Stuart Area Sockeye Salmon Runs and their Importance to the First Nations of the Upper Fraser River Watershed

Prepared by:

David Levy, James Woodey[1] and Lisa Hardy
Upper Fraser Fisheries Conservation Alliance
1041 Whenun Road
Prince George, B.C.
V2K 5X8

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[1]Fisheries Consultant
887 – 254th Street
Aldergrove, BC V4W 2R8

Preface

Life is a copiously branching bush, continually pruned by the grim reaper of extinction, not a ladder of predictable progress

Stephen Jay Gould

After many lean years and many frustrating meetings, and after hearing the elders of the Carrier Sekani Tribal Council express their fears about the dwindling sockeye runs in the Stuart River, the Upper Fraser Fisheries Conservation Alliance decided to tackle the job of preparing a Stuart sockeye stock status report. The completion of this report is no small feat given the current plethora of demands on First Nations organizations. The UFFCA found both the resources and the person capable of writing the report, Dr. Dave Levy. I believe that Dr. Levy has undertaken the work with integrity and has prepared the report with a focus on the First Nations peoples who are the most affected,

The purpose of this report as I see it is to document the current state of the Stuart sockeye runs and to draw a parallel between the current precarious state of the run to the growing sense of despair, fear, and urgency felt by the Native people in whose territory the Stuart sockeye spawn. The people of this region have had a long relationship with the sockeye based on spiritual values of connectedness and respect; the fish have provided food for social and ceremonial (spiritual) purposes for centuries, and as the run continues to decline so to does the spirit of the people who have relied for millennia on this bounty.

While this report may seem stark it is direct in its approach and is both engaging and startling. I found it accessible for anyone with an interest in conservation. In short I find the report refreshing, in a dark way. The fact is, we may be witnessing the extinction of a once large and highly valued species of sockeye on the Fraser River. It is my hope the recommendations contained in this report coupled with the passion of the Carrier people to preserve this species will lead to conservation of these sockeye for generations to come.

Since the decline became apparent, the Carrier people have done their part for conservation to little avail. Even as this report is being prepared the Stuart people are once again being asked to stay out of the water to protect the few returning Stuart sockeye, a scenario that repeats itself year after year, further demoralizing the people.

The report also raises the issue of climate change, and while this may not be the only limiting factor, it is affecting every stage of the life cycle of these animals, from the fry to the adult stage, and from the lakes and streams to the marine environment. Climate change may turn out to be the single greatest factor contributing to the Stuart sockeye decline and the sad fact is that this is one variable we have little control over. I should note that there are still a lot of unknowns and that this report marks a very important beginning to what I hope will be an ongoing body of much needed work to further understand and rectify the situation.

Marcel Shepert
Chairman and Facilitator
UFFCA

Executive Summary

Early and Late Stuart sockeye are two of the most vulnerable salmon populations in the Fraser River by virtue of their extended migration distance covering 1200 km from the Fraser River mouth. The fish are highly valued by the First Nations from the Upper Fraser who depend on the runs for food, social and ceremonial purposes. Since the late 1990's, both populations have declined severely and there are major concerns about the future survival of these sockeye runs.

The Upper Fraser Fisheries Conservation Alliance undertook this review to summarize the status of Early and Late Stuart sockeye and to analyze the causes for the declines. Since 1938, Early Stuart escapements have fluctuated in abundance, and low escapements occurred during the 1950's and 1960's. The population re-bounded during the 1970's and 1980's, but has declined steadily since the mid-1990's. The main factor in the recent demise of the population has been a crash in the Driftwood River population that started in 1997.

Explanations that could account for the population declines were systematically evaluated. The results are summarized below:

Explanation	**Likelihood**	
	Early Stuart	**Late Stuart**
Overharvesting	Unlikely	Uncertain
Spawning and Egg Incubation Conditions	Unlikely	Unlikely
In-lake Conditions	Unlikely	Unlikely
Competition with Kokanee	Uncertain	Uncertain
Logging	Uncertain	Uncertain
Pollution	Highly unlikely	Highly unlikely
Migration Conditions and In-River Mortality	Highly likely	Likely

The main conclusion of the review is that adverse migration conditions and high in-river mortality are largely responsible for the reduced abundance of Early and Late Stuart sockeye. Early Stuarts can only migrate effectively in a window defined by the descending limb of the flow hydrograph at the front end of their migration, and the ascending limb of the thermograph at the back end of their migration. High temperatures have also caused physiological stress for Late Stuart sockeye that has reduced survival and production.

Adverse migration conditions will likely deteriorate further with ongoing climatic warming in the Fraser River. Additional biological studies are recommended in the three main nursery lakes to provide a basis for experimental lake fertilization targeting the Early Stuart sockeye. Mitigation of the physical conditions (flow and temperature) does not appear to be feasible and it is unlikely that the runs will be able to sustain the food, social, and ceremonial needs of Upper Fraser First Nations. It is recommended that sharing arrangements be developed to access more abundant sockeye runs from Babine Lake and/or the Chilko/Adams/ Horsefly runs on their dominant cycle years. It is further recommended that Early and Late Stuart sockeye be formally listed as endangered under COSEWIC and SARA so as to protect the populations in future.

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1. Introduction

First Nations throughout the British Columbia region strongly identify with sockeye salmon from the Stuart Lake system. The Early Stuart run is revered as the first sockeye run that returns to the Fraser River. The fish have a high fat content, making them a prized food fish, and they serve as an integral component of First Nations culture. These sockeye are especially important to Upper Fraser River First Nations as they are the main source of food fish. Fishing for Stuart Lake sockeye, both Early- and Late-Run has taken place since time immemorial, and there are a variety of traditional fishing practices that have been developed to harvest and process the catches (Figure 1.1).

Figure 1.1. Fish trap called a Tehskai for use in lakes. Photo taken at Fort St. James circa 1891.

Both Early and Late Stuart sockeye have been severely depleted in recent years and fisheries have been curtailed, causing hardship and dissatisfaction within numerous communities. First Nations in the Upper Fraser have been most strongly affected by the downturn in the runs and the associated conservation closures. The Takla Lake First Nation is especially vulnerable to the decline of the Early Stuart sockeye, as these fish are the only sockeye available for harvesting. Tl'azt'en and Nak'azdli First Nations are also highly vulnerable as they are largely dependent on Early and Late Stuart sockeye to provide fish for food, social and ceremonial purposes.

The Stuart Lake watershed consists of three large interconnected lakes and associated tributary streams located in the northwestern portion of the Fraser River watershed between the eastern slope of the Coastal Range and the western extent of the Interior Plateau (Figures 1.2 and 1.3). Two major sockeye stock complexes, termed Early Stuart and Late Stuart sockeye, utilize the spawning and lake rearing habitats for incubation and early growth. Early Stuart sockeye migrate and arrive in terminal fishing areas approximately one month before Late Stuart sockeye and spawn in the upper portion of the Stuart Lake watershed in smaller streams tributary to Takla and Trembleur Lakes and Middle River. Late Stuart sockeye spawn in the rivers between lakes, i.e., Middle and Tachie Rivers, and in tributaries to both these rivers, i.e., Kazchek, Kuzkwa and Pinchi Creeks. Figure 1.4 identifies the streams where Early and Late Stuart sockeye are present.

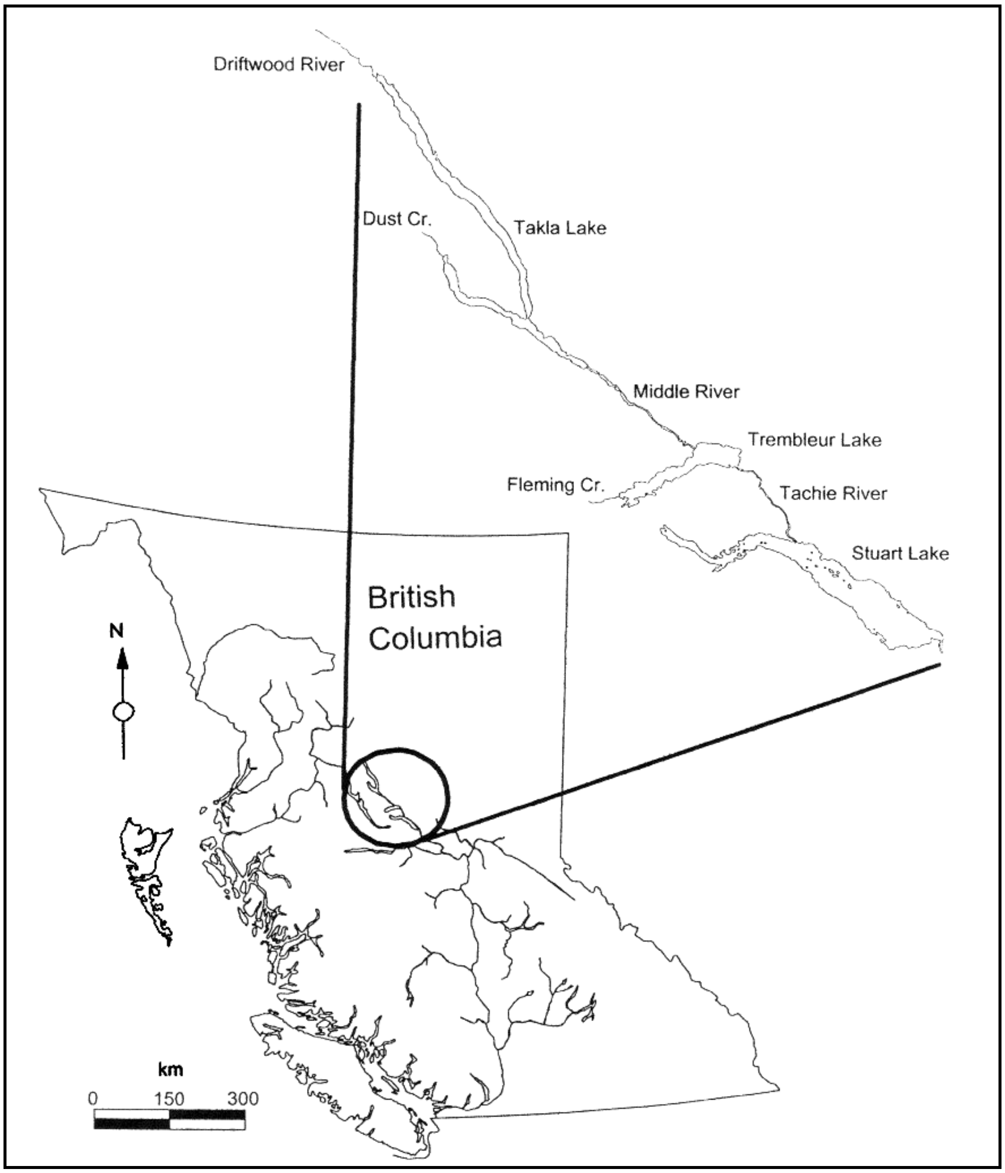

Figure 1.2. Location of the Stuart Lake system in northern British Columbia.

Figure 1.3. Satellite image mosaic for the Stuart/Takla area. Babine Lake (Skeena River) appears to the left of Stuart, Trembleur and Takla Lakes. Clear cut areas show up as white patchwork patterns on the landscape.

The differentiation between Early and Late Stuart sockeye reflects differences in spawning timing, as shown in the Table below, as well as differences in the locations of spawning tributaries (Figure 1.4).

	Early Stuart	**Late Stuart**
Peak Spawning 2006	Aug. 6-18	Sep. 15-31
Spawning Tributaries	Small streams (many) • Middle R. tributaries • NW Takla Lake	Lake outlet streams (few) • Middle R. • Tachie R.
Escapement 2006	35,600	28,200

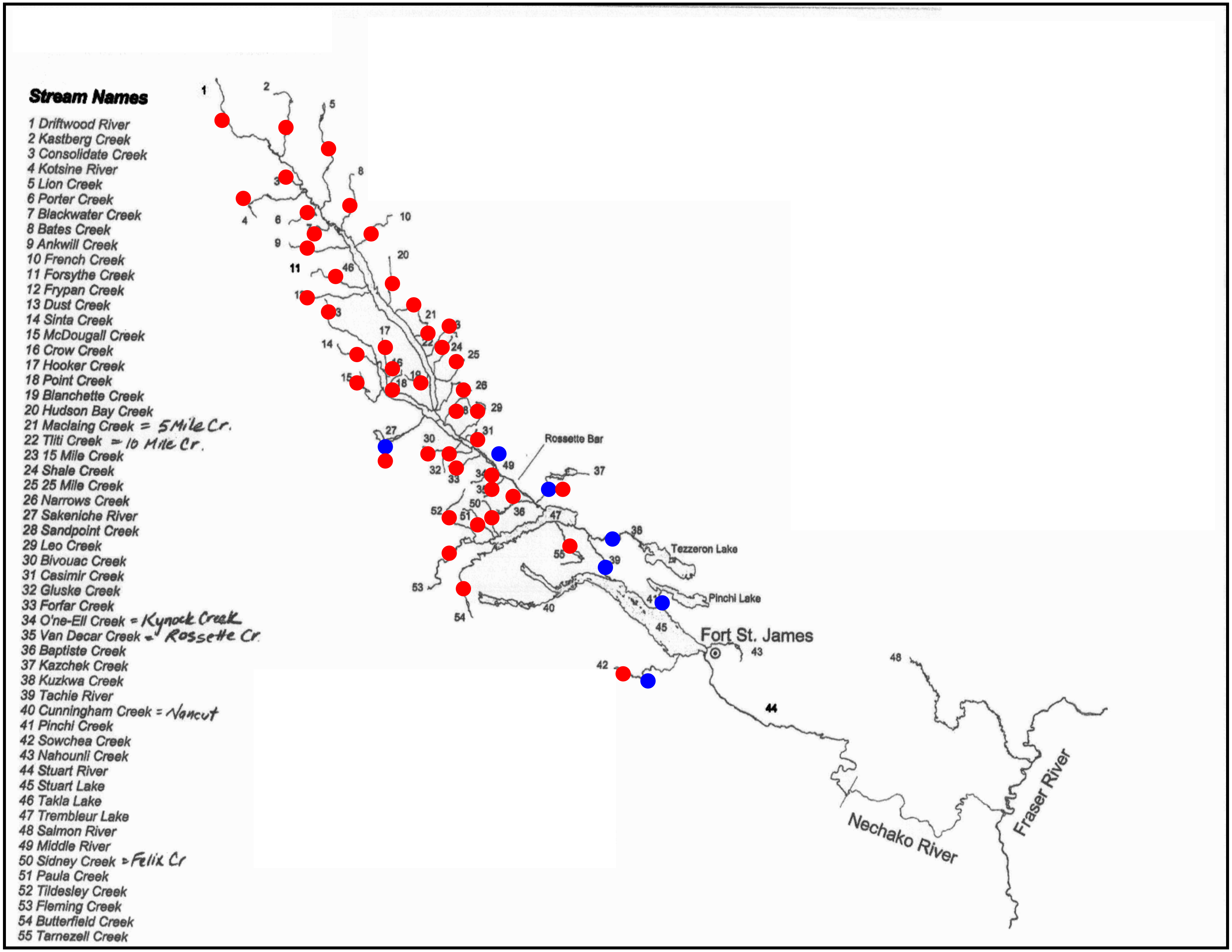

Figure 1.4. Distribution of Early Stuart (red dots) and Late Stuart (blue dots) sockeye in the Stuart Lake system.

The Upper Fraser Fisheries Conservation Alliance (www.uffca.ca) was formed to undertake co-operative management for the protection of fish species and the ecosystem upon which fish depend. This is accomplished by taking an integrated approach with Aboriginal organizations in the Upper Fraser River, federal and provincial governments and, where appropriate, other parties with an interest in fish. The following Aboriginal Governments and Tribal Councils are either members, or qualify for membership, in the UFFCA:

T'exelc (Williams Lake First Nation)
Stwecem'c Xgat'tem (Canoe Creek First Nation)
Tsq'escen (Canim Lake First Nation)
Xats'ull Cmetem' (Soda Creek First Nation)
Cariboo Tribal Council
Lhoosk'uz (Kluskus First Nation)
Lhtako (Red Bluff First Nation)
Ndazkho (Nazko First Nation)
Tl'esqox (Toosey First Nation)
Ulkatchot'en (Ulkatcho First Nation)
Carrier-Chilcotin Tribal Council
Wet'suwet'en First Nation
Burns Lake First Nation
Stellat'en First Nation
Nadleh Whut'en First Nation
Saik'uz First Nation
Takla Lake First Nation
Nak'azdli First Nation
Carrier Sekani Tribal Council
Xeni Gwet'in (Nemiah First Nation)
Yunesit'in (Stone Indian First Nation)
Tsi Del Del (Alexis Creek First nation)
Tl'etinqox (Anaham First Nation)
Esdilangh (Alexandria First Nation)
Tsilhqot'in National Government
Esketemc First Nation
Lheidli T'enneh First Nation
Tl'azt'en Nation
Yekooche First Nation

To inform the members of the UFFCA, the present report was prepared to evaluate the status of Early and Late Stuart sockeye populations, with a view towards clarifying the causes underlining the declines and determining what the UFFCA can do about it. The report was researched and prepared by Dr. David Levy, Habitat Biologist for the UFFCA, Dr. James Woodey, former Chief Biologist of the Pacific Salmon Commission, and Lisa Hardy, Fisheries Biologist Trainee with the UFFCA.

2. Status of Early and Late Stuart Sockeye

The number of sockeye which reach their spawning ground is called the escapement. DFO (and formerly the Pacific Salmon Commission), with the assistance of First Nations, collect annual escapement information to monitor the populations. Enumeration methods have included counting fences, streamside visual inspections, and aerial overflights. Four enumeration fences are presently operated, three in the Middle River area (Gluske, Forfar and Kynoch Creeks) and one in a tributary that flows into the NW area of Takla Lake (Dust Creek). A comparison of these escapements (known from the fence counts) with the observations from foot surveys conducted above the fences permits the calibration of visual observations and the calculation of escapement for the other populations. Recent escapement records are shown in Figure 2.1.

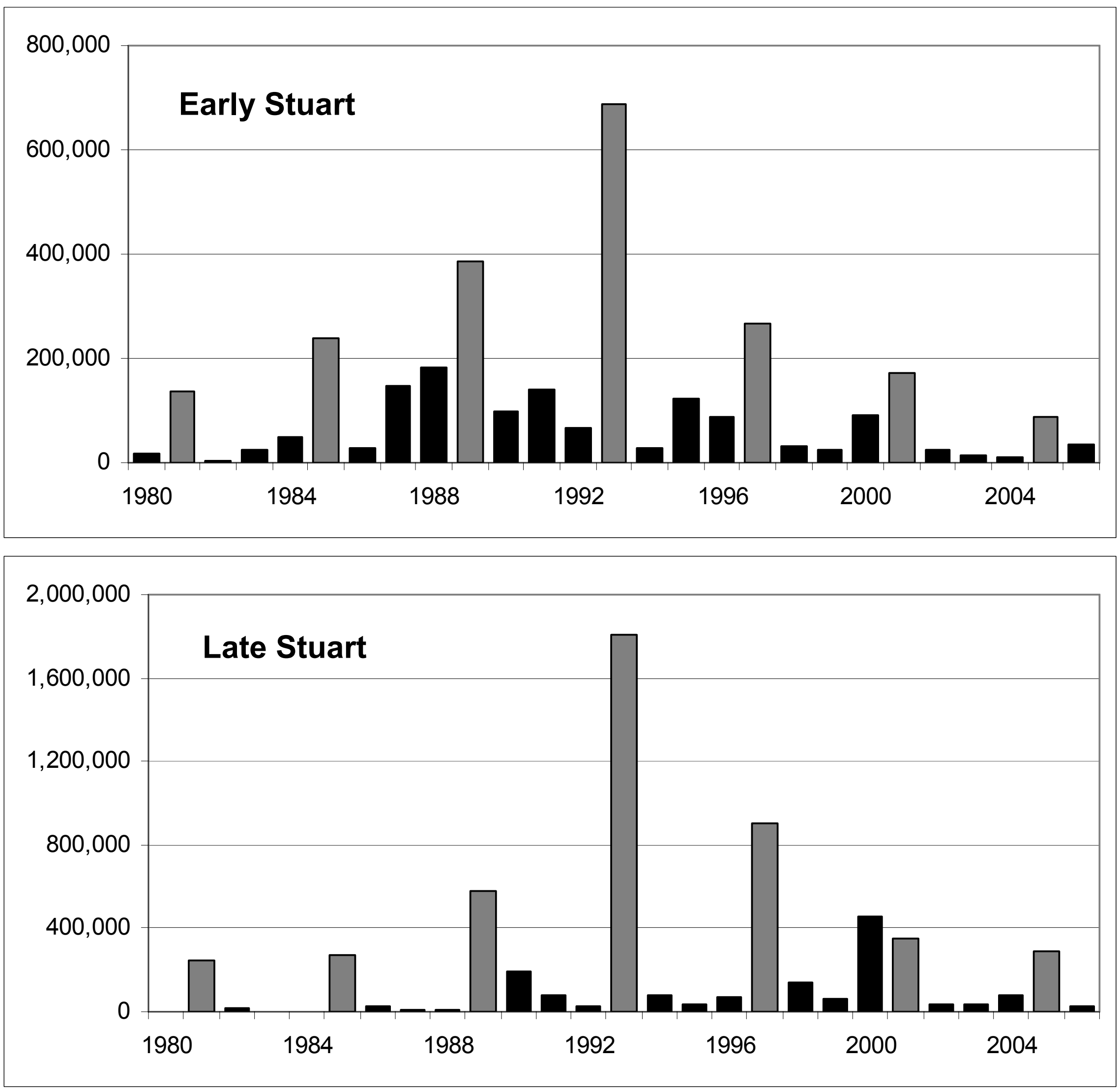

Figure 2.1. Recent Early and Late Stuart sockeye escapements, 1980 to present. Dominant cycle lines are shaded gray.

The time series shown in Figure 2.1 is a great source of concern. For both Early and Late Stuart sockeye, escapements built up and reached a peak in 1993. Since that time, there has been a steady decline in spawner abundance such that in 2006, escapement of Early and Late Stuart sockeye was 36,000 and 28,000 fish respectively. Both populations are strongly cyclic and display population behavior known as cyclic dominance (Appendix 3). It is therefore necessary to compare these values with escapements on similar cycle lines (i.e. 2006 with 2002, 1998, 1994, etc.). This comparison is shown in Figure 2.3.

Early and Late Stuart sockeye have one of the longest escapement time series in the Fraser River watershed. The available Early Stuart escapement information since 1938 (Figure 2.2) provides a longer term perspective on the status of the population. Following the Hell's Gate slide in 1913, and until the late 1940's, escapements were very low, numbering between hundreds to tens of thousands. Thereafter in 1949, there was an escapement of 580,000. The 1950's were a period of moderate production, with escapements reaching tens or hundreds of thousands. During the 1960's the escapements were low, and considerably below present levels. Escapements increased substantially between 1969 through 1993 when they peaked at 688,000. Thereafter there has been a steady decline that puts the present escapement at levels last seen in the 1960's and 1970's.

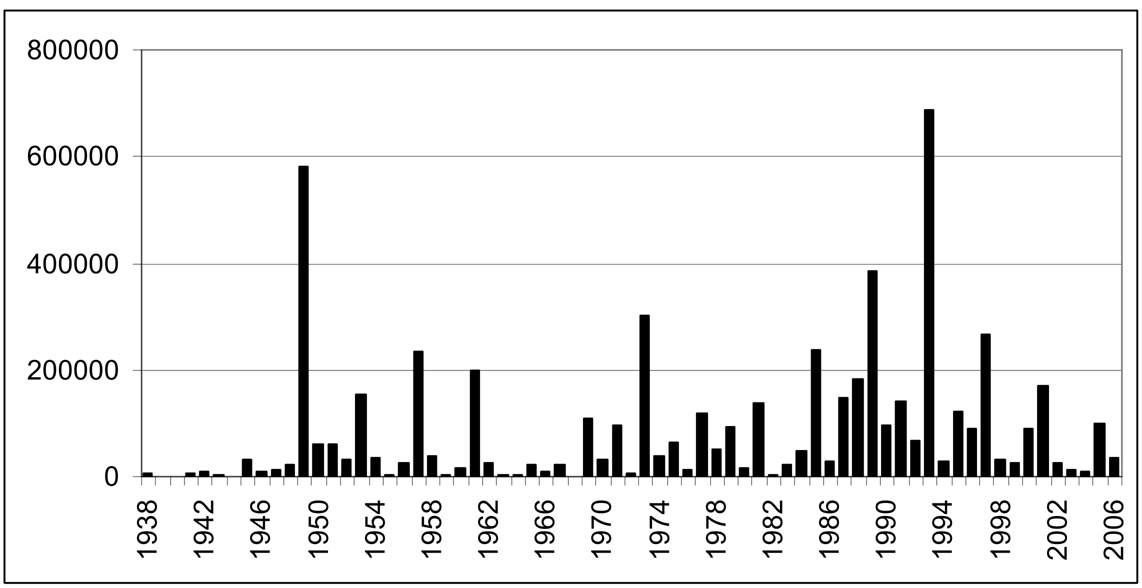

Figure 2.2. Early Stuart sockeye escapements, 1938 to present. Source: DFO.

Consideration of the longer duration escapement time series in Figure 2.2 suggests:

1. there has been a significant decline in Early Stuart escapement since 1993;
2. a similar decline took place during the 1950's and 1960's;
3. the population rebounded during the 1970's and 1980's.

In conclusion, the Early and Late Stuart sockeye populations are presently in decline, and there is justifiable concern about the depressed status of these stocks, especially in view of recent environmental changes associated with climate change. A similar pattern of decreasing escapements of Early Stuart sockeye also occurred during the 1950's and 1960's during a period of high commercial fisheries exploitation. The fact that the population rebounded during the 1970's and 1980's indicates that it probably still has the capacity to rebuild, if and when the negative impacts on the population are removed. Section 4 evaluates different causes for the present declines.

When disaggregated by cycle line (Figure 2.3) the Early Stuart data clearly show a decline in the 4 populations since the late 1980's. The 2007 cycle line shows the greatest percentage decrease, while the 2005 cycle line (the dominant line) shows the greatest decrease in absolute magnitude. Leaving aside the high 1990 escapement value, the 2006 line appears relatively stable. The 2004 cycle line has also shown a sharp decrease in escapement since the peak value in 1988.

Late Stuart sockeye also show a decrease from the late 1980's and early 1990's (data shown in Appendix 2). However escapement levels are similar or greater than those shown in the 1960's and 1970's. As with Early Stuart sockeye, if the negative influences on the population can be mitigated, there is a chance that the population will recover to the higher levels seen in the 1980's and 1990's.

The Driftwood River sockeye population was formerly the most abundant component of the Early Stuart stock complex, reaching an escapement of over 400,000 fish in 1993 (Figure 2.4). This population subsequently crashed and accounts for most of the Early Stuart decline. Other populations have also declined, but the extent of the decrease is not as severe. In order to rehabilitate the Early Stuart population, it will be necessary to kick-start the Driftwood River population if overall numbers are to return to their former levels.

