age Composition (Ugashik, Egegik, Naknek-Kvichak, Nushagak, and Togiak fishing districts)	Historic annual data used	Data used for assessment of pre-season forecast accuracy and for in-season assignment of catch to stock of origin	Data used for brood tables and for catch allocations
Smolt Enumeration (Kvichak, Naknek, Egegik, Ugashik, Wood, and Nuyakuk)	Historic annual data used at times	Not used	Not used, but have potential for escapement goals

Appendix M Reviewer comments on the draft report and the authors' responses.

REVIEW 1/3

Reviewer Name: Alan Martin
Date: January 5th 2011

The authors' responses to reviewer comments are provided in bold text at the end of each section below:

1. Identify the strengths and weaknesses of this report.

The report provides a good overview of the First Nations commercial and recreational fisheries on Fraser Sockeye and describes and summarizes the programs and methodologies used for pre-season run size predictions, in-season run size abundance, harvest rates and escapement. It provides a qualitative assessment of the accuracy, precision and reliability of these elements. The logic, approach and results are well explained and presented. The report is well supported by the appendices that include the regression approach summarized by the management unit. The comparison of Alaska and BC fisheries illustrates the differences in context and complexity, as well as the variances in management objectives affecting performance in meeting escapement targets.

The executive summary addresses programs and approaches to making forecasts and targets. These are well explained from an aggregate stock management perspective (the four run timing groups).

The authors do not make recommendations on how to deal with the shift in management due to the Wild Salmon Policy, from aggregate stock management by run timing groups, to individual stock management by unit or CU.

They state that escapement targets at the MU level would greatly increase the complexity of in-season management given the shift from aggregate stock management to management by CU.

A Structured Decision Making Process is required for the determination of escapement levels in managing conservation units above the Limit Reference points. These points clearly state the variety of objectives, boundaries, tradeoffs and consequences of escapement targets. The Water

Use Planning process in British Columbia has used this approach. It is expensive and would require a substantial increase in DFO's budget for both the science and the facilitation processes required to support it.

LGL Response: Recommendations on "how to deal with the shift in management due to the Wild Salmon Policy" was not requested in our Statement of Work. However, we did provide the following recommendation:

> **"Escapement goals for each CU and run-timing group need to be clearly defined and communicated to fishers to facilitate the regulation of fisheries and evaluation of management performance. The goals for highly cyclic stocks (e.g., Quesnel and Late-Shuswap) and their respective run-timing groups should be consistent with the cycle nature of these stocks (i.e., goals for dominant and sub-dominant cycle years should be different from those for off-cycle years)."**

2. Evaluate the interpretation of the available data and the validity of any derived conclusions. Overall, does the report represent the best scientific interpretation of the available data?

I note that of the 16 active information requests, 7 were incomplete. The relevance of the missing information is not highlighted by the authors.

The report is a good scientific interpretation of the data based on a quantitative and qualitative assessment the purposes and methods of collection.

LGL Response: The incomplete responses to our information requests affected our report in the following ways:

Request #1: First Nation FSC sockeye allocations were provided for 2009 only, so trends in allocations could not be examined.

Request #3a: The 2009 AFS Agreements were reviewed and provided sufficient information to address the tasks defined in the SOW.

Request #4: The response was considered incomplete because detailed catch data was not provided by DFO. The PSC provided catch estimates for 1986-09 which covers most of the 1980-09 period initially requested.

Request #5: Sockeye allocations by gear type were obtained for 2001-2009 from Counterpoint which covers approximately 30% of the 1980-2009 period in the original request. This was not a major information gap because catches have been very similar to the defined allocations in recent years.

Request #6: The response to this request was incomplete because the methods currently used to estimate commercial catch have not been documented; however, interviews were conducted with various DFO staff to obtain information on the estimation methods. The two reports provided and information from interviews was sufficient to address the tasks defined in the SOW.

Request #7: This information gap was not a serious issue because the sport fisheries are a relatively small component of the Fraser sockeye harvest.

Request #9: For the purposes of our report, we defined non-retention to include those fish captured and released and those fish that encounter fishing gear but escape capture. The first category of non-retention is primarily associated with in-river recreational fisheries while the second category is primarily associated with in-river gillnet fisheries. The information requested on fisheries where sockeye non-retention restrictions have been implemented would have been helpful to confirm the locations, times and gear-types for these fisheries but this information was not essential for our review of the consequences of non-retention fisheries on sockeye physiology, survival and abundance.

3. Are there additional quantitative or qualitative ways to evaluate the subject area not considered in this report? How could the analysis be improved?

The report could be strengthened by addressing the following:

Would in-season management decisions be sufficiently accurate to achieve harvest rate goals, or would lower harvests be required to achieve individual escapement targets given the existing monitoring and assessment programs?

The authors have pointed out that recognition and assessment of en route losses is critical for deriving reliable estimates of total abundance and exploitation rates. How could these losses influence location, as well as the complexity and costs of management by CU?

LGL Response: Our report explicitly addresses the first question above as follows:

"In general, in-season forecasts have been sufficiently accurate, precise, and timely to make

the necessary management decisions to achieve harvest rate goals defined for each of the four run-timing groups.”

The magnitude and location of en-route losses for the major indicator stocks and run-timing groups could be estimated using currently available telemetry techniques. The annual costs would be in the range of $350-400K depending on the type and quantity of tags applied.

4. Are the recommendations provided in this report supportable? Do you have any further recommendations to add?

The recommendations in the report are supportable with two exceptions:

Recommendation Number Three: The analytical resources currently allocated to pre-season forecasts should be reallocated to defining a clear set of escapement goals and in-season management models that will assist managers in fisheries planning and the achievement of the goals. I support defining a clear set of escapement goals and in-season management models that will assist managers in both fisheries planning and goal achievement.

The resources currently allocated to pre-season forecasts are inadequate. In order to improve their accuracy, performance and precision there is a need for research and development of better processes and predictive models that incorporate changing freshwater and marine conditions. Rather that reallocating I suggest investing in this area.

Recommendation Number Eight:

DFO needs to maintain its commitment to the recovery efforts for Cultus Lake sockeye and the monitoring programs needed to evaluate such efforts.

I agree with the recommendation as far as it goes. However there are a variety of sockeye salmon stocks at risk in addition to Cultus Lake. An integrated program is required. There is a need to examine the range of drivers affecting the sustainability of the species for successful recovery and a requirement that information be provided to prevent similar events occurring in other MU’s if possible.

LGL Responses:

With regard to Recommendation #3, we clearly disagree with the reviewer regarding the

utility of pre-season forecasts. Pre-season forecasts have been very unreliable in recent years due to high variability in marine survival and few if any decisions regarding Fraser fisheries are based on pre-season forecasts.

Recommendation #8, only relates to Cultus sockeye because one of our tasks was to assess the status and recovery plan for Cultus sockeye. We agree that Cultus is not the only sockeye stock at risk within the Fraser watershed and recovery plans for these other stocks at risk should be developed. However, we do not agree that the concerns identified for these few stocks would justify concerns regarding the sustainability of the species.

5. What information, if any, should be collected in the future to improve our understanding of this subject area?

The authors state that escapement goals should be established for each run timing group for ease of performance. The single escapement goals have tradeoffs between stock conservation, First Nation fisheries, commercial fisheries, recreational fisheries, and ecosystem values as stated in the Wild salmon policy.

The constraints, tradeoffs and benefits between these areas need to be quantified.

The priority and minimum goal for stock conservation is to achieve the Low Escapement Benchmarks or Limit Reference Points; both are technically straightforward to establish at a MU level.

Escapement goals incorporating the other values increase complexity. Moving from wild salmon policy to practise at the MU level will require quantification of the values. The analytical resources currently allocated to pre-season forecasts.

LGL Response: It is not clear what additional information the reviewer would like to see collected. Escapement goals for each run-timing group and indicator stock must be defined based on the biological characteristics of these groups. The Low Escapement Benchmarks or Limit Reference Point (the point when no fisheries are permitted to target a specific indicator stock or run-timing group) should take into consideration biological factors and the tradeoffs between conservation and harvest opportunities for the various indicator stocks within overlapping migration timing.

6. Please provide any specific comments for the authors.

None

REVIEW 2/3

Reviewer Name: Marc Labelle
Date: January 2, 2011

Details on the findings of this peer review are provided [below] this review form. Only the major highlights are given [in the form].

1. Identify the strengths and weaknesses of this report.

Strengths: The report documents many monitoring and assessment programs, and provides a synthesis of pertinent statistics that are not always easy to obtain from fishery agencies, especially for recent years, and within a short period.

Weaknesses:

- Evaluations conducted are very qualitative in nature, but might be improved IF the authors had extra time to conduct more rigorous assessments.
- Some data and information gaps and the literature review could be more extensive.
- Excessive attention focused on the Bristol Bay sockeye fishery context.
- Too little attention drawn on shortcomings of the current assessment and management methods that could potentially explain (at least partly) why the 2009 returns were way lower than the forecasts (and those of 2010 were way higher than forecasted).

2. Evaluate the interpretation of the available data, and the validity of any derived conclusions. Overall, does the report represent the best scientific interpretation of the available data?

The report provides little in terms of data interpretation, and does not represent the best scientific interpretation of the available data. But this may partly be due to time constraints, which limited the amount and type of data that could be compiled, and the types of analyses that could be conducted.

3. Are there additional quantitative or qualitative ways to evaluate the subject area not considered in this report? How could the analysis be improved?

Alternative analytical methods could be applied to assess the influence of some factors on the unanticipated low returns of sockeye in 2009, but might require the availability of some data not provided in this report. The analyses could be improved via the use of more sophisticated bio-statistical modelling procedures to evaluate hypotheses about the effects of deficiencies in the monitoring and assessment procedures used. Typical run reconstructions are dated stochastic assessment procedures. More sophisticated analytical approaches should be used, even if this requires additional information.

