Calibration of Visual Assessment Methods for Fraser River Sockeye Salmon *(Oncorhynchus nerka)* – Year 7

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INTRODUCTION

The enumeration of Fraser River Sockeye salmon *(Oncorhynchus nerka)* spawning escapements have historically followed a well-established two-tiered protocol developed by the former International Pacific Salmon Fisheries Commission (IPSFC). An abundance threshold of 25,000 spawners determined the methodology employed, with low precision visual techniques for escapements less than 25,000, and high precision techniques (fences, sonar or mark-recaptures) for escapements greater than 25,000. Decreasing financial resources coupled with larger spawning escapements led to an increase in the abundance threshold from 25,000 to 75,000 spawners in 2004. As a result, visual methods are now being used to enumerate streams and abundances much larger than they were historically. The standard expansion factor of 1.8 currently applied to visual counts to account for the consistent underestimation of live counts was developed using ground survey methods on very small, clear stream populations with relatively low (less than 25,000) spawner abundances in the Fraser River system. Its application to larger streams with larger abundances will lead to substantial negative bias in spawning estimates.

In 2015, the Southern Boundary Restoration and Enhancement Fund (SEF) funded the seventh of a multi-year calibration study to minimize bias in visually enumerated Sockeye salmon populations in the Fraser River watershed. Summaries of the first six years of the calibration study have been presented in Welch et al. 2011, Benner et al. 2012, Benner et al. 2013, Benner et al. 2014 and Benner et al. 2015. The following report provides a summary of the 2015 specific calibration activities as well as a summary of all calibration data collected by DFO since 1988.

METHODS

In 2015, calibration efforts focused on two populations where concurrent high precision spawning escapement enumeration projects were implemented - the Stellako and Harrison river populations. A hydroacoustic imaging system (DIDSON) was employed at the Stellako River (DFO and Carrier Sekani Tribal Council delivered) and a mark-recapture study was conducted at Harrison River (DFO delivered).

For the purpose of calibration, low precision visual counts (live and dead) were conducted at the peak of spawn in both systems. Expansion factors (indices) were generated for each population by dividing the respective high precision estimate by the peak visual count (live plus dead). A more detailed description of the calibration methods employed in this study is presented in Welch et al. 2011 including a comprehensive description of stream morphology and characteristics for all Sockeye spawning stream types in the Fraser River watershed (Appendix 1).

In addition to the data collected in 2015, all calibration data collected by DFO on Fraser Sockeye populations from 1988 through 2015 are summarized and examined. It should be

noted that previous SEF reports on the calibration study (Welch et al. 2011, Benner et al. 2012, Benner et al. 2013, Benner et al. 2014 and Benner et al. 2015) focused on Fraser River Sockeye salmon populations less than 125,000 spawners. In this report, we include all historical calibration data collected by DFO since 1988 regardless of abundance in the summary and analysis.

It should be noted that the historical calibration time series was revised to reflect inappropriate stream type classifications and biased data points. These include changes to the 1993, 1997, 2007 and 2011 Stellako River data points where the river size was revised from large to medium. Similarly, for the 2012 Upper Chilliwack River, the river size was revised from small to medium. Lastly, the 1990 Scotch Creek data point was removed from the time series as it was considered biased due to an incomplete aerial survey.

RESULTS

2015 CALIBRATION ACTIVITIES

Stellako River

One paired aerial and ground survey of the Stellako River was conducted over a two day period from September 28th - 29th with a total of 68,244 and 64,436 Sockeye salmon (live + dead) enumerated, respectively. The indices generated from comparing the aerial and ground counts to the system sonar (DIDSON) estimate of 101,215 Sockeye salmon are 1.48 and 1.57, respectively (Table 1).

Harrison River

One aerial survey of the Harrison River was conducted on November 10th with a total of 11,218 Sockeye salmon (live + dead) enumerated. The index generated from comparing the aerial count to the M/R estimate of 115,715 Sockeye salmon is 10.32 (Table 1).

Table 1. Summary of low precision visual counts, high precision escapement estimates and the resulting indices at Stellako and Harrison rivers, 2015.

			Low Precision		High Precision		
Stream	Size	Water Clarity	Method	Count [a]	Method	Estimate [b]	Index
Stellako	Medium	Clear	Aerial	68,244	Sonar	101,215	1.48
Stellako	Medium	Clear	Ground	64,436	Sonar	101,215	1.57
Harrison	X-Large	Pt. Turbid	Aerial	11,218	M/R	115,715	10.32

[a] Peak live count plus dead carcasses observed.

[b] Estimate does not include fish spawning below Stellako sonar fence.

SUMMARY OF CALIBRATION ACTIVITIES (1988-2015)

Since calibration efforts began in 1988 a total of 127 calibration data points (indices) have been generated on Fraser River Sockeye salmon populations (Appendix 2). Of these, 83 were based on ground surveys and 44 were based on aerial surveys. The vast majority of ground calibrated systems are from streams that have been categorized as very small with water clarity categorized as clear (Table 2); whereas, the number of aerial calibrated systems has focused primarily on medium and extra-large sized streams with either clear or partially turbid/tannic water clarity (Table 3).

From 1988 to 2015, the average index generally increases with stream size and water clarity (from clear to turbid) for both ground and aerial survey methods. Indices generated for very small, clear streams (all ground based) average 1.7 and range between 1.07 and 2.85 with a Coefficient of Variation (CV) of 0.22 (Table 2), while larger stream sizes (i.e. small, medium, large and extra-large) reveal notably higher average indices and higher variability (CV ranging between <0.01 to 0.72) (Tables 2 and 3).

Table 2. Summary of ground calibration surveys stratified by stream size and water clarity for Fraser Sockeye salmon populations, 1988-2015.

Size	Water Clarity	Number of calibration surveys (n)	Average Population Estimate	Population Range	Average Index	Index Range	Standard Deviation	Coefficient of Variation
Very Small	Clear	53	9,005	167 - 38,248	1.70	1.07 - 2.85	0.38	0.22
	Pt. Turbid / Tannic	0	-	-	-	-	-	-
	Turbid	0	-	-	-	-	-	-
Small	Clear	0	-	-	-	-	-	-
	Pt. Turbid / Tannic	0	-	-	-	-	-	-
	Turbid	0	-	-	-	-	-	-
Medium	Clear	20	99,820	26,298 - 202,358	2.22	1.10 - 4.21	0.80	0.36
	Pt. Turbid / Tannic	2	35,306	14,420 - 56,192	2.42	2.17 - 2.67	0.35	0.15
	Turbid	0	-	-	-	-	-	-
Large	Clear	6	325,207	52,713 - 676,624	4.11	2.22 - 9.04	2.57	0.63
	Pt. Turbid / Tannic	2	67,022	56,006 - 78,038	2.46	2.18 - 2.74	0.40	0.16
	Turbid	0	-	-	-	-	-	-
Extra Large *	Clear	0	-	-	-	-	-	-
	Pt. Turbid / Tannic	0	-	-	-	-	-	-
	Turbid	0	-	-	-	-	-	-

* Extra Large streams not surveyed using ground methods

Table 3. Summary of aerial calibration surveys stratified by stream size and water clarity for Fraser Sockeye salmon populations, 1988-2015.

