

State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2020

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OF PACIFIC CANADIAN MARINE ECOSYSTEMS IN 2020

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Abstract

Boldt, J.L., Javorski, A., and Chandler, P.C. (Eds.). 2021. State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2020. Can. Tech. Rep. Fish. Aquat. Sci. 3434: vii + 231 p.

Fisheries and Oceans Canada is responsible for the management and protection of marine resources on the Pacific coast of Canada. Oceanographically there is strong seasonality in coastal upwelling and downwelling, considerable freshwater influence, and variability from coupling with events and conditions in the tropical and North Pacific Ocean. The region supports ecologically and economically important resident and migratory populations of invertebrates, groundfish, pelagic fishes, marine mammals and seabirds.

Since 1999 an annual State of the Pacific Ocean meeting has been held by DFO to bring together the marine science community in the Pacific Region and present the results of the most recent year's monitoring in the context of previous observations and expected future conditions. The workshop to review ecosystem conditions in 2020 was convened virtually, March 2-4, 2021, due to the COVID-19 pandemic. This technical report includes submissions based on presentations given at the meeting and a few poster summaries.

Climate change is a dominant pressure acting on North Pacific marine ecosystems, causing, for example, increasing temperatures, deoxygenation, and acidification, and changes to circulation and vertical mixing. These pressures impact ecosystem nutrient concentrations and primary and secondary productivity, which then affect higher trophic levels through the food chain.

Résumé

Boldt, J.L., Javorski, A., and Chandler, P.C. (Eds.). 2021. State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2020. Can. Tech. Rep. Fish. Aquat. Sci. 3434: vii + 231 p.

Pêches et Océans Canada est chargé de la gestion et de la protection des ressources maritimes sur la côte Pacifique du Canada. Sur le plan océanique, il y a une forte saisonnalité dans les remontées d'eaux profondes côtières et les plongées d'eaux, une forte incidence des eaux douces, et une variabilité provenant des phénomènes et des conditions dans l'océan Pacifique tropical et l'océan Pacifique Nord. La région soutient des populations résidentes et migratrices écologiquement et économiquement importantes d'invertébrés, de poissons de fond, de poissons pélagiques, de mammifères marins et d'oiseaux de mer.

Depuis 1999, une réunion annuelle sur l'État de l'océan Pacifique est organisée par le MPO afin de réunir la communauté scientifique dans la région du Pacifique et de présenter les résultats de la dernière année de surveillance dans le contexte d'observations précédentes, ainsi que les conditions futures attendues. En raison de la pandémie de COVID-19, l'atelier organisé du 2 au 4 mars 2021 pour examiner les conditions de l'écosystème en 2020 s'est déroulé virtuellement. Le présent rapport technique comprend des soumissions basées sur les présentations données durant l'atelier et des résumés d'affiches.

Les changements climatiques constituent une pression dominante qui agit sur les écosystèmes marins du Pacifique Nord et sont la cause, entre autres, de l'augmentation des températures, de la désoxygénation et de l'acidification, et des changements dans le régime de circulation et le mélange vertical. Ces pressions ont des effets sur les concentrations d'éléments nutritifs et la productivité primaire et secondaire des écosystèmes, ce qui a une incidence sur les niveaux trophiques supérieurs par l'intermédiaire de la chaîne alimentaire.

Highlights, Introduction, and Overview

1. HIGHLIGHTS

1. Climate change is a dominant pressure acting on North Pacific marine ecosystems. There continues to be a long term trend of increasing sea surface temperatures.
2. A marine heatwave in the NE Pacific was observed in 2019-2020; the cooling influences of a La Niña that emerged in the latter half of 2020 kept extreme warm ocean temperatures away from coastal B.C. waters.
3. B.C. air temperature and precipitation data show trends to warmer and wetter conditions. In 2020, B.C. river discharges were greater and peaked later than normal.
4. Oxygen concentrations in the deeper water of the continental shelf were at near-normal levels, but continued to decrease at Ocean Station P. Strait of Georgia oxygen concentrations were below the 20 year normal.
5. The duration of severe pH conditions observed in the Northern Salish Sea and Fitz Hugh Sound was shorter in 2020 than in 2019; however, ocean acidification will continue to intensify as anthropogenic carbon input increases.
6. Off the west coast of Vancouver Island, the winter downwelling season ended early in 2020 but there was a slow transition to the upwelling season. The magnitude of the upwelling-favourable winds in the summer of 2020 was near-normal with an expectation of average productivity.
7. Winter surface nutrient concentrations and offshore chlorophyll concentrations were lower than average, and while summer nutrient concentrations varied by region, the offshore chlorophyll concentrations were at the lower end of the normal range.
8. In winter, the phytoplankton community composition was similar to 2015 (a marine heatwave year) but in the summer, it was similar to pre-marine heatwave years. There was no survey in the spring of 2020. Strait of Georgia spring bloom timing was average.
9. The zooplankton community composition was close to average in coastal areas, however, warm water zooplankton species have dominated some areas on and off of the continental shelf since the 2014-2016 marine heatwave. Strait of Georgia zooplankton biomass increased.
10. The Fraser River index of Eulachon spawning stock biomass in 2020 was at its highest point since 2001.
11. Pacific Herring biomass varied among assessed areas; for example, West Coast of Vancouver Island stock biomass was low and Strait of Georgia stock biomass was high.
12. The returns of most Sockeye, Chinook, and Chum salmon stocks were low in 2020, while the returns of Coho and Pink salmon varied by stock.
13. Average groundfish stock status declined from 1950 to ~2000 and has remained relatively stable since then.

14. Marine aquatic invasive species continue to spread in B.C.; in July 2020, European Green Crab was detected for the first time on Haida Gwaii, the most northern detection to date.

2. INTRODUCTION

Fisheries and Oceans Canada (DFO), Pacific Region, conducts an annual review of the physical, chemical and biological conditions in the ocean off Canada's west coast, to develop a picture of how the ocean is changing and to help provide advance identification of important changes which may potentially impact human uses, activities, and benefits from the ocean. These reviews take the form of a two day meeting, usually held in February or March of the year following the year under review. The first meeting was held in 2000 to assess conditions in 1999; reports from these reviews are available at (see bottom of web page):

<http://www.dfo-mpo.gc.ca/oceans/publications/index-eng.html>

Reviews and reports from 2007 to 2013 were conducted under the direction of the Fisheries & Oceans Canadian Science Advice Secretariat (CSAS). In 2014, these State of the Pacific Ocean reviews were moved to a separate process and are now presented as Fisheries & Oceans Canada Technical Reports. The report from 2020 (for conditions in 2019) is available at

<https://www.dfo-mpo.gc.ca/oceans/publications/soto-rceo/2019/index-eng.html>

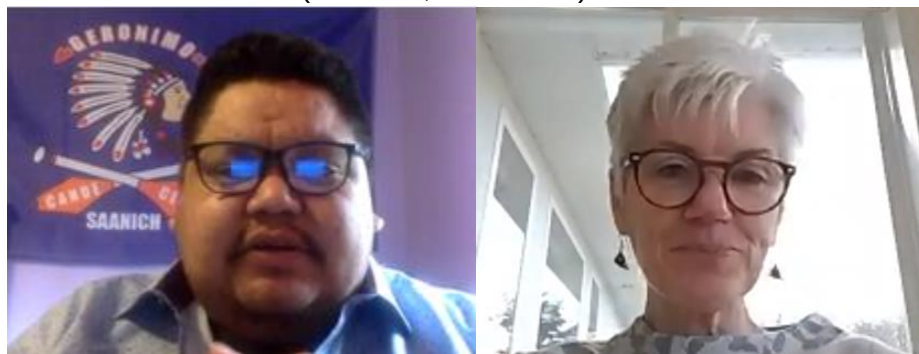
Due to the COVID-19 pandemic, in 2021, the meeting on conditions observed on the west coast of Canada (Figure 2-1) in 2020 was convened virtually, March 2-4, 2021. Due to the meeting's online platform, this year's meeting reached a larger and broader audience; it was attended by 477 DFO and non-DFO participants from the Pacific Coast marine science community, including other federal and B.C. governments, First Nations and Indigenous groups, academia, national and international partners, and the private sector. Scientists from the DFO, Ministry of Environment, Parks Canada, Environment and Climate Change Canada, Haida Nation, Hakai Institute, Province of B.C., University of British Columbia, University of Victoria, Ocean Networks Canada, North Pacific Anadromous Fish Commission, North Pacific Marine Science Organization, Grieg Seafood, T Buck Suzuki Foundation, among others, participated. These annual meetings represent a unique opportunity for scientists from different disciplines to highlight the results of atmospheric, oceanographic and marine species observations in 2020 in the context of historical observations.



Figure 2-1. Map of regions described in this report.

Joe Seward, Community and Language Advisor from the W̱SÁNEĆ Tsartlip First Nation, provided a meeting welcome and prayer. Regional Director of Science, Carmel Lowe, provided a welcome and introduction to the SOPO meeting, including challenges overcome during the COVID-19 pandemic and highlights from 2020 ocean and ecosystem conditions. While several monitoring programs were cancelled due to COVID there were other surveys that were able to proceed at least partially. At the meeting, 38 talks were presented. There was a special presentation of the newly released National State of the Oceans report

Canada's Oceans Now, which is a high-level summary of status and trends in all three of Canada's oceans highlighted through engaging infographics and plain language science writing. In addition, there was a presentation summarizing the successful 2020 surveys conducted on the new Canadian Coast Guard Ship (CCGS) Sir John Franklin, the Pacific Region's new Offshore Fisheries Science Vessel (Gauthier, Section 31).



Joe Seward, Community and Language Advisor from the W̱SÁNEĆ Tsartlip First Nation (left), provided a meeting welcome and prayer. Regional Director of Science, Carmel Lowe (right), provided a welcome and introduction to the SOPO meeting.

Since the meeting was virtual, no poster session was held; however, some poster summaries are included in this report. Poster abstracts are presented in Appendix 1, the agenda for the meeting is presented in Appendix 2, and the meeting participants are listed in Appendix 3. The meeting was co-chaired by Peter Chandler (Institute of Ocean Sciences) and Jennifer Boldt (Pacific Biological Station), organized by Ania Javorski, and all technical aspects of the virtual meeting were run by Stephen Page (Institute of Ocean Sciences).



2020 SOPO meeting organizers, Ania Javorski (top left), Stephen Page (top right), Jennifer Boldt (bottom left), and Peter Chandler (bottom right).

This technical report presents the highlights and summaries of the presentations and discussions at the workshop. These summary reports are not peer reviewed, and present the status of data, interpretation, and knowledge as of the date of this meeting. For use of, or reference to these individual presentations, please contact the individual authors.

In memory of Dr. Kim Hyatt

Dr. Kim Hyatt, a long-time dedicated participant and contributor to SOPO meetings and reports, passed away on May 25, 2021. Dr. Hyatt was committed to salmon conservation and improving our understanding of factors affecting salmon. He made significant scientific contributions to at least 17 SOPO meetings and reports, including this report. His ability to effectively share his knowledge and expertise, especially on Sockeye Salmon, will be greatly missed.

This report is dedicated to the memory of Dr. Kim Hyatt.



3. OVERVIEW AND SUMMARY

Climate change continues to be a dominant pressure acting on Northeast (NE) Pacific marine ecosystems. Globally, land and ocean temperatures in 2020 were the second warmest on record. B.C. air temperature and precipitation data show trends to warmer and wetter conditions (Anslow, Section 6). In 2020, B.C. river discharges were greater and peaked later than normal (Anslow, Section 6; Chandler, Section 35). The long-term record of sea surface temperatures (SSTs) collected at lighthouses along the B.C. coast showed that 2020 was generally cooler than 2019 but was still a continuation of the warm period that started in 2014 (Chandler, Section 10). Overlying the multi-year oscillations in the annual SST there remains a long-term trend towards rising ocean temperatures: 0.88°C over the last 100 years (Figure 3-1; Chandler, Section 10). Increasing CO_2 in the atmosphere has increased the acidification of the ocean, which will continue to intensify with the rise of anthropogenic carbon levels in the atmosphere (Evans, Section 34). In 2020, the occurrence of severe high- pCO_2 , and acidic conditions varied seasonally; however, the duration of severe conditions was shorter than in 2019 (Evans, Section 34).

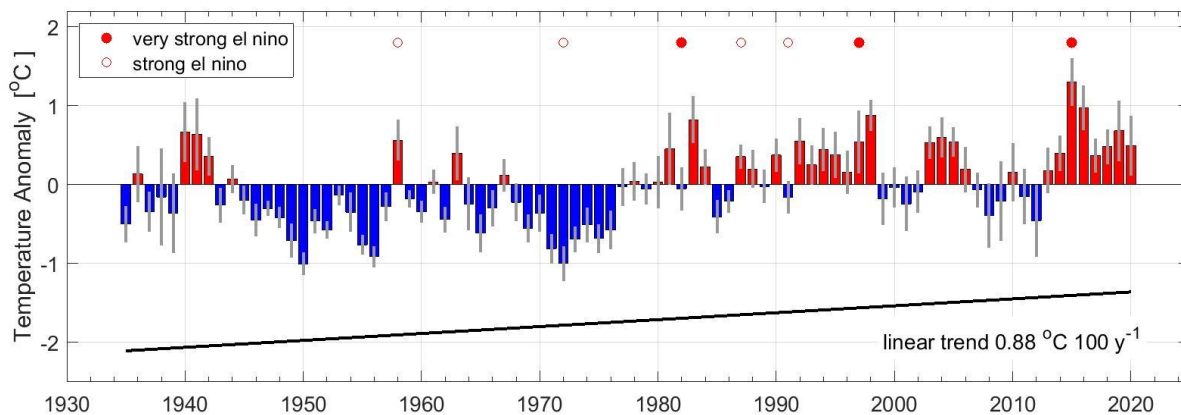


Figure 3-1. The trend in the annual temperature based on the observations of all lighthouses. The data shown are the anomalies from the long-term average temperature (1935-2020). The bars represent the anomalies averaged over all stations (a coast wide indicator), (red – above average, blue – below average), the vertical grey lines show the variability in the lighthouse data for each year. Source: Chandler, Section 10.

For most of 2020, the NE Pacific was in marine heatwave conditions for both surface and subsurface waters, which was a continuation of the marine heatwave that started in 2019 (Ross and Robert, Section 7). Marine heatwave (MHW) conditions persisted, despite the cooling effects of La Niña conditions throughout the latter half of 2020, suggesting that temperatures would have been warmer in the NE Pacific if not for the phase of the ENSO cycle (Figure 3-2). The MHW resulted in above average SST anomalies in both surface and subsurface waters (Figure 3-3; Ross and Robert, Section 7; Sastri, Section 14). The occurrence of MHWs in the NE Pacific is increasing, with MHWs observed in 2014-2016, 2018, and 2019-2020; this span of eight warm years (2014-2020) has been observed only once before in the last 80 years (during 1992-1998; Chandler, Section 35).

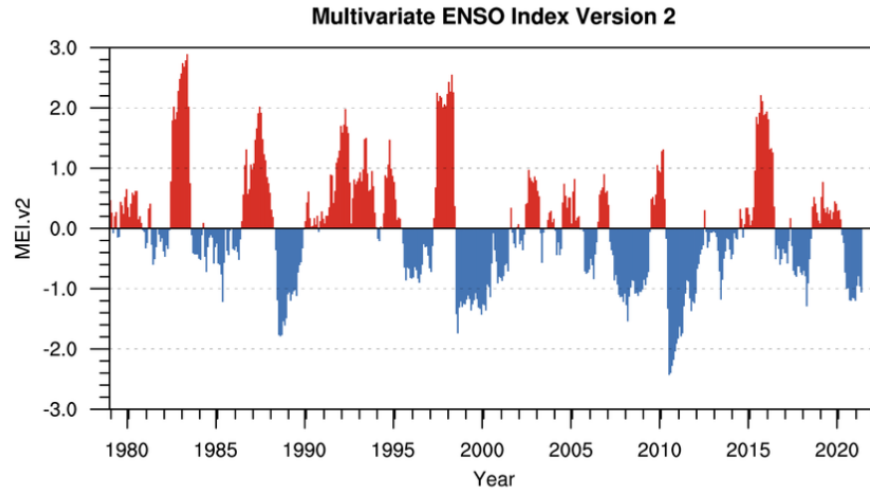


Figure 3-2. The multivariate ENSO Index. Data source: NOAA/ESRL/Physical Sciences Division – University of Colorado at Boulder/CIRES; <https://psl.noaa.gov/enso/mei/>

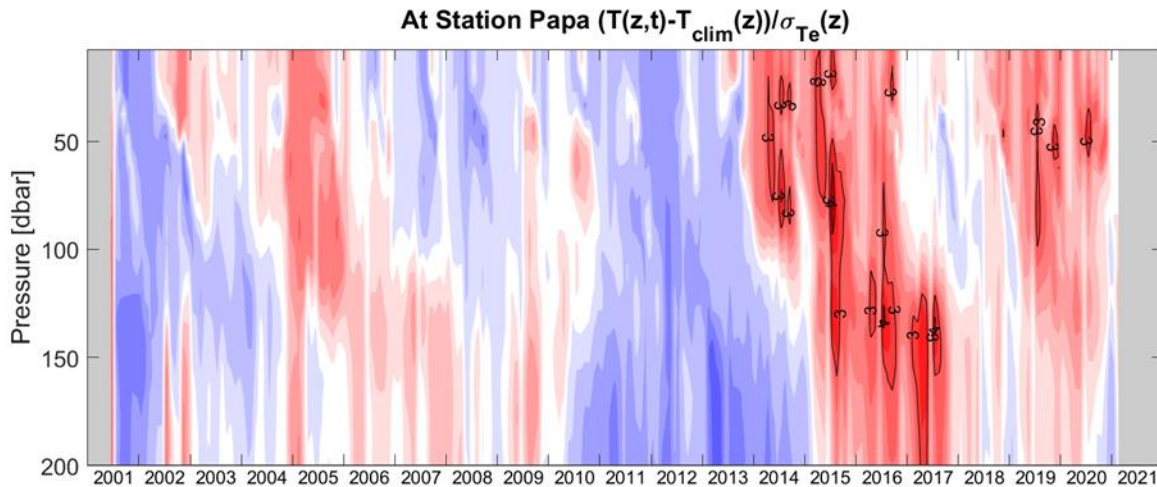


Figure 3-3. Plot of temperature anomalies relative to the 1956-2012 seasonally-corrected mean and standard deviation (from the Line P time series), as observed by Argo floats near Station Papa (P26: 50°N, 145°W). The cool colours indicate cooler than average temperatures and warm colours indicate warmer than average temperatures. Dark colours indicate anomalies that are large compared with the 1956-2012 standard deviations. The black lines highlight regions with anomalies that are 3 and 4 standard deviations above the mean. Source: Ross and Robert, Section 7.

Marine heatwaves are associated with reduced vertical mixing causing increased winter stratification. This results in decreased nutrient supply from deep to surface offshore waters. The winter stratification was strong in 2019/20, but not as strong as the previous winter which showed extremely low winter mixing, similar to the winters during the ‘Blob’ years (2013/14, 2014/15; Freeland 2015; Ross and Robert, Section 7). This suggests that nutrient supply from deep waters should have been weaker and therefore early spring nutrient levels lower in the spring of 2020, but not quite as low as in 2019 (Ross and Robert, Section 7).

Reduced ecosystem productivity during MHWs has been identified as the cause of reduced abundance of lipid-rich boreal copepods (Galbraith and Young, Section 18), seabird die-offs

(Jones et al. 2018), reduced size-at-age and late entry into streams and rivers by adult salmon (Hyatt et al., Section 24) due to prolonged drought in northern B.C. (Anslow, Section 6).

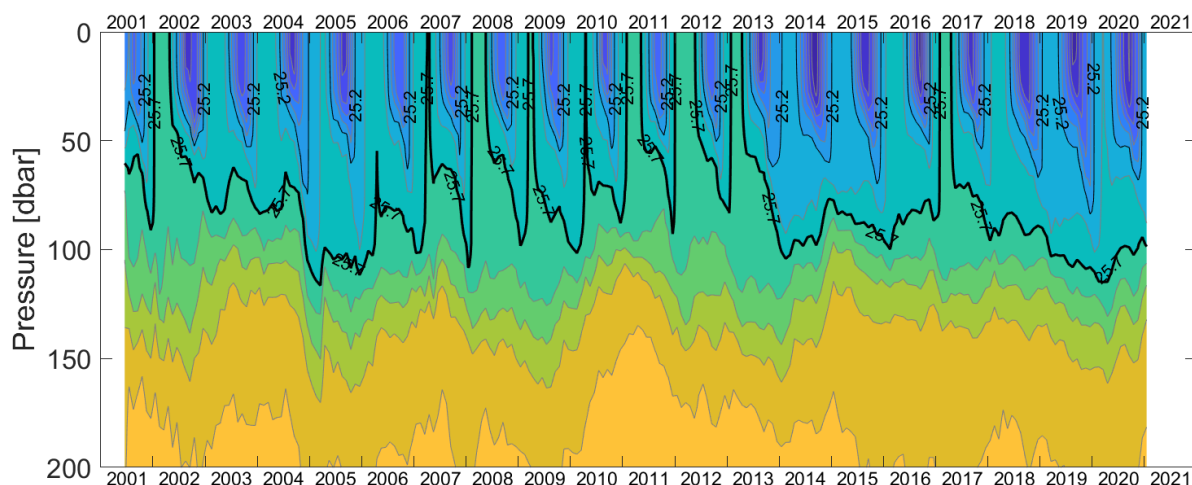


Figure 3-4. Coloured contour plot of density as observed by Argo floats near Station Papa (P26: 50° N, 145° W). The colours indicate potential density (yellow is denser and blue lighter). The black lines highlight the σ_{θ} 25.2 kg/m³ (thin) and 25.7 kg/m³ (thick) isopycnals. Source: Ross and Robert, Section 7.

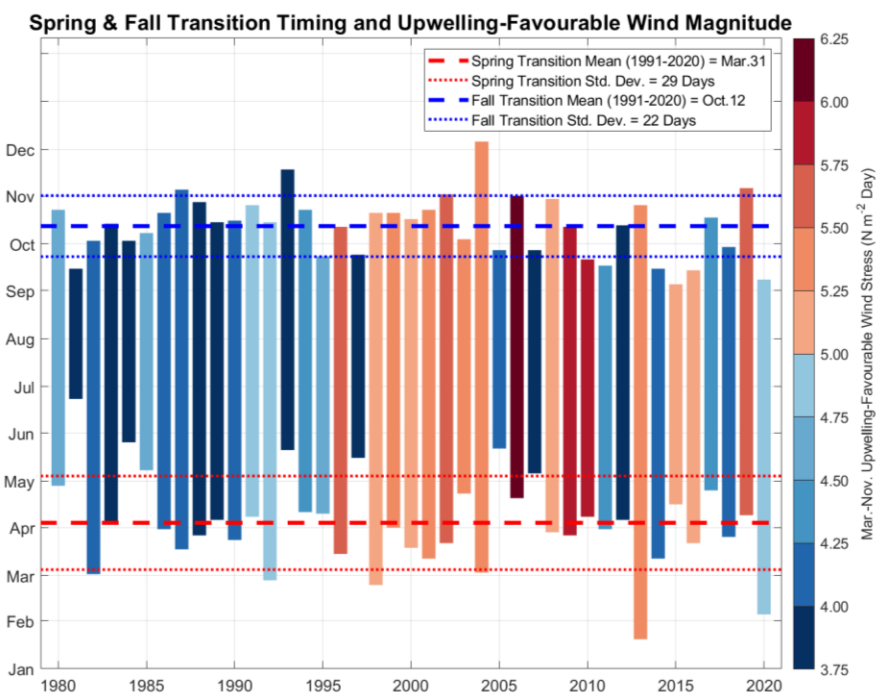


Figure 3-5. Annual Spring and Fall Transition Timing and March-November upwelling-favourable wind stress magnitude, 1980-2020. The length of the bar corresponds to the duration of the upwelling season, coloured by the intensity of the upwelling (red indicates intense upwelling, blue indicates weak upwelling). Bold dashed lines indicate the average spring (red) and fall (blue) transition dates. Light-dashed lines indicate standard deviations of the spring (red) and fall (blue) transition dates. Source: Roy Hourston, Section 8.

The timing and magnitude of upwelling of deep, nutrient-rich water off the west coast of Vancouver Island (WCVI) is an indicator of marine coastal productivity across trophic levels from plankton to fish to birds. Variability in the upwelling index corresponds with variations in the strength and/or longitudinal position of the Aleutian low-pressure system in the Gulf of Alaska. In 2020, the winter downwelling season ended early but there was a slow start to the upwelling season. The magnitude of the upwelling-favourable winds in the summer of

2020 was near-normal with an expectation of average productivity (Hourston and Thomson, Section 8; Dewey et al., Section 36). The 2020 Spring Transition timing was very early relative to the 1991-2020 mean and this is associated with average to above-average upwelling-based coastal productivity (Hourston and Thomson, Section 8; Dewey et al., Section 36; Figure 3-5).

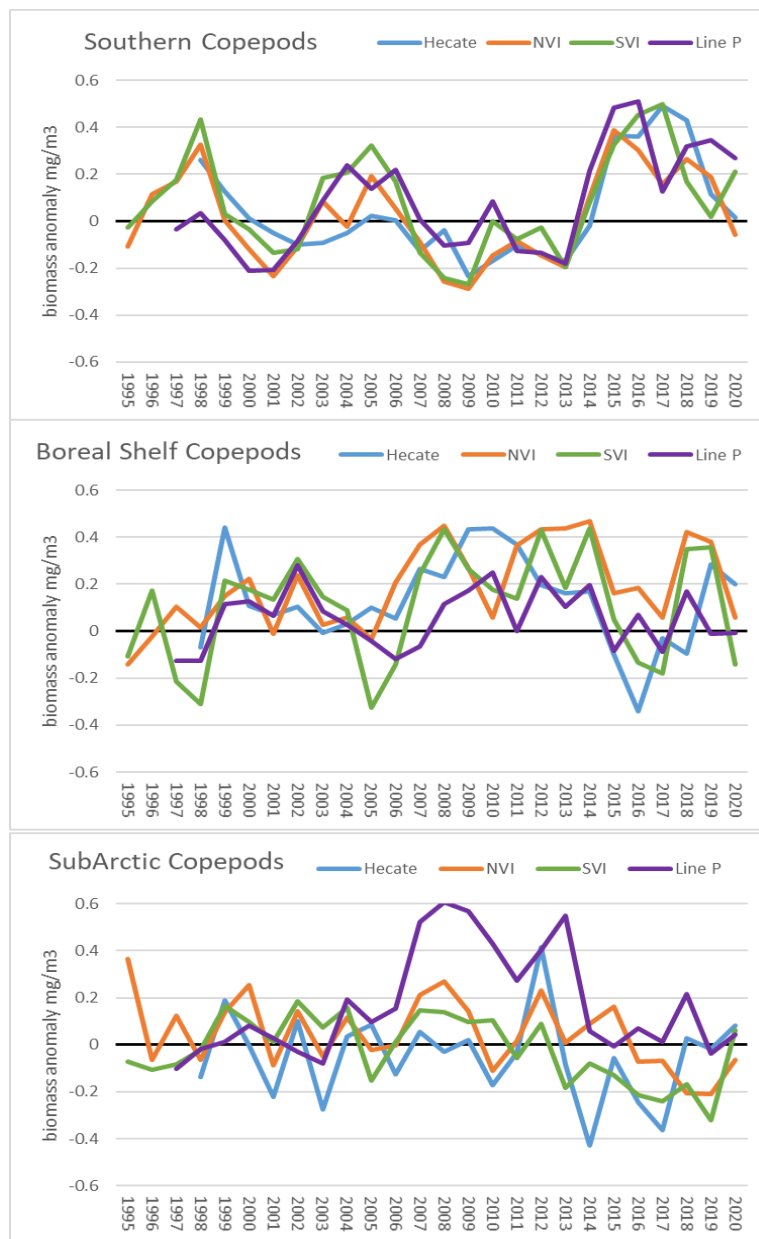


Figure 3-6. Zooplankton species-group anomaly time series for the regions shown in Figure 16-1. Line graphs are annual log scale anomalies. Southern Vancouver Island (SVI) green; Northern Vancouver Island (NVI) orange; Hecate Strait blue; Line P purple - for all graphs. Blank years mean no samples were collected. Source: Galbraith and Young, Section 16.

In 2020, winter surface nutrient concentrations along Line P were among the lowest on record due to increased stratification that restricted nutrient renewal from vertical transport, similar to that observed in previous years (Peña and Nemcek, Section 16). A Haida eddy with lower than normal surface nutrients was present at the offshore stations of Line P in winter of 2020. By summer, surface nutrients were similar to or higher than those observed in winter. Phytoplankton biomass was relatively low along Line P in 2020 but community composition was similar to that of previous years, except for a decrease in diatom abundance (Peña and Nemcek, Section 16; Batten and Ostle, Section 19).

In some areas off the WCVI, the zooplankton community continued to reflect warm water conditions, with above average abundances of southern species (e.g., southern copepods along Line P and southern chaetognath species in all areas) (Galbraith and Young, Section 18) and, on the shelf, a dominance of small-sized copepod species (Batten and Ostle, Section 19). Large subarctic and boreal copepods are more favourable for fish growth than small, southern copepod species. In 2020, biomass anomalies of boreal and subarctic copepods anomalies moved to near average in most areas (Galbraith and Young, Section 18; Figure 3-6). Southern copepod anomalies were

positive along and off the south coast of Vancouver Island (Figure 3-6; (Galbraith and Young, Section 18); warm water copepods were still abundant in offshore waters (Ostle and Batten, Section 19).

Changes to the physical environment, and phytoplankton and zooplankton communities can have impacts on higher trophic levels. The survey that usually monitors WCVI Smooth Pink Shrimp biomass, which is negatively correlated with SST (lagged 1 year), was cancelled in 2020 due to COVID-19. Groundfish surveys were also cancelled; however, new analyses of groundfish biological status from published stock assessments have been provided. The average groundfish stock status declined from 1950 to around 2000 and has remained relatively stable since then. The change around 2000 followed the implementation of individual transferable quotas for the trawl fleet and the commencement of the synoptic trawl surveys (Anderson et al., Section 27). Albacore tuna annual catch-per-unit-effort (CPUE) increased in 2018-2020 (Zhang, Section 28).

The growth rate of Cassin's Auklets is linked to the abundance of their primary prey, *Neocalanus cristatus* copepods, which are more abundant during relatively cold years (Hipfner et al. 2020). In 2020, growth rates of Cassin's auklet nestlings on Triangle Island could not be measured due to COVID. Marine mammal population trends are not updated annually; however, readers are referred to the 2020 SOPO report for recent information.

The Salish Sea spring biophysical survey was cancelled due to the COVID-19 pandemic. The summer survey showed near-normal temperature and salinity conditions through most of the Salish Sea with lower than normal oxygen concentrations in the upper 100 m. The fall survey captured an intrusion of cooler, saltier and poorly oxygenated water from the Pacific Ocean. Water exchange in Haro Strait mixed this low oxygen Pacific water with fresher and warmer water from the Strait of Georgia causing lower than normal oxygen conditions extending northwards through the Strait of Georgia at depths of 50-100 m. (Chandler, Section 35). The Fraser River discharge was significantly higher than normal in 2020 (about 30% more than the 100 year average) (Figure 3-7; Chandler, Section 35).

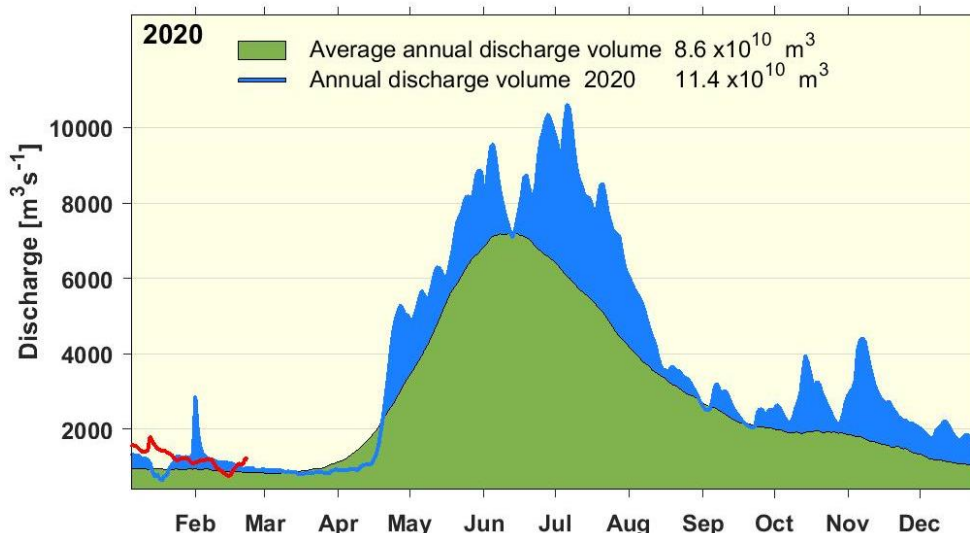


Figure 3-7. Fraser River discharge at Hope B.C.; 2020 (blue), 108 year average (green), the above normal discharge in early 2021 (red line). Extracted from the Environment and Climate Change Canada Real-time Hydrometric Data web site (https://wateroffice.ec.gc.ca/mainmenu/real_time_data_index_e.html) on 23 Feb 2021.

There were local *Heterosigma akashiwo* blooms with concentrations reaching thousands cells per mL in Cowichan Bay, Sunshine Coast, and Irvine's Sechelt in July and August, 2020. The *Heterosigma* blooms of 2020 were more abundant than in 2015-2017 and 2019, but less than in 2018 (Esenkulova et al., Section 38). European Green Crab, an Aquatic Invasive Species that was first observed in B.C. following the 1997/98 El Niño, is widespread along the WCVI and found in low numbers on the Central B.C. coast and in the Salish Sea (Howard and Therriault, Section 43). This high-impact invader that negatively affects eelgrass, an important fish habitat, was detected for the first time on Haida Gwaii in July 2020 (Howard and Therriault, Section 43). Vessel traffic introduces a variety of stressors to marine ecosystems (e.g., oil, noise, shipstrikes, etc). Marine vessel traffic intensity increased in the Salish Sea from 2015-2017 for nearly all types of vessels and evidence of increasing intensity for recreational and other vessels (O'Hara et al., Section 44).

Annual variation in spring bloom timing and community composition may affect the food web, through a temporal match or mismatch between prey and their predators. In the SoG, the spring bloom timing was similar to the long-term average (Allen et al., Section 37; Dewey et al., Section 36) – which implies good feeding conditions for juvenile fish.

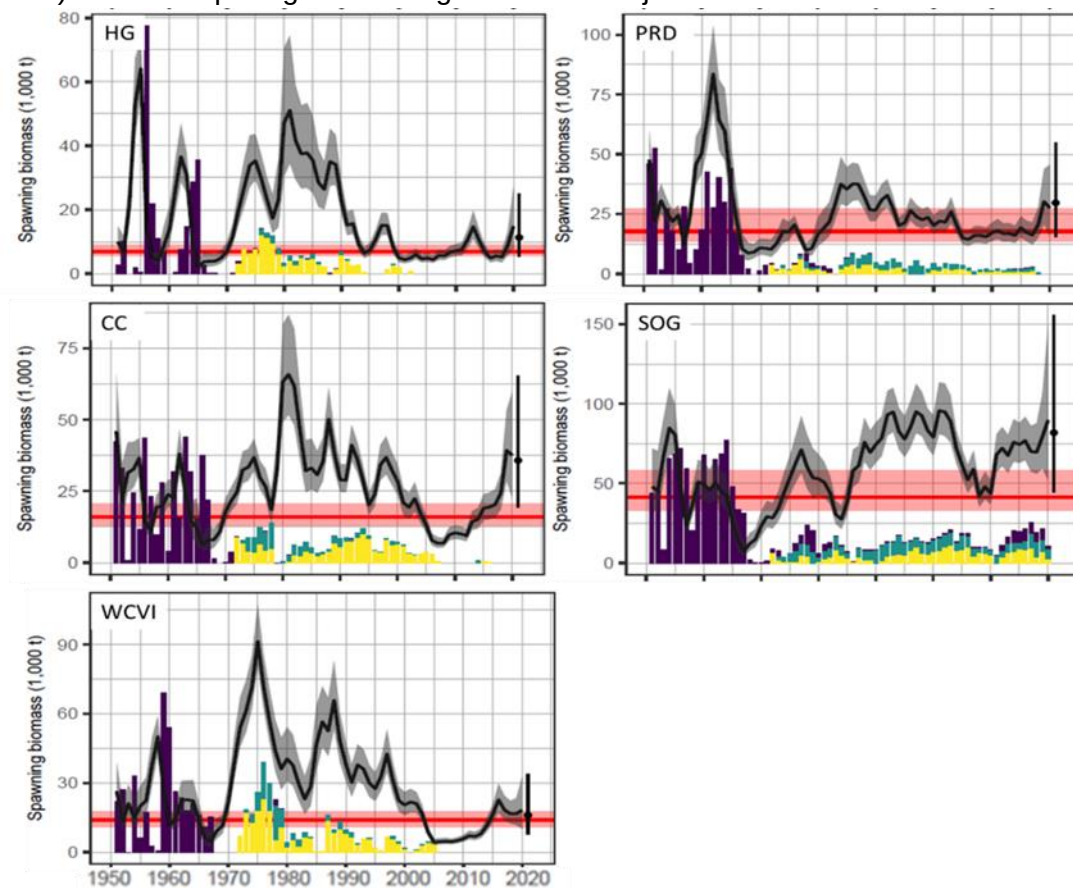


Figure 3-8. Summary of the dynamics of the five Pacific Herring stocks from 1951 to 2020, where solid lines with surrounding grey envelopes, represent medians and 5-95% credible intervals. Also shown is the reconstruction of spawning biomass for each year, with unfished values shown at far left (solid circle and vertical lines) and the projected spawning biomass given zero catch shown at the far right (solid circle and vertical lines). Time series of thin vertical lines denote commercial catch (excluding commercial spawn-on-kelp; colours indicate different gear types; see DFO 2021). Red line= limit reference point (0.3B0). B0 = unfished biomass. Figure adapted from DFO (2021). Figure adapted from DFO (2020).

In 2020, SoG zooplankton biomass was above the long-term average (Young et al., Section 39). The abundance and biomass trends were similar to those observed in 2019 for crustacean zooplankton taxa, that are important food for juvenile salmon (Young et al., Section 39). In 2020, Pacific Herring spawning biomass varied among assessed areas. For example, since 2000, Haida Gwaii biomass has been low with an increase in 2020. Also, in 2020, the Strait of Georgia stock biomass was relatively high compared to historic levels (Cleary et al., Section 21; Figure 3-8). In 2020, the Strait of Georgia juvenile Pacific Herring survey was cancelled due to COVID. In 2020, the index of Fraser River Eulachon spawning stock biomass was estimated to be relatively high (~624 tonnes), approximately equal to the 2001 index and higher than all years since 2001 (Flostrand, Section 20). In 2020, a freshwater benthic diatom known as *Didymo* was confirmed to be a major component of the material collected in the Fraser River Eulachon egg and larval survey water samples. The extensive growth of *Didymo* in upper watersheds in B.C. and high outflow of *Didymo* in the lower Fraser River have unknown and possibly negative implications to upper and lower watershed habitats and ecosystem (Flostrand, Section 20).

In the SoG, the spring juvenile Pacific salmon survey was cancelled but the fall survey was completed revealing the index of Coho Salmon abundance was the fourth highest observed in the time series (Neville, Section 40). Also, the index of Chinook Salmon abundance was the largest observed in the time series (Neville, Section 40). The summer Integrated Pelagic Ecosystem Survey was cancelled, so updates of Pacific Herring and juvenile Pacific Salmon abundance could not be updated. In October 2020, a juvenile salmon survey was conducted in Queen Charlotte Sound, Dixon Entrance, and Hecate Strait to measure relative abundance, condition, and genetic stock identification of different species (Anderson et al. Section 22). Abundance and condition anomalies varied among regions and species (Anderson et al., Section 22). Adult Sockeye, Chinook, and Chum, Salmon returns in 2019 were generally poor (Grant et al., Section 23). Coho and Pink Salmon returns in 2020 were mixed: Pink Salmon generally had better returns than most species in recent years in some areas of Johnstone Strait, while Coho returns were generally average to below average with a few exceptions (Grant et al., Section 23). In 2015-2020, most B.C. Sockeye Index stocks generally exhibited returns below to far below their 40 year average (Hyatt et al. Section 24) and returns and productivity of the Fraser River Sockeye Salmon aggregate were poor (Figure 3-9, Grant et al., Section 23). Fraser River Sockeye Salmon that matured in odd-numbered years were generally smaller than those that matured in even-numbered years, with size at age in 2019 and 2020 among the lowest observed in over 60 years (Latham et al., Section 26). For the entire North Pacific, recent salmon abundances were at (2018) or near all-time high levels until 2020 when far fewer salmon returned than expected; the North Pacific ecosystem may have been sufficiently disrupted by consecutive abundant Pink Salmon years to reduce salmon returns in 2020 (Irvine et al., Section 25).

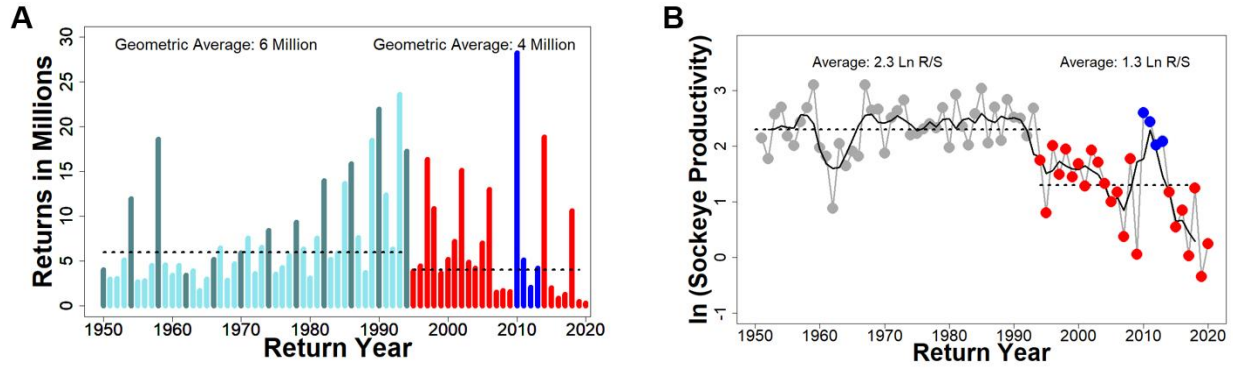


Figure 3-9. (A) Total Fraser Sockeye annual returns. For years from 1950 to 1994 dark green bars are the 1950 cycle line, and light blue bars are for the three other cycle lines. For years from 1995 to 2020, red vertical bars highlight a period of reduced Fraser Sockeye productivity, with the exception of a period from 2010 to 2013 (blue vertical bars) where productivity was closer to the previous period (1950-1994). (B) Total Fraser Sockeye productivity (loge (returns/effective female spawners)). The grey dots and lines represent annual productivity estimates. Productivity and returns have declined in recent decades, highlighted red, with the exception of four years from 2010-2013, which were closer to the previous period (1950-1994), highlighted blue. For both figures, the dashed line is the time series average. Source: Grant et al., Section 23.

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5. ACKNOWLEDGMENTS

The authors and contributors to this Technical Report wish to thank all the officers and crew of the many vessels that have been involved in collecting data and maintaining monitoring stations for these studies. Without their assistance many of the reports in this document would not be possible.

**Individual reports on conditions in the Northeast Pacific and British
Columbia's outer coast**

6. LAND TEMPERATURE AND HYDROLOGICAL CONDITIONS IN 2020

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6.1. Highlights

- El Niño Southern Oscillation conditions were neutral trending toward a developing La Niña by late spring.
- B.C. experienced above normal precipitation, near normal maximum daily temperatures and above normal minimum daily temperatures in 2020.
- Normal to above normal snowpack persisted well into June in southeast and northern B.C.
- Late spring and summer were wet to record wet and brought very cold daily maximum temperatures.
- Trends in temperature were positive for the period 1950 – 2020 with $T_{\min}$ increasing faster than $T_{\max}$. Precipitation shows no significant trend over that timescale.

6.2. Introduction

The seasonal conditions that transpire on land have impacts on nearby coastal waters through river discharge volumes, temperatures and nutrients from rivers and streams and, on an event basis, impacts of wildfire sedimentation on ocean waters. As part of a holistic approach to describing the state of the Pacific Ocean, a description of these processes is warranted. To address that need at a basic level, this section will describe the evolution of seasonal weather and snowpack conditions relevant to the coastal waters of British Columbia. The particular records that are described are temperature and precipitation observations from the national, provincial and private weather observing networks across the province and measurements of water equivalent snow pack on a monthly basis. This section also references indicators of the El Niño Southern Oscillation (ENSO).

6.3. Description of the time series

6.3.1. *Temperature and Precipitation*

Observations of temperature and precipitation made at British Columbia weather stations have been compiled on an ongoing basis since 2010 under the Climate Related Monitoring Program. The dataset consists of observations from the Climate Related Monitoring Program partners: the provincially run networks, BC Hydro, the Capital Regional District, Metro Vancouver and Rio Tinto. The data set also includes data from Environment Canada's observing network and, in aggregate, span the years 1872 to present. Long-term records of daily minimum and maximum temperature and daily precipitation totals were used to calculate 30-year climate normals for each month of the year for the 1981 – 2010 averaging period. Anomalies in monthly temperature and precipitation are calculated relative to these normals and the anomaly data are then interpolated onto a $0.5^\circ \times 0.5^\circ$ grid covering British Columbia. The time series of gridded anomalies is then spatially divided among the BC River Forecast Centre's Snow Index Basin regions. Average anomalies are taken across each region for each month to form a time-series

of regional anomaly that can then be used to rank individual years. The monthly data are also aggregated into seasons and annual values to assess the longer time scale fluctuations in temperature and precipitation and to rank the anomalies in time. An example of the resulting annual anomaly data is shown in Figure 6-1; regionally averaged annual anomalies in average daily minimum temperature (left panel) and for anomalies in precipitation (right panel). The temperature and precipitation anomalies are expressed as percentiles among the number of observed months/seasons in the sample. We define the first percentile and number 1 ranking as the warmest/wettest and the highest percentile as the coldest/driest that corresponds to a ranking of 121 for 2020. We define broad anomaly categories ranging from record cold/record dry, much below normal, below normal, near normal, above normal, much above normal, record warm/record wet. These categories are defined by the percentile bins 100th, 100th – 90th, 90th – 66th, 66th – 33rd, 33rd – 10th, 1st.

6.3.2. *Snow*

Measurements of the province's snow pack are made by the Ministry of Environment and Climate Change Strategy and BC Hydro on a monthly basis through manual snow surveys. Additional data are gathered from automated snow pillow stations. The Ministry of Forests Lands and Natural Resource Operations and Rural Development's River Forecast Centre compiles snowpack data on a monthly basis from early January through June. Snowpack in regions is compared with data from previous years to determine how the current year's accumulated snow amount compares with historical expectations. In terms of river flow, snowpack dictates the added potential (or lack thereof) for flooding during the spring melt season. For this section, the evolution of the mapped anomalies in snow pack is described.

6.4. **Status and trends**

6.4.1. *Temperature and Precipitation*

Temperatures were higher than normal across British Columbia as a whole when compared with the long-term (1900 – 2020) record. Averages for daily minimum temperature was among the top 15 for all of southern B.C. north to Prince George and Smithers. Northward from there, daily minimum temperatures were among the top 23 years in the long term record. Averages for daily maximum temperature were closer to median values with temperature ranking in the middle one third quantile throughout the province with the exception of the northwest of the province near Atlin B.C. and the southeast corner in the southern Kootenay mountains where temperatures were above normal ranking 41st to 14th warmest. Precipitation anomalies across the province were above normal to much above normal with the highest anomalies tracing a band from southwest B.C. northward to Prince George and Valemount. This area experienced anomalies among the 13th to 5th wettest in the long term record. Wetter than normal areas to the north had rankings of 26th to 32nd while wetter than normal areas to the southeast were among the 16th to 27th wettest. Dry conditions extended across northern B.C. while near normal precipitation fell in the southern Kootenay Mountains near Cranbrook.

On seasonal and monthly timescales, the primary anomalies lie in summer conditions. The northern half of B.C. from Smithers and Prince George northward experienced record breaking precipitation for the summer season. Southward, conditions were wet, but less extremely so and trending to normal or drier than normal conditions across the southernmost portion of the

province eastward of the Coast Mountains. This was the second consecutive summer of high precipitation and the wildfire season responded as it had in 2019 with very low activity.

The wet summer was accompanied by temperature anomalies that are typical for cloudy conditions. The average of daily maximum temperatures was very cold with much below to below normal anomalies recorded throughout the province except the Southern Kootenay Mountains. These cold daytime temperatures were accompanied by warm nighttime temperatures that were above normal from the Smithers and Prince George areas southward and much above normal northward.

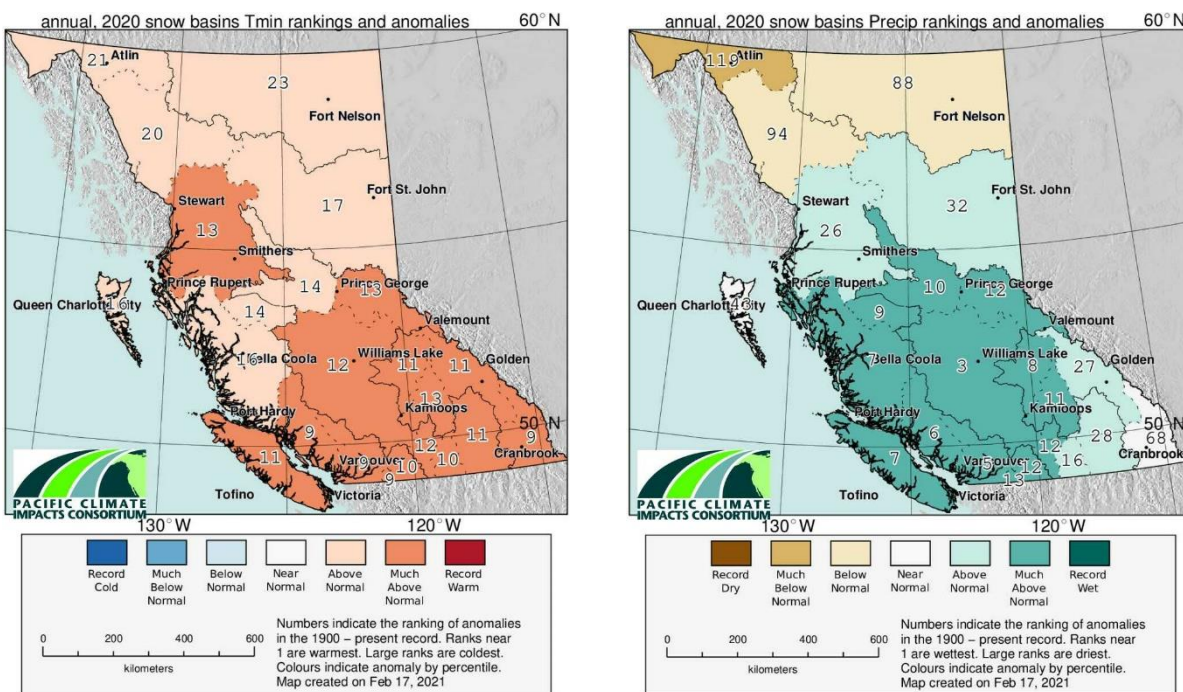


Figure 6-1. Annual anomalies in average daily minimum temperature (left panel) and total annual precipitation (right panel) for 2020 in British Columbia. Quantiles defining the colour scale are given in the text. Numbers on the map correspond to ranking in the 121 observation years from 1900 through 2020.

Using the province-wide seasonal and annual temperature and precipitation anomalies, trends are calculated for the full record spanning from 1900 through 2020 and for the period 1950 through 2020. Note that precipitation data early in the record are sparse and have greater uncertainty than those for temperature, thus we exclude the long-term precipitation trends. Temperature trends are more certain because of the reduced spatial and interannual variability of temperature anomalies compared to precipitation. The trend values for annual average daily minimum temperature and those for annual average maximum temperature are positive and statistically significant ($p < 0.05$) for both the full and 1950 – 2020 records (Table 6-1). The trends in annual average daily minimum temperature are greater than those for daily average maximum temperature by a factor of two in the long-term record and a factor of 1.5 in the 1950 onward record. The trends in precipitation are positive but not statistically different from zero.

Table 6-1. Trends in annual average of daily minimum and daily maximum temperature and for annual total precipitation. Analysis periods are 1900 – 2020 and 1950 – 2020. The long-term trend for precipitation is not presented due to low confidence in the spatial representativeness of the precipitation network early in the century. Statistically significant trends are in bold font.

Annual Temp. and Precip. Trends	1900 – 2020	1950 – 2020
T_{max} ($^{\circ}\text{C yr}^{-1}$)	0.01	0.02
T_{min} ($^{\circ}\text{C yr}^{-1}$)	0.02	0.03
Precip. ($\% \text{ yr}^{-1}$)		0.07

6.4.2. Snow

The evolution of B.C.'s snowpack during the winter of 2019/2020 was mostly typical until punctuated in western B.C. by warm, dry conditions during spring. Snow accumulation was 88% – 144% of normal at the end of March with the lowest values recorded on Vancouver Island while the Upper Fraser basin was well above normal (Figure 6-2). The somewhat warm and dry spring in western B.C. yielded low snow amounts by the end of May. Southwestern B.C.'s snowpack had dropped from 22% of normal on Vancouver Island to 78% of normal along the central coast. To the north and east snow amounts remained above normal supported by above normal precipitation amounts (Figure 6-2). The transition from near normal amounts of snow to low snowpack suggests accelerated melting and an earlier than normal spring freshet in southwestern B.C. while the high retained snow amounts in the rest of the province corresponded to later than normal peaks in the spring freshet. Ongoing cool daytime temperature and high precipitation amounts prolonged the spring peak in runoff into early summer.

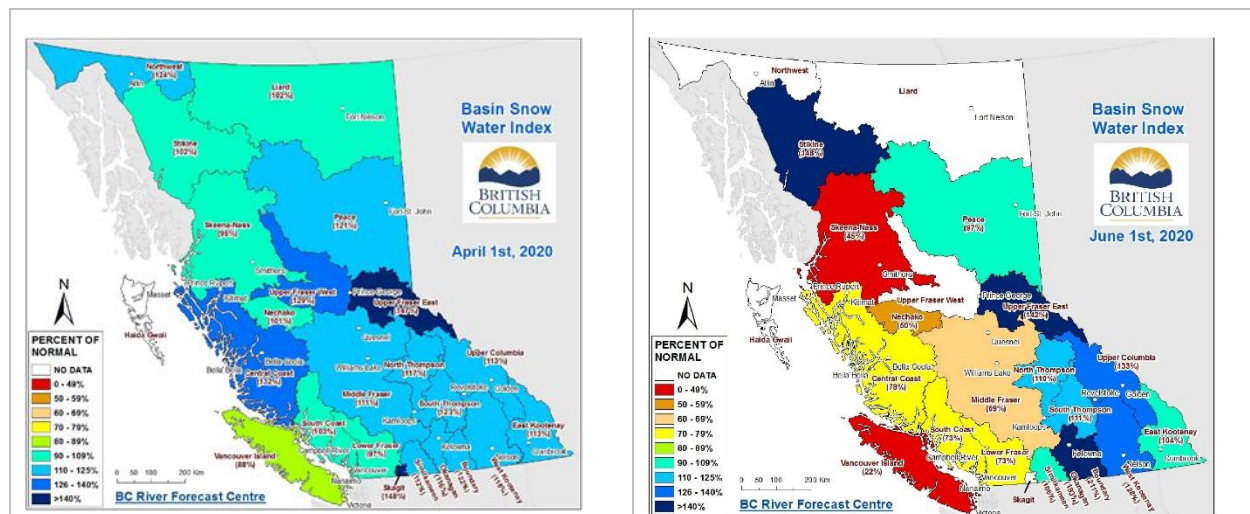


Figure 6-2. Anomalies in B.C. snowpack for April (left) and June (right), 2020. Maps are produced by the BC Ministry of Forests Lands and Natural Resource Operations and Rural Development's River Forecast Centre (River Forecast Centre 2020).

6.5. Discussion

2020 in British Columbia was slightly warmer than normal with the highest anomalous temperatures occurring in September. Precipitation was higher than normal over much of central and southern B.C. with the late spring and summer season being extremely wet.

The observed anomalous conditions are likely due in part to ongoing warming in B.C. and may be associated with ENSO activity. The year began as ENSO neutral so, through winter and into spring, there was little forcing from this teleconnection. However, a La Niña pattern of ocean temperatures formed in late spring and persisted through the remainder of 2020. ENSO impacts typically peak in late winter and spring, so it's possible that the developing La Niña played a role in the very wet late spring and summer (Stahl et al. 2006). Although La Niña conditions are associated with cooler than normal temperatures, the spring/summer wet period saw cold days but warm nights that made the daily average temperatures near normal. Leading into fall, the impact of ENSO on B.C. weather is typically weak, so anomalies are attributable to natural variability.

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7. MARINE HEATWAVE PERSISTS DESPITE GROWING LA NIÑA

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7.1. Highlights

- For most of 2020, the NE Pacific was in marine heatwave conditions for both surface and subsurface waters.
- The mixing in the winter of 2019/20 was weak, suggesting lower surface nutrient levels in the spring of 2020, but not as low as 2019.
- Marine heatwave conditions persisted, despite La Niña conditions throughout the latter half of 2020, suggesting that temperatures would have been warmer in the NE Pacific if not for the phase of the ENSO cycle.

7.2. Summary

Based on NOAA land and sea surface temperature data dating back to 1880, 2020 was the second warmest year on record globally (NOAA State of the Climate 2020). This is consistent with the recent trend, wherein 9 of the ten warmest years are in the last decade. In ranked order, the ten warmest years are 2016, 2020, 2019, 2015, 2017, 2018, 2014, 2010, 2013 and 2005. Sea surface temperatures (SSTs) in the Northeast Pacific (NE Pacific) were about 1°C above the average for the 1981-2010 base period

(www.ncdc.noaa.gov/sotc/service/global/map-blended-mntp/202001-202012.png).

In the NE Pacific, the SSTs were warm throughout 2020 (Figure 7-1). In fact, the SSTs were so

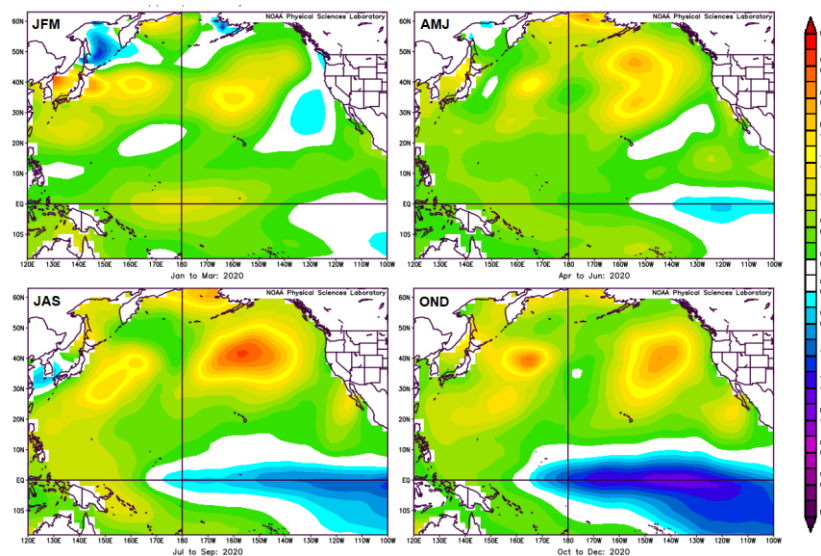


Figure 7-1. Seasonal maps of temperature anomalies in the Pacific Ocean for 2020. The colour bar on the right, showing the temperature anomaly in °C, applies to all panels. Anomalies are relative to 1981-2010 base period. Source: NOAA Extended SST v4 <http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl>.

warm that the NE Pacific was in marine heatwave conditions through much of the year. This is a continuation of the marine heatwave that started in 2019 (Amaya et al. 2020; Hannah et al. 2020; Ross and Robert 2020). In contrast to the 2014-2016 marine heatwave, when positive SST anomalies were amplified by a large El Niño in 2015, Figure 7-1 shows that La Niña conditions grew throughout 2020. La Niña conditions

typically decrease SST in the NE Pacific; thus the marine heatwave would likely have been stronger without the La Niña.

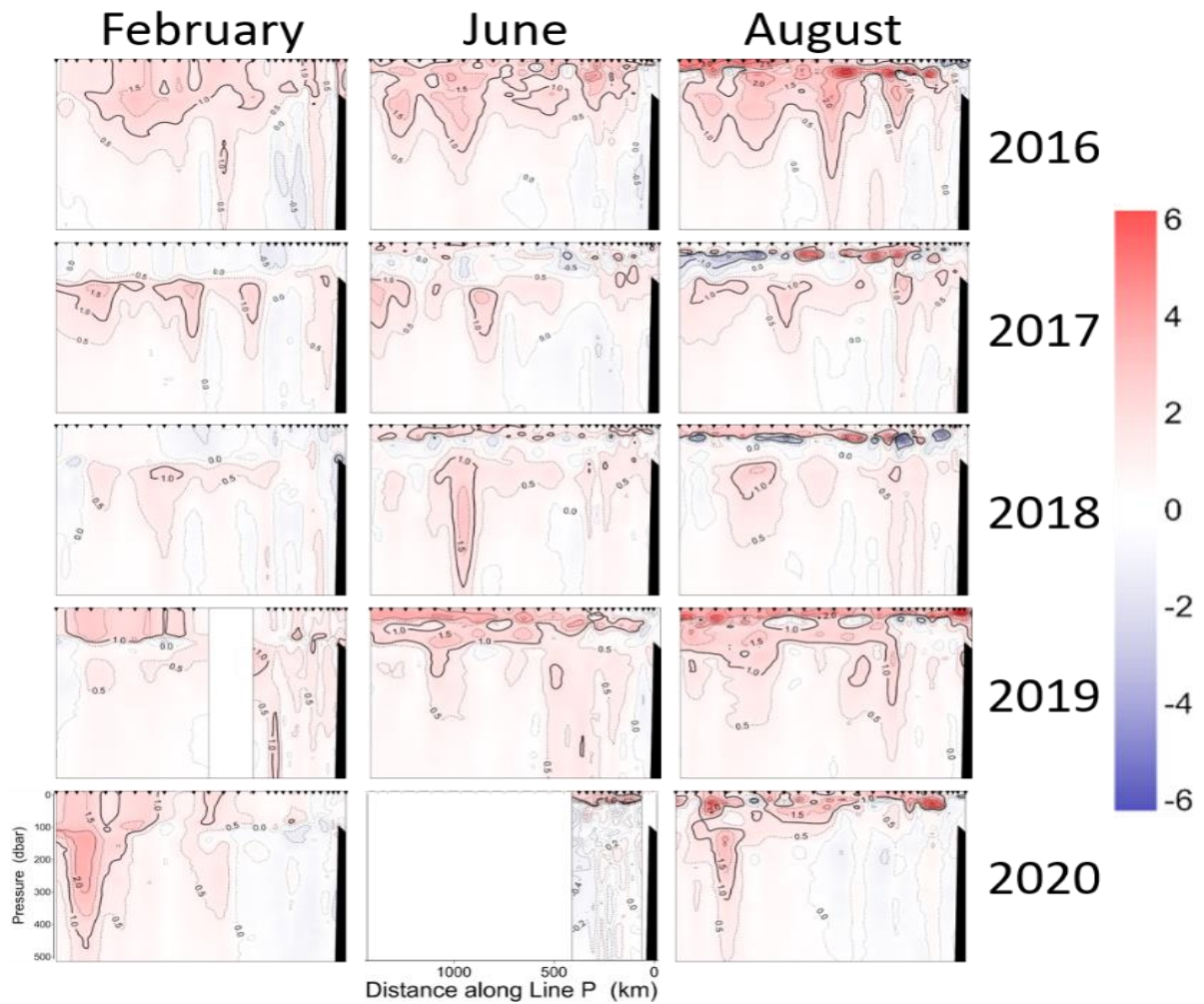


Figure 7-2. Temperature anomalies ($^{\circ}\text{C}$) along Line P from 2016 to 2020 with respect to the 1981-2010 mean.

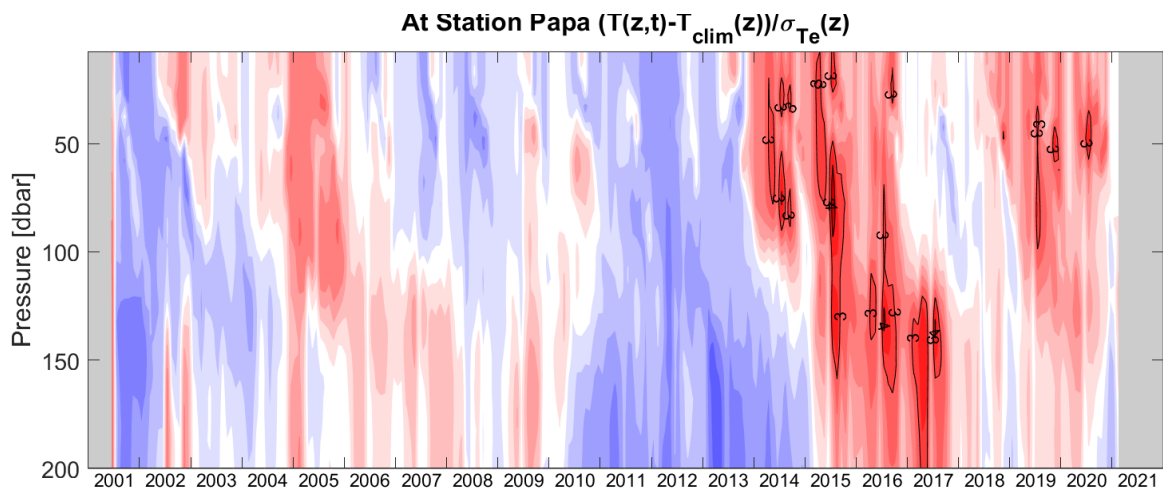


Figure 7-3. Plot of temperature anomalies relative to the 1956-2012 seasonally-corrected mean and standard deviation (from the Line P time series), as observed by Argo floats near Station Papa (P26: 50°N , 145°W). The cool colours indicate cooler than average temperatures and warm colours indicate warmer than average temperatures. Dark colours indicate anomalies that are large compared with the 1956-2012 standard deviations. The black lines highlight regions with anomalies that are 3 and 4 standard deviations above the mean.

Above average temperatures (relative to both the 1981-2010 (Figure 7-1 and 7-2) and 1956-2012 (Figure 7-3) means) were observed in subsurface waters as well. Temperature anomalies at Station Papa (based on the interpolation of Argo float data onto the location of Station Papa; Figure 7-3), showed above average subsurface temperatures at Station Papa throughout 2020. This is very similar to 2019. The strongest anomalies (reaching 3 standard deviations above the mean) were at about 100 m depth, just above the permanent pycnocline. Unlike for the 2014-16 marine heatwave, there is no indication that the depth of the peak temperature anomaly increased over time. The marine heatwave was observed across the entirety of Line P (Figure 7-2; note that an eddy was present near the offshore end of the line in February, thus the deep temperature anomalies were related to that transient feature and not the marine heatwave). The anomalies were largest in the August 2020 data, which showed only slightly weaker anomalies than in 2019, despite La Niña conditions.

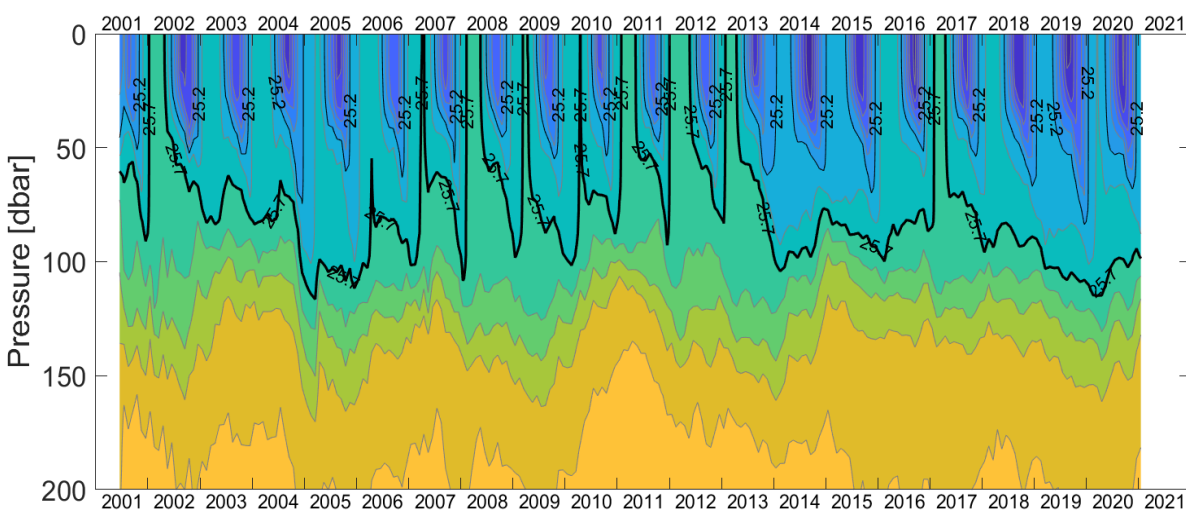


Figure 7-4. Coloured contour plot of density as observed by Argo floats near Station Papa (P26: 50° N, 145° W). The colours indicate potential density (yellow is denser and blue lighter). The black lines highlight the $\sigma_\theta=25.2$ kg/m³ (thin) and 25.7 kg/m³ (thick) isopycnals.

The winter stratification was strong in 2019/20, but not as strong as the previous winter which showed extremely low winter mixing, similar to the winters during the ‘Blob’ years (2013/14, 2014/15; Freeland 2015). During 2017-2018, it appeared that winter mixing had returned to normal, but the recent marine heatwave has again reduced winter mixing. The history of the $\sigma_\theta=25.7$ kg/m³ isopycnal (highlighted with a thick black line in Figure 7-4) illustrates this nicely. It remained very deep throughout the 2014-2016 marine heatwave, deeper even than much of the 2003-2005 warm period, and shoaled in the winter of 2015/16 to levels last experienced during 2003-2005, while in 2016/17 stratification had returned to a level similar to the winters of 2010/11 and 2011/12. This return to weak mixing suggests that nutrient supply from deep waters should have been weaker and therefore early spring nutrient levels lower in the spring of 2020, but not quite as low as in 2019. With the marine heatwave conditions appearing to be tailing off (Figure 7-3) and a La Niña winter, it is likely that 2020/21 will experience stronger winter mixing.

Looking at the climate indices collectively (Figure 7-5), they indicated that 2020 should have been a cool year; all indicating a cool period, except the NPGO. However, the NE Pacific experienced a very warm year with marine heatwave conditions throughout most of the year.

7.3. Climate Indices

The **Oceanic Niño Index (ONI)** is a monthly index which is a 3-month running mean of sea surface temperature (SST) anomalies in the Niño 3.4 region (5° N-5° S, 120°-170° W) plotted on the center month. The SST anomalies are calculated based on 30-year base periods that are updated every 5 years, which accounts for global warming and some of the decadal-scale SST variability (as seen in the PDO index). The ONI is provided by the NOAA's National Weather Service National Centers for Environmental Prediction CPC and is available from:

http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml.

The **North Pacific Index (NPI)** is the area-weighted sea level pressure over the North Pacific Ocean from 30° N to 65° N and 160° E to 140° W. This index, like the Aleutian Low Pressure Index (ALPI; Surry and King 2015) reported last year, is a useful indicator of the intensity and a real extent of the Aleutian Low Pressure system. The NPI was generally positive (blue) from 1950 to 1976, and generally negative (red) from 1977 to 2008; a change than can be attributed to the strengthening of the Aleutian Low Pressure system after 1977. From 2008 to present, the NPI was mostly positive, due to weaker Aleutian Lows. The NPI anomaly, plotted in Figure 7-5, was calculated from the NPI by removing the 1950-2018 mean. Monthly time series of the NPI are provided by the Climate Analysis Section, NCAR at Boulder, Colorado and based on Trenberth and Hurrell (1994):

https://climatedataguide.ucar.edu/sites/default/files/cas_data_files/asphilli/npindex_monthly.txt.

The **Pacific Decadal Oscillation (PDO) Index** is defined as the leading mode of monthly sea surface temperature variability (1st principal component [PC] of SST) in the North Pacific (Mantua et al. 1997). It represents a long-lived El Niño-like pattern of Pacific climate variability, generally indicating warm/cool patterns that persist for a decade or more. The PDO is provided by the Joint Institute for Studies of Atmosphere and Ocean of NOAA and is available from: <http://research.jisao.washington.edu/pdo/>.

The **Southern Oscillation Index (SOI)** is the anomaly in the sea level pressure difference between Tahiti (17°40' S 149°25' W) and Darwin, Australia (12°27'0" S 130°50'0" E). It is a

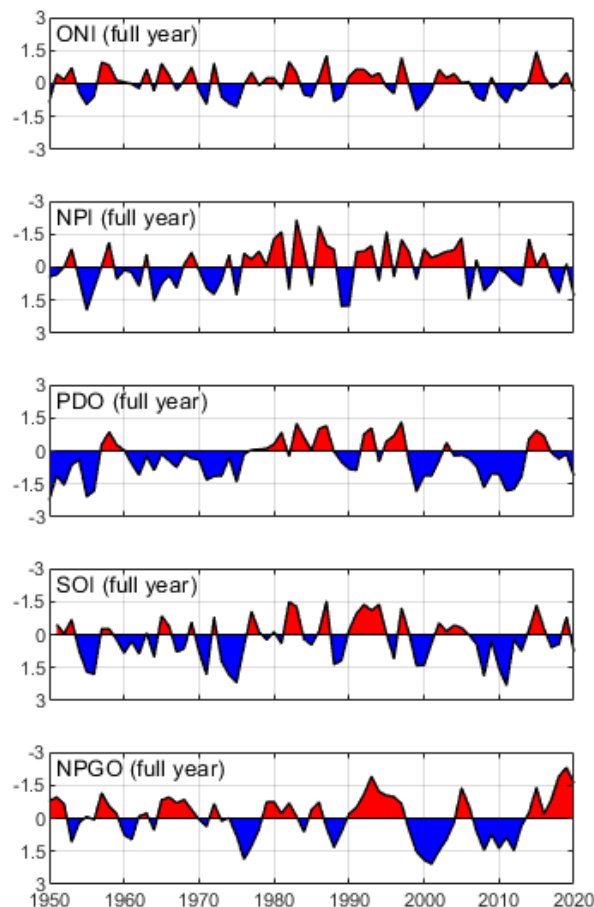


Figure 7-5. Time series of Pacific Ocean climate indices. Each of the monthly indices were averaged over the full year. Some series are inverted (negative values are above the axes) so that all series are red when coastal B.C. temperatures are anomalously warm. See text for a description and the source of each index.

measure of the large-scale fluctuations in air pressure occurring between the western and eastern tropical Pacific (i.e. the state of the Southern Oscillation) and, as it represents the changes in winds that set up El Niño/La Niña events, the ONI follows it quite closely. SOI is provided by the NOAA's National Weather Service National Centers for Environmental Prediction CPC and is available from: www.cpc.ncep.noaa.gov/data/indices/soi.

The **North Pacific Gyre Oscillation (NPGO)** is a climate pattern that emerges as the second dominant mode of sea surface height (SSH) variability (2nd PC of SSH) in the Northeast Pacific. The NPGO has been shown to be significantly correlated with fluctuations of salinity, nutrients and chlorophyll-a from long-term observations in the California Current (CalCOFI) and Gulf of Alaska (Line P) (Di Lorenzo et al. 2008). Monthly values of NPGO are available from: <http://www.o3d.org/npgo/>.

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8. WIND-DRIVEN UPWELLING/DOWNWELLING ALONG THE NORTHWEST COAST OF NORTH AMERICA: TIMING AND MAGNITUDE

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8.1. Highlights

- Based on the timing of upwelling-favourable winds and alongshore currents, the 2020 Spring Transition timing was very early relative to the 1991-2020 mean. This timing is associated with average to above-average upwelling-based coastal productivity.
- Stronger-than-average upwelling-favourable winds are generally associated with increased coastal productivity. Between 45°-60° N, the magnitude of upwelling-favourable winds in 2020 were near the 1991-2020 average during the warm season. This favoured average upwelling-based coastal productivity.
- As with the winter of 2018-2019, the 2019-2020 winter was characterized by weaker-than-average downwelling-favourable winds, indicating winter storms were weaker in intensity, shifted westward offshore, the storm season was shorter, or some combination of all three. These conditions are associated with marine heatwaves, as in 2013-2014. The winter of 2020-21 appears to be about average as of December, 2020.

8.2. Upwelling Timing: The Spring Transition Index

The shift in spring from predominantly downwelling-favourable poleward winds in winter to predominantly upwelling-favourable equatorward winds in summer is referred to as the Spring Transition. The reverse process in fall is called the Fall Transition. The alongshore winds drive a seasonal cycle in the alongshore surface currents over the continental slope, from poleward in winter to equatorward in summer. The Spring and Fall Transitions for the Pacific coast are derived using along-shore wind stress time series from NCEP/NCAR Reanalysis-1 (Kistler et al. 2001), along-shore wind velocity from the Environment and Climate Change Canada meteorological buoy 46206, and the along-shore current velocity at 35 and 100 m depth at mooring A1 (Figure 8-1; Folkes et al. 2017; Thomson et al. 2013).

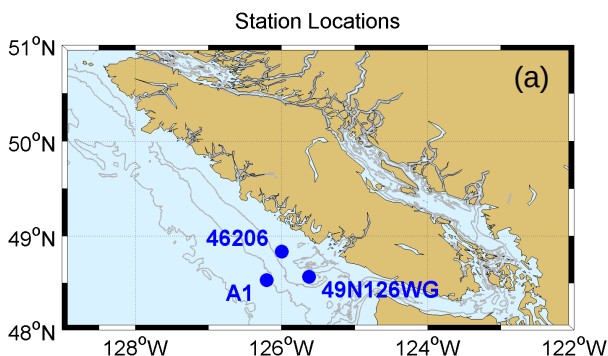


Figure 8-1. (a) Locations of observations delineating historical Spring and Fall Transitions.

The onset of seasonal upwelling that accompanies the Spring Transition varies from year to year (Thomson et al. 2014). In years such as 2005 and 2010, when the Spring Transition was relatively late, marine coastal productivity across trophic levels, ranging from plankton to fish to birds, was generally average to below-average, and was particularly poor in 2005 (DFO 2006). In years when the spring transition timing was average to early, such as 1999 and 2014, productivity was generally average to above-average (cf. Chandler et al. (2015) reports on outer British Columbia).

