Improving pre-season planning and in-season assessments of Fraser River sockeye stocks through stock- and cycle line-specific estimates

Southern Boundary Restoration and Enhancement Fund: Final Report

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Executive Summary

The PSC Secretariat Staff is responsible for estimating daily abundances of sockeye salmon (*Oncorhynchus nerka*) upon entry to marine areas during their migration to the Fraser River. These time series are derived using reconstruction models and are used to provide post-season estimates of marine timing, and diversion rate (percentage of adult salmon migrating around Vancouver Island via Johnstone Strait instead of the Strait of Juan de Fuca) for Fraser River sockeye salmon, as required under the terms of the Pacific Salmon Treaty. While heavily relied upon as an in-season tool, the reconstruction models were inflexible to evaluating different model assumptions and did not allow for the finer stock resolution in the underlying source files. As part of an overarching commitment to make our data more accurate, transparent, and accessible and to fulfill Treaty obligations, we created a new suite of post-season run reconstruction models using updated and finer-resolution source data, and a more robust set of modelling assumptions and standards. In addition, a new SQL Server database was developed to house multi-year timeseries of reconstructed daily abundances with the flexibility to summarise results over a range of stock resolutions (e.g. Fraser River Panel management groupings, DFO Conservation Units, DNA baseline stocks etc.). The results from this project are a set of updated timeseries of reconstructed marine abundances and derived variables such as timing and diversion rates, and a standardized template and archival system for updating and maintaining records into the future.

Acknowledgements

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Introduction

Run reconstructions have been a key tool for salmon fisheries management for over 80 years; their application first thoroughly described by Starr and Hilborn (1988). The Pacific Salmon Commission (PSC) Secretariat Staff (hereafter referred to as “Staff”) are responsible for developing and applying run reconstruction models for Fraser River sockeye and pink salmon (Cave and Gazey 1994) and archiving their results. Within these reconstruction models, stock-specific daily marine and lower river catches are added to daily escapement estimates from the PSC Mission hydroacoustic facility (Conrad et al. 2019) to reconstruct the salmon run as they approach the marine areas. The resulting daily marine abundance estimates provide the data for several key pieces of information used for pre-season planning and in-season fisheries management.

Historical time series of marine timing (date at which 50% of a run passes through Area 20), northern diversion (percent of a run migrating through Johnstone Strait), spread (number of days it takes for 95% of the run to migrate through an area), and delay (days holding in the Gulf) are calculated from annual run reconstructions after the fishing season concludes. These migratory parameters are used by DFO to develop pre-season forecasts of timing and diversion (Folkes et al. 2018) which are critical inputs in pre-season fisheries planning simulations (Cave and Gazey 1994; PSC 2018), and are also used as informative priors in Bayesian in-season run size models (Michielsens and Cave 2018). In addition, Staff use historical run reconstructions in retrospective evaluations to estimate fishery harvest rates (PSC Tech Rep # 6 1995) and to develop decision rules for updating in-season test fishery catchability coefficients and estimating marine abundance (C. Michielsens, pers. comm.).

Even though this project relates to post-season reconstructions, it should be noted that in-season, partial timeseries of the marine reconstructed abundances themselves are used as data within a time-density model to predict total run size and arrival timing to marine approach fisheries (Michielsens and Cave, 2019). At the end of the season, the run size is the sum of the daily reconstructed abundances – or the sum of Mission passage estimates plus seaward catch. This final in-season estimate of run size can differ, sometimes substantially, from the post-season run size estimate based on the number of spawners at the spawning grounds, catch and a run size adjustment (Patterson et al. 2019). Run size adjustments (RSAs) are based on post-season evaluation of factors influencing en route mortality and an evaluation of biases for estimates of spawning escapements and catch (and other ‘miscellaneous’ biases).

Historically, updates to reconstruction models have lagged the improvements to other assessment tools (PSC 1995). The most recent and influential change to reconstructions occurred as the result of the SEF project *S16-I03 & S15-I11: Improvements to predicting en-route loss estimates for Fraser sockeye salmon 2015-16* (Patterson et al. 2017), during which historical catch and Mission escapement estimates were re-generated at more finely resolved stock resolutions due to updating of DNA baselines. In addition, management needs have also changed, with greater demands for stock-specific estimates of abundance, diversion and timing. While Staff has been proactive in responding to these changes in-season, less emphasis has been placed on improvements to the historical time series generated from run reconstructions. As a result, estimates from past years are at a coarser stock resolution, in a variety of file formats, and based on inconsistent sets of assumptions and do not always reflect changes to Mission passage or catches produced during the post-season. These limitations affect Staff’s ability to reconstruct reliable, and long time series of stock-specific migration characteristics.

Given the critical reliance on run reconstructions for pre-season planning, in-season stock assessments, and the post-season derivation of biologically relevant time series, we proposed a multi-step process to standardise historical run reconstructions, and to make the data and underlying model assumptions more consistent with new PSC data standards and recently updated Mission passage and marine catch information (Patterson et al. 2017). This report documents our approach for the development of a post-season run reconstruction tool and some preliminary findings, including:

1. Updates and verification of historical data used as model inputs
2. Changes to model assumptions and structure
3. Development of a SQL database
4. Analysis of updated timeseries

As a result of this project, PSC Staff will meet their obligations under the Pacific Salmon Treaty with improved performance and efficiency, and will uphold their mandate to increase the reliability, transparency, and availability of our data.

Methods

Data Sources

As part of the SEF project *S16-I03 & S15-I11: Improvements to predicting en-route loss estimates for Fraser sockeye salmon 2015-16* (Patterson et al. 2017), Staff undertook an exhaustive process of updating daily catch and Mission passage by stock from 1996 – 2017. Updates included post-season corrections to catch and passage information, re-evaluation of DNA baselines, and standardisation of rules for applying stock composition percentages to daily catch and passage estimates. This timeframe also matches with the years of data analysed by Michielsens and Cave (2018) and represent years where structured purse seine test fisheries operated in Johnstone and Juan de Fuca Straits. Since then, these data have been extended to include recent years. The post-season reconstruction files now link directly to the high-resolution catch and escapement files described above. The stock ID used in the creation of these data files was also applied to test fishery catch-per-unit-effort data (Table 1).

Reconstructions require several decisions to be taken that require expert judgement. These decisions become extremely complicated at a fine stock resolution and therefore are made at a coarser stock resolution. More specifically, the reconstruction groups correspond with the 4 management units (Early Stuart, Early Summer, Summer and Late run) but accounts for the different life history characteristics of Harrison sockeye and delaying Late run sockeye by splitting the Summer run group into Harrison sockeye (Harr) and Summer run sockeye excluding Harrison (SeHa) and splitting the Late run group into Birkenhead, Big Silver (BiBS) and Late run excluding the Birkenhead group (SeBi). Table 1 provides an overview of how reconstructions groups relate to in-season stock group and management groups.

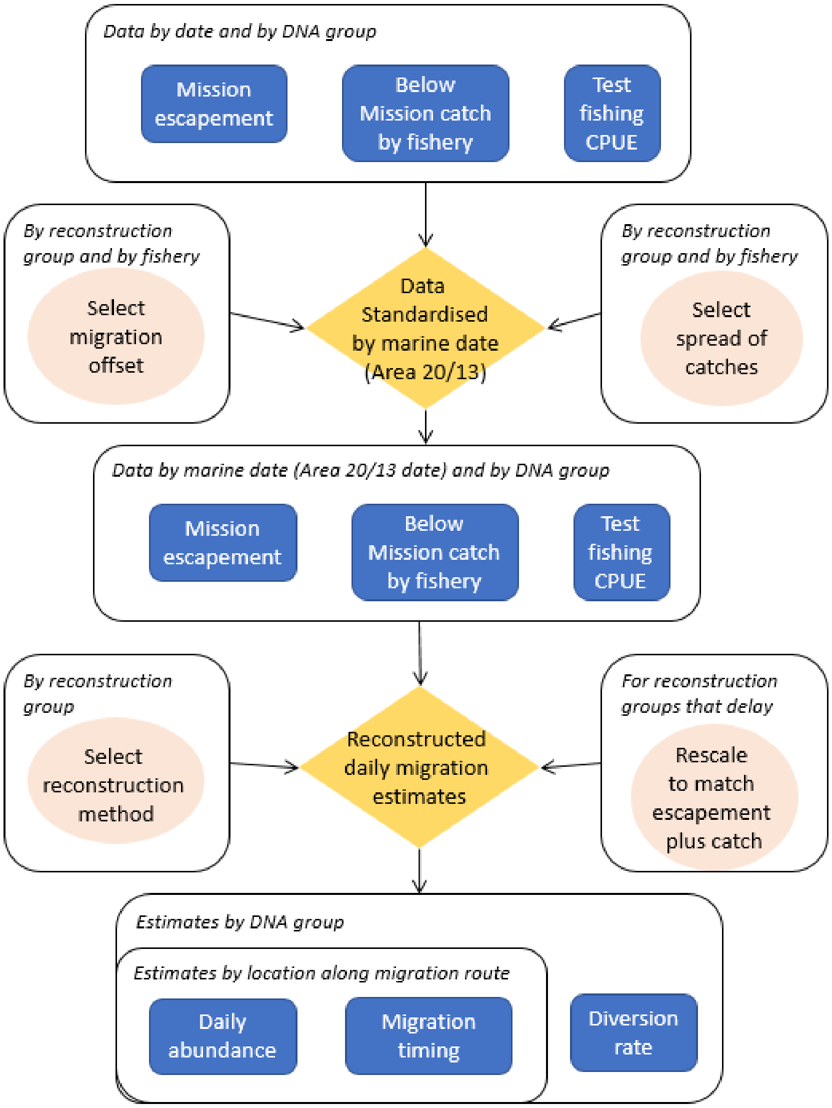

Figure 1. Flow diagram showing the key pieces of data used in the reconstruction model as well as the expert decisions made in the reconstruction process. First, the escapement, catch and CPUE data are all standardized to correspond to marine dates prior to selecting migration offset, spread and reconstruction methods used to derive the daily reconstruct marine abundances, timing, and diversion rate estimates.

Table 1 Stock grouping definitions used in the post-season Fraser River sockeye salmon marine reconstruction files. Data are imported at the resolution of the DNA stock groups, which is the finest resolution currently available. In-season stock groups reflect the resolution most commonly used for in-season analyses and stock assessments. Management Groups are aggregations used by the Fraser River Panel to make in-season management decisions. Reconstruction groups is the resolution at which most of the expert decisions within the marine reconstruction files are made.

DNA STOCK	IN-SEASON STOCK	MANAGEMENT GROUP	RECONSTRUCTION GROUP
DRIFTWOOD-NARROWS	EStu (Early Stuart)	EStu (Early Stuart)	EStu (Early Stuart)
DUST-SINTA	EStu	EStu	EStu
BIVOUAC-ROSSETTE	EStu	EStu	EStu
PAULA-FELIX	EStu	EStu	EStu
CHILLIWACK_KOK	Chwk (Chilliwack)	ESum (Early Summer)	ESum (Early Summer)
CHILLIW_LAKE	Chwk	ESum	ESum
DOLLYVARDEN_CR	Chwk	ESum	ESum
PITT_RIVER	PiAC (Pitt-Allouette-Coquitlam)	ESum	ESum
COQUITLAM_KOK	PiAC	ESum	ESum
ALOUETTE_KOK	PiAC	ESum	ESum
NADINA____	NdBo (Nadina-Bowron)	ESum	ESum
BOWRON_____	NdBo	ESum	ESum
GATES_CREEK	GaNh (Gates-Nahatlatch)	ESum	ESum
NAHATLATCH	GaNh	ESum	ESum
TASEKO	Tsko (Taskeo)	ESum	ESum
UPPER_BARRIERE	NBar (North Barriere)	ESum	ESum
SCOTCH____	ESTh (Early South Thompson)	ESum	ESum
SEYMOUR___	ESTh	ESum	ESum
EAGLE_____	ESTh	ESum	ESum
UPPER_ADAMS	ESTh	ESum	ESum
CAYENNE____	ESTh	ESum	ESum
HARRISON__	Harr (Harrison)	Summ (Summer)	Harr (Harrison)
WIDGEONSLOUGH	Widg (Widgeon)	Summ	Harr
MIDDLE_RIVER	LStu (Late Stuart)	Summ	SeHa (Summers excluding Harrison)
PINCHI_CREEK	LStu	Summ	SeHa
TACHIE____	LStu	Summ	SeHa
KUZKWA_CREEK	LStu	Summ	SeHa
STELLAKO__	Stel (Stellako)	Summ	SeHa
CHILKO_SOUTH	Chil (Chilko)	Summ	SeHa
CHILKO_NORTH	Chil	Summ	SeHa
CHILKO_____	Chil	Summ	SeHa
LOWER_HORSEFLY	Hfly (Horsefly)	Summ	SeHa
MCKINLEY	Hfly	Summ	SeHa
MID_HORSEFLY	Hfly	Summ	SeHa
UPPER_HORSEFLY	Hfly	Summ	SeHa
MITCHELL____	Mtch (Mitchell)	Summ	SeHa
WASKO-ROARING	Mtch	Summ	SeHa
BLUE_LEAD_CK	Mtch	Summ	SeHa
RAFT_______	RaNT (Raft North Thompson)	Summ	SeHa
NORTHTHOMPSON	RaNT	Summ	SeHa
*BIRKENHEAD_*	BiBS (Birkenhead-Big Silver)	Late (Lates)	BiBS (Birkenhead-Big Silver)
BIG_SILVER	BiBS	Late	BiBS
EAGLE_LATE	LShP (Late Shuswap-Portage)	Late	LeBi (Lates excluding Birkenhead)