4. Are the recommendations provided in this report supportable? Do you have any further recommendations to add?

The authors provide a few on pages 148-149. One is superfluous, some seemingly lack sufficient justification, one is considered as low priority. Observations supporting these views and additional recommendations are provided in the separate attachment.

5. What information, if any, should be collected in the future to improve our understanding of this subject area?

Numerous suggestions are provided in the attachment. The most pertinent ones concerning management and assessment activities (not those for other Commission of Inquiry investigations), that might provide further insight on why major differences between the anticipated and actual returns were observed in 2009-2010 concern the reliability of methods used to estimate catch composition (age/stock), smolt outputs from major systems to improve forecasts, and improved test fishing operations.

6. Please provide any specific comments for the authors.

See below

The draft report amounts to an impressive compilation of facts given the relatively short period available to assemble these, and conduct the reviews and assessments required by the Cohen Commission Inquiry. From experience, I can attest that some of the figures and methods described in this report are not always readily obtainable from the Department of Fisheries &

Oceans (DFO) on short notice, and especially those for the most recent periods. In fact, the same could be said about other fishery agencies I worked with. This issue aside, the following comments [must] focus attention on the perceived gaps and shortcomings (if any) of the draft report presented by LGL Ltd.

Editorial issues

The report covers much ground and is fairly well written, but many editorial changes seem justified; there are redundancies, typographical errors, unnecessary and subjective qualifiers, excessive and misleading use of some terms (e.g., derive; when no derivatives or derivations are implied), incomplete sentences, missing words and etc. The writing style is somewhat verbose, and in many places, a few simple equations would be more suitable than long descriptions. Additional and detailed maps should be provided to help the reader visualize some locations and boundaries not clearly shown by the maps provided. The report contains many references to reports written by or co-authored by LGL staff (self-glorification?), but omits others that address similar issues. Some reports cited are outdated, with more recent ones not mentioned. Some references are incomplete, either lacking the number of pages, dates, sources, etc. (e.g., DFO 2009b, Gazey 2001-2002, IFMP 2001, Staley 2010). Some citations are inconsistent; that of Holt et al. (2010) on p. 83 is cited as Holt et al. 2009 on p. 159. There should also be a glossary that defines all terms, acronyms and symbols used throughout.

LGL Response: Our report includes over 165 citations of which only 16 were prepared by LGL Limited. All of the citations of reports prepared by LGL are appropriate and relevant to the topics being examined. Given the large volume of work LGL has done specifically related to Fraser sockeye, Bristol Bay sockeye, and stock assessment for Pacific salmon over the past 25 years, most readers would not be surprised to see citations to these 16 LGL reports or papers in this review of Fraser and Bristol Bay sockeye fisheries. We will review the citations identified by the reviewers and correct any errors found.

Content issues

Page 1. The heading ‘Non-Retention Fisheries’ is used, but the following text focuses primarily on the so-called ‘en-route losses’, which should not be under this heading since non-retention fishery issues typically cover by-catch and incidental mortalities after release. In the following sections, the ‘on-route losses’ refer mainly to differences between escapement estimates from the lower Fraser River monitoring operations (near Mission, etc.), and spawning ground estimates of mature adults. Differences can be caused by monitoring deficiencies even in the absence of losses (i.e., deaths *per se*), and are akin to accounting errors. However, as written, the en-route losses can also include deaths or removals in-river due to poaching, catch monitoring deficiencies, predation, stress and physiological limitations, and etc. In recent years, efforts were made via tagging and experimentation to quantify and determine the factors responsible for the losses. It would be advisable to distinguish between the two possible definitions (monitoring errors versus deaths), and the authors should emphasize that the past ‘en-route’ loss figures provided for 1980-1991 (Fig. 21) are at best, crude guesses that may not represent deaths during the in-river migration.

LGL Response: we have added a sentence describing our findings regarding catch and release fisheries to the non-retention section of our executive summary. The sentences related to “en-route losses” should remain because one of the unintended impacts of in-river gillnet fisheries could be greater “en-route losses” resulting from fish that encounter fishing gear but escape capture.

Page 20: The catch estimation methods for FN fisheries are described based largely on the various old reports by ESSA staff (Alexander, 1998 to 2002a). The authors conclude from those and other recent summaries of survey coverage and monitoring activities (Tables 8-10) that many estimates are reliable, and particularly for recent years. This conclusion is not entirely supported by recent DFO investigations, and the major changes underway to rectify the apparent deficiencies of catch monitoring operations. The authors should note that fishing activities and catches were accounted for via an excessively large number of procedures including trained observers, fishery officer checks, hails, voluntary reports, creel surveys, over-flight sightings, landing records, and etc. Some data are recorded directly on paper forms, while others are reported by phone or electronically logged. The catch reporting software program MERCI (http://www.essa.com/tools/MERCI/index.html) developed by ESSA has been used by DFO and First Nations since 1998 for some in-season catch reporting. MERCI is being replaced by the CREST data entry and extraction program to provide more details when fully implemented. The set of monitoring procedures used currently is termed the Lower Fraser Fishery Monitoring and Catch Reporting (FMCR) program. Recently, some DFO staff noted that this program has not been modified to keep up with some fishery changes, and provide the data needed to address emerging issues associated with potential ecosystem impacts, conservation objectives, and management problems. The major issues of concern include (i) the inaccuracy of some catch estimates for lack of adequate monitoring, (ii) some FSC harvests are not routinely monitored, (iii) the lack of special monitoring operations for drift gill-net fisheries, (iii) the insufficient resolution (time/area) in catch records which precludes the formulation of detailed fisheries agreements for some bands, (iv) the lack of standardized monitoring and reporting procedures across commercial and EO fisheries targeting the same stocks/species, (v) the fact that over-flight surveys cannot determine how much fishing occurs in periods of poor visibility or at night, (vi) there is no mandatory release and effort validation for many FSC and EO fisheries. Some of the major problems and potential solutions have been highlighted in DFO discussion papers by Sigurdsen (Sigurdsen. (no date provided). Catch Monitoring in First Nations Fisheries in the lower Fraser River. Power Point Presentation. Fisheries and Oceans Canada. 22 pp.), Anon (2008) (Anon. 2008. Interim fishery monitoring and catch reporting standards for commercial salmon fisheries. Unpublished internal DFO report for discussion purposes. 24 p.), and Lightly and Masson (2009) (Lightly, D., and C. Masson. 2009 (in prep.). First Nation FSC Catch Monitoring and Reporting: Preliminary Considerations, Standards and Recommendations. Draft report prepared for the Can. Dept. of Fisheries & Oceans. Sept. 2009. 31 p.). Surely, LGL Ltd. can ask DFO to provide copies of recent documents and discussion papers (as that of Ionson 2009) to help determine with more certainty if FN catches (and even commercial ones) are potentially biased (precision levels is usually of secondary concern).

LGL Response: Two of our formal requests to DFO were for documents that describe the current (2005-2009) and historical (1980-2004) methods used to estimate First Nation and commercial catch of Fraser sockeye (See Appendix B – DFO Request #3b and #6). The references related to catch monitoring in our report include all the reports provided by DFO.

Page 36: In earlier sections, the authors note that US catches of Fraser River bound sockeye in 2009 were relatively low (Table 1). Apparently, only scale samples and used in SE Alaska to determine stock contribution estimates, while Washington uses DNA and scale sample. The authors seem to take for granted the US opinion that their figures are 'highly accurate' despite the near total lack of dock side validation, yet categorize the accuracy of Fraser River catch estimates as good, and highly reliable. Seems like a farfetched conclusion. In light of what happened in 2009, it could be hypothesized that US and north coast catches of Fraser River sockeye were seriously underestimated because of some anomaly. No evidence is reported to support or refute this hypothesis, but it should be investigated more thoroughly.

LGL Response: In more than 20 years of conducting run reconstruction analyses for Alaskan and Northern B.C. fisheries, no one has previously suggested that "U.S. and north coast catches of Fraser River sockeye were seriously underestimated". Catches of Fraser River sockeye in Alaskan and Northern B.C. fisheries have varied substantially from year to year. However, this variability appears to be consistent with the timing and location of fisheries and environmental characteristics of the years. The catches of Fraser sockeye in Alaska and Northern B.C. fisheries have been assessed using scale pattern analyses that are annually reviewed and approved by the PSC. The average annual catch of Fraser sockeye in Alaska and Northern B.C. fisheries was 120,000 from 1982-2008 (range 0-453,000). The highest catches occur in El Nino years when water temperatures are warmer in the Gulf of Alaska and Fraser sockeye migrate through southern southeast Alaska fisheries.

Page 60: The authors make extensive use of two statistics throughout the document to assess accuracy and precision, namely the Mean Absolute Percent Error (MAPE) and the Mean Percent Error (MPE). MAPE is the mean of the series of absolute errors (AE) x 100, but the authors opt to use the median instead of the mean reduce the influence of aberrant figures (fair enough). Each AE of MAPE is defined in Appendix F (p. F-2) as = |forecast-actual| / forecast. However, the equation commonly used for AE is different and = |actual-forecast| /actual (http://en.wikipedia.org/wiki/Mean_absolute_percentage_error). If so, the authors have it backwards by using the forecasted value as the denominator instead of the actual value. This small distinction is important. Let actual = 10 and forecast = 12. The AE as defined by the authors is |12-10|/12 = 2/12 = 0.167. The correct definition yields |10-12|/10 = 2/10 = 0.200. The authors need to address this issue, and provide corrections, clarifications or both, because an erroneous use of absolute error values changes many trends and conclusions in their report.