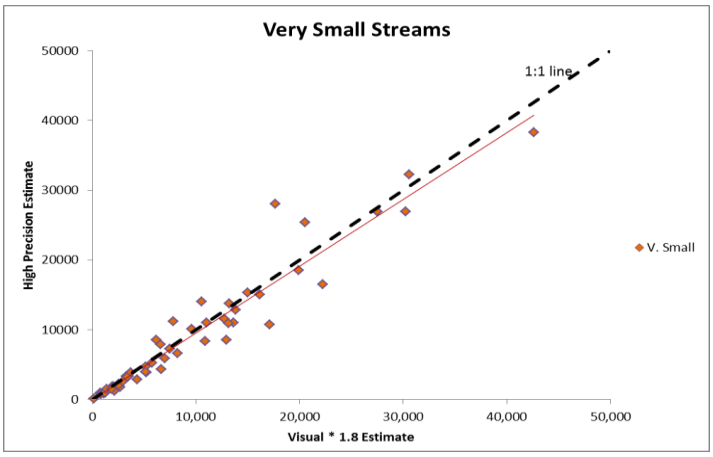
Size	Water Clarity	Number of calibration surveys (n)	Average Population Estimate	Population Range	Average Index	Index Range	Standard Deviation	Coefficient of Variation
Very Small *	Clear	0	-	-	-	-	-	-
	Pt. Turbid / Tannic	0	-	-	-	-	-	-
	Turbid	0	-	-	-	-	-	-
Small	Clear	0	-	-	-	-	-	-
	Pt. Turbid / Tannic	2	12,710	2,387 - 23,032	2.54	2.04 - 3.05	0.72	0.28
	Turbid	0	-	-	-	-	-	-
Medium	Clear	12	86,442	26,298 - 137,993	2.35	1.48 - 3.28	0.57	0.24
	Pt. Turbid / Tannic	6	82,910	13,682 - 209,318	2.92	2.13 - 3.40	0.43	0.15
	Turbid	2	49,900	28,478 - 71,322	5.80	4.17 - 7.44	2.32	0.40
Large	Clear	2	100,441	52,713 - 148,169	6.63	3.28 - 9.97	4.73	0.71
	Pt. Turbid / Tannic	2	67,022	56,006 - 78,038	2.48	2.48 - 2.49	0.01	<0.01
	Turbid	0	-	-	-	-	-	-
Extra Large	Clear	3	228,751	19,345 - 416,790	2.88	2.30 - 3.73	0.75	0.26
	Pt. Turbid / Tannic	15	157,522	28,309 - 491,098	3.78	1.48 - 10.32	2.73	0.72
	Turbid	0	-	-	-	-	-	-

* Very Small streams not surveyed using aerial methods

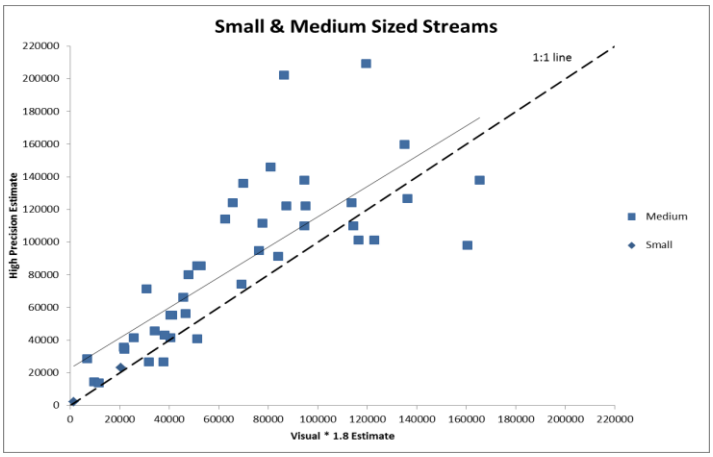
When comparing the relationship between high precision estimates and visually generated estimates with the standard 1.8 index expansion factor applied, the majority of the data points fall on or very close to the 1:1 line for very small streams (Figure 1A). In contrast, the majority of the data points are considerably higher than the 1:1 line for small/medium and large/extra-large streams indicating the 1.8 expansion factor typically results in biased low estimates for larger streams (Figure 1B-C).

When comparing the relationship between the index and abundance for very small (A), small and medium (B) and large/extra-large (C) streams, the very low R-square values indicate that abundance appears to have little or no influence on the indices for all stream sizes (Figure 2A-C).

A) Very Small (n = 53)



B) Small (n = 2) and Medium (n = 42)



C) Large (n = 12) and Extra-Large (n = 18)

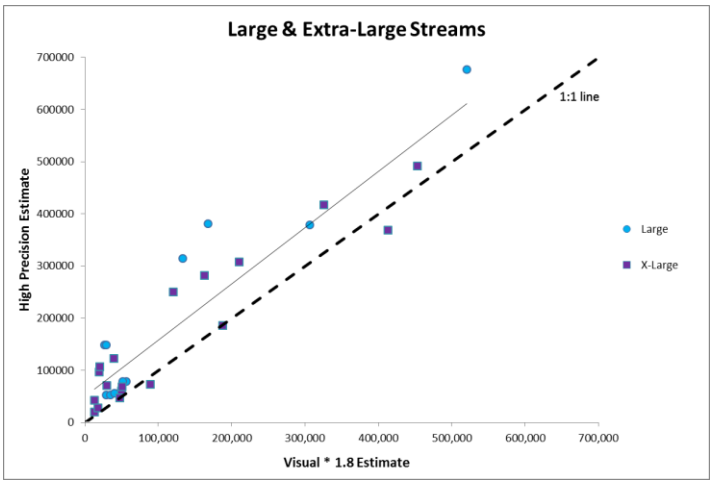
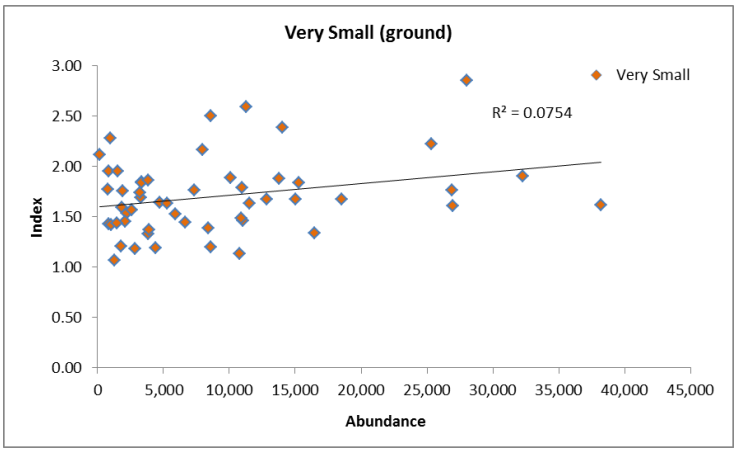
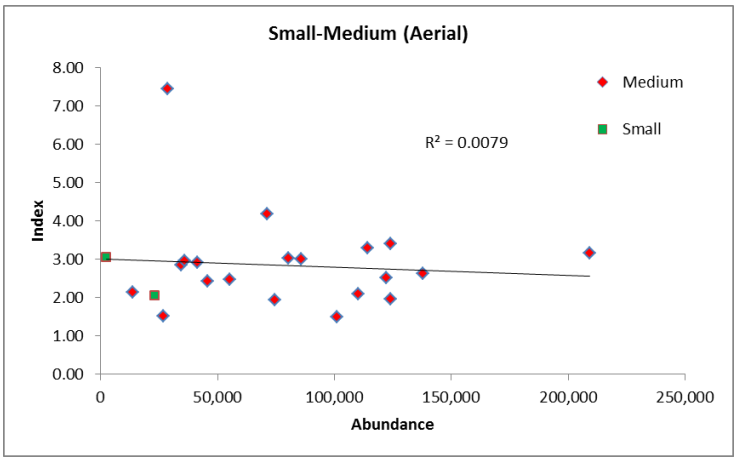


