Calibration of Visual Assessment Methods for Fraser River Sockeye Salmon *(Oncorhynchus nerka)* -Year 8

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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 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 commonly leads to substantial negative bias in spawning estimates. Two population types are of concern: stream and lake shore spawners. There has been only limited calibration work on larger streams that typically support populations with larger abundances and even less work has been done to validate lake shore spawning estimation.

In 2016, the Southern Boundary Restoration and Enhancement Fund (SEF) funded the eighth of a multi-year calibration study to minimize bias in visually enumerated Sockeye salmon populations in the Fraser River watershed. Summaries of the first seven 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, Benner et al. 2015 and Benner et al. 2016. The following report provides a summary of the 2016 specific calibration activities as well as a summary of all calibration data collected by DFO since 1988.

METHODS

In 2016, calibration efforts focused on six populations where high precision spawning escapement enumeration projects were implemented - the Nadina River, Upper Chilliwack River, Chilliwack Lake, Stellako River, Birkenhead River and Harrison River populations. Hydroacoustic imaging systems (DIDSON and/or ARIS) were employed at the Nadina, Upper Chilliwack, Lower Chilliwack and Birkenhead rivers, while an enumeration fence was operated at Stellako River and a mark-recapture study was conducted at Harrison River.

Low precision ground and/or aerial visual counts (live and dead) were conducted at the peak of spawn in all river populations. Expansion factors (indices) were generated for each population by dividing the respective high precision estimate by the peak visual count (live plus dead). Simultaneous ground surveys were paired with aerial surveys at a number of locations throughout the Fraser Watershed to permit the direct comparison of the two counting methods. A more detailed description of the calibration methods is presented in Welch et al. 2011.

Additional effort was also invested in the Chilliwack system where two SONAR sites (upstream and downstream of the lake) were used to generate a high precision escapement estimate of Sockeye spawning directly in Chilliwack Lake based on the difference of upstream passage counts at the two SONAR sites. The high precision estimate was then compared to the historical low precision escapement estimate derived solely from the standard carcass recovery effort expansion method.

In addition to the data collected in 2016, all calibration data collected by DFO on Fraser Sockeye populations from 1988-2016 are summarized and examined.

RESULTS

2016 CALIBRATION ACTIVITIES

Nadina River

Two aerial surveys of Nadina River were conducted on September 10th and 16th with a total of 4,451 and 5,023 Sockeye salmon (live + dead) enumerated, respectively. The index generated from comparing the peak aerial count on September 16th to the sonar estimate of 16,672 Sockeye salmon is 3.32 (Table 1).

Upper Chilliwack River

Two aerial surveys of the Upper Chilliwack River were conducted on August 17th and 25th with a total of 15,502 and 16,783 Sockeye salmon (live + dead) enumerated, respectively. The index generated from comparing the peak aerial count on August 25th to the sonar estimate of 56,003 Sockeye salmon is 3.34 (Table 1).

Chilliwack Lake

Seven weekly carcass recovery surveys were conducted on Chilliwack Lake from August 17th to September 27th. A total of 167 lake-origin Sockeye carcasses were recovered resulting in a lake spawner population estimate of 556 sockeye using the standard recovery effort expansion method. This compares to the estimate of -333 lake spawners calculated by taking the difference between the lower and upper sonar site estimates of 57,043 and 57,376, respectively. Further results and details related to the 2016 Chilliwack Lake calibration activities are presented in Appendix 5.

Stellako River

One paired aerial and ground survey of the Stellako River was conducted on September 29th with a total of 22,605 and 22,054 Sockeye salmon (live + dead) enumerated, respectively. The indices generated from comparing the aerial and ground counts to the system fence estimate of 27,774 Sockeye salmon are 1.23 and 1.26, respectively (Table 1).

Harrison River

One aerial survey of the Harrison River was conducted on November 10th with a total of 5,536 Sockeye salmon (live + dead) enumerated. The index generated from comparing the aerial count to the mark-recapture estimate of 65,758 Sockeye salmon is 11.88 (Table 1).

Birkenhead River

One aerial survey of the Birkenhead River was conducted on September 16th with a total of 7,439 Sockeye salmon (live + dead) enumerated. The index generated from comparing the aerial count to the sonar estimate of 36,439 Sockeye salmon is 4.90 (Table 1).