As for the Mean Percent Error (MPE), the authors use a median instead of the mean for the same reasons. The error term used = (forecast-actual) / actual (p. F-1), which is the correct term to use (see http://en.wikipedia.org/wiki/Mean_percentage_error). However, the authors seemingly interpret the trends backwards. The Fig. 11 caption for instance (on p. 69), it is noted that positive values indicate that forecasts under-estimate the actual abundance, but based on the above equation, positive values are obtained when the forecast exceeds the actual value. If so, the captions need to be corrected.

LGL Response: The reviewer advises us to make percent error relative to the actual return instead of the forecasted value based on convention. The use of forecast or actual return as the denominator in MPE and MAPE calculations is arbitrary (i.e., when forecast is the denominator, results express forecasting error relative to forecasted values; when actual return is the denominator, results express forecasting error relative to actual returns). We used forecast as the denominator and our results were described accordingly. However, the reviewer rightly pointed out an inconsistent reporting of the methods in an Appendix (i.e., text was wrong, calculations were right). To avoid ambiguity and potential conflict with the norm, we have sided with the reviewer and now present errors relative to actual returns. We have also edited the text accordingly: Instead of saying "the percent error in forecasted returns is X% higher or lower than forecasted values", we now say "percent error in forecasted returns is X% higher or lower than actual returns". Although changes to the MAPE and MPE calculations have changed the scale of the errors (i.e., % error values are inflated when forecasts over-estimated returns and deflated when forecasts underestimated returns), which caused some changes in ranked error among indicator stocks and run-timing groups, the resulting changes in MPE and MAPE values did not change the overall trends in accuracy or precision over time nor have we had to modify the principal conclusions of our report.

The caption of Figure 11 has been corrected.

Page 60: Attention is also drawn to the use of linear regressions of total returns versus forecasts for many stocks. The authors compute coefficients of determination (r^2) and use it as a measure of fit to explain the proportion of the variation in total returns explained by the independent variable (here the forecast). However, there is no reason to assume that the relations are linear. A non-linear exponential functions would likely provide a better fit to the data for the early Stuart and Early Summer stocks (p. G-3 and G-4), and a quadratic might be more suitable for the Birkenhead stock (p. G-7). These observations suggest that for some stocks, the best forecasting relations may lack a crucial co-factor that has yet to be identified. Some of the other relations are seemingly linear, but the bi-variate error structure does not always look normal. If so, it would be advisable to use non-parametric correlation coefficients (Kendall or Spearman's, see Zar 1984 p. 318) (Zar, J.H. 1984. Biostatistical Analysis. Second edition. Prentice-Hall. New Jersey. 718 p.) to crudely gage the functional dependence of one variable on the other, and perhaps use it as an 'indicator of reliability' for other comparisons in the report.

LGL Response: We disagree, there is indeed reason to assume the relationship between forecast and return will be linear because the actual return value is exactly what a forecast is meant to match. If the forecast predicts 1M fish, we expect the return to be 1M. If the forecast predicts 1,000 fish, we expect the return to be 1,000. We agree the formulae used to derive forecast values are not linear and loaded with multiple co-factors (we review forecast models elsewhere in the report), but the (lack of) linearity in forecast models is irrelevant to the complaint raised here by the reviewer.

We have re-run the regression analyses on log_{10} transformed data to improve the bivariate distribution of data in the regression analyses. In general, R^2 values were lowered which further substantiates our conclusion that pre-season forecasts do not adequately predict actual returns and management decisions should rely instead on in-season test fishing and in-season estimates etc. We have revised figures and text throughout report and appendix.

Page 67: The authors note that Bayesian statistical techniques have recently been use to a greater extent for in-season monitoring. They note that some Bayesian models were formulated by Bill Gazey, but no references are given to confirm that a peer review was done to support the notion that this method is superior to others used previously.

Pages 72 & 75: It is noted that fishwheels are used to "estimate the near-shore species composition in recent years". This is actually a recently implemented and very expensive project conducted by LGL Ltd in the lower Fraser River. A few additional comments seem required to ensure the reader does not assume that it is cost-effective and accurate sampling method, or that this operation provides reliable estimates of the ‘near-short species composition’. It is a well-known that fishwheels have highly variable catchability rates (i.e. sampling efficiencies) that are a function of location, water depth, flow rates and circulation patterns, water turbidity, and the spatial distribution of the species sampled. Fishwheels can be considered as useful devices to harvest salmon selectively, apply tags and collect samples, but it is doubtful estimates based on this sampling device are sufficiently accurate, precise and reliable to ‘adjust’ the figures obtained by long-standing test fishing operations. Might be better and simply more cost-effective to extend the spatio-temporal range of test fishing to adjust historical records and estimates.

LGL Response: The reviewer makes a number of unsubstantiated statements regarding the use of fishwheels to provide near-shore species composition estimates for the Mission hydroacoustic estimates. The readers are referred to Robichaud et al. (2010) for a detailed description of the findings from systematic evaluations of the lower Fraser fishwheels. To date, efforts to obtain reliable near-shore species composition estimates using gillnet test fishing methods have failed and have not been more cost-effective than fishwheels.

Page 77: As noted, mark-recapture operations are conducted to obtain escapement estimates for some stocks, by tagging of 1% of salmon escapements and then sampling carcasses [supposedly] in proportion to abundance, so as to yield mark-recapture estimates that are within ± 25% of the actual abundance. Unfortunately, no information is presented on typical survey conditions or the availability of partial enumeration structures. Some with considerable field expertise may find the report conclusions hard to believe. The report of Schubert and Houtman (2007) cited appears to focus on some 1998 Fraser River runs, and is not a primary publication subject to strict and impartial peer review. Additional details and comments should be given on the suitability of the method in various contexts since.

LGL Response: We agree with the reviewer that it would be helpful to have a report on the methods used in recent years. However, the reader should be aware that DFO and the PSC conduct detailed annual reviews of the escapement estimates derived from the mark-recapture operations. We are not aware of any scientists within DFO or the PSC that have expressed serious concerns regarding the reliability of the spawning ground escapement estimates derived from mark-recapture studies.

Page 82: The Statement of Work identified (3.15) says that “The Contractor will evaluate the scientific basis for determining escapement targets...”. The authors note that a recent MSC certification review of Fraser River sockeye (Devitt et al. 2010, incidentally co-authored with LGL staff), required that fishery managers define Limit and Target Reference Points for each stock management unit. MSC certification guidelines are basically commercial constructs formulated by NGOs, and do not dictate conservation and management guidelines used by the DFO, which generally comply with or even exceed those proposed by the United Nations (UN/FAO). Still, Limit and Target reference points are commonly used by several national and international fishery agencies for assessment and management purposes, but the threshold (or benchmark) values used by various agencies are not always identical for similar fisheries/species. The authors note the targets used by DFO staff changed over the years, and must now meet those based on the new Wild Salmon Policy (WSP). The ones being formulated are apparently described by Holt et al. (2010, or 2009), but the interim guidelines used recently are given by DFO (2009b). The latter report was unavailable at the time of this writing, but some threshold values are given in Table 24 along with illustrations (Fig. 15) of the so-called Total Allowable Mortality (TAM) rule used to guide DFO management. The TAM rule is similar to some US fishery management guidelines based on the Magnuson-Stevens Fishery Conservation and Management Act (MSA), with thresholds for maximum fishing mortality and minimum stock size that are functions of productive capacity, biomass levels and allowable exploitation rates.

Unfortunately, the TAM rule or 'interim' management guidelines used recently by the DFO (i.e. DFO 2009b) are not critically reviewed, but the Table 24 figures are used to determine if DFO met their minimum escapement goals since 1970 (Fig. 16-20). The report should emphasize that past or even interim minimum escapement goals may not be scientifically defensible, at a minimum because of possible (and often hypothesized) changes in habitat capacity over time. This view is supported by that of another peer reviewer who attended the Commission of Inquiry workshop in late November (Mr. Al Martin) and recommended that the carrying capacity of the some nursery lakes be re-assessed. Basically, the latest/current escapement goals (minimum or targets) may be excessive and no longer realistic.

LGL Response: There is a wide range of views on whether the latest/current escapement goals are too high or too low and whether or not these goals are scientifically defensible. DFO has initiated a peer review process for a new set of goals (benchmarks) for each Fraser sockeye conservation unit (CU) (Grant et al. 2010). As indicated in our report, "The large year to year variability in escapement targets makes it difficult to regulate fisheries and evaluate management performance." Consequently, we have recommended that "Escapement goals for each CU and run-timing group need to be clearly defined and communicated to fishers to facilitate the regulation of fisheries and evaluation of management performance."

Page 100+: The report section describing the state of the Cultus Lake population is based partly on the preliminary opinions of Bradford et al. (in prep.), COSEWIC assessments, and ironically, and why some precautionary measures (i.e., SARA Schedule 1 listing) were not implemented.

The reported excerpts from Bradford et al. (in preps) support the growing body of scientific results showing that ecosystem tampering and productivity enhancements (hatchery supplementation, captive breeding) are not always successful or beneficial to the long term, so it is important to use the best techniques available with caution. However no information is provided to support the notion that DFO will cease making efforts to protect and rehabilitate this population, so Recommendation 8 provided on p. 149 seems superfluous.

LGL Response: During the MSC review of Fraser sockeye, several NGOs expressed concerns regarding DFO's commitment to implementing the recovery strategy for Cultus sockeye. Thus, one of the conditions associated with MSC certification of Fraser sockeye was a clear commitment from DFO that they will continue to implement the recovery strategy for Cultus sockeye.

