

# Improvements to predicting en-route loss estimates for Fraser sockeye salmon<sup>†</sup>

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<sup>†</sup>The materials in this report represent in-progress research. As such, the contents of this report (unless previously published) are not to be cited without permission of the principal investigators and individual authors.

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## BACKGROUND

The Fraser River sockeye salmon (*Oncorhynchus nerka*) fishery is the largest salmon fishery in Canada. There is a growing body of literature that has linked the negative effects of adverse environmental conditions in the Fraser River on the survival and health of Fraser sockeye salmon populations during their annual upstream migration (Macdonald et al., 2010; Patterson et al., 2016), and this is likely negatively affecting the productivity of those populations. These negative impacts on in-river survival are predicted to worsen and create more variability in spawning escapements and possible returns as climate change progresses (Martins et al., 2011; Hague et al., 2011).

Fraser sockeye salmon populations are managed using four population aggregates, called run-timing groups, based on when they return to the Fraser River in the spawning season: Early Stuart, Early Summer, Summer and Late. Returning Fraser River sockeye salmon experience different thermal histories and exposure to different levels of discharge dependent upon the run timing group and migration path. Although links between adverse river conditions and mortality of migrating sockeye salmon have been identified and quantified (see Johnson et al. 2012 and Patterson et al. 2016 reviews), there is still a great deal of uncertainty in which variables are most important in describing and predicting spawning migration mortality. This issue creates complications for fisheries managers who must allocate sockeye salmon among different stakeholders and make decisions regarding fishery openings and closures.

Currently, no methodology has been developed to directly measure migration mortality due to inherent challenges in estimating mortality in large turbid river systems (Patterson et al., 2007b.). Hence, managers use a discrepancy between lower-river potential spawning escapement (PSE) estimates and up-river spawning ground escapement (SE) estimates as a means to estimate in-river mortality. PSE is defined as the number of salmon that could potentially reach spawning grounds. This value is based on the estimated number of sockeye salmon that past a lower River hydroacoustic counting facility at Mission, B.C., minus the catch estimate between Mission and the spawning grounds. This discrepancy between estimates (DBE) encompasses all potential sources of unaccounted for loss, including errors in catch

estimates, errors in estimating escapement past Mission, error in the spawning escapement estimates, errors in catch estimates (e.g. unreported catch), as well as natural mortality. Managers can forecast DBEs which are then used to adjust harvest levels to attempt to mitigate forecasted loss during spawning migration using models that use environmental data (Macdonald et al. 2010). These adjustments are referred to as “management adjustments” (MAs) and are applied in-season to increase the likelihood that spawning ground escapement targets will be reached. Managers use two types of MA models; descriptive and predictive. Descriptive models are best used for simulations of pre-season scenarios and for post-season run-size adjustments (RSA) while predictive models are used in-season for management purposes.

Previous work on Fraser sockeye management adjustment models has shown that a mean temperature and discharge centered over the date at which 50% of the run-timing group pass through Hell’s Gate are the environmental variables that most accurately describe DBE values for the Early Stuart, Early Summer and Summer run timing groups. The Late run timing group DBE estimates are most accurately described by run timing and not average temperature and discharge. Although MA models have undergone rigorous testing and analysis for their efficacy (Cummings et al., 2011), there have been occasions where these models have failed to accurately predict DBE estimates. In 2013, MA models failed to predict an accurate DBE estimate for the Summer run timing group which resulted in a loss of fishing opportunities for Fraser sockeye. This was major reason for the Southern Endowment Fund (SEF) to prioritize an update and improvements to management adjustment models.

Our first objective is to create a database of stock-specific DBE estimates from 2002 onward when DNA became available for stock identification. This objective has been modified to include years from 1996 to 2001, based on confidence in the scale analysis during those years. The intent of this work is to feed into the other two objectives in an attempt to understand why some stocks survive adverse river conditions while others do not. The information from this database allows us to examine the effect of environmental conditions on DBE estimates at the stock level. The second objective of this research is to update the current management adjustment models and include additional variables in order to improve model fit. To address

the lack of confidence in MA models, we will update the current MA models and assess other environmental variables in an attempt to improve model fit. The third objective was to explore alternative approaches to predicting en-route loss. This last objective has since been modified and is now part of second SEF project that is looking at alternatives methods for estimating en route loss for both in-season and post-season applications.

## CHAPTER 1: STOCK-SPECIFIC EN-ROUTE LOSS INFORMATION

### Data Processing

Significant process has been made with respect to re-analysis of historical stock-specific daily catch (commercial, recreational, First Nations, and test fishery) and Mission passage data. The purpose of the re-analysis was to:

- 1) Apply standard processes to apply stock ID to catches without any associated sample
  - a. E.g. apply stock ID from neighbouring fisheries, “drag down/up” available stock ID from neighbouring days, interpolate stock composition between samples etc.
- 2) Re-analyse 2002-2015 DNA samples using updated DNA baseline information
- 3) Provide finer resolution DNA-based stock ID (from 20 to 50 Fraser sockeye stock groups)
- 4) Standardise assumptions used to combine and weight stock ID samples from downstream and upstream catches to estimate stock-specific Mission passage
  - a. Weightings are applied from marine and in-river stock ID samples on the basis of sample size and preference for in-river samples
- 5) Standardise models and assumptions used to spread catches and stock ID percentages across catches upstream of Mission (where direct stock ID samples are not collected)
  - a. Upstream passage models were refined given the finer stock resolution in DNA years to more accurately reflect stock-specific vulnerability to in-river catches as stocks leave the mainstem and enter terminal spawning areas (i.e. no longer available for catch).

Timelines vary slightly from those originally proposed, as it was more efficient to address data processing in temporal blocks rather than by management group (i.e. process data for all management groups for a given year at once, rather than all years for a given management group). Data processing has occurred in three major steps, depending on the historical nature of the data:

- 1) 1996-2002 (scale-based identification)
- 2) 2003-2008 (early DNA years)
- 3) 2009-2015 (recent DNA years)

### 1996 – 2002

Although not part of the original proposal, we were able to finalise scale-based stock ID and age classification from 1996-onwards and apply it to all fishery catches, Mission passage estimates, spawning escapements, and run size adjustments (RSAs). Scale-based years required a separate data processing step because (1) scale-based stock ID groupings are on a coarser resolution than in DNA years, (2) data was historically organised in a different way, and (3) age data can be automatically assigned in the same step because the source for stock ID and age are one and the same.

Catch and racial data were re-entered into standardised templates and rules were created for applying stock ID/age to catches and passage estimates for which direct samples were not collected. A translation table was used to map individual spawning streams to each scale-based stock group. Annual spawning ground proportions were then applied to the scale-based stock ID groups to further partition the daily catch and passage estimates to the resolution of DFO spawning stream (i.e. the finest resolution possible). Direct stock ID/age samples are not available for catches above Mission. Therefore, an upstream passage model was developed which adjusted stock proportions in discrete river reaches as catches were removed and stocks “escape” into terminal areas and are removed from upstream passage calculations.

Error checks were performed throughout the modelling process and data was compiled into database-ready formats at the resolution of daily catch and passage, and annual spawning escapement by-stream-by-age.

### 2003-2008

Work on these DNA-based years required reformatting of historical genotype files and the re-analysis of DNA samples using updated baselines (as completed for 2009-2015). Data preparation required additional steps compared to the 2009-2015 years as historical catch and racial data was not managed in the same way, necessitating additional processing stages. Catch

and Mission passage by stock information for 2003-2008 have now been added with the exception of 2007.

### 2009-2015

Originally, catch and Mission passage by stock were stored in catch and racial files managed by the Pacific Salmon Commission (Ian Guthrie) at the resolution of approximately 20 DNA-based stock groups. However, there was variation in these stock group assignments from year to year and DNA baselines have changed over time, resulting in current improvements to classification and resolution of Fraser sockeye stocks.

With assistance from DFO staff at the Pacific Biological Station, original DNA files were re-analysed using current baselines from 2009-2012. All years were updated to provide an updated resolution of 50 Fraser sockeye stock groups and 37 non-Fraser components. New catch and racial template files were created for storing data at this improved resolution and to compile outputs in a database ready format. Visual basic code was developed to facilitate more efficient data entry and error checking processes.

An extensive error-checking process was used to ensure any differences between the historical 20-group catch and racial files and the updated files were only a function of updated stock ID and/or updated modelling assumptions for Mission passage and upstream catches.

All data processing for this time period is complete up until 2015.

### Database Development

The PSC employed the services of database expert Kent Collens to develop a new the Run Size, Fishery and Escapement (RuFEs) database (Figure 1). This database is designed to hold catch, Mission passage, and spawning escapement data at the finest stock resolution possible (DFO spawning stream), by age, by sex. For the purpose of the current SEF project, priority has been placed on first resolving records at the stock ID level only. Given the large number of data records, the database structure uses a SQL Server “back end” to hold the data, and a Microsoft Access “front end” for the end-user.

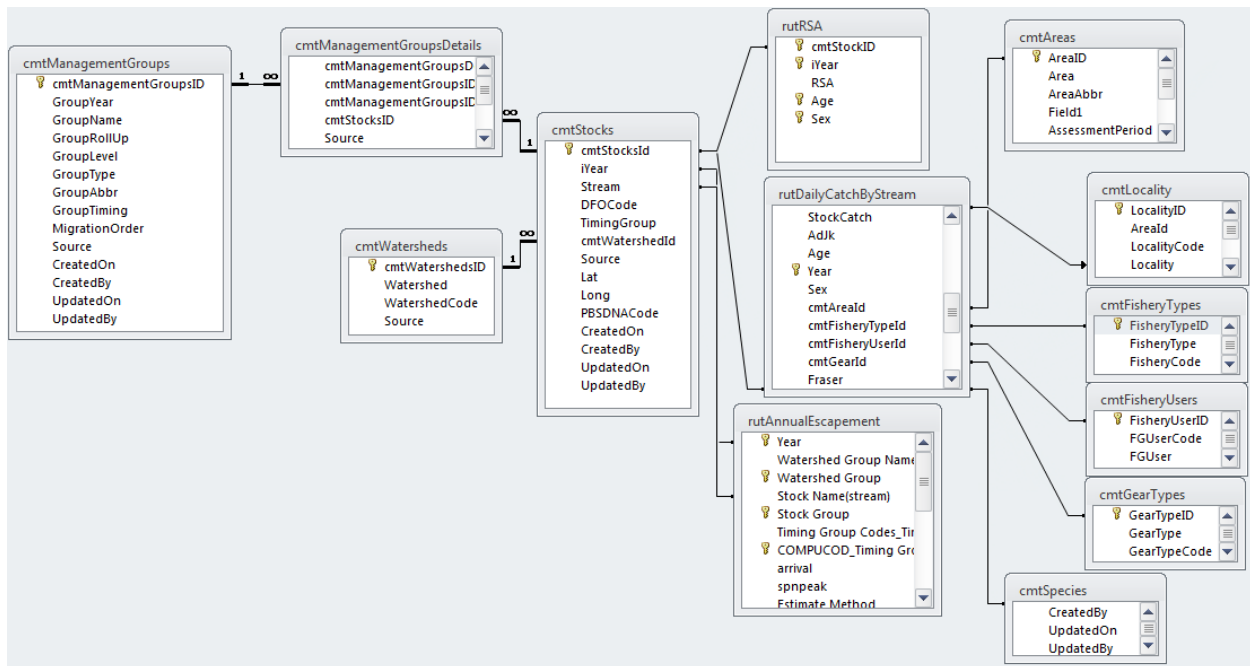


Figure 1. The current database schematic for the Run-Size, Fishery, and Escapement (RuFEs) database. The schematic is designed to house all the historical daily catch proportioned down to the finest resolution possible (DFO Stock), as well as the Mission Passage numbers, annual ESSR, RSA, and Spawning Escapement data. This layout also displays the Management Group table schematic responsible for creating multiple dynamic roll-ups as required by the user, allowing stocks to be aggregated at various levels of granularity. Note: a full accompanying database dictionary and list of field descriptions will be produced upon completion of the final SEF report

Several processes are currently built into the RuFEs structure:

### 1) Export-Transform-Load (ETL)

Data from the DFO spawning escapement data base, PSC catch and racial files from DNA years and PSC catch and racial files from scale-based years are extracted from original Excel files, normalised into the database-ready format and uploaded into standardised tables on the SQL server.

### 2) Calculation of spawning stream resolution

Originally, data was going to remain at the resolution available from the scale-based or DNA-based analysis. However, to facilitate the ability to aggregate catch and passage information for stocks across years and with the greatest flexibility, an additional data

processing step was added which further partitions the racial data to the level of DFO spawning stream on the basis of spawning escapement proportions. For scale-years, data was entered into RuFEs at the resolution of DFO spawning stream (i.e. this data processing step occurred externally during the data preparation process). For DNA years, the database uses a series of relational tables mapping spawning stream escapements to DNA stock ID groups in order to more finely resolve catch and passage data to the stream level based on the 50 Fraser sockeye stocks in the updated catch and racial files. While RuFEs holds daily estimates at the resolution of spawning stream, given the assumptions involved (particularly for small components of the run), the catch and racial data is only intended to be exported at some higher level of stock-aggregation. Again, because the original resolution for the scale-based years is coarser than for the DNA-years, finer-scale stock aggregations will be of variable quality moving through time.

### 3) Stock aggregation “roll-ups”

The same stock ID relational tables are also used to “map” escapement streams to varying scales of stock aggregation – including management groups (Early Stuart, Early Summer, Summer, Lates), DFO watersheds, productivity aggregations used for forecasting and RSA calculations, or any customisable “roll-up” developed by the end-user. The ability to re-aggregate the catch and racial data in this manner is the most powerful feature of the database and provides the flexibility to easily adjust if stocks are re-assigned to different groups over time, or to explore the sensitivity of model assumptions to different stock classifications. The ability to re-aggregate the data at any level was the main impetus for storing the information at the finest resolution possible on the basis of the spawning ground proportions.

### 4) MA-specific database queries

Once data has been re-aggregated to the appropriate stock-grouping, custom queries are then used to generate output required for fitting management adjustment models: Mission passage,

spawning escapement, catches upstream of Mission, and Mission 50% date (date at which 50% of a group has been enumerated at the Mission hydroacoustic facility). These outputs will also be used to calculate the annual “Difference Between Estimates”.

## CHAPTER 2: UPDATES TO CURRENT MANAGEMENT ADJUSTMENT MODELS

### *INTRODUCTION*

Management adjustment models have been used since the mid-1990's to adjust for adverse environmental conditions (Macdonald 2000; Macdonald et al. 2000). Since their development and implementation they have been evaluated to be an effective way of managing Fraser sockeye to adjust for losses based on information up until 2007 (Macdonald et al., 2010; Cummings et al., 2011). Recently, there is a lack of confidence in the efficacy of these methods due to large differences between the discrepancies predicted by management adjustment models and what was actually observed post season. This necessitated a re-evaluation of model performance and an update to current management adjustment models to determine if other explanatory variables can improve descriptive model fit and subsequent predictive model capabilities.

Current MA models use mean lower river temperature and discharge measured on the Fraser River near Hope, B.C. and centered over run timing through Hell's Gate for each run timing group. While this has been demonstrated to be effective in the past, downstream environmental variables fail to capture the full exposure to adverse conditions that a stock or group of stocks experience in their migration. Hague and Patterson (2008) demonstrated that water temperatures throughout the Fraser watershed are correlated during the summer but that correlation decreases with increasing distance from Hope. This suggests that for stocks that undertake a longer migration, upstream temperatures closer to their spawning grounds may more accurately predict DBE. Additionally, smaller tributaries of the Fraser are more likely to exceed thermal tolerances of migrating sockeye salmon; especially in the Thompson system where summer water temperatures are consistently warm. Discharge is largely viewed as being problematic for Early Stuart and Early Summer run timing groups based on historic observations (e.g. Macdonald 2000), but it has been included in the Summer run timing group descriptive MA model. Recent work by Stiff et al. (2017) suggests that there may actually be a negative effect of discharge in the Chilcotin River and Quesnel River for those respective Summer run

stocks. Stiff suggests that discharge levels that exceed 260 cms in the Chilcotin River and 340 cms in the Quesnel River negatively impact sockeye migration rates.

Different stocks of Fraser sockeye are currently managed together in run timing groups based on the timing of their marine exit, reflective of vulnerability to marine and lower River commercial fisheries. However, research has demonstrated that different stocks exhibit different tolerances to environmental conditions that are outside of their optimal range (e.g. Chilko higher thermal tolerance - See Eliason et al., 2011). This research, in conjunction with the stock specific DBE database from Chapter 1, provide a rationale for exploring the utility of looking at stock specific MA models. Similarly, there could be consistent biases in any of the factors that contribute to DBE uncertainty that are stock-specific, such as spawning escapement estimates, catch estimates, or behaviour past Mission. If these population specific traits exists, disaggregating the DBE into stock-specific components could conceivable aid in reducing the overall error in DBE estimates. This requires examining how the proportion of key stocks of interest influence descriptive MA model fit to determine which stocks may be driving the relationships we observe at the run timing group level.