Figure 1. Relationship between high precision estimates and visual estimates (aerial and ground surveys) with the 1.8 index expansion factor applied for very small (A), small and medium (B) and large/extra-large (C) Fraser River Sockeye streams, 1988-2015.

A)Very Small (n = 53)



B)Small (n = 2) and Medium (n = 20)



C)Large (n = 4) and X-Large (n = 18)

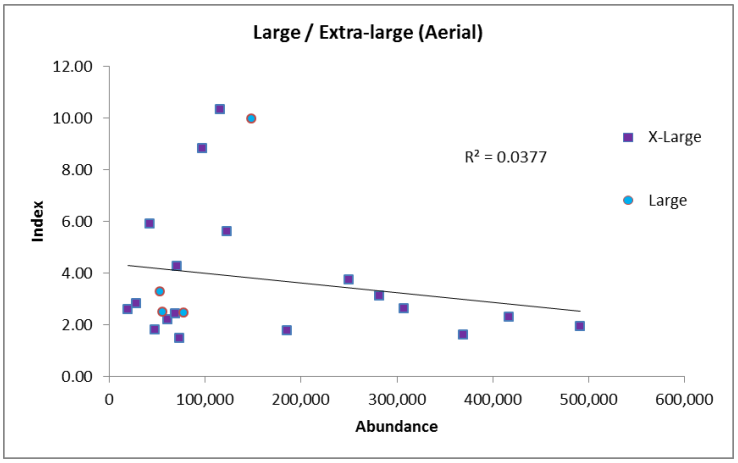


Figure 2. Relationship between stream index and abundance for aerial calibrated for very small (A), small and medium (B) and large/extra-large (C) Fraser River Sockeye streams, 1988-2015.

DISCUSSION

There are many factors that contribute to the development of indices, however, the main drivers relate to the observer's ability to effectively observe spawning salmon (observer efficiency) (OE) and spawner replenishment (Welch et al. 2011).

Data suggests that the overall size of the stream (depth and width) and water clarity has a strong influence on OE and the development of indices (Tables 2 and 3). It is intuitive that OE would become compromised as stream clarity decreases and the stream size (depth and width) increases. Therefore, all Fraser Sockeye spawning streams have been classified into fifteen stream types based on size and water clarity for the purpose of developing stream-type indices (i.e. an index developed at one location may be applied to other streams that share similar stream type criteria) (Appendix 3). As OE can differ considerably between ground and aerial visual methods, indices must also be method-specific (Benner et al. 2013). Complicating the relationship between OE, stream size and clarity are the numerous factors such as wind, glare and shadows that exacerbate counting conditions on all streams, but likely have a greater effect on the larger or more turbid or tannic streams where only a slight degradation in counting conditions can shift observer efficiency from poor to unmanageable.

Calibration data collected to date indicates that abundance appears to be less of a driver behind OE and the development of indices as previously thought. However, it is recognized that the complexity of migration and spawning behavior generally increases with abundance which typically results in a longer run duration (i.e. total number of days that any fish from the run are present in the stream) and a higher rate of spawner replenishment (Benner et al. 2013). Spawner replenishment can be defined as the rate in which fish spawn, die and are replaced with additional spawners. Estimating the rate of spawner replenishment is very difficult, but can be roughly estimated by measuring the survey life (SL) of a stream. SL can be defined as the time a spawning fish is available for observation in a particular stream or survey area (Simpson et al. 2000). If the SL is protracted it increases the likelihood that the same fish will be available for observation multiple times during consecutive visual surveys which are typically conducted every 5 to 7 days during the spawning period on Fraser Sockeye. A stream exhibiting a short SL will inevitably reduce the probability of multiple observations. SL can be highly variable on an annual basis within a given stream, as well as between streams. It can be influenced by numerous factors, such as: stream size, water clarity, geographic location, temperature, inter and intra-species densities, sex ratio, fish health and predation amongst others (R. Bailey, DFO, pers. comm.).

Some streams consistently reveal higher variability amongst the annual indices due to high inter and intra-annual variability in fish behavior and / or viewing conditions. For example, the Tachie River is a large deep tannic system with dark substrate that requires ideal lighting conditions and relatively low water levels in order to effectively observe spawning salmon. As a result the ten aerial based indices collected on the Tachie River since 1988 have been highly variable ranging from 1.61 and 8.83 (Appendix 2). In contrast, there are other streams that have much less variability in the annual indices. For example, the Stellako River is a medium

sized, clear system where observers typically experience reasonable counting conditions on an annual basis regardless of weather and water level conditions. As such, the six aerial based indices collected on the Stellako River since 1988 have a much more narrow range between 1.48 and 3.01 (Appendix 2).

Efforts to date indicate that the 1.8 expansion factor appears to be adequate for visual assessments on very small sized streams only; its application on small/medium and large/extra-large streams may grossly underestimate abundance.

SUMMARY

Since calibration efforts began in 1988 most of the work has focused on very small sized streams, with relatively little data collected on the larger sized streams that typically support populations with larger abundances. Additional funding by the Southern Boundary and Enhancement Fund since 2007 has led to increased calibration efforts on these larger sized systems resulting in the generation of 26 data points (16 medium, 6 large and 4 extra-large) on populations up to 125,000 spawners. Although this represents significant progress towards the development of stream-type and method-specific indices on these larger populations, significant gaps still exist.