Page 106+: The section on the Bristol Bay sockeye fishery is disproportionately long. That section could be reduced by citing recent papers that summarize more succinctly some of the management and assessment procedures used (see for example Hilborn et al.1999) (Hilborn, R., B.G. Bue and S. Sharr. 1999. Estimating spawning escapements from periodic counts: a comparison of methods. Can. J. Fish. Aquat. Sci. 56: 888-896.). Irrespective of this fact, one is lead to question the rationale used to require a review of the procedures used in a different country, and in a context that is radically different from that of the Fraser River. What pertinent conclusions stem from this review could induce short term and substantial modifications of the DFO management practices, the current US/Canada treaty, and the current PSC operational procedures? If any, the authors do not highlight them in the report. For comparative purposes, one could use another major Canadian sockeye system, such as the Skeena River which was recently subject to a peer review by an independent science panel of experts (Walters, C.J., J.A. Lichatowich, R.M. Peterman, and J.D. Reynolds. 2008. Report of the Skeena Independent Science Review Panel. A report to the Canadian Dept. of Fisheries and Oceans and the British Columbia Ministry of Environment. May 15, 2008. 144 p.). Potentially important issues to the Commission of Inquiry, and recommendations that come to mind from the review of the Bristol Bay system could include the following:

- Is there any evidence to suggest that the Fraser River sockeye catch in Alaskan fisheries might have been vastly underestimated, and would account (at least partly) for the low returns observed during 2009.
- The ADF&G forecasting methods are apparently not readily available so are not described in detail and compared to DFO methods. Given the trends in Fig. 35, the methods seem to have improved over time. If so, one recommendation should be to have scientists from both countries compare the performance and merits of alternative forecasting methods and where further improvements are possible. If some US methods

are suitable to the Fraser River context, and seem to perform better, DFO should consider using these even if forecasts mainly serve to provide advice to industry. Providing advice to industry should not be viewed as a minor objective by natural resource managers, especially if the latter are public servants.

LGL Response: With regard to the first bullet, there is no evidence to suggest that the Fraser River sockeye catch in Alaskan fisheries might have been vastly underestimated, and the relative small sockeye catches in Alaskan fisheries in 2009 would not account (even partly) for the low returns observed during 2009. The PSC estimates of 2009 catches of Fraser sockeye in Alaska District 104 (14,000-15,000 sockeye) are still preliminary. The total (all stocks) catch of sockeye in District 104 was 109,371. For comparison, about 150,000 Fraser River sockeye were estimated to be caught in District 104 in 2007 (just under 10% of that year's run) and nearly 300,000 Fraser River sockeye were caught up there in 2005 (about 4% of that year's return).

With regard to the second bullet, the description of the ADF&G pre-season forecasting methods is similar to that provided for the B.C. pre-season forecasting methods. The Bristol Bay suite of models is virtually the same as the ones used on the Fraser. Furthermore, the technique for choosing the best model for a given year is the same—they both use retrospective performance over recent years. Finally, the reduction in Bristol Bay forecasting error in the most recent decade has been attributed to two factors: (1) a change in process for selecting the forecast from the alternative models, and (2) greater stability of the Bristol Bay run size during the most recent time period. As indicted in the report, prior to 2001, forecasts were the average of four alternative models given equal weight. Beginning in 2001, the forecasts have been based on the top performing model over the previous three years. Given the improved performance of Bristol Bay forecasts since 2001, Fraser managers should seriously consider using a single best performing forecast model for several years, rather than the current process that has resulted in forecasts from a different model for almost every stock each year.

Page 148: The authors do not provide much support for recommendation #3, namely the re-allocation of resources for pre-season forecasts to the improvement of escapement goals and in-season management models. Forecasts are important, and substantial improvements could possibly be achieved by having more estimates of actual smolt outputs than currently available (Chilko, Cultus, Nadina and Weaver, P. 53). In light of this, and previous comments in the present report, a substitute recommendation would be to make more efforts to improve forecasts, and in part by monitoring the smolt outputs of more systems. And after years using in-season management practices, these should be finely tuned by now. However, many stock-assessment experts have drawn attention to recent changes in test fishing practices due to various factors (budgets, legal issues, pseudo-conservation goals, etc.). A substitute recommendation would be to reverse this trend, and improve test fishing operations. These two adjustments might have helped better manage the unusually large returns of 2010 as well.

LGL Response: The reviewer comments refer to both pre-season forecasts and in-season test fishing practices. We obviously disagree with the reviewer's point of view that pre-season forecasts are important for the management of Fraser sockeye fisheries. As stated in our report, "the recognized challenges with forecasting salmon returns have led most managers to rely on in-season information to manage sockeye fisheries." We definitely support the continued use and improvement of in-season assessments and forecasting efforts. However, the in-season systems are reasonably good and the biggest deficiency in management of Fraser sockeye fisheries is the lack of clearly defined escapement goals. Therefore, we stand firmly behind recommendation #3.

Recommendation #7 states that en-route losses should be estimated (fair enough), and the estimates should be 'incorporated' into run-reconstruction procedures. These deterministic accounting procedures are dated, and more sophisticated models should be used for all assessments in BC. As for recommendation #8, as noted earlier, it is superfluous.

LGL Response: With regard to Recommendation #7, run-reconstruction procedures have been used for many years to assess returns for Pacific salmon stocks. While more sophisticated models could be developed, the three important reasons why run-reconstruction methods continue to be used: (1) these methods integrate all the available information on run-timing, migration speeds, en-route losses, stock composition, catch and escapement to produce run size and exploitation rate estimates for each stock, (2) these methods and results can be readily understood by fisheries managers and the various fishing sectors that are being managed, and (3) they emphasize the importance of reliable estimates of catch and escapement that are essential for management of salmon fisheries.

The reviewer's comments regarding Recommendation #8 have been addressed above.

Some attention should focus on the reliability of the ageing methods and sampling rates used by DFO + ADF&G in providing accurate estimates of the age composition in catches and adult returns. Age composition estimates based on scale patterns can be subject to considerable uncertainty due to sampling deficiencies and reader subjectivity. It could be hypothesized that poor ocean conditions may simply have lead some sockeye to remain at sea one year longer. The extent of phenotypic plasticity for Fraser River sockeye stocks is not well known, but if true, this hypothesis could help explain why there was an abnormally low return in 2009, followed by an abnormally high return in 2010. Basically some sockeye expected to return in 2009 would have returned in 2010 instead, but that would be evidenced mainly by detecting changes in the age composition of various spawning stocks, if the estimates are reliable.

In light of the above, it is recommended that the authors consider making adjustments to some sections and passages throughout the report, and then adjusting the executive summary accordingly.

LGL Response: Information on the age composition of catches and adult returns is routinely collected by the PSC. The reviewer's hypothesis regarding a shift in the age composition (2009 four year olds delaying their return until 2010) has been assessed by PSC scientists. The age composition of the 2010 returns did not show a higher than normal portion of age 5 returns. Rather, the age-5/2 proportion was unusually low (Steve Latham, PSC Biologist, pers. comm.). Scale-based age estimates are highly reliable for Fraser sockeye, especially for fishery samples from marine or lower river areas. Sockeye ages in marine samples are often compared to those derived from an ADF&G laboratory in Alaska and, except for some difficult ages (e.g., sockeye that don't rear in lakes), there is excellent agreement among independent estimates. Sampling was more comprehensive in 2010 than in any other year (over 5,000 matched samples from marine areas and over 4,000 from in-river fisheries). A contractor has examined otoliths collected from spawning grounds in 2010 and these independent age estimates confirm the low proportion of age-5/2 sockeye provided by our scale laboratory in-season. In addition to the information from these age samples, it should be noted that over 70% of the 2010 return can be attributed to one lake, Shuswap, and the number of age-4 sockeye expected to return to Shuswap Lake in 2009 (off-cycle year) was small. The stocks that should have carried the returns in 2009 were Chilko (record smolt output in 2007) and Quesnel (dominant cycle). Quesnel was a small player in the 2010 return, especially considering 2010 is its sub-dominant cycle. There were no jacks observed for Quesnel in 2008, and the age composition of Quesnel in 2010 comprises less than 5% age 5 sockeye. There is no evidence of good production of Quesnel sockeye from the 2005 brood year. For Chilko, the age composition in 2010 was over 97% age-4/2 (the vast majority) and age-5/3 sockeye. These age-4/2 and age-5/3 fish went to sea in 2008 (Chilko Lake's second highest smolt migration on record) and were not part of the forecast for the 2009 return. The preliminary estimate of the 2010 return rate of 2008 Chilko smolts is average. In summary, available data support the conclusion that the main reason for the large run of Fraser River sockeye in 2010 is the strong return of four-year-old sockeye (particularly from Shuswap Lake). The data do not support the hypothesis that the large 2010 run resulted from sockeye expected to return in 2009 returning at age-5 in 2010 instead (Steve Latham, pers. comm.).

REVIEW 3/3

Reviewer Name: Dr Sean Cox
Date: 24 January 2011

1. Identify the strengths and weaknesses of this report.

Overview

This report provides a highly detailed accounting of Fraser River sockeye fisheries, scientific stock assessments, and fisheries management for the period 1980 – 2009. Harvesting activity by all sectors, including First Nations, commercial, and recreational, is assessed via the authors compilation of catch records from both ocean and in-river fisheries. The overall quality of each catch information source is judged based on the author's definitions for accuracy, precision, and reliability.

Strengths

The author's involvement in many aspects of Fraser River sockeye fisheries assessment, management, and scientific research provides analytical depth that would otherwise not occur if it were written as a mere compilation of data.

The authors examine accuracy, precision, and reliability of both pre-season and in-season forecasting methods by comparing predictions with what are considered "true" run sizes based on direct post-season enumeration of catch and escapement. This provides the necessary context for judging the information used to manage sockeye fisheries.

The attempt to provide a consistent approach to judging the quality of information (i.e., accuracy, precision, and reliability) used to assess and manage Fraser River sockeye salmon fisheries is appreciated because it allows the report to identify key areas where data and methods could be improved.