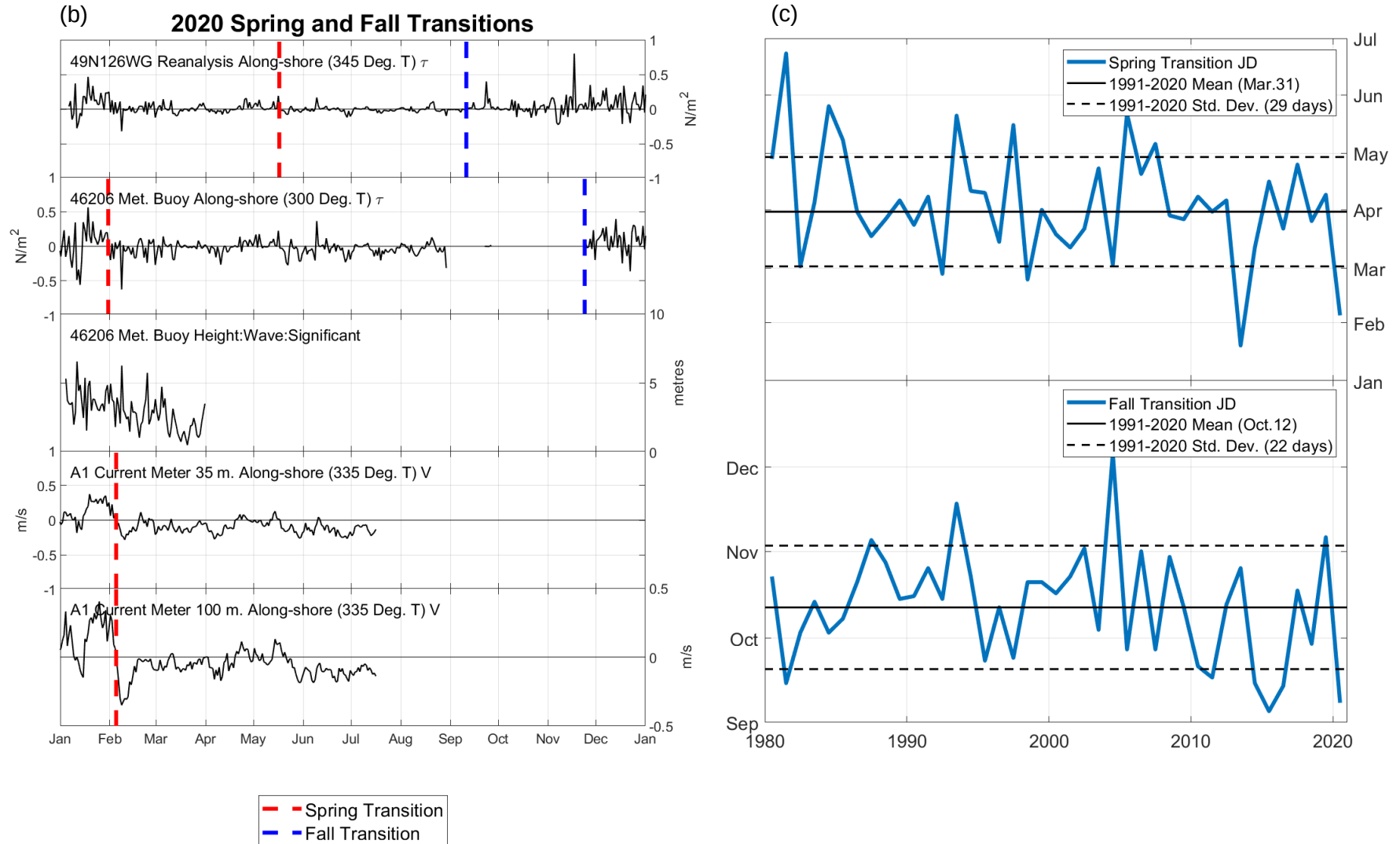


Figure 8-1. (b) Time series depicting the Spring and Fall Transitions off the west coast of Vancouver Island in 2020. Wind stress at Reanalysis-1 grid point 49N126W and meteorological buoy 46206; significant wave height at 46206; along-shore current velocity at 35 and 100 m depth at mooring A1 (Folkes et al. 2017; Thomson et al. 2013). Positive flow is poleward (downwelling-favourable) and negative flow is equatorward (upwelling-favourable). Vertical dashed lines show derived transition times using a cumulative sum approach (e.g. Foreman et al. 2011). (c) The annual Spring and Fall Transitions derived from time series in panel (b).

8.3. Status and trends

In 2020, the Spring Transition timing was very early compared to the 1991-2020 mean (Figure 8-1 and Figure 8-4), and the second earliest since 2013. There are not enough data to assess the 2020 Fall Transition with confidence. Since 2005 there appears to be a slight trend to an earlier spring transition. The same appears to be the case for the Fall Transition timing (from upwelling to downwelling conditions, also shown in Figure 8-1 and Figure 8-4), such that the upwelling season may be trending earlier, but not longer.

8.3.1. Upwelling Magnitude: The Upwelling Index

Because they drive offshore surface Ekman transport and compensating onshore transport at depth, the strength (duration and intensity) of upwelling-favourable (northwesterly) winds are considered indicators of coastal productivity (e.g., see Xu et al. 2019). To gauge low-frequency variability in coastal productivity, we have summed upwelling-favourable-only wind stresses by month along the west coast of North America from 45°-60° N latitude (Figure 8-2) using the NCEP/NCAR Reanalysis-1 analyses (Kistler et al. 2001) and subtracted the 1991-2020 mean to derive the Upwelling Index.

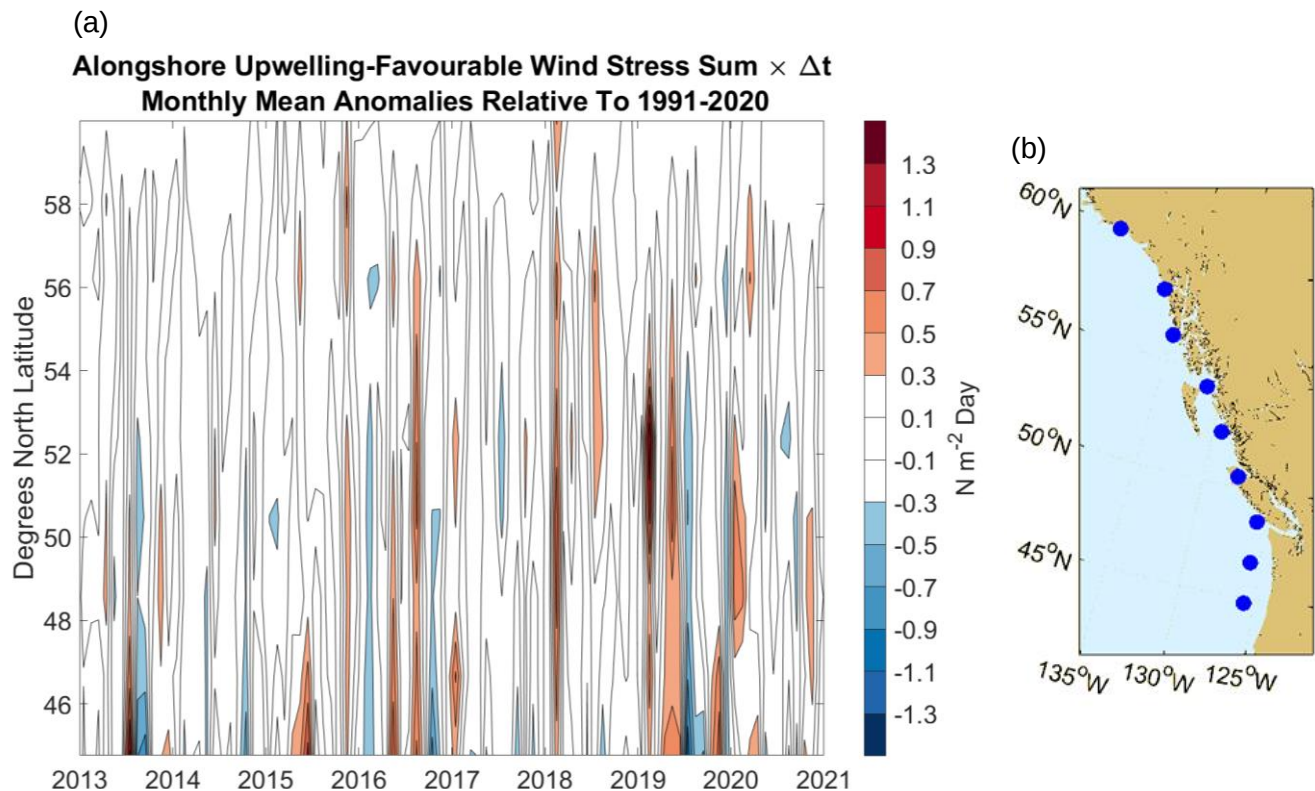


Figure 8-2. Recent (2013 to 2021) monthly mean anomalies (relative to 1991-2020) of monthly sums of alongshore upwelling-favourable (equatorward) wind stress (a) from the NCEP/NCAR Reanalysis-1 coastal surface wind stress grid locations, 45-60° N (b).

The Upwelling Index time series (Figure 8-2) indicates that upwelling-favourable wind stress was back to near average over the 45°-60° N latitude range in 2020 after a period of much higher variability in 2019. It marks a return to conditions similar to the 2013-2018 period over

which the upwelling index had been average or below average over the warm seasons. No recent trends in upwelling-favourable winds are evident in Figure 8-2.

8.3.2. Downwelling Magnitude: The Downwelling Index

Analogous to the Upwelling Index, the Downwelling Index is derived in the same way but by

Alongshore Downwelling-Favourable Wind Stress Sum $\times \Delta t$
Monthly Mean Anomalies Relative To 1991-2020

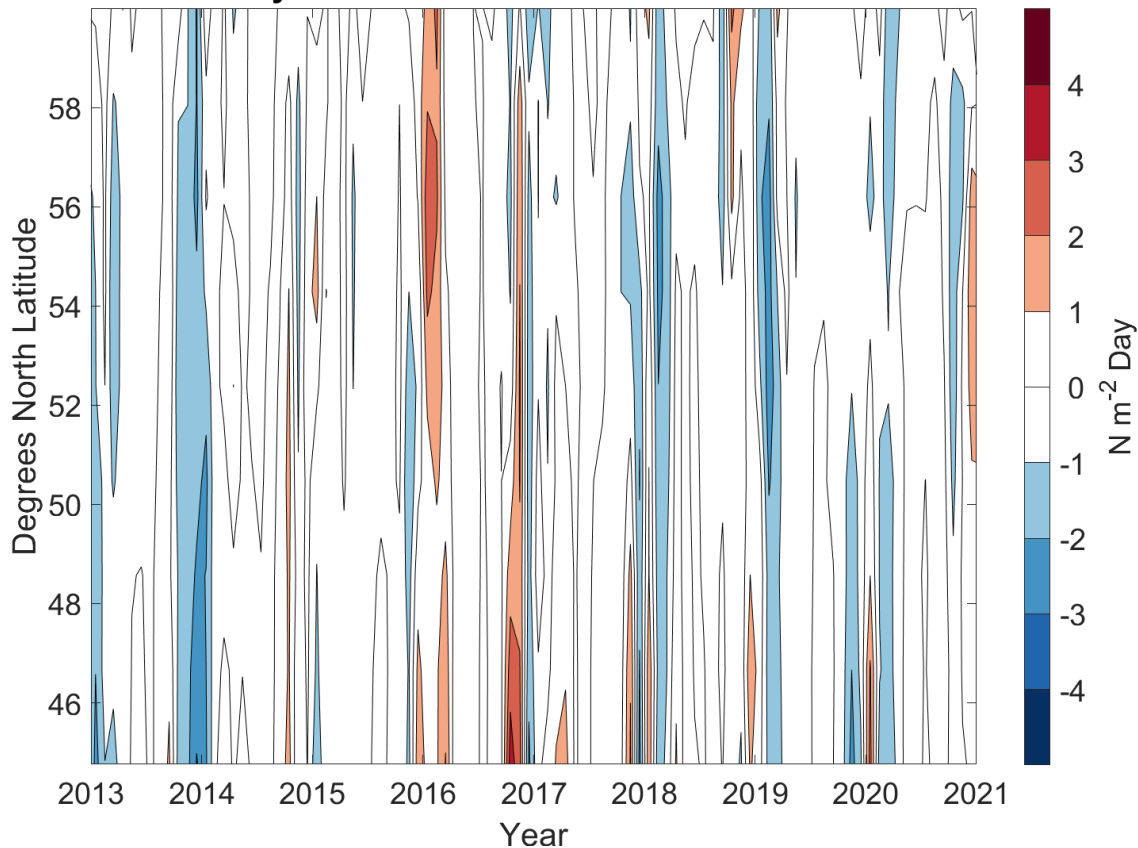


Figure 8-3. Recent (2013 to 2021) monthly mean anomalies (relative to 1991-2020) of monthly sums of alongshore downwelling-favourable (poleward) wind stress from the NCEP/NCAR Reanalysis-1 coastal surface wind stress grid locations, 45-60° N in Figure 8-2(b).

only considering poleward (downwelling-favourable) wind stress (Figure 8-3). Since this is typically stronger in winter as a result of storms tracking eastward across the North Pacific, this index can reflect the strength of storms hitting the B.C. coast, a shift of storm tracks closer or further away from the coast, a longer or shorter storm season, or some combination of all three. The index also reflects the strength/weakness of wintertime vertical mixing of the surface water column near the coast.

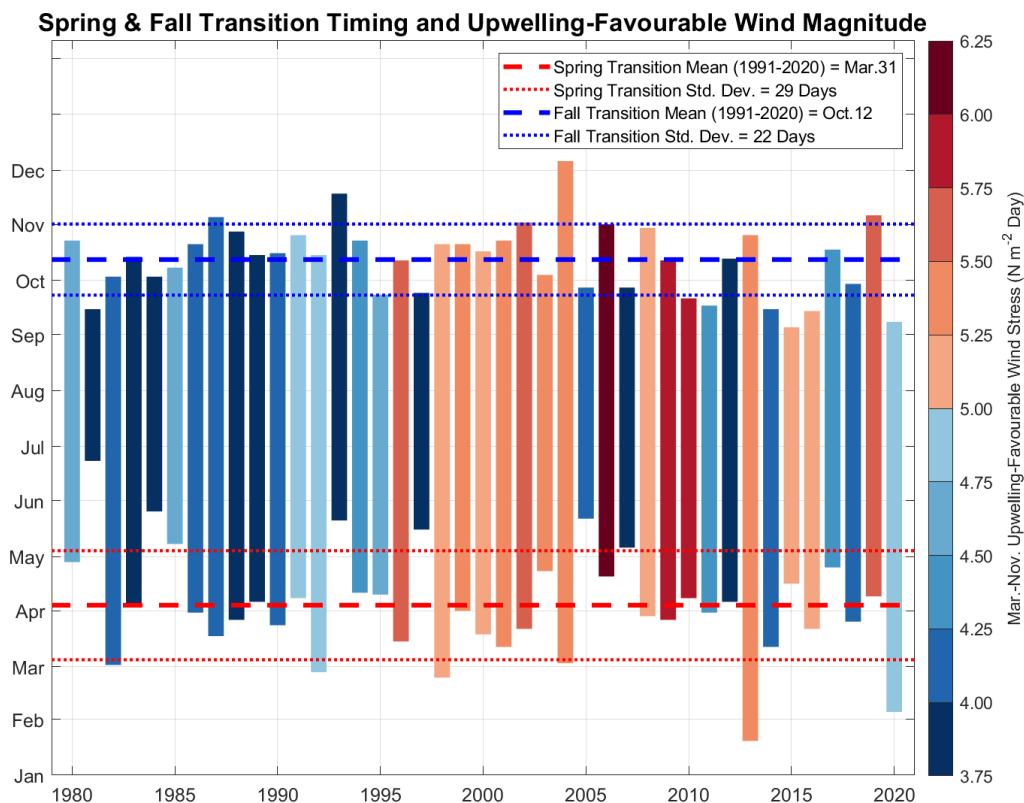


Figure 8-4. Annual Spring and Fall Transition Timing and March-November upwelling-favourable wind stress magnitude, 1980-2020.

Over the previous winters of 2017-2018, 2018-2019, and 2019-2020, the Downwelling Index was lower than average, like the winter of 2013-2014, but not quite as low. This indicates reduced wintertime surface mixing near the coast and is usually associated with higher surface temperatures the following summer, such as the marine heatwave conditions observed in 2014 and 2019.

8.4. Factors influencing trends

Why the Spring Transition Index may possibly be occurring earlier over the last 15 years is unknown. While the Upwelling and Downwelling indices were higher than average for ten years over the 2000-2010 period (indicating a period of consistently both stronger summertime and wintertime winds), the Downwelling Index has been lower than average for the last seven years north of 50° N, excluding 2015-2016. This indicates weaker winter storms, or a shorter winter storm season, or winter storms that are tracking further northwest away from the coast, or some combination of the three factors. The significantly weaker-than-average Downwelling Index in the winter of 2013-2014 was an accurate indicator of the weaker than average wintertime winds associated with the marine heatwave that year (Bond et al. 2015), and is likely also the case for 2019 and 2020.

8.5. Implications of those trends

The implications of the apparent recent trend toward an earlier Spring and Fall Transition Timing (Figure 8-1c and Figure 8-4) are unknown. Trends in the Upwelling Index are not readily

apparent. Recent years of a weaker than average Downwelling Index are associated with marine heat wave events.

8.6. Acknowledgements

NCEP/NCAR Reanalysis-1 wind stress provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their web site at <http://www.esrl.noaa.gov/psd/>.

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9. VANCOUVER ISLAND WEST COAST SHELF BREAK CURRENTS, TEMPERATURES, AND WIND STRESS

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9.1. Highlights

- Sea surface temperatures were near average throughout most of 2020 at weather buoy 46206 on the west coast of Vancouver Island, but were significantly below average in October-November. No subsurface temperature data were available from the nearby mooring A1 due to instrument problems and mooring reconfiguration (Figure 9-2).
- Alongshore flow at mooring A1 in 2020 was anomalously and strongly equatorward (upwelling-favourable) in February and March for the third year in a row.
- In 2020, west coast shelf-break wind stress and surface and subsurface currents were below-average in magnitude (stronger equatorward and/or weaker poleward) when compared to the stronger than average poleward and equatorward flow associated with the 2014-2016 El Niño and marine heatwaves. Temperatures that were higher than average throughout the water column over 2014-2016, returned to near-average near the surface and above-average at depth over the following few years.

9.2. Description of the time series

Subsurface temperature and current velocities at the shelf break have been observed at mooring A1, water depth ~500 m (Figure 9-1) since 1985. Nearby meteorological buoy 46206 has provided sea surface temperature at 80 cm depth and wind velocity time series at 5 m height since 1988. We have combined these series to obtain the vertical structure of temperature and flow through the water column.

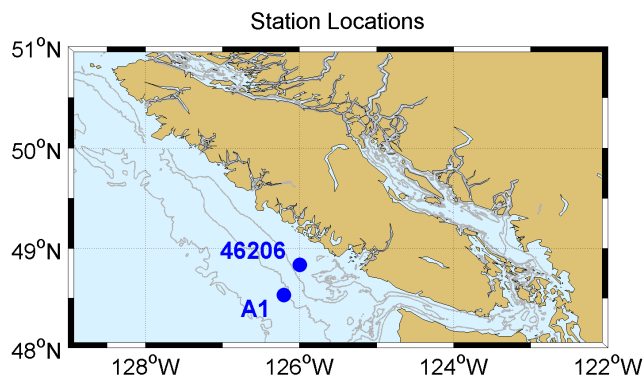


Figure 9-1. Locations of mooring A1 and meteorological buoy 46206.

9.3. Status and trends

In 2020, temperatures at the surface were near average throughout most of the year except in Oct.-Nov. when they were significantly below average (Figure 9-2, left). There were no temperature data at subsurface depths due to instrument losses in the first half of the year and no instruments deployed in the second half. Surface temperatures did not indicate marine heatwave conditions.

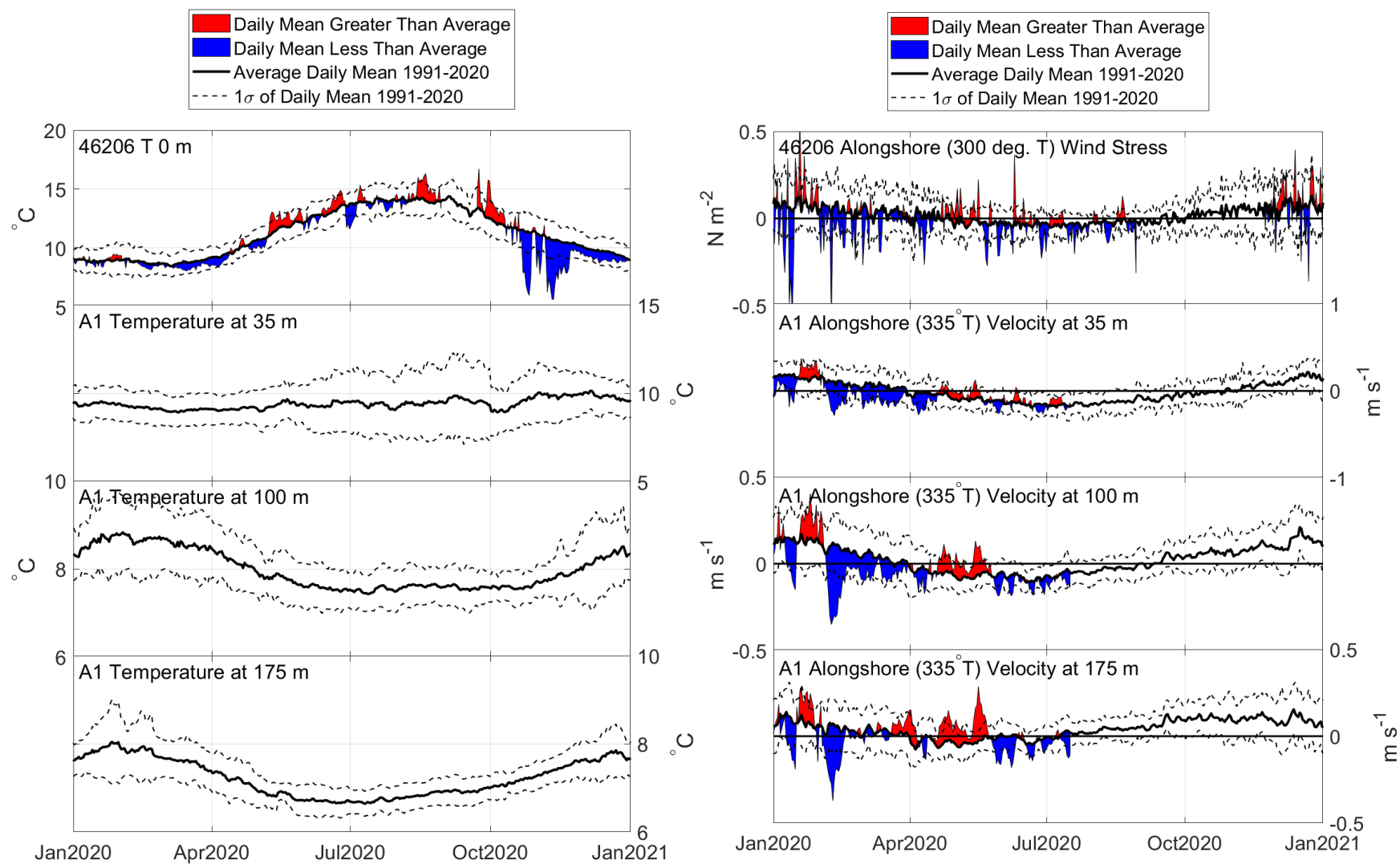


Figure 9-2. Daily means. Temperature (left panels) and alongshore wind stress/ocean current (right panels) at the surface, 35 m, 100 m, and 175 m depth from meteorological buoy 46206 and mooring A1. Angle in brackets ($^{\circ}\text{T}$) is the principal direction of the wind or current vector in degrees true compass bearing.

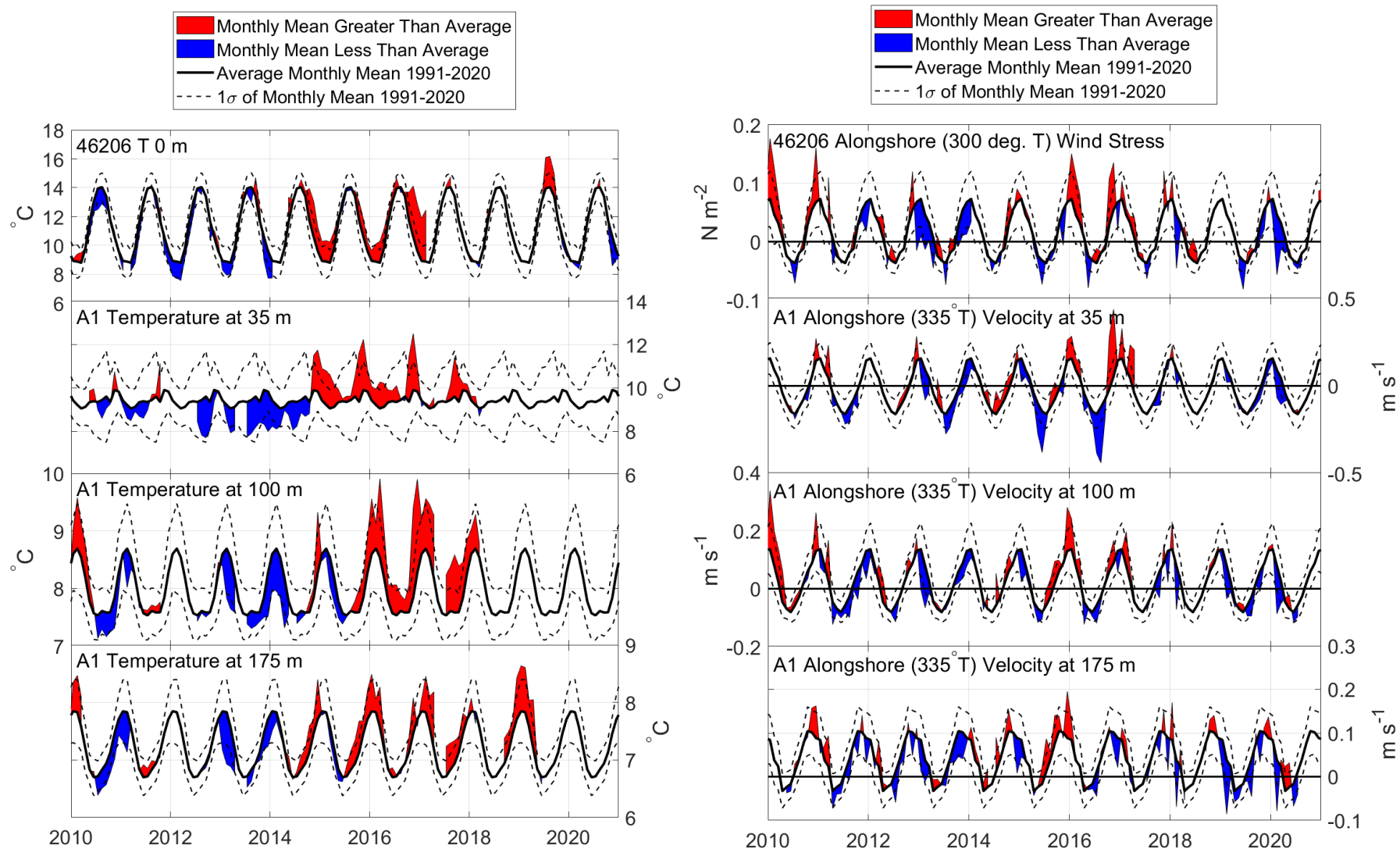


Figure 9-3. Monthly means. Temperature (left panels) and alongshore wind stress/ocean current (right panels) at the surface, 35 m, 100 m, and 175 m depth from meteorological buoy 46206 and mooring A1. Angle in brackets (°T) is the principal direction of the wind or current vector in degrees true compass bearing.

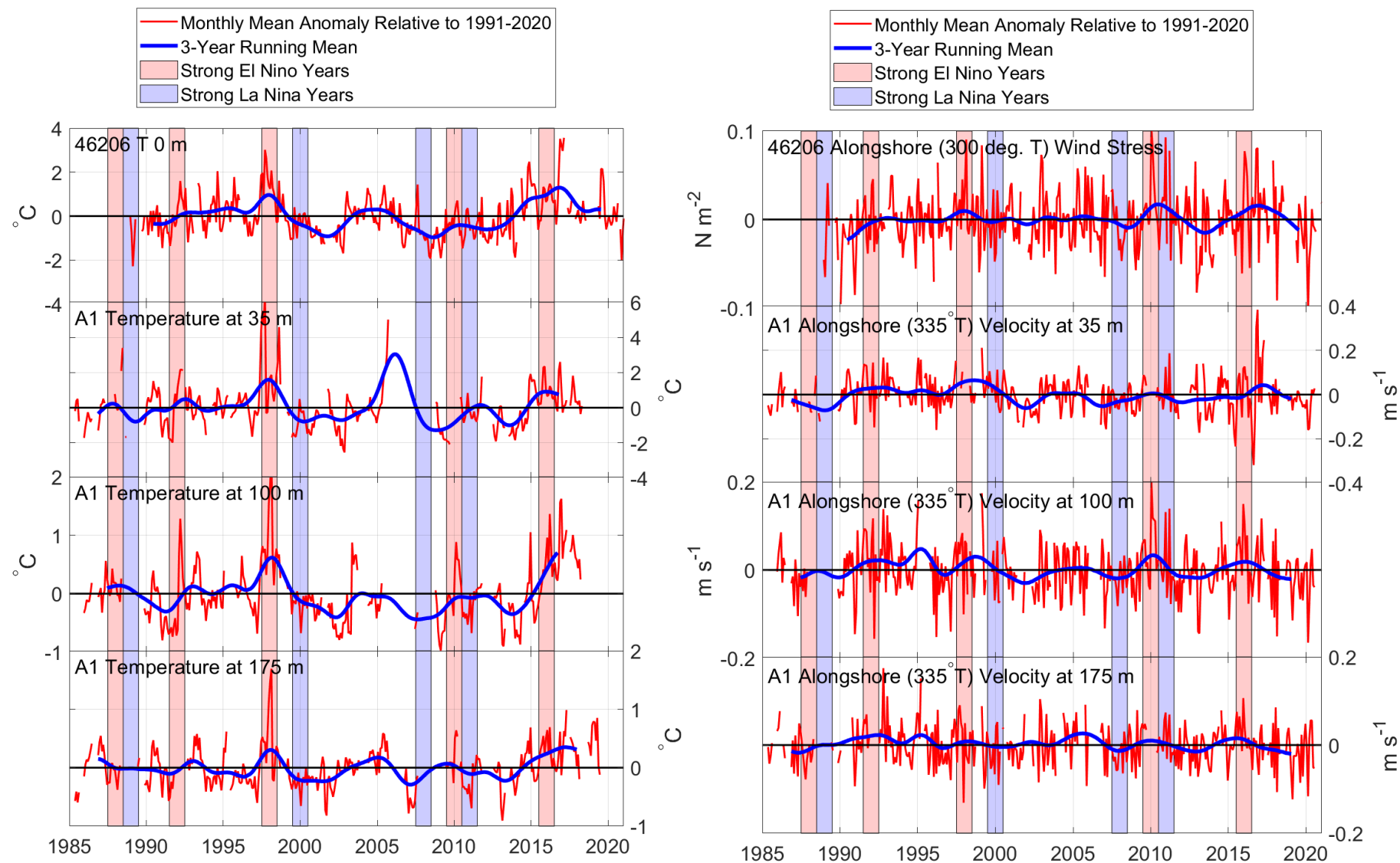


Figure 9-4. Monthly anomalies. Temperature (left panels) and alongshore wind stress/ocean current (right panels) at the surface, 35 m, 100 m, and 175 m depth from meteorological buoy 46206 and mooring A1. Angle in brackets (°T) is the principal direction of the wind or current vector in degrees true compass bearing.

Alongshore surface winds and currents were generally near 1991-2020 average conditions (Figure 9-2, right). However, flow was consistently and anomalously strongly equatorward (upwelling-favourable) in February-March. There are no subsurface data after July as that mooring deployment will be recovered in summer, 2021.

Positive temperature anomalies were associated with the marine heatwave and El Niño during 2014-2016 (Figure 9-3). The positive temperature anomalies reappeared in 2019 at the surface and continued at 175 m depth but there were no data at other depths. For alongshore flow, strong anomalies occurred in 2013 (weak poleward flow in winter preceding the marine heatwave), and enhanced equatorward flow in the summers of 2015 and 2016, and also enhanced poleward flow over the winters of 2015-2016 and 2016-2017. These features are likely due to stronger large-scale surface atmospheric circulation features (Aleutian Low and North Pacific High) associated with El Niño. The stronger poleward flow may also have been due to an eastward shift of winter storm tracks toward the coast. For the third year in a row, in 2020 there was anomalous strong equatorward (upwelling-favourable) flow in February.

Higher temperatures and enhanced poleward flow were also observed during the previous strong El Niño in 1997-1998 (Figure 9-4). While flow now appears to be more equatorward (or weaker poleward) than average, a lack of recent observed temperature anomalies prevents their assessment.

There do not appear to be trends in surface and subsurface temperatures and currents on the shelf/shelf break on the west coast of Vancouver Island over 1985-2020.

9.4. Factors influencing trends

Although long-term trends do not appear evident, the strong El Niño of 2015-16 and recent years of increased occurrences of marine heatwaves are reflected in higher than average ocean temperatures at the surface and at depth. Weaker than average poleward flow in winter is also associated with marine heatwaves (weaker storm activity and/or storm activity shifted westward). Strong El Niños like that of 2015-2016 are associated with enhanced poleward flow in winter which was evident over the 2015-2016 winter.

9.5. Implications of those trends

Recent El Niño and marine heatwave events were associated with significant departures from average ocean surface and subsurface temperatures and currents. However, conditions returned to average a year or two after these events, and the most recent observations indicate conditions are near average, with no trend apparent. If these events increase in frequency in the future, they could influence long-term trends.

10. SEA SURFACE TEMPERATURE AND SALINITY OBSERVED AT SHORE STATIONS AND WEATHER BUOYS ALONG THE B.C. COAST IN 2020

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10.1. Highlights

- The average annual sea surface temperature (SST) from 10 of the contributing shore stations in 2020 (10.42 °C) was generally cooler than in 2019 with a coast-wide average annual decrease in SST of 0.23 °C.
- Anomalies from the long-term average (1935-2020) shore station SST record show periodic warm and cold periods with durations of several years; 2020 was a continuation of a warm period starting in 2014. This span of above normal annual SST is the longest warm period on record.
- Seven of the 12 coastal weather buoys provided sufficient data in 2020 for statistical analysis. The average annual SST from the seven coastal wave buoys in 2020 (10.76 °C) was cooler than in 2019 with a coast-wide average annual decrease in SST of 0.27 °C.
- The long-term data from the shore stations show a linear trend to warmer coastal SSTs of 0.88 °C over 100 years.
- Annual salinity observations showed a decrease at nine of 12 shore stations with an average coast wide decrease of 0.60 (standard deviation of 0.53).

10.2. Description of the time series

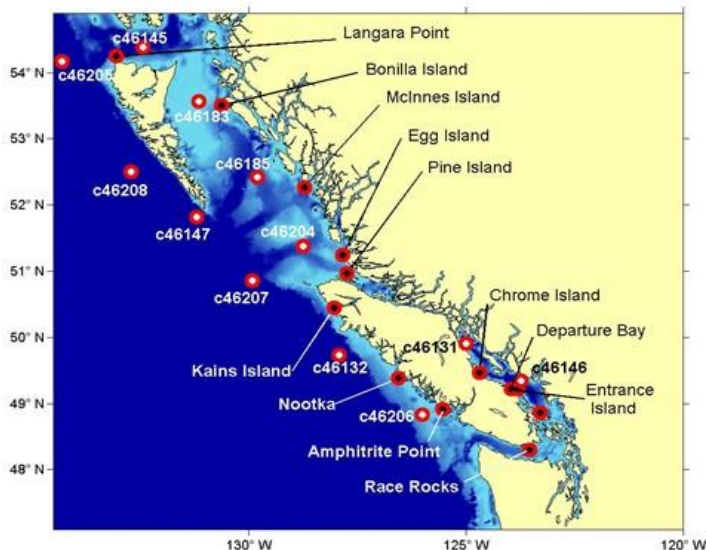


Figure 10-1. Red dots with black centers show the locations of 12 shore stations. Red dots with white centers show the locations of 12 weather buoys in the Canadian weather buoy network. See table below for details.

Station	Years of data	Buoy ID	Buoy Location	Years of data
Departure Bay	106	c46146	Halibut Bank	28
Race Rocks	98	c46131	Sentry Shoal	28
Nootka	53	c46206	Laperouse	31
Amphitrite	86	c46132	South Brooks	26
Kains	85	c46207	East Dellwood	31
Langara	84	c46147	South Moresby	27
Entrance	84	c46208	West Moresby	29
Pine Island	83	c46205	West Dixon	32
McInnes	66	c46145	Central Dixon	29
Bonilla	60	c46204	West Sea Otter	31
Chrome	59	c46185	South Hecate	29
Egg Island	50	c46183	North Hecate	29

Two sources of data are used to describe changes in sea surface conditions in the coastal waters of B.C. in 2020. As part of the British Columbia Shore Station Oceanographic Program, SST and salinity are measured daily at 12 shore stations, at the first daylight high tide. Most stations are at lighthouses (Figure 10-1), with observations taken by lighthouse keepers using a

handheld electronic instrument (YSI Pro 30). The buoy data are provided by Environment and Climate Change Canada from a network of Offshore Data Acquisition System (ODAS) buoys that collect data hourly.

10.3. Status and trends

The shore station observations show that the annual average daily SST (Figure 10-2, upper panel) at all stations was generally cooler in 2020 than in 2019 (mean decrease of 0.23 °C at ten stations with sufficient data for statistical analysis). The ODAS buoys data show an annual average decrease in daily SST from 2019 to 2020 of 0.27 °C (excluding stations with high uncertainty due to missing data or sensor accuracy). The coast wide SST in 2020 remained consistently lower than conditions in 2015 during the marine heat wave known as “the Blob”. By convention the mean value, or normal, is determined by averaging over the most recent 30-year period finishing in a year ending with 0 (e.g. previously 1981–2010 now 1991–2020). The previous and current normals for each station are included in Figure 10-2 and show the temperature normals increasing coast wide by 0.9 °C (from 10.35 to 10.44 °C).

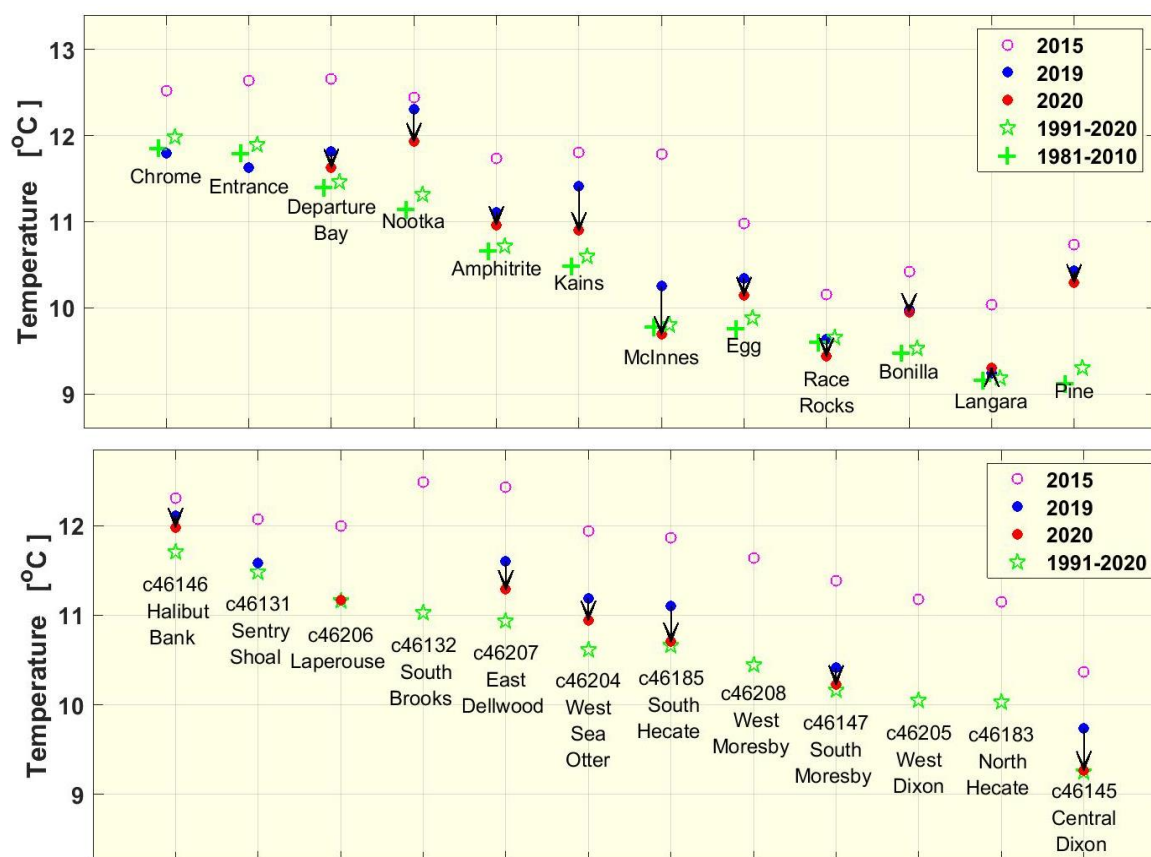


Figure 10-2. Upper panel: The average SST in 2019 (dark blue dots), and 2020 (red dots) from daily observations at shore stations along the west coast of Canada. The stars represent the new climatological mean annual temperature. Lower panel: The average SST from hourly observations at weather buoys along the west coast of Canada. The open circles show conditions in 2015 when SST was significantly higher than normal.

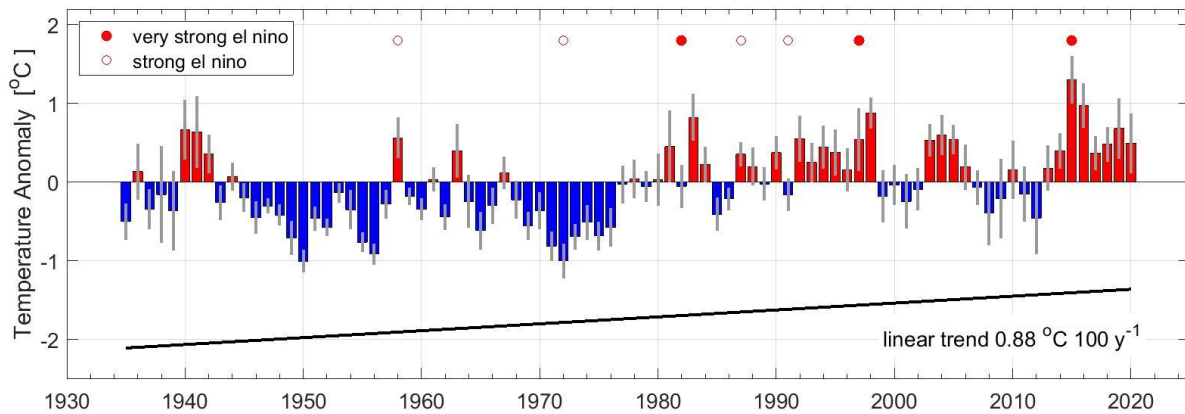


Figure 10-3. The trend in the annual temperature based on the observations of all lighthouses. The data shown are the anomalies from the long-term average temperature (1935-2020). The bars represent the anomalies averaged over all stations (a coast wide indicator), (red – above average, blue – below average), the vertical grey lines show the variability in the lighthouse data for each year.

Assuming a linear change over the entire data record, the time series of temperature at all of the shore stations show a warming trend at a 95% confidence level. Figure 10-3 shows a coast wide warming trend (using data from all shore stations) as 0.88°C over 100 years.

Figure 10-4 shows sea surface freshening at representative stations for each of three regions (North Coast, West Coast Vancouver Island, and the Strait of Georgia). A linear trend analysis applied to the salinity shows a continuing long-term trend toward less saline conditions.

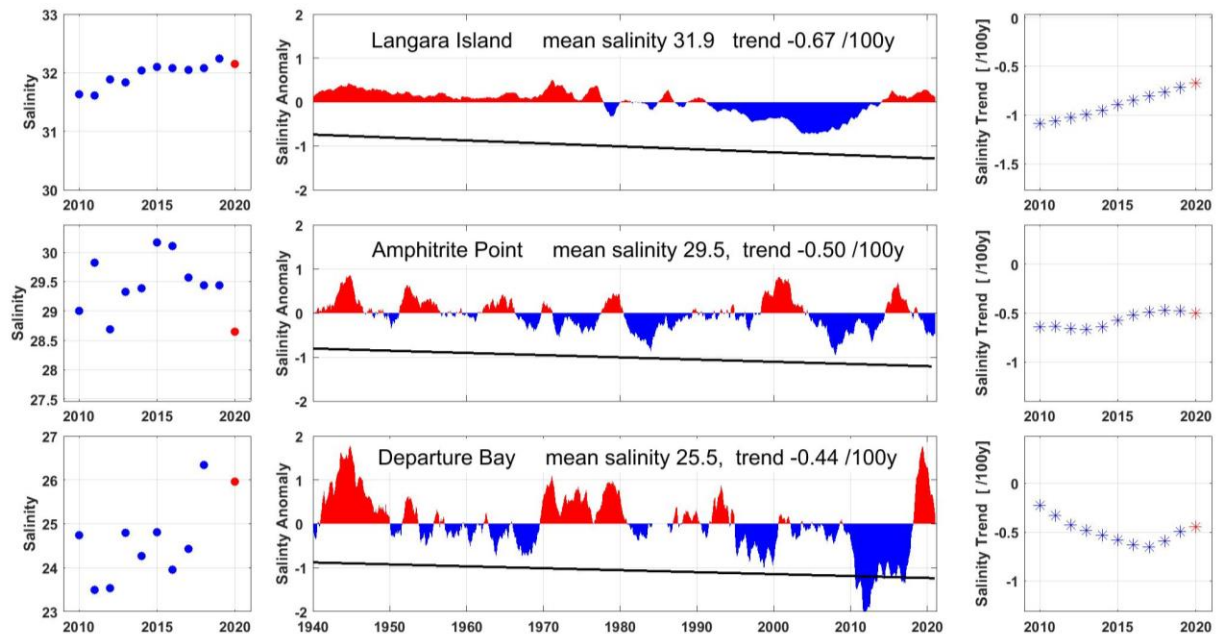


Figure 10-4. Time series of daily salinity observations, averaged over 12 months, at stations representing the North Coast, West Coast of Vancouver Island and Strait of Georgia. Positive anomalies from the average salinity of the entire record are shown in red, negative in blue. The left panel shows the annual mean salinity for the year shown on the x-axis. The right panel shows the slope of the trend lines calculated using only data up to the year shown on the x-axis.

10.4. Factors influencing trends

Ocean temperature is an important environmental indicator because it influences physical processes such as circulation and mixing, chemical process such as deoxygenation, and the condition and behaviour of species that live in the ocean. Sea surface temperature (SST) is an effective indicator of long-term change because direct observations have been made for many decades and, with satellite sensors, autonomous monitoring platforms and other technical advances, the amount of data included in SST analyses continues to expand.

Although SSTs were warmer during the marine heatwave of 2014-16, the conditions in 2020 continue the period of warmer than normal water (where normal is defined as the average on the long-term SST record starting in 1935). This warm water period has lasted for eight years, the longest span of above normal temperature in the time series. While the record shows multi-year oscillations in the annual SST there remains a long-term trend towards rising ocean temperatures.

The long-term salinity observations show a trend to less saline conditions at most stations along the B.C. Coast. Variability in the salinity signal along the Pacific coast is governed by a combination of the integrated effects of atmospheric forcing and coastal precipitations; the Strait of Georgia is strongly influenced by the discharge from the Fraser River (Cummins and Masson 2014).

10.5. Implications of those trends

There is growing interest in determining the predictability of the physical processes of the North Pacific Ocean, including associated biological responses, on time scales of months to years. The models that are being used for this are similar to those used for climate change studies. The process of developing, evaluating, and improving forecast systems can provide important insights into the key processes controlling physical, chemical, and biological ocean properties. It remains an open question the extent to which the ecosystem responses to slow warming will resemble those that were associated with the recent marine heatwaves. The impacts of these changes will depend on the time and space scales relevant to organisms of interest and are described for various trophic levels in B.C. waters in Peña and Nemcek (Section 16), Galbraith (Section 18), and Neville (Section 40).

10.6. References

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11. SEA LEVEL IN BRITISH COLUMBIA, 1910 TO 2020

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11.1. Highlights

- The annual mean water levels at Victoria, Tofino and Prince Rupert for 2020 were below the long-term trend line.
- Removing the vertical tectonic uplift changes the long-term trend at the three locations.

11.2. Summary

The Canadian Hydrographic Service monitors sea levels along the B.C. coast. The annual deviations from the long-term average are shown in Figure 11-1 for Victoria, Tofino and Prince Rupert. Both Tofino and Victoria have records that began in 1910, while the record at Prince Rupert began in 1912.

A linear trend line was fitted to the data for each location. In 2020, the average sea level for all three stations was below the 1910-2020 trend line.

The linear sea level rise trend relative to the land at each location (in cm/century):

Prince Rupert	+10.7
Victoria	+6.9
Tofino	-12.2

Tectonic motion is lifting the land at Tofino faster than sea level is rising, such that local sea level (measured relative to the land) is dropping at an average rate of 12 cm per 100 years. Removing the tectonic motion from the sea level values using an average from the years 1994-2017 of 1.9 mm annual uplift (Thomas James, Geological Survey of Canada, pers. comm. 2018) applied to the years 1910-2020 results in a linear trend at Tofino of 6.8 cm per 100 years (Figure 11-2).

The land is also rising at Victoria and Prince Rupert although not at the same rate as at Tofino. When this movement is removed at Victoria the linear trend becomes 12.6 cm per 100 years and at Prince Rupert the linear trend becomes 15.7 cm per 100 years (Figure 11-2).

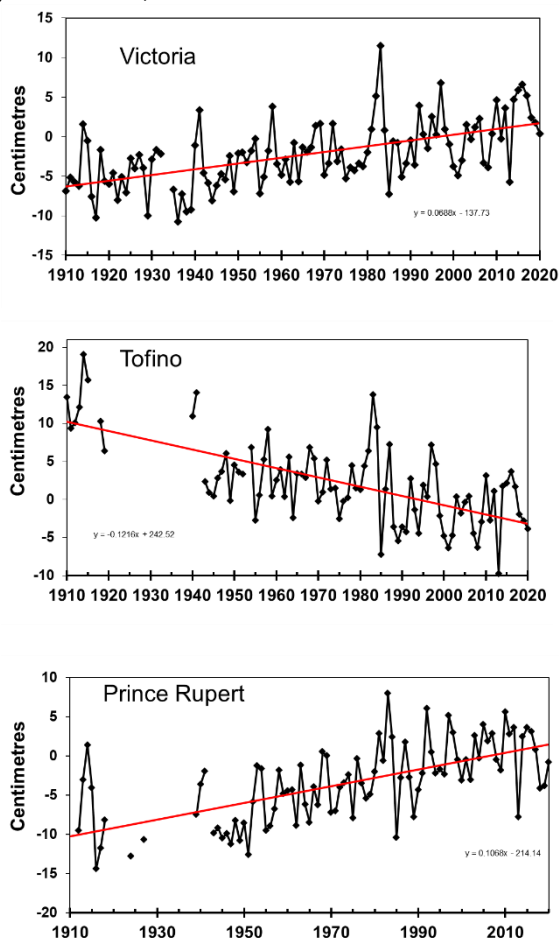


Figure 11-1. Annual-average sea level anomalies at three British Columbia ports. Reference years for anomaly calculation are 1981 to 2010. Average linear trends are plotted as red lines.

The linear sea level rise trend at each port corrected for vertical land movement (in cm/century):

Prince Rupert	+15.7
Victoria	+12.6
Tofino	+6.8

Global sea levels rose by 17 ± 5 cm in the 20th century (Church and White 2011). The Intergovernmental Panel on Climate Change (IPCC 2014) predicts sea level to rise from 26 to 55 cm to 45 to 82 cm toward the end of the 21st century, depending on levels of mitigation of CO₂ emissions, but recent observations of ice melt in Greenland and Antarctica suggest these projections might be too low. Therefore, we can expect to observe greater rates of sea level rise in British Columbia in the future.

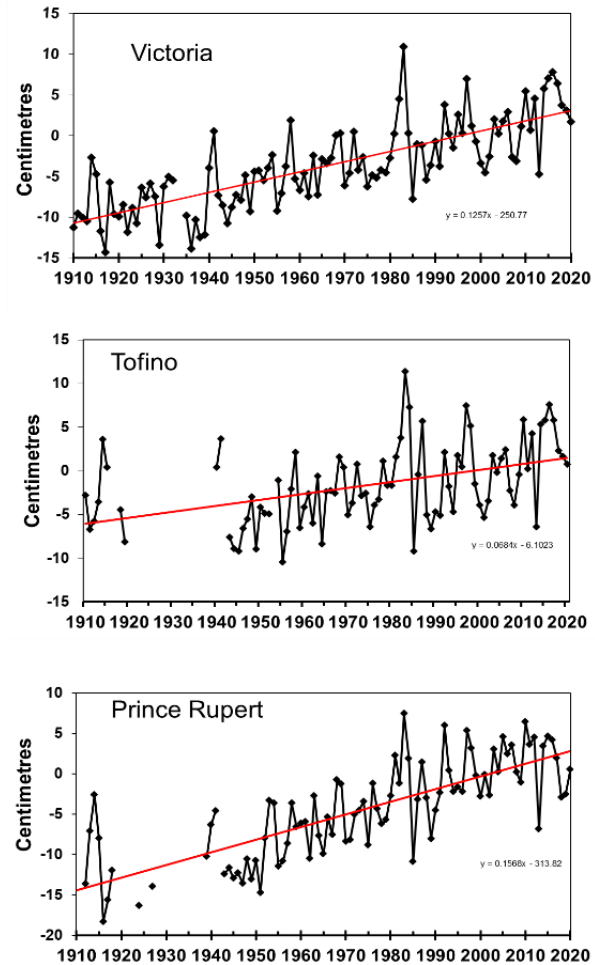


Figure 11-2. Annual-average sea level anomalies at three British Columbia ports with vertical land movement removed. Reference years are 1981 to 2010. With vertical land movement removed.

11.3. References

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12. OXYGEN IN SUBSURFACE WATERS ON THE B.C. SHELF

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12.1. Highlights

- The concentration of dissolved oxygen (O_2) continued to decline at Ocean Station P where it has been monitored for 65 years. Little overall change has been observed at Station P4 on the continental slope, due to increasing O_2 since 2010. However, there are large decadal changes.
- In late summer, O_2 in subsurface waters on the continental shelf off southwest Vancouver Island was generally low. Observations in 2020 showed normal low levels, in contrast to very low O_2 from 2017-2019.
- Lower O_2 in subsurface water on the continental shelf in the past 30 years is generally associated with denser, saltier water that flows from the south. However, the sudden decline in O_2 observed in early 1990s was associated with fresher water.

12.2. O_2 on the continental shelf

Historical near-bottom O_2 observations made in the summer reveal locations where hypoxia was observed (Figure 12-1). Hypoxia is defined as O_2 less than 1.4 ml/L or 60 $\mu\text{mol/kg}$. Many observations in inlets were hypoxic, where deep seawater is normally hypoxic due to low rates of water inflow from outside regions.

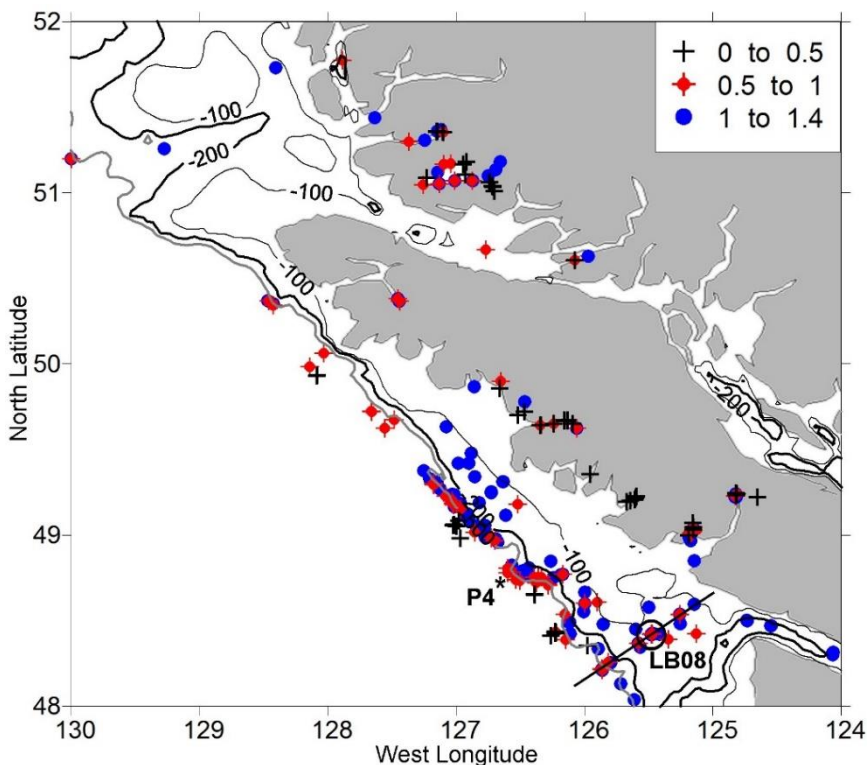


Figure 12-1. Oxygen concentration (O_2 , ml/L) in the summer within 20 m of the ocean bottom for regions of the continental shelf and slope where bottom depth is less than 1000 m. (1 ml/L = 43.5 $\mu\text{mol/kg}$). Each symbol represents a measurement by DFO research programs. Only observations with O_2 less than 1.4 ml/L (60 $\mu\text{mol/kg}$) are plotted. The symbol $\bullet$ denotes the location of Station LB08, where O_2 has been monitored since 1979. LB Line is indicated by a black line through LB08. The location of station P4 along Line P is shown by the symbol *. Figure is based on Crawford and Peña (2013).

Lower levels of O_2 are found in deeper water on the continental shelf and slope because O_2 decreases with increasing depth and increasing

water density. The lowest O_2 observed on the shelf in the summer is off southwest Vancouver Island along sampling Line LB, largely due to stronger upwelling of deeper water and increased respiration of decaying organic matter. DFO has monitored oxygen concentration off SW Vancouver Island since 1979. Decreasing O_2 in subsurface waters is normally accompanied by increasing acidity. Both trends are of great concern to marine life.

O_2 is usually lowest between mid-August and early October (days 230 to 280; Figure 12-2). There is a general decrease in late summer with higher O_2 from 1979 - 2005 to lower O_2 from 2006 - 2019, excluding 2015. Concentrations from 2017-2019 (blue squares) were near record lows. However, O_2 in 2020 (black triangle) was close to average for this season. The high O_2 in late summer 2015 is attributed to “the Blob”, a mass of fresher water, rich in O_2 , as described in previous State of the Ocean Reports.

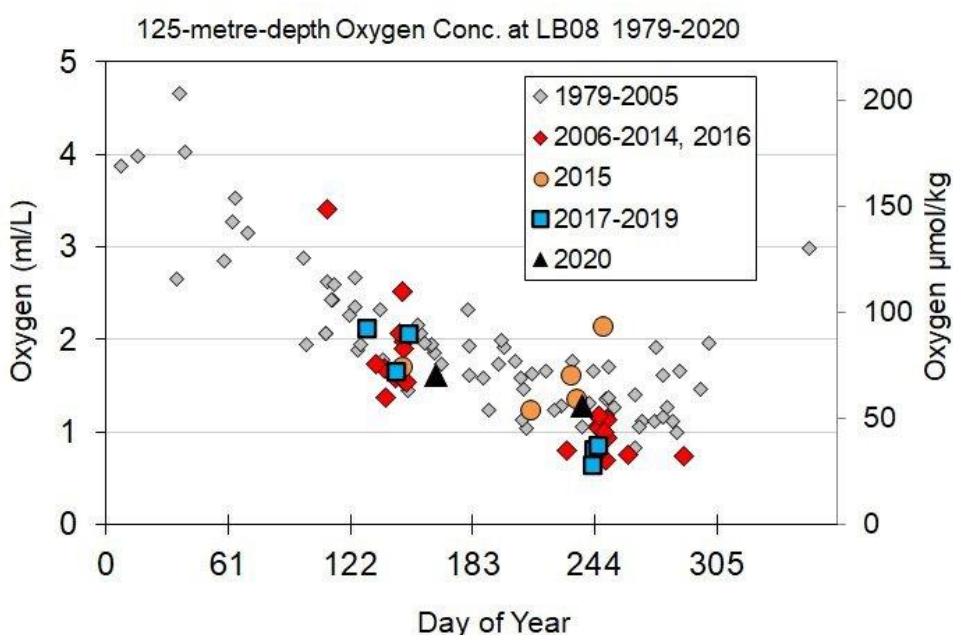


Figure 12-2. Oxygen concentration (O_2) at 125 m below the ocean surface at Station LB08. Symbols represent observations plotted on the day of the year the sample was collected. Day 244 is 1 Sept. The depth of ocean bottom here is 145 m. Figure is based on Crawford and Peña (2013).

Variations in O_2 at LB08 in late summer since 1991 tends to be observed in denser, saltier water, possibly due to an increase in northward flow of saltier Pacific Equatorial water along the continental slope. Highest O_2 is usually found in fresher water that flows from the west. Therefore, some of the interannual variability is due to different blends of these two water types. However, observations prior to 1991 reveal saltier and denser waters, with high O_2 concentration, indicating there was a change in O_2 within these two water types in the early 1990s.

O_2 in late summer 2019 was the lowest ever measured at 125 m depth at LB08 (Figure 12-3). Figure 12-3b shows higher O_2 below 100 m in 2020 than observed at this depth in 2019. These 2020 O_2 concentrations are close to the long-term average for this time of year. O_2 in subsurface waters off central and northern Vancouver Island were also close to average in August 2020.

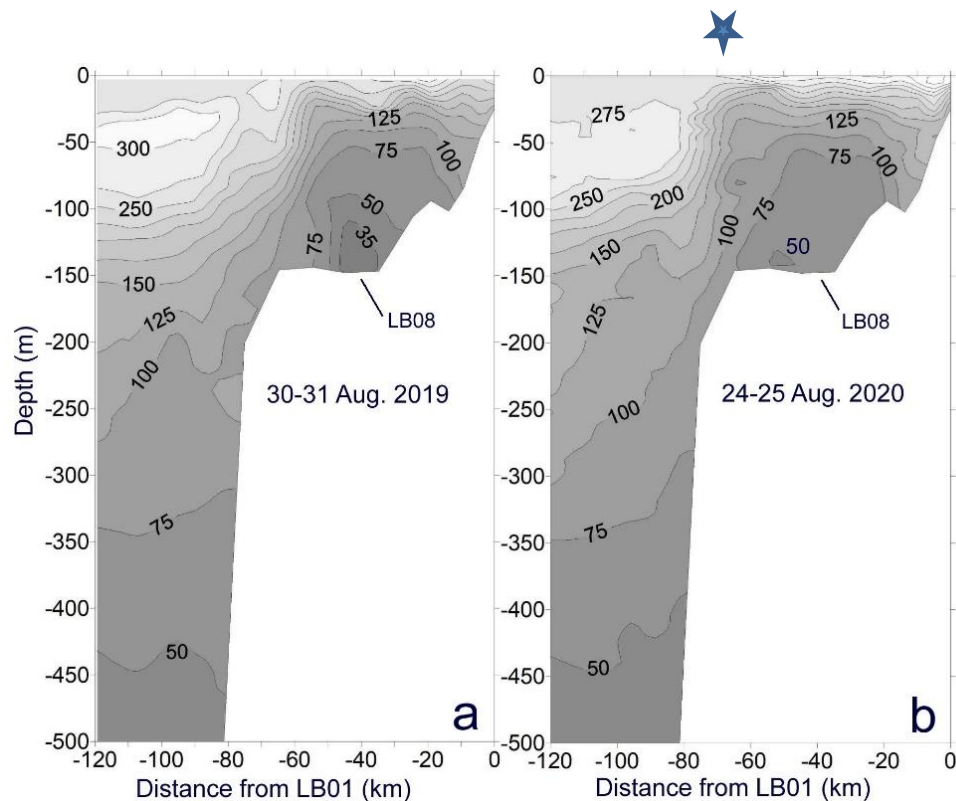


Figure 12-3. Oxygen concentration ($\mu\text{mol/kg}$) on the continental shelf and slope along LB Line of DFO sampling stations off southwest Vancouver Island. Contours show concentration for (a) August 2019 and (b) August 2020. See Figure 12-1 for location of LB Line.

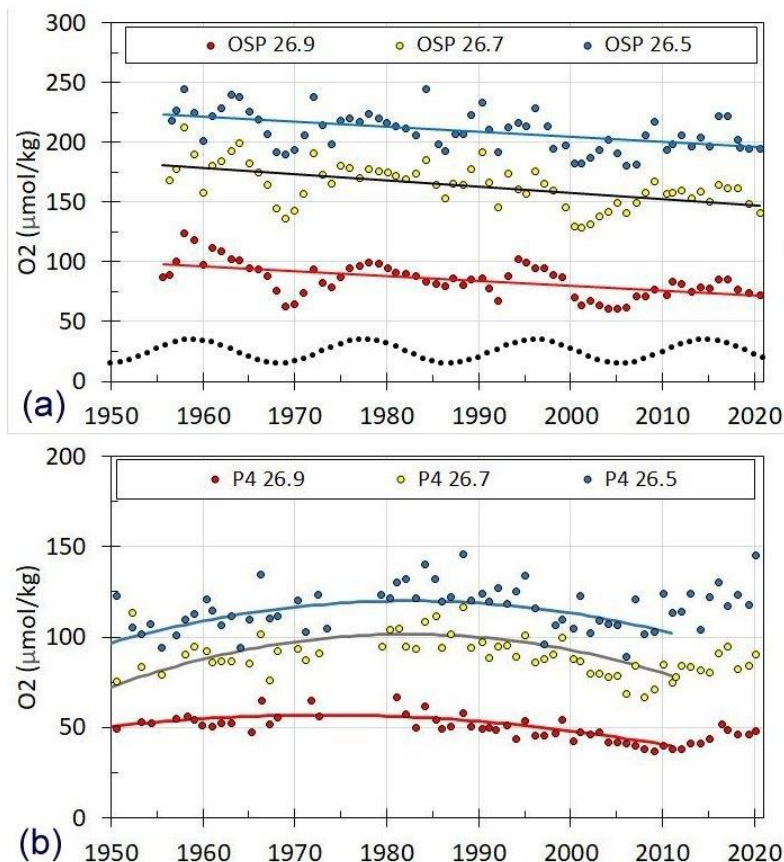
12.3. Oxygen concentration in continental slope and offshore waters

There are few stations in the continental slope and offshore waters with regular sampling before 1980. To evaluate trends prior to 1980, we composited observations in areas around each of the intensive sampling stations along Line P and included all observations in the archives. Details of this process and results up to 2011 are described by Crawford and Peña (2016). We present updates for Ocean Station P26 (OSP) and for Station P4 in Figure 12-4 below. OSP lies about 1400 km seaward along Line P in 4300 m of water. P4 is on the continental slope in 1300 m of water (Figure 12-1).

Seaward of the continental shelf, the dynamic height of subsurface waters moves up and down with the seasons and in some cases with changes in local winds, creating a noisy record of O_2 at constant depth. To suppress this noise, we calculate O_2 on constant-density surfaces rather than at constant depth (Figure 12-4).

There is a general decrease in O_2 at OSP since 1956 (Figure 12-4a), modulated by an oscillation that fits the 18.6-year lunar nodal cycle (black dotted line); a feature first noted by Whitney et al. (2007). O_2 at constant depths have also decreased in this period (Cummins and Ross 2020).

O_2 at P4 peaked in about 1980 with lower concentrations in the 1950s and 2000s, as defined by the solid curves for 26.5, 26.7 and 26.9 density surfaces (Figure 12-4b). O_2 at P4 has increased



since 2012, but concentrations were still below the peak in the 1980s for the 26.7 and 26.9 surfaces. There is little trend in these three series, but large decadal variability.

Figure 12-4. Annual average oxygen concentration (O_2) at (a) Ocean Station P (OSP) in offshore region, and (b) Station P4 on the continental slope. O_2 has been interpolated onto the constant-density surfaces 26.5, 26.7, and 26.9, representing potential densities of 1026.5 to 1026.9 kg/m^3 . Typical depths of these density surfaces are 130 (+10), 170 (-10) and 300 (-40) m at OSP, and 180 (-20), 280 (-25) and 490 (0) m at P4. Numbers in parentheses show trends in depth of these density surfaces over the full length of each series, with the sign denoting shoaling (+) or deepening (-). O_2 trends at OSP are $-0.4 \mu mol kg^{-1} y^{-1}$ on the 26.5 and 26.9 surfaces, and $-0.5 \mu mol kg^{-1} y^{-1}$ on the 26.7 surface. Figure is based on Crawford and Peña (2016) and Whitney et al. (2007).

12.4. References

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12.5. Acknowledgements

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13. SURFACE CURRENT ALONG THE SHELF EDGE AND CONTINENTAL SLOPE OFF THE BRITISH COLUMBIA COAST

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13.1. Highlights

- In 2020 the summer/fall equatorward surface current at a West Vancouver Island transect was stronger than normal and the year-round poleward surface current at a Queen Charlotte Sound transect was weaker than normal.

13.2. Description of the time series

Geostrophic surface currents were calculated at two transects (Figure 13-1), using 10-day interval along-track satellite altimetry sea surface height data from October 1992 to December 2020 and following the method outlined in Han et al. (2014). One transect is located on the west coast of Vancouver Island (WCVI). The other is located at the mouth of Queen Charlotte Sound (QCS). The geostrophic surface currents are in the direction normal to the transect (positive poleward) and represent approximately the along-shelf flow. The calculated geostrophic surface currents are further averaged both seasonally and over-transect. At the WCVI transect (Figure 13-2, upper panel), the winter surface current is poleward and the summer surface current is equatorward, with the long-term mean surface current close to zero. At the Queen Charlotte Sound transect (Figure 13-2, lower panel), the surface current is poleward year-round, stronger in winter and weaker in summer.

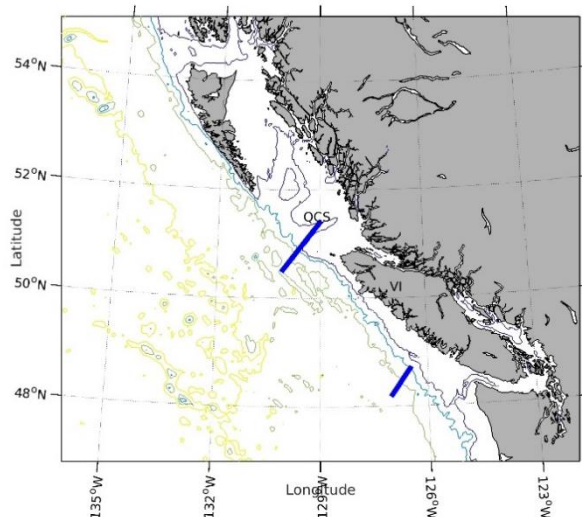


Figure 13-1. The study area showing the location of two transects and bathymetry (200-, 1000-, 2000- and 3000-m isobaths).

13.3. Status and trends

There are no apparent long-term trends in the geostrophic surface currents at either transect over 1992-2020. Interannual variations are evident; for example, stronger equatorward surface current in the summer of 2015 and 2016, and stronger poleward surface current in the fall of 2015-2016 and 2016-2017 (Hourston and Thomson 2020). In both the summer and fall of 2020, the equatorward surface current at the WCVI transect was stronger than normal and the poleward surface current at the QCS transect was weaker than normal.

13.4. Factors influencing trends

Stronger surface currents at the WCVI transect have occurred in El Niño and La Niña years, consistent with Hourston and Thomson's (2020) results from in situ measurements. The surface currents could also be influenced by the Pacific

Decadal Oscillation, possibly via its impacts on regional wind patterns. In 2020, moderate La Niña was developed and the Pacific Decadal Oscillation was in the cool phase.

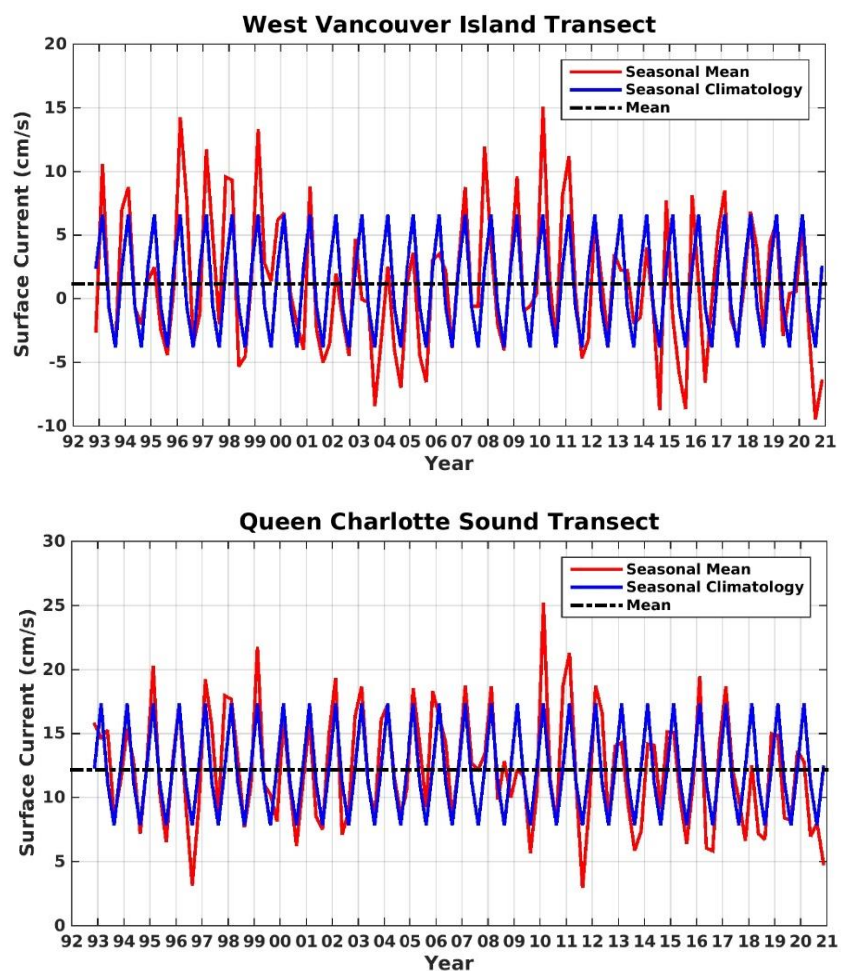


Figure 13-2. Seasonal-mean geostrophic surface currents (positive poleward) at the two transects located off the west coast of Vancouver Island (WCVI) (upper panel) and at the mouth of Queen Charlotte Sound (QCS) (lower panel).

13.5. Implications of those trends

Surface currents along the shelf edge and continental slope can affect heat and salt exchange as well as nutrient supply. They can also impact transport and distribution of fish eggs and larvae. Folkes et al. (2018) showed that surface currents can be a useful predictor for the return timing and northern diversion rate of Fraser sockeye salmon.

13.6. References

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14. OCEANOGRAPHIC CONDITIONS OFF THE WEST COAST OF VANCOUVER ISLAND: 2020

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14.1. Highlights

- There were positive temperature anomalies in the surface mixed layer at most sampling stations during the June-July survey (0.36 - 1.8 °C) and during the late-summer survey (0.6 - 2.6 °C); with offshore surface mixed layer temperature anomalies increasing with latitude (1.5 - 2.6 °C).
- The upper water column (< 100 m) was generally fresher than average during both surveys with the exception of mid-north island shelf stations, which were saltier than average in June.
- Conditions in late-summer 2020 were similar, but less extreme than the marine heatwave conditions observed in September 2019.

14.2. Description of the time series

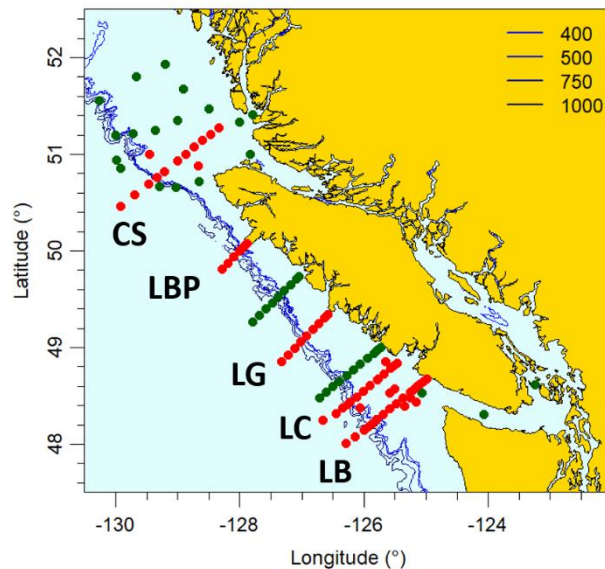


Figure 14-1. Map of the La Perouse-West Coast of Vancouver standard survey stations. Stations for each of the survey lines (labelled) discussed in this report are identified with red symbols. Bathymetric contours indicate the shelf break and contour-specific depths (m) are identified in the legend.

This time-series of the zooplankton survey of the Vancouver Island continental margin extends from 1979 to present for southern Vancouver Island, and from 1990 to present for northern Vancouver Island. The La Perouse/WCVI survey generally takes place in May and September each year and provides synoptic snapshots of physical, chemical, and biological patterns at shelf, slope, and offshore stations. Each of the biannual surveys is 11-13 days in duration and generally falls within the annual upwelling period. The May survey typically occurs within 30 days of the onset of upwelling positive winds (see Hourston and Thomson, Section 8; Dewey et al., Section 36). Note, however, development and implementation of COVID-safe field protocols delayed the start of the first 2020 survey to June 22, 2020. Transition timing from upwelling to downwelling varies with latitude,

however, the September survey generally precedes this transition along southern Vancouver Island. This report focuses on the most regularly sampled lines (red symbols in Figure 14-1): 1) LB, LC, and LG lines for Southern Vancouver Island; and 2) LBP and CS lines for Northern Vancouver Island. The time series average for CS and LBP lines was estimated as the average temperature or salinity for each station-specific pressure-bin for 1998-2014 and the annual period corresponding to each survey. The time-series average for LG, LC, and LB lines was

calculated as per the northern lines but relative to the 1981-2010 time series averages. Anomalies were calculated as the difference in temperature and salinity for each 2020 survey station-specific pressure bin and its corresponding time-series average.

14.3. Status and trends

Upper ocean temperatures in the survey area vary with latitude, season, and bottom depth. Here, 'mixed layer' refers to the surface mixed layer (surface to the depth of maximum squared buoyancy frequency, N^2). The mean mixed layer temperatures for the period corresponding to the June 2020 survey (22 June – 6 July, 2020) tended to be cooler along the northern lines (10.45 °C) relative to southern lines (11.81 °C) with only moderate differences between shelf (less than 200 m bottom depth) and shelf-break and offshore stations. Summer surface warming and westward Ekman transport of surface waters over the shelf yield a more pronounced pattern of warmer temperatures offshore (~13.4 °C) relative to shelf (~12.0 °C) stations for all 5 lines extending off of the west coast of Vancouver Island.

In June 2020, mean mixed layer depths for LB, LC and, LG lines varied between 15 and 27 m for shelf stations. The mean mixed layer depth at CS shelf stations was 39 m. Rough seas prevented sampling at LBP line shelf stations in June 2020. Offshore, mean mixed layer depth was less variable, but similar and ranged from 16 to 32 m at each line. The mixed layer temperature at shelf stations for CS line in June 2020 was 1.71°C warmer than average. Offshore, CS and LBP lines were 0.36 and 1.45 °C warmer than their respective time series averages. Temperatures between 100 m and the base of the mixed layer were slightly cooler than the time series average for each line; temperatures at greater depth (100-250 m) were moderately warmer (~0.5 °C) than average offshore for all but CS line stations which were typical. Mixed layer temperature anomalies for the southern LB and LC shelf stations were warmer than average (1.37 and 1.67 °C, respectively) and LG shelf stations were 0.22 °C cooler and 0.26 psu saltier than average. Offshore southern stations were also warmer than average with LB, LC, and LG mixed layer temperature anomalies of 1.30, 1.81, and 0.48 °C.

The July-September period following the June survey and leading to the August-September survey (August 24 – September 1, 2020) was characterized by weak, below-average intensity upwelling positive winds (Hourston and Thomson, Section 8; Dewey et al., Section 36). SST anomalies (see Ross and Robert, Section 7; Chandler, Section 10) were consistently warmer (>1 °C) than average in the northern CS and LBP lines area, whereas the pattern of SST anomaly was more heterogeneous along the southern WCVI coast.