In odd years, adult pink salmon co-migrate with the Summer and Late run Fraser sockeye and can confound assessment estimates at Mission. If the estimates of run size in the lower river are affected by pink abundances, the in-season predicted DBE estimate could result in a bias in potential spawning escapement values. The impact of whether or not it is a pink salmon year or not has not yet been tested for descriptive MA models. Although other species such as Thompson Chinook or early timed chum may impact estimates at Mission, pink salmon are most likely to impact this assessment. Updating the current management adjustment models to determine if the top models for describing and predicting DBEs have or have not changed is important for ensuring that managers have the best available information to make the most informed decision possible.

## *METHODS AND RESULTS*

### *Data Sources*

The data tested for updating and improving management adjustment models is a time series of PSE and SE estimates, and in-river temperature and discharge for each run timing group from 1977 to 2016 (Appendix A). Previous work by Macdonald et al. (2010) examined years from 1977 to 2006. Lower river estimates of PSE are generated from the Mission hydroacoustic facility while estimates of SE are obtained through several survey methods on natal spawning streams. Additionally, we receive a similar time series dataset for the stock-specific information generated in Chapter 1 with additional variables of catch information at the stock level for marine catches, and freshwater catches both above and below Mission from 1996 to 2014 and excluding 2007. River temperature and discharge information was taken from the Water Survey of Canada online database (Environment Canada 2017) and temperatures at Fort St. James, Qualark and Ashcroft were taken from the DFO Environmental Watch Program.

### *Guidelines for Excluding Years*

Currently MA models do not include stock-specific information in spite of known differences in tolerances to adverse environmental conditions due to the lack of stock specific data. In an attempt to mitigate this lack of stock specific information, reducing the number of years for predicting DBE's based on expected stock composition is often used (e.g using Scotch-Seymour dom/sub-dom historic DBE to predict DBE dom/sub-dom years). Additionally, some years of data are often excluded based on decision guidelines outlined in Appendix B (as determined by Pacific Salmon Commission staff). Although, there is often a reasonable rationale for excluding a year of data, it is important to consider whether or not the reason for the exclusion will happen again in the future. For example, 2015 and 2016 are excluded for Early Stuart predictive and descriptive MA models because of a low sockeye abundance relative to Chinook in the early part of their migration (Appendix B). The Early Stuart run timing group has been in decline so it may be unreasonable to exclude these years for this issue as it is probable that this will occur in the future. Altering the years that are included or excluded from predictive and descriptive MA models can additionally influence the model fit (Table 1). While the model fit

for the Early Summer, Summer and Late run timing groups did not change more than 2-3%, the model fit for the Early Stuart run timing group improved by 10% with the new exclusion rules. Although model fit improved for the Early Stuart run timing group, the new exclusion rules as of 2017 exclude both historically hot years of 2015 and 2016.

Table 1. Adjusted R<sup>2</sup> and top models for the 31- day descriptive management adjustments (MA) chosen by AICc for the four Fraser sockeye run-timing groups using all years of data, the old exclusion rules and the new exclusion rules set out by the Pacific Salmon Commission. n is the number of years included in the analysis

<b>Run Timing Group</b>	<b>Exclusion</b>	<b>Variables in Top Model</b>	<b>Adj R<sup>2</sup></b>	<b>n</b>
<b>Estu</b>	All Years	Q + Q2 + T + T2	0.46	40
	Old Exclusion	Q + T + T2	0.48	34
	New Exclusion	Q + T + T2	0.58	31
<b>Esum</b>	All Years	T + T2	0.11	40
	Old Exclusion	Q + Q2 + T	0.27	39
	New Exclusion	Q + Q2 + T	0.24	38
<b>Sum</b>	All Years	T + T2	0.31	40
	Old Exclusion	T + T2	0.32	39
	New Exclusion	T + T2	0.34	38
<b>Lates</b>	All Years	R + N + Q + Q2	0.72	40
	Old Exclusion	R + Q + Q2	0.86	25
	New Exclusion	R + Q + Q2	0.86	25

Changing which years are excluded can also impact our ability to test effects of other explanatory variables on descriptive and predictive MA models. We tested the effect of an upstream weighted average temperature at Fort St. James for the Early Stuart's using the old

exclusion and the new exclusion rules. The inclusion of the weighted average temperature parameter improved the descriptive MA model  $R^2$  fit by approximately 3% under the old exclusion rules while the weighted average temperature at Fort St. James was not included in the top model under the new exclusion rules. This may be driven by the fact that 2015 and 2016 are both hot years which are no longer included in the analysis under the new exclusion rules.

### Updates to Current MA Models

We followed a similar methodology to Macdonald et al. (2010) for updating the current MA models and testing the effect of additional environmental variables on the descriptive management adjustment models using the new exclusion criteria outlined by the PSC (see Appendix A).

Descriptive and predictive management adjustment models use multiple linear regression to describe the relationship between loss and environmental variables observed in season:

$$(1) \quad \ln(SE/PSE) \sim T + T^2 + Q + Q^2 + N + R$$

where  $\ln(SE/PSE)$  is the measurement of the response to environmental effects by each run timing group,  $T$  is the 31 day or 19 day centered mean temperature at Hell's Gate,  $T^2$  is the quadratic of the mean temperature variable,  $Q$  is the 31 day or 19 day centered mean discharge at Hell's Gate,  $Q^2$  is the quadratic of the discharge variable,  $N$  is the potential spawning escapement estimated at Mission, and  $R$  is the date at which 50% of the run has migrated through Hell's Gate. The log transformation of the loss variable is necessary to meet assumptions of homoscedasticity required for linear modelling. AICc is then used to determine the most parsimonious model to represent the relationship between our predictor variables and loss for each run timing group. We use this same model form but add additional predictor variables to determine if the inclusion of the new variables increases the adjusted  $R^2$  of the model and if the new variable is included in the top model chosen by AICc. This same methodology was used for assessing descriptive model fit for the stock specific DBE data.

The first step to improving the current MA models was to update the current dataset to include more recent years (2007-2014) and compare the fit of the models using the historic dataset (1977-2006) to the complete dataset (1977-2014). This modeling exercise used the four management groups currently used for the MA models. The systematic procedure (model coded in R) to evaluate the utility of most variables (continuous) in both describing and predicting MAs for specific management groups and key stocks, similar to methods used by Macdonald et al. (2010) and Cummings et al. (2011). We have validated the model structure and have begun updating the current models with new post-2006 information. The evaluation tested whether there have been major changes in both the utility of the current MA models and in the selection of key variables for the models. This was completed for both descriptive (31-day information) and predictive models (19-day). We found that there were slight changes in R-squared values between models that included more recent data (1977-2014) when compared to historical datasets (1977-2006). This work now provides a solid basis to both evaluate new variables as well as alternative methods. The detailed model results of these evaluations are presented below. The main results of comparing the model results from 2006 to 2014 per running group are as follows:

**Early Stuart** – Model performance has increased, especially for predictive models. Top models still rely on combinations of temperature and flow (Table 2 and 3).

**Early Summer** – No change in overall model performance or in the variable selection (Table 4 and 5).

**Summer** – Decline in model performance (less variance explained by the models now), similar reliance of quadratic temperature metrics. However, there is still a significant benefit of including environmental variables than having no model or an historic loss model (Table 6 and 7).

**Lates** – Model performance is still high for late run stocks, but overall still limited by the requirement for accurate forecasts of run timing (Table 8 and 9).

Table 2. Comparison of top descriptive management adjustment model for the Early Stuart run timing group with the updated data (blue) compared to the previously tested top model (grey) selected by AICc

<b>Early Stuart descriptive models</b>						
Model No.	Model	df	DeltaAIC	Weight	Adj_R2	2006 Adj_R2
1	Q +T +T2	5	0	0.43	<b>54</b>	NA
2	N +Q +T +T2	6	2.45	0.13	53	NA
3	R +Q +T +T2	6	2.78	0.11	52	NA
4	Q +Q2 +T +T2	6	2.94	0.10	52	42
5	T +T2	4	3.91	0.06	45	31
6	R +N +Q +T +T2	7	4.93	0.04	52	NA
7	R +T +T2	5	5.27	0.03	45	30
8	R +Q +Q2 +T +T2	7	5.74	0.02	51	40
9	N +Q +Q2 +T +T2	7	5.74	0.02	51	42
10	N +T +T2	5	6.67	0.02	43	32
11	Q +Q2 +T	5	6.86	0.01	43	NA
12	N +Q +Q2 +T	6	7.57	0.01	45	NA
13	R +N +T +T2	6	7.60	0.01	45	9
14	R +N +Q +Q2 +T +T2	8	8.33	0.01	51	38
15	R +Q +Q2 +T	6	9.85	0.01	41	NA

Table 3 Comparison of top predictive management adjustment model for the Early Stuart run timing group with the updated data (blue) compared to the previously tested top model (grey) selected by AICc

### Early Stuart predictive models

Model No.	Model	df	DeltaAIC	Weight	Adj_R2	2006 Adj_R2
1	Q +T +T2	5	0.00	0.41	<b>43</b>	NA
2	T +T2	4	1.59	0.19	37	<b>15</b>
3	R +Q +T +T2	6	2.57	0.11	42	NA
4	R +T +T2	5	2.65	0.11	39	14
5	Q +Q2 +T +T2	6	3.05	0.09	41	13
6	Q +Q2 +T	5	5.76	0.02	32	NA
7	R +Q +Q2 +T +T2	7	5.81	0.02	40	9
8	Q +Q2	4	5.81	0.02	29	6
9	R +Q +Q2	5	7.95	0.01	28	3
10	R +Q +Q2 +T	6	8.81	0.01	30	NA

Table 4. Comparison of top descriptive management adjustment model for the Early Summer run timing group with the updated data (blue) compared to the previously tested top model (grey) selected by AICc

### Early Summer descriptive models

Top updated model    Top 2006 models

Model No.	Model	df	DeltaAIC	Weight	Adj_R2	2006 Adj_R2
1	Q +Q2 +T	5	0	0.273	<b>24</b>	NA
2	Q +Q2 +T +T2	6	1.469	0.131	25	<b>27</b>
3	N +Q +Q2 +T	6	2.425	0.081	23	NA
4	R +Q +Q2 +T	6	2.709	0.071	22	NA
5	T	3	3.196	0.055	10	NA
6	T +T2	4	3.288	0.053	13	17
7	Q +Q2	4	4.22	0.033	11	
8	R +Q +Q2 +T +T2	7	4.289	0.032	23	24
9	N +Q +Q2 +T +T2	7	4.316	0.032	23	29
10	Q +T	4	4.807	0.025	10	
11	R +N +Q +Q2 +T	7	5.247	0.02	21	25
12	R +T +T2	5	5.534	0.017	12	
13	R +T	4	5.61	0.017	8	
14	Q +T +T2	5	5.646	0.016	12	
15	N +T	4	5.66	0.016	8	

Table 5 Comparison of top predictive management adjustment model for the Early Summer run timing group with the updated data (blue) compared to the previously tested top model (grey) selected by AICc

### Early Summer predictive models

Top updated model    Top 2006 models

Model No.	Model	df	DeltaAIC	Weight	Adj_R2	2006 Adj_R2
1	Q +Q2 +T	5	0.00	0.41	<b>24</b>	NA
2	Q +Q2 +T +T2	6	2.56	0.11	22	<b>17</b>
3	R +Q +Q2 +T	6	2.84	0.10	21	NA
4	Q +Q2	4	3.27	0.08	13	10
5	T	3	3.82	0.06	8	NA
6	Q +T	4	4.51	0.04	10	NA
7	T +T2	4	4.86	0.04	9	6
8	Null	2	5.59	0.03	0	NA
9	R +Q +Q2 +T +T2	7	5.63	0.02	19	13
10	R +Q +Q2	5	5.73	0.02	11	7

Table 6. Comparison of top descriptive management adjustment model for the Summer run timing group with the updated data (blue) compared to the previously tested top model (grey) selected by AICc

<b>Summer descriptive models</b>						
Top updated model						Top 2006 models
Model No.	Model	df	DeltaAIC	Weight	Adj_R2	2006 Adj_R2
1	T +T2	4	0.00	0.33	<b>35</b>	56
2	Q +T +T2	5	1.95	0.13	35	NA
3	Q +Q2 +T +T2	6	2.33	0.10	37	53
4	N +T +T2	5	2.48	0.10	34	54
5	R +T +T2	5	2.59	0.09	33	<b>55</b>
6	R +Q +Q2 +T +T2	7	4.63	0.03	36	53
7	R +Q +T +T2	6	4.78	0.03	33	NA
8	N +Q +T +T2	6	4.78	0.03	33	NA
9	T	3	5.02	0.03	23	NA
10	R +N +T +T2	6	5.34	0.02	32	53
11	N +Q +Q2 +T +T2	7	5.40	0.02	35	52
12	Q +Q2 +T	5	6.04	0.02	27	NA
13	Q +T	4	6.46	0.01	23	NA
14	N +T	4	7.14	0.01	21	NA
15	R +T	4	7.15	0.01	21	NA

Table 7. Comparison of top predictive management adjustment model for the Summer run timing group with the updated data (blue) compared to the previously tested top model (grey) selected by AICc

<b>Summer predictive models</b>						
Top updated model						Top 2006 models
Model No.	Model	df	DeltaAIC	Weight	Adj_R2	2006 Adj_R2
1	T	3	0.00	0.24	<b>23</b>	NA
2	T +T2	4	1.25	0.13	23	<b>40</b>
3	Q +Q2 +T	5	1.35	0.12	26	NA
4	R +Q +Q2 +T	6	1.53	0.11	29	NA
5	Q +T	4	1.95	0.09	22	NA
6	R +T	4	2.31	0.07	21	NA
7	Q +Q2 +T +T2	6	3.13	0.05	26	37
8	Q +T +T2	5	3.41	0.04	22	NA
9	R +T +T2	5	3.80	0.04	21	38
10	R +Q +T	5	3.81	0.04	21	NA
11	R +Q +Q2 +T +T2	7	3.89	0.03	28	35

Table 8. Comparison of top descriptive management adjustment model for the Late run timing group with the updated data (blue) compared to the previously tested top model (grey) selected by AICc

<b>Late descriptive models</b>							Top updated model	Top 2006 models
Model No.	Model	df	DeltaAIC	Weight	Adj R2	2006 Adj R2		
1	R +Q +Q2	5	0.00	0.65	<b>89</b>	<b>90</b>		
2	R +Q +Q2 +T	6	3.41	0.12	88	NA		
3	R +N +Q +Q2	6	3.44	0.12	88	89		
4	R +Q +Q2 +T +T2	7	5.87	0.03	89	88		
5	Q +Q2 +T	5	6.81	0.02	85	NA		
6	R +N +Q +Q2 +T	7	6.99	0.02	88	NA		
7	R +Q	4	7.43	0.02	82	NA		
8	Q +Q2 +T +T2	6	8.48	0.01	85	85		
9	R +N +Q +Q2 +T +T2	8	9.95	0.00	88	87		
10	N +Q +Q2 +T	6	10.32	0.00	84	NA		
11	R +Q +T	5	10.69	0.00	82	NA		
12	R +N +Q	5	10.82	0.00	81	NA		
13	N +Q +Q2 +T +T2	7	12.43	0.00	85	82		
14	Q +T	4	12.78	0.00	78	NA		
15	R +T	4	13.40	0.00	77	NA		

Table 9. Comparison of top predictive management adjustment model for the Late run timing group with the updated data (blue) compared to the previously tested top model (grey) selected by AICc

<b>Late predictive models</b>							Top updated model	Top 2006 models
Model No.	Model	df	Delta	Weight	Adj R2	2006 Adj R2		
1	R +Q +Q2	5	0.00	0.42	<b>84</b>	<b>88</b>		
2	R +Q	4	0.51	0.33	82	NA		
3	R +Q +Q2 +T	6	3.40	0.08	83	NA		
4	R +Q +T	5	3.42	0.08	81	NA		
5	R +T	4	5.09	0.03	78	NA		
6	R	3	6.95	0.01	73	NA		
7	R +Q +T +T2	6	7.05	0.01	80	NA		
8	R +Q +Q2 +T +T2	7	7.67	0.01	82	88		
9	Q +Q2 +T	5	7.89	0.01	77	NA		
10	Q +T	4	7.98	0.01	74	NA		
11	R +T +T2	5	8.42	0.01	76	71		
12	Q +T +T2	5	11.32	0.00	73	NA		
13	Q +Q2 +T +T2	6	11.73	0.00	76	86		
14	Q	3	16.03	0.00	60	NA		
15	Q +Q2	4	16.32	0.00	63	73		

## Biological Rationale for Predictor Variables

Table 10. Set of new predictor variables considered for improving and updating the descriptive management adjustment models for each major Fraser River sockeye salmon run timing group

Variable	Description	Justification
$T_{FSJ}$	Mean temperature at Fort St. James (FSJ) centered over a 31-d period surrounding the date 50% date past Mission lagged for migration timing up to FSJ	FSJ is the temperature station furthest from the currently used Qualark and is most likely to improve descriptive MA model fit for the Early Stuart run timing group
$T_A$	Mean temperature at Ashcroft centered over a 31-d period surrounding the 50% date past Mission lagged for migration timing to Ashcroft	Ashcroft is typically one of the hottest locations in the Fraser watershed throughout the sockeye migration and is most likely to improve descriptive MA model fit for stocks migrating through the Thompson system
$Q_Q$	Mean discharge in the Quesnel River at Quesnel centered over a 31-d period surrounding the 50% date past Mission lagged for migration timing to Quesnel	Stiff et al., 2017 determined that discharge levels greater than 340 cms negatively impacted sockeye migration
$Q_C$	Mean discharge in the Chilcotin River at Big Creek centered over a 31-d period surrounding the 50% date past Mission lagged for migration timing to Big Creek	Stiff et al., 2017 determined that discharge levels greater than 260 cms negatively impacted sockeye migration
$P$	Whether or not it is a pink salmon run year or not, 0 for no and 1 for yes	Pink salmon migrate at the same time as many sockeye stocks and can confound estimates at Mission
$P_A$	Pink abundance relative to the abundance of the entire run-timing group	Pink salmon migrate at the same time as many sockeye stocks and can confound estimates at Mission
$p_{Cw}$	Proportion of Chilliwack relative to Early Stuart	While the Chilliwack and Early Stuart stocks are not typically combined together, Chilliwack has more run timing overlap with Early Stuart than with the Early Summer run timing group
$p_{SS}$	Proportion of Scotch- Seymour relative to the Early Summer run timing group	This is the most abundant stock group within this run timing group
$p_{Ck}$	Proportion of Chilko relative to the Summer run timing group	Chilko sockeye are more resilient to adverse temperatures and are therefore less likely to be impacted negatively by environmental factors

pW

Proportion of Weaver relative to the Late run timing group

Weaver tends to have high losses and has historically been combined with the late run timing group

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We tested the effect of mean 31 and 19-day centered temperature in the Stuart River at Fort St. James on the DBE of the Early Stuart run timing group for the years of 1995 - 2016. We centered the temperatures based on an estimated arrival at Fort St. James of 18 days from Mission. This date was generated from migration rates estimated from telemetry analysis (Eduardo Martins unpublished Data, UNBC) over the in-river distance between Mission and Fort St. James. This location is also the furthest up-river from the Qualark temperature site and has the lowest correlation between sites (Hague and Patterson, 2008). We also tested the effect of mean 31 and 19- day centered temperature in the Thompson River at Ashcroft for the years of 1995 – 2015 because Ashcroft and Chase are often the warmest temperatures in the watershed. Ashcroft was used instead of Chase because the dataset was more complete and sockeye stocks that migrate to tributaries of the North Thompson also pass through this location. The 50% date through Ashcroft was calculated as the 50% date through Mission lagged by 6 days forward. We also tested the effect of mean 31 and 19- day centered discharge at the Chilcotin River at Big Creek (lagged by 10 days from Mission) and Quesnel River at Quesnel (lagged by 14 days from Mission) based on research suggesting that sockeye migration rates were negatively impacted by high discharge at these locations (Stiff et al., 2017a and b).

