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

Brett T. Johnson[1], Julian C.L. Gan[1], Carly V. Janusson[1], and Brian P.V. Hunt[2, 3]

[1]**Hakai Institute Quadra Island Ecological Observatory, Heriot Bay, BC V0P1H0**
[2]**UBC EOS, IOF**

Corresponding author:
Brett T. Johnson[1]

Email address: brett.johnson@hakai.org

ABSTRACT

The majority of out-migrating juvenile Fraser River salmon (*Oncorhynchus* spp.) pass northwest through the Strait of Georgia, the Discovery Islands, and Johnstone Strait. The Discovery Islands to Johnstone Strait leg of the migration is a region of poor survival for juvenile salmon relative to the Strait of Georgia. The Hakai Institute Juvenile Salmon Program has been monitoring key components of this migration since 2015 to better understand drivers of early marine survival. Here we present key aspects of the 2018 migration in comparison to averages from the 2015–2018 study period, which we use to define 'normal'. In 2018 sockeye (*Oncorhynchus nerka*), pink (*O. gorbuscha*), and chum (*O. keta*) all migrated earlier than normal. The median capture date was May 23rd for sockeye, five days earlier than normal; and June 12 for pink and chum, which is five days earlier for pink and three days earlier than normal for chum. Sea lice prevalence was lower than normal for sockeye, pink, and chum. Notably, there were no *Lepeophtheirus salmonis* sea lice observed in Johnstone Strait in 2018. Sockeye were longer than normal in 2018 whereas pink and chum were smaller than normal. Sea surface temperatures in May and June were the warmest on record in the study period (2015–2018). Pink salmon dominated the catch in 2018, followed by chum, and then sockeye.

INTRODUCTION

Pacific salmon (*Oncorhynchus* spp.) traverse numerous ecosystems during different phases of their lifecycle, which makes it challenging to understand the mechanisms that influence survivorship. During their migrations, salmon are subjected to risks associated with each new environment they encounter (Cooke et al. 2004; McKinnell et al. 2012). The risks and associated mortality from the sum of these migrations can be understood in aggregate by quantifying the productivity (recruits per spawner) of a certain stock (Malick and Cox 2016; Grant, MacDonald, and Michielsens 2017). Salmon are an excellent indicator species because they integrate terrestrial, lacustrine, fluvial, estuarine, nearshore marine, and high-seas conditions; a problem in any one of these environments will be reflected in the productivity of salmon stocks (Rand et al. 2006). To better manage and predict the productivity of salmon stocks we need estimates of mortality and an understanding of the factors driving mortality in each landscape that salmon traverse. One such area in which we lack understanding is the early marine environment (Grant, MacDonald, and Michielsens 2017). Juvenile salmon are particularly vulnerable during the early marine phase of their life history because they are undergoing physiological adaptations to a saline environment (Orsi et al. 2000; Duffy, Beauchamp, and Buckley 2005; Tucker et al. 2009; Beamish et al. 2012).

The Hakai Institute Juvenile Salmon Program has been monitoring juvenile salmon migrations in the Discovery Islands and Johnstone Strait (Figure 1) since 2015 in an effort to understand what factors may be influencing early marine survival of sockeye, pink, and chum (Hunt et al. 2018). The effects of pathogens, parasites, predators, and the impacts of climate change on food web dynamics may be amplified during this stressful transition period. Factors on which we are currently monitoring and reporting include