Oceanographic conditions during the 2020 September survey were similar to 2019 and reflected the weak upwelling conditions coupled with seasonal surface heating during the July-September period as notably warmer mixed layer temperature anomalies for all stations along each of the 5 lines discussed here. Mean mixed layer depth varied between 12 and 31 m at shelf stations along LB, LC, LG, and LBP lines. Offshore, mean mixed layer depths were less variable, ranging between 18 and 25 m. Surface mixed layer temperatures for shelf stations along the southern lines, LB, LC, and LG, were 1.1, 1.6, and 0.8 °C warmer than their respective time series averages. Offshore station mixed layer temperatures for LB, LC, and LG, were 1.5, 1.7, and 1.9 °C warmer than average. These patterns were similar, but less extreme, to survey observations during the 2019 marine heatwave. The mixed layer for LBP line (off of Brooks Peninsula) shelf and offshore stations was 0.6 and 2.3 °C warmer than the time series average.

Temperature anomalies for shelf and offshore CS line stations were 2.6 and 2.5 °C warmer than the time series average and notably warmer than in September 2019. As above, water column temperature within the surface mixed layer was above average for all lines, increasing with latitude from 1.5 to 2.5 °C for offshore stations. Extremes were largely limited to the surface, with vertical patterns of temperature anomaly below the mixed layer depth less extreme (± 0.5 °C) and similar to the June survey (Figure 14-2). The surface mixed layer over the shelf was 0.4, 0.7, and 0.5 psu fresher than average for the three southern lines, LB, LC, and LG, whereas, mixed layer salinity was anomalously high, for the northern shelf stations, LBP and CS. Offshore, anomalously fresh conditions extended from the surface through the mixed layer down to ~75m (Figure 14-3). Salinity was not appreciably different from each time-series average at depths below 75 m. This pattern is similar to June-July 2020 (Figure 14-3, left-hand panel) when surface waters (< 100 m) were generally fresher than each time-series average. Note however, the exception of a saltier than average mixed layer in June and sub-surface (20-100m) in August 2020 for LG shelf stations and LBP shelf break stations (Figure 14-3).

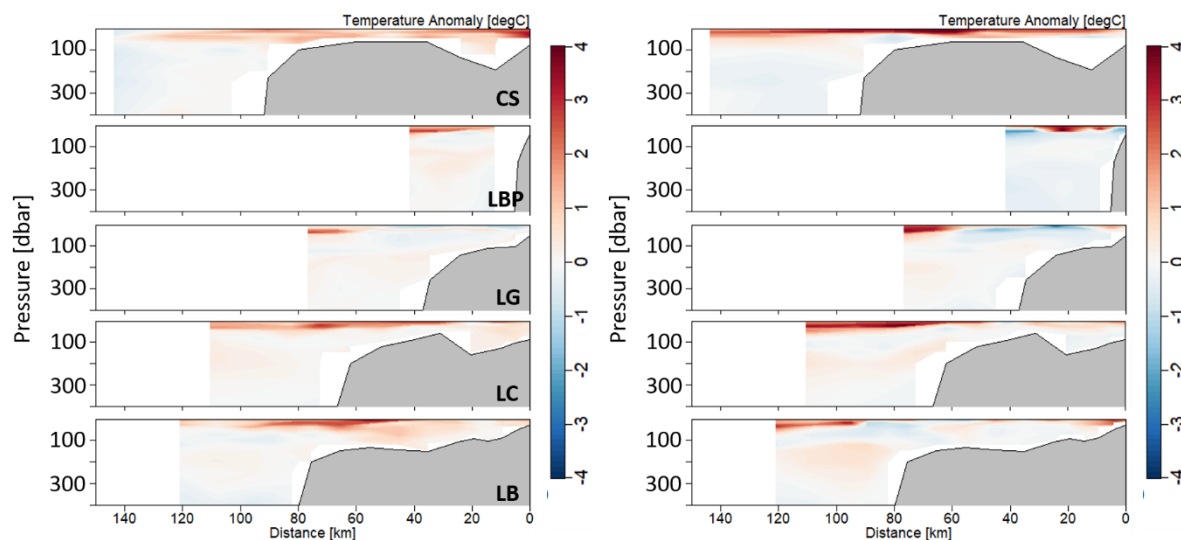


Figure 14-2. Temperature anomaly (°C) section plots across each sampling line. Maximum depth set at 400 dbar. Top to bottom represents northern to southern lines (see Figure 14-1). Left to right represent May and September survey sections, respectively. The time series average for CS and LBP lines was estimated as the average temperature for each station-specific pressure-bin for 1998-2014 and the annual period corresponding to each survey. The time-series average for LG, LC, and LB lines was calculated as per the northern lines but relative to the 1981-2010 time series averages. Anomalies calculated as the difference in temperature for each 2020 survey station-specific pressure bin and its corresponding time-series average. Temperature values greater and less than the time series averages are represented by 'warm' and 'cool' colours, respectively.

14.4. Factors influencing trends

Broad-scale temporal and spatial patterns describing warmer than average upper water column temperatures in 2020 for the Gulf of Alaska (Ross and Robert, Section 7) also extended to the west coast of Vancouver Island. Downwelling favorable winds were diminished early (mid-February) in 2020, followed by a quiescent period before transition to upwelling in mid-May (Hourston and Thomson, Section 8; Dewey et al., Section 36). The June-July La Perouse survey (June 22 – July 6, 2020) was preceded by this 'calm' period but took place during a

period of active upwelling along the southern west coast of Vancouver Island, as reflected by cool salty surface conditions over the shelf mid-island (LG line). Surface mixed layer temperatures offshore are expected to warm seasonally due (in part) to westward Ekman transport of shelf waters. Cross-shelf patterns of surface temperature in August-September reflect weak but consistent upwelling in the period between surveys. Note, however, that the surface mixed layer for both shelf and offshore stations along the northern CS line were anomalously warm ($> 2^{\circ}\text{C}$) reflecting anomalously weak upwelling in the north through much of 2020. Patterns of upper water column temperature and salinity along the west coast of Vancouver Island were similar, but less extreme in 2020 relative to 2019 (Sastri 2020; Ross and Robert 2020). These patterns reflect warmer than average temperatures at the regional scale conditions and limited but intermittent upwelling events along the southern West coast of Vancouver Island.

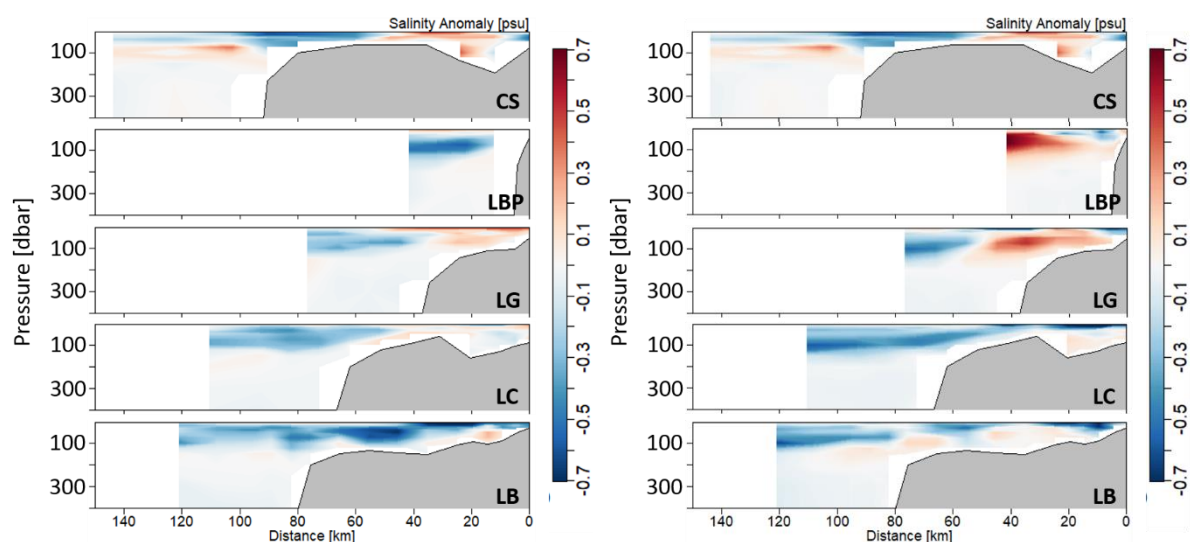


Figure 14-3. Salinity anomaly (psu) section plots across each sampling line. Maximum depth set at 250 dbar. Top to bottom represents northern to southern lines (see Figure 14-1). Left and right represent June-July and August-September surveys, respectively. The time series average for CS and LBP lines was estimated as the average salinity for each station-specific pressure-bin for 1998-2014 and the annual period corresponding to each survey. The time-series average for LG, LC, and LB lines was calculated as per the northern lines but relative to the 1981-2010 time series averages. Anomalies calculated as the difference in salinity for each 2020 survey station-specific pressure bin and its corresponding time-series average. Salinity values greater and less than the time series averages are represented by 'warm' and 'cool' colours, respectively.

14.5. Implications of those trends.

Warmer than average mixed layer temperatures along the west coast of Vancouver Island are often associated with a greater abundance and biomass of smaller, less lipid-rich zooplankton relative to the larger, lipid-rich, boreal and subarctic groups which tend to dominate under cooler conditions (Galbraith and Young, Section 18). Warmer than average conditions have also been linked to reduced and earlier biomass peaks for larger subarctic zooplankton and lower than average productivity for pelagic fish and seabirds (Mackas et al. 2007; Hipfner et al. 2020).

14.6. References

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15. ASSESSING OCEAN HABITAT FOR SEABIRDS – SCOTT ISLANDS MARINE NATIONAL WILDLIFE AREA

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15.1. Highlights

- Comprehensive assessment of the marine environment affecting seabirds using the Scott Islands Marine National Wildlife Area (NWA) is facilitated by coordinating periodic ship-based sampling, continuous data recorded by instrumented sub-surface moorings, analysis of satellite data, and deployment of GPS drifters.
- Recent drifter observations highlight the fundamental differences between surface drift in the winter and summer.
- In the summer, the overall pattern is that drifters in southern Queen Charlotte Sound drift out of the Sound through the Scott Islands and then south along the shelf break; consistent with the general circulation. Individual drifters exhibit substantial variability about this pattern.
- Analyses of the relationship between satellite chlorophyll-a (a proxy for phytoplankton biomass) and Rhinoceros Auklet fledgling success for the period 1998 to 2008 has been extended to 2020 as a hindcast of fledgling success over the last 12 years. Field data can now be used to test whether this statistical relationship between an environmental variable and bird life history variable has continued to hold.

15.2. Description

The Scott Islands NWA was established by the Government of Canada in 2018 (Figure 15-1). The NWA provides for conservation and research on migratory seabirds, and the ocean foraging habitats essential to support their breeding and productivity. About 40% of seabirds breeding in Canada's Pacific Ocean breed on the Scott Islands, including about ½ of the world's Cassin's Auklet (*Ptychoramphus aleuticus*), and about 7% of the world's Rhinoceros Auklet (*Cerorhinca monocerata*).

- Seabirds are marine wildlife:
 - All their food comes from the ocean.
 - Ocean conditions influence seabird breeding through effects on forage species.
 - Seabirds can help indicate ocean conditions as they are affected by ocean dynamics similar to other marine predators such as fish and marine mammals.
- In 2015, the Canadian Wildlife Service of Environment and Climate Change Canada, and Ocean Sciences Division of Department of Fisheries and Oceans Canada developed a Collaborative Agreement, currently running to the end of fiscal year 2021 - 2022. The purpose of the Agreement was to build on past success by jointly providing funding and expertise, for expanded use of oceanography to assess seabird habitats. The Scott Islands project is part of the long-term and coast-wide ocean monitoring

initiated by the Ocean Sciences Division to understand causes and effects of changes in the ocean environment on the marine ecosystem and resources. Results will assist in the understanding of marine habitats for all marine predators.

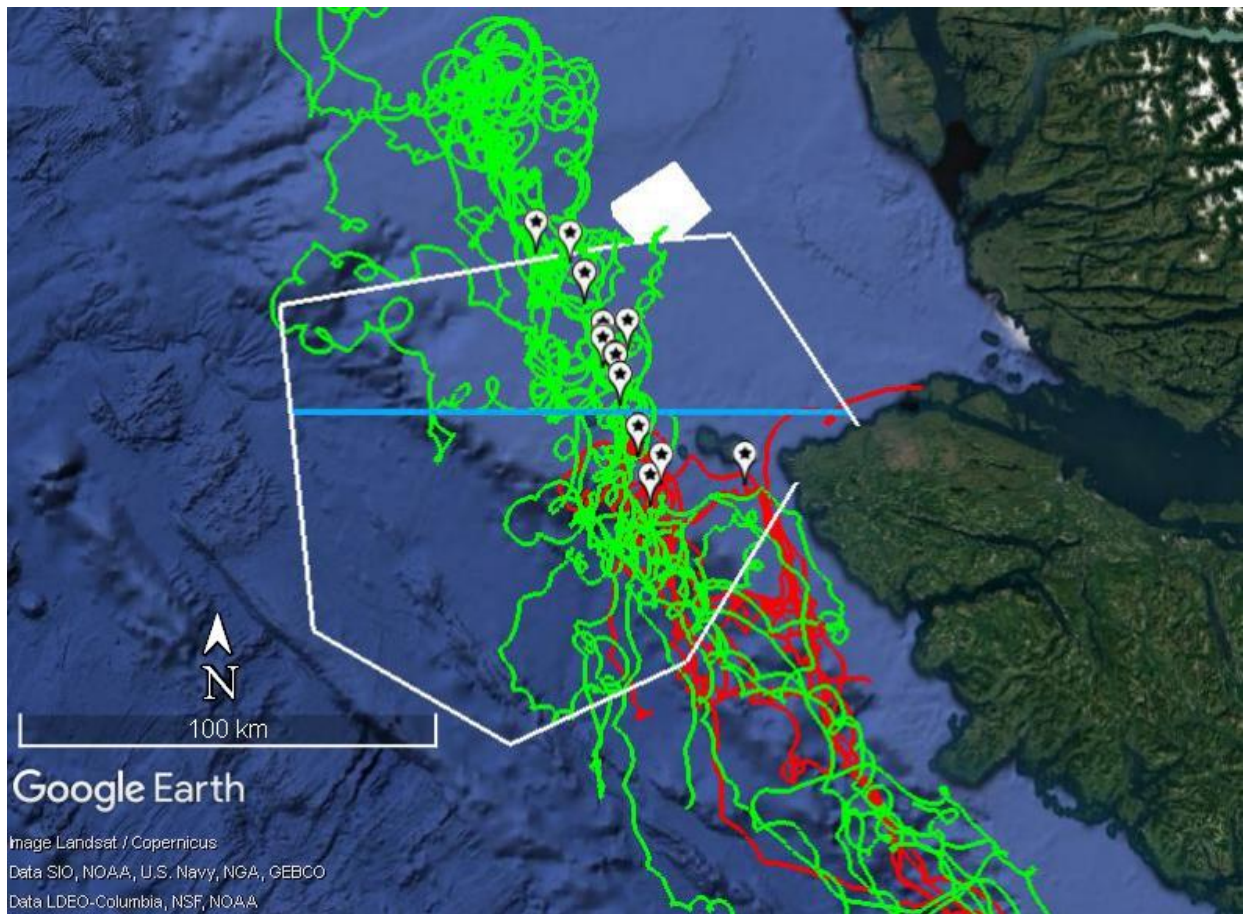


Figure 15-1. Tracks of 25 GPS drifters released in July 2016, 2017, and 2020 in the NWA. Only drifters with more than 6 days of data were included. Of 17 released north of Triangle Island, 9 drifted northward and 8 southward. All 8 released south of Triangle Island drifted southward, 1 of which then went eastward through Scott Channel. No drifters went westward past the NWA boundary. Drifters were released in the NWA in other months and years. White line: NWA boundary. Solid white polygon: Glass Sponge Reefs MPA. Green lines: drifters released north of Triangle Island. Red lines: drifters released south of Triangle Island. Blue line: Latitude of Triangle Island - 50° 52' 20" N. White balloons: Locations drifters were deployed.

- The most important projects implemented in the NWA up to 2019 were summarized in Jones and Hannah (2020).
- This year we emphasize that any defined area in the ocean is not isolated but is a part of the overall marine environment so an ecosystem approach is needed. The Southern Reef of the Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs Marine Protected Area (MPA) has a common boundary with the NWA, so is included in analysis of GPS drifter data along with the NWA as part of the marine ecosystem (Figures 15-1 and 15-2).
- GPS drifters released in the NWA in July 2016, 2017, and 2020 showed several patterns of movement (Figure 15-1):

- Nine of the 17 drifters released north of Triangle Island drifted northward, and 8 southward.
- All 8 drifters released south of Triangle Island drifted southward. One of these drifting southward after release, subsequently went eastward leaving the area via Scott Channel.

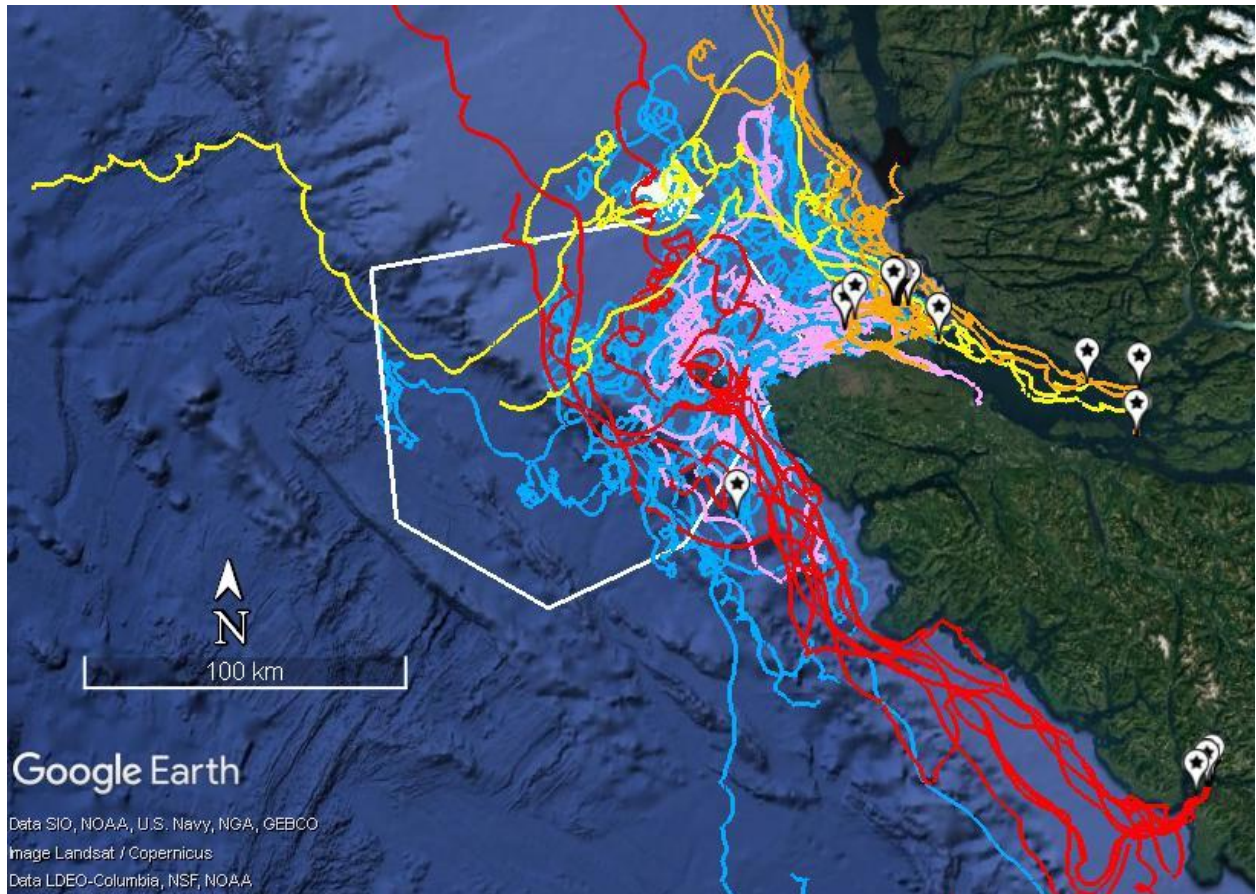


Figure 15-2. Tracks of 54 GPS drifters with more than 6 days of data or meaningful end points before failing. Thirty-four exiting Queen Charlotte Strait entered the NWA (May to October, 2014 – 2020 except 2018), 9 of which subsequently left it and drifted back eastward. Three drifters released in Johnstone Strait in January 2019 entered the NWA. Of the nine other drifters exiting Queen Charlotte Strait; 3 drifted northward past the NWA, 4 circulated near the release point, and 2 landed on shore. Eight drifters released in Muchalat Inlet (December to February, 2020 – 2021) drifted northward past Brooks Peninsula, 6 entering the NWA. Blue lines: drifters released east of the Scott Islands that drifted into the NWA and did not return eastward. Purple lines: drifters released east of the NWA, that drifted into it then drifted back eastward. Yellow lines: drifters released in Johnstone Strait in January 2019. Red lines: drifters released at site of the sunken shipwreck leaking oil in Muchalat Inlet – MV Schiedyk. Orange lines: drifters exiting Queen Charlotte Strait that did not enter the NWA. White line: NWA boundary. Solid white polygon: Glass Sponge Reefs MPA. White balloons: locations drifters were deployed.

- Drifters moved haphazardly inside the NWA before moving out.
- No drifters were carried by currents west of the NWA boundary.
- Thirty-seven of 46 drifters deployed in, or exiting, Queen Charlotte Strait from May to October, 2014 – 2020 (no such samples in 2018), and January 2019, were carried into the NWA by winds and currents (Figure 15-2).
- Drifters entering the NWA showed two major patterns. Some went north, then swung southwesterly, others went generally westward, crossing into the NWA at

- any point along the eastern boundary. Drifters entering from the east generally concentrated in the Cook Bank area. In July, 8 of 17 drifters in the Cook Bank area drifted northward towards Goose Island Bank.
- This result is consistent with the Borstad et al. (2011) conclusion that nutrients from eastern Queen Charlotte Sound are carried westward by currents into the Scott Islands area.
 - One-quarter (nine) of the 37 drifters entering the NWA from the east, in spring through fall, subsequently exited and drifted back eastwards.
 - Nine of the 46 drifters exiting Queen Charlotte Strait in spring through fall did not enter the NWA. Three of these drifted northward near the mainland coast, suggesting a nearshore northward current. Three others circulated near the release site, and 2 beached.
 - Substantial variation of drifter movements, including returning eastward after moving westward into the NWA, indicates complex currents in this region.
- Queen Charlotte Strait is a significant corridor for ship traffic into or out of Johnstone Strait. The spring, summer, fall and winter drifter results demonstrate that substances from these Straits could be carried into and affect the Scott Islands NWA, and the adjacent Glass Sponge Reefs MPA.
 - Drifters were released in December 2020, and January – February 2021, near the site of a sunken shipwreck leaking oil (Figure 15-2) in Muchalat Inlet. The drifters are part of an inter-governmental partnership assessing impacts of, and cleaning up, the oil (Bligh Island Shipwreck, <https://www.spillresponsebc.ca>).
 - Eight drifters left Muchalat Inlet drifting northward, 6 of which travelled about 180 km straight line distance into the NWA, and 2 failed north of Brooks Peninsula before reaching the Scott Islands.
 - Two entering the NWA then kept going north. One went about 520 km total straight line distance from the shipwreck release site, the other about 680 km straight line distance from the shipwreck, both 21 days after deployment.
 - Of the 9 total drifters entering the NWA in winter (Figure 15-2), only 1 travelled west past the shelf break and another appeared heading that way until battery failure. It appears that most surface current in winter is northward rather than westward across the shelfbreak.
 - Work under the Agreement continues to be conducted on an ocean ecosystem basis. Some analyses include all existing and proposed marine protected areas on a partnership basis with responsible agencies – Fisheries and Oceans, Parks Canada, and Environment and Climate Change Canada (Devred et al. 2021; Hilborn et al., Section 45; Figure 15-3).
 - Reproduction success of Rhinoceros Auklet, a piscivorous seabird, improves with availability of nutritious forage fish when needed to provide to their chicks. In the NWA production of their chicks is best when the spring phytoplankton bloom is in early April (Borstad et al. 2011). In the NWA, the highest quality forage fish is the Pacific sand lance, *Ammodytes hexapterus*.
 - Borstad et al. (2011) provided information supporting a direct relationship between productivity of Rhinoceros Auklets, measured as weight of their chicks, with concentration of chlorophyll-a (Chl-a) within a radius of 45 km from the Triangle Island, the most important area of the Scott Islands for seabird breeding.

- Telemetry in the NWA has shown that this species forages up to about 80 km from Triangle island, in other areas this species has been shown to go 90 km (McFarlane et al. 2005). The distance travelled to forage for their chicks will depend on the distance needed to find adequate fish for feeding and may vary year to year.

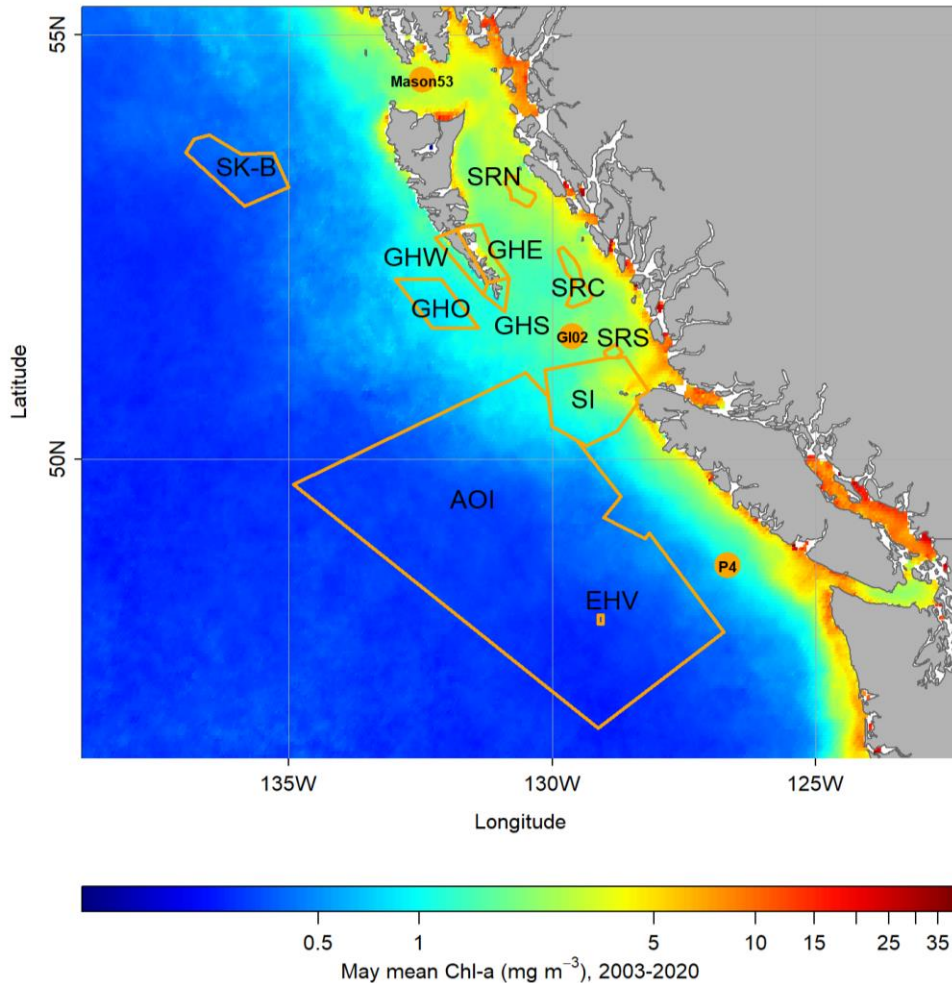


Figure 15-3. Areas for which standard time series are being developed, many are existing or proposed protected areas. Figure shows mean Chl-a in May from 2003 through 2020. SK-B: SGaan Kinghlas-Bowie Seamount Marine Protected Area. GH: Gwaii Haanas National Park Reserve, East, South and West sections. GHO: Gwaii Haanas Offshore. SR: Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA, North, Central and Southern reefs. SI: Scott Islands Marine National Wildlife Area. EHV: Endeavour Hydrothermal Vents Marine Protected Area. AOI: Offshore Pacific Area of Interest. Orange icons: standard oceanographic stations.

- The relationships between Chl-a and Rhinoceros Auklet chick production in Borstad et al. (2011) were based on data from 1998 – 2008. Reproducing the result was more difficult than expected when using the same dataset (SeaWiFS OC4 Chl-a product) and following the methodology described in the paper. With some small modifications we were able to nearly replicate the slope they had found. The results are also sensitive to details such as the basic processing algorithm used to produce the Chl-a estimates.
- We used our results to extend the proxy for fledgling weight to 2020 (Figure 15-4). Field data can now be used to test whether this statistical relationship between an

environmental variable and bird life history variable has continued to hold. Since the seabird's primary prey, Pacific sand lance, is several trophic levels above Chl-a, the relationship may not be highly sensitive to Chl-a.

- Given that ecosystems and food-webs can evolve over time, it is possible that a statistical relationship spanning several trophic levels may hold in one decade and not in another. Testing the relationship with more recent field data would validate the results.

Satellite Chl-a converted to chick production

Chick data (green), SeaWiFS from Borstad (blue), SeaWiFS v2018 (red), MODISA v2018 (purple)

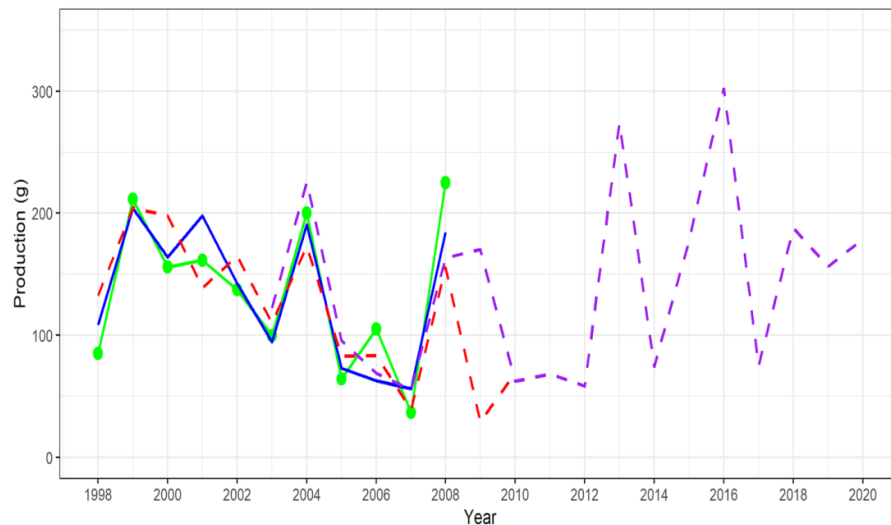


Figure 15-4. Preliminary predicted weight (g) of Rhinoceros Auklet chicks 1998 to 2020, following the relationship with phytoplankton biomass (Chl-a) published by Borstad et al. (2011). The green line is the chick weight data, the blue is the result of Borstad et al. (2011) for 1998-2008, the red line is our result based on the SEAWIFS data, and the purple line is our hindcast for 2003-2020 based on MODISA.

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16. NUTRIENTS AND PHYTOPLANKTON ALONG LINE P

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16.1. Highlights

- Winter surface nutrient concentrations along Line P in 2020 were among the lowest on record due to increased stratification that restricted nutrient renewal from vertical transport, similar to that observed in previous years.
- A Haida eddy with lower than normal surface nutrients was present at the offshore stations of Line P in winter of 2020. By summer, surface nutrients were similar to or higher than those observed in winter.
- Phytoplankton biomass was relatively low along Line P in 2020 but community composition was similar to that of previous years, except for a decrease in diatom abundance.

16.2. Description of the time series

Monitoring changes in nutrients, phytoplankton biomass and community composition is important for the evaluation of ecosystem function and status, as well as for the study of biogeochemical cycles. Phytoplankton community composition, chlorophyll-a (“Chl-a”, an indicator of phytoplankton biomass) and nutrients are normally measured on DFO cruises along Line P in the northeast subarctic Pacific three time a year in February, June, and August/September. Sampling for phytoplankton composition has been carried out at most of the stations along Line P (Figure 16-1) since June 2010. In 2020, because of Covid-19 restrictions, sampling during the June cruise was limited and did not extend beyond P12.

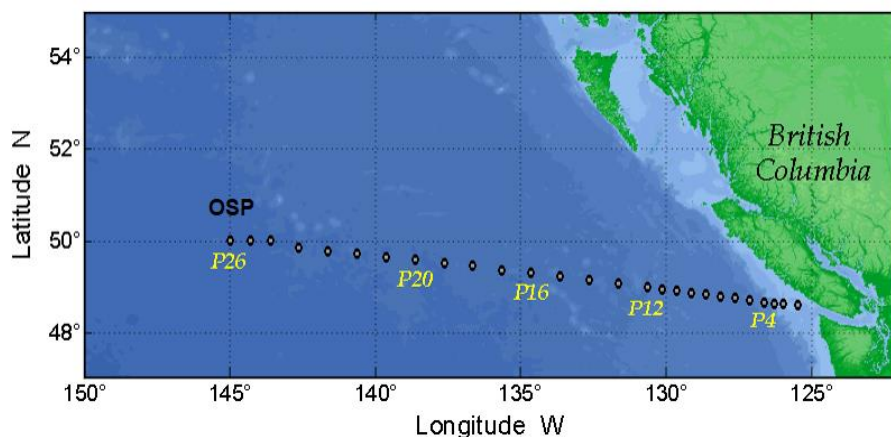


Figure 16-1. Location of sampling stations along Line P (P26 is Ocean Station Papa (OSP)).

The abundance and composition of phytoplankton are determined using a chemotaxonomic approach based on phytoplankton pigments (chlorophylls and carotenoids) analyzed by high performance liquid chromatography (HPLC) as described in Nemcek and Peña (2014). The HPLC pigment data are processed using a factorization matrix program (CHEMTAX) to estimate

the contribution of the main taxonomic groups of phytoplankton to total Chl-a (Mackey et al. 1996).

16.3. Status and trends

Line P extends from the southwest corner of Vancouver Island to Ocean Station Papa (OSP, Figure 16-1) in the high-nutrient low-chlorophyll (HNLC) region where surface nutrient concentrations are usually high ($>5 \text{ mmol m}^{-3}$) and Chl-a concentrations are low ($<0.5 \text{ mg m}^{-3}$) year-round due to Fe limitation of phytoplankton growth. In these Fe-poor offshore waters, small flagellates (mainly haptophytes) dominate phytoplankton biomass whereas on the shelf there is high seasonal variability in nutrient concentrations, phytoplankton biomass and composition. In the winter of 2019/2020, nutrient renewal from vertical transport was restricted due to increased stratification, similar to that observed in previous years. In addition, a Haida eddy with lower nutrient concentrations than surrounding water was observed at the most offshore stations. As a result, surface nitrate and silicate values in winter 2020 were at the lower range of previous years, in particular at the most offshore stations where the eddy was present (Figure 16-2). However, summer nutrient concentrations were similar or higher than winter values at these offshore stations. At other stations, summer mixed layer nutrients in 2020 were below average values but not as low as in 2019 when nitrate depletion extended for the first time to OSP. Similarly, winter and summer Chl-a concentrations were at the lower range of values from previous years (Figure 16-2).

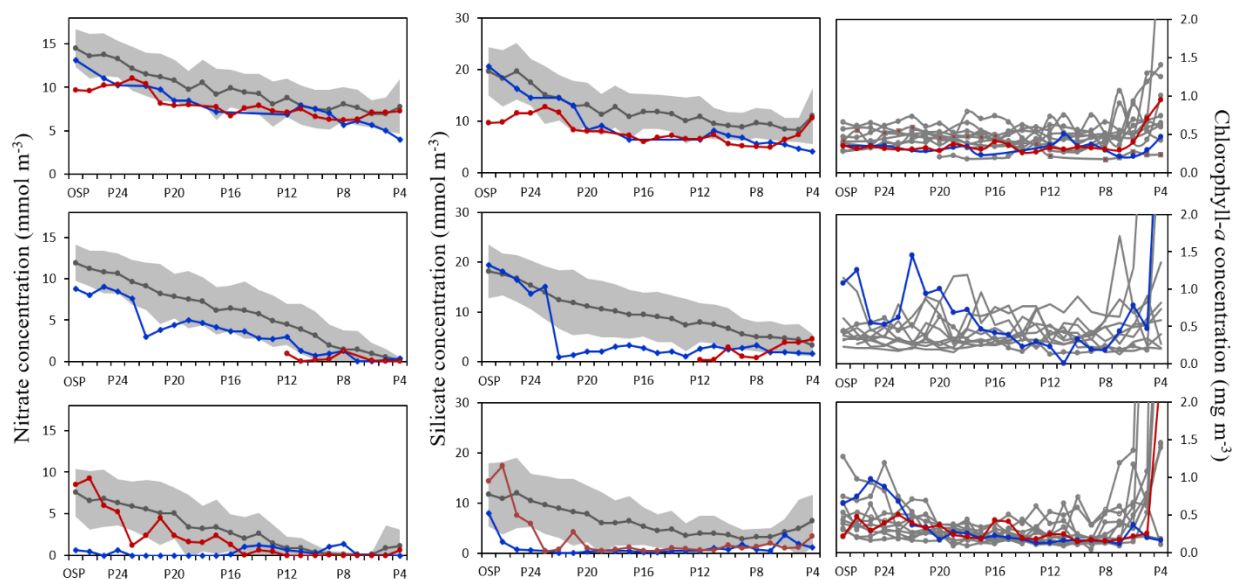


Figure 16-2. Nitrate (left panels, mmol m^{-3}), silicate (center panels, mmol m^{-3}), and chlorophyll-a (right panels, mg m^{-3}) in surface waters along Line P from P4 to OSP in winter (top panels), spring (middle panels) and summer (bottom panels). The left and center panels show the average (grey line) and standard deviation (shaded area) of nutrient concentrations in 2000-2019. The right panel shows all values in 2009-2020. In all panels, data for 2019 are shown in blue and for 2020 in red.

Phytoplankton assemblage composition in 2020 was in general similar to that observed in previous years with haptophytes dominating phytoplankton biomass at most stations (Figure 16-3), except for a decrease in the relative abundance of diatoms during the summer.

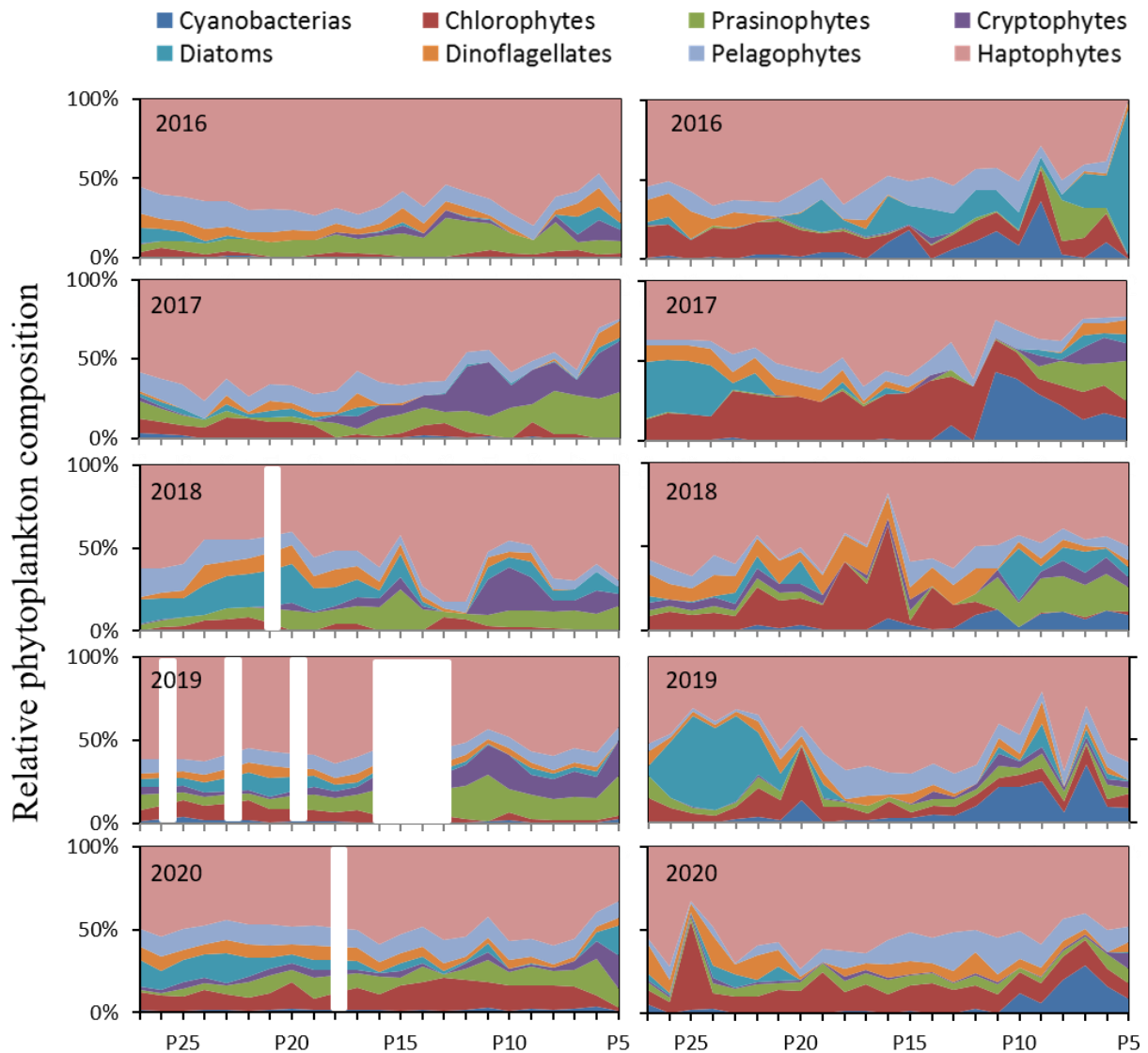


Figure 16-3. Relative phytoplankton composition in the upper layer at stations along Line P (see Figure 16-1) in February (left panels) and Aug./Sept. (right panels) of 2016 to 2020. Blank spaces indicate no data were collected.

16.4. Factors influencing trends

Several environmental factors including temperature, irradiance and nutrient availability, as well as grazing pressure, determine phytoplankton abundance and community composition. During the Blob in 2015, changes in phytoplankton abundance and composition were observed along Line P likely in response to the increase in surface temperature and changes in nutrient availability (Peña et al. 2019). Since then, nutrient availability, phytoplankton biomass and diatom abundance have shown significant fluctuations in the NE subarctic Pacific. These include the unprecedented depletion of mixed layer nitrate, and to a lesser degree of silicate, in the HNLC region of Line P in the summer of 2019, as well as sporadic increases in diatom abundance at the most offshore stations of Line P in September of 2017 and 2019 and their

decrease at most stations in summer of 2020. These changes could be due to an increase in Fe availability or to anomalous transport of nutrient-depleted waters into the region.

16.5. Implications of trends

Phytoplankton abundance and community composition are key factors influencing trophic processes and biogeochemical cycles in the ocean. Organic matter produced by phytoplankton is continuously transferred from lower to higher trophic levels, so the abundance, composition and distribution patterns of phytoplankton ultimately affect the sustainability of all marine life. The observed changes at the base of the food web during and after the Blob could have ecosystem-wide implications.

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17. DOMOIC ACID SURVEILLANCE IN PACIFIC CANADIAN WATERS: 2016 - 2020

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17.1. Highlights

- The phytotoxin domoic acid (DA), a human health and marine ecosystem stressor, was found in measurable concentrations in 70% of samples collected in Canada's NE Pacific waters, 2016-2020.
- DA concentrations equal to or above 100 pg/ml (defined as a 'Concentration of Concern') were not common (i.e. they occurred in about 4% of samples).
- DA was present in all years; the highest concentrations were in 2020 along the west coast of Vancouver Island, with a peak concentration (over 2000 pg/ml) in June.
- DA was significantly related to the abundance of *Pseudo-nitzschia* spp., but with low explanatory power.
- DA increased with salinity and abundance of *Pseudo-nitzschia* at some B.C. salmon farms.
- Multiple phytotoxins are present in B.C. coastal waters year-round, raising the possibility of chronic exposure and cumulative effects.

17.2. Description of the issue

The marine heatwave in the NE Pacific from 2014 to 2016 was accompanied by an extraordinary bloom of phytoplankton along the continental shelf of western North America in 2015. This bloom persisted from May to September, and extended from California to Alaska. Prominent among the phytoplankton taxa in this bloom were species of the pennate diatom, *Pseudo-nitzschia* (McCabe et al. 2016). Under certain conditions some species of *Pseudo-nitzschia* produce a neurotoxin, which is responsible for human illnesses and several deaths (Amnesiac Shellfish Poisoning). Consequently, this is one of the phytotoxins of concern that is monitored routinely in shellfish by the Canadian Food Inspection Agency. However, this toxin also has deleterious impacts on the marine ecosystem. It has been found in many species of marine mammals in Alaska (Lefebvre et al. 2016), has been implicated in large whale deaths along the B.C. coast in 2015-2016 (Savage 2017), and has been found to raise the risk of cardiac disease in sea otters off California (Moriarty et al. 2021). After the 2015 event, DFO provided funding to begin a large-scale at-sea domoic acid surveillance program in 2016, to assess the presence and patterns of domoic acid in Pacific Canadian waters. In 2019, additional DFO funding was provided to study domoic acid and other algal toxins in the vicinity of nearshore aquaculture facilities, in collaboration with the B.C. salmon farming industry. This

report presents a short summary of the initial results from the large-scale surveillance program from 2016 to 2020, and for the nearshore aquaculture program in 2020.

In the large-scale surveillance program, samples for domoic acid were collected on oceanographic surveys conducted by Fisheries and Oceans Canada. One liter of sea water was collected from surface waters, filtered onboard, and the filters stored at -80°C. Additional samples were collected from the same Niskin bottle for phytoplankton taxonomy, nutrients, and other physical and chemical properties. The domoic acid samples were extracted and analysed in the laboratory using the Enzyme-Linked ImmunoSorbent Assay (ELISA) method. Sampling at B.C. salmon farms was carried out bi-weekly by filtering 1 L of seawater from the surface or at 5 m and storing both the filter and filtrate at -20°C. Taxonomic samples and environmental data (temperature, salinity, dissolved oxygen) were collected at the same time. Solid phase adsorption toxin tracking (SPATT) samplers were also deployed at some sites to assess long-term exposure. Domoic acid was measured using ELISA and other phytotoxins by liquid chromatography-tandem mass spectrometry (LC-MS/MS).

17.3. Status and Trends

A total of 396 samples were collected from 2016 to 2020 in the large-scale surveillance program. Locations sampled included the Strait of Georgia (N=174), west coast of Vancouver Island (N=141), northeast Pacific (N=30) and Queen Charlotte Sound (N=49) (Figure 17-1).

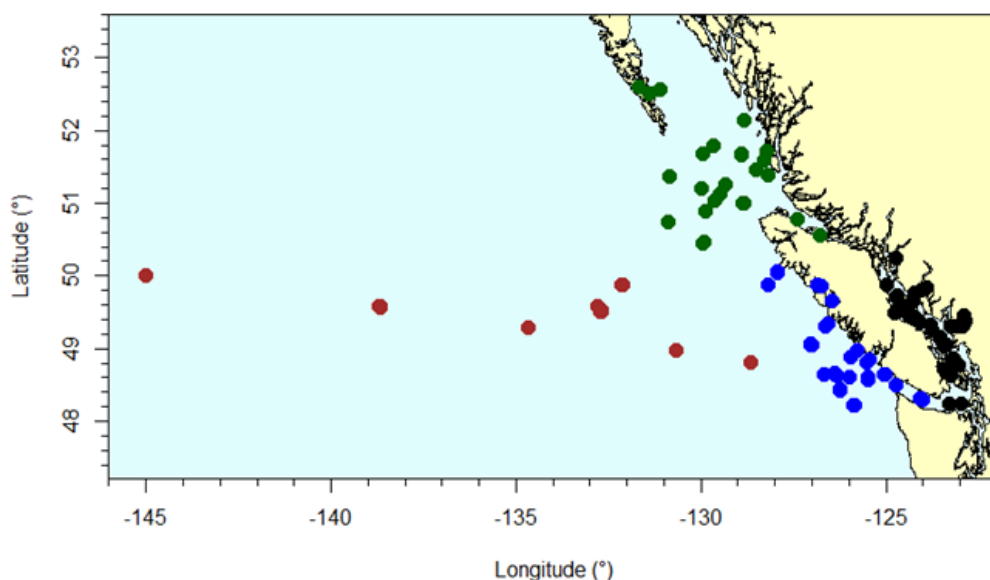


Figure 17-1. Location of samples collected for domoic acid analyses from 2016 to 2020. Black dots: Strait of Georgia; blue dots: west coast Vancouver Island; red dots: NE Pacific; green dots: Queen Charlotte Sound.

Concentrations of particulate domoic acid (excluding values below the detection limit, which were defined here as 0 pg/ml) in seawater ranged from 0.02 to 2104 pg/ml. Thirty-one percent of the observations had domoic acid concentrations below the limit of detection for the ELISA technique. The most common concentration range was greater than 0 and less than or equal to 1 pg/ml (37%) (Figure 17-2). The concentration of domoic acid indicating deleterious effects to mammals is unknown, although the National Oceanic and Atmospheric Administration (NOAA)

in Seattle considers concentrations greater than 200 pg/ml to be ‘of concern’ (Trainer and Hardy 2015). Given the uncertainty over how much domoic acid may cause problems for marine mammals, and that domoic acid is not uncommon in the NE Pacific marine food web, a concentration of 100 pg/ml was selected as a precautionary ‘concentration of concern’ for this report. The percentage of observations with domoic acid concentrations equal to or greater than 100 pg/ml in the areas sampled in this program was 4.3%.

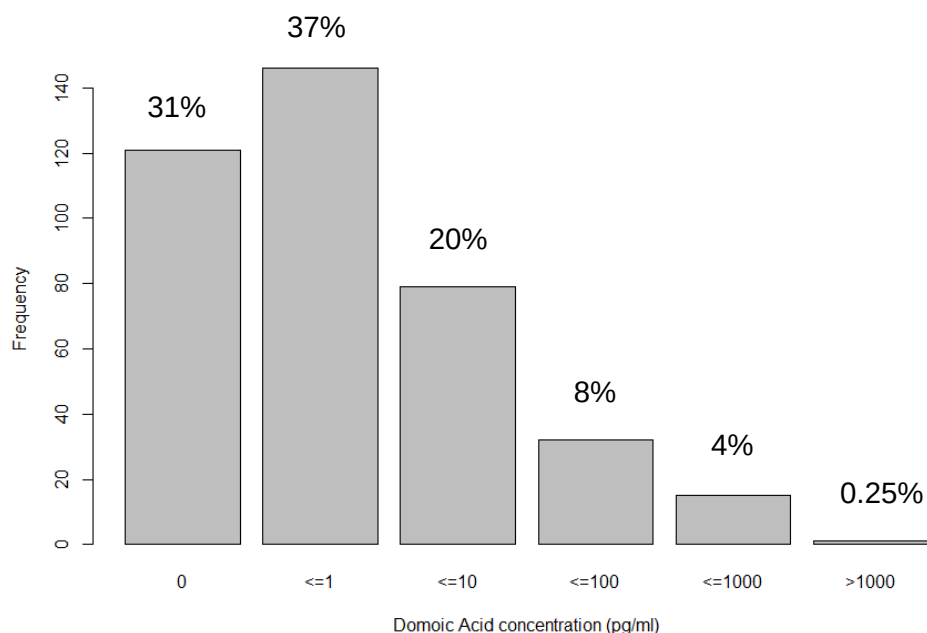


Figure 17-2. Frequency of domoic acid concentrations observed from 2016 to 2020 in the large-scale surveillance program. Bars represent $\log_{10}$ categories. Numbers above each bar represent the percentage of samples that occurred within each concentration range.

At least some domoic acid concentrations exceeded the ‘concentration of concern’ in this study in all years, except for 2019 (Figure 17-3, top). By month, median domoic acid concentrations were highest in April, May and October, although some (maximum of four) samples exceeded the ‘concentration of concern’ in each of May, June, August, September and October (Figure 17-3, bottom).

The northeast Pacific region had the lowest median domoic acid concentration (near zero) with only one observation (out of 30) at 100 pg/ml. The median concentration for the Strait of Georgia was 1.9 (as $\log_{10}$ pg/L), with only one (out of 174) observation above 100 pg/ml. Queen Charlotte Sound had a median concentration of 2.2 (as $\log_{10}$ pg/L), with two observations (out of 49) greater than 100 pg/ml. The west coast of Vancouver Island had the highest median concentration (2.8 as $\log_{10}$ pg/L) with 12 observations greater than 100 pg/ml. The highest domoic acid concentration observed in this study (2104 pg/ml) occurred off Estevan Point along the west coast of Vancouver Island in June 2020 (several other nearby locations also had domoic acid concentrations greater than 100 pg/ml during that survey).

A total of 28 filtered water and particulate filter samples with corresponding taxonomic and environmental data were collected from B.C. salmon farms by industry partners Grieg Seafood and Cermaq Canada between May and October 2020 (Figure 17-4).

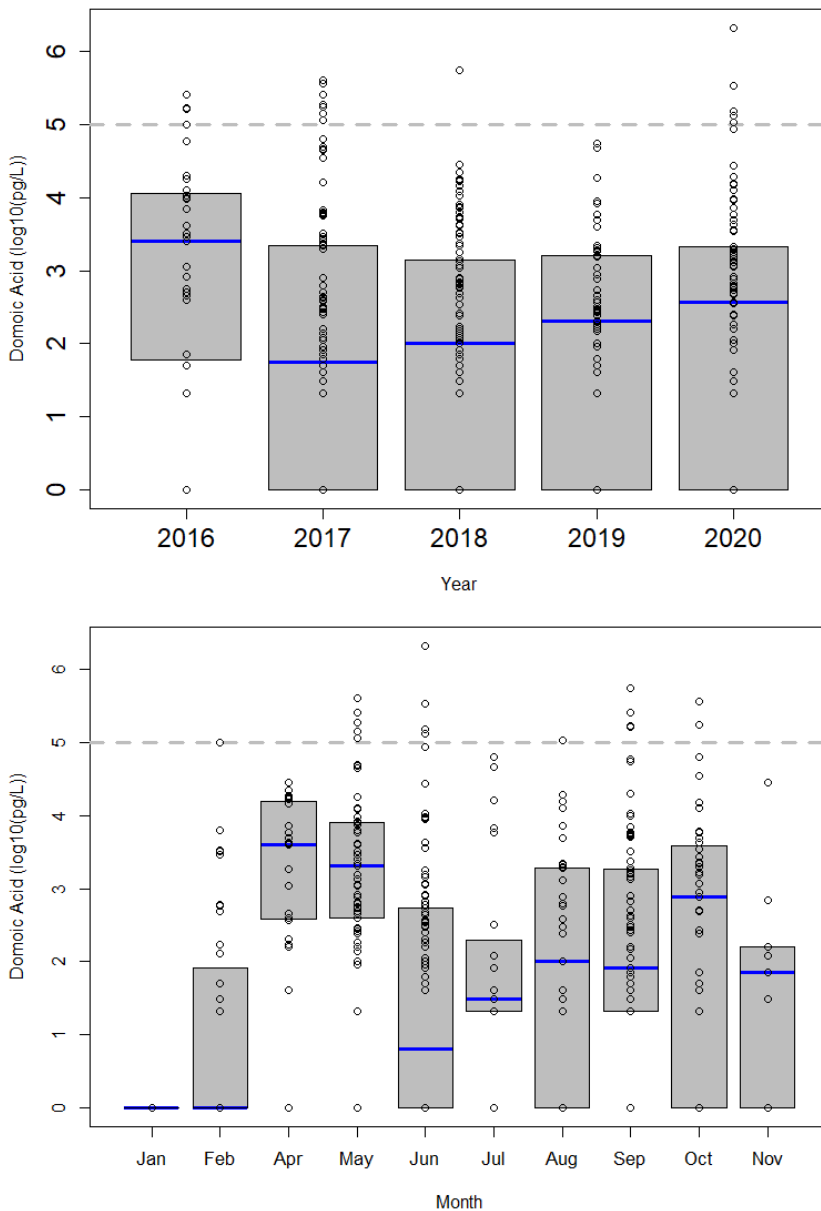


Figure 17-3. Boxplots of domoic acid concentration from 2016 to 2020 from the large-scale surveillance program, by year (top panel), and month (bottom panel). Blue line represents the median, top and bottom of the grey boxes represent the 75th and 25th percentiles of the sample distribution, respectively. Open dots represent the concentrations of individual samples. Horizontal dashed grey line represents the domoic acid 'concentration of concern' used in this study (100 pg/ml; Note the units on the Y axis are log₁₀ pg/L, therefore 5 equals 10⁵ pg/L or 100 pg/ml).



Figure 17-4. Locations of B.C. salmon farms at which samples were collected for biotoxin analysis. Filtered water, particulate filter, and taxonomic samples were collected at Farms B, C and D in 2020 and the filters were analyzed for domoic acid. SPATT samples collected at Farms A, B, D and E in 2017 and 2018 were analyzed for other toxins.

Results obtained for filter samples collected at 5 m showed that domoic acid concentration tended to increase with the number of toxigenic *Pseudo-nitzschia* cells but remained relatively low, the highest concentrations being observed at Farm C (72 pg/mL in July 2020). LC-MS/MS analysis of filters, and of extracts obtained from SPATT samplers deployed in 2017 and 2018, revealed that toxins associated with paralytic and diarrhetic shellfish poisoning (PSP, DSP) were also present in B.C. coastal waters, showing seasonal and inter-annual variability (Figure 17-5).

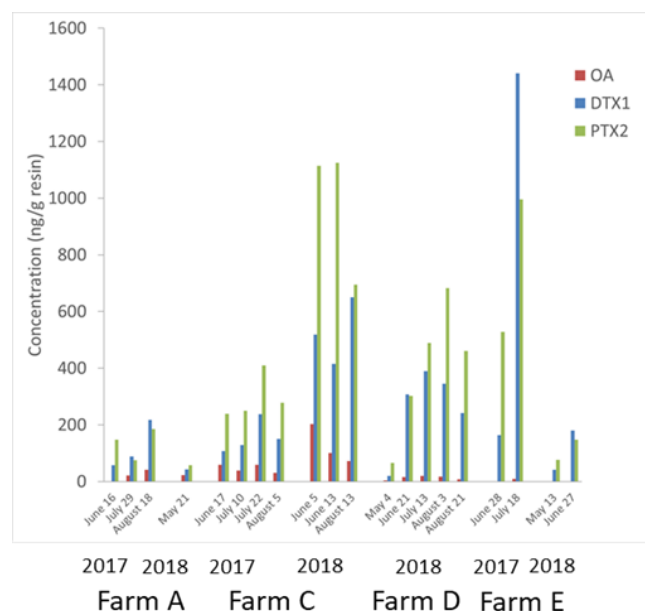


Figure 17-5. Distributions of DSP toxins okadaic acid (OA), dinophysitoxin-1 (DTX1) and pectenotoxin-2 (PTX-2) measured in extracts from SPATT samplers deployed near B.C. salmon farms during 2017 and 2018. Yessotoxin (YTX) was also present in most extracts (not shown), especially those obtained from Farm C in 2018.

17.4. Factors influencing these trends

It is believed that domoic acid is produced only by species of the genus *Pseudo-nitzschia*. Therefore, at least two conditions are necessary for domoic acid to be present: 1) the presence of *Pseudo-nitzschia* spp., and 2) that these cells are actively producing domoic acid. The conditions leading to domoic acid production, however, are poorly known. It may be due to bacteria, phosphate limitation, elevated CO₂ concentrations, or other factors. There was a significant ($P < 0.001$) positive linear relationship between the ($\log_{10}$) concentration of domoic acid and the ($\log_{10}$) abundance of total *Pseudo-nitzschia* spp. observed in the large-scale surveillance program, although the relationship had very low explanatory power ($\text{adj}R^2 = 0.12$). A similar relationship was observed at B.C. salmon farms, where domoic acid concentration also appeared to increase with salinity. Work is ongoing to examine additional factors which may improve the relationship between *Pseudo-nitzschia* abundance and domoic acid production, including temperature, salinity, and nutrient ratios.

17.5. Implications of these results

Domoic acid can be a significant human health hazard. Responsibility for monitoring domoic acid in the Canadian human food supply resides with the Canadian Food Inspection Agency (CFIA). Further work will compare the results from the large-scale surveillance program with CFIA data on shellfish contamination by domoic acid. However, domoic acid does occur in the marine food web, and has been implicated in behavioural changes and mortalities of marine mammals along the west coast of North America and elsewhere. A regular domoic acid surveillance program would help to understand how often and where domoic acid occurs, where and when it exceeds the 'concentration of concern', what that 'concentration of concern' should be, and potentially the impacts to the marine ecosystem. Chronic exposure to multiple phytotoxins, and other stressors, could also result in cumulative impacts on marine organisms. Routine monitoring of these toxins would help to better understand and mitigate their impacts on wild and farmed species while shedding light on the conditions that give rise to their production.

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18. WEST COAST BRITISH COLUMBIA ZOOPLANKTON BIOMASS ANOMALIES 2020

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18.1. Highlights

- Warm water southern zooplankton community species continue to be found along the shelf break and slope during the late summer and early fall of 2020.
- Gelatinous zooplankton decreased in biomass throughout all regions in comparison to 2014-2019.
- Total biomass was low, reflecting a below-average boreal/subarctic zooplankton community.

18.2. Description of the time series

Zooplankton time-series are available for southern Vancouver Island (SVI; 1979-present), northern Vancouver Island (NVI; 1990-present), Line P (1980-present), and Hecate Strait (1998-present), although with lower density and/or taxonomic resolution for NVI and Hecate Strait earlier in the time series. For this report, we present data from 1995 onwards; except Line P which is 1997 to present. The 'standard' sampling locations are averaged within the SVI, NVI, Line P and Hecate regions (Figure 18-1). Additional locations are included in averages when they are available. See Mackas 1992 and Mackas et al. 2001 for methodology of zooplankton surveys along the west coast.

A zooplankton climatology was estimated for each region, using the data from the start of each time series through to 2008 as a baseline, and compared to monthly conditions during any single year to produce biomass anomaly time series. For a more detailed description see earlier reports (Mackas 1992; Mackas et al. 2001).

Zooplankton species, from the west coast of British Columbia, with similar zoogeographic ranges and ecological niches usually have very similar anomaly time series (Mackas et al. 2006); therefore, multiple species were averaged within species groups (and size classes within major taxa) to show interannual variability (see Table 16-1 Boldt et al. 2019; Galbraith and Young 2017; Mackas et al. 2013a; Irvine and Crawford 2013). Due to Covid, there were no spring to early summer samples to analyze, the annual anomalies are based on June and September samples. All data presented here are very preliminary as analysis is on-going; numbers will change but directions of trends *usually* do not change.

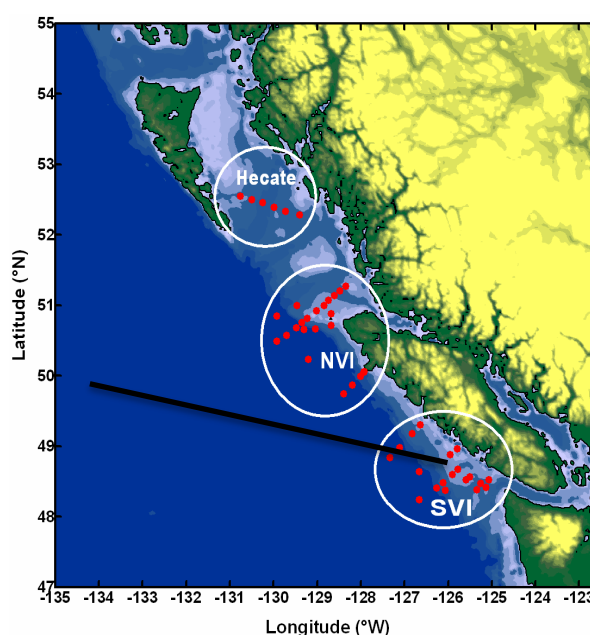


Figure 18-1. Zooplankton time series sampling locations (red dots; Line P – black line) in B.C. marine waters. Data are averaged for samples within each area. There are more samples included in the analysis than shown in figure.

18.3. Status and trends

The biomass anomaly time series for copepod species groups, representative chaetognaths and euphausiids in the SVI, NVI, Line P and Hecate statistical areas are shown in Figures 18-2, 18-3, and 18-4. Cool years tend to favour endemic ‘northern’ taxa; whereas warm years favour colonization by ‘southern’ taxa. See Mackas et al. 2013b for pre-1995 anomalies, and descriptions on how to interpret the anomaly patterns.

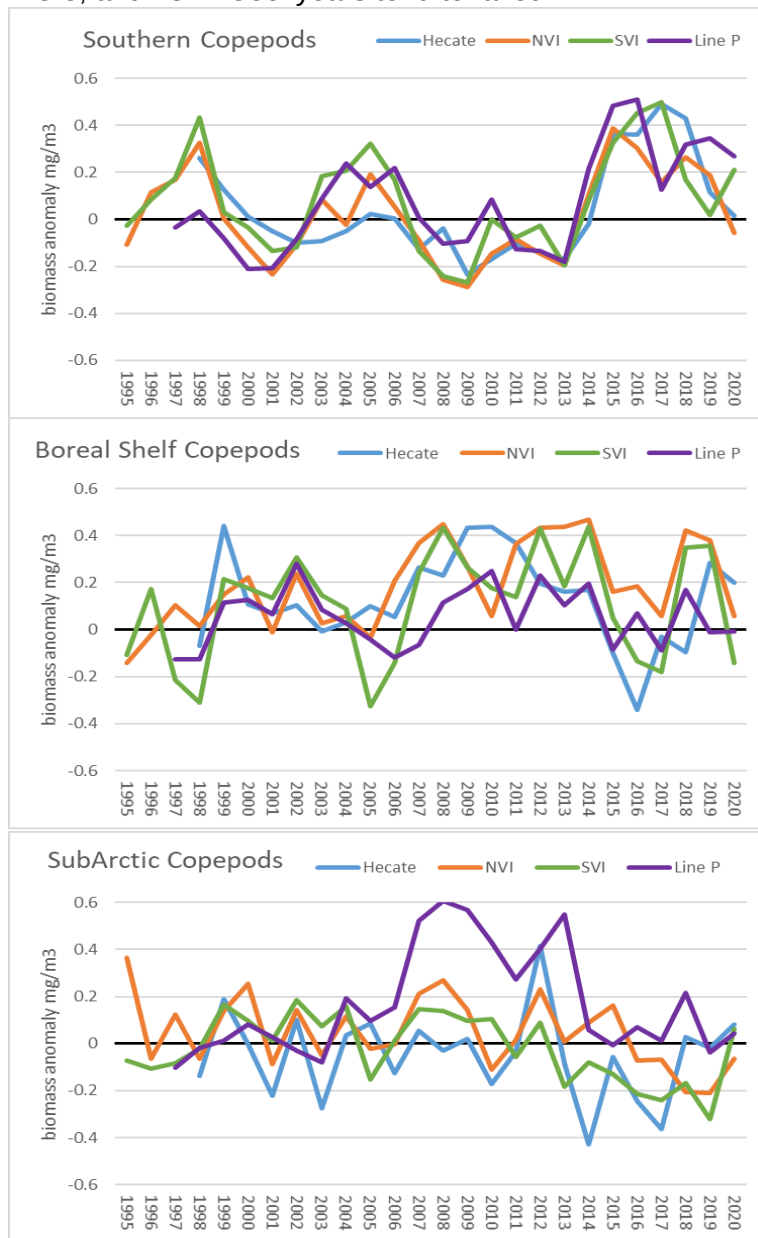


Figure 18-2. Zooplankton species-group anomaly time series for the regions shown in Figure 18-1. Line graphs are annual log scale anomalies. Southern Vancouver Island (SVI) green; Northern Vancouver Island (NVI) orange; Hecate Strait blue; Line P purple - for all graphs. Blank years mean no samples were collected.

Southern region of Vancouver Island and Line P had positive anomalies for southern copepods (Figure 18-2), southern chaetognaths (Figure 18-3), and doliolids (not shown).

Biomass increased throughout the year as warm nearshore water, with higher abundances of southern oceanic zooplankton species, moved poleward. However, the 2020 biomass anomaly was not as strong as in previous marine heatwaves, most likely mitigated by winter cooling via a La Niña.

Boreal copepods and subarctic copepods trended towards average (increase in subarctic and decrease in boreal) in all areas with SVI slightly negative for boreal copepods. Southern copepod anomalies were positive in all regions, but not as strong as in 2014-2018 and were negative for NVI in 2020 (Figure 18-2, top panel).

There has been above average biomass of southern chaetognaths since 2014, the start of a series of warming events off the west coast. This year, southern chaetognaths were prevalent in all areas but started to decrease in abundance, especially in NVI and Hecate (Figure 18-3, bottom panel). *Parasagitta elegans* (northern chaetognath) biomass had started to increase,

nearing average values in 2019 then decreasing to below average in all areas except Hecate in 2020 (Figure 18-3, top panel). The majority of southern copepods and chaetognaths occurring in BC waters are epipelagic, nearshore taxa; therefore, the two graphs (Figure 18-2, top panel and Figure 18-3, bottom panel) appear very similar, moving in sync within the warm water masses.

Euphausiids had generally positive anomalies off the west coast of Vancouver Island but since 2018 trended towards average biomass which continued in 2020 (Figure 18-4). *Euphausia pacifica* is a shelf break to oceanic species whereas *Thysanoessa spinifera* is a shelf species. Therefore, the lower biomass anomaly of *T. spinifera* along Line P was not unexpected; and it was replaced by *T. inspinata* in the offshore/oceanic areas. Hecate would be the northern extent of *T. spinifera* range where it is replaced by *T. inermis* and *T. longipes*. Euphausiid species whose distribution centers off Oregon/California (*Thysanoessa gregaria* and *Nematocelis difficilis*) continued to be found along the Vancouver Island shelf edge, in low numbers compared to previous years (data not shown).

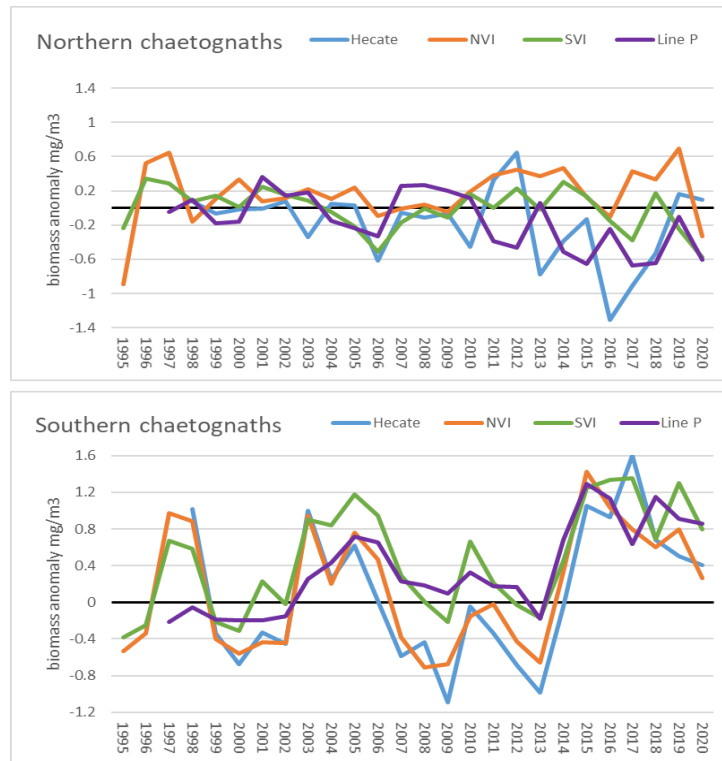


Figure 18-3. Chaetognath anomaly time series (vs climatological baseline) for all the regions. Chaetognaths divided into northern (top) and southern (bottom) species groups. Blank years mean no samples were collected.

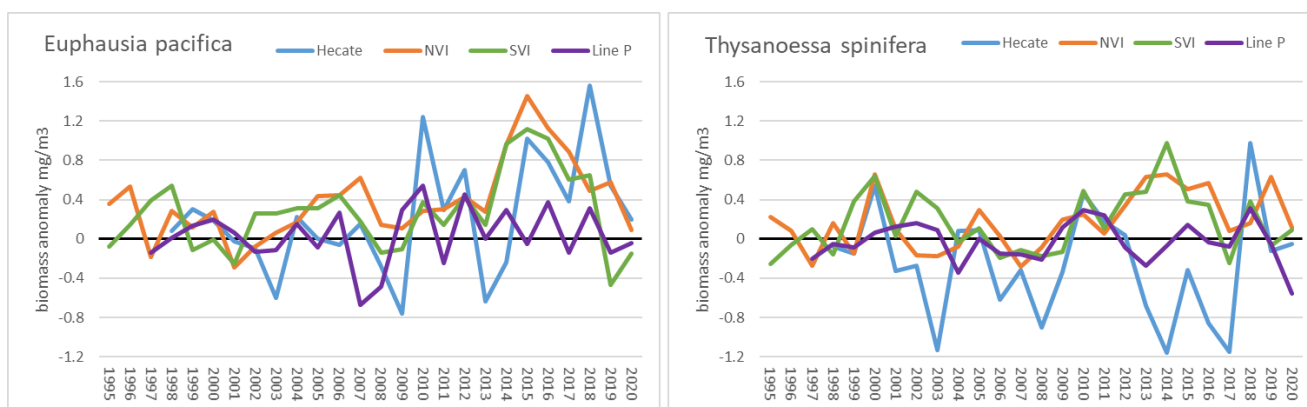


Figure 18-4. Euphausiid biomass anomaly time series (vs climatological baseline) for all the regions shown in Figure 18-1. Euphausiid biomass corrected for day/night sampling. Blank years mean no samples were collected.

Larvaceans, doliolids, siphonophores and hydromedusae biomass anomalies continued to be positive for 2020 in all regions. There was a sharp decrease in ctenophore biomass across all regions, beginning in 2019 and continuing into 2020. This had a moderating effect on the CSIndex or “Crunchies (crustacean): Squishies (gelatinous)” Index (see Galbraith and Young 2019 for detailed explanation) through the averaging of regional data. For Line P, the cnidarian community did not show much change. Doliolids were found at the inner Line P stations (P4-P12) and the offshore area of Vancouver Island; not on the shelf or in Hecate. There were influxes of salps at the outer stations of Line P (P20 and P26). Doliolids and salps had been increasing since 2014 in the gelatinous community in Hecate Strait (Figure 18-5), but appeared to be replaced by siphonophores and larvaceans in 2020.

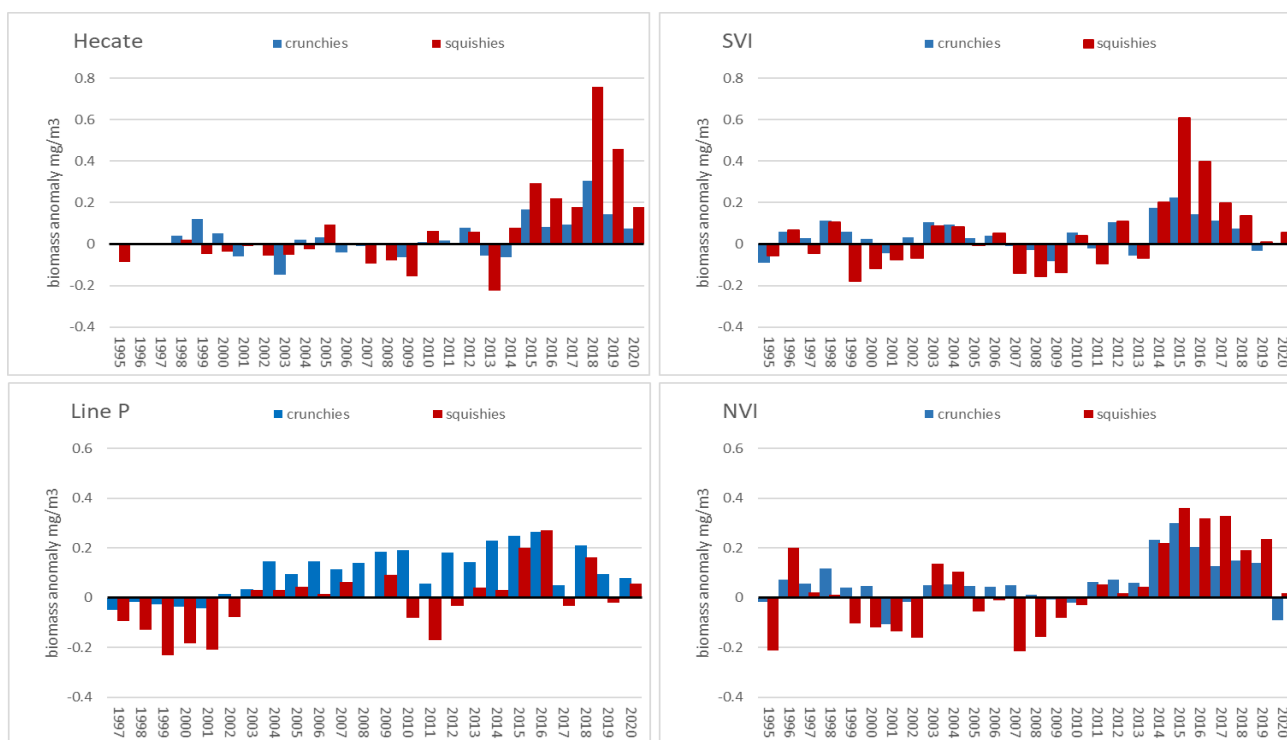


Figure 18-5. CSIndex: Comparing the gelatinous zooplankton (i.e. squishies) versus arthropod taxa (i.e. crunchies, ignoring meroplankton and removing southern crustacean species) biomass anomalies, within grouping and then by area. Note the different scales on the y-axes.

All areas showed positive crunchie and squishy biomass anomalies but reduced from 2019 overall except for NVI where it was negative for crunchies (Figure 18-5). The index reflects a return to average biomass contributions which would imply lower biomass overall for 2020 in comparison to previous years. Pteropods were removed from this years' squishies category as they appear to be reacting to different physical parameter(s) whereas the CSIndex basically tracks changes in community structure due to oceanic sea surface temperatures and salinities.

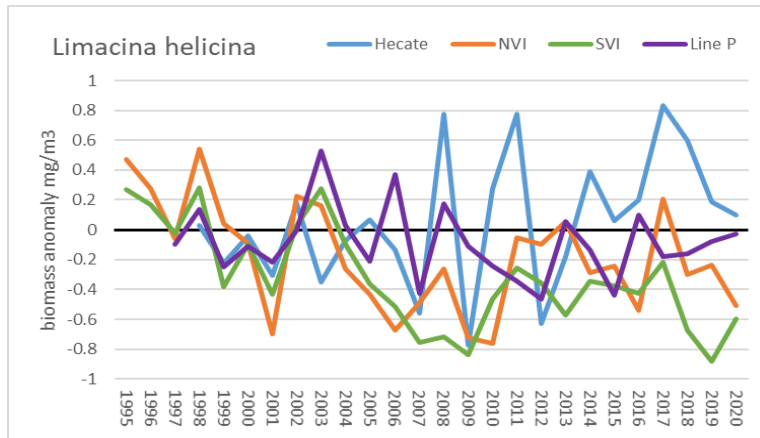


Figure 18-6. Pteropods, mainly *Limačina helicina*, biomass anomalies, by area.

Thecosomatous pteropods (e.g. *Limačina helicina*) are planktonic snails. Unlike the previous two groups, their bodies are not gelatinous, but they use a large external gelatinous feeding web to capture their food. Long term trends of *L. helicina* are declining over all areas, except Hecate and Line P (Figure 18-6). R^2 for the linear trends of SVI and NVI were 0.45 and 0.18, respectively.