Pink salmon confound estimates from the hydroacoustic system at Mission when they co-migrate with sockeye (Xie et al. 2002). Including whether or not it is a pink year in the descriptive management adjustment models we can determine if the errors in estimation of PSE due to pink salmon are impacting MA model DBE estimates. Including the abundance of pink salmon relative to each run timing group will also help to determine if it is only large pink returns that result in assessment problems.

Run-timing groups are comprised of several smaller stocks of sockeye that co-migrate up the Fraser River. These stocks have different tolerances to suboptimal environmental conditions and have different abundance levels. This results in a few stocks driving the observed DBE

relationships. By determining the impact of the proportion and abundance of these key stocks within each run timing group we can attempt to account for this issue in the future. The proportion of Chilliwack sockeye relative to Early Stuart was chosen to test because there is more of a migratory overlap between Chilliwack and Early Stuart than there is with the Chilliwack and Early Summer run timing group. Scotch-Seymour was chosen to test against the Early Summer due to the extreme fluctuations in abundance of these populations. Chilko sockeye was chosen to test against the Summer run timing group due to their high thermal tolerance relative to other stocks and high overall abundance. The proportion of Weaver was chosen to test against the Late run timing group because it has high en-route loss and is the major late run stock in non-Late Shuswap years.

### Stock-Specific Information

We tested the full suite of descriptive environmental MA models for each stock using the DBE, Mission estimates and spawning escapement estimates generated by the PSC and used AICc model selection to determine the best fit descriptive model for each stock. However, a null model for many stocks was chosen as the top model. The top models that were generated for individual stocks are similar in model fit ( $R^2$  values) and the environmental variables included in the top models to the top models for the respective run timing groups.

Table 11. Environmental variables included in the top model for stock specific DBE information for the stocks that produced a descriptive model where T is temperature, Q is discharge, N is run size, R is run timing and T2 and Q2 are the temperature and discharge quadratic term. Top models were selected using AICc

Stock	Top Model	$R^2$
Chilko	T + N	0.34
Chilliwack	Q + Q2 + T + N	0.64
Cultus	T + T2 + N	0.39
Early Stuart	Q + T + T2	0.55
Horsefly	R	0.13
Late Shuswap	R + Q + Q2	0.83

This suggests that certain stocks are driving the relationships for the run timing groups. With the exception of the Early Stuart run timing group (Figure 1), we can see directly that certain stocks are driving the patterns in loss. Examining the relationship between  $\ln(\text{PSE})$  and  $\ln(\text{SE})$  reveals that we frequently over predict the number of returning sockeye as many of the points lie below the 1:1 line (Figure 1, 2, 3 and 4). However, there are several instances where more salmon returned than we predicted which is indicative in assessment issues.

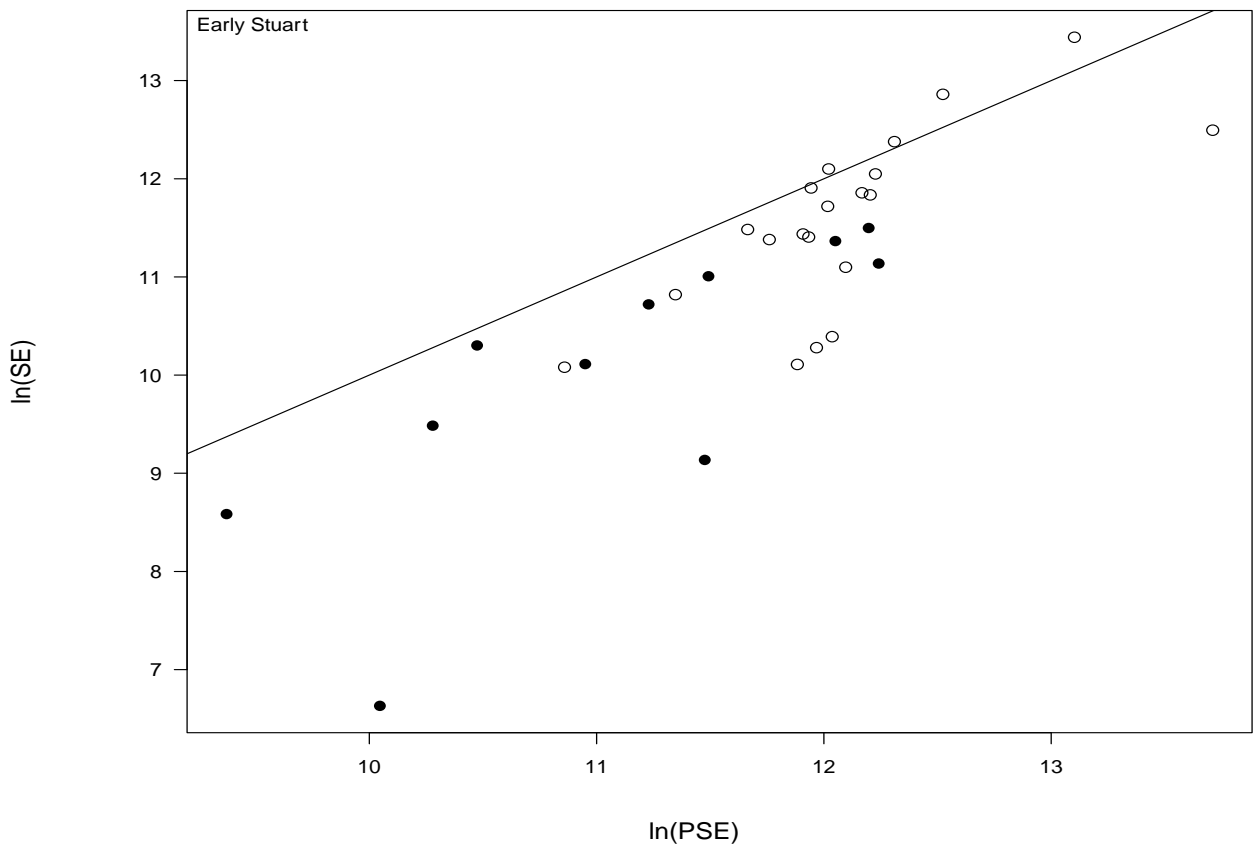


Figure 2.  $\ln(\text{SE})$  by  $\ln(\text{PSE})$  for the Early Stuart run timing group for 1996 – 2016 and excluding 2007. Black dots are years after 2002 where DNA analysis became available for stock identification.  $\ln(10)$  is 22,000 fish and  $\ln(13)$  is 440,000 fish.

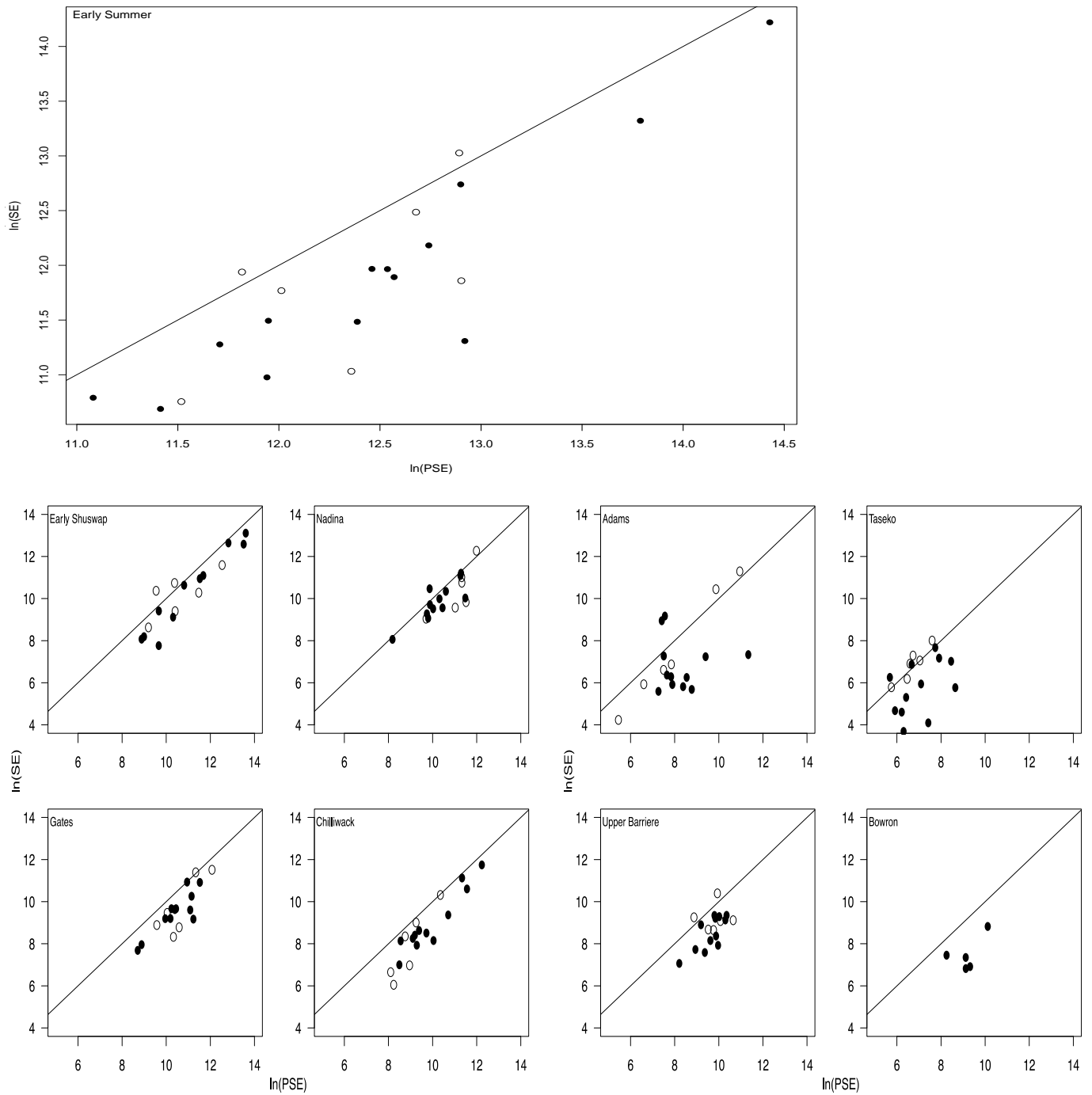


Figure 3.  $\ln(\text{SE})$  by  $\ln(\text{PSE})$  for the Early Summer run timing group as a whole and eight stocks (Gates, Chilliwack, Early Shuswap, Nadina, Adams, Upper Barriere, Taseko and Bowron) that are a part of this run timing group for 1996 – 2015 and excluding 2007. Black dots indicate years 2002 and later when DNA became available for stock identification.  $\ln(14)$  is 1.2 million fish and  $\ln(4)$  is 55 fish.

In the Early Summer run timing group, there is a clear trend of over-predicting the number of returning sockeye (Figure 3) but there are some years where more sockeye returned than predicted. The pattern in the data for the Early Summer run timing group as a whole is very similar to the observed pattern in the Early Shuswap stock suggesting that this relationship is largely driven by this particular stock.

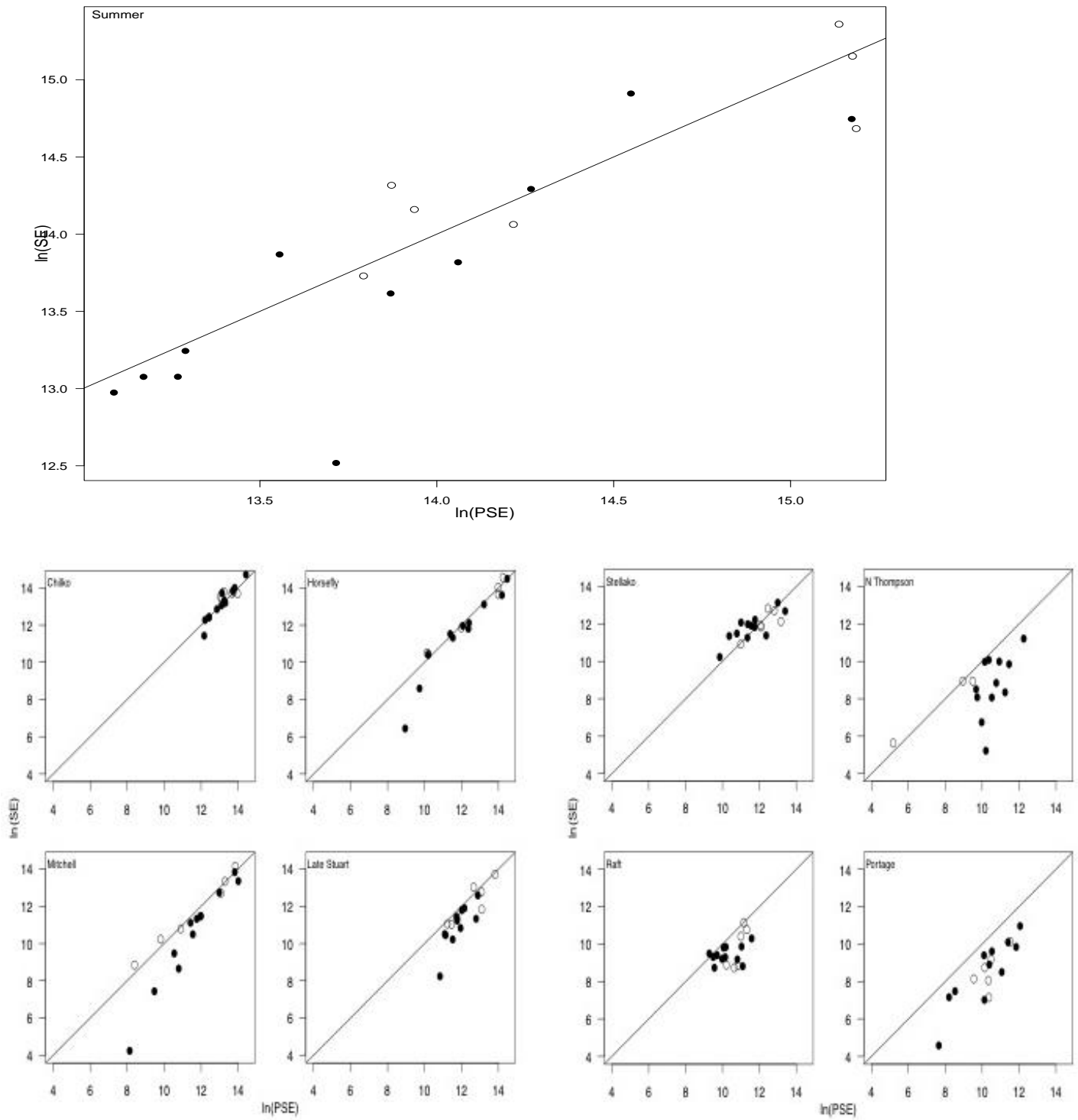


Figure 4.  $\ln(\text{SE})$  by  $\ln(\text{PSE})$  for the Summer run timing group as a whole and four stocks (Chilko, Horsefly, Early Mitchell, Late Stuart, Stellako, North Thompson, Raft and Portage) that are a part of this run timing group for 1996 – 2015 and excluding 2007. Black dots indicate years 2002 and later when DNA became available for stock identification.  $\ln(4)$  is 55 fish and  $\ln(15)$  is 3.3 million fish

The relationship between downstream potential spawning escapement estimates and upstream spawning ground escapement estimates for the summer run timing group appears to be largely driven by Chilko sockeye (Figure 4). Chilko sockeye are frequently underestimated downstream with much of the data being above the 1:1 line while Horsefly, Mitchell and Late Stuart are often over-estimated downstream.