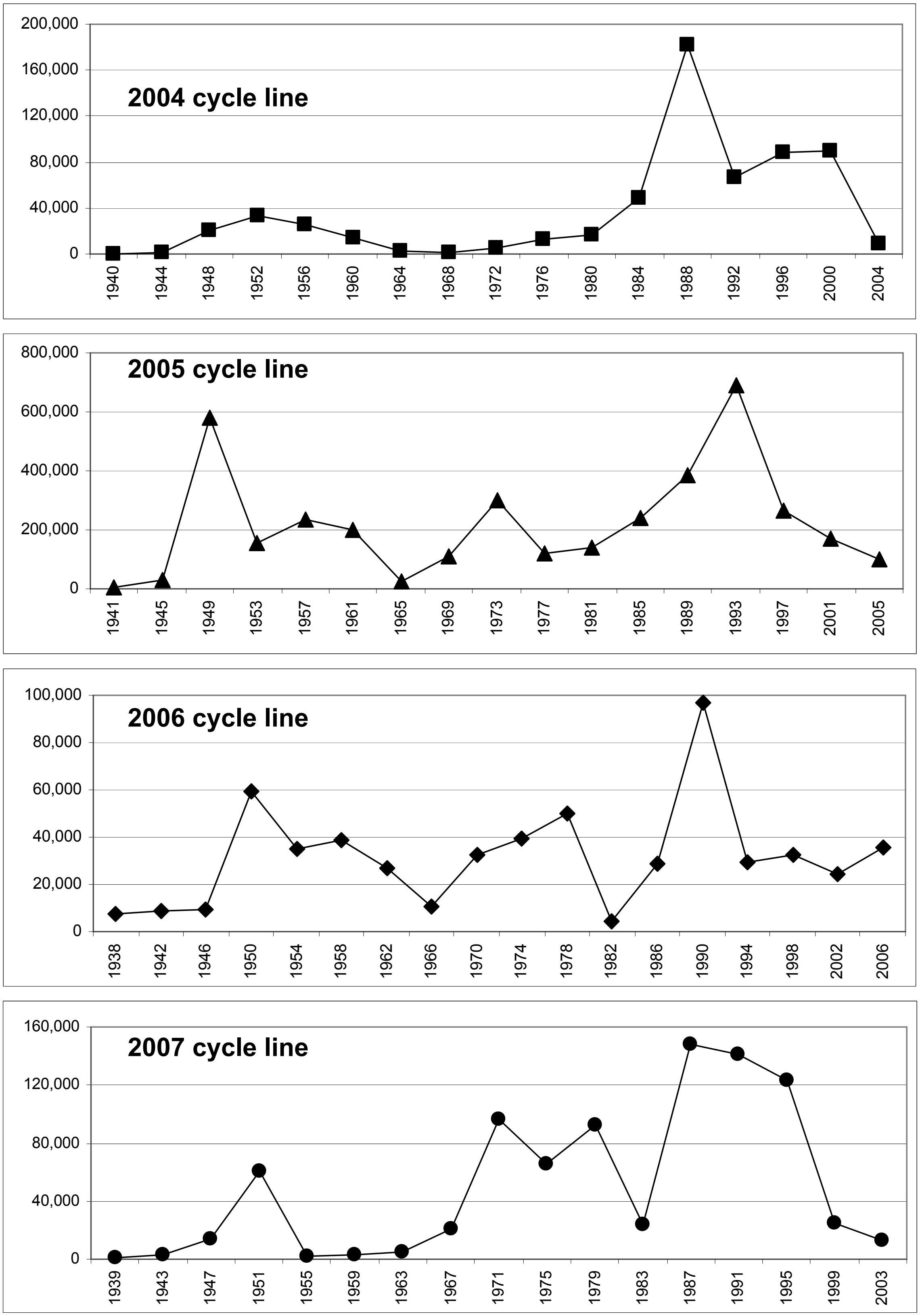

Figure 2.3. Early Stuart escapement time series from 1938 to the present. Note different y-axes on the 4 graphs; 2005 is the dominant cycle line.

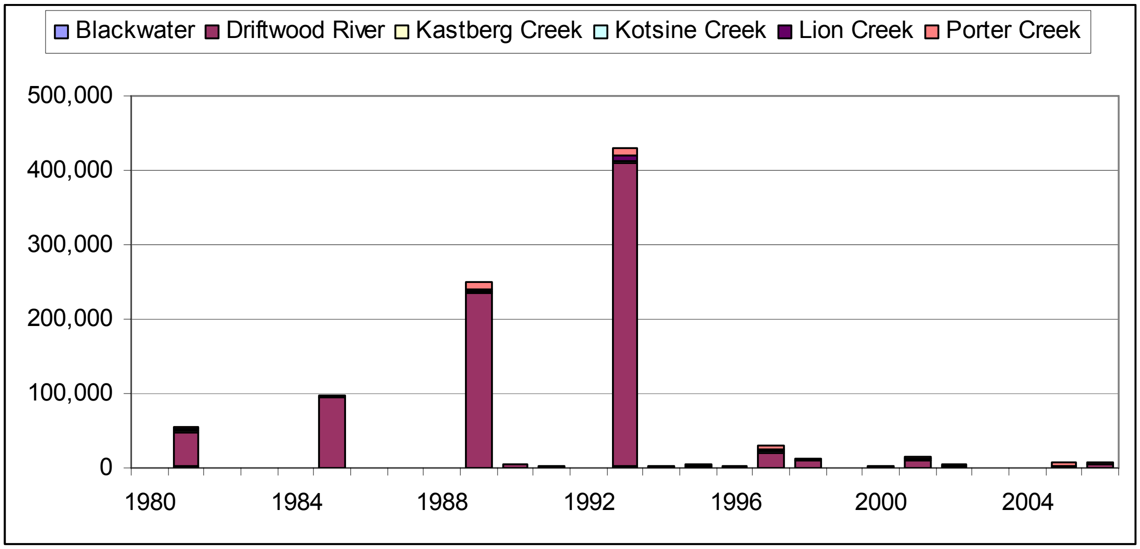

Figure 2.4 Time series of Driftwood River escapements.

Why has the Driftwood population declined severely? This may be related to migratory blockages in 1997 (Section 4; Appendix 3) and a migration timing that made the population especially vulnerable to these impacts.

Due to the use of counting fences, the Early Stuart population can be enumerated fairly reliably compared to other systems which rely on periodic streamside visual inspections. However, escapement data need to be interpreted with caution due to inherent inaccuracies. A more complete indicator of population abundance is total return (Figure 2.5) which is the sum of catch, escapement and in-river mortality. The return data below also reflect the post mid-1990's decrease in both the Early and Late Stuart populations. Of note in the Early Stuart return data is the substantial increase in en-route losses associated with the environmental conditions during upstream migration. These trends are further evaluated in Section 4.

In conclusion, it is apparent that Early and Late Stuart sockeye have declined since the 1990's, in some cases severely (Driftwood River population). Viewed from a longer term perspective, the populations went through similar fluctuations during the 1960's and 1970's, suggesting that recovery may be possible provided that harvest rates are kept low and that environmental conditions remain suitable. This includes conditions in the marine environment, conditions during upstream migration, and conditions within the freshwater incubation and nursery habitats.

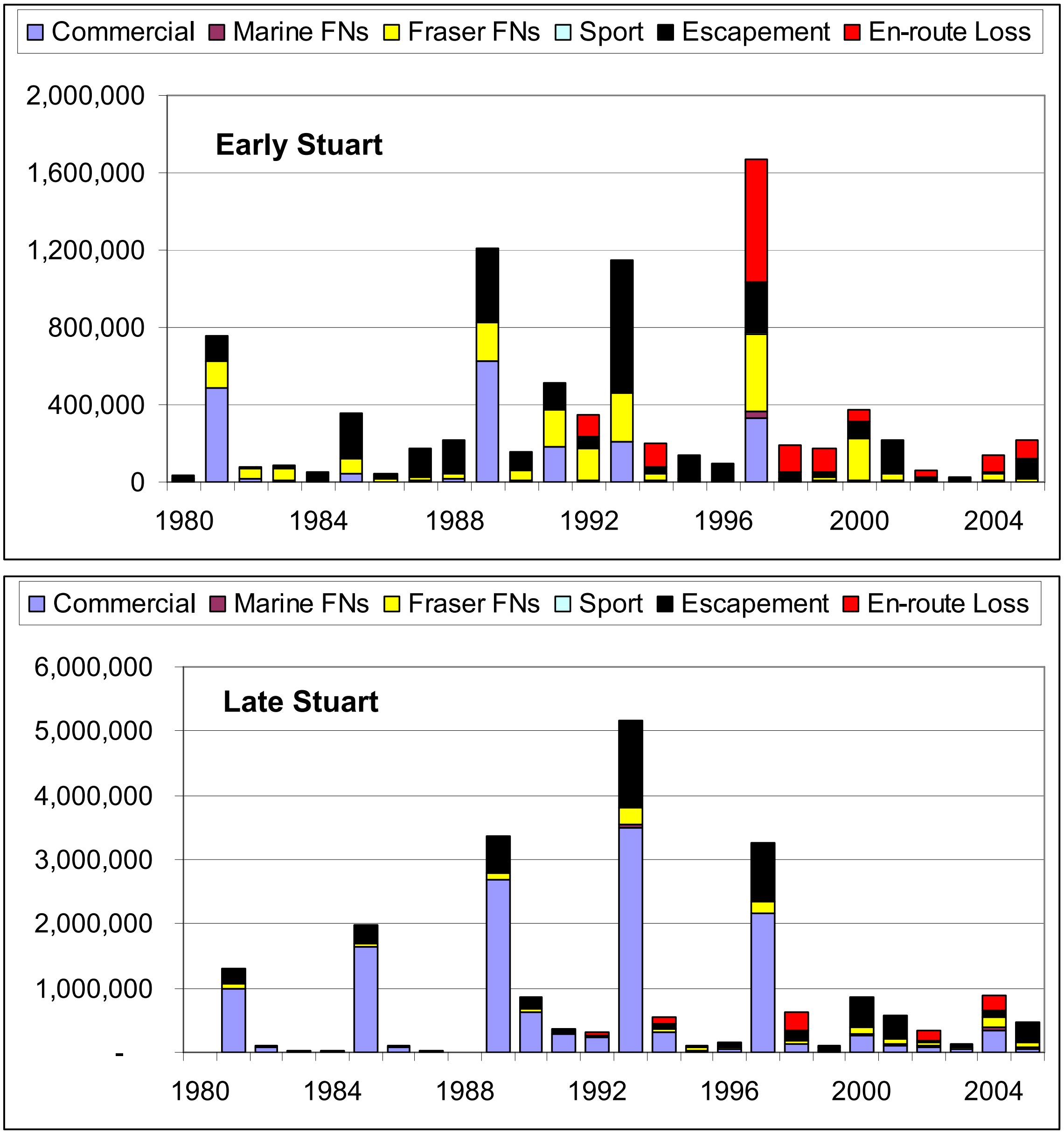

Figure 2.5. Time series of total return data for Early and Late Stuart sockeye.

3. First Nations Food, Social and Ceremonial Use

Much of the information presented in this section of the report was provided by Chief Thomas Alexis, Tl'azt'en Nation. Photos originate from the BC Archives; several were taken at Fraser Lake and illustrate fishing activities that are (were) also practiced in the Stuart Lake system. The Carrier people and Tl'azt'en have extensive knowledge of the timing and habits of the various fish species in the traditional territory and developed appropriate technologies to harvest these resources. The fishing practices, coupled with investments of labour, resulted in successful fishing seasons for thousands of years.

Figure 3.1. Cottonwood dugout canoe in Fraser Lake circa 1908.

Figure 3.2. Woman cleaning salmon at Stuart Lake August 1909.

Figure 3.3. Salmon weir at Fraser Lake October 1903.

Figure 3.4. Smokehouse where the fish are hung during the first stage of processing. Roof is constructed from spruce bark.

Sockeye salmon is the single most essential item for food and subsistence for the Tl'azt'en and the Carrier people; several different methods of catching them were developed. Weirs and traps were the most productive the fishing devices and allowed for large quantities of salmon to be taken during peak migration periods. Fishing methods varied according to location.

Effective conservation of the sockeye runs was achieved by constructing weirs 10 days after the first fish observed. This time lag allowed the first part of the run to reach the spawning grounds and also provided for upstream fishers.

Several types of traps were designed specifically for capturing Sockeye salmon. They were constructed with an open trellis or lattice made out of split fir, spruce or pine; these were all tied together by spruce roots. The fisherman in Figure 3.5 is shown holding a two-pronged gaff. A fish trap is shown in the background.

Figure 3.5. Local fisherman from the Stuart Lake watershed.

There were at least seven types of traps that were utilized for catching sockeye and other fish species:

- Weir-Es (two types)
- Nazgwet – funnel like fish trap
- Kes – tube like fish trap
- Yetaskai – live box
- Koonsai – partial weir with a live box
- Teskai – dip net
- Tehskai – coffin shaped trap for low water (see Figure 1.1)

The Es trap (Figure 3.6) was fished under high water conditions and in strong currents. It was a toboggan-shaped trap that was used as a partial weir. The trap required minimal attention and only required emptying when full.

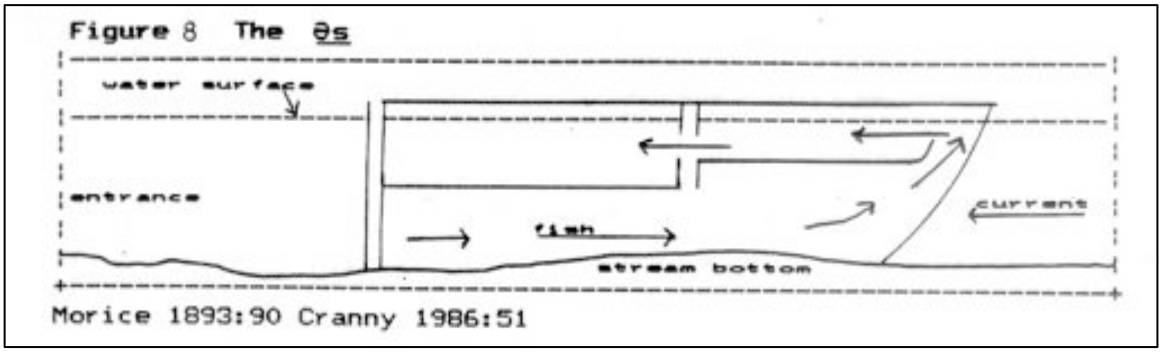

Figure 3.6. Sketch of an Es trap.

Under low water conditions, weirs (Figure 3.7) were constructed to block small streams. They were used in conjunction with fish traps, and required constant attention. A photo of a weir that was used in conjunction with a fish trap is shown in Figure 3.8.

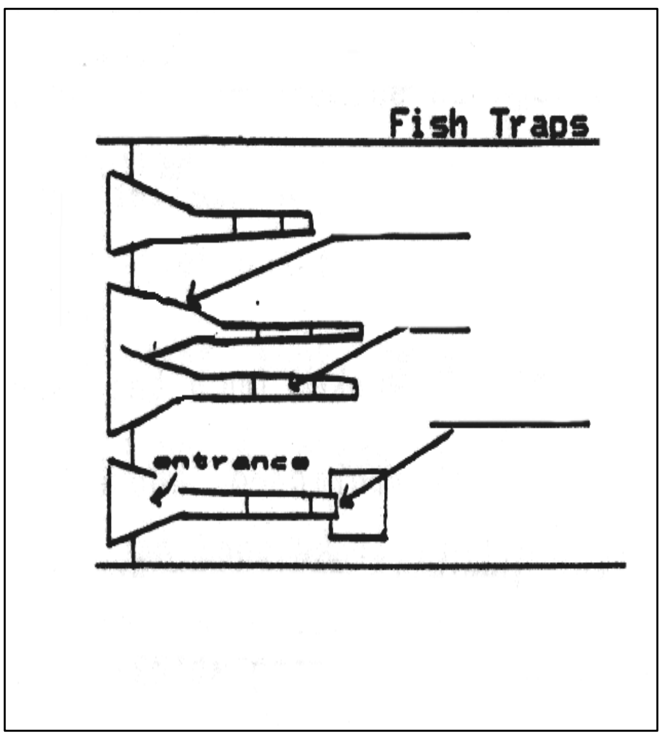

Figure 3.7. Sketch of fishing weirs used in conjunction with fish traps.

Figure 3.8. Partial weir and fish trap known as a koonsai for fishing kokanee on the Tachie River.

Partial weirs were also used in conjunction with fish traps. Fish were driven into the weir by canoe. These weirs could be easily set up in numerous locations.

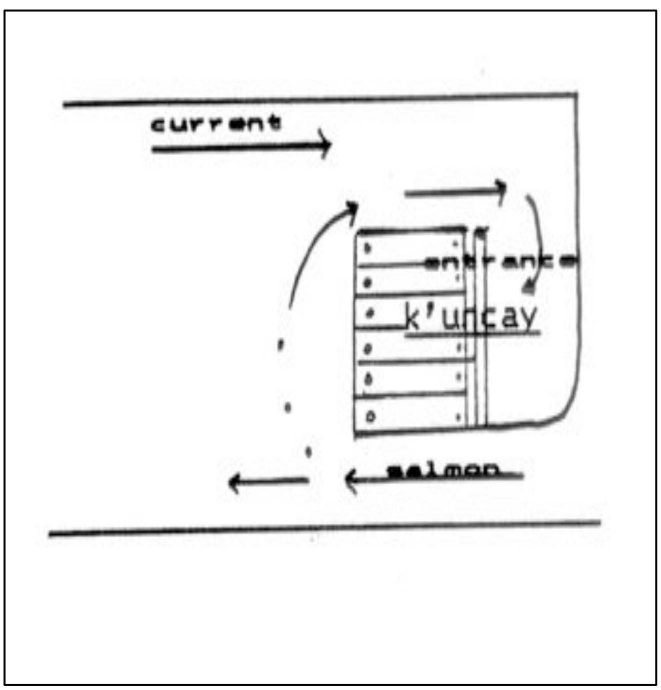

Figure 3.9. Sketch of a partial weir and trap known as a k’uncay.

Fish, and sockeye in particular, were the most important subsistence item of the Carrier people in the Stuart Lake region. With a location in the headwaters of the Fraser River system, there were (are) few options available for sockeye harvesting, apart from the Early and Late Stuart Runs. Sockeye availability varied from year-to-year due to cyclic dominance, and relatively weak runs occurred in 3 years out of 4, as they do at present. During the off-cycle years, Carrier people obtained sockeye from the Skeena River system, especially in the vicinity of Babine Lake.

4. Explanations for the Declining Trends

This section of the report evaluates the underlying causes for the declines in Early and Late Stuart sockeye. Sub-sections below are presented as hypotheses to explain the recent declining trends. The explanations are evaluated and where possible, they are rejected if they are inconsistent with the available data and evidence. If they cannot be rejected, they are retained as possible explanations for inclusion in management evaluations (Section 5).

Overharvesting

Both Early and Late Stuart sockeye have contributed to fisheries for thousands of years. Upper Fraser First Nations devised numerous fishing methods (Section 3) that were customized for catching the sockeye that sustained people through the fall, winter and spring months. Subsequently commercial fishing was undertaken to supply a Hudson's Bay trading post at Fort St. James, one of BC's (formerly New Caledonia) oldest European settlements. More recently, modern fisheries developed and the fish are now captured in commercial vessels in the marine environment and in various Food, Social and Ceremonial fisheries. Overharvesting has been implicated in the decline of many fish species. The assessment below evaluates whether the declines in Early and Late Stuart sockeye are related to commercial and First Nations fisheries overharvesting.

The catch records (Figure 4.1) clearly reflect the cyclic dominance pattern in the returns, with one year out of four (2004 cycle line) showing substantially higher catches than those on the other cycle lines. This pattern mirrors the escapement records (Section 2).

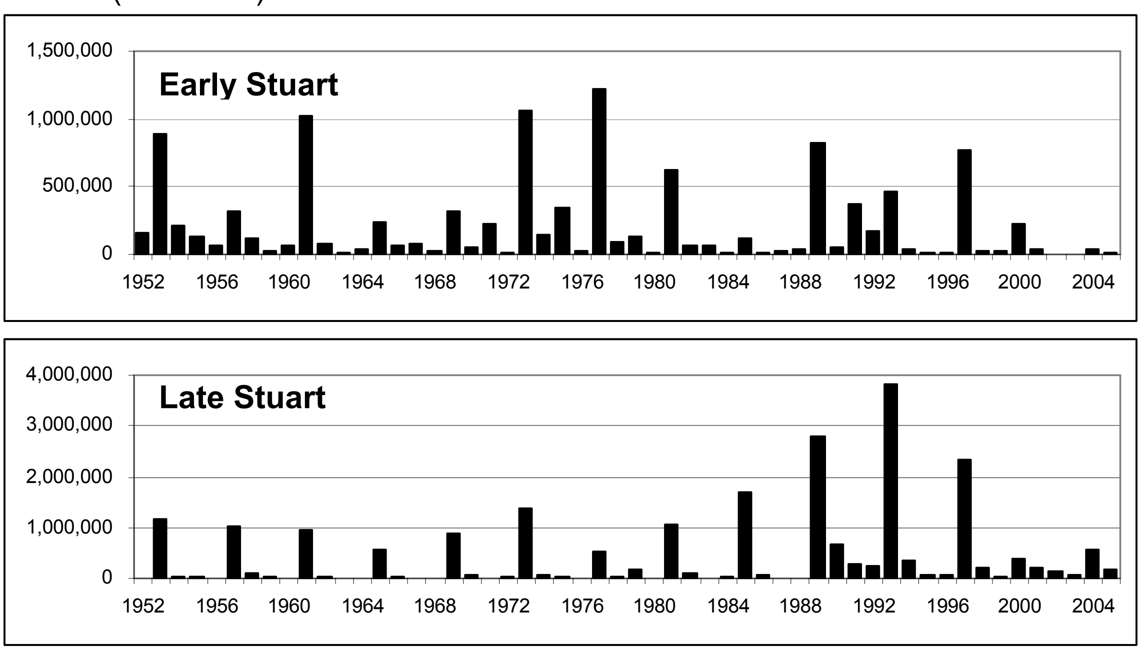

Figure 4.1. Time series of Early and Late Stuart sockeye catches. Source: DFO.

Since 1997, there have been very low catches in response to conservation closures directed at the commercial sector, and more recently, at aboriginal fisheries. A breakdown of catches in the marine environment (commercial plus marine First Nations) and in the Fraser River Food, Social and Ceremonial fisheries is shown in Figures 4.2 and 4.3 for Early and Late Stuart sockeye respectively. The histograms in the upper panels represent total returns and show escapement and the Mission Discrepancy as well as catch. The Mission Discrepancy is the difference in the spawning ground estimate from the Mission counting facility that is operated by the Pacific Salmon Commission in the Lower Fraser River. The lower panels show breakdowns of catch in the marine environment and in the Fraser River, as well as the overall harvest rate.

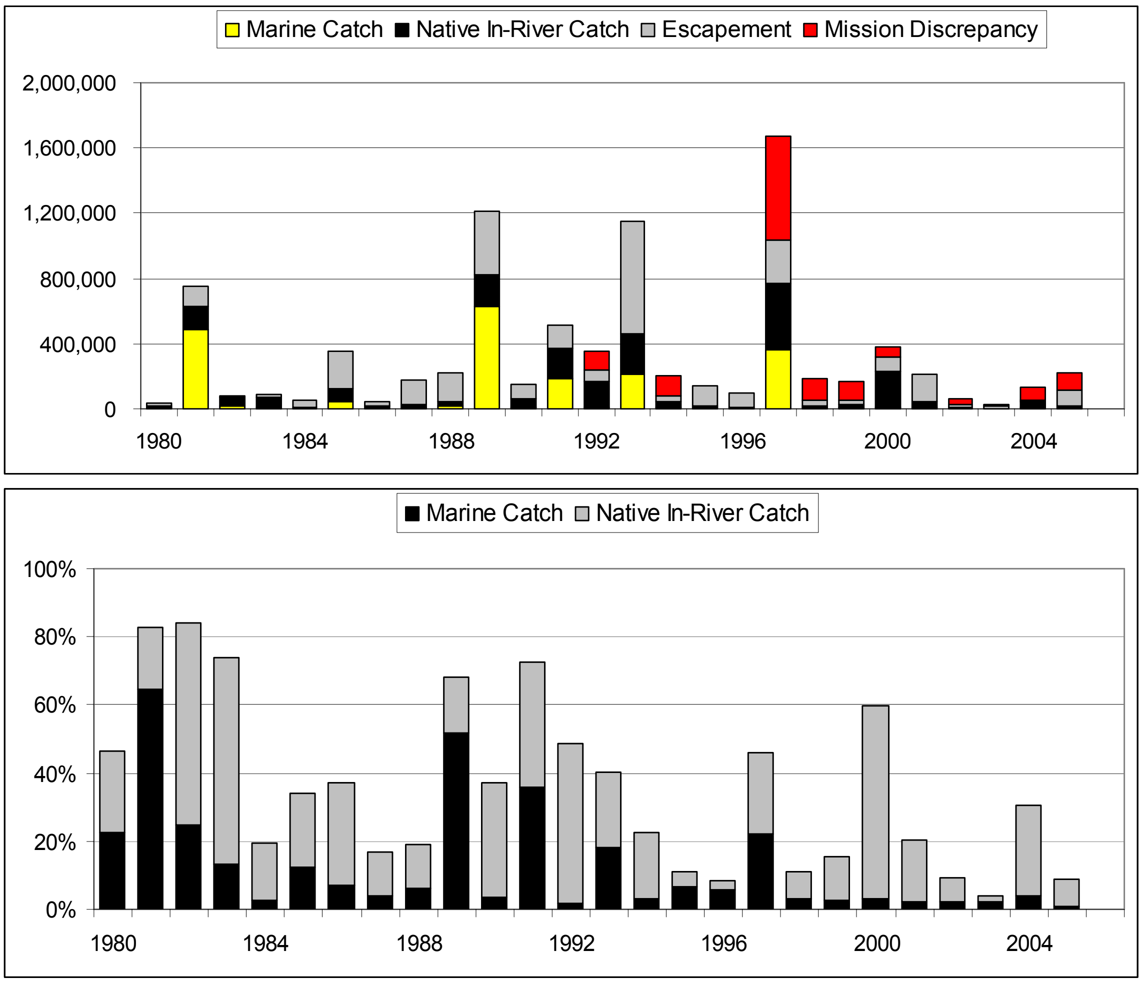

Figure 4.2. Early Stuart sockeye return data (upper) and the total harvest rate (lower). Source: DFO.

The marine commercial catch has been phased out for Early Stuarts since 1997, and the small remaining catch has been taken in the Fraser River Food, Social and Ceremonial (FSC) fishery. In recent years the FSC fishery has been closed, and only incidental catches of Early Stuart sockeye have occurred. Of significance for the purpose of the present evaluation is the greatly reduced total harvest rate for Early Stuarts after 2000. This is inconsistent with the overharvesting explanation as a cause for the decline in the population. With the low harvest rate since 2001, this should have provided an opportunity for rebuilding; this has not occurred.

Unlike Early Stuart sockeye which can be managed separately from other sockeye runs due to their unique run timing, Late Stuart sockeye form a component of the Summer Run and co-migrate with Stellako, Chilko and Horsefly fish. They are therefore potentially vulnerable to overharvesting in fisheries that target the stronger Summer Run stocks.

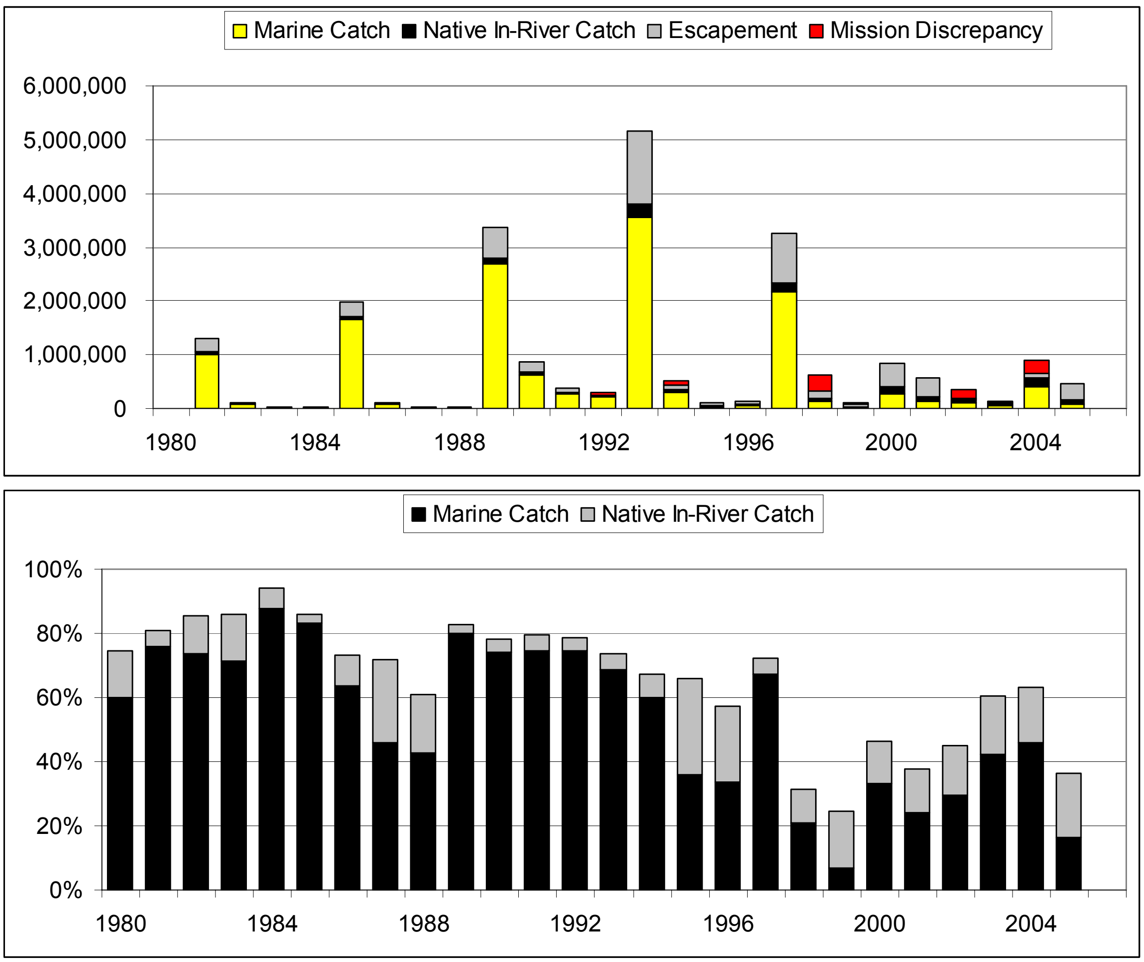

Figure 4.3. Late Stuart sockeye return data (upper) and the total harvest rate (lower). Source: DFO.

