



STATE OF THE  
SALMON PROGRAM

# Fraser salmon cross-species escapement and productivity database for investigating habitat stressors

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## Abstract

Abundance, attribute, and spatial data for Fraser River Sockeye, Chinook, and Coho salmon were organized and consolidated using R Software scripts. A web interface was developed using Shiny and Leaflet packages for R to view, filter, select, and download data from the consolidated data sets. Outputs of this work will be used to support the examination of salmon responses to freshwater habitat stressors, regulation, and restoration measures.

Salmon data were aggregated at the spawning site and WSP Conservation Unit (CU) level, and include: escapement data; unique identifiers for spawning sites and CUs used in DFO's NuSEDS escapement database and spatial data files; recruitment data where available; salmon life-history types (ocean-type, river-type, stream-type, or lake-type), freshwater adaptive zones (FAZ) (Holtby and Ciruna 2007); broad area; run timing; spatial coordinates representing site and CU location; CU boundaries; and stream spatial data.

For each of the three species, R scripts were developed to automate escapement data cleaning, treatment, and aggregation. Through this work, expert knowledge on data quality, gap filling, and changes in site resolution over time, was encoded into scripts. Code scripts also compile and calculate recruitment data for Sockeye and Coho CUs, to integrate into these datasets. An overall wrapper script was developed to integrate these final escapement and recruitment data across species. Integrated escapement and recruitment outputs are organized into two files, at the site and CU level. Separately, salmon life-history types (based on freshwater rearing stages), FAZs, and spatial coordinates were collated also into site and CU level files.

A web interface was developed for data selection through two different tabs, one using drop down menus, and the other using the Fraser watershed stream network maps. This web interface links to DFO's State of the Salmon Synoptic Status Evaluation Tool (SOS-SSET). Through integration within SOS-SSET, escapements and annual WSP status information can also be accessed and explored spatially and temporally, and data can be exported into the SEF-DFO funded State of the Salmon Spatial Pattern Analysis tool (SPAT) prototype (Pestal and Barrus 2020). The web interface can be used with these DFO State of Salmon tools to assist with prioritization and tracking of habitat-related projects, by enabling users to quickly identify, select, and compare data sets from selected areas in the Fraser watershed.

The resulting datasets and web interface from this project will be maintained and updated by DFO's State of the Salmon Program, and will be made available more broadly in the coming years to support tracking of salmon trends and statuses annually within DFO and the PSC. An immediate application being pursued is the updating of synoptic statuses for Fraser Sockeye, Chinook and Coho, to track recent trends, and responses of these CUs to the 2019 Big Bar landslide on the Fraser River.

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# 1 Background

Many salmon populations have been declining, particularly at southern latitudes (Grant et al. 2019b). This includes Sockeye (Grant et al. 2011, 2019a, Grant and Pestal 2012, DFO 2018), Chinook (DFO 2016), and Coho (DFO 2015) Conservation Units (CUs) in the Fraser watershed located in southwestern British Columbia (BC). Many of these CUs are in DFO's Wild Salmon Policy's (WSP) Red status zone (Grant et al. 2011, Grant and Pestal 2012, DFO 2015, 2016, 2018). These Red CUs face an imminent risk of extinction, and result in lost salmon production to support their ecosystems, and fisheries (DFO 2005).

These broad scale salmon trends are linked to climate change (Grant et al. 2019b, MacDonald et al. 2019, Crozier et al. 2019). Earth's land-ocean temperatures have risen by 1°C over the last century, and the last five years were the warmest on record (Morice et al. 2012, Hartmann et al. 2013). These global changes are affecting salmon ecosystems.

Recent warm Pacific Ocean temperatures have caused a deterioration in salmon food quality, as zooplankton communities near the base of food webs become increasingly dominated by smaller, lipid-poor, southern species (Galbraith and Young 2018, Young et al. 2018). In BC & Yukon freshwater ecosystems, river discharges are more extreme, with higher and shorter periods of peak flows, and a greater frequency of drought (Bush and Lemmen 2019, Grant et al. 2019b, MacDonald et al. 2019, Crozier et al. 2019). This can lead to egg scouring, dewatering at egg and juvenile stages, and more demanding adult upstream migrations. These freshwater impacts are expected to increase under climate change, and are exacerbated by habitat changes (Nelitz et al. 2007, McDaniels et al. 2010, Crozier et al. 2019).

Agriculture, mining, urbanization, forestry, and other human land use activities have long been altering salmon freshwater habitats through deforestation and water extraction. This can lead to even warmer river temperatures, greater changes to river flows, and more erosion and landslides, than those caused by climate change alone (Pike et al. 2008, 2010, Cloutier et al. 2016). These habitat effects are more localized, and contribute to variability in the observed salmon trends across populations and CUs.

For example, in recent years there have been several major landslides in Pacific Salmon watersheds that are further compounding the impacts of climate change on upstream salmon populations (Guthrie et al. 2012, Gaboury et al. 2015; Government of B.C. et al. 2019). The Big Bar landslide on the Fraser River has been particularly concerning, as it has blocked upstream access to critical Sockeye, Chinook, and Coho spawning areas since 2019. Work is on-going to remove the blockage and monitor fish passage and health related to this.

Global temperatures are expected to rise 1.5°C to 3.7°C above the 1850-1900 average by the end of this century. The extent that human society curbs our CO<sub>2</sub> and other greenhouse gas emissions will determine where in this range future temperatures fall (IPCC 2013). However, not all salmon CUs will be lost under climate change (Grant et al. 2019b, Crozier et al. 2019).

Humans have the capacity to influence outcomes for some salmon CUs, possibly even under the dire climate predictions (IPCC 2014, 2018, Bush and Lemmen 2019, Grant et al. 2019b, Crozier et al. 2019). Some CUs may be helped by actions related to freshwater habitat regulation and adaptation, one key lever humans can employ to improve salmon responses.

Unfortunately, most habitat-related projects are initiated *ad hoc*, without systematic evaluation of watershed level salmon needs or priorities. Further, salmon responses to freshwater habitat regulation and adaptation activities are generally not monitored, and therefore, limited data are available to refine future actions.

The challenges with our habitat approach have stemmed largely from major gaps in data availability and the absence of frameworks to explore these data. There are aspects of this that we cannot fix, particularly those related to the limited historical freshwater juvenile salmon and habitat monitoring data available for most CUs. However, examining covariation of CU total survival and/or escapement trends tied spatially to their freshwater distributions may assist in understanding how freshwater factors might link to particular salmon trends.

Several publications have examined covariation across particular salmon species survival trends, and linked shared patterns to broader regional conditions (Peterman et al. 1998, Pyper et al. 1999, 2001, Peterman and Dorner 2012, Malick and Cox 2016, Malick et al. 2017, Dorner et al. 2018). However, these rely on one-off, static data compilation exercises, across which data treatments are inconsistent, and knowledge gained through data processing is often undocumented. Further, the resulting data products are not comparable or usable for other analyses, and are not easily updated.

Until now, Fraser River salmon abundance, attribute, and freshwater habitat distribution data have not been organized or consolidated for broad use. They have also not been integrated into an easy data filtering and map selection web interface. These data are managed separately within DFO's species-specific programs, DFO publications, and Government of Canada and BC data portals, in various formats for different types of analyses and purposes.

Through financial support from the PSC Southern Endowment Fund (SEF), and in-kind support from DFO, we have created a system for processing and compiling Fraser Sockeye, Chinook and Coho salmon escapement and recruitment data into consistent multi-species datasets that can be used to investigate inter-species patterns and correlations at the 1) site and 2) CU level. The datasets can be easily updated annually by DFO's State of the Salmon Program to provide users with consistent, up-to-date data across species.

A web interface was developed to enable filtering and selection of data to support investigations of responses of salmon populations to various local habitat stressors, regulation, and restoration actions. This interface was coded using the Shiny and Leaflet packages for R Software. The interface facilitates data selection to support the exploration of spatial patterns in salmon abundance data.

The web interface became a critical part of the current project, recognizing that having a way to select and filter data is key to using the data for their intended purpose: to

explore and compare salmon data at different spatial and temporal scales, to examine their responses to habitat stressors, regulation, and restoration actions.

This mapping interface links to DFO's State of the Salmon Synoptic Status Evaluation Tool (SOS-SSET), through which users may explore the data, as well as WSP status metrics. Data filtered and selected through the web interface can be viewed and downloaded. These selected data can then be used within the SEF funded and DFO supported State of the Salmon Spatial Pattern Analysis tool (SPAT) prototype (Pestal and Barrus 2020).

A first prototype of the SOS-SPAT tool has been completed through 2018-2019 SEF funding, led by Gottfried Pestal, Michael Barrus, and DFO's State of the Salmon Program, Sue Grant & Bronwyn MacDonald (Pestal and Barrus 2020). This tool will be used to visualize and compare trends in data across CUs, populations, and data-types. The previously completed SOS-SSET tool will be used in the coming months to generate updated synoptic statuses for Fraser Sockeye, Chinook, and Coho.

## 2 Methods and Results

### 2.1 Overview

The current project involved consolidating and organizing data for Fraser Sockeye, Chinook, and Interior Fraser Coho. The goal of this project was to automate steps to produce integrated data sets that can be used to track and compare trends across populations and CUs organized by freshwater habitat distributions, to be used with the SOS-SPAT data visualization tool (Pestal and Barrus 2020). These results will enable users to explore, select, and compare salmon data at different spatial and temporal scales to examine responses to habitat stressors, regulation, and restoration actions.

The following Sockeye, Chinook and Coho data were consolidated for the current project:

- escapement data
- unique identifiers for escapement sites and CUs used for identification in NuSEDS
- recruitment data where available
- freshwater adaptive zones (FAZ) (Holtby and Ciruna 2007; Appendix 1)
- broad area location in freshwater (Lower Fraser, Fraser Canyon, Mid Fraser, Upper Fraser, Lower Thompson, and Thompson)
- broad run timing for adult upstream migration (for Sockeye: Early Stuart, Early Summer, Summer, and Late; for Chinook: Spring, Summer, and Fall)
- life history types (ocean-type: immediate migrants with no extended rearing in freshwater as juveniles; river-type: for Sockeye with a juvenile rearing period in rivers; stream-type: for Chinook with a juvenile rearing period in rivers; lake-type: a juvenile rearing period in lakes)

- latitude and longitude coordinates for escapement sites and CU locations
- CU boundaries
- digital Fraser watershed stream spatial data and satellite maps

Escapement and recruitment data are available in the Fraser by site and CU for Sockeye (B. Leaf, T. Cone, & S.C.H. Grant, DFO, B. Davis, DFO, and S. Latham, PSC, and key WSP reports), Chinook (Government of Canada's Open Data web portal NuSEDS database) and Coho (L. Ritchie, DFO). Chinook recruitment data are not available by site or CU level at this time (Brown et al. 2020). Fraser Chum salmon escapement data are not available (J.A. Tadey, DFO, pers. comm.), and Fraser Pink salmon escapement has not been directly assessed since 2001 (Grant et al. 2014).