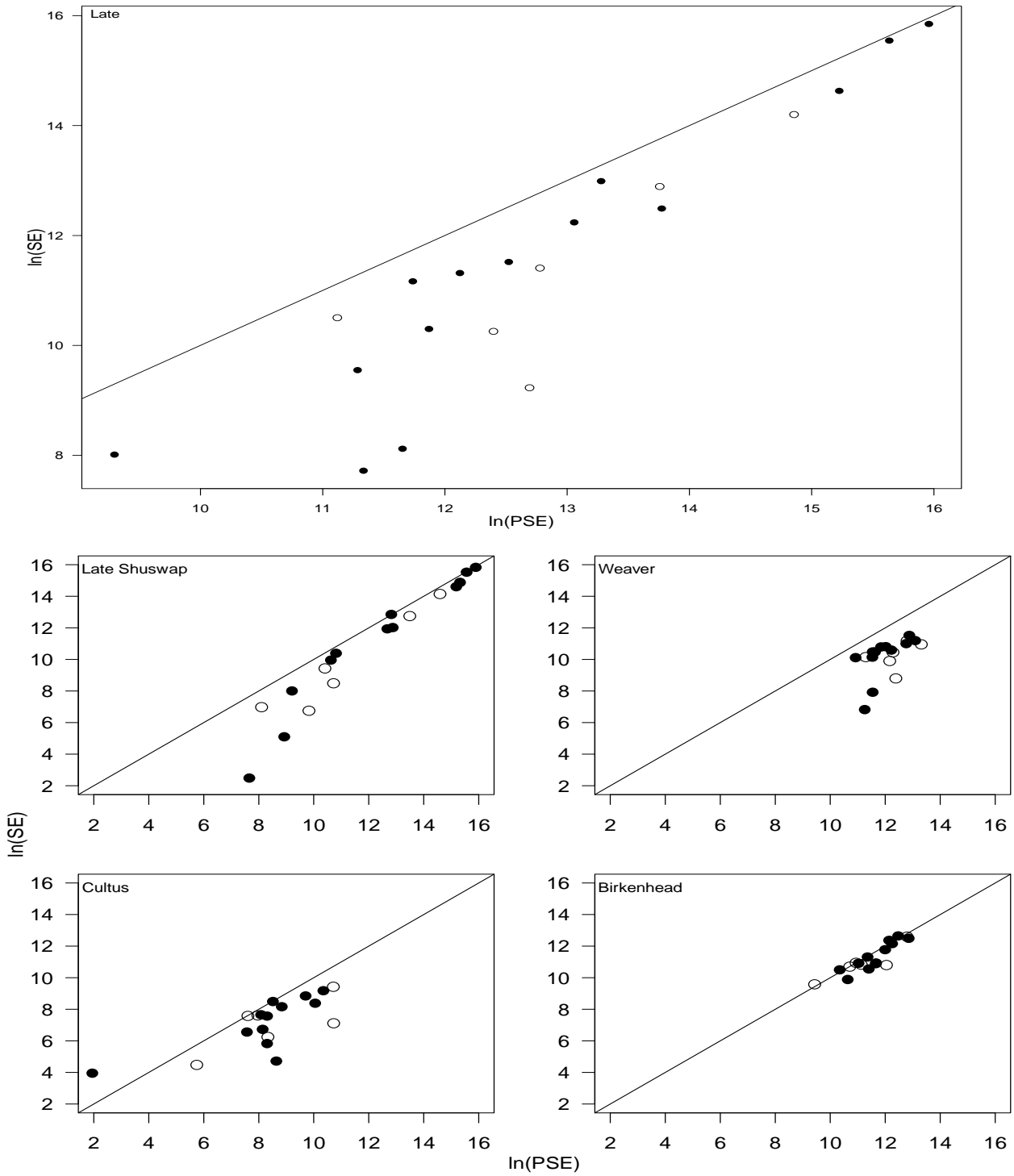


Figure 5.  $\ln(\text{SE})$  by  $\ln(\text{PSE})$  for the Late run timing group as a whole and four stocks (Late Shuswap, Weaver, Cultus and Birkenhead) that are a part of this run timing group for 1996 – 2015 and excluding 2007. Black dots indicate years 2002 and later when DNA analysis became available for stock identification.  $\ln(2)$  is 7 fish and  $\ln(16)$  is 8.9 million fish

The patterns in the relationship between lower river and spawning ground escapement estimates in the late run timing group are largely driven by the abundant Late Shuswap stock (Figure 5). This figure also demonstrates that Weaver sockeye are experiencing a great deal of en-route loss or that there is a chronic assessment issue for this stock in particular.

The results of the stock-specific analysis suggest that disaggregating the data from run-timing group to the stock level is unlikely to provide better information for in-season management of Fraser sockeye. The relationships between what we expect and what we observe (downstream potential spawning escapement vs. on ground spawning escapement estimates) at the run-timing group level are largely driven by key stocks. However, Chilliwack sockeye may be more effectively managed as a separate stock due to the evidence suggesting that Chilliwack would benefit from environmental based MA models separately (Table 11). It is unlikely that fitting stock specific descriptive management adjustment models to alternative environmental variables will provide any meaningful additional information for managers when the relationships at the run timing group level are driven by one strong stock. Additionally, there are many smaller stocks that current environmental models do not appear to be appropriate.

### Fish Densities

Stock composition for each run timing group can change based on the cyclic dominance of many Fraser sockeye stocks. This can lead to assessment difficulties at Mission in addition to possible bottlenecks to migration passage through Hell's Gate (Macdonald et al., 2000). To test this potential impact on descriptive MA models, we tested the proportion of key stocks relative to the overall abundance of the run timing group.

Proportion of key stocks relative to the overall run timing group was calculated as:

$$(2) \quad P = \frac{SE_k}{(SE_k + SE_R)}$$

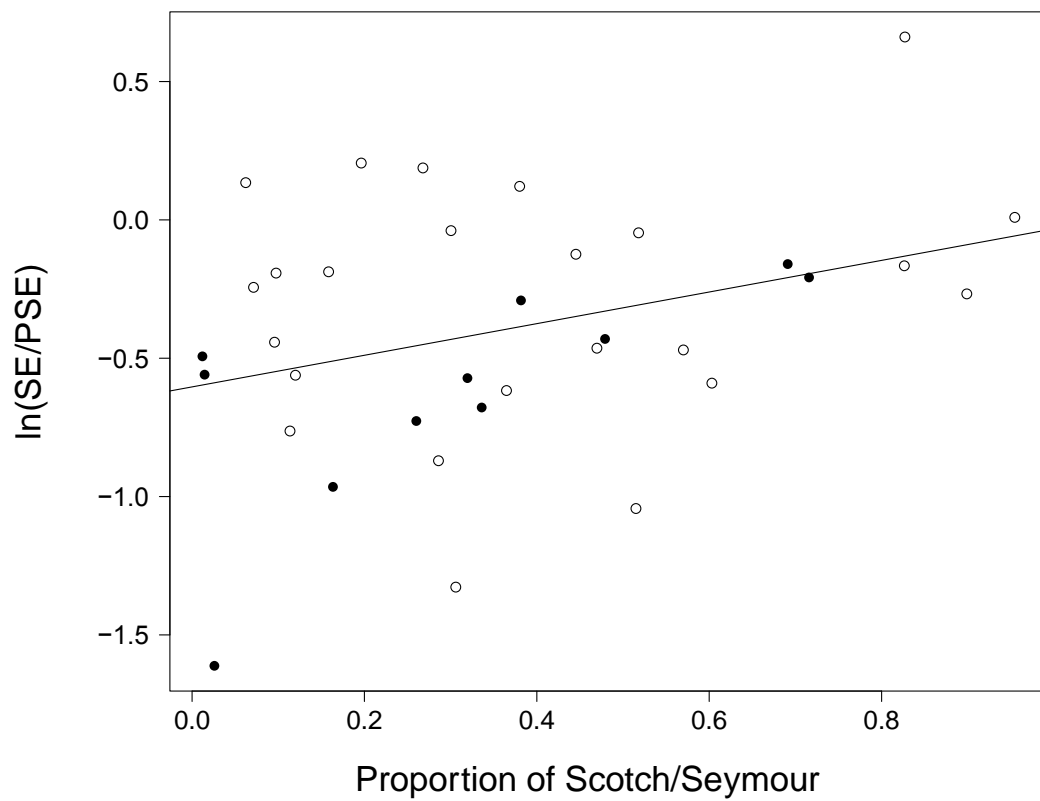
where  $P$  is the proportion of the spawning escapement of key stocks ( $SE_k$ ) relative to the spawning escapement of the run timing group ( $SE_R$ ).



suggesting that there is more loss in years where abundances of Chilliwack sockeye are high compared to Early Stuart. However, this regression relationship is largely driven by the years 2004 and 2011 (Figure 6) and the exclusion of those years from analysis does not exhibit any improved model fit or new parameters included in the top model. This relationship provides further evidence to the enumeration difficulties between Early Stuart and Chilliwack at Mission. If assessment issues at Mission for the Early Stuart run timing group is causing an overestimation of PSE, then DBE values will be large and be more reflective of the assessment issue as opposed to representing an en-route loss estimate. This issue could be potentially mitigated by including a proportion of Chilliwack variable for Early Stuart MA models.

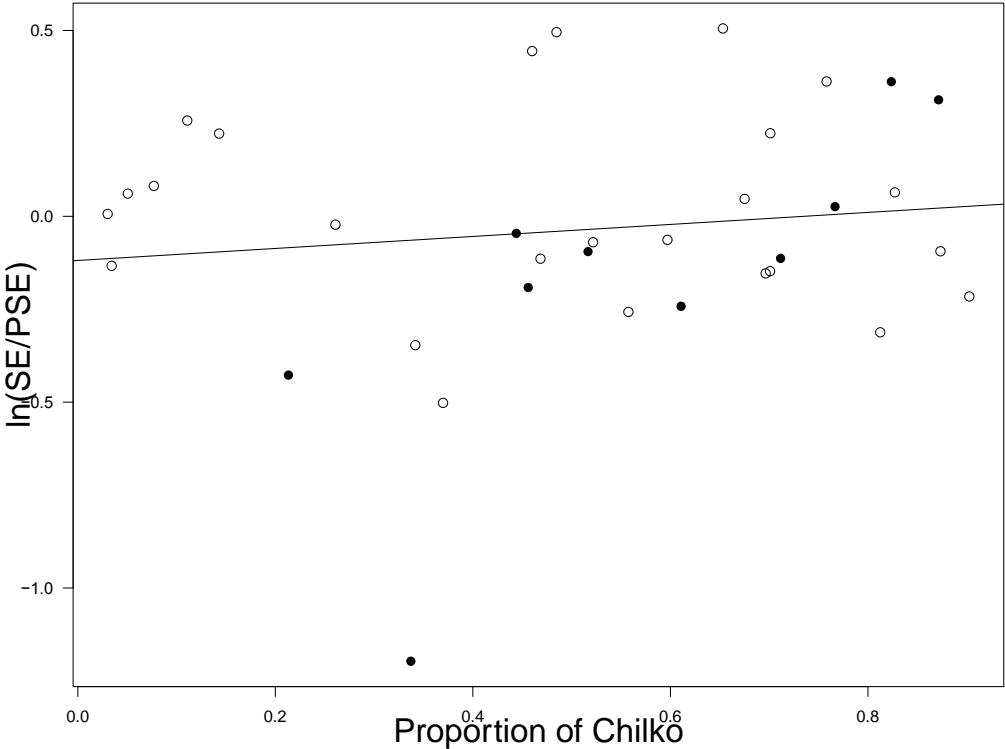
The Early Summer run timing group has large changes in stock composition between years due to the cyclic dominance of abundant stocks such as Scotch/Seymour and Nadina. We tested the effect of the proportion and abundance of Nadina and Scotch/Seymour relative to the Early Summer run timing group as a whole. There was no effect of the proportion or abundance of Nadina but there was an improvement to model fit for the descriptive MA when the proportion of Scotch/Seymour was included as an explanatory variable in the model (Adjusted  $R^2 = 0.32 >$  Adjusted  $R^2 = 0.24$ ). The top model chosen by AICc included the proportion of Scotch/Seymour but not the absolute abundance. The regression of the log spawning escapement over potential spawning escapement against the proportion of Scotch/Seymour relative to the Early Summer's demonstrates a positive relationship suggesting that when proportions of Scotch/Seymour are high, there is a smaller DBE and therefore less loss (Figure 7).

Figure 7. Log of spawning escapement over potential spawning escapement by the proportion of Scotch/Seymour sockeye relative to the Early Summer run timing group. Black points indicate years after 2007.



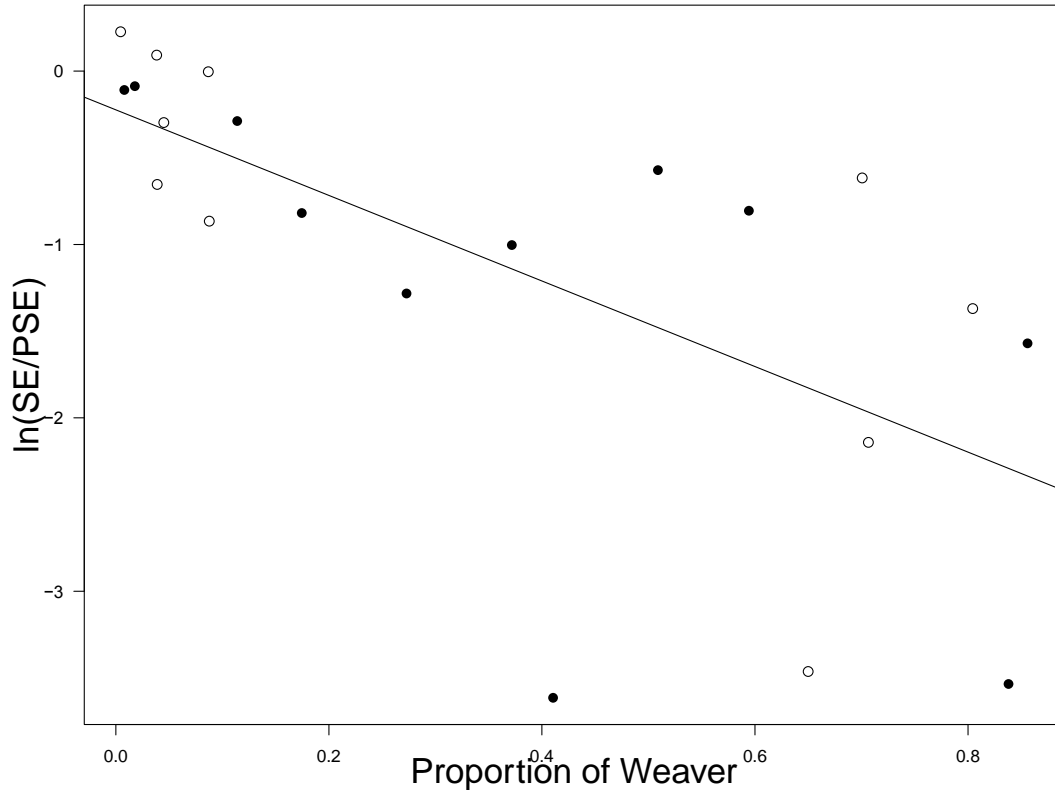
The Summer run timing group includes Harrison/Widgeon, Late Stuart/Stellako, Chilko, Quesnel and Raft/North Thompson sockeye. We tested the effect of abundance and proportion of Harrison sockeye, Late Stuart/Stellako and Chilko sockeye against the log spawning escapement over potential spawning escapement for the Summer run timing group as a whole for all of the years included in the new exclusion. The only stock that improved model fit ( $\text{Adjusted } R^2 = 0.44 > \text{Adjusted } R^2 = 0.34$ ) was Chilko. Additionally, both the proportion and spawning ground abundance of Chilko were included in the top model chosen by AICc. The regression relationship between the log spawning escapement over potential spawning escapement and the proportion of Chilko sockeye exhibits a positive relationship suggesting that when the proportion of Chilko sockeye is high, there is a smaller DBE or less loss (Figure 8). This result for the Summer run timing group is what is expected based on the literature (Eliason et al., 2011).

Figure 8. Log management adjustment by the proportion of Chilko sockeye relative to the Summer run timing group. Black points indicate years that are later than 2007.