There has been a substantial marine harvest of Late Stuart sockeye which until recently, has greatly surpassed the Fraser River FSC catch (Figure 4.3). Total harvest rates were as high 60% in both 2003 and 2004. Of significance for the present assessment of overharvesting, exploitation rates were high (between 60-90%) during the 1980's and early 1990's coincidental with increasing Late Stuart escapements (Figure 2.1). It seems unlikely therefore that overharvesting has caused the population declines.

In conclusion, the presently low harvest rate of Early Stuarts and the occurrence of a vigorous fishery for Late Stuarts in the 1980's during a period of population increase, are inconsistent with an overharvesting explanation for the population declines.

Spawning and Egg Incubation Conditions

There are various land and water impacts e.g. sedimentation which could potentially impair the capacity of the streams to provide suitable spawning and egg incubation habitats. If such impacts were to occur they would reduce the overall productivity of the Early and Late Stuart runs. Early Stuart sockeye would be most vulnerable to such impacts as they are distributed primarily in small tributaries, while Late Stuarts occur primarily in larger streams.

This explanation can be tested by comparing DFO data on egg deposition and fry production. Production data are available for three streams tributary to the Middle River: Forfar, Gluske and Kynoch Creeks (Table 4.1). Data are also available for the Stellako River (Table 4.2) which provide a "control" site for comparative purposes.

There does not appear to be any reduction in the capacity of the three Early Stuart creeks to produce fry. Variations in fry numbers appear to be related to fluctuations in the numbers of the parental spawners such that dominant cohorts of fry are much more abundant than other fry numbers for the other 3 cycle lines. A direct measure of spawning habitat quality is egg-to-fry survival (Figure 4.4). The data do not indicate any reduction in egg survival over time. As well, the data are similar to values measured in the Stellako River, a system in a neighboring Nechako River tributary. It seems unlikely therefore that the reduction in the Early Stuart population is related to impaired spawning and egg incubation conditions.

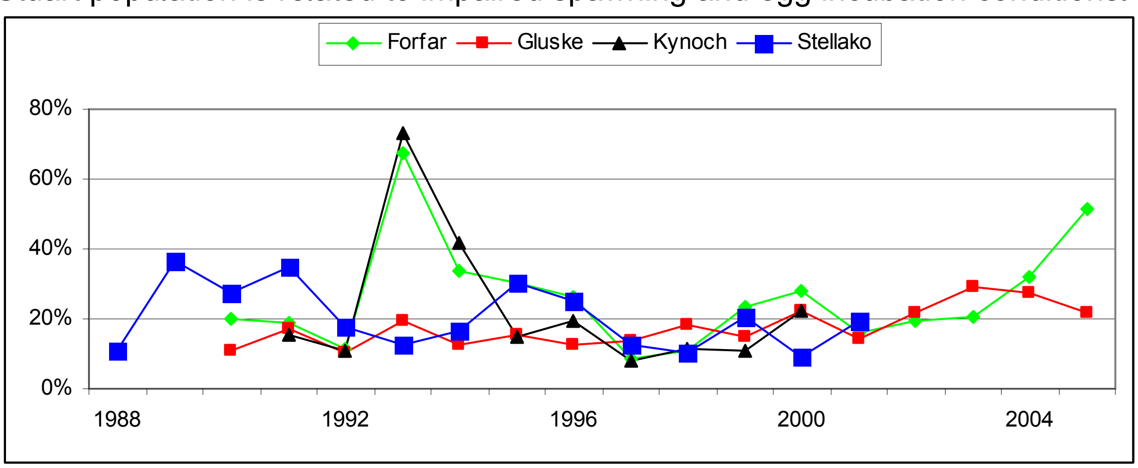

Figure 4.4. Egg-to-fry survival trends in the Stellako River compared with 3 Early Stuart streams. Source: DFO.

Table 4.1. Brood year effective female escapement, mean fecundity, potential egg deposition, subsequent fry production and egg to fry survival for three Early Run Stuart River sockeye stocks: Forfar, Gluske and Kynoch creeks, 1990-2005 brood years. Source: DFO.

Forfar Creek

	Effective Females at age		Mean Fecundity at age				
Brood Year	4_2	5_2	4_2	5_2	Potential egg deposition	Estimated fry migration	Egg to fry survival
1990	7,021	810	3,917	3,436	30,286,000	5,869,000	19.9%
1991	12,318	880	3,534	4,494	47,489,000	8,945,130	18.8%
1992	6,712	479	3,606	3,279	25,774,000	2,877,000	11.2%
1993	9,929	355	3,097	3,923	32,147,000	21,606,000	67.2%
1994	1,822	456	3,585	4,137	8,400,000	2,818,000	33.6%
1995	7,827	903	3,082	3,901	27,645,000	8,410,000	30.4%
1996	3,189	1,196	3,939	4,153	17,532,000	4,616,500	26.3%
1997	3,367	0	3,626	-	12,208,000	1,040,000	8.5%
1998	90	346	3,553	3,997	1,703,000	187,000	10.8%
1999	825	0	3,764	-	3,106,000	720,000	23.2%
2000	2,893	96	3,864	4,489	11,610,000	3,259,000	28.1%
2001	2,503	3,934	3,459	4,591	26,717,000	4,226,000	15.8%
2002	299	758	3,704	4,495	4,515,000	879,000	19.5%
2003	1,065	171	3,900	4,642	4,948,000	1,013,000	20.5%
2004	623	0	3,850	-	2,399,000	769,000	32.1%
2005	2,810	72	3,310	3,795	9,576,000	4,951,049	51.7%

Gluske Creek

	Effective Females at age		Mean Fecundity at age				
Brood Year	4_2	5_2	4_2	5_2	Potential egg deposition	Estimated fry migration	Egg to fry survival
1990	5,761	199	3,602	3,597	21,469,000	2,309,000	10.8%
1991	9,366	323	3,604	5,157	35,416,000	6,062,450	17.1%
1992	1,759	0	3,429	-	6,032,000	627,000	10.4%
1993	11,256	1,249	3,178	4,147	40,948,000	7,842,000	19.2%
1994	1,427	454	3,389	2,966	6,163,000	759,300	12.3%
1995	7,479	394	3,557	4,631	28,425,000	4,456,200	15.7%
1996	3,530	1,059	3,633	4,178	17,248,000	2,143,200	12.4%
1997	3,823	0	3,667	-	14,017,000	1,920,000	13.7%
1998	136	339	4,463	3,908	1,932,000	348,000	18.0%
1999	735	0	3,758	-	2,762,000	414,000	15.0%
2000	1,861	64	3,812	3,700	7,331,000	1,621,000	22.1%

2001	1,978	2,968	3,784	4,419	20,602,000	2,893,000	14.0%
2002	170	1,031	3,687	4,564	5,333,000	1,146,000	21.5%
2003	530	252	3,386	4,642	2,964,000	867,000	29.3%
2004	631	45	3,692	4,795	2,546,000	699,000	27.5%
2005	1,860	48	3,281	3,795	6,284,000	1,358,565	21.6%

Kynoch Creek							
	Effective Females at age		Mean Fecundity at age				
Brood Year	4_2	5_2	4_2	5_2	Potential egg deposition	Estimated fry migration	Egg to fry survival
1991	16,120	879	3,627	4,385	62,316,000	9,754,100	15.7%
1992	5,618	408	3,395	3,304	20,423,000	2,210,000	10.8%
1993	10,657	762	3,093	4,013	36,019,000	26,261,000	72.9%
1994	1,676	495	3,313	5,289	8,170,000	3,408,200	41.7%
1995	13,408	1,241	3,393	4,402	50,950,000	7,549,000	14.8%
1996	4,173	1,206	3,845	4,153	21,052,000	4,053,000	19.3%
1997	5,769	52	3,554	4,400	20,735,000	1,607,000	7.8%
1998	172	541	3,409	3,928	2,712,000	303,000	11.2%
1999	2,621	0	3,786	-	9,924,000	1,071,000	10.8%
2000	4,550	239	3,814	4,542	18,441,000	4,134,000	22.4%
2001	4,567	3,165	3,706	4,552	31,335,000	-	-
2002	369	776	3,704	4,495	4,864,000	-	-
2003	1,814	212	3,386	4,642	7,127,000	-	-
2004	943	67	3,543	4,814	3,664,000	-	-
2005	6,055	103	3,420	3,795	21,098,000	-	-

Table 4.2. Brood year effective female escapement, mean fecundity, potential egg deposition, subsequent fry production and egg to fry survival for Stellako River sockeye, 1988-2004 brood years. Source: DFO.

Stellako River							
	Effective Females at age		Mean Fecundity at age				
Brood Year	4_2	5_2	4_2	5_2	Potential egg deposition	Estimated fry migration	Egg to fry survival
1988	171,579	28,958	3,499	4,247	723,340,000	76,488,000	10.6%
1991	47,020	7,328	2,996	3,926	180,000,000	65,558,880	36.4%
1992	50,349	4,841	2,743	3,438	192,508,000	53,022,000	27.5%
1993	18,429	24,430	2,753	3,784	143,181,000	49,770,000	34.8%
1994	64,503	6,984	3,080	4,176	227,834,424	39,866,000	17.5%
1995	44,466	10,334	2,915	3,776	168,644,000	21,233,000	12.6%
1996	61,313	1,418	3,476	4,566	219,597,000	36,942,000	16.8%
1997	9,867	14,300	2,803	3,757	81,384,000	24,851,000	30.5%
1998	72,294	24,667	3,232	3,216	312,982,000	79,020,000	25.2%
1999	46,342	19,738	2,953	3,230	200,591,000	24,681,000	12.3%
2000	195,386	0	3,640	-	711,163,000	75,156,000	10.6%
2001	17,227	44,363	3,491	3,917	233,916,000	48,435,000	20.7%
2002	159,669	17,899	3,602	4,967	664,085,000	60,290,000	9.1%
2003	22,765	21,064	3,142	4,174	159,442,000	30,593,000	19.2%
2004	51,389	2,416	3,301	3,821	178,859,000	-	-

In-lake Conditions

Most sockeye salmon depend on a lake to provide juvenile nursery habitat. Following emergence, fry migrate into the open-water areas of lakes where they reside for a 1-year period prior to downstream migration as yearling (occasionally 2-year old) smolts. If there was a potential decrease in lake productivity this could manifest itself as a reduction in fry survival and reduced adult returns.

Limnological characteristics of Stuart, Takla and Trembleur Lakes were evaluated by Shortreed et al. (2001) during a province-wide study to evaluate factors limiting juvenile sockeye production and enhancement potential for selected BC nursery lakes. Results are summarized in Table 4.3.

Table 4.3. Limnological and biological characteristics of Stuart, Takla, and Trembleur Lakes. Source: Shortreed et al. (2001).

	Stuart Lake	**Takla Lake**	**Trembleur Lake**
Latitude (^{o}N)	$54^{o}38'$	$55^{o}15'$	$54^{o}50'$
Longitude (^{o}W)	$124^{o}49'$	$125^{o}44'$	$125^{o}05'$
Elevation (masl)	680	689	686
Surface Area (km^2)	359	246	116
Mean Depth (m)	20	107	40
Water Residence Time (yr)	1.7	15	1.9
Mean Epilimnetic Temp (^{o}C)	13.6	11.6	12.2
Thermocline Depth (m)	20.3	13.7	20.0
Euphotic Zone Depth (m)	6.6	6.9	6.0
pH	7.80	7.51	7.62
Total Alkalinity (mg $CaCO_3$/L)	41.6	27.9	34.6
Nitrate (g N/L)			
Spring Overturn	37	74	57
Mean Epilimnetic	14	48	34
Seasonal Minimum	3.3	29	21
Total Phosphorous (g/L)			
Spring Overturn	9.8	4.7	8.8
Mean Epilimnetic	7.4	4.9	8.1
Chlorophyll (g/L)	1.92	1.02	1.40
Daily Photosynthetic Rate (mg C/m^2)	138	55	84
Zooplankton Biomass (mg dry wt/m^2)			
Total	1410	562	1134
Daphnia	139	91	231
Sockeye Fall Fry			
Mean Weight (g)	3.4	3.1	5.1
Mean Density (N/ha)	418	252	390

The 3 lakes have different morphometric and limnological characteristics in particular with respect to depth and thermal characteristics (Figure 4.5). Takla Lake is much deeper than Trembleur and Stuart, and is more sheltered from prevailing winds and as a result has a shallower thermocline depth.

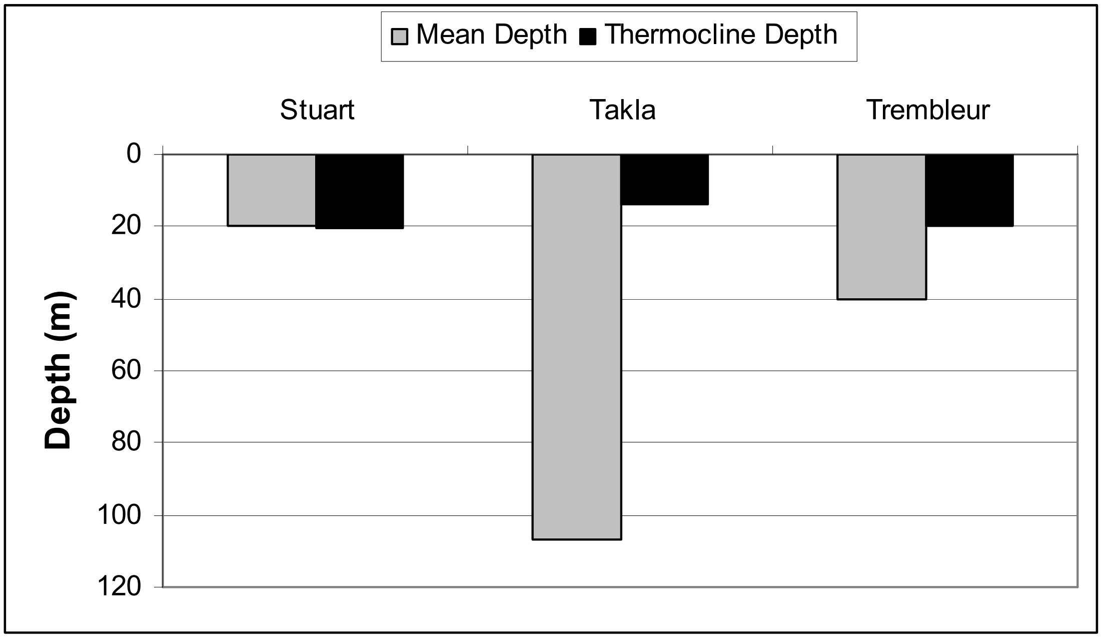

Figure 4.5. Mean depths and thermocline depths in Stuart, Takla and Trembleur Lakes.

The relative productivity of the three lakes (Table 4.4) can be evaluated by comparing and ranking the different measurements summarized in Table 4.5. The comparison shows that Stuart Lake is the most productive, followed by Trembleur Lake and lastly Takla Lake.

Table 4.4. Rank index of relative productivity across different trophic levels.

	Stuart Lake	**Takla Lake**	**Trembleur Lake**
Total Alkalinity	1	3	2
Mean Epilimnetic Phosphorus	2	3	1
Chlorophyll	1	3	2
Daily Photosynthetic Rate	1	3	2
Zooplankton Biomass	1	3	2
Mean Weight Fall Fry	1	3	2

Some comments from the Shortreed et al. (2001) study include:

Stuart Lake

- *With a seasonal average of 1,410 mg dry wt/m^2, macrozooplankton was the highest of any Fraser system sockeye lake with the exceptions of Anderson Lake and meso-eutrophic Fraser Lake…..*

- *Mean fall O. nerka fry ranged from 2.5 to 3.9 g in size, indicating an adequate food supply at the low limnetic fish densities present…..*

- *Stuart Lake sockeye comprise about 75% of what is commonly called the Late Stuart run, with the remainder of Late Stuart sockeye rearing in Trembleur Lake. Average escapement to the lake is 279,000, substantially lower than the Photosynthetic Rate model predicted optimum escapement of 1,659,000. This suggests that increased fry recruitment is needed to increase the abundance of the stock.*

Trembleur Lake

- *Trembleur Lake has an abundant zooplankton community….*

- *Of the three Stuart system lakes, Trembleur had the largest (mean=5.1g) fall sockeye fry.*

- *Trembleur Lake provides an excellent rearing environment for juvenile sockeye and with an optimum escapement of 326,000 predicted by the Photosynthetic Rate model, the lake could support an order of magnitude greater fry numbers than were present during our study.*

Takla Lake

- *During our study, Takla Lake O.nerka densities were low (mean=252/ha) and kokanee averaged about 53% of the population. Mean fall O.nerka fry ranged from 2.5-3.9 g in size, indicating an adequate food supply at the low limnetic fish densities present.*

- *Takla Lake sockeye comprise about 75% of the Early Stuart run, with the remainder of Early Stuart sockeye rearing in Trembleur Lake. The Photosynthetic Rate model predicts an optimum escapement of 453,000 and indicates that the lake could support approximately 10 times more sockeye fry than were present during our study.*

- *If fry densities were substantially higher, it is probable that lake fertilization would be of benefit to the growth and survival of Takla Lake sockeye fry.*

The Shortreed et al. (2001) study was undertaken by carrying out monthly sampling between May – October of 1996-1998, bracketing the time period when Early and Late Stuart sockeye declined severely. The conditions in the lakes were measured and found to be excellent for supporting the growth and survival of sockeye fry. It therefore appears unlikely that within-lake environmental conditions are associated with the recent downturns in Early and Late Stuart sockeye.

Competition with Kokanee

Kokanee are land-locked and co-occur with the anadromous form of sockeye salmon. They are the same species, *Oncorhynchus nerka*, and are closely related to sockeye but are reproductively isolated and genetically distinct (Wood et al. 1999). During their juvenile stage, kokanee are similar ecologically to sockeye. If kokanee had a competitive advantage over sockeye, this potentially could have adverse impacts on sockeye.

The distribution of kokanee spawning streams in the Stuart Lake system (Figure 4.6) indicates that kokanee are mostly concentrated in Takla Lake tributaries. While the distribution information does not necessarily indicate relative kokanee abundance, it does suggest that any potential competitive effects as described above would be most likely to occur in Takla Lake, the main nursery lake for Early Stuart sockeye.

Takla Lake juvenile sockeye and kokanee were studied in August of 1988 and 1991 (Wood et al. 1999). Ecological interactions were investigated by using genetic markers to identify and distinguish kokanee and sockeye.
While juvenile *O. nerka* were evenly distributed throughout Takla Lake, sockeye predominated in the west arm whereas kokanee predominated in the north arm, reflecting sockeye spawner densities in the brood years studied. The two forms were intermingled with no detectable difference in relative abundance by depth or among trawl catches. Sockeye salmon were significantly larger than kokanee (Figure 4.7) and their food habits strongly overlapped (both forms feed on large-bodied zooplankton), leaving open the possibility of food competition. In view of the larger body size of juvenile sockeye, it seems likely that juvenile sockeye would have a competitive advantage over kokanee, however, the intensity of any competitive interactions would also depend on the relative abundance of the two forms.

The possibility that Early Stuart sockeye are being impacted by kokanee competition cannot be ruled out. There is insufficient information to either reject or support the explanation. This points to the need for additional information on juvenile sockeye and kokanee lake ecology, particularly for Takla Lake which presents the greatest opportunity for competitive interactions with Early Stuart sockeye to take place.

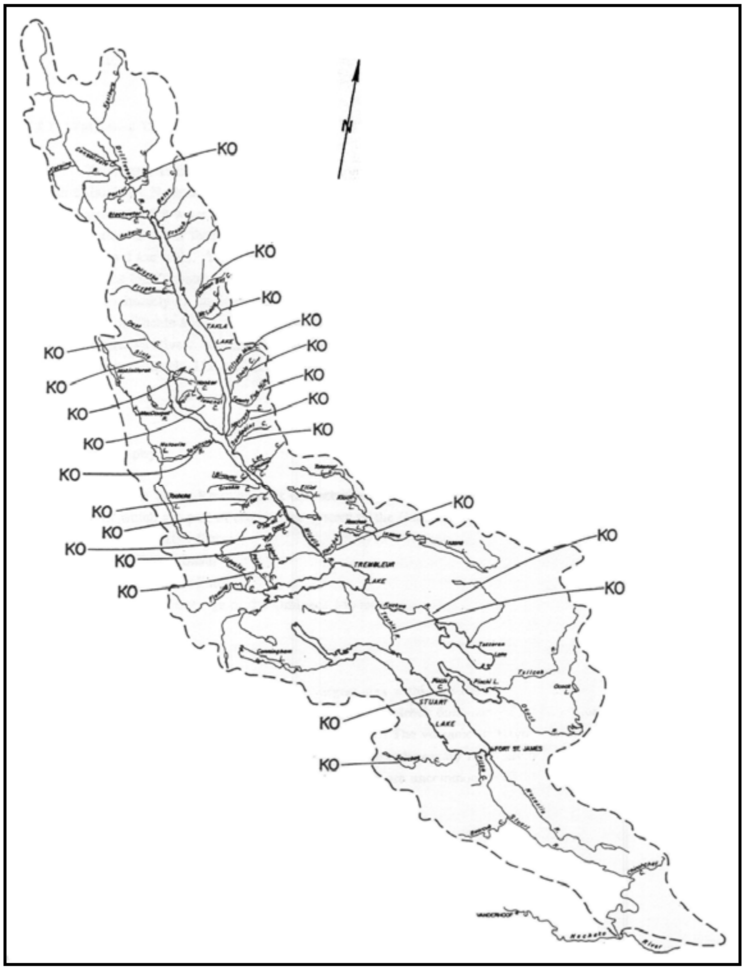

Figure 4.6. Location of known kokanee spawning streams. KO = kokanee. Source: Langer et al. (1992).

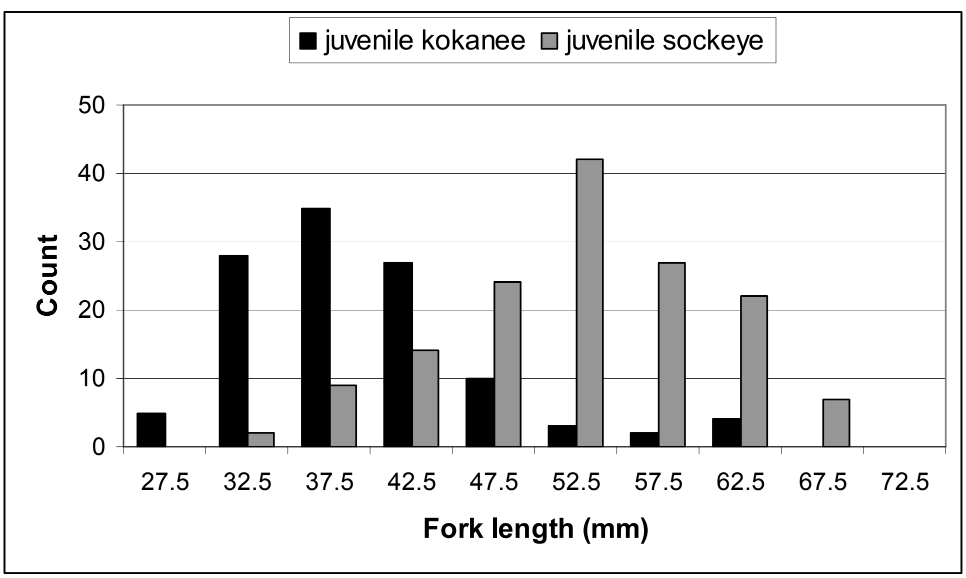

Figure 4.7. Size distribution of juvenile sockeye and kokanee from Takla Lake in 1988 and 1991. Source: Wood et al. (1999).

Logging

Logging is a predominant feature of the Stuart-Takla watershed (Figure 1.3). In view of the magnitude and high number of clearcuts, it is possible that this activity could adversely affect sockeye runs. Early Stuart sockeye are the most vulnerable to such effects since they spawn in smaller tributaries which may be the most sensitive to logging effects.

The effects of logging on different components of the aquatic ecosystem were analyzed during the 1990's by DFO as part of the Stuart-Takla Fisheries/Forestry Interaction Project (Macdonald et al. 1992). The study was carried out in four adjacent watersheds: Bivouac and Gluskie Creeks tributary to lower Takla Lake, and Forfar and O'Ne-eil Creeks, tributary to the upper Middle River (Figure 4.8).

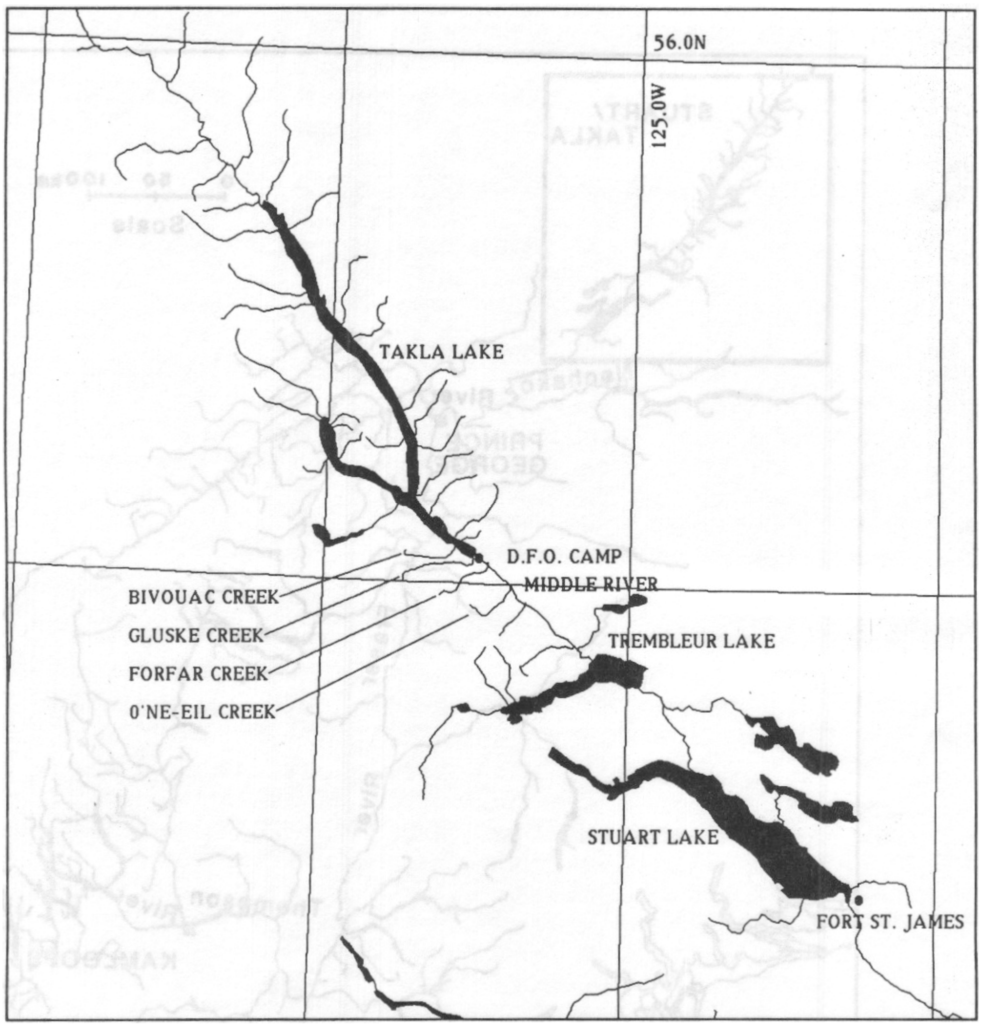

Figure 4.8. Location of creeks utilized by DFO to study fisheries forestry interactions. Source: Macdonald et al. 1992.

The study design involved the use of Forfar Creek as an unlogged control, and the use of Gluske and O'Ne'eil Creeks as treatment areas where logging took place. After 1994, the focus shifted towards the analysis of smaller tributaries, particularly those in the Upper Gluske area and Baptiste Creek, an adjacent watershed. Cutting treatments included clearcutting and various retention strategies including cutting trees < 20 cm diameter breast height, everything retained (unlogged control) and patch cutting. The logging treatment was situated primarily in the Upper Gluske watershed.