18.4. Implications of those trends

Overall, 2020 saw movement down towards historical average biomass of the boreal/subarctic community, with a return to near-average in the biomass crustaceans and gelatinous animals, in most regions. The decrease to near average in euphausiid biomass anomalies, coupled with the decline in boreal copepods (high lipid) and the inundation of southern zooplankton species (e.g., southern copepods and southern chaetognaths), may be of concern for larval fish, juvenile fish (especially out-migrating juvenile salmon), and planktivorous sea birds. Although near average, the lower 2020 biomass (in comparison to previous years) could equate to potential match/mismatch for the animals that rely on the spring and summer bonanza of crustaceans in the shelf areas. Average to negative biomass for crustaceans may link to poor survival of juvenile fish and seabirds in 2020.

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19. LOWER TROPHIC LEVELS IN THE NORTHEAST PACIFIC

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19.1. Highlights

- Mean Copepod size (an index of community composition) remained small in 2020 in both the offshore and shelf regions, this has been the case since the marine heatwave (2014-2016).
- Phytoplankton community indicators appear to be returning to values of pre-heatwave (2014-2016) in both regions.
- Sampling using the Continuous Plankton Recorder (CPR) has been able to continue during the COVID-19 pandemic due to its semi-autonomous methodology.

19.2. Sampling

Sampling from commercial ships towing a CPR occurred approximately monthly, 6-9 times per year between March and October in the NE Pacific (Figure 19-1) continuing a time series that begun in 2000. Each CPR sample contained the near-surface (about 7 m depth) plankton from an 18.5 km length of transect, filtered using 270 µm mesh, and afterwards analyzed

microscopically to give taxonomically resolved abundance data.

Fortunately, the 2020 CPR sampling has not been impacted by the COVID-19 pandemic; since CPR sampling is semi-autonomous, the ships have been comfortable in taking the equipment on board and deploying it. All 2020 tows were completed as scheduled (Figure 19-1, see yellow circles), however there is a delay in the lab-based microscope analysis of the samples due to lab restrictions that have occurred (and are still ongoing) because of the COVID-19 pandemic. 2020 data (where shown) are therefore provisional and likely to change.

Sea Surface Temperature (SST) data from 2000 to 2020 were

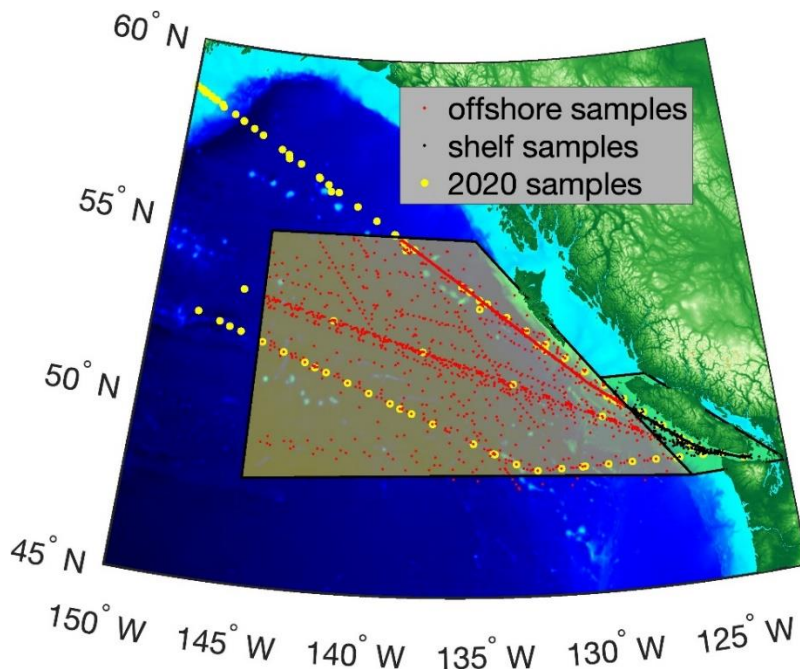


Figure 19-1. Map showing the location of historic CPR samples (2002-2019) red = offshore, black = shelf. Yellow circles are the location of the 2020 samples.

obtained from the International Comprehensive Ocean-Atmosphere Data Set (ICOADS, 1° enhanced data, www.esrl.noaa.gov/psd/data/gridded/data.coads.1deg.html) for each region to characterize the physical environment.

19.3. Description of the Plankton Time Series

19.3.1. Phytoplankton

The CPR effectively retains larger phytoplankton cells, especially chain forming diatoms and hard-shelled dinoflagellates, and several time series are generated which reflect abundance and community composition changes in the offshore and shelf regions: i) mean monthly diatom abundances, ii) broad community composition, and iii) mean annual Community Temperature Index (CTI) using each taxon's mean abundance and Species Temperature Index (STI; mean temperature in which the taxon was found in CPR samples with in situ temperature recorded; taxa found in warmer waters have a higher STI than taxa found in colder waters).

19.3.2. Zooplankton

Mesozooplankton, especially crustacea, are well sampled by the CPR and several zooplankton time series are generated: i) total zooplankton abundance, ii) taxon specific lengths and abundances are used to calculate the mean copepod length each month, and iii) annual mean zooplankton abundance for zooplankton groups of interest, such as warm water species.

19.4. Status and Trends

19.4.1. Phytoplankton

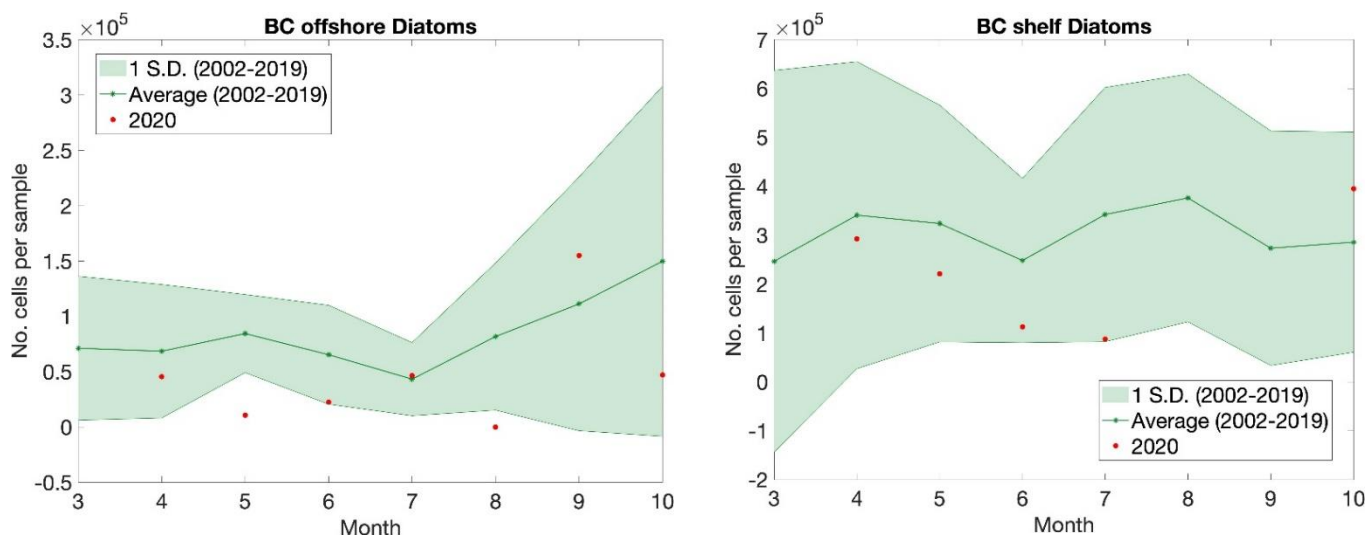


Figure 19-2. Monthly mean Diatom abundances for 2020 (red circles) overlaid on historical means (2000-2019, solid green line) offshore (left) and on the shelf (right). Shaded green area shows 1 standard deviation (S.D.) around the long-term mean. Note: 2020 data are provisional.

Diatom abundance in the offshore was slightly lower in May and August of 2020, but within one standard deviation of the average for all other months. In the shelf region, diatom abundance in all months sampled in 2020 was not significantly different from the long-term average (Figure 19-2).

The SST recorded in both regions in 2020 was still relatively warm, though not as warm as 2015 and 2019. The 2020 phytoplankton community composition was similar to that of 2015-16 in the offshore, and 2005 on the shelf. There was a relatively high proportion of round, centric-type diatoms compared to rod-like diatoms and dinoflagellates on the shelf, and fairly even numbers of round and rod-like diatoms in the offshore (Figure 19-3).

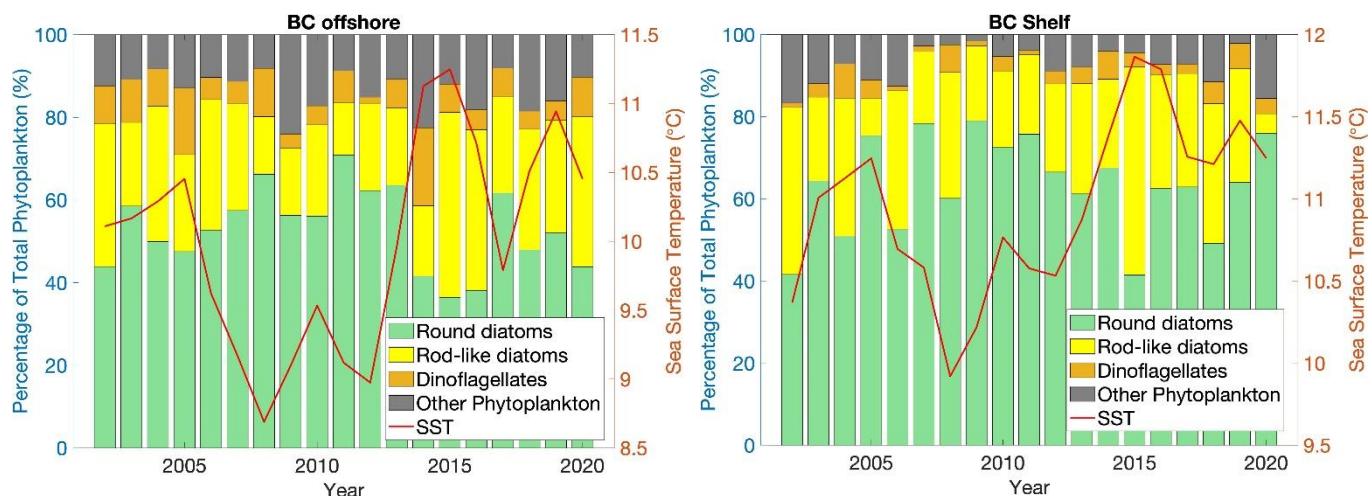


Figure 19-3. Contribution of each group to the mean annual phytoplankton community offshore (left) and on the shelf (right). SST is shown in red (right-hand axis, °C). Note: 2020 data are provisional.

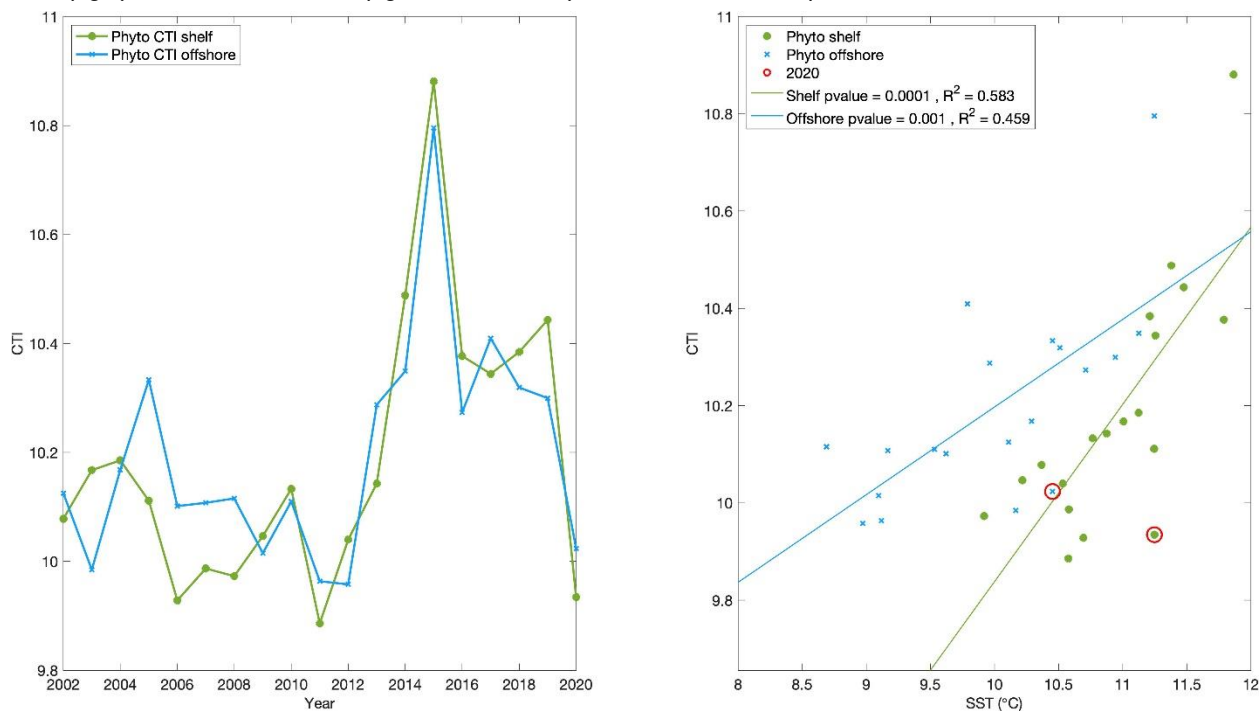


Figure 19-4. The mean annual phytoplankton Community Temperature Index for each region (left) and the relationship between SST and CTI (right). Note: 2020 data are provisional.

Both offshore and shelf regions show similar trends in phytoplankton CTI which correlate with observed SST; warmer communities in the mid-2000s, cooler communities in the 2007 to 2013

period before reaching a maximum in 2015 (Figure 19-4). The CTI values for 2020 are similar to the long-term average CTI values, and are much lower than recent years.

19.4.2. Zooplankton

Zooplankton abundance was above average in May 2020 in the offshore region, and April on the shelf. But it was likely below average in late summer for both regions. While the offshore saw a close to average copepod size seasonal profile (larger copepods in spring, smaller in summer) the shelf region saw communities biased towards smaller species than average throughout the year, however these results are not significantly different as they are within 1 standard deviation of the mean (Figure 19-5). The anomalously high zooplankton abundance and low copepod length in May 2020 in the offshore region was driven by high counts of *Pseudocalanus spp.*, which are relatively small copepods (Figure 19-5).

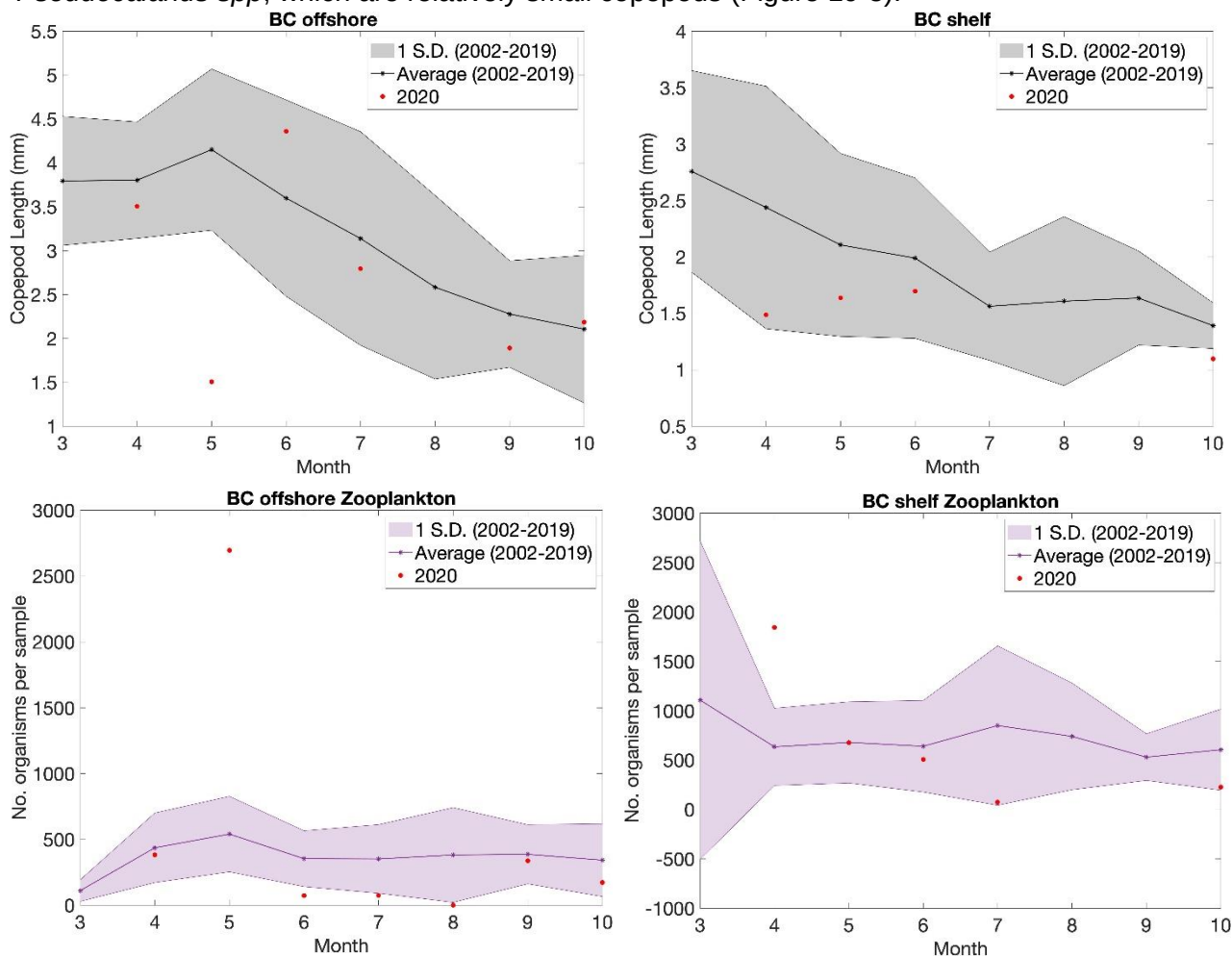


Figure 19-5. Monthly mean copepod size (top, black) and monthly mean zooplankton abundance (bottom, purple) from 2002-2019 and monthly means in 2020 (red circles) for the offshore (left) and shelf (right) regions. Shaded area shows 1 standard deviation around the long-term mean. Note: 2020 data are provisional.

The annual mean warm water copepod abundance for 2020 was low on the shelf but still relatively high in the offshore region (Figure 19-6). The annual mean size of copepods in both regions remained small in 2020 (Figure 19-6). Low numbers of salps and doliolids (gelatinous

plankton) were recorded in 2020 in both regions, though the CPR only catches small ones (Figure 19-6).

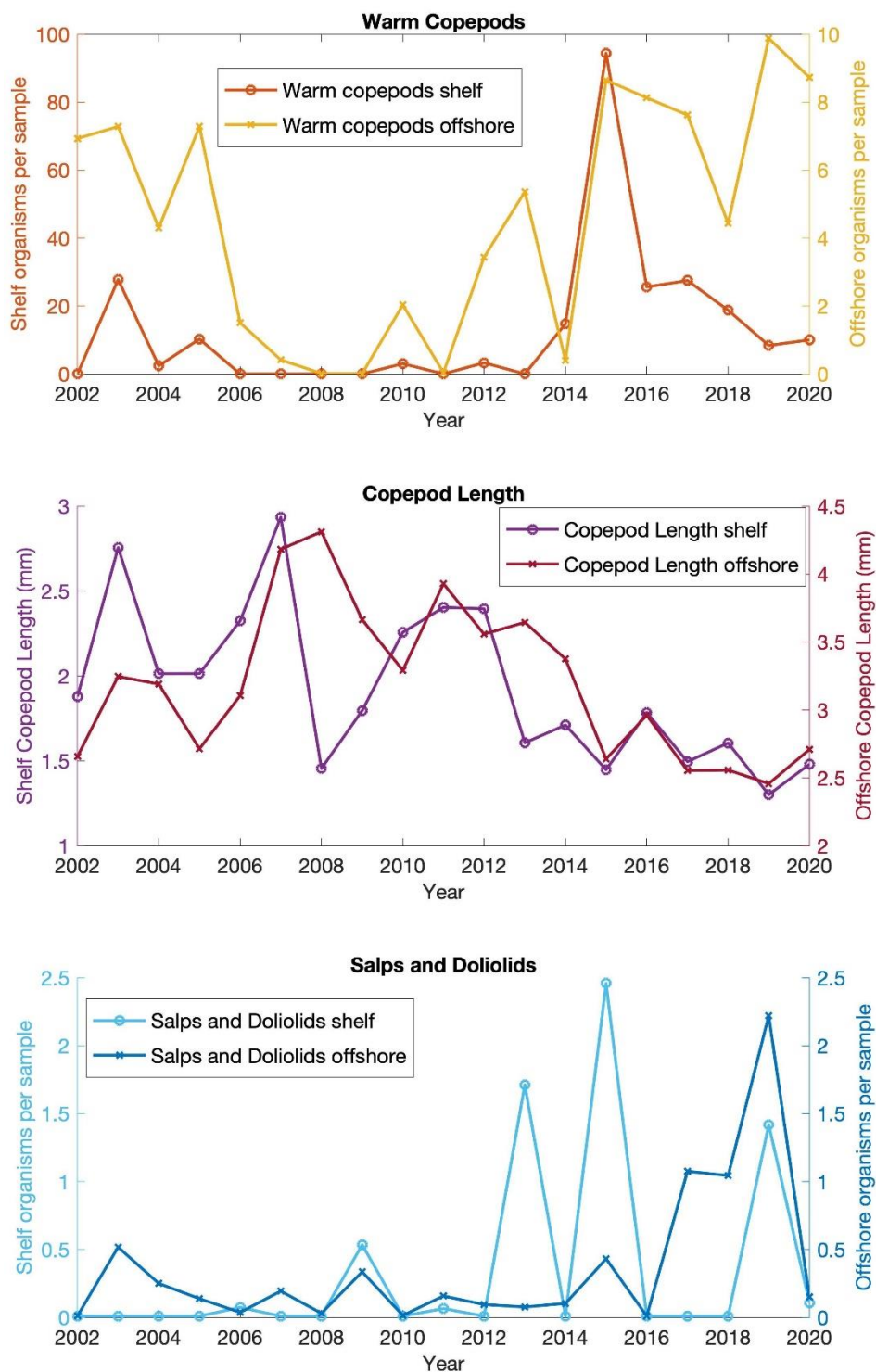


Figure 19-6. The mean annual abundance of warm water copepods (top), copepod length (middle), and salp and doliolid abundance (bottom) for both the shelf (left axis) and offshore (right axis) regions of BC. Note: in March 2019 high numbers of thecosomes (a small pteropod) on the shelf were reported though not plotted here. Note: 2020 data are provisional.

19.5. Factors Influencing the trends

Although ocean temperatures were still relatively high in 2020 (Figure 19-3), the phytoplankton communities appear to be returning to average values (Figure 19-4) following the marine heatwave of 2014-2016 (DiLorenzo and Mantua 2016). However, the size of the copepods in both regions remained small in 2020, this trend has been apparent since the marine heatwave (Figure 19-6).

Increased stratification and lower nutrients can affect the phytoplankton composition by promoting growth of smaller and narrower cells because of a relatively larger surface area over which to absorb nutrients. In turn, the size and composition of the phytoplankton will impact the zooplankton that are able to feed on them, and so the effects pass up the food chain.

19.6. Implication of these trends

Warmer water favours certain taxa over others, as seen by the fact that warmer water taxa are more prevalent and there are higher CTI values during warm years. Such communities may apparently persist for several years after a heatwave event, especially if waters remain warm, however it appears that after 7 years of warmer conditions, some plankton communities might be returning to average values. However, the reduction in large copepod abundance on the shelf and offshore regions is still apparent and will likely influence the food web functioning, creating nutritional impacts on zooplankton predators (e.g. fish and some seabirds) since these copepods store more lipids. While we cannot be certain how changing taxonomic composition of the prey affects predators via nutritional contributions to their diet, there is likely to be some impact.

19.7. References

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20. EULACHON STATUS AND TRENDS IN SOUTHERN B.C. AND LOWER FRASER RIVER DIDYMO OBSERVATIONS

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20.1. Highlights

- In 2020, the Fraser River Eulachon egg and larval survey index of Eulachon spawning stock biomass was estimated to be relatively high (~624 tonnes), approximately equal to the 2001 index and higher than all years since 2001.
- In 2020, the freshwater benthic diatom known as Didymo was confirmed to be a major component of the material collected in the Fraser River Eulachon egg and larval survey water samples.
- There was no 2020 spring west coast of Vancouver Island multispecies bottom trawl survey, therefore no 2020 Eulachon marine survey observations; however, additional analyses of Eulachon catch per unit effort (CPUE) and standard length data from 2000-2019 surveys were done to statistically weight catch levels and biological samples by the number of Eulachon caught by fishing event. Revised trends confirm moderate increases in CPUE in 2019 for relatively small (≤ 12.5 cm) and large (> 12.5 cm) Eulachon.

20.2. Description of indices

Eulachon (*Thaleichthys pacificus*) trends used to monitor population dynamics over time are based on indices from:

- 1) An annual springtime Fraser River Eulachon egg and larval survey (1995 to 2020) used to characterize spawner abundance (Hay et al. 2002; McCarter and Hay 2003).
- 2) Eulachon catches and catch samples from spring small-mesh multispecies bottom trawl surveys off the west coast of Vancouver Island (WCVI, 1973-2019) and in the Queen Charlotte Sound (QCS, 1998-2012, 2016).
- 3) In river catches of spawning Eulachon from past commercial fishing in the Fraser River (1900-2004), in the Columbia River (1888-2010 and 2014-2015), and from standardized gillnet surveys in the Fraser River (1995-2004 and 2017-2020; not reported here).

Didymo (*Didymosphenia geminata*) was detected in notable amounts in Lower Fraser River Eulachon egg and larval survey water samples and a subset of 2020 water samples was analysed to characterize trends in Didymo density and outflow over the survey season.

20.3. Status and trends

20.3.1. Eulachon

Long-term declines of spawning Eulachon have been observed in many rivers throughout their distribution from California to Alaska in the past 2-4 decades. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed Eulachon in British Columbia as three designatable units (DUs) in 2011: the British Columbia Central Coast and Fraser River DUs

were assessed as endangered, and the Nass/Skeena DU was assessed as a species of special concern (COSEWIC 2011, 2013).

Eulachon is an important First Nation fishery resource and in-river Eulachon Food, Social and Ceremonial fisheries have occurred in years up until and including 2020 (DFO 2020). Commercial fishing for Eulachon has been closed since 2004 but there was an active commercial fishery for Eulachon in the Fraser River for over 90 years until a closure in 1997, followed by temporary openings in 2002 and 2004 (DFO 2020).

In 2020, the index of Eulachon spawning stock biomass in the Fraser River was estimated to be relatively high (~624 tonnes), approximately equal to the 2001 index and higher than all years since 2001 (Figure 20-1).

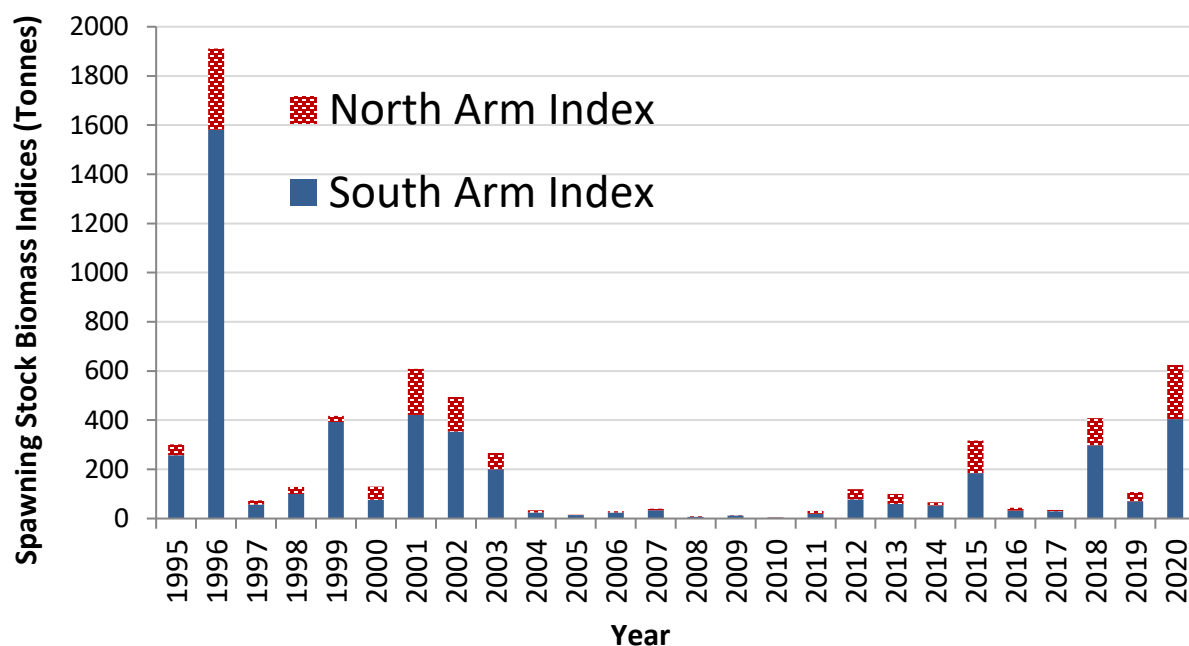


Figure 20-1. Estimated spawning stock biomass indices (SSB in tonnes) of Eulachon from the South and North Arms of the Fraser River, 1995-2020.

The 2020 spring WCVI multispecies bottom trawl survey was canceled due to concerns over the COVID-19 pandemic so 2019 was the most recent year of observations. Additional analyses of Eulachon CPUE and standard length data were conducted for years when samples of Eulachon size by fishing event were available (2000-2019). These analyses were used to statistically weight observed fish length distributions by each year's estimates of Eulachon numbers caught by fishing event (Figure 20-2, bottom panel and Figure 20-3, left panel). This was done in contrast to past annual reporting of Eulachon CPUE trends as mean weight (and 95% CI) per fishing time (kg/hr, Figure 20-2, top panel) and pooled fish length observations across all fishing events (Figure 20-3, right panel).

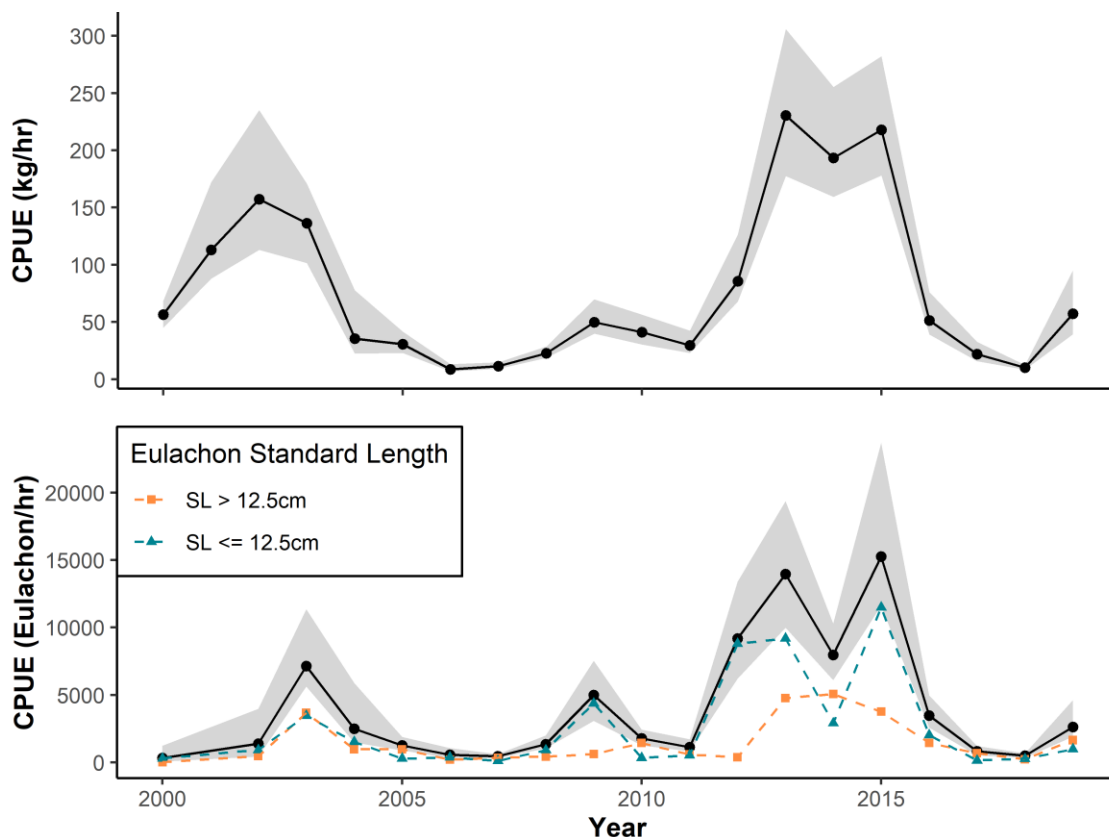


Figure 20-2. Eulachon mean CPUE from spring WCVI multispecies trawl surveys (2000- 2019) and 95% studentized bootstrap confidence intervals (gray envelopes), as weight per trawl tow duration (kg/hour, top panel) and number of fish per tow duration (bottom panel). Dashed lines represent mean catch number per unit effort of Eulachon greater than 12.5 cm standard length (orange squares) or less than or equal to 12.5 cm standard length (blue triangles).

Based on modal trends in fish length frequencies (Figure 20-3), CPUE observations were divided into two size groups, fish ≤ 12.5 cm and fish > 12.5 cm. Annual Eulachon standard length frequency distributions are represented in two ways. One way shows statistically unweighted standard length frequency histograms (Figure 20-3, right panel) where fish length observations were pooled across all fishing events (therefore each fish specimen observation has equal statistical weight and total catch of Eulachon per fishing event is irrelevant). The other way shows standard length frequency histograms where samples of fish length observations were statistically weighted by the estimated total number of Eulachon caught in each fishing event and standardized by the fishing duration (in hours) of each fishing event (Figure 20-3, left panel). This method of weighting resulted in a shift to more small-sized Eulachon for several surveys years (i.e. 2000, 2008, 2009, 2011, 2012, and 2013).

20.3.2. *Didymo*

Since 2018, the spring Fraser River Eulachon egg and larval survey has collected relatively high densities of a fine fibrous material that was initially believed to be wood fibers. In 2020, the freshwater diatom known as *Didymo* was confirmed to be a major component of the material. In following laboratory methods described in Hillebrand et al. (1999), preliminary analyses were conducted on a subset of 17 water samples collected biweekly from April 10-June 4, 2020.

Specimens from oblique sampling of the top 10 meters of a mid channel New Westminster site were conducted to characterize trends in Didymo density and outflow over the survey period.

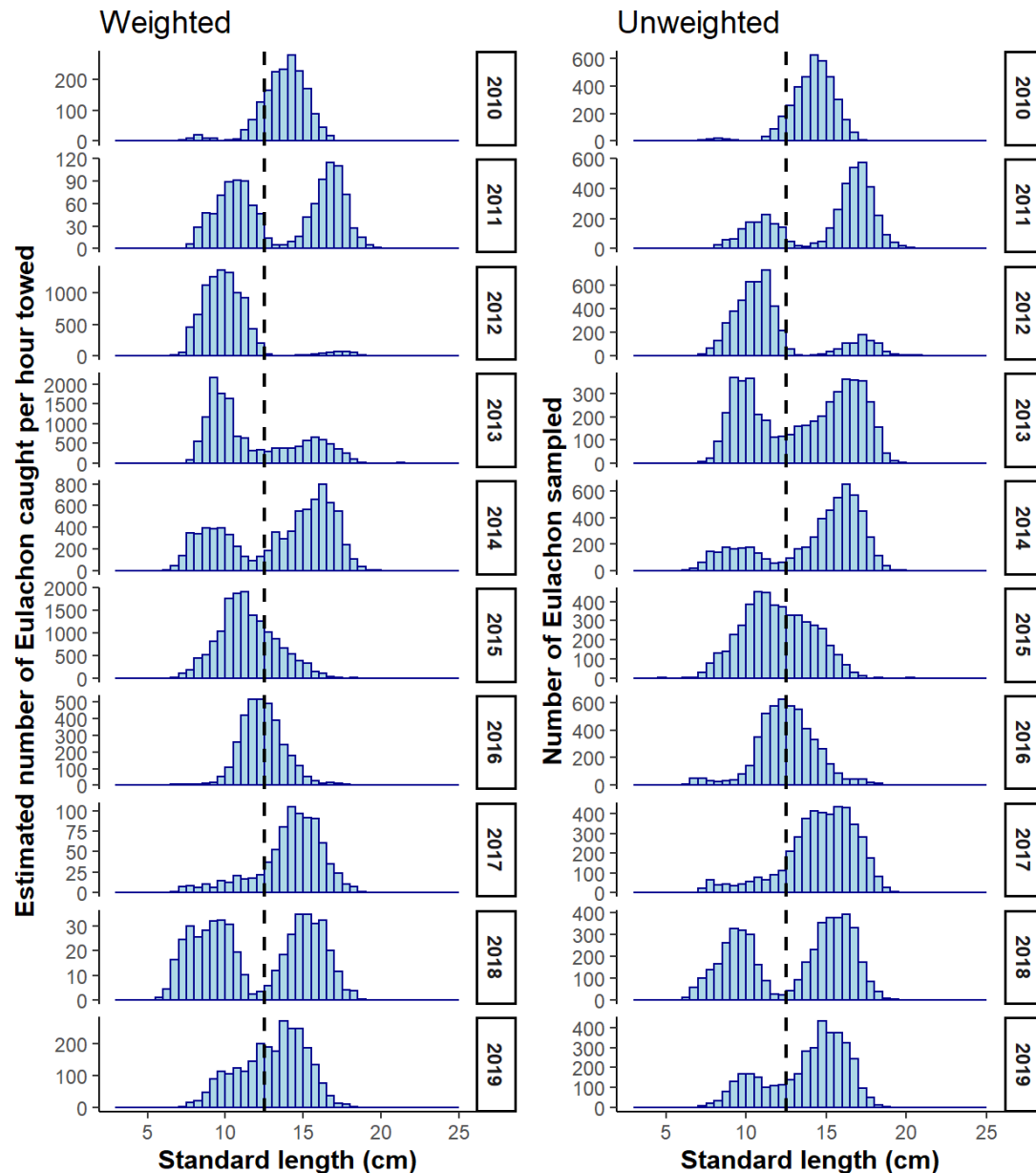


Figure 20-3. Eulachon standard length frequency histograms (cm) from 2010-2019 WCVI survey samples. Left panel: fish length observations were statistically weighted by the estimated total number of Eulachon caught in each fishing event and standardized by the fishing duration. Right panel: statistically unweighted standard length frequency histograms, where fish length observations were pooled across all fishing events. Dashed vertical lines are visual markers at 12.5 cm to assist comparisons between positions and shapes of length distributions.

Three replicate subsampling fractions were analysed per water sample, where each fraction ranged from representing 1/25 to 1/3075 of the entire sample. This subset of survey samples was selected because: 1) New Westminster sites are the least affected by tides compared to other downstream sites in the north and south arms; 2) observations from oblique water

sampling were thought to be most conducive to calculating Didymo outflow rates from densities estimates; and 3) the north and south arm samples were being analysed to count Eulachon eggs and larvae required for the annual spawning stock biomass index.

Preliminary estimates of Didymo density ranged from ~ 0.1 to 20 mg/m^3 , showing an increasing trend after April 20th and a declining trend after May 7th. To characterize trends in Didymo outflow, each Didymo density estimate was multiplied by a respective Fraser River daily mean discharge rate (Water Survey of Canada Hope, B.C., Station 08MF005), multiplied by the number of seconds in a day (86,400) and converted to kg/day (Figure 20-4). Preliminary estimates of daily Didymo biomass outflow rates ranged from ~ 6 to $10,125 \text{ kg/day}$ with a maximum relative standard error (RSE) of 33.04% (mean RSE 10.82%), showing a similar pattern to trends in density estimates with a peak in outflow on April 30th (Figure 20-4).

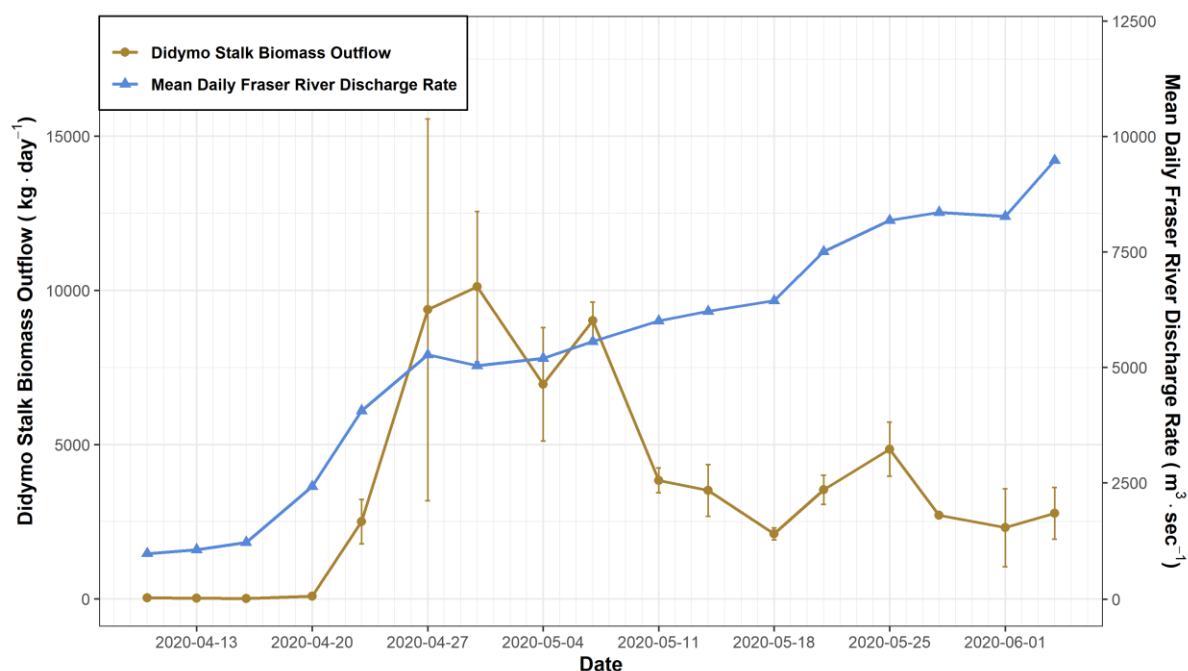


Figure 20-4. Trends in *Didymosphenia geminata* (Didymo) outflow estimates (kg/day) from oblique water sampling of the top 10 meters from a New Westminster mid channel Fraser River sampling site (brown trend line with circles). Error bars represent two standard errors from the mean. Also shown are mean daily Fraser River water discharge rates (m^3/sec) from the Water Survey of Canada Station 08MF005 in Hope, B.C. (blue trend line with triangles).

Reported Didymo outflow estimates are underestimates because New Westminster daily river water discharge rates are greater than discharge rates recorded at Hope (there are several tributaries between Hope and New Westminster). Furthermore, macroscopic observations from other sites where water sampling was conducted at targeted depths of surface, 5 m and 10 m suggest Didymo density increased with proximity to the river bottom. Estimates of bottom depths recorded when the New Westminster mid channel sampling was conducted ranged from 13.4 m to 17.9 m (with a mean of ~ 16 m); therefore oblique sampling of the top 10 m of the water column overrepresented surface waters and omitted representing the depths of the river expected to have the greatest Didymo loads. Additional sample analyses are planned with limited resources to obtain Didymo density and outflow estimates associated with other survey

sites and sampling depths and to further explore degrees of error associated with water sample subsampling.

20.4. Factors causing those trends

20.4.1. *Eulachon*

There is considerably high uncertainty associated with the ecology and stock dynamics of Eulachon. The relatively high 2020 Eulachon spawner index from the egg and larval survey was not anticipated and the reasons for the large interannual variation in spawner index estimates in recent years is not well understood. It is uncertain what age range and composition comprise the spawning stock each year and to what degree spawning stocks and cohorts may mix and be under metapopulation influences. It is generally believed that most Eulachon die after spawning but there is some evidence to suggest that some individuals (especially females) may repeat spawn (Dealy and Hodes 2019).

For years when low Eulachon spawner levels are evident, it is stated in Schweigert et al. (2012) that “no single threat could be identified as most probable for the observed decline in abundances among DUs [designatable units] or in limiting recovery. However, mortality associated with coastwide changes in climate, fishing (direct and bycatch) and marine predation were considered to be greater threats at the DU level, than changes in habitat or predation within spawning rivers.”

20.4.2. *Didymo*

Didymo observed in the Lower Fraser River originates in upper watershed rivers and streams where it can rapidly grow on substrates during periods of good light penetration. Its presence in the Lower Fraser River is attributed to it being flushed downstream following spring rain and snowmelt associated with freshet conditions. The vast majority of Didymo biomass is the stalk material that is primarily composed of polysaccharides and generally believed to be highly resistant to decay. It is also a species that can outcompete other algal species by its ability to grow in freshwater environments with reduced nutrients. Increased growth of Didymo in upper water systems has been linked to longer growing seasons and shifts in periods of increased turbidity and nutrients linked to climate change (Brahney et al. 2021). The presence of large quantities of a fine fibrous material collected in Fraser River Eulachon egg and larval surveys since 2018, confirmed in 2020 to be related to Didymo, is consistent with the findings reported by Brahney et al. (2021) for upper watersheds in southeastern British Columbia.

An increasing trend in Didymo density and outflow from April 20th to May 7th is consistent with increases in river discharge rates at the early part of the freshet. The decreasing trend in Didymo estimates following May 7th may be due to decreases in upstream loads of loose Didymo as well as possible effects from gradual increases in river depth and increases in sampling distance from the river bottom. The effect of gravity is consistent with macroscopic water sample observations suggesting Didymo density increases with proximity to the river bottom.

There is considerable uncertainty associated with the reported Didymo estimates and trends. The Fraser River Eulachon egg and larval survey design is limited in its site, depth and seasonal representation to quantify and characterize Didymo density and outflow dynamics

throughout a season. For the 2020 sampling, a limited amount of resources were obtained to acquire preliminary observations. Estimates of *Didymo* density and outflow are expected to have large degrees of error based on extremely small subsampling fractions of each water sample.

20.5. Implications of those trends

20.5.1. *Eulachon*

Reduced biomass of *Eulachon* has negative implications for First Nations, commercial and recreational fishers. *Eulachon* are socially and culturally significant to many First Nations who have been harvesting *Eulachon* at low levels and commercial and recreational fisheries targeting *Eulachon* have been closed for over a decade (DFO 2020). Incidental capture of *Eulachon* in the marine environment has negative implications on trawl fisheries targeting other species, as trawl fisheries may be subject to area closures or reduced fishing effort to reduce *Eulachon* mortality.

Reduced *Eulachon* abundance also likely has negative impacts on their predators. Important predators of *Eulachon* include: marine mammals (particularly seals and sea lions at or near estuaries), Chinook and Coho Salmon, Spiny Dogfish, Pacific Hake, White Sturgeon, Pacific Halibut, Walleye Pollock, Sablefish, rockfish, Arrowtooth Flounder, and others (Levesque and Therriault 2011). Diet data time series of all animals in the ecosystem would improve our ability to examine temporal trends in predator-prey interactions and the implications of those trends.

20.5.2. *Didymo*

The extensive growth of *Didymo* in upper watersheds in British Columbia and high outflow of *Didymo* in the lower Fraser River have unknown and possibly negative implications to upper and lower watershed habitats and ecosystems. When environmental conditions are favourable, *Didymo* can aggressively colonize new habitat initiating a bloom.

Macroscopic observations and preliminary *Didymo* density and outflow estimates from 2020 *Eulachon* egg and larval survey samples suggest that, at minimum, several hundred tonnes of *Didymo* stalk material outflowed and were deposited to Lower Fraser River and estuary from April to early June. The actual cumulative outflow and deposition amounts may be in the order of thousands of tonnes with outflow and deposition continuing long after June 4, when the egg and larval survey ended, and when river water discharge rates were still on an increasing trend (Figure 20-4). Uncertainties in the magnitude of outflow and deposition amounts and their ecological impacts to freshwater and estuarine species in these habitats is concerning, especially given its slow rate of decomposition.

Relatively high densities of *Didymo* have negative implications for acquiring *Eulachon* spawning stock index estimates because the fibrous material overwhelms other components of the egg and larval survey water samples and makes viewing and counting eggs and larvae more time consuming, expensive and requiring subsampling strategies which introduce additional error (DFO 2020). Resources for obtaining *Didymo* observations from future *Eulachon* egg and larval surveys have not been identified.

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21. PACIFIC HERRING IN BRITISH COLUMBIA, 2020

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21.1. Highlights

- Estimated herring spawning biomass varied among assessed areas. Since 2000, Haida Gwaii biomass has been low with an increase in 2020. The 2020 biomass of the Prince Rupert District stock was similar to that of 2019. There was an increase in Central Coast and West Coast Vancouver Island biomass estimates in recent years. In 2020, the Strait of Georgia stock biomass was relatively high compared to historic levels.
- In recent years, there has been a continued increase of weight-at-age in all stocks, following a declining trend during approximately 1980 to 2010.
- Spawn timing for Pacific Herring can be mostly explained by the day length, the number of degree days over 5 °C and the mean salinity or temperature at the time of spawning.
- The location of spawning by herring is predictable within stocks using localized environmental conditions and the total biomass of the stock, but the local conditions determining the distribution of spawn appear to vary across stocks.

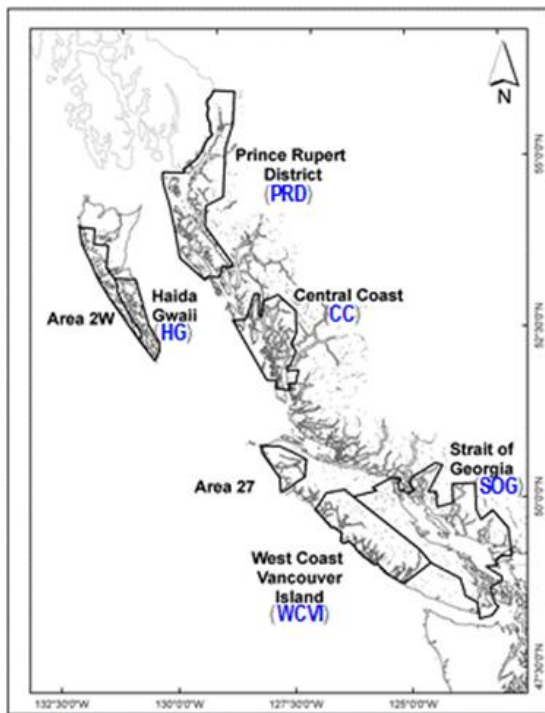


Figure 21-1. Location of the five major (Strait of Georgia, West Coast of Vancouver Island, Prince Rupert District, Haida Gwaii, and Central Coast) as well as two minor (Area 2W, and Area 27) Pacific Herring stocks in B.C.

21.2. Summary

In B.C., Pacific Herring are managed as five major stocks (Strait of Georgia, SOG; West Coast of Vancouver Island, WCVI; Prince Rupert District, PRD; Haida Gwaii, HG; and Central Coast, CC), and two minor stocks (Area 2W and Area 27) (DFO 2021; Figure 21-1). For each stock, herring population trends are based on model estimates of Pacific Herring biomass. Statistical catch-at-age models are fit to time series data: commercial and test fishery biological samples (age, length, weight, sex, etc.), herring spawn survey data (spawn index), and commercial harvest data. In 2021, the model was used to provide (in part) estimates of Pacific Herring spawning biomass and age-2 recruit abundances (DFO 2021). Herring biomass, recruit abundance, and weight-at-age are important indicators of stock status; however, there are additional considerations such as timing and distribution of spawn, which are currently being examined using a variety of machine learning and statistical methods. Readers are referred to DFO (2021) for important additional information regarding the status of B.C. Pacific Herring stocks.

21.3. Status and trends

In all five major herring stocks there was a declining trend in weight-at-age from the 1980s through 2010, with an increase in recent years (Figure 21-2). Since 2000, the HG stock has been in a low biomass state (DFO 2021). In 2019 and 2020, survey biomass increased; however, these estimates are highly uncertain due to high estimated natural mortality rates (DFO 2021). The estimated stock biomass for PRD has shown minimal trend from 2005 to 2018, with a modest increase in 2019. Survey biomass in 2020 is almost identical to 2019 (DFO 2021). The CC stock biomass and productivity was low from approximately 2005 to 2014. An increasing trend in CC biomass has been observed in recent years, but has higher interannual variability than was observed prior to 2005 (DFO 2021). The SOG spawning biomass increased and is relatively high compared to historic estimates (Figure 21-3). The estimated spawning biomass for the WCVI stock was low during 2004-2014; an increasing trend has been observed in recent years, but biomass remains low relative to historic levels (Figure 21-3).

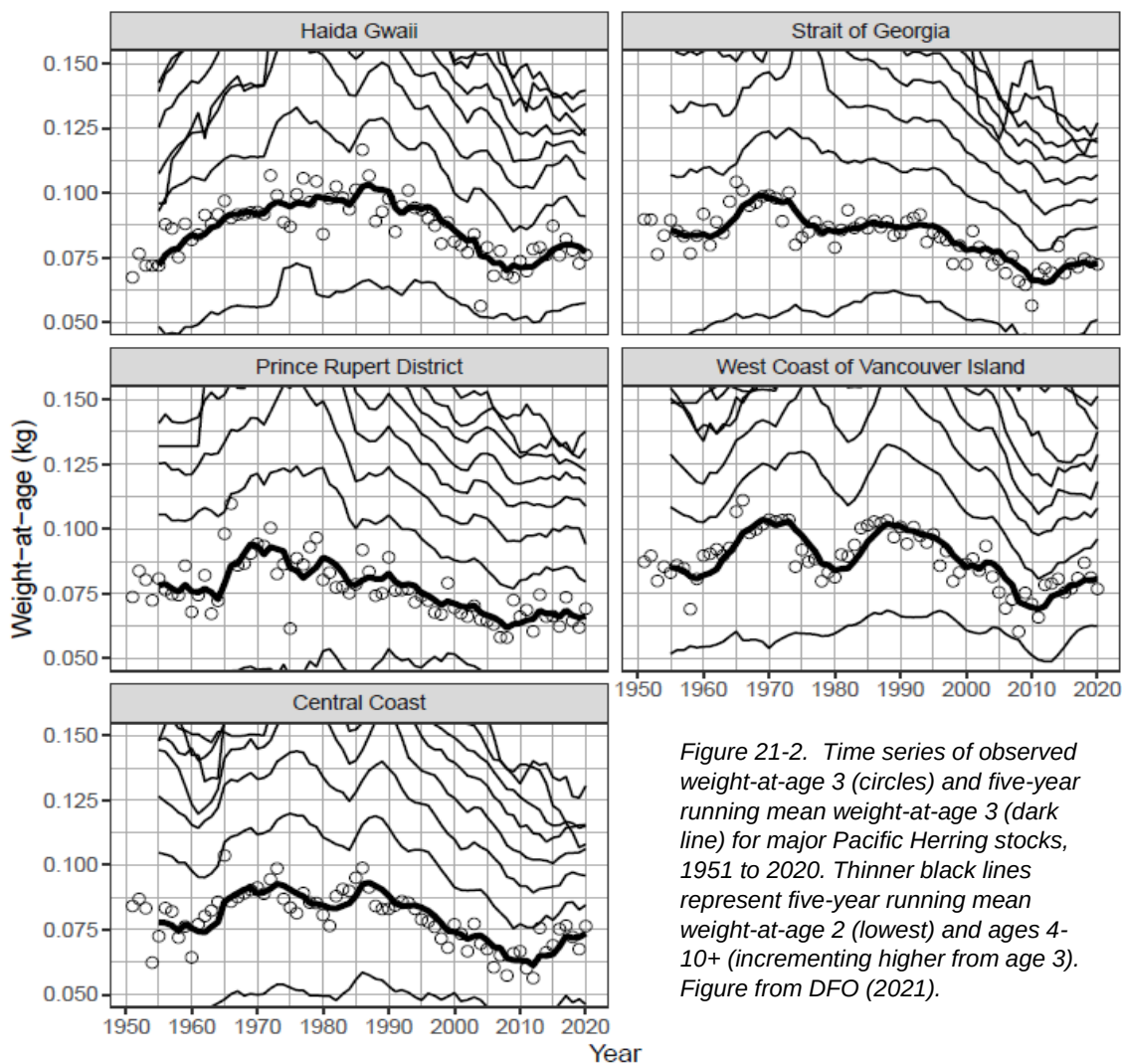


Figure 21-2. Time series of observed weight-at-age 3 (circles) and five-year running mean weight-at-age 3 (dark line) for major Pacific Herring stocks, 1951 to 2020. Thinner black lines represent five-year running mean weight-at-age 2 (lowest) and ages 4-10+ (incrementing higher from age 3). Figure from DFO (2021).

With the exception of the central coast stock of herring, spawning has occurred earlier in the year for herring stocks in B.C. This has ranged from spawning occurring about 5 days earlier

(on average) for the WCVI and PRD stocks to a spawning of about 10 days later for the CC stock. Spawn timing is affected by day length, number of degree days > 5 °C, salinity, slope of temperature over the previous month, slope of salinity over the previous month, and slope of salinity over the previous week (Figure 21-4).

The spatial distribution of spawning has varied among years for each of the stocks. Most of the spatial variability can be explained by expansion and contraction of the spawning area as the populations increase and decrease. However, some of the variability in realized spawning distribution can likely be explained by changing environmental conditions (Figure 21-5).

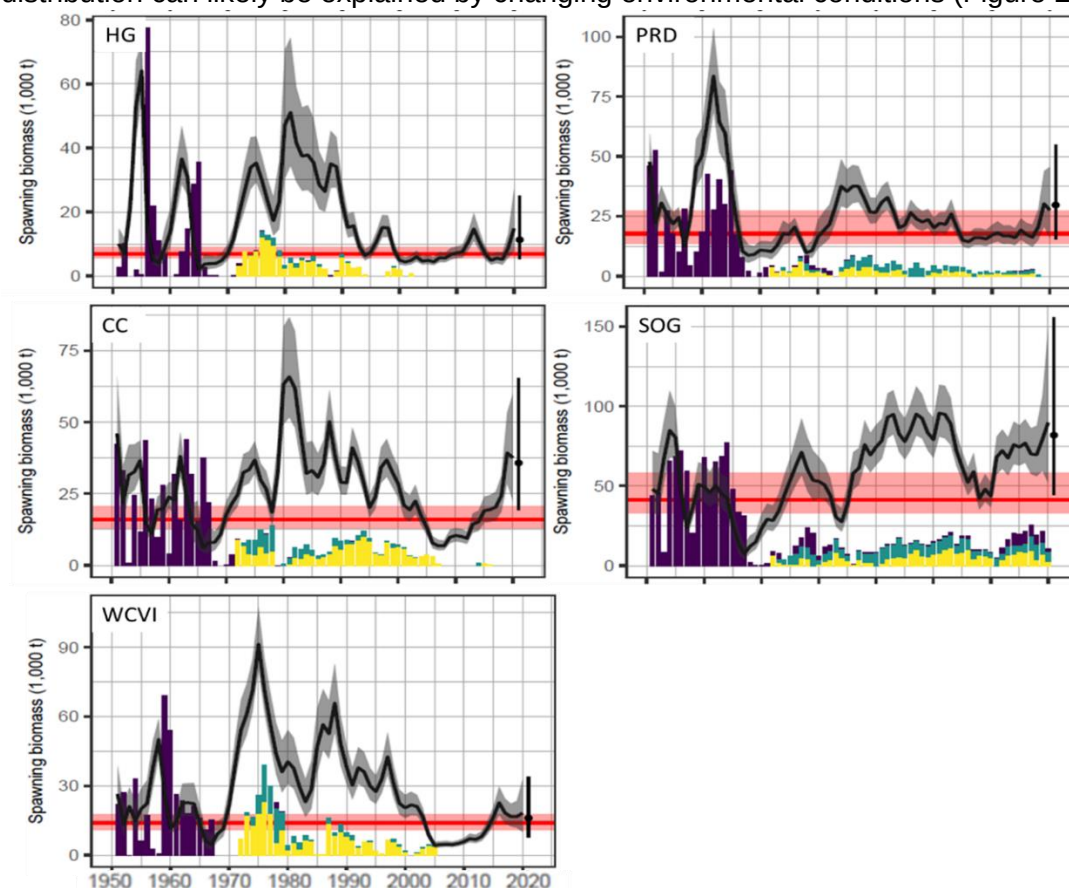


Figure 21-3. Summary of the dynamics of the five Pacific Herring stocks from 1951 to 2020, where solid lines with surrounding grey envelopes, represent medians and 5-95 % credible intervals. Also shown is the reconstruction of spawning biomass for each year, with unfished values shown at far left (solid circle and vertical lines) and the projected spawning biomass given zero catch shown at the far right (solid circle and vertical lines). Time series of thin vertical lines denote commercial catch (excluding commercial spawn-on-kelp; colours indicate different gear types; see DFO 2021). Red line= limit reference point ($0.3B_0$). B_0 = unfished biomass. Figure adapted from DFO (2021).

21.4. Factors influencing trends in herring biomass

Common trends in herring weight-at-age observed for all stock areas suggests that large-scale factors may be influencing herring. Changes in environment, food supply and quality, predator abundance, and competition are factors that could affect trends in herring biomass and weight-at-age (Schweigert et al. 2010; Hay et al. 2012).

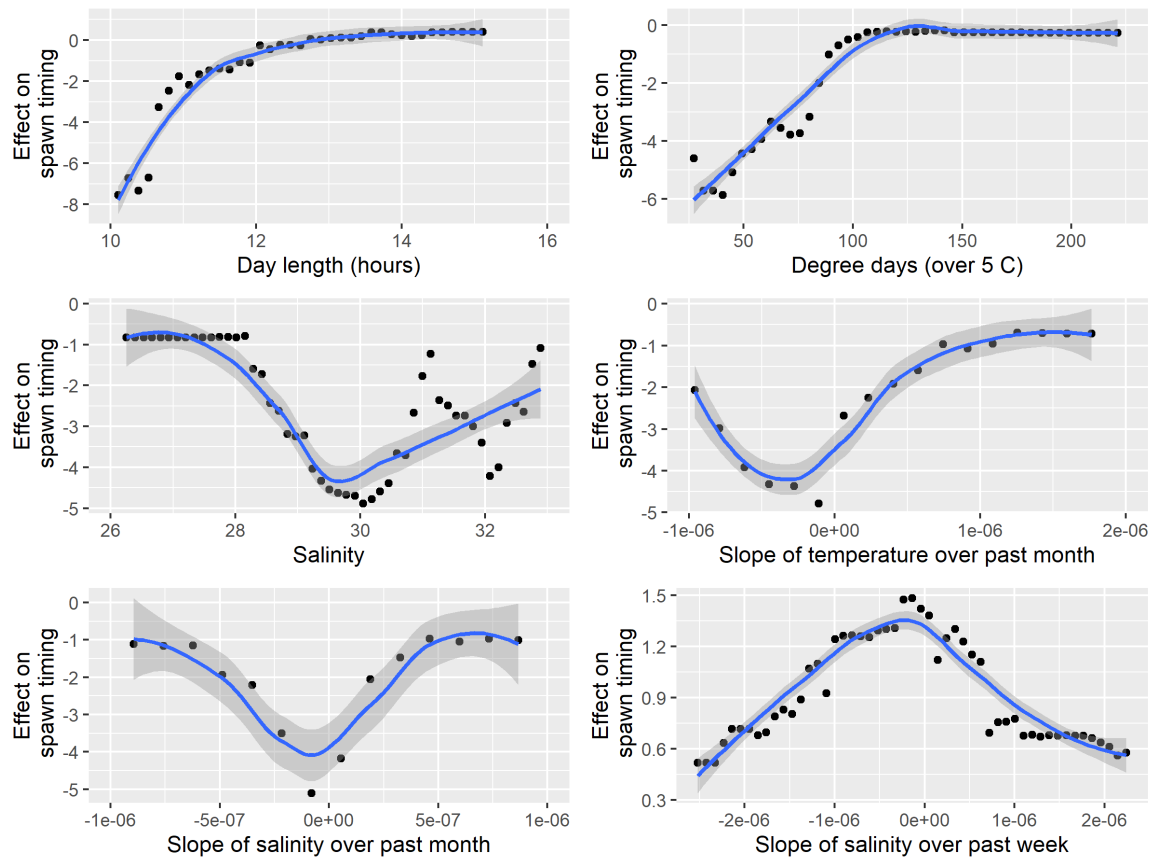


Figure 21-4. Effects on herring spawn timing by day length (hours), degree day (> 5 °C), salinity, slope of temperature over the previous month, slope of salinity over the previous month, and slope of salinity over the previous week.

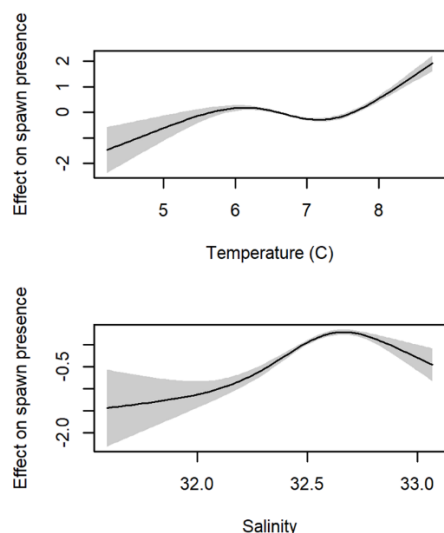


Figure 21-5. Effects on herring spawn presence by temperature (°C) and salinity.

Pacific Herring are zooplanktivorous, consuming primarily euphausiids (krill) and some copepods (Wailes 1936). Changes in ocean conditions, such as temperature or currents, could affect the amount and types of prey available. For example, a northerly current direction could result in the presence of California current waters off the WCVI, bringing California Current zooplankton species that have a lower energetic value, creating poorer feeding conditions for herring (Schweigert et al. 2010; Mackas et al. 2004).

There are a wide variety of herring predators, including Pacific Hake, Lingcod, Spiny Dogfish, Pacific Cod, Sablefish, Arrowtooth Flounder, Pacific Halibut, Steller Sea Lions, Northern Fur Seals, Harbour Seals, California Sea Lions, and Humpback Whales (Schweigert et al. 2010). Off the WCVI, the abundance of most marine mammal predators has increased (Olesiuk 2008; Olesiuk

et al. 1990). Spatio-temporal model results suggest that the strongest drivers of summer distribution and biomass of Pacific Herring off the WCVI include: 1) zooplankton prey availability, 2) predator avoidance, particularly Pacific Hake, and 3) competition with sardines (Godefroid et al. 2019).

The trends in herring spawn timing (to earlier timing) appear to be caused primarily by changing patterns in ocean temperature and salinity. The other factor influencing spawn timing (day length) has not changed. The trend in realized spawn distribution indicate that as biomass changes the distribution of spawning will change. Perhaps as the the oceans become warmer there will be some localized changes in the spatial distribution of spawning as well.

21.5. Implications of trends

Trends in herring biomass have implications for both fisheries and predators. Pacific Herring comprise an important component of commercial fisheries in British Columbia. Fisheries Management uses forecasts of herring biomass, in conjunction with simulation-tested management procedures and performance metrics (including Limit Reference Points), to set total allowable catches.

Trends in herring biomass have implications for herring predators, such as fish, marine mammals and seabirds. The relative importance of herring in each predator's diet varies; however, herring may represent up to 88% of Lingcod diet (Pearsall and Fargo 2007), 40% of Pacific Cod and Pacific Halibut diets (Ware and McFarlane 1986), and 35% to 45% of pinniped diets (Olesiuk et al. 1990; Womble and Sigler 2006; Trites et al. 2007; Olesiuk 2008). Depending on the level of diet specialization and ability to switch to alternate prey, herring abundance and condition may affect predators' growth and abundance. Time series of diets of animals in this ecosystem would improve our ability to examine temporal trends in predator-prey interactions and implications of those trends. The trends in spawn timing and distribution may impact future recruitment of herring through changing temporal and spatial mis-match between the hatching of larvae and spring ecosystem productivity cycles.

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22. 2020 FALL JUVENILE SALMON SURVEY ON THE NORTH COAST OF BRITISH COLUMBIA

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22.1. Highlights

- Juvenile Pink Salmon were the most widespread species, whereas juvenile Coho and Sockeye were mainly caught in Dixon Entrance. Juvenile Chum Salmon were most abundant in southern Hecate Strait. Only one juvenile Chinook Salmon was caught in Hecate Strait.
- Notable anomalies in relative abundance of juvenile salmon include below average Chinook abundance and above average Sockeye abundance in Dixon Entrance; above average abundance of Coho in Hecate Strait; and below average abundance of Chum and Coho in Queen Charlotte Sound.
- Notable anomalies in condition of juvenile salmon include above average Chum condition in Dixon Entrance and Hecate Strait; below average Pink condition in Hecate Strait; and below average Sockeye condition in Hecate Strait and Queen Charlotte Sound.

22.2. Description of the time series

Fisheries and Oceans Canada (DFO) has conducted juvenile salmon trawl surveys on the Coast of British Columbia since 1998, although not every area was surveyed in every year. During October 6-16, 2020, DFO surveyed three regions: Dixon Entrance, Hecate Strait, and Queen Charlotte Sound. This ecosystem-based survey was conducted along standard transects during daylight hours on the *CCGS M.R.V. Sir John Franklin*. A midwater trawl net was towed at 0 m and 15 m head rope depths. All catch was identified to species, weighed, and enumerated. Fish weights and lengths were measured and stomach contents were examined. Stomach contents were identified to broad taxonomic groups and the prey volume estimated at sea. Juvenile Pacific Salmon CPUE anomalies were calculated as the mean of natural log-transformed (plus one) catch counts per swept volume (km^3), and expressed as standardized anomalies within each region. Fish condition was estimated from residuals calculated from the log length to log weight relationship from 1998 to 2020. Vertical CTD casts and zooplankton samples were collected at nearly every station (Anderson et al. 2021).

22.3. Status and Trends

Generally, the juvenile catch rate of Sockeye Salmon and Coho Salmon were highest in Dixon Entrance, while Chum Salmon catch rate was highest in southern Hecate Strait and Pink Salmon was widespread. There was only one juvenile Chinook Salmon caught in Hecate Strait (Figure 22-1).

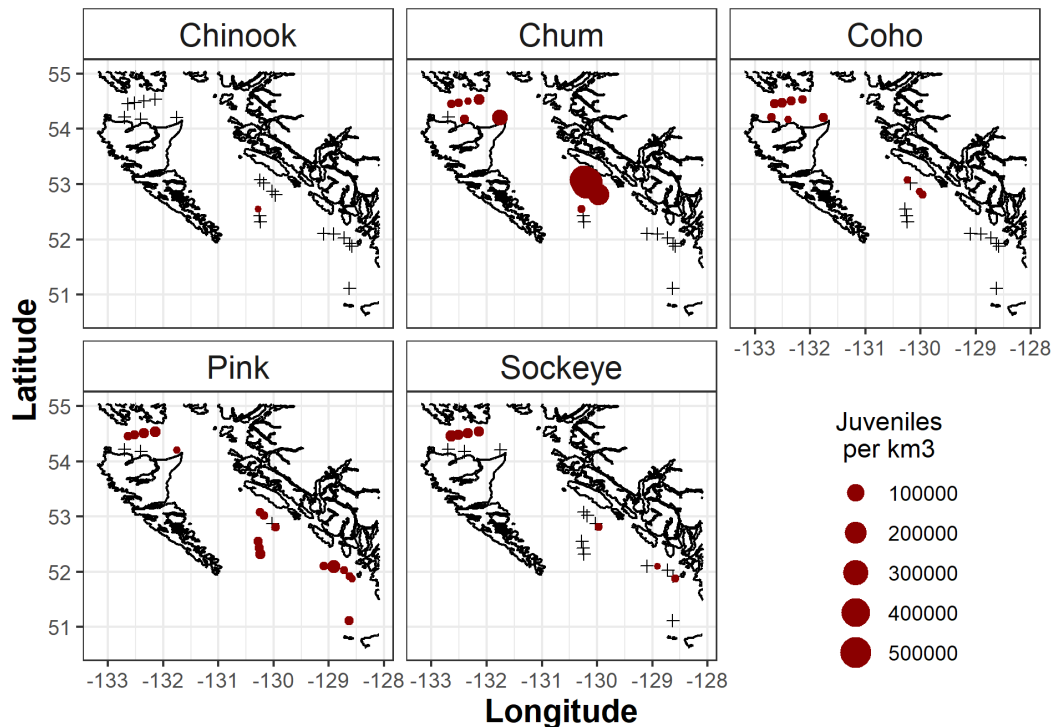


Figure 22-1. Juvenile Pacific Salmon (*Oncorhynchus* spp.) caught in October 2020 in Dixon Entrance, Hecate Strait, and Queen Charlotte Sound. Red circles are proportional to catch abundance, and zero catches are shown with a black cross (+).

Regional CPUE anomalies for juvenile Pacific salmon were variable in October 2020, depending on the region and species (Figure 22-2). The single catch of Chinook Salmon led to below average CPUE anomalies in Dixon Entrance and Queen Charlotte Sound. Juvenile Chum Salmon CPUE anomalies were above average in Dixon Entrance, average in Hecate Strait, and below average in Queen Charlotte Sound. Juvenile Coho Salmon CPUE anomalies were above average in Dixon Entrance and Hecate Strait, and below average in Queen Charlotte Sound. Juvenile Pink Salmon CPUE anomalies were slightly below average or average in Dixon Entrance and Hecate Strait, and above average in Queen Charlotte Sound. Juvenile Sockeye Salmon CPUE anomalies were above average in Dixon Entrance and Queen Charlotte Sound, and below average in Hecate Strait.

Juvenile Chum and Coho Salmon condition was above average in Dixon Entrance and Hecate Strait. Juvenile Pink and Sockeye Salmon condition was above average in Dixon Entrance, but below average in Hecate Strait and Queen Charlotte Sound (Figure 22-3). The percentage of empty stomachs was lowest in juvenile Chum salmon (~2%) which is reflected in the higher condition estimates.

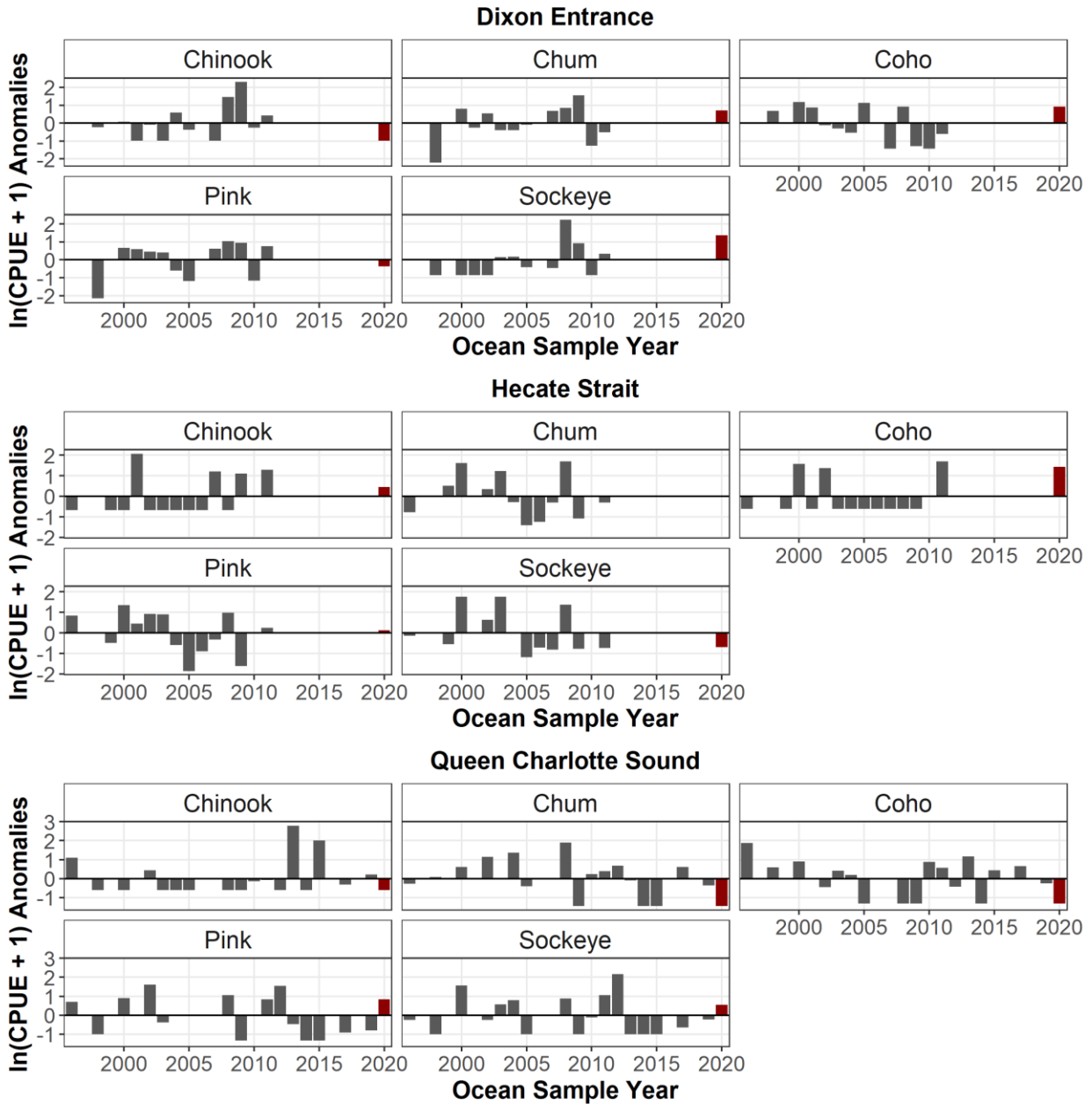


Figure 22-2. Annual catch per unit effort (CPUE) anomalies in the fall (September, October, and November) from 1998-2020 for juvenile Pacific Salmon in Dixon Entrance, Hecate Strait, and Queen Charlotte Sound. Positive anomalies represent above average regional abundance; negative anomalies represent below average regional abundance. The 2020 data is highlighted with red.

Genetic stock identification (GSI) has been completed for Chinook, Chum, and Coho Salmon, using methods summarized in Beacham and Wallace (2019). Juvenile Chum Salmon caught in Dixon Entrance and Hecate Strait originated from Coastal Washington to SE Alaska. Juvenile Coho Salmon caught in Dixon Entrance originated from Oregon to Lower Skeena. Juvenile Coho Salmon sampled in Hecate Strait, ranged from Puget Sound to Central British Columbia Inlets (Mussel-Kynoch) in October 2020.