Currently descriptive management adjustment models for the Late run timing group have a strong model fit (Adjusted  $R^2 = 0.86$ ), but all descriptive models include a run timing variable. At this time, predicting run timing is difficult in season which makes using predictive MA models to predict DBE and management adjustments problematic. To determine if stock composition also influences the DBE and MA estimates for the lates, we tested the proportion and abundance of Harrison and Weaver sockeye relative to the late run timing group as a whole. There was no effect of Harrison evident, but the proportion of Weaver relative to the late run timing group improved model fit (Adjusted  $R^2 = 0.93 > \text{Adjusted } R^2 = 0.86$ ) and the proportion of Weaver was included in the top model chosen by AICc. However, the relationship of the log spawning escapement over potential spawning escapement and the proportion of Weaver relative to the Late run timing group shows a negative relationship suggesting that years when the proportion of Weaver is high relative to the late run timing group, there is a larger DBE or more loss (Figure 9). Including a proportion of Weaver relative to the Late run timing group as a whole can be used to more accurately predict DBE's for this run timing group. The Weaver and Late Shuswap stocks dominate the Late run timing group and there is a known high en-route loss for Weaver sockeye (Donaldson et al. 2012; Robinson et al. 2015). This suggests that in Weaver years, there will be more loss than expected and the inclusion of an effect of the proportion of Weaver sockeye will likely result in more accurate predictions of DBE for this run timing group.

Figure 9. Log of the management adjustment by the proportion of Weaver sockeye relative to the Late run timing group using the years included in the new exclusion rules as outlined by the Pacific Salmon Commission in 2017. Black points indicate years that are later than 2007.

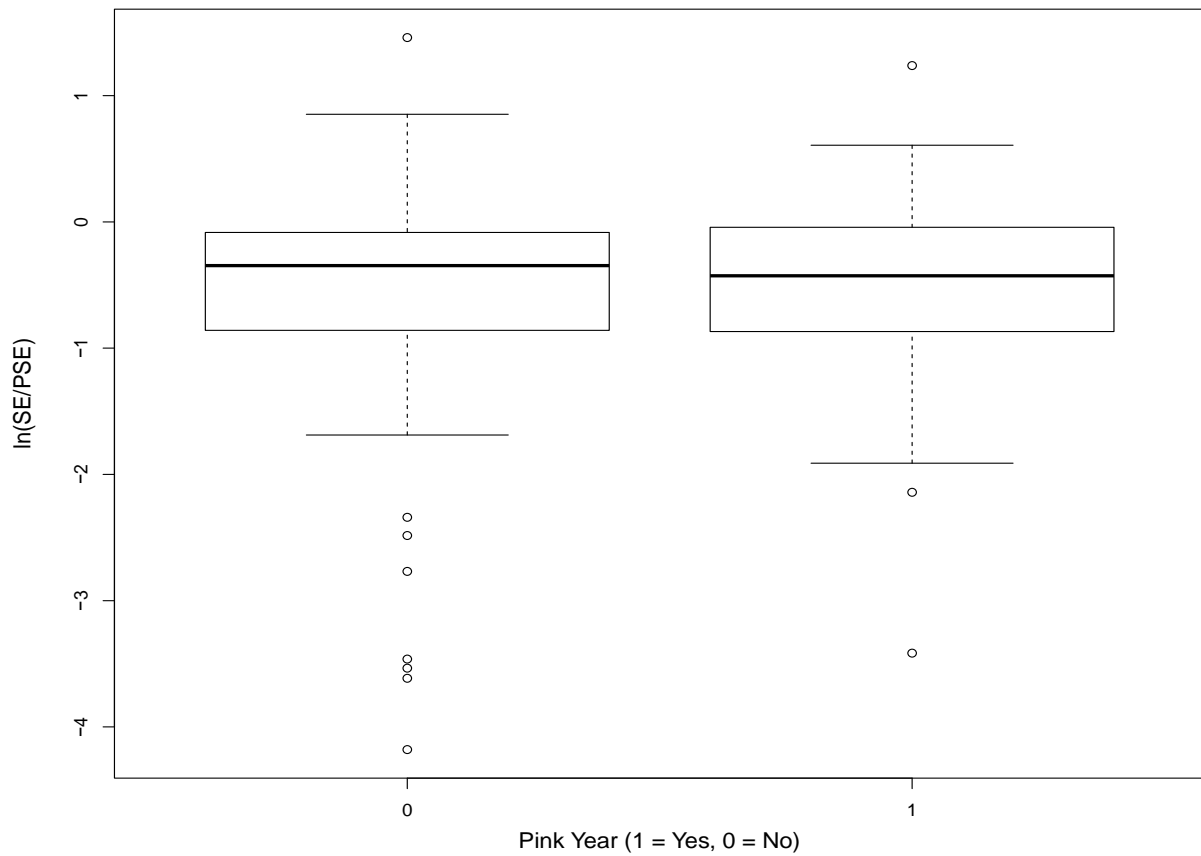


### Multi-Species Presence

In odd numbered years, pink salmon co-migrate with summer and late Fraser sockeye salmon. This creates difficulties for enumerating sockeye at Mission as pink and sockeye salmon are morphologically similar. However, the pink salmon are not included as a factor in descriptive or predictive management adjustment models to date. We included the presence or absence of pink salmon as a variable in descriptive management adjustment models for all run timing groups to determine if the model fit improved. In pink years, the mean log spawning escapement over potential spawning escapement was lower than in non-pink years (PinkYear:  $\ln(\text{SE}/\text{PSE}) = -0.56 \pm 0.66$ ; Non-PinkYear:  $\ln(\text{SE}/\text{PSE}) = -0.50 \pm 0.87$ ) suggesting that there is typically greater loss observed in pink years than in non-pink years when examining all run

timing groups (Figure 10). However, a Welch's two-sample t- test of the means for pink and non-pink years determined that the difference is not significant ( $p = 0.58$ ).

Figure 10.  $\ln(\text{SE}/\text{PSE})$  in pink years (1) or non-pink years (0) for all run timing groups using the years not excluded in the rules outlined by the Pacific Salmon Commission in 2017.



We also tested the effect of pink year on the run-timing groups individually (Figure 11) which showed that the difference in mean log MA between pink years and non-pink years except for the Early Summer run timing group where model fit improved by approximately 5% (Adjusted  $R^2 = 0.29 > \text{Adjusted } R^2 = 0.24$ ). Pink abundance was not included in the top model and did not improve model fit for any of the run timing groups. Proportion of pink salmon relative to each run timing group was also tested where the spawning escapement of pink salmon was added to the spawning escapement of each run timing group in order to calculate the proportion. Proportion of pink salmon improved model fit for Early Stuart (Adjusted  $R^2 = 0.71 > \text{Adjusted } R^2 = 0.58$ ) and for Early Summer (Adjusted  $R^2 = 0.37 > \text{Adjusted } R^2 = 0.24$ ). However, this result is spurious because pink salmon do not co-migrate with Early Stuart and only overlap with the end of the Early Summer run timing group.

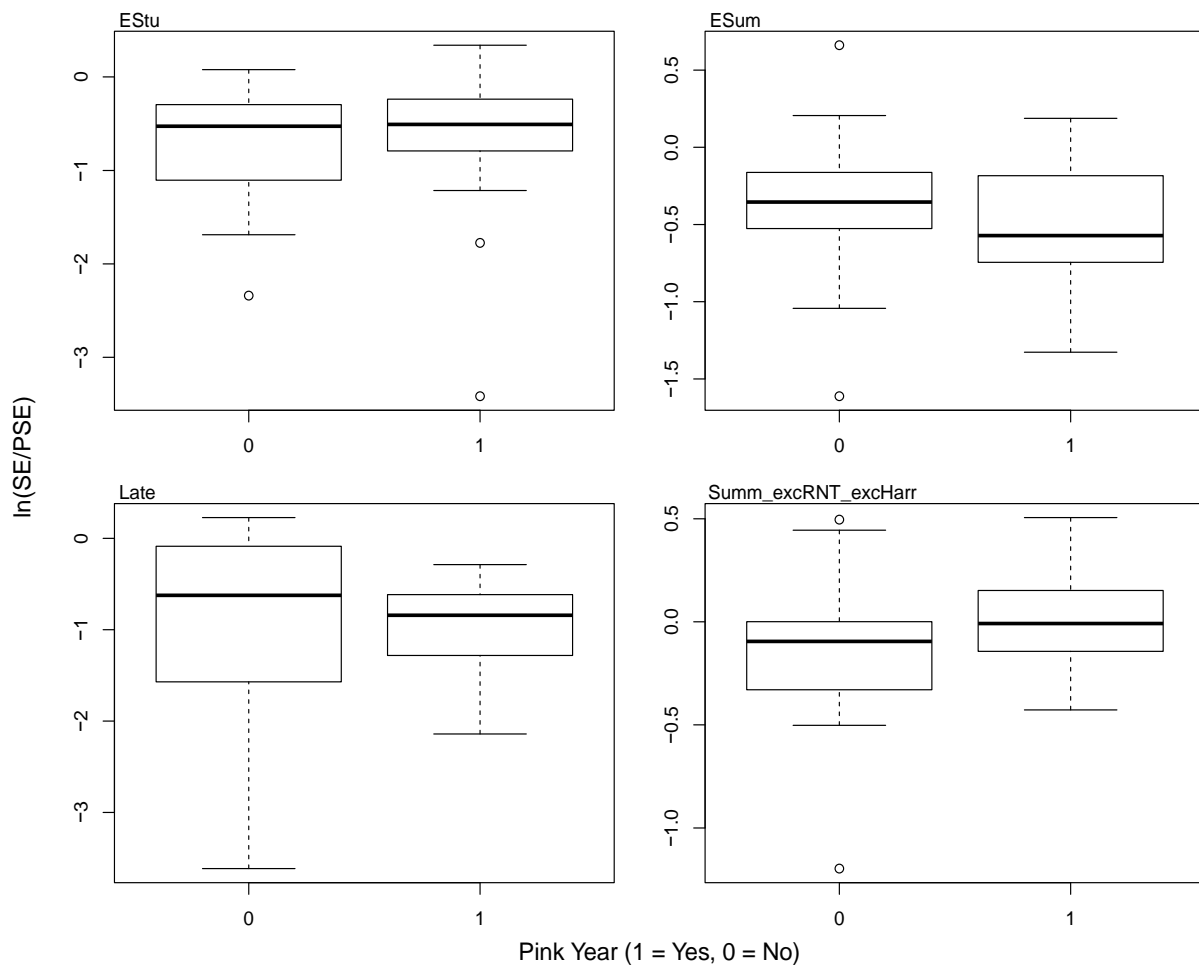


Figure 11.  $\ln(\text{SE}/\text{PSE})$  by pink and non- pink years by run timing group using all years not excluded in the new exclusion rules outlined by the Pacific Salmon Commission in 2017.

## Multi-Site Environmental Data

Current management adjustment models use a centered 31-day average (descriptive) and 19-day average (predictive) temperature and discharge variable in the lower Fraser River as a measure of environmental conditions in the river. Although river temperatures throughout the watershed are correlated to the lower river temperature (Hague et al., 2008), the lower river temperature does not fully encompass the thermal exposure of Early Stuart sockeye migration. Additionally, work by Hague and Patterson (2007) and by Gardner and Patterson (2017) has allowed for the expansion of river temperature forecasting models that are flexible for different watersheds without the need for complex physical models (See Hague and Patterson 2014). For these reasons, we tested the effect of the temperature in the Stuart River at Fort St. James on descriptive MA model fit. The first metric we tested was a 31-day mean temperature at Fort St. James centered for run timing from 1995 to 2016 because we only have daily temperature information at Fort St. James available from 1995 onward. Upstream centered mean temperature and the quadratic term for this variable were both included in the top model chosen by AICc and model fit improved by ~3% ( $\text{Adj } R^2 = 0.61 > \text{Adj } R^2 = 0.58$ ). When both downstream and upstream temperature variables were included in the model, the top model did not include downstream temperature variables but did include upstream temperature information variables. Interestingly when we examine how the loss changes based on upstream and downstream temperature, a similar but lagged pattern is evident (Figure 12) suggesting that the timing of this run timing group is experiencing higher temperatures in the upper river than the lower river. The effect of upstream temperatures in FSJ is negative while the effect of temperature at Qualark is positive. This suggests that warmer temperatures upstream are more likely to impact loss than the lower river.

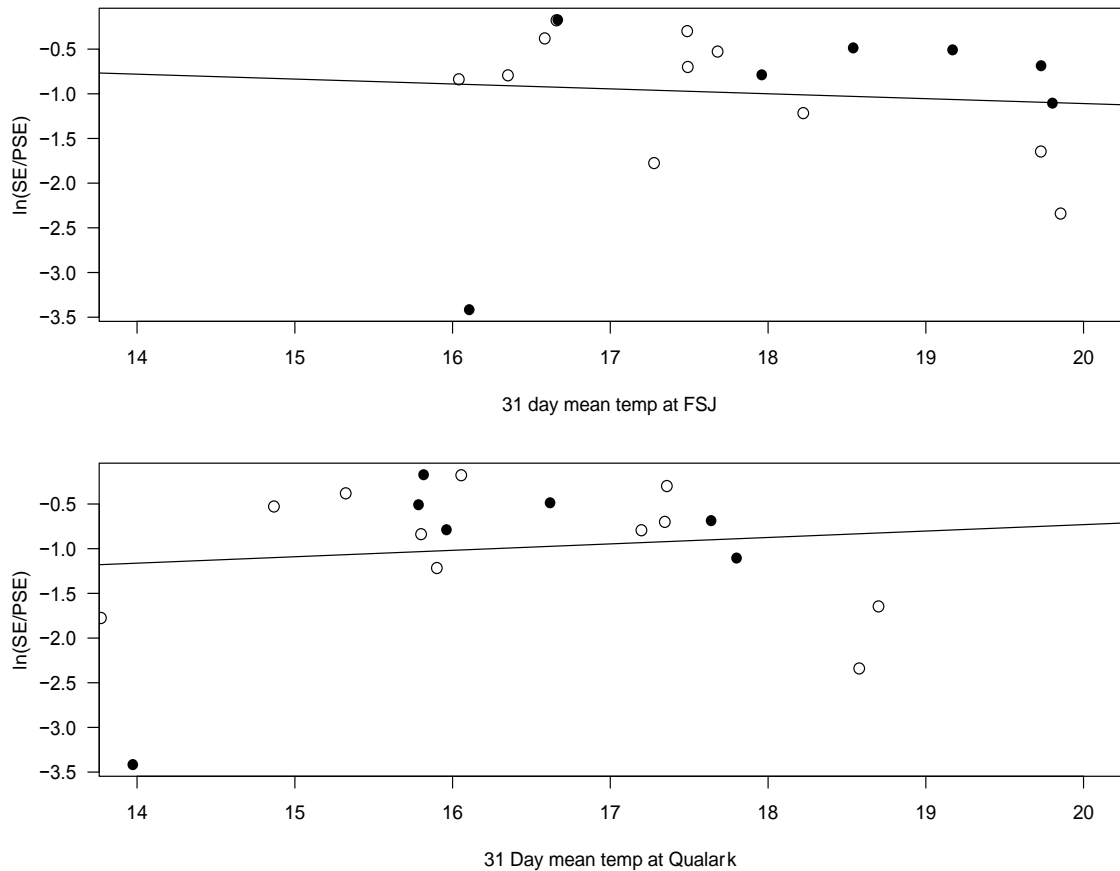


Figure 12. The natural log of spawning escapement over potential spawning escapement by 31 day mean river temperatures centered for run timing at Qualark and FSJ for the Early Stuart run timing group. Black dots are years after 2007

This may be indicative that for sockeye that return and spawn early, upstream temperature may have a greater ability to describe and predict en-route loss. Further examination of other stocks and the impact of upstream temperatures is necessary to support this argument.

In addition to the centered average temperature in the Stuart River at Fort St. James, we tested a weighted average upstream temperature variable at Fort St. James. The weighted average is calculated by averaging the daily temperature by the daily number of fish exposed to this temperature. This creates a more biologically relevant variable for predicting en-route loss as it considers the proportion of the run size exposed to adverse environmental impacts. Despite being more biologically relevant, the upstream weighted average temperature was not included

in the top model chosen by AICc when we ran the descriptive management adjustment model. It was however included in the third best model with an adjusted  $R^2$  value of 0.52. This variable requires further analysis however because the fish passage by day at Mission information used in the calculation of the weighted average was the 2016 data only. It would be necessary to include fish passage by day information for all years tested before excluding this variable from analysis.

While FSJ is the furthest upstream temperature data location from Qualark and Hope, the Thompson River is typically the warmest major tributary within the watershed (Hague and Patterson, 2008). We tested the effect of 31 and 19 day mean river temperature centered for run timing in the Thompson River at Ashcroft. Ashcroft was chosen rather than Chase although it is often warmer because there were less missing data in the Ashcroft dataset and North Thompson stocks also pass through this location. Plotting the effect of mean temperatures centered for run timing at Ashcroft and Qualark against the log of the management adjustment for the Early Summer run timing group demonstrates that there is a stronger negative effect of temperatures at Ashcroft than at Qualark resulting in more loss when temperatures are higher in Ashcroft (Figure 13). When we included Ashcroft temperature in the descriptive management adjustment model, the top model included 31-d mean temperature at Ashcroft, 31-d temperature at Qualark and the quadratic transformation of the lower river temperature variable. This model had an  $R^2$  value of 0.81 which is a drastic improvement for the Early Summer management adjustment models with an  $R^2$  of 0.24.