Aerial to Ground Counts

Simultaneous aerial to ground counts occurred at 9 locations from August 10th to November 10th in 2016 (Table 2).

Table 1. Summary of low precision visual counts, high precision escapement estimates and the resulting indices at Upper Chilliwack, Nadina, Stellako, Harrison, and Birkenhead rivers, 2016.

			Low Precision		High Precision		
Stream	Stream Size	Water Clarity	Method	Count [a]	Method	Estimate	Index
Nadina	Medium	Tannic	Aerial	5,023	Sonar	16,672	3.32
Chilliwack (Upper) [b]	Medium	Clear	Aerial	16,783	Sonar	56,003	3.34
Stellako [b]	Medium	Clear	Aerial	22,672	Fence	27,774	1.23
Stellako [b]	Medium	Clear	Ground	22,121	Fence	27,774	1.26
Harrison	Extra Large	Clear	Aerial	5,536	M/R	65,758	11.88
Birkenhead	Medium	Pt. Turbid	Aerial	7,439	Sonar	36,439	4.90

[a] Peak live count plus dead carcasses observed.

[b] Estimates do not include live spawners below the fence.

Table 2. Summary of aerial to ground comparison surveys by stream for Fraser Sockeye salmon spawning populations, 2016.

Stream	Date	Stream Size	Water Clarity	Aerial Count [a]	Ground Count [a]	Aerial / Ground ratio
Adams River (Lower)	28-Sep	Large	Clear	15	18	0.83
Chilliwack (Upper)	17-Aug	Medium	Clear	14,390	19,880	0.72
Chilliwack (Upper)	25-Aug	Medium	Clear	12,465	17,115	0.73
Dust	10-Aug	Small	Tannic	7	13	0.54
Harrison	10-Nov	X-Large	Clear	5,343	1,290	4.14
Kazchek	19-Sep	Small	Clear	22	24	0.92
Kuzkwa	19-Sep	Medium	Tannic	588	591	0.99
Nadina	10-Sep	Medium	Tannic	2,875	6,201	0.46
Nadina	16-Sep	Medium	Tannic	3,278	5,660	0.58
Stellako	29-Sep	Medium	Clear	22,356	21,804	1.03
Summit	24-Sep	V. Small	Clear	16	21	0.76

[a] Counts may only represent a portion of the stream

SUMMARY OF CALIBRATION ACTIVITIES (1988-2016)

Since calibration efforts began in 1988 a total of 132 calibration data points (indices) have been generated on Fraser River Sockeye salmon populations (Appendix 2). Of these, 83 were based on ground surveys and 49 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 3); 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 4).

It should be noted that two revisions were made to the historical calibration time series to reflect an inappropriate stream type classification and a biased data point. These include changes to the 2005 Kuzkwa River where the water clarity was revised from tannic to clear, and the removal of the 2012 Upper Chilliwack River ground based calibration, where after further investigation, the live count was deemed to be biased due to an incomplete survey.

Table 3. Summary of ground calibration surveys stratified by stream size and water clarity for Fraser Sockeye salmon populations, 1988-2016.

Size	Water Clarity	Number of calibration surveys (n)	Average Population Estimate	Average Index	Index Range	Standard Deviation	Coefficient of Variation
Very Small	Clear	53	9,005	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	95,101	2.16	1.1 - 4.21	0.82	0.38
	Pt. Turbid / Tannic	2	35,306	2.42	2.17 - 2.67	0.35	0.15
	Turbid	0	-	-	-	-	-
Large	Clear	6	325,207	4.11	2.22 - 9.04	2.57	0.63
	Pt. Turbid / Tannic	2	67,022	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 typically not surveyed using ground methods

Table 4. Summary of aerial calibration surveys stratified by stream size and water clarity for Fraser Sockeye salmon populations, 1988-2016.