Weaknesses

The report addresses a very specific set of tasks, where each task is presented at the beginning of each major section. This certainly helps guide the reader through the report; however, there could be better continuity and synthesis across the various tasks and sections. For instance, catch monitoring (Fisheries Harvesting section) was not as good prior to 2001 as it is now, and the authors suggest that historical catch was probably under-estimated. Yet, such under-estimation was not discussed in the "Extent of Overharvesting" sub-section later where, in some cases, the authors suggest that high harvest rates may have been "sustainable". The latter sub-section could use some discussion of the implications of under-estimating historical harvest rates. Thus, in general, the report could use a Synthesis section that presents the author's view on the key issues in Fraser River sockeye fisheries assessment and management.

There is some inconsistency in application and presentation of data accuracy, precision, and reliability metrics, which is understandable given the breadth of information included in the report. For instance, pages 5/6 are devoted to explaining how accuracy, precision, and reliability were determined, and then, on page 7, a new, qualitative scaling is introduced that seems different. This apparently different set of criteria leaves me wondering which method is going to be used and when.

LGL Response: We will clarify in the report that the definitions of accuracy and precision provided on page 5/6 are for quantitative assessments and to distinguish between evaluations of methods and evaluations of estimates. Quantitative assessments of accuracy are limited to pre-season and in-season forecasts where the final run size estimates are the "true" values that we are trying to forecast. Quantitative assessments of precision are possible for some catch and escapement estimates. The definitions provided on page 7 are used to provide a qualitative summary of our findings related to sockeye catch estimates. It is not possible to quantitatively assess the accuracy of catch estimates because the true catch is not known. The available information on the precision of catch estimates is not sufficient to produce a quantitative summary for all fisheries.

2. Evaluate the interpretation of the available data, and the validity of any derived conclusions. Overall, does the report represent the best scientific interpretation of the available data?

Some analyses present basic statistics (e.g., correlations, regressions) as indicators of accuracy, precision, or reliability. I think of at least four issues arising from the use of these statistics: (i) the use of correlation/regression analyses over-state the "reliability" of both pre-season and in-season forecasting methods. Table 21 uses regressions to indicate reliability, precision, and accuracy, yet the regression statistics are not even close to independent, and the associations to quality are vague. The Median Absolute Percent Errors in forecasts are pretty large and not consistent with any of the regression statistics. (ii) one cannot judge reliability of in-season forecasts without considering the timing of these forecasts relative to timing of fisheries. In-season forecasts that eventually correlate well with post-season abundance estimates cannot be reliable if they are highly biased early in the season when fishery openings need to be determined. Note that the Initial Statement of Work was vague on this to begin with. (iii) Basing assessments of reliability on four run-timing groups masks a great deal of unpredictability and risk at the Conservation Unit or indicator stock level. Although such analyses may not be possible at the moment, there should be some qualification of reliability assessments based on recruitment aggregated across many stocks. (iv) Finally, assessment of pre-season forecast reliability, in particular, is based on a small sample size and continually changing choices for pre-season forecast models. Thus, any assessment of past reliability may not do well in predicting future reliability, or reliability under very different circumstances…in other words, the reliability metrics may not be reliable.

LGL Response: (i) Our objective was to determine whether there was a statistical relationship between forecasted values and actual returns. If there was no such relationship (i.e., returns varied at random with respect to forecasts) we deemed the forecast to be unreliable. If the relationship was significant, we deemed the forecast to reliably track the general rises and falls of the actual returns, and then took further steps to describe "how good" the forecast was based on regression and MAPE statistics. This is a reasonable approach that has been used in other fisheries publications evaluating forecast performance (e.g., our analyses were derived Haesaker, Peterman et al. 2008 *N Am J Fish Management*). We have added text to better describe how we relate regression parameters and MAPE estimates to (1) precision, where increased dispersion around the linear relationship causes MAPE to increase and R^2 to decrease, and (2) accuracy, where accuracy improves when regression slope approaches 1 and intercept approaches 0. We base our interpretations of forecast precision and accuracy on the following simple facts: a perfect relationship between forecast and return will have a regression slope=1, intercept=0, R^2=1.0, and MAPE= 0. As any of these values depart from optimal, either precision or accuracy erodes. MAPE becomes useful when slopes depart substantially from 1 (an instance where R^2 would be very low), because MAPE describes dispersion around the fit line independently of slope. This final point also explains why MAPE and R^2 values do not always agree (e.g., Fig 9-10, as noted by the reviewer): MAPE can remain constant (e.g., 25%), even if R^2 decreases rapidly with decreasing regression slope. We agree with the reviewer that there are more complex ways to analyze these data, but we stand behind our methods as an adequate and easily accessible approach to determine whether there is indeed a relationship between forecast and return – significantly, we identified several indicator stocks where no such relationship exists. Now that we have provided a relative comparison of each stocks' forecast performance, future inquiry can single out individual stocks-of-interest and employ more rigorous and complex analytical techniques (e.g., Bayesian methods) to parameterize the forecasting error (i.e., parse and

explain the unexplained error for individual stocks). Embarking on such an endeavour here is beyond the scope of this report.

(ii) Information on the timing of fisheries for each run-timing group have been added to the report;

(iii) We have presented our evaluation of the pre-season forecast results for each indicator stock and each run-timing group. We have included additional text describing the uncertainty associated with the pre-season forecasts for each indicator stock.

iv) Additional text has been added to the report to emphasize that changing environmental conditions can undermine the utility of even the best performing pre-season forecasts based on historical data, and the reliability of future forecasts may be substantially different from that for past forecasts. Yet another reason why pre-season forecasts are of little use in the management of Fraser sockeye and many southern B.C. salmon stocks.

The report's definition of "precision" - "the 95% confidence intervals expressed as a percentage of the estimate (e.g., ±10%)" - is not a standard one and this leads to confusion later. Typically, expressing error levels as a percentage of the estimate implies a coefficient of variation (CV), which is the standard error of the estimate (s.e.) divided by the estimate and then multiplied by 100%, i.e., CV = 100% x s.e./estimate. This would not be a major problem, except that the authors later quote precision levels provided in other documents and reports, which probably do not use the same definition. For instance, P77L31-32 quotes a DFO paper, which states that target precision for sex-specific escapement enumeration is ±25% (Schubert and Houtman 2007). If precision is based on 95% confidence intervals, then a goal of ±25% would be extremely optimistic, and therefore I doubt it is true.

LGL Response: Text was added to explain that 95% confidence intervals describe precision associated with catch and escapement estimates, other measures of precision are used to describe precision associated with run-size forecast estimates. The precision estimates reported in Schubert and Houtman 2007 are 95% confidence intervals expressed as a percent of the escapement estimate.

In general, I agree with most of the data quality assessments for in-river fisheries. However, the authors do not mention two peculiar patterns that appear in catch and allocation tables (Table 11 and Table 12). In Table 11, there are three FSC catches (1995, 2000, and 2005) that are several times larger than what is typical for other years. On the next page in Table 12, there are several instances where all catch is assigned to FSC fisheries, even though these numbers are much larger than historical. In most cases, catches seem to get assigned to FSC fisheries when allocation shows "No agreement", and these catch amounts are not trivial. It is not clear how this affects "reliability" of in-river catch estimates, especially considering that 2004-09 reliability is considered "Good" (and that, according to the report, FSC catch statistics are among the least reliable).

LGL Response: Reliability is considered to be good for the period 2004-2009 because of the separation of FSC and sales fisheries and better catch monitoring programs. We have added some additional text to the report to quantify the observation that reported FSC catches tend to be larger in years without sockeye allocation agreements.

It is not possible to judge "sustainability" of exploitation rates based on short time-series such as those presented. The text on P96L24-25, i.e., "70-80% exploitation rates…appeared to be sustainable in the early years", should be re-worded to, e.g., "70-80% exploitation rates…were common in the early years".

LGL Response: The sentence has been changed to read "While 70-80% ERs are very high in recent context of low and declining productivity, the substantially higher productivity of Fraser sockeye from 1960-1980 appeared to support these higher ERs."

I don't think the interpretation made on P97L10-16 can be made either in this report, or at all. The text implies that an inadvertent over-escapement for Quesnel in 2002 caused an abnormally low recruitment in 2006. There is no evaluation of what happened to any other stocks in 2006, nor is there any evaluation of stock-recruitment relationships to suggest whether such observations are consistent with past recruitment. In fact, another Cohen Commission report examined spawner-recruitment relationships and suggested that a Larkin model best explained Quesnel population dynamics. This would therefore suggest that spawner abundances in years prior to 2002 may be equally important.

LGL Response: Text on page 97 has been edited to acknowledge that the very small fall fry observed in 2003 were likely the result of large escapements in two successive years. Small fall fry result in small smolts that typically have lower survival than larger smolts.

3. Are there additional quantitative or qualitative ways to evaluate the subject area not considered in this report? How could the analysis be improved?

The section on "Extent of Overharvesting" could provide more specific information on potential overharvesting. For example, overlaying time-series of abundance and exploitation rate provides only a qualitative indication of potential over-harvesting (i.e., abundance declines after a long period of high harvest rates) and the text seems to confirm that approach. An alternative approach would be to use a "phase plot" in which recruitment (R_t) is plotted on the x-axis and exploitation rate (ER_t) on the y-axis. Recognition of the time-series nature of the data can be accounted for by connecting each (R_t,ER_t) pair with a line segment. Data points lining up along a horizontal line indicate that harvest rates are independent of recruitment, and therefore, one only needs to evaluate whether the average harvest rate is too high, or too low according to whether the implied escapement is above or below optimal levels (however that is defined). Data points forming a negative relationship, in which high exploitation occurs at low abundance and low exploitation occurs at high abundance, is a sign of serious and potentially destabilizing over-harvesting. Again, the severity of potential impact depends on the absolute exploitation levels, but such analyses provide a better indication of over-harvesting risks than qualitative descriptions of temporal patterns.