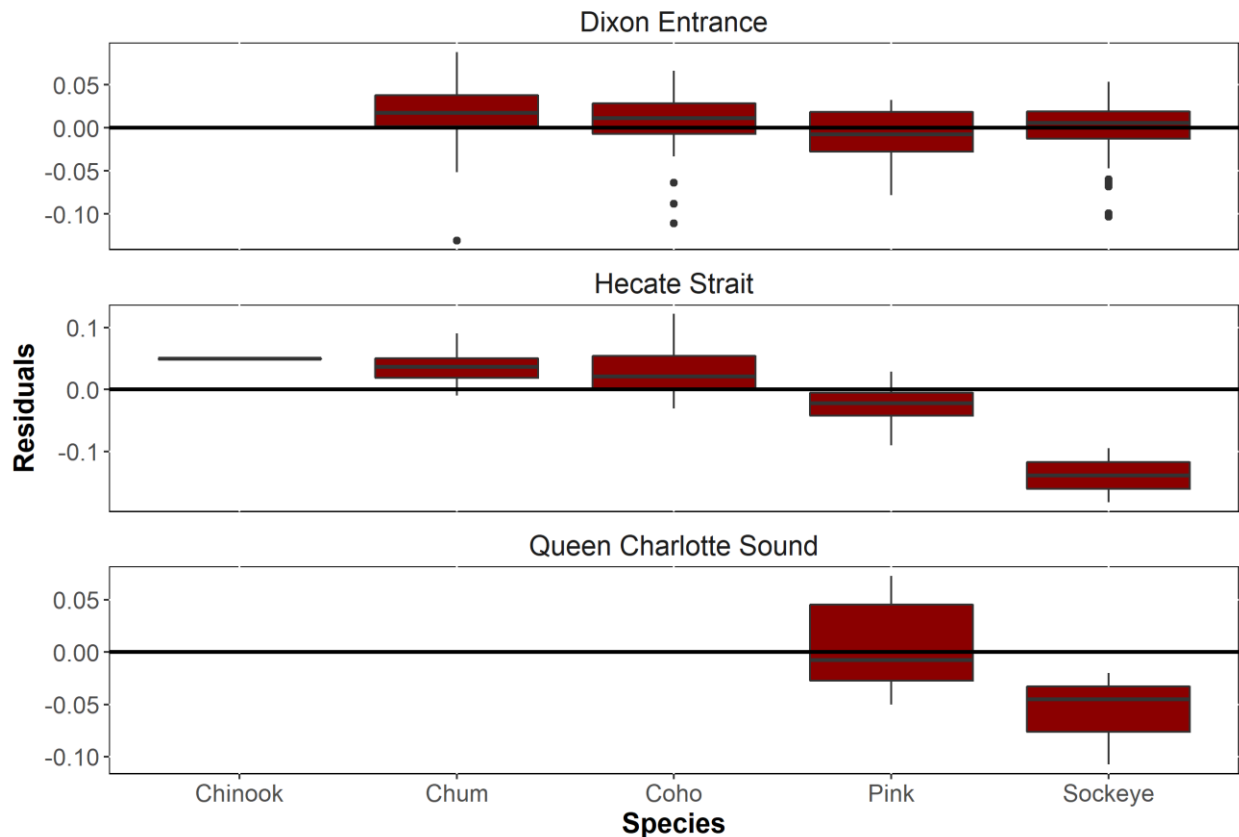


Figure 22-3. Juvenile Pacific Salmon condition in Dixon Entrance, Hecate Strait, and Queen Charlotte Sound in 2020 as measured by residuals from the log length to log weight relationship by species from 1998 to 2020. The boxes represent the lower quantile and upper quantile, the mean is the black line within the box, and outliers are dots.

22.4. Factors influencing trends

The relative abundance of juvenile Pacific Salmon in coastal regions reflects cumulative impacts, including but not limited to spawner-egg-fry productivity in freshwater, in-river mortality for out-migrating smolts, and ocean conditions coupled with trophic impacts (prey quality and availability, predation) in the first few months in the ocean. Basin-wide climate and ocean patterns (e.g. Pacific Decadal Oscillation and North Pacific Gyre Oscillation) have been linked through coastal processes, to coherency in broad-scale patterns in Pacific Salmon marine survival (Malick et al. 2017). Adding to this complexity is the occurrence of recent extreme ocean warming events, i.e. marine heatwaves. Juvenile Pacific Salmon survey catch rate anomalies throughout the northeastern Pacific and the Bering Sea exhibited highly variable responses across regions after the 2015 marine heatwave (King et al. 2020). Juvenile Pacific Salmon caught in the fall of 2020 exhibit similar complexities, varying by species and catch region.

22.5. Implications of those trends

Low catch rates and/or poor condition were more prevalent in southern surveyed regions (i.e. Queen Charlotte Sound) which may lead to low spawner returns (e.g. southern Coho and southern Sockeye Salmon). Higher catch rates and improved condition factors were found in

more northern regions (i.e. Dixon Entrance), which may support moderate returns in certain stocks and species (e.g. SE Alaska Chum and northern Sockeye Salmon). Nevertheless, juvenile Chinook Salmon returns will likely be extremely low given the low catch in 2020. The juvenile Pacific Salmon encountered in these surveys will return to spawn at varying times, but generally these catch rates apply to Coho and Pink Salmon returning in 2021, Chinook and Sockeye Salmon returning in 2022, and Chum Salmon returning in 2023.

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23. STATE OF CANADIAN PACIFIC SALMON IN 2020

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23.1. Highlights

- Sockeye returns in 2020 were generally poor. This is a continuation of recent trends for these species, where low returns have been observed, particularly at southern latitudes.
- Chinook Salmon returns in 2020 were generally poor due to low productivity among stream-type stocks in the north west. This is consistent with poor trends for this species throughout its North American Pacific Coast range. There was improvement in some Strait of Georgia stocks in 2020.
- Chum Salmon returns in 2020 were also poor. This diverges from the recent trend for this species, which was generally exhibiting better returns than other Pacific Salmon.
- Coho and Pink returns in 2020 were mixed. Pink Salmon have generally had better returns than most species in recent years in some areas of Johnstone Strait, while Coho returns in 2020 were generally average to below average with a few exceptions, including a strong showing at Big Qualicum.
- These salmon trends coincide with global climate change responses in the freshwater and marine ecosystems salmon inhabit. Climate change impacts in freshwater have been further exacerbated by land and water use activities.
- Actions to mitigate Big Bar landslide on the Fraser River in 2020 improved adult migration passage over 2019 in general. Work is on-going to attempt to mitigate this landslide and monitor salmon responses.

23.2. Description of the Canadian Pacific Salmon time series

Time series data are aggregated for several key salmon groups. This includes catch time series for the five Pacific Salmon species DFO manages (Sockeye, Chinook, Coho, Pink and Chum), which are published by the North Pacific Anadromous Fish Commission (NPAFC:

<https://npafc.org/statistics/>). These Canadian catch data are updated in recent years by A. Velez-Espino (DFO), and are currently available up to 2020. Although in-season salmon catch data are available to manage particular fisheries, there is generally a lag of one year to finalize and integrate these data into a standardized format available through the NPAFC.

For 2020, most salmon return information is only available qualitatively at the time of this report. Qualitative input on 2020 returns was provided for the Salmon Outlook by various DFO Area leads: Northern BC-Alaska transboundary updates: A. Foos; Yukon: M. Folkes & C. Carli; Inside

Chum: P. Van Will; North Coast all species: C. Carr-Harris; Fraser Chinook: C. Parken; South Coast: W. Luedke.

Quantitative return data for 2020 are available for key Sockeye populations, and are presented in the Hyatt et al. (Section 24). Fraser Sockeye return and productivity data for 18 key Fraser River Sockeye populations are provided by S. Latham, from the Pacific Salmon Commission (PSC), and S. Decker, B. Leaf, Y. Xu, and B. Davis from DFO.

23.3. Canadian Pacific Salmon status and trends

23.3.1. Trends in salmon catch

Catch for all five DFO-managed Pacific Salmon species has declined in the past decade (Figure 23-1). This is due to declines in target salmon population abundances and constraints placed on mixed-stock fisheries to protect co-migrating salmon populations in poor status (Grant et al. 2019). Low returns in 2019 and 2020 led to extremely low Canadian catch in these two years of 1.9 million and 3.1 million, respectively.

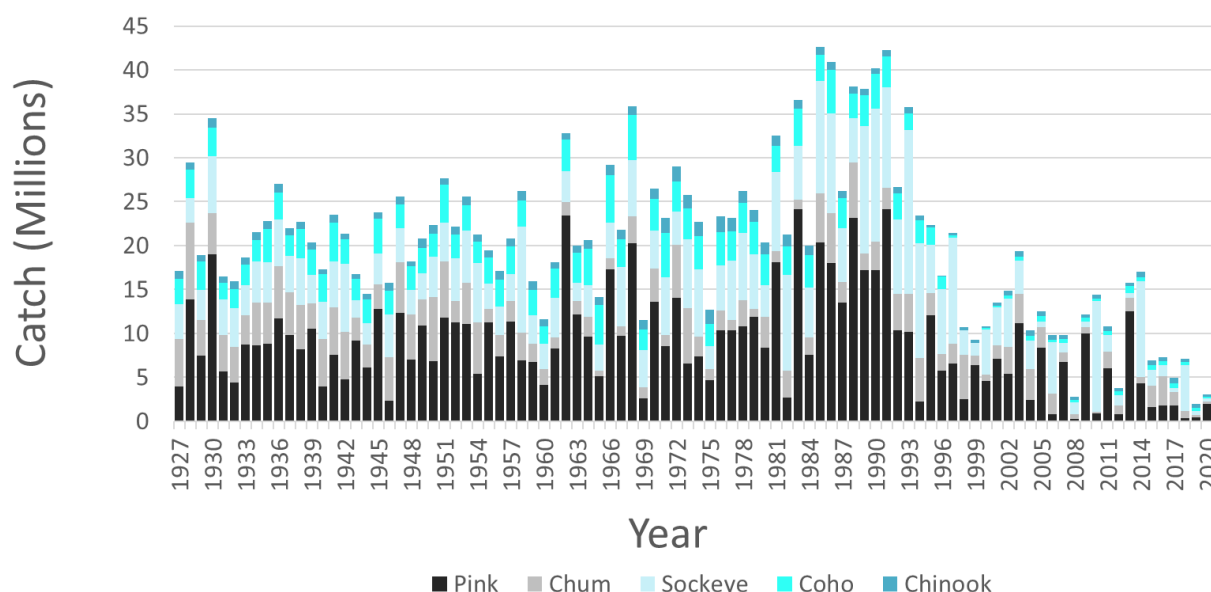


Figure 23-1. Commercial, recreational and Indigenous subsistence catch of Canadian Pink, Chum, Sockeye, Coho and Chinook Salmon (Grant et al. 2019; NPAFC statistics: <https://npafc.org/statistics/>). Average catch from 1925-1993 was 24.2 million, and from 1994-2017 was 11.6 million. Returns in the last two years were extremely low at 1.9 million in 2019 and 3.1 million in 2020.

23.3.2. Qualitative Canadian Pacific Salmon returns in 2020

Total returns of Chinook in 2020 were poor, which continued the recent trend of generally low abundances (Grant et al. 2019). Some exceptions in 2020 included the Upper and Lower Georgia Strait and Georgia Strait Spring and Summer Stock Management Units.

Sockeye returns in 2020 were also poor, continuing the low abundance trends observed for this species in recent years, particularly in central to southern latitudes of B.C. (Grant et al. 2019;

Hyatt et al. 2020; Hyatt et al., Section 24). Populations in the Taku River of the Northern BC-Alaska transboundary region were exceptions to the sockeye trend in 2020.

Coho marine survival remained low relative to the 1980s while several new survival/escapement indicators are in development, including for Cowichan and Sakinaw.

Pink salmon returns in 2020 were also mixed but generally better than other species.

Chum salmon generally exhibited poor returns in 2020, in contrast with their recent positive trend (Grant et al. 2019).

23.3.3. Fraser Sockeye salmon in 2020

Fraser Sockeye aggregate returns and productivity were poor in 2020 (Figure 23-2). These returns were the lowest on record, followed by 2019, and 2016. The 2019 and 2020 productivities were synchronously low across all 18 key Fraser Sockeye populations (Figure 23-3).

In 2020, the majority of the adult Fraser Sockeye were able to successfully migrate past the Big Bar slide area north of Lillooet area following the remediation work that has taken place since the slide occurred in 2019 (Government of B.C. et al. 2019 and 2020). The upstream migration of Early Stuart sockeye remained seriously impeded given the high discharge levels throughout the watershed and at Big Bar early in the season.

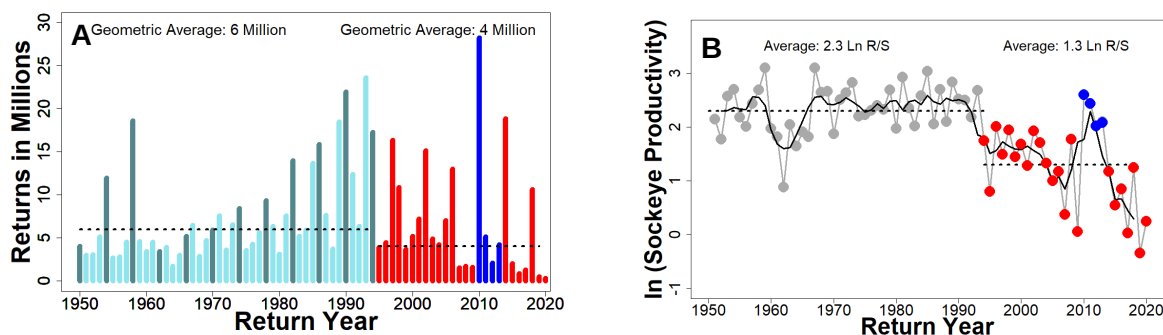


Figure 23-2. (A) Total Fraser Sockeye annual returns. For years from 1950 to 1994 dark green bars are the 1950 cycle line, and light blue bars are for the three other cycle lines. For years from 1995 to 2020, red vertical bars highlight a period of reduced Fraser Sockeye productivity, with the exception of a period from 2010 to 2013 (blue vertical bars) where productivity was closer to the previous period (1950-1994). (B) Total Fraser Sockeye productivity ($\log_e$ (returns/effective female spawners)). The grey dots and lines represent annual productivity estimates. Productivity and returns have declined in recent decades, highlighted red, with the exception of four years from 2010-2013, which were closer to the previous period (1950-1994), highlighted blue. For both figures, the dashed line is the time series average.

23.4. Factors Influencing Pacific Salmon Trends

At DFO's first State of the Salmon meeting in 2018, scientists concluded that Canadian Pacific Salmon and their ecosystems are responding to climate change (Grant et al. 2019). These marine and freshwater ecosystem changes are impacting Pacific Salmon at every stage of their life-cycle.

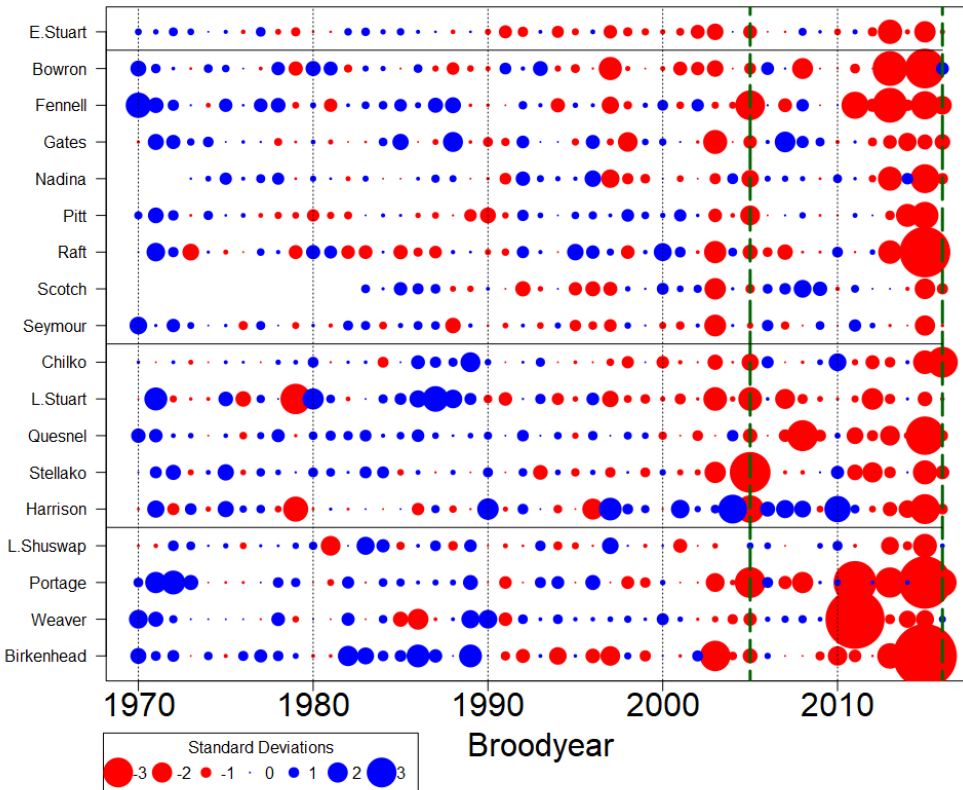


Figure 23-3. Four-year-old Fraser Sockeye productivity (Ricker model residuals for all populations except Scotch, Seymour, Quesnel, and Late Shuswap, which are Larkin residuals) up to the 2016 brood year (2020 return year) across 18 key populations. The 2016 brood year (2020 return year) productivities are preliminary. A brood year is the year of the parental spawners, and since most Fraser Sockeye are four year old fish, the brood year is four years prior to the return year. Some exceptions described below. Red dots indicate below average productivity and blue dots indicate above average productivity. Dot sizes represent the deviation from average productivity for each stock. The 2005 and 2016 brood years (2009 and 2020 return years) have been highlighted using a broken vertical green line. The 2005 brood year was the initiation of the Cohen Inquiry into the declines of Fraser Sockeye. Both freshwater and marine factors contribute to the observed productivities.

Exceptions: Since Pitt are comprised of predominantly five-year-olds, productivity is estimated for four plus five-year-olds, and are, therefore unavailable for the 2016 brood year, since five-year-olds from 2021 have not yet returned. Harrison are comprised of three and four-year-olds, so productivities are estimated for three plus four-year-olds. Late Shuswap had extremely low brood year escapements and associated returns in 2004, 2008 and 2012 brood years, and these estimates are considered too uncertain given their low numbers. They were therefore removed from the data set, and productivities were not estimated for these years.

Warming in the Northeast Pacific Ocean, and marine heatwaves like “The Blob” are affecting ocean food webs. These factors resulted in lipid-poor, southern zooplankton species, typically centred 1,000 km south of the southern British Columbia coast, dominating lower levels of the salmon food web (Galbraith and Young 2020). Shifts in species composition were observed in waters along the West and North Coast of Vancouver Island, and broadly in the NE Pacific (Boldt et al. 2020). These southern species are considered poorer quality food for salmon. In cooler years, larger, lipid-rich, higher-quality boreal copepods typically dominate zooplankton composition from the coast of Oregon up to the Bering Sea, while subarctic copepods inhabit

deeper areas of the subarctic Pacific and Bering Sea from North America to Asia (Galbraith and Young 2020).

British Columbia and Yukon air and water temperatures are increasing, and precipitation patterns are changing, altering freshwater habitats (Grant et al. 2019). The effects of climate change in freshwater are compounded by natural and human-caused landscape change, which can lead to differences in hydrology, and increases in sediment loads and frequencies of landslides.

23.5. Implications of those trends.

Recent trends in salmon abundances yield a growing, but still incomplete, view of salmon vulnerability to climate change. This vulnerability is determined by multiple factors, including salmon spawning and rearing locations, warming water temperatures, ecosystem changes, freshwater habitat alteration, salmon traits, and more. All these factors acting alone or cumulatively increase our current uncertainty related to salmon population responses to climate change.

Improving information on salmon vulnerability to changing climate and habitats will help ensure our fisheries management, salmon recovery, and habitat restoration actions are aligned to future salmon production and biodiversity (Nelitz et al. 2007; Hunter and Wade 2015; Hunter et al. 2015; Grant et al. 2019; Crozier et al. 2019; Crozier et al. 2021). To accomplish this, we must integrate and develop new research across disciplines and organizations. One mechanism to improve integration of salmon-ecosystem science across organizations is the formation of a Pacific Salmon-Ecosystem Climate Consortium, which has been initiated by DFO's State of the Salmon Program, with the goal to conduct vulnerability assessments for Canadian Pacific Salmon under climate change (Grant et al. 2019).

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24. COAST-WIDE SOCKEYE SALMON PERFORMANCE INDICATORS, REGIONAL OVERVIEW OF TRENDS, 2020 RETURNS, AND 2021-2023 OUTLOOK

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24.1. Highlights

- Returns of B.C.'s Transboundary, North Coast, West Coast Vancouver Island (WCVI), Fraser, and Okanagan Sockeye Salmon 'Index Stocks' in 2020 were generally below (4 conservation units (CUs)/ management units (MUs)) to somewhat above (1 CU/MU) median management forecasts and all-year average return estimates.
- Large returns of Sockeye Salmon to Bristol Bay, AK in recent years (totals of 62, 56 and 58 million fish in 2018, 2019, 2020 respectively, versus a 48 million all-year average; ADFG 2020a) and weak returns to Southeast Alaska and B.C. locations, corroborate the multi-year persistence of a south-to-north inverse production pattern for Sockeye stocks along the eastern rim of the Pacific Ocean (Hyatt et al. 2019).
- Sockeye index stocks from south of the Aleutians, with sea entry and migration in 2017-2018 and maturation in the Gulf of Alaska (GOA) in 2018 and 2019, displayed sub-average returns in 2019 and 2020 in contrast to Bristol Bay Sockeye, with sea-entry north of the Aleutians and maturation in the Bering Sea. Okanagan Sockeye returns also exceeded forecasts in 2020.

24.2. Time Series – Annual Returns of Coast-wide Sockeye “Indicator Stocks”

Hyatt et al. (2020b) have briefly described sources of salmon population data comprising a *de facto* international network of coast-wide Sockeye Salmon performance indicators (Figure 24-1) from which inferences about trends in geographic patterns of abundance and biological traits may be made. Sockeye return data comprise fisheries management estimates of total annual catch plus total 'escapement' to spawning grounds based on standard site-specific methods (e.g. counting weirs, electronic counters, mark-recapture, etc.). Historical returns and pre-season forecasts are generally available as published or unpublished observations from DFO and Alaska Department of Fish and Game assessment biologists and resource managers.

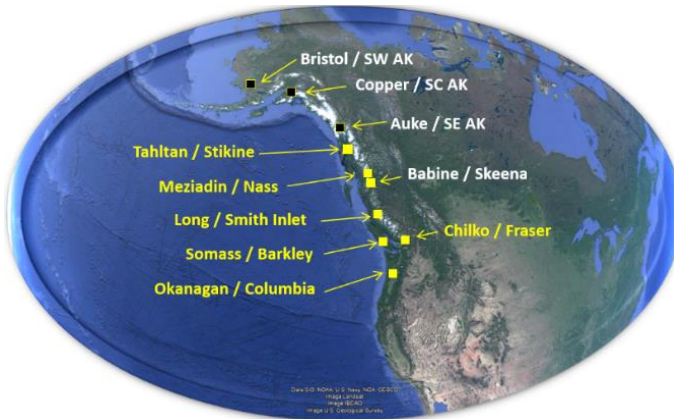


Figure 24-1. Coast-wide Sockeye Performance Indicator Stocks. Approximate points of sea entry for a network of relatively data-rich Sockeye stocks monitored by DFO (yellow) and ADFG (black) on an annual basis for biological traits (age-at-return, size-at-return, return timing etc.) and total returns (catch plus escapement) relative to predicted returns.

Production trends of “data-rich” Sockeye populations comprising single CUs or stock aggregates constituting MUs are assumed to represent other populations (i.e., serve as “index stocks”) sharing the same marine domains that characterize the critical first weeks of early marine life (Hyatt et al. 2016). Representative domains and associated stocks are loosely defined by sea-entry points spanning 2,400 km of the west coast from western Alaska in the north to the Oregon border in the south (Figure 24-2).

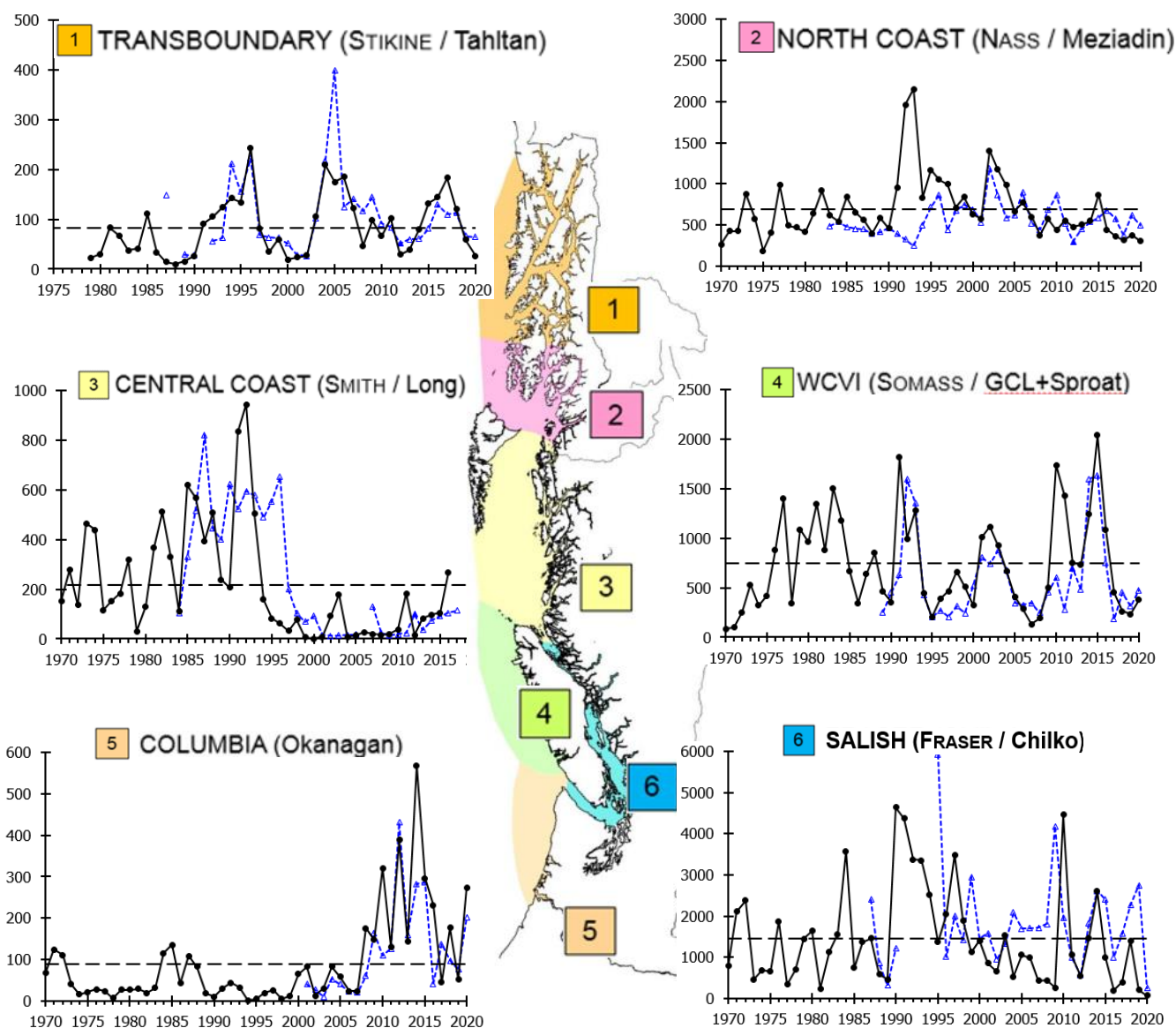


Figure 24-2. Trends in the total annual returns (thousands of fish; black line) and management forecasts (blue line) for British Columbia Sockeye index stocks, by DOMAIN (WATERSHED/Stock): (1) TRANSBOUNDARY; (2) NORTH COAST; (3) CENTRAL COAST; (4) WCVI; (5) COLUMBIA and (6) SALISH.

24.3. Status and Trends Exhibited by Coast-wide Sockeye Indicators

In 2015-2020, most B.C. Sockeye Index stocks generally exhibited returns below to far below their 40 year average (Figure 24-2). Escapement goals were not met for many stocks, and Sockeye fisheries were closed or highly restricted in Canadian waters. By contrast, Bristol Bay

(Alaska) Sockeye achieved record returns in 2018, 2019 and 2020 (62, 56 and 58 million fish respectively; ADFG 2020a). Exceptional returns to Bristol Bay, sub-average returns to south-central Alaska (Cook Inlet; ADFG 2020b, 2020c), and weak returns to southeast Alaska¹ and B.C. comprise a persistent south-to-north inverse production pattern for Sockeye stocks along the eastern rim of the Pacific Ocean (Hyatt et al. 2018, 2019, 2020b). That pattern was altered in 2020 by unexpectedly high Okanagan returns in the Columbia (the most southerly Sockeye Index Stock watershed), which exceeded forecast and long-term average values (Figure 24-2).

Environmental conditions in freshwater and marine ecosystems for the past 3-5 years have not favoured improved survival at multiple salmonid life stages (Hyatt et al. 2018, 2020b; MacDonald et al. 2018). Consequently, declining returns to B.C. systems in 2019 and 2020 relative to larger returns during 2014-2016 were generally anticipated by forecasting routines (e.g. 2020 forecast errors were 21% high for Somass, 39% for Nass, 58% for Tahlitan, and 73% high for Chilko, but 26% low for Okanagan; Figure 24-2).

24.4. Factors Influencing Trends in Numbers and Biological Traits of Sockeye

Environmental conditions have been warmer than average in B.C., Yukon, and the Northeast Pacific Ocean, affecting multiple life stages of Pacific salmon broods (2014-2016) for most stocks returning in 2018-2020, leading to coast-wide declines in abundance, smaller body sizes, reduced fecundity, and generally greater variability in total production (DFO 2020).

Warmer than average air temperatures characterized most of 2015-2019² along with the strongest El Niño event in the past 70 years in late 2015 through early 2016. Further, a marine heatwave (MHW) occurred in the Northeast Pacific from late 2013 to autumn 2016.

The eastern Pacific Ocean reverted towards more normal physical conditions in 2017 and 2018, but biological conditions encountered by Sockeye smolts making sea-entry in 2016-2018 “continued to reflect a warmer ocean” (DFO 2020, p. 54). The latter was characterized by less nutritious, low-lipid zooplankton prey, predators ‘foreign’ to juvenile salmon, and competitive invertebrate populations (e.g. jellyfish, salps; Galbraith and Young 2019) which may affect sub-adult growth and survival. Another MHW – “Blob 2.0” – occurred in the NE Pacific in summer 2019 and persisted into early 2020 (Amaya et al. 2020), potentially limiting marine growth and survival of 2020 returns.

The ENSO index³, which identifies multi-year alternations in “warm” vs “cold” sea surface temperatures (SST), is generally a reasonable predictor of marine survival of Sockeye stocks that directly enter the northern California Current System (CCS)⁴ (Hyatt et al. 2016, 2018) and possibly the Salish Sea (MacDonald et al. 2018). Alignment of El Niño and La Niña events from the ENSO Index with annual B.C. Sockeye Salmon indicator stock returns indicated that:

¹ pers. comm. S. Vulstek, Auke Bay Research Station (NOAA), Juneau [25-Feb-2021].

² Pacific Climate Impacts Consortium [Seasonal Anomaly Maps](#) (downloaded: March 2021)

³ ENSO: El Niño Southern Oscillation Oceanic Niño Index (ONI 3.4) ([Barnston and Tippett 2013](#)).

⁴ However, see [Hyatt et al. \(2020a\)](#) for contrasting results for Somass Sockeye (Barkley Sound, WCVI).

- Cool ocean conditions associated with moderate-to-strong La Niña events (e.g. 1989, 1999, 2008, 2011) were generally associated with above-average returns for most B.C.-origin Sockeye stocks 2-3 years later, with near-record returns in 2010 and 2015 for some stocks.
- Warm ocean conditions linked to moderate-to-strong El Niños (e.g. 1983, 1998, 2003, 2010, 2016) were associated with sub-average returns for many stocks, most evidently for those entering directly into the CCS. The recent strong El Niño event in 2015/16 was followed by declines in the majority of Sockeye stocks to below-average returns from 2017 to 2020.

24.5. Implications and Outlook for Returns in 2021-2023

Across the life-history of B.C. Sockeye populations returning in 2021, conditions in freshwater and marine ecosystems have been or are generally neutral, providing little additional skill for forecasts from environmental observations. The onset of a weak La Niña in 2016 and a stronger one in 2020-21 – associated with a return of B.C. outer coast (but not Salish Sea) temperatures close to the climatological mean in 2018 (Chandler 2019) – signaled some potential for improvement in survival for juvenile Sockeye at sea entry in 2018 (e.g. Okanagan and Barkley Sockeye MUs performed above or at pre-season expectations (Figure 24-2). However, these slight improvements for increased returns in 2020 were likely outweighed by several negative events noted in last year's State of the Ocean Report (Hyatt et al. 2020b). The onset of a stronger La Niña in 2020-21 suggests productivity of southernmost Sockeye stocks (Barkley Sound, Okanagan and possibly Fraser) will improve for return year 2023.

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25. WERE THE LARGEST SALMON RETURNS ON RECORD IN THE NORTH PACIFIC DURING 2018/2019 RESPONSIBLE FOR LOW RETURNS IN 2020?

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25.1. Highlights

- Recent salmon abundances in the North Pacific were at (2018) or near all-time high levels until 2020 when far fewer salmon returned than expected.
- Odd-numbered year returns of the most populous species Pink Salmon were more numerous than genetically distinct even-year returns except for 2018, which saw record high returns.
- Depending on species, marine age, and ocean distribution, many salmon returning in 2020 shared the ocean with one or more consecutive year classes (i.e. 2018 and 2019) of abundant Pink Salmon.
- Without a traditional even-year recovery period in 2018, the North Pacific ecosystem may have been sufficiently disrupted by consecutive abundant Pink Salmon years to reduce salmon returns in 2020.

25.2. Description of the time series

Abundance estimates for Pink Salmon (*Oncorhynchus gorbuscha*), Chum Salmon (*O. keta*), and Sockeye Salmon (*O. nerka*) in the North Pacific Ocean from 1925–2015 (Ruggerone and Irvine 2018) were extended to include preliminary values for 2016–2020. In aggregate, other salmonid species constituted less than 5% of total abundances and were not included. Abundance was the number of salmon surviving to become adults (i.e. sum of the number of fish caught in fisheries (NPAFC 2020) plus the number that escaped to freshwater to spawn).

Because spawner escapement estimates for the North Pacific were not available for 2016–2020, abundance for these years was estimated based on previous recent relationships between catches and returns. The same approach was used for 2020 based on preliminary catch estimates (e.g. Velez-Espino et al. 2021). For Washington, Oregon and California, where abundances of these species are relatively minor compared to the sum of other regions (PMFC 2021), we assumed 2020 catches were the same as during 2016–2019.

25.3. Status and trends

Total (natural- plus hatchery-origin) annual abundance of adult salmon was highly variable in the early part of the time series, peaking in the late 1930s at 530×10^6 fish (Figure 25-1). Abundance declined near the end of World War II and remained near 310×10^6 fish until the

mid-1970s, increasing to 543×10^6 fish after the 1977 ocean regime shift (1977–2004) and to 665×10^6 fish during 1990–2015. Total salmon abundance was higher during 2005–2015 (721×10^6 fish) than in any earlier period. During 1990–2015, numerical adult abundance was dominated by Pink Salmon (67% of the combined abundance of all three species), followed by Chum Salmon (20%) and Sockeye Salmon (13%) (Ruggerone and Irvine 2018).

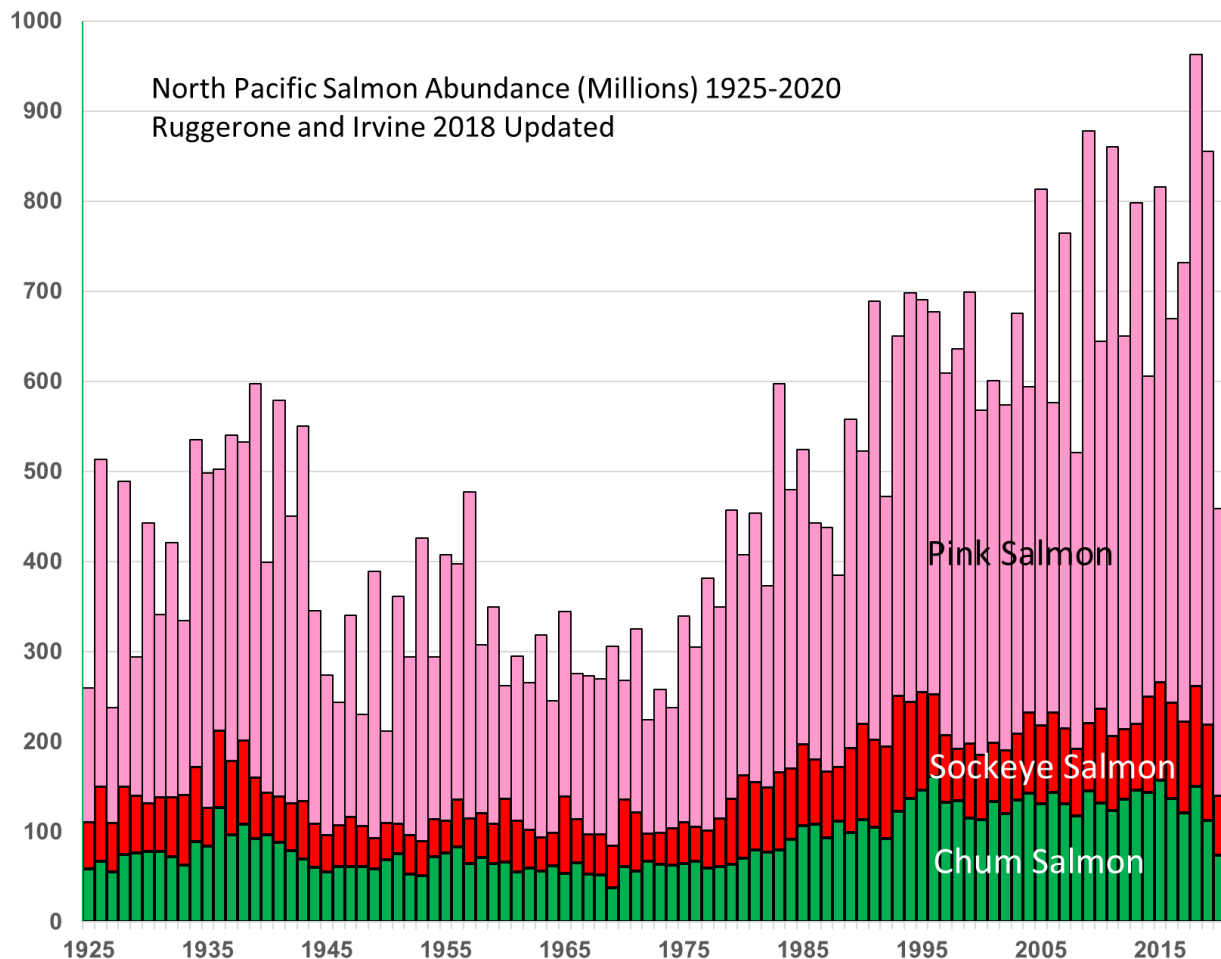


Figure 25-1. Abundance (millions of fish) of Chum Salmon, Sockeye Salmon, and Pink Salmon in the North Pacific Ocean, 1925–2020 updated from Ruggerone and Irvine (2018). Numbers after 2015 are preliminary.

After 2015, estimates remained near all-time high levels until 2020 (Figure 25-1). More salmon returned in 2018 than any previous year because of exceptionally high numbers of Pink Salmon that were primarily of Russian origin. Before 2018, Pink Salmon were almost always more numerous in odd-numbered years than even-years; 2018 was anomalous.

Although estimates are preliminary, returns in 2020 reflect much lower than anticipated catches (Radchenko 2021) (Figure 25-1). Pink Salmon were less than half as abundant as in 2018, and the lowest of any year back to 1992. 2020 returns of Chum and Sockeye were the lowest in 40 and 20 years respectively. This is particularly noteworthy for Sockeye Salmon because Bristol Bay (Alaska) catches were quite high.

As a result of exceptionally high numbers of primarily Russian Pink Salmon in 2018 plus above average odd-year returns throughout the North Pacific in 2019, many salmon that returned in 2020 shared the ocean ecosystem with one or more consecutive year classes of abundant Pink Salmon. This is the first time this has happened in over a century of monitoring salmon abundance (Figure 25-1).

25.4. Implications of those trends.

Physical oceanographic conditions alone cannot explain biennial biological patterns observed in the North Pacific ecosystem. Changes in Pink Salmon abundance have been correlated with growth and/or survival of other salmon species including Sockeye (e.g. Ruggerone and Connors 2015; Ruggerone et al 2016; Connors et al. 2020), Chinook (e.g. Claiborne et al. 2020; Kendall et al. 2020; Ruggerone and Goetz 2004), and Coho Salmon (Shaul and Geiger 2014). High numbers of Pink Salmon have also been correlated with changes to other non-salmon species ranging from diatoms and zooplankton (Batten et al. 2018), seabirds (Springer and van Vliet 2014; Springer et al. 2018), and even killer whales (Ruggerone et al. 2019), supporting the hypothesis that Pink Salmon can cause marine trophic cascades (Batten et al. 2018).

There are various reasons why salmon growth and survival can change besides competition. For instance, Connors et al. (2020) suggested that ocean warming associated reductions in survival for southern Sockeye Salmon populations were exacerbated with competition with Pink Salmon. Interestingly, they also found that ocean warming increased survival for northern populations of Sockeye Salmon, which was only partially negated by increased competition.

Pink Salmon, with their distinct biennial patterns provide a naturally occurring experiment to examine interactions between salmon and other species in the North Pacific ecosystem. Without a traditional even year recovery period in 2018, we hypothesize the North Pacific ecosystem may have been sufficiently disrupted by consecutive abundant Pink Salmon years to result in depressed salmon returns in 2020. We acknowledge there are other possible explanations including a new regime with lower than recent survivals.

We encourage other researchers to look for biennial patterns in other North Pacific time series and if found, consider what the mechanistic linkages with salmon abundance might be. Interesting questions to consider include the relative importance of bottom-up versus top-down processes in determining salmon abundance, and since hatchery salmon constitute ~40% of the biomass of salmon in the North Pacific (Ruggerone and Irvine 2018), what role hatchery salmon play in the ecosystem and whether governments (including Canada) should consider making changes to hatchery releases.

25.5. Acknowledgements

Thanks to Jason Parsley (DFO Nanaimo) for preliminary Canadian catch estimates for 2020 and the NPAFC Secretariat for assistance assembling preliminary 2020 catch estimates for Japan, Russia, and Alaska.

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26. SIZE AND AGE TRENDS OF MATURE FRASER RIVER SOCKEYE SALMON (*ONCORYNCHUS NERKA*) THROUGH 2020

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26.1. Highlights

- Fraser River Sockeye Salmon that matured in odd-numbered years were generally smaller than those that matured in even-numbered years.
- Sizes of mature Sockeye in both odd- and even-numbered years declined strikingly from the 1970s to early 1990s, then increased in the early 2000s, and decreased again through the 2010s.
- Over the entire 60+ year time series, both 2019 and 2020 ranked lowest (for odd- and even-numbered years, respectively) for size of ocean age-3 Sockeye.

26.2. Description of the time series

Body size measurements of maturing salmon likely integrate bottom-up and top-down effects of their environment. Three time series were examined to evaluate size-at-age and age-at-maturity of Fraser River Sockeye Salmon. The first was average length (mm) of carcasses on spawning grounds. Using only ages derived from otoliths and a minimum sample size threshold for each sex of each stock, age- and sex-specific standard length anomalies were estimated for return years. Anomalies were averaged between the sexes for ocean age-2 and -3. Methods were similar to those of McKinnell et al. (2012) for this data set, with recent years added, and excluding results for some of the earliest years thought to have unreliable estimates. Stocks that were not well-represented throughout the time series were also excluded. Minimum sample sizes by sex were $n = 20$ for ocean age-2 Sockeye and $n = 10$ for ocean age-3 Sockeye.

The second time series was collected during the fishery management process (Pacific Salmon Commission 2020) for Fraser River Sockeye Salmon. Samples were obtained from gillnet, purse seine, and reef net catch from areas in the Fraser River downstream of Mission and in Johnstone, Georgia, and Juan de Fuca straits from 2004-2020. These data comprised matching stock, age, sex, post-orbital fork length (POF), and weight information, which permitted calculation of condition factor for these fish during their return to the Fraser River. Fish were included if their DNA stock identification met a minimum threshold for confidence (minimum Bayes posterior stock identity was 50%), and stock-year combinations were only included for stocks with $n > 10$ matching weight and length for each sex and age (analyses were limited to ocean age-2 and -3 Sockeye). Anomalies were averaged for the sexes. Condition factor, K , was calculated using the POF in mm and fish mass in grams as $K = (\text{fish mass} \cdot 10^5) / \text{POF}^3$.

The third time series, age-at-maturity, comprised stock-recruit data (estimated total return by age for each brood year) for brood years 1949-2016 for lake-type stocks and for brood years 1952-2017 for Harrison River Sockeye, sea-type. Recruits were the sum of estimates of catch, escapement, and migration mortality within the Fraser River. Proportions of each brood year's production returning at ocean age-1, -2, and -3 were calculated from these estimates for brood

years with total production of these ages greater than 5,000. The most recent two years of return data, 2019 and 2020, were based on preliminary data (without post-season adjustments to run size estimates).

26.3. Status and trends

26.3.1. Spawning ground lengths of Fraser River Sockeye Salmon

Harrison River Sockeye differ from most other Fraser River Sockeye due to their 'sea-type' life history, which is more like that of Fraser Pink Salmon (see Ruggerone and Connors 2015), potentially leading to stronger ecological interactions in early marine life. Spawning ground lengths of Harrison ocean age-2 Sockeye (Figure 26-1a) were similar in odd- and even-numbered return years but, in the latter part of the time series, Harrison ocean age-3 Sockeye (Figure 26-1b) that returned in odd-numbered years tended to be smaller than those that returned in even-numbered years.

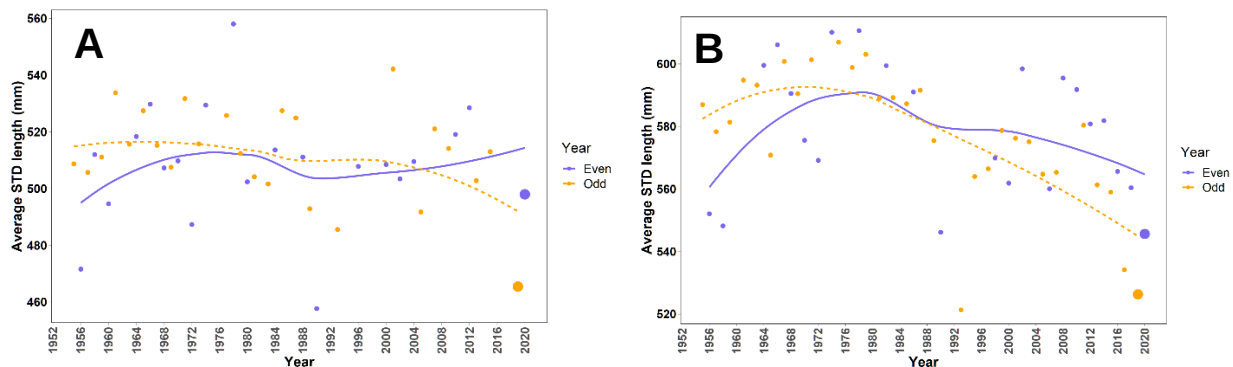


Figure 26-1. Average standard (STD) lengths of sea-type Harrison River Sockeye Salmon on their spawning grounds. Values are estimates for males and females, averaged together for each year, for fish of ocean age-2 (panel A) and ocean age-3 (panel B), respectively. Separate curves were fit (using the LOESS smoothing function in R) to the averages for odd-numbered and even-numbered return years.

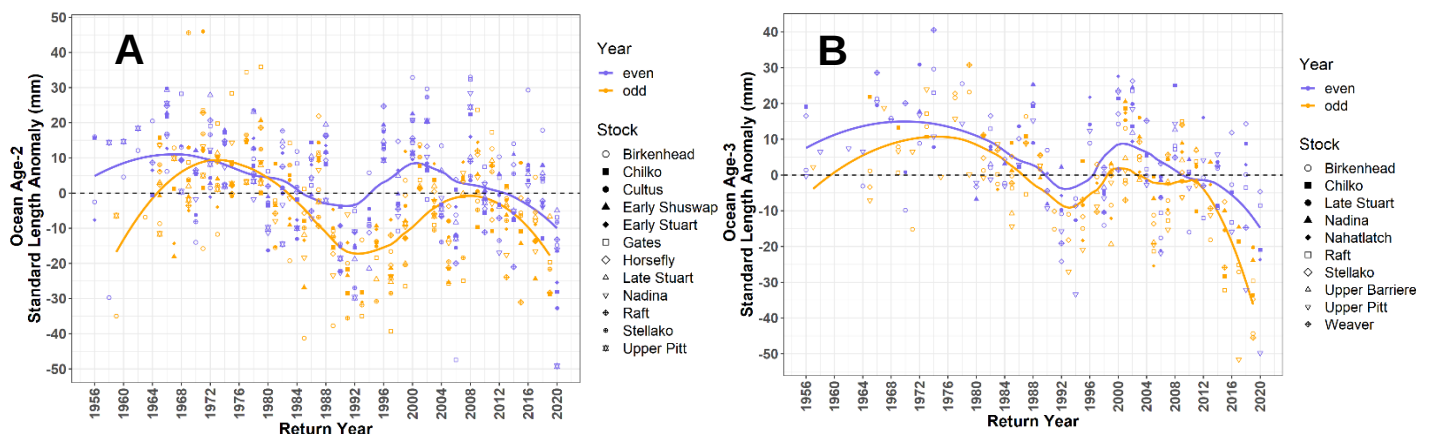


Figure 26-2. Average standard lengths of lake-type Fraser Sockeye Salmon on their spawning grounds. Annual anomalies were calculated relative to long term averages for males and females for each stock, for fish of ocean age-2 (panel A) and ocean age-3 (panel B), respectively. These anomalies were then averaged together for males and females each year for each stock, and LOESS curves were fit to aggregate anomalies among stocks, summarizing odd-numbered and even-numbered return years separately.

Like sea-type Harrison Sockeye, lake-type Sockeye that matured at ocean age-3 (Figure 26-2b) in odd-numbered years tended to be smaller, but this was also observed in ocean age-2 fish (Figure 26-2a). Spawning ground lengths of lake-type Fraser Sockeye were among the smallest on record in 2019 and 2020. Lengths in 2019 were remarkable for both ocean age-3 (lowest in the time series) and ocean age-2 (4th lowest). Average length anomalies in 2020 were higher than in 2019, ranking 3rd and 6th lowest for ocean age-3 and ocean age-2 Sockeye overall, respectively, but were very low for even-numbered return years (lowest for each age class among 32 even-numbered years in the data series).

26.3.2. Weight and condition factor of returning Fraser Sockeye

Matching weight and stock information was limited to recent years (after DNA technology was adopted for stock identification) and a relatively small number of individuals of most stocks. But weight and condition factor of Sockeye as they approach the Fraser River may be more informative regarding the marine conditions they encountered than the lengths of fish that eventually reach the spawning grounds, supporting the value of developing this time series. Weights appeared to decrease over the time series (Figure 26-3a), in agreement with length estimates for recent years, and 2020 weights were very low for an even-numbered year. Condition factor demonstrated less decline over the available years of data (2019 and 2020 condition factors were not as anomalous as weights in those years) but more strongly exemplified a biennial pattern (Figure 26-3b). Sockeye were skinnier in odd-numbered years.

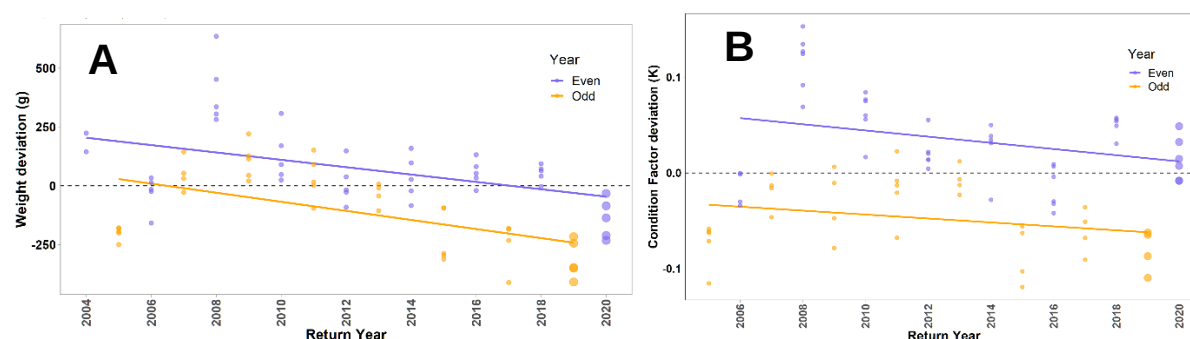


Figure 26-3. Average weights (panel A) and body condition factors (panel B) of Fraser Sockeye caught in fisheries and identified to stock by DNA analysis. Select stocks met sample size requirements for estimating joint anomalies (“deviations”) among age and sex categories across years. Simple linear regression lines were fit separately to estimates in odd- and even-numbered return years; larger symbols were used for 2019 and 2020 for emphasis.

26.3.3. Fraser Sockeye age-at-maturity

The estimated production of ages at which Fraser Sockeye returned to southern B.C. varied widely among stocks and among years within stocks, but an overall transition toward increased age-at-maturity could be seen in both sea-type Harrison Sockeye (Figure 26-4a) and lake-type Sockeye (Figure 26-4b), in both odd- and even-numbered brood years. This change was broader and more complete for Harrison Sockeye; the transition appeared more abrupt for lake-type Sockeye occurring over approximately 20 years from the 1970s to the 1990s. The 2019 and 2020 returns of ocean age-3 Sockeye were not extreme in terms of maturity schedule by brood year, but they did reflect continued older age-at-maturity of lake-type Sockeye in odd-numbered brood years versus even-numbered brood years. Sea-type Harrison Sockeye, on the other hand, showed a decrease in this biennial fluctuation in recent years.

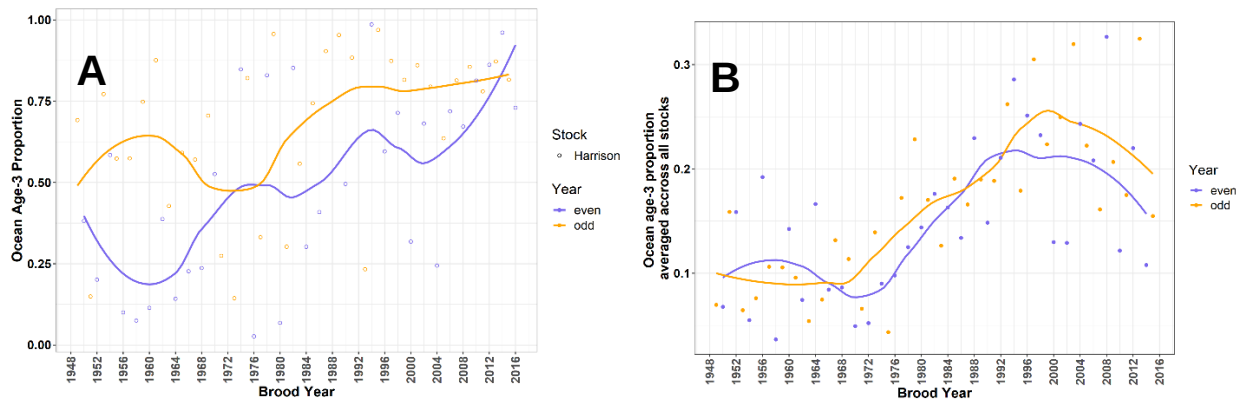


Figure 26-4. Proportion of brood year production maturing at ocean age-3 for sea-type Harrison Sockeye (panel A) and lake-type Fraser Sockeye stocks (panel B), estimated from stock-recruit tables, excluding brood years with production estimates below a total across ages of 5,000 recruits. LOESS curves were fit as in Figures 26-1 and 26-2.

26.4. Factors influencing trends

The three time series demonstrated historical and recent declines in size-at-age of Fraser Sockeye, a biennial fluctuation in which Sockeye tended to be shorter, lighter, and skinnier when returning in odd-numbered years, and a later maturity for Sockeye with odd-numbered brood years (potentially related to the observed biennial patterns in size). One hypothesis for these trends involves a mixture of direct and indirect effects of sea surface temperatures. Increased marine temperatures result in increased metabolic demands of Sockeye (Cox and Hinch 1997) and also result in reduced abundance and/or quality of food resources (DFO 2020). These may negatively affect Fraser Sockeye even in the absence of competition with Pink Salmon, but increased temperatures may also result in exacerbated impacts from Pink Salmon, whose overall abundance throughout the North Pacific Ocean has benefitted from warming temperatures (Connors et al. 2020). Our updates to these time series continue to support an effect of Pink Salmon on age-at-maturity and especially size-at-age in Fraser Sockeye, as previously reported (see McKinnell et al. 2012; Ruggerone and Connors 2015). Furthermore, increasing predominance of odd-year broodline Pink Salmon over the even-year broodline throughout the historical record (Irvine et al. 2014) could explain the generally greater odd/even year differences in Fraser Sockeye size and maturity in the latter halves of the long-term data series presented herein.

Growth rate and metabolic resources can interact with heritable predispositions to determine maturity schedules of individuals. Biennial fluctuation in maturity schedules supports the influence of marine growth on observed patterns. Trends in size-at-return and age-at-return of lake-type Fraser Sockeye were only broadly congruent, though: transitions to smaller sizes that began in the 1970s were accompanied by reduced maturation at ocean age-1 (not shown) and increased maturation at ocean age-3 (see Figure 26-4b). Subsequent changes in size, beginning with an increase observed in the 2000s, did not seem to influence age-at-maturity.

26.5. Implications of those trends

Size of salmon is of great importance to their value, both in fisheries and on the spawning grounds (where egg size and fecundity are strongly related to body size, and nutrient transport to natal locations from the ocean relies directly on body size). Size may also directly influence

marine survival, success of upriver migration, and successful egg deposition. In Prince William Sound, competition with hatchery Pink Salmon was estimated to reduce the productivity of wild Pink Salmon populations by approximately 15% through resulting reductions in body size (see Wertheimer et al. 2004). Fraser Sockeye and other populations and species rearing in the Gulf of Alaska may also be less productive through this mechanism.

In most salmon species, negative impacts from changes in size-at-age may be mitigated by remaining at sea for an additional year of growth. Preliminary estimates of overall size indicate that Fraser Sockeye have become smaller despite their increased age-at-maturity (PSC, unpublished data). Furthermore, delayed maturity may introduce additional harms, through an additional year of exposure to marine mortality risks and reduced speed of evolutionary response to climate change. For Fraser Sockeye, environmental pressures toward reduced size-at-age and increased age-at-maturity are likely deleterious to management objectives.

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27. TRENDS IN PACIFIC CANADIAN GROUND FISH STOCK STATUS

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27.1. Highlights

- Average groundfish stock status declined from 1950 to around 2000 and has remained relatively stable since then. The change around 2000 followed the implementation of ITQs (individual transferable quotas) for the trawl fleet and the commencement of the synoptic trawl surveys.
- As of their last assessment, four stocks (Strait of Georgia Lingcod [Area 4B], coastwide Bocaccio, and inside and outside Quillback Rockfish) had a > 5% probability of being below their Limit Reference Point (LRP; i.e., in the “critical zone”); Pacific Cod in Area 3CD had a 4.6% probability.
- Roughly one-third of stocks had a greater than 1 in 4 chance of being below their Upper Stock Reference (USR; i.e., in the “cautious zone”).
- Conversely, two-thirds of assessed groundfish stocks had a high (> 75%) probability of being above the USR (i.e., in the “healthy zone”).

27.2. Fisheries-independent groundfish surveys

DFO conducts a suite of randomized surveys using bottom trawl, longline hook, and longline trap gear that, in aggregate, cover Canada’s Pacific Coast (Anderson et al. 2019). Synoptic trawl surveys in Queen Charlotte Sound (Areas 5A and 5B) and Hecate Strait (Areas 5C and 5D) are conducted in odd numbered years, while the West Coast of Vancouver Island (WCVI; Areas 3C and 3D) and the West Coast of Haida Gwaii (WCHG; Area 5E) surveys are conducted in even numbered years. In addition, four biennial Hard Bottom Longline (HBLL) surveys are conducted, two in “inside” waters (east of Vancouver Island; Area 4B) and two others in “outside” waters (everywhere else). Lastly, a coast-wide longline trap survey targeting sablefish is conducted every year and DFO collects biological information from the International Pacific Halibut Commission (IPHC) Setline Survey. In 2020, only the synoptic WCHG trawl survey, outside HBLL south survey, IPHC setline survey, and sablefish survey were conducted. The synoptic WCVI survey did not occur due to COVID-19. At the time of writing, the only 2020 data available in DFO’s survey databases are the WCHG and sablefish surveys. Because of this, and because of legislative changes described below, we focus our report this year on groundfish biological status from published stock assessments over the last decade.

27.3. A state-space model of groundfish stock status

Recent amendments to Canada's *Fisheries Act* via the [Fish Stocks provisions](#) have increased DFO's focus on stock status with respect to biological reference points. The amendments are based on Canada's Precautionary Approach (PA) Framework, which describes two stock status reference points: (1) the Limit Reference Point (LRP), a "status below which serious harm is occurring to the stock"; and (2) the Upper Stock Reference Point (USR), which represents the "threshold below which removals must be progressively reduced in order to avoid reaching the LRP" (DFO 2009; Figure 27-1a). The USR defines the breakpoint between the healthy and cautious zone and the LRP defines the breakpoint between the cautious and critical zone (Figure 27-1a). The LRP and USR are often calculated based on B_{MSY} (biomass at maximum sustainable yield) at provisional levels of $0.4 B_{MSY}$ and $0.8 B_{MSY}$, but in other cases can be based on proxies, such as average or minimum historical biomass levels (e.g., Forrest et al. 2020).

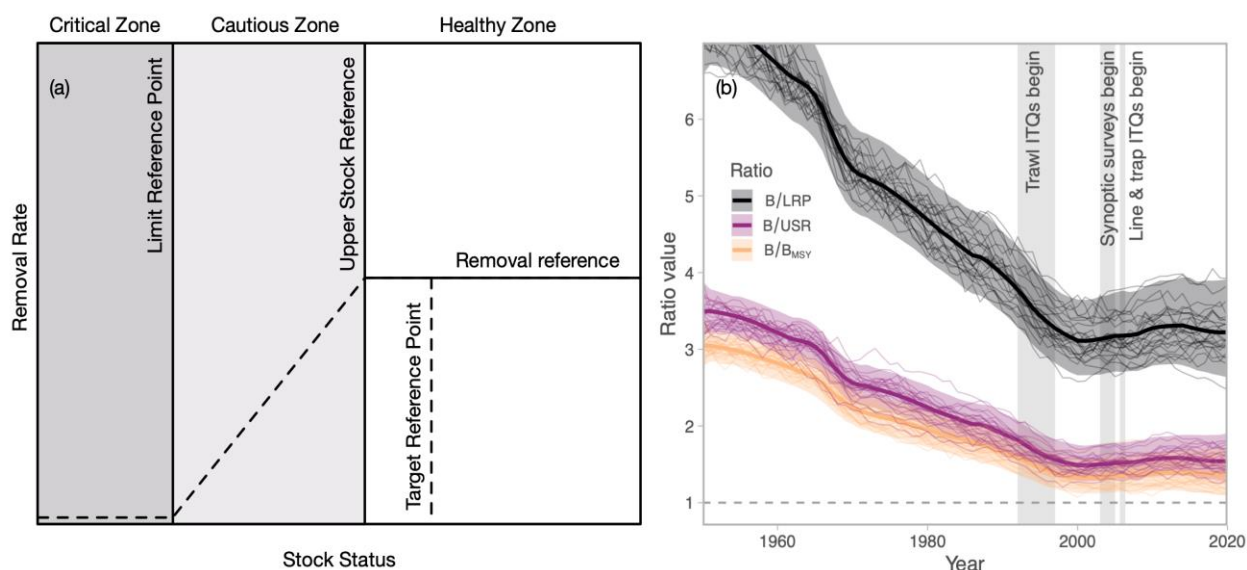


Figure 27-1. (a) Illustration of DFO's Precautionary Approach Framework. The two vertical lines—the Limit Reference Point (LRP) and Upper Stock Reference (USR)—are the focus of this analysis. Based on DFO (2009). (b) Overall mean biomass status (x_t) across all stocks for B/LRP , B/USR , and B/B_{MSY} . Dark lines represent the median, shaded ribbons represent 95% quantile credible intervals, and thin lines represent 25 illustrative draws from the posterior distribution.

Scientists conduct regular stock assessments for major fish stocks in BC. These assessments combine fishery-dependent data (such as commercial catches) with fishery-independent data (data from scientific surveys) to estimate quantities such as spawning stock biomass, growth, and maturity, and derive measures of stock status and fishing intensity. Here, we gathered output data from assessments for 24 stocks representing the Bayesian posterior distribution of estimated biomass (B) compared to three measures of stock status: (1) B/LRP (biomass divided by the LRP), (2) B/USR (biomass divided by the USR), (3) B/B_{MSY} (biomass divided by B_{MSY}). We develop a hierarchical Bayesian state-space time-series model to explore trends in these measures of status across all stocks until the year 2020. To do this, we built on a model described in Hilborn et al. (2020) in two ways: (1) we incorporated uncertainty in stock-specific status; and (2) we projected the latent underlying stock-specific status forward to the last year (2020). The latter accounts for not all stocks having an up-to-date stock assessment and

accounts for future possible stock states based on the time-series properties of the fitted stock trajectories.

We modelled overall (i.e., all stocks combined) log stock status x at time t as $x_{t=1} = x_0$ and $x_{t>1} = x_{t-1} + \eta_t$, $\eta_t \sim \text{Normal}(0, \sigma_\eta^2)$, where η_t is a random walk deviation with standard deviation σ_η . We assumed an auto-regressive observation model:

$$\begin{aligned}\hat{y}_{j,t} &\sim \text{Normal}(y_{j,t}, \hat{\tau}^2), \\ y_{j,t} &= x_t + \alpha_j + \epsilon_{j,t}, \epsilon_{j,t} \sim \text{Normal}(\rho\epsilon_{j,t-1}, \sigma_\epsilon^2),\end{aligned}$$

where $\hat{y}_{j,t}$ is the mean log stock status for stock j and time t (from an assessment), $y_{j,t}$ is the unobserved “true” mean stock-specific status, and $\hat{\tau}$ is the standard deviation of the log stock status from an assessment. The symbol α_j represents a stock-specific intercept that is constrained such that the sum of all α_j is zero to make the overall mean x_t identifiable. The symbol $\epsilon_{j,t}$ represents a first-order autoregressive (AR1) deviation with correlation ρ and standard deviation σ_ϵ . We placed half-Normal (0, 1) priors on σ_ϵ and σ_η , Normal (0, 5²) priors on x_0 and α_j , and a Normal (0, 1) [-1, 1] prior on ρ . We fit the models with Stan (Carpenter et al. 2017; Stan Development Team 2020), sampling 1000 iterations on each of 6 chains and discarding the first half as warm up. Data and code to reproduce our analysis are available at <https://github.com/pbs-assess/gftrends>.

27.4. Status and trends

Of the 24 groundfish stock status time series included in the analysis, four stocks provided historical reference points for management advice, 18 provided MSY-based reference points, and two (Rock sole in Areas 5AB and 5CD) provided both historical and MSY reference points (we herein use the MSY-based ones). The most recent assessments were for the Rougheye/Blackspotted Rockfish complex, Pacific Cod, Bocaccio, inside and outside Yelloweye Rockfish, and Sablefish.

Across all stocks, there was a decline in average stock status for all three indices prior to approximately 2000 (Figure 27-1b). The late 1990s and early 2000s marked the beginning of a relatively stable average status. We estimated the overall mean B/LRP in 2020 to be 3.2 (95% credible interval [CI]: 2.6–3.9). The overall mean B/USR and B/B_{MSY} in 2020 was 1.5 (95% CI: 1.3–1.9) and 1.4 (95% CI: 1.1–1.7), respectively. Uncertainty in average status in the last few years increased because not all stocks had a current assessment (Figure 27-1b).

The clear pattern in the average biological status has been accompanied by considerable variation within and across individual stocks (Figure 27-2). Within individual stocks, Pacific Cod and Walleye Pollock—both with shorter generation times compared to many other stocks here—exhibited strong patterns of decadal variation. Across stocks, Redstripe Rockfish in northern and southern BC and coastwide Yellowtail Rockfish are examples of stocks with B/LRP trajectories consistently above the average. Conversely, Lingcod in 4B and coastwide Bocaccio are examples of stocks with B/LRP estimated consistently below the average. Sablefish followed the average B/LRP trajectory until around 1990 when they continued to decline while

the average stabilized. The Sablefish stock trajectory has shown signs of increase since around 2015 because of large recent recruitments (DFO 2020a; Figure 27-2).

Estimated biomass was above the LRP and USR for most stocks as of the most recent assessment (Figure 27-3). Lingcod in 4B and coastwide Bocaccio were the only stocks (with full posterior distributions available) with > 5% posterior density below their LRP as of their most recent assessment (Figure 27-3). Pacific Cod in 3CD almost met this threshold with a 4.6%

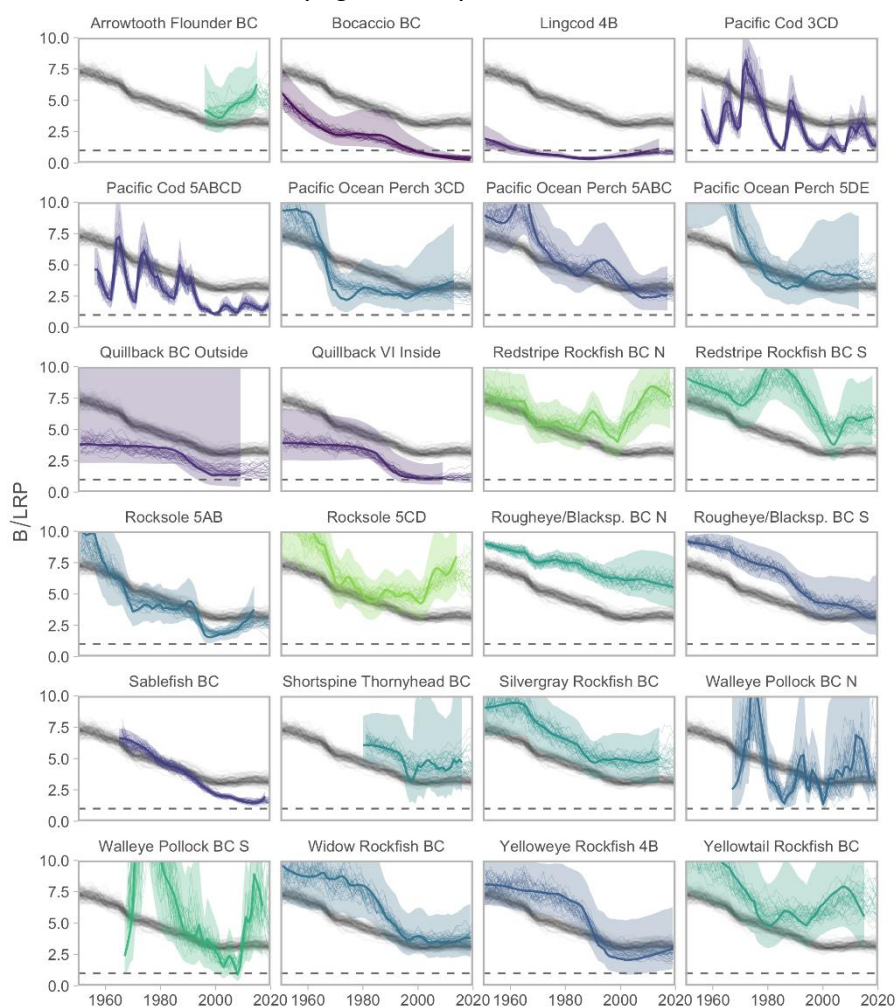


Figure 27-2. Trends in B/LRP for 24 groundfish stocks in BC. Coloured lines and ribbons represent the individual stocks. Colours represent the ratio in the last year of assessment such that green stocks are highest and purple are lowest. Dark coloured lines and shaded ribbons represent output from stock assessments: trajectories of median B/LRP 95% quantile credible intervals. Thin lines represent draws from the posterior distribution of $y_{j,t}$ (latent stock-specific mean trends; colours) and x_t (latent overall mean trend; grey). The overall mean trend (x_t ; grey) is the same across panels (see Figure 27-1b).

transferable quotas (ITQs) for the trawl fleet and the introduction of 100% at-sea observer coverage over the period 1992–1997 (Turris 2000) and with the initiation of the current synoptic trawl surveys in 2003.

probability $B < LRP$ in 2020. The assessment of Bocaccio, however, projected the stock to rebuild above the LRP by 2023 due to a very large recruitment event in 2016 (DFO 2020b). Quillback Rockfish in both outside and inside waters had > 5% posterior density below their LRPs as of the 2011 assessment, but the full posterior distribution was not available (quantiles are shown in Figure 27-2). Considering the USR instead of the LRP, 7/22 of the stocks in Figure 27-3 had > 25% probability of being below their USR as of their most recent assessment.

27.5. Factors influencing trends

The factors most likely influencing the trends illustrated here have been fishery removals and management interventions. The transition from declining average B/LRP and B/USR to a relatively stable trajectory coincided with the implementation of individual

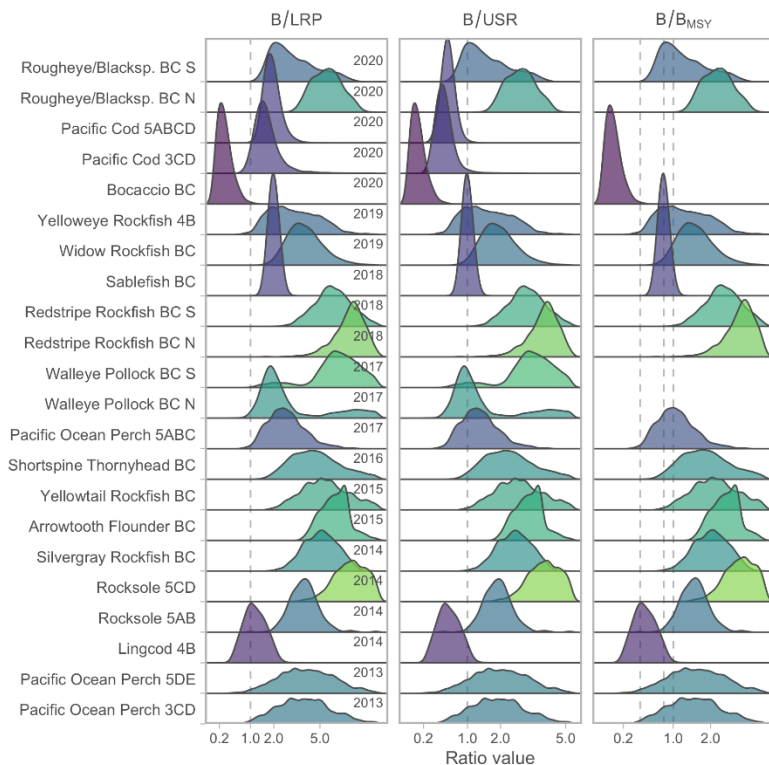


Figure 27-3. Posterior distribution of the three measures of stock status for 22 of the 24 stocks. Stocks are arranged in order of assessment with the most recent assessments at the top; years in the first column represent the year the status represents. Colours represent the mean B/LRP value such that green is highest and purple is lowest. Stocks with missing data in the B/B_{MSY} column are assessments where historical reference points were used instead of MSY -based reference points. Vertical dashed lines are at values of 1.0 in all columns and at values of 0.4 and 0.8 in the B/B_{MSY} column (0.4 and 0.8 B_{MSY} are provisional LRP and USR values in the PA Framework). The x-axis has been square-root transformed to slightly compress high ratio values for visualization. In a few cases (e.g., Bocaccio) the status represents a one- or two-year projection from the last year of available data. The full posteriors were not available for Quillback Rockfish stocks, which are shown in Figure 27-2.

Furthermore, ITQs and electronic at-sea monitoring were introduced into the longline and trap fisheries in 2006 (Stanley et al. 2015). Following these major management changes, quota for many stocks has remained relatively constant over the last two decades (DFO 2019). The decadal patterns in assessed status for Pacific Cod (Forrest et al. 2020) and Walleye Pollock (Starr and Haigh, in press) in early decades are largely driven by trends in commercial catches and catch per unit effort. Consistently poor recruitment for decades is thought to be the primary driver behind stock declines for some rockfish such as Bocaccio (DFO 2020b), although many stocks are data-limited and there is therefore considerable uncertainty around recruitment trends, which may be confounded with other factors such as the management changes noted above. In terms of absolute stock status, estimates of B_{MSY} for data-limited species may be highly uncertain, or in some cases biased (Forrest et al. 2018).

There are also potential species interactions and climatic effects on trends in local biomass density of these species. Loss of spawning habitat due to recent oceanographic conditions has been hypothesized to have led to years of low recruitment in some groundfish (e.g., Pacific Cod in nearby Alaskan waters; Laurel and Rogers 2020). Conversely, after decades of poor recruitment, Bocaccio experienced a year of extremely strong recruitment (44 times the average for Bocaccio in 2016; DFO 2020b) possibly due to the availability of oxygen-rich water at depth during gestation (Schroeder et al. 2019). The slow recovery of Area 4B Lingcod since initial fishery-driven declines between the 1930s and 1980s may be a result of changes in the Strait of Georgia ecosystem (e.g., plankton timing, pinnipeds; DFO 2015). Underlying these stock-level

trends, recent work suggests that temperature velocity—the pace a fish would have to move to maintain consistent temperature—may be related to a fine-scale redistribution of groundfish species density in Canadian Pacific waters (English et al. 2021).

27.6. Implications of those trends

The Sustainable Fisheries Framework and the Fish Stocks provisions of the *Fisheries Act* require that major fish stocks be maintained above their LRP with high probability. Stocks below their LRP will require a rebuilding plan. While average stock status was clearly above the LRP as of 2020, there was considerable variation among stocks. Four stocks had > 5% probability of being below their LRP and roughly one-third of assessed stocks had > 25% probability of being in the cautious zone where removals should be progressively reduced to avoid reaching the LRP. Rebuilding and precautionary management of stocks in the critical and cautious zones, respectively, should help ensure stock status improves over time in response to reduced fishing pressure and favorable environmental conditions if and when they occur.

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28. ALBACORE TUNA ABUNDANCE AND TRENDS IN PACIFIC CANADIAN AND U.S. EEZS

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28.1. Highlights

- Albacore tuna annual catch-per-unit-effort (CPUE) decreased substantially in 2016 and 2017 from high values in 2013-2015, and the CPUE increased in 2018-2020.
- In 2019 and 2020, differences in CPUE between the Pacific Canadian exclusive economic zone (EEZ) and the U.S. EEZ were smaller than in most of the earlier years.
- CPUEs are significantly and positively correlated with North Pacific Gyre Oscillation (NPGO) indices in both the Pacific Canadian and the U.S. EEZs.

28.2. Description of the time series

North Pacific Albacore Tuna (*Thunnus alalunga*) is a highly migratory pelagic species. Some juvenile albacore of 2-4 years of age migrate seasonally into the waters off the northwest coast of North America in June-July and leave in October. The Canadian Albacore fishery primarily takes place in the Canadian and U.S. EEZs, and adjacent high seas waters, using troll gear. Canada has a long history of fishing for Albacore Tuna, but catch reporting was unreliable prior to 1995 (Stocker et al. 2007). No scientific surveys have been conducted on juvenile albacore in the Canadian and the U.S. EEZs, and the time series data presented here were derived from the fishery-related statistics collected since 1995. CPUE was calculated by dividing total catch in metric tons by total number of fishing days by all Canadian fishing vessels in the interested area, and was used to indicate relative albacore abundance. The CPUE in the U.S. EEZ in 1995 is excluded, as little catch effort (2.2%) was spent there by the Canadian fishery. No CPUE data exists in the U.S. EEZ in 2013, as no Canadian albacore fishing occurred there.