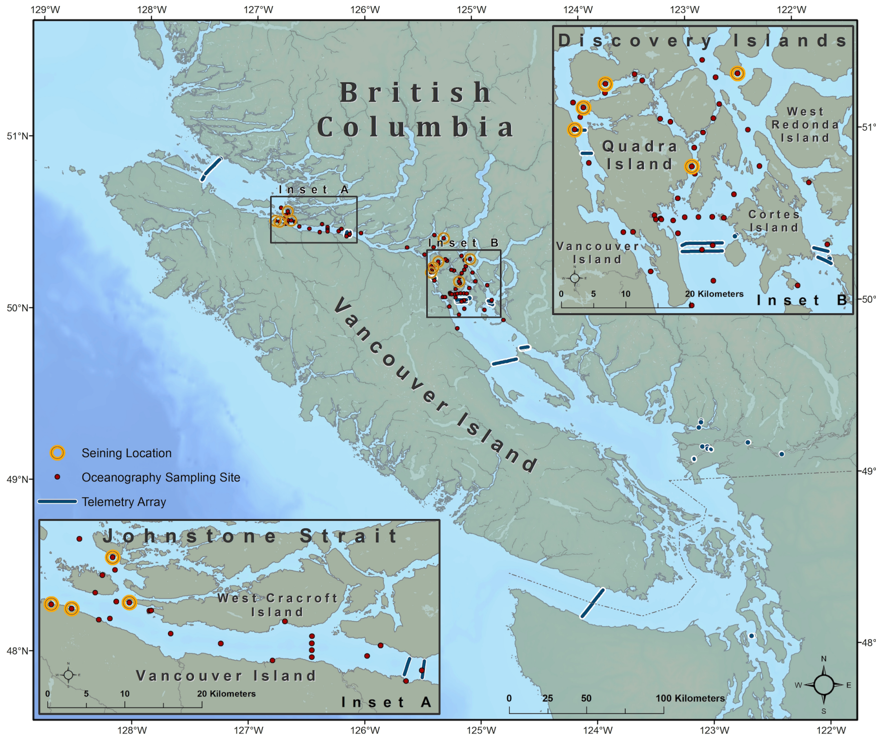

Figure 1. Sampling locations in 2018

migration dynamics, growth, parasites and pathogens, and the ocean's physical condition.

METHODS

Field methods

See Hunt et al. (2018) for a detailed description of field and lab methods. Briefly, we collect juvenile salmon weekly from the Discovery Islands and Johnstone Strait during their northward migration from the Strait of Georgia to Queen Charlotte Strait near northern Vancouver Island, British Columbia. Sampling is conducted from May to July each year since 2015 using purse seine nets (bunt: 27 m x 9 m with 13 mm mesh; tow: 46 m x 9 m with 76 mm mesh). We sample in nearshore marine habitats with depth $>$ 10 m and effectively sample sockeye (*Oncorhynchus nerka*), pink (*O. gorbuscha*), chum (*O. keta*) and incidentally capture coho (*O. kisutch*), chinook (*O. tshawytschya*) and Pacific herring (*Clupea pallasii*). All animal care was in accordance with Animal Care Guidelines under permit A16-0101. Temperature data were collected by deploying an RBR conductivity, temperature, and depth profiler to depths $>$ 30 m at station QU39 (Figure 1) in the northern Strait of Georgia.

Statistical methods

All metrics reported are in relation to the time series average (2015-2018). The mean for each parameter of interest was calculated for all years combined, and the z-score was calculated for each parameter to determine the number of standard deviations away from the mean a given parameter was in each year.

$Z = \frac{x_i - \bar{X}}{S}$

Annual migration timing for each species was measured by calculating the median date of capture in the Discovery Islands, the date at which the 50 percent of the fish passed through the region. To visualize migration timing we plotted cumulative catch abundance between May 1st and July 9th each year and fit a logistic growth line. Species proportions were calculated by dividing the total number of each species caught that season across all seines by the sum of all species caught that season. Fork length distributions were visualized by calculating density estimates from fork length data. The prevalence of sealice was calculated as the number of individuals of a host species infected with a particular parasite species divided by Number of hosts examined (Margolis et al. 1990). Sea surface was defined as the top 30 m of the water