This inter-disciplinary study analyzed numerous components of the ecosystem including:

- Radiation and temperatures
- Thermal units
- Escapement estimates
- Incubation and outmigration success
- Lake productivity
- Hydrology
- Channel morphology
- Sediment budget
- Streambed composition
- Invertebrate production
- Fish diets
- Beaver effects
- Bedload movement
- Historic channel changes
- Incubation habitat
- Predation studies, and
- Resident fish research

The intensity of logging activity was fairly modest in the experimental watersheds and the study did not detect major changes in fish production that could be associated with logging activity. Temperature effects associated with logging activities were detected that could presumably affect egg incubation rate and emergence timing of fry. However, no emergence timing shifts were observed in the fry populations that were monitored. Although the study did not produce unequivocal evidence that logging harmed sockeye production, such effects might be detectable by using a different experimental design.

Additional information that logging by itself is not responsible for Early Stuart sockeye declines is related to the spatial distribution of clearcuts which are mostly located at considerable distance from the spawning areas. This spatial separation would tend to buffer the fish from logging related habitat impacts. As well, the time series of Early Stuart escapement (Figure 2.1), involving a steep increase through the 1980's and 1990's and a steep decrease thereafter, is inconsistent with the slow steady expansion of logging in the Takla Lake watershed.

In conclusion, logging can neither be accepted nor rejected as a contributing factor in the Early Stuart decline. However sockeye, by virtue of their life history utilize the creeks only for spawning, egg incubation and juvenile migration to a rearing lake (in this case Takla and Trembleur Lakes) making them less vulnerable to logging effects than other species of stream dwelling salmonids e.g. trout, Chinook salmon and coho salmon. These species are potentially more vulnerable to logging effects by virtue of the extended residency of juveniles in the tributaries for one or more years.

Pollution

In the event that water quality conditions were poor, this could adversely impact Stuart Lake sockeye populations. This explanation is unlikely for two reasons:

1. the decline in Stuart/Takla Lake sockeye has occurred independently from many upriver salmon populations e.g. Stellako River sockeye, Nechako River Chinook, most of which are presently healthy. Since these upriver salmon populations all experience similar water quality during their migration, it seems unlikely that Stuart Lake sockeye would be selectively more vulnerable to water pollution; and,

2. water quality improved significantly during the period of the 1990's and after 2000[2], simultaneously with the most recent Stuart sockeye declines. This relationship is opposite to that which would be predicted if water pollution was associated with Stuart/Takla Lake sockeye declines.

Migration Conditions and In-River Mortality

There is growing evidence that environmental conditions during upstream migration have adversely affected both Early Stuart and Late Stuart sockeye. Early Stuarts have been especially affected. They have more severe migration difficulties than Late Stuart sockeye because their earlier run timing often

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[2] In the report of the Fraser River Action Plan (FRAP 1998), they state: *"The main stem river upstream of the estuary and its major tributaries do not exhibit significant concentrations of contaminants at most locations. This is largely due to production changes in pulp mills in the early 1990's, which resulted in the significant reduction of dioxins and furans in the mills' effluents, and recent improvements in municipal waste water treatment plants. Large reductions in the use of some chemicals, such as polychlorinated biphenyls (PCBs), lead, pentachlorophenol and some pesticides over the past two decades are also responsible for the low levels of contaminants observed."*

coincides with seasonal maximum Fraser River flows. They also have a longer migration distance (1,200 km to the major spawning stream[3]).

Over time, the Early Stuart arrival date at the Fraser River has shifted later by about 5 days (Figure 4.9). Reasons for the shift in migration date appear to be related to warmer sea surface temperature conditions. Other Summer Run sockeye have also shown later migration timing in recent years.

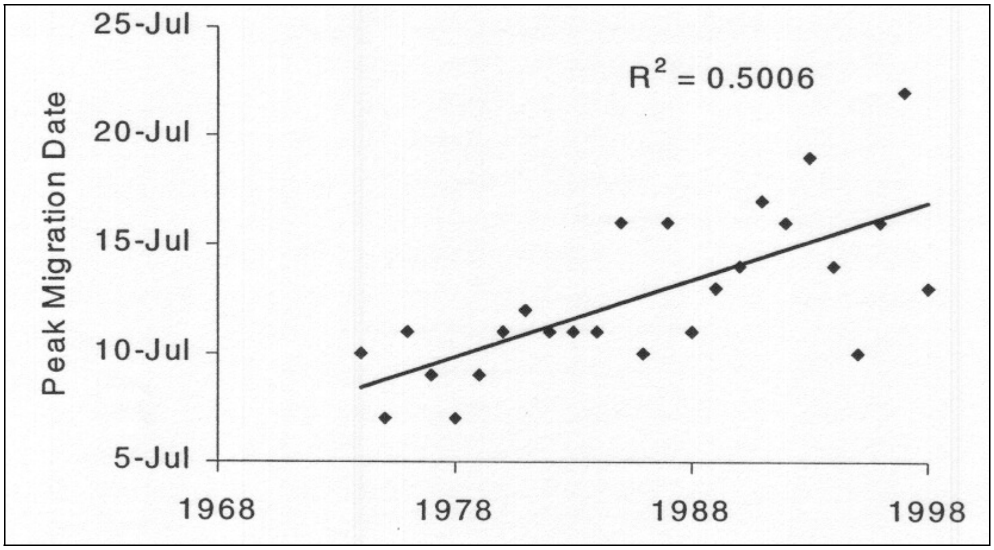

Figure 4.9. Trend in peak date of passage of Early Stuart sockeye past Hell's Gate from 1974 to 1998. Source: Macdonald et al. (2000).

The adverse effects of migration conditions for Early Stuart sockeye were very evident in both 1997 (Macdonald 2000) and 1998 (Macdonald et al. 2000). Extensive research has been conducted by DFO and is reviewed below to elaborate the causes for the severe in-river losses in the 2 return years.

In 1997 a record 1,671,000 Early Stuart sockeye returned during a period when Fraser River discharge conditions were approaching the highest on record (Figure 4.10). The fish were smaller than average and in sub-optimal condition for the long migration to their spawning grounds. This led to the largest recorded en-route mortality of a single stock of Fraser River sockeye salmon. Approximately 681,000 fish enumerated at Mission did not arrive at the spawning grounds.

[3] The longest known sockeye migration distance is 1438 km for sockeye returning to Redfish Lake, Snake River, Idaho. These fish are maintained entirely on hatchery inputs to sustain the population.

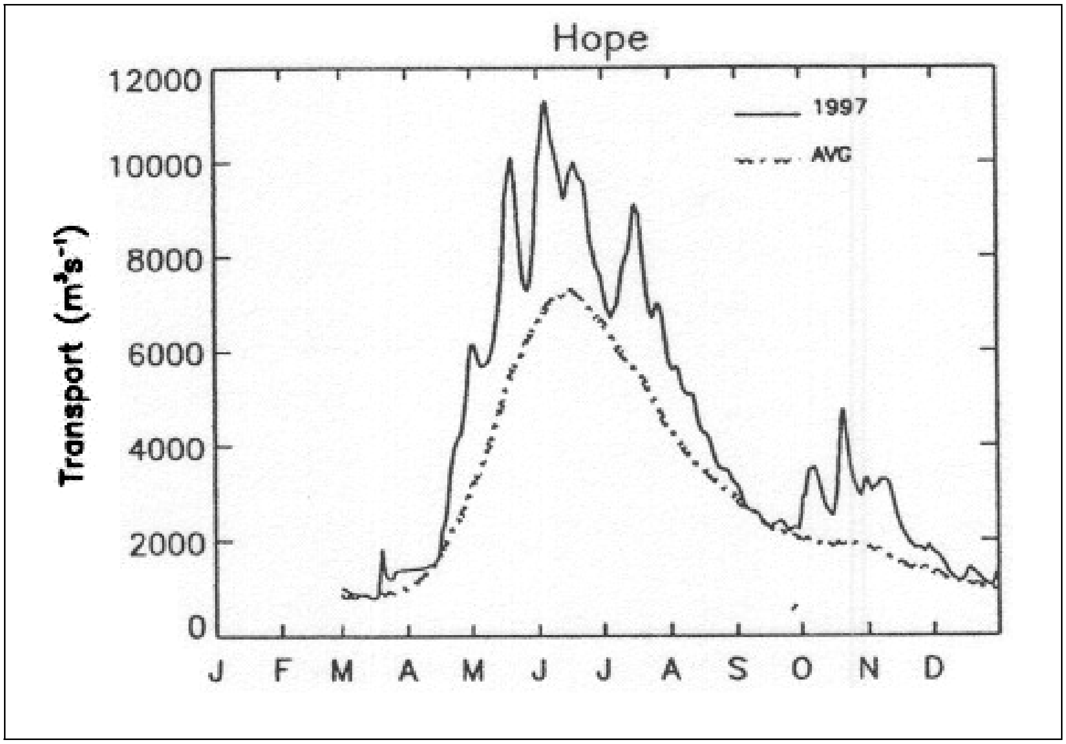

Figure 4.10. Comparison of Fraser River discharge conditions at Hope during 1997, with long term average conditions. Source: DFO.

As described in Appendix 3, at higher river discharge levels (>6,000cms) migration speeds slow and migration times increase rapidly with higher discharge levels. High discharge (> 8,000 cms) from heavy snow packs or summer rain events exceeds the upper threshold for successful passage of sockeye through the Fraser Canyon and slows or temporarily blocks migration. During 1997, flow conditions were above 7000 cms for a major portion of the Early Stuart migration. Of those fish that successfully migrated to their spawning grounds, only 34% were females (females are slightly smaller than males and may suffer greater stress at high discharge levels) and of those, 19% died before spawning.

High en route mortality has occurred prior to 1997 and has been documented as early as the 1950s (Table 4.5). During 1997, migration delays caused stress and energy reserves declined. As flow exceeded 8000 cms many fish entered non-natal Fraser River tributaries in the lower river (first report July 17th) as well as in the Prince George and Fort St. James area. Some fish attempted to spawn; others may have delayed their migration to seek temporary refuge from the river currents. The stressful migration conditions probably also reduced egg viability and may have contributed to reduced egg:fry survival (Donaldson 1990).

Table 4.5. Population estimates of Early Stuart sockeye migrating past Mission and arriving at the spawning grounds during years of water velocity blockage. Maximum water velocities are at Hells Gate between July 10th and 25th. Source: Macdonald (2000).

Year	Max. Water Velocities (cms)	Mission Population Estimate	Escapement	Estimated Mortality
1955	8920	30,000	2,200	93%
1960	8160	30,000	14,600	52%
1964	9340	32,000	2,400	94%
1982	7780	90,000	4,600	95%

Macdonald (2000) summarized the 1997 Early Stuart migration as follows:

1. warm sea surface temperatures forced fish further north in the Pacific ocean;
2. the fish arrived at Fraser River mouth several days late where they encountered above average water discharges;
3. high fish densities coincidentally with high water velocities led to migration impediments and blockages;
4. as water levels receded, water temperatures rose to stressful levels causing disease outbreaks; and,
5. nearly half of the fish that were expected to return failed to make it to their spawning grounds - many diverted to non-natal tributaries or languished and died in the margins of the mainstem

Very different migration conditions were encountered by Early Stuarts in 1998, but they were just as lethal (Macdonald et al. 2000). Water discharge during the 1998 sockeye migration period was near the 86 year minimum flows. Between early July and mid-September flows declined from 4000 cms to 1000 cms in contrast to 1997 when flows exceeded 9000 cms for several days in July. Years in which river discharge is below average are frequently years during which water temperatures are above average. Mean daily water temperatures at Hell's Gate were the highest on record for most days during the summer of 1998, frequently exceeding 20^{o}C in late July and early August. During 1998, there was a Mission – Upstream discrepancy of 75% (Table 4.6).

Table 4.6. Comparison of Early Stuart estimated population size at Mission and on the spawning grounds during 1998. Source: Macdonald et al. (2000).

	Estimated Number
Mission Hydroacoustic Estimate	183,800
In-river Catch	15,300
Spawning Escapement	31,000
Mission-Upstream Discrepancy	137,500

Between 1992 and 1998, 6 of 7 years showed lower upstream estimates than those obtained at Mission. During this time period, 2 years had very warm river water temperatures (1994 and 1998) and in a third, the river discharge was extremely high (1997). The discrepancy between upstream estimates and Mission estimates were highest during these extreme years. All discrepancies were negative: 1994 – 64%; 1997 – 52%; and 1998 – 73%.

In 1998, pre-spawning mortality in seven of eight stocks was at or below mean observed levels and well below maximum observed levels. Early Stuart sockeye were the exception to this pattern with the 1998 return having the highest pre-spawning mortality on record (Figure 4.11 – 4.12).

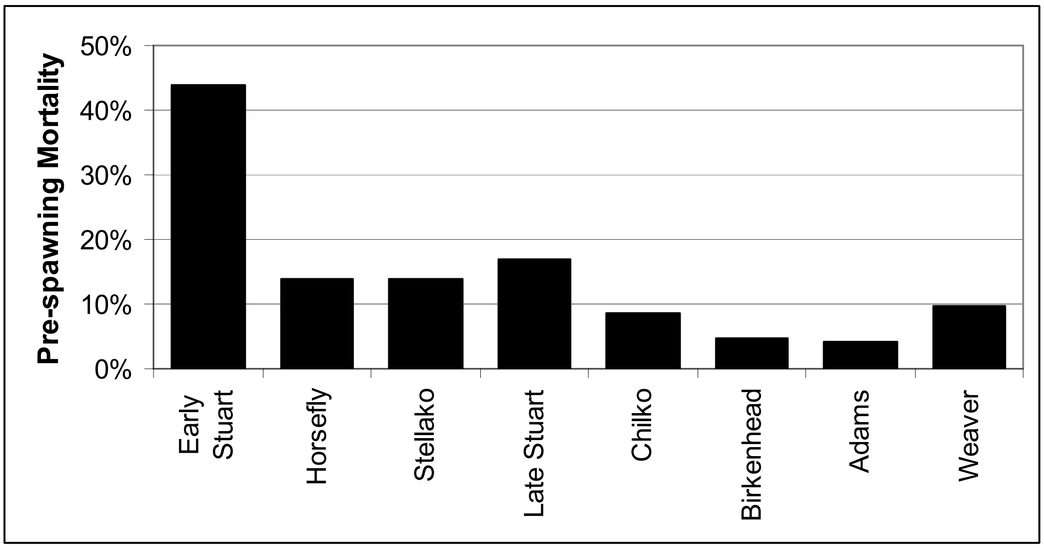

Figure 4.11. Estimated pre-spawning mortality rates for 8 Fraser sockeye stocks during 1998. Source: Macdonald et al. (2000).

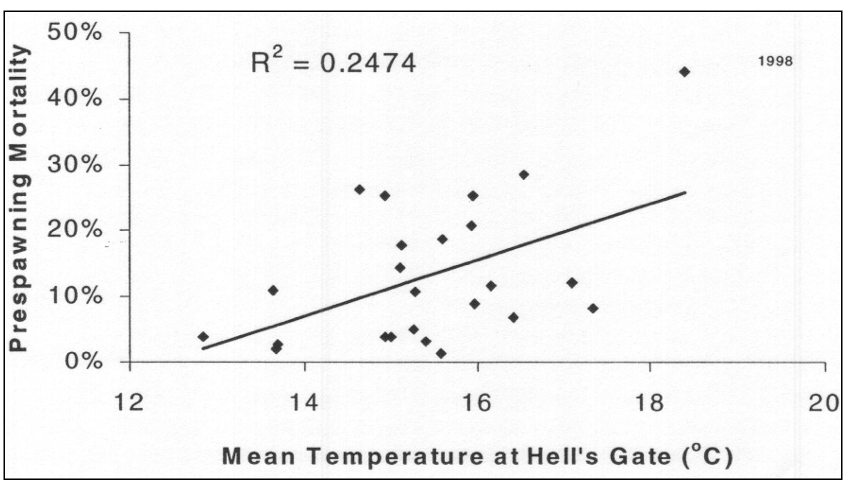

Figure 4.12. Relationship between mean water temperature at Hells Gate (weighted by daily escapement) experienced by Early Stuart sockeye during passage with pre-spawning mortality. Source: Macdonald et al. (2000).

Macdonald et al. (2000) concluded that migration blockages, susceptibility to diseases, impaired maturation processes, increases to stress parameters, reduced efficiency of energy use, and reduced swimming performance are all factors that become more hazardous as temperatures exceed 17 ^{o}C. The long migration coupled with large river temperature deviations likely caused the 1998 failure of the Early Stuart sockeye run.

The conclusion from the preceding analysis is that Early Stuart sockeye are vulnerable to both high discharge conditions during migration, and warmer than average temperatures. Migratory losses have been correlated with high river discharge and/or water temperature. The passage problems are associated with high water levels in the lower and middle Fraser, while high temperatures are most problematic in the upper river.

These relationships are summarized in Figure 4.13. This graph shows long term discharge and temperature conditions encountered by Early Stuart sockeye (actual values have been calculated by Patterson et al. 2007 for a 19-day migration period centered on the Hell's Gate migration date). Early Stuarts migrate upstream on the descending limb of the flow hydrograph, and on the ascending limb of the temperature curve. In the event that high discharge constrains the upstream migration, then the fish become more exposed to high temperature conditions. This migration window is defined by discharge conditions at the beginning of the return, and high temperature conditions at the tail end. In effect, the Early Stuart sockeye are respectively sandwiched between high discharges and warm temperatures during the front and tail ends of their migration.

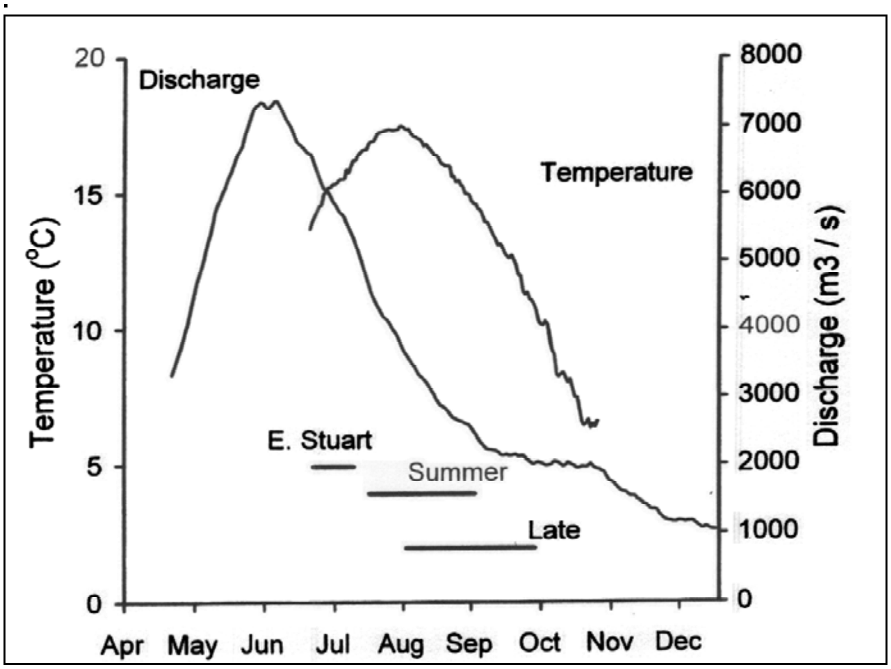

Figure 4.13. Migration timing (median river entry dates) of Early Stuart, Summer and Late Run sockeye in relation to mean temperature and discharge conditions between 1952-2000. Source: J. Grout, DFO, unpublished data.

While it is apparent that migration conditions and in-river mortality are adversely impacting Early Stuarts, this connection is not as strong for the Late Stuarts. These fish co-migrate with Stellako sockeye which have not shown a simultaneous decline in abundance, thus making migratory stressors a weaker explanation for the Late Stuarts. Additional information is required to determine what specific mechanism(s) are decreasing recruitment rates for the Late Stuarts. Comparisons of the stock composition of Summer Run sockeye (Chilko, Horsefly, Late Stuart and Stellako) utilizing DNA analysis at different points along the upstream migration would verify whether Late Stuart sockeye are selectively susceptible to migratory stressors.

Summary

The conclusions from the present analysis are shown in Table 4.7; the explanations are summarized by ranking them into one of 5 categories:

- Highly likely
- Likely
- Uncertain
- Unlikely
- Highly unlikely

Table 4.7. Conclusions from Section 4 pertaining to the explanations for the declining trends in Early and Late Stuart sockeye.

Explanation	**Likelihood**	
	Early Stuart	**Late Stuart**
Overharvesting	Unlikely	Uncertain
Spawning and Egg Incubation Conditions	Unlikely	Unlikely
In-lake Conditions	Unlikely	Unlikely
Competition with Kokanee	Uncertain	Uncertain
Logging	Uncertain	Uncertain
Pollution	Highly unlikely	Highly unlikely
Migration Conditions and In-River Mortality	Highly likely	Likely

The analysis suggests that out of all of the explanations considered, only the migration condition and in-river mortality explanation is highly likely for the Early Stuarts and likely for the Late Stuarts. The management implications from these findings are addressed in Section 5.

5. Conclusions

Section 4 concluded that adult migration conditions and in-river mortality are largely responsible for the observed declines in Early and Late Stuart sockeye declines. There is no doubt that environmental conditions in the river have changed over the past half century. Both maximum and mean river temperatures have increased significantly over this period (Figure 5.1).

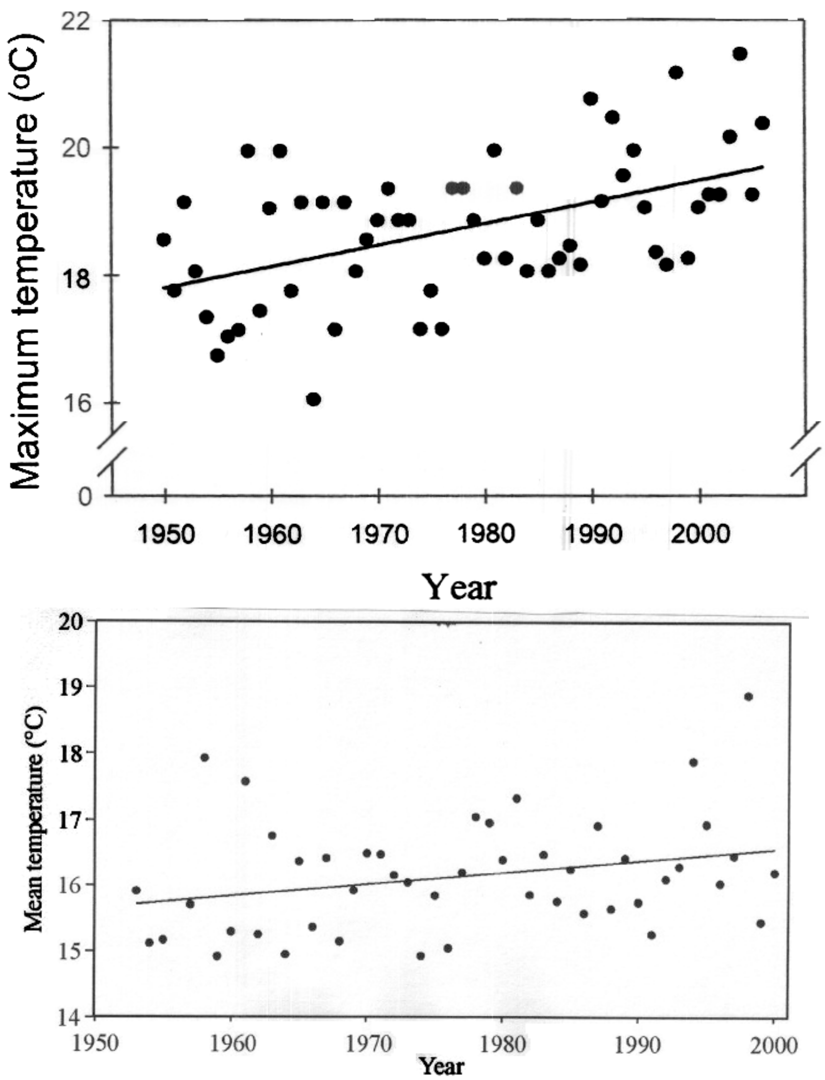

Figure 5.1. Trends in Fraser River maximum (upper) and mean (lower) water temperatures. Both relationships are statistically significant ($p<0.05$). Sources: A.D. Farrell (unpublished data; upper) and Morrison et al. (2002; lower).

Due to their long duration migration, Early and Late Stuart sockeye are especially vulnerable to a deterioration of migration conditions associated with increasing temperature or discharge. There is strong evidence that the warm water migration conditions encountered in 1998 led to severe in-river mortality. In spite of the fact that Early Stuart sockeye are adapted to migrating under high discharge conditions (Appendix 3), extreme discharges associated with a large snow pack or with summer rain events can have catastrophic consequences on survival, as occurred in 1997. Other salmon populations are vulnerable to adverse migration conditions, however, they encounter these conditions for a shorter period compared with the Stuart populations and are thus partially buffered from the impacts. With future climate change, it is not only the duration of adverse conditions during migration, but also their frequency (i.e. temperatures above 20^{o}C) that will likely increase. Within limits, over evolutionary time periods, sockeye have considerable adaptive capacity. Whether it is sufficient to cope with the large-scale changes that are predicted for the Fraser River (Morrison et al. 1992) remains to be seen.

What can be done to mitigate these trends and assist the Stuart sockeye populations to re-build? It is largely impractical to manipulate river temperature and discharge conditions. The Kemano Reservoir on the Nechako River has a Summer Temperature Management Program at the Skins Lake Spillway to mitigate adverse (>20^{o}C) water temperatures associated with reservoir operations. However even this program, which involves high volume flow discharges, does not strongly affect water temperatures below the Nechako-Stuart confluence, and the effects would be undetectable downstream of Prince George. The key area in the Fraser River where migration passage difficulties are the greatest is between Sawmill Creek and Lillooet, encompassing Hell's Gate and several smaller rapids. Any mitigative influence on flow would need to target this region of the river. Due to the high volume flows (around 4,000 to 8,000 cms) and other environmental sensitivities it is not feasible to utilize flow control reservoirs to mitigate the flow impacts. Although the entire Fraser River generally has sub-optimal temperature conditions for summertime sockeye migrations, the key stretch of river where temperature problems are the most acute is probably the lower Nechako and the Stuart Rivers. It is unlikely that these temperature conditions can be easily mitigated.

Utilization of conventional sockeye salmon enhancement technologies, e.g. hatcheries, spawning channels and lake fertilization might provide an opportunity to rebuild the populations. However, as the number of adults returning is presently low, it is doubtful whether these enhancement methods would be effective, since it is unlikely that spawning and rearing habitat availability presently limits production under the low density conditions. Fertilization of Takla Lake could be effective for the dominant (juvenile) brood of Early Stuart sockeye – this will occur next in the year 2010. In other years, the juvenile sockeye densities would be so low that insufficient numbers of fry would be present to take advantage of any increased zooplankton food production.

For the near future, the following management actions are recommended:

1. Maintain minimal fisheries exploitation of depressed Early Stuart sockeye populations until the population recovers to higher levels of abundance.

2. Initiate a long-term study of juvenile sockeye/kokanee biology and population sizes in Stuart area lakes.

3. Discuss with DFO the short-term fertilization of Takla Lake on an experimental basis in 2010 (dominant brood year fry present) to aid the recovery of Driftwood and Takla Lake tributary stream populations of Early Stuart sockeye.

4. Formalize arrangements for importing food fish to affected communities.

5. Undertake COSEWIC listing of Early Stuart and Late Stuart sockeye. It would be strategic to list these populations separately as the Early Stuarts, by virtue of their discrete migration timing, would also be candidates for SARA listing once a COSEWIC listing had been obtained. The temporal overlap of Late Stuarts with other Summer Run sockeye would likely make SARA listing of this population problematic.

6. Initiate a Stuart Sockeye Recovery Planning Committee that could be tasked with:

    - Improving migration conditions, especially in known areas where there are passage difficulties at various flows;
    - Lake monitoring; and,
    - Moving away from managing Late Stuart as part of the Summer Sockeye aggregate in order to reduce exploitation rates (develop stock-specific harvesting strategies).

The question needs to be raised - will Stuart Lake sockeye populations ever recover to former levels of abundance, especially in view of ongoing climatic warming? It is a somewhat disturbing conclusion of this review that we may need to (reluctantly) accept that Stuart sockeye may no longer support viable fisheries, and that some of the sub-populations (individual creeks) of Early Stuart sockeye may be lost in future. By virtue of their long migration distance, these stocks may be the first “canaries in the coalmine” when the effects of climate change become more pronounced. Since Early and Late Stuart sockeye are highly sensitive to climate change, they need to be closely monitored as part of a broader salmon response strategy to climate change. This strategy needs to address the requirements of other early, long-migrating salmon stocks that return to spawning grounds in the Upper and Middle Fraser River tributaries.