Size	Water Clarity	Number of calibration surveys (n)	Average Population Estimate	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	2.54	2.04 - 3.05	0.72	0.28
	Turbid	0	-	-	-	-	-
Medium	Clear	15	75,651	2.32	1.23 - 3.34	0.66	0.28
	Pt. Turbid / Tannic	7	76,698	3.37	2.84 - 4.90	0.70	0.21
	Turbid	2	49,900	5.80	4.17 - 7.44	2.32	0.40
Large	Clear	2	100,441	6.63	3.28 - 9.97	4.73	0.71
	Pt. Turbid / Tannic	2	67,022	2.48	2.48 - 2.49	0.01	<0.01
	Turbid	0	-	-	-	-	-
Extra Large	Clear	4	188,002	5.13	2.3 - 11.88	4.54	0.88
	Pt. Turbid / Tannic	15	157,522	3.78	1.48 - 10.32	2.73	0.72
	Turbid	0	-	-		-	-

* Very Small streams not surveyed using aerial methods

From 1988 to 2016, 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 3), 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 0.88) (Tables 3 and 4). The highest variability is associated with streams categorized as large clear, extra-large clear and extra-large partially turbid/tannic. This high variability can be linked to a few streams within each group, as outlined in Tables 5 and 6. Streams displaying a CV greater than 0.50 include the Eagle, Adams (lower), Harrison, Middle, and Tachie rivers.

Since 2002, a total of 65 independent aerial to ground visual comparisons have been completed on all stream sizes throughout the Fraser watershed (Appendix 4). Aerial to ground ratios generally increase with stream size; however, the data reveals similar results amongst the moderately sized (small, medium and large) streams (Table 7).

Table 5. Summary of ground calibration surveys by stream for Fraser Sockeye salmon populations, 1988-2016.

Size	Water Clarity [a]	Stream	Number of calibration surveys (n)	Average Population Estimate	Average Index	Index Range	Standard Deviation	Coefficient of Variation
V. Small	Clear	Barriere (Upper)	4	19,095	1.94	1.53 - 2.59	0.46	0.24
	Clear	Crow	1	845	1.95	-	-	-
	Clear	Forfar	17	7,080	1.67	1.19 - 2.28	0.30	0.18
	Clear	Gluske	17	5,485	1.61	1.07 - 2.11	0.28	0.17
	Clear	Narrows	1	2,846	1.18	-	-	-
	Clear	O'Ne-Ell	10	11,258	1.73	1.13 - 2.50	0.47	0.27
	Clear	Paula	1	4,702	1.64	-	-	-
	Clear	Weaver	2	33,145	2.23	1.62 - 2.85	0.88	0.39
Medium	Clear / Pt. Turbid / Tannic	Seymour	4	55,700	2.21	1.43 - 2.67	0.57	0.26
	Clear	Stellako	17	99,031	2.15	1.10 - 4.21	0.86	0.40
	Clear	Raft	1	66,292	2.62	-	-	-
Large	Clear	Adams (Lower)	6	325,207	4.11	2.22 - 9.04	2.57	0.63
	Pt. Turbid / Tannic	Pitt (Upper)	2	67,022	2.46	2.18 - 2.74	0.40	0.16

[a] Water Clarity can differ on an annual basis in some systems

Table 6. Summary of aerial calibration surveys by stream for Fraser Sockeye salmon populations, 1988-2016.