Although preliminary, recent analysis of historical data suggest that future focus may have to shift away from solely developing stream-type indices based on stream size and water clarity alone. While it appears that this approach may be appropriate for most streams, it may be prudent to develop and apply stream-specific indices for streams that produce highly variable indices as a result of annual variability in viewing conditions and/or fish behavior (e.g. Tachie River) instead of applying a one-size fits all approach that does not take into account these unique complexities.

Moving forward it may be reasonable to consider using visual methods to assess streams that display little to moderate variability in the annual indices (e.g. Stellako) for larger abundances than previously thought (i.e. greater than 75,000). In contrast, using visual methods to enumerate streams that display high variability in the annual indices (e.g. Tachie), regardless of abundance or stream-type, will produce estimates with considerably higher uncertainty. However, it should be understood that using visual methods to enumerate any stream will produce estimates with higher uncertainty and should never be used when precise high quality estimates are required.

As calibration work continues it is recommended that the standard 1.8 index continue to be applied to all visually enumerated Sockeye stream populations until one of the following conditions have been met for all stream-type or stream-specific groups: i) a minimum of five data points with an error (CV) of 25% or less is obtained or ii) 10 data points have been generated. While the error will likely reduce in most cases as we obtain more data points, it may never reach levels considered optimal for management purposes (i.e. less than 25%).

As annual calibration opportunities are limited, continued calibration work over the long term will be required to satisfy these conditions for all stream-type and stream-specific classifications. It is important that calibration efforts continue anywhere possible regardless of stream-type and abundance as these data points will continue to inform this work and refine the indices and the associated variability.

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APPENDICES

Appendix 1. Stream morphology and characteristics definitions for Sockeye salmon spawning stream-types in the Fraser River watershed.

Stream Size

Very Small:	Typically on average <5 m wetted width. Wadable in all locations (e.g. Forfar Creek).
Small:	Typically on average 5-10 m wetted width. Wadable at most locations (e.g. Penfold Creek).
Medium:	Typically on average 10m-30m wetted width. Wadable in some locations. Possible the use of a jet boat and Raftable. Cannot wade in all places (e.g. Mitchell River).
Large:	Typically on average >30m wetted width, depth less than 4 m. Not Wadable. Boat or Raft only. Survey requires 2 or more observers, scanning bank to bank from a vessel (e.g. Adams River).
X-Large:	Typically on average >30 m wetted width, depth greater than 4 m. Not Wadable. Counting from a boat is ineffective. Survey requires scanning bank to bank from a helicopter (e.g. Harrison River).

Water Clarity

Clear:	Visibility usually >3m; can see bottom of deep pools and shallow areas to count spawners and holders (e.g. Horsefly River).
Tannic:	The leaching of highly water soluble tannins from decaying vegetation and leaves along a stream that produces a tea-colour apperance that can sometimes create difficult counting conditions (e.g. Nadina River).
Partially Turbid:	Visibility 1-3m depending on weather; can only observe fish in shallow areas (likely spawners) with fish holding or spawning in deeper pools being difficult or impossible to observe (e.g. Harrison River).
Turbid:	Visibility usually <1m; Fish are very difficult, if not impossible to observe (e.g. Taseko River).

Substrate Colour

Light:	White, light blue, light green substrates that provide good contrast with redds and fish are clearly visible (e.g. Adams River).
Medium:	Yellow, orange and light brown substrate that can reduce counting efficiency in deeper pools and riffles (e.g. Horsefly River).
Dark:	Substrate includes tannic systems; difficult to distinguish fish from dark bottom substrate, unless fish are directly on or over a redd (e.g. Tachie River).

Canopy Cover

Low:	Small amount of overhead vegetation. Little to no influence on counting efficiency (accuracy). Canopy Cover <25%. Aerial surveys typically used. (e.g. Tachie River).
Medium:	Moderate amount of overhead vegetation. Some influence on counting efficiency (accuracy). Canopy Cover 25-75%. Ground surveys typically used (e.g. Ankwill Creek).
High:	Large amount of overhead vegetation. Significant influence on counting efficiency (accuracy). Canopy Cover >75%. Ground surveys always used (e.g. Narrows Creek).

Appendix 2. Comprehensive summary of calibrated Sockeye salmon populations in the Fraser River watershed by year and stream type characteristics, 1988-2015.

Year	Stream	Size	Water Clarity	Low Precision Visual Method	Low Precision Visual Count	High Precision Estimate Method	High [a] Precision Estimate	Index
1988	Barriere River, upper	V. Small	Clear	Ground	15,284	Fence	26,932	1.76
1989	Stellako River	Medium	Clear	Ground	21,142	MR	43,189	2.04
1990	Forfar Creek	V. Small	Clear	Ground	7,329	Fence	13,770	1.88
1990	Gluske Creek	V. Small	Clear	Ground	7,578	Fence	11,058	1.46
1991	Forfar Creek	V. Small	Clear	Ground	11,083	Fence	18,522	1.67
1991	Gluske Creek	V. Small	Clear	Ground	8,321	Fence	15,294	1.84
1991	O'Ne-Ell Creek	V. Small	Clear	Ground	11,413	Fence	25,352	2.22
1991	Stellako River	Medium	Clear	Ground	42,300	MR	94,931	2.24
1992	Forfar Creek	V. Small	Clear	Ground	3,674	Fence	7,940	2.16
1992	O'Ne-Ell Creek	V. Small	Clear	Ground	3,430	Fence	8,585	2.50
1992	Stellako River	Medium	Clear	Ground	89,103	MR	97,985	1.10
1993	Stellako River	Medium	Clear	Ground	46,658	MR	91,443	1.96
1994	Adams River, lower	Large	Clear	Ground	289,040	MR	676,624	2.34
1994	Barriere River, upper	V. Small	Clear	Ground	3,879	Fence	5,919	1.53
1994	Forfar Creek	V. Small	Clear	Ground	3,692	Fence	4,377	1.19
1994	Gluske Creek	V. Small	Clear	Ground	1,825	Fence	3,372	1.85
1994	O'Ne-Ell Creek	V. Small	Clear	Ground	2,904	Fence	3,860	1.33
1994	Mitchell River	Medium	Pt. Turbid	Aerial	36,500	MR	124,148	3.40
1994	Seymour River	Medium	Pt. Turbid	Ground	25,866	MR	56,192	2.17
1994	Tachie River	X-Large	Tannic	Aerial	7,216	MR	42,688	5.92
1995	Adams River, lower	Large	Clear	Ground	170,346	MR	378,952	2.22
1995	Bowron River	Medium	Tannic	Aerial	12,110	Fence	34,431	2.84
1995	Barriere River, upper	V. Small	Clear	Ground	4,343	Fence	11,251	2.59
1995	Forfar Creek	V. Small	Clear	Ground	12,343	Fence	16,478	1.34

Continued

Appendix 2. Comprehensive summary of calibrated Sockeye salmon populations in the Fraser River watershed by year and stream type characteristics, 1988-2015 (cont'd).