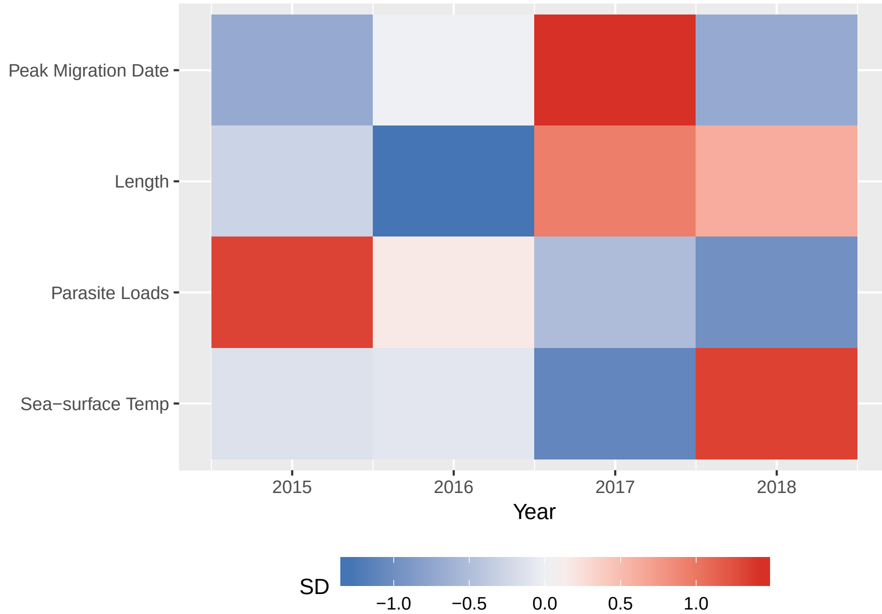

Figure 2. This heatmap indicates the number of standard deviations (Z-score) from the time series average (2015-2018) for key migration parameters. Blue colour indicates less than average, white indicates average, red indicates greater than average. Peak migration date is based on the median date of sockeye capture in the Discovery Islands. Mean sea-surface temperature is 30 m depth integrated temperature from station QU39 in the Northern Strait of Georgia from May and June. Parasite load is the average prevalence of all sea lice species in their motile life stage for both the Discovery Islands and Johnstone Strait regions combined.

column. The mean temperature from which to compare any single year to was calculated from the top 30 m of the water column in May and June from all years. To visualize temperature anomalies we applied a loess regression to sea surface temperatures from all four years to develop a model that would represent the seasonal trend.

Item	Quantity
Widgets	42
Gadgets	13

RESULTS

The heatmap below summarizes the amount of variation each parameter exhibits over the past four years by visualizing the number of standard deviations from the time-series average (Z-score) (Figure 2). Peak migration date, parasite loads, and fork lengths were all calculated for sockeye.

Sea-surface temperatures in May and June at QU39 were warmer than normal, or 1.33 standard deviations greater than the time series mean. The peak migration date in the Discovery Islands occurred earlier than average in 2018 (-0.71 SD). Across the Discovery Islands and Johnstone Strait, parasite loads were lower than average (-0.98 SD), and fork lengths were longer than average (0.62 SD).

Migration Timing

The bulk of the sockeye migration in the Discovery Islands occurred earlier in 2018 when compared to the time-series's four-year average (Figure 3). The median date of capture for 2018 sockeye was May 22nd, whereas the time series average was May 27th. Conversely, the 2018 sockeye migration occurred later than normal in Johnstone Strait, where the median date of capture was June 6th, which is two days later than the time-series average. See Table @ref(tab:mt_di) and Table @ref(tab:mt_js) for the interqurtile range of migration timing for sockeye, pink, and chum in 2018, contrasted to the time series averages for