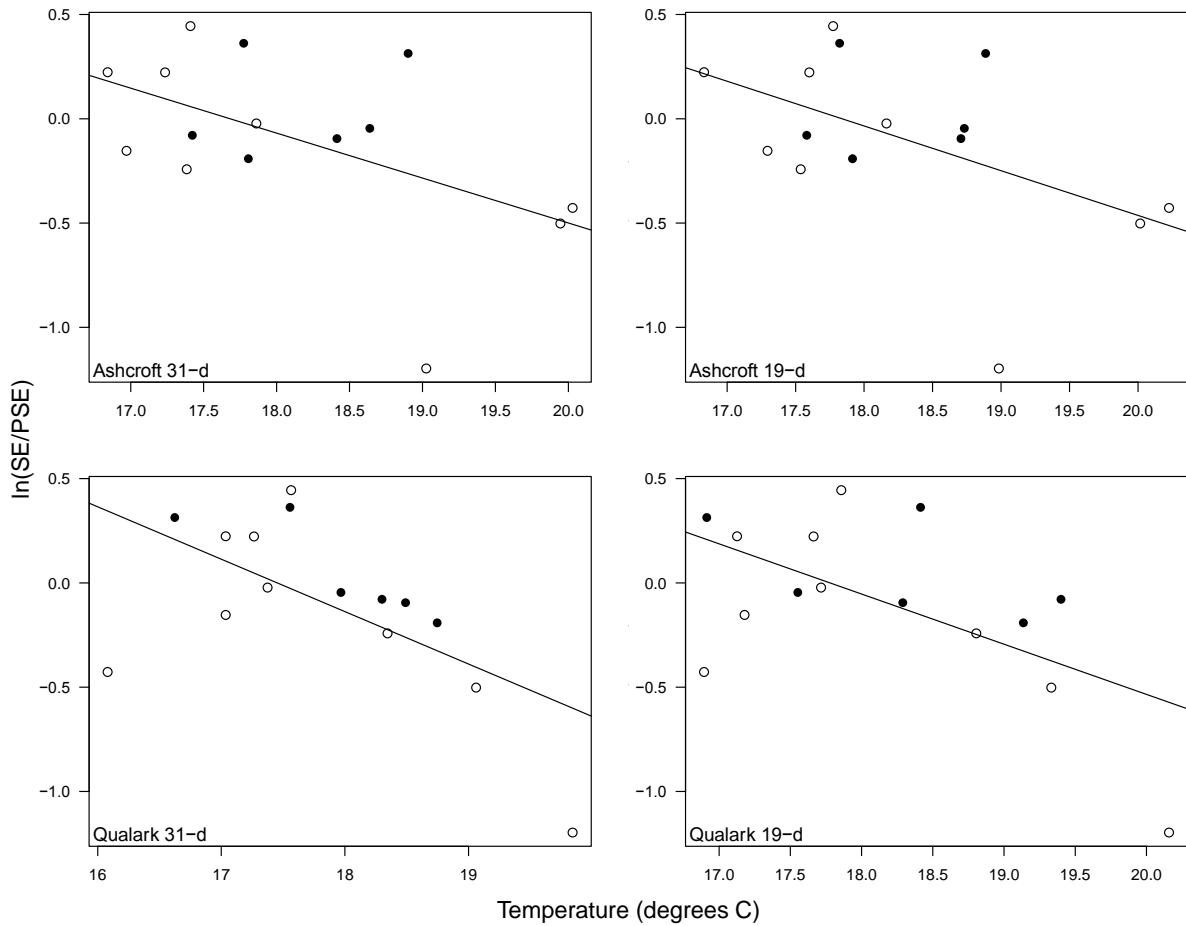


Figure 13.  $\ln(SE/PSE)$  by 19 and 31 day mean temperature centred for run timing at Ashcroft and Qualark for the Early Summer run timing group using the years included from the dataset as outlined by the exclusion rules outlined by the Pacific Salmon Commission in 2017. Black points indicate years later than 2007

Upstream discharge in the lower Chilcotin River and in the Quesnel River were determined to inhibit migratory success in sockeye (Stiff et al., 2017). Based on this research, we tested the effect of 19 and 31 day centered average discharge values in the Chilcotin River at Big Creek and the Quesnel River near Quesnel on the log management adjustment of the Summer run timing group. Model selection using AICc determined that all of the centered mean discharge variables at these locations did not improve descriptive MA model fit. Additionally, increased discharge at these locations appeared to have a positive effect on the log spawning escapement over the potential spawning escapement variable (Figure 14) which is contrary to what we would expect based on the work from Stiff et al. (2017). It is likely that the positive relationship

is due to the decreased temperatures in the river associated with higher discharge values upstream.

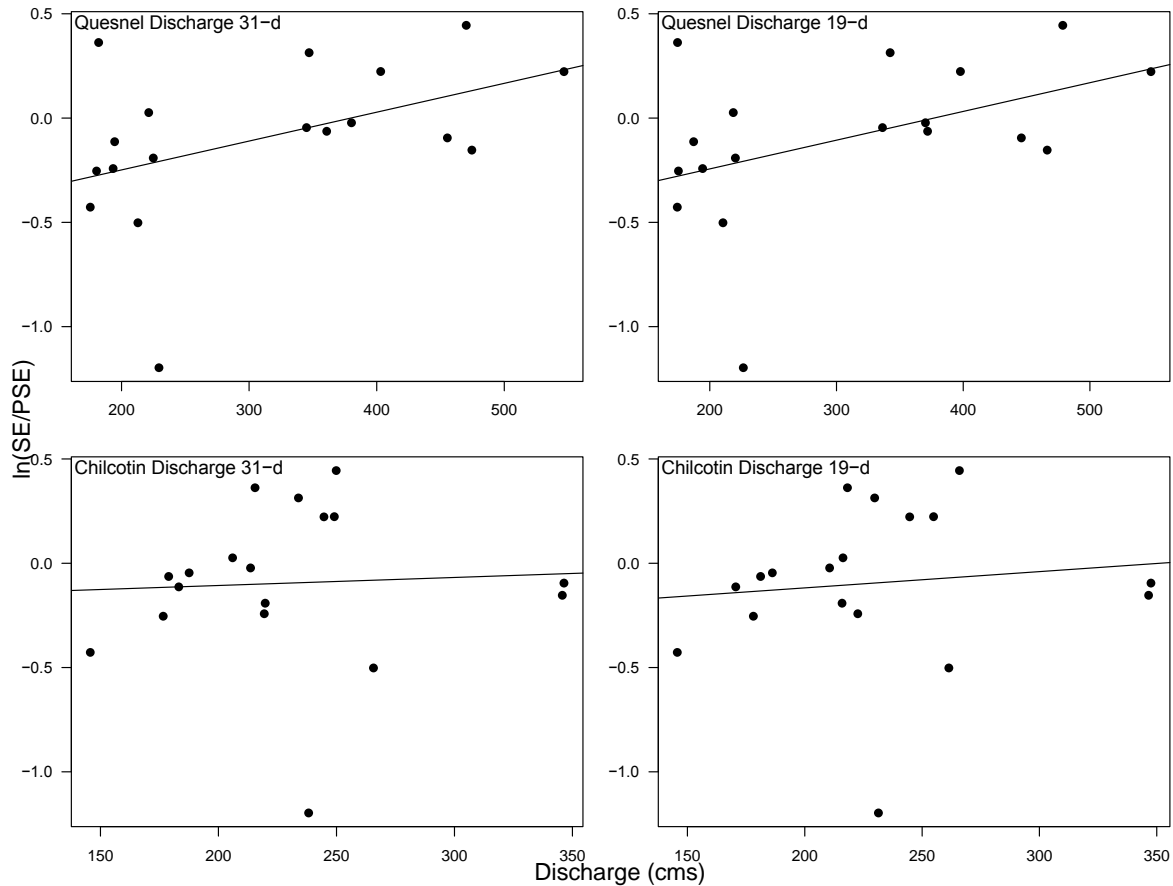


Figure 14. Logarithm of the management adjustment for the Summer run timing group by 19 and 31 day centered average discharge in the Chilcotin River at Big Creek and the Quesnel River near Quesnel from 1995 to 2016. Centering of the discharge was based on run timing and shifted to account for migration to each location based on assumptions outlined in English et al., 2010.

## Recommendations

### *All Run Timing Groups*

- Include all years of data because this will lead to greater confidence in the model due to more years of data. However, years can be excluded if the reasoning behind the exclusion of that year is unlikely to occur again in the future.
- Disaggregating run timing groups to stocks is not useful for MA models because most stocks were not able to be described by current descriptive MA models. However, the

Chilliwack stock exhibited a strong relationship between environmental variables and loss in descriptive MA models which suggests that it may be more effectively managed on its own instead of with the Early Summer run timing group.

- Proportions of key stocks relative to run timing groups can improve MA model fit because it accounts for the different patterns of loss exhibited by stocks within run timing groups.

#### *Early Stuart*

- Include an effect of the proportion of Chilliwack sockeye relative to the Early Stuart sockeye because of the assessment issues between the two stocks.
- Include an effect of upstream temperature at Fort St. James lagged by the expected arrival at Fort St. James. This also suggests that it may be worthwhile to consider forecasting temperatures at Fort St. James for managing Early Stuart sockeye. This could be done with the RGM model (Gardner, MRM project, 2017).

#### *Early Summer*

- Include an effect of the proportion of Scotch-Seymour sockeye relative to the run timing group as a whole because these abundant stocks drive the relationship between DBE's and environmental variables.

#### *Summer*

- Include an effect of the proportion of Chilko sockeye relative to the run timing group as a whole because of the physiological resilience of this stock to adverse environmental conditions.
- Include an effect of upstream temperature at Ashcroft as this is the warmest location within the Fraser watershed typically and many stocks from this run timing group migrate through this location. It may also be worthwhile to consider forecasting temperature at this location in-season for this run timing group. This could be done with the RGM model (Gardner, MRM project, 2017).

#### *Late*

- Include an effect of the proportion of Weaver relative to the Late run timing group as a whole because of the high rate of en-route loss for this stock. Weaver sockeye are also one of the dominant stocks for the Late run timing group in years that the Late Shuswap stock is not dominant.

## CHAPTER 3: ALTERNATIVE APPROACHES TO PREDICTING EN-ROUTE LOSS

### INTRODUCTION

A major component of this work was the realization that more qualitative information was being sought by the Fraser Panel in the current decision making. We have since developed a separate SEF proposal “Evaluation and coordination of information useful for predicting en-route loss in Fraser sockeye” to address these information needs and focus the remaining effort on this proposal to critically examine the utility of new research on multiple factors linked to en-route loss on a stock-specific basis. Delays in stock-specific information have resulted in our work on alternative methods for predicting en route loss to switch to data gathering and information support for the second SEF project titled. The majority of work completed to date for this section has focussed on fishery interactions and fish condition information.

#### Fishing interactions

We have been working with academic partners over the past few years developing a two CSAS research documents on estimating fishing related incidental mortality (Patterson et al., 2017a; Patterson et al, 2017b). The work has identified several 1000 of publications (primary and grey literature) related to quantifying non-catch related mortality. We have examined the utility of this information for use in predicting en route loss by focussing on the potential for of drop-off mortality (e.g. escape mortality) and underestimation of release mortality.

#### *Data Sources*

The stock specific DBE files from the PSC generated in Chapter 1 offered the values of marine and freshwater catch by stock which were then re-aggregated into run timing groups in R. 31-day models for all run timing groups were fit with the data from the MA data aggregated at the stock level (Appendix A).

Currently, we have access to marine and freshwater catch data for all stocks which can be aggregated into run-timing groups. The availability of catch data without any information on effort has necessitated that we test the effect of total catch and the exploitation rate as variables to include in descriptive management adjustment models (Table 12). We also tested catch and exploitation rate for freshwater and marine environments with an interaction the 31-day centered mean temperature at Qualark. Marine catch and exploitation rate, and freshwater below Mission catch and exploitation rate were all not included in any of the top descriptive MA models selected by AICc suggesting that these variables are not important for describing and predicting en-route loss.

Table 12. Description of variables used for testing the effect of fishing on  $\ln(SE/PSE)$  for descriptive 31-d MA models for all run timing groups using the new exclusion rules outlined by the PSC in 2017

<b>Variable Tested</b>	<b>Variable Description</b>	<b>Exploitation Rate Calculation</b>
Marine Catch	Catches in the marine environment for each run timing group	Marine Catch/Marine Escapement
FWBM	Freshwater catches below Mission	FWBM/Mission Escapement
FWAM	Freshwater catches above Mission	FWAM/TotalPSE

Freshwater exploitation rate above Mission was an important factor for the 31- day descriptive Early Stuart run timing group but there was no evidence of interaction between temperature and exploitation rate or discharge and exploitation rate. We observe minor improvements in model fit compared to the old descriptive management adjustment models but the top models that are within two AICc values vary substantially between which variables are included suggesting that we should be cautious in adopting this additional variable (Table 13).

Table 13. Evidence for 31-day descriptive management adjustment top models selected by AICc using freshwater exploitation rate above Mission (ERFWAM), mean 31-day temperature centered for run timing (T), the quadratic transformation of the temperature variable (T2), mean 31-day discharge centered for run timing (Q), and the quadratic transformation of the discharge variable (Q2) for the Early Stuart run-timing group from 1996-2014 excluding 2007

Model	AICc	DeltaAIC	R2	Coefficients					
				Intercep t	ERFWA M	T	T2	Q	Q2
<b>ERFWAM + Q + Q2</b>	39.4	0	0.67	-5.3	-6.1	-	-	0.002	-1.9
<b>T + T2</b>	40.8	1.3	0.53	-74.5	-	8.9	-0.3	-	-
<b>Q + Q2</b>	41.1	1.6	0.52	-7.1	-	-	-	0.002	-2.1
<b>ERFWAM</b>	41.5	1.9	0.51	0.67	-7.3	-	-	-	-

The Summer run timing group 31-day descriptive management adjustment model demonstrated an increase in  $R^2$  from 0.34 to 0.7 with the inclusion of an interaction between freshwater exploitation rate and temperature in the descriptive management adjustment model (Table 14). This suggests that for this run-timing group, in-river exploitation is particularly detrimental when river temperatures are high. However, the exploitation rate without the interaction with temperature is a positive effect suggesting that when catches are high there is less loss without the covariance of temperature.

Table 14. Evidence for 31-day descriptive management adjustment top models selected by AICc using freshwater exploitation rate above Mission (ERFWAM), mean 31- day temperature centered for run timing (T), and the quadratic transformation of the temperature variable (T2) for the Summer run timing group from 1996-2014 excluding 2007.

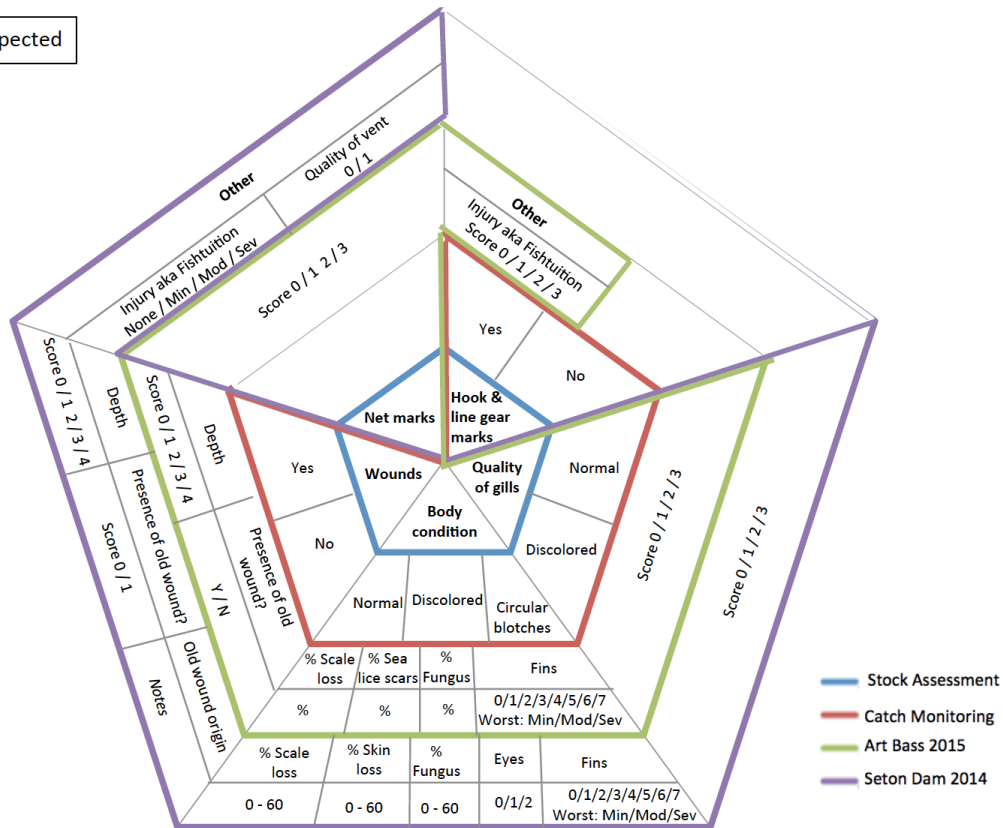
Model	AICc	DeltaAIC	R2	Coefficients				
				Intercep t	ERFWA M	T	T2	ERFWAM *T2
ERFWAM + T + T2 +ERFWAM* T	15.6	0	0.73	-49.2	44.2	5.3	-0.14	-2.45
T + T2	16.4	0.86	0.48	-46.7	-	5.4	-0.15	-

Fish Condition:

We have continued to compile more research on energy status, pathogen presence, and overall stress to examine the utility of each with respect to predictive ability. We are working with Art Bass at UBC who is compiling research on the ability of fish condition to predict fate. A large portion of this work has been incorporated into the new ‘qualitative’ SEF project on predicting en route loss. A recent paper has been prepared on the ability to predict en route mortality via fish condition (Bass et al. in prep), this will be submitted soon.