Year	Stream	Size	Water Clarity	Low Precision Visual Method	Low Precision Visual Count	High Precision Estimate Method	High [a] Precision Estimate	Index
1995	Gluske Creek	V. Small	Clear	Ground	8,972	Fence	15,044	1.68
1995	O'Ne-Ell Creek	V. Small	Clear	Ground	16,784	Fence	26,985	1.61
1995	Seymour River	Medium	Clear	Ground	28,509	MR	40,687	1.43
1995	Stellako River	Medium	Clear	Ground	75,611	Fence	126,743	1.68
1996	Crow Creek	V. Small	Clear	Ground	433	Fence	845	1.95
1996	Barriere River, upper	V. Small	Clear	Ground	16,994	Fence	32,278	1.90
1996	Forfar Creek	V. Small	Clear	Ground	6,055	Fence	8,381	1.38
1996	Gluske Creek	V. Small	Clear	Ground	7,179	Fence	8,582	1.20
1996	O'Ne-Ell Creek	V. Small	Clear	Ground	9,527	Fence	10,772	1.13
1996	Narrows Creek	V. Small	Clear	Ground	2,409	Fence	2,846	1.18
1996	Paula Creek	V. Small	Clear	Ground	2,866	Fence	4,702	1.64
1996	Weaver Creek	V. Small	Clear	Ground	23,681	MR	38,248	1.62
1997	Forfar Creek	V. Small	Clear	Ground	5,329	Fence	10,070	1.89
1997	Gluske Creek	V. Small	Clear	Ground	7,098	Fence	11,557	1.63
1997	Middle River	X-Large	Tannic	Aerial	90,598	MR	281,472	3.11
1997	Stellako River	Medium	Clear	Ground	22,853	Fence	55,385	2.42
1997	Tachie River	X-Large	Tannic	Aerial	251,926	MR	491,098	1.95
1998	Eagle River (early)	Medium	Turbid	Aerial	3,827	MR	28,478	7.44
1998	Forfar Creek	V. Small	Clear	Ground	420	Fence	956	2.28
1998	Gluske Creek	V. Small	Clear	Ground	459	Fence	812	1.77
1998	Weaver Creek	V. Small	Clear	Ground	9,828	MR	28,042	2.85
1999	Adams River, lower	Large	Clear	Ground	93,320	MR	380,869	4.08
1999	Forfar Creek	V. Small	Clear	Ground	1,488	Fence	1,797	1.21
1999	Gluske Creek	V. Small	Clear	Ground	1,183	Fence	1,264	1.07
1999	O'Ne-Ell Creek	V. Small	Clear	Ground	4,585	Fence	6,630	1.45
1999	Little River	X-Large	Clear	Aerial	7,432	MR	19,345	2.60

Continued

Appendix 2. Comprehensive summary of calibrated Sockeye salmon populations in the Fraser River watershed by year and stream type characteristics, 1988-2015 (cont'd).

Year	Stream	Size	Water Clarity	Low Precision Visual Method	Low Precision Visual Count	High Precision Estimate Method	High [a] Precision Estimate	Index
1999	Seymour River	Medium	Pt. Turbid	Ground	5,399	MR	14,420	2.67
1999	Stellako River	Medium	Clear	Ground	38,867	MR	136,105	3.50
2000	Forfar Creek	V. Small	Clear	Ground	4,144	Fence	7,315	1.77
2000	Gluske Creek	V. Small	Clear	Ground	2,877	Fence	3,936	1.37
2000	O'Ne-Ell Creek	V. Small	Clear	Ground	7,325	Fence	10,890	1.49
2000	Raft River	Medium	Clear	Ground	25,308	MR	66,292	2.62
2000	Adams River, upper	Medium	Turbid	Aerial	17,116	MR	71,322	4.17
2000	Tachie River	X-Large	Tannic	Aerial	229,427	MR	368,966	1.61
2001	Dust Creek	Small	Tannic	Aerial	11,309	Fence	23,032	2.04
2001	Forfar Creek	V. Small	Clear	Ground	7,704	Fence	12,868	1.67
2001	Gluske Creek	V. Small	Clear	Ground	6,142	Fence	10,990	1.79
2001	O'Ne-Ell Creek	V. Small	Clear	Ground	5,881	Fence	14,010	2.38
2002	Dust Creek	Small	Tannic	Aerial	783	Fence	2,387	3.05
2002	Forfar Creek	V. Small	Clear	Ground	1,088	Fence	1,912	1.76
2002	Gluske Creek	V. Small	Clear	Ground	1,173	Fence	1,866	1.59
2002	O'Ne-Ell Creek	V. Small	Clear	Ground	1,432	Fence	2,201	1.54
2002	Seymour River	Medium	Clear	Ground	43,099	MR	111,501	2.59
2003	Adams River, lower	Large	Clear	Ground	73,880	MR	313,913	4.25
2003	Gluske Creek	V. Small	Clear	Ground	611	Fence	872	1.43
2003	O'Ne-Ell Creek	V. Small	Clear	Ground	1,949	Fence	3,295	1.69
2003	Tachie River	X-Large	Tannic	Aerial	9,994	MR	28,309	2.83
2004	Forfar Creek	V. Small	Clear	Ground	706	Fence	1,003	1.42
2004	Tachie River	X-Large	Tannic	Aerial	27,706	MR	60,862	2.20
2005	Forfar Creek	V. Small	Clear	Ground	3,225	Fence	5,274	1.64
2005	Gluske Creek	V. Small	Clear	Ground	1,822	Fence	3,342	1.83
2005	Kuzkwa River	Medium	Tannic	Aerial	6,415	Fence	13,682	2.13

Continued

Appendix 2. Comprehensive summary of calibrated Sockeye salmon populations in the Fraser River watershed by year and stream type characteristics, 1988-2015 (cont'd).