Size	Water Clarity [a]	Stream	Number of calibration surveys (n)	Average Population Estimate	Average Index	Index Range	Standard Deviation	Coefficient of Variation
Small	Pt. Turbid / Tannic	Dust	2	12,710	2.54	2.04 - 3.05	0.72	0.28
Medium	Clear	Upper Chilliwack	2	89,081	2.93	2.52 - 3.34	0.64	0.22
	Clear	Horsefly	2	89,628	2.21	1.96 - 2.46	0.35	0.16
	Clear	Stellako	7	75,658	2.12	1.23 - 3.01	0.74	0.35
	Clear	Kuzkwa	1	13,682	2.13	-		
	Clear	Seymour	1	114,013	3.28	-		
	Clear / Pt. Turbid / Tannic	Mitchell	3	81,398	2.58	1.93 - 3.40	0.75	0.29
	Pt. Turbid / Tannic	Birkenhead	3	50,773	3.63	2.96 - 4.90	1.10	0.30
	Pt. Turbid / Tannic	Bowron	1	34,431	2.84	-		
	Pt. Turbid / Tannic	Nadina	1	16,667	3.32	-		
	Pt. Turbid / Tannic / Turbid	Eagle (*Early*)	2	118,898	5.30	3.15 - 7.44	3.03	0.57
	Turbid	Adams (Upper)	1	71,322	4.17	-		
Large	Clear	Adams (Lower)	2	100,441	6.63	3.28 - 9.97	4.73	0.71
	Pt. Turbid / Tannic	Upper Pitt	2	67,022	2.48	2.48 - 2.49	0.01	0.00
Extra Large	Clear	Little	2	218,068	2.45	2.30 - 2.60	0.21	0.09
	Clear / Pt. Turbid / Tannic	Harrison	5	161,993	6.57	2.63 - 11.88	4.22	0.64
	Pt. Turbid / Tannic	Middle	2	177,371	2.29	1.48 - 3.11	1.15	0.50
	Pt. Turbid / Tannic	Tachie	10	151,400	3.49	1.61 - 8.83	2.44	0.70

[a] Water Clarity can differ on an annual basis in some systems

Table 7. Summary of aerial to ground comparison surveys by stream size for Fraser Sockeye salmon spawning populations, 2002-2016.

Stream	N	Aerial / Ground ratio [a]
Very Small	10	0.73
Small	14	0.84
Medium	30	0.83
Large	8	0.82
X-Large	3	3.01

[a] Aerial Proportion (i.e aerial count divided by ground count).

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).

Results of the calibration work to date 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 3 and 4). It is recognized that OE becomes 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). 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 nil.

Calibration data collected to date indicates that abundance appears to be less of a driver behind OE and the development of indices than previously thought (Benner et al. 2016). 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 very high inter and intra-annual variability in fish behavior and viewing conditions, contributing to higher variability amongst the annual indices. 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. Any deviations from these conditions immediately begin to negatively impact OE, resulting in highly variable indices ranging between 1.61 and 8.83 with a CV of 0.70 (Table 6). Similarly, indices generated at the Harrison River range between 2.63 and 11.88 with a CV of 0.64 (Table 6). Indices generated from aerial surveys at the Adams River range between 3.28

and 9.97 with a CV of 0.71 (Table 6); however, the high variability appears to be less associated with variable viewing conditions or OE, but rather with high spawner replenishment. The Adams River is fairly unique in that most of the spawning occurs within a few kilometres of a large oligotrophic lake (i.e. Shuswap Lake). Adams River Sockeye complete their maturation process by holding in the lake prior to spawning. Once fish are fully mature, they enter the river and complete their spawning, die and are immediately replaced with additional spawners in a relatively short period of time. Because of this pattern, only a small fraction of the population would typically be available for observation during each visual survey. Similar patterns likely occur in other streams where fish hold in the lake for extended periods of time prior to spawning.

In contrast, there are other streams that appear to exhibit more consistency with fish behavior and viewing conditions and have much less variability in the indices. For example, the Stellako River is a medium sized, clear system with lighter substrate that typically provides reasonable counting conditions on an annual basis. In addition, as confirmed by years of fence and hydroacoustic operation, most of the population is typically in the river and available for observation by the time peak live count surveys typically occur. As such, aerial based indices for the Stellako River range between 1.23 and 3.01 with a CV of 0.35 (Table 6).

As OE can differ considerably between aerial and ground visual methods, indices must also be method-specific (Benner et al. 2013). When comparing aerial to ground based surveys it is assumed that the ground based counts are more accurate in most cases since observers are able to move at a slower and constant rate when counting and viewing the stream from a closer and constant distance. Generally, conditions encountered during ground surveys when compared to aerial surveys are considerably less varied (Crawford et al. 2007; Edgar et al. 2007), which should provide greater standardization and precision in ground survey methodology. Exceptions remain in extremely wide systems, such as the Harrison River, where the ability to view the entire channel from a ground survey is virtually impossible.