LGL Response: We examined the relationship between recruitment (R) and exploitation rate (ER) as suggested by Dr. Cox. We prepared plots for each run-timing group by cycle year (see Figures Cox 1-4, below). Most of the 16 plots (4 timing groups times 4 cycle years) did not show any clear relationship between R and ER. The 2006 cycle year (dominant cycle) for the Early Summer timing group was the only instance where abundance had increased with declining ERs (i.e., indication of potential over-harvesting). The ERs were relatively high (70-90%) and recruitment was relatively low (<700K) for the first eight cycles in this time series. There was an increase in both the magnitude and variability of recruitment as ERs were reduced and the highest observed recruitment occurred after the exploitation rate was reduced to the 40% level. These observations are consistent with our interpretation of the trends in the time-series plots for Early Summer stocks where we indicate that "it is likely that many of the Early Summer stocks were overharvested during the period 1960-1989."

One other noteworthy pattern was observed for the 2005 cycle year (dominant cycle) for Summer-run stocks. There has been a wide range of recruitments (3-20 M) at relatively high ERs (70-85%) followed by a steady decline in recruitment as ERs were reduced from 70% to 10% between 1993 and 2009. This reflects the management response to reduce fishing pressure during a period of decline in productivity (recruits/spawner) for Summer-run stocks.

Most of the statistical assessments of accuracy and precision do not take the uncertainty of post-season estimates into account. One way to do that is to examine whether/when pre-season or in-season estimates fall within the 95% confidence limits of the post-season estimates.

LGL Response: Confidence limits are not available for the post-season estimates of run

size.

Figures showing errors for pre- and in-season forecasts only use bar plots, which seems to ignore some important information, such as the range of forecast errors and how frequently very large errors are encountered. A box plot would also show medians, as desired, but also inter-quartile ranges and outliers.

LGL Response: **Bar graphs have been replaced by box plots.**

4. Are the recommendations provided in this report supportable? Do you have any further recommendations to add?

As noted above, the report could use a separate Synthesis section, and probably also a Recommendations section.

1. The authors recommend that "A clearly defined set of escapement goals for each run-timing group and indicator stock would be much easier to communicate to fishers than the current complex Total Allowable Mortality (TAM) rules". I agree that having a clear set of easily understood operating rules would benefit everyone involved in Fraser River sockeye fisheries, including harvesters. However, the authors could be more specific about what they mean and what potential consequences might follow from their recommendations. For example, (1) do they mean stock-specific, fixed escapement goals? (2) how well could those be determined? (3) how would 19 stock-specific escapement goals make it easier to manage fisheries given that many stocks will sometimes have returns below these goals?

LGL Response: Further clarification has been added to the report. What we are suggesting is similar to what is proposed under the WSP. We are recommending that a Limit Reference Point (LRP) and Target Reference Point (TRP) be defined by cycle year for each indicator stock. One difference between these reference points and those currently used by DFO is they may differ by cycle year. There should be at least two different LRPs and two TRPs for each cyclic stock, whereas for non-cyclic stocks, the values for each cycle year would likely be the same. There is ample data available to define these types of reference points/escapement goals and these efforts have been initiated in the recent CSAS working papers prepared by DFO (Grant et al. 2010). These escapement goals would make it easier to assess stock status and trends for each cycle year relative to these defined goals and determine if fisheries should be permitted to target specific stocks in a specific year. For example, if the run size is below the escapement LRP for a stock, no fisheries should be permitted to target that stock. These stock-specific goals could also be used to define the LRPs, TRPs and total allowable mortality (harvest plus natural mortality) for each run-

timing group that could be used in-season to manage fisheries. The LRP and TRP for a run-timing group would be the sum of the values for the component stocks. The total allowable mortality for each run-timing group should be based on the in-season assessment of the total return, environmental conditions and status of each stock relative to its LRP and TRP.

2. In some cases, the report makes observations that could be re-worded into recommendations. For example, P1L7-11 observes the "limited documentation for DFO catch monitoring programs…leaves substantial room for improvement…". This could be re-worded to suggest, for instance, what minimal documentation levels are needed for particular assessment and management functions. (One could continue this process of generating specific recommendations throughout the Executive Summary.)

LGL Response: We have modified our first recommendation as follows:

1. **DFO needs to ensure that all catch monitoring programs (First Nations, commercial, and recreational) have complete documentation and information on catch and annual survey effort is maintained in easily accessible databases so managers and decision makers are aware of changes and trends in catch and monitoring efforts.**

3. I found Table 20 particularly interesting. Why do forecasting models change every year? One could argue that forecasting models are being chosen at random. Presumably, in a given year, the model with the best retrospective performance is chosen, but the data are random and the past errors are random, so the "best" model will be chosen at random. This makes it hard to take any forecast seriously, not mention the challenges of predicting future forecasting performance.

LGL Response: As indicated in our report, DFO has adopted an approach where retrospective analyses are used to evaluate the performance of the various forecast models and determine the "best performing model" each year. This combined with the addition of new models to address issues such as declining trends in productivity and the poor performance of past models has resulted in more year to year variability in the "best performing model" in recent years. This is yet another reason for re-allocating the analytical effort used to prepare annual forecasts to some other more useful function.

4. The two separate issues of (1) escapement goals and (2) fishery operating procedures needs to be clarified in DFO, especially since management of Fraser River sockeye is going to get more complicated, not less, in the future. The terminology alone in the section on Current Escapement

Goals can easily generate confusion (generally not the fault of the report's authors): "escapement goals", "referent points", "benchmarks", "targets", "caps", "constraints", "cut-back-point", "no-fishing-point", etc. are even used interchangeably at times. I can see how the TAM rules would seem complicated to anyone outside (or even inside) the small group working on escapement goals. Table 24 says it contains "Operational reference points", but most of the contents really are not "operational" given DFOs interpretation of "benchmarks".

LGL Response: The term "operational reference points" is a term used in the Marine Stewardship Council (MSC) fishery certification process. We have removed this term from the Table 24 caption. The caption is now:

Table 24. Low escapement benchmarks for each indicator stock and fixed escapement targets by run-timing group as defined through the Fraser River Sockeye Spawning Initiative (DFO 2009b).

Most of the other terms are defined in Figure 15. On page 83 the reader is referred to Staley (2010) for a more detailed description of FRSSI and their terminology.

5. The report seems to make a recommendation (P96L27-29) to keep exploitation rates on Early Stuart sockeye below 13% to allow for rebuilding "if recruits-per-spawner improves". Although I agree with such a recommendation, the last part that I've quoted raises the question: what should be done if recruits-per-spawner does not improve? Is this possibly the next Cultus Lake sockeye situation?

LGL Response: We have added the following sentence to the report: "If recruits per spawner do not improve, ERs should be reduced to close to zero for this stock." There are a number of substantial differences between Early Stuart sockeye and Cultus Lake sockeye (location, run size, timing, overlap with other stocks, etc.) so the measures used to conserve and rebuild these stocks could be very different.

5. What information, if any, should be collected in the future to improve our understanding of this subject area?

What information should be collected in the future to improve our understanding of Fraser River sockeye fisheries and fisheries management?

Documentation of in-season decision-making processes (e.g., Fraser Panel) would allow for analysis of those decisions, improve our understanding of how limited scientific information is used in decision-making, and also improve our understanding of the non-scientific factors that influence harvesting decisions.

Sockeye salmon fisheries are destined to change in the future as higher priority is placed on First Nations and Wild Salmon Policy commitments. Finer-scale spatial and temporal resolution of harvesting decisions will be needed in an attempt to meet CU-specific escapement and harvesting objectives. Although the details are still unclear, these changes will generally require more intensive in-season and post-season information gathering. In-season information should include better stock-specific run timing, particularly early in the season where abundance forecasting errors are largest, yet most critical. Increasing in-river fisheries will require careful planning given stock-specific migration rates and spatial/temporal patterns of enroute loss.

LGL Response: We agree that two key focus areas for improvements in information are in-season abundance estimation and estimates of en-route loss. This information is needed to manage in-river fisheries under changing environmental conditions (e.g., water temperature and flow) and meet commitment related to FN agreements and WSP.

6. Please provide any specific comments for the authors.

The comments below are mostly for editorial or clarification purposes. I found quite a few typos and probably missed some, so I suggest some close proof-reading as well.

P5L34-36: This quasi-probabilistic interpretation of a confidence interval would irk most statisticians, … the Bayesians in particular.

LGL Response: The conventional expression of "confidence interval" is a range of values that we are 95% confident will contain our sample estimate. In our report we express our sample estimates of precision as a percentage of the mean, so we are effectively saying that we are 95% confident that our sample estimate is a value that is (say) 25% different from our mean; i.e., the 25% difference is contained by an upper and lower %value (our confidence limits). I guess this could lead to confusion (as a matter of semantics), to express % confidence for a % value, but since we defined our term as such there is nothing technically wrong.

There are several Table and Figure captions that could more accurately describe the contents being shown. In general, I did not find the table captions helpful in interpreting the tables; I usually had to carefully examine and interpret the headers, which were sometimes incorrect (Table 24 was notable).

Also, regarding tables summarizing accuracy, precision, and reliability, the "Total" row apparently shows averages of quality indices over fisheries (e.g., Table 2). I would remove those

Total rows from all these tables because I cannot see how one could make a decent attempt at averaging qualitative indices across such diverse fisheries.

LGL Response: The "Total" row reflects the quality of the estimates for the major components of the catch or the average of the quality rating for the different catch estimates. We agree that it is difficult to average qualitative indices across diverse fisheries, but these averages are useful for summarizing our findings. The addition of the "Total" row with average ratings does not detract from the other details provided in the report, so they have not been removed.

Personal communications typically require more information than what is presented in the report (e.g., (Ionson, pers. comm.)).