LITTLERIVER-LITTLESHU	LShP	Late	LeBi
LOWER_ADAMS	LShP	Late	LeBi
LOWER_SHUSWAP	LShP	Late	LeBi
MIDDLESHUSWAP	LShP	Late	LeBi
PORTAGE_CREEK	LShP	Late	LeBi
WEAVER____	WeCu (Weaver-Cultus)	Late	LeBi
CULTUS_LAKE	WeCu	Late	LeBi

Migration distance and timing offsets

A QGIS database was created to store information related to the distance of potential migration routes through Johnstone Strait and Juan de Fuca Strait and to overlay these routes with polygons describing statistical fishing areas in both Canada and the United States. In combination with migration speeds, this information allows us to derive how many days it takes sockeye to migrate from marine areas 20 and 13 to other parts along the migration routes such as the hydroacoustic site at Mission, i.e. derive the migration "offsets". There are 5 alternative routes in total: two routes through Johnstone strait splitting around Texada Island, and 3 routes through Juan de Fuca going through, around the east of, or around the west of the San Juan Islands (Figure 2). Also indicated are the location of key test fisheries and the Mission hydroacoustics program, both used in the assessment of Fraser River returns. While not shown in Figure 2, the QGIS database also covered the migration route from South East Alaska to Vancouver Island.

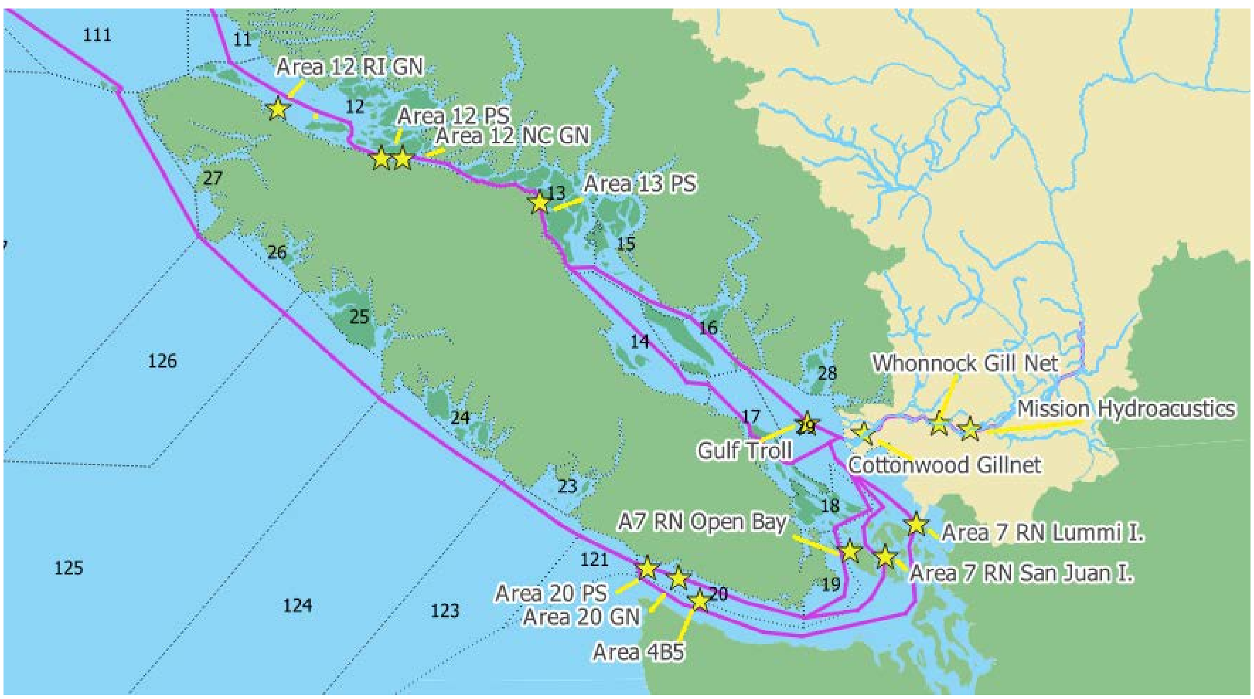

Figure 2. Screenshot of QGIS map showing migration routes (purple lines) through DFO management areas (black outlines).

Within the reconstruction files, the user can specify the assumed migration route. Under the assumption of a 6-day migration time between the Area 20 marine test fishery and the Mission hydroacoustics location, distances within the QGIS database were used to calculate the migration time through each relevant fishing area as well as the offset between key reconstruction points of interest and Mission. By default, the shortest routes are selected but the user has the option to select alternatives paths and/or swim speeds if deemed more consistent with post-season observations. Users can also specify longer "offsets" for different stocks, e.g. to account for slower migration rates of Late-run sockeye salmon. Table 2 illustrates the offsets (days it takes for the salmon to migrate from the marine purse seine test fisheries in areas 20 and 13 to other parts along the migration route) , and the spread (number of days the salmon are susceptible to be caught by a fishery in a particular statistical areas) under three alternative migration rate assumptions, reported as the number of days travel time between Area 20 or 13 and the Mission hydroacoustics site. Traditionally, a 6-day travel time is assumed for early-timed stocks, and an 8-day migration is assumed for slower swimming late-timed stocks.

Table 2 Offsets (days it takes for the salmon to migrate from the marine purse seine test fisheries in Areas 20 and 13 to other parts along the migration route) and spread (number of days the salmon are susceptible to be caught by a fishery in a particular statistical areas) under alternative migration rate assumptions associated with 8-, 6-, and 12-day offsets between the Area 20 and Area 13 purse seine test fisheries and Mission location. A separate set of values is generated for each fishery seaward of the Mission hydroacoustic site.

	Days A20 to Mission			Days A20 to Mission		
	8	6	12	8	6	12
Name	Offset 1	Offset 2	Offset 3	Spread 1	Spread 2	Spread 3
a104Ps	-13	-9	-19	2	1	3
a1Tr	-33	-24	-47	3	2	4
a11Gn	-3	-2	-4	1	1	1
a11Tr	-3	-2	-4	1	1	1
a12Gn	-2	-1	-3	1	1	1
a12riGnTf	-1	-1	-1	1	1	1
a12TrG	0	0	0	2	1	3
a12Gn	-1	-1	-1	2	1	3
a12Ps	-2	-1	-3	2	1	3
a12PsTf	0	0	0	1	1	1
a12Ps	0	0	0	1	1	1
a12ncGnTf	0	0	0	1	1	1
a12Tr	-1	-1	-1	3	2	4
aMFN-JS12	-1	-1	-1	3	2	4
a13PsTf	2	1	3	1	1	1
a13Ps	2	1	3	2	1	3
a13Gn	2	1	3	2	1	3
aMFN-JS13	2	1	3	2	1	3
aFFN-FSC-JS	2	1	3	2	1	3
a16PsTf	5	4	7	1	1	1
a16Ps	5	4	7	1	1	1
aRecJS	2	1	3	2	1	3
a13-16Tr	2	1	3	2	1	3
aMFN-WCVI	-5	-4	-7	2	1	3
a20PsTf	0	0	0	1	1	1
a20GnTf	0	0	0	1	1	1
a20Ps	0	0	0	4	3	6
a20Gn	0	0	0	4	3	6
aRecJF	0	0	0	4	3	6
aMFN-JF	0	0	0	4	3	6
a4b5Tf	0	0	0	1	1	1
a4b56cTIgn	0	0	0	2	1	3
a4b56cTICS	0	0	0	2	1	3
a6-7TIPs	3	2	4	3	2	4
a6-7TIGn	3	2	4	3	2	4
a6-7TICS	3	2	4	3	2	4

a6-7ACPs	3	2	4	3	2	4
a6-7ACGn	3	2	4	3	2	4
a6-7ACRn	3	2	4	3	2	4
a7Tf	4	3	6	1	1	1
aUSRec	6	4	9	1	1	1
a7aTIPs	5	4	7	1	1	1
a7aTIGn	5	4	7	1	1	1
a7aACPs	5	4	7	1	1	1
a7aACGn	5	4	7	1	1	1
a7aACRn	5	4	7	1	1	1
a7aTICS	5	4	7	1	1	1
a29aPsTf	6	4	9	1	1	1
a29aGnTf	6	4	9	1	1	1
a29aTrTf	7	5	10	1	1	1
a29aPs	7	5	10	1	1	1
aFFN-FSC-SG	7	5	10	1	1	1
aFFN-EO-SG	7	5	10	1	1	1
a17-29aTr	5	4	7	1	1	1
aRecSG	5	4	7	1	1	1
aMFN-SG	5	4	7	1	1	1
a29bGnTf	7	5	10	1	1	1
a29bGn	7	5	10	1	1	1
aMFN-FR	7	5	10	1	1	1
aFFN-FSC-RM-PM	7	5	10	1	1	1
aFFN-EO-RM-PM	7	5	10	1	1	1
aAlbionCharter	8	6	11	1	1	1
a29dGnTf	8	6	11	1	1	1
a29dGn	8	6	11	1	1	1
aFFN-FSC-PM-Mis	8	6	11	1	1	1
aFFN-EO-PM-Mis	8	6	11	1	1	1

Run Reconstruction Model Description, Equations, & Assumptions

There are two main approaches used to estimate daily marine abundances of adult Fraser River sockeye salmon at various locations along their migratory approach route. The model can be operated as either a “forwards” reconstruction model, in which catches are *removed* from marine abundances estimated primarily from test fishery catch-per-unit-effort data to predict the salmon abundance en route to Mission, or a “backwards” reconstruction model, where marine abundances are estimated by *adding* seaward catches onto estimates of Mission escapement (Figure 3).