The comparison of simultaneous aerial to ground counts on small, medium and large sized streams calibrated since 2002 reveals that on average aerial counts are approximately 83% of ground based counts (Table 7). Similar comparisons on very small and extra-large streams reveal aerial to ground ratios of 73% and 301%, respectively. These data outline the importance of selecting the most adequate visual method for surveying each stream. In this case, it is clear that ground based surveys are not adequate to use on extra-large streams, and similarly, aerial based surveys are not adequate to use on very small streams.

Historically, the standard carcass recovery effort expansion method which assumes each survey recovers 5% of the population has been used to enumerate lake spawning sockeye populations in the Fraser River watershed where visual live counts cannot be reasonably conducted (eg. Chilliwack, Taseko, and Nahatlatch lakes). Escapement estimates based on this method are highly uncertain and more reasonably provides annual estimates of relative abundance rather than true estimates of spawning escapement. In 2016, it was anticipated that a precise estimate of the Chilliwack Lake spawning population could be generated by subtracting the precise upper Chilliwack River sonar estimate from the total Chilliwack system estimate (lower sonar site). It was hoped that this estimate could then be directly compared to the estimate derived from the historical carcass recovery effort method for calibration purposes. Unfortunately, this was not possible since the estimates generated at both sonar sites were statistically identical with the difference between the point estimates being a negative number (-333). The negative value simply reflects the uncertainty in the two sonar estimates (95% confidence intervals for the lower and upper sonar sites were 50,152 - 63,394, and 42,613 - 69,391 Sockeye, respectively). While the method of using two sonars did not provide an estimate to adequately compare and calibrate the historical carcass recovery expansion method, it supports the existing information collected from the carcass recovery data, as well as limited remote underwater video surveys, which suggests that relatively low numbers of Sockeye spawned in Chilliwack Lake in 2016.

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 and even less work has been done to validate lake shore spawning estimation. 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 31 data points (20 medium, 6 large and 5 extra-large) on stream populations up to 125,000 spawners. Although this represents significant progress towards the development of indices on larger stream populations, substantial gaps still exist.

Although preliminary, the data suggests that 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 fish behavior instead of applying a one-size fits all approach that does not take into account these unique complexities. Preliminary results indicate that stream-specific indices may be more appropriate for the lower Adams, Middle, Tachie and Harrison river populations.

Moving forward it may be reasonable to consider using visual methods to assess streams that display little to moderate variability (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 (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, regardless of abundance or the level of variability, will produce estimates with higher uncertainty and should never be used when precise high quality estimates are required.

It is likely that the challenges experienced with Chilliwack Lake calibration in 2016 would be similar in any system where the lake spawning population is relatively small. In these cases the lake spawning component is likely to fall within the error bounds of the high precision system estimate. Therefore moving forward, it is recommended that no further effort be directed at the calibration of the carcass recovery effort expansion method. Instead it is recommended that high precision total system estimates are generated for systems with lake shore spawning populations whenever possible. A total system estimate paired with upstream surveys (live and dead counts) to provide relative spawner distribution information would provide the resolution required to meet both international and domestic management requirements. The switch to system estimates at Quesnel and Taseko in recent years has improved the quality of the estimates and reduced bias associated with the lake spawning populations. It is recommended that this approach be considered in other systems with lake shore spawners such as the Chilliwack, Nahatlatch and Shuswap.

As calibration work continues on stream populations 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 use of a jet boat and Raftable (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, 1988-2016.

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, 1988-2016 (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, 1988-2016 (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	Clear	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, 1988-2016 (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

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	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 (early)	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
2016	Birkenhead River *	Medium	Pt. Turbid	Aerial	7,439	Sonar	36,439	4.90
2016	Chilliwack River, upper *	Medium	Clear	Aerial	16,783	Sonar	56,003	3.34

Appendix 2. Comprehensive summary of calibrated Sockeye salmon populations in the Fraser River watershed by year and stream type characteristics, 1988-2016 (cont'd).