Figure 15. Comparison of fish condition parameters used by different groups in the Fraser River to describe sockeye salmon.

Catch Inspected



### Prespawn mortality of early VS late MA groups

We also explored the possibility of using the condition of fish that arrived on the spawning for early timed groups as a surrogate for en route loss for later groups, as this information would potentially be available in-season. The idea being that egg retention is a surrogate for poor condition and that there is high co-variance among stocks within a year.

Difference between estimates (DBE) is calculated as the difference between Mission and spawning ground escapements. Proportional DBE (pDBE) is calculated by dividing the difference between estimates (DBE) by the potential spawning escapement ( $pDBE = DBE/SE$ ). Post-season management data were analyzed to determine whether prespawn mortality of early MA groups is indicative of prespawn mortality of later MA groups. If there is a connection, in-season decisions could be informed by prespawn mortality of early MA groups. The following MA

groups were included in this analysis: Early Stuart (EStu), Early Summer (Esum), Summer (Summ), Late.

Correlation coefficients were generated using proportional DBE for these four MA groups from 1977-2015. Data were not included from years where errors were indicated in the post-season management adjustment calculations of the Early Stuart MA. This analysis explores whether prespawn mortality of Early Stuart MA correlated with other management groups later in the run (Figures 15-17). This work has shown some promise and we recommend future analysis.

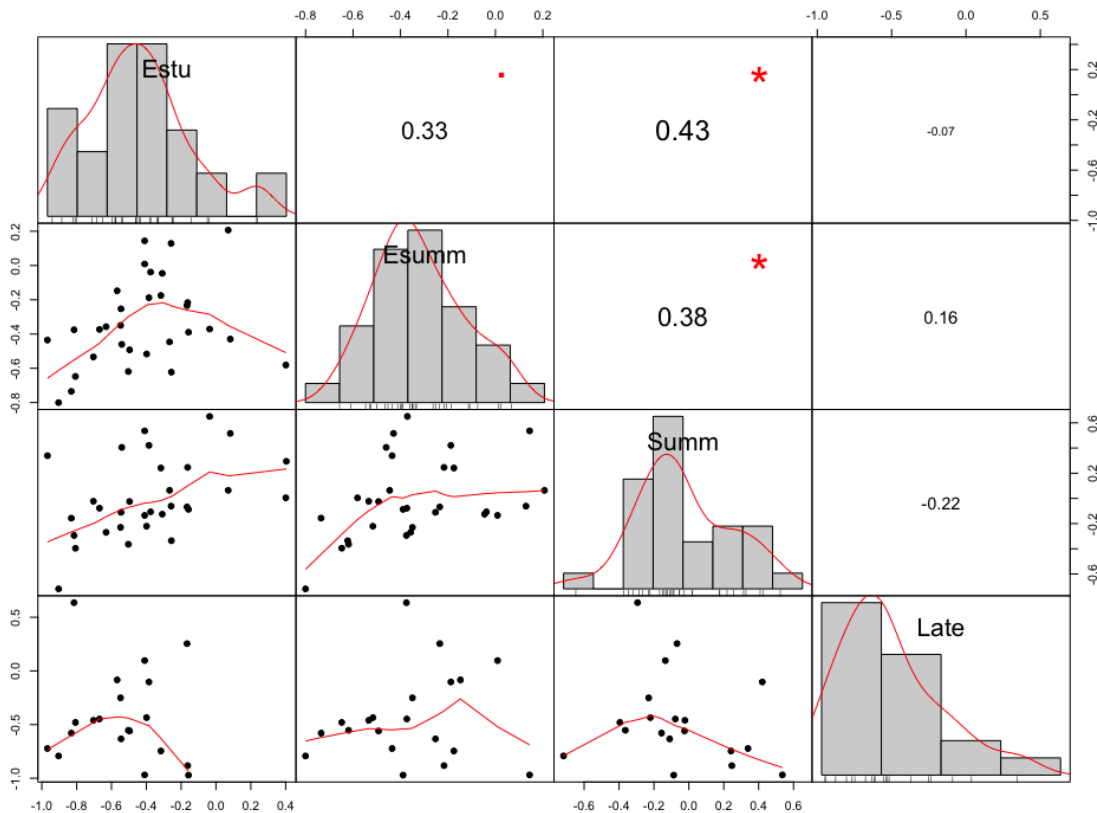


Figure 15: Correlation coefficients between Early Stuart, Early Summer, Summer, and Late MA groups from 1977-2015 (excluding years with errors for Early Stuart 1977, 1980, 1982, 1984, 1986, 2012). The distribution of each variable is shown on the diagonal. On the bottom of the diagonal, the bivariate scatter plots with a fitted line are displayed. On the top of the diagonal, the value of the correlation plus the significance codes (0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 '' 1).

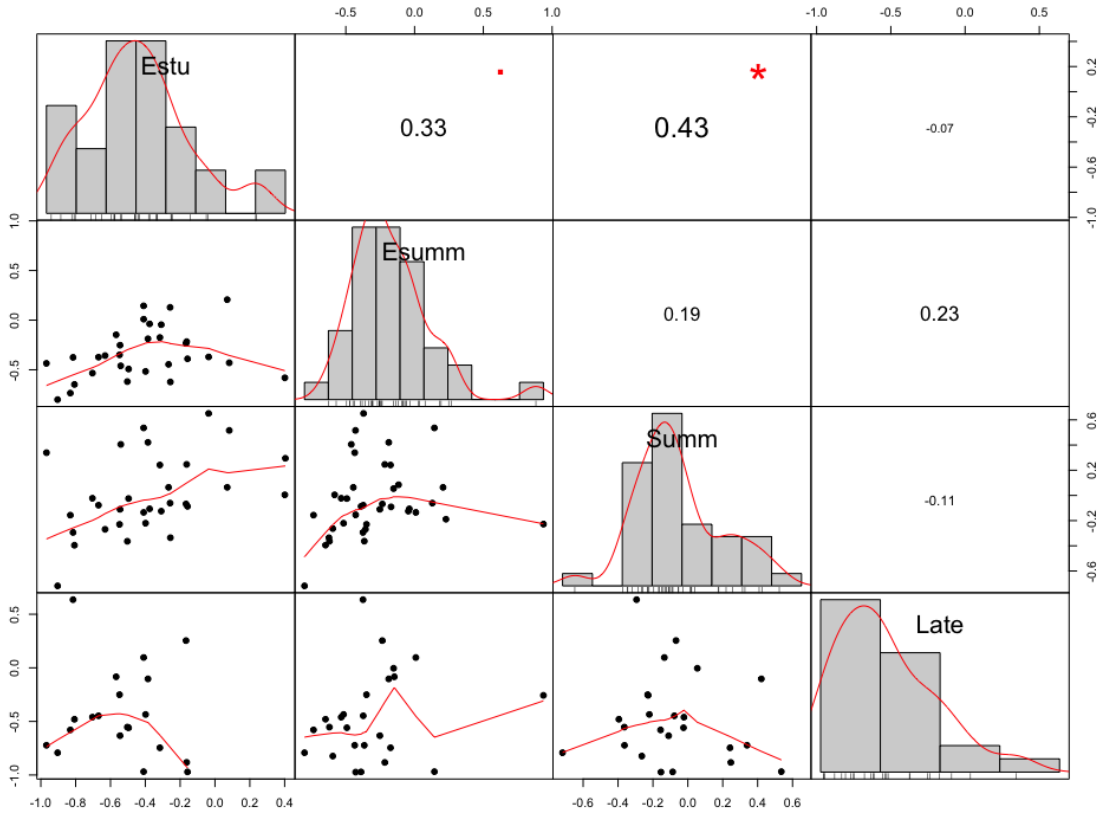


Figure 16: Correlation coefficients between Early Stuart, Early Summer, Summer, and Late MA groups from 1977-2015 (all years). The distribution of each variable is shown on the diagonal. On the bottom of the diagonal, the bivariate scatter plots with a fitted line are displayed. On the top of the diagonal, the value of the correlation plus the significance codes (0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 '' 1).

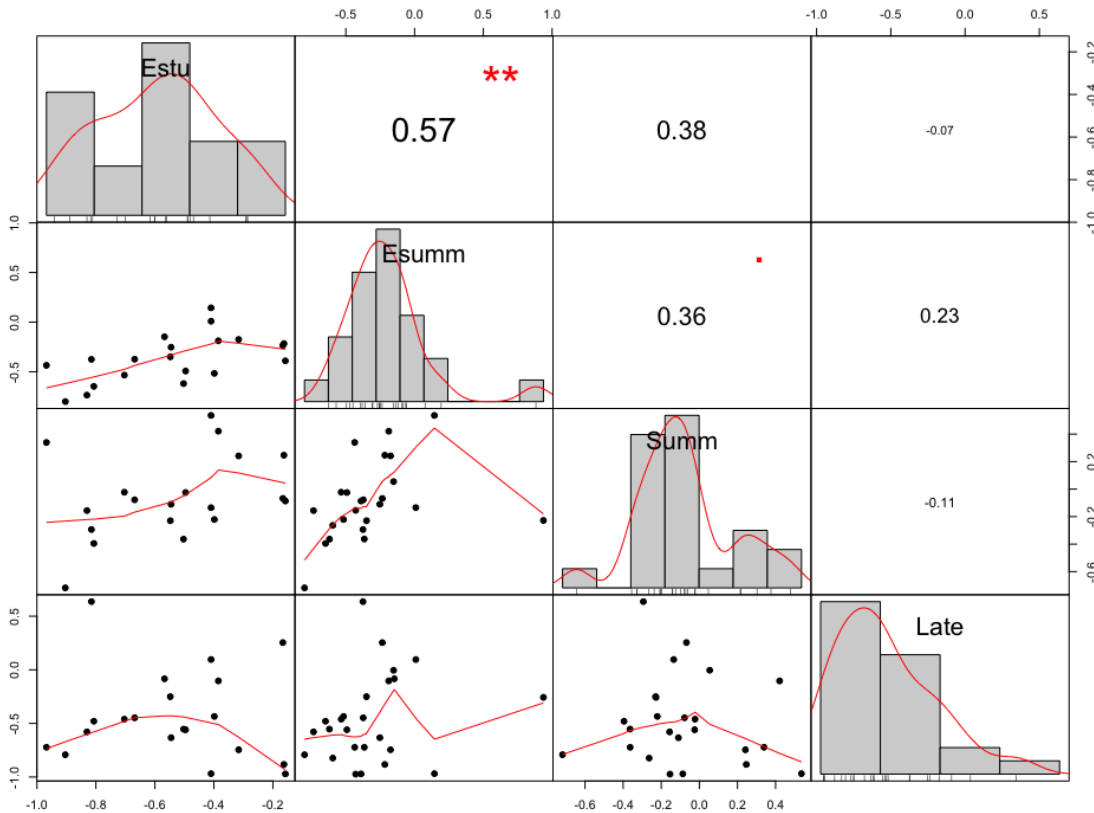


Figure 17: Correlation coefficients between Early Stuart, Early Summer, Summer, and Late MA groups from 1977-2015 (excluding years with errors for Late MA group 1977, 1979, 1980, 1981, 1983, 1984, 1985, 1987, 1988, 1989, 1991, 1992, 1993, 1995, 2006). The distribution of each variable is shown on the diagonal. On the bottom of the diagonal, the bivariate scatter plots with a fitted line are displayed. On the top of the diagonal, the value of the correlation plus the significance codes (0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 '' 1).

### Behaviour:

Stock-specific variability in migration behaviour is currently not included in the estimates of en-route loss for Summer-run stocks. We have been examining migration behaviour of Harrison River sockeye salmon. Based on this preliminary work we shown they exhibit a variety of migration behaviours ranging from early river entry (3 months before spawning), slow migration, variable pre-spawn holding locations (Fraser River, Harrison River and Harrison Lake). In 2015 and 2017, we were involved in large tagging projects on summer run sockeye.

We have been working with the proponents of this work to look at stock specific variability in both mortality and behaviour. This work will be incorporated in the second SEF project.

#### Assessment methods:

We have been working with Dr. Eduardo Martins on analyzing the error distribution in assessment estimates to see what influence they could potentially have on the MA values. We have also been working with Tracy Cone to get more accurate reconstruction of the different spawning ground assessment methods that have been used for different stocks since 1977, to determine whether having high vs. low precision estimates is influencing the discrepancy estimates and the ability to predict loss. This information will now be matched with the recently available stock-specific DBE estimates to determine if precision in estimates spawning escapements influences the bias and/or uncertainty in DBE values.

#### Cumulative Effects Methods:

We have been collaborating with other researchers to explore new methods for reducing the current uncertainty in describing and predicting en-route loss. The main collaboration has been with Dr. Eduardo Martins this past year. He has made good progress on a cumulative effects modelling approach. The model framework being developed will be used to quantify the impact of specific stressors and assess the efficacy of alternative management actions. In other words, alternative management actions can be simulated to assess how specific management actions could mitigate, compensate, or even exacerbate the cumulative effects of stressors on Fraser River sockeye salmon populations. The models developed in this research will form an important tool for the decision making process of managers given their potential utility on not just the immediate goal of achieving spawning escapement targets, but also their long-term impact on population viability. A preliminary draft publication on this work will be ready within the next few months.

## Recommendations

- Explore the interaction between temperature and exploitation rates on the Summer run timing group and determine points in their migration where they might be vulnerable (eg. Ashcroft).
- Explore where in the watershed freshwater catches above Mission may be influential on loss for Early Stuart
- Multiple factors – apply a framework to evaluate the potential impact that variable environmental conditions may have on the assessment estimates of catch, lower river escapement, spawning ground escapements as well as the discrepancy between these estimates. Considerations of uncertainty include stock assignment and variable assessment methods (e.g. Hydroacoustics, CPUE, M/R, visual, landed vs. creel).
- Continue to explore the connection between PSM of early timed groups and DBE for later timed stocks
- Support cumulative effects methods
- Focus on pre-season MA modelling support given the continued high uncertainty of in-season DBE values
- Explore other potentially available fish condition data; annual variability in energy status or pathogens loads

## GLOSSARY

**Conservation Unit (CU)** – Introduced by the Wild Salmon Policy (WSP) of Fisheries and Oceans Canada (DFO), CUs are defined as mutually interchangeable groups of wild salmon with similar adaptations that are reproductively coupled. The units are defined to protect the diversity of wild Pacific salmon and account for achievements in meeting WSP goals.

**Difference between Estimates (DBE)** – The difference between the estimated escapement beyond Mission minus the estimated spawning ground escapement adjusted for the catch upstream of Mission.

**Predicted DBE** – A modelled DBE estimate generated from the MA model (Macdonald et al. 2010) that uses historic discrepancy information and either observed (post-season) or forecasted environmental conditions (pre-season or in-season).

**Revised DBE** – The recalculated DBE based on RSA-escapement and RSA-catch; this DBE value is not used outside of the RSA process (i.e. for MA models).

**En-route Loss** – The loss of a salmon from the ultimate post-season run size estimate. It could be the result of unaccounted for harvest and/or natural mortality.

**En-route Mortality (ERM)** – The mortality of adult salmon from the marine approach areas (Area 20/12) through to their assessment in spawning areas; however, this is typically represented as In-River Mortality given that most of the modelled mortality is upstream of Mission.

**Exploitation Rate (ER)** – The harvested proportion of the total adult returns for a set time period.

**Fishing-Induced Mortality (FIMS)** – Mortality that is directly or indirectly associated with fish interacting with fishing activity. Most common form is capture-and-release mortality, but

incidental capture and escape (e.g. net drop-outs) as well as gear avoidance are also possible.

**Gross Escapement** – The total number of fish escaping past a defined fishing boundary.

**Harvest Rate** – Typically the percent of the abundance of fish (for a fixed time period) in a fishing area (defined by gear, location and timing) that are killed in that fishery.

**In-River Loss** – See En-Route Loss; however, loss (i.e. unaccounted for catch and/or natural mortality) is estimated in river only.

**In-River Mortality** – The mortality of adult salmon that occurs within the Fraser River, typically synonymous with mortality from Mission through to their assessment in spawning areas

**Lower River Escapement** – The number of salmon that escape a fishery and survive to pass Steveston on their spawning migration to natal streams.

**Management Adjustment (MA)** – An in-season harvest adjustment target (i.e. estimate of the number of additional fish required) applied to increase the probability of achieving escapement targets on the spawning grounds (Macdonald et al. 2010).

**Mission Escapement** – The number of salmon that escape a fishery and survive to pass Mission on their spawning migration to natal streams.

**Potential Spawning Escapement (PSE)** – The number of salmon that could potentially reach their natal spawning grounds based on the estimate of escapement past Mission after accounting for catch upstream of Mission.

**Pre-Spawn Mortality (PSM)** – Salmon that die on the spawning grounds prior to successfully spawning. A more precise definition is egg retention estimates, given that PSM is estimated using female carcass observations (Gilhausen 1990).