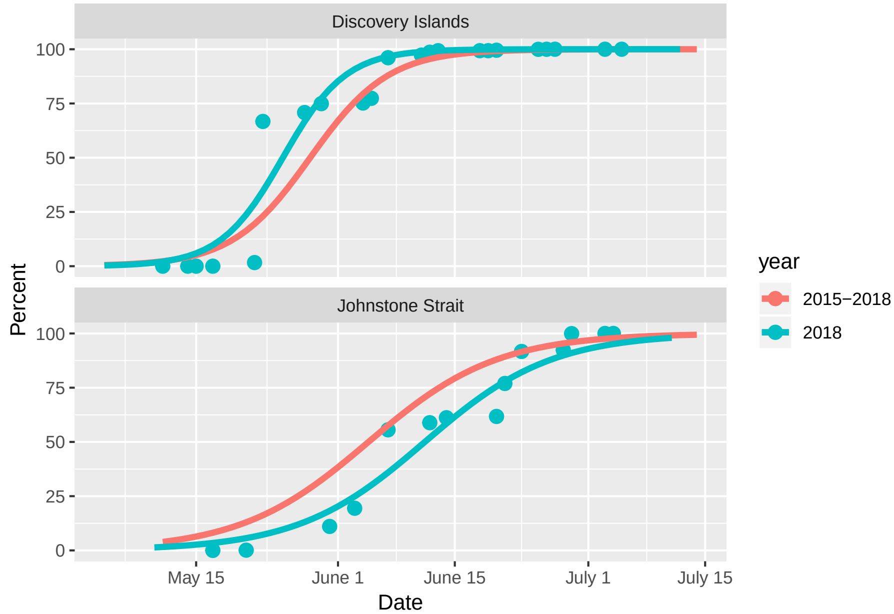

Figure 3. Cumulative catch of juvenile sockeye salmon migrating through the Discovery Islands compared to the average for 2015–2018. Migration curves were predicted by fitting a logistic growth equation to the cumulative percent the selected fish caught. The points (circles) for the year being compared to the time-series is the cumulative catch percent

the Discovery Islands and Johnstone Strait, respectively. Based on the comparison of peak migration dates between the two zones, we estimate that the average residence time of juvenile salmon in the Discovery Islands for 2018 was approximately two weeks.

Discovery Islands

Species	Year	25%	50%	75%
Sockeye	TSA	May 25	May 27	June 03
	2018	May 22	May 22	June 03
Pink	TSA	June 04	June 12	June 15
	2018	June 06	June 11	June 17
Chum	TSA	June 05	June 14	June 21
	2018	June 06	June 11	June 19

Table 2. Interquartile range for the cumulative catch of sockeye, pink, and chum salmon in the Discovery Islands in 2018, compared to the Time-Series Average (2015–2018). Odd years were excluded from the TSA calculation for pink salmon due being the ”off” years in the outmigration cycle.

Species Proportions

Pink salmon dominated the catch in the Discovery Islands and Johnstone Strait in 2018, which is the first time observed in the time-series (Figure 4). This may be due to post-smolts being from the dominant odd-year pink returning broodlines (Krkošek et al. 2011; T. D. Beacham et al. 2012; Irvine et al. 2014) coupled with Fraser River sockeye from the weak 2016 brood year, which was lowest recorded return in 100 years (McKinnell et al. 2012; Grant, MacDonald, and Michielsens 2017; Pacific Salmon Commission 2017).

Length

Fish lengths varied between regions, species and year (Figure 5). Sockeye were longer than average in 2018…

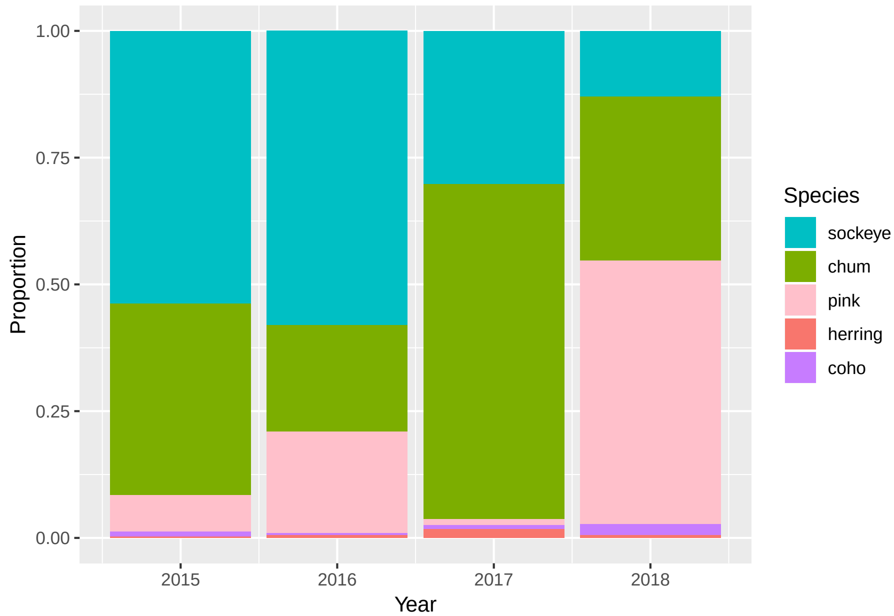

Figure 4. The annual proportion of fish captured in the Discovery Islands and Johnstone Strait combined.