LGL Response: This was the only pers. comm. reference that did not have the individual's full name and affiliation. It will be expanded to "(Bert Ionson, retired DFO Aboriginal Fisheries Program Manager, Vancouver, BC, pers. comm.)".

List of typos and editorial comments:

P32L13: "follow" needs and "ing" **Response: Corrected.**
P34L1: The company is "…Marine Research…" **Response: Corrected.**
Table 15: insert "commercial" before "allocations" **Response: Corrected.**
Table 15: the table entries needs to be better explained in the caption. **Response: Corrected.**
Table 16: It would be interesting to show the % recreational of Fraser River fisheries.
Response: These %s are provided in the Table.
P45-50: Much of this section on Non-Retention Fisheries seems like academic review and chatter that could have been condensed and focused on a couple of main points. **Response: We were asked to describe and summarize the consequences of non-retention fisheries on sockeye physiology, survival and abundance. There is a fair amount of literature on sockeye physiology but few direct measures of the consequences fish capture and release on sockeye survival. Most of this section focuses on the results of a few recent studies that have provided some direct estimates survival for sockeye caught and released by anglers, beach seines, fishwheel and tangle nets.**
P53L18: insert "female" before "parents" **Response: Corrected.**
P53L19: substitute "from the ocean" in place of "to spawn" **Response: Corrected.**
P55L11-13: reword **Response: Corrected.**
P55L16: insert "middle" before "50" **Response: No, positive and negative confidence limits are not symmetrical, so 50 is not in the middle.**
P55L15-24: the text and figure captions explain the 25-75% interval differently, which made me

flip back and forth here. **Response: Text has been edited to be consistent with captions.**
P56-57: Figures 5-8 seem to show the same statistics, but the figure titles differ: some have "Precision" in the title and others have "Accuracy". The captions should also be re-worded to accurately describe the contents of the figure as well as providing an indications as to which years were Good, Fair, etc. **Response: Text has been added, figure titles have been corrected.** Finally, these figures are all cited out of order in the text. Figures 9-10 are cited first. **Response: Corrected.**
Figures: none of the color-schemes can be used when printed in black-and-white. **Response: We have kept the number of color figures to a minimum and adjusted several of the color figures so they can be interpreted if printed in black and white.**
P68L1-24: needs to be explained more clearly and consistently with Figure 11. The text says that estimates are biased low, but the figure shows errors that are positive. I can see that it is correct, but one needs to jump through some mental hoops to get on with interpreting the results shown in the figures. **Response: Corrected.**
P73L12: delete one of the "in September"s. **Response: Corrected.**
P74L19: replace "bean" with "beam" **Response: Definitely.**
P75L17: "throughout"? **Response: Corrected.**
P78L1: does "exceeded by a considerable margin" mean that precision was < 25%? **Response: Clarified.**
P79L38: insert "wide" after "m" **Response: Corrected.**
P82L31-32: Is this statement correct, or do I misunderstand it? Capping the exploitation rate means that there is no upper bound to escapement. **Response: Corrected.**
Table 24: change "run size" to recruitment and "log" to "logarithm". **Response: This table was extracted from a DFO report so the headings were not changed.**
Table 25: indicate the units (1,000s of fish). **Response: Corrected.**
Figure 21: the caption should re-state that enroute losses were not estimated prior to 1992. **Response: Corrected.**
P100L3: why has "Sockeye" suddenly become capitalized everywhere? **Response: Corrected.**
P100L28-29: I would delete "with certainty" here, unless one knows the long-term gains, but is just uncertain. **Response: Corrected.**
P101L11-12: I think that Bradford is just being honest, not pessimistic. **Response: edited.**
P103L25: This short section on Recovery Objectives should appear at the beginning of this section on P100. It would have provided some important context for the section. **Response: edited.**

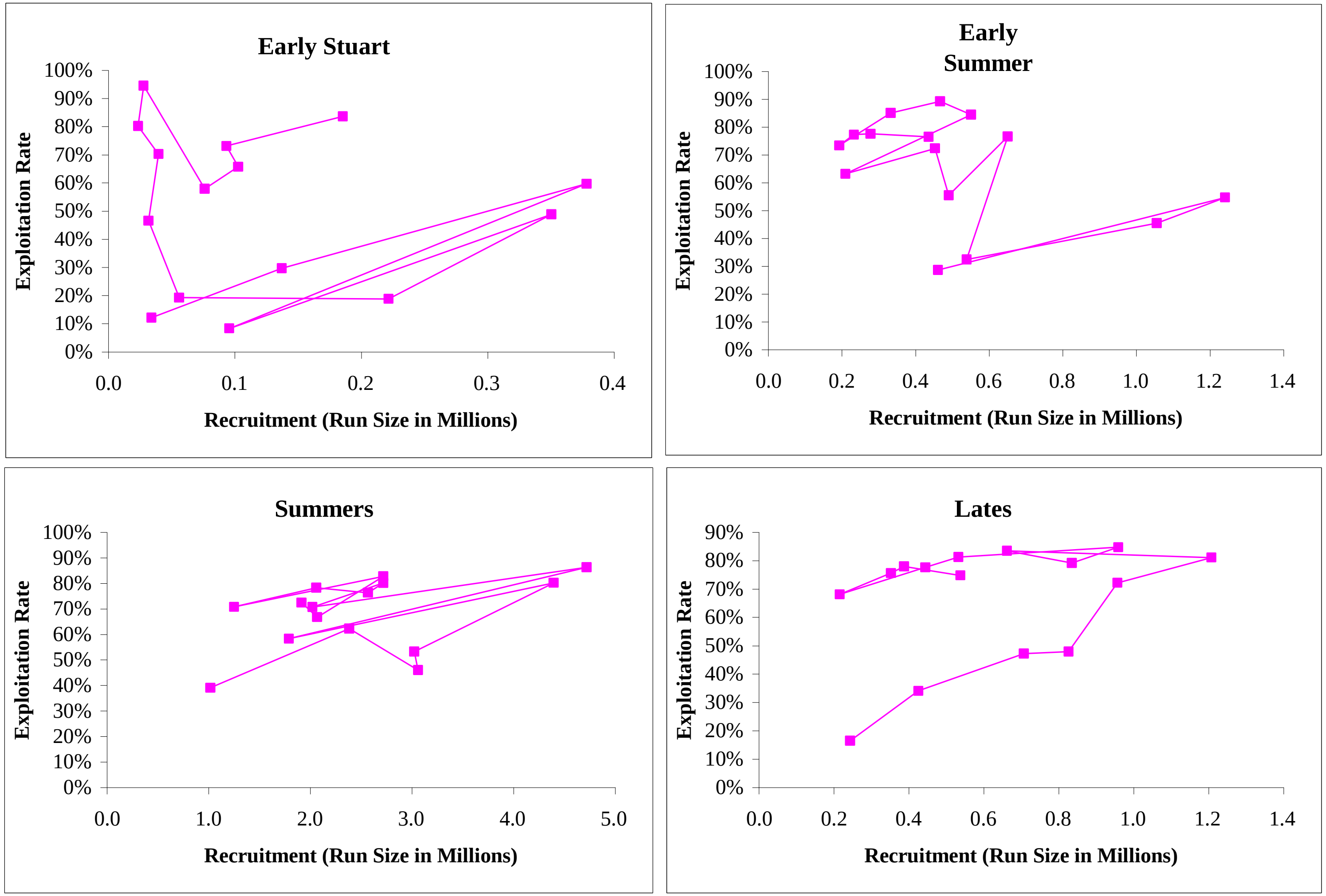

Figure Cox -1. Time-series plots for the 2004 cycle year for each run-timing group. Each time series is 1952-2008 where the highest exploitation rates occurred in the first years of each time series.