It is questionable whether Upper Fraser River First Nations, particularly those in the Stuart/Takla area will be able to meet all of their future food, social and ceremonial requirements due to the depressed status of Early and Late Stuart sockeye. For those First Nations that are most seriously affected, it may be necessary to develop arrangements for importing sockeye from neighboring drainages, e.g. Skeena River (Babine Lake). There was a traditional use of Babine Lake sockeye by Tl'azt'en Nation during off-cycle years, providing a precedent for such a practice. Recent arrangements to provide the Takla Lake First Nation with food fish have included the harvest of fish from the Sustut-Bear system. In addition to accessing Skeena River sockeye, it may be practical to successively harvest (in different years) dominant runs returning to the Chilko, Horsefly and Adams Rivers and to export the fresh fish to the Stuart/Takla areas. Sharing arrangements with local First Nations will need to be developed. Nevertheless, the practice may serve to provide affected First Nations with food fish in the short term. These measures will also assist to conserve Stuart sockeye stocks while future research and recovery efforts are underway.

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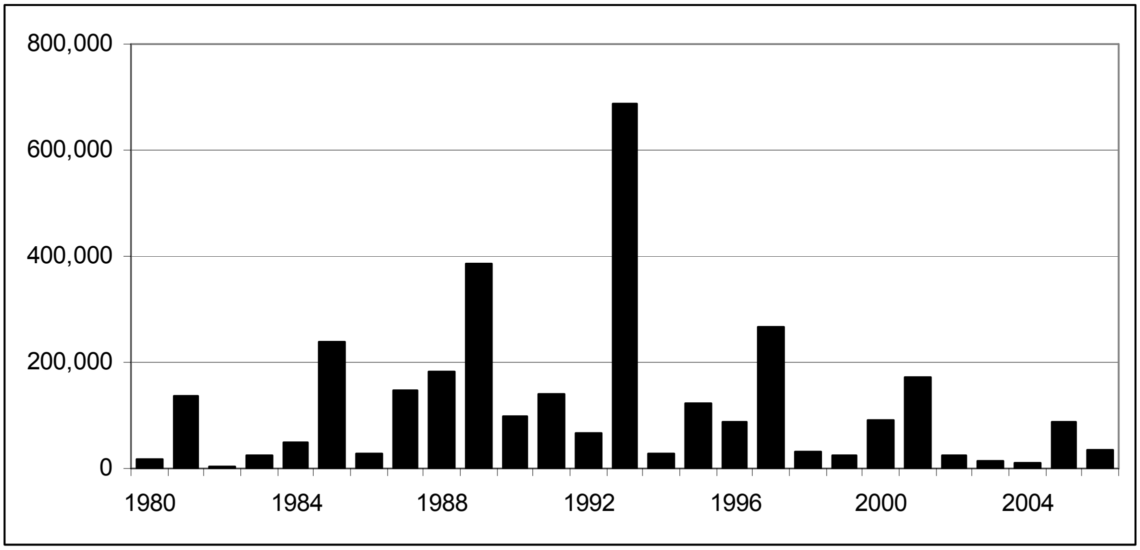
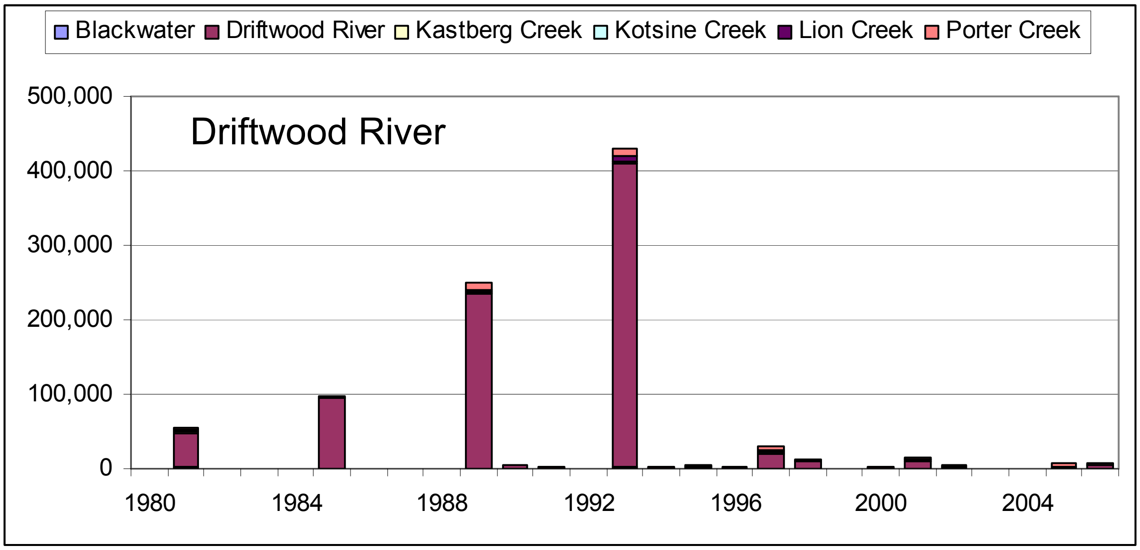
Appendix 1: Early Stuart sockeye escapement

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Driftwood River
Kastberg Creek
Kotsine Creek
Lion Creek
Porter Creek
Driftwood River
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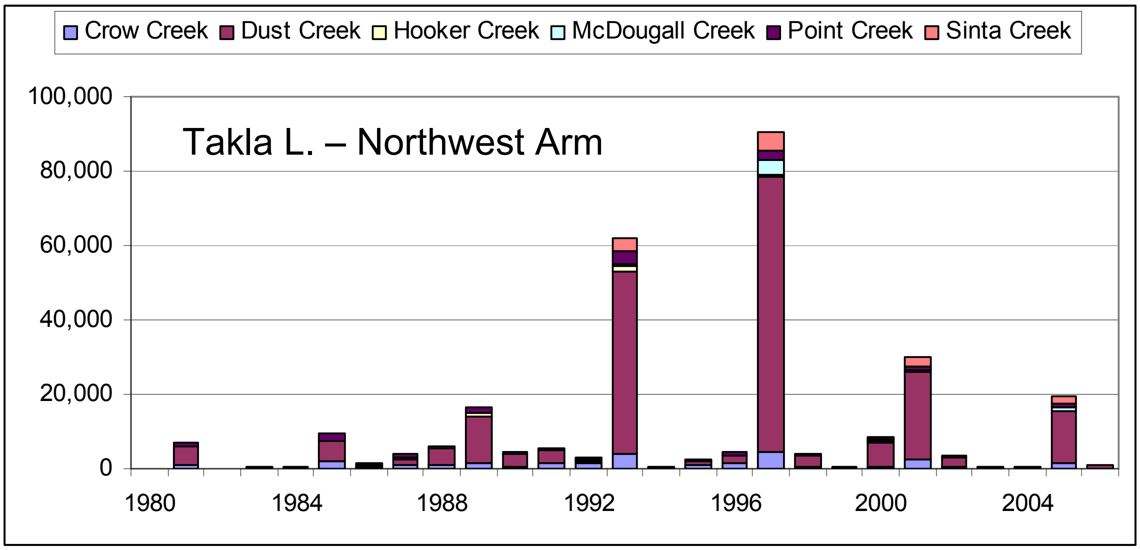
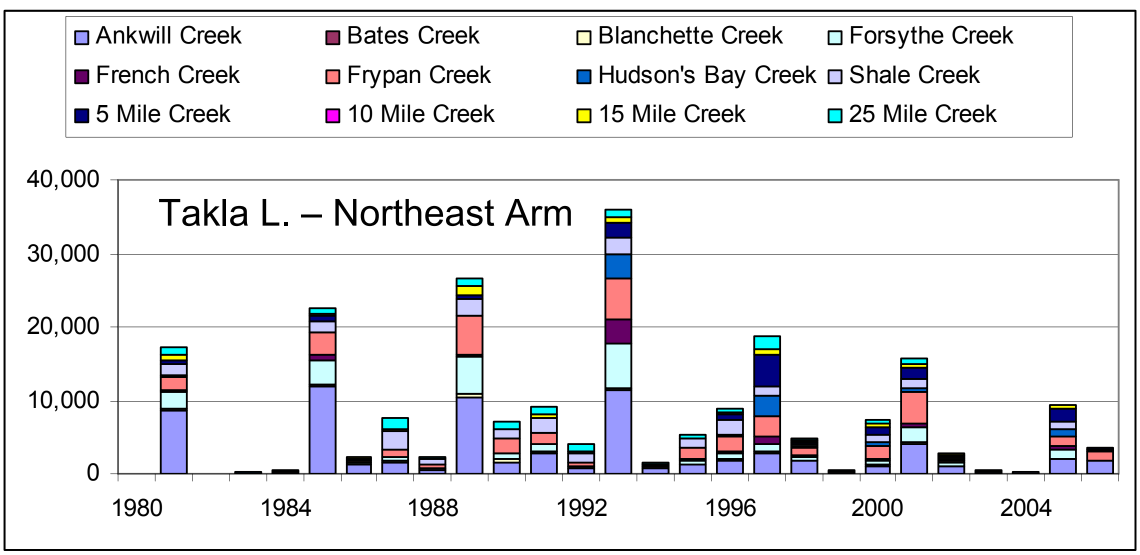
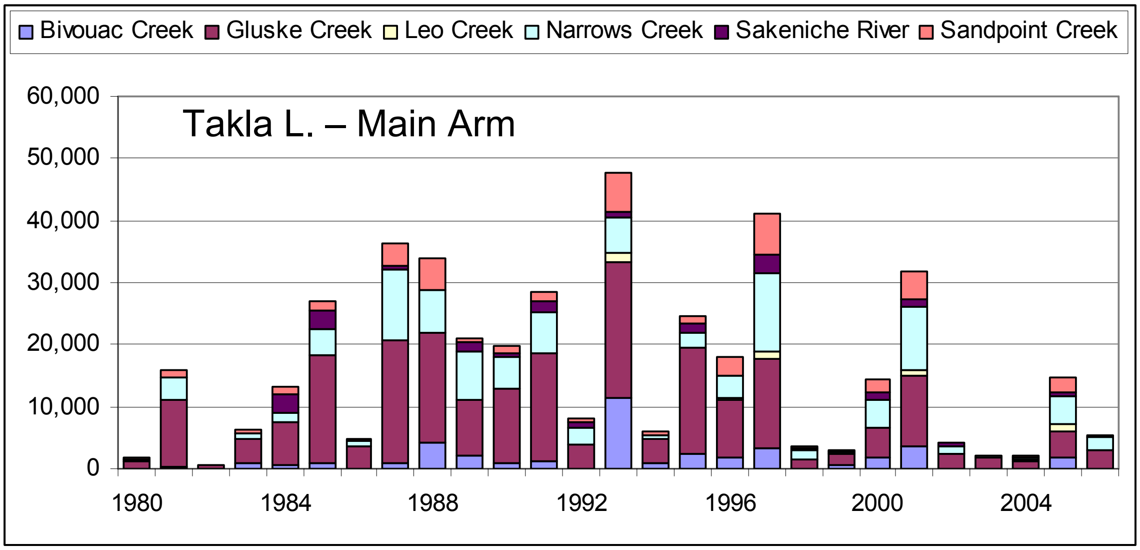
400,000
300,000
200,000
100,000
0
1980
1984
1988
1992
1996
2000
2004


Crow Creek
Dust Creek
Hooker Creek
McDougall Creek
Point Creek
Sinta Creek
Takla L. – Northwest Arm
100,000
80,000
60,000
40,000
20,000
0
1980
1984
1988
1992
1996
2000
2004


Ankwill Creek
Bates Creek
Blanchette Creek
Forsythe Creek
French Creek
Frypan Creek
Hudson's Bay Creek
Shale Creek
5 Mile Creek
10 Mile Creek
15 Mile Creek
25 Mile Creek
Takla L. – Northeast Arm
40,000
30,000
20,000
10,000
0
1980
1984
1988
1992
1996
2000
2004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Gluske Creek
Leo Creek
Narrows Creek
Sakeniche River
Sandpoint Creek
Takla L. – Main Arm
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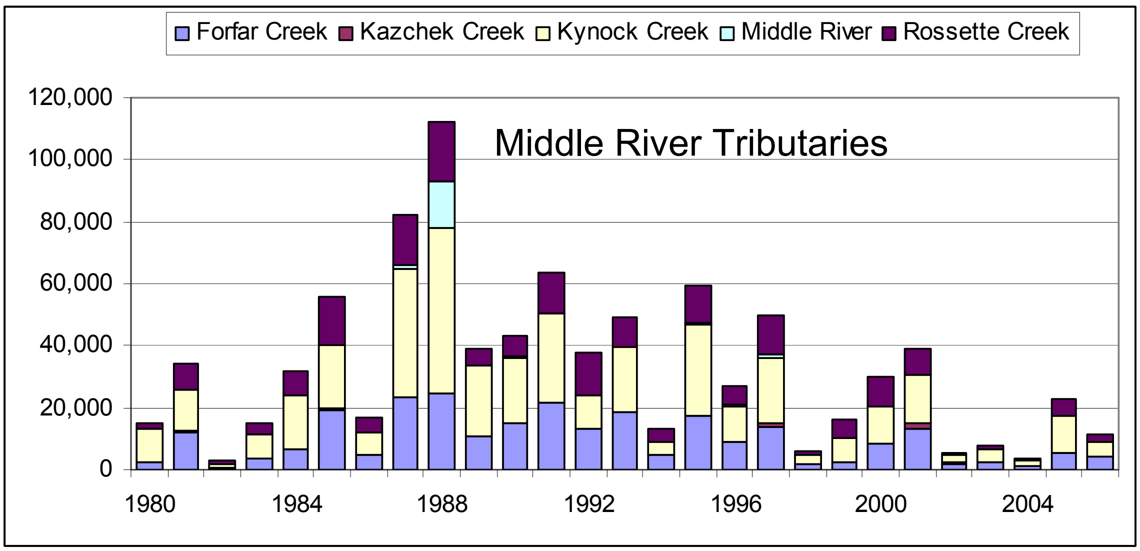
50,000
40,000
30,000
20,000
10,000
0
1980
1984
1988
1992
1996
2000
2004


Forfar Creek
Kazchek Creek
Kynock Creek
Middle River
Rossette Creek
Middle River Tributaries
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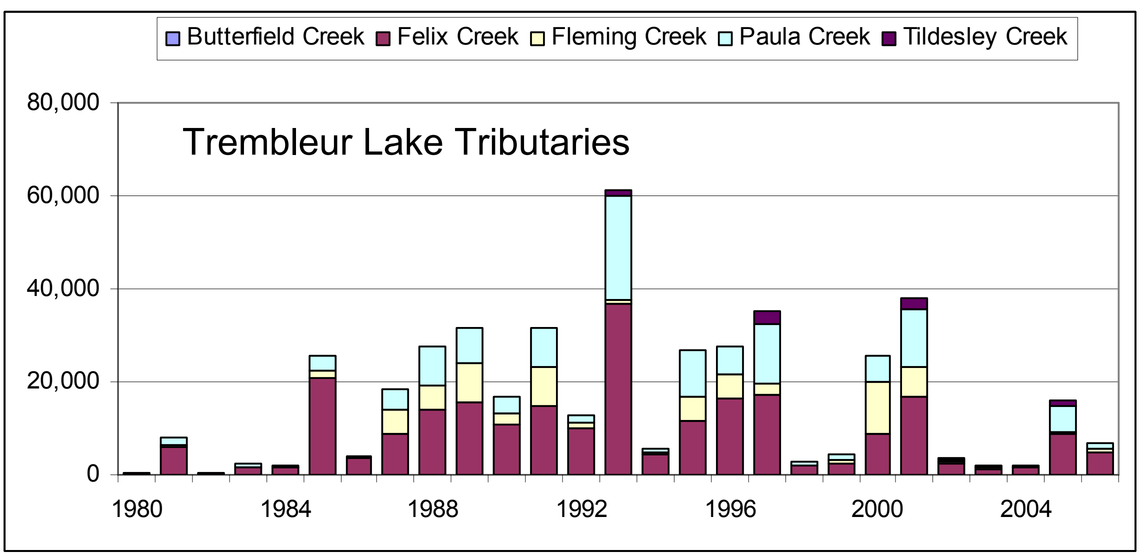
100,000
80,000
60,000
40,000
20,000
0
1980
1984
1988
1992
1996
2000
2004


Butterfield Creek
Felix Creek
Fleming Creek
Paula Creek
Tildesley Creek
Trembleur Lake Tributaries
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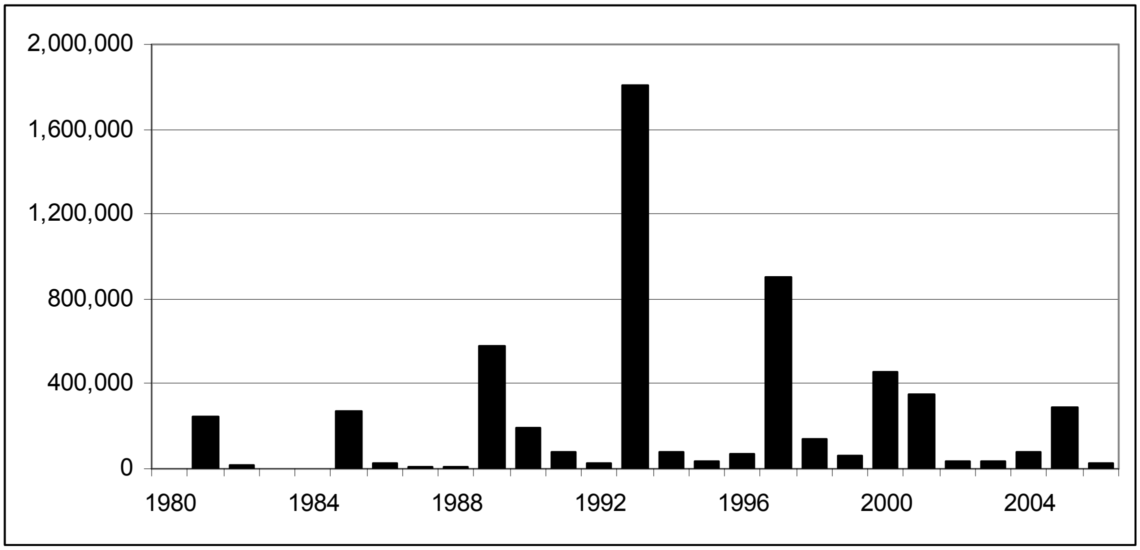
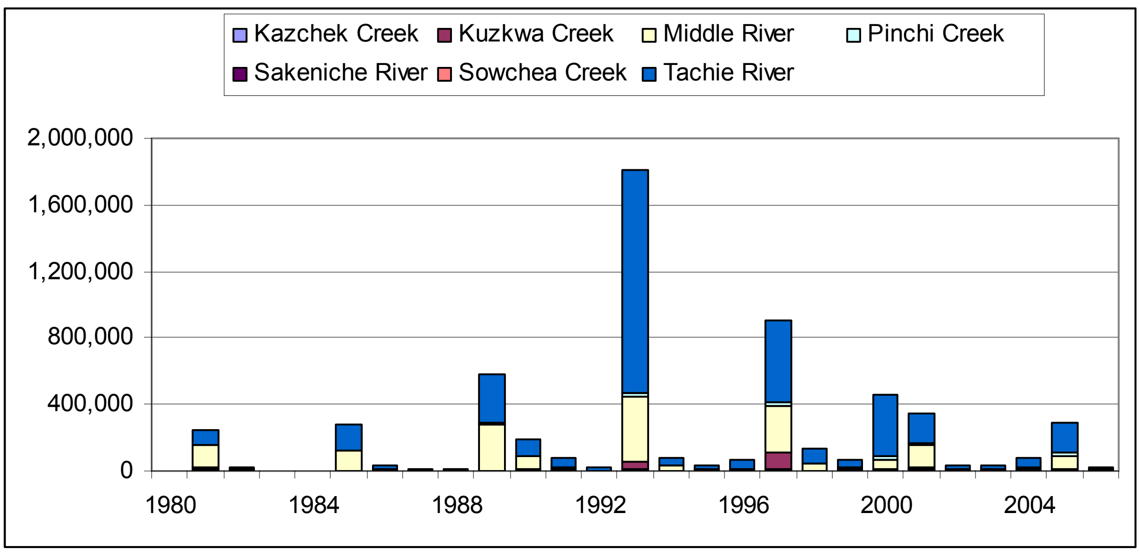
60,000
40,000
20,000
0
1980
1984
1988
1992
1996
2000
2004

Appendix 2: Late Stuart sockeye escapement





Appendix 3: Stuart Lake Sockeye Biology and Fisheries Evaluation

INTRODUCTION

Recruitment and escapement of both Early Stuart and Late Stuart sockeye have been depressed on most cycle lines in the 1997-2006 period. After high recruitment and escapement in the late 1980s and early-mid 1990s, due in part to favorable ocean survival, Early Stuart escapements were severely impacted by alternating years of high discharge and high water temperature in the Fraser Canyon from 1997 to 1999. Subsequent low recruitment rates and periodic en route losses have plagued the stock and led to a continuation of low annual runs and escapements. Late Stuart sockeye appear to have been adversely affected by high water temperatures during upstream migration in 1998 and 2004 and by cycle-line interactions between adjacent broods within the rearing lakes. The backgrounds to the depressed states of recruitment for the two stock complexes need to be understood before looking for solutions. In this appendix to the main report, an overview of the biology and habitat utilization of these stocks is provided. This is followed by reviews of recent production and utilization patterns.

The Stuart Lake watershed consists of three large interconnected lakes and associated tributary streams located in the northwestern portion of the Fraser River watershed between the eastern slope of the Coastal Range and the western extent of the Interior Plateau (Figure A1). Two major sockeye stock complexes, termed Early Stuart and Late Stuart sockeye, utilize the spawning and lake rearing habitats for incubation and early growth. Early Stuart sockeye migrate and arrive in terminal areas approximately one month before Late Stuart sockeye and spawn in the upper portion of the Stuart Lake watershed in smaller streams tributary to Takla and Trembleur Lakes and Middle River. Late Stuart sockeye spawn in the rivers between lakes, i.e., Middle and Tachie Rivers, and in tributaries to these two rivers.

Both Early and Late Stuart sockeye have displayed cyclic dominance in the escapement and recruitment on the 2005 cycle line for the years of record from 1945 to the late 1990s or early 2000s (Figures A2 and A3) and were cyclical in earlier years. While this pattern is similar to several other stocks occupying large lakes in the upper Fraser watershed, the pattern of abundance on non-dominant lines differs from the cyclical pattern typified by Shuswap and Quesnel sockeye. Understanding the causes and dynamics of cyclical production is fundamental to the management and utilization of these stock complexes.

Early Stuart fish possess many physical, behavioural and habitat utilization traits that are unique among the stocks of Fraser River sockeye. These fish migrate 1,000 to 1,100 km from the mouth of the Fraser at Steveston to their spawning grounds, the longest migration distance for sockeye in the Fraser River watershed. Adaptations for migrating long distances early in the summer often at high Fraser discharge levels are evident in the body shape and physiology of the fish. As the earliest arriving sockeye each year in the Fraser River, Early Stuart sockeye are highly sought by all groups of fishers. As such, Early Stuart sockeye have been a focus of active fisheries management for the past 40+ years.

Due to their early season migration, Early Stuart sockeye are particularly vulnerable to extreme environmental conditions during upstream migration, particularly in the Fraser Canyon between Hope and Lytton (Macdonald et al. 2000). As a result, this stock complex has shown high variability in recruitment during the 1952-2005 period, the time period for which suitable quality data are available. At the date of this report (2007), Early Stuart sockeye escapements are badly depressed on two (2003 and 2004) of the four cycle lines used to track spawning and subsequent recruitment and are somewhat depressed on the other two lines (2005 and 2006).

Late Stuart sockeye are considered one of the four stocks comprising the Summer-run run-timing group, along with Quesnel, Chilko and Stellako sockeye. While Late Stuart sockeye generally produce more fish than the Early Stuart, the Late Stuart sockeye tend not to be the focus of management concern at their time of arrival due, in part, to the higher abundance of co-migrating stocks. Late Stuart sockeye have also shown substantial reductions in escapement, particularly on the dominant line in recent years compared to escapements observed in the late 1980s and 1990s. However, all non-dominant lines have been much stronger in recent years than historically. One non-dominant line (1996-2000) appears to have recently surpassed the long-standing dominant line.

BIOLOGY AND HABITAT UTILIZATION

Spawning

Early Stuart sockeye are a complex of populations that spawn in approximately forty small to medium size streams tributary to Takla and Trembleur Lakes and to Middle River, the interconnecting “trunk” stream between these two lakes. Four broad groupings of sockeye spawning populations have been traditionally identified: Driftwood River, Takla Lake tributaries, Middle River tributaries and Trembleur Lake tributaries (Figure A1). Fisheries and Oceans Canada (DFO) now groups streams in three separate regions of Takla Lake. These three regions are combined as “Takla Lake tributaries” for the purpose of the present analysis. Within each traditional grouping there are between four and twenty-five individual streams utilized by sockeye. Analysis of spawning population abundance strongly suggests that each of these populations normally return to their natal stream. The role of straying in the system is poorly understood, but may occur in extreme situations if low discharges prevent natal stream access or where fish are highly stressed due to migration difficulties and subsequently divert to non-natal spawning areas.

Early Stuart sockeye spawning peaks in early August but active spawning usually occurs from late-July to late-August. Spawning time may be synchronized to the temperature cycle in the tributary streams used for spawning. Fall weather conditions cause early cooling in these low discharge streams and winter weather often presents extreme cold conditions. Interestingly, populations spawning in the Middle River tributaries tend to spawn earliest, possibly due to cold groundwater fed stream incubation environments, while the more northerly Driftwood River populations appear to be among the latest arriving and spawning fish. The Driftwood water temperatures in fall may cool less rapidly and thus provide more rapid embryonic development and hatching prior to extensive freeze-up, thus resulting in selection for somewhat later spawning.

Late Stuart sockeye spawn primarily in Middle River and Tachie River, with smaller populations utilizing tributaries to both these rivers, i.e., Kazchek, Kuzkwa and Pinchi Creeks (Figure A1). The rivers between the large lakes cool more slowly in the fall because the lakes accumulate heat during the summer and dissipate that heat slowly in fall and early winter, maintaining higher water temperatures in the lake outlet streams in fall compared to small tributaries that respond more rapidly to changes in air temperature. Peak spawning timing of Late Stuart sockeye is normally in mid- to late-September, but spawning can occur from early-September to mid-October, depending on the year. Deposition of sockeye eggs is necessarily timed to ensure appropriate incubation time and emergence in the spring when ice cover retreats and biological production provides food for newly emerged fry.

Lake residence

Sockeye fry emerge from spawning areas in spring (May) timed to enter the large lakes of the system at the average time of zooplankton population growth. Here mixed populations of age 0 juvenile sockeye and ages 0, 1+, 2+ and 3+ kokanee, the landlocked form of sockeye appear to compete for food (Wood et al. 1999) and are themselves prey for predatory fish.

The lakes vary in size and mean depth with Takla Lake being the second largest (area = 246 km^2) but deepest (avg. depth = 107 m). Trembleur is the smallest lake (area = 116 km^2; avg. depth = 40m) and Stuart is the largest (area = 359 km^2) lake but the shallowest with an avg. depth of 20m (Shortreed, et al. 2001). Summer epilimnial (above the thermocline) temperatures average 12-15°C and mean euphotic zone depths are 6-7m which suggests that juvenile sockeye would not be restricted from access to the epilimnion of the lakes and should overlap high in the water column near their preferred food species during certain diel periods. Limnological sampling data indicate that Stuart Lake is the warmest and has the highest density of zooplankton with each lake up the chain having slightly lower mean epilimnial (surface to thermocline) temperature and less zooplankton. Takla Lake has the lowest zooplankton standing crop of the three lakes and is also one of the lowest in the Fraser watershed. This may be associated with low nutrient concentrations and restricted euphotic zone depth of the lake. Takla Lake also has low total alkalinity and the lowest phytoplankton growth and zooplankton production.

Newly emerged Early Stuart sockeye fry enter Takla and Trembleur Lakes, while Late Stuart sockeye fry enter Trembleur and Stuart Lakes. Although the rearing pattern is not confirmed by actual sampling, it is likely that the juveniles rear primarily in the lake of entry. Lake habitat utilization was studied by Fisheries and Oceans Canada (DFO) in 1996-1998 when juvenile sockeye from the 1995, 1996 and 1997 brood year spawning populations were surveyed (Shortreed et al. 2001). Juvenile sockeye and kokanee were the primary species in the pelagic (offshore – deep water) zone. Fish abundance was estimated via hydroacoustic methods and samples obtained by trawling provided mean weight and stomach content data.