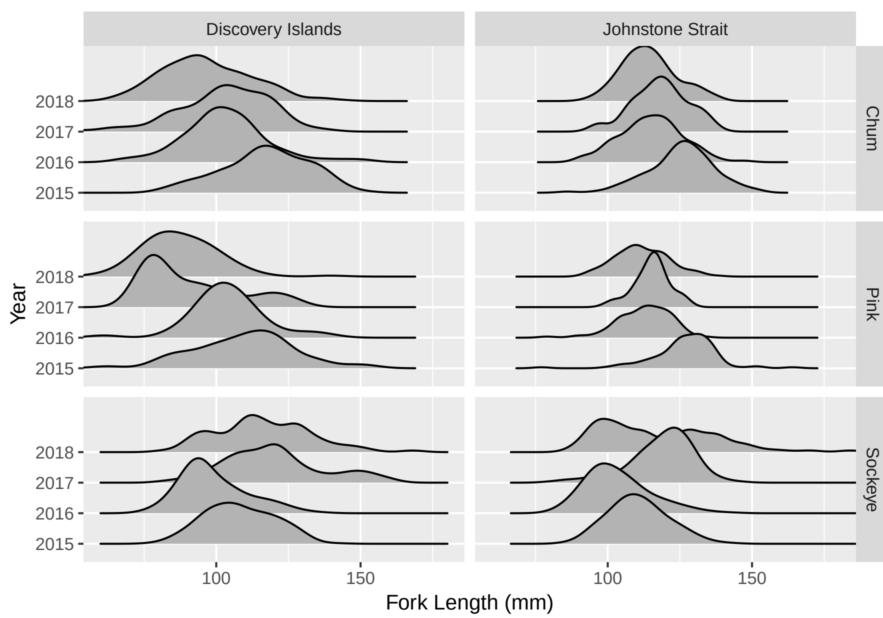

Figure 5. Kernel density distributions of juvenile salmon fork lengths for each year in the selected region. Note that these distributions contain multiple age-classes.

Johnstone Strait				
Species	**Year**	**25%**	**50%**	**75%**
Sockeye	TSA	June 01	June 04	June 17
	2018	June 06	June 06	June 20
Pink	TSA	June 15	June 21	June 22
	2018	June 13	June 20	June 22
Chum	TSA	June 10	June 17	June 25
	2018	June 13	June 20	June 27

Table 3. Interquartile range for the cumulative catch of sockeye, pink, and chum salmon in Johnstone Strait in 2018, compared to the Time-Series Average (2015–2018). Odd years were excluded from the TSA calculation for pink salmon due being the ”off” years in the outmigration cycle.

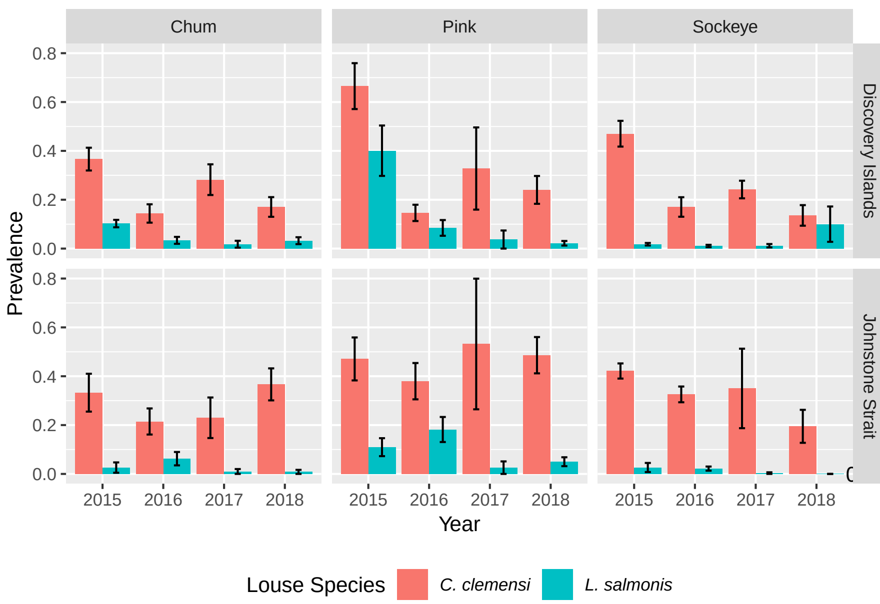

Figure 6. The prevalence (+/-SE) of motile sea lice on juvenile salmon in the Discovery Islands and Johnstone Strait.