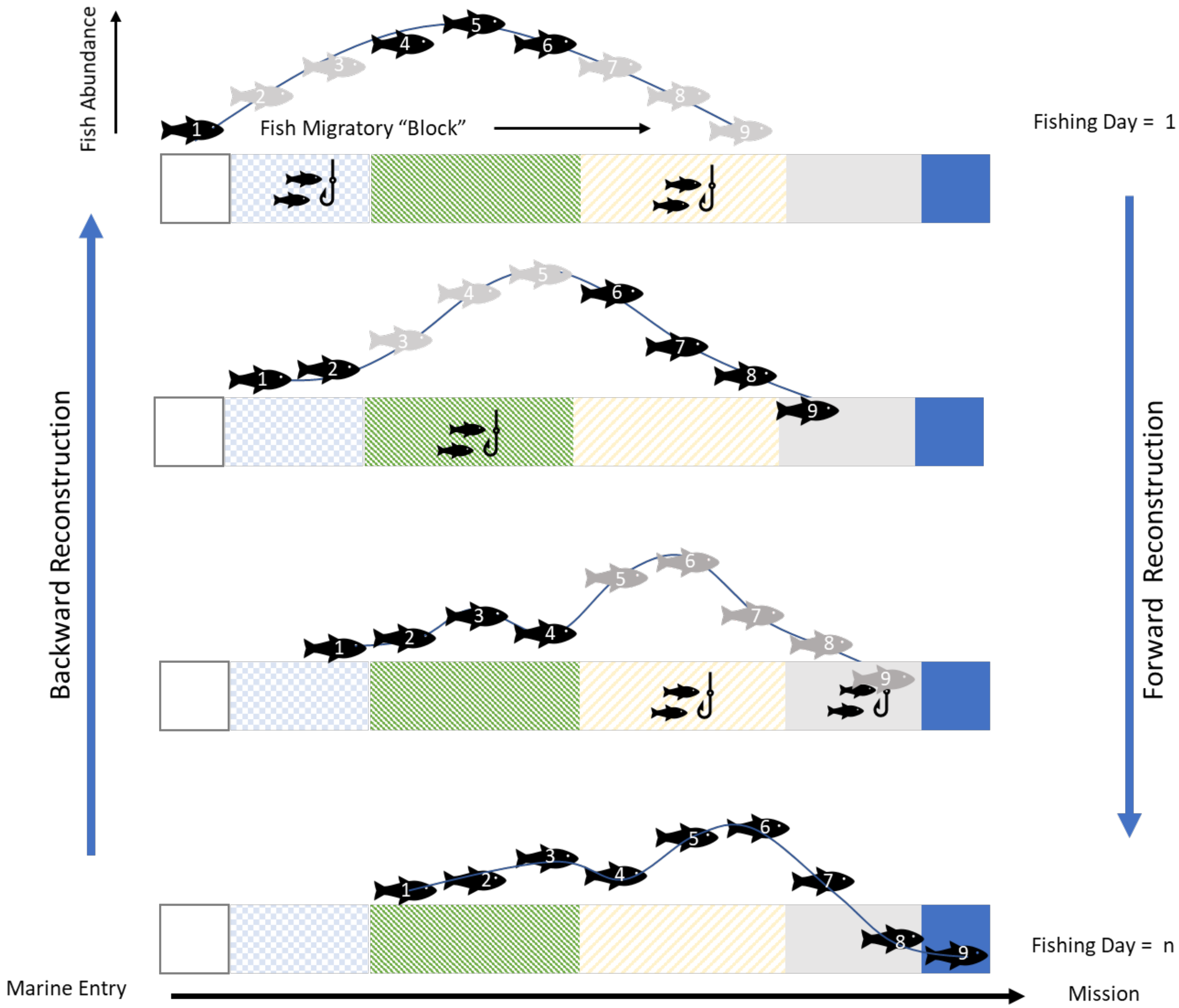

Figure 3 Schematic illustration of a basic "boxcar" run reconstruction model. The coloured bars represent different statistical fishing areas, with the left most square representing the most seaward location. Each "fish/hook" represents one day of fishing. Each fish represents one daily "block" of migration. Black fish in each panel are not exposed to a fishery opening on a given day. Grey fish in each panel are exposed to a fishery opening. Each panel represents a daily snapshot of the distribution of blocks of fish across statistical areas. The top panel represents the shape of the unfished run prior to entering marine approach fisheries. The bottom panel represents the shape of the distribution of salmon as it might appear at Mission, with certain blocks of fish depleted due to catch removals.

backwards reconstructions are used in-season to update estimates of test fishery catchability and to reconstruct daily marine abundances for non-delaying stocks, as well as to derive final in-season total run size estimates for all Fraser River sockeye salmon. Alternatively, forward reconstructions are used in-season to make predictions about the number of salmon anticipated to reach Mission, and to reconstruct daily abundances for stock groups which delay and redistribute in the Strait of Georgia, prior to migrating upstream (Lapointe et al. 2003). "Delaying" Fraser River sockeye stocks are defined as salmon populations which have historically held in the Strait of Georgia for an extended number of days (or weeks) prior to migrating upstream. In addition to delaying their upstream migration, these stocks will also redistribute into a generally bi-modal distribution (Figure 4).

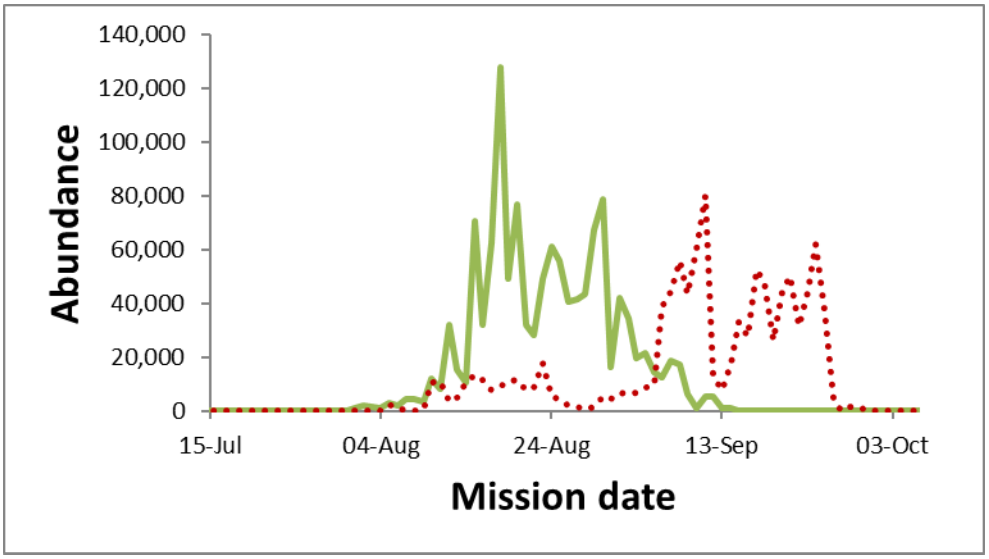

Figure 4. Example illustrating the differences in the shape of the daily run distribution for Late-run sockeye salmon between marine approach areas (green, solid line) and Mission (red, dashed line).

As a result, the "order of movement" assumption that underlies our backwards reconstruction model is broken and Mission escapements for these stocks cannot be aligned with seaward catches. In addition, test fishery-based marine abundances are used to calculate diversion rates around Vancouver Island, which are applied to total marine abundance timeseries derive estimates for each approach route.

Marine Abundance Estimation – Test Fishery Data

Calculation of daily diversion rates (percent of fish migrating through Johnstone Strait) and in-season marine abundances for delaying stocks primarily rely on test fishery information, where $CPUE_{f,s,d,A}$ is test fishery (*f*) catch-per-unit-effort (*CPUE*) on a given day (*d*) for a particular DNA group (*s*). However, as discussed in the section *Reconstruction Decision Rules*, alternative approaches to estimate route specific abundance are also possible when reliable CPUE data does not exist.

To simplify the reconstruction, all CPUE, catch and escapement data are standardized to a common marine migration date (Area 20) by applying the offsets to Area 20 (o_{A20}), i.e. the number of days it would take to migrate from Area 20 to the location of interest. The "offset" (*o*), or number of days migration, between fisheries (by default assigned to the center of each statistical fishery area) is calculated as distance/migration rate:

(1) $$CPUE_{f,s,d_{A20}} = CPUE_{f,s,(d-o_{A20,A})},$$

The daily CPUE index derived for each approach route (Johnstone Strait (*NE*) and Strait of Juan de Fuca (*SE*)) is then converted to an absolute estimate of marine abundance (*M*) using:

(2) $$M_{f,s,d_{A20},A_{NE}} = \frac{CPUE_{f,s,d_{A20},NE}}{q_{f,g,d_{A20},NE}}$$

(3) $$M_{f,s,d_{A20},A_{SE}} = \frac{CPUE_{f,s,d_{A20},SE}}{q_{f,g,d_{A20},SE}}$$

where q is the catchability for the reconstruction group of stocks (g, Table 1) for test fishery f. Post-season daily catchabilities are estimated by aligning the abundance estimates from the backwards reconstruction (Equations 11 and 12) with the test-fishing based estimates for the non-delaying stocks. Observed catchability estimates for non-delaying stocks are then used to estimate daily q for delaying groups (e.g. non-Birkenhead Late-run and Harrison).

If there are several test fisheries operational on an approach route, this will result in more than one potential time series of marine abundances. Expert judgement is used to determine if the resulting time series could be averaged to derive the best estimate of marine abundance based on test fishery data or if some characteristics of the CPUE data or the catchability estimate make the estimates from particular test fisheries unreliable on certain days. The best available marine abundance estimates based on test fishery data are subsequently used to derive daily diversion rates (v):

$$v_{d_{A20}} = \frac{\sum_{b=1}^{5} M_{s,d_{A20},A_{NE}}}{\sum_{b=1}^{5} M_{s,d_{A20},A_{NE}} + \sum_{b=1}^{5} M_{s,d_{A20},A_{SE}}} \quad (4)$$

For delaying stocks, to ensure that the sum of the daily reconstructed marine abundances derived from test fishery data corresponds to the total escapement plus catch from the backwards reconstruction, the daily abundances are proportionally rescaled based on the ratio of the total test fishery based abundance vs. total escapement plus catch (i.e. M/N):

$$N_{s,d_{A20},A} = M_{s,d_{A20},A} \cdot \frac{N_s}{M_s} \quad (5)$$

Finally, these estimates can be converted into total abundances migrating through Johnstone Strait and Juan de Fuca strait by adding seaward catches (C):

$$N_{s,d_{A20}} = N_{s,d_{A20},A} + \sum_{a=f+1}^{n} C_{s,d_{A20},A_{a,a+1}} \cdot v_{d_{A20}} \quad (6)$$

where the catches refer to any fisheries seaward of the test fishing location.

Marine Abundance Estimation – Mission plus Catch

For stocks which maintain order of movement between seaward test fisheries and the river, the model operates as a backwards “box car” reconstruction (Cave and Gazey 1994), initialized with Mission daily stock-specific escapement estimates. Seaward catches are re-distributed to align with these daily migratory “boxes” or “blocks” of salmon on the dates the fish were assumed to be present in marine areas. While simple in theory, the complexity of a reconstruction lies in the multiple spatial and temporal dimensions and the rules required to assign catches correctly to a “block” of fish migration. Errors in the redistribution of catches can result in misconceptions about the timing and distribution of the run at marine entry, as well as the assumed harvest rate impacts of a given fishery.

Assumed migration routes and migration rates are used to “move” the run back in space and time, through seaward fisheries, to correctly align days of fish migration with fishery removals from daily catch records. Fish present in an area on a day of fishing are assumed to be vulnerable to the fishery, and the fishing effort is assumed to be equally distributed throughout that area. The catch assigned to each day of migration is “added” to the Mission abundances to calculate the daily abundance of salmon entering a particular fishery on a particular day, and the process is repeated until the index location of interest (e.g. a test fishery) is reached. In some cases, catch from a single fishery taking place over a large statistical area may need to be redistributed over multiple days of fish migration (Figure 3).

Incorrect distribution of catches related to incorrect assumptions of fish behaviour can create erroneous estimates of fish catchability and fishery harvest rates (PSC Tech Rep #6 1995; Starr and Hilborn 1988).

Sockeye salmon catch is received by the PSC for each fishery (*f*), statistical area (*A*) and date (*d*). Stock identification is applied by PSC staff to further resolve the data at the DNA stock level (*s*). For large statistical areas, caches reported on a given day ($C_{f,s,d,A}$) are spread evenly across two or more (*n*) migration days depending on the length of the statistical area, so that the sum of the catch proportions (p_n) equals the total catch reported:

(7) $$C_{f,s,d,A} = \sum_1^n p_n \cdot C_{f,s,d-n+1,A}$$

Similar to the CPUE data, the re-alignment of the catch time series to a common date index (d_{A20}; "Area 20 date", which corresponds to an Area 13 date in Johnstone Strait) is presented by the following equation:

(8) $$C_{f,s,d_{A20},A} = C_{f,s,(d-o_{A20,A}),A}$$

while the re-alignment of the Mission escapement time series to the common date index is provided by:

(9) $$N_{s,d_{A20},A_{Mission}} = N_{s,(d-o_{A20,Mission}),A_{Mission}}$$

All seaward catches are summed together with the Mission escapement estimates for the same blocks of fish to reconstruct daily marine abundance estimates prior to any fisheries:

(10) $$N_{s,d_{A20}} = N_{s,d_{A20},A_{Mission}} + \sum_{a=1}^{n-1} C_{s,d_{A20},A_{a,a+1}}$$

These reconstructions however to not allow the assessment of abundances along the different migration routes, i.e. Johnstone Strait (North entry, *NE*) versus Juan de Fuca Strait (South entry, *SE*). This can be achieved by relying on the daily diversion rate (*v*) based on CPUE data from marine test fisheries (Putman et al, 2014).

(11) $$N_{s,d_{A20},A_{NE}} = N_{s,d_{A20}} \cdot v_{d_{A20}}$$

(12) $$N_{s,d_{A20},A_{SE}} = N_{s,d_{A20}} \cdot (1 - v_{d_{A20}})$$

Reconstructions to Areas of Interest

It is often important to have a timeseries of escapements into particular fisheries, as this data is required for harvest rate analysis and catchability estimation. Following the estimation of the total abundances at the entry of the two different approach areas, it is possible to generate reconstructed timeseries for different locations of interest (yellow lines in Figure 5) by iteratively removing catches along the migration routes through a forward reconstruction.