Data was organized through the following steps:

1. Separate R code was developed for each species to automate escapement data cleaning, treatment, and aggregation steps, to convert data from disparate source files into integrated datasets. Initial work to select and treat escapement data sets were originally done through WSP status assessment work for Fraser Sockeye (Grant et al. 2011), Southern BC Chinook (DFO 2016), and Interior Fraser Coho (DFO 2015). Automation of site selection and data treatment had not been previously conducted and/or finalized. Recruitment data are added to these data sets where available. An overall wrapper code was developed to integrate escapement and recruitment data across the three species to produce two datasets organized at the: 1) site-level and 2) CU-level.
2. Information on life-history, run timing, area, FAZ, and latitude and longitude coordinates were obtained in separate files for each of the three species. These were integrated into two datasets organized at the 1) site-level and 2) CU-level.
3. A web interface, coded using the Shiny and Leaflet packages for R Software, was developed to 1) filter data sets of interest with drop down menus; 2) select CUs and sites on a Fraser watershed stream network map; 3) view and download user selected data.

## 2.2 Data Sources

Escapement data for Fraser Sockeye, Chinook and Coho are obtained from the following three sources:

- Sockeye (source: [Brian.Leaf@dfo-mpo.gc.ca](mailto:Brian.Leaf@dfo-mpo.gc.ca) from DFO's Fraser-BCI Area Stock Assessment Division)
- Chinook: DFO's OpenPortal NuSEDS (New Salmon Escapement Database System) database (<https://open.canada.ca/data/en/dataset/c48669a3-045b-400d-b730-48aafe8c5ee6>)
- Interior Fraser Coho (source: [Lynda.Ritchie@dfo-mpo.gc.ca](mailto:Lynda.Ritchie@dfo-mpo.gc.ca) from DFO's Fraser-BCI Area Stock Assessment Division)

Although the only publically accessible DFO database for escapement data is NuSEDS, we did not use this for Sockeye and Coho, as the datasets managed by Fraser-BCI



Area Stock Assessment staff contain more detailed information than what is uploaded into NuSEDS, and are generally available earlier in the year than NuSEDS uploads. For Chinook, multiple steps of data verification and treatment have been previously identified using NuSEDS data through the Southern BC Chinook WSP biological status evaluation process (DFO 2016). Therefore, NuSEDS was used specifically for Chinook. To update these core data annually, State of the Salmon Program staff, Sue Grant & Bronwyn MacDonald, will access these data from the three DFO sources.

Recruitment data were provided by DFO's Fraser-BCI Area Stock Assessment Division for Sockeye (source: [Brooke.Davis@dfo-mpo.gc.ca](mailto:Brooke.Davis@dfo-mpo.gc.ca)) and Coho (source: [Lynda.Ritchie@dfo-mpo.gc.ca](mailto:Lynda.Ritchie@dfo-mpo.gc.ca)). Details on Sockeye stock-recruitment data are provided in the Government of Canada's open data web portal [https://search.open.canada.ca/en/od/?od-search-portal=Open%20Data&search\\_text=ogden](https://search.open.canada.ca/en/od/?od-search-portal=Open%20Data&search_text=ogden) (Ogden et al. 2015). Recruitment data are not available at this time for Chinook at the site or CU level (Brown et al. 2020).

Latitudes and longitudes for Fraser Sockeye, Chinook and Coho CUs and escapement sites, and associated CU boundaries, were separately obtained from the Government of Canada's open data web portal, and were linked to site and CU data using NuSEDS unique identifiers obtained through DFO's Fraser-BCI Stock Assessment Division staff and NuSEDS. Coordinates do not have to be updated annually, though periodic reviews should be conducted to adjust data sets to changes in data collection and aggregation over time, including adding this data to sites as additional data become available.

Information on life history types, FAZ, run timing, and broad area were aggregated from NuSEDS and Fraser-BCI Area Stock Assessment staff.

## 2.3 Data Cleaning and Treatment Code

### 2.3.1 Overview

We developed code on a species-specific basis to clean and treat the core escapement data described in the previous section. These code pieces produce flat files which are then merged by the species aggregation code. Species-specific data treatment files were necessary in order to update species data independently, as input files are updated by DFO's Fraser-BCI Area Stock Assessment Division and NuSEDS data management staff on different time lines. Additionally, source files differ across species programs in terms of the fields of available data, formats, range of data quality information, and pre-treatments performed by DFO's Fraser-BCI Area Stock Assessment Division staff. Species-specific data cleaning and treatment code can be run individually to align with data updates by species if necessary.

Data cleaning processes primarily ensure that the correct estimates are used for each escapement site, as directed by DFO's Fraser-BCI Area Stock Assessment Division staff. This step also ensures that data are encoded properly, data quality classifications are consistent across and within data sources, and that the correct spawning sites are selected to aggregate into CU totals. Data treatment processes include filtering data by estimate quality, infilling missing estimates, calculating recruits where necessary, and

aggregating population estimates into CU estimates. Coding of both the data cleaning and treatment steps required working back and forth with DFO's Fraser-BCI Area Stock Assessment Division staff to ensure that the correct tasks are performed for each specific data type.

Data cleaning and treatment steps performed by the code package are described in general for each data type, with species-specific details described below. Though options are currently set to operate as described here, the code is built with flexibility to accommodate alternative options with regards to quality filtering, and infilling. Flexibility is described below where it exists. All code was written in R.

### 2.3.2 Escapement

For each species, escapement data are aggregated at two levels: by site and CU. Escapement survey sites are aggregated into CUs using CU lists defined through the WSP processes for each species group. These were obtained from WSP documents and DFO's Fraser-BCI Area Stock Assessment Division staff.

Two types of escapement estimates are generated for each aggregation level: escapements that are appropriate for abundance metrics (abundance-type), and escapements that are appropriate for trend metrics (trend-type). These estimate types are used for calculating WSP metrics, and methods to generate such estimates have been verified for these three species of Fraser salmon through official WSP biological status processes (Grant et al. 2011, DFO 2015, 2016). However, due to the specific data collection programs operated by species, the two types of estimates only differ for Fraser Sockeye. One further subset within the datasets separates wild from total escapements for each estimate type. For Fraser Sockeye, since hatchery contributions cannot be separated for Pitt, and dominate Cultus, hatchery versus wild are not separated. Production channels are also included in Fraser Sockeye data sets and not separated for hatchery versus wild.

In total, there are, therefore, eight types of escapement data for each species:

- total escapements for abundance metrics by CU
- wild escapements for abundance metrics by CU
- total escapements for trend metrics by CU
- wild escapements for trend metrics by CU
- total escapements for abundance metrics by site
- wild escapements for abundance metrics by site
- total escapements for trend metrics by site
- wild escapements for trend metrics by site

### 2.3.3 Recruits

Recruitment and return data are only available for Fraser Sockeye and Coho. They are not currently available for Chinook (Brown et al. 2020). This code package provides recruits at the CU level only, and separates them into wild and total recruits where applicable. Data for Fraser Sockeye are provided by DFO's Fraser-BCI Area Stock Assessment Division in the form of recruits-at-age by stock for fisheries management

purposes. However, these data are managed by the PSC and must undergo some pre-processing by DFO's Fraser-BCI Area Stock Assessment Division staff. The stock aggregates provided primarily align with CUs for Fraser Sockeye, apart from one CU, which is the sum of two stock aggregates (Shuswap-ES CU combines the Scotch and Seymour stocks). Fraser Coho return data are maintained by DFO's Fraser-BCI Area Stock Assessment Division at the spawning site level. These data are converted into recruits and aggregated across sites into CUs, as described in the relevant section below.

### 2.3.4 Attributes

To accompany the escapement and recruit datasets produced through this project, we collected CU and spawning site attributes from DFO's Fraser-BCI Area Stock Assessment Division, and the Government of Canada's Open Data web portal NuSEDS database. Attributes include unique identifiers for spawning sites used to identify sites in NuSEDS, life history types, as well as geographical information in the form of latitude/longitude coordinates, and Holtby & Ciruna (2007) FAZs. This information is used in applications of this dataset to feed into the mapping interface, described in subsequent sections.

## 2.4 Fraser Sockeye

### 2.4.1 Escapement Estimates

Fraser Sockeye escapements are available as a DFO flat file containing all site estimates from 1950 to 2018 for most populations, though there are exceptions. Only two Fraser Sockeye CUs have hatchery supplementation: Pitt Sockeye, and Cultus Sockeye. Pitt Sockeye escapements are not assessed separately for wild versus hatchery fish, and the contributions of hatchery fish have declined in recent years (R. Galbraith, DFO Salmonid Enhancement Branch, pers. comm.). Cultus Sockeye escapements are assessed separately for wild versus hatchery fish, however, only a total number is provided in the escapement flat file. Regardless, most Cultus fish in recent years are hatchery origin, and are not considered wild, regardless of whether they have hatchery fin clips or not.

For Fraser Sockeye only, escapements are estimated more precisely through the inclusion of the spawning success for a population. Spawning success is calculated as the proportion of eggs (0%, 50%, or 100%) successfully spawned, based on spawning ground surveys of female carcasses.

Effective total escapements are used for abundance-type estimates, because these metrics are used by fisheries management and other processes, therefore total escapements are most relevant. Effective total spawners is the total adult (male + female) escapement multiplied by the spawner success.

Effective female escapements are used for trend-type estimates for Fraser Sockeye because these data more precisely represent the annual reproductive capacity of the

population. Effective female spawners is the female escapement multiplied by the spawner success.

#### 2.4.2 Site Escapements

Fraser Sockeye escapement estimates by site are taken directly from the DFO flat file. No gap filling is conducted for these sites at this stage. This provides the basic escapement data by year and site.