Year	Stream	Size	Water Clarity	Low Precision Visual Method	Low Precision Visual Count	High Precision Estimate Method	High [a] Precision Estimate	Index
2016	Harrison River *	X-Large	Clear	Aerial	5,536	MR	65,758	11.88
2016	Nadina River *	Medium	Tannic	Aerial	5,023	Sonar	16,672	3.32
2016	Stellako River *	Medium	Clear	Aerial	22,605	Fence	27,774	1.23
2016	Stellako River *	Medium	Clear	Ground	22,054	Fence	27,774	1.26

* 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	**<u>Takla Lake, N.W. Arm</u>**			
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
	<u>Takla Lake, S. Arm</u>			
	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
	<u>Middle River</u>			
	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
	<u>Trembleur Lake</u>			
	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	**<u>Stuart Lake</u>**			
Stuart	Kuzkwa River	Medium	Clear / 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 (cont'd)	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

Appendix 4. Summary of aerial to ground comparison surveys by specific streams for Fraser Sockeye salmon spawning populations, 2002-2016.

Stream	Year	Stream Size	Water Clarity	Aerial Count	Ground Count	Aerial / Ground Ratio
Anstey River	2002	Small	Part. Turbid	3,710	10,855	0.34
Eagle River - Lower (below Perry)	2002	Medium	Part. Turbid	17,538	31,470	0.56
Eagle River - Upper (above Perry)	2002	Small	Clear	2,675	3,867	0.69
Kuzkwa River	2005	Medium	Tannic	3,019	3,784	0.80
North Thompson River	2006	X-Large	Part. Turbid	3,800	970	3.92
Adams River (Lower)	2007	Large	Clear	15,450	18,788	0.82
Horsefly River	2007	Medium	Clear	6,464	7,964	0.81
Stellako River	2007	Medium	Clear	10,110	12,489	0.81
Forfar Creek	2008	V. Small	Clear	767	1,956	0.39
Kuzkwa River	2008	Medium	Tannic	1,856	2,624	0.71
Kuzkwa River	2008	Medium	Tannic	827	942	0.88
O' Ne-Ell Creek	2008	V. Small	Clear	2,109	4,303	0.49
Big Silver Creek	2009	Small	Clear	2,659	3,255	0.82
Cameron Creek	2009	V. Small	Clear	88	130	0.68
Chilliwack River (Upper)	2009	Medium	Clear	772	919	0.84
Little Horsefly River	2009	Small	Clear	2,840	3,376	0.84
Stellako River	2009	Medium	Clear	17,520	21,274	0.82
Ankwill Creek	2010	Small	Clear	1,215	1,115	1.09
Ankwill Creek	2010	Small	Clear	1,369	1,469	0.93
Chilliwack River (Upper)	2010	Medium	Clear	185	290	0.64
Horsefly River	2010	Medium	Clear	511	861	0.59
Kuzkwa River	2010	Medium	Tannic	824	827	1.00
Little Horsefly River	2010	Small	Clear	2,154	2,117	1.02
Paula Creek	2010	V. Small	Clear	348	384	0.91
Adams River (Lower)	2011	Large	Clear	12,345	16,393	0.75
Chilliwack River (Upper)	2011	Medium	Clear	363	352	1.03
Corbold Creek	2011	Small	Clear	6,050	6,319	0.96
Hazeltine Creek	2011	V. Small	Tannic	36	40	0.90
Horsefly River	2011	Medium	Clear	1,868	2,460	0.76
Pitt River (Upper)	2011	Large	Part. Turbid	15,215	16,510	0.92
Stellako River	2011	Medium	Clear	28,490	29,313	0.97
Wasko Creek (Lower)	2011	V. Small	Clear	50	76	0.66
Chilliwack River (Upper)	2012	Medium	Clear	35,200	40,201	0.88
Chilliwack River (Upper)	2012	Medium	Clear	14,200	14,191	1.00

Continued

Appendix 4. Summary of aerial to ground comparison surveys by specific streams for Fraser Sockeye salmon spawning populations, 2002-2016 (cont'd).