**Return** – The total number of sockeye salmon of all age classes that return to the fishery for a given year.

**Run Size Adjustment (RSA)** – A post-season adjustment to total run size that estimates the total number of actual fish that were not accounted for in near final escapements and official catch reports. RSA is normally associated with mortality in river.

**RSA-Escapement** – RSA associated with known biases of spawning ground escapement assessment numbers estimated to be greater than 10% of the near final estimate.

**RSA-Catch** – RSA associated with known biases of catch estimates that are estimated to be greater than 10% of the FRP catch estimates.

**RSA-Mortality** – RSA associated with an estimate of en-route mortality.

**Run Size** – The estimated number of adult salmon that returned to the fishery. Pre-season, in-season and post-season run size estimates are assessed each season. The post-season estimate is the sum of the spawning escapement, catch and RSA.

**Run-Timing Group** – A management classification that categorizes returning sockeye salmon into four groups (Early Stuart, Early Summer, Summer and Late) based on their timing of entry into the Fraser River. Major stocks are assigned to each timing group, but stocks can move between years as behavioural information is continually updated (e.g. Harrison to Summers).

**Spawning Escapement (SE)** – The number of adult salmon that escape all fisheries and reach natal spawning grounds.

**Preliminary SE** – Spawning escapement estimates based on in-season data that have not been fully verified.

**Near-Final SE** – Verified spawning escapement estimates available post-season.

**Stock** – A genetically similar group of fish, usually returning to a specific geographic area and/or time period (Beacham et al. 2004).

**Forecasted Stocks** – Nineteen Fraser River stocks that have historic recruitment information. This is used on annual basis to generate forecasts for the next season (Grant et al. 2011)

## **ACKNOWLEDGEMENTS**

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### Appendix A: Subset of the MA Dataset

Stock_Group	Year	Excl	Mission_Escapement	Mission_50_Date	Catch_Above_Mission	PSE	SE	DBE	lnDBE	QMn_31	TN_31	TMn_31	QMn_19	TMn_19
EStu	1977	0	344694	10-Jul-77	87000	257694	117416	-140278	0.78605	4870.0	31.0	15.1	4845.3	14.8
EStu	1978	1	140700	04-Jul-78	56000	84700	50004	-34696	0.527013	4934.2	31.0	16.5	5151.6	15.9
EStu	1979	1	211499	05-Jul-79	63000	148499	92746	-55753	0.470714	5227.1	29.0	15.3	5565.3	14.3
EStu	1980	0	43700	09-Jul-80	7000	36700	16939	-19761	0.773158	4137.4	31.0	16.1	4275.3	15.6
EStu	1981	1	334600	09-Jul-81	135000	199600	138031	-61569	0.368837	4927.4	31.0	15.9	5000.0	14.8
EStu	1982	0	89500	08-Jul-82	41000	48500	4557	-43943	2.364899	7468.1	31.0	15.3	7658.4	15.0
EStu	1983	1	105000	08-Jul-83	53000	52000	23867	-28133	0.778747	5286.8	28.0	15.4	5120.0	15.1
EStu	1984	0	50714	07-Jul-84	9000	41714	48037	6323	-0.141135	6876.8	31.0	13.7	7474.7	12.9
EStu	1985	1	294916	11-Jul-85	73000	221916	237532	15616	-0.068003	4646.1	31.0	16.3	5161.1	15.4
EStu	1986	0	38517	09-Jul-86	14000	24517	28584	4067	-0.153477	5523.9	31.0	15.5	5938.9	14.9
EStu	1987	1	174803	11-Jul-87	21000	153803	148194	-5609	0.03715	4070.3	29.0	17.4	4544.2	17.1
EStu	1988	1	192191	07-Jul-88	26000	166191	179807	13616	-0.078746	4704.8	31.0	16.0	5108.9	15.4
EStu	1989	1	464618	06-Jul-89	190000	274618	384799	110181	-0.33734	4271.3	31.0	16.8	4468.4	16.2
EStu	1990	1	167389	10-Jul-90	51000	116389	97035	-19354	0.181866	6386.5	31.0	15.5	7247.9	14.9
EStu	1991	1	369412	16-Jul-91	177000	192412	141119	-51293	0.310035	5765.2	31.0	16.9	6286.3	16.2
EStu	1992	1	324098	14-Jul-92	145000	179098	66098	-113000	0.996795	3654.8	31.0	18.7	3955.8	17.9
EStu	1993	1	701973	15-Jul-93	212000	489973	688013	198040	-0.339457	3444.8	31.0	17.3	3542.6	16.7
EStu	1994	1	193559	12-Jul-94	36000	157559	29125	-128434	1.688203	5144.5	31.0	17.0	5555.8	15.6
EStu	1995	1	171517	07-Jul-95	6000	165517	122856	-42661	0.298061	4141.9	31.0	17.4	4526.3	16.8

EStu	1996	1	130626	10-Jul-96	2566	128060	87571	-40489	0.380051	6444.8	31.0	15.3	6790.5	14.7
EStu	1997	1	1259456	18-Jul-97	359422	900034	266863	-633171	1.215697	6997.1	31.0	15.9	7655.8	15.3
EStu	1998	1	183679	09-Jul-98	14919	168759	32570	-136189	1.645082	3967.1	31.0	18.7	4145.8	18.1
EStu	1999	1	166908	09-Jul-99	22084	144825	24552	-120273	1.77473	8785.8	31.0	13.8	9346.8	13.0
EStu	2000	1	340279	04-Jul-00	188045	152235	89858	-62377	0.527192	6764.2	31.0	14.9	7061.6	14.1
EStu	2001	1	240556	06-Jul-01	36394	204162	170968	-33194	0.177437	5165.2	31.0	16.1	5020.0	15.9
EStu	2002	1	61310	11-Jul-02	4364	56945	24637	-32308	0.837845	6735.2	31.0	15.8	7518.4	14.8
EStu	2003	1	29486	11-Jul-03	372	29115	13166	-15949	0.793599	4426.1	31.0	17.2	4937.4	16.4
EStu	2004	1	128920	12-Jul-04	32576	96344	9281	-87063	2.339957	3790.3	31.0	18.6	4035.3	17.8
EStu	2005	1	214550	23-Jul-05	16349	198201	98513	-99688	0.699093	4167.4	31.0	17.3	4660.0	16.8
EStu	2006	0	53457	14-Jul-06	5301	48156	35816	-12340	0.296053	3597.1	31.0	18.5	3896.3	17.9
EStu	2007	1	12547	07-Jul-07	789	11758	5347	-6411	0.787981	6817.4	31.0	16.0	7051.8	15.3
EStu	2008	1	38946	05-Jul-08	3557	35389	29808	-5581	0.17163	5439.4	31.0	15.8	6221.6	15.2
EStu	2009	1	82498	05-Jul-09	7197	75301	45297	-30004	0.508251	4692.9	31.0	15.8	4948.9	14.7
EStu	2010	1	100542	11-Jul-10	2577	97965	60262	-37703	0.485907	4111.3	31.0	16.6	4545.8	15.8
EStu	2011	1	24762	10-Jul-11	1686	23077	758	-22710.387	3.43272615	8424.1	31.0	14.0	8904.3	13.4
EStu	2012	0	182478	10-Jul-12	6640	175838	26230	-149608	1.90265932	8066.5	31.0	15.4	8844.7	14.4
EStu	2013	1	180501	09-Jul-13	9323	171177	86262	-84915	0.68530893	5287.7	31.0	17.6	6072.5	16.7
EStu	2014	1	227888	15-Jul-14	20791	207097	68610	-138487	1.10474899	4759.0	31.0	17.8	5068.0	17.5
EStu	2015	0	31933	12-Jul-15	631	31302	10087	-21215	1.13243453	3593.6	31.0	19.5	3998.8	19.8
EStu	2016	0	17884	09-Jul-16	1527	16357	8608	-7749	0.64196394	4369.4	31.0	17.9	4452.9	17.3

## **Appendix B: Excluding Years from the Management Adjustment Model Documentation**

Differences between estimates (DBEs) are calculated from spawning escapement (SE) minus potential spawning escapement (PSE; Mission escapement minus estimates of catches that occur in areas upstream of Mission but downstream of the spawning areas). DBEs can be generated for each management group from 1977 to the present and they form the basis for the expected DBEs used for management adjustment (MA) estimates. However, before DBEs are formally included as part of the MA calculations, data for each year are reviewed to ensure all components are complete and estimates are representative<sup>1</sup>. General principles which guide the inclusion or exclusion of DBE data are reviewed below.

### *Principles that guide data inclusion decisions*

All data are included unless there is a good reason to exclude it. Data are excluded if:

1. The year is not representative.
2. The data collection was not comparable to current practice.
3. The circumstances resulting in the estimates are unlikely to happen again.

Some explanations for excluding data in the past are:

1. The low relative abundance of a management group that has led to possible species and stock composition uncertainty.
2. Incomplete Mission hydroacoustic estimates.
3. Incomplete spawning ground estimates.
4. A biased estimate that was detected but is not expected in future estimates

### *Years excluded from the MA model*

Based on the above criteria DBE data for the years indicated in Table 1 were excluded from any historical MA median calculations and from data sets used to fit MA models

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<sup>1</sup> Ideally the data should be “representative”, but the data set includes estimates from a mixture of different techniques (see Table 3).

Table B1. Years excluded from the MA model

Management Group	Year	Reasons data were excluded
<i>Early Stuart</i>	1977	River test fishery CPUE-based
	1980	River test fishery CPUE-based
	1982	River test fishery CPUE-based
	1984	River test fishery CPUE-based
	1986	River test fishery CPUE-based
	2006	Non-representative in-season Mission estimate
	2015	Low sockeye abundance relative to Chinook and first half of migration estimated from river test fishery CPUE
	2016	Low sockeye abundance relative to Chinook and first third of migration estimated from river test fishery CPUE
<i>Early Summer run</i> <sup>1</sup>	1993	Very low abundance relative to Summer-run and stock ID imprecision
	2006	Non-representative in-season Mission estimate
<i>Summer run</i> <sup>2</sup>	2002	Incomplete spawning ground estimates
	2006	Non-representative in-season Mission estimate
<i>Late run</i> <sup>3,4,5</sup>	1977	Largely test fishery CPUE-based
	1979	Largely test fishery CPUE-based
	1980	Largely test fishery CPUE-based
	1981	Largely test fishery CPUE-based
	1983	Largely test fishery CPUE-based
	1984	Largely test fishery CPUE-based
	1985	Largely test fishery CPUE-based
	1987	Largely test fishery CPUE-based
	1988	Largely test fishery CPUE-based
	1989	Largely test fishery CPUE-based
	1991	Largely test fishery CPUE-based
	1992	Largely test fishery CPUE-based
	1993	Largely test fishery CPUE-based
	1995	Largely test fishery CPUE-based
	2006	Non-representative in-season Mission estimate

<sup>1</sup> The Early Summer run excluding Pitt

<sup>2</sup> The Summer run excluding Harrison

<sup>3</sup> The Late run excluding Birkenhead

<sup>4</sup> When calculating medians for Late run, only years since early upstream timing began (>1996) are included.

<sup>5</sup> When calculating Late-run MA, years excluded are reviewed annually and documented in the Fraser Panel Annual Reports

*Special circumstances: subcomponents of Management Groups.*

In recent years, the Panel has split-out particular stock components from management aggregates to help with particular fishery management challenges. This has resulted in the desire for management adjustment estimates for Chilliwack, Pitt, Harrison and Birkenhead. While the general principles outlined above apply, each component posed unique data challenges. One of the challenges relates to the level of resolution of the stock identification methods used to estimate each component's potential spawning escapement. Since past years' stock identification methods (pre-2003) were based on scale pattern analyses and these components were part of a stock group with similar scale patterns, components usually must be split out from their groups based on relative spawning escapements. The method assumes that components relative to potential spawning escapement (PSE) is the same as its relative spawning escapement. The resulting PSE estimates are therefore not independent of the spawning ground estimates. This method also implicitly assigns the same pDBE to all the components that are assigned to the group, regardless of whether members of the group share a common exposure to river conditions en route to their spawning areas. This source of error is particularly relevant to Pitt, Chilliwack and Birkenhead components which have often been part of a group that included upper river populations (e.g. Nadina, Gates; Early Stuart; Late Shuswap, Stellako, Quesnel) in the scale based analyses.

Chilliwack sockeye have only been uniquely identified when DNA based stock ID was used (post- 2003). Furthermore, estimates of potential spawning escapement are highly uncertain in years when Chilliwack sockeye abundance is small relative to co-migrating stocks because the number of individuals classified to Chilliwack is relatively small. Thus, an additional data quality filter (see Table 2 below) was applied to ensure estimates of DBEs included in the MA data sets were technically defensible.

Pitt sockeye do not pass Mission and thus for many years, Pitt were not included in estimates of Early Summer-run management adjustments. Furthermore, estimates of Pitt potential spawning escapement must be derived from either lower river stock ID samples (i.e. Cottonwood), or marine samples lagged for appropriate travel times. Because of this

circumstance, in-season estimates of the potential spawning escapement of Pitt are particularly uncertain and there were some past years when in-season estimates were replaced by spawning ground estimates, thus invalidating the inclusion of the DBEs for those years. In years of scale-based stock ID, Pitt sockeye were often part of a stock-group that included Nadina and Gates. In some years Pitt may have been split out from its group by comparing Cottonwood (includes Pitt) and Whonnock (excludes Pitt) estimates of Nadina/Gates/Pitt proportions. The above factors explain the need expressed previously to target the Pitt MA data set for further evaluation. This could result in future changes to the years included in the MA data set.

Chilliwack and Pitt are part of the Early Summer-run aggregate.

Harrison sockeye were not consistently identified to stock of origin prior to the DNA years and thus only years with DNA based stock ID are currently included in MA data sets. However, PSC staff could not determine the rationale for why 2002 and 2003 were excluded from the data set based on potential spawning escapement estimates. Thus, the Harrison MA data set likely also requires further evaluation. This could result in future changes to the years included in the MA data set. Harrison is part of the Summer-run aggregate.

Estimates of DBEs for Birkenhead<sup>2</sup> sockeye are available for most past years. A comparison of Birkenhead DBEs pre and post 1995 found that Birkenhead DBEs actually decreased slightly post-1995, so a recommendation was made at that time to use all data pre and post 1995 for Birkenhead (see FRP secure site: [K:\Panel\2011\2011-06-15\\_SunPeaks\2ei\\_FRP2011Late-runmgtOptionsrevisitedJune.pptx](K:\Panel\2011\2011-06-15_SunPeaks\2ei_FRP2011Late-runmgtOptionsrevisitedJune.pptx)). However, estimates of Birkenhead sockeye potential spawning escapement were generated by splitting out Birkenhead from the stock group that it was part of in each past year. This process is not particularly problematic in the years when DNA was used to estimate stock proportions, but would have required assumptions in the scale based years. Depending on the year, the Birkenhead group was part of a larger aggregate that may have included, Late Shuswap (on off lines), Cultus, Stellako, Horsefly, etc. thus the Birkenhead data set should also be further reviewed and documented. This could result in

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<sup>2</sup> Birkenhead refers to Birkenhead, Big Silver and other miscellaneous streams that are part of this stock group.

future changes to the years included in the MA data set. Birkenhead is part of Late-run aggregate.

It is important to note that the DBEs for each of these components are not predicted in-season based on river conditions, but rather remain fixed as median values estimated pre-season. Thus, they impact the DBEs for their respective aggregates through weighted average calculations that depend on their relative abundances. Pre-season, median (p50) forecast abundances are used to determine weighted averages. In-season, these abundances are based on in-season run size estimates as they become available.

Table B2. Description of the years excluded from the MA models for Chilliwack, Pitt, Harrison and Birkenhead.

Subcomponents of Management Groups	Year	Reasons data were excluded
<i>Chilliwack</i>	pre2004 2005 2006 2007 2009 2010 2011 2014 2015	Not uniquely identified prior to DNA Less than 30 fish identified as Chilliwack by DNA Not a Dom/Subdom cycle year Not a Dom/Subdom cycle year Less than 30 fish identified as Chilliwack by DNA Not a Dom/Subdom cycle year Not a Dom/Subdom cycle year Not a Dom/Subdom cycle year Not a Dom/Subdom cycle year
<i>Pitt</i>	1982 1983 1999 2005 2006	In-season estimates were replaced by spawning ground estimates In-season estimates were replaced by spawning ground estimates In-season estimates were replaced by spawning ground estimates In-season estimates were replaced by spawning ground estimates In-season estimates were replaced by spawning ground estimates
<i>Harrison</i>	pre2004 2006	Not consistently identified to stock of origin prior to DNA Non-representative in-season Mission estimate
<i>Birkenhead</i>	1979 2002 2006	Largely test fishery CPUE-based No available spawning ground estimate Non-representative in-season Mission estimate

Table B3. Techniques used for data collection

Techniques used
Single beam acoustics through 2003
Split beam acoustics 2004-present
Right-bank DIDSON estimates included from 2011 onward.
Left-bank DIDSON estimates included 2009, 2011, 2013, 2015 (minimum impact on sockeye estimates).
Larger fractions of sockeye estimated from test fishery CPUE (particularly later in the season on odd years since 2005 due to earlier upstream migration of Late-run sockeye and Fraser pink salmon).
Scale based stock identification through 2002
Genetic (DNA) based stock identification since 2003
The expected threshold escapement triggering the use of high precision techniques to generate spawning ground estimates changed in 2005.