Year	Stream	Size	Water Clarity	Low Precision Visual Method	Low Precision Visual Count	High Precision Estimate Method	High [a] Precision Estimate	Index
2005	Middle River	X-Large	Tannic	Aerial	49,636	MR	73,270	1.48
2005	Tachie River	X-Large	Tannic	Aerial	104,532	MR	185,889	1.78
2006	Forfar Creek	V. Small	Clear	Ground	2,071	Fence	3,850	1.86
2006	Gluske Creek	V. Small	Clear	Ground	1,429	Fence	2,075	1.45
2006	Little River	X-Large	Clear	Aerial	180,953	MR	416,790	2.30
2006	Stellako River	Medium	Clear	Ground	44,997	Fence	146,035	3.25
2007	Adams River, lower *	Large	Clear	Aerial	16,050	MR	52,713	3.28
2007	Adams River, lower *	Large	Clear	Ground	19,405	MR	52,713	2.72
2007	Horsefly River *	Medium	Clear	Aerial	22,405	MR	55,181	2.46
2007	Gluske Creek	V. Small	Clear	Ground	79	Fence	167	2.11
2007	Stellako River *	Medium	Clear	Aerial	14,242	MR	41,481	2.91
2007	Stellako River *	Medium	Clear	Ground	22,435	MR	41,481	1.85
2008	Forfar Creek	V. Small	Clear	Ground	1,667	Fence	2,608	1.56
2008	Gluske Creek	V. Small	Clear	Ground	778	Fence	1,515	1.95
2008	Tachie River	X-Large	Tannic	Aerial	21,940	MR	123,014	5.61
2008	Stellako River	Medium	Clear	Ground	75,026	MR	159,749	2.13
2009	Forfar Creek	V. Small	Clear	Ground	1,862	Fence	3,244	1.74
2009	Gluske Creek	V. Small	Clear	Ground	1,042	Fence	1,494	1.43
2009	Harrison River	X-Large	Pt. Turbid	Aerial	116,891	MR	307,373	2.63
2009	Mitchell River	Medium	Clear	Aerial	18,950	Sonar	45,741	2.41
2009	Stellako River	Medium	Clear	Aerial	17,566	Fence	26,298	1.51
2009	Stellako River	Medium	Clear	Ground	20,874	Fence	26,298	1.27
2009	Tachie River	X-Large	Tannic	Aerial	26,275	MR	47,452	1.81
2010	Horsefly River *	Medium	Clear	Aerial	63,187	Sonar	124,074	1.96
2010	Mitchell River *	Medium	Clear	Aerial	38,405	MR	74,304	1.93
2010	Stellako River	Medium	Clear	Ground	48,016	Fence	202,358	4.21

Continued

Appendix 2. Comprehensive summary of calibrated Sockeye salmon populations in the Fraser River watershed by year and stream type characteristics, 1988-2015 (cont'd).

Year	Stream	Size	Water Clarity	Low Precision Visual Method	Low Precision Visual Count	High Precision Estimate Method	High [a] Precision Estimate	Index
2011	Adams River, lower	Large	Clear	Ground	16,393	MR	148,169	9.04
2011	Adams River, lower	Large	Clear	Aerial	14,860	MR	148,169	9.97
2011	Pitt River, upper *	Large	Pt. Turbid	Aerial	22,512	MR	56,006	2.49
2011	Pitt River, upper *	Large	Pt. Turbid	Ground	25,737	MR	56,006	2.18
2011	Stellako River *	Medium	Clear	Ground	29,313	MR	85,628	2.92
2011	Stellako River *	Medium	Clear	Aerial	28,490	MR	85,628	3.01
2012	Pitt River, upper *	Large	Pt. Turbid	Aerial	31,527	MR	78,038	2.48
2012	Pitt River, upper *	Large	Pt. Turbid	Ground	28,475	MR	78,038	2.74
2012	Harrison River *	X-Large	Pt. Turbid	Aerial	16,600	MR	71,002	4.28
2012	Tachie River *	X-Large	Tannic	Aerial	28,244	MR	68,568	2.43
2012	Chilliwack River, upper *	Medium	Clear	Aerial	48,530	Sonar	122,158	2.52
2012	Chilliwack River, upper *	Medium	Clear	Ground	52,771	Sonar	122,158	2.31
2012	Stellako River	Medium	Clear	Aerial	52,586	MR	137,993	2.62
2012	Stellako River	Medium	Clear	Ground	91,877	MR	137,993	1.50
2013	Birkenhead River *	Medium	Pt. Turbid	Aerial	26,559	Sonar	80,121	3.02
2013	Harrison River	X-Large	Clear	Aerial	67,090	MR	250,117	3.73
2013	Stellako River *	Medium	Clear	Ground	63,461	Sonar	109,220	1.72
2013	Stellako River *	Medium	Clear	Aerial	52,530	Sonar	109,220	2.08
2013	Tachie River *	X-Large	Tannic	Aerial	11,005	MR	97,155	8.83
2014	Birkenhead River *	Medium	Pt. Turbid	Aerial	12,064	Sonar	35,759	2.96
2014	Eagle River	Medium	Pt. Turbid	Aerial	66,378	Sonar	209,318	3.15
2014	Seymour River *	Medium	Clear	Aerial	34,770	MR	114,013	3.28
2015	Stellako River *	Medium	Clear	Aerial	68,244	Sonar	101,215	1.48
2015	Stellako River *	Medium	Clear	Ground	64,736	Sonar	101,215	1.56
2015	Harrison River *	X-Large	Pt. Turbid	Aerial	11,218	MR	115,715	10.32

[a] Projects that were enumerated using sonar or tradational weirs do not include fish that were observed spawning downstream of the fences.

* Funded by the Southern Boundary Restoration and Enhancement Fund (SEF).

Appendix 3. Comprehensive list of all Sockeye salmon spawning streams within the Fraser watershed by stream size, water clarity, and visual method under typical conditions (water clarity and method may vary annually).

Population Group	Stream	Size	Water Clarity	Visual Method
Lower Fraser	Blue Creek	Very Small	Clear / Part. Turbid	Ground
	Corbold Creek	Small	Clear	Ground / Aerial
	Chilliwack River, upper (Dolly Varden Cr.)	Medium	Clear	Ground / Aerial
	Depot Creek	Very Small	Clear	Ground
	Nahatlatch River	Medium	Clear / Part. Turbid / Turbid	Ground
	North Boise Creek	Very Small	Clear / Part. Turbid	Ground / Aerial
	Pitt River, upper	Large	Clear / Part. Turbid / Turbid	Ground / Aerial
	South Boise Creek	Very Small	Clear	Ground
	Upper Pitt Channel	Very Small	Clear	Ground
	Widgeon Slough	Very Small	Clear	Ground
Harrison-Lillooet	Big Silver Creek	Small	Clear	Ground / Aerial
	Birkenhead River	Medium	Clear / Part. Turbid / Turbid	Ground / Aerial
	Cogburn Creek	Small	Clear	Ground
	Douglas Creek	Small	Clear	Ground / Aerial
	Green River	Medium	Turbid	Ground / Aerial
	Harrison River	X-Large	Clear / Part. Turbid	Aerial
	Hatchery Creek	Very Small	Clear	Ground
	Miller Creek	Small	Turbid	Ground
	Pemberton Creek	Very Small	Turbid	Ground
	Poole Creek	Very Small	Turbid	Ground
	Railroad Creek	Very Small	Clear	Ground
	Sampson Creek	Very Small	Clear	Ground
	Ryan River	Medium	Turbid	Ground
	Sloquet Creek	Very Small	Clear	Ground
	Tipella Creek	Small	Part. Turbid	Ground
	Weaver Channel	Very Small	Clear	Census
	Weaver Creek	Very Small	Clear	Ground
Seton-Anderson	Bridge River	Medium	Part. Turbid / Turbid	Ground / Aerial
	Cayoosh Creek	Small	Clear	Ground / Aerial
	Churn Creek	Very Small	Clear	Ground
	Gates Channel	Very Small	Clear	Census
	Gates Creek	Very Small	Clear	Ground
	Portage Creek	Small	Clear	Ground
	Seton River	Medium	Clear / Part. Turbid	Aerial
	Yalakom River	Small	Clear	Aerial