To facilitate the reconstruction, catches of all fisheries between two index fishery locations (e.g. A12 GN test fishery and A12 PS test fishery) are aggregated:

(13) $$C_{s,d_{A20},A_{a,a+1}} = \sum_{f\,A} C_{f,s,d_{A20},A}$$

Then the seaward catch aggregates (i.e. the catches occurring between two yellow lines in Figure 5) are then removed to calculate escapements to each area of interest:

$$N_{s,d_{A20},A_a} = N_{s,d_{A20},A_{a+1}} - C_{s,d_{A20},A_{a,a+1}} \quad (14)$$

Finally, the Area 20 marine dates can be converted back into location-specific dates to correspond with the daily abundances associated with a particular area, or index fishery.

$$N_{s,d,A_a} = N_{s,(d+o_{A20,a}),A_a} \quad (15)$$

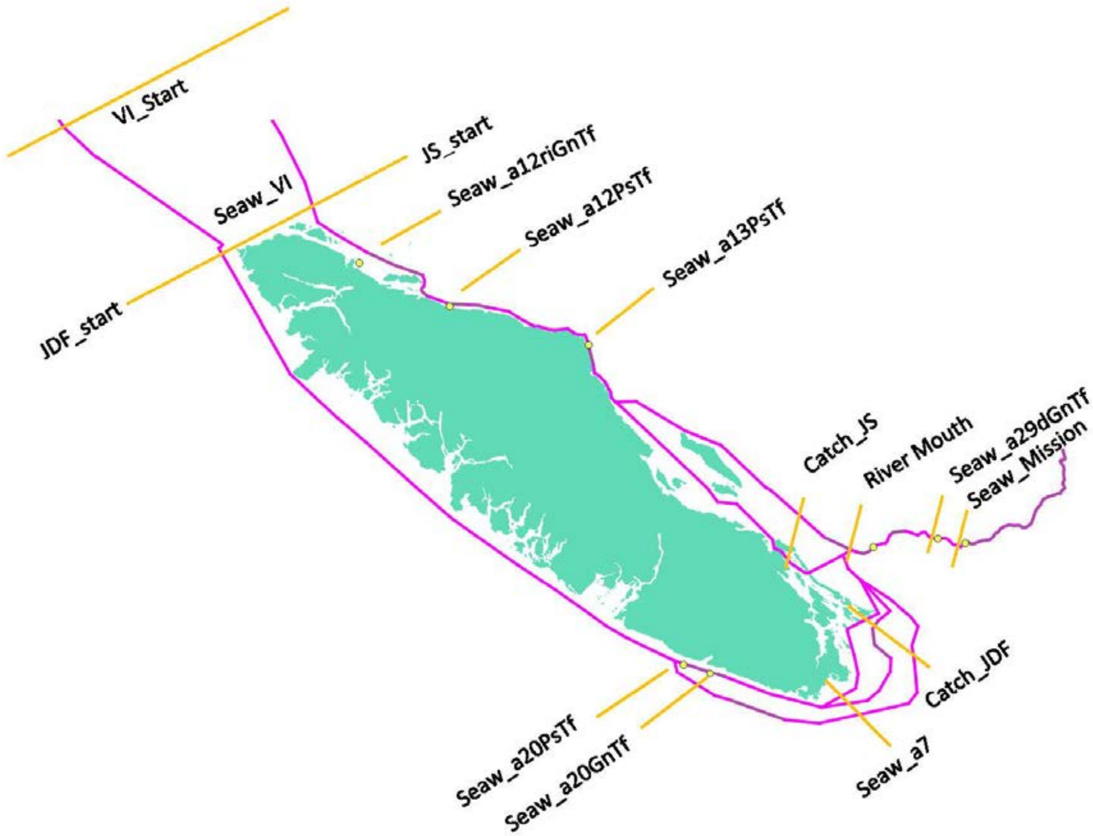

Figure 5. Locations of reconstructed Fraser River sockeye timeseries generated by the reconstruction model.

Reconstruction Decision Rules

The previous reconstruction model solely relied upon test fishery CPUE data to separate marine abundances between the Johnstone Strait and Juan de Fuca Strait approach routes. However, the new post-season model also has increased flexibility for defining route-specific marine abundances using other available sources of information (e.g. commercial catch data) (Table 3). For example, one of the key improvements includes the ability to identify days when route-specific catches are near, or exceed, the daily reconstructed abundance estimates based on test fishing data. Assuming a maximum harvest rate of 80% smoothed over 5-days, the modeller can choose to replace test-fishing based abundances with abundances calculated as catch/harvest rate threshold, (e.g. $C/0.8$).

Due to the increased number of options, the decision-making process for selecting the 'best' marine abundance estimate entering each approach is complex and varies between non-delaying and delaying stocks. A set of decision rules (Figure 6) was developed to try and standardise the process, but there will still be some instances in which expert judgement must be applied to resolve contradictory estimates. As it would be exceedingly complex, and uncertain, to estimate catchability and derive marine abundance at a fine stock-resolution, decision rules were developed at the level of the reconstruction groups identified in Table 1. Once the decision process has been applied to all reconstruction groups and verified, the same rules are then applied to all DNA groups within the same reconstruction group (Table 1) to produce timeseries at a finer stock resolution.

To populate each year of marine abundances, the modeller initiates the process in Figure 6 for the most-abundant, non-delaying stock aggregate (e.g. Summer excluding Harrison). For non-delaying stocks, while abundance estimates for the northern and southern approaches are evaluated separately, the selection of approaches from Table 3 must be constrained such that the total marine abundance is equivalent to the Mission reconstructed value for the same days. As such, the same set of test fishery data must be used to estimate the abundance along each approach. Alternatively, if a catch-based estimate is applied along one route, then the abundance along the alternative route must the equal the difference between the Mission reconstructed total and the abundance along the first route. If this approach results in a harvest rate exceeding 80% along the alternative route, then the harvest rate threshold can be adjusted to produce more reasonable results.

Some additional steps are required to estimate the daily marine abundance for delaying stocks. Because the total marine reconstructed daily abundances are not constrained to equal Mission escapement plus seaward catches, it is possible to apply independent decisions rules for Johnstone Strait versus Strait of Juan de Fuca abundances (Figure 6). Once daily abundances have been selected for all days on both routes, the total marine abundance is then compared to the total reconstructed Mission-based estimate for the reconstruction group and the daily abundances are proportionally re-scaled. In some cases, this rescaling re-introduces new harvest rate errors, and the modeller will have to re-evaluate some of their initial estimation methods. If the scaler is much greater than, or less than, 1, then the modeller may also want to reconsider some of their original selections (e.g. if total marine abundance is much greater than the Mission reconstructed value, then switch to alternative test fishery data that produces lower estimates on some days).

While there is expert judgement involved in the reconstructions, sensitivity analyses of reconstructions performed by two different experts revealed that overall, reconstructions for non-delaying stocks groups are robust to different decisions within the reconstruction process. There were no differences in the total reconstructed abundance or the overall migration timing, and only minor differences in diversion rates, route specific timing estimates, and route specific abundance estimates. Differences tended to be smaller for more abundant and non-delaying stock groups. For delaying stocks, the impact of expert judgement is more pronounced, especially given the fact that the final reconstructed abundances have to be rescaled to match the total escapement plus catch. Overall, both abundance estimates as well as timing and diversion rate estimates of delaying stocks should be considered of lower quality (i.e. more uncertain) compared to those of non-delaying stocks.

Table 3. Alternate data sources/approaches for estimating marine abundance.

Method Abbreviation	**Method Description**	**Additional comments**
A12-20 gn	Gill net test fishery	Gill net-based abundance estimate for both approaches
A12-20 ps	Purse seine test fishery (no Area 13)	Area 12 PS used to estimate Johnstone Strait abundance and Area 20 used to estimate Juan de Fuca abundance
A13-20 ps	Purse seine test fishery (no Area 12)	Area 13 PS used to estimate Johnstone Strait abundance and Area 20 used to estimate Juan de Fuca abundance
A1213-20 ps	Purse seine test fishery (all Areas)	Area 12 and Area 13 data averaged to estimate Johnstone Strait abundance and Area 20 used to estimate Juan de Fuca abundance.
A12-20 gnps	Gill net-purse seine test fishery (no Area 13)	Area 12 gill net and purse seine averaged to estimate Johnstone Strait abundance and Area 20 gill net and purse seine used to estimate Juan de Fuca abundance.
A13-20 gnps	Gill net-purse seine test fishery (no Area 12 ps)	Area 12 gill net and Area 13 purse seine averaged to estimate Johnstone Strait abundance and Area 20 gill net and purse seine used to estimate Juan de Fuca abundance.
A1213-20 gnps	All test fisheries	Area 12 gill net, Area 12 purse seine and Area 13 purse seine averaged to estimate Johnstone Strait abundance and Area 20 gill net and purse seine used to estimate Juan de Fuca abundance.
Catch (JS+JDF)	Catch/0.8 applied to both routes	This method adjusts the catches based on 80% exploitation but does this for both approaches in the same way. This method will not be appropriate post-season for non-delaying stocks as the sum of the abundances in both approaches will not add up to the Mission + catch estimate. This approach could be used for delaying stocks when catches in both approaches exceed abundances. This method could also be used in-season for non-delaying stocks.
Catch (Tot) – JS	Catch/0.8 for Johnstone Strait	This method would be used if the catch in Johnstone Strait is larger then the abundance in that area. It assumes 80% exploitation rate (but can be adjusted if needed). For non-delaying stocks, the abundance in Juan de Fuca Strait is the difference between the total reconstructed abundance and the abundance in Johnstone Strait. For delaying stocks, the estimates from method 9 equal the estimates produced by method 8 and 10.
Catch (Tot) – JdF	Catch/0.8 for Juan de Fuca Strait	This method would be used if the catch in Juan de Fuca Strait is larger then the abundance in that area. It assumes 80% exploitation rate (but can be adjusted if needed). For non-delaying stocks, the abundance in Johnstone Strait is the difference between the total reconstructed abundance and the abundance in Juan de Fuca Strait. For delaying stocks, the estimates from method 9 equal the estimates produced by method 8 and 10
Assumed Diversion	Mission reconstruction*assumed diversion rate	This method is used when there is no marine test fishing information and when marine catches are also insufficient to provide information on the proportion of the run migrating through Johnstone Strait versus Juan de Fuca strait. This method is mainly used at the start or the end of run when there is no marine test fishing data and catches are small. The estimate used in column AE regarding the assumed diversion rate should be based on the 5-day average diversion rate closes to that date. Hand enter the diversion rate estimate in column AI rather than using an equation based on the diversion rate values in column AK since this will lead to a circular reference. Johnstone Strait abundance = Mission*5-day average diversion rate Juan de Fuca Strait abundance = Mission*(1-5-day average diversion rate)
Rescaled Abundance	For delaying stocks only	Daily abundances after post-season adjustments so that total marine reconstructions are equal to total Mission reconstructions
Custom	User-defined place holder	
		For combinations of the above selections when applied differently across routes for delaying stock aggregates. The main purpose is to allow picking catch-based abundance estimates in case catches are larger than abundances on one route but allow relying on test fishing data for the other route especially if total catches in the other route are very small compared to the abundance estimates derived from test fishing data.