28.3. Status and trends

Albacore CPUEs in the Canadian EEZ by the Canadian fishery showed a slight decline from 1995 to 1997, after which there was a general increase until 2010, reaching a maximum of 0.81 mt per vessel-day. CPUE declined by over 50% between 2010 and 2011, and remained depressed in 2012. CPUEs increased in 2013-2015, reaching the highest observed level of 0.90 mt per vessel-day in 2014. After 2015 there was a dramatic decline, in 2017 reaching the lowest observed level since 1995. CPUEs have been increasing since the drastic drop in 2017 (Figure 28-1A). Albacore CPUEs in the U.S. EEZ by the Canadian fishery showed a general increasing trend between 1996 and 2015. CPUEs also largely decreased in 2016 and 2017 but increased in 2018-2020 (Figure 28-1B). Ratios of CPUEs in the Canadian EEZ to CPUEs in the U.S. EEZ showed substantial variation between 1996 and 2020, although the ratios were all below one (Figure 28-2). This ratio was higher than 0.9 in 2002, 2005, 2010, and 2019. Although this ratio decreased to 0.82 in 2020, it was still considerably higher than the overall mean of 0.70.

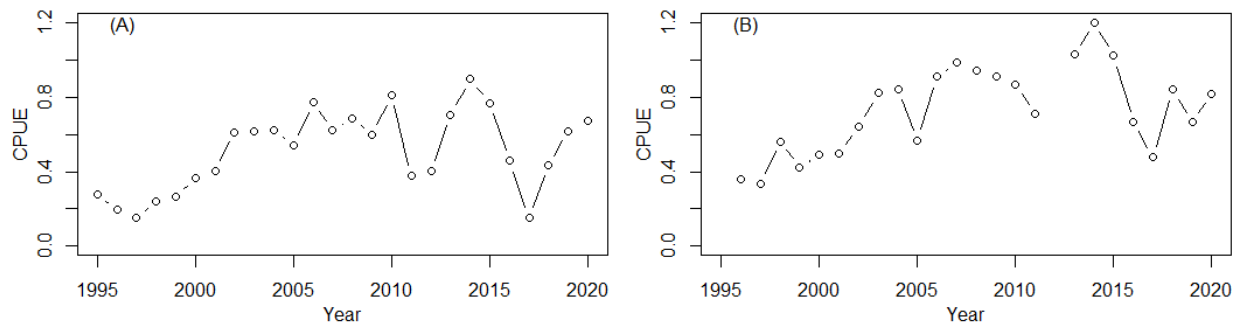


Figure 28-1. Annual Catch-per-unit-effort (CPUE) in the Canadian EEZ (A) and the U.S. EEZ (B) for the Canadian fishery.

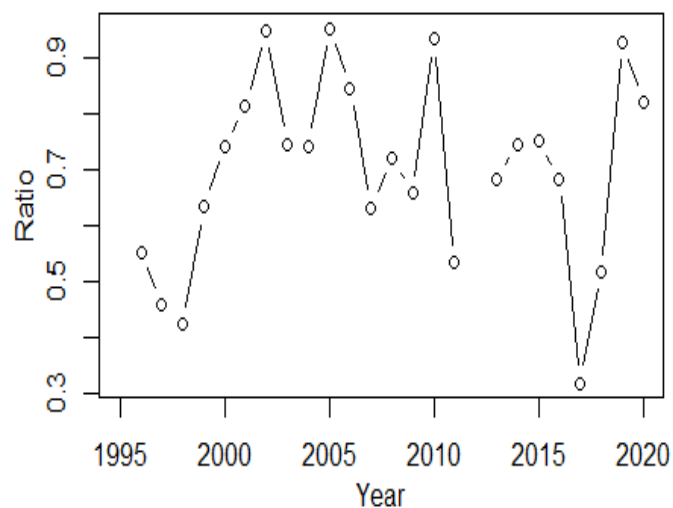


Figure 28-2. Ratio of annual CPUE in the Canadian EEZ to annual CPUE in the U.S. EEZ for the Canadian fishery.

28.4. Factors influencing trends

Factors influencing relatively high CPUEs in the Canadian EEZ in the four years of 2002, 2005, 2010 and 2019 are unknown. Canadian fishers measure water surface temperatures in the fishing grounds. Mean measured temperatures varied from low, intermediate and high levels in these four years.

CPUEs in either the Canadian EEZ or the U.S. EEZ are significantly and positively correlated with the NPGO index. Figure 28-3 shows the relationships between CPUEs and the NPGO index three years earlier.

The NPGO closely reflected inter-annual variations in salinity, nutrient upwelling, and surface chlorophyll *a* in the ocean (Di Lorenzo et al. 2008), and was positively correlated with phytoplankton abundance in Oregon (Menge et al. 2009) and productivity of the North Pacific albacore stock (Zhang et al. 2014). As a result, the NPGO may have some positive influence on the abundance of Albacore in the East Pacific Ocean.

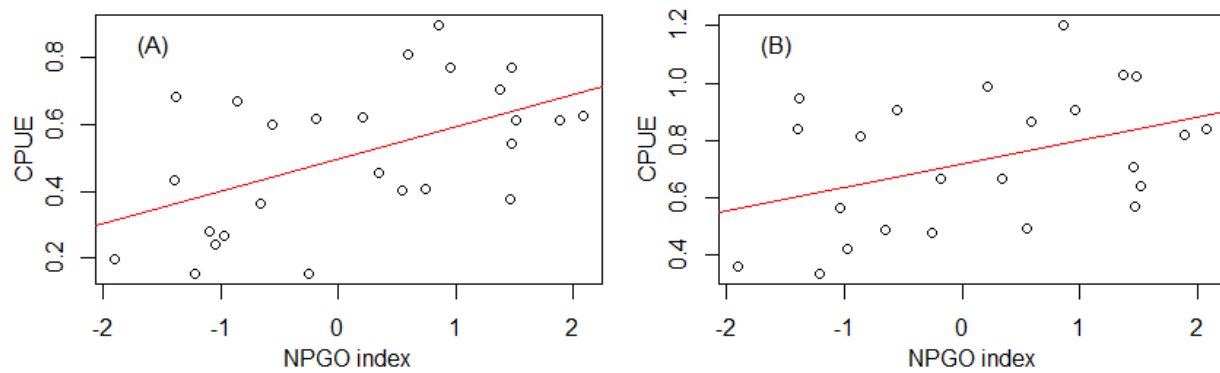


Figure 28-3. Correlation between annual means of NPGO indices three years earlier and CPUEs in the Canadian EEZ (A) and in the U.S. EEZ (B) for the Canadian fishery.

28.5. Implications of those trends

Albacore is an economically important tuna species in the Pacific Ocean. Albacore abundance in the Canadian EEZ is of particular importance to Canadian Albacore fishers, as most of them only fish in the Canadian EEZ. Albacore abundance appears to have increased faster in the Canadian EEZ than in the U.S. EEZ in the past three years. Physical and biological mechanisms for such a difference are not known. Longer time series of catch data are needed to determine if this is a general trend, and to evaluate the amount of the NPGO influence on Albacore abundance in the Canadian and U.S. EEZs.

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29. A PROPOSED MONITORING FRAMEWORK FOR THE SGaan KINGLAS-BOWIE SEAMOUNT PROTECTED AREA

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29.1. Highlight

- The development of a monitoring plan is a priority for implementing the SGaan Kinghlas-Bowie Seamount Marine Protected Area (SK-B MPA) management plan. The Council of the Haida Nation (CHN) and DFO technical team is currently developing a monitoring framework via a peer-review Canadian Scientific Advisory Secretariat (CSAS) process.
- This framework will include recent fieldwork and CSAS processes conducted by DFO science and novel approaches to ecological monitoring, providing a road map to inform the future monitoring plan for the SK-B MPA, and is expected to be concluded in fall 2021.

29.2. Brief history of SK-B MPA establishment

In 1997, SGaan Kinghlas seamount was designated as a Haida protected area. In 2008, SGaan Kinghlas-Bowie (SK-B), as well as its two neighbouring seamounts, were designated as a MPA under the *Oceans Act* and operates under a cooperative management agreement between the Haida Nation (represented by the Council of the Haida Nation, CHN) and Government of Canada (represented by Fisheries and Oceans Canada, DFO). The management plan for the SK-B MPA was finalized in 2019 (CHN and DFO 2019). The ecological significance and protection of these seamounts are of interest to a global community of marine scientists and conservationists.

29.3. Science advice for a monitoring plan

The development and implementation of a monitoring plan for the SK-B MPA is a priority, as the status and trends for the indicators identified to be monitored will enable the SK-B Management Board to evaluate the effectiveness of management efforts and to make adjustments as necessary. For that reason, a monitoring framework is currently underway and will be released as peer-reviewed CSAS publications (Science Advisory Report and Working Paper; RSIA 2016OCN03). Expected to be concluded in fall 2021 it will encompass the following objectives:

- Review the state of baseline knowledge of the SK-B MPA ecosystem.
- Identify the conservation goals and objectives outlined in the SK-B MPA Management Plan.
- Propose monitoring indicators, protocols, and strategies for the collection and analysis of data.
- Anticipated changes (e.g. perceived threats, recoveries).
- Develop a framework for monitoring that may be used to determine if the MPA is effective in achieving the conservation objectives.

- Evaluate the monitoring framework against conservation objectives described in the SK-B MPA management plan.
- Examine and identify uncertainties.

29.4. Recent CSAS peer-review and other processes informing the SK-B MPA monitoring framework

The SK-B MPA monitoring framework will include relevant information provided by recent DFO-led scientific advice (Nov 2020-Jan 2021), related to deep-sea monitoring, and within the context of the SK-B MPA conservation objectives (see Table 29-1). Other processes and recent publications will also be considered for this science advice, such as information and lessons-learned from the Pacific Region Rockfish Conservation Areas (RCAs), monitoring of human/fishing activities (Dunham et al. 2020) and climate change indicators (Iacarella et al. 2020, and recent DFO-led workshop on climate change and MPAs, February 16-18, 2021).

Table 29-1. Recent DFO processes and workshops and their relevance to the SK-B MPA monitoring framework.

RECENT CSAS PEER-REVIEW PROCESS	RELEVANCE TO THE SK-B MPA MONITORING FRAMEWORK
1. Important seamount areas in the Offshore Pacific Bioregion and proposed Offshore Pacific Marine Protected Area, Canada <i>*Co-authored by Cherisse Du Preez & Tammy Norgard</i>	(1) Provides background information for all 62 seamounts offshore of B.C.; (2) a summary of what data exists; (3) how SK-B seamounts compare to all others; (4) identification of important/ representative areas on the SK-B seamounts.
2. A national monitoring framework for coral and sponge areas identified as Other Effective Area-Based Conservation Measures	(1) Provides terminology & workflow; (2) method for selecting indicators (state & stress); (3) examples of good corals & sponge indicators; (4) what to consider for tools, techniques, & methodologies.
3. Gully Marine Protected Area monitoring review	(1) 10 years of monitoring experience; (2) real-world considerations & limitations; (3) next steps; (4) the importance and need for data portals.
4. Workshop: Integrating Climate Change in the Design, Monitoring, and Management of MPAs and Marine Conservation Networks in Canada	(1) Reviews current information on the impacts of climate change on marine ecosystems and how climate change has been addressed within Marine Protected Area (MPA) management both nationally and abroad. (2) Proposes a tangible path forward and recommendations for how climate change can be considered in the design, monitoring and ongoing management.

The monitoring framework intends to provide a step-wise approach (Figures 29-1 and 29-2), with indicator and methodology options to inform the SK-B MPA monitoring plan development. A series of tables, one leading to the next, similar to a “choose your own adventure” story, where the deciding factors will also include feasibility considerations for implementation (i.e. existing baseline data, cost, reliability, etc.).

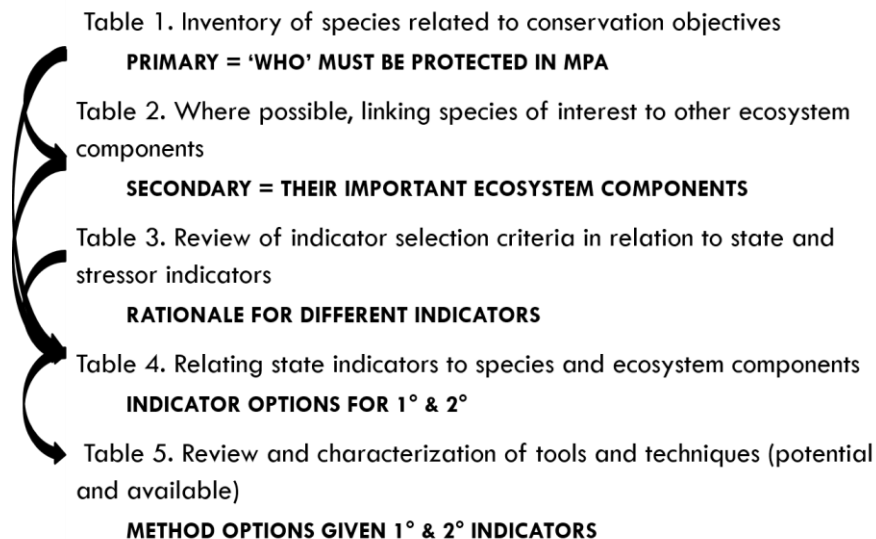


Figure 29-1. Step-wise approach for selection of indicators and methodologies.

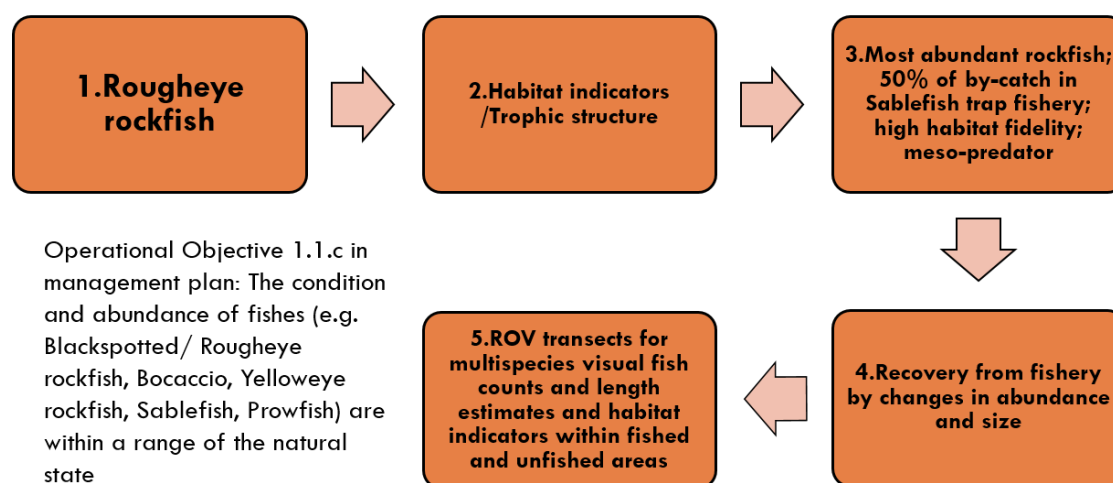


Figure 29-2. Step-wise approach example in relation to operational objective described in the SK-B management plan.

29.5. Reference

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30. UNUSUAL EVENTS IN CANADA'S PACIFIC MARINE WATERS IN 2020

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² Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, B.C.

30.1. Highlights

- Unusual events occur in Canada's Pacific marine waters every year but are often not reported on or related to the broader environmental context.
- Some unusual events in 2020 that were reported include: unusual species that are normally warm-water species (baraccuda and striped dolphin), krill die-offs, and some rare sightings of species.

30.2. Description of the time series

Every year, unusual marine events occur in the Northeast Pacific: some are reported to DFO, many are not. These are often seen as “one-off” events, which are isolated from other events, in time, space, and by different observers. It is therefore difficult to make a complete story or a synthesis of such observations. However, if enough of these events are observed and reported, it may be possible to identify broader patterns and processes that collectively tell us how our marine ecosystems are changing and responding to diverse pressures. For example, the REDMAP (Range Extension Database and Mapping Project; <http://www.redmap.org.au>) program in Australia engages citizen scientists and the interested public to report their observations of unusual organisms and events to a structured network, which can subsequently be used in scientific (and other) publications (e.g. Pecl et al. 2014; Lenanton et al. 2017). This report presents a selection of unusual events in Canada's Pacific waters in 2020 that have been reported to or noted by DFO Science staff. Some of these events may be included in other reports in this document, whereas other observations may not be presented in detail or at all. In addition, participants were invited to provide their own observations of weird and wonderful unusual events during the State of the Pacific Ocean meeting, which are included in this report.

30.3. Status and trends

Observations in 2020 that were reported to DFO by participants at the 2021 State of the Pacific Ocean workshop are presented in Table 30-1. During the initial COVID-19 lockdown, sound pressure levels in the Strait of Georgia (near Nanaimo) were reduced by 86% (Table 30-1). Unusual species that are normally warm-water species were observed in B.C. in 2020, including a Baraccuda in Alberni Inlet and a Striped Dolphin on Haida Gwaii. A King-of-the-salmon was washed up on shore near Sooke; this species is in B.C. waters, but is a deep water species, so it was an unusual occurrence. Common Thresher Shark was observed off the west coast of Vancouver Island (WCVI) – a rare sighting. The A5 pod of Killer Whales was observed in the Broughton Archipelago for the first time in >20 years. Die-offs of krill and perch were reported in a few places. Sunfish are distributed in B.C. waters and had been presumed to be one species; however, a recent study showed that some sunfish previously thought to be *Mola mola* have

been re-identified as *Mola tecta*. Another recent study showed that, globally, a parasitic worm has been increasing in abundance (Fiorenza et al. 2020).

Table 30-1. Observations of weird, wonderful and/or unusual marine events reported during 2020 or reported at the 2021 State of the Pacific Ocean meeting.

Event	Where	When	Reported by	(Brief) Details
Krill die-off	Beach at Sechart	March 2020	Ian Perry (DFO)	Large number of dead krill.
Reduced noise	Snake Is. (near Nanaimo)	April 2020	Dana Haggarty (DFO), et al.	Sound pressure levels reduced by 86%, compared to April 2019, due to COVID lockdown.
Stranded Striped Dolphin	Haida Gwaii	05/06/2020	Alex Rinfret (discoverer), Karissa Gall (local journalism initiative reporter)	Warm-water species. First-ever recorded sighting of a striped dolphin north of Vancouver Island. Only one other was observed swimming in B.C. waters in September 2019.
Barracuda caught	Alberni Inlet	07/13/2020	Tyler Vogrig (fisherman), Binny Paul (local journalism initiative reporter)	Fishermen caught it during salmon testing program for DFO. Predatory fish, usually distributed in tropical and subtropical waters. One other record along the eastern North Pacific coast, July 27, 1904.
<i>Mola mola</i>	Inside waters off Painter's Lodge, Campbell River	08/18/2020	Mike Morley	Caught by sport fisherman.
<i>Mola tecta</i> (Hoodwinker sunfish)	Northeast Pacific, including B.C.	2020	Marianne Nyegaard (scientist), Jade Prevost-Manuel (CBC)	A number of sunfish previously thought to be <i>Mola mola</i> have been re-identified as <i>Mola tecta</i> . Pictures were taken to help with identification.
Perch die-off	Powell River	09/07/2020	Ed Oldfield	Thousands of perch (same place as krill die off in April 2019).

King-of-the-salmon washes ashore	Whiffen Spit, near Sooke	09/22/2020	Dana LeCompte (discoverer), Darron Kloster (Times Colonist)	Rare ribbonfish, king-of-the-salmon (<i>Trachipterus altivelis</i>), a deepsea-species; distribution: Chile to Alaska.
Krill stranding	Neck Point beach, Nanaimo	09/28/2020	Jennifer Boldt (DFO)	Large number of recently beached <i>Thysanoessa spinifera</i> (most still alive).
Common Thresher Shark	Off WCVI (49.07222, -126.48675)	10/07/2020	Erika Anderson	4.6 m <i>Alopias vulpinus</i> captured and released alive during offshore net gear trials.
A5 pod Killer Whales returned to Broughton Archipelago	N. Vancouver Island	01/05/2021	Jared Towers (DFO), Zoe Ducklow (Black Press)	A5 pod returned to Broughton Archipelago, their traditional winter hunting ground, with baby; first time in >20 years.
Increase in Anisakis spp. abundance	Global	1962-2015	Fiorenza et al. 2020, Global Change Biology https://doi.org/10.1111/gcb.15048	Anisakid nematodes cause disease and are transmitted to humans in undercooked/raw seafood.

30.4. Factors influencing trends

Potential factors influencing these events include a changing climate, natural population changes, and anthropogenic pressures. Disease is a potential factor causing mortality, but is difficult to assess. As the climate changes, extreme weather will continue to be a factor in affecting marine biology and long-term temperature increases will continue. Increased temperatures will bring species from warmer waters into B.C.'s marine ecosystems.

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31. CCGS SIR JOHN FRANKLIN: THE PACIFIC REGION'S NEW OFFSHORE FISHERIES SCIENCE VESSEL

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31.1. Highlights

- The CCGS Sir John Franklin, accepted on June 29, 2019, is Fisheries and Oceans Canada Pacific Region's new Offshore Fisheries Science Vessel.
- Three successful science missions were carried out in 2020.
- The vessel has a wide range of capabilities for fisheries and oceanographic sampling, which will continue to foster new fisheries science time-series along our coast.

31.2. Description

The Canadian Coast Guard Ship (CCGS) Sir John Franklin is the Pacific Region's new Offshore Fisheries Science Vessel (OFSV). It is replacing the CCGS W.E. Ricker, which had its last science mission in August and September 2016, after more than 30 years of providing fisheries science surveys and research for the Government of Canada. The CCGS Sir John Franklin was the first of three OFSV built in Vancouver. Construction began in 2015 and the vessel was accepted on June 29, 2019. Following a series of tests, exercises, and familiarization, the CCGS Sir John Franklin completed three successful science missions in 2020, the first of which consisted of gear and instrument trials for research on Pacific Hake (*Merluccius productus*) and associated fauna (this report), followed by two surveys on Pacific salmon (see reports from Neville, Section 40; and Anderson, Section 22).

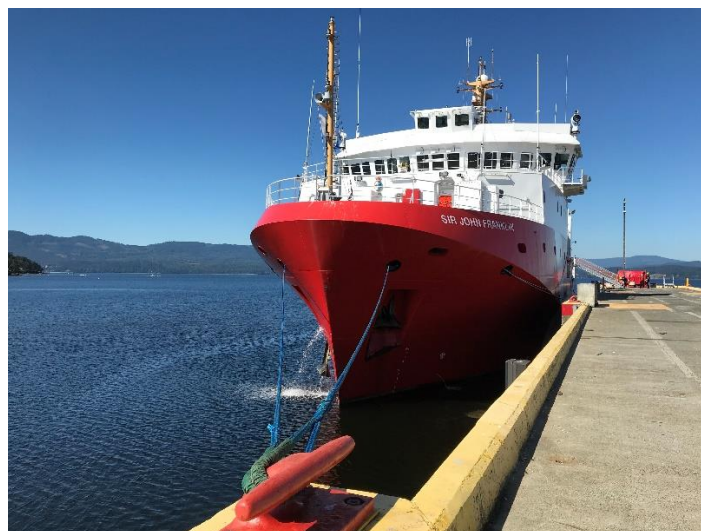


Figure 31-1. CCGS Sir John Franklin at the Institute of Ocean Sciences, Patricia Bay, Sidney, British Columbia (photo credit: S. Gauthier).

The first mission of the CCGS Sir John Franklin in August 2020 included a range of instrument tests and calibrations, as well as some survey transects and research in open water. Calibration of acoustic instruments and practical deployments of oceanographic instruments took place in Saanich Inlet, and were followed by the collection of acoustic data along transects and scientific biological samples using trawl nets off the West Coast of Vancouver Island, along the shelf break between Barkley and Clayoquot canyons.

The new vessel is equipped with state of the art fisheries acoustic tools, including a 6-frequency Simrad EK80 broadband echosounder system and an MS70 high-resolution side-scan multi-beam sonar that are installed on a drop-keel system. The vessel is also equipped with an Acoustic Doppler Current profiler (ADCP, Teledyne), High Precision Acoustic Positioning system (Simrad HIPAP), a Simrad EA600 bathymetric echosounder, and a Simrad SX90 long range fish finding sonar. This assortment of science tools will provide unique opportunities to improve fisheries science and ecosystem assessments.

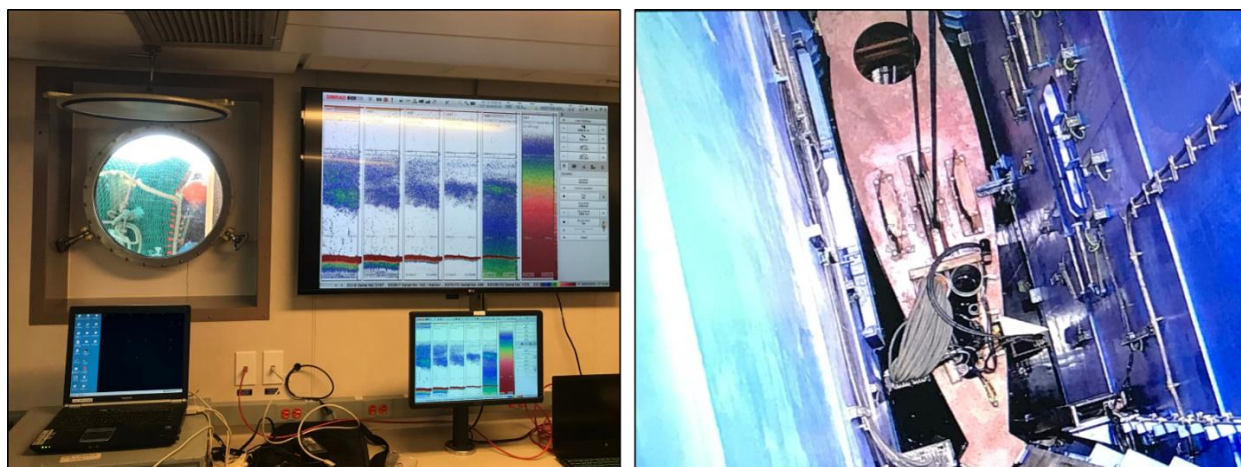


Figure 31-2. Display of the scientific echosounder (SIMRAD EK80) in the CCGS Sir John Franklin control lab, along with a view of the chamber containing the drop-keel in the centre of the ship. The tear-shape keel houses all 6 transducers for the Simrad EK80 scientific echosounder, as well as the side-scan MS70 multi-beam sonar. The drop-keel can be deployed to bring the echosounder transducers below the hull of the vessel, and to operate the multi-beam.

Targeted midwater trawling was carried out using a Cantrawl 250 pelagic net on detected pelagic scattering layers from 50 m to 280 m depth, sampling a wide range of pelagic species from myctophids to Pacific Hake and Walleye Pollock. In addition to trawling using a range of surface, midwater, and bottom trawl gear, the CCGS Sir John Franklin is equipped with two LARS (Launch And Recovery System) on the starboard side. One of these systems is dedicated to a CTD rosette, while the aft section can be used to deploy various plankton nets and other instruments or drop systems. During this first mission, we successfully deployed paired bongo nets, and towed a larger MOCNESS (Multiple Opening/Closing Net and Environmental Sensing System) to sample zooplankton species, as well as small larval fish.

Some technical issues and operational challenges were identified as part of these first missions, and these are being addressed in preparation for the 2021 field season. The CCGS Sir John Franklin is a capable and science tailored vessel that is a welcome addition to the Pacific Region's fleet.

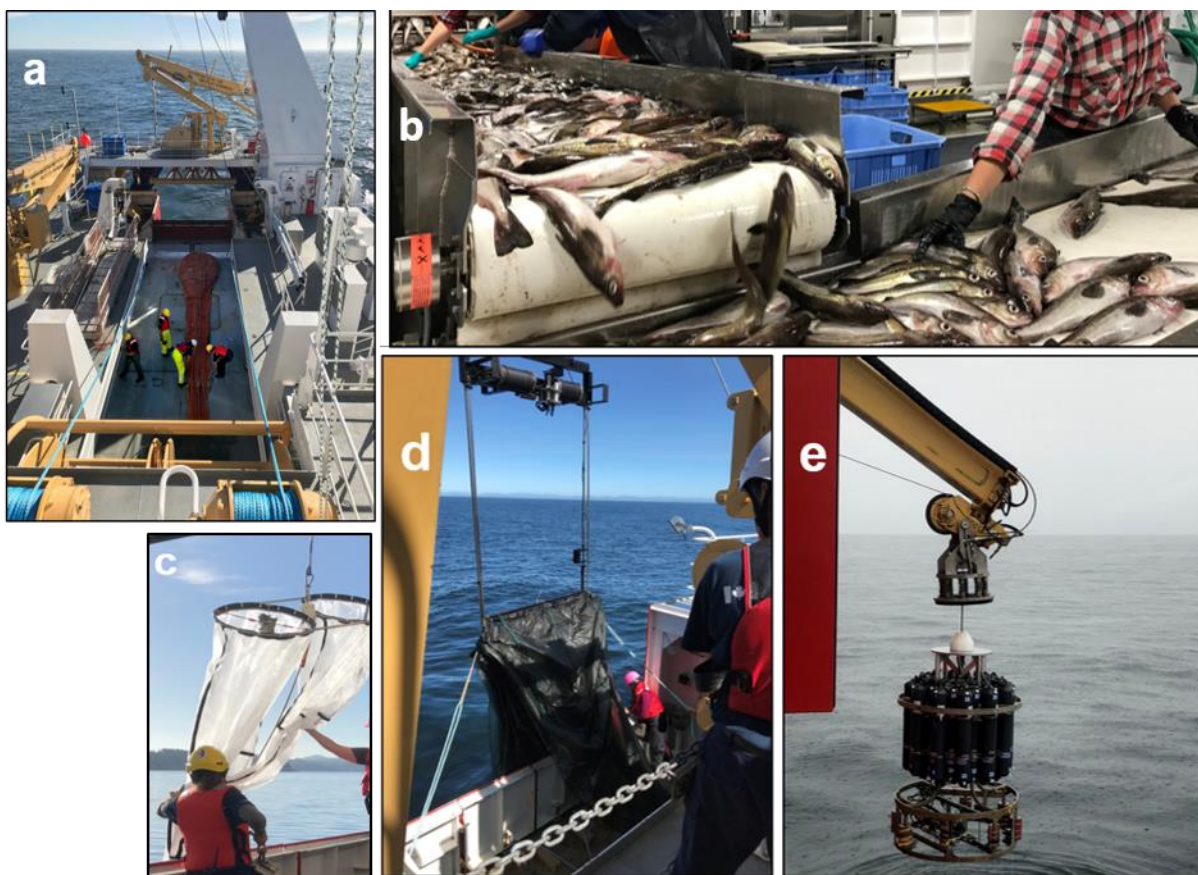


Figure 31-3. Sampling on board the CCGS Sir John Franklin; a) Midwater trawl catch on the aft deck of the vessel, b) sorting and processing the catch in the wet-lab, c) deployment of bongo net, d) deployment of the larger MOCNESS, and e) deployment of the rosette CTD. (All photos S. Gauthier except e) by Erica Anderson).

32. CANADA'S OCEANS NOW, 2020 – STATE OF CANADA'S OCEANS

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32.1. Highlights

- Canada's State of the Ocean reports are annual summaries of the current status and trends of marine ecosystems in Canada's three oceans. The public and technical reports alongside associated products for the [State of the Atlantic Ocean](#) was released in April 2019 followed by the [State of the Arctic Ocean](#) in April 2020.
- In March 2021, the [National State of the Oceans](#) report *Canada's Oceans Now, 2020* was released. The report is a high-level summary of status and trends in all three oceans highlighted through engaging infographics and plain language science writing.
- The State of the Pacific Ocean products, including the technical report, public report and communication products will be released in the 2021 cycle. The public-facing content may include plain language science writing, case studies, infographics and engaging visuals for social media and outreach.

32.2. Summary

Canada's State of the Ocean reports are annual summaries of the current status and trends of ecosystems in Canada's three oceans. The State of the Ocean initiative is in keeping with the Government of Canada's commitment to inform Canadians on the science on which decision-making is based. The ongoing reporting cycle presents technical and plain-language science information on one of Canada's oceans per year; followed by a national report being undertaken in the fourth year.

State of the Ocean (SOTO) products are developed by Fisheries and Oceans Canada (DFO) Science and include both a technical and public report. Both reports include status and trend information with key findings on the health of Canada's marine ecosystems. Alongside a plain-language summary report are science communication products such as infographics, videos and other engaging visuals for social media and outreach.

The first SOTO report and accompanying products on the State of the Atlantic Ocean were released in April 2019 followed by the State of the Arctic Ocean and associated products in April 2020. In March 2021, the National State of the Oceans report *Canada's Oceans Now, 2020* was released alongside communication products. The public report is a high-level summary of status and trends from all three oceans with engaging infographics and plain language science writing. Additional communication products accompanying the release included a video (<https://dfo-mpo.gc.ca/videos/soto-rceo-national-2020-eng.html>), infographics, and five outreach activities (<https://www.dfo-mpo.gc.ca/oceans/publications/soto-rceo/2020/outreach-sensibilisation-eng.html>), all found on the DFO SOTO website.

The State of the Pacific Ocean public report is being drafted by DFO scientists in the Pacific Region including a report outline, key messages from the most recent and relevant science information and infographics. A plain-language science writer and graphic designer have been

contracted to work on the draft public report. The State of the Pacific Ocean public report, technical report, and communication products will be released in the 2021 cycle.

Individual reports on inside waters (including the Strait of Georgia)

33. RIVERS AND BUTE INLET WATER PROPERTIES IN 2020 COMPARED TO A HISTORICAL TIME SERIES

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33.1. Highlights

- In Rivers Inlet, deep water began cooling in September, suggesting that the impact of the 2014 to 2016 marine heatwave may be diminishing.
- A massive landslide at Elliott Creek on November 28th caused rapid cooling of the deep water in Bute Inlet.
- In both Rivers Inlet and Bute Inlet, intermediate and deep water had less oxygen in 2020 than the 1951 to 2010 average but a similar oxygen concentration as the 1991 to 2020 average.

33.2. Description of the time series

Temperature, salinity, and oxygen data have been collected in Rivers and Bute Inlet since 1951. From 1951 to 1993, temperature was measured with a reversing thermometer, and salinity and oxygen were measured from water collected by a Niskin or Nansen bottle. Since 1998, temperature and salinity were measured using a Seabird or RBR CTD sensor and oxygen was measured with a Seabird or Rinko oxygen sensor.

From 1951 to 1987, the University of British Columbia collected data. From 1990 to 2018 in Rivers Inlet and 1989 to 2014 in Bute Inlet, Fisheries and Oceans Canada collected data. From 2008 to present in Rivers Inlet and 2017 to present in Bute Inlet, the Hakai Institute has collected data. The focus of this report is station DFO2 (maximum depth 334 m) in Rivers Inlet and station BU4 (maximum depth 626 m) in Bute Inlet (Figure 33-1). As of February 2021, 170 temperature and salinity profiles and 142 oxygen profiles have been collected at DFO2, with more than 96% of the data collected since 2000. As of February 2021, 130 temperature and salinity profiles and 116 oxygen profiles have been collected at BU4, with 31% of the data collected since 2000.

Following water type definitions in fjords (Farmer and Freeland 1983; Jackson et al. 2021), three water types were defined. These water types were surface (potential density relative to surface pressure of less than 1022 kgm^{-3}), intermediate (from the base of surface layer to sill depth) and deep (below sill depth). The intermediate water at DFO2 was defined as the base of the surface layer to 140 m and the intermediate water at BU4 was defined as the base of the surface layer to 355 m. The deep water at DFO2 was defined as 141 to 334 m and the deep water at BU4 was defined as 356 to 626 m. There is significant seasonal variation of water properties throughout the water column, which normally dominates interannual variation. To compare 2020 to the long-term time series, first a monthly average of temperature, salinity and oxygen using all data from 1951 to 2010 was calculated for all water types. Then the monthly average from 2020 was calculated. To compare the 2020 data with a more recent climatology, the 1991 to 2020 monthly average was also calculated.



Figure 33-1. Rivers Inlet is a fjord about 46 km long and 3 km wide located on British Columbia's central coast. At the mouth of Rivers Inlet is a sill that is approximately 140 m deep at low tide (Pickard 1961), and the fjord deepens to a basin that is about 340 m deep that shoals towards the head of the inlet. Bute Inlet is a fjord about 76 km long and 4 km wide. Bute Inlet's sill is about 355 m at low tide (Pickard 1961), and the fjord deepens towards a maximum depth of 660 m. For this study, results are from station DFO2 in Rivers Inlet and station BU4 in Bute Inlet.

33.3. Status and trends

33.3.1. Rivers Inlet

Comparing the long-term times series to 2020 for the surface water (Figure 33-2) shows that the surface was fresher and had less oxygen than either the 1951 to 2010 or 1991 to 2020 average. The coldest surface temperature (6.7 °C) was observed in February and the warmest surface water (12.3 °C) was observed in September. The freshest surface water (18.0) was observed in June, which is similar to the typical June freshet (Wolfe et al. 2015) and the June salinity minimum (Tommasi et al. 2013) observed from 2006 to 2010. Surface oxygen was lower from May to September than either the 1951 to 1990 or 1991 to 2020 climatologies. The autumn of 2020 showed higher temperatures and fresher water than either the 1951 to 1990 or 1991 to 2020 climatologies.

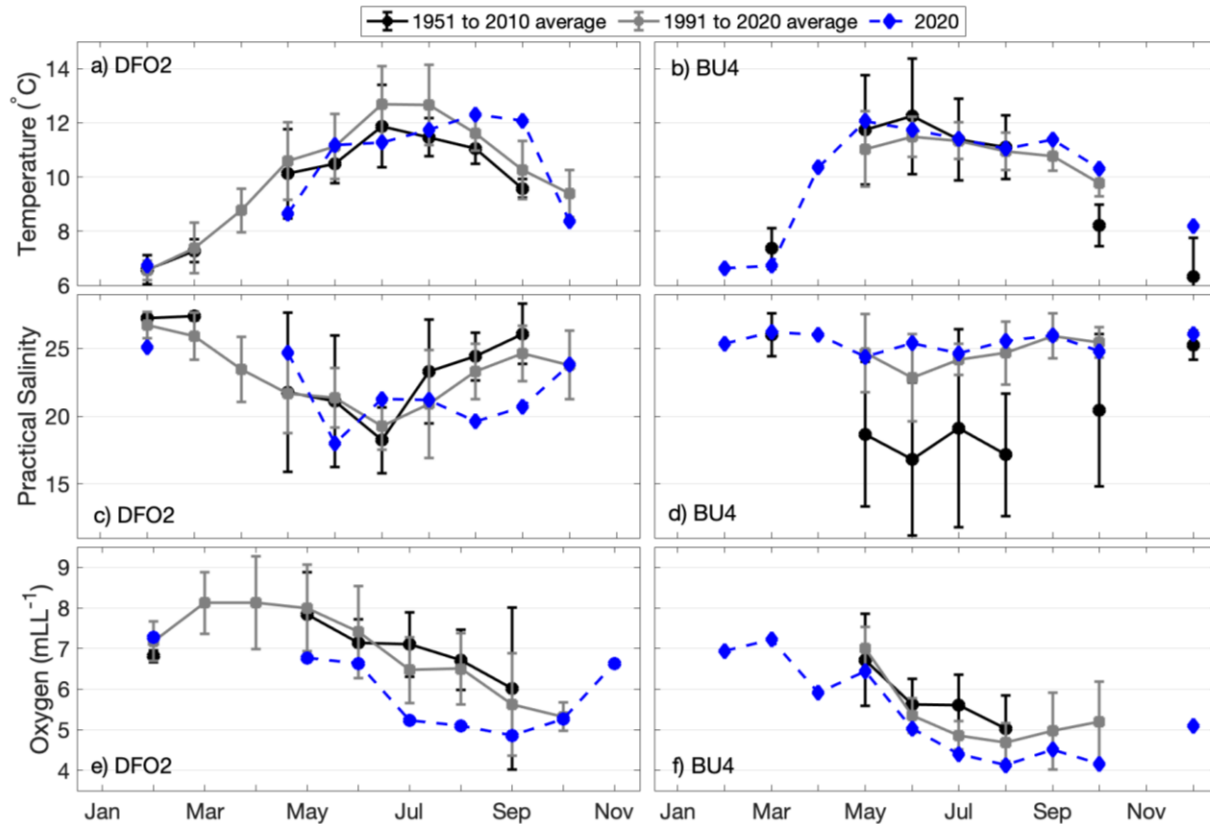


Figure 33-2. The monthly average surface (defined as water fresher than 1022 kg m^{-3}) conditions for (top) temperature, (middle) practical salinity, and bottom (oxygen) at stations DFO2 in Rivers Inlet (panels a, c) and BU4 in Bute Inlet (panels b, d, and f). The solid black line denotes the monthly average from 1951 to 2010, the solid grey line represents the monthly average from 1991 to 2020, and the dashed blue line shows the 2020 monthly average. Error bars represent the standard deviation of the 1951 to 2010 and 1991 to 2020 time series and only months that were sampled on at least 3 different years were shown.

In 2020, intermediate (Figure 33-3) water was warmer than the 1951 to 2010 climatology but similar to the 1991 to 2010 climatology. The warmest water (9.2°C) was observed in October and the coldest water (8°C) was observed in February. Salinity and oxygen were similar to both the 1951 to 2010 and 1991 to 2020 climatologies.

In 2020, the deep (Figure 33-4) water in February was about 0.6°C warmer than the 1951 to 2010 climatology and 0.4°C warmer than the 1991 to 2020 climatology. By October, 2020 was 0.2°C warmer than the 1951 to 2010 climatology and similar to the 1991 to 2020 climatology. These results suggest that the impact of the 2014 to 2016 marine heatwave on Rivers Inlet (Jackson et al. 2018) is starting to erode, about 6 years after the deep waters first warmed. Salinity and oxygen in 2020 were similar to the 1991 to 2020 climatology. Recent research has shown that from 1951 to 2020, deep water in Rivers Inlet became saltier by 0.2 salinity units and lost 0.7 mL L^{-1} of oxygen (Jackson et al. 2021). The similarity of salinity and oxygen in 2020 to the 1991 to 2020 climatology suggests that neither of these properties changed significantly in 2020.

33.3.2. Bute Inlet

Comparing the long-term times series to 2020 for the surface water (Figure 33-2) shows that while the temperature was similar to the 1951 to 2010 and 1991 to 2020 climatologies, the oxygen was lower and the salinity was higher than average. The coldest surface temperature (6.6 °C) was observed in February and the warmest surface water (12.1 °C) was observed in May. The freshest surface water (24.4) was observed in May and the relatively high salinity throughout the year suggests that sampling did not occur during the freshet.

In 2020, both intermediate (Figure 33-3) and deep (Figure 33-4) water were warmer, saltier, and less oxygenated than the 1951 to 2010 climatology. Jackson et al. (2021) found that, between 1951 and 2020, deep water in Bute Inlet warmed by 1.3 °C, became saltier by 0.2 units, and lost 0.6 mL L⁻¹ of oxygen. In 2020, deep water continued to be saltier than the 1991 to 2020 climatology, while oxygen was similar. A sudden cooling of deep water temperature in December 2020 can be attributed to a massive landslide in Elliott Creek, where about 9 million cubic meters of debris were pushed into a glacial lake, which created a tsunami that transported glacial lake water and sediment into the bottom of Bute Inlet (<https://www.hakaimagazine.com/news/massive-landslide-cools-fjord/>).

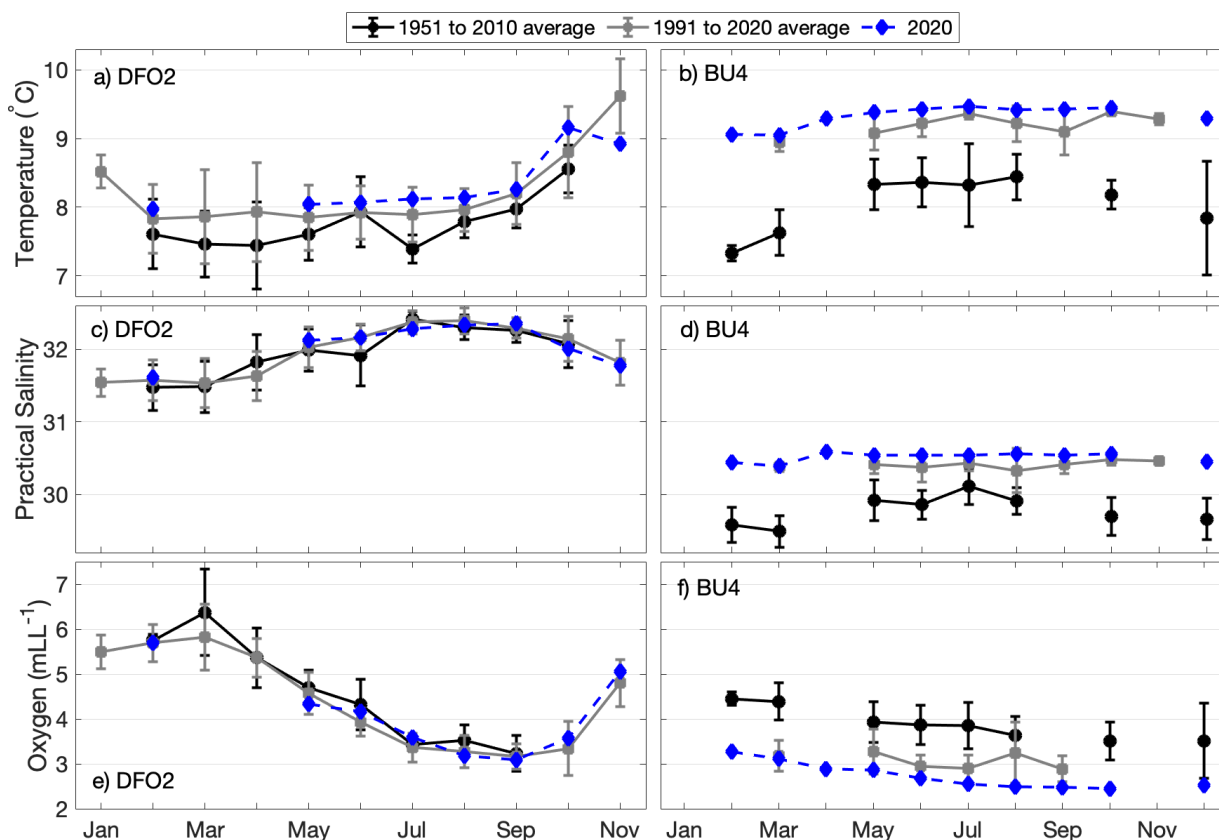


Figure 33-3. As in Figure 33-2 but for intermediate water, which was defined as water between the base of the surface layer and the 140 m sill depth for DFO2 (Rivers Inlet) and from the base of the surface layer to 355 m for BU4 (Bute Inlet).

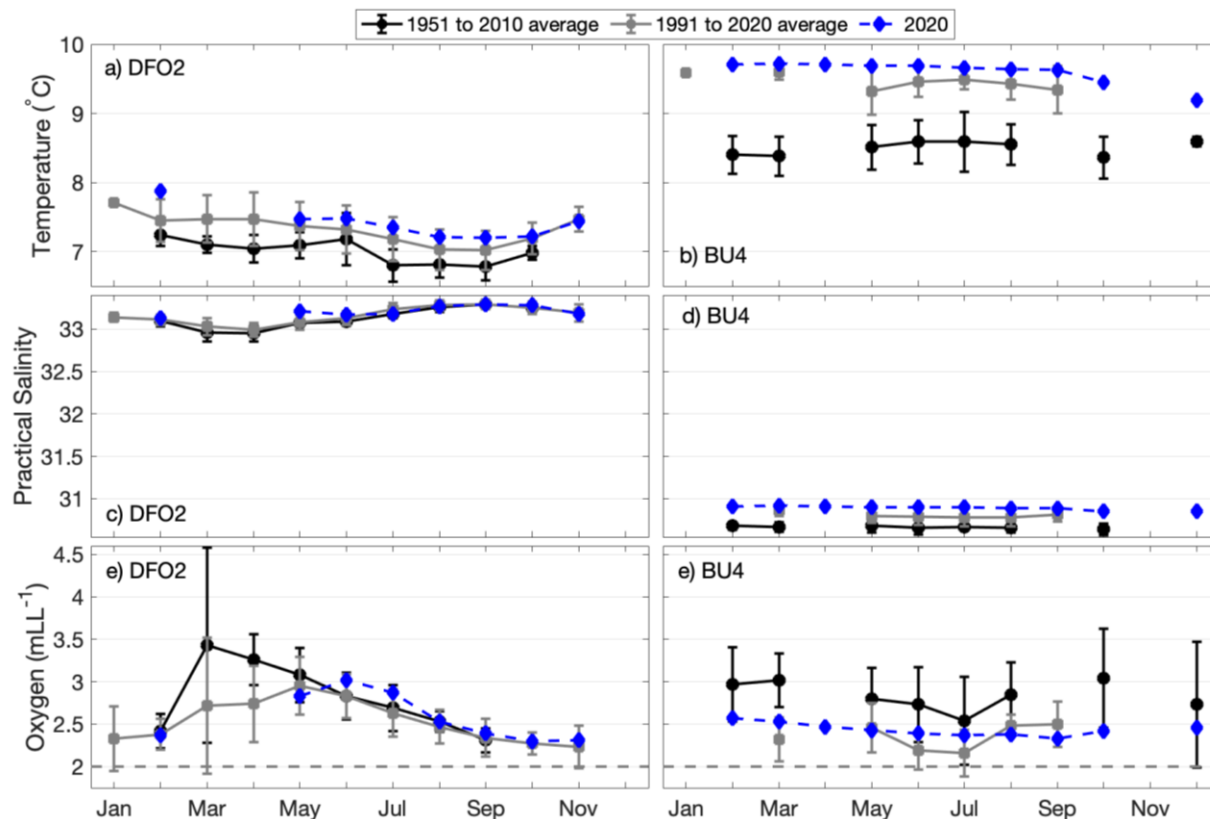


Figure 33-4. As in Figure 33-2 but for deep water, defined as water between the sill depth of 140 m and the bottom (334 m) in Rivers Inlet and between the sill depth of 355 m and the bottom (632 m) in Bute Inlet. The horizontal grey dashed line in the bottom panel indicates 2 mL/L of oxygen, or hypoxic water.

33.4. Implications of those trends.

Since 2015, the anomalously warm ocean conditions experienced on the coast of British Columbia were associated with an influx of southern copepod species and an abundance of other warm water taxa (Hipfner et al. 2020). The zooplankton communities associated with warm water are known to be lipid poor- and poor-quality prey for juvenile salmon, forage fish and some marine seabirds. Therefore, the 2020 inlet conditions were likely associated with reduced salmon growth during the 2020 outmigration. Since October, deep water in both inlets have appeared to cool, suggesting that the impact of the 2014 to 2016 marine heatwave may finally be eroding, which could impact the zooplankton composition.

Warming explains about 28% of the long-term oxygen loss in the deep water of Rivers Inlet and about 39% of the loss in Bute Inlet (Jackson et al. 2021) thus warming is expected to enhance deoxygenation. If the 2014 to 2016 marine heatwave impacts are eroding, it is possible that oxygen concentrations will increase. Research from Saanich Inlet (Chu et al., Section 42) shows that the biodiversity changes with different oxygen concentrations and this suggests that the oxygen concentrations in Rivers and Bute Inlet will have a significant impact on the local ecosystem.

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34. COASTAL CO₂ OBSERVATIONS FROM FITZ HUGH SOUND AND THE NORTHERN SALISH SEA IN 2020

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34.1. Highlights

- Indicators of pH and calcite saturation state show severe conditions vary seasonally and span a majority of the water column in the northern Salish Sea and more than 25% of the water column in Fitz Hugh Sound.
- The duration of severe conditions was shorter in 2020 than in 2019.

34.2. Description of CO₂ datasets

Marine CO₂ system observations are presented from two regions: the central British Columbia coast in the area of Fitz Hugh Sound, and the northern Salish Sea. Observations from Fitz Hugh Sound were collected on a surface buoy (known as the KC buoy positioned at the mouth of Kwakshua Channel; <https://www.nodc.noaa.gov/ocads/data/0208810.xml>) and from an adjacent hydrographic station (KC10; 51.650396°N, 127.9508157°W). The buoy observations were hourly and the hydrographic station was occupied at a near monthly frequency with samples collected at 12 depths through the water column to a maximum depth of 300 m. Observations from the northern Salish Sea were made at the Quadra Island Field Station from a 1 m surface seawater supply (<https://www.nodc.noaa.gov/ocads/data/0208638.xml>) and from a nearby hydrographic station (QU39; 50.03044358°N, 125.1052797°W) where discrete samples were collected ever 2 weeks at 12 depths through the water column to a maximum depth of 260 m. At both hydrographic locations, observations of oxygen and density from conductivity-temperature-depth (CTD) profilers are provided with the CO₂ system observations for context.

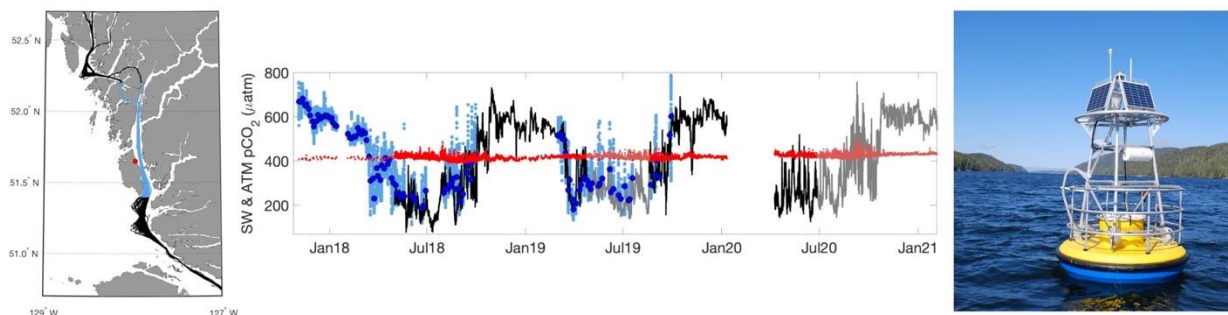
34.3. Patterns in CO₂ Datasets

34.3.1. *Fitz Hugh Sound*

We used the cumulative upwelling index (CUI) from 51°N, 131°W provided by NOAA as a metric for the strength of upwelling in the Queen Charlotte Sound region, which showed weak conditions in 2020. CUI values for 2020 indicated downwelling conditions in January that abated over February before weak upwelling commenced from March to late April as defined using metrics from Jackson et al. (2018). This early period of upwelling terminated in May with a short period of downwelling, and then conditions were near neutral until downwelling resumed in October and persisted for the remainder of the year. In addition to 2020 being a weak upwelling year, provisional rainfall data from locations on Calvert Island showed moderately higher rainfall in 2020 compared to the previous three years, particularly in autumn and early winter (<https://hecate.hakai.org/sn/p/viewsndata.pl?dataTable=1hourSamples&measurements=BuxtonEast.24hourRain,Hecate.24hourRain,PruthDock.24hourRain&noFlags>).

Surface CO₂ partial pressure (pCO₂) observations have been made in Fitz Hugh Sound since November of 2017. Data up to May 2018 were collected by the Alaska Marine Highway System ferry M/V *Columbia*, and on May 1 2018 the KC buoy was deployed at the mouth of Kwakshua

Channel and began serving as an observational platform in the region (Figure 34-1). Both surface seawater (2 m from the M/V *Columbia* and 1 m from the KC buoy) pCO₂ and atmospheric marine boundary layer pCO₂ were measured from both platforms. Average seawater measurements from the M/V *Columbia*, which transits through the region, track observations from the KC buoy, suggesting the buoy broadly captures surface pCO₂ conditions in Fitz Hugh Sound (Figure 34-1). Surface pCO₂ in the area varies seasonally; high values (near 700 µatm) with respect to the atmosphere occur during autumn and winter months due primarily to vertical mixing of high-CO₂ subsurface waters, and low values (near 200 µatm) are typical during spring and summer months owing to seasonally elevated rates of net community production.



*Figure 34-1. Surface water pCO₂ (µatm) in Fitz Hugh Sound on the central British Columbia coast. Fitz Hugh Sound is represented by the blue colored M/V *Columbia* observations in the left map, with the red dot as the position of the KC buoy. Hydrographic station KC10 is near the buoy pictured on the right. Light blue data in the time series plot are measurements from the *Columbia* with averages from each transit as dark blue circles. Black and gray data are final (submitted to SOCAT) and provisional seawater pCO₂ measurements, respectively, from the KC buoy. Dark and light red data are final (submitted to SOCAT) and provisional atmospheric pCO₂ measurements, respectively, from both the M/V *Columbia* and KC buoy. Real-time data from the KC buoy can be found on the GOA-ON data portal: http://portal.goa-on.org/Explorer?action=oiw:fixed_platform:HAKAI_KCBuoy:observations:H1_CO2.*

No surface pCO₂ observations were made from the M/V *Columbia* and KC buoy in early 2020 because the ferry halted service in October 2019, and the KC buoy platform was serviced in early 2020 with an equilibrator issue that delayed data collection until April 8. Surface pCO₂ was already undersaturated with respect to the atmosphere when measurements resumed. Notably, there was a higher degree of variability seen in the buoy record over the summer months than had been witnessed in the previous two years. Between April and August there were nearly a dozen excursions from values near 200 µatm to levels near or above atmospheric values. Additionally, between August 19 and October 2, seawater pCO₂ exceeded atmospheric levels, and such a period of sustained over-saturation in summer had not been observed previously in this short record. Unfortunately, conductivity sensor failure on the buoy prevented directly evaluating the cause of these conditions; however, water column measurements and rainfall data suggest the broadly fresher surface layer evoked higher pCO₂ conditions presumably due to the respiration of organic matter.

CTD profiling at KC10 began in 2013, and oxygen (relative to saturation) and density are shown in Figure 34-2. High surface oxygen content in spring and summer results from seasonally elevated rates of net community production. Simultaneously, oxygen in the water column decreases as stratification increases and upwelled source water with low oxygen content reaches KC10 (seawater with density > 1026 kg m⁻³). Autumn and winter storms break down the

surface stratification, decreasing oxygen content at the surface while increasing oxygen content in the upper ~100 m of the water column. It is notable that CTD oxygen measurements in the upper water column appeared lower in 2020 than in previous years and coincide with higher freshwater content (not shown). Also, the presence of denser water ($> 1026 \text{ kg m}^{-3}$) appeared to decrease in late spring as the period of weak upwelling abated, but then rebounded somewhat in the late summer.

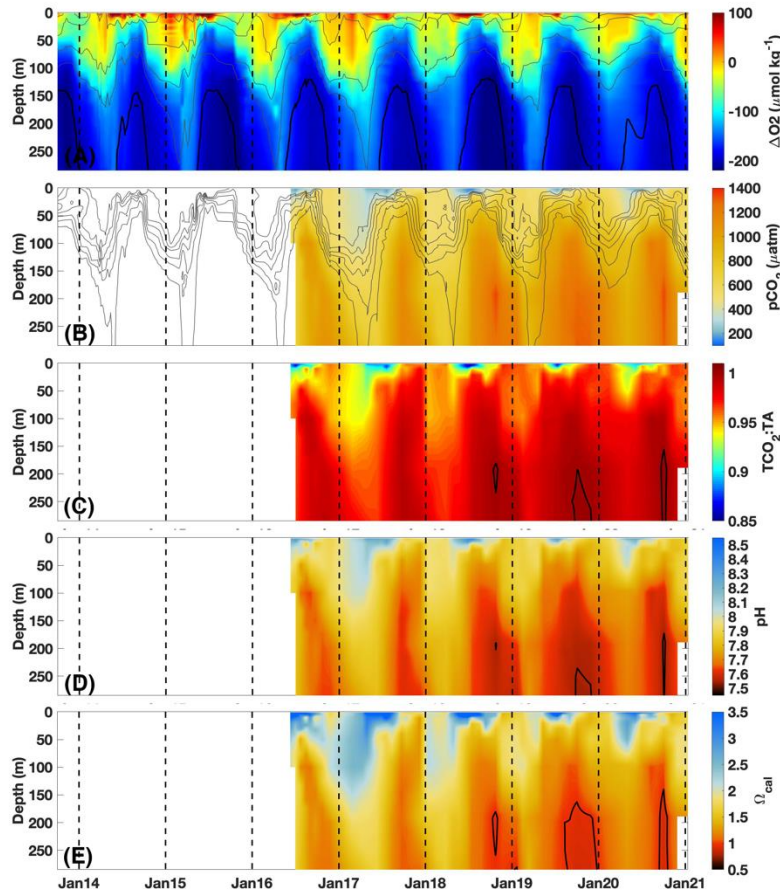


Figure 34-2. Water column observations from hydrographic station KC10. (A) CTD observations of oxygen (in color and presented as measured minus saturated values, ΔO_2 , in $\mu\text{mol kg}^{-1}$) and potential density (isopycnals contoured are 1023, 1024, 1025, 1025.5, and 1026 kg m^{-3} , with the last in bold). (B) $p\text{CO}_2$ with contours of ΔO_2 . (C) Ratio of total dissolved inorganic carbon (TCO_2) to total alkalinity (TA) with the bold contour marking unity. (D) pH on the total hydrogen scale with 7.55 contoured. (E) Calcite saturation state (Ω_{cal}) with 0.97, 1 minus the estimated uncertainty reported in Evans et al. (2019), contoured.

Discrete $p\text{CO}_2$ and total dissolved inorganic carbon (TCO_2) measurements collected at KC10 show similar patterns to the oxygen and density observations. During summer when oxygen content is high in the upper water column, $p\text{CO}_2$ is undersaturated with respect to the atmosphere. TCO_2 is also decreased, in part due to net community production but also due to dilution with freshwater. Autumn and winter storms mix the water column and increase $p\text{CO}_2$ and TCO_2 near the surface. At depth, $p\text{CO}_2$ and TCO_2 both increase with the presence of denser, upwelled water. Since 2018, sub-surface $p\text{CO}_2$ has appeared to be slightly higher during the upwelling season than it had been in 2016 and 2017. Examining the ratio of TCO_2 to total alkalinity (TA) shows the higher $p\text{CO}_2$ conditions coincide with periods of TCO_2 :TA ratios closer to unity, creating CO_2 system conditions of weaker buffering, higher $p\text{CO}_2$, lower pH, and a more corrosive state for calcium carbonate biominerals (Millero 2007; Cai et al. 2021; Evans et al. 2019; Jiang et al. 2019). Figure 34-2 shows instances of low pH (less than

7.55) and corrosive conditions for calcite (calcite saturation state, Ω_{cal} , < 1) near and below 200 m late in the year in 2018, 2019, and 2020.

34.3.2. Northern Salish Sea

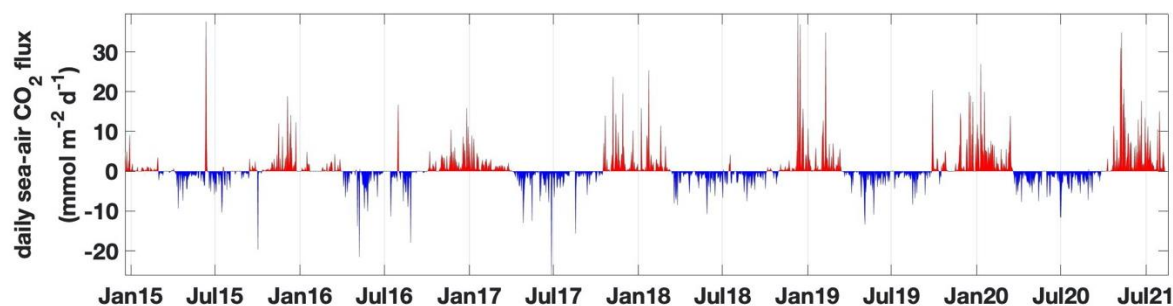


Figure 34-3. Sea-air CO₂ flux (mmol m⁻² d⁻¹) in the northern Salish Sea. Fluxes were computed using surface seawater and atmospheric marine boundary layer pCO₂ measured at the Quadra Island Field Station. Real-time data from this site can be found on the GOA-ON data portal: http://portal.goa-on.org/Explorer?action=oiw:fixed_platform:HAKAI_Quadra1:observations:H2_CO2. Gas transfer velocities were computed using the wind speed parameterization from Wanninkhof (2014) using Quadra Island Field Station wind speeds (<https://hecate.hakai.org/sn/1hourSamples/last12weeks-Quadra.1hourSamples.html>).

Surface seawater and marine boundary layer pCO₂ measurements have been made continuously for the last six years at the Quadra Island Field Station in the northern Salish Sea. Presented here are sea-air CO₂ fluxes computed from these measurements. The transition from atmospheric CO₂ source in autumn and winter to atmospheric CO₂ sink in spring and summer is driven by the drawdown of seawater pCO₂ to undersaturated values with respect to the atmosphere during this period of seasonally high rates of net community production. The spring phytoplankton bloom marks the first instance of high net community production in the year and the time of transition from atmospheric CO₂ source to sink. This source-to-sink transition time was March 22 in 2020, nearly in the mid-point of previous years that spanned March 1 in 2015 and April 10 in 2017. Summertime atmospheric CO₂ uptake was continuous in 2020 but with variability in the magnitude owing to variability in the sea-air pCO₂ gradient and wind forcing. No summer outgassing events were observed as were seen in 2015, 2016, and 2018.

Autumn CO₂ outgassing was appreciably stronger than in previous years. The sink-to-source transition timing was similar to other years and occurred on October 9 in 2020. However, no period of autumn CO₂ drawdown, owing to late season phytoplankton blooms, occurred in 2020 like had been seen in 2015, 2018, and 2019. CO₂ efflux was episodically intense through autumn, with cumulative autumn outgassing (computed as the sum from the sink-to-source transition date to December 31) equal to 385 mmol m⁻². Previously observed autumn cumulative outgassing values were 170 mmol m⁻² in 2015, 174 mmol m⁻² in 2016, 198 mmol m⁻² in 2017, 196 mmol m⁻² in 2018, and 225 mmol m⁻² in 2019.

CTD profiling began at QU39 in 2015, and oxygen content in the upper water column shows similar patterns as those described for KC10; elevated levels during spring and summer due to seasonally high net community production, and lower levels in autumn and winter as stratification is reduced and low oxygen sub-surface water is mixed vertically (Figure 34-4). It is notable that during most autumns and winters, deep mixing of higher oxygen water is evident to 100 m or even deeper (e.g. 2015 and 2018). Intermediate water (50 to 200 m) is typically thought to acquire oxygen by mixing in Haro Strait before transiting northward from the southern

Strait of Georgia (Johannessen et al. 2014). However, these deep mixing events clearly reach into the intermediate water core and may play a role in both re-oxygenating intermediate water and, perhaps more importantly given the baseline oxygen content maintained by mixing in Haro Strait (Johannessen et al. 2014), outgassing CO₂ that has built up by the respiration of organic matter through the spring and summer.

Seasonal patterns of the CO₂ system in the intermediate water of the northern Salish Sea are striking, particularly over the last few years (Figure 34-4). pCO₂ content tends to inversely follow that of oxygen, like at KC10. However, a key difference between these sites is that the oxygen content in sub-surface water at KC10 reaches lower values than sub-surface water at QU39, but the pCO₂ content is significantly higher at QU39 (Figures 34-2 and 34-4). This is because of the

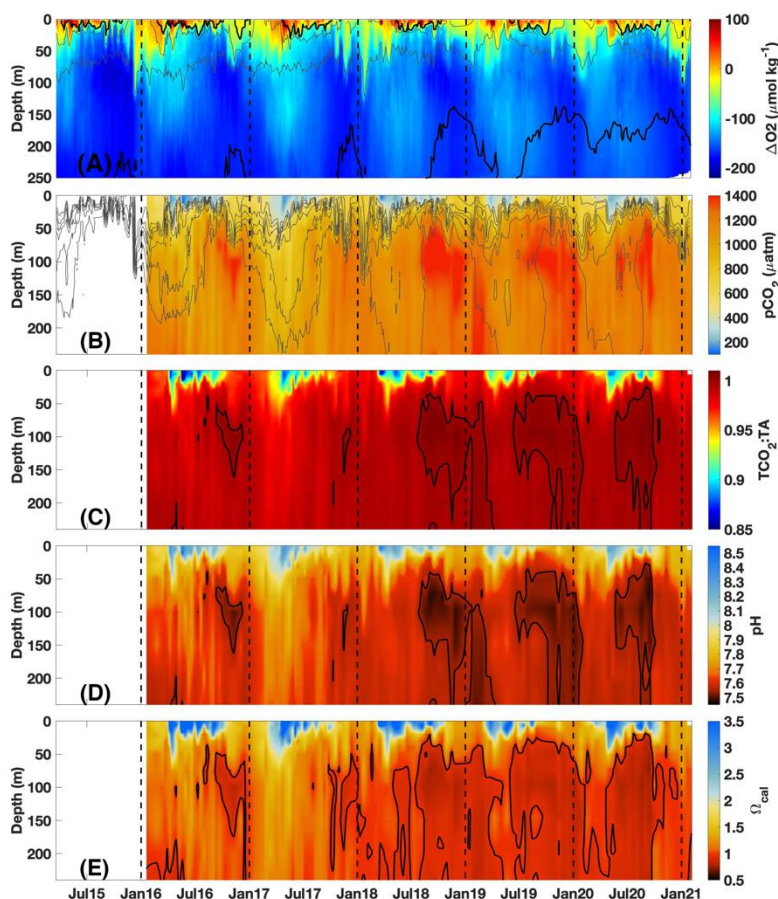


Figure 34-4. Water column observations from hydrographic station QU39. (A) CTD observations of oxygen (in color and presented as measured minus saturated values, ΔO_2 , in $\mu\text{mol kg}^{-1}$) and potential density (isopycnals contoured are 1023, 1024, 1025, 1025.5, and 1026 kg m^{-3} , with the last in bold). (B) pCO₂ with contours of ΔO_2 . (C) Ratio of total dissolved inorganic carbon (TCO₂) to total alkalinity (TA) with the bold contour marking unity. (D) pH on the total hydrogen scale with 7.55 contoured. (E) Calcite saturation state (Ω_{cal}) with 0.97, 1 minus the estimated uncertainty reported in Evans et al. (2019), contoured.

influence of mixing in Haro Strait on maintaining a base level Strait of Georgia oxygen content (Johannessen et al. 2014) coupled with the Salish Sea being extremely weakly-buffered and subsequently a high-pCO₂ environment (Fassbender et al. 2018; Evans et al. 2019; Hare et al. 2020). Instances of weakest buffering occur when the TCO₂:TA ratio is near 1, which has happened in intermediate and deep (> 200 m) water during late summer and autumn over the last three years (Figure 34-4). These conditions, most likely supported by the respiration of organic matter produced in the surface layer (< 50 m) during spring and summer, manifest a high-pCO₂, low-pH, and corrosive state for calcium carbonate biominerals (Figure 34-4).

It is important to note that the northern Salish Sea is extremely vulnerable to the influence of year-to-year variability in the CO₂ system, which can impact whether or not such high-pCO₂, low-pH, and corrosive conditions are observed. For instance, 2017 showed no evidence of such conditions, with both pCO₂ and oxygen being generally higher

throughout the water column at the start of the year compared to other years in the time series. This initial low $p\text{CO}_2$ content may help to mitigate the influence of TCO_2 increase from the seasonal respiration of organic matter such that high- $p\text{CO}_2$, low-pH, and corrosive conditions weren't observed. This internal variability in the system is occurring in conjunction with long-term change associated with anthropogenic CO_2 input (Evans et al. 2019). Accounting for the anthropogenic CO_2 input greatly reduces the instances of severe CO_2 system conditions in the northern Salish Sea (Evans 2020).

34.4. Implications of CO_2 patterns

The implications of the CO_2 patterns presented here are that they describe very different habitats between the northern Salish Sea and Fitz Hugh Sound with regard to the occurrence of high- $p\text{CO}_2$, low-pH, and corrosive conditions. These conditions have been shown to negatively impact a variety of marine organisms that reside in both of these areas (Bednarsek et al. 2020; McLaskey et al. 2016; Waldbusser et al. 2015; Bednarsek et al. 2021; Gimenez et al. 2018). Figure 34-5 shows indicators of pH and calcite saturation state severity based on the percentage of the water column below a pH of 7.55 and a calcite saturation state of 0.97 (1 minus estimated uncertainty). These indicators clearly show the duration and vertical extent of severe conditions, which span a majority of the water column in the northern Salish Sea and more than 25% of the water column in Fitz Hugh Sound. During 2020, the duration of these severe conditions was shorter in both areas than what was experienced in 2019. We will continue to track these indicators and urge the research community studying the marine CO_2 system along the western Canadian coast to report observations to the United Nations Decade of Ocean Science for Sustainable Development Goal (SDG) 14.3 (<https://oa.iode.org/>) designed to help “minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels”. Both hydrographic stations KC10 and QU39 are present in the SDG 14.3.1 data portal as indicator sites for western Canada.

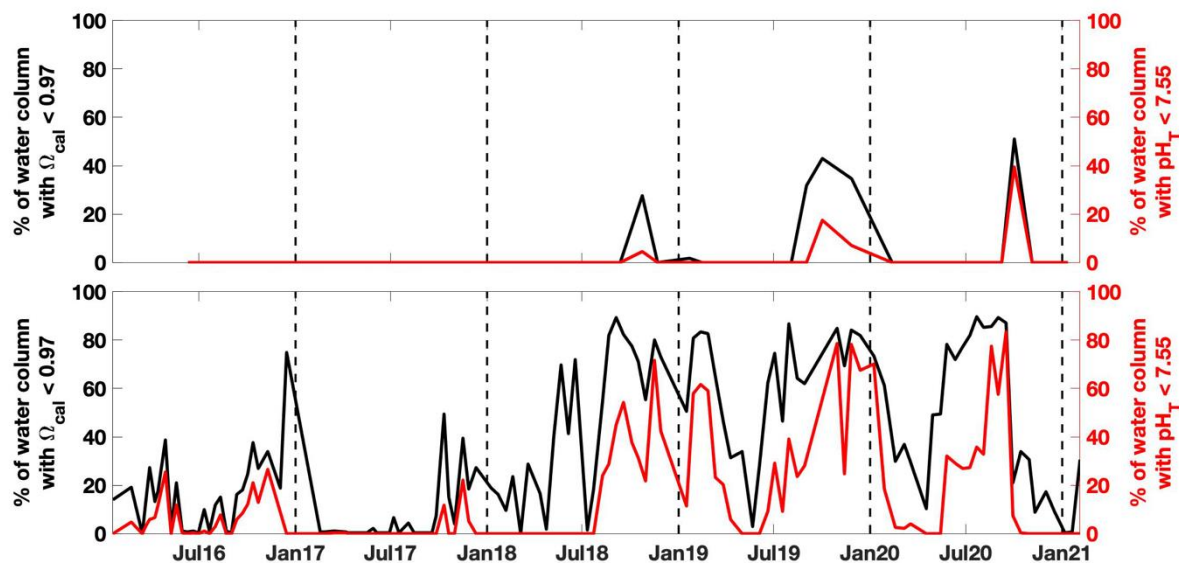


Figure 34-5. Percent of the water column with Ω_{cal} values < 0.97 (black) and pH_T values < 7.55 (red) in Fitz Hugh Sound (top) and the northern Salish Sea (bottom).

34.5. Acknowledgements

We are grateful to Chris O'Sullivan, Chris Mackenzie, Emma Myers, Bryne Fedje, and Eva Jordison for the collection of data from KC10 and QU39. We are also grateful for the continued support from the Tula Foundation.

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35. SALISH SEA TEMPERATURE, SALINITY AND OXYGEN OBSERVATIONS IN 2020

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35.1. Highlights

- The Salish Sea Spring Survey was cancelled due to the COVID-19 pandemic. The summer survey showed near-normal temperature and salinity conditions through most of the Salish Sea with lower than normal oxygen concentrations in the upper 100 m. The fall survey captured an intrusion of cooler, saltier and poorly oxygenated water from the Pacific Ocean. Water exchange in Haro Strait mixed this low oxygen Pacific water with fresher and warmer water from the Strait of Georgia causing lower than normal oxygen conditions extending northwards through the Strait of Georgia at depths of 50-100 m.
- There were relatively few CTD profiles made by CFMETR in the Nanoose region (eight in 2020 compared to the annual average of over 55) making details in the annual temperature and salinity properties in the water column difficult to resolve. However, the overall temperature and salinity structure in 2020 is consistent with the long-term average conditions. The linear trend of depth averaged water temperature is shown to be increasing at 1.3 °C per 100 years.
- The Fraser River discharge was significantly higher than normal in 2020 (about 30% more than the 100 year average).

35.2. Description of the time series

Two sources of data are used to describe changes in the water properties of the Strait of Georgia (between mainland British Columbia and Vancouver Island) and Juan de Fuca Strait (between Washington State and Vancouver Island). The first is profile data collected with a SeaBird 911 CTD during the Salish Sea water properties surveys (Figure 35-1). In 2020, surveys were carried out in the summer (June 17–22), and in the fall (Oct 7–18). The second dataset is provided by the Department of National Defence from temperature and salinity profiles collected in 2020 with a SeaBird 19 CTD at its Maritime Experimental and Test Range (CFMETR) near Nanoose. Data from both sources collected since 1999 are used to calculate long-term averages and identify the 2020 anomalies from these average conditions.

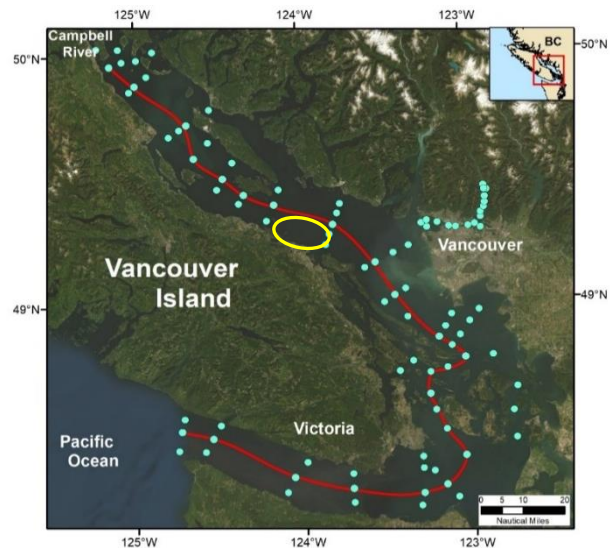


Figure 35-1. Dots show the locations of stations sampled during the water properties surveys. The thalweg is shown as the red line joining the deepest stations along the centerline of the Straits. The yellow ellipse marks the CFMETR data collection area.

35.3. Status and trends

Observations of temperature, salinity and oxygen made in 2020 are compared to the 1999-2020 averages and shown as anomalies in Figure 35-2. Oxygen concentrations in the Salish Sea were generally lower than normal throughout 2020, especially in the upper 100 m; the source of this low oxygen water is the North Pacific. The exchange of water between the Pacific Ocean and Strait of Georgia is evident in the Haro Strait/Boundary Pass region of the Salish Sea.