#### 2.4.3 CU Escapements

CU-level escapement estimates are generated by summing escapements across consistently assessed sites within the CU (Grant et al. 2011). A site had to be 'consistently assessed', meaning the site had to be assessed for greater than 70% of the time-series between 1950 and 2009 to be included (Grant et al. 2011). Effective female escapements are used as the escapement data for trend metrics, while total effective escapements are used for abundance metrics.

Gap infilling is performed on the effective female escapement estimates to ensure that data are comparable throughout the time-series (Appendices 2 & 5 of Grant et al. 2011). This is done only to produce the escapements for trend analyses. Years for which escapement data are missing are infilled using one of two methods: cycle-line average method and the mean proportion method. The cycle-line average method is for CUs with only one site, or for CUs with multiple sites where no sites have escapement estimates in a given year. Using the cycle average method, abundance estimates for any missing year (e.g. 1942) are interpolated by inserting the mean of the same cycle year (4-year cycle) from the immediately previous (e.g. 1938) and subsequent generation (e.g. 1946). If the cycle year of either of the closest two generations is missing (i.e., 4 years previous or subsequent to the missing point), the corresponding cycle year no more than two generations away (e.g. 1934 & 1950) is used to calculate the mean. This is explained in Appendix 5 of Grant et al. (2011).

The mean proportion method is used for missing data points in CUs with multiple sites that are spatially proximate and correlated in terms of abundance (Grant et al. 2011, Appendices 2 & 5). This approach fills gaps based on the proportion each site contributes to the total group abundance, when averaged across years for which data are available for all populations. In addition, for highly cyclic stocks, the gap filling approach separates dominant and subdominant years (and in some cases also weak cycle years), since site proportions vary by cycle year (e.g. for Shuswap Complex-L the dominant and subdominant cycles are gap filled and for Takla-Trembleur-ESTu all cycles are separated and then gap filled) (Appendices 2 & 5).

A full explanation of data treatment methods, including where gap filling occurs for each site and CU, and specific gap filling methods used for each CU, is provided in Appendices 2 & 5 of Grant et al. (2011).

Escapements for abundance metrics are not gap filled, except for years with large gaps, which are gap filled by the PSC, and retained in DFO files. All effective total escapements across all sites for each CU are summed together from the DFO flat file.

#### 2.4.4 Recruitment Estimates

Fraser Sockeye recruits are sourced from the stock-recruitment brood year tables provided by DFO's Fraser-BCI Area Stock Assessment Division. DFO's Fraser-BCI Area Stock Assessment Division receives these data from the PSC (S. Latham) as a production file. This file contains recruit data by age, aligned to brood year. Recruitment is the sum of DFO escapement & catch, where escapement and catch data are aligned using PSC stock identification and age data. In the past decade, estimates of Sockeye en-route mortality during upstream migration to natal spawning grounds are also added to the recruitment estimates (Grant et al. 2011).

#### 2.3.5 Code Flexibility

The processing code for the Sockeye data is set up for easy adaptation to future updates and modifications. Matching sites/populations across source files (DFO Fraser-BCI Area data and nuSEDS data) is done through a versatile sequence of text string matching that generates minimalized identifiers (e.g. remove blank spaces and underscores, convert to lower case, change "River" to "R" etc.). Site-to-CU matches are done based on a stand-alone lookup file in csv format that can be easily shared for review and updated.

### 2.4 Chinook

#### 2.4.1 Escapement Estimates

Fraser Chinook escapements are sourced from NuSEDS, and subsequently undergo several stages of treatment. Start years vary by site and CU, and are available up to 2018. Prior to this project, persistently assessed Chinook sites were identified by the WSP working group in preparation for the WSP biological status assessment of SBC Chinook. The WSP working group reviewed available data and local knowledge to identify Chinook sites that were persistently and consistently surveyed. These sites were used for the WSP assessment, and are used for this project.

Code has been developed to prepare persistent Chinook sites through a series of steps. Step one pulls escapement data for persistent sites from NuSEDS and merges in other data sources, such as records from the Salmon Enhancement Program (SEP) database (EPAD), or verified data from the 2012 Southern BC Chinook WSP process. A set of decision rules was created through the WSP assessment process to inform how this would proceed (Brown et al. 2020). Data are then filtered based on NuSEDS quality classifications, dropping levels with data quality of level 5 (relative abundance) or lower. Records pulled in from the Salmon Enhancement databased (EPAD), and verified WSP data are not dropped. Missing data are then infilled using the methods described by English et al. (2007). Since Southern BC Chinook are heavily enhanced, one further step corrects estimates for enhancement. Estimates are multiplied by the squared proportion of natural escapements ( $pNOS$ )<sup>2</sup>, calculated across all years of data.

### 2.4.2 Site Escapement

Site-level estimates are generated as above. Estimates are retained prior to the pNOS correction to get total escapements, while estimates corrected for pNOS are wild escapements.

### 2.4.3 CU Escapement

Persistent sites are summed across CUs as defined through the WSP process. As above, estimates adjusted for pNOS are used for wild escapements, while uncorrected estimates are used for total escapements.

### 2.4.4 Recruitment Estimates

Recruitment estimates are not available for Fraser Chinook at this time.

### 2.4.5 Code Flexibility

The processing code for the Chinook data is set up for easy adaptation to future updates and modifications.

Site-specific and CU-specific lookup files have been developed through previous processes (Brown et al. (in prep)) and are available in csv format that can be easily shared for review and updated. These lookup files document not only how sites are matched to CUs, but also capture expert knowledge about individual data sets (e.g. whether a site has persistent surveys of adequate quality for inclusion in the analysis).

Data processing for Chinook data includes several steps, and each step has been set up for easy updating and revisions (e.g. to test the effect of alternative assumptions), specifically:

- Infilling criteria (i.e. how many of the sites have to have data before you can fill in the missing records). For example, in a CU with 8 persistent sites, if the setting is 0.5, then at least 4 sites must have data in order to infill the other 4 sites.
- Quality filtering criteria (e.g. exclude records with nuSEDS quality rating of 5 or worse)
- Enhanced contribution calculation criteria (e.g. which subset of records to use to calculate the proportion of hatchery influence).

## 2.5 Coho

### 2.5.1 Escapement Estimates

Interior Fraser Coho escapements are sourced from the Fraser-BCI Stock Assessment Division, as this is the most up-to-date source of data (DFO 2015). Coho escapements are available starting from either 1975, 1983/4, or 1998, depending on the CU. Data are

available up to 2018. All Coho data have been truncated to start at 1998 onwards, as estimates prior to 1998 can be heavily infilled, and only data back to 1998 were verified through the WSP process. This was because escapement survey coverage increased in 1998 for all Fraser Coho CUs (L. Ritchie, DFO, pers. comm.; WSP CSAS Research Document, unpublished).

Code was developed to automate data filtering according to quality restrictions defined in the 2014 WSP process, and to infill where estimates are missing. Spawning sites are filtered out of the dataset based on WSP data quality requirements. Sites are removed if they have Type-5 data quality or lower for more than 50% of the time-series between the start year and 2013 (pers. comm. Lynda Ritchie, Fraser Stock Assessment, October 11, 2019).

DFO's Fraser-BCI Area Stock Assessment Division previously completed infilling of the provided dataset using the English et al. (2007) method to infill years with missing, or with Type-5 or lower, data, up to 2017.. The Coho cleaning and treatment code automates infilling where estimates are missing or removed, beginning in a user-defined year. Currently this process only needs to be executed for the 2018 data.

### 2.5.2 Site Escapements

Site-level Coho escapement estimates are used as-is, after the data treatment processes described above. Only total escapement estimates are available; separate estimates are not generated for wild escapements.

### 2.5.3 CU Escapements

To get CU-level estimates for the five Interior Fraser Coho CUs, escapements estimates are summed across sites within each CU, using the escapement data described above for the sites selected based on the data quality criterion. The enhanced contribution for each CU is calculated as the annual ratio of the hatchery returns to total returns provided by DFO's Fraser-BCI Area Stock Assessment Division. Natural escapements are then calculated by multiplying the total escapements by the natural contribution (1 – enhanced contribution), and are categorized as wild in our dataset.

### 2.5.4 Recruitment Estimates

Fraser Stock Assessment provides Interior Fraser Coho returns at the level of spawning site, separated into wild and hatchery components. In the Coho code, sites used are filtered based on the escapement data quality specifications described above. Returns are summed across sites to get CU-level estimates. Age-structured recruits are calculated from the returns by multiplying by the average age proportion of pre-fishery returns for each CU. This information is provided in the WSP documentation (L. Ritchie, DFO, pers. comm.; CSAS Research Document, unpublished).

### 2.5.5 Code Flexibility

Coho code is separated into a series of functions, each performing one step of data preparation and treatment. These functions are generic to some degree, and can be

chained together and customized as needed, to be used in different contexts. Escapement data can be produced at the site level or CU level, filtered according to user-selected data quality, infilled starting at a user-defined year or not infilled, and truncated to cut off early estimates that are inappropriate. Recruits can be produced using the same selections, though infilling is not run.

## 2.6 Species Aggregation Code

The aggregation code is a stand-alone R script. The species aggregation code reads in flat files produced for each species by the data cleaning and treatment steps, and merges these into two multi-species datasets: 1) merged site data; and 2) merged CU data. Each of these files contains the four sub-types of escapement data (abundance-type wild estimates, abundance-type total estimates, trend-type wild estimates, and trend-type total estimates), and two sub-types of recruitment data (wild and total) across the three species, where available.

## 2.7 Web Interface

### 2.7.1 Interface Description

The web interface was developed using the Shiny and Leaflet packages for R Software. This was a critical component of the current project, necessary to integrate abundance, attribute, and spatial information for effective filtering and selection of data.

The web application pulls together digital Fraser watershed stream data from the BC Freshwater Atlas (<https://www2.gov.bc.ca/gov/content/data/geographic-data-services/topographic-data/freshwater>), spatial information on location and boundaries of CUs and sites available through Canada's Open Data web portal, and the data files created through this project. It is intended to (1) provide a simple intuitive portal to the data that allows users to view and filter based on spatial context, as well as other criteria (2) provide some basic preview capabilities (3) allow users to apply analytical tools developed in the SOS-SSET context and (4) prepare and extract datasets for further analysis via SPAT or other tools.