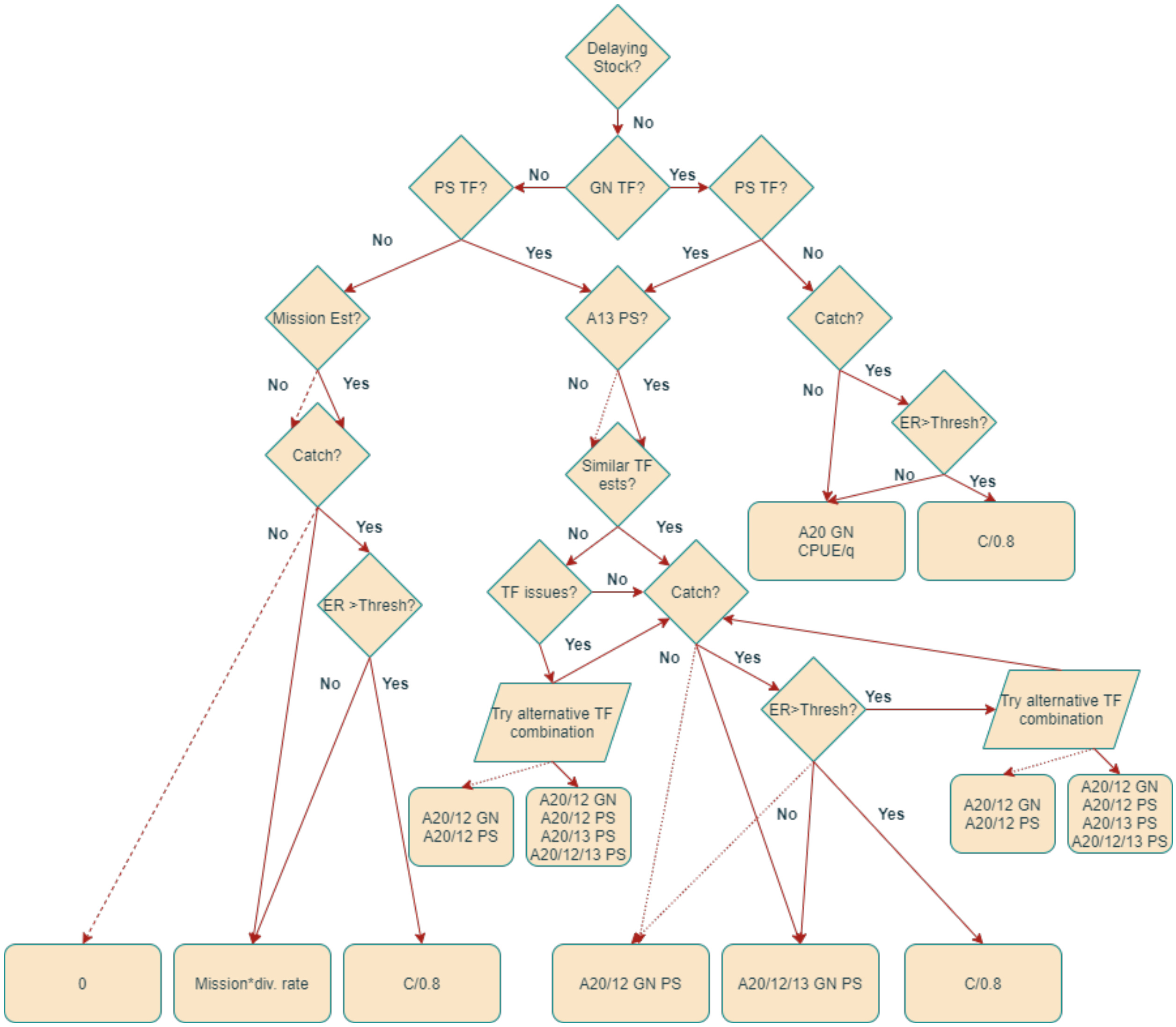

Figure 6. Decision framework for deriving 'best' estimates of marine abundance along a specific migration route for a non-delaying stock. For non-delaying stocks, equivalent approaches must be applied to each route on the same day such that the total abundance estimate remains equal to the Mission reconstructed value. For delaying stocks, the abundance along each route can be independently assessed. "TF Issues" include criteria such as reduced set count, highly variable CPUE across sets, or extremely low catchability.

Model Implementation

The reconstruction model was built in Excel with VBA and R applications used for data manipulation purposes. The workbook format for this approach was selected to facilitate dynamic linking to underlying data sources, and full transparency for modellers as expert judgement must be applied during some steps in the process. The resulting multi-year timeseries of reconstructed daily abundance estimates at multiple key locations and associated meta-data is stored in an Access database (DARMA – Daily Reconstructed Marine Abundance database). Figure 7 provides a schematic illustration of the connectivity across different structural components of the model, with a more detailed description of the data and processes associated with individual files provided in Table 4.

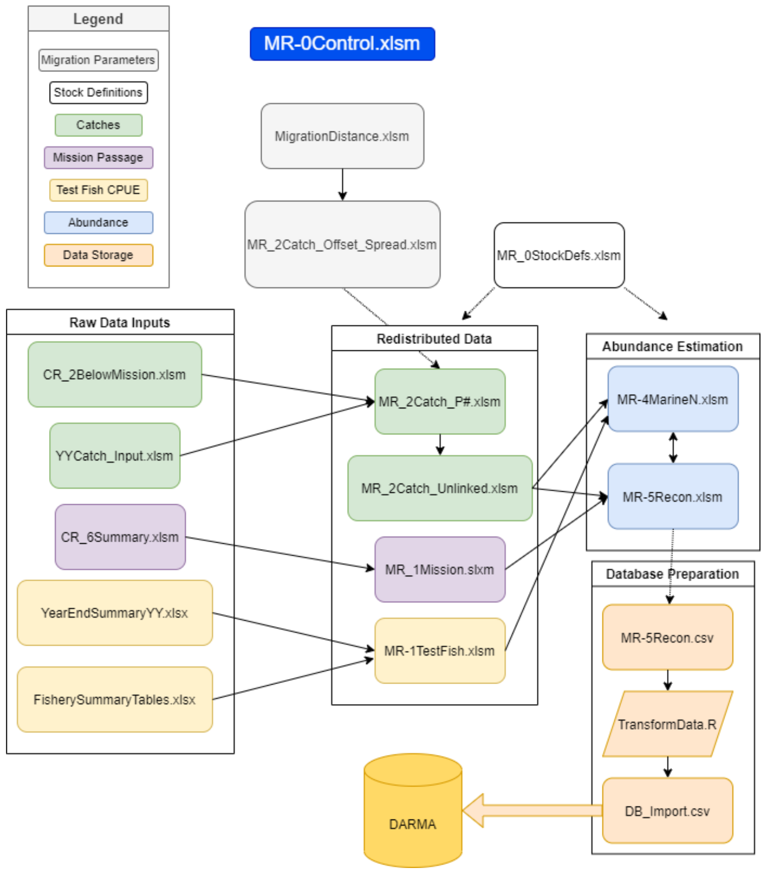

Figure 7. Schematic illustrating the file structure and connectivity for the post-season Fraser River sockeye salmon reconstruction files. A detailed description of each file can be found in Table 4

Table 4 Description of post-season Fraser River sockeye salmon marine reconstruction files.

FILE NAME	DESCRIPTION
	DATA PREPARATION FILES
MR-0CONTROL.XLSM	Consolidates a series of macros for easy file manipulation: entering user-defined inputs, file updating, and opening/closing of files. This file can also be used to easily extend the reconstruction files e.g. to include additional fisheries.
MIGRATIONDISTANCE.XLSM	Distance through statistical fishery areas along 5 alternative migration routes
MR_2CATCH_OFFSET_SPREAD.XLSM	User-defined inputs relating to migration offsets and spreads at the in-season stock group level defined in Table 1.
MR_0STOCKDEFS.XLSM	Definitions of alternative stock aggregations used through the marine reconstruction files. For more detailed information see Table 1.
CR_6SUMMARY.XLSM	Daily Mission passage estimates for >50 Fraser sockeye DNA groups.
YYCATCH_INPUT.XLSM	This file contains the daily percentage of Area 12 catch located seaward of the Area 12 gill net test fishery and is used to separate Area 12 catches into sub-areas so that abundances up until the test fishery location can be accurately recreated.
CR_2BELOWMISSION.XLSM	Catches below Mission by stock, fishery (area, gear, user), and date for >50 Fraser sockeye DNA groups.
YEARENDSUMMARYYY.XLSX	By-set test fishery catch-per-unit effort data for total sockeye salmon
FISHERYSUMMARYTABLES.XLSX	Daily test fishery catch-per-unit-effort data for total sockeye salmon
MR_2CATCH_P1.XLSM TO MR_2CATCH_PN.XLSM	Catch by fishing day in each area are offset relative to a common date index and re-distributed according to the days of fish migration which would have been vulnerable

	to a given fishery opening. Due to the complexity of the calculations and the amount of data, the import is broken into multiple files to improve workbook stability.
MARINE RECONSTRUCTION MODEL FILES	
MR_2CATCH_UNLINKED.XLSM	Consolidates all data from MR_2Catch_P1…Pn.xlsm but breaks original links to improve file stability.
MR_1MISSION.XLSM	Daily Mission passage estimates but adjusted dates relative to timing through Area 20 based on assumed migration rates, route and resulting offsets.
MR-1TESTFISH.XLSM	Imports test fishery data, applies stock proportions and adjusts date indexing according to user-defined offsets.
MR-4MARINE.XLSM	Reconstruction daily abundance estimates for individual reconstruction groups along salmon migration routes. This fille allows for user selection of the best time series to derive daily marine abundance estimates along each approach route. Options include test fishery CPUE-based estimates, estimates derived using total daily catches in combination with assumed daily exploitation rates, Mission escapement plus seaward catches multiplied by CPUE-based diversion rates. For non-delaying stock groups, the CPUE data are used in combination with post-season catchability estimates while for delaying groups, the resulting daily reconstructed abundances are rescaled to ensure the totals match total reconstructed abundances based on Mission escapement plus seaward catches.
MR-5RECON.XLSM	The file contains daily reconstructed estimates of abundance for >50 sockeye DNA groups at different key locations along the migration route (Area 12 GN, Area 12 PS, Area 13 PS, Area 20 GN, Area 20 PS, Area 7 PS). The file also contains summaries of catches between key locations as well as Mission escapement. Total reconstructed marine abundances are calculated from 1) Mission escapement plus catch for non-delaying stocks or 2) test fishing CPUE x expansion line for delaying stocks (re-scaled so total equals Mission escapement plus catch). To get marine abundance at an index location, catches are iteratively subtracted along the migration route from the total reconstructed marine abundance.
DATABASE PREPARATION FILE AND DATABASE	
MR-5RECON.CSV	Intermediate flat file prior to conversion to database ready format.
TRANSFORMDATA.R	File used to transform the Excel data into a database ready format through normalization.
DB_IMPORT.CSV	Normalized file of daily reconstructed abundances for database import.
DARMA	Daily Reconstructed Marine Abundance database containing daily reconstructed abundance estimates of sockeye DNA groups at key locations along the migration route in addition to summarized catches between locations.

DARMA Database

The Daily Reconstructed Marine Abundance (DARMA) database was created as a multi-year repository for daily reconstructed abundances by location (Figure 5) and stock. It involves a SQL back-end and Access front-end interface (Figure 8 and Figure 9).

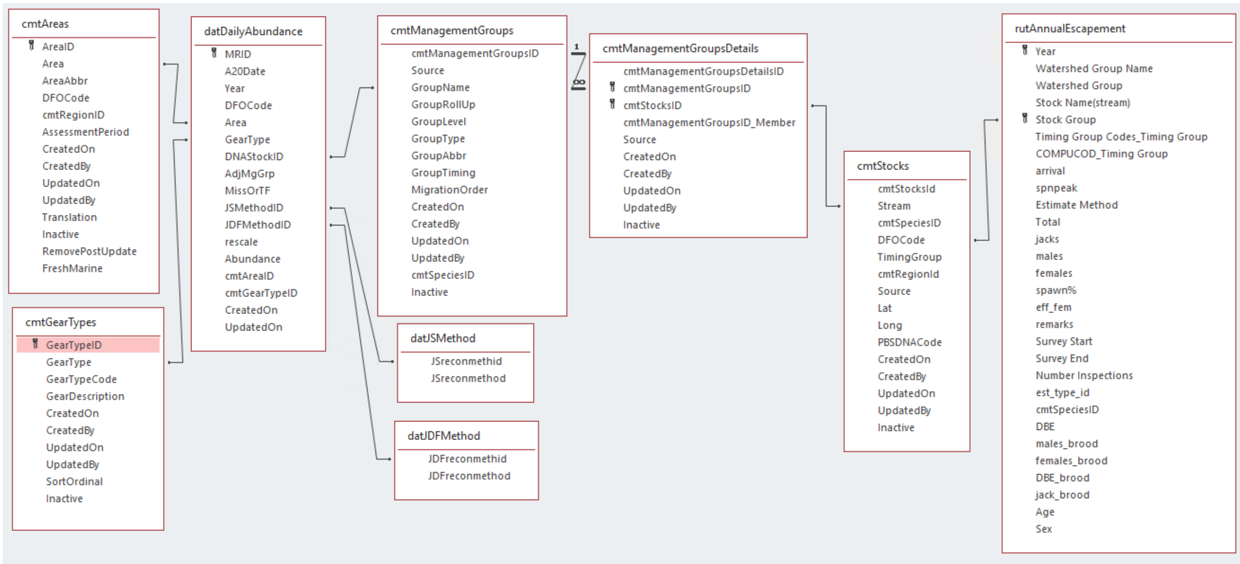

Figure 8. Daily Reconstructed Marine Abundance (DARMA) database schema and relationships. This schematic shows how the reconstructed run data are stored (datDailyAbundance table) and the relationships with other entities/tables, including the Fraser Panel Management Groups, Populations (DFOCode) and Annual Escapement (rutAnnualEscapement).

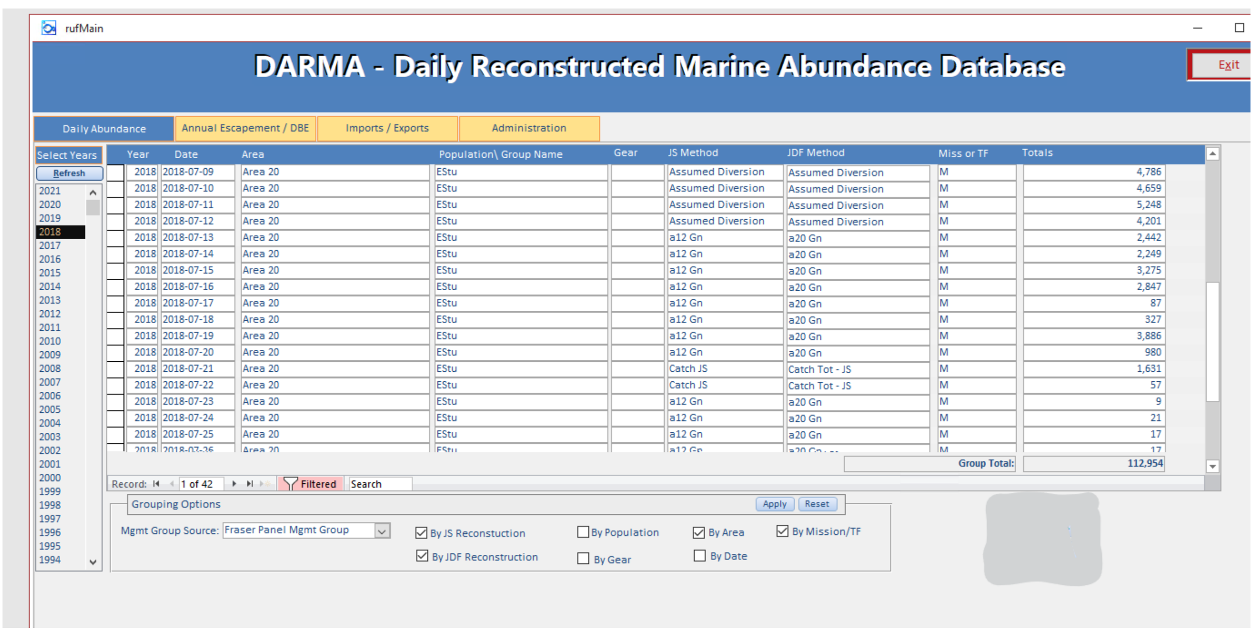

*Figure 9. Screen capture of the DARMA Access front-end highlighting the daily abundances and associated meta-data available. This view shows reconstructions to the Area 20 purse seine test fishery for the Early Stuart management group. For each day, the reconstruction method is identified as "M" (based on Mission + seaward catch, applied for non-delaying stocks) or "TF" (marine based – usually test fishery CPUE/catchability, applied for stocks that delay their upstream migration and therefore violate order of movement assumptions). The specific combination of data used to derive the proportions along each migration route are shown in the columns "JS Method" and "JDF Method". As this screen capture illustrates, a variety of different approaches (Mission abundance * assumed diversion rate; gill net test fisheries; assumed harvest rates etc.) were applied depending on the data availability and quality on a given day.*

Not only does DARMA provide a secure, multi-year repository for post-season marine reconstructions, it also includes functionality to disaggregate and aggregate time-series at a variety of stock resolutions, similar to the PSC RUFES database described in the SEF project *S16-I03 & S15-I11: Improvements to predicting en-route loss estimates for Fraser sockeye salmon 2015-16* (Patterson et al. 2017). Drawing from the RUFES process, DARMA uses relational tables to "map" populations from the DFO spawning escapement database (T. Cone, DFO) to DNA stock groups. Upon import, DARMA uses a series of decision rules to derive abundance time series at an even finer stock resolution i.e. the population level. The rules for partitioning the data, and special exceptions, are described in Table 5.

Table 5. Rules for partitioning catch and passage at the DNA group level into assumed estimates of daily marine abundance reconstructed to different locations within the Strait of Georgia, Johnstone Strait, and Juan de Fuca Strait. This same set of decision rules are applied within the Rufes database.

Scenario	Example	Database Assumption	Possible Bias
Marine reconstructions exist for a DNA baseline group and escapements were enumerated for ALL spawning streams/sites associated with that baseline	Default	The percentage of adult spawners in each stream relative to the sum of all adult spawners in streams associated with that DNA baseline group is used to weight the "raw" reconstruction data.	Assumes equal proportional DBEs associated with each sub-component of the DNA baseline group.
Reconstructions exist for a DNA baseline group, but SOME spawning streams/sites associated with this group were not enumerated in a given year	e.g. Horsefly, Mitchell, Late Shuswap systems	Un-enumerated sites are assigned zero escapement. The percentage of adult spawners in each stream relative to the sum of all adult spawners in streams associated with that DNA baseline group is used to weight the "raw" reconstruction data.	Assumes un-enumerated sites had low (near zero) spawning abundance. Data should be rolled up appropriately to minimise this bias.
Reconstructions exist for a DNA baseline group, but NONE of the spawning populations associated with this group were enumerated in a given year	Horsefly River, Birkenhead River, Mitchell River (2002)	PSC Staff provide total spawning escapement estimates for each system. Equal weighting assigned to individual spawning stream within the DNA group. Un-enumerated sites treated as zero escapement.	Could be large biases in assumed spawning escapement and data should be rolled up to minimise bias.
There is a many-to-one relationship between DNA baseline groups and populations enumerated on the spawning ground	Chilko River and Lake (north) and Chilko Lake (south) are identified as separate baseline groups but DFO only enumerates a single spawning escapement for Chilko.	Historically, DFO enumerated all three Chilko DNA baseline groups separately. Assign zero escapement to Chilko Lake (south) and Chilko Lake (north) in recent years.	All three Chilko baseline groups must be rolled together for analysis. Important to note that "Chilko River" in DFO escapements in recent years is not equivalent to "Chilko River" DNA baseline.
Reconstructions exist for a DNA baseline group, but ALL spawning populations associated with this group had zero escapement.	Could occur with very small, well-identified stocks mixed in with large ones (like Widgeon buried in Shuswap dominant years) where a small stock % is multiplied by a large daily total causing an inflated estimate.	Equal weighting assigned to individual spawning stream within the DNA group.	Data should be rolled up to a higher aggregation to minimise bias.
There are no reconstructions for a given DNA baseline group but there are associated spawning escapements	Quite often happens with very small, well-identified stocks mixed in with large ones (like Widgeon buried in Shuswap dominant years).	Assign zero abundance to a single day (e.g. October 20) for that baseline group.	Reconstruction is obviously underestimated since fish arrived on the spawning grounds. Should not be treated individually but as part of a larger stock aggregation.

Given the assumptions and potential sources of bias described in Table 5, the intention is not to use DARMA to analyse reconstructions at such a finely resolved stock level, but to provide flexibility such that data can also easily be re-aggregated at various other resolutions upon export. For example, under the PST, the Secretariat is responsible for providing marine timing information at the management group level (Early Stuart, Early Summer, Summer, Late-run), but data is increasingly being requested at the Conservation Unit level as well. Figure 10 shows a screen capture of the alternative aggregations available for summarizing the reconstructed abundances.

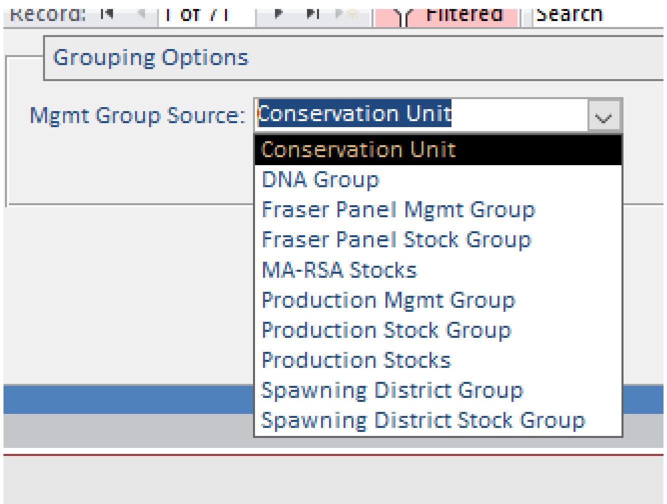

Figure 10. A drop-down illustrating the list of stock aggregate options the user can select for displaying the reconstructed data.

Project Results

During the development of the updated post-season sockeye marine reconstruction model and DARMA database, several limitations and data inaccuracies in the existing PSC reconstruction framework were addressed. The improvements achieved as a direct result of this SEF project improve the historical data quality and integrity, data archival and security, and provide a flexible framework for adapting to changing biological conditions and management requirements moving forward. Table 6 provides a summary of the key advancements resulting from this project.

Table 6. Description of key improvements to Fraser River sockeye salmon run reconstruction models as a direct result of this project.

Improvement	**Issue Addressed**
File standardization	No standardized template or approach across the time series
Finer stock resolution	Low stock resolution was inconsistent with updated catch and escapement timeseries
Improved data integrity	Linked to in-season data which was not updated post-season
Separation of in-season and post-season processes	Time-series of marine timing and diversion based on in-season files. No consistent updating post-season.

Transparent but flexible migration assumptions	Fixed travel time assumptions with unclear underlying assumptions about route distance and migration speed
Standardised marine abundance decision rules	Deviations from default assumptions for marine abundances were inconsistent and poorly documented.
More robust marine abundance estimation	Did not take into account other data sources which could inform route-specific abundance estimates (e.g. catches)
Improved post-season reconstruction of delaying stocks	Marine reconstructions for delaying stocks were not rescaled based on catch plus escapement information
Multi-location reconstructed timeseries	For many years, only total abundances reconstructed to a standardized Area 20 timing were created.
Stock-specific annual and daily diversion rates	Difficult to extract stock-specific diversion rates from historical files.
Archival of post-season catchability	In-season and post-season catchability estimates stored in the same file structure, lending to confusion and over-writing.
Multi-year database repository	Data insecurely stored across multiple files with potential for corruption.
Recording of meta-data	Fields to record decision making and additional considerations when deriving daily marine abundance estimates

Sample Outputs – 2018 Case Study

During the 2018 season, Fraser Panel members noticed that the estimated abundance of salmon passing through Johnstone Strait seemed low compared to catches. Normally, PSC staff do not report route-specific abundance estimates but these data were available in 2018 as part of a SEF project analysing the potential for commercial purse seine ITQ data to estimate Johnstone Strait abundances (Ma et al. 2018 – *S18-FRP29-Evaluating the use of commercial fishery data to inform the in-season management of salmon fisheries*). Upon closer evaluation post-season, it was clear that catch exceeded daily marine reconstructed abundances during certain periods of the season, even after adjusting for potential delay or slower migration rates. However, these analyses and the required adjustments to correct for the bias in diversion rate were not straightforward under the existing file structure. As such, 2018 is an excellent case study for the potential improvement to reconstructed marine abundances using the more robust and flexible post-season model.

We applied the decision rules outlined in Figure 6 to estimate marine abundances and produce a revised estimate of daily northern diversion through Johnstone Strait. Figure 11 and Figure 12 illustrate some of the alternative marine abundances for the Summer run excluding Harrison group, with the selected values highlighted in black. Similar data is also produced for Early Stuart, Early Summer, Harrison, Lates excluding Birkenhead, and Birkenhead aggregates. Once we had identified the "best" method for selecting marine abundances, we used this data to update the in-season estimate of diversion rate. While our in-season and post-season diversion rates closely matched for much of the timeseries, the post-season tool clearly identified and corrected the period of underestimation occurring in the latter half of August (Figure 13). This is one clear example highlighting the importance and value of the new reconstruction model in improving our historical time series of marine migration parameters.

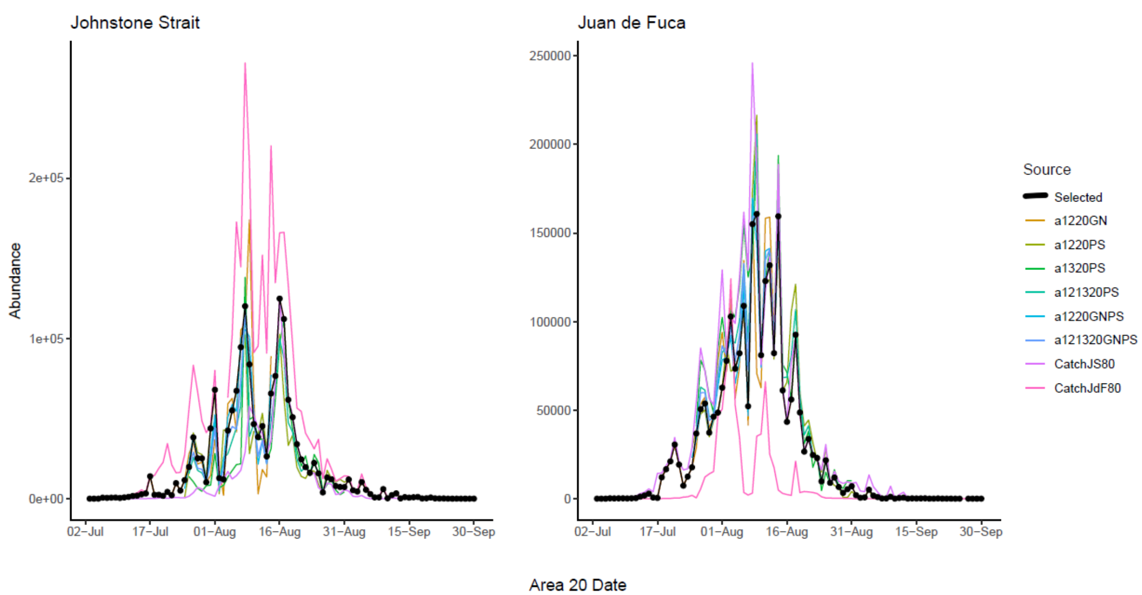

Figure 11 Alternative marine abundances for the 2018 Summer run excluding Harrison (i.e. non-delaying component) with the user-selected "best estimate" for the Johnstone Strait and Juan de Fuca approaches shown in black. On any given day the sum of the abundance along the two approaches is constrained to equal the reconstructed Mission-based estimate. As such, the same source must be used for both routes on a given day.

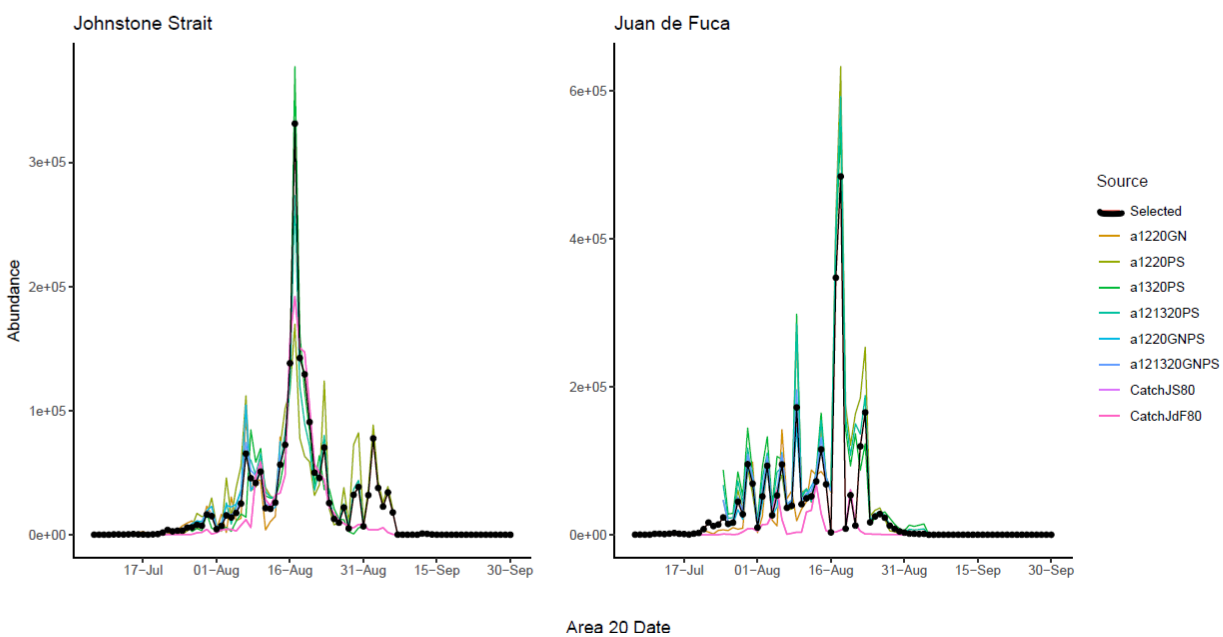

Figure 12 Alternative marine abundances for the 2018 Late run excluding Birkenhead (i.e. delaying component) with the user-selected "best estimate" for the Johnstone Strait and Juan de Fuca approaches shown in black. The data source selected for each route can vary on a given day as the sum of the two abundances is not aligned with a Mission reconstructed value due to the delay and redistribution of the fish prior to migrating upstream. Marine

abundances were divided by a scaler of 0.88 to produce annual totals equivalent to the total Mission reconstructed estimate (Mission + seaward catch).

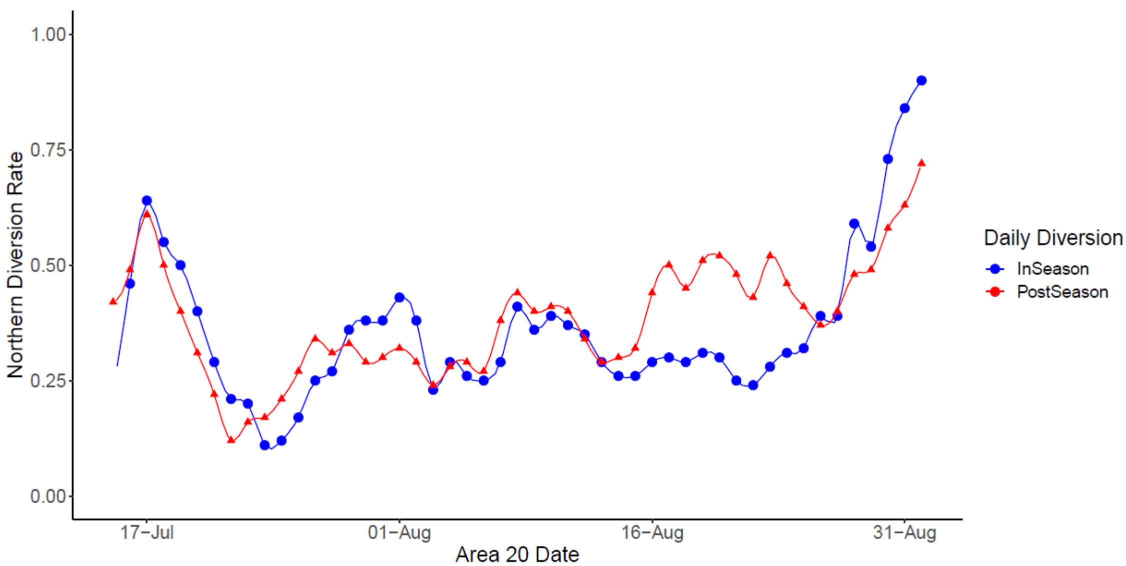

Figure 13. A comparison of in-season and post-season reconstructed daily diversion rate estimates for the total Fraser River sockeye salmon return in 2018.

DARMA can be used to evaluate the timing, spread, diversion for a variety of stock aggregates and to a variety of different locations along the approach routes around Vancouver Island. For example, Figure 14 and Figure 15 illustrate reconstructions by management group for multiple locations along Johnstone and Juan de Fuca Straits. The differences in abundance across the lines reflect the impact of catch removals along each migration route. Previously, only total marine reconstructions were reported, and diversion rate was only recorded at the level of total sockeye, and rarely at any finer stock resolution.

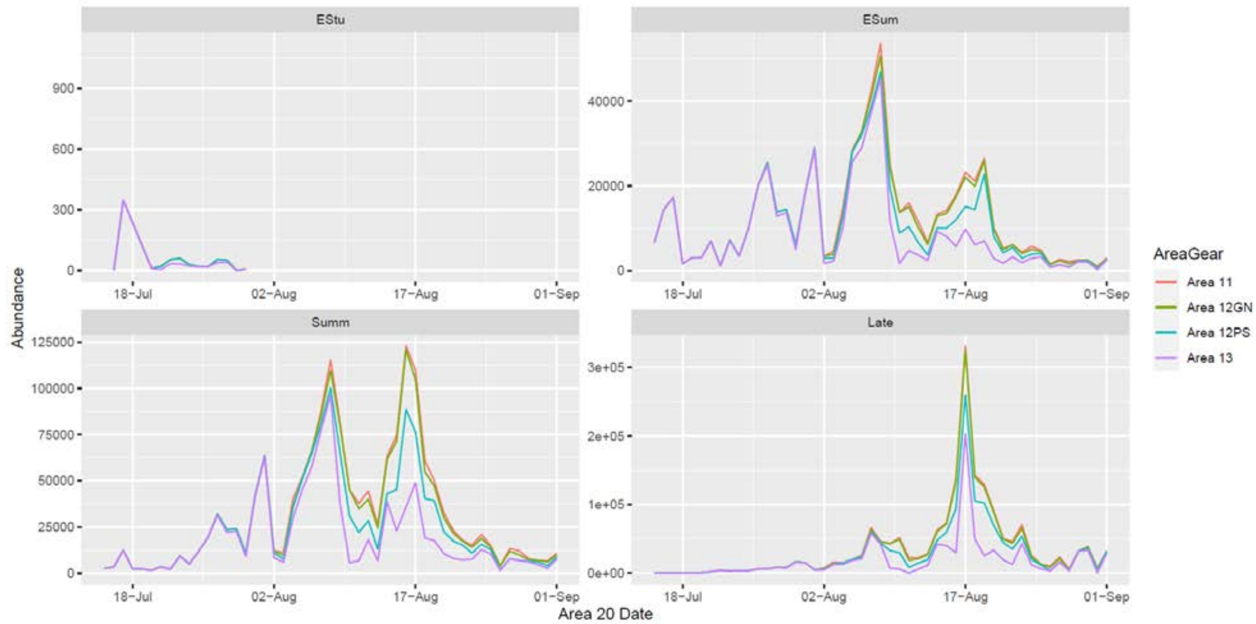

Figure 14. Daily reconstructed abundances by management group at 4 different locations along the Johnstone Strait migration route and indexed to a common Area 20 date. Area 11 is the most seaward, and Area 13 is the closest to the river. Differences between the lines indicate catch removals. Early Stuart and Early Summer run abundances are based solely on backwards reconstructions (Mission escapement + catch), while Summer and Late-run reconstructions are a combination of backwards and forwards (marine abundance – catch) reconstructions.

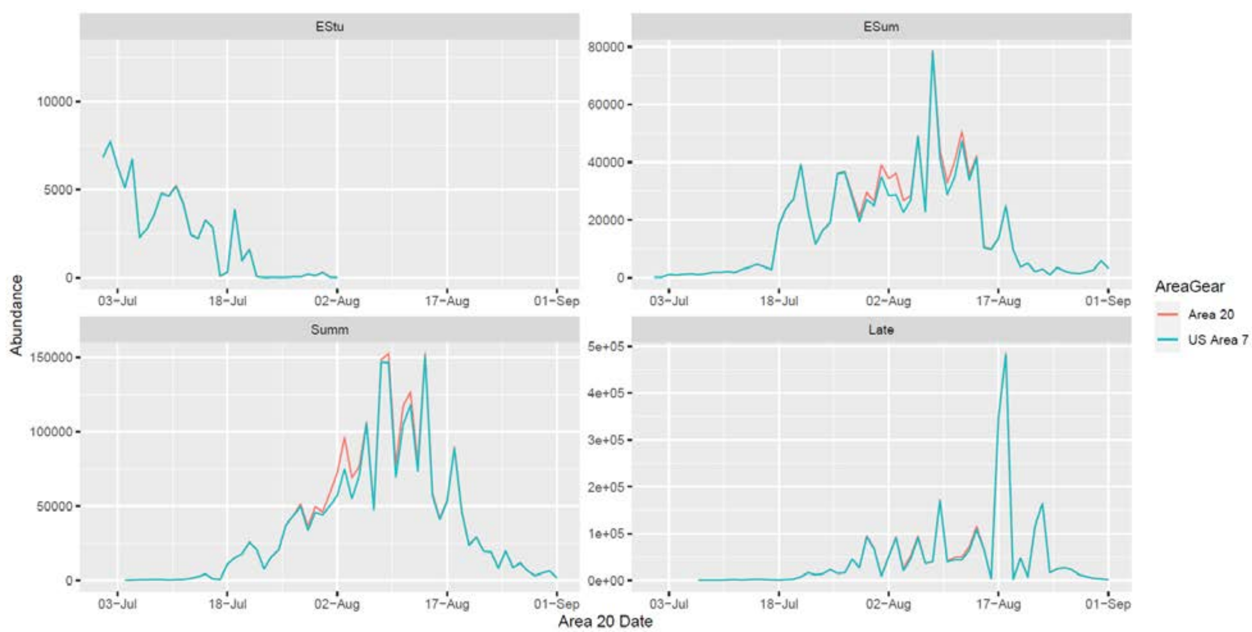

Figure 15. Daily reconstructed abundances by management group at 2 different locations along the Strait of Juan de Fuca migration route and indexed to a common Area 20 date. Area 20 is the most seaward, and Area 7 is the closest to the river. Differences between the lines indicate catch removals. Early Stuart and Early Summer run abundances are based solely on backwards reconstructions (Mission escapement + catch), while Summer and Late-run reconstructions are a combination of backwards and forwards (marine abundance – catch) reconstructions.

Not only can we easily extract data at the level of management group, but DARMA also allows biologists to re-create similar figures for alternative stock groupings – such as Conservation Units (CU). This aggregation structure is increasingly requested from the PSC to inform processes related to Wild Salmon Policy and the Species At Risk Act. However, it is imperative for users of the data to recognize that the finer the data resolution, smaller the sample sizes on which stock specific estimates are based. As a result, while the data is reliable at a management group level, inaccuracies and even negative abundances may arise for reconstructions which are parsed out on a finer scale. This is particularly a concern when dealing with small stocks, or low abundances at the "tails" of a distribution, or during periods when diversion rates are strongly skewed to one approach area. The assumption of a normal timing curve is also less evident at a finer stock resolution compared to the management group aggregate.

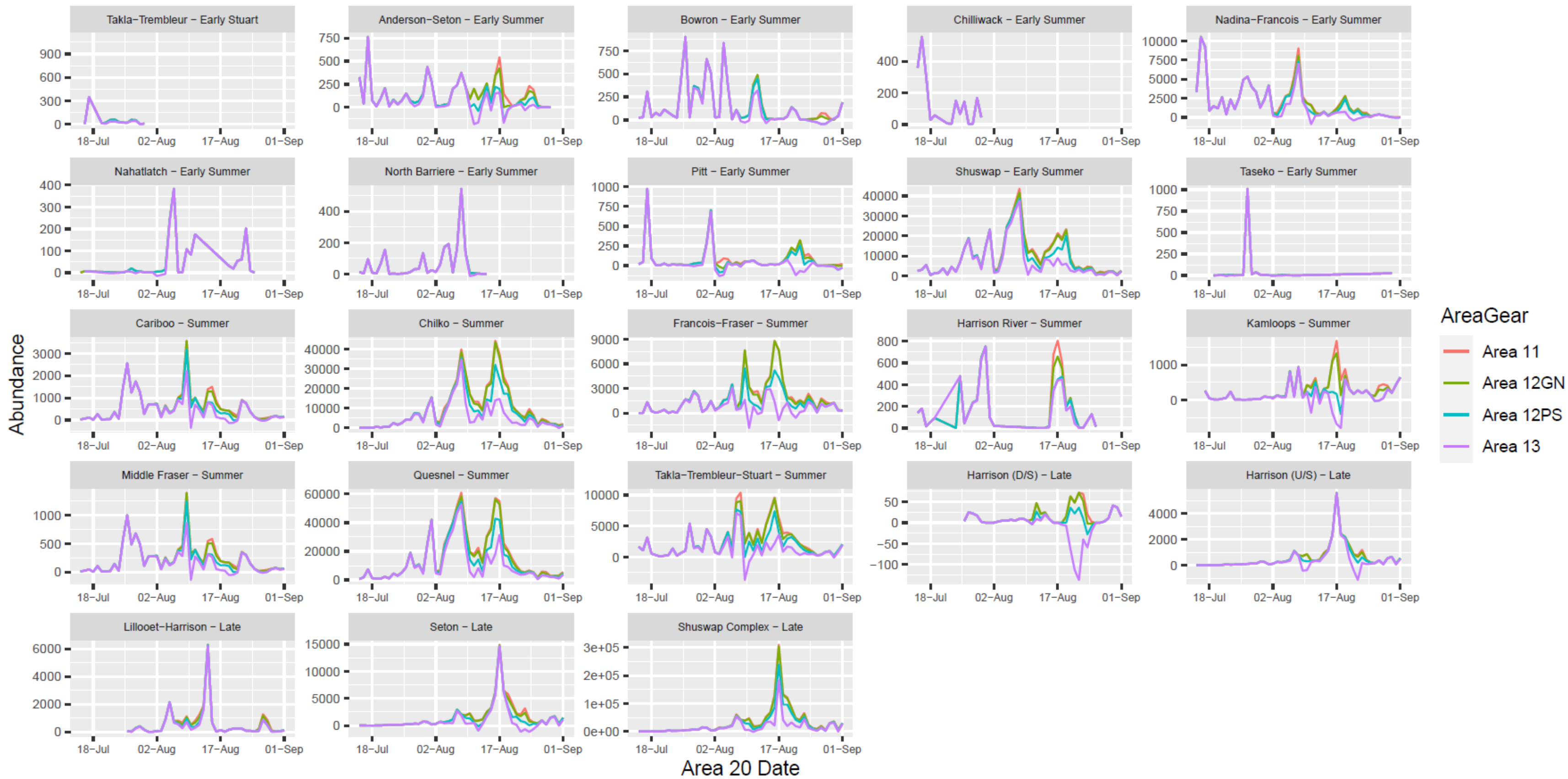

Figure 16. Daily reconstructed abundances by CU at 4 different locations along the Johnstone Strait migration route and indexed to a common Area 20 date. Area 11 is the most seaward, and Area 13 is the closest to the river. Differences between the lines indicate catch removals. Early Stuart and Early Summer run abundances are based solely on backwards reconstructions (Mission escapement + catch), while Summer and Late-run reconstructions are a combination of backwards and forwards (marine abundance – catch) reconstructions. Negative reconstructions can arise at low run sizes due to errors in model assumptions which are more pronounced at finer stock resolutions.

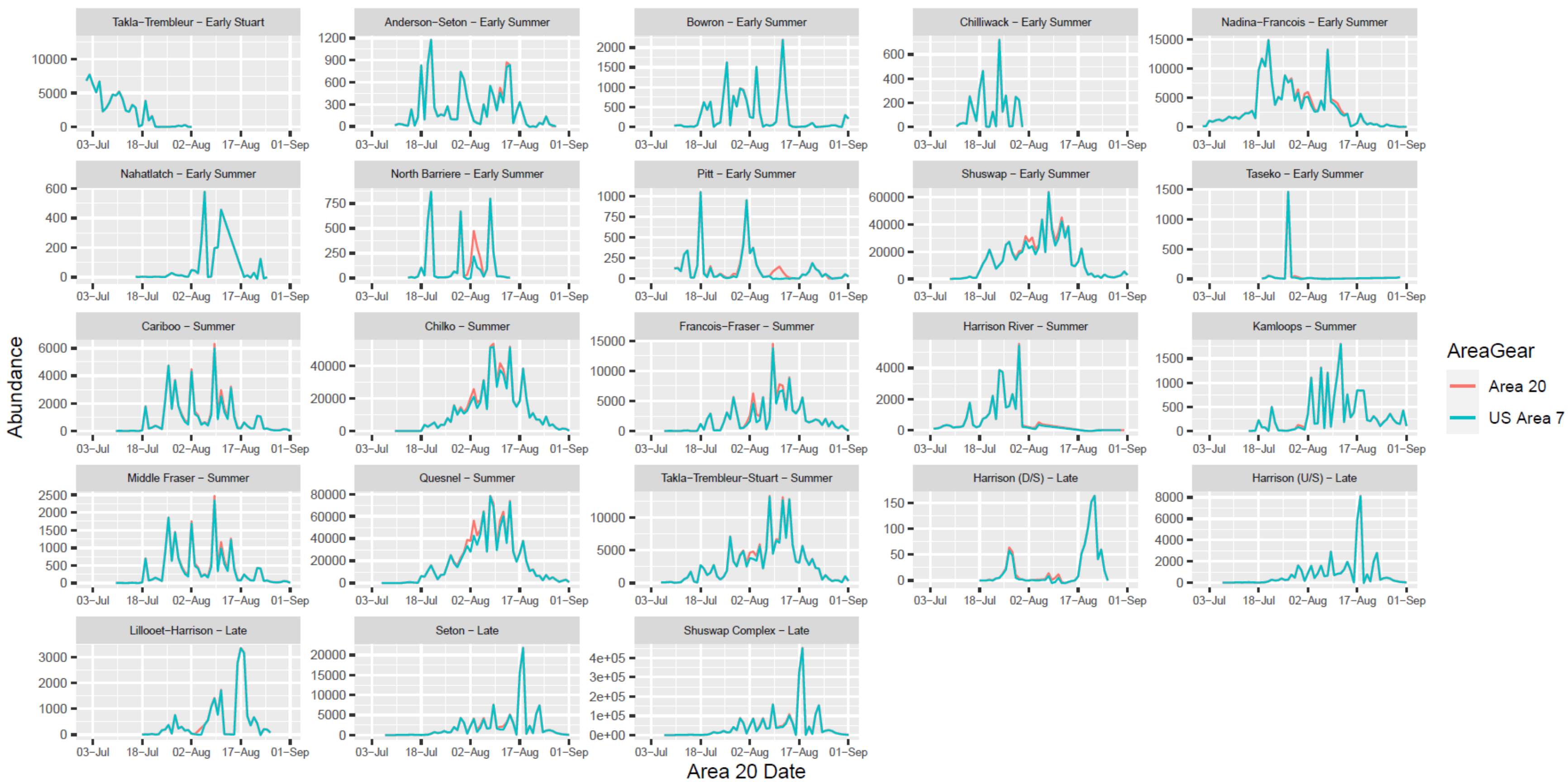

Figure 17 Daily reconstructed abundances by CU at 4 different locations along the Strait of Juan de Fuca migration route and indexed to a common Area 20 date. Area 11 is the most seaward, and Area 13 is the closest to the river. Differences between the lines indicate catch removals. Early Stuart and Early Summer run abundances are based solely on backwards reconstructions (Mission escapement + catch), while Summer and Late-run reconstructions are a combination of backwards and forwards (marine abundance – catch) reconstructions. Negative reconstructions can arise at low run sizes due to errors in model assumptions which are more pronounced at finer stock resolutions.

Conclusion

The PSCs new post-season marine reconstruction files address several outstanding issues related to data quality, file structure and flexibility, and standardization of biological and management-related modelling assumptions. There is now a direct connection between the data in these files and the post-season catch-by-stock records held in the PSC RUFES database - increasing quality standards and stock resolution of the marine reconstruction data to the same level as already existing for catch and Mission passage information. The ability to reconstruct abundances to multiple key locations along each incoming migration route will lead to the development of new historical time series of spread, diversion rate, and timing which can be used to refine pre-season forecasts and priors used during in-season stock assessment. The improved spatial resolution can help improve our forecasts of sockeye salmon availability through Johnstone vs. Juan de Fuca Straits – which is beneficial for both pre-season and in-season fisheries planning. In addition, the updated time series can be used to re-evaluate historical catchability and harvest rates of various fisheries and allow PSC staff to better support ongoing SEF projects involving the exploration of using FSC catches to predict marine abundances and assess run size.

Improving the stock resolution of the reconstructed timeseries will facilitate stock-specific comparisons of annual and daily diversion rates, which were not previously readily accessible. In addition, using DARMA, PSC staff can more readily respond to data requests for information at different stock resolutions and help support assessments related to SARA or the Wild Salmon Policy, as well as provide data for projects such as the Pacific Salmon Explorer (Pacific Salmon Explorer). Moving forward, PSC Staff will continue to populate the DARMA database and explore the patterns and information present in the updated reconstructed time series.

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Financial Statements

See Attached.