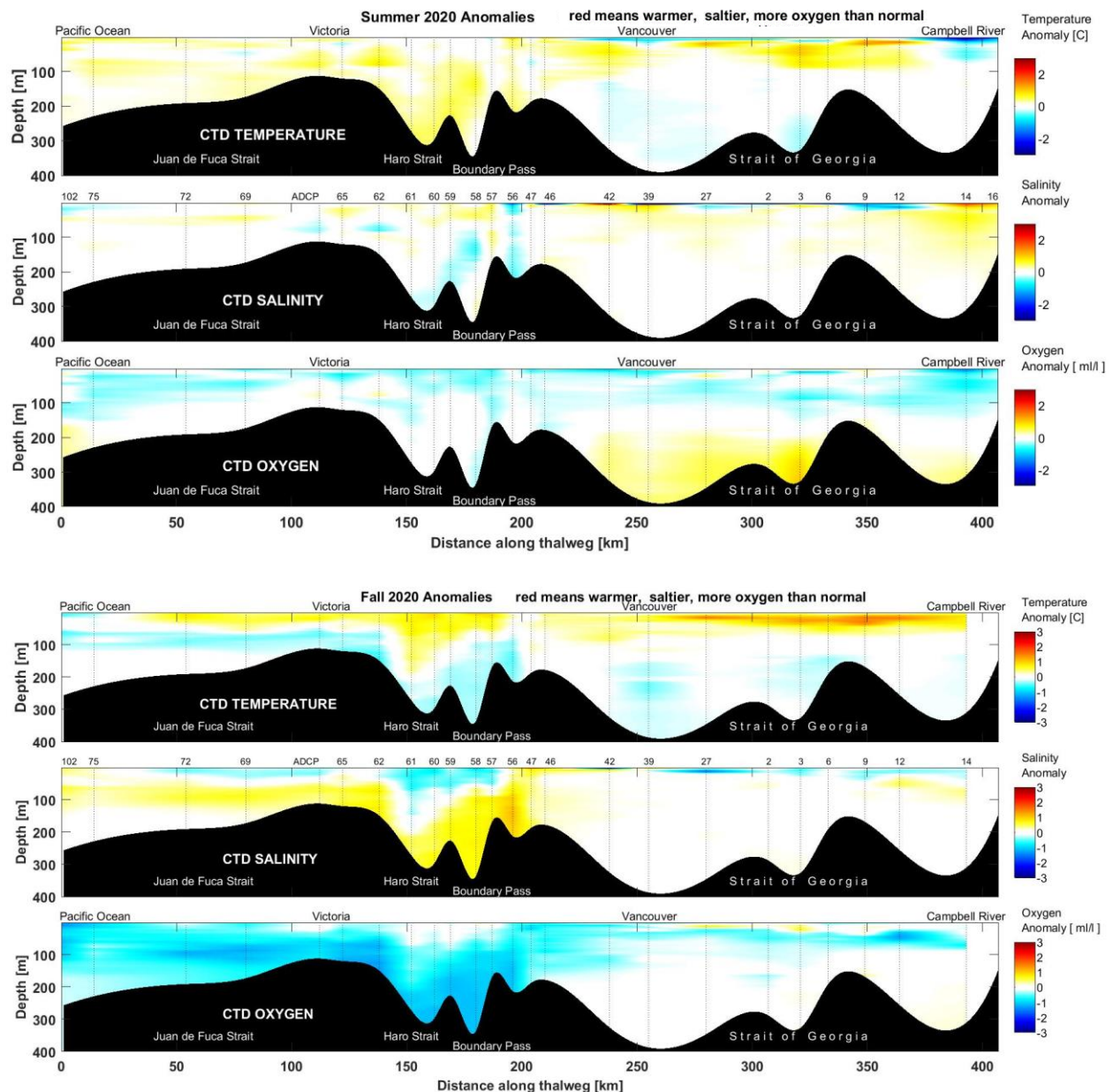


Figure 35-2. Temperature, salinity and oxygen anomalies along the thalweg observed in the summer (top three panels) and fall (bottom three panels) of 2020.

The interannual variations in the depth averaged water temperature collected near Nanoose (Figure 35-3, upper panel) show depth averaged temperatures in 2020 at levels consistent with the past few years, although the lack of 2020 data make it difficult to resolve any detail in the annual cycle. The long-term temperature time series shows a warming trend at a linear rate of 1.27 °C per 100 years.

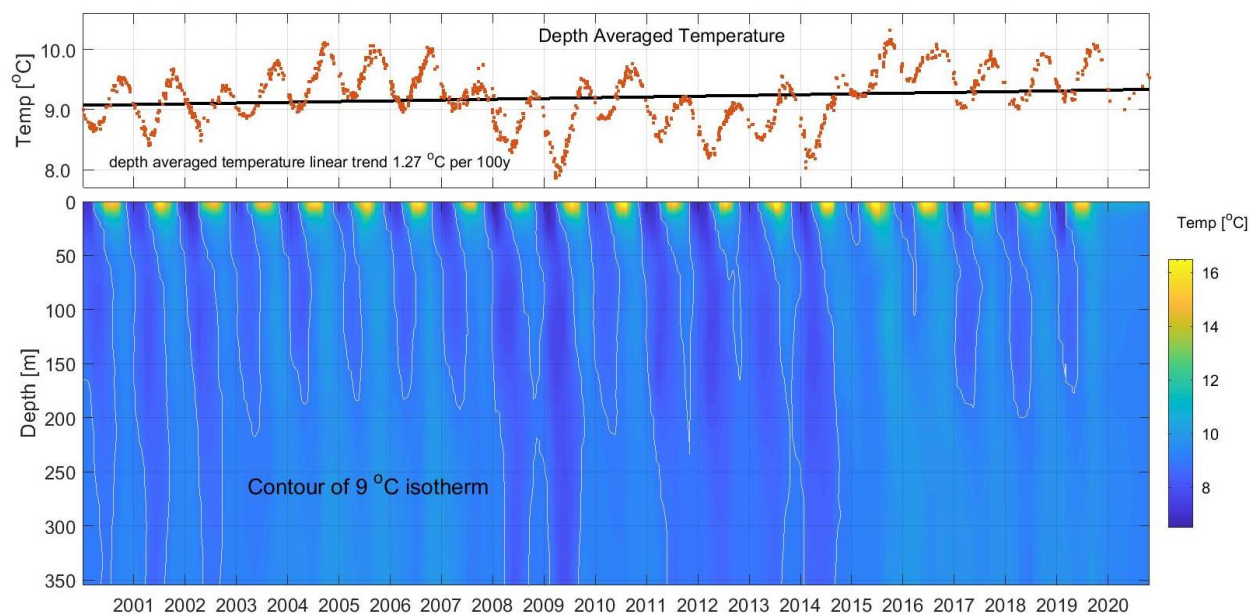


Figure 35-3. The time series of depth averaged temperature collected near Nanoose in the central Strait of Georgia (upper panel); the vertical distribution of these data (lower panel). Source: The Canadian Forces Maritime Experimental and Test Range (CFMETR).

The influence of the Fraser River discharge affects the salinity of the surface waters of the central and southern Strait of Georgia, and is a driving force for the Vancouver Island Coastal Current that flows northwards along the west coast of Vancouver Island. The 2020 annual discharge of the Fraser River measured at Hope, B.C. (see Figure 35-4) was significantly above average but there were few CTD measurements available to identify its effect on the Salish Sea. The annual discharge of the Fraser River is increasing at a rate of $4.7 \times 10^{-9} \text{ m}^3$ per 100 years.

35.4. Factors influencing trends

Water properties in the Salish Sea are considerably influenced by ocean conditions at the western entrance of the Strait of Juan de Fuca, and the freshwater discharge of rivers, primarily the Fraser River. In addition to summer warming and winter cooling, seasonal changes occur as salty, oxygen-poor ocean water is upwelled during the summer months, and Fraser River runoff peaks during the early summer. The global trends of ocean warming are reflected directly in the Salish Sea water temperature, and the trend of increased discharge of the Fraser River as glacier melt increases. The intense tidal mixing that occurs in Haro Strait effectively controls the exchange of water masses between Juan de Fuca Strait and the Strait of Georgia (Masson 2002, Pawlowicz et al. 2007).

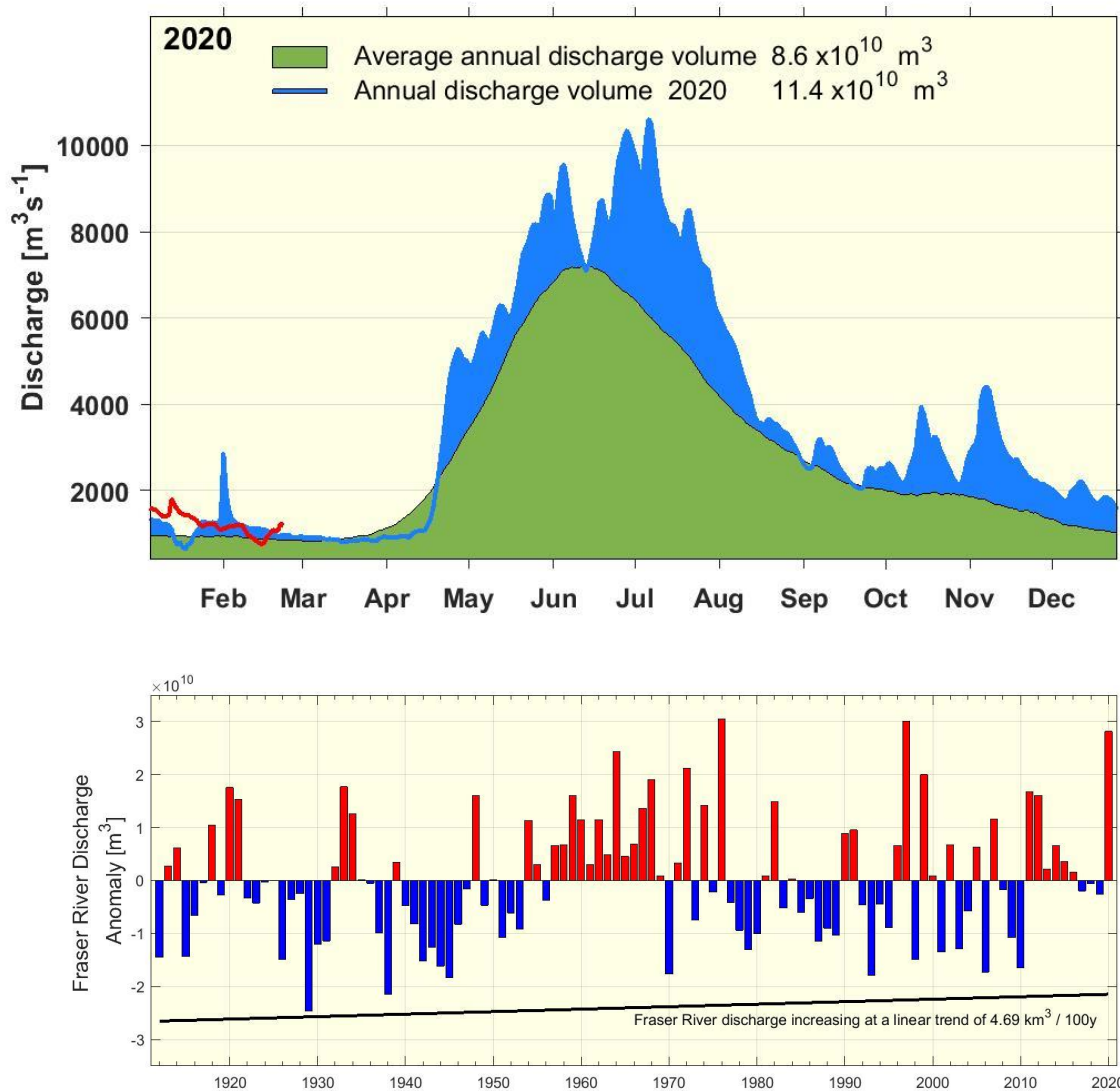


Figure 35-4. (Upper panel) Fraser River discharge at Hope B.C.; 2020 (blue), 108 year average (green), the above normal discharge in early 2021 (red line). (Lower panel) The time series of the annual Fraser River discharge anomaly. Extracted from the Environment and Climate Change Canada Real-time Hydrometric Data web site (https://wateroffice.ec.gc.ca/mainmenu/real_time_data_index_e.html) on 23 Feb 2021.

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36. SURFACE, WATER COLUMN, AND DEEP PROPERTIES IN THE SALISH SEA DURING 2020: CABLED INSTRUMENTS AND FERRIES

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36.1. Highlights

Assessment of the 2020 marine conditions around the coast of southern Vancouver Island, both off-shore and in-shore, reveal several characteristics:

- Early down-welling was strong in February, but was not sustained, while up-welling started late and was neither strong nor sustained. Fall down-welling followed the long-term average in strength and duration.
- Fall 2020 down-welling failed to bring in significantly warmer near surface (>100m) waters, despite the persistence of a general upward step in temperatures (~0.5 °C) following the Blob years of 2014-16.
- Mid-depth water properties within the Salish Sea remained slightly warmer than the long term mean following the intrusion of Blob water in 2015, but the winter cooling and summer warming variations in 2020 were not remarkable, and well within the climatological norms.
- Surface conditions in the Strait of Georgia as revealed by the sensors on the Queen of Alberni Ferry reveal a spring phytoplankton bloom starting on March 7, 2020, similar to the long-term timing.
- Preliminary data from a new station in Baynes Sound reveal a strong seasonal warming cycle and strong biological forcing from an intense spring bloom and sustained mid- to late-summer respiration.

36.2. Description of the Time Series

Here we report on several time series recorded from a number of permanent installations, including a weather buoy west of Cape Flattery, and cabled platforms at Folger Passage (Barkley Sound) and Strait of Georgia, including Baynes Sound. We also report on data from instruments installed on the Queen of Alberni BC Ferry, which crosses the Strait of Georgia from Tsawwassen to Duke Point up to six times a day.

1. NOAA Weather Buoy 46119 is at Cha'Ba La Push (48°N 125°W). The Bakun Upwelling index (text file) is available from the NOAA Pacific Fisheries Environmental Laboratory web site:

<https://www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/upwelling.html>

The Bakun Index uses the daily average along-shore wind stress (scaled by f) to derive a volume estimate of the amount of ocean water transported off (positive - upwelling) or on-shore (negative – down-welling) per 100m of coastline.

2. Ocean Network Canada's (ONC) Folger Passage Deep (100m) site is a fixed point cabled installation at 48° 48' N and 125° 17' W. The instrument platform is located on the west coast of Vancouver Island (WCVI) inner shelf at the mouth of Barkley Sound, and the time series discussed here started in Sept. 2009. This time series provides an indicator of the near shore, mid-depth water properties (T, S, O₂) that are strongly influenced by local up- and down-welling conditions.
3. ONC's Strait of Georgia (East 170m) site is a fixed cabled installation at 49° 2.5' N and 123° 19' W. The instrument platform sits on the bottom in the southern central Strait, along the eastern side at 170m depth. The platform was installed in Sept. 2008. This time series provides an indicator of the mid-water properties (T, S, O₂) in the southern Strait.
4. ONC has instruments installed on the BC Ferries M/V Queen of Alberni, which operates between Tsawwassen and Duke Point. The system was installed in May 2012. This time series provides an indicator of the surface water properties (T, S, O₂, Chla) across the southern Strait, that are strongly influenced by the Fraser River.
5. In 2019, ONC, in collaboration with Vancouver Island University, installed a new cabled monitoring station, a fixed surface buoy in Baynes Sound at 49° 29' N and 124° 46' W, with water property instruments located at 5, 20, and 40m depths. In addition to a surface weather station, the standard sensor suite includes the measurement of pCO₂ to provide information on ocean acidification.



Figure 36-1. Southern coast of B.C., showing ONC's installed and instrumented assets. Sites where data will be shown have been highlighted with red/white circles (NOAA Buoy, west of Washington State, Folger Passage, near the entrance to Barkley Sound, and Strait of Georgia (SoG) East and Baynes Sound, within the Salish Sea) and the Queen of Alberni Ferry route (red line in map inset).

36.3. Status and Trends - 2020

36.3.1. Upwelling

The coastal waters of BC and the Salish Sea are strongly influenced by upwelling conditions along the west coast. For the Salish Sea, this includes the region near the entrance to Juan de Fuca Strait. The outward surface flow and in-bound deep flow associated with the estuarine circulation allows for recently upwelled water to enter Juan de Fuca Strait along the bottom. In particular, deep water in-flow during upwelling season enters primarily through the canyons along the continental shelf break, including the Juan de Fuca canyon (Figure 36-1). Prevailing winds blowing towards the south, which generally occurs during the summer and are associated with the North Pacific High pressure zone off the west coast of North America are upwelling favourable. North bound winds, generally associated with winter and storm conditions, and the establishment of the Aleutian Low in the Gulf of Alaska, are down-welling favourable. Upwelling winds push surface waters off-shore, bringing deeper off-shore (salty nutrient rich) waters closer to shore, and into the Juan de Fuca Canyon and Strait. During down-welling conditions, surface waters (typically warmer and fresher) are pushed towards the coast, pushing down the deeper salty waters.

When the daily upwelling indices are summed cumulatively from January 1 through December 31 of each year, we can assess the character of the local upwelling and down-welling conditions affecting the coastal waters of southern B.C. (Figure 36-2). The winds of 2020 show a few noteworthy characteristics. First, a strong storm system in late January accounts for a majority of the early year down-welling. There was weak down-welling winds in February, March, and April. Upwelling was relatively short, starting late on May 16, finishing a little early on Sept 9, resulting in a net “weak” upwelling season, about 30% less than average. Down-welling in the fall was typical, following the long-term average.

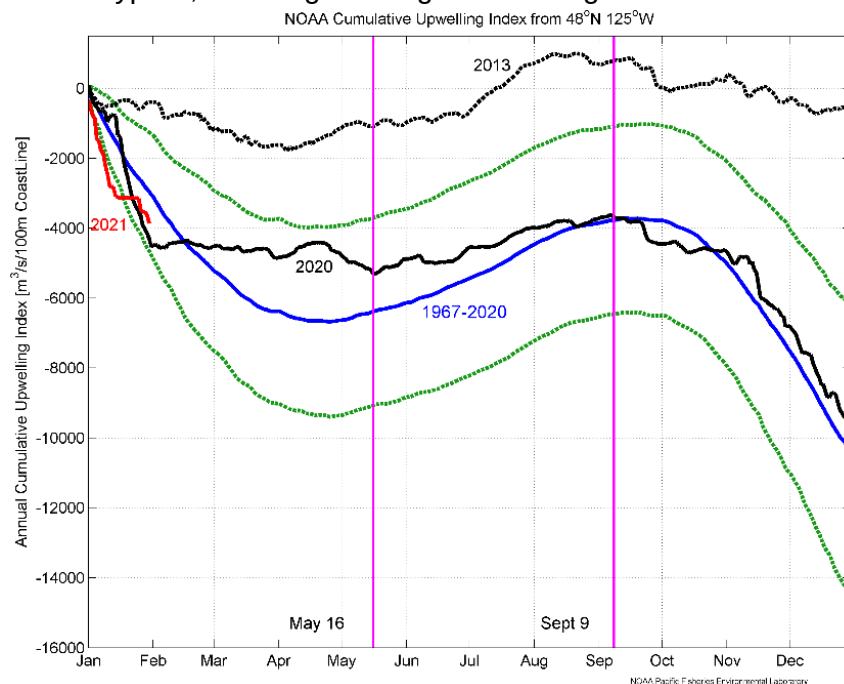


Figure 36-2. The cumulative upwelling index from along shore winds recorded at 48°N 125°W, west of Washington State (Figure 36-1). Downward (down-welling) trends occur during northward winds (winds from the south) and upward (upwelling) trends occur during southward winds (winds from the north). 2020 is shown in a black solid line. The blue curve is the long-term daily average, with plus and minus one standard deviation (green dashed curves). 2013 is shown as the weakest down-welling year on record, contributing to the development of the warm blob in the Northeast Pacific. The vertical lines indicate the beginning (May 16) and end (Sept 9) of the 2020 upwelling season.

36.3.2. Folger Passage

On the west coast of Vancouver Island, the off-shore cable has a station at Folger Passage (Figure 36-1) near the entrance to Barkley Sound. While density is dominated by variations in salinity, oxygen and temperature are inversely correlated with density. All variations have a strong linkage with the regional up-welling and down-welling signal. During the winter down-welling months, oceanic surface waters are pushed eastward towards the shore, causing the coastal water to be fresher and warmer. During the up-welling season, cooler salty water is entrained into the coastal waters.

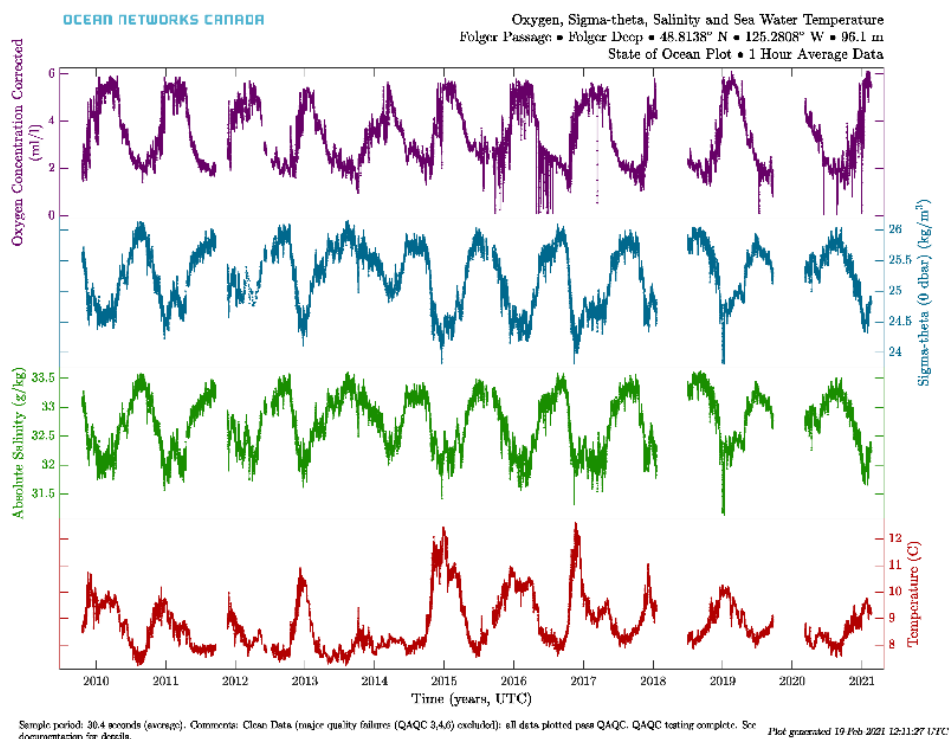


Figure 36-3. Time series of water properties from the cabled station at Folger Passage (100 m) located near the entrance to Barkley Sound along the WCVI (Figure 36-1). Shown are the CTD and Oxygen records (top to bottom): Oxygen (magenta), Density anomaly (σ) (blue), Salinity (green), and Temperature ($^{\circ}\text{C}$) (red). Instrument failures in early 2018 and late 2019 have introduced data gaps.

Several signals are noteworthy. The system was not operational over the winter down-welling season (2019-20), but was re-initialized in early March. At this time the water was already cool ($\sim 8.5^{\circ}\text{C}$), suggesting an early upwelling start, several months ahead of the long-term average (late April). During the fall down-welling season, which the winds would suggest was rather typical, the maximum temperature reached in the late fall was only 9.3°C , several degrees cooler than any period since the warm Blob of 2014. Nothing remarkable is evident in the salinity, density, or oxygen measurements. All values, including temperatures, are more similar in character to pre-Blob (2014) conditions.

36.3.3. Strait of Georgia Mid-Depth Waters

Moving into the Salish Sea, we highlight the time series from ONC's SoG East location (Figure 36-1), located in the south-central region at a depth of 170 m. This site is located along the right-hand (east) side of the thalweg, between the shallow southern Strait and the deep central basin, where maximum depths exceeding 400 m. Shown in Figure 36-4 are the CTD and oxygen records, starting in 2008. The 2020 patterns most closely resemble 2010, an El Niño

year. Apart from a few data gaps associated with sensor failures and plugged conductivity cells, the data reveal several key features of the intermediate water properties in the Strait. First there are the annual cycles in all channels, with salinity dominating density variations, salinity and temperature variations tied to seasonal forcing, with colder fresh waters in the winter and warmer salty waters in the summer, and oxygen influenced by local respiration and winter ventilation. Solid banding indicated high-frequency (tidal) fluctuations, but suggestive of lateral variations that circulate around the basin. Temperatures vary with local atmospheric heating and cooling. Salinity is forced by general freshening during the rainy winter season and the in-flux of salty Pacific waters during the summer up-welling season. It is worth noting while there are local sources for fresh water (rivers and rain), there is only one source for saltier water (increases in salinity), and that is the Pacific Ocean, linked through deep water exchange via Juan de Fuca Strait. Oxygen is generally drawn down via respiration (summer) and is replenished during the winter months by deep (top-down) ventilation from the surface. “Ventilation” is primarily driven by tidal mixing within the approach channels of the Gulf and San Juan Islands and over shallower banks.

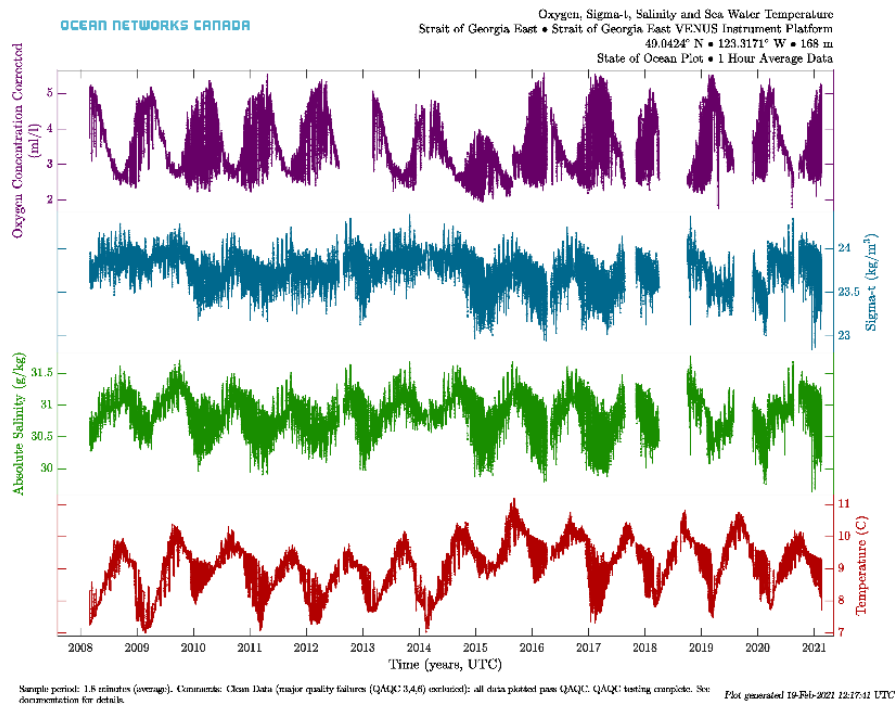


Figure 36-4. Seawater properties from the ONC SoG East (170 m) cabled station, showing (top to bottom): Oxygen, Density (σ_t), Salinity, and Temperature. Of note is the baseline step up in temperatures during the intrusion of the Northeast Pacific Blob in late 2014 and early 2015. From 2015 onward, the entire deep basin of the Strait of Georgia is on average over 0.7 °C warmer than prior to 2015. 2020 most closely resembles 2010, an El Niño year. Solid bands indicate high short-term variability and in the winter are associated cold ventilation events.

36.3.4. Surface Waters Properties from BC Ferries

ONC also maintains a thermosalinograph (TSG) system on the Queen of Alberni Ferry, which runs between Duke Point and Tsawwassen (Figure 36-1, inset). This system is equipped with oxygen and chlorophyll fluorometer sensors, which pick up the spring phytoplankton bloom. The spring phytoplankton bloom is perhaps most identifiable, with a clear transition to higher Chl-a concentrations (Figure 36-5, fourth column) on March 7 (Figure 36-5, black horizontal line).

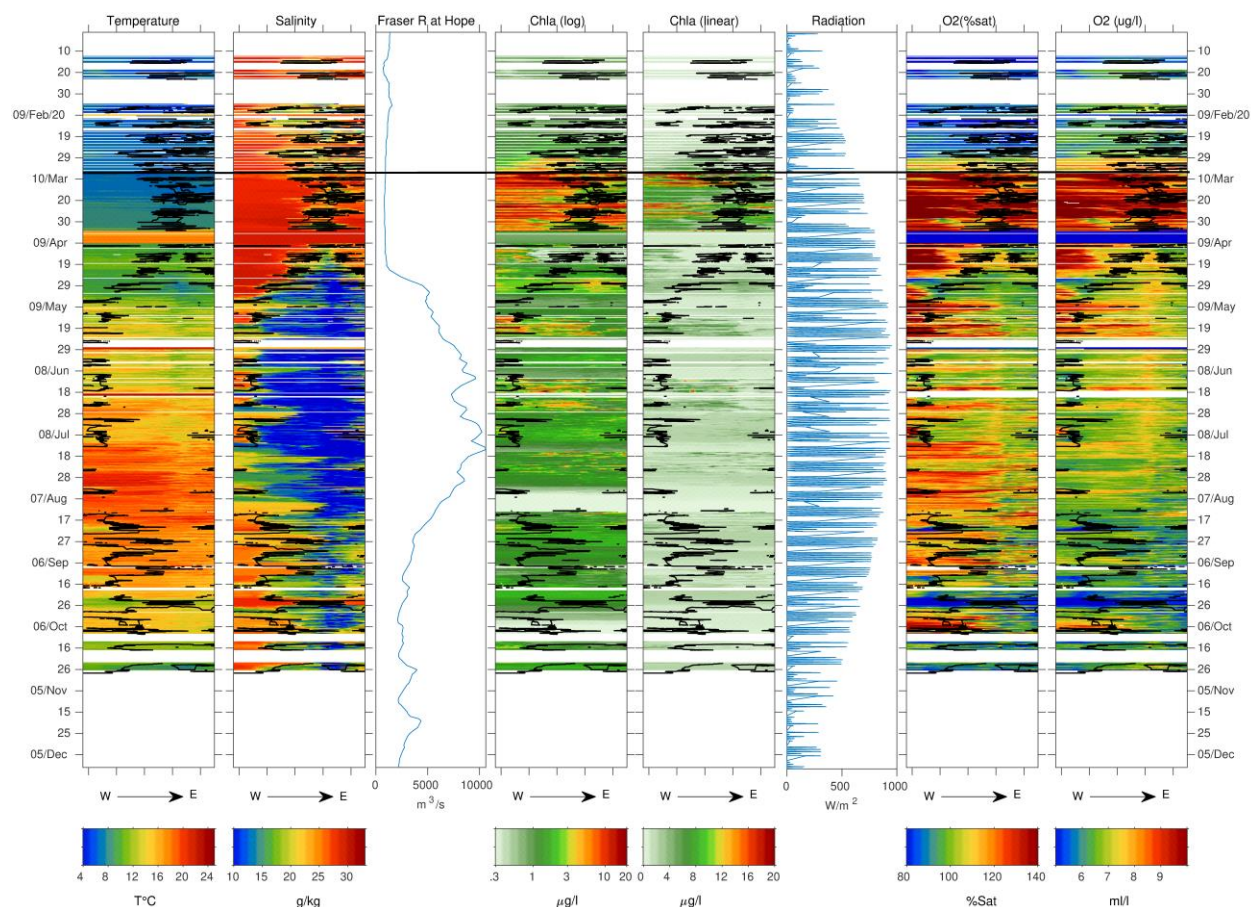


Figure 36-5. Time and Space times series from sensors mounted on the Queen of Alberni Ferry, with time progressing top-to-bottom and space from left (west, Duke Point) to right (east, Tsawwassen). Columns are (from left to right): Sea-surface Temperature, Salinity, Fraser River Discharge (at Hope), Chl-a in both log and linear scaling, solar radiation, and dissolved Oxygen, in both % saturation and $\mu\text{g}/\text{l}$. The start of the spring phytoplankton bloom is approximately March 7 (black line), when Chl-a and Oxygen concentrations dramatically increase, and the Fraser River freshet is identified as the blue pattern in column 2 (and 3), starting about April 19.

36.3.5. Baynes Sound Monitoring Station

ONC operates a moored cabled platform (installed in 2019) in the southern basin of Baynes Sound to assess the marine conditions and ocean acidification (OA) important to the aquaculture industries located there. Collaborations include Vancouver Island University that hosts the shore landing of the cable at the Deep Bay Marine Field Station and Hakai Institute that monitors OA conditions in the area. Key signals include; the seasonal warming (summer) and cooling (winter) that initially stratifies the water column, and is then broken down by winter storms, a spring bloom (starting April), which decreases surface pCO_2 and increases surface dissolved oxygen (Figure 36-6). Respiration is the dominant signal at deeper depths, leading to an increase in pCO_2 and a decrease in DO relative to the surface.

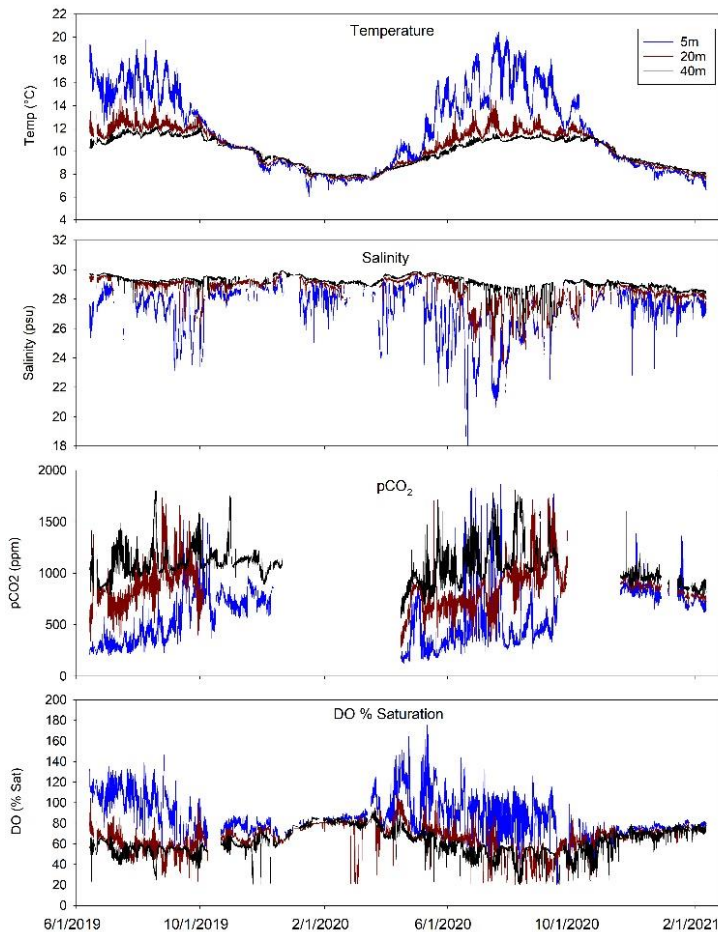


Figure 36-6. Time series of Temperature, Salinity, $p\text{CO}_2$ and Oxygen from ONC's Baynes Sound monitoring station, with sensors at 5 m (blue), 20 m (brown), and 40 m (black) depths in 55 m of water.

36.4. Summary

The 2020 season was characterized by a set of observations indicating a more typical year, with few extremes, at least in comparison to the previous few years, that included the very warm coastal conditions of the Northeast Pacific warm “Blob”. The upwelling season along the southern coast of BC, which strongly influences the character of the coastal water properties, was notable in that the late winter downwelling winds were weaker than average and the transition to the summer upwelling season was pro-longed by a few re-starts between early April and late May. Mid-depth and surface water property ranges and variations in the Salish Sea were similar to historical averages, including a spring bloom start near March 7, 2020. A new ocean acidification monitoring station in Baynes Sound revealed strong seasonal warming and stratification, and strong oxygen production and respiration cycles.

37. SPRING PHYTOPLANKTON BLOOM TIMING, INTERANNUAL SUMMER PRODUCTIVITY IN THE STRAIT OF GEORGIA

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37.1. Highlights

- The timing of the spring bloom in 2020 was average. The spring bloom timing has changed little between consecutive years since 2006, unlike the 10 years previous.
- Summer primary productivity in 2020 was low compared to the long term average.
- The contribution of diatoms to modelled summer phytoplankton productivity in 2020 was very low compared to the 2007-2020 mean.
- The timing of the 2021 spring bloom is predicted to be average to late.

37.2. Description of the time series

Here we use two numerical models to show interannual variations in the phytoplankton in the Strait of Georgia (SoG).

37.2.1. *One-dimensional Biophysical Model: SOG: for Spring Bloom*

SOG is a vertical one-dimensional physical model coupled to a Nitrate-Diatom biological model (Collins et al. 2009). All lateral oceanographic processes not resolved by the model are parameterized. The model location, STRATOGEM station S3, is on the Tsawwassen to Duke Point ferry route in Central SoG (Perry et al. 2021). The model is forced by winds measured at Sand Heads, clouds and temperature measured at YVR (Vancouver) airport and river flow measurements at Hope and the Englishman River or Nanaimo River when the Englishman is not available (e.g. 2021). The flow at Hope represents the snow melt dominated part of the Fraser River while the Englishman River or Nanaimo River represents all other rivers and the rainfall dominated part of the Fraser River. We have produced a time series of spring bloom time back to 1967 (Allen and Wolfe 2013).

37.2.2. *Three-dimensional Biophysical Model: SalishSeaCast*

SalishSeaCast is a three-dimensional coupled bio-chemical-physical model of the Salish Sea. The physical model is based on NEMO (Madec et al. 2015). Grid resolutions are about 500 m in the horizontal and 1–22 m in the vertical, with higher resolution near the surface (Soontiens et al. 2016). It is forced by realistic winds and solar radiation from Environment and Climate Change, Canada's HRDPS 2.5 km model (Milbrandt et al. 2016). River input is based on a climatology (Morrison et al. 2011), or in the case of the Fraser River, on observations at Hope. The biological model, SMELT, is a 3 nutrient, 3 phytoplankton, 2 zooplankton, 3 detritus class model (Olson et al. 2020). Here we present results for the spring bloom from an experimental version that best captures the timing of the spring bloom. We present summer productivity based on the current version of the model, which best captures the summer productivity and for which we have a 14-year time series.

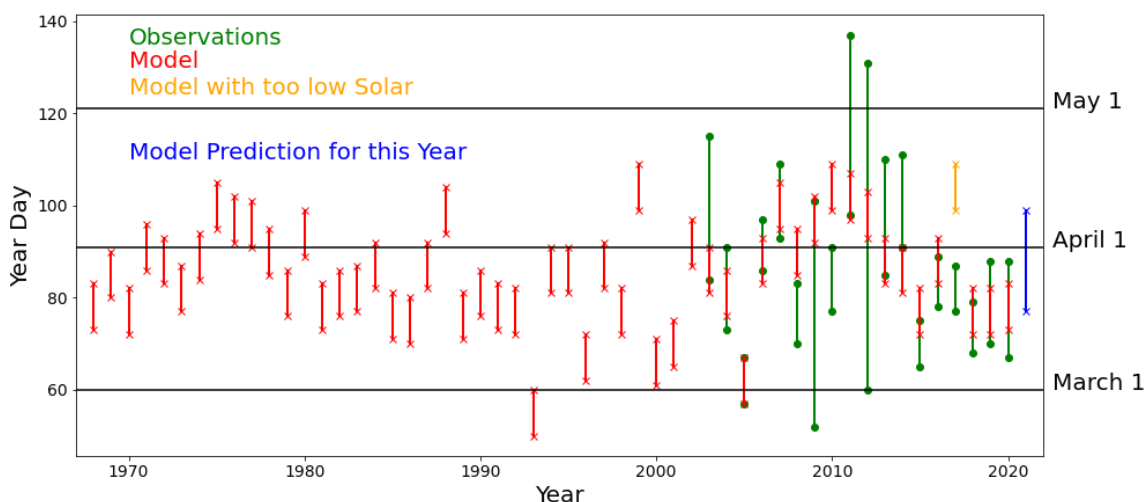


Figure 37-1. Time series of the timing of the peak of the Spring Phytoplankton Bloom. Green- observations from ferry systems. Red – SOG model. Orange – SOG model with too little solar radiation (see Allen et al. 2018). Blue –SOG prediction for 2021.

37.3. Status and trends

37.3.1. Spring Bloom

The 2020 spring bloom happened between March 13 – March 23, 2020 according the SOG model (Figure 37-1). The ferry observations give ½ peak height to ½ peak height bloom timing of March 7 – March 28, 2019 (Figure 37-1). For details on the ferry observations see Dewey et al., Section 36. The 2021 spring bloom is predicted to peak between March 17 – April 8, 2021.

The 2020 spring bloom had typical timing. The mean of the SOG timeseries is March 26 with a standard deviation of 11 days. As noted last year, since 2011, the spring bloom timing has not varied strongly between years. This small variation is similar to the time series before 1993 and very different from the large swings seen between 1993 and 2006.

37.3.2. Summer Productivity

To measure summer productivity, we sum the primary productivity of the three phytoplankton groups in the model: diatoms (representing both centric and pennate diatoms), flagellates (primarily haptophytes, cryptophytes and prasinophytes) and ciliates (representing, *Mesodinium rubrum*), and then integrate over the top 30 m and average over the summer months of June, July and August. Summer productivity (Figure 37-2, top left panel) is higher in the northern and southern SoG than the central region. Throughout the Strait, except in some inlets and the far south, summer productivity in 2020 was much lower than the fourteen-year mean by about 10-25%. In 2019, the summer productivity was also low but only by 5-10% and a larger fraction of the photosynthesis was done by flagellates compared to diatoms. In 2020, the diatoms were largely absent through the summer with productivity contributions 50% lower than the mean.

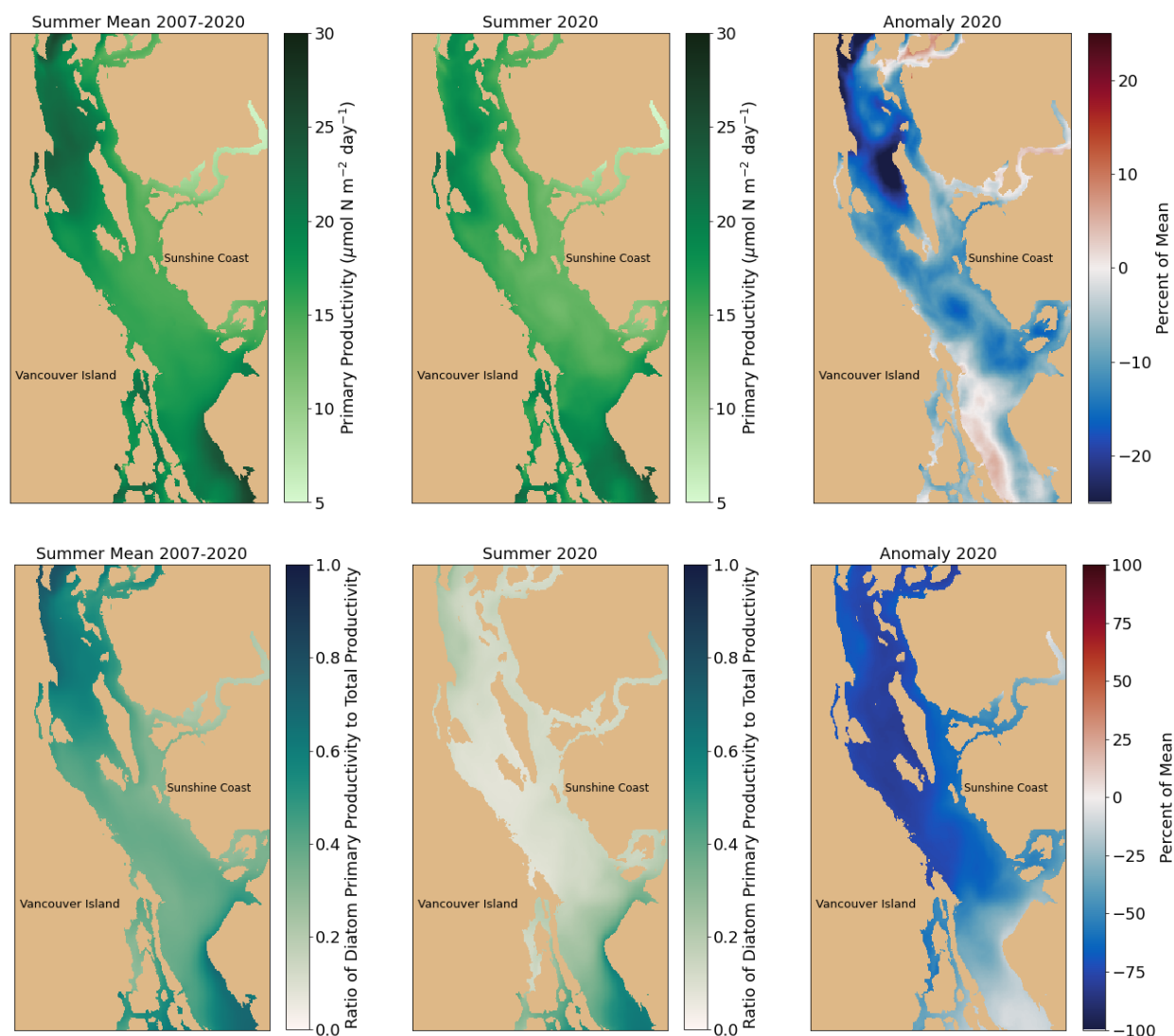


Figure 37-2. Summer productivity in the Strait of Georgia and its variation in 2020 compared to mean over 2007-2020. Values are averaged over June, July and August and integrated through the top 30-m of the water column. Only water depths greater than 35 m are shown. Top row: primary productivity in the model. Bottom row: ratio of diatom primary productivity compared to total. Left column: mean over fourteen years. Middle column: 2020. Right column: anomalies from the mean for 2020 in percent.

37.4. Factors influencing trends

37.4.1. Spring Bloom

According to the SOG model, the 2020 spring bloom commenced in late February as winds were weak and there were fewer clouds than typical (Figure 37-3). The bloom was interrupted by a large storm in late February and smaller storms into early March suppressed growth. Thereafter the bloom was quick and peaked on March 18.

37.4.2. Summer Productivity

According to the SalishSeaCast model, diatoms responded to the wind-driven impulses in late May and the first week in June but after that biomass remained low except for one pulse in July. From mid-April to mid-May, winds were low particularly in the northern Strait (not shown). In the model, this lack of wind caused reduced nitrate availability and low phytoplankton biomass which in turn caused very low microzooplankton biomass. When nutrients returned in May, the flagellates grew quickly, out-pacing their major grazers, the microzooplankton. The flagellates increased the depth of the nutricline, suppressing diatom growth. In the model, this flagellate dominated system was stable through the summer. At the time of writing, observations supporting a flagellate dominated summer in the SoG ecosystem are not available. However, the chlorophyll observations by the Citizen Science program (Esenkulova et al., Section 38) show anomalously low values in the summer of 2020.

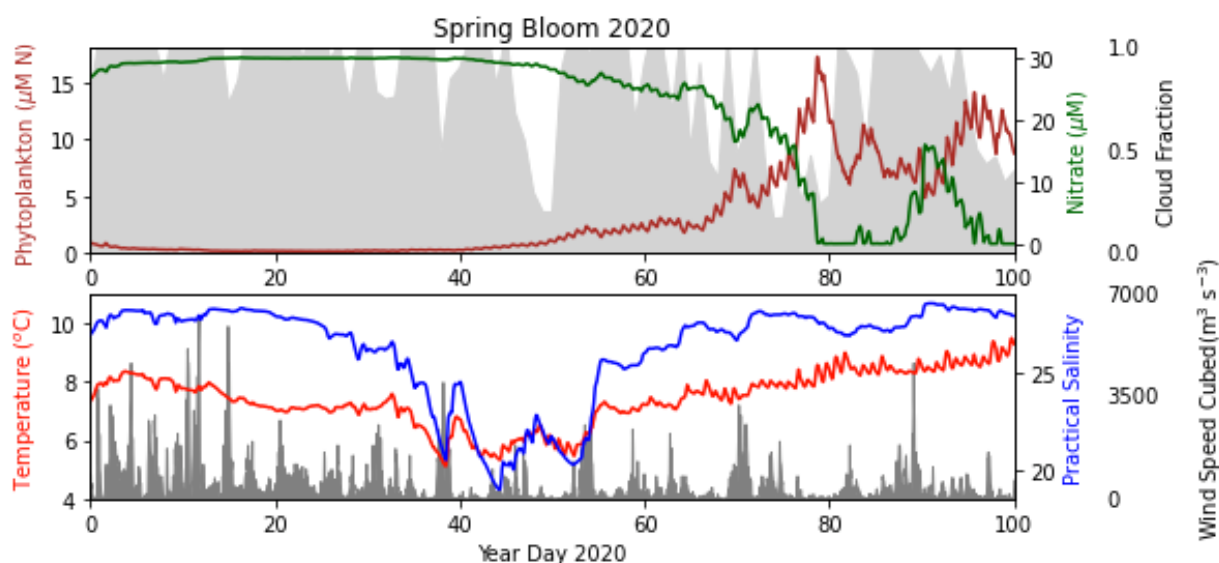


Figure 37-3. Hindcast of the 2020 spring bloom and related conditions in the Strait of Georgia. The lower panel shows temperature (in red) and salinity (in blue) averaged over the upper 3 m of the water column; in grey is the wind-speed cubed which is directly related to the strength of the mixing. The top panel shows phytoplankton biomass (in dark red) and nitrate (in green); in grey is the cloud fraction averaged over the day. The 2020 spring bloom was March 18 plus or minus 5 days. Plots span the period January 1, 2020 to April 9, 2020.

37.5. Implications of those trends

The timing of the spring phytoplankton bloom can impact age-0 herring abundance, with abundance being larger for blooms with typical timing (Boldt et al. 2018). Thus, the spring bloom timing in 2020 was good for age-0 herring. Extreme shifts of timing have led to poor zooplankton growth (e.g. Sastri and Dower 2009). Consistent spring bloom timing seen in the 2010's should be good for zooplankton such as copepods.

The rate of primary productivity should determine bottom-up food availability for higher trophic levels. In 2020, summer productivity was very low according to SalishSeaCast and in particular, the diatom productivity was far below the typical values over the fourteen year time series. At

the time of writing there were no observations showing anomalously low zooplankton in summer 2020.

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38. HARMFUL ALGAL BLOOMS AND OCEANOGRAPHIC CONDITIONS IN THE STRAIT OF GEORGIA 2020

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38.1. Highlights

- Near-surface temperature and dissolved oxygen were near typical, salinities were lower, especially in the northern SoG; summer chl-a was lower.
- There were local *Heterosigma akashiwo* blooms with concentrations reaching thousands of cells per mL in Cowichan Bay, Sunshine Coast, and Irvine's Sechelt in July and August; *Heterosigma* blooms of 2020 were more abundant than in 2015-2017 and 2019, but less than in 2018.
- There were no pennate diatom *Pseudo-nitzschia* spp. and *Rhizosolenia setigera* blooms; dinoflagellates *Alexandrium* spp. and *Dinophysis* spp. (PSP and DSP producing taxa) were very abundant.
- A die-off of thousands of perch was reported in Powell River at the beginning of September.

38.2. Citizen Science Program

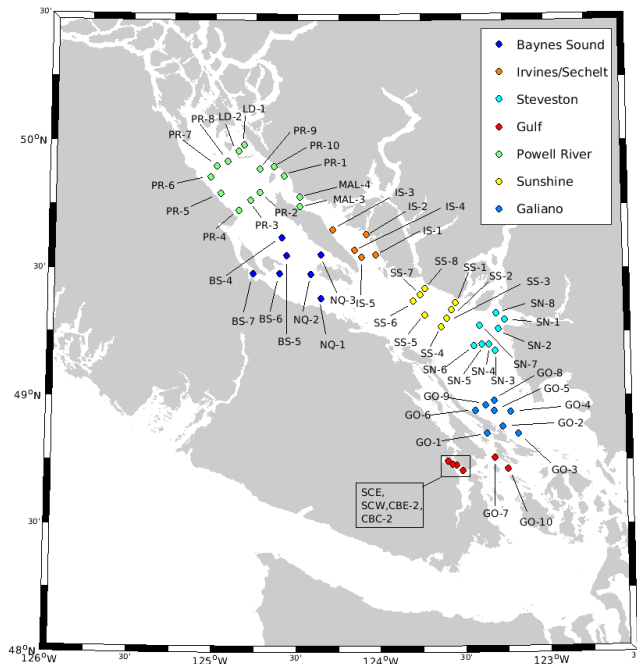


Figure 38-1. Map of the Strait of Georgia with CitSci program sampling locations in 2020. Different colours represent different patrols.

The concept of using “citizens” to gather oceanographic data in B.C. waters was initially proposed by Dr. Eddy Carmack, DFO. He envisioned a ‘mosquito fleet’ of private boats collecting data for science everywhere in the Strait of Georgia (SOG) at once. Eventually this idea was implemented by the Pacific Salmon Foundation (PSF), who have managed and operated such a program since 2015. Several dozen trained members of different local communities, organized into 7-10 patrols centered on a particular vessel and backed up by technical assistance from PSF, as well as its partners at Ocean Networks Canada, Fisheries and Oceans Canada, and the Universities of Victoria and British Columbia, collected information in the SoG on a regular schedule (about 20 times a year) between February and October. The scope and coverage of this data is unprecedented; more details

about this program and the CitSci dataset, as well as figures showing oceanographic conditions over 2015-2019, are provided in Pawlowicz et al. (2020). A digital version of this atlas is now under development and will be placed on the Strait of Georgia Data Centre (sogdatacentre.ca).

38.3. Description of the time series

In 2020, coordinated sampling in the CitSci program occurred at approximately ~55 sites (Figure 38-1), a slight decrease from ~75 sites sampled in 2015-2018. Conductivity-Temperature-Depth-Dissolved oxygen-Chlorophyll fluorescence (CTD/O₂/FI) profiles down to 150 m were collected at all stations, 2 to 3 times a month between February and October with an additional “winter” sampling date in December, for a total of ~700 profiles. RBR Concerto CTD probes were used, and raw data were archived by Ocean Networks Canada, who also processed these data into 1 m binned profiles. A complete dataset with additional quality control is available at the Strait of Georgia Data Centre (sogdatacentre.ca).

Nutrient samples were also collected at two depths at ~30 stations, phytoplankton samples at all stations, and zooplankton at three stations. Sample/measurement processing and analysis was done at the PSF, UBC, Ocean Networks Canada, Fisheries and Oceans Canada, and University of Victoria. Phytoplankton samples were analyzed on a Sedgewick-Rafter slide; the identification of specimens is done to the lowest taxonomic level possible and the enumeration (as cells mL⁻¹) was performed for the species or group that is dominant in the sample and species that were known or suspected to have a negative effect on salmonids in B.C. (Haigh et al. 2004). This current report is based on over ~1350 samples (~85% of the total number of samples collected in 2020).

38.4. Status and trends

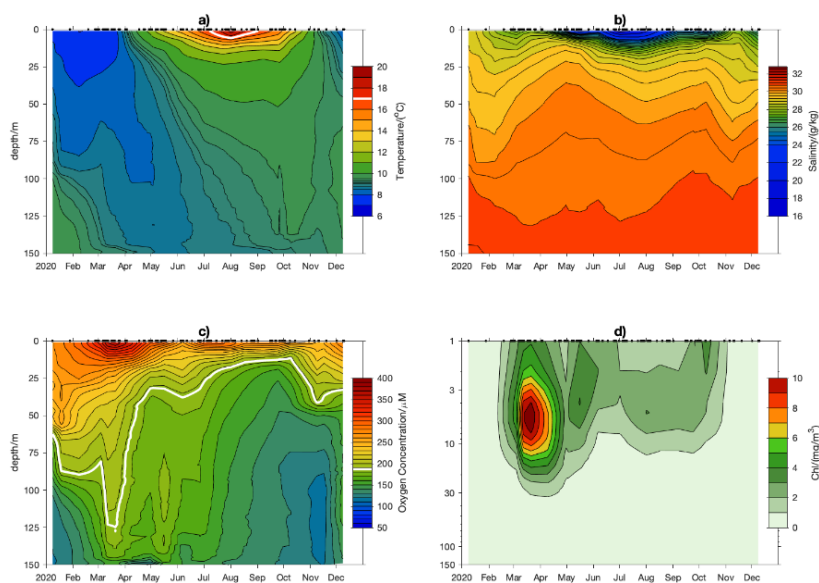


Figure 38-2. Annual cycle for water properties in the Strait of Georgia in 2020. White lines mark conservative physiological boundaries for salmonids (warmest temperature 17 °C, lowest O₂ 6ppm or 187 µM).

Only CTD and phytoplankton data are presently available for 2020. Averaging over the whole Strait, it can be seen that dissolved oxygen levels are less than 6ppm or 187 µM in waters deeper than 15 m depth in late summer (Figure 38-2). For salmonids in particular, studies found avoidance behaviors at concentrations of 4.5 to 6 ppm (BCMECCS 1997b), with B.C. Water Quality Guidelines suggesting an acceptable instantaneous oxygen threshold of 5 ppm to prevent harm to all life stages of aquatic life (BCMECCS 1997a). Based on

expert recommendations, we highlight a slightly more conservative upper limit of 6 ppm (or 187 μM) in our figures.

Similarly, temperatures about 17 °C are thought to cause physiological stress in salmonids (US EPA 2003) and the upper 6 m of the water column were warmer than this in July and August.

Comparing 2020 against previous years (Figure 38-3), near surface water temperatures were slightly warmer but dissolved oxygen (DO) levels were near typical in 2020, and surface salinities were lower. There is a link between these low salinities and larger Fraser river flows, especially in mid-summer, but the lowest salinity anomalies in 2020 actually occurred in the northern Strait (not shown). Integrating our chlorophyll fluorescence profiles (after calibrating to water samples), we found a large spring bloom in March, at the same time as the bloom was estimated using measurements from the B.C. ferries

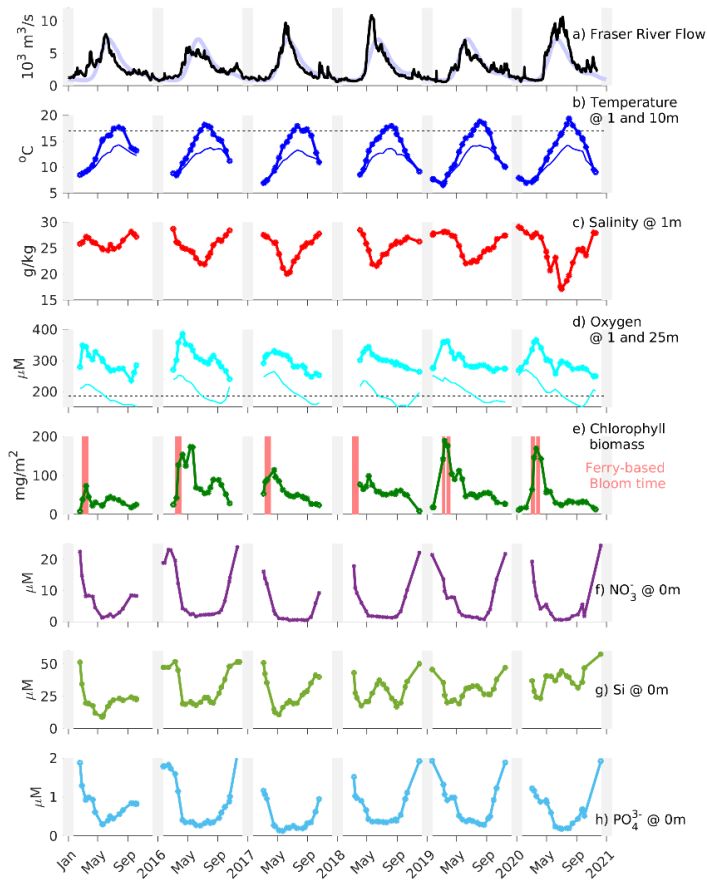


Figure 38-3. Strait-wide trends in surface properties 2015-2020.

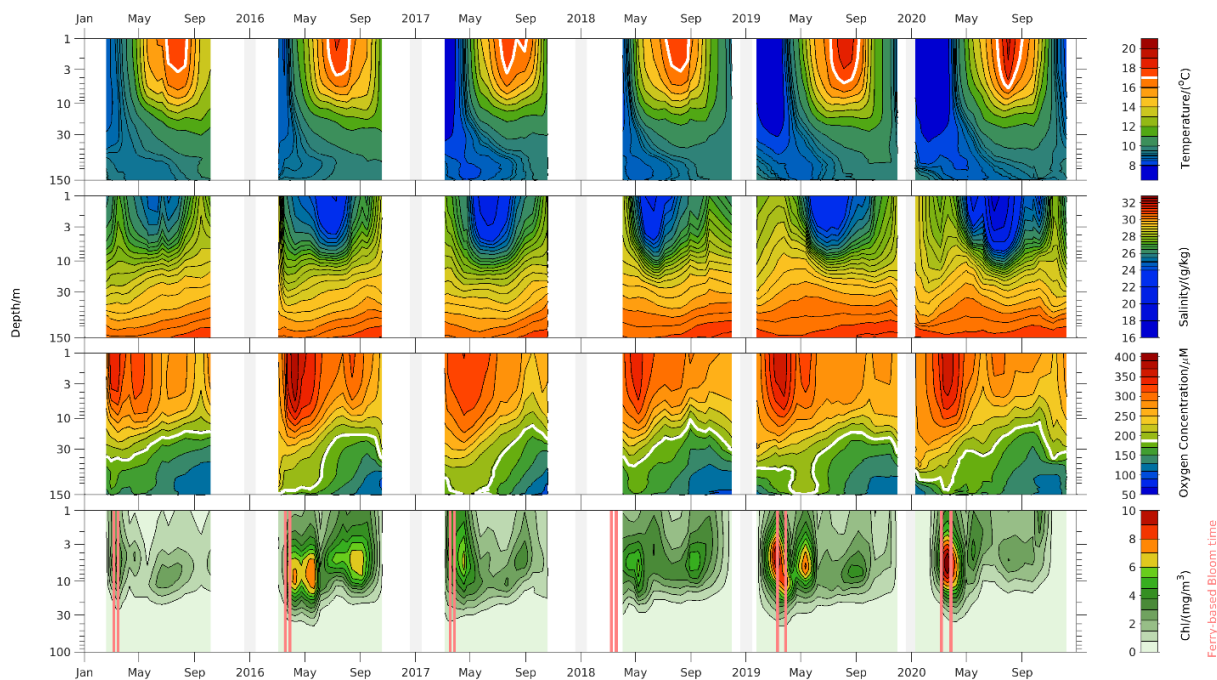


Figure 38-4. Strait-wide trends in water column properties from 2015-2020.

monitoring program in the southern Strait operated by Ocean Networks Canada. Note that comparison with these ferry-based bloom time estimates suggests that the CitSci program may not have captured the bloom in some earlier years. After the bloom, summer phytoplankton biomass was lower in 2020 than it was in previous years.

In addition to the slightly warmer surface waters in 2020, the depth of the mean 17 °C contour was deeper (~6 m) relative to the ~3 m depths seen in 2015-2018 (Figure 38-4). However, depths of the 6 ppm DO limit are the same as in previous years. Oxygen levels near the surface are high in all summers, and are particularly high during the spring bloom period, related to the high levels of primary productivity at that time (Wang et al. 2019).

After the annual spring bloom, which comprised several diatom species, similar to 2016-2019 (but not similar to the nearly monospecific spring bloom of 2015), several harmful algal blooms were noted. There were a few local blooms of ichthyotoxic raphidophyte - *Heterosigma akashiwo*. Dense blooms with maximum concentrations reaching 7,000 cell mL⁻¹ were seen in Cowichan Bay on August 25, 2020; blooms with concentrations of 1,000-3,500 cell mL⁻¹ were seen in Irvine's Sechelt, Steveston, and Sunshine coast in June and July. *Heterosigma* with concentrations over 200 cell mL⁻¹ appeared in ~6% of surface June-August samples. For comparison, it was 0% in 2015-2017, 10% in 2018, and 2% in 2019. There were no pennate diatoms *Pseudo-nitzschia* spp. and *Rhizosolenia setigera* blooms in 2020 (Table 38-1).

Table 38-1. Maximum cell concentration (cell mL⁻¹) recorded.

Species	2015	2016	2017	2018	2019	2020
<i>Heterosigma akashiwo</i>	6	150	20	11,000	25,000	7,000
<i>Pseudo-nitzschia</i> spp.	40	600	300	4,500	30	70
<i>Rhizosolenia setigera</i>	250	800	1,800	4,000	500	5

Dinoflagellates *Alexandrium* spp. and *Dinophysis* spp. were very abundant (Table 38-2). Both genera appear to have the highest frequency of occurrence in 2020 compared to previous years.

Table 38-2. Frequency of occurrence (%) in surface samples.

Year	<i>Alexandrium</i>	<i>Dinophysis</i>
2015	10.7	1.7
2016	16.3	0.7
2017	18.1	1.6
2018	15.7	5.1
2019	10.1	3.7
2020	18.3	5.5

A die-off of thousands of perch in Powell River was reported by the citizen scientist Ed Oldfield on September 7 (Figure 38-5). He reported that it was “in the same place that the April 2019 krill die-off happened”. Samples were collected and provided to IOS, DFO by the citizen scientists and PSF.



Figure 38-5. Photo of dead perch from Beach Gardens, Powell River, September 7, 2020. Photo by Ed Oldfield.

38.5. Factors influencing trends

Phytoplankton dynamics are directly governed by primary environmental factors. Harmful algae concentrations in SoG are linked to environmental parameters.

38.6. Implications of those trends

Salmonids are vulnerable to warm waters and hypoxia. The SoG was too warm and approached the DO limits for salmonids in several areas at the end of summer 2020. Blooms of *Heterosigma* in SoG are linked to poor salmon returns (Rensel et al. 2010) and are the largest cause of direct B.C. farmed salmon losses (Haigh and Esenkulova 2014).

In our data series, 2020 was the second worst year (after 2018) for *Heterosigma* blooms. Some species from genera *Alexandrium*, *Dinophysis*, and *Pseudo-nitzschia* produce toxins that cause paralytic, diarrhetic, and amnesic shellfish poisoning respectively (PSP, DSP, ASP). High abundance of *Alexandrium* and *Dinophysis* may lead to high PSP and DSP toxin concentrations.

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39. ZOOPLANKTON STATUS AND TRENDS IN THE CENTRAL AND NORTHERN STRAIT OF GEORGIA, 2020

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39.1. Highlights

- Despite COVID restrictions, samples were collected approximately monthly through the year; however, no samples were collected in April, May and July for 2020, making comparisons to historical data difficult.
- Overall, zooplankton biomass has been trending up, with 2020 having a higher than average biomass (preliminary).
- Zooplankton biomass is an important factor in early marine survival of several Chinook salmon stocks in the Strait of Georgia from 1996 to 2018 (Perry et al. 2021).

39.2. Description of the time series

Zooplankton samples have been collected at approximately 20 standardized stations monthly from February to October since 2015, with historic (but sporadic sampling effort) data going back to 1995. However, due to COVID restrictions in 2020, no samples were collected in April, May and July of this year.

The three main objectives of the zooplankton sampling program are to investigate: 1) the seasonal and inter-annual patterns of the zooplankton community; 2) the possible causes of any changes; and 3) the potential consequences of those changes.

For this report, we address the first objective and describe current trends of abundance (m^{-3}) and biomass (mg m^{-3}) as monthly averages of all samples processed in 2020 (30% of collected samples for this report) in the deep (bottom depths greater than 50 m, and vertical net haul samples which covered over 70% of the water column) central and northern Strait of Georgia (averaged together; Figure 39-1). Data were restricted to the central and northern regions as they have the most complete time series available at this time. Sample processing is ongoing to fill in the other regions, and results are preliminary.

For historical comparison, the seasonal variability in the zooplankton data was removed by calculating a regional, log-scale biomass anomaly for selected species for a given year. A multi-

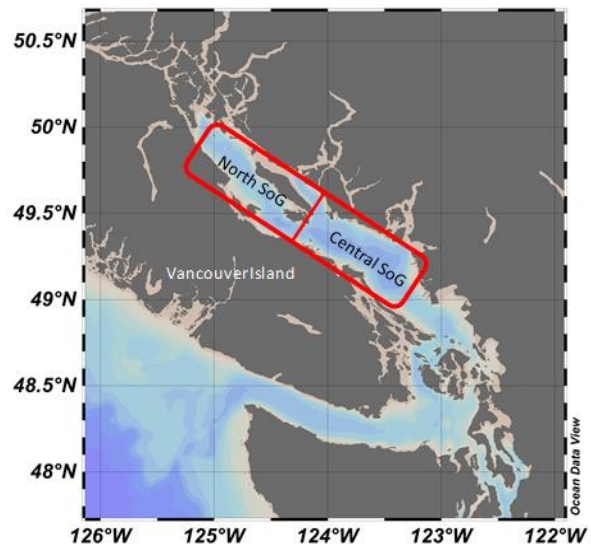


Figure 39-1. The central and northern Strait of Georgia (SoG) shown by the red boxes.

year (1996-2010) average seasonal cycle (“climatology”) was calculated as a baseline to compare monthly conditions during any single year. Seasonal anomalies were then averaged within each year to give an annual anomaly (Mackas et al. 2013; Perry et al. 2021).

39.3. Status and trends

The total zooplankton biomass in 2020 ranged from 17.4- 201.1 mg m⁻³, with the lowest biomass occurring in the winter and peaking in the late summer (Aug-Sept; Figure 39-2). The summer peak was lower and later in season than in previous years, however no samples were collected in April, May or July (Figure 39-2).

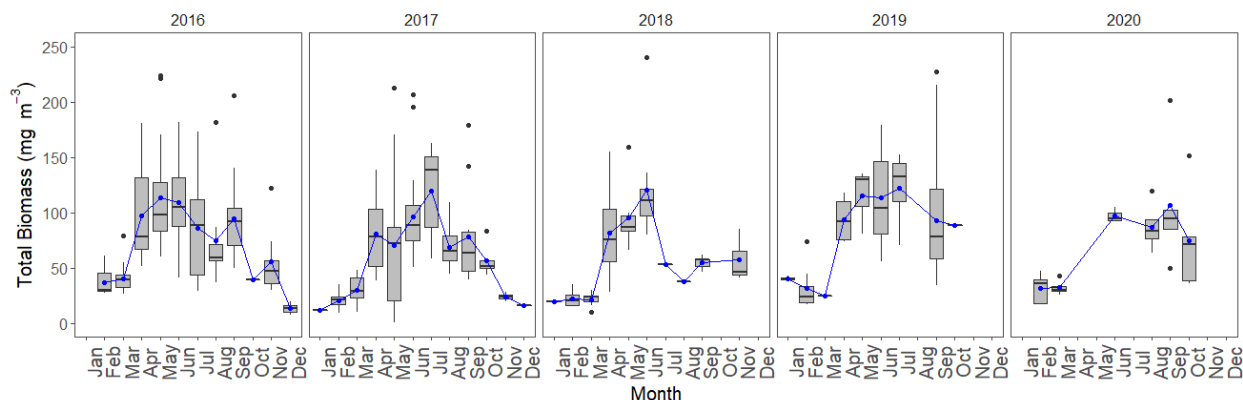


Figure 39-2. Average total biomass (mg m⁻³) of zooplankton by month in the north and central (averaged together) Strait of Georgia for 2016-2020. Boxplots show median and spread of data, blue dot and line follows the mean biomass.

Overall, total biomass was above average in 2020 (Figure 39-3).

The peak timing of the abundance and biomass of the zooplankton in the SoG varied by species (Figure 39-4). Within the crustacean groups considered as preferred food for juvenile salmon (‘fish food’), abundance and biomass trends were similar to 2019. Euphausiid abundance peaked in spring, mostly due to large numbers of eggs and larval stages (Figure 39-4). Euphausiid biomass was highest in the late summer/fall, when most of the individuals were adults. Decapod (crab and shrimp) larval abundance peaked in the spring, but their biomass dropped through the spring/summer as they transitioned from planktonic larvae to benthic adults. In 2020, amphipod abundance and biomass both increased in the summer and remained high through the fall (Figure 39-4).

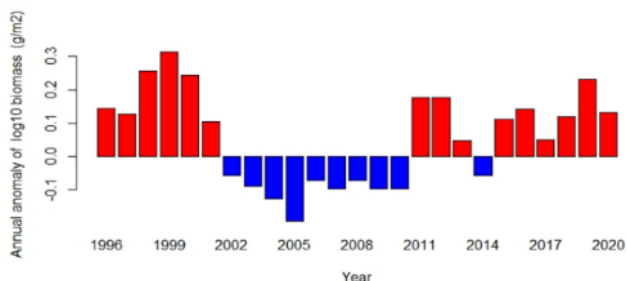


Figure 39-3. Annual biomass anomalies of total zooplankton biomass in the deep waters of the central and northern Strait of Georgia, 1996-2020.

Copepods, in particular calanoid copepods, dominated the zooplankton by abundance (Figure 39-4, left). Medium- and large-body calanoid copepods and the larger crustaceans (euphausiids and amphipods) dominated the biomass (Figure 39-4, right).

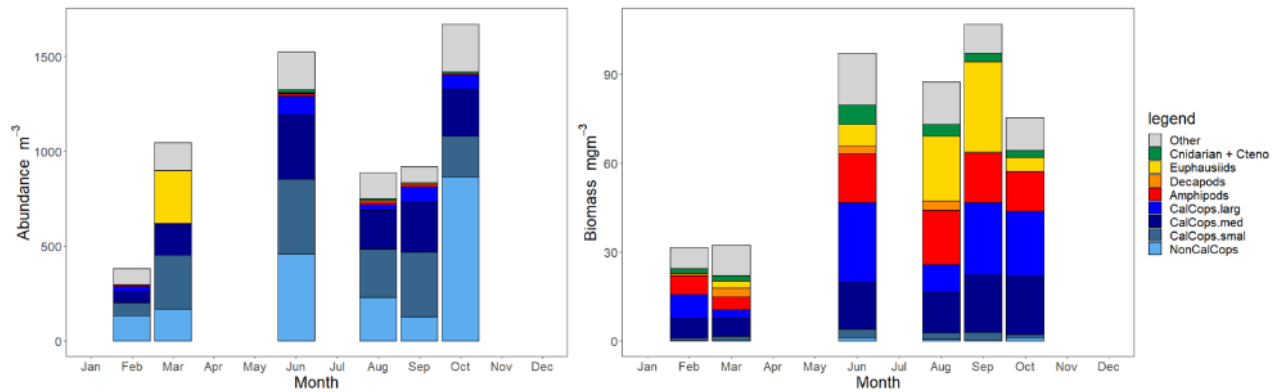


Figure 39-4. Taxonomic composition of zooplankton from northern and central Strait of Georgia in 2020, averaged by month. Left: abundance (m^{-3}); Right: biomass (mg m^{-3}). Legend: CalCops.larg – calanoid copepods, prosome length (PL) >3 mm; CalCops.med – calanoid copepods PL 1-3 mm; CalCops.smal – calanoid copepods PL <1 mm; NonCalCops – all other copepods; Amphipods – all amphipods (hyperiid and gammarid); Decapod – all decapods (shrimp, crab larvae); Euphausiid – all euphausiids (eggs, larvae and adults); Cnidarian + Cteno – all Cnidarian (medusa and siphonophores) and Ctenophores; Other – everything else: Molluscs, Polychaetes, Chaetognaths, Ichthyoplankton, Larvaceans, etc.

Within the copepods, smaller species (such as *Pseudocalanus* spp. and cyclopoid-type copepods) were very abundant, but they contributed little to the overall biomass (Figure 39-5). Medium and large-sized copepods, such as *Metridia pacifica*, *Calanus* sp. (mostly *C. pacificus* and *C. marshallae*), and *Eucalanus bungii* made up the majority of the copepod biomass (Figure 39-5) representing a change from the typical spring dominant large copepod *Neocalanus plumchrus* (Figure 39-6).

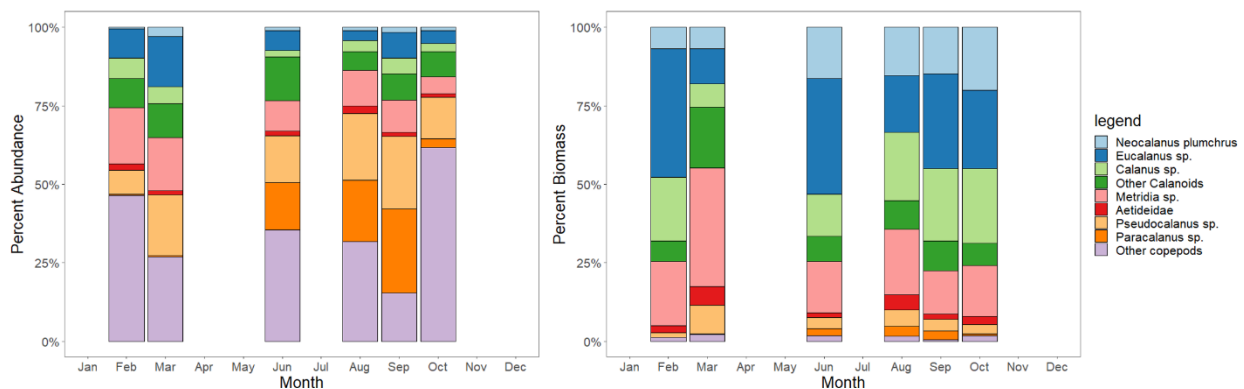


Figure 39-5. Relative abundance (left) and relative biomass (right) of all copepods collected from northern and central Strait of Georgia in 2020, averaged by month. Legend: Other copepods – all non-calanoid copepods; Paracalanus sp. – *P. indicus* and *P. parvus*; Pseudocalanus sp. – mix of *P. minutus*, *P. moultoni*, *P. newmani* and *P. mimus*, varies by season; Metridia sp. – mainly *M. pacifica* but also *M. pseudopacifica*; Aetideidae – all Aetidid copepods such as *Aetidius divergens*, *Gaetanus* sp.; Calanus sp. – *C. pacificus* and *C. marshallae*; Neocalanus plumchrus – all stages (CI-adults) of *N. plumchrus*; Eucalanus sp. – mainly *E. bungii* but with rare instances of *E. californicus*; Other calanoids – all other calanoid copepods.

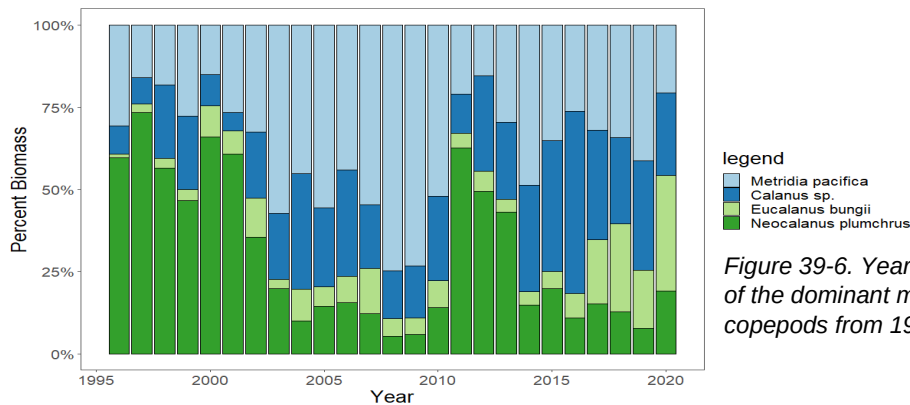


Figure 39-6. Yearly averaged percent biomass of the dominant medium and large calanoid copepods from 1996-2020.

Most species of ichthyoplankton, notably Pacific Herring (*Clupea pallasii*), peak in the springtime (April-May), and unfortunately there was no sampling during those months in 2020.

Gadiformes, mainly Hake (*Merluccius productus*), abundance and biomass (5.78 m^{-3} and 0.95 mg m^{-3} , respectively) was higher in March 2020 than in March 2019. Osmerid, mainly Northern Smoothtongue (*Leuroglossus schmidtii*), biomass increased slightly this summer compared to 2019 (Young et al. 2020). Northern Anchovy (*Engraulis mordax*) eggs and larvae were also found in June and August 2020 samples.

39.4. Factors influencing trends

Trends in zooplankton composition and biomass have been linked to large scale climate indices, such as the Southern Oscillation Index (SOI), the North Pacific Gyre Oscillation (NPGO) and the Pacific Decadal Oscillation (PDO; Li et al. 2013; Mackas et al. 2013; Perry et al. 2021), as well as local factors such as: timing of the Fraser River freshet (Mackas et al. 2013); sea surface salinity, and timing of the peak date of the spring phytoplankton bloom (Perry et al. 2021).

39.5. Implications of those trends

The SoG zooplankton community is more similar to the oceanic subarctic area rather than the neighbouring B.C. continental shelf, linked through offshore deep water renewal events that bring offshore deep water in through the bottom waters of the SoG (Masson 2002; Mackas et al. 2013). Medium and large sized crustaceans (calanoid copepods, euphausiids and amphipods) dominated the total biomass of zooplankton in the Strait, and variations in these groups over time have been shown to be important variables in the modeled marine survivals of some Chinook and Coho Salmon populations that enter the Strait as juveniles (Perry et al. 2021). Field observation programs such as this current project, in support of the Salish Sea Initiative started in response to the Cohen Commission, are very important for understanding changes occurring in the marine environment. A consistent zooplankton monitoring program in the Salish Sea can assist with projections of future abundances of juvenile salmon.