Abundance of sockeye/kokanee was low to moderate in all three lakes in the years surveyed, however, the combined Early and Late Stuart effective female spawners (EFS) were low for the 1995 and 1996 brood years (74,000, and 68,000, respectively) and the 1997 Early Stuart spawners (73,000 of the total 488,000 EFS) appear to have been badly stressed during migration that may have led to low egg to fry survival. *Daphnia* and *Heterocope* were the preferred zooplankton species utilized by the juvenile sockeye. Mean weights in fall surveys for Takla Lake juvenile *O. nerka*, i.e. mixed age 0 sockeye and kokanee ranged from 2.5 to 3.9 g. Trembleur Lake juvenile fall fry *O. nerka* were the largest in the system at a mean of 5.1 g. Stuart Lake juvenile *O. nerka* were 2.5-3.9 g in weight for fall surveys in the three years (Shortreed et al. 2001). Mean weight differences between years are likely due to interannual density dependent growth differences and variable proportions of sockeye and smaller body sized kokanee. Takla Lake age 0 sockeye in 1988 and 1991were significantly larger (53 mm) than age 0 kokanee (39 mm) collected in the same trawl catches and individually identified by protein electrophoresis (Wood et al. 1999). This would indicate a substantial mean weight difference (> 2X) in juveniles of the two forms in summer. Diet studies indicated that juvenile sockeye and kokanee had identical feeding habits, suggesting that competition may occur between the two forms.

In spring (May) of the year following emergence, juvenile sockeye undergo smoltification when physiological changes take place that are required for the juveniles to tolerate seawater. Size of smolts is in the upper portion of the range of sizes observed in Fraser watershed lakes. At this stage they are approximately 21 months of age (from egg deposition) and average approximately 95 mm in length and 9g in weight (average of seven years of data).

The Stuart watershed lakes comprise approximately 30% of the surface area of sockeye rearing lakes in the Fraser watershed with Stuart Lake being the largest in the watershed. However, on average, only 13% of the annual Fraser sockeye escapement spawns in the Stuart system. Shortreed et al. (2001) suggest that the lakes of the Stuart system could support increased numbers of juvenile sockeye given the relatively low densities of juveniles they found in summer and fall surveys in 1996-1998. However, as noted above, the number of sockeye spawners appeared to be low in two of the three years surveyed and in the third, may have experienced excessive mortality due to migratory stress. Takla Lake reared juvenile sockeye from the large 1993 brood escapement showed a substantial decrease in average scale circuli count to the annulus compared to earlier and following dominant line circuli counts (12.5 vs.15.1), but growth did not appear to be severely depressed at the highest EFS density yet observed (Pacific Salmon Commission, unpublished data).

Ocean phase

Sockeye smolts migrate approximately 1,000 km from the Stuart River system, down the Nechako River and the mainstem Fraser to the Strait of Georgia. After transition to seawater, the smolts appear to migrate rapidly northward principally through Johnstone Strait to the ocean north of Vancouver Island (Groot and Cooke 1987). Juvenile sockeye appear to follow the continental shelf into Alaska before migrating offshore into the Gulf of Alaska in late summer. Ocean residence for Early Stuart sockeye has been determined as being located south and west of Ocean Station “P” by correlation of sea surface temperatures with variation in onshore migration timing (Blackbourn 1987). Most Stuart Lake watershed sockeye remain in the offshore areas of the north Pacific for approximately one and a half years before beginning to mature. Maturation stimulates migration in an easterly or southeasterly direction toward the coast of British Columbia in late spring resulting in their arrival in Juan de Fuca and Johnstone Straits from mid-June to mid-July for the Early Stuart sockeye and mid-July to late-August for Late Stuart fish.

The marine life span of age 4 fish is approximately 26 mo. but a portion (10%) do not mature until age 5. Weight of age 4 Early Stuart sockeye upon arrival on the coast averages 2.5kg (5.5lb), while Late Stuart fish are slightly smaller at approximately 2.4kg (5.3lb). Body size information from spawning ground samples indicates that ocean growth in the North Pacific Ocean subsequent to the regime change in 1977 has been lower than during the period of 1952 to 1976. Mean length of male and female Early Stuart sockeye that spawn in Kynock Creek show a slight decline in size and Late Stuart sockeye in Middle River show the a much larger decline in size associated with ocean conditions (Figures 4 and 5). Particularly striking is the change in Late Stuart sockeye mean length by approximately four centimeters from the early 1950s during a cold ocean phase to the 1989-1997 period of warm ocean conditions. Since the late 1990s, fish size has been near the long-term average.

Coastal and Fraser River migration

The peak arrival date of Early Stuart sockeye in Juan de Fuca Strait (Area 20) is July 3 and for Late Stuart is August 5. Migration time from the entrance of Juan de Fuca Strait to the river mouth is approximately 5 days. At low discharge conditions, upstream migration between Steveston and Fort St. James takes approximately nineteen days for Early Stuart sockeye - six days to Hells Gate (28km/d) and thirteen days from Hells Gate to Fort St. James (57km/d). At higher river discharge levels (>6,000cms) migration speeds slow and migration times increase rapidly with higher discharge levels. Travel times from Mission to the Middle River tributary weirs (1991-2006) was 7 days earlier, on average, when Hope discharge levels were less than 6,000cms compared to years of discharge over 6,000cms. The Fraser Canyon between Hope and Hells Gate presents the most difficult challenges to migration and slows the progress of fish due to points of restricted passage and the need to rest between periods of exertion. While average migration speed of travel for Early Stuart sockeye from the lower Fraser to Fort St. James is as fast or faster than any other Fraser sockeye (Killick 1955), Early Stuart sockeye migrate through the Canyon at slower average speeds than stocks that migrate later in the season at lower water levels.

Upon arrival in the Stuart Lake watershed in mid July to mid August, the maturing Early Stuart fish quickly migrate to their spawning grounds and commence spawning within 7-10 days. Spawning dates vary between streams but Middle River tributary stocks have average peak spawning periods in the first week of August. Delays in spawning times occur in years of late onshore arrival and/or high Fraser River discharge. At maturity and spawning the majority of Early Stuart sockeye are 4-years of age (92%), while approximately 8% are 5-year-olds and 1% are age 3 or age 6 fish.

Little specific data exist regarding Late Stuart sockeye migration speeds. However, Late Stuart and Stellako River sockeye migrate at similar times and studies on Stellako sockeye show these fish migrate at slower rates of travel averaging 36km/d despite typically encountering lower river discharge levels (Killick 1955). This appears to be an adaptation to the later spawning timing of these fish and the need to conserve energy for a period of holding in the lakes prior to spawning. Late Stuart sockeye arrival at Fort St. James occurs in mid-August to mid-September and spawning occurs approximately three to four weeks later in early September to early October. Late Stuart sockeye also mature primarily at age 4 (89.7%) and age 5 (9.8%), with small numbers of age 3 and age 6 fish.

Adaptations

Early Stuart sockeye have adapted to the selective pressures associated with synchrony of migration and spawning in several aspects of their biology, particularly in body form and behaviour, attesting to the challenges these fish encounter during upstream migration. Less is known of the Late Stuart sockeye adaptations.

Run timing

Early Stuart sockeye have adapted to egg/alevin development in the late summer cooling and long, cold winters in the Stuart Lake watershed by spawning in summer (late-July to late-August) in a variety of surface water and ground water fed tributary streams. Their long migration and early spawning time require that they enter the Fraser early in the season, migrate upstream at a rapid rate and spawn shortly after arrival. Their median date of arrival at the mouth of the Fraser is July 8, the earliest of all Fraser sockeye, and peak spawning occurs about one month later in early August. This is the shortest time between river entry and spawning of all but a few Late-run stocks in the Fraser. The rapid migration rate is clearly an adaptive trait aimed at migrating as late as possible to avoid high Fraser discharges in late spring-early summer (May-June) at the same time as allowing maturation and spawning in early August in order to permit egg development and hatching prior to freeze-up. While Early Stuart sockeye have adapted to this narrow timing window for migration and spawning, the stock is the most vulnerable in the Fraser to variable Fraser River spring and early summer discharge conditions.

Passage conditions

Early Stuart sockeye migrate upstream on the descending limb of the normal discharge peak which occurs in late May-June. However, at times, high discharge (> 8,000 cms) from heavy snow packs or summer rain events exceeds the upper threshold for successful passage of sockeye through the Fraser Canyon and slows or temporarily blocks migration. While high discharge of the Fraser may present difficult passage conditions in the Fraser Canyon, lower than normal discharge levels in some years may be accompanied by high water temperatures associated with hot dry weather in the interior of British Columbia combined with the long day length in July and early August. There is an inverse relationship between Fraser River discharge and water temperature (Figure A6).

Early Stuart sockeye migrate in the Fraser at higher average discharge levels than any other stock. Adaptation to the higher velocities that they encounter include arrival at the river mouth with a very high level of body lipids (fat) which are metabolized by the fish for energy during migration and for development of eggs and sperm. In order to optimize energy expenditure during migration, Early Stuart sockeye have evolved a highly fusiform or bullet-like body form to minimize friction drag and, hence, improve energy utilization efficiency during migration through the Fraser Canyon and upstream points of difficult passage. Males develop minimal sexual dimorphism such as head size and kype (snout). Physical characteristics of Early Stuart sockeye promote successful migration to their spawning grounds under high discharge conditions. Whether the adaptations observed in Early Stuart sockeye are optimal for migration at high water temperatures requires further study.

Late Stuart sockeye migrate later in the summer (late July-August) and, hence typically encounter lower flows but higher water temperatures. Little specific data are available on Late Stuart sockeye lipid content and other physiological adaptations, but other Summer-run sockeye stocks that spawn at similar times (e.g., Chilko and Stellako) enter the river with high lipid content for their long migration and extended life in freshwater. Presumably, Late Stuart stocks have evolved similarly. Whereas Late Stuart sockeye enter the Fraser nearly one month after the Early Stuart sockeye, i.e., with one month additional ocean growth opportunity, they are smaller-sized fish.

PRODUCTION HISTORY

In the following section, the number of maturing fish returning to coastal waters each year, i.e., the <u>annual run</u>, is differentiated from the number of offspring from a single spawning population or brood year, i.e., the <u>recruitment</u>. Recruits from a brood year spawning population (e.g., 2001) return as maturing fish 3, 4, 5 and, at times, 6 years later (in 2004, 2005, 2006 and 2007). These fish contribute to the annual runs along with other age fish from prior and subsequent brood years. Biologists determine the age composition of a sample of fish obtained from the annual run and attribute estimates of recruits by age group to the appropriate brood year. Most Stuart area sockeye mature and return as 4-year-old fish and, as such, the annual runs often are dominated by age 4 fish. At times, the annual runs are predominantly composed of age 5 fish because of low recruitment from spawners four years previous or large numbers of age 5 fish, particularly from dominant cycle line years.

Annual runs

<u>1820-1899</u>

Studies by Cooper and Henry (1962) indicated that Early Stuart sockeye were not a consistent or major contributor to the annual Fraser return in the nineteenth century based on analysis of Hudson’s Bay Company records from Fort St. James. Records of catches in late July and early August were lacking in most years suggesting that Early Stuart sockeye were of lesser abundance in most years. The large run at the time appeared to be the Late Stuart sockeye. Comments regarding failures of sockeye runs (Early and Late Stuart) were not infrequent. In 1899, marine commercial fishery catches by July 14 totaled 220,000 fish, most of which would have been Early Stuart sockeye based on later years of data regarding arrival timing of the various stocks. However, Fort St. James records indicate a total failure of the sockeye runs. Data are inadequate to be confident that the Stuart stocks displayed cyclic dominance in this period, but because they were cyclical when adequate data became available and other upper Fraser sockeye stocks were cyclical, it is likely that cyclic dominance was a trait of Stuart area stocks, as well.

<u>1900-1948</u>

Commercial catch records and calculated fishing intensity suggest that poor to mediocre annual abundance of Early Stuart sockeye occurred in this period. Cooper and Henry (1962) provide calculated total abundance estimates by year and cycle line. They estimated that annual runs averaged approximately 47,000 fish. The range in run size estimates was 700 to 600,000 fish. A strong cyclical pattern of abundance was evident in their data after 1921, with increases in annual runs on the cycle line until 1933. However, a major failure of the dominant line run was observed in 1937. This failure was undoubtedly due to extremely high Fraser River water levels that occurred in the early summer of 1933 when a very late spring runoff resulted in Hope discharges over 8,000 cms for 24 days, June 25-July 18, and high water for another two weeks into early August. No specific recruitment data on Late Stuart sockeye in this period were collected. However, escapement data showed a strong cyclical pattern to recruitment with large dominant line escapements in 1945 and 1949, after fishways were constructed to assist fish at the points of difficult passage.

<u>1949-2006</u>

Early Stuart sockeye annual runs averaged 330,000 fish in the period from 1949 to 2006. During this period, fishery regulations limited the intensity of fishing on stocks of concern and construction of fishways between 1945 and mid-1960s in the Fraser Canyon improved the capability of early timed fish to ascend past points of difficult passage at Hells Gate and other sites. The largest run on record was nearly 1,700,000 fish in 1997. Until 1997, dominant line runs were not adversely affected by high discharges and produced well while some non-dominant line runs suffered severe depletion from the effects of high discharge and did not produce well for many of the years in the period.

A strong cyclic dominance pattern is evident in escapement data between 1949 and 1997 (Figure A2), with less pronounced dominance in years since 1997, due to the high discharge in mid-July of that year and subsequent reduced recruitment.

Late Stuart sockeye runs averaged 579,000 fish in the period 1953-2005. The history of rebuilding of this stock complex is one of initial recovery on the dominant line in the 1950s followed by recruitment declines in the 1960s before strong recovery in the 1980s and 1990s. Non-dominant line recruitment was low until the late 1980s when these lines began producing greater numbers of fish (Figure A3).

Recruitment

Between 1948 and 2002 brood years, total recruitment from brood year spawners of Early Stuart sockeye varied between approximately 10,000 (1968 brood) and 1.8 million (1993 brood) fish (Table A1). The average recruitment was 330,000 fish, but the geometric mean was 160,000 fish, indicating a highly skewed distribution of run sizes. This latter stems from the cyclical recruitment pattern of Early Stuart sockeye. The 1949-1953…1997-2001 line has been the dominant line with an average recruitment of 849,000 fish. The three other lines have averaged 150,000 recruits, and generally have been quite similar (line 2 average: 106,000; line 3 average: 192,000; and line 4 average: 141,000).

Recruitment can also be expressed as a rate, i.e., the number of recruits per spawner. The natural logarithm of the number of recruits (R) per effective female spawner (EFS) provides the best measure of the recruits per spawner because of the highly variable proportion of effective females within the population. The geometric mean R/EFS for Early Stuart sockeye for 1948-2002 broods is 7.41, which means that 7.4 adult fish have, on average, returned for each effective female spawner in the brood year. Cycle average R/EFS estimates are: Dominant line: 7.39; Line 2: 5.93; Line 3: 8.41; Line 4: 8.42. However, consistency in the mean values belies a large variation in the annual values (Figure A2). Recruitment rates have declined in the 1990s and 2000s as a result of low freshwater survival and less favorable marine conditions. Annual geometric mean R/EFS for brood years 1997-2002 averaged only 2.95 fish/EFS, less than 40% the long-term average. Several years in this period may have had low egg to fry survival due to en route stress associated with high discharge or high water temperature.

Late Stuart sockeye have displayed even greater variability in recruitment rate (Figure A3). Inadequate estimation procedures on non-dominant line years at times provided poor quality estimates of escapement which introduced a great amount of uncertainty into the recruitment rate estimates (Table A2). The result is the increase in year-to-year variability in the geometric mean recruitment rates. The long-term mean recruitment rate is 11.8 fish/EFS. Cycle average R/EFS estimates are: Dominant Line – 8.71; Line 2 – 9.36; Line 3 – 11.50; Line 4 – 21.42. Annual mean R/EFS for the 1997-2001 brood years averaged 2.73 fish/EFS, less than one quarter the long-term average.

While recruitment rates declined in the late 1980s and early-mid 1990s with larger escapements, recruitment rates in the later 1990s and early 2000s were as low, if not lower (with some exceptions), despite smaller effective female spawner abundance (see dominant line data in Figures A8 and A9). There appears to be a correlation between the residuals of the recruitment rate to the regressions fit to the data for Early and Late Stuart dominant line sockeye. However, the correlation (adj. $R = 0.284$; $p < 0.05$) is significant only because of three very low data points, 1961, 1997 and 2001, in the fourteen years (Figure A10).

Cyclic dominance

The term “cyclic dominance” in Fraser River sockeye is used to describe the recurring 4-year pattern of recruitment and escapement wherein one line, historically the 1901-1905….1997-2001 line (Line 1), usually is larger than the other three lines and is termed the “dominant” line. Despite past debate regarding the initiation and maintenance of cyclic dominance in the Fraser system, it has recently been interpreted as a natural, biologically efficient pattern of recruitment (Woodey et al. 2005). Ward and Larkin (1965) concluded that most, if not all, sockeye stocks in the upper Fraser were cyclical on the 1901 line in the 1800s. The 1913 Hells Gate blockage of migration and subsequent over-fishing appears to have destroyed cyclic dominance. Upon recovery, several stocks became cyclical again, but some on a different cycle line than originally observed, particularly those in Shuswap Lake.

The key mechanism in cyclic dominance is the suppression of recruitment on off-cycle lines associated with the abundance of juveniles on the dominant line. This appears to take place in the lake environment. Dominance on the same cycle line is common to all stocks in Shuswap and Quesnel Lakes, the largest producers of sockeye in the Fraser watershed. In Shuswap Lake, Early Summer-run stocks, such as Seymour River, and Late-run Adams and Lower Shuswap sockeye are now synchronous. The chance of this occurring randomly is small. Similarly, all stocks within the Stuart watershed are cyclical on the same line, which strongly suggests that biological forces are at play that have led to the cyclical pattern.

Whereas both Early and Late Stuart sockeye display strong cyclical recruitment patterns, close examination suggests that Early Stuart cyclical pattern is principally due to the cyclical nature of the Takla Lake tributary populations. A cyclic pattern is discernable in Middle River and Trembleur Lake tributary populations, but at reduced intensity of difference between cycle lines. Middle River tributary Early Stuart stocks have shifted dominance between the 1997-2001 and the 1995-1999 cycle lines in the past. However, non-dominant lines in Takla tributaries and, in particular, Driftwood River, generally have been weak in relation to the dominant 1997-2001 line.

Late Stuart sockeye spawning in Middle River and in Tachie River have consistently shown strong cyclic dominance on the 1997-2001 cycle line until the recent ascent of the 1996-2000 line. For the first time on record, the line 4 escapement in 2000 was larger than the following 2001 dominant line escapement (Table A2; Figure A3).

In general, sockeye stocks that have shown cyclic dominance in the past should produce more fish in total during periods of strong cyclic dominance than in periods when escapements are more similar between cycles. The hypothesis for this is as follows: (1) large differences in escapements between years result in large variations in fry numbers each year in the lakes, which (2) lead to dampening of predator populations because their food (juvenile sockeye) is only available in abundance one of four years, which (3) results in a decrease in predation mortality rates for juvenile sockeye, leading to (4) an increase in adult sockeye recruitment rate. Bowron River is the only example of a stock that has switched from a non-cyclical to a cyclical pattern in the Fraser watershed in recent history. This stock showed higher rates of total recruitment and R/EFS during the period of cyclic dominance than in periods before and after the cyclical period. While no data on predation rates in Bowron Lake are available, the lower recruitment rate during non-cyclical periods may have been due to higher predation mortality rates.

Effects of migratory difficulties

<u>Early Stuart</u>

En route losses of Early Stuart sockeye have occurred frequently in the recorded history of the stock. High discharges in the 1960s-1970s severely damaged line 4 recruitment for five consecutive returns. Three years of high discharge (1997, 1999, 2002; Figure A10) and four years of high water temperatures (1992, 1994, 1998, 2004; Figure A11) have occurred in the past fifteen years (1992-2006) and initiated and maintained the current depressed state of escapement and recruitment. Passage conditions through the Canyon deteriorated badly in three consecutive years: 1997, 1998 and 1999, leading to en route losses and placing severe stress on those fish that survived and added to the poor outcomes of escapement in these years. Line 2 runs in 1996 and 2000 encountered benign river conditions and reproduced satisfactorily. However, when this line returned in 2004, it encountered extremely high water temperatures that devastated the escapement. Details for each year provide insight into how fish are affected by environmental conditions.

From 1950 to 1976, high discharge (July average > 6,000cms) occurred during in 13 of 27 years (Figure A7). Eight of these (1954, 1955, 1960, 1964, 1968, 1972, 1974 and 1976) averaged greater than 7,000cms and appear to have adversely affected escapement of Early Stuart sockeye, and hence, subsequent recruitment. Escapement in 1955 declined to 2,200 fish from 60,000 fish in 1951 (Table A1), attesting to the severe effects of high discharge levels on the success of passage if the fish are delayed beyond their normal capability to survive extremely high discharge. Line 4 escapements in 1960, 1964, 1968, 1972 and 1976 were adversely affected by high discharges with the 1968 escapement dropping to 1,600 adults as the cumulative effect of reduced recruitment from prior brood years and en route losses devastated the escapement (Table A1). With benign river conditions and conservation efforts instituted to protect returning adults, escapements on the line rebuilt and three generations later, in 1988, an escapement of 180,000 fish was recorded, the largest on the cycle.

1997: Fraser sockeye were smaller than average and (probably) in low condition due to the El Niño event that year. The Early Stuart run reached the lower Fraser slightly later than normal, but many fish had already migrated upstream when a severe rain storm July 5-10 resulted in flood conditions in the Fraser Canyon July 13-20. The high discharge (> 9,000cms) and high particulate matter blocked fish already in the Canyon and beyond and severely affected fish to the point that when water levels declined, many did not resume upstream migration. Approximately, 680,000 Early Stuart sockeye perished en route (Table A3). In addition, of those fish that succeeded migrating to their spawning grounds, only 34% were females (females are slightly smaller than males and may suffer greater stress at high discharge levels), and of those, 19% died before spawning. Fish were very late arriving at the spawning streams and had been severely stressed while migrating in adverse water conditions. DFO stream monitoring programs found that average survival of deposited eggs to emergent fry in three monitored streams was the lowest on record at 11.3%, or about one half the average (K. Benner, DFO, pers. comm.; Figure A12). The expanded fry abundance was estimated at less than 10% of the 1993, parent year spawning. Particularly severely impacted was the escapement to Driftwood River. These fish appear to migrate somewhat later than do fish headed to Middle River and Trembleur Lake tributaries. The timing of the July flood appears to have had a disproportionately greater impact on the Driftwood sockeye.

1998: Low snowpack following the 1997 El Niño resulted in low discharges in the Fraser River in July and August. Also, summer air temperatures in the interior of B.C. were among the highest on record. Daily water temperatures averaged 21°C for 9 days in late July-early August, the first time on record since temperature monitoring began in 1942. The July average water temperature in the Fraser Canyon was 19.0°C. Early Stuart sockeye were physiologically stressed and approximately 138,000 fish (75% of the 184,000 gross escapement) were lost en route (Table A3). Females that did arrive on the Early Stuart spawning grounds suffered very high pre-spawning mortality (44%). The population of successful spawning female sockeye was estimated at 9,300 fish. Egg to fry survival of deposited eggs was again low at 13.2%.

1999: The snow pack in the watershed during the 1998-99 winter stands as the highest of the years surveyed. The spring runoff occurred approximately one week later than normal peaking on June 23 at 11,000cms. The river remained above 9,000cms until July 19 and was above 7,000cms all but one day until August 5. July average discharge was 8,640cms, the highest recorded in the 1952-2006 period (Figure A10). Passage through the Fraser Canyon is extremely difficult for sockeye when water levels exceed 8,000cms and is impaired above about 7,000cms. Early Stuart sockeye were devastated for the third consecutive year. Approximately, 139,000 out of 167,000 escapement (83%) died en route, leaving only 25,000 fish for spawning (Table A1). Again, a low proportion (39%) were females and the pre-spawning mortality was elevated (15%). Egg to fry survival was marginally better than for the 1997 and 1998 broods, but at 14.0% was the third lowest of the 17 years of data (Figure A12).

2004: The 2000 brood escapement of 90,000 fish produced only 136,000 total recruits. Age 4 fish returned in 2004 to another year of extreme river temperature conditions. Temperatures increased earlier in the season than in 1998, reaching 19°C on July 18. These very high river water temperatures (July average = 18.5°C) led to a severe en route loss estimated at 86,000 fish. In total, only 9,300 fish of the total gross escapement of 132,000 fish in 2004 survived to spawn (Table A3). While egg to fry survival was reasonably high (29.7%), only a small number of fry were produced that will contribute to the 2008 run.

Subsequent to the poor escapements in 1997-1999, recruitment and gross escapement were reduced. Spawning populations in 2001-2003 were smaller than in their respective brood years and while fry production estimates were higher, they were well below estimates on the lines prior to the 1997-1999 spawnings. Fry production from the 2003 and 2004 spawning populations will likely produce only low numbers of adults. The 2005 dominant line spawning may provide an increase in recruitment for the dominant line. The 2006 brood EFS (15,900) was a 23% increase over the poor 2002 spawning, but is unlikely to produce exploitable numbers of adults. In summary, the total returns in 2007 through 2010 are likely to be below spawning requirements.

<u>Late Stuart</u>

In the preceding section, we analyzed the recruitment rates of dominant line Early and Late Stuart sockeye (Figures A8 and A9). While there was a correlation in residuals around the respective regressions of recruitment rate on EFS, it appeared that this result was present because three of the years gave low recruitment rates for both stock complexes, 1961, 1997 and 2001 broods. The 1961 brood sockeye for a number of stocks had poor recruitment and the low 1997 Early Stuart recruitment appears to be due to poor egg to fry survival. However, the observation that the Late Stuart sockeye had similar low recruitment may be associated with poor physical condition and late timing of fish arriving from the ocean during the 1997 El Niño. Low lipid reserves may have adversely affected the ability of Late Stuart fish to migrate and spawn viable eggs. In addition, a very high recruitment rate of the 1996 brood spawning presented the possibility that 1996 brood juvenile foraging in the lakes adversely affected growth and survival of the 1997 brood juveniles. Lake surveys during the residency of 1996 and 1997 brood juveniles in 1997 and 1998 indicated that there were fewer age 0 juvenile sockeye in the lakes following the 1997 brood year spawning than after the 1996 spawning despite a seven-fold greater EFS escapement (J. Hume, DFO, personal communication).

Possible cycle-line interaction may also have affected the 2001 brood recruitment of Late Stuart sockeye. Low egg to fry survival affected Early Stuart sockeye, but the expanded fry abundance had only slightly lower than normal survival to adults (0.50%). Late Stuart recruitment rate was again lower than Early Stuart possibly because a relatively large 2000 brood juvenile population may have adversely affected recruitment of the 2001 brood. Juvenile growth of the 2001 Late Stuart brood appears to have been lower than expected based on effective female spawner abundance, leading to the speculation that food was limited. This occurs in other lakes associated with cyclic dominance. The unusually strong recruitment of the 1996 and 2000 brood Early and Late Stuart sockeye may well have signaled a switch in dominance in these stocks. While poised to become the dominant line, the 2004 escapements of both Early and Late Stuart sockeye were badly depleted by en route losses in the Fraser Canyon associated with the highest water temperatures observed on the Fraser (July 20-August 25 mean = 20.1°C). Combined Early and Late Stuart effective female spawners dropped from 262,000 in 2000 to 56,000 in 2004 (Table A2).

UTILIZATION PATTERNS

Early Stuart

The early return timing and high quality of Early Stuart sockeye lead to a highly diverse fishery. Commercial, marine First Nations, sport and Fraser First Nations fishers have actively harvested these fish when fisheries are scheduled. Since 1980, commercial fisheries targeting Early Stuart sockeye have occurred only on dominant line returns (Table A3). Fraser First Nations fisheries generally harvest higher fractions of the non-dominant line runs. Average Early Stuart catches in the Fraser First Nations have equaled commercial catches in the 1980-2005 period. In recent years (1998-2005), the conservation of the smaller returns and the expression of First Nations' aboriginal rights has led to a diminished commercial fishery and a larger fraction of the catch being taken by Fraser First Nations fishers.

Within the Fraser watershed, the catch of Early Stuart sockeye is taken primarily in the mainstem Fraser, with a smaller fraction of the catch taken in terminal areas (Table A4). The Fraser First Nations 1986-2005 average (omitting the 1992 data) Early Stuart sockeye catch was estimated at 82,000 fish, despite several years of fishery closure during the main portion of the migration. Catches on dominant cycle years (1989, 1993 and 1997) averaged 286,000 fish until the collapse of that cycle line in 2001 and 2005. The average catch on years other than these three dominant cycle years, was 44,000 fish.