Continued

Appendix 3. Comprehensive list of all Sockeye salmon spawning streams within the Fraser watershed by stream size, water clarity, and visual method under typical conditions (water clarity and method may vary annually) (cont'd).

Population Group	Population	Size	Water Clarity	Visual Method
South Thompson	**Adams Lake**			
	Bush Creek	Very Small	Clear	Ground
	Cayenne Creek	Very Small	Tannic	Ground
	Momich Creek	Small	Clear	Ground
	Pass Creek	Very Small	Clear	Ground
	Upper Adams River	Medium	Part. Turbid / Turbid	Ground / Aerial
	Upper Momich Creek	Very Small	Clear	Ground
	Shuswap Lake - Main Arm			
	Adams River (lower)	Large	Clear	Ground / Aerial
	Adams Channel	Very Small	Clear	Ground
	Huihill Creek	Very Small	Clear	Ground
	Nikwikwaia Creek	Very Small	Clear	Ground
	Hlina Creek	Very Small	Clear	Ground
	Onyx Creek	Very Small	Clear	Ground
	Ross Creek	Very Small	Clear	Ground
	Scotch Creek	Small	Clear	Ground / Aerial
	Shuswap Lake - Salmon Arm			
	Canoe Creek	Very Small	Clear	Ground
	Crazy Creek	Very Small	Clear	Ground
	Eagle River (below Perry)	Medium	Part. Turbid / Turbid	Ground / Aerial
	Eagle River (above Perry)	Small	Clear	Ground / Aerial
	Gorge Creek	Very Small	Clear	Ground
	Loftus Creek	Very Small	Clear	Ground
	Perry River	Small	Part. Turbid / Turbid	Ground
	Reinecker Creek	Very Small	Clear	Ground
	Sicamous Creek	Very Small	Clear	Ground
	Tappen Creek	Very Small	Clear	Ground
	Yard Creek	Very Small	Clear	Ground
	Shuswap Lake - Seymour Arm			
	Blueberry Creek	Very Small	Clear	Ground
	Celista Creek	Small	Clear	Ground
	McNomee Creek	Very Small	Tannic	Ground
	Seymour River	Medium	Clear / Part. Turbid	Ground / Aerial
	Shuswap Lake - Anstey Arm			
	Anstey River	Small	Clear / Part. Turbid	Ground
	Hunakwa Creek	Very Small	Tannic	Ground
	Four Mile Creek	Very Small	Clear	Ground

Continued

Appendix 3. Comprehensive list of all Sockeye salmon spawning streams within the Fraser watershed by stream size, water clarity, and visual method under typical conditions (water clarity and method may vary annually) (cont'd).

Population Group	Population	Size	Water Clarity	Visual Method
South Thompson (cont'd)	**Shuswap River**			
	Bessette Creek	Very Small	Clear	Ground
	Blurton Creek	Very Small	Clear	Ground
	Cooke Creek	Very Small	Clear	Ground
	Fortune Creek	Very Small	Clear	Ground
	Johnson Creek	Very Small	Clear	Ground
	Kingfisher Creek	Very Small	Clear	Ground
	Noisy Creek	Very Small	Clear	Ground
	Shuswap R., (Lower)	Large	Clear	Ground / Aerial
	Shuswap R., (Middle)	Medium	Clear	Ground / Aerial
	Trinity Creek	Very Small	Clear	Ground
	Tsuius Creek	Small	Clear	Ground
	Wap Creek	Small	Clear	Ground / Aerial
	South Thompson River			
	Little River	X-Large	Clear	Aerial
	South Thompson River	X-Large	Clear	Aerial
North Thompson	Barriere River	Medium	Clear	Aerial
	Barriere River, upper (Fennell Cr.)	Very Small	Clear	Ground
	Clearwater River	Large	Clear	Ground / Aerial
	Dunn Creek	Very Small	Clear	Ground
	Finn Creek	Very Small	Tannic	Ground
	Grouse (Moul) Creek	Very Small	Clear	Ground
	Harper Creek	Very Small	Clear	Ground
	Hemp Creek	Very Small	Clear	Ground
	Lemieux Creek	Very Small	Clear	Ground
	Lion Creek	Very Small	Clear	Ground
	Mann Creek	Very Small	Tannic	Ground
	North Thompson River	X-Large	Part. Turbid / Turbid	Aerial
	Raft River	Medium	Clear	Ground
Chilcotin	Chilko River	Large	Clear / Part. Turbid	Ground / Aerial
	Elkin Creek	Very Small	Clear	Ground / Aerial
	Yohetta Creek, upper	Very Small	Clear / Part. Turbid	Ground / Aerial
	Yohetta Creek, lower	Small	Part. Turbid	Ground / Aerial
Mid-Fraser	Baezaeko River	Medium	Tannic	Aerial
	Hawks Creek	Very Small	Clear	Ground
	Williams Lake River	Small	Tannic	Ground

Continued

Appendix 3. Comprehensive list of all Sockeye salmon spawning streams within the Fraser watershed by stream size, water clarity, and visual method under typical conditions (water clarity and method may vary annually) (cont'd).