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40. JUVENILE SALMON IN THE STRAIT OF GEORGIA

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40.1. Highlights

- The fall survey was successfully completed for the first time fishing from the new CCGS Sir John Franklin.
- In the fall of 2020, the CPUE of Coho Salmon was the fourth highest observed in the time series.
- Chinook Salmon CPUE was the largest observed in the time series.

40.2. Description of the time series

Juvenile salmon generally enter the Strait of Georgia (SoG) from April to June and many may remain and rear in the SoG until the fall. The juvenile trawl surveys are designed to sample juvenile salmon throughout the SoG during this first ocean summer and fall. In 2020, there were several changes to our surveys. Covid-19 resulted in the cancellation of our summer (June) survey. Our fall (September) survey was successfully completed but for the first time we were fishing from the new Canadian Coast Guard Ship (CCGS) Sir John Franklin. This vessel has the capacity to fish our gear with the parameters identified in the survey protocol. However, delays in gear testing and training resulted in the crew having to include this training during our survey. This included maintaining the gear at specified depths with required opening and speed. Additionally, our survey changed from using the Cantrawl 250 net to the LFS 7742 net. These nets have similar mouth opening and codend mesh sizes and comparison of the gear was completed in 2018 (Anderson et al. 2019). However, due to these changes, the 2020 results should be interpreted with caution. More detailed analysis will be completed after additional 2021 surveys with the new vessel.

In 2020, the standard survey area (standard track line) in the Strait of Georgia was fished using the protocols in Beamish et al. (2020) and Sweeting et al. (2003). Catch-per-unit-effort (CPUE) was calculated using trawl sets conducted on this standard track line in the main basin of the SoG (Canadian waters) and for specified habitat depths (Chinook Salmon 0-60 m, Coho Salmon 0-45 m, Pink, Chum and Sockeye Salmon 0-30 m) (Beamish et al. 2000; Sweeting et al. 2003). For the given sets, the total catch and area surveyed is used to calculate average catch per hour. In addition to catch, time series of average length of juvenile salmon included salmon < 350 mm in the September survey. This 23-year time series demonstrates that there are both interannual changes and longer term trends in the abundance, distribution, and condition of juvenile salmon rearing in the SoG.

40.3. Status and trends

In the fall of 2020, the CPUE of Coho Salmon was the fourth highest observed in the time series (Figure 40-1). Additionally, the size of the Coho Salmon was above average and followed the trend that has occurred since 2010. Chinook Salmon CPUE was the largest observed in the time series. Sockeye Salmon in the SoG in September are dominated by the ocean type Harrison stock. In 2020, the catch of these fish within the SoG remained low, similar to observations since 2015. In September, Chum and Pink Salmon have on average represented 50% of all juvenile salmon caught. However, in 2020 these two species represented only 20% of the salmon catch and the CPUE of Chum Salmon was the fourth lowest observed in the time series.

In addition to salmon, other species are captured in the survey. In 2020 there were some notable changes. Northern Anchovy that had been abundant over the last few years, were only caught in small numbers (< 100) and very few (<20) Spiny Dogfish were captured. Additionally, the observations of gelatinous species was lower than has been observed since 2014. Species encountered in greater frequency or abundance included small squid, Pacific sand lance and juvenile Walleye Pollock. Young of year Pacific Herring were observed in about 20% of the sets. The average fork length of these juveniles was smaller than the past few years (88 ± 8.3 mm).

40.4. Factors influencing trends

The size and condition of juvenile salmon, especially Coho Salmon, suggests good early marine growth within the SoG. Declines in the catch of Northern Anchovy, Spiny dogfish and gelatinous species and increased occurrence of Walleye pollock, Pacific sand lance and young-of-year herring compared to the last 3-4 years suggests a possible shift in the ecosystem of the Strait of Georgia, however, due to the change in vessel and gear, interpretations should be considered with caution.

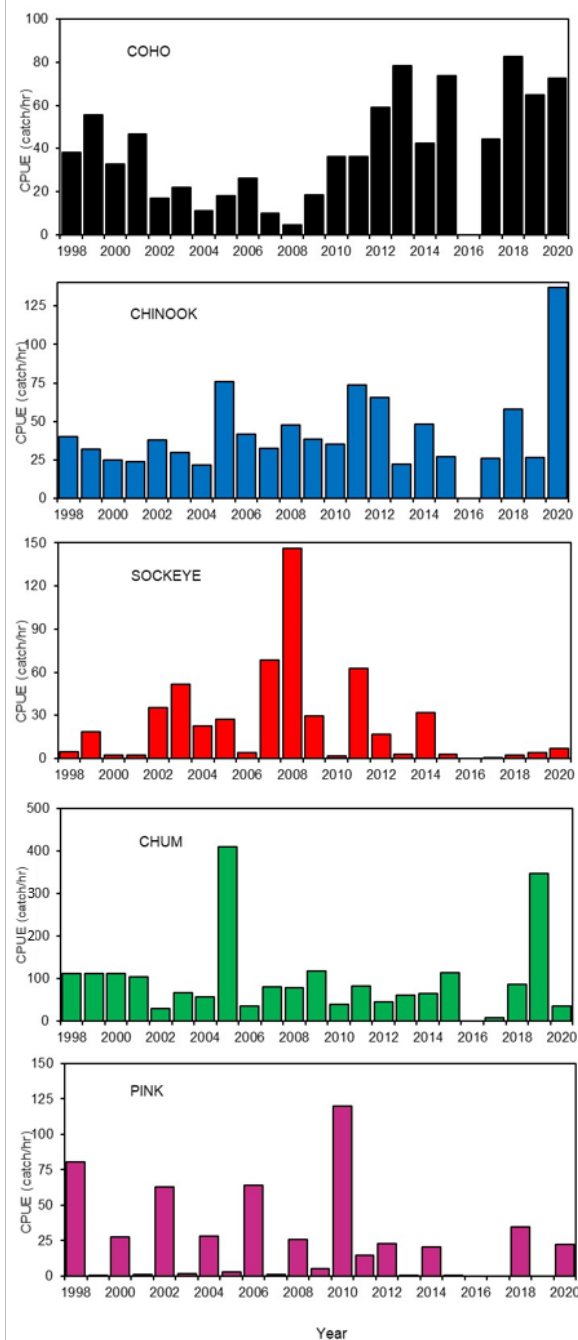


Figure 40-1. CPUE of juvenile salmon in fall, 1998-2020.

40.5. Implications of those trends.

Changes and trends observed in the catch rates, distribution and size of juvenile salmon in the SoG over time indicate that factors regulating these are not random. Several hypotheses suggest that growth and energy storage during the first marine summer are directly related to the ability of fish to survive their first marine winter and affect their total marine survival. A productivity shift in the SoG for Coho Salmon around 2010 resulted in increased CPUE and size of the juveniles by September (Beamish and Neville, in press). There is increased variability between the abundance of these juveniles in the fall and subsequent returns suggesting that conditions after the first marine winter may also have increased variability. Increases in catch of juvenile Chinook Salmon and declines in Chum Salmon require further research but the ability to understand the drivers of these changes and the implications to total marine survival may provide new tools to provide early forecasts early in the marine residence of these species.

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41. ADULT CHINOOK SALMON DIETS AS AN INDICATOR OF SPATIAL AND TEMPORAL VARIATION IN COASTAL FOOD WEBS

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41.1. Highlights

- Chinook Salmon stomach fullness in the Salish Sea was fairly stable from 2017-2020.
- The quantity of Pacific Herring in stomachs increased from 2017-2020.
- Northern Anchovy were more important from 2017-2018 than from 2019-2020.

41.2. Description of the time series

Predator diet sampling can provide insights into dynamics of lower trophic levels that may not be available through other research methods (Thayer et al. 2008) and can be a valuable complement to traditional fishery-independent surveys. Since 2017, the Adult Salmon Diet Program (ASDP) has been developed as a low-cost, citizen science-based program to sample adult Chinook and Coho Salmon diets throughout the year in British Columbia (Quindazzi et al. 2020). In the short term, the ASDP seeks to characterize spatial and seasonal variation in adult salmon diets and to determine if diets have changed since historical diet studies (the most recent published adult salmon diet data for British Columbia are from the 1960s; Beacham 1986). In the long term, the program will provide a novel perspective on variability and trends in forage fish communities and their implications for salmon trophic ecology.

Digestive tracts of Chinook and Coho Salmon captured in the public fishery were submitted by individual fishers or collected at fish cleaning stations or derbies. Samples were frozen with a catch card indicating species, capture location, capture date, adipose fin status (clipped or unclipped) and length and/or weight along with additional capture observations. Gravimetric diet compositions were determined in the lab.

Provisional indices of interannual changes in diet composition were developed using only Chinook Salmon samples from the Canadian Salish Sea as this was the only region for which samples were available in all years (2017-2020). The indices were based on mean “partial fullness scores” (Magnussen 2011) for each prey category. These scores were proportional to prey category weight divided by the cube of salmon length. To account for different seasonal and spatial distributions of samples between years, data were stratified into season by region groups. Seasons were defined as winter (October to March) and late summer (August to September). To prevent splitting the winter between calendar years, the months of October to December were considered part of the following calendar year. The April to July period was excluded from analysis as retention of Chinook Salmon was closed during this period in much of the sample region beginning in 2019. Regional groupings were based on a cluster analysis of a Bray-Curtis dissimilarity matrix of mean percent weight of prey categories in Pacific Fishery

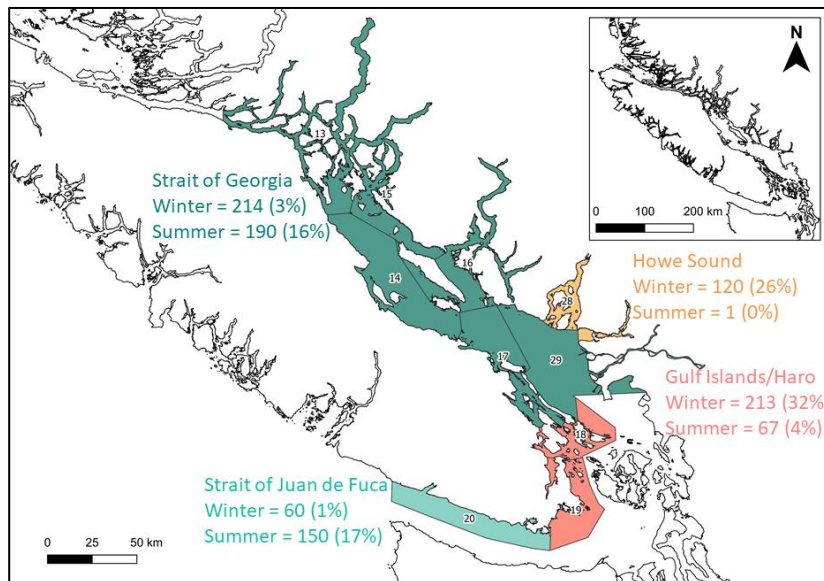


Figure 41-1. PFMA groupings for Chinook Salmon prey partial fullness indices. The total sample size available for each region and season combination is indicated with its weighting in the annual indices indicated in parentheses.

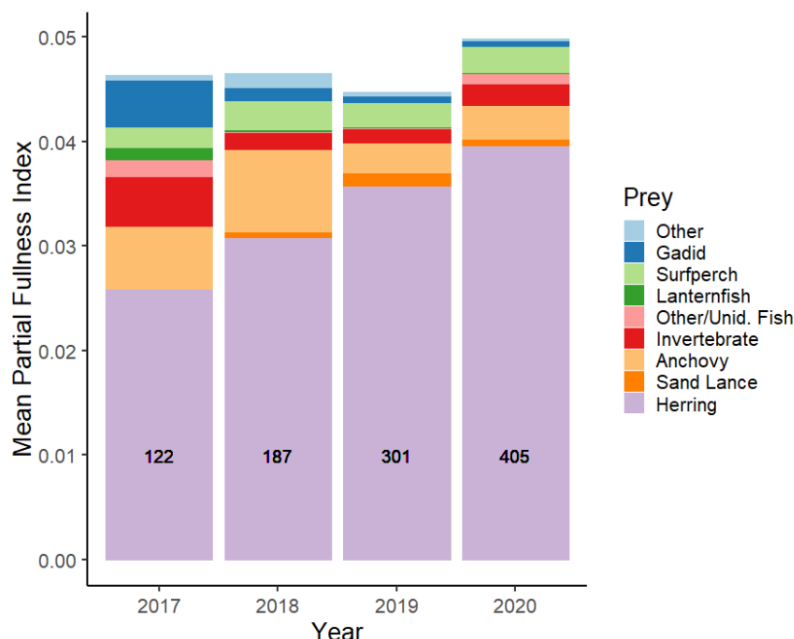


Figure 41-2. Mean prey group-specific partial fullness indices for Salish Sea Chinook Salmon stomachs from 2017-2020. Total sample size is overlaid and region by season weightings are provided in Figure 41-1.

Management Areas (PFMAs) within the Salish Sea from April to September. This approach resulted in identification of four regions (Figure 41-1). Pacific Herring overwhelmingly dominated diets in the Strait of Georgia and Strait of Juan de Fuca while Northern Anchovy were important in Howe Sound and Pacific Sand Lance were important in the Southern Gulf Islands and Haro Strait. This regionalization is provisional and its suitability for stratifying year-round data is currently being assessed. Partial fullness scores were calculated as weighted averages where region-by-season groupings were weighted based on their minimum sample size across years. Of the 2238 Chinook Salmon diet samples processed to date by the ASDP, 1014 were used for this time series.

41.3. Status and trends

Pacific Herring dominated Salish Sea Chinook salmon diets across years and increased in importance from 2017 to 2020 (Figure 41-2). Overall, stomach fullness was similar across years. Northern Anchovy were less than half as important in 2019 and 2020 than in the preceding two years. The low partial fullness values observed for Pacific

Sand Lance in this time series were likely a consequence of the omission of April to July data due to fisheries closures. These months are when most Sand Lance occur in diets. Interannual differences also varied among regions of the Salish Sea.

41.4. Factors influencing trends

With only four years of data, it is too early for meaningful trend analysis. As the time series develops, comparison to fishery independent data including Pacific Herring spawn surveys and age-0 abundance surveys will facilitate analysis of whether herring recruitment and spawning stock biomass regulates availability to Chinook Salmon. Northern Anchovy increased in abundance in the Salish Sea during the anomalously warm conditions of 2015 and 2016 (Duguid et al. 2019). It is possible that the decline in the importance of Anchovy in 2019 and 2020 reflects the end of this pulse of reproduction. A similar decline has been observed in the frequency of occurrence of anchovy in age-0 Pacific Herring surveys (Boldt et al. 2020). While we present spatially aggregated time series here, trends varied strongly among regions of the Salish Sea. Future analysis should occur at a sub basin level.

41.5. Implications of those trends

Changes in the partial fullness scores for different prey groups may reflect both changes in the abundance of that prey group and in the abundance of alternative prey. Given the importance of Pacific Herring to Chinook Salmon diets, one of the key questions is whether salmon would find adequate alternative prey should herring become less abundant. Recent spawning stock biomass of Pacific Herring in the Strait of Georgia has been above average (Cleary et al., Section 21) while age-0 herring abundance has been low but relatively stable (Boldt et al. 2020). Should an event, such as the Pacific Herring recruitment failure of 2007 occur, this adult Chinook Salmon diet index will provide valuable insights into the implications for higher trophic levels. As climate change results in expansions or contractions of the range or abundance of species such as Northern Anchovy (Duguid et al. 2019) this index will provide information on the importance of changes in food web composition.

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42. THE SAANICH INLET TRANSECT 2020: USING ROVS TO MONITOR THE VULNERABILITY OF BENTHIC BIODIVERSITY TO MARINE HEAT

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42.1. Highlights

- In Saanich Inlet, biologically-relevant hypoxia exposure could not be calculated for the second year in a row as a result of a two-month data gap in the ONC-VENUS time-series.
- The density of commercial shrimp (e.g. Spot Prawn *Pandalus platyceros*) remains at levels comparable to the benchmark period.
- A sustained population of the striped nudibranch *Armina californica* remains after being introduced during the 2016 hypoxia event.
- The Sea Whip (*Halipteris willemoesi*) population decreased after a brief period of recruitment. The population remains at <5% of their abundance numbers prior to the 2016 marine heatwave.

42.2. Description of the time series

This near-annual survey (except for 2014-2015) is the longest-running time-series in Canada designed to monitor benthic biodiversity using standardized remotely-operated vehicle (ROV) methods. Since 2006, ROVs with onboard CTD and dissolved oxygen (DO) sensors, and high-definition cameras have repeated the same benthic transect (n=17) in Patricia Bay, Saanich Inlet, B.C. (Chu and Tunnicliffe 2015; Gasbarro et al. 2019). The transect begins in the deep basin and transitions through zones of low-to-high oxygen over a gradual soft-bottom slope from 180 to 40 m bottom depths. This survey generates imagery-based, soft-bottom epifaunal abundance data with concomitant measurements of oxygen occupancy made at 1 m above the seabed.

Ocean Network Canada's (ONC) VENUS cabled observatory (96 m depth) has also measured DO at one-minute or finer intervals since 2006. The stationary VENUS instrument platform (VIP) is stationed at approximately the mid-way point along the transect. Seasonal variability in the spatial oxygen gradient and the species assemblage has been assessed at this site with ROV surveys in the Spring, Summer, and Fall of 2013 (Chu and Tunnicliffe 2015) and 2016 (Gasbarro et al. 2019), Spring 2017, Fall 2018, and Spring 2019. Data integrity of this time-series has been maintained with standardized protocols adapted for use on four different ROV platforms that have been used throughout this time-series (Chu et al. 2020).

Hypoxia has been validated with ecophysiological experiments and oxygen occupancy of several key species at this site (vary from 0.3-1.1 ml L⁻¹) which allows for direct comparisons of hypoxia-induced shifts in their distributions over time (Chu and Tunnicliffe 2015; Chu and Gale 2017). Among the 55 species historically documented in this survey, we use the Slender Sole (*Lyopsetta exilis*) and Squat Lobster (*Munida quadrispina*) as indicator species of the hypoxia-tolerant community, Spot Prawn (*Pandalus platyceros*) as an indicator of the hypoxia-sensitive community, and the Sea Whip (*Halipteris willemoesi*), a cold-water coral, as an indicator of the sessile community (Chu and Tunnicliffe 2015). We also report on two additional species, the Striped Nudibranch *Armina californica* and the White Sea Cucumber *Pentamera* cf.

pseudocalcigera. Both species were not observed in this system prior to 2016 but established populations after a notable marine heatwave created anomalous conditions of severe warming

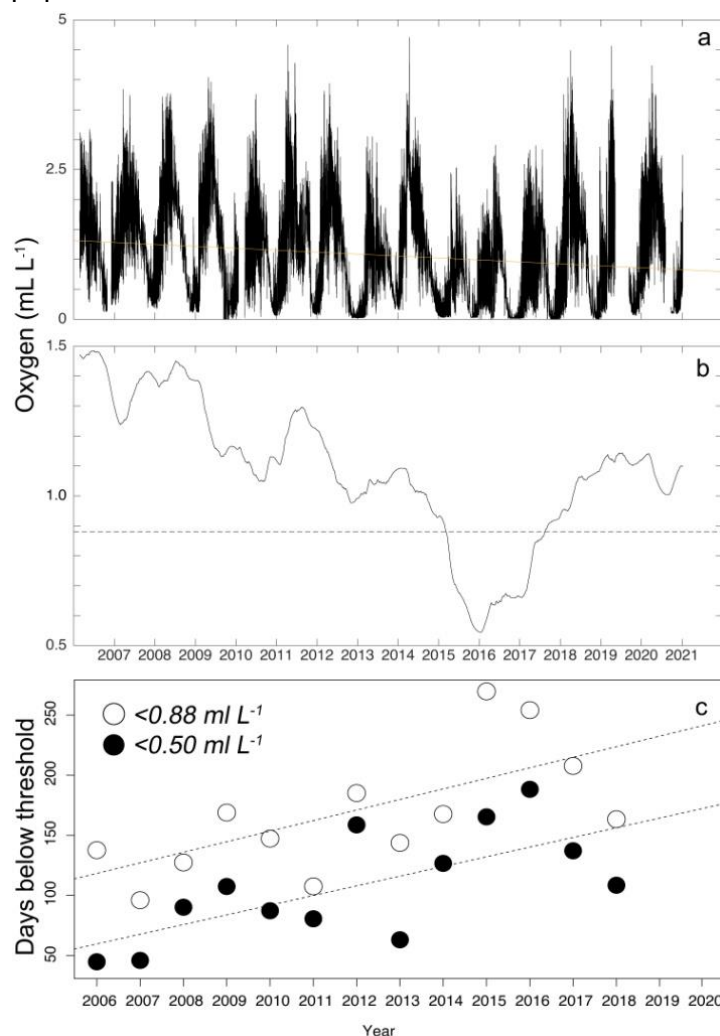


Figure 42-1. The 15-year continuous ONC-VENUS dissolved oxygen (DO) records measured per-minute at 96 m in Patricia Bay, Saanich Inlet. (a) Long-term DO decline (linear trend). (b) One-year running mean of panel-a. Dashed line is the 0.88 ml L⁻¹ East Pacific hypoxia threshold. (c) The cumulative annual days below hypoxia thresholds. Dashed line indicates hypoxia duration trend from 2006-2018. Points for 2019 and 2020 could not be calculated because of the data gaps in the ONC-VENUS records.

and hypoxia in 2016. While multiple co-occurring climate stressors can drive change in marine biodiversity, the severe hypoxia was the primary driver of concomitant shifts in community structure and function in the Saanich system (Gasbarro et al. 2019).

42.3. Status and trends

A two-month data gap (between August to September) in the 2020 ONC-VENUS records prevented the annual hypoxia exposure metrics from being calculated for the second year in a row. We qualitatively report on trends while considering the potential effect of the recent data gap in the records. As of January 2021, the annual rate of oxygen decline was -0.03 ml L⁻¹ year⁻¹ (Figure 42-1a). While this is an improvement over the -0.05 ml L⁻¹ rate reported since 2018, this rate is now influenced by the substantial data gaps that have occurred since 2019 where the missing data are from the seasonal low-oxygen period of the year.

Following the sustained period of hypoxia from 2015-2017, seafloor oxygen levels in Saanich Inlet have continued to measure above the 0.88 mL L⁻¹ hypoxia threshold (Figure 42-1b) which have coincided with population-level recovery trajectories for several of the indicator taxa. However, from 2006 to 2018, the

annual duration of hypoxia at this site has been increasing (Figure 42-1c). The number of days ONC-VENUS has measured oxygen conditions below the 0.88 ml L^{-1} and the 0.5 ml L^{-1} severe hypoxia thresholds has increased by a respective 9 and 8 days year⁻¹. We are unable to update this annual hypoxia exposure trend for 2020 because of the data gaps.

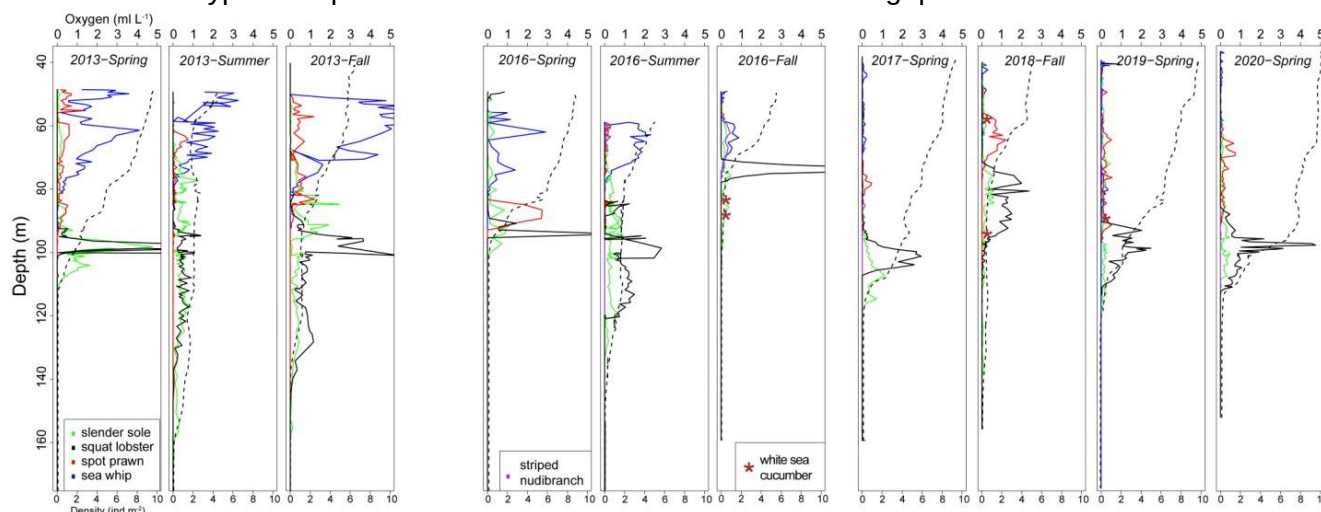


Figure 42-2. Surveys of key species depth-based densities in Patricia Bay, Saanich Inlet relative to DO gradient (dashed line) in 2013 (n=3), 2016 (n=3), 2017 (n=1), 2018 (n=1), 2019 (n=1). No surveys were conducted in 2014-2015. Earlier surveys (2006-2012) are not presented but are published in Chu and Tunnicliffe (2015).

A marked hypoxia-induced shift in the species assemblage occurred in Fall 2016, following the onset of a notable period of sustained oxygen deficiency from 2015 to 2017 (Gasbarro 2017; Chu et al. 2018; Gasbarro et al. 2019). Most notable were the absence in Fall 2016 of Spot Prawn and other commercial shrimp species (*P. jordani* and *P. hypsinotus*), the decline in Sea Whips and generally low populations of other epifauna (Gasbarro et al. 2019), and the occurrence of two 'new species' (the Striped Nudibranch *Armina californica* and the White Sea Cucumber *Pentamera cf. pseudocalcigera*) not observed in this system prior to 2016 (Gasbarro et al. 2019). Surveys since the 2016 marine heatwave have monitored the recovery trajectory of the species assemblage.

In 2020, hypoxia-tolerant species (Slender Sole and Squat Lobster), and spot prawn had distributions, abundance, and densities that were typical of patterns observed prior to the hypoxia-induced community disassembly in 2016 (Figure 42-2 and 42-3). The White Sea Cucumber was absent while the Striped Nudibranch population persists. The Sea Whip appears to have been the species most vulnerable to the severe hypoxia event as the total population remains low. With only n=75 sea whips observed in 2020, the population appears to have declined again after a brief period of juvenile recruitment occurring last year. Few juveniles were present in the survey this year indicating the recruitment event last year did not contribute to long-term recovery potential of the Sea Whip. The Sea Whip population remains at <5% of the benchmark period abundance numbers.

42.4. Implications of these trends

Based on distribution, total abundance, and average density, most populations of mobile fauna have recovered from the severe hypoxia event after 3 years of habitat conditions where the

ONC-VENUS VIP oxygen measured above the 0.88 ml L⁻¹ East Pacific hypoxia threshold.

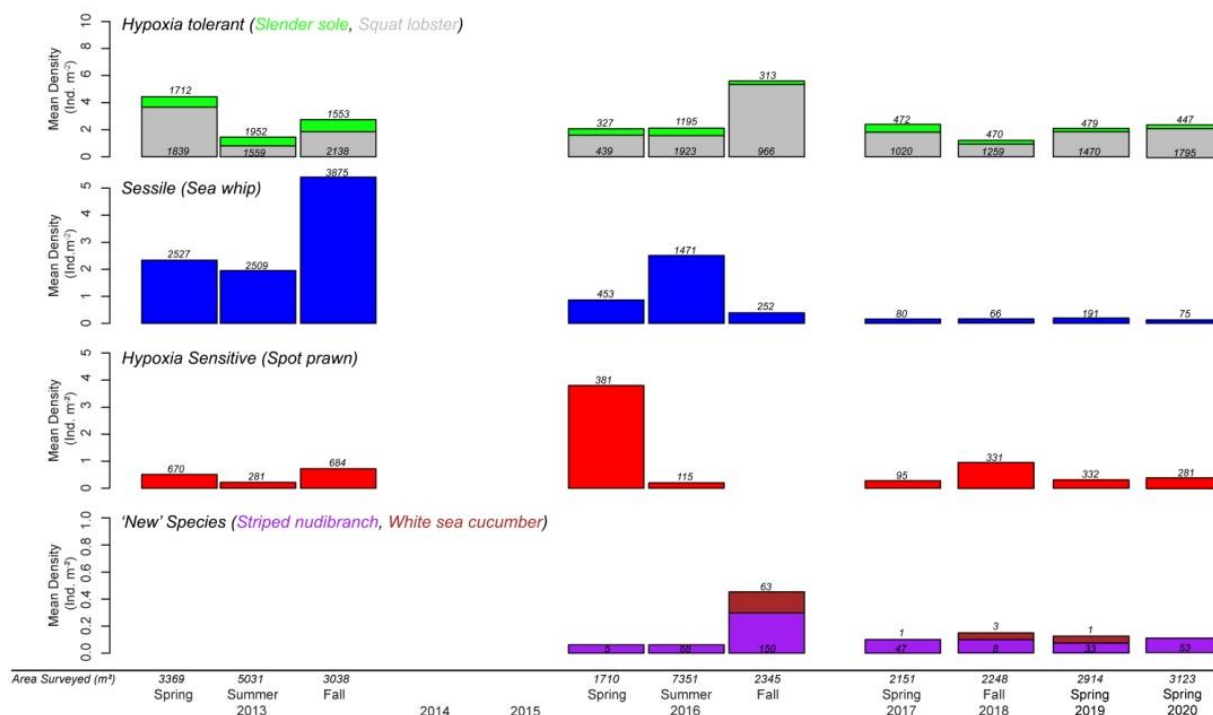


Figure 42-3. Average densities per survey for each key species presented. Total counts are indicated on each bar. Total area surveyed (m²) for each year is indicated on the x-axis. Differences in area surveyed among years is primarily attributable to truncation of the deeper portion of the transect and varying field performance among different ROV platforms. No surveys were performed in 2014-2015. 'New species' (Striped nudibranch, White Sea Cucumber) are taxa that were absent from 2006-2013 benchmark period. Average densities were calculated from abundances occurring in 20 m² sections along each transect where species occurred. Earlier surveys (2006-2012) are not presented but are published in Chu and Tunnicliffe (2015).

Brief recruitment events do not appear to lead to a sustained recovery trajectory in the sea whip population. This is evident in the sudden decline in the population numbers from 2019-2020 (191 to 75 individuals) as a result of juvenile Sea Whip having not survived past year 1. The increase in the striped nudibranch population, which is now also the primary predator of Sea Whip in this system, suggests the added predation pressure is now working antagonistically against population-level recovery. The sustained, low-numbers in the sea whip population, their population-level sensitivity to hypoxia, and the increasing hypoxia exposure trend indicates cold-water corals may be one of the major "climate change losers" among benthic taxa occurring in this region. In Canada, this time-series remains as the only benthic, ROV-based monitoring program that has empirically linked climate stressor variability with community-level responses.

42.5. Acknowledgements

We thank ONC for donating ship time and taking the initiative to continue this time-series with the use of the ROV *Oceanic Explorer* in March 2020. We are additionally grateful to the

captain and crew of the CCGS JP Tully, the ROV team, and staff at ONC and DFO for logistics and field expertise. All contribute towards making the continuation of this informative time-series possible.

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43. ONGOING RANGE EXPANSIONS OF INVASIVE MARINE INVERTEBRATES IN THE PACIFIC REGION

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43.1. Highlights

- Marine Aquatic Invasive Species (AIS) continue to spread in B.C.
- European Green Crab (*Carcinus maenas*) was detected for the first time on Haida Gwaii in July 2020.
- Early detection of AIS can inform management and policy.
- Preventing the spread of AIS requires management of anthropogenic pathways and vectors.

43.2. Description of indices - Monitoring Aquatic Invasive Species in Pacific Region

Marine Aquatic Invasive Species (AIS) are increasingly common throughout British Columbia. Two long-term monitoring programs are reported on here: the Settlement Plate Program, which monitors fouling AIS province-wide, and the European Green Crab Trapping Program, which targets the invasive European Green Crab (*Carcinus maenas*) (Figure 43-1). These monitoring programs have improved our understanding of the role of anthropogenic pathways, aided early detection and rapid response efforts, and resulted in productive partnerships with First Nations and stakeholders.

43.2.1. Settlement Plate Program

Since 2014, the standardized method for monitoring fouling AIS in BC has been weighted PVC plates (14 cm²) deployed from floating docks. Plates are analyzed for both the presence/absence and abundance of AIS. Because this method detects fouling species most likely to establish in the upper water column and on anthropogenic structures, it is an effective method for understanding the risk of spread of fouling AIS by small vessels (Clarke Murray et al. 2011) and static structures like floating fishing lodges and docks (Iacarella et al. 2019).

43.2.2. European Green Crab Trapping Program

Green crabs have been monitored in BC since 2006, eight years after their introduction from the United States via natural larval dispersal (Gillespie et al. 2007). Because Green Crabs are an intertidal species, they are trapped at or above chart datum using baited Fukui fish traps.

The dataset generated by the trapping program has been useful for understanding the ongoing spread of Green Crab throughout coastal British Columbia, and has been the basis for species distribution modelling and genetic studies. Moreover, the program has led to the early detection and targeted eradication of Green Crabs in new areas, including the Salish Sea and Haida Gwaii.

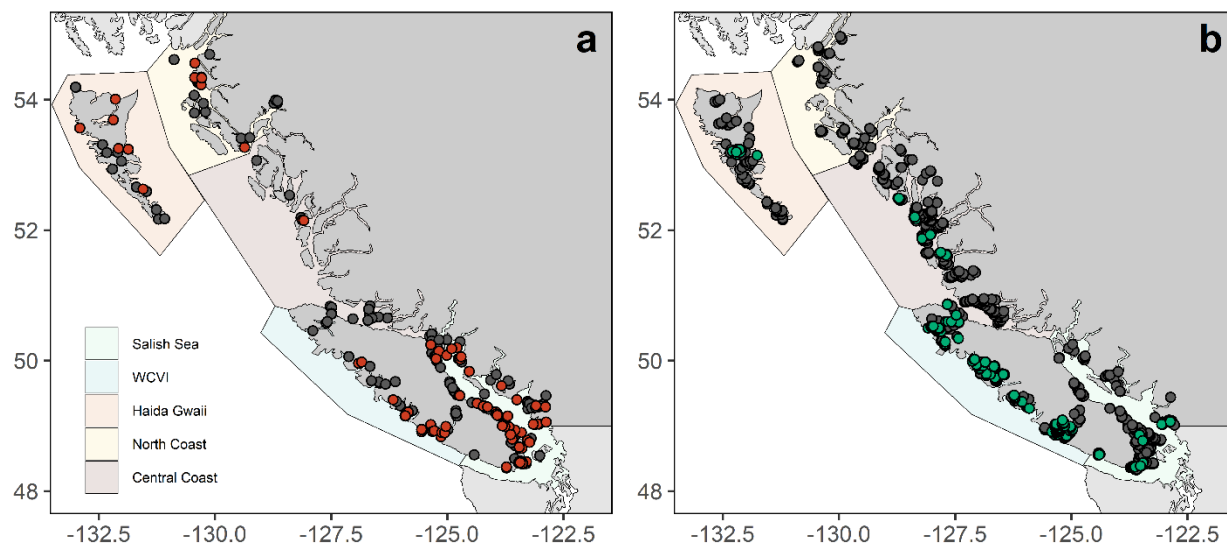


Figure 43-1. a) All settlement plate deployment sites between 2006 and 2020. To demonstrate the range of some species of interest, points indicate whether invasive colonial tunicates (*B. violaceus* and *B. schlosseri*) have been detected (red) or not detected (black). b) All locations trapped for European Green Crab by DFO or partners between 2006 and 2020. Points show whether Green Crab has been detected (green) or not detected (black). Shaded polygons indicate generalized geographical areas used to describe trends in AIS spread and abundance.

43.3. Status and Trends - Upward trend in AIS spread and abundance

Changes in the observed abundance of fouling AIS on settlement plates is species and area-specific (Figure 43-2). No new species of fouling AIS were detected in BC in 2020, but several range expansions of known AIS were observed. This was the first year that *Diplosoma listerianum* was detected in Masset, although the species is abundant in other parts of Haida Gwaii. In the Prince Rupert area, both *Botrylloides violaceus* and *Botryllus schlosseri* continued to spread to new sites since their initial detection in 2018. *D. listerianum*, *B. violaceus*, and *B. schlosseri* also demonstrated local range expansions throughout the Salish Sea. Finally, the invasive tunicate *Ascidia zara* was detected for the first time in the Salish Sea, specifically Ladysmith, having previously only been known from sites in Prince Rupert.

Although the invasion of European Green Crab has been largely restricted to the West Coast of Vancouver Island until recently (Figure 43-3a), the species' thermal and salinity tolerances suggest it can survive along much of the coast. This was confirmed with the first detection of Green Crab on Haida Gwaii, in the summer of 2020 (Figure 43-1b). While the catch per unit effort (CPUE) of Green Crab in both the Salish Sea and Haida Gwaii remain low (Figure 43-3b), CPUEs on the West Coast of Vancouver Island demonstrate the potential for this species to become hyper-abundant under favourable conditions (Figure 43-3a).

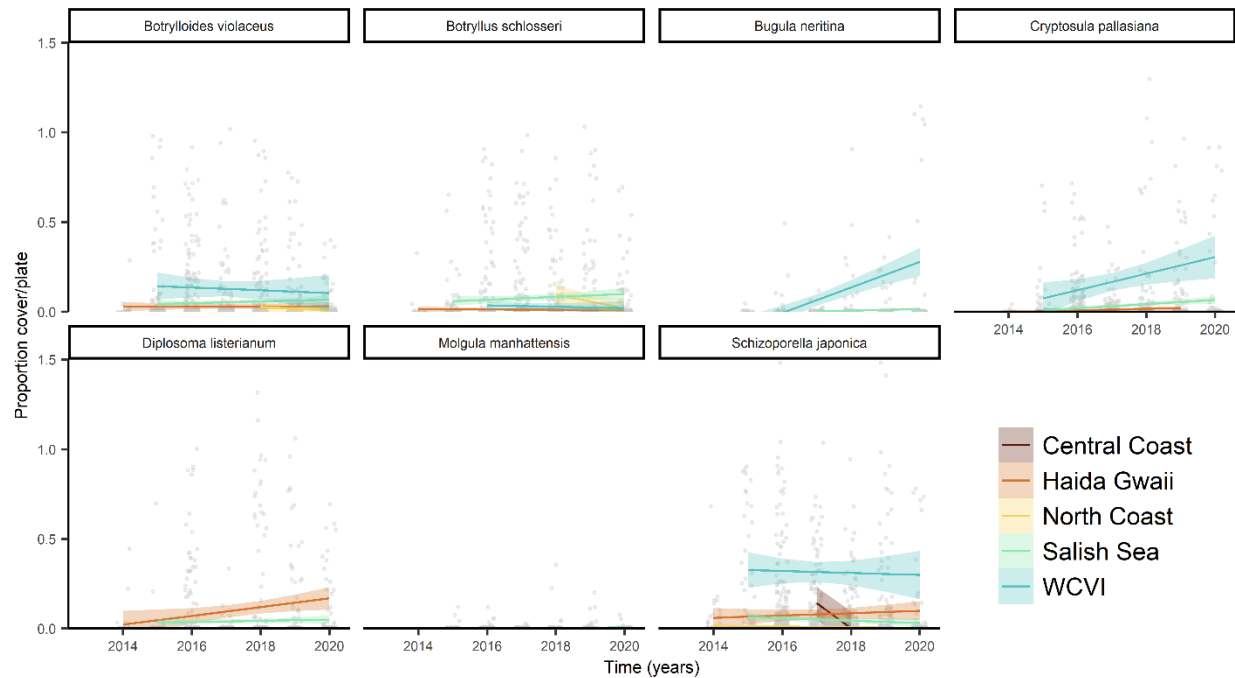


Figure 43-2. Change in abundance of some AIS found on settlement plates in each of five areas, presented as the smoothed conditional mean of the proportion of the plates covered ($\pm 95\%$ CI), by each species, per area. Grey points are proportion AIS cover for individual plates (raw data). Proportions can be greater than 1.0 due to species growing in layers, such that more than one occurrence of AIS may be recorded per point.

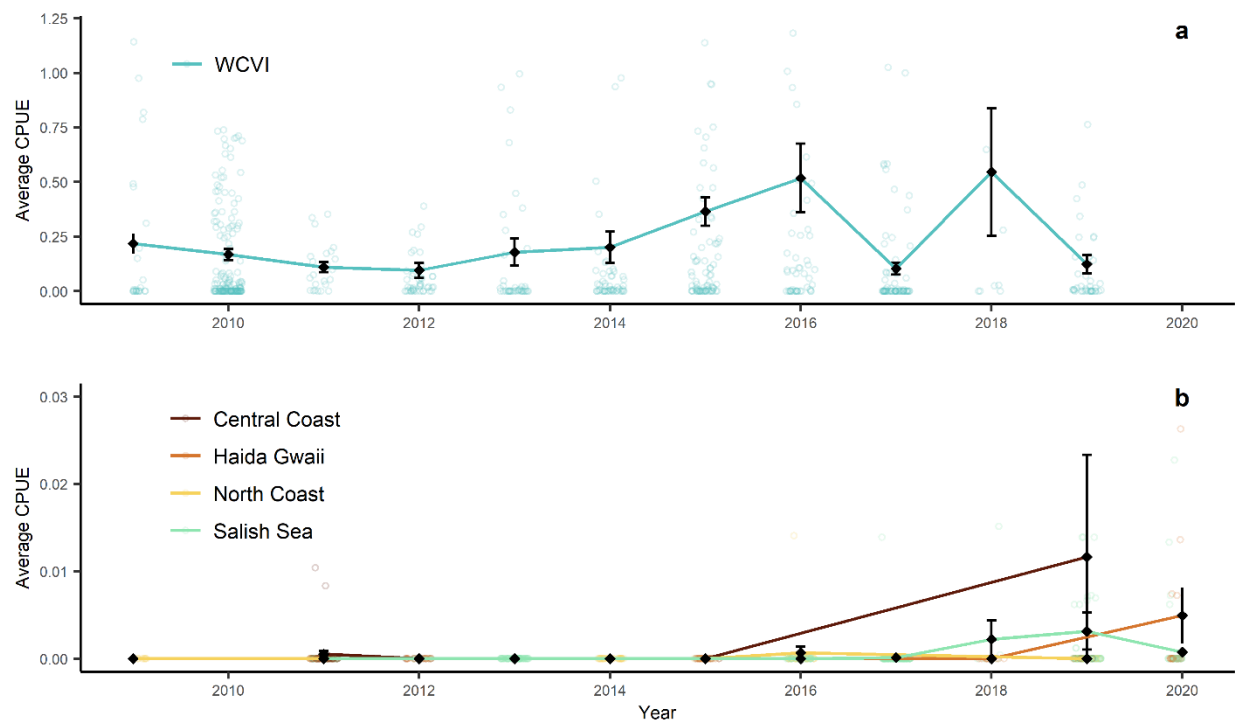


Figure 43-3. Annual average CPUE for European Green Crabs ($\pm$ SE) for all traps set on a) the West Coast of Vancouver Island and b) four other areas of the coast (note scale differences). Coloured points indicate individual trapping events within each area. All raw data are plotted, but most CPUEs are too small for points to be visible.

43.4. Factors influencing spread and abundance of AIS

In BC, climate change is likely to permit the survival of AIS currently restricted to more southern locations, and periods of significant warming will facilitate population spikes and natural long-range larval dispersal events for AIS (Gillespie et al. 2007; Brasseale et al. 2019). Concerns about the potential for northward spread of AIS in the Pacific Region was validated in 2020 with the detection of invasive European Green Crab in Skidegate Inlet, Haida Gwaii. The potential for additional anthropogenic spread of AIS via infested vessels, structures, and equipment will continue to be a primary vector for both existing (known) and novel AIS in BC.

43.5. Implications of AIS range expansions in the Pacific Region

The potential for localized, anthropogenic spread of AIS combined with increasing abundance means AIS will continue to have greater impacts on native species, ecosystems, and industry. Expanded AIS Regulations in the *Fisheries Act* and new management plans for high risk AIS are being developed.

The Settlement Plate Program has been a useful proxy for tracking dispersal of fouling AIS and has led to increased public awareness of these species. By engaging with the public and focusing management on key vectors, there is a better chance of reducing spread of both established AIS and newly introduced or undetected ones whose impacts are not yet known.

European Green Crab are known to have significant negative impacts on bivalve populations, especially clams, and on eelgrass habitats (Howard et al. 2019). The trend in increasing abundance and spread of this species has resulted in the Salish Sea Transboundary Action Plan for Invasive European Green Crab (Drinkwin et al. 2019), a joint management plan between DFO and Washington State partners, and a dedicated early detection and eradication program for Green Crab managed by the Fish and Fish Habitat Protection Program (FFHPP). However, the arrival of Green Crab on Haida Gwaii has highlighted the need for similar multi-agency management plans for other parts of BC, including transboundary areas like Alaska, in order to limit the ecosystem impacts of this invader.

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44. RECENT TRENDS IN MARINE TRAFFIC AND ASSOCIATED THREATS IN THE SALISH SEA BASED ON AUTOMATIC IDENTIFICATION SYSTEM FOR SHIPS (AIS) AND NOVEL TRAFFIC DATA COLLECTION TECHNIQUES

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44.1. Highlights

- Marine vessel traffic intensity increased in the Salish Sea from 2015-2017 for nearly all types of vessels based on data collected using the Automatic Identification System for ships (AIS).
- There is evidence of increasing intensity for recreational and other vessels not required to carry and broadcast AIS, but these categories were under-represented.
- Trends and associated stressors estimated based on AIS data and interpretations of these estimates should take into account the under-representation for some types of vessels in AIS data.

44.2. Introduction

Documenting and understanding spatial and temporal variability in marine vessel traffic patterns is fundamental for the conservation of marine species and important habitats upon which they depend. There are a number of threats or stressors associated with marine vessel movements including oily discharges (Fox et al. 2016), noise pollution (Williams et al. 2015), disturbance (Bejder et al. 2006), interactions with fisheries (Fox et al. in press), introduced species (Herborg et al. 2009), and ship-strikes (Williams and O'Hara 2010; Nichol et al. 2017). Increasingly, research and conservation efforts depend on Automatic Identification System (AIS) for ships to monitor vessel movements and collect data for assessing threats associated with marine vessels. Although AIS is very useful and a welcome source of information for marine vessel associated stressors that were very difficult to quantify previously, AIS was designed primarily for maritime safety and it can be challenging to base threat models and develop conservation-oriented policy entirely on data collected by AIS. For example, because not all vessel operators are obligated to carry and broadcast AIS, not all vessel types are equally well represented by data collected using AIS. As well, AIS data are typically collected using satellite-borne (s-AIS) and terrestrial-based (t-AIS) receivers, which have their own particular strengths and weaknesses in terms of spatial and temporal coverage. To address these short-comings, there are other sources of information on marine vessel traffic that should be considered (for a

comprehensive review see Iacarella et al. 2020) depending on objectives of the analyses based on these marine traffic data. Access to both s-AIS and t-AIS can be challenging and expensive, and recently acquired access to both data sources will allow us to update completely our trend analysis by next year.

Here we report on trends in marine vessel traffic in the Salish Sea based on data collected using s-AIS receivers and a receiver mounted on the National Aerial Surveillance Program (NASP of Transport Canada) aircraft. We also present preliminary analyses based on complementary traffic data collected using an autonomous AIS-camera system (AACS). The AACS are remotely controlled systems that couple imagery taken with AIS data collected in situ (i.e., an integrated AIS receiver), and are described by Le Baron (2021). AACS data are collected continuously but are limited spatially, and allow us to compare AIS monitoring with optical imagery of vessel traffic to estimate the proportion of vessels not included in AIS data. Our system overlooking Boundary Pass was first installed in 2016 and is currently operational. We will have a fully updated analyses completed by early next year, including a trend analysis.

44.3. Marine Vessel Annual Trends

We used data collection using the AACS overlooking Boundary Pass (from a location on East Point, Saturna Island, B.C.) to estimate the proportion of vessels captured by AIS by vessel category and season. Unsurprisingly, AIS was almost perfectly representative of Cargo, Tanker, and Tug vessels (Ferries do not pass through Boundary Pass), which are the categories of vessels required to carry AIS Class-A. However, fishing vessels (both commercial and sport) and other recreational vessels (motorboats and sailing vessels) were under-represented by as much as 90% in AIS data captured in situ. Further, vessels in these categories that do carry AIS tend to broadcast using AIS Class-B, which is transmitted by transponders with lower wattage, and is given lower priority by AIS systems with overloaded receivers (O'Hara MS, in prep). This is important for interpreting the following trends based entirely on AIS data.

There has been an increase in s-AIS captured traffic throughout the Salish Sea between and including 2013-2016 (Figure 44-1). Analyses based on traffic data collected in Boundary and Active Passes (McWhinnie et al. 2021), two important navigational pathways in the Salish Sea, indicate that the biggest increases occurred for passenger vessels (primarily BC Ferries vessel passages) in Active Pass, and Cargo vessels in Boundary Pass. Furthermore, there were significant increases in traffic (refer to McWhinnie et al. 2021 for statistics) over the years in all categories except for ferries and recreational/tour vessels in Boundary Pass and recreational/tour vessels in Active Pass. These trends are consistent with trends based on AIS data collected using NASP aircraft-based receivers, with some interesting differences (Serra-Sogas et al. 2019; Figure 44-2). Numbers of vessels detected per NASP flight broadcasting AIS Class-A in the Salish Sea increased from 2015-2017. As mentioned earlier, vessels broadcasting this AIS class include Cargo, Tankers, Tugs and Ferries. Increased detection rates by NASP for Class-A are most likely caused by increases in traffic intensity, and not as a result of increases in implementation of AIS or because of improvements to AIS receivers (the receiver on the aircraft was the same throughout this period of time). Implementation and broadcast of AIS Class-B is voluntary and an increasing number of commercial fishers and

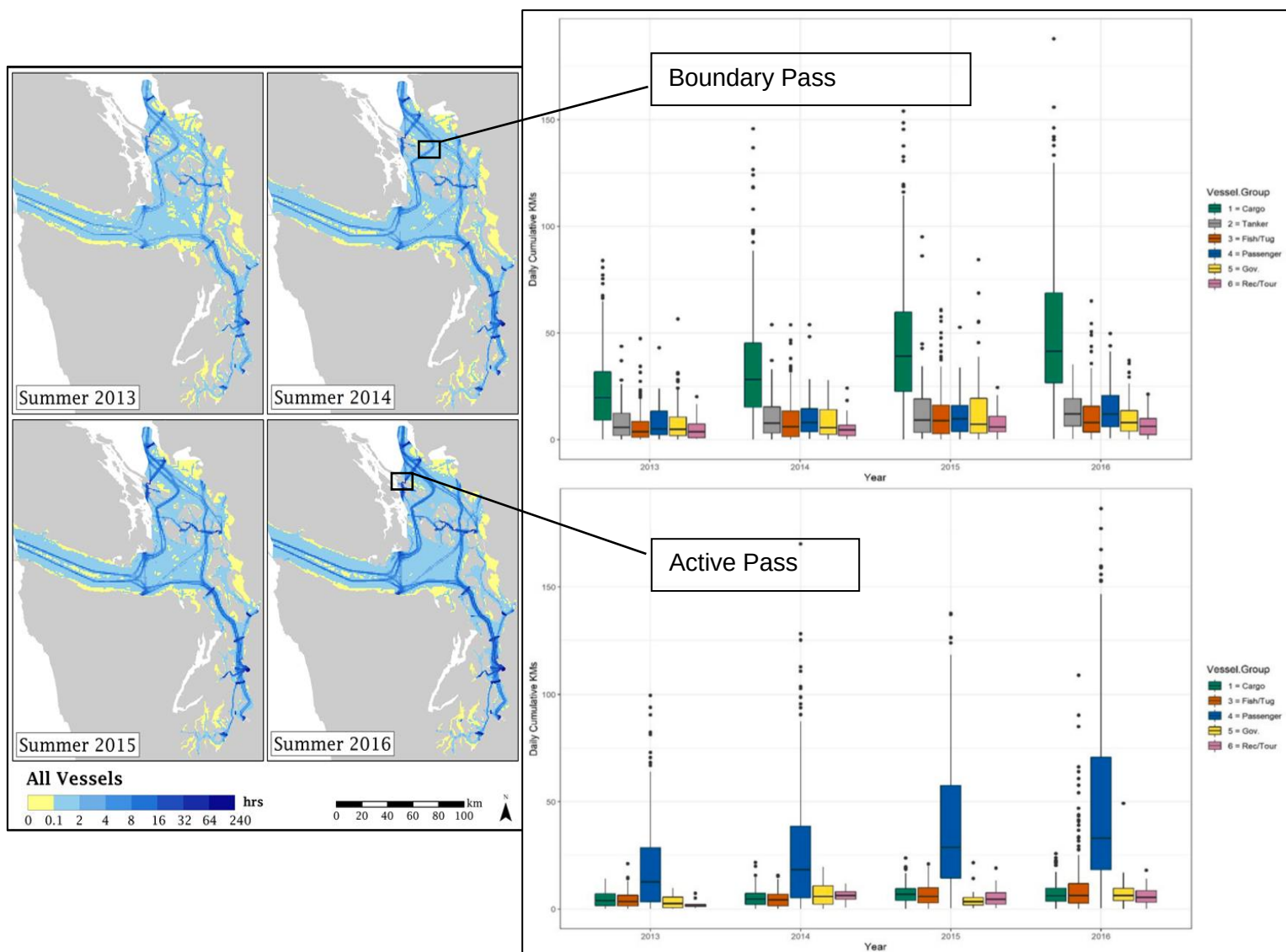


Figure 44-1. General annual trends in marine vessel traffic throughout the Salish Sea (left panel), and vessel category specific trends in Boundary and Active Passes (right panel), based on s-AIS. All vessel categories increased from 2013 to 2016 inclusive, except for ferry and recreational/tour vessels in Boundary Pass and recreational/tour vessels in Active Pass. (see McWhinnie et al. 2021 for details).

recreational boaters are opting to broadcast Class-B. Increased AIS Class-B detections and improvements to AIS in general increased capabilities of handling the lower priority weaker Class-B signals.

We are currently finalizing data collection from the AACS overlooking Boundary Pass, and we will have trends for all vessel categories based on both in situ AIS as well vessel data pulled from the optical imagery. These data will be used to compare with trends such as those based on s-AIS and NASP-based AIS, with a particular emphasis on recreational vessels not obligated to broadcast AIS. It is likely that recreational vessel traffic has been increasing at much higher rate than implied by AIS data alone.

44.4. Implications of those trends

Larger vessels such as Cargo, Tanker, Ferries, Passenger (including both Cruise and B.C. Ferry vessels) are well represented by AIS, and movement patterns can have important implications with associated threats and stressors particularly for Southern Resident Killer Whales (SRKW) and larger whale species such as the Humpback Whale, whose numbers have been increasing in this region. Increased intensity of these vessels likely results in increased exposure to noise pollution, oily discharges, disturbance, and ship-strike. Ship-strike is one the biggest threats challenging conservation of large whale species (see Williams and O'Hara 2010; Nichol et al. 2017) and a recent study has shown that it is also a threat for Southern Resident Killer Whales as well (Raverty et al. 2020). Fishery interaction also has been identified as a major challenge for SRKW conservation (https://www.sararegistry.gc.ca/document/doc1341a/p2_e.cfm#s2_2_2). However, fishery activity is poorly captured by AIS, requiring complementary measures such as access to fishing log entries (data maintained by DFO – see Fox et al. in press), Vessel Monitoring System data, or optical based systems such as those developed by us (NASP based and/or AACs). Fishery interaction is also important for many marine bird species resulting in incidental take (e.g. Fox et al. in press) and competition (Furness et al. 2000).

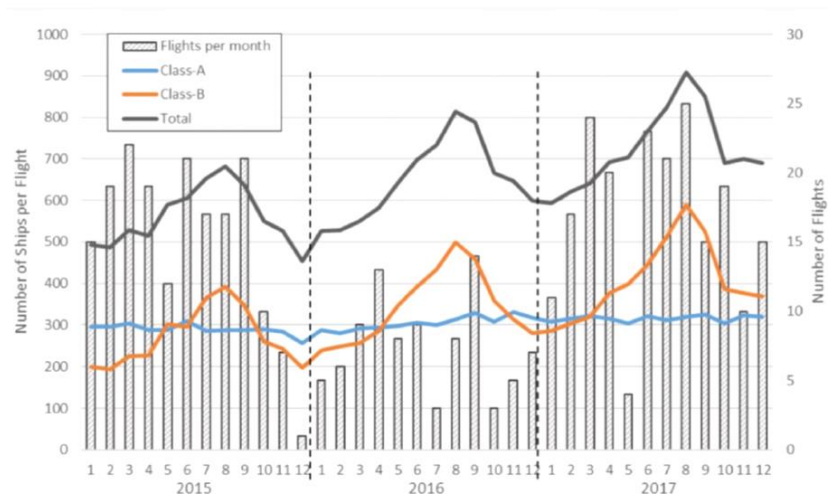


Figure 44-2. Vessels detected per NASP flight per month from 2015-2017, for vessels broadcasting AIS Class-A and Class-B.

Oily discharges associated with marine traffic is an important conservation challenge particularly for marine birds, however; it is highly likely that discharges associated with recreational boating activity is a major source of oil pollution particularly in coastal regions of B.C. (Bertazzon et al. 2014; Berry et al. 2018; NRC 2003). As well, recent studies have shown that noise from small vessel traffic can dominate noise-scapes, particularly in shallow water ecosystems (Hermannsen et al. 2019). Growing and compelling evidence indicate that fish can be impacted by noise both from larger and smaller vessels, among other anthropogenic sources of noise (Duarte et al. 2021) and this can lead to impacts at higher trophic levels. For these reasons, it is important to integrate monitoring systems that are complementary to AIS, such as those utilized in our studies, to complete the marine vessel traffic picture and comprehensively estimate potential impacts on marine species and habitats important to them.

44.5. Acknowledgements

We would like to thank Leh Smallshaw, Gregory O'Hagan, and Nicole Le Baron for python script development, data processing and analyses, and GIS layers based on these layers and analyses; Dr Rosaline Canessa, the Coastal and Ocean Resource Analysis Lab (CORAL) of the University of Victoria, Institute of Ocean Sciences, and the Canadian Wildlife Service for in-kind

support; Saturna Island Marine Research and Education Society for in-kind support; and, funding support as well as access to ExactEarth AIS data from the Marine Environmental Observation, Prediction and Response Network (MEOPAR).

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Appendix 1 - Poster Abstracts

45. ONGOING MONITORING OF THE NORTHEAST PACIFIC USING SATELLITE CHLOROPHYLL-A AND SEA SURFACE TEMPERATURE

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Satellite oceanographic datasets are integral for monitoring long-term, large-scale oceanographic events. In recent years, satellite-based measurements of sea surface temperature (SST) have been essential for monitoring anomalously high temperatures in the Northeast Pacific. Chlorophyll-a (Chla) estimates from optical satellite sensors make it possible to observe and quantify phytoplankton biomass at the synoptic scale. SST and Chl-a satellite measurements have been validated for the Canadian Pacific region in recent studies (see Clay et al. 2019; Devred et al. 2021; and for Strait of Georgia see Carswell et al. 2017). To improve monitoring capabilities and access to remote sensing data, we present here multiple datasets building upon this research currently undergoing publication (Table 45-1).

Table 45-1. Datasets published in 2020-2021 and currently in process. Underlined titles indicate datasets currently available online. Currently, all data is available at 4km spatial pixel resolution. All spatial datasets will also be provided at 1km spatial pixel resolution in the near future.

	Region of Coverage	Availability	Time Period	Parameters
Chl-a Time series	Areas of Interest (Figure 45-1)	Public (to be published in OpenData)	2003-2021	Monthly mean Seasonal trends Daily cumulative Chl-a
SST Time series (night)	Areas of Interest (Figure 45-1)	Public (to be published in OpenData)	1981-2020	Monthly mean (night) Seasonal trends
Monthly Chl-a Climatology	Canadian Pacific Exclusive Economic Zone	Public (currently publishing in OpenData)	2003-2020 Excluding January and December	Geometric mean Geometric standard deviation factor Number of valid pixels
Monthly SST Climatology (night)	Canadian Pacific Exclusive Economic Zone	Public (currently publishing in OpenData)	1981-2010 1990-2020	Mean (night) Standard deviation Number of valid pixels
<u>Phytofit application</u>	Canadian Pacific and Atlantic Regions	https://github.com/BIORSG/PhytoFit/blob/master/USERGUIDE.md	2003-2020	Daily and 8-day Chl-a composites Bloom-fitting algorithms

Satellite Chl-a and night SST time series of multiple Marine Protected Areas and other regions of interest have been summarized in a recent report (Devred et al., 2021), utilizing the Advanced Very-High-Resolution Radiometer (AVHRR) Pathfinder record available from NOAA

and standard Chl-a data products available from NASA. In the near future we will provide time series for regions and stations shown in the Canadian Pacific region (Figure 45-1) and these will be updated quarterly. Accompanying monthly climatology maps for these parameters in the Canadian Pacific Exclusive Economic Zone at 4 km and 1 km spatial resolution are being published in the OpenData catalogue. Further, to address the differing performance of satellite Chl-a algorithms in coastal and open-ocean waters, satellite Chl-a datasets processed with alternative algorithms are available through the Phytocfit app (Table 45-1; see Clay et al. 2019 for further details).

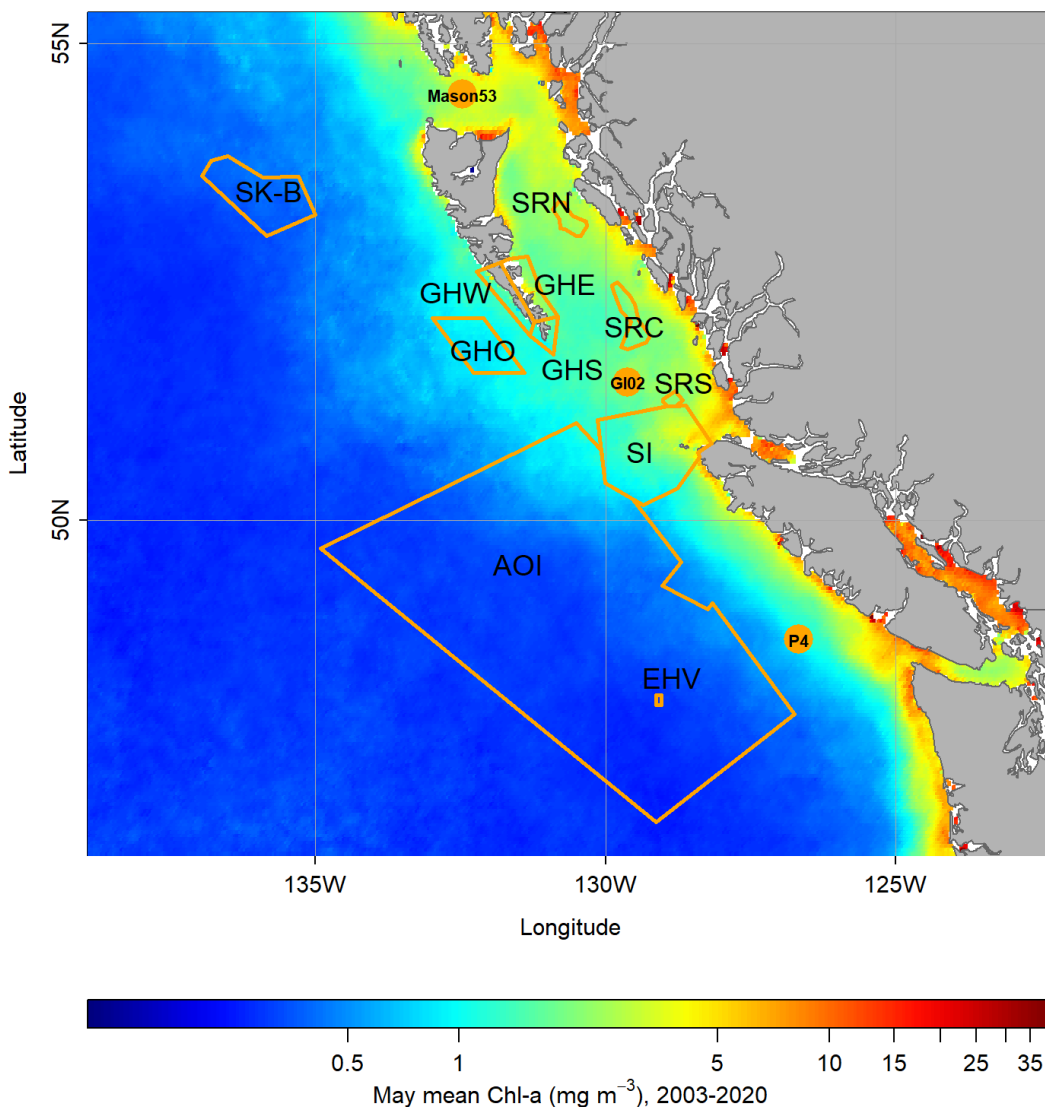


Figure 45-1. Reporting regions (orange lines) including selected standard oceanographic stations (orange circles). AOI: Offshore Pacific Area of Interest. EHV: Endeavour Hydrothermal Vents Marine Protected Area. SK-B: SGaan Kinghlas-Bowie Seamount Marine Protected Area. GH: Gwaii Haanas National Park Reserve, east, south, west and offshore sections. SRN: Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA, north, central and southern reefs. SI: Scott Islands Marine National Wildlife Area. Standard oceanographic stations with satellite statistics thus far are G102, Mason53 and P4.

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46. WATER PROPERTIES IN CLAYOQUOT SOUND, BRITISH COLUMBIA CANADA IN 2020

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Researchers from the University of Washington Tacoma (UWT) have been collecting oceanographic data from Clayoquot and Barkley Sound since 2000. Data for Clayoquot Sound, starting in 2001, primarily consists of CTD profiles (temperature, salinity, density, oxygen, fluorescence and transmissivity are regularly obtained) in every major inlet and connecting channel, with just over 50 stations collected annually throughout the sound, typically in the early fall (Figure 46-1). In addition, discrete water samples for oxygen, chlorophyll, nutrients, phytoplankton, microplastics and sediment samples were collected at a subset of stations in some years. Data collection through 2015 was made possible through a collaboration with Dr. Richard Keil at University of Washington, Seattle, who allowed UWT to piggyback on his research cruises aboard the R/V Barnes. Data collection since then has been done with local small boats and has been supported with funds cobbled together from a variety of sources, most recently from internal university funding combined with funds from the Clayoquot Biosphere Trust (CBT).

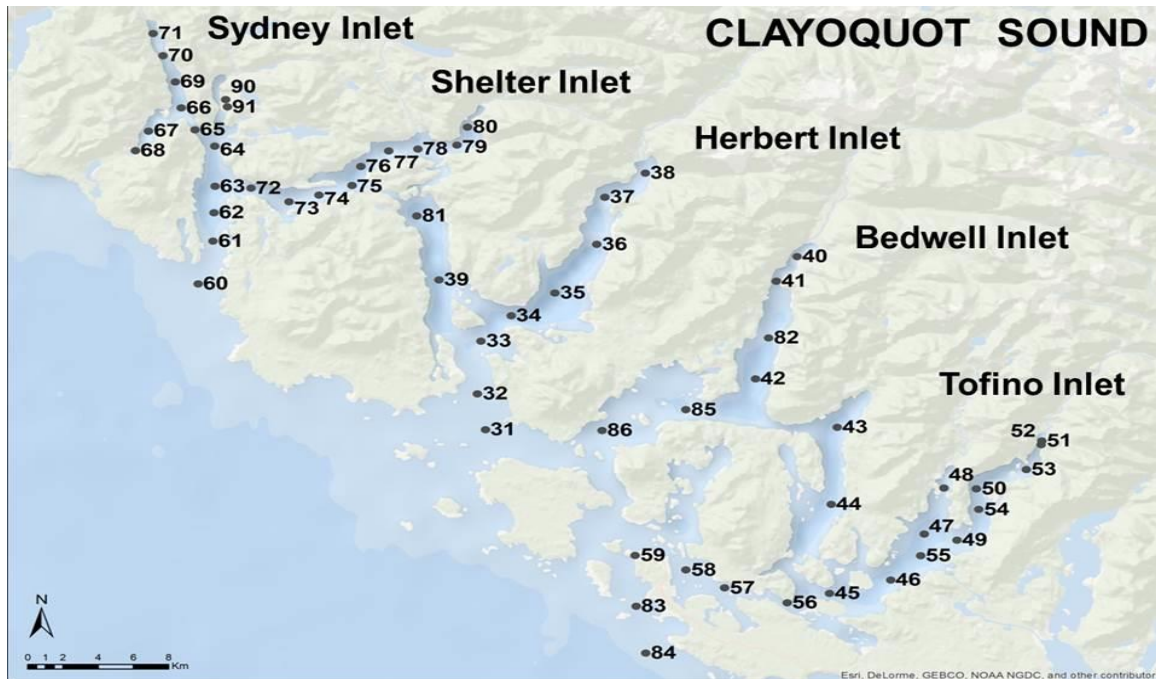


Figure 46-1. All UWT CTD sampling stations in Clayoquot Sound on the west coast of Vancouver Island British Columbia, Canada. Stations sampled vary from year to year and data collection has occurred annually since 2001 typically in late summer/early fall.

Restrictions due to the COVID pandemic prevented the UWT research team from traveling to Canada to collect data in 2020. To keep this valuable long time series going, UWT arranged with the Hakai Institute to collect data in 2020. We worked with the CBT to transfer all field work funding from UWT directly to the Hakai Institute for their services. We are very grateful to both

the Hakai Institute and the CBT for working with us to make this happen during this time of international travel restrictions.

CTD data profile data (temperature, salinity, density, oxygen, fluorescence, transmissivity and PAR) were collected at 44 Clayoquot Sound stations on 5-6 October 2020. Temperature ranged from 9.68-17.32 °C, salinity from 12.78-32.02 PSU and dissolved oxygen from 0-6.62 ml/l. Highest temperatures and lowest salinities were found in Tofino Inlet at the surface at stations 54 and 50. The coldest, saltiest water was found at the bottom of Sydney Inlet at stations 69-71. The head of Tofino Inlet, in Deer Bay and Tranquil Inlet, were anoxic at the bottom, which is historically quite common. Upper Herbert Inlet was also close to anoxic, which has also been observed in prior years.

47. UPDATING FRASER RIVER SOCKEYE SALMON RUN SIZE ESTIMATION USING BOOSTED REGRESSION TREE METHOD

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47.1. Highlights

- A Boosted Regression Trees model (BRT) was developed to study the mathematical relationships between Fraser River Sockeye Salmon recruitment and multiple biological and environmental variables.
- In general, the BRT models are able to reproduce major variations observed and can explain over 50% of the variability in recruitment of all selected Sockeye Salmon stocks.
- BRT models identify effective female spawners or juvenile abundance as the top contributor for predicting the recruitments of 15 (out of 19) Sockeye Salmon stocks while the contributions of various environmental parameters are less preeminent (<30 % of the total recruitment variance) and diverse in their relationships with the recruitments of the stocks.
- BRT forecasts of Sockeye Salmon recruitment are a viable alternative to current forecast models to inform harvest and stock assessment planning for the coming fishing season.

47.2. Descriptions of data time series and the machine learning method

47.2.1. Fish Population Data

The Fraser Sockeye Salmon (*Oncorhynchus nerka*) recruitment time series (1948-2016) were provided by the Pacific Salmon Commission (PSC) and the time series of effective female spawners (EFS) and juvenile abundance (JUV) for the same period were provided by DFO for 19 major stocks (Figure 47-1). These data sets, detailed in Grant et al. (2011) were used to forecast Sockeye run size in 2020 (Hawkshaw et al. 2020).

47.2.2. Environmental Data

The 2019 forecast models incorporated time series of the Pacific Decadal Oscillation (PDO, Nov-Mar), sea surface temperatures (SST) from Pine Island (Apr-Jul), Entrance Island (Apr-Jun), and Fraser River discharge (Apr-Jun) at Hope as environmental covariates. In this new forecast, we added additional oceanographic variables and climate indices as candidate covariates

(Table 47-1). The oceanographic variables include: the averaged SST of the Gulf of Alaska from the Centennial *in-situ* Observation-Based Estimates model (COBE; Ishii et al. 2005), and regional upwelling and downwelling favourable wind stress (Kistler et al. 2001; Hourston and Thomson, Section 8). The climate indices considered are: the seasonal and annual North Pacific Gyre Oscillation (NPGO; Di Lorenzo et al. 2008), the Northern Oscillation Index (NOI; Schwing et al. 2002) and the North Pacific Current Bifurcation Index (BI; Cummins and Freeland 2007). The time series of these all the variables are from 1950-2018 except for BI (from 1967-2018).

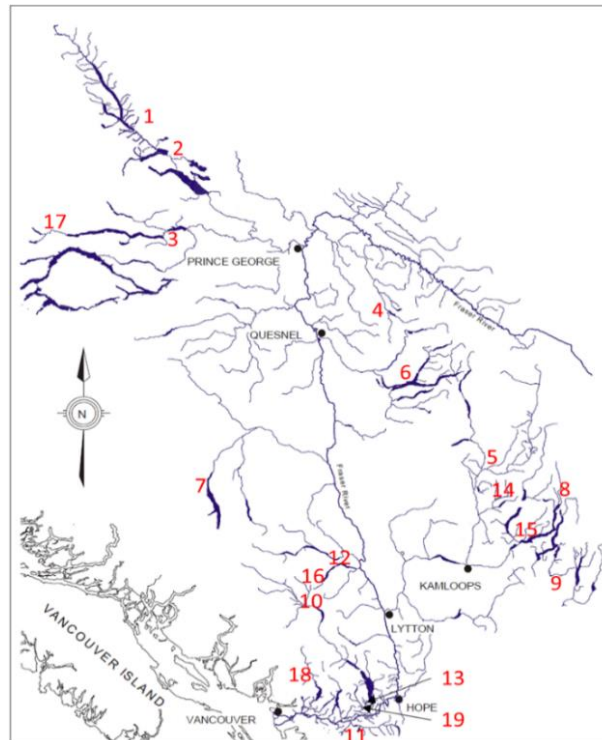


Figure 47-1. Locations of 19 major Fraser Sockeye Salmon stocks where spawning data were collected.
 1. Early Stuart
 2. Late Stuart
 3. Stellako
 4. Bowron
 5. Raft
 6. Quesnel
 7. Chilko
 8. Seymour
 9. Late Shuswap
 10. Birkenhead
 11. Cultus
 12. Portage
 13. Weaver Creek
 14. Fennel Creek
 15. Scotch Creek
 16. Gates
 17. Nadina
 18. Upper Pitt River
 19. Harrison

Table 47-1. Leading environmental factors identified by Boosted regression trees model. All environmental factors are currently tested for an offset of two years after brood year (i.e., smolt outmigration year).

Environmental Variables	Variable Description	Abbreviation in BRT model
Climate indices	Spring PDO (Pacific Decadal Oscillation Mar, Apr, May)	pdo.spr
	Summer and Autumn NPGO (Jun, Jul, Aug)	npgo.aut, npgo.sum
	Winter NOI (Northern Oscillation Index)	noi.win
	Bifurcation Index	BI
Regional sea surface temperature and salinity	Averaged Entrance Island and Pine Island SST	eisst, pisst
	Monthly Entrance Island SST (Apr, Jun)	apesst, jnesst
	Monthly Pine Island April SST (Apr, May, Jun, Jul)	appsst, mapsst, jnpsst
		jlpst
	Annual Gulf of Alaska SST	ocean.sst.annual
	Summer Gulf of Alaska SST (Jun, Jul, Aug)	ocean.sst.sum
	Autumn Gulf of Alaska SST (Sep, Oct, Nov)	ocean.sst.aut
	Averaged Race Rocks and Amphitrite Point SSS (Jul, Aug, Sep)	stn2js
Wind stress	Annual and spring upwelling-favourable at Central Coast	wind.cc.up.annual
	Summer downwelling-favourable at Central Coast	wind.cc.up.spr
	Annual, autumn and winter downwelling-favourable at Prince Rupert District	wind.cc.dn.sum
		wind.prd.dn.annual
		wind.prd.dn.aut
	Annual and winter downwelling-favourable at Prince Rupert District	wind.prd.dn.win
		wind.prd.up.annual
		wind.prd.up.win

47.2.3. *Boosted regression trees model*

A BRT (Elith et al. 2008) model was developed to study the mathematical relationships between Sockeye recruitment and multiple environmental co-variables since 2019 (Xu et al. 2019, 2020). This model is based on a machine learning method and has three advantages: 1) it can fit complex nonlinear relationships easily with multiple predictors; 2) it is not sensitive to outliers and data transformation; and 3) it is able to handle missing data. The BRT model was implemented using packages of “gbm” (generalized boosted regression models, v2.1.5) and “dismo” (species distribution modeling, v1.1-4) in R (R Development Core Team 2021). No major model changes have been made since last year (Xu et al. 2020).

47.3. Status and trends

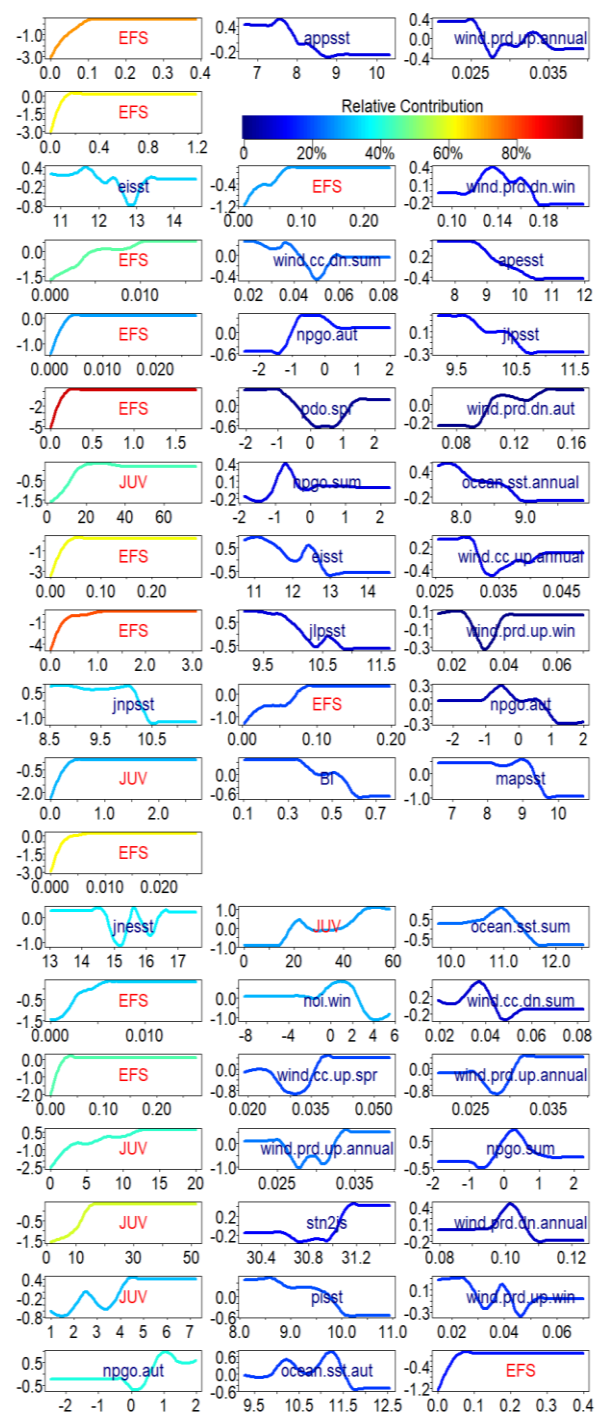