Stream	Year	Stream Size	Water Clarity	Aerial Count	Ground Count	Aerial / Ground Ratio
Corbold Creek	2012	Small	Clear	5,100	5,525	0.92
Horsefly River	2012	Medium	Clear	51	60	0.84
North Boise Creek	2012	V. Small	Part. Turbid	39	41	0.95
Pitt River (Upper)	2012	Large	Part. Turbid	29,706	27,539	1.08
Stellako River	2012	Medium	Clear	52,586	89,325	0.59
Adams River (Lower)	2013	Large	Clear	37,898	65,593	0.58
Corbold Creek	2013	Small	Clear	5,865	6,360	0.92
Kazchek Creek	2013	Small	Clear	680	942	0.72
Kuzkwa River	2013	Medium	Tannic	1,675	1,781	0.94
North Boise Creek	2013	V. Small	Part. Turbid	430	706	0.61
Pitt River (Upper)	2013	Large	Part. Turbid	12,183	16,434	0.74
Stellako River	2013	Medium	Clear	52,530	63,461	0.83
Seymour	2014	Medium	Clear	15,750	16,870	0.93
Adams River (Lower)	2015	Large	Clear	1,110	1,292	0.86
Dust Creek	2015	Small	Tannic	113	163	0.69
Harper Creek	2015	V. Small	Clear	26	28	0.93
Horsefly River	2015	Medium	Clear	7,433	5,864	1.27
Kuzkwa River	2015	Medium	Tannic	180	232	0.78
Little River	2015	X-Large	Clear	78	80	0.98
Stellako River	2015	Medium	Clear	67,218	63,710	1.06
Adams River (Lower)	2016	Large	Clear	15	18	0.83
Dust Creek	2016	Small	Tannic	7	13	0.54
Kazchek Creek	2016	Small	Clear	22	24	0.92
Kuzkwa River	2016	Medium	Tannic	588	591	0.99
Nadina River	2016	Medium	Tannic	2,875	6,201	0.46
Stellako River	2016	Medium	Clear	22,355	21,804	1.03
Summit Creek	2016	V. Small	Clear	16	21	0.76
Harrison River	2016	X-Large	Clear	5,343	1,290	4.14
Nadina River	2016	Medium	Tannic	3,858	6,490	0.59
Chilliwack River (Upper)	2016	Medium	Clear	14,390	19,880	0.72
Chilliwack River (Upper)	2016	Medium	Clear	12,465	17,115	0.73

Overview and objectives

In 2016 Fraser Sockeye Stock Assessment conducted a calibration study in the Chilliwack River system. The study included two SONAR sites (lower Chilliwack River downstream of Chilliwack Lake, and Upper Chilliwack River upstream of the lake) to generate a high precision escapement estimate of Sockeye spawning directly in Chilliwack Lake based on the difference of upstream passage counts at the two SONAR sites. The high precision estimate could then be compared and calibrated to the historical low precision escapement estimate derived solely from the standard carcass recovery effort expansion method that assumes that each survey recovers 5% of the population.

Results

Lower Chilliwack SONAR site

The lower Chilliwack SONAR unit (ARIS) was operated continuously from July 6 to September 8, with recording delineated into 20 minute files. Initial channel width at the SONAR site was reduced to ≈ 17 m through the installation of weir material on both banks. Additional weir material was added to further reduce channel width as water levels decreased over the course of the study. It was necessary to operate the ARIS on the low-resolution setting (as opposed to high resolution), because the ensonified window was greater than 15 m in length.

The estimated net upstream passage of Sockeye past the lower SONAR site was 57,043 (95% CI: 50,152-63,394; ±12%). The relatively broad 95% CI (for a SONAR project) was largely the result of observer error (estimated as the difference between paired observer counts). Observer error was exacerbated by the fact that files had to be recorded at low-resolution, that the route of upstream migrating Sockeye extended across the entire channel, and that substrate size in the ensonified area was quite large. Numbers of Chinook Salmon migrating past the SONAR site increased towards the end of the period of SONAR operation, but the crew were confident that they were able to correctly separate the two species in their counts of the ARIS files based on the generally larger size of the Chinook. Regardless, combined counts of Sockeye and Chinook for the major period of migration overlap were small relative to the total net upstream passage of Sockeye, so any error associated with species misidentification was presumably small.

No high water events occurred in the Chilliwack River during the period of SONAR operation. However, the ARIS unit stopped recording files on two occasions, resulting in missing data for two periods (July 17, 1430 to July 18, 1000; and July 18, 1740 to July 19, 920). Hourly 20 minute counts of Sockeye net upstream passage for these periods were extrapolated based on the average of the hourly net upstream counts for same 20 min period, 24 hours previous to and 24 hours following each hour of missing data. The Sockeye passage total derived from infilling represented 7.5% of total passage.