Changes to fishery reporting areas over time hinder comparisons of Early Stuart sockeye catch between areas. Prior to 1994, reporting areas in the Fraser Canyon were split at Boston Bar and beginning in 1994, Sawmill Creek became the dividing line. Largest shares of the catch occurred in the mainstem Fraser between Mission and Sawmill Creek (50.4%) and between Sawmill Creek and Prince George (34.3%). Terminal Stuart River watershed catches (avg. = 3,700 fish) amounted to approximately 4.5% of the annual catch.

Late Stuart

Late Stuart sockeye are extensively exploited in commercial fisheries along with co-migrating Summer-run stocks (Table A5). Catches averaged 528,000 fish or 63% of the run between 1980 and 2005. However, since 1997, the lower abundance of Late Stuart sockeye along with conservation concerns for Late-run sockeye have resulted in much lower catches. Fraser First Nations catches averaged 56,000 fish or 7% of the run between 1980 and 2005. Marine First Nations and sport catches form smaller fractions of the catch.

Within the Fraser River watershed, Late Stuart sockeye catches averaged 66,000 fish during the 1986-2005 period (Table A6). Catches on the three years of large dominant line runs in 1989,1993 and 1997 averaged 172,000 fish while the average catch was 47,000 fish on the other 17 years (Table A4). Similar to Early Stuart sockeye, the First Nations fishery catches in the Fraser watershed were primarily taken in the mainstem areas. Fisheries between Steveston and Mission landed 25% of Late Stuart sockeye, Mission to Sawmill – 42%, and Sawmill to Prince George – 27%. Local catches in the Nechako River (1.6%) and Stuart River watershed (4.4%) were similar to the fractions observed in the Early Stuart catch.

STOCK STATUS

Early Stuart

The failure of many Early Stuart sockeye to successfully migrate and spawn in 1997, 1998 and 1999 resulted in recruitment on these lines that was lower than the number of fish that escaped to spawn in the parent years (Table A1). Restrictions on harvest and lower en route losses allowed higher proportions of the 2001, 2002 and 2003 runs to survive to spawn. However, annual returns on these years were much lower than in the brood years (307,000 fish total for 2001 to 2003 vs. 2,033,000 fish in 1997 to 1999). Subsequently, the dominant line in 2001 only produced at the rate of 1.5 fish per adult spawner. The 2002 brood escapement (24,600 adult sockeye) appears to have produced only about 26,000 age 4 fish in 2006.

The 2003 brood escapement (13,200) is forecast to produce a low abundance of sockeye in 2007. En route losses of the 2004 escapement in the Fraser caused that cycle spawning to decrease from 90,000 fish in 2000 to 9,300 in 2004. The dominant line escapement in 2005 was 99,000 fish, and had good egg-to-fry survival. Total escapement in 2006 was 36,000, up from 25,000 in 2002. Thus, all cycle lines of Early Stuart sockeye are currently depressed (2005 and 2006) or severely depressed (2003 and 2004).

Annual return prospects are not good for 2007 (DFO forecast is 42,000 fish, in total) and should be lower in 2008, based on expanded fry numbers. While the dominant line return in 2009 may provide an improvement, based on fry production estimates, it will not produce enough fish to permit harvesting if the run is to be rebuilt to a productive level.

Of the Early Stuart substocks, the Driftwood River and Takla Lake populations are currently lowest relative to their historical escapements. Middle River and Trembleur Lake spawning populations, while depressed on all cycles, are not as low. The somewhat later migration timing of the Driftwood sockeye and the severe effects of the 1997 mid July flood event may be responsible for the severe decline in this population. Also, by migrating later in the season on average than other populations of Early Stuart sockeye, Driftwood and Takla Lake sockeye populations would have greater overlap with Early Summer-run sockeye stocks which which were targeted for harvest in river fisheries.

Late Stuart

The 1997 dominant cycle escapement of Late Stuart sockeye produced only 0.5 fish per spawner (Table A2), or about 10% the average recruitment rate. As a result, the escapement in 2001 was only 352,000 compared to 908,000 in 1997. A part of this decline on the dominant line may be associated with the very successful recruitment from the 1996 off-cycle line spawning. The 1996 brood recruitment was over 1,000,000 fish from the spawning of 27,000 effective females. Cycle line interaction effects of one brood on the following year recruitment rate were evident in the data. Thus, the very successful 1996 brood juveniles may have adversely impacted 1997 brood juvenile survival, resulting in a decline in the dominant line abundance in 2001. Similarly, the 2000 brood may have suppressed the 2001 brood juvenile survival. While unfortunate, the 2004 escapement was adversely affected by high river water temperatures during upstream migration. A much lower 2004 escapement (82,000 vs. 454,000 in 2000) should have a lower impact on dominant 2005 line juveniles. While very late in upstream migration timing, the 2005 brood spawned at a normal time and may allow the historical dominant line to recover.

Escapements in 2002 and 2003 were lower than those observed in their respective brood years as a result of low recruitment rates and en route losses. Neither or these lines has consistently produced well in the past and cannot be expected to produce well in 2007 and 2008.

RECOMMENDATIONS

Conservation

The current depletion of Early Stuart sockeye, in particular, is very troubling. Recruitment rates have been low and the probability of environmental stress impacting the runs in coming years is high. For example, the current high snow pack in the Fraser watershed may result in high discharges during the upstream migration of early timed sockeye in 2007. If a significant fraction of Early Stuart sockeye fail to reach their natal streams, the cycle line escapement could further decline. The return in 2008 may well be at a similar level, or lower. Thus, there are no prospects for viable commercial fisheries on Early Stuart sockeye in the near term.

Fisheries in 2007 and for the next several years should be conducted in ways to ensure that greater proportions of Early Stuart sockeye successfully arrive on their spawning grounds despite adverse environmental conditions. Recommendations to DFO (and hence, to the Pacific Salmon Commission) and First Nations authorities to conserve Early Stuart sockeye would be of foremost importance. While local Stuart area First Nations have the inherent right to harvest Early Stuart and Late Stuart sockeye for food, subsistence and ceremonial purposes, contingency planning to obtain sockeye from alternate sources would make sense, if this option is acceptable to the affected First Nations. Conservation in itself will not make a substantial difference to future recruitment without relief from stress on the fish during upstream migration.

Biological studies

Study of the basic biology of Early Stuart sockeye egg to fry production has been undertaken by DFO since 1988. This program should be continued, and expanded, if possible. DFO also studies juvenile sockeye/kokanee populations and zooplankton food resources in several lakes in B.C., including the large populations in Quesnel and Shuswap Lakes. Results of a program of study on Stuart system sockeye in 1996-1998 should be thoroughly analyzed to determine if a lake survey program on Stuart system lakes could provide improved understanding regarding the current depressed state of the stocks. Discussions with DFO about potentially surveying Stuart watershed lakes now when sockeye populations are depressed would appear to be a natural extension of their work.

Included in the recommendation for biological study is the assessment of kokanee populations. It is possible that niche space formerly occupied by juvenile sockeye may now be occupied by kokanee. If kokanee populations have expanded during the period of sockeye depletion, juvenile sockeye growth and survival may be adversely affected and, hence, sockeye stock recovery could be slowed. Spawning ground adult populations should be estimated relative to historical data and in-lake juvenile populations should be estimated and compared to those present in the lakes during the 1988 and 1991 study (Takla Lake only) and during the 1996-1998 study of all three lakes. Evaluation of the status of predator populations would also be of value.

Enhancement

Inadequate sockeye fry recruitment appears to be the fundamental problem with regard to Early Stuart stock growth. Low escapements and low egg-to-fry survival appear to have limited the recovery of the stocks. Juvenile growth rates and fry to adult survival estimates appear normal, but with only about 0.5% of fry surviving to adulthood, either more fry are needed or the fry that are produced must experience higher survival to adults in order to increase recruitment.

Attempting to increase egg-to-fry survival in those Early Stuart sockeye that successfully arrive at the spawning grounds would be difficult. With forty or more spawning streams, intervention in egg to fry survival in more than a few streams would be impractical. Placing one facility such as a hatchery or spawning channel would present major logistical and cost considerations. Fry might concentrate at one location in the lake system, overtaxing the lake rearing capacity of that lake while the other lakes remain underutilized. While strategies might be developed, the lack of access and infrastructure present major considerations.

Short-term lake fertilization may be a feasible option for increasing sockeye smolt production. Spring-early summer lake fertilization might be employed to spur zooplankton growth so that sockeye fry rapidly outgrow their predators and hence, experience lower in-lake mortality rates. Takla Lake has one of the lowest standing crops of zooplankton in the Fraser watershed, and presumably would respond well to lake fertilization. Targeted fertilization of the Northwest Arm of Takla Lake would potentially enhance survival of sockeye fry from Driftwood River, Dust Creek and other nearby streams. Full lake fertilization would require much larger effort and cost, but would potentially benefit fry from a number of streams. Lake fertilization requires low capital costs and is a flexible strategy, particularly if the fertilizer is applied via an airplane.

Results of DFO's experimental fertilization of Chilko Lake suggest that short-term, targeted lake fertilization could be used as a viable enhancement technique. In Chilko Lake the number of smolts per effective female spawner was higher on fertilized years compared to non-fertilized years. As well, the size of smolts was larger than observed in non-fertilized years relative to the number of smolts produced. Both effects appear to have enhanced recruitment for Chilko sockeye during the experiment. Short-term fertilization, particularly on the 2009 dominant line brood could produce the desired effect of re-establishing the dominant line of Early Stuart sockeye in Takla Lake which formerly produced the large majority of fish. The activity would require careful monitoring as long-term fertilization would also enhance the kokanee in the Stuart area lakes, possibly resulting in an increase in food competition.

Dominant line Late Stuart sockeye may have been negatively impacted by cycle-line interaction effects by juveniles from the successful 1996 and 2000 brood year spawning populations on the following year dominant line juveniles. If so, the lower escapement in 2004 may result in stronger 2005 brood year adult recruitment in 2009. Study of juvenile sockeye and kokanee ecology in Stuart and Trembleur Lakes is important to developing future management plans. Regulation of fisheries to increase escapement of Late Stuart sockeye on the dominant line is currently the recommended approach.

SUMMARY

Examination of Early Stuart and Late Stuart sockeye migration, spawning and recruitment in recent years suggests that the following factors are involved:

Early Stuart

1. High Fraser River discharges or high river water temperatures have produced physiological stress on migrating adults and led to high en route losses in several recent years.
2. Eggs deposited by stressed females that have successfully arrived at their natal spawning streams have low egg-to-fry survival.
3. Increased competition from larger juvenile kokanee populations occupying niche space formerly occupied by sockeye may have led to reduced growth of juvenile sockeye in some recent years.

Late Stuart

1. Ocean conditions (El Niño) may have adversely affected lipid reserves available for migration and egg production.
2. High Fraser River water temperatures have led to en route losses associated with physiological stress.
3. Cycle-line interaction between 1996-2000 brood year juveniles and following 1997 and 2001 dominant line juveniles in Stuart and Trembleur Lakes may have slowed growth and lowered survival of dominant line juveniles leading to much lower recruitment rates than expected.
4. Increased competition from age 0 and older kokanee may have also reduced juvenile sockeye growth and survival.

Recommendations:

7. Manage fisheries to reduce exploitation of depressed Early Stuart sockeye returns in the next several years.
8. Initiate a long-term study of juvenile sockeye/kokanee biology and population sizes in Stuart area lakes.
9. Initiate a study on the kokanee populations in all three Stuart watershed lakes.
10. Discuss with DFO the short-term fertilization of Takla Lake to aid the recovery of Driftwood and Takla Lake tributary stream populations of Early Stuart sockeye.

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Appendix Tables

Table A1. Early Stuart sockeye salmon escapement and recruitment statistics, 1948-2006 (dominant line in bold).

Brood Year	Adult Escapement	Effective Females	Total Recruits	Recruits per EFS	ln R/EFS
1948	19,979	12,012	198,153	16.50	2.80
1949	**582,228**	**168,471**	**1,036,968**	**6.16**	**1.82**
1950	59,104	25,658	241,666	9.42	2.24
1951	60,423	29,787	173,654	5.83	1.76
1952	29,925	15,483	88,600	5.72	1.74
1953	**154,036**	**78,332**	**540,891**	**6.91**	**1.93**
1954	35,050	18,010	155,823	8.65	2.16
1955	2,159	1,397	27,467	19.66	2.98
1956	25,020	16,662	110,394	6.63	1.89
1957	**234,850**	**119,278**	**1,222,936**	**10.25**	**2.33**
1958	38,807	22,196	103,107	4.65	1.54
1959	2,670	1,297	20,835	16.06	2.78
1960	14,447	7,401	74,149	10.02	2.30
1961	**198,921**	**87,809**	**255,842**	**2.91**	**1.07**
1962	26,716	14,075	75,785	5.38	1.68
1963	4,607	2,590	92,554	35.73	3.58
1964	2,390	1,300	42,887	32.99	3.50
1965	**23,045**	**11,242**	**417,211**	**37.11**	**3.61**
1966	10,830	5,959	84,786	14.23	2.66
1967	21,044	11,167	339,693	30.42	3.42
1968	1,522	793	10,423	13.14	2.58
1969	**109,655**	**48,687**	**1,375,594**	**28.25**	**3.34**
1970	32,578	15,806	182,136	11.52	2.44
1971	95,940	45,612	431,210	9.45	2.25
1972	4,657	2,253	32,232	14.31	2.66
1973	**299,892**	**153,870**	**1,352,082**	**8.79**	**2.17**
1974	39,518	21,603	144,398	6.68	1.90
1975	65,752	26,248	224,052	8.54	2.14
1976	11,761	6,792	31,854	4.69	1.55
1977	**117,445**	**53,381**	**761,694**	**14.27**	**2.66**
1978	50,004	20,005	72,852	3.64	1.29

Brood Year	Adult Escapement	Effective Females	Total Recruits	Recruits per EFS	In R/EFS
1979	92,746	36,172	107,936	2.98	1.09
1980	16,939	7,361	63,501	8.63	2.15
1981	**129,457**	**67,227**	**350,141**	**5.21**	**1.65**
1982	4,557	2,158	27,816	12.89	2.56
1983	23,867	13,121	188,896	14.40	2.67
1984	45,201	21,868	242,040	11.07	2.40
1985	**234,219**	**116,610**	**1,208,877**	**10.37**	**2.34**
1986	28,584	15,219	145,942	9.59	2.26
1987	148,194	75,970	525,920	6.92	1.93
1988	179,807	88,069	379,932	4.31	1.46
1989	**384,799**	**211,039**	**1,138,815**	**5.40**	**1.69**
1990	97,035	47,063	166,098	3.53	1.26
1991	141,119	85,454	144,637	1.69	0.53
1992	65,617	36,293	100,376	2.77	1.02
1993	**687,967**	**385,694**	**1,814,783**	**4.71**	**1.55**
1994	29,096	14,467	29,030	2.01	0.70
1995	122,710	57,261	189,600	3.31	1.20
1996	87,570	41,063	465,689	11.34	2.43
1997	**265,697**	**73,053**	**147,575**	**2.02**	**0.70**
1998	32,570	9,331	28,692	3.07	1.12
1999	24,532	8,124	30,563	3.76	1.33
2000	89,747	35,315	135,795	3.85	1.35
2001	**170,906**	**82,833**	**260,767**	**3.15**	**1.15**
2002	24,637	12,939	30000*	2.32	0.84
2003	13,166	6,947			
2004	9,281	5,179			
2005	**98,537**	**51,152**			
2006	35,816	15,915			
All-year means	**95,921**	**45,222**	**329,914**	**9.96**	**2.00**
Cycle means					
Line 1 (1949…2005)	256,651	118,395	848,870	10.39	2.00
Line 2 (1950…2006)	36,363	17,463	106,295	6.97	1.76
Line 3 (1951…2003)	61,982	30,323	192,078	12.21	2.13
Line 4 (1948…2004)	42,470	20,905	141,145	10.43	2.13

Table A2. Late Stuart sockeye salmon escapement and recruitment statistics, 1949-2006 (dominant line in bold).

Brood Year	Adult Escapement	Effective Females	Total Recruits	Recruits per EFS	ln R/EFS
1949	**107,752**	**39,085**	**1,530,202**	**39.15**	**3.67**
1950	5,843	1,834	39,681	21.64	3.07
1951	4,364	1,247	63,810	51.19	3.94
1952	35	16	3,973	248.31	5.51
1953	**368,634**	**78,689**	**1,552,239**	**19.73**	**2.98**
1954	5,470	2,687	137,965	51.34	3.94
1955	7,582	3,274	51,345	15.68	2.75
1956	913	466	46,102	98.87	4.59
1957	**531,108**	**300,029**	**1,329,884**	**4.43**	**1.49**
1958	23,619	13,152	54,677	4.16	1.42
1959	8,225	4,090	7,392	1.81	0.59
1960	2,396	1,307	9,617	7.36	2.00
1961	**410,887**	**194,469**	**778,478**	**4.00**	**1.39**
1962	18,643	9,073	45,069	4.97	1.60
1963	3,222	1,092	12,049	11.03	2.40
1964	1,816	824	3,101	3.76	1.33
1965	**214,943**	**122,789**	**1,124,519**	**9.16**	**2.21**
1966	9,027	4,164	74,079	17.79	2.88
1967	1,629	897	16,556	18.46	2.92
1968	389	179	31,299	174.85	5.16
1969	**207,014**	**114,306**	**1,625,590**	**14.22**	**2.65**
1970	14,978	8,027	70,838	8.83	2.18
1971	1,535	725	66,770	92.09	4.52
1972	7,341	3,411	18,766	5.50	1.71
1973	**214,230**	**116,706**	**666,098**	**5.71**	**1.74**
1974	14,190	7,371	50,395	6.84	1.92
1975	14,229	5,679	197,390	34.76	3.55
1976	2,898	1,674	3,339	2.00	0.69
1977	**146,459**	**75,890**	**1,357,741**	**17.89**	**2.88**
1978	12,738	7,115	79,447	11.17	2.41
1979	31,918	16,711	6,854	0.41	-0.89
1980	946	286	21,440	75.01	4.32

Brood Year	Adult Escapement	Effective Females	Total Recruits	Recruits per EFS	ln R/EFS
1981	**249,494**	**120,124**	**2,033,901**	**16.93**	**2.83**
1982	16,758	8,681	60,989	7.03	1.95
1983	2,246	1,451	17,944	12.37	2.52
1984	1,228	672	14,744	21.94	3.09
1985	**274,621**	**159,101**	**3,507,629**	**22.05**	**3.09**
1986	28,715	15,044	816,561	54.28	3.99
1987	6,472	2,393	380,071	158.84	5.07
1988	7,117	3,638	208,786	57.39	4.05
1989	**575,697**	**327,096**	**5,327,124**	**16.29**	**2.79**
1990	189,079	111,747	389,194	3.48	1.25
1991	76,860	40,200	107,387	2.67	0.98
1992	19,513	12,422	135,399	10.90	2.39
1993	**1,363,826**	**744,565**	**3,764,256**	**5.06**	**1.62**
1994	76,462	40,717	115,440	2.84	1.04
1995	34,362	17,181	133,437	7.77	2.05
1996	62,991	27,297	1,022,797	37.47	3.62
1997	**907,652**	**415,149**	**431,149**	**1.04**	**0.04**
1998	138,397	67,836	277,093	4.08	1.41
1999	61,574	33,801	132,001	3.91	1.36
2000	454,397	226,558	901,711	3.98	1.38
2001	**351,515**	**179,526**	**443,507**	**2.47**	**0.90**
2002	34,498	17,821	N/A		
2003	36,647	19,208			
2004	81,962	50,437			
2005	**293,124**	**164,548**			
2006	27,504	14,283			
All-year means	**133,926**	**68,254**	**590,525**	**28.96**	**2.47**
<u>Cycle means</u>					
Line 1 (1949…2005)	423,131	213,395	1,819,451	12.72	2.16
Line 2 (1950…2006)	42,609	22,881	170,110	15.26	2.24
Line 3 (1951…2003)	19,555	9,903	91,770	31.61	2.44
Line 4 (1952…2004)	43,229	21,442	186,236	57.49	3.06

Table A3. Early Stuart sockeye catches, spawning escapement and en route loss estimates, 1980-2005 (dominant line in bold).

Return Year	Commercial*	Marine First Nations	Fraser First Nations	Sport	Spawning Escapement	Estimated En route loss	Total Return	Environmental Conditions
1980	7,124	0	7,665		16,939	0**	31,728	
1981	**486,469**	**0**	**139,575**	**0**	**129,457**	**0****	**755,501**	
1982	19,885	0	47,361	0	4,557	8322***	71,803	High discharge
1983	12,208	70	54,843		23,867	0**	90,988	
1984	1,555	0	9,289	0	45,201	0**	56,045	Mod. high discharge
1985	**44,784**	**83**	**77,428**	**16**	**234,519**	**0****	**356,830**	
1986	3,162	0	13,853	0	28,584	0**	45,599	
1987	6,541	646	22,385	1	148,194	0**	177,767	
1988	13,359	6	28,403	0	179,807	0**	221,575	
1989	**627,450**	**0**	**199,254**	**296**	**384,799**	**0****	**1,211,799**	
1990	4,806	372	52,084	568	97,035	0**	154,865	Mod. high discharge
1991	182,002	928	188,394	10	141,119	0**	512,453	Mod. high discharge
1992	6,667	113	164,524	0	65,617	113,481	350,402	High temperature
1993	**208,616**	**1**	**255,059**	**0**	**687,967**	**0****	**1,151,643**	
1994	5,806	0	40,254	354	29,831	128,000	204,245	
1995	7,932	228	6,518	1,086	122,710	0**	138,474	

Return Year	Commercial*	Marine First Nations	Fraser First Nations	Sport	Spawning Escapement	Estimated En route loss	Total Return	Environmental Conditions
1996	5,410	0	2,577	0	88,411	0**	96,398	Mod. high discharge
1997	**332,974**	**28,916**	**404,934**	**4,883**	**265,703**	**634,331**	**1,671,741**	**V. high discharge**
1998	5,308	685	15,027	0	30,972	137,787	189,779	V. high temperature
1999	4,470	0	22,335	0	24,532	120,293	171,630	V. high discharge
2000	11,358	92	214,508	0	89,748	62,487	378,193	Mod. high discharge
2001	**4,814**	**115**	**38,337**	**13**	**170,908**	**0****	**214,187**	
2002	1,259	18	4,441	0	24,637	32,309	62,664	Mod. high discharge
2003	692	0	469	0	13,166	15,949	30,276	
2004	4,809	113	35,483	351	9,286	86,249	136,291	V. high temperature
2005	**1,971**	**37**	**17,193**	**10**	**98,537**	**99,664**	**217,412**	**Very late arrival**
Averages	77,363	1,247	79,315	316	121,389	55,021	334,626	
% of total	23.10%	0.37%	23.68%	0.09%	36.24%	16.43%	100.00%	

* Includes test fishing and miscellaneous catches.

** No substantial difference between estimates.

*** Minimum estimate.

Table A4. Fraser River First Nations catches of Early Stuart sockeye by region, 1986-2005.

Year	Below Mission	Mission to Sawmill Cr.[1]	Sawmill Cr.[2] to Pr. George	Pr. George to Isle Pierre	Stuart River Area	Total
1986	272	9,343	1,977	7	2,254	13,853
1987	1,055	9,438	5,418	31	6,443	22,385
1988	2,172	9,997	6,735	154	9,345	28,403
1989	9,403	124,196	58,272	776	6,607	199,254
1990	906	34,920	14,858	900	500	52,084
1991	11,872	114,238	54,189	1,140	6,955	188,394
1992	19,524		145,000*			164,524
1993	42,706	105,182	97,930	280	8,961	255,059
1994	4,587	18,408	17,109	0	150	40,254
1995	222	611	1,139	0	4,546	6,518
1996	10	51	1,217	286	1,013	2,577
1997	50,395	222,342	120,113	3,197	8,887	404,934
1998	108	6,265	5,632	442	2,580	15,027
1999	251	10,849	10,645	60	530	22,335
2000	26,463	85,333	99,637	842	2,233	214,508
2001	1,956	8,130	20,103	2,627	5,521	38,337
2002	76	2,945	1,058	57	305	4,441
2003	98	136	122	6	107	469
2004	3,258	17,095	13,311	277	1,542	35,483
2005	1,430	7,558	6,665	0	1,540	17,193
Averages[3]	8,276	41,423	28,217	583	3,685	82,185
%[3]	10.07%	50.40%	34.33%	0.71%	4.48%	100.00%

[1]Mission to North Bend for 1986-1993
[2]North Bend to Pr. George for 1986-1993
[3]Averages without 1992.
* Total catch estimate upstream of Mission from Pearce Investigation.

Table A5. Late Stuart sockeye catches, spawning escapement and en route loss estimates, 1980-2005 (Data courtesy of the Pacific Salmon Commission).

Return Year	Commercial*	Marine First Nations	Fraser First Nations	Sport	Spawning Escapement	Estimated En route loss	Total Return	Environmental Conditions
1980	2,292	0	550	0	946	0**	3,788	
1981	**994,160**	**3,871**	**66,336**	**0**	**249,494**	**0****	**1,313,861**	**High temperature**
1982	83,558	0	13,279	0	16,758	0**	113,595	
1983	11,241	48	2,247	0	2,246	0**	15,782	
1984	18,746	42	1,424	0	1,228	0**	21,440	
1985	**1,643,361**	**2,536**	**56,792**	**701**	**274,621**	**0****	**1,978,011**	
1986	68,937	0	10,336	0	28,715	0**	107,988	
1987	10,368	135	5,913	6	6,472	0**	22,894	
1988	7,686	5	3,335	129	N/A	0**	11,155	
1989	**2,685,235**	**5,489**	**97,937**	**2,729**	**575,697**	**0****	**3,367,087**	
1990	630,461	3,318	33,684	1,372	189,079	0**	857,914	High temperature
1991	277,882	1,408	18,280	672	76,860	0**	375,102	
1992	222,872	2,036	12,445	474	19,513	45,048	302,388	V. high temperature
1993	**3,499,477**	**48,935**	**255,365**	**2,220**	**1,356,737**	**0****	**5,162,734**	**High temperature**
1994	308,549	1,602	66,429	569	76,462	92,037	545,648	V. high temperature
1995	34,864	774	31,663	300	34,362	0**	101,963	

Return Year	Commercial*	Marine First Nations	Fraser First Nations	Sport	Spawning Escapement	Estimated En route loss	Total Return	Environmental Conditions
1996	47,132	3,060	34,513	234	65,898	0**	150,837	
1997	2,165,240	11,963	163,049	7,677	907,652	0**	3,255,581	
1998	121,284	7,916	64,923	689	137,177	288,162	620,151	V. high temperature
1999	5,099	1,212	17,802	353	62,666	13,443	100,575	High discharge
2000	264,077	15,189	112,586	3,236	454,478	0**	849,566	
2001	**114,055**	**18,212**	**76,149**	**4,308**	**351,827**	**0****	**564,551**	
2002	90,446	7,974	53,646	2,334	34,521	154,592	343,513	
2003	48,328	4,074	25,796	2,327	38,474	14,058	133,057	High temperature
2004	330,929	61,463	152,058	13,113	81,991	245,017	884,571	Extremely high temp.
2005	**47,953**	**27,251**	**87,410**	**1,490**	**293,180**	**0****	**457,284**	**Very late arrival**
Averages	528,240	8,789	56,306	1,728	205,271	32,783	833,117	
% of total	63.41%	1.05%	6.76%	0.21%	24.64%	3.93%	100.00%	

* Includes test fishing and miscellaneous catches.

**No substantial difference between estimates.

Table A6. Fraser River First Nations catches of Late Stuart sockeye by region, 1986-2005 (Data courtesy of the Pacific Salmon Commission).

Year	Below Mission	Mission to Sawmill Cr.[1]	Sawmill Cr.[2] to Pr. George	Pr. George to Isle Pierre	Stuart River Area	Total
1986	231	2,703	4,206	76	3,120	10,336
1987	158	1,963	1,536	17	2,239	5,913
1988	103	763	809	0	1,660	3,335
1989	7,297	41,246	43,834	401	5,159	97,937
1990	3,872	15,823	11,664	1,900	425	33,684
1991	2,767	8,706	5,487	132	1,188	18,280
1992	1,830		10,615*			12,445
1993	61,153	153,044	37,278	629	3,261	255,365
1994	15,308	26,667	21,071	0	3,383	66,429
1995	9,381	12,113	7,349	0	2,820	31,663
1996	8,858	16,905	6,941	567	1,242	34,513
1997	74,941	38,838	42,545	3,391	3,334	163,049
1998	12,531	27,753	19,219	1,983	3,437	64,923
1999	1,659	6,045	5,866	972	3,260	17,802
2000	22,509	42,107	41,252	1,654	5,064	112,586
2001	19,109	26,054	24,443	2,931	3,612	76,149
2002	13,792	18,503	11,839	3,373	6,139	53,646
2003	5,325	10,126	6,378	689	3,278	25,796
2004	47,258	67,384	33,502	1,645	2,269	152,058
2005	18,382	35,246	30,612	0	3,170	87,410
Averages[3]	17,086	29,052	18,728	1,072	3,056	66,166
%[3]	24.76%	42.11%	27.14%	1.55%	4.43%	100.00%

[1]Mission to North Bend for 1986-1993
[2]North Bend to Pr. George for 1986-1993
[3]Averages without 1992.
* Total catch estimate upstream of Mission from Pearce Investigation.