Parasite Loads

The prevalence of motile (pre-adult and adult life stage) sea lice in 2018 was the lowest recorded in the time-series (Figure 6). Notably, no *Lepeophtheirus salmonis* were detected on sockeye in Johnstone Strait, despite being present in the Discovery Islands. Pink salmon appeared to have higher counts of *Caligus clemensi* in 2018 compared to chum and sockeye.

Sea Surface Temperature

Sea surface temperature was warm (Figure 7)

DISCUSSION

Beacham, Terry D., Brenda Mcintosh, Cathy MacConnachie, Brian Spilsted, and Bruce A. White. 2012. “Population structure of pink salmon (Oncorhynchus gorbuscha) in British Columbia and Washington, determined with microsatellites.” *Fishery Bulletin* 110 (2): 242–56. doi:10.2337/diabetes.51.4.1093.

Beamish, R. J., C. Neville, R. Sweeting, and K. Lange. 2012. “The synchronous failure of juvenile pacific salmon and herring production in the strait of georgia in 2007 and the poor return of sockeye salmon to the Fraser river in 2009.” *Marine and Coastal Fisheries* 4 (1): 403–14. doi:10.1080/19425120.2012.676607.

Cooke, S. J., S. G. Hinch, A. P. Farrell, M. F. Lapointe, S. R. M. Jones, J. S. Macdonald, D. A. Patterson, M. C. Healey, and G. Van Der Kraak. 2004. “Abnormal Migration Timing and High en

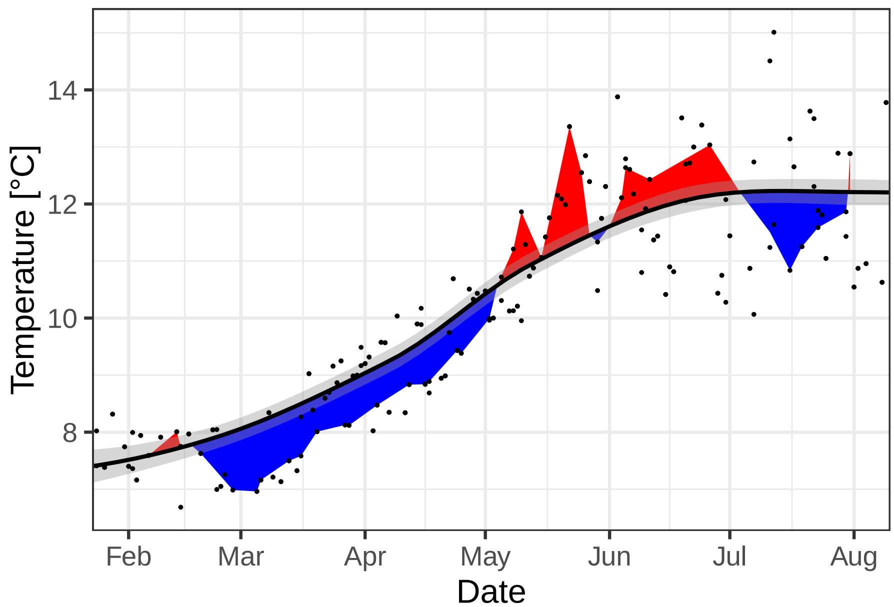

Figure 7. Time series of 30 m depth integrated temperature anomalies observed at Hakai Oceanographic Monitoring station QU39. Blue areas represent temperatures that are below normal, red areas represent above normal temperatures at the selected station in 2018. Normal is the solid black line which is a loess regression based on temperatures from 2015-2018. The shaded grey area is 1 SE of the loess regression. The black dots are the daily minimum and maximum temperatures observed over the time series.

route Mortality of Sockeye Salmon in the Fraser River, British Columbia." *Fisheries* 29 (2): 22–33. doi:10.1577/1548-8446(2004)29[22:AMTAHE]2.0.CO;2.