The web interface provides a set of selector widgets that allow users to select the type of escapement data of interest and also provides the option to filter data based on species, life history characteristics, and other CU attributes collected and curated as part of this project (Figure 1). The default setting is to include all the Sockeye, Chinook and Coho data available. This is the first tab a user encounters when accessing the Fraser salmon data within the web interface.



Start here: Choose the data you want to work with

**Step 1: Filter data**

By DataType:	SpnForAbd_Total
By Species:	3 items selected
By Freshwater Adaptive Zone:	8 items selected
By Area:	6 items selected
By Run Timing:	7 items selected
By Life History Traits:	5 items selected
By Average Generation Length:	4 items selected
By Conservation Unit:	43 items selected

Figure 1. First tab on the web interface filters data based on user specifications. This includes data type (see section 2.3.2), species (Sockeye, Chinook, Coho), FAZ (see Appendix 1), area (Lower Fraser, Fraser Canyon, Mid Fraser, Upper Fraser, North Thompson, Thompson), run timing (Sockeye: Early Stuart, Early Summer, Summer and Late; Chinook: Spring and Fall), life-history traits (ocean-type: immediate migrants with no extended rearing in freshwater as juveniles; river-type: for Sockeye with a juvenile rearing period in rivers; stream-type: for Chinook with a juvenile rearing period in rivers; lake-type: a juvenile rearing period in lakes). This determines what data are included in the mapping and data view and download tabs. The default setting is to include all Fraser Sockeye, Chinook, and Coho data available.

The second tab in the web interface is the Fraser watershed mapping tab (Figure 2). This mapping view defaults to presenting all the data, unless the user selects particular data sets in the first tab (Figure 1). The interactive map of the Fraser watershed serves as both a visualization and a data filtering tool, and is the core of the web interface (Figure 2).

Users can interact with the map to zoom and pan to specific areas of interest, and control visibility of different layers (CUs, CU boundaries, sites, streams, satellite imagery). Users can also select/highlight CUs and sites in the map in various ways, either through selection of individual sites/CUs (by clicking on individual markers), or through group selection, by drawing shapes. Selection is also possible by stream reach, via clicking on a point on the stream network, which selects/highlights all CUs (and, optionally, sites) upstream of the identified point.

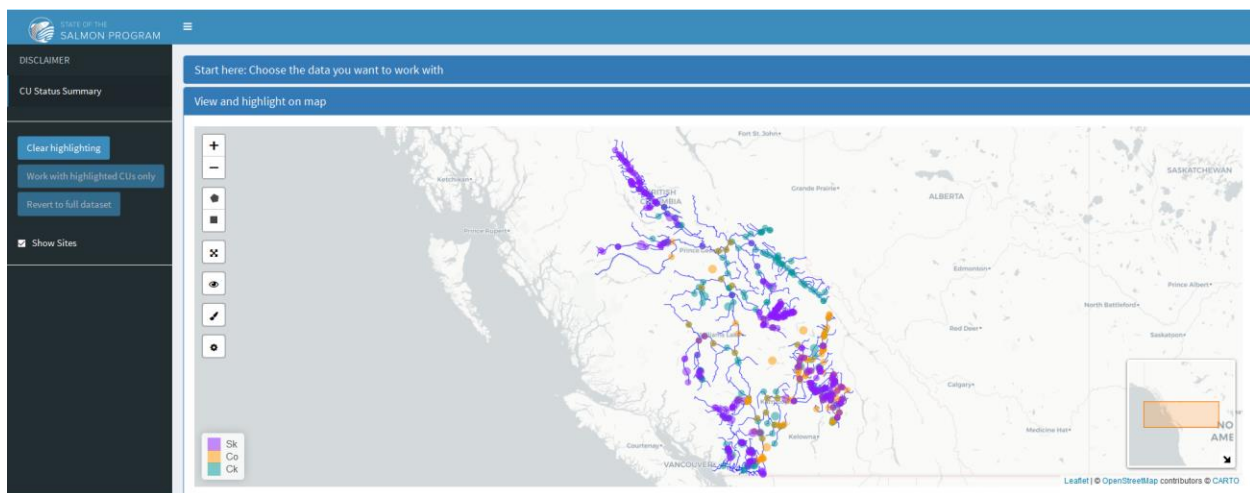
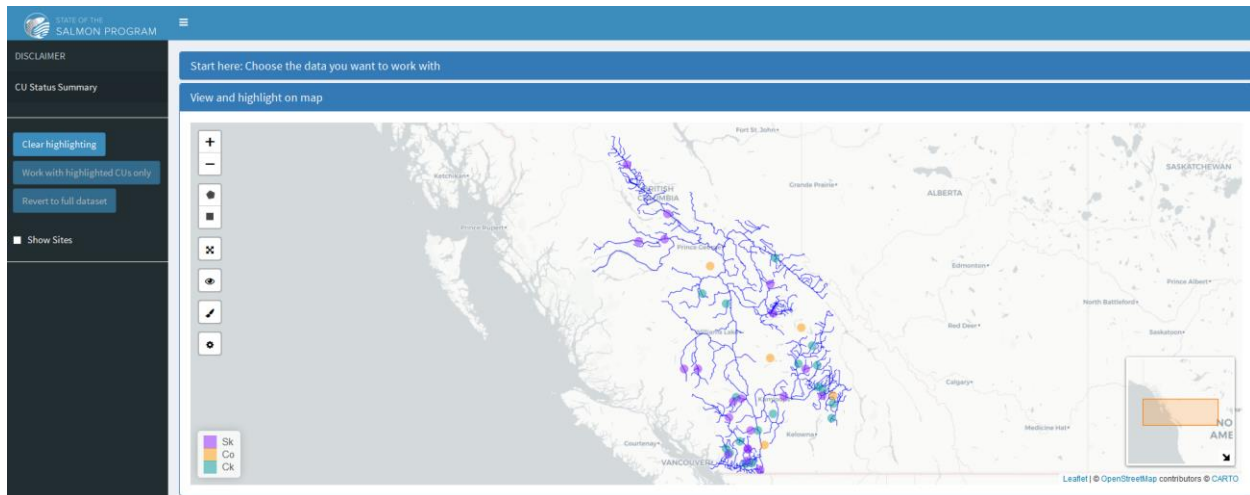


Figure 2. Second tab on the web interface that presents either CU information when CUs are selected in the left black panel (top image), or site information when populations are selected in the left black panel (bottom image). The user can control map layers, select and filter for particular CUs or populations, and zoom into particular areas within this watershed.

To enable upstream selection, a custom stream dataset had to be created that combines digitized stream courses from the BC Freshwater Atlas with information on CU and site location. Line segments representing stream reaches were extracted from the BC Freshwater Atlas and split up at entry points of tributaries and side channels, and site and CU information was attached to the resulting coverage using a series of GIS overlay operations. A new hierarchical code, conceptually similar to the code used in the BC Freshwater Atlas, serves as a unique identifier for each newly created segment and also encodes the connective relationship between segments. This code provides the foundation for algorithmic traversal of the custom stream coverage and thus forms an integral part of the spatial data structure necessary to implement upstream selection.

In addition to allowing users to filter and highlight data based on different selection criteria, the app also provides some basic visualization of time series data. Stacked interactive sparkline widgets allow for quick side-by-side comparison of historical escapement patterns and also give users the option to drill down from there to individual data values (Figure 3).

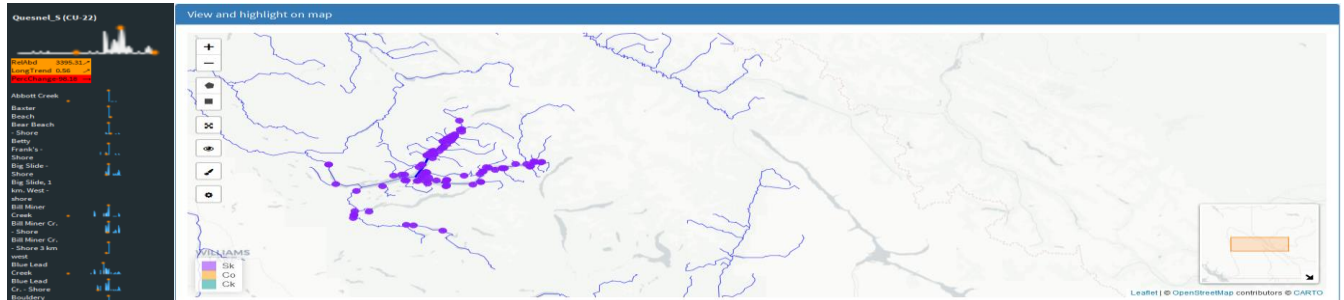


Figure 3. Map interface zoomed into the Quesnel CU sites selected as indicated by the purple filled circles. The sparklines on the left of the map showing escapement data for sites within the time series. The minimum and peak years are highlighted on the sparklines in orange. These are interactive, so you can hover over years presented in the sparkline time series to see the escapement value. Only a subset of sites is presented in this figure, all sites can be viewed by scrolling down on the black area on the left.

Finally, users can also view data in table format (Figure 4). The data table view provides yet another mode of data filtering and selection, by giving users the option to sort CUs and sites by attribute and highlight CUs/sites by selecting the corresponding table rows (Figure 4). The CUs/sites highlighted in this way are also automatically highlighted on the map on the second tab (Figure 2), and the associated time series data are shown in the preview pane. The table view further provides the option to export custom datasets generated through the web interface to csv for further analysis.

Pop_ID	MapData_Species	TimeSeriesData_Species	Species	MapData_Pop_Name	GEO_FEATUR	Lat	Lon	FAZ_ACRO	MAZ_ACRO	JAZ_ACRO	TimeSeriesData	
CK-03.46034	46034	CK	CK_SBC	Ck	HARRISON RIVER	Stream	49.21890306	-121.9450663	LFR	GStr	LFR+GStr	HARRISON RIVER
CK-04.46101	46101	CK	CK_SBC	Ck	BIRKENHEAD RIVER	Stream	50.30644079	-122.6070114	LILL	GStr	LILL+GStr	BIRKENHEAD RIVE
CK-04.46111	46111	CK	CK_SBC	Ck	GREEN RIVER/LILL	Stream	50.30147365	-122.7224003	LILL	GStr	LILL+GStr	GREEN RIVER
CK-04.69055	69055	CK	CK_SBC	Ck	RYAN RIVER	Stream	50.3589405	-122.8356076	LILL	GStr	LILL+GStr	
CK-04.69350	69350	CK	CK_SBC	Ck	COQUITLAM RIVER	Stream	49.22648915	-122.8055618	LFR	GStr	LFR+GStr	

Figure 4. Final table tab to view and download data filtered from tab 1 and tab 2. This outputs .csv file that can be used directly by SOS-SSET or SOS-SPAT data visualization tools or other user-specified purposes.