Upper Chilliwack SONAR site

The upper Chilliwack SONAR (DIDSON) unit was operated continuously from July 20 to September 2, with recording delineated into 20 minute files. The SONAR site was located ≈ 400 m upstream of the river mouth. Initial channel width at the site was reduced to ≈ 8 m through the installation of weir material on both banks. This allowed the DIDSON to be operated at high frequency to optimize image quality.

The estimated net upstream passage of Sockeye past the upper Chilliwack SONAR site was 56,002 (95% CI: 42,613-69,391; ±24%). Based on weekly live count/carcass recovery data, an estimated 1,373 Sockeye spawned in the upper Chilliwack River downstream of the SONAR site. Combining these values, the estimated total escapement to upper Chilliwack River was 57,376 Sockeye. The relatively broad 95% CI (for a SONAR project) was mainly the result of high process error (i.e., hour-to-hour variability in Sockeye passage rate). However, there was also significant observer error, despite the narrow ensonified window and the excellent clarity of the high resolution files. The upper Chilliwack SONAR sites lies within spawning habitat and milling behaviour by Sockeye spawning in the immediate area contributed to observer error.
No high water events occurred in the upper Chilliwack River during the period of SONAR operation. Loss of data due to interruptions in file recording was minimal: the DIDSON stopped recording for 11 hours on Aug 10th, for five hour s on August 16th, and for one hour on August 20th. Interpolated values accounted for only 1.7% of the total upstream passage estimate (935 Sockeye). Net upstream passage was negative after August 28th. Therefore data for August 29-September 2 were excluded from the analysis, based on the assumption that the majority of Sockeye counting moving downstream past the SONAR site were moribund, post-spawners, as opposed to milling pre-spawners.

Calibration of carcass recovery-based escapement estimate for Chilliwack Lake

Seven weekly carcass recovery surveys were completed on Chilliwack Lake from August 17 to September 27 in 2016. A total of 205 Sockeye carcasses were recovered. This total was adjusted downward to 167 carcasses to account for Sockeye that actually spawned in the upper Chilliwack River and then drifted out into the lake (the majority of carcasses recovered in the lake each year are in the vicinity of the river mouth; however, this area also contains known shoreline spawning sites). The adjustment was based on a simple mark-recapture study whereby all Sockeye recovered within the lower 1 km of the river (2,580) where marked with a ‘nose chop’, and the marked carcasses were recorded separately (5 marked carcasses were recovered) during the lake recovery surveys to provide an estimate of the proportion of river-origin carcasses in the lake recovery samples.

The recovery of 167 presumed lake-origin carcasses over seven surveys resulted in a lake spawner population estimate of 556 Sockeye. In addition, an estimated 50 Sockeye spawned in

Depot Creek, a tributary of Chilliwack Lake. This combined total of 606 spawners (Chilliwack Lake and Depot Creek) compares to a high precision estimate of -333 Sockeye for Chilliwack Lake and Depot Creek (difference in net upstream passage between the two SONAR sites). This negative value reflects the substantial uncertainty in the two SONAR estimates (95% confidence intervals for the lower and upper SONAR sites were 50,152 - 63,394, and 42,613 - 69,391 Sockeye, respectively; see above). A 95% confidence interval for the SONAR-derived estimate for Chilliwack Lake + Depot Creek can be obtained by summing the variance for the two SONAR estimates, and taking the square root of this value to obtain the standard deviation. This results in a 95% CI of -15,392 to 14,725 Sockeye, which can be interpreted as there being a 95% probability that the spawning population for Chilliwack Lake + Depot Creek was between 0 – 14,725 Sockeye, which is not very informative. However, if you consider only the mean point estimate for the difference between SONARs (-333 Sockeye), it supports the existing information we have from the carcass survey data (i.e., escapement estimate of 606 Sockeye for Chilliwack Lake + Depot Creek), and also from general observations gained during extensive boat surveys and limited remote underwater video surveys, that suggests that relatively few of the Sockeye returning to the Chilliwack River system spawn in Chilliwack Lake, at least in a year when the return is large relative to other years.