Appendix Figures

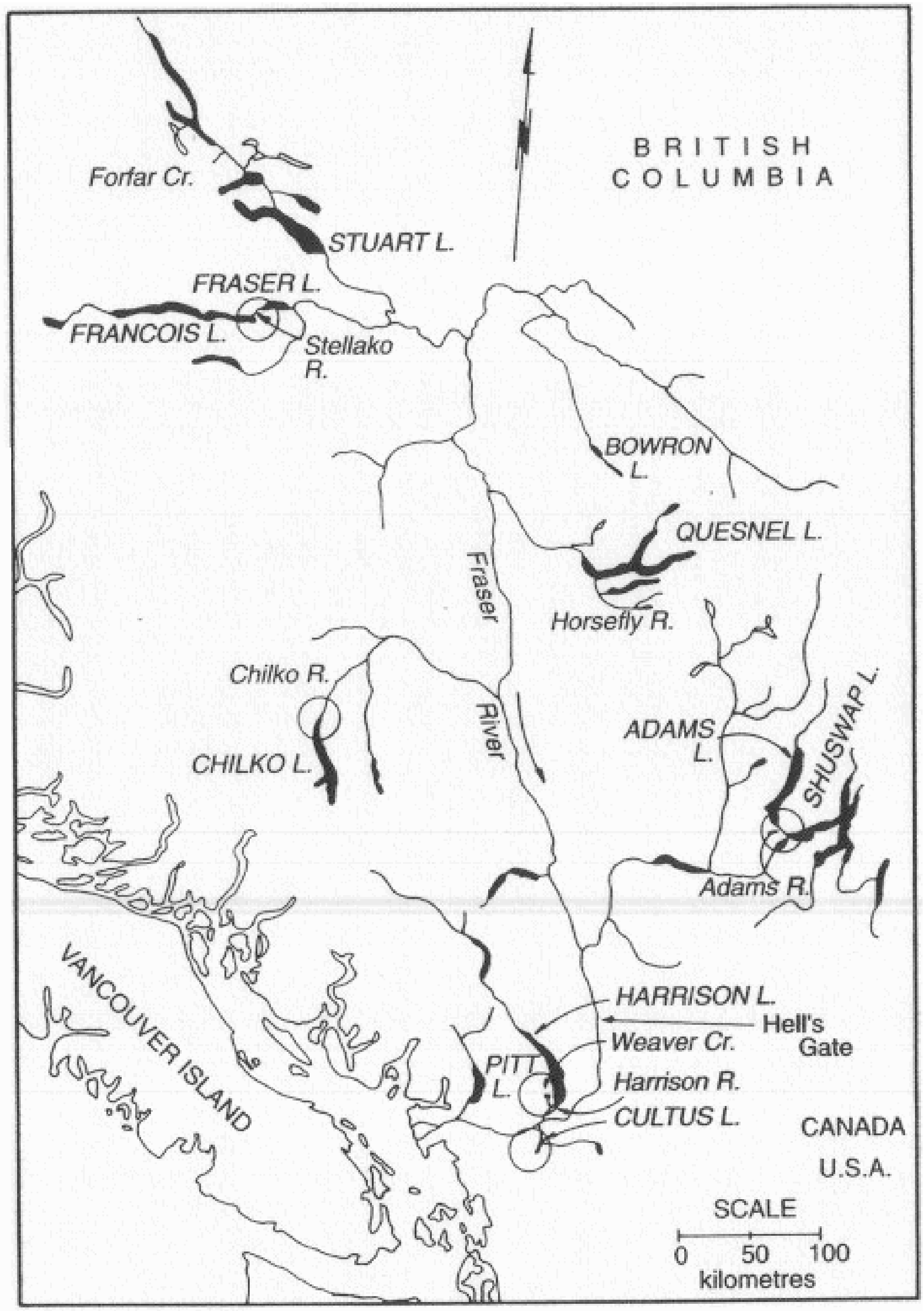

Figure A1. Location of the Stuart Lake system in the Fraser River watershed.

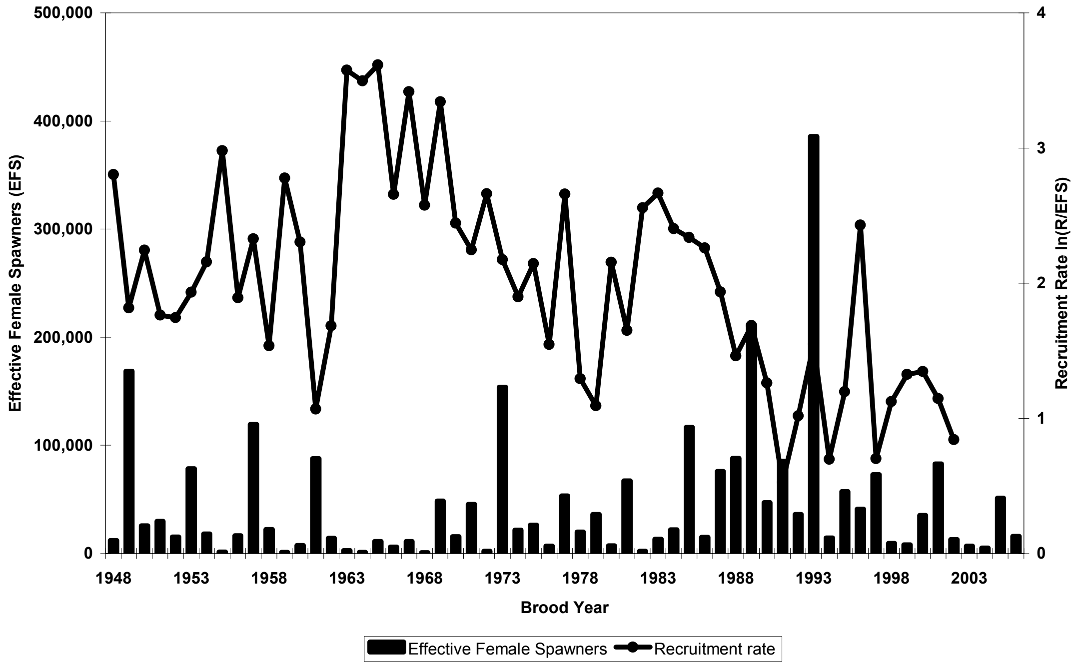

Figure A2. Early Stuart effective females and recruitment rate by brood year.

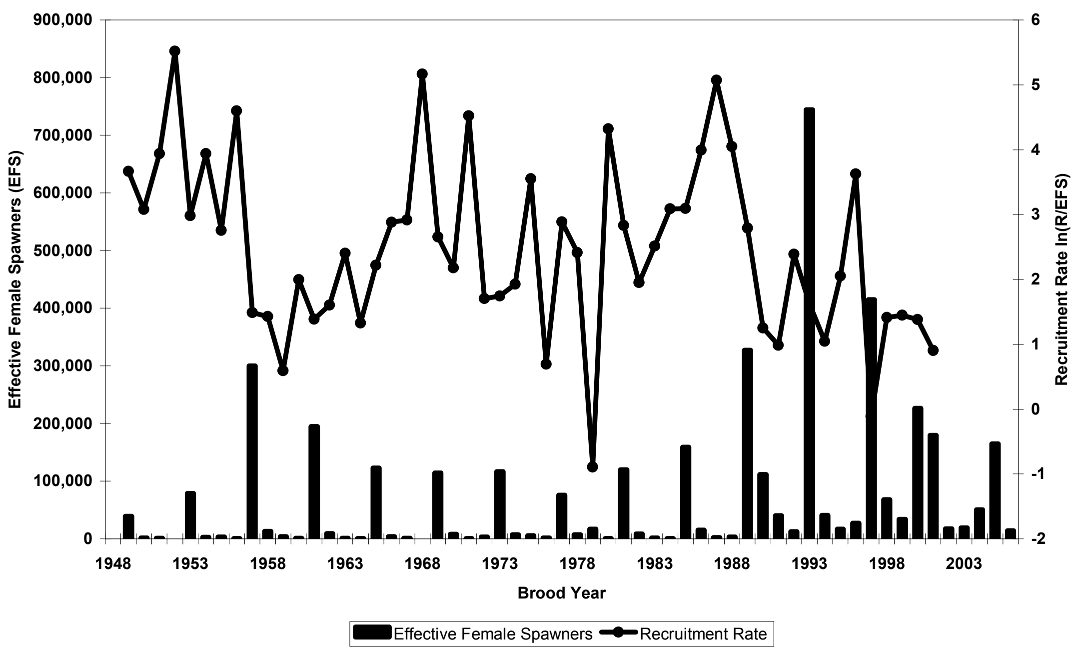

Figure A3. Late Stuart effective females and recruitment rate by brood year.

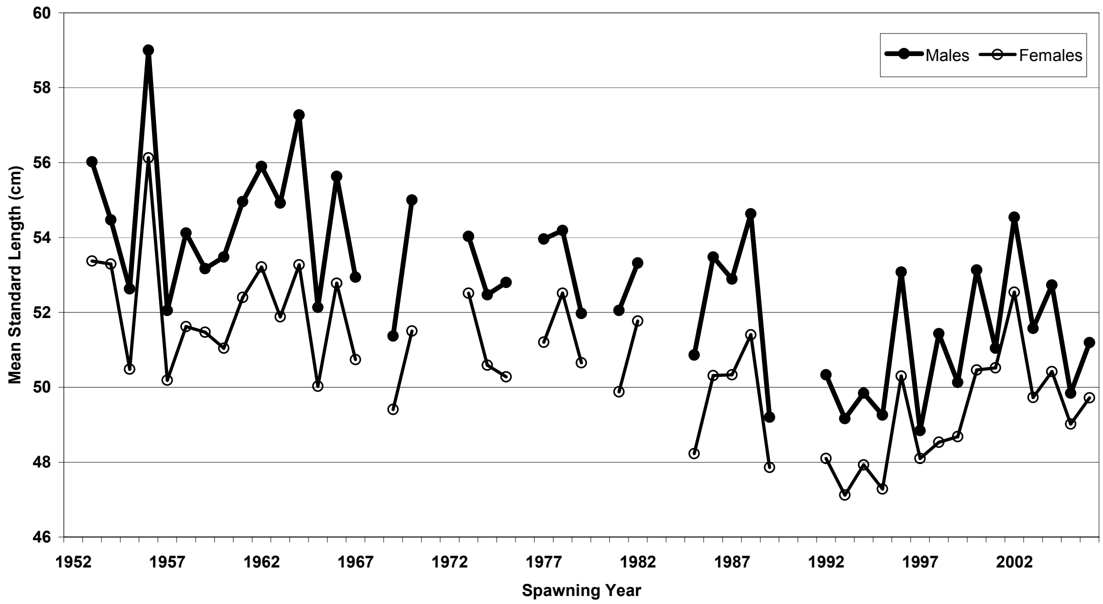

Figure A4. Early Stuart (Kynock Creek) sockeye mean standard length of spawners.

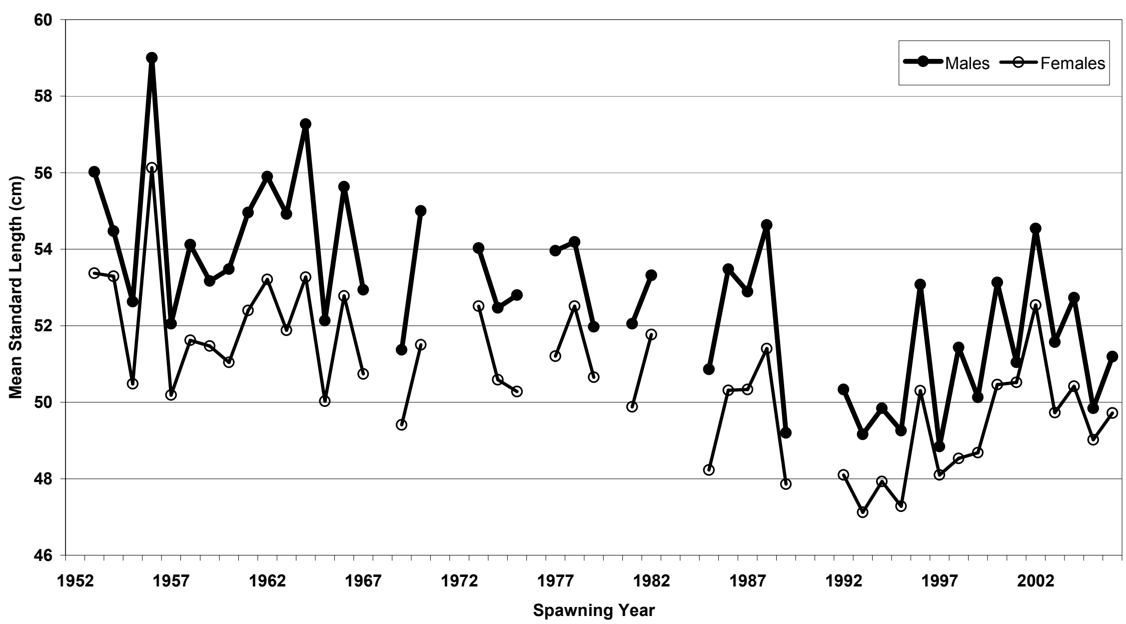

Figure A5. Late Stuart (Middle River) sockeye mean standard length of spawners.

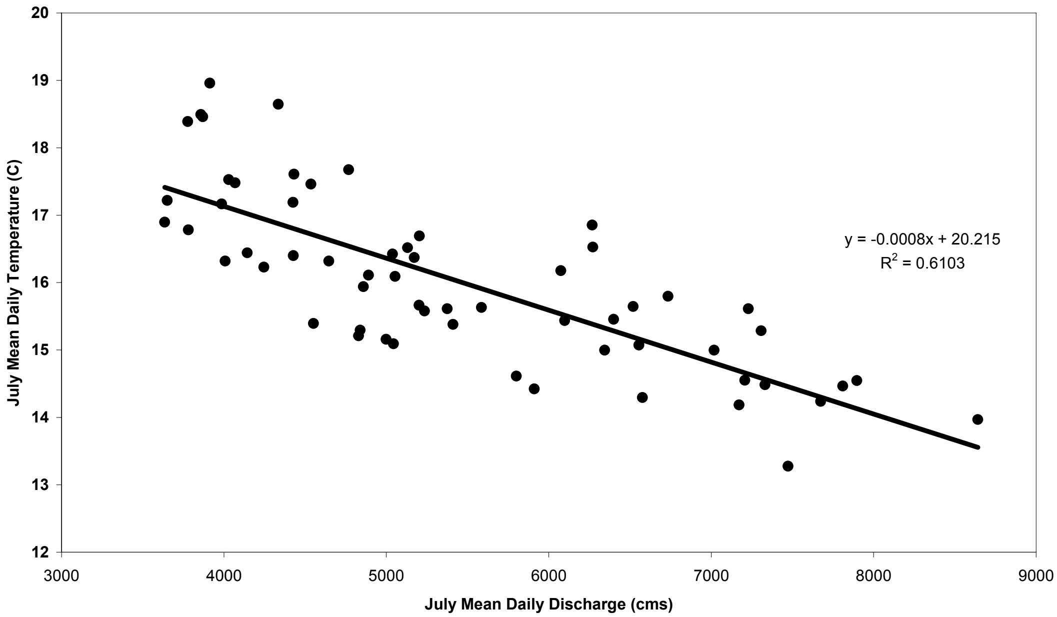

Figure A6. Average Fraser River water temperature at Hells Gate vs. discharge at Hope for July.

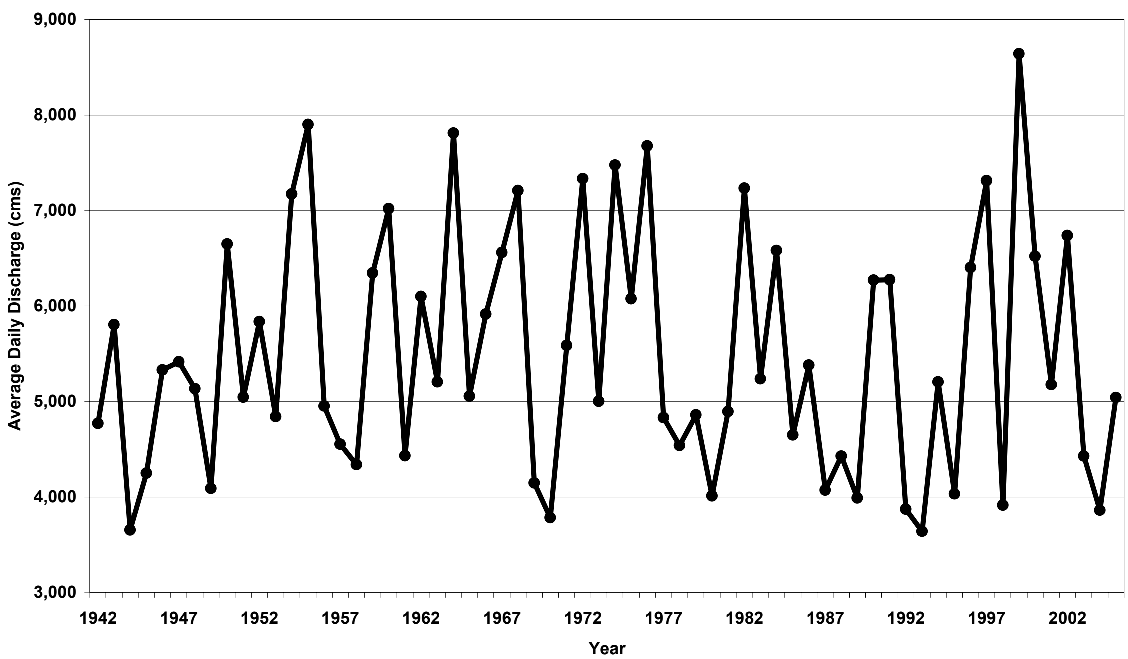

Figure A7. Fraser River at Hope July average daily discharge (cms).

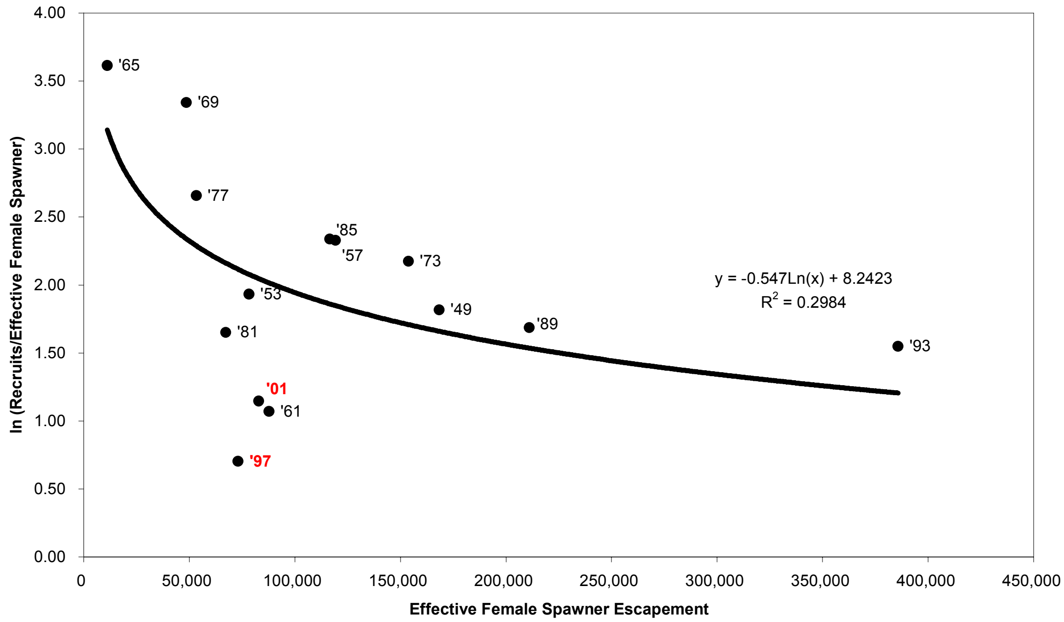

Figure A8. Early Stuart dominant line sockeye recruitment rate vs. effective female escapement.

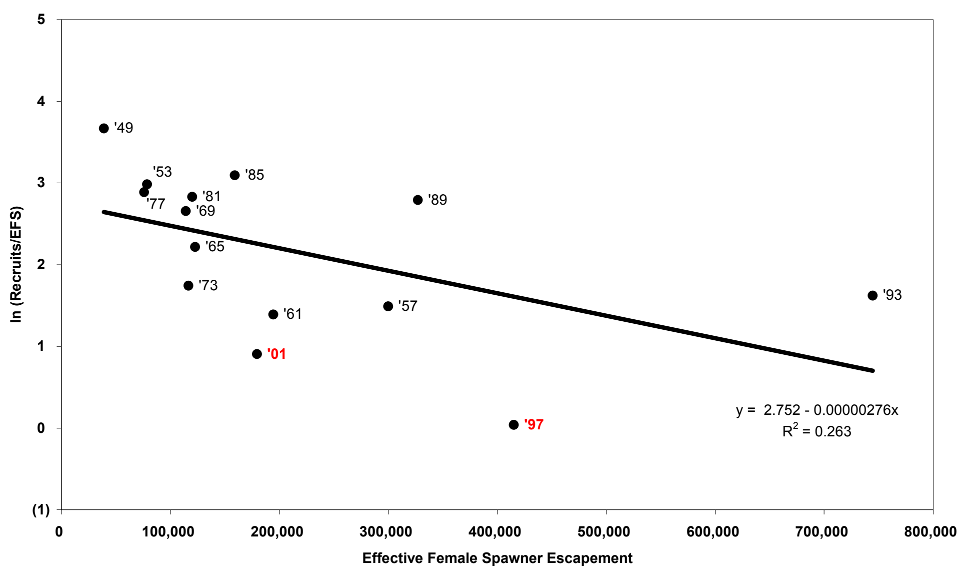

Figure A9. Late Stuart dominant line sockeye annual recruitment rate vs. effective female spawner escapement.

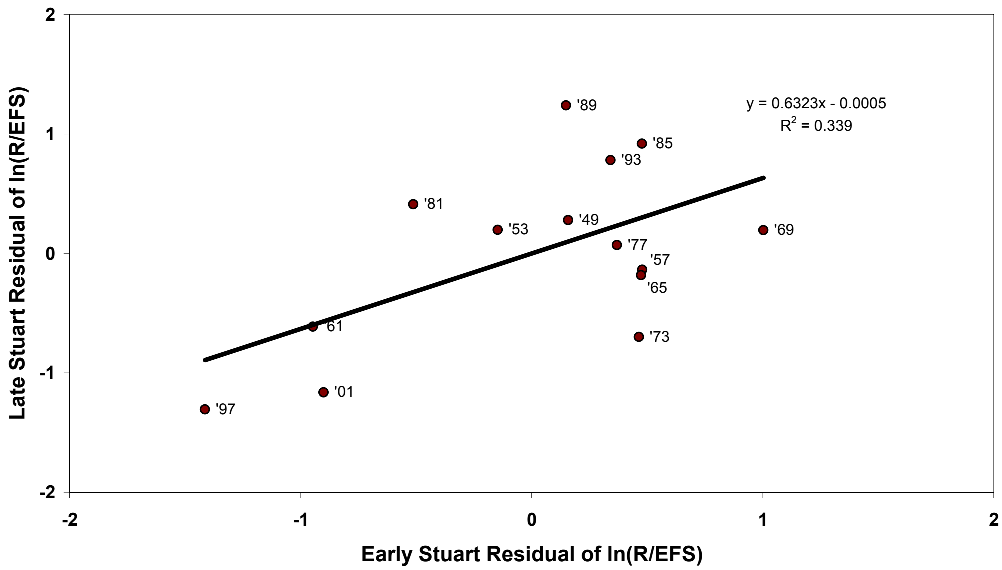

Figure A10. Comparison of Early and Late Stuart sockeye recruitment residuals.

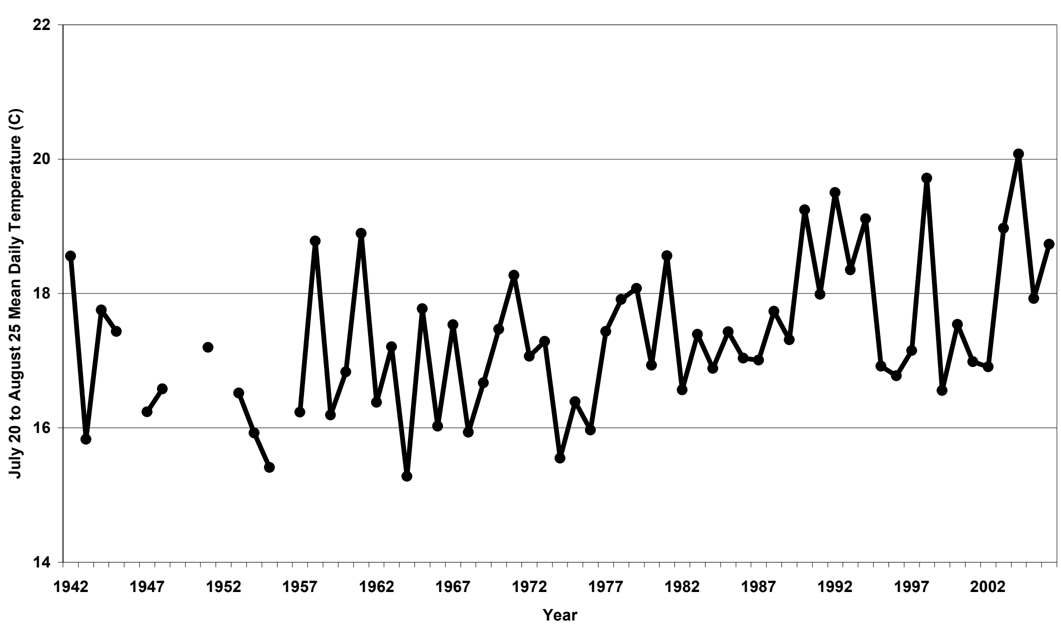

Figure A11. Fraser River at Hells Gate July 20 to August 25 mean daily temperature (°C).

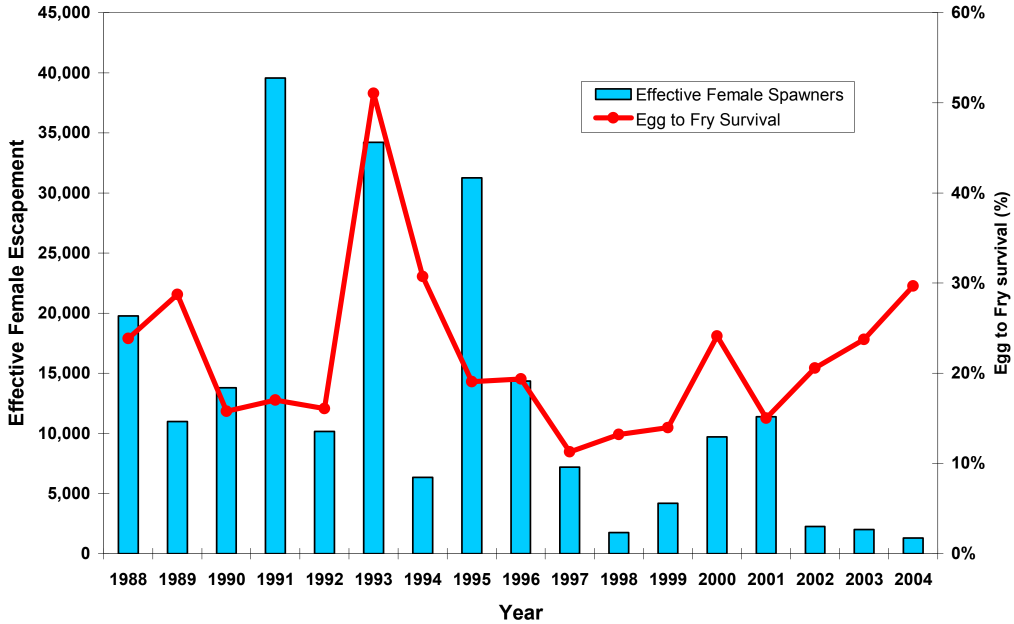

Figure A12. Early Stuart sockeye effective female spawners and estimated mean egg-to-fry survival for Middle River tributary streams.