### 2.7.2 Integration with Analytical Tools

The web interface utilizes Shiny reactive data structures and Crosstalk to integrate the database interface with the analytic toolbox developed in the context of SOS-SSET, with the intent to provide a seamless user experience through an integrated, easy-to-use online tool. The web interface also provides the option to export both time series and attribute data in csv for further analysis in SPAT or other tools.

### 2.7.3 Code Flexibility

The Shiny app is organized into modules for expandability and ease of maintenance. Customization of the user interface is abstracted as far as possible from the functional implementation, and customization options are combined into a separate file for easy access. A 'Shared Components' module isolates functionality necessary for data access and live integration through Shiny reactive data structures. By utilizing the interface provided in this module, additional analytical tools can easily be added to the current code base and integrated into the web interface, without requiring modifications to the existing code base. Although some of the current functionality is specifically tailored to the Fraser context, integration of additional species and management areas would require only relatively minor changes to the code.

The custom stream coverage at the heart of the map interface was created through a stand-alone process. Most of the workflow for generating this coverage has been incorporated into a stand-alone R script and is thus easily repeatable if/when spatial information is updated, though some pre-processing of the spatial data sources was done manually in QGIS, primarily to cut down on processing time. Since the R script was written to be generic, the process could also easily be adapted to create appropriate coverages for other species and/or areas.

## **3 Summary of Outputs from the Current Project**

Through this project we developed the following in order to enable examine salmon responses to freshwater habitat stressors, regulation, and restoration measures by feeding into the SOS-SSET and SOS-SPAT data visualization tools:

- 1) a code package that automates the cleaning, treatment, and collation of Fraser Sockeye, Chinook and Coho escapement data, creating analysis-ready output files, with multiple times-series' for each species, incorporating various data treatments appropriate for different analyses. The code package is written in separate pieces so that each species may be updated and merged into the final data files as species data become available. In such, the final data files can be kept as up-to-date as possible, using consistent methods over time. This automation will improve the efficiency of data preparation, and appropriate use of these datasets.
- 2) A centralized data store of Fraser Sockeye, Chinook and Coho salmon data, compiled from individual species datasets through wrapper code. This includes

information on spawning escapements, recruitments where available, and data quality; these data are collated into two files organized at the 1) the site; and 2) CU level.

- 3) Attribute files containing geographic information at the spawning site and CU-level, accompany the biological data files produced. This includes life-history, FAZ, and latitude and longitudes for sites and CUs. The additional information in these files are used to group populations at varying geographic scales within the Fraser watershed. Two files are also organized for these data also at the 1) site; and 2) CU level.
- 4) A web interface to enable the filtering and selection of data to support investigations of responses of salmon populations to various local habitat stressors, regulation, and restoration actions. The web interface was coded using the Shiny and Leaflet packages for R Software, was developed to enable data filtering and selection through: 1) drop down menus on a filtering tab; 2) site and CU selection on a Fraser watershed map tab. Selected data can be viewed and downloaded on subsequent tabs. This mapping interface links to DFOs State of the Salmon Synoptic Status Evaluation Tool (SOS-SSET) through which users may explore the data. Data selected and filtered through the two SOS-SSET tabs (drop down menu and map) can be viewed and downloaded in a third tab. These selected and filtered data can then be used within the SEF funded and DFO supported State of the Salmon Spatial Pattern Analysis tool (SPAT) prototype.

## 4 Applications

Outputs from this code package can be used by scientific staff within DFO and the PSC staff, and PST process to evaluate trends in spawning escapements, and survival where recruitments are available, across salmon populations that co-occupy habitats. Data can be accessed by scientists and used independently to answer their research questions regarding cross-species patterns. In such, users may identify areas where there may be habitat-related factors limiting productivity across populations and/or species.

Outputs from this project are also directly functional within the toolkit being developed by DFO's State of the Salmon Program. The State of the Salmon Program has developed two data visualization and analysis tools, with funding support from the Salmon Endowment Fund and DFO's Salmon Enhancement Program: the State of the Salmon - Synoptic Status Evaluation Tool (SOS-SSET), and the Salmon Pattern Analysis Tool (SPAT). Biological and geographical data prepared through this project can be operationalized within both of these tools to explore trends in Fraser salmon.

### 4.1 State of Salmon-Synoptic Status Evaluation Tool (SOS-SSET)

The Synoptic Status Evaluation Tool (SOS-SSET) presents data visualizations and allows users to interact with two types of data: escapement, and WSP metrics. Prior to

this project, SSET was populated with solely Fraser Sockeye escapements and WSP metrics, since these were easily accessible, and metrics were formally updated recently, in 2017, through a CSAS process (DFO 2018, Grant et al. 2020). These data sets for Fraser Sockeye were static, did not include recruitment or other attribute data, and updates were not automated or integrated with other species. WSP metrics have also been available for Fraser Chinook and Coho, though they were calculated less recently, through WSP processes in 2012 for Fraser Chinook (included in Southern BC Chinook) and 2014 for Interior Fraser Coho.

Code was developed through a previous project to automate calculation of WSP metrics using the data format produced by this SEF project. As such, the new data outputs generated from this current project have been run through the WSP metric code to update WSP metrics for Fraser Sockeye, Coho, and Chinook CUs up to 2018. The WSP metrics code package can now be used in tandem with the current data preparation and organization code package to annually update datasets used within SOS-SSET, providing users with up-to-date escapement data and WSP metrics across all three species of Fraser salmon. Note that WSP metrics are only calculated at the CU level; only escapement data is presented for spawning sites within SOS-SSET.

The web interface developed through this project has been incorporated within the body of the original SOS-SSET application. In the first tab, data selection can be conducted by data type, species, FAZ, Area, run timing, life-history traits, average generation length, and CU (Figure 5).

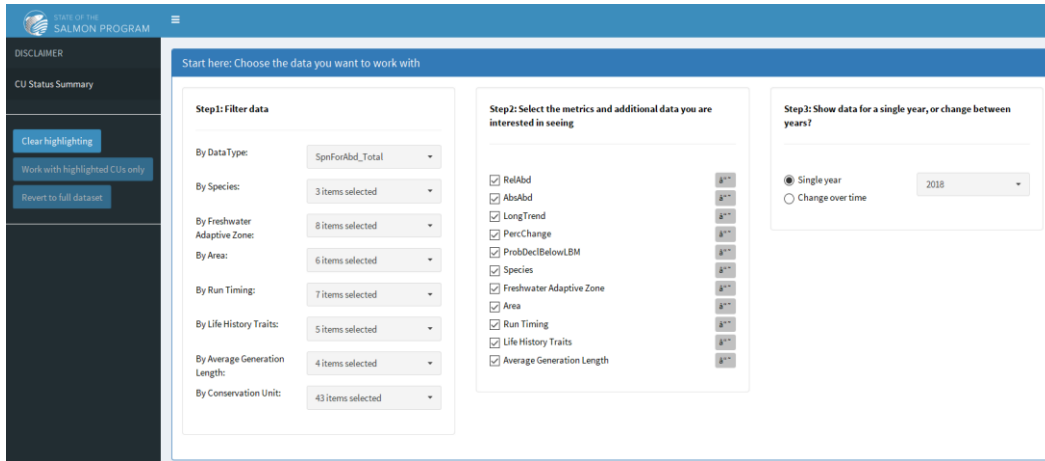
Selected data in the first tab appear in the second mapping tab to enable spatial data exploration and selection at the escapement site (also referred to as population) and CU level (Figure 6). The second mapping interface tab enables interactive data selection through multiple means: clicking on CU or spawning site markers, drawing polygons over areas of interest, or clicking on stream networks to select upstream sites or CUs (Figure 7) [Covered in 2.7 above]. The tool allows users to explore data at various spatial scales, ranging from individual sites to watersheds. Display of sites overlaid over the most recent satellite imagery allows users to visually evaluate and select sites with relation to land use and natural disturbances.

When escapement sites are shown within SOS-SSET, users may select sites to view time-series plots of escapements linked to that site for each species present. They can also identify the corresponding CUs for the sites, and by clicking on the CU marker, can view escapement time-series plots for all sites within that CU, and the appropriate CU time-series generated by the data preparation code (Figure 8).

At the CU level, colours can also be set on the mapping tab to reflect Red, Amber or Green WSP statuses for different metrics (short-term trends, long-term trends, integrated statuses) for each CU (Figure 9).

When CUs are selected, the selection carries through into subsequent tabs within SOS-SSET where users may further interact with, and download, this data. In the download tab of the tool, users can view data for selected CUs in a table, and can download either the WSP metric values, or the underlying escapement data for either the selected CUs only, or the entire dataset. When sites are selected, escapement data for the selected sites or the full dataset may be downloaded (Figure 10).

a)



b)