Population Group	Population	Size	Water Clarity	Visual Method
Quesnel	**Quesnel River**			
	Cariboo River, lower	Large	Clear / Part. Turbid	Aerial
	Cariboo River, upper	Large	Part. Turbid / Turbid	Aerial
	Quesnel River	Large	Clear	Aerial
	Horsefly River			
	Archie Creek	Very Small	Tannic	Ground
	Horsefly Channel	Very Small	Clear	Census
	Horsefly River	Medium	Clear	Aerial
	Little Horsefly River	Small	Clear	Ground / Aerial
	Lower McKinley Creek	Small	Clear	Ground
	Moffat Creek	Very Small	Clear	Ground
	Upper McKinley Creek	Very Small	Clear	Ground / Aerial
	Tisdall Creek	Very Small	Tannic	Ground
	Mitchell River			
	Cameron Creek	Very Small	Clear	Ground / Aerial
	Mitchell River	Medium	Clear / Part. Turbid	Aerial
	Penfold Creek	Small	Clear / Part. Turbid	Ground / Aerial
	Quesnel Lake - East Arm			
	Bill Miner Creek	Very Small	Clear	Ground
	Blue Lead Creek	Small	Part. Turbid / Turbid	Ground / Aerial
	Bouldery Creek	Very Small	Clear	Ground
	Buckingham Creek	Very Small	Clear	Ground
	Franks Creek	Very Small	Clear	Ground
	Killdog Creek	Very Small	Clear	Ground
	Lynx Creek	Very Small	Clear	Ground
	Stranger Creek	Very Small	Clear	Ground
	Summit Creek	Very Small	Tannic	Ground
	Taku Creek	Very Small	Clear	Ground
Quesnel	**Quesnel Lake - North Arm**			
	Adams Creek	Very Small	Clear	Ground
	Bowling Creek	Very Small	Clear	Ground
	Devoe Creek	Very Small	Clear	Ground
	Grain Creek	Very Small	Clear	Ground / Aerial
	Isaiah Creek	Very Small	Clear	Ground
	Junction Creek	Very Small	Clear	Ground
	Limestone Creek	Very Small	Clear	Ground

Continued

Appendix 3. Comprehensive list of all Sockeye salmon spawning streams within the Fraser watershed by stream size, water clarity, and visual method under typical conditions (water clarity and method may vary annually) (cont'd).

Population Group	Population	Size	Water Clarity	Visual Method
Quesnel (cont'd)	**Quesnel Lake - North Arm**			
	Long Creek	Very Small	Clear	Ground
	Marten Creek	Very Small	Clear	Ground
	Roaring River	Small	Clear / Part. Turbid	Ground
	Service Creek	Very Small	Clear	Ground
	Sue Creek	Very Small	Clear	Ground
	Trickle Creek	Very Small	Clear	Ground
	Wasko Creek, lower	Very Small	Clear	Ground / Aerial
	Wasko Creek, upper	Very Small	Clear	Ground / Aerial
	Watt Creek	Very Small	Clear	Ground
	Quesnel Lake - West Arm			
	Abbott Creek	Very Small	Tannic	Ground
	Hazeltine Creek	Very Small	Tannic	Ground
	Spusks Creek	Very Small	Clear	Ground
	Tasse Creek	Very Small	Clear	Ground
	Whiffle Creek	Very Small	Clear	Ground
Early Stuart	**Driftwood River**			
	Blackwater Creek	Very Small	Clear	Ground
	Driftwood River	Medium	Clear / Part. Turbid	Aerial
	Kastberg Creek	Very Small	Tannic	Aerial
	Kotsine Creek	Small	Turbid	Aerial
	Lion Creek	Very Small	Clear	Ground / Aerial
	Porter Creek	Very Small	Clear	Ground
	Takla Lake, N.E. Arm			
	Ankwill Creek	Small	Clear	Ground / Aerial
	Bates Creek	Very Small	Tannic	Ground
	Blanchette Creek	Very Small	Clear	Ground
	French Creek	Very Small	Tannic	Ground
	Frypan Creek	Very Small	Clear	Ground / Aerial
	Lovell Creek (Forsythe Cr.)	Very Small	Clear	Ground
	Fifteen Mile Creek	Very Small	Clear	Ground
	Hudson's Bay Cr.	Very Small	Clear	Ground
	Maclaing Creek (Five Mile Cr.)	Very Small	Clear	Ground
	Shale Creek	Very Small	Clear	Ground
	Tliti Creek (Ten Mile Cr.)	Very Small	Clear	Ground
	Twenty-Five Mile Creek	Very Small	Clear	Ground
	Unnamed Creek (N. of Blanchette)	Very Small	Clear	Ground

Continued

Appendix 3. Comprehensive list of all Sockeye salmon spawning streams within the Fraser watershed by stream size, water clarity, and visual method under typical conditions (water clarity and method may vary annually) (cont'd).

Population Group	Population	Size	Water Clarity	Visual Method
Early	**Takla Lake, N.W. Arm**			
Stuart	Crow Creek	Very Small	Clear	Ground
(cont'd)	Dust Creek	Small	Tannic	Ground / Aerial
	Hooker Creek	Very Small	Clear	Ground
	McDougall Creek	Very Small	Tannic	Ground
	Point Creek	Very Small	Clear	Ground
	Sinta Creek	Very Small	Clear	Ground
	Takla Lake, S. Arm			
	Bivouac Creek	Very Small	Clear	Ground
	Gluske Creek	Very Small	Clear	Ground
	Leo Creek	Very Small	Clear	Ground
	Narrows Creek	Very Small	Clear	Ground
	Sakeniche River	Medium	Tannic	Aerial
	Sandpoint Creek	Very Small	Clear	Ground
	Middle River			
	Baptiste Creek	Very Small	Tannic	Ground
	Forfar Creek	Very Small	Clear	Ground
	Kazchek Creek	Small	Clear	Ground
	O'Ne-Ell Creek (Kynock Cr.)	Very Small	Clear	Ground
	Van Decar Creek (Rossette Cr.)	Very Small	Clear	Ground
	Trembleur Lake			
	Fleming Creek	Very Small	Clear	Aerial
	Paula Creek	Very Small	Clear	Ground
	Sidney Creek (Felix Cr.)	Very Small	Clear	Ground
	Tarnazell Creek	Very Small	Tannic	Ground
	Tildesley Creek	Very Small	Tannic	Aerial
Late	**Stuart Lake**			
Stuart	Kuzkwa River	Medium	Tannic	Ground / Aerial
	Middle River	X-Large	Tannic	Aerial
	Pinchi Creek	Very Small	Clear	Ground
	Sowchea Creek	Very Small	Tannic	Ground
	Tachie River	X-Large	Tannic	Aerial
Nechako	Endako River	Medium	Tannic	Aerial
	Glacier Creek	Very Small	Clear	Aerial

Continued

Appendix 3. Comprehensive list of all Sockeye salmon spawning streams within the Fraser watershed by stream size, water clarity, and visual method under typical conditions (water clarity and method may vary annually) (cont'd).

Group	Population	Size	Water Clarity	Visual Method
Nechako	Nadina Channel	Very Small	Clear	Census
	Nadina River	Medium	Tannic	Aerial
	Nechako River	Large	Clear	Aerial
	Nithi River	Small	Tannic	Ground
	Ormonde Creek	Very Small	Tannic	Ground
	Stellako River	Medium	Clear	Ground / Aerial
Upper Fraser	Bowron River, lower	Medium	Clear	Aerial
	Bowron River, upper	Medium	Tannic	Aerial
	Huckey Creek	Very Small	Tannic	Aerial