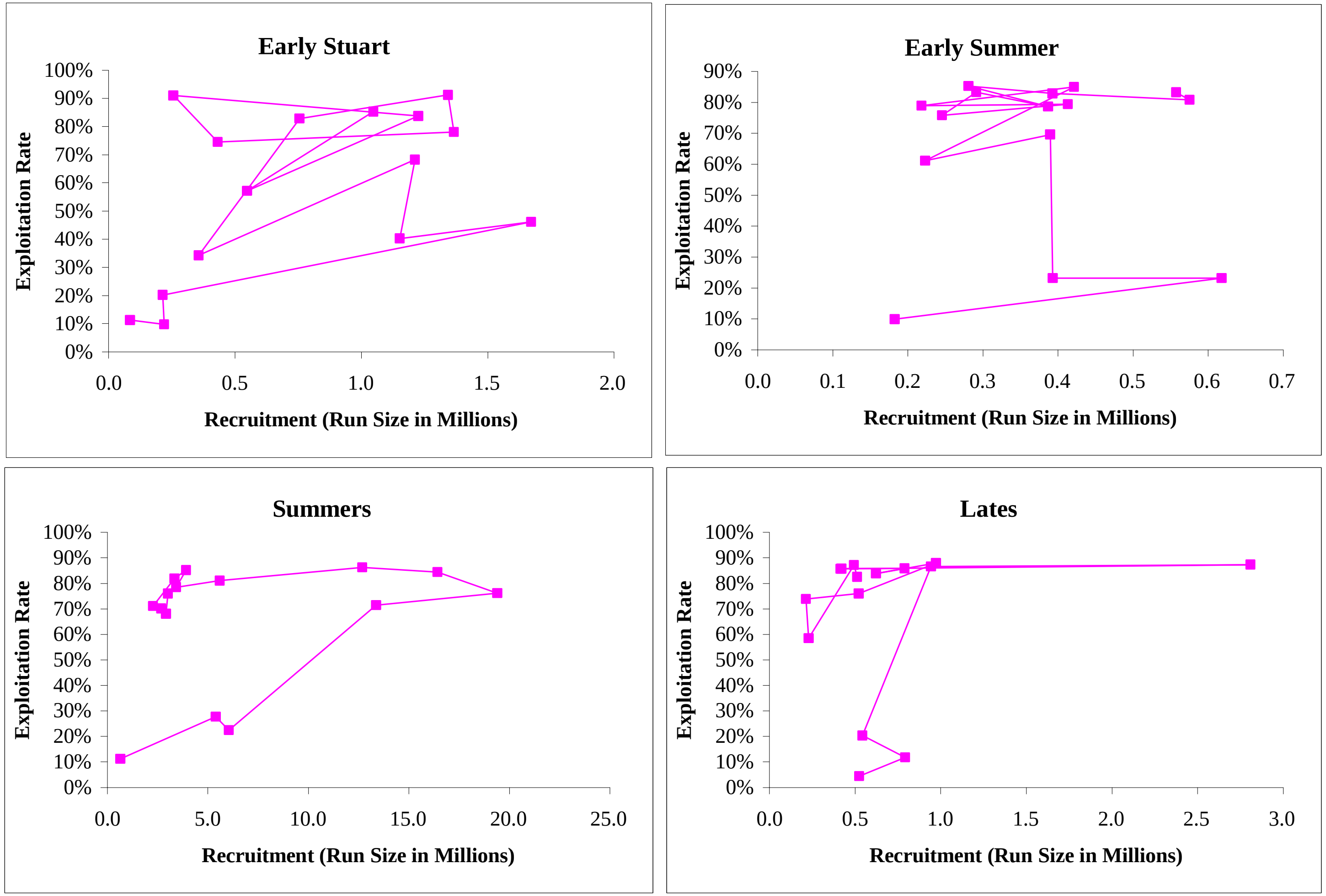

Figure Cox -2. Time-series plots for the 2005 cycle year for each run-timing group. Each time series is 1953-2009 where the highest exploitation rates occurred in the first years of each time series.

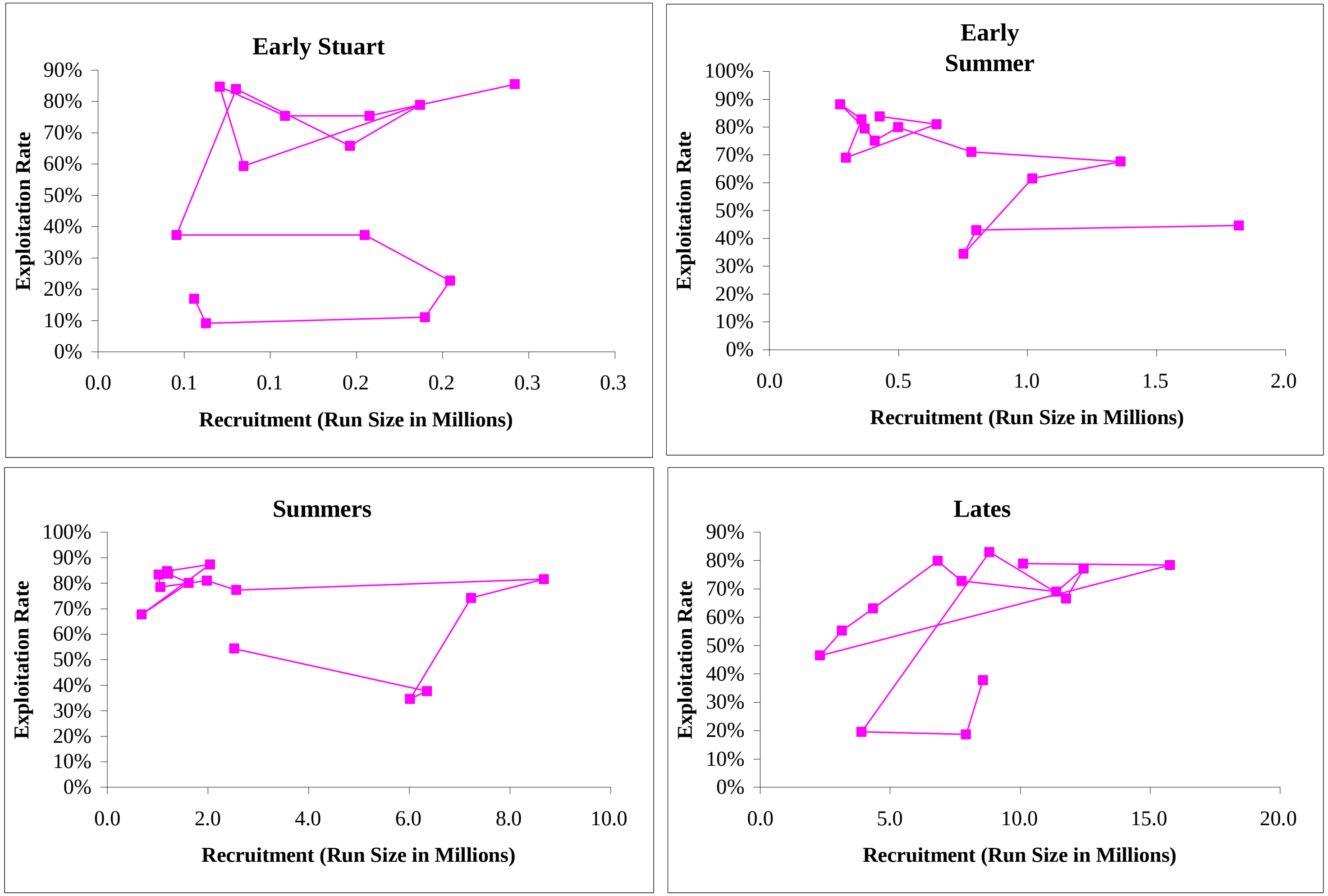

Figure Cox -3. Time-series plots for the 2006 cycle year for each run-timing group. Each time series is 1954-2006 where the highest exploitation rates occurred in the first years of each time series.

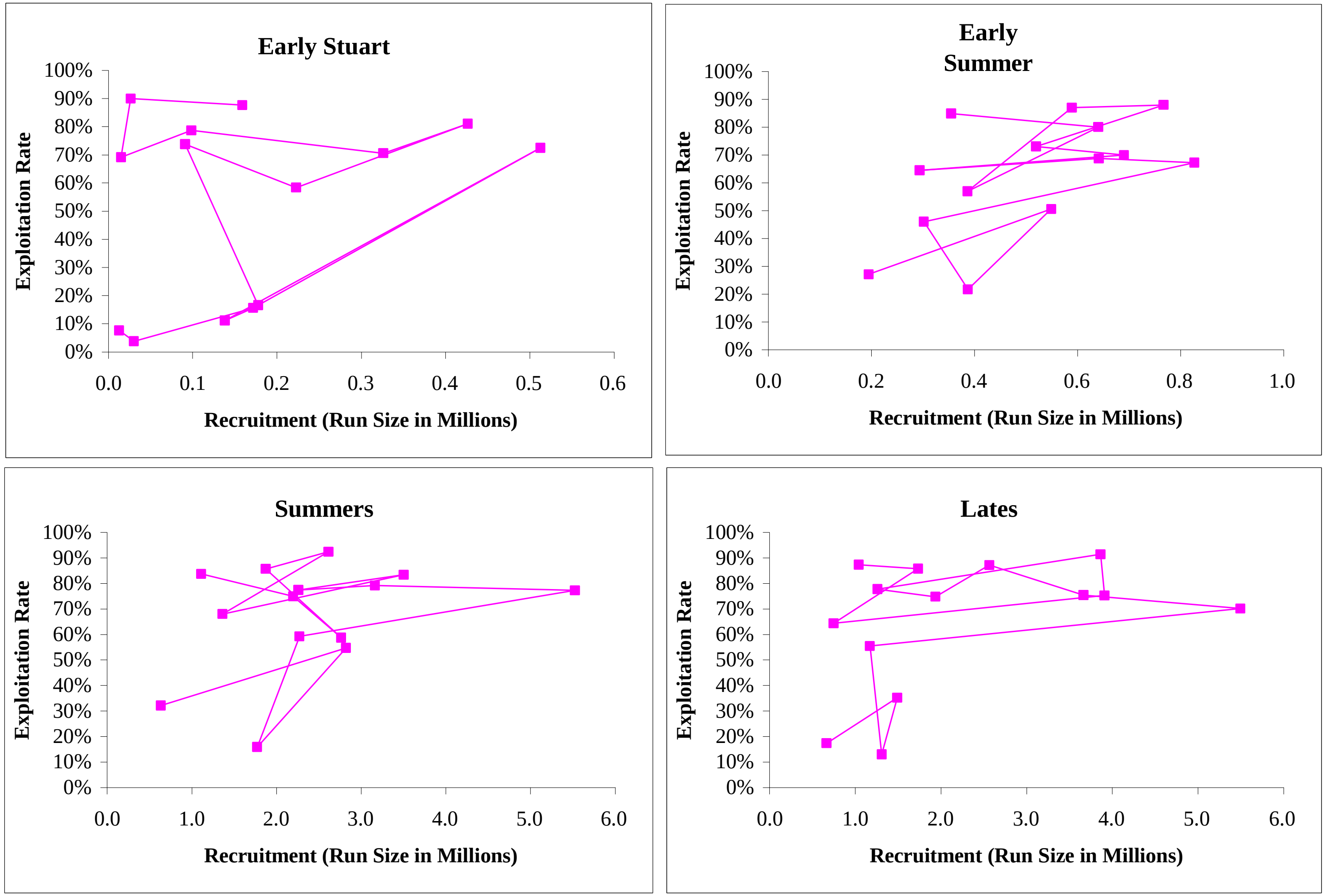

Figure Cox -4. Time-series plots for the 2007 cycle year for each run-timing group. Each time series is 1955-2007 where the highest exploitation rates occurred in the first years of each time series.