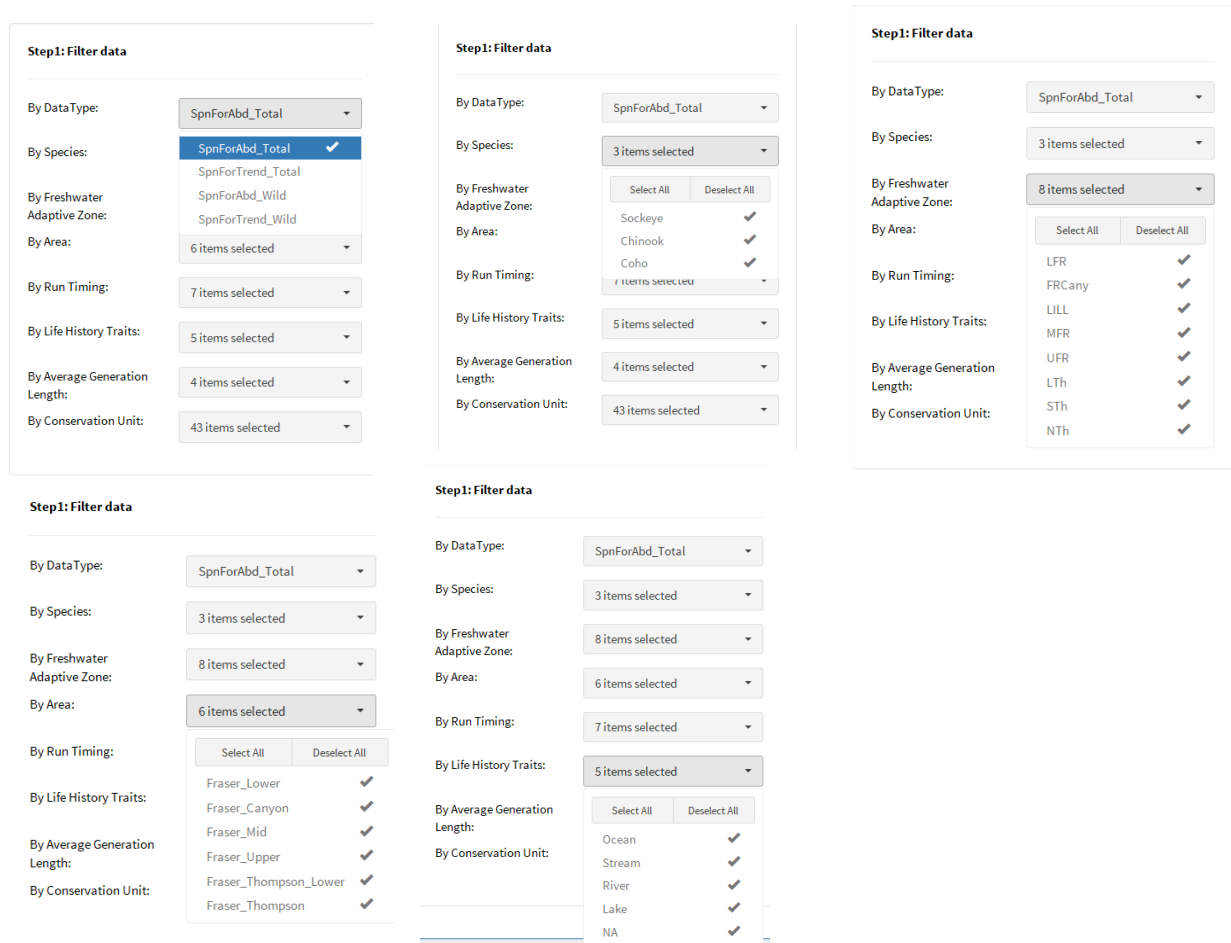


Figure 5. Data selection tab. This tab filters the data being used in subsequent tabs using drop down menus: A) select the attributes and metrics to show. Select the last year of data. B) Specific drop down menus for the data filtering step. Data may be filtered on the data type, species, FAZ, area of the watershed, run timing, life history type, generation length, or CU. The default setting is to include all the available data in subsequent tabs.



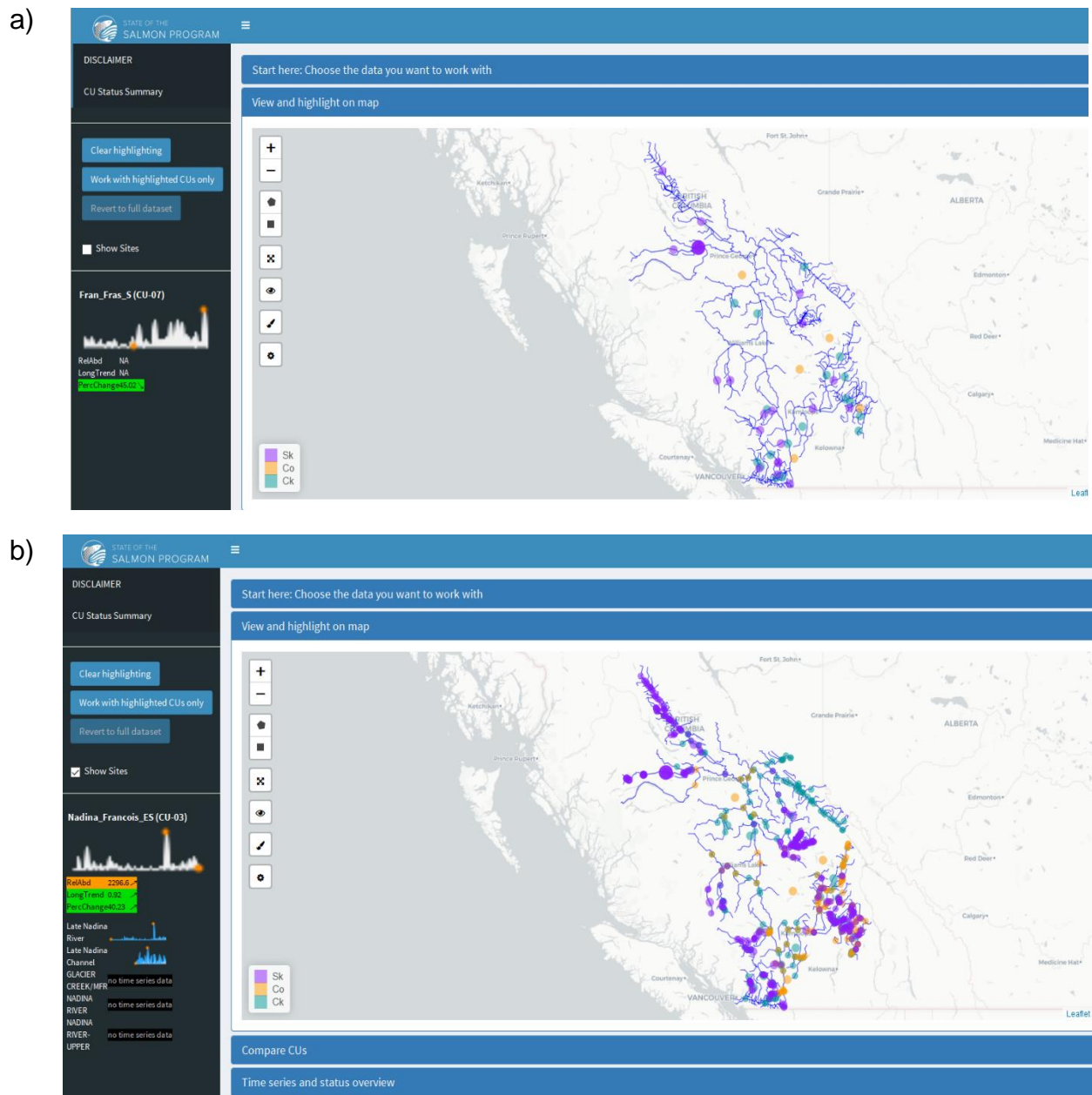


Figure 6. Map interface inset within SOS-SSET. Panel a) shows Fraser salmon CUs by location for sockeye in purple, coho in yellow, and Chinook in blue. Users may select CUs by clicking on circle symbols, drawing polygons on the map, or selecting the stream network. This will highlight selected CUs, which generates CU time-series plots and a table of WSP metrics on the left side panel for those highlighted, and highlights these CUs in subsequent tabs within SOS-SSET where users may further interact with this data. Panel b) shows escapement sites on the map, which may be used to select sites to view associated time-series, or select CU markers associated with sites, to view each site time-series within the CU and the aggregated CU time-series and WSP metrics.



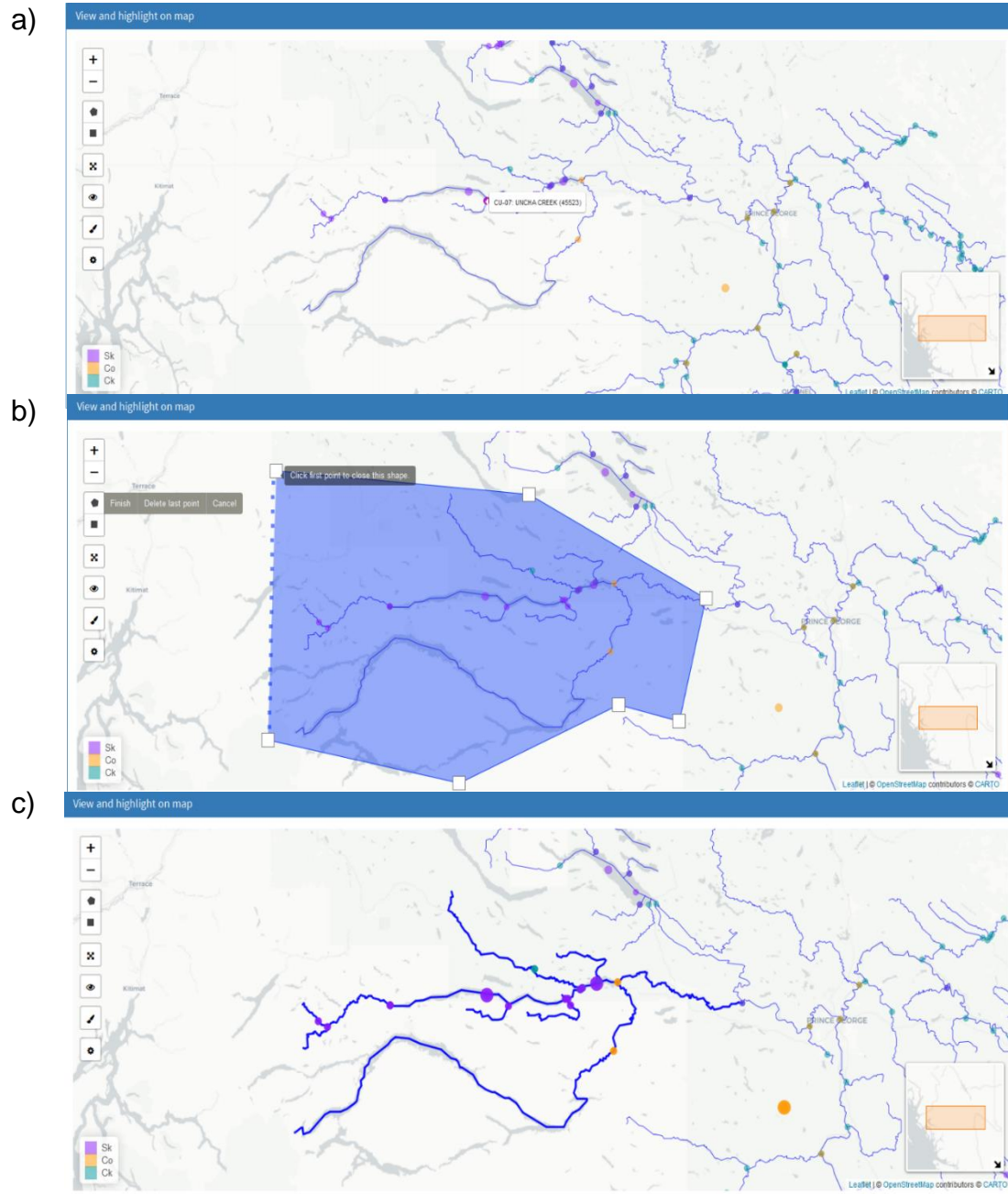


Figure 7. Methods of selection. Screen grabs show the three methods through which sites and CUs may be selected. A) Sites are selected on an individual basis by clicking on the site markers, here shown for Uncha Creek. B) Sites are selected by drawing a polygon around the area of interest, here the Nechako drainage above the confluence with the Stuart River is included within the polygon and all sites within the area will be highlighted. C) Sites are selected using the river network, here all sites in the Nechako drainage above the Stuart River are selected by clicking on the Nechako River upstream of the Stuart River confluence.