Duffy, Elisabeth J., David A. Beauchamp, and Raymond M. Buckley. 2005. "Early marine life history of juvenile Pacific salmon in two regions of Puget Sound." *Estuarine, Coastal and Shelf Science* 64 (1 SPEC. ISS.): 94–107. doi:10.1016/j.ecss.2005.02.009.

Grant, Sue C.H., Bronwyn L. MacDonald, and Catherine G.J. Michielsens. 2017. "Fraser River Sockeye: Abundance and Productivity Trends and Forecasts." North Pacific Anadromous Fish Commission; Fisheries; Oceans Canada; Pacific Salmon Commission. `http://www.npafc.org`.

Irvine, J.R., C.J.G. Michielsens, M. O'Brien, B.A. White, and M. Folkes. 2014. "Increasing Dominance of Odd-Year Returning Pink Salmon." *Transactions of the American Fisheries Society* 143 (4): 939–56. doi:10.1080/00028487.2014.889747.

Krkošek, Martin, Ray Hilborn, Randall M. Peterman, and Thomas P. Quinn. 2011. "Cycles, stochasticity and density dependence in pink salmon population dynamics." *Proceedings of the Royal Society B: Biological Sciences* 278 (1714). The Royal Society: 2060–8. doi:10.1098/rspb.2010.2335.

Malick, Michael J., and Sean P. Cox. 2016. "Regional-scale declines in productivity of pink and chum salmon stocks in western North America." *PLoS ONE* 11 (1): 1–23. doi:10.1371/journal.pone.0146009.

Margolis, L., G. W. Esch, A.M. Kuris, and G.A. Schad. 1990. "The Use of Ecological Terms in Parasitology (Report of an Ad Hoc Committee of the American Society of Parasitologists)." *The Journal of Parisitology* 68 (1): 131–33. doi:10.2307/3281335.

McKinnell, Stewart M., Enrique Curchitser, Cornelius Groot, Masahide Kaeriyama, and Katherine W. Myers. 2012. "PICES Advisory Report on The Decline of Fraser River Sockeye Salmon Oncorhynchus nerka (Steller, 1743) in Relation to Marine Ecology." PICES Scientific Report. Vancouver, B.C.: Cohen Commission; North Pacific Marine Science Organization (PICES). `www.cohencommission.ca`.

Orsi, Joseph A., Molly V. Sturdevant, James M. Murphy, Donald G. Mortensen, and Bruce L. Wing. 2000. "Seasonal Habitat Use and Early Marine Ecology of Juvenile Pacific Salmon in Southeastern Alaska." *North Pacific Anadromous Fish Commission Bulletin*, no. 2: 111–22.

Pacific Salmon Commission. 2017. "Report of the Fraser River Panel to the Pacific Salmon Commission on the 2016 Fraser River Sockeye Salmon Fishing Season." Pacific Salmon Commission.

https://www.psc.org/publications/annual-reports/fraser-river-panel/.

Rand, P. S., S. G. Hinch, J. Morrison, M. G. G. Foreman, M. J. MacNutt, J. S. Macdonald, M. C. Healey, A. P. Farrell, and D. A. Higgs. 2006. "Effects of River Discharge, Temperature, and Future Climates on Energetics and Mortality of Adult Migrating Fraser River Sockeye Salmon." *Transactions of the American Fisheries Society* 135 (3): 655–67. doi:10.1577/T05-023.1.

Tucker, S., M. Trudel, D. W. Welch, J. R. Candy, J. F. T. Morris, M. E. Thiess, C. Wallace, et al. 2009. "Seasonal Stock-Specific Migrations of Juvenile Sockeye Salmon along the West Coast of North America: Implications for Growth." *Transactions of the American Fisheries Society* 138 (6): 1458–80. doi:10.1577/T08-211.1.