Juvenile Salmon Migration Observations in the Discovery Islands and Johnstone Strait in 2018

Abstract

The Hakai Institute Juvenile Salmon Program has been monitoring juvenile salmon migrations in the Discovery Islands and Johnstone Strait since 2015 with the specific purpose to understand how ocean conditions experienced by juvenile salmon during their early marine migration impacts their growth, health and ultimately survival. We found that during the two of the warmest years of sea-surface temperature recorded in British Columbia waters, juvenile sockeye, pink, and chum left the Strait of Georgia one to two weeks earlier than previously. The temporal distribution of sockeye migration timing out of the Strait of Georgia north through the Discovery Islands was skewed right, indicating that many sockeye migrate together in late May and abundance tails off late into June and July. Pink and chum migrations are more protracted, lasting from early May to late July. Our results indicate that juvenile sockeye exit the Strait of Georgia en masse, likely in response to ocean temperature and foraging conditions. This report summarizes migration timing, fish length and weight, sea-louse loads, purse seine catch composition, and ocean temperatures observed from the first four years of this research and monitoring program. Combining key variables from this research program with observations from freshwater and high-seas sampling will provide, for some stocks, a complete account of the conditions salmon experience during their migration from their natal river to the high seas. These measures will further our knowledge of what drives early marine mortality, and better our understanding of how salmon are adapting to climate change.

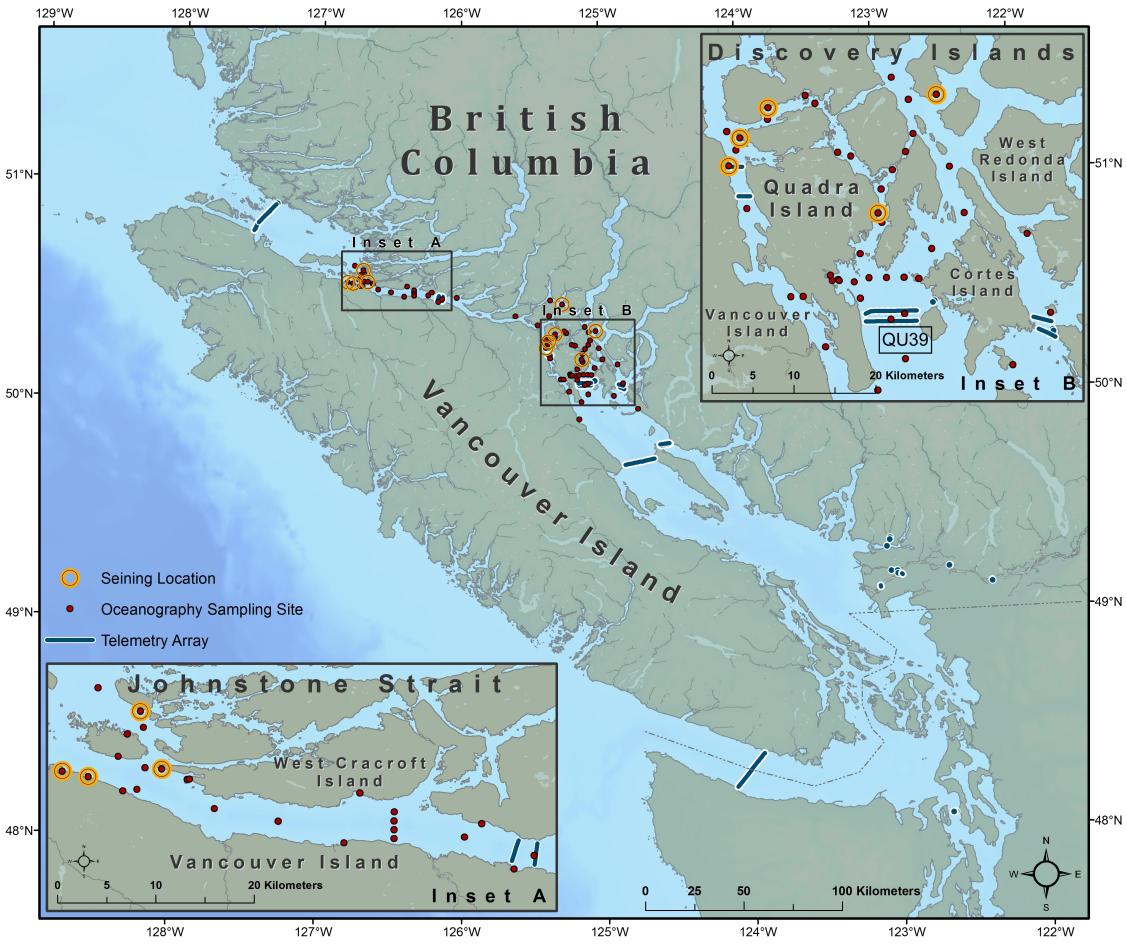

Figure 1: Sampling locations in 2019

1 Results

The peak migration date for sockeye in the Discovery Islands in 2019 was on May 21, 6 days earlier than the study-period average of May 27. The peak migration date for chum in the Discovery Islands was on June 24, 8 days later than the average of June 16. Peak migration timing for pink salmon is not reported because we expect catches of juvenile pink salmon do not originate from the Fraser River in odd years.

Catch proportion was dominated by sockeye salmon in the Discovery Islands and Johnstone in 2019 making up 37.7 % of the catch (Table 5) while chum made up 27.7 % and pink 33.8 % (Figure 5).

Fish lengths varied between regions and among species and years (Figure 6) though in 2019 sockeye were longer, pink were shorter, and chum were longer than their respective study-period averages in the Discovery Islands and Johnstone Strait combined. Sockeye length was 116.7 mm (Table 4), which is 7.2 mm longer than the study-period average ($p < 0.0001$, 95% CI 6.3 -8). Average pink lengths were 102.7 mm, which is 2.1 mm shorter than the study-period average ($p < 0.0001$, 95% CI 4.5-0.3). Chum were on average 118.1 mm, which is 5.9 mm longer than the study-period average ($p < 0.0001$, 95% CI 4.1-7.7).

Sea-surface temperature in May and June during the juvenile salmon out-migration at QU39 in the northern Strait of Georgia was -0.41 degrees C different than average.

```
## # A tibble: 65 x 6
##     year Estimate    SD     Z measure          spp
##    <int> <chr>    <dbl> <dbl> <chr>            <chr>
```

```
##  1  2015 May 23     NA  -0.52 Migration Timing Sockeye
##  2  2016 May 28     NA   0.2  Migration Timing Sockeye
##  3  2017 June 07    NA   1.66 Migration Timing Sockeye
##  4  2018 May 23     NA  -0.52 Migration Timing Sockeye
##  5  2019 May 21     NA  -0.81 Migration Timing Sockeye
##  6  2015 272.2     480.  0.77 Catch Intensity  Sockeye
##  7  2016 307.2     432.  1.18 Catch Intensity  Sockeye
##  8  2017 131.5     158. -0.9  Catch Intensity  Sockeye
##  9  2018 113.7     290. -1.11 Catch Intensity  Sockeye
## 10  2019 212.2     536.  0.06 Catch Intensity  Sockeye
## # ... with 55 more rows
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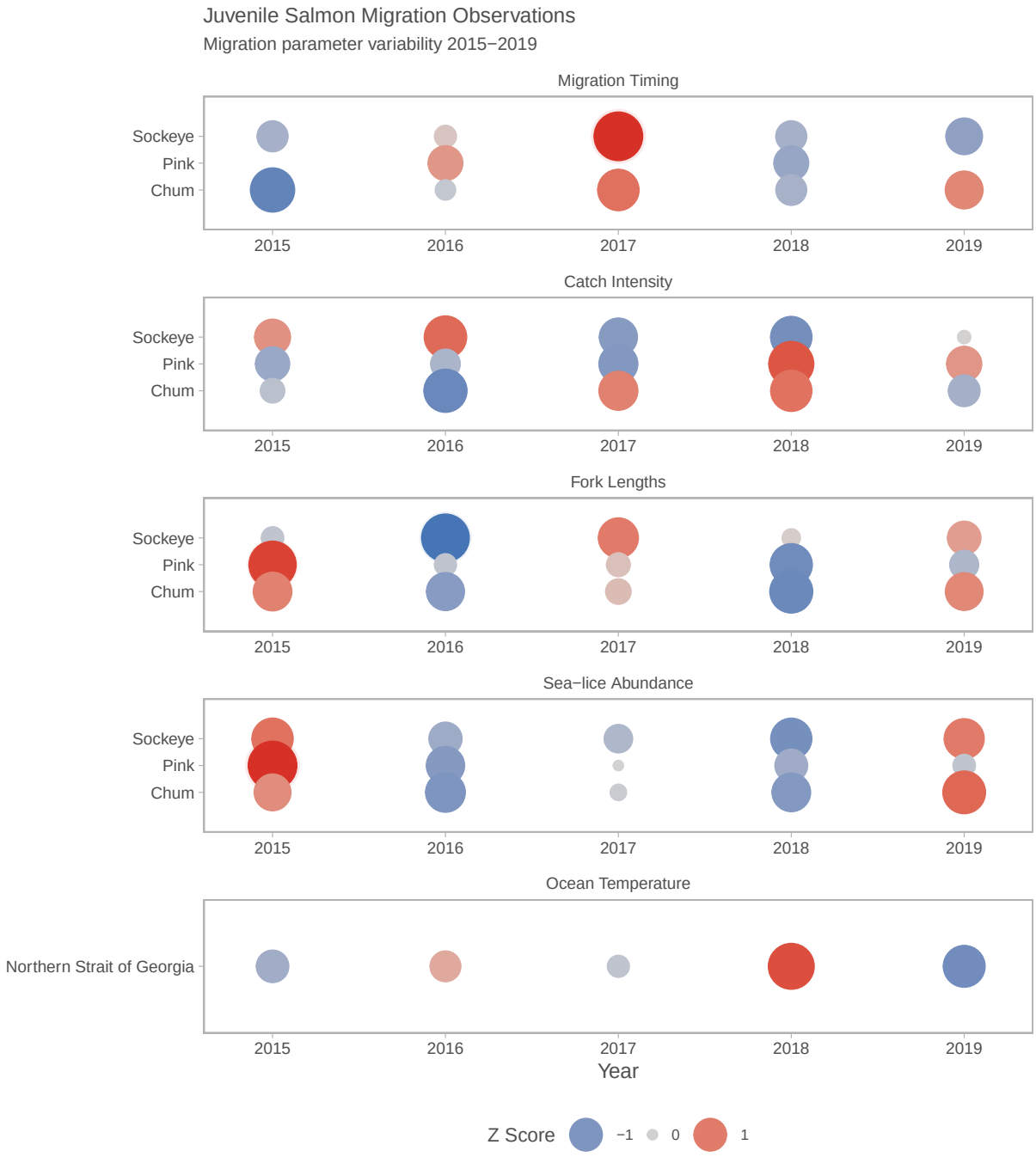

Figure 2: The number of standard deviations (z score) from the study-period average (2015-20192019) for key migration parameters. Size and colour saturation of circles indicates the magnitude of the anomaly. Blue colour indicates less than average; grey indicates average; red indicates greater than average. Peak migration date is based on the median date of fish capture in the Discovery Islands. Length is based on the average fork length from the Discovery Islands and Johnstone Strait combined. Parasite load is the average abundance of all sea-louse species in their motile life stages for both the Discovery Islands and Johnstone Strait regions. Ocean temperature describes the mean ocean temperature in the top 30 m at station QU39 in the northern Strait of Georgia in May and June.

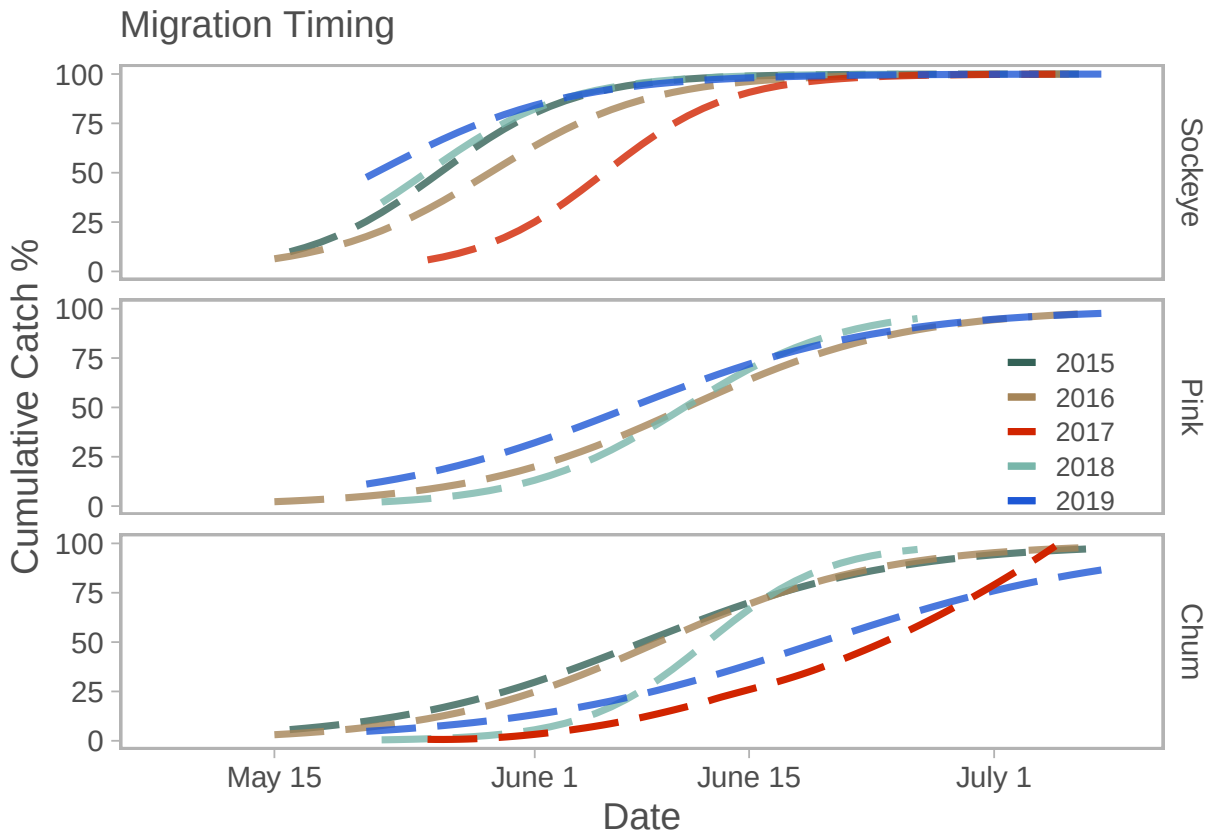

Figure 3: Cumulative catch of sockeye, pink, and chum, in the Discovery Islands and Johnstone Strait between 2015 and 2019.

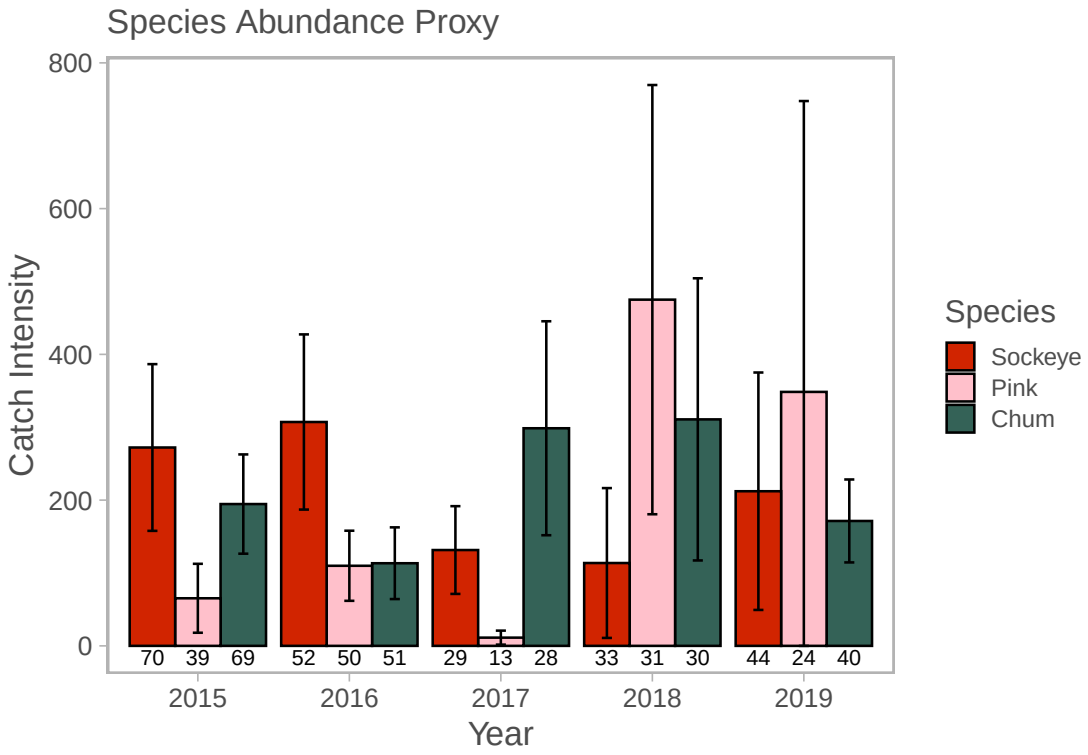

Figure 4: The catch intensity (our proxy for abundance) of sockeye, pink, and chum salmon in the Discovery Islands and Johnstone Strait. Numbers under each bar indicate the number of seines in which the species was caught, and error bars indicate the 95 percent confidence region.

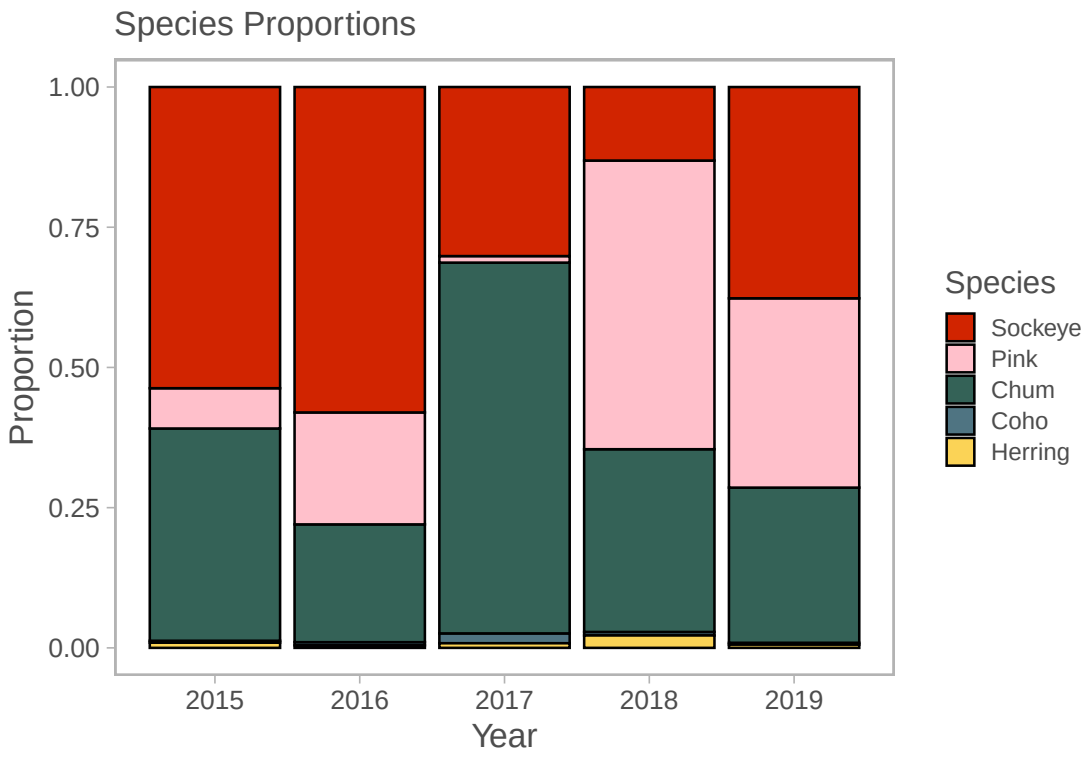

Figure 5: The annual proportion of fish captured in the Discovery Islands and Johnstone Strait combined.

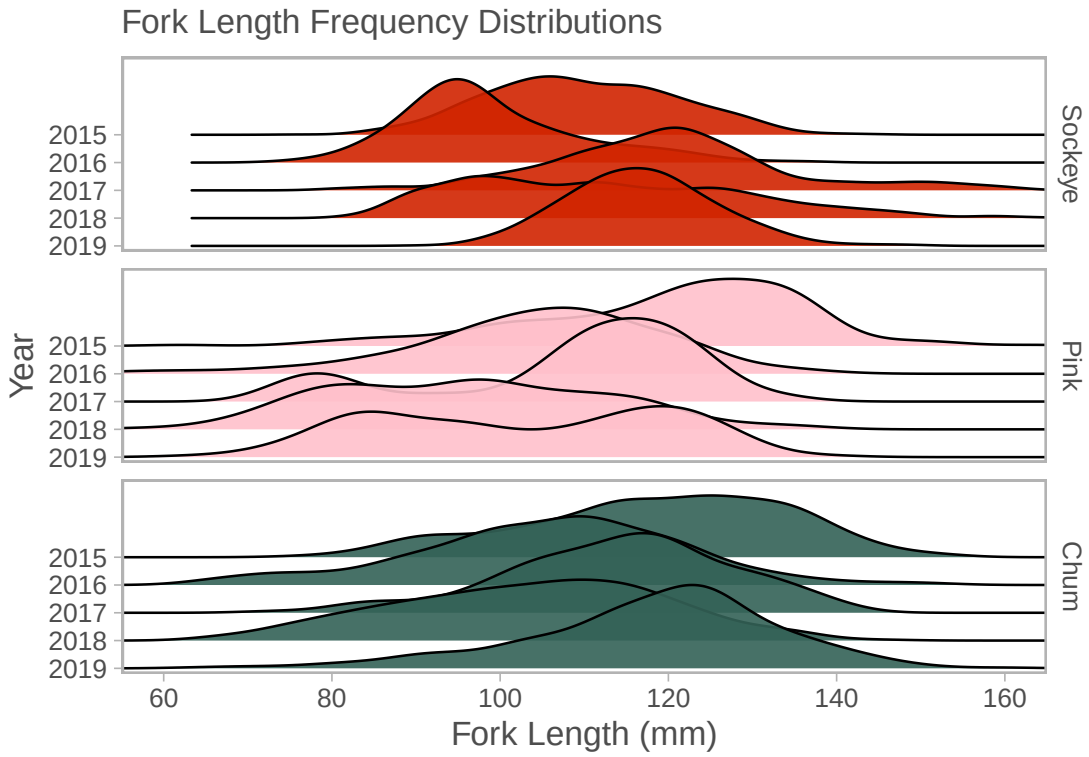

Figure 6: Distributions of juvenile salmon fork lengths for each year in the Discovery Islands and Johnstone Strait. Note that these distributions contain multiple age classes.

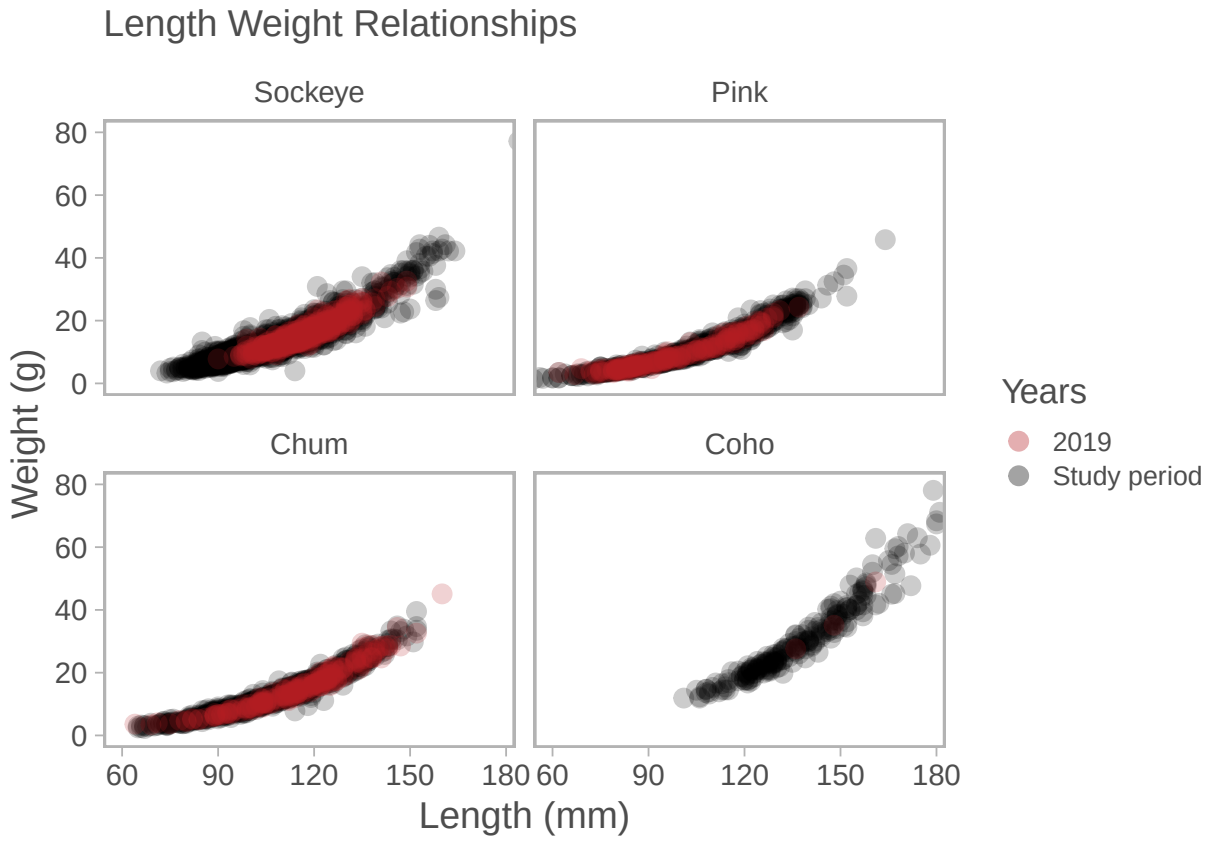

Figure 7: Length and weight regressions for juvenile salmon caught in the Discovery Islands and Johnstone Strait in 2019 coloured red, compared to all other years in black.

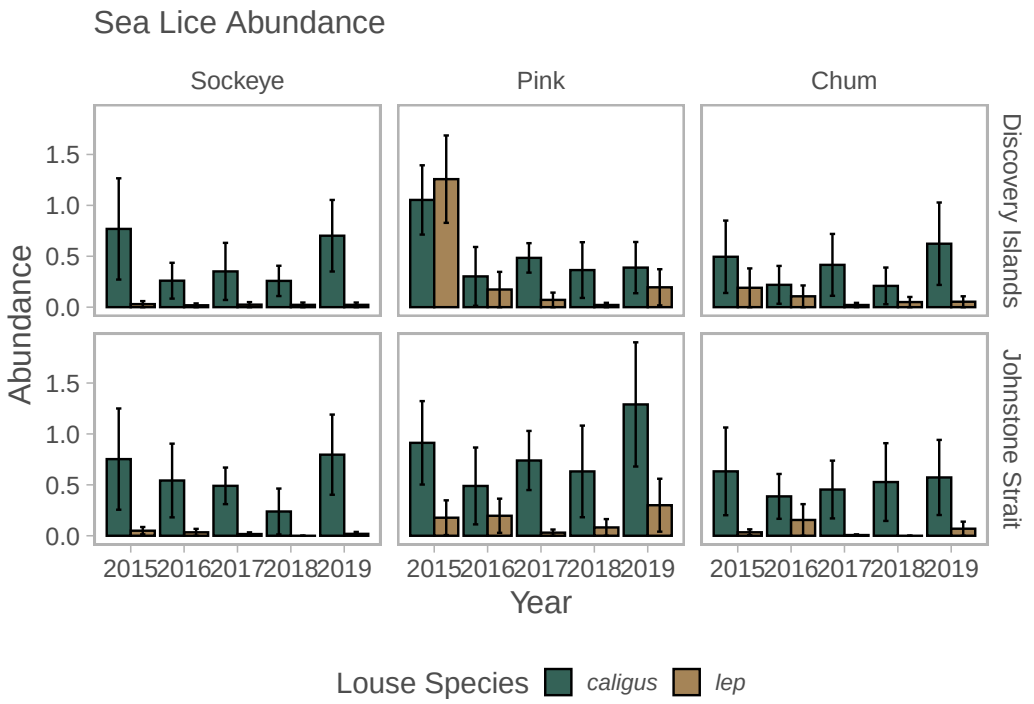

Figure 8: The abundance of motile sea lice on juvenile salmon in the Discovery Islands and Johnstone Strait. The numbers under each bar indicate the sample size and the error bars indicate the 95 percent confidence region.

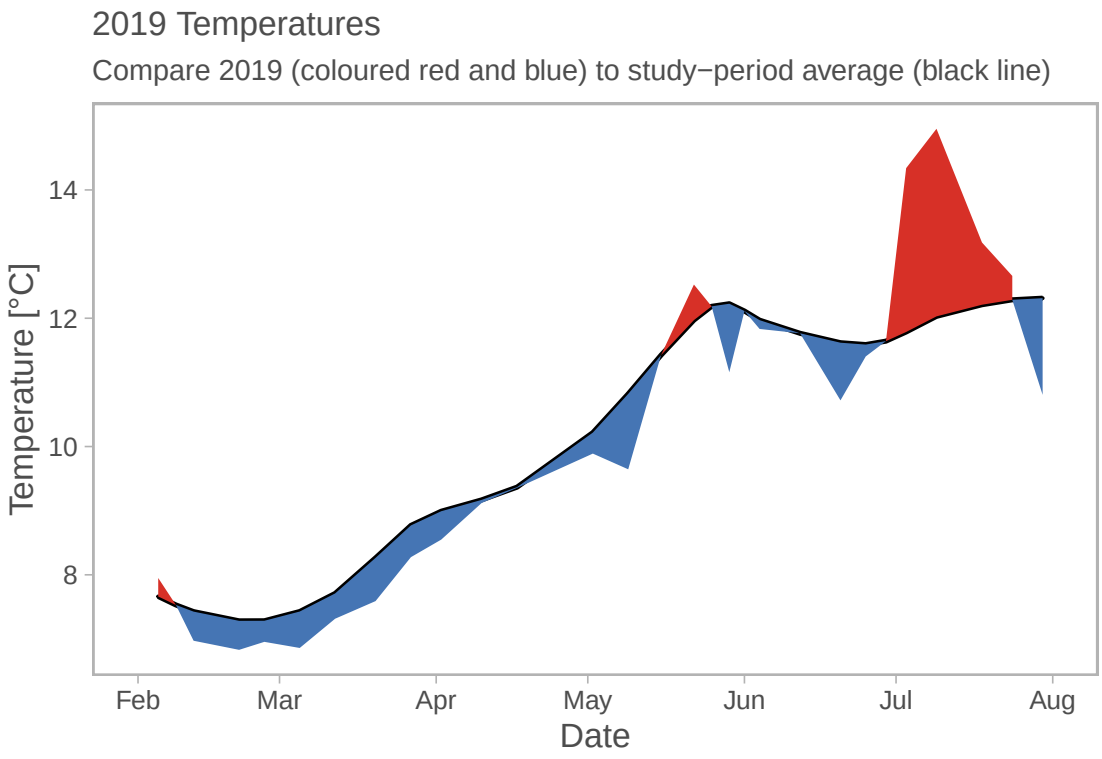

Figure 9: Thirty-meter depth-integrated ocean temperatures at station QU39 in the northern Strait of Georgia is the solid black line which represents average temperatures from 2015–2019. Blue areas represent temperatures from 2019that are below the 2015–2019average and red areas represent above average temperatures. The shaded grey area is 1 SE of the loess regression. The black dots are the daily minimum and maximum temperatures observed over the study-period.

2 Data

Some of the models and methods used to produce statistics and visualizations in this report will undergo ongoing development as we seek to improve the accuracy of current estimates, incorporate historical observations from other organizations, and add new variables to our annual observations. The development of our annual observations data, code, and analyses can be observed and contributed to from our code and data repository at https://github.com/HakaiInstitute/jsp-time-series. Summarized data can be observed in the tables below or accessed digitally at the web-address mentioned above and utilized under the Creative Commons Attribution 4.0 International License (CC-BY 4.0). The R code written to produce the figures and statistics in this report can be accessed in our repository and used to reproduce, contribute to, or alter this analysis. An interactive data explorer tool for this developing time series can be accessed online at http://hecate.hakai.org/shiny/JSP/.

3 Tables

Table 1: Key salmon health, growth, and migration annual estimates. Migration timing estimates are the median capture date in the Discovery Islands, catch intensity estimates are the mean catch when greater than one sockeye are caught in the Discovery Islands and Johnstone Strait combined, length estimates are the mean fork length (mm) in both regions combined, parasite loads are mean abundance for motile lice from both regions combined, and SST is the mean sea-surface temperature in degrees celcius at station QU39 in the northern Strait of Georgia. Standard deviation is denoted by SD and is the within-year standard deviation (note no SD for median capture dates). Z score is the number of standard deviations the annual estimate is away from the study period mean.

Species	Year	Parameter	Estimate	SD	Z score
Sockeye	2015	Migration Timing	May 23	NA	-0.52
Sockeye	2016	Migration Timing	May 28	NA	0.20
Sockeye	2017	Migration Timing	June 07	NA	1.66
Sockeye	2018	Migration Timing	May 23	NA	-0.52
Sockeye	2019	Migration Timing	May 21	NA	-0.81
Sockeye	2015	Catch Intensity	272.2	479.80	0.77
Sockeye	2016	Catch Intensity	307.2	431.70	1.18
Sockeye	2017	Catch Intensity	131.5	158.20	-0.90
Sockeye	2018	Catch Intensity	113.7	289.90	-1.11
Sockeye	2019	Catch Intensity	212.2	535.80	0.06
Sockeye	2015	Fork Lengths	109.8	11.13	-0.21
Sockeye	2016	Fork Lengths	98.7	10.66	-1.58
Sockeye	2017	Fork Lengths	119.7	14.35	1.02
Sockeye	2018	Fork Lengths	112.5	17.01	0.12
Sockeye	2019	Fork Lengths	116.7	8.82	0.64
Sockeye	2015	Sea-lice Abundance	0.76	0.52	1.10
Sockeye	2016	Sea-lice Abundance	0.36	0.28	-0.62
Sockeye	2017	Sea-lice Abundance	0.41	0.41	-0.41
Sockeye	2018	Sea-lice Abundance	0.25	0.24	-1.09
Sockeye	2019	Sea-lice Abundance	0.74	0.93	1.02
Pink	2015	Migration Timing	NA	NA	NA
Pink	2016	Migration Timing	June 15	NA	0.71
Pink	2017	Migration Timing	NA	NA	NA
Pink	2018	Migration Timing	June 12	NA	-0.71
Pink	2019	Migration Timing	NA	NA	NA
Pink	2015	Catch Intensity	65.3	145.80	-0.68
Pink	2016	Catch Intensity	109.9	169.10	-0.46
Pink	2017	Catch Intensity	11.3	15.90	-0.95
Pink	2018	Catch Intensity	475.1	802.90	1.37
Pink	2019	Catch Intensity	348.5	945.10	0.73
Pink	2015	Fork Lengths	120.4	15.91	1.54
Pink	2016	Fork Lengths	104.7	14.79	-0.20
Pink	2017	Fork Lengths	108.7	15.67	0.25
Pink	2018	Fork Lengths	96.1	16.14	-1.16
Pink	2019	Fork Lengths	102.7	17.36	-0.43
Pink	2015	Sea-lice Abundance	0.98	0.75	1.66
Pink	2016	Sea-lice Abundance	0.39	0.28	-0.91
Pink	2017	Sea-lice Abundance	0.61	0.49	0.05
Pink	2018	Sea-lice Abundance	0.46	0.35	-0.60

Species	Year	Parameter	Estimate	SD	Z score
Pink	2019	Sea-lice Abundance	0.55	0.58	-0.21
Chum	2015	Migration Timing	June 05	NA	-1.31
Chum	2016	Migration Timing	June 15	NA	-0.16
Chum	2017	Migration Timing	June 26	NA	1.11
Chum	2018	Migration Timing	June 12	NA	-0.51
Chum	2019	Migration Timing	June 24	NA	0.88
Chum	2015	Catch Intensity	194.6	283.40	-0.27
Chum	2016	Catch Intensity	113.4	175.10	-1.23
Chum	2017	Catch Intensity	298.6	378.60	0.95
Chum	2018	Catch Intensity	310.8	518.50	1.10
Chum	2019	Catch Intensity	171.4	178.00	-0.55
Chum	2015	Fork Lengths	118.5	15.51	0.93
Chum	2016	Fork Lengths	105.8	15.90	-0.89
Chum	2017	Fork Lengths	114.1	13.36	0.30
Chum	2018	Fork Lengths	103.5	15.72	-1.22
Chum	2019	Fork Lengths	118.1	14.96	0.87
Chum	2015	Sea-lice Abundance	0.55	0.46	0.82
Chum	2016	Sea-lice Abundance	0.31	0.31	-1.00
Chum	2017	Sea-lice Abundance	0.43	0.28	-0.09
Chum	2018	Sea-lice Abundance	0.32	0.35	-0.93
Chum	2019	Sea-lice Abundance	0.6	0.68	1.20
Northern Strait of Georgia	2015	Ocean Temperature	11.21	0.99	-0.59
Northern Strait of Georgia	2016	Ocean Temperature	11.57	0.96	0.51
Northern Strait of Georgia	2017	Ocean Temperature	11.33	1.18	-0.20
Northern Strait of Georgia	2018	Ocean Temperature	11.87	1.03	1.43
Northern Strait of Georgia	2019	Ocean Temperature	11.03	1.03	-1.14

Table 2: Migration timing statistics for the cumulative catch of sockeye, pink, and chum salmon in the Discovery Islands in 2018, compared to the time-series average (2015 - 2019). Q1 is when 25 % of the species passed through the regions, peak date is the median when 50 % passed through, Q3 is 75%, and Spread is the difference between Peak Date and Q1. The region DI indicates the Discovery Islands while for species SO is sockeye, PI is pink, and CU is chum.

Year	Region	Species	Q1	Peak Date	Q3	Spread
2015 - 2019	DI	Chum	June 07	June 16	June 25	9
2015 - 2019	DI	Pink	June 05	June 13	June 13	9
2015 - 2019	DI	Sockeye	May 25	May 27	June 02	1
2015 - 2019	JS	Chum	June 10	June 17	June 26	7
2015 - 2019	JS	Pink	June 16	June 23	June 23	6
2015 - 2019	JS	Sockeye	June 02	June 04	June 14	2
2015	DI	Chum	June 03	June 05	June 22	2
2015	DI	Sockeye	May 23	May 23	June 01	0
2015	JS	Chum	June 09	June 16	June 19	7
2015	JS	Sockeye	May 26	May 29	June 13	3
2016	DI	Chum	June 02	June 15	June 15	13
2016	DI	Pink	June 02	June 15	June 15	13
2016	DI	Sockeye	May 24	May 28	June 04	4
2016	JS	Chum	June 02	June 10	June 24	8
2016	JS	Pink	June 18	June 24	June 24	6

Year	Region	Species	Q1	Peak Date	Q3	Spread
2016	JS	Sockeye	June 02	June 03	June 18	1
2017	DI	Chum	June 13	June 26	July 04	13
2017	DI	Sockeye	June 05	June 07	June 07	2
2017	JS	Chum	June 20	June 27	June 28	7
2017	JS	Sockeye	June 06	June 14	June 21	8
2018	DI	Chum	June 07	June 12	June 20	5
2018	DI	Pink	June 07	June 12	June 12	5
2018	DI	Sockeye	May 23	May 23	June 04	0
2018	JS	Chum	June 14	June 21	June 23	7
2018	JS	Pink	June 14	June 21	June 23	7
2018	JS	Sockeye	June 07	June 07	June 21	0
2019	DI	Chum	June 11	June 24	July 02	13
2019	DI	Sockeye	May 21	May 21	May 23	0
2019	JS	Chum	June 05	June 11	July 04	6
2019	JS	Sockeye	May 29	May 29	May 29	0

Table 3: Catch intensity—our proxy for abundance—for sockeye, pink, and chum in the Discovery Islands and Johnstone Strait combined.

Year	Species	Catch Intensity
2015	Chum	194.6
2015	Pink	65.3
2015	Sockeye	272.2
2016	Chum	113.4
2016	Pink	109.9
2016	Sockeye	307.2
2017	Chum	298.6
2017	Pink	11.3
2017	Sockeye	131.5
2018	Chum	310.8
2018	Pink	475.1
2018	Sockeye	113.7
2019	Chum	171.4
2019	Pink	348.5
2019	Sockeye	212.2

Table 4: Mean fork lengths for each year, species, and region with the 95 % confidence interval (95% CI). The column n indicates the number of fish measured.

Year	Region	Species	N	Fork Length	CI
2015	DI	Sockeye	479	109.0	1.0
2015	DI	Pink	65	110.4	4.3
2015	DI	Chum	184	113.4	2.4
2015	JS	Sockeye	347	110.9	1.2
2015	JS	Pink	127	125.5	2.2
2015	JS	Chum	122	126.1	1.9
2016	DI	Sockeye	649	96.9	0.8
2016	DI	Pink	173	98.6	2.3

Year	Region	Species	N	Fork Length	CI
2016	DI	Chum	183	99.7	2.4
2016	JS	Sockeye	361	102.0	1.1
2016	JS	Pink	132	112.6	1.6
2016	JS	Chum	126	114.6	1.9
2017	DI	Sockeye	275	121.0	2.0
2017	DI	Pink	28	92.6	6.4
2017	DI	Chum	126	106.2	2.3
2017	JS	Sockeye	240	118.2	1.4
2017	JS	Pink	57	116.6	1.8
2017	JS	Chum	165	120.2	1.6
2018	DI	Sockeye	193	114.6	2.4
2018	DI	Pink	205	87.7	1.7
2018	DI	Chum	190	97.6	2.2
2018	JS	Sockeye	178	110.1	2.5
2018	JS	Pink	110	111.6	1.8
2018	JS	Chum	110	113.8	1.8
2019	DI	Sockeye	351	114.9	1.0
2019	DI	Pink	199	98.2	2.3
2019	DI	Chum	224	114.6	2.2
2019	JS	Sockeye	254	119.2	0.9
2019	JS	Pink	50	120.6	1.9
2019	JS	Chum	128	124.2	1.5

Table 5: The species proportions of total catch in each year for sockeye, pink, chum, herring, coho, and Chinook.

Year	Chum	Coho	Herring	Pink	Sockeye
2015	0.378	0.003	0.009	0.072	0.537
2016	0.210	0.006	0.005	0.200	0.580
2017	0.661	0.018	0.008	0.012	0.301
2018	0.326	0.006	0.022	0.515	0.131
2019	0.277	0.003	0.006	0.338	0.377

Table 6: Mean sea-louse abundance, prevalence, and intensity (as defined in Margolis et al. 1990) across the study period (2015-2019) for each fish, region, and year. 95% confidence intervals were calculated from annual averages. The region DI indicates the Discovery Islands and JS Johnstone Strait.

Year	Region	Species	Louse Species	Mean Abundance	95% CI
2015	DI	Sockeye	caligus	0.77	0.27 - 1.27
2015	DI	Sockeye	lep	0.03	0 - 0.06
2015	DI	Pink	caligus	1.05	0.71 - 1.39
2015	DI	Pink	lep	1.26	0.83 - 1.69
2015	DI	Chum	caligus	0.49	0.14 - 0.85
2015	DI	Chum	lep	0.19	0 - 0.38
2015	JS	Sockeye	caligus	0.75	0.26 - 1.25
2015	JS	Sockeye	lep	0.05	0.01 - 0.09
2015	JS	Pink	caligus	0.91	0.5 - 1.32

Year	Region	Species	Louse Species	Mean Abundance	95% CI
2015	JS	Pink	lep	0.18	0.01 - 0.35
2015	JS	Chum	caligus	0.63	0.2 - 1.06
2015	JS	Chum	lep	0.03	0.01 - 0.06
2016	DI	Sockeye	caligus	0.26	0.08 - 0.44
2016	DI	Sockeye	lep	0.02	0 - 0.04
2016	DI	Pink	caligus	0.30	0.01 - 0.59
2016	DI	Pink	lep	0.17	0 - 0.35
2016	DI	Chum	caligus	0.22	0.03 - 0.41
2016	DI	Chum	lep	0.11	0 - 0.21
2016	JS	Sockeye	caligus	0.54	0.18 - 0.9
2016	JS	Sockeye	lep	0.03	0 - 0.07
2016	JS	Pink	caligus	0.49	0.11 - 0.87
2016	JS	Pink	lep	0.20	0.03 - 0.36
2016	JS	Chum	caligus	0.39	0.17 - 0.61
2016	JS	Chum	lep	0.16	0 - 0.31
2017	DI	Sockeye	caligus	0.35	0.07 - 0.63
2017	DI	Sockeye	lep	0.02	0 - 0.05
2017	DI	Pink	caligus	0.48	0.34 - 0.63
2017	DI	Pink	lep	0.07	0 - 0.14
2017	DI	Chum	caligus	0.42	0.11 - 0.72
2017	DI	Chum	lep	0.02	0 - 0.04
2017	JS	Sockeye	caligus	0.49	0.31 - 0.67
2017	JS	Sockeye	lep	0.02	0 - 0.03
2017	JS	Pink	caligus	0.74	0.45 - 1.03
2017	JS	Pink	lep	0.03	0 - 0.06
2017	JS	Chum	caligus	0.45	0.17 - 0.74
2017	JS	Chum	lep	0.01	0 - 0.01
2018	DI	Sockeye	caligus	0.26	0.11 - 0.41
2018	DI	Sockeye	lep	0.02	0 - 0.05
2018	DI	Pink	caligus	0.36	0.09 - 0.64
2018	DI	Pink	lep	0.02	0 - 0.04
2018	DI	Chum	caligus	0.21	0.03 - 0.39
2018	DI	Chum	lep	0.05	0 - 0.1
2018	JS	Sockeye	caligus	0.24	0.01 - 0.46
2018	JS	Sockeye	lep	0.00	0 - 0
2018	JS	Pink	caligus	0.63	0.18 - 1.08
2018	JS	Pink	lep	0.08	0 - 0.16
2018	JS	Chum	caligus	0.53	0.15 - 0.91
2018	JS	Chum	lep	0.00	0 - 0
2019	DI	Sockeye	caligus	0.70	0.35 - 1.05
2019	DI	Sockeye	lep	0.02	0 - 0.05
2019	DI	Pink	caligus	0.39	0.14 - 0.64
2019	DI	Pink	lep	0.20	0.02 - 0.37
2019	DI	Chum	caligus	0.62	0.22 - 1.03
2019	DI	Chum	lep	0.05	0 - 0.11
2019	JS	Sockeye	caligus	0.80	0.4 - 1.19
2019	JS	Sockeye	lep	0.02	0 - 0.04
2019	JS	Pink	caligus	1.29	0.68 - 1.9
2019	JS	Pink	lep	0.30	0.04 - 0.56
2019	JS	Chum	caligus	0.57	0.2 - 0.94
2019	JS	Chum	lep	0.07	0 - 0.14

4 References