**Sites currently highlighted**

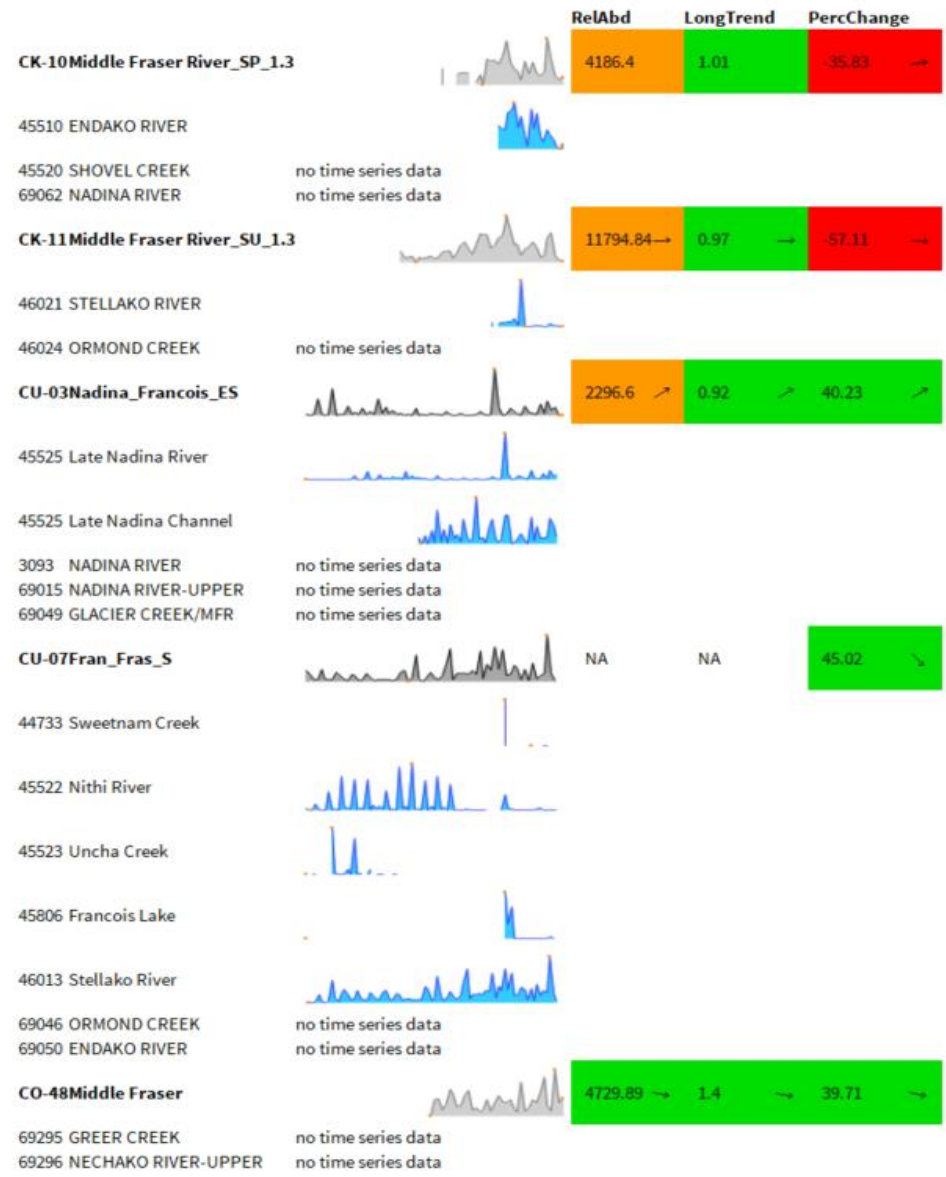


Figure 8. Escapement time-series and WSP metrics for sites selected in Figure 2c.. Escapement time-series sparklines are shown for each site, where available (blue), along with the CU escapement time-series (grey). WSP metric values and associated colour zones are shown for the selected CUs. Details of metric calculations and benchmarks are specific by species, and are defined in their corresponding WSP implementation documents (Grant and Pestal 2012, DFO 2015, 2016). Metrics are as follows: RelAbd = Relative Abundance (current escapement in the most recent generation compared to upper and lower abundance benchmarks); LongTrend = Long-term Trend (ratio of the escapement in the most recent generation to the long-term average); and PercChange = Percent Change (average percent change over the most recent three generations of smoothed data).

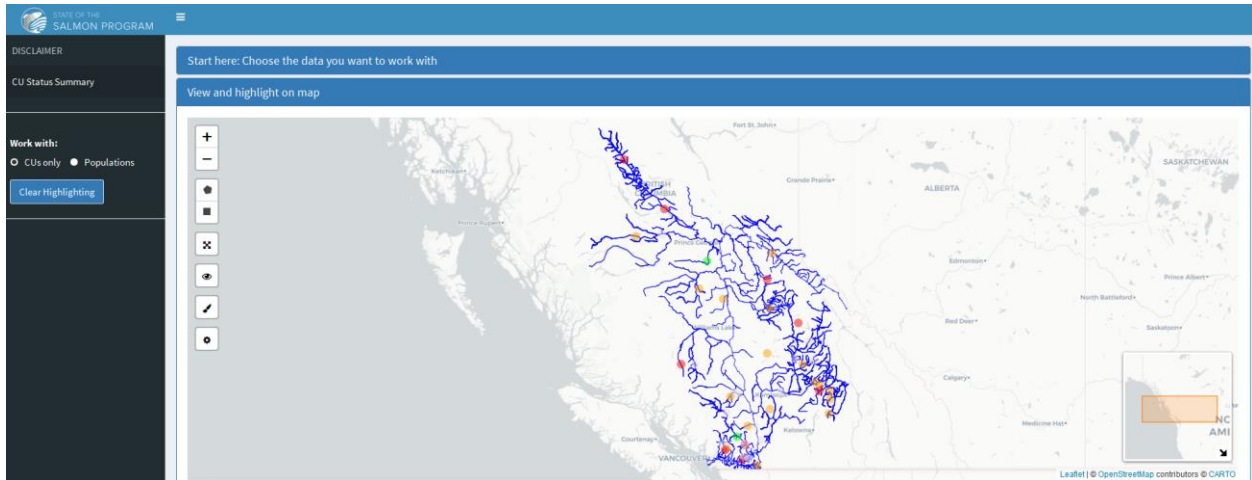


Figure 9. Map interface inset within SOS-SSET with colours set to reflect the short-term trend metrics statuses for each CU: Red, Amber and Green statuses.

The screenshot shows the 'Table view and download' tab of the SOS-SSET application. A pop-up dialog titled 'Dataset to download' is open, allowing users to choose between 'Table as shown' (selected) and 'Time series data'. Below the dialog, the table view shows a list of CUs with various metrics. The table has columns for 'RelAbd', 'RelAbd.Status', 'AbsAbd', 'AbsAbd.Status', 'LongTrend', 'LongTrend.Status', 'PercChange', 'PercChange.Status', 'ProbDeclBelowLBM', 'ProbDeclBelowLBM.Status', 'Species', 'Freshwater Adaptive Zone', 'Area', 'Run Timing', 'Life History Traits', and 'Average Generation Length'. The table shows 13 rows of data for CUs CK-03 through CK-13. A 'Download' button is visible in the top right corner of the table view.

CU	RelAbd	RelAbd.Status	AbsAbd	AbsAbd.Status	LongTrend	LongTrend.Status	PercChange	PercChange.Status	ProbDeclBelowLBM	ProbDeclBelowLBM.Status	Species	Freshwater Adaptive Zone	Area	Run Timing	Life History Traits	Average Generation Length
CK-03	51460.2589	Red	51460.2589	Green	0.85	Green	-36.494	Red	0.0333		Ck	LFR	Fraser_Lower	Fall	Ocean	4
CK-04	390.2959	Amber	390.2959	Red	0.9	Green	-39.048	Red	0		Ck	LFR	Fraser_Lower	Spring	Stream	5
CK-05							-41.793	Red	0.0333		Ck	LFR	Fraser_Lower	Summer	Stream	5
CK-06	749.6271	Green	749.6271	Red	1.69	Green	136.6922	Green	0		Ck	LFR	Fraser_Lower	Summer	Stream	5
CK-08							-105.4551	Red	0.0333		Ck	FRCany	Fraser_Upper	Spring	Stream	5
CK-09							-85.3894	Red	0.0333		Ck	MFR	Fraser_Upper	Fall	Stream	5
CK-10	4186.4004	Amber	4186.4004	Amber	1.01	Green	-35.825	Red	0.0333		Ck	MFR	Fraser_Upper	Spring	Stream	5
CK-11	11794.8354	Amber	11794.8354	Green	0.97	Green	-57.1125	Red	0.0333		Ck	MFR	Fraser_Upper	Summer	Stream	5
CK-12	12653.2649	Amber	12653.2649	Green	2.7	Green	-56.3981	Red	0.0333		Ck	UFR	Fraser_Upper	Spring	Stream	5
CK-13	82676.4028	Amber	82676.4028	Green	1.81	Green	-2.2616	Green	0		Ck	STH	Fraser_Thompson	Summer	Ocean	4

Figure 10. Table view and data download tab of SOS-SSET. The tab shows the WSP metric values for the CUs selected; however, upon pressing on the Download button, the pop-up tab allows users to download WSP metrics or the escapement time-series data for either only the selected CUs or the full dataset.

## 4.2 State of Salmon-Spatial Pattern Analysis Tool (SOS-SPAT)

The Salmon Pattern Analysis Tool (SPAT) is a Shiny/R-based statistical tool that performs key data exploration and analysis tasks that meet the research needs of fisheries staff, identified through a series of user-interviews (Pestal and Barrus 2020). Three key tasks addressed by the tool enable users to explore their data:

- 1) Exploring patterns in time-series variables based on user-defined filters. This panel shows trends of variables in one or separate plots, in which users may transform variables, offset variables and calculate indices across the group of variables displayed.
- 2) Exploring pairs of variables to identify similarities and differences in patterns. This panel allows users to plot variables on the same axis, transform variables independently, offset variables, and explore correlation between the two variables over time.
- 3) Identifying correlations between variables. This panel visualizes the correlation across all, or a subset of variables in the dataset within a user-defined time period. This visualization also allows users to cluster variables based on their strength of correlation.

The Fraser salmon dataset can be uploaded into this tool in its entirety, or in the form of sites selected through SOS-SSET, to explore trends in escapements, recruitments, and survival, where available, across salmon populations. The tool can be used to identify correlated populations within user-defined time-frames for further investigation, which may lead to hypotheses about possible survival mechanisms.

The intent with the two tools (SPAT and SOS-SSET) was to develop platforms through which users may explore salmon data temporally and spatially, to identify and track trends in salmon populations and their biological statuses. In such, users can identify issues with survival, and populations at risk, leading to the development of hypotheses regarding mechanisms that may be affecting survival.

Expansion of these tools through the addition of Fraser Coho and Chinook populations, as well as the automation data preparation across the three species of Fraser salmon data available, furthers the capacity of these tools, and subsequently their users, in multiple ways. The tools now allow watershed scale comparisons to be made across species, which can narrow down areas where habitats may be limiting factors of survival, and can inform alternative hypotheses. In such, the tools can be used to identify and prioritize habitat areas for further investigation of potential mechanisms of survival. Further, the tools can be used to annually update synoptic WSP statuses for CUs, monitor changes in statuses, and identify potential habitat, and other issues that may be related to changes in statuses.

## 5 Next Steps

### 5.1 Accessibility

This project has automated and standardized data treatment and storage for three Fraser salmon species: Sockeye, Chinook, and Coho. This quality-controlled data will be available to users within the PSC staff, and DFO Science over the coming year(s). In the near-term, DFO's Fraser-BCI Area Stock Assessment Division staff will be given access to both data outputs and the code package, to verify and update their own data sets, and provide input into code revisions as needed.

Both of SOS-SSET and SOS-SPAT tools will be available also over the coming year(s), linked to these data, to support future Pacific Salmon Treaty and non-Treaty processes, after a period iterative testing and refinements. The SOS-SPAT prototype was recently completed and provided to the PSC in completion of the SEF funded project for immediate use (Pestal & Barrus 2020).

### 5.2 Maintenance

Code and resulting data files will be kept within DFO's State of the Salmon Program. This Program is responsible for keeping code files up to date, and for updating data sets as annual updates become available. DFO's Fraser-BCI Area Stock Assessment Division will be engaged in annual updating processes to validate data and methods.

### 5.3 Upcoming Work

The outputs from this current project feed into the SOS-SSET and SPAT tools to facilitate the examination of salmon responses to freshwater habitat stressors, regulation, and restoration measures. Relevant DFO, PSC and external groups will be provided access to the output of the current project, and the SOS-SSET and SPAT tools to support their investigations. This includes recently initiated Programs in DFO related to research and management of freshwater habitats through DFO Science and the Fish and Fish Habitat Protection Program (FFHPP), and the Salmonid Enhancement Branch, Resource Restoration Unit (SEP-RRU). This work can be used to evaluate and prioritize habitat regulation and restoration projects, and also assess salmon responses to habitat stressors within the Fraser watershed.

An immediate application being pursued by DFO's State of the Salmon Program is the updating of synoptic statuses using SOS-SSET for Fraser Sockeye, Chinook and Coho to track recent trends, and also responses of these CUs to the Big Bar landslide on the Fraser River in 2019. This will engage experts on these species within DFO, the PSC, First Nations and key stakeholder groups. It is critical right now to maintain up-to-date trends in salmon abundances and statuses to inform the management systems during this time of considerable change.

The process of providing access to the DFO State of the Salmon data visualization tools and data sets will occur systematically over the next couple of years. The roll out period will be iterative, as a range of users are trained, given the opportunity to provide feedback, and refinements are made. This is to ensure that the tools remain effective and applicable to user task requirements.

Data sets for additional watersheds will be sequentially added as data and resources become available. For Fraser Chinook, recruitment data are available at the stock level only, which includes one or more CUs and sites. Including these different scales in the existing framework may also be considered in a next step.

## **6 Acknowledgements**

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## Appendix 1. Freshwater Adaptive Zones of British Columbia

Table 1-1. A number, descriptive name and acronym for each of the 32 FAZ in British Columbia. The FAZ index increases with latitude. The mean coordinates are of the SEDS sites within each FAZ. Reprinted from Holtby & Ciruna (2007), Table 51, page 290.

FAZ	FAZ acronym	FAZ code	number of sites	mean latitude	mean longitude
Okanagan	OK	1	1	49.08	-119.51
Boundary Bay	BB	2	12	49.06	-122.67
Lower Fraser	LFR	3	145	49.26	-122.18
Lillooet	LILL	4	18	50.26	-122.70
Fraser Canyon	FRCany	5	20	49.61	-121.47
Middle Fraser	MFR	6	203	53.18	-122.97
Upper Fraser	UFR	7	45	53.65	-120.89
Lower Thompson	LTh	8	21	50.32	-120.99
South Thompson	STh	9	81	50.91	-119.18
North Thompson	NTh	10	48	51.70	-119.70
S Coastal Streams	SC	11	253	50.24	-124.93
E Vancouver Island	EVI	12	128	49.59	-125.03
W Vancouver Island	WVI	13	321	49.56	-126.14
Homathko - Klinaklini Rivers	HK	14	6	51.06	-125.25
Rivers-Smith Inlets	RSI	15	31	51.61	-127.10
Bella Coola - Dean Rivers	BCD	16	41	52.38	-126.51
Queen Charlottes	QCI	17	250	53.01	-131.98
N Coastal Streams	NC	18	125	53.35	-128.42
Hecate Lowlands	HecLow	19	250	52.97	-129.11
Lower Skeena	LSK	20	114	54.46	-128.79
Middle Skeena	MSK	21	121	55.10	-127.25
Upper Skeena	USK	22	22	56.43	-127.45
Lower Nass - Portland	LNR-P	23	78	55.08	-129.81
Upper Nass	UNR	24	24	56.05	-129.01
Unuk River	UNUK	25	2	56.35	-130.74
Lower Stikine	LStk	26	19	57.21	-131.43
Whiting River	Whtng	27	1	58.18	-133.20
Taku	Taku	28	19	58.75	-132.76
Lynn Canal	Lynn	29	4	59.66	-136.04
Alsek	Alsek	30	9	59.81	-137.31
Teslin Headwaters	TesHW	31	4	59.72	-132.32
Lower Liard	Liard	32	1	59.52	-124.07

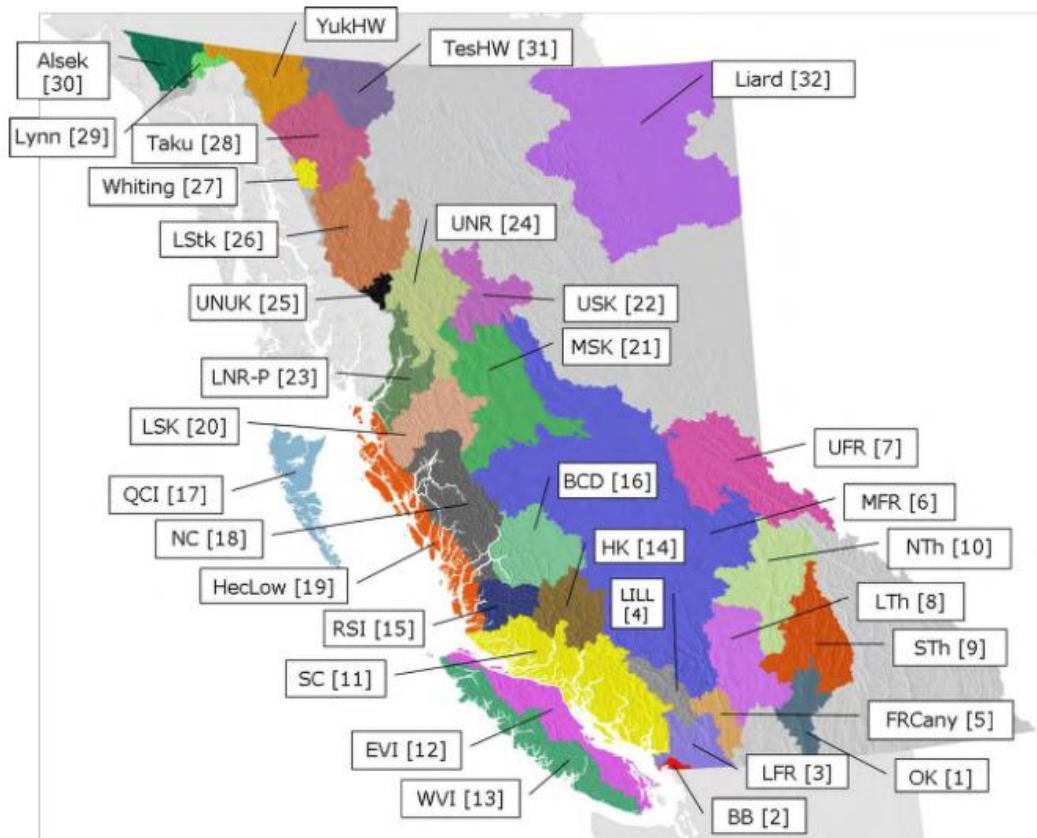


Figure 1-1. Map of British Columbia showing the Freshwater Adaptive Zones (FAZ) from Table 1-1. Reprinted from Holtby & Ciruna (2007), Figure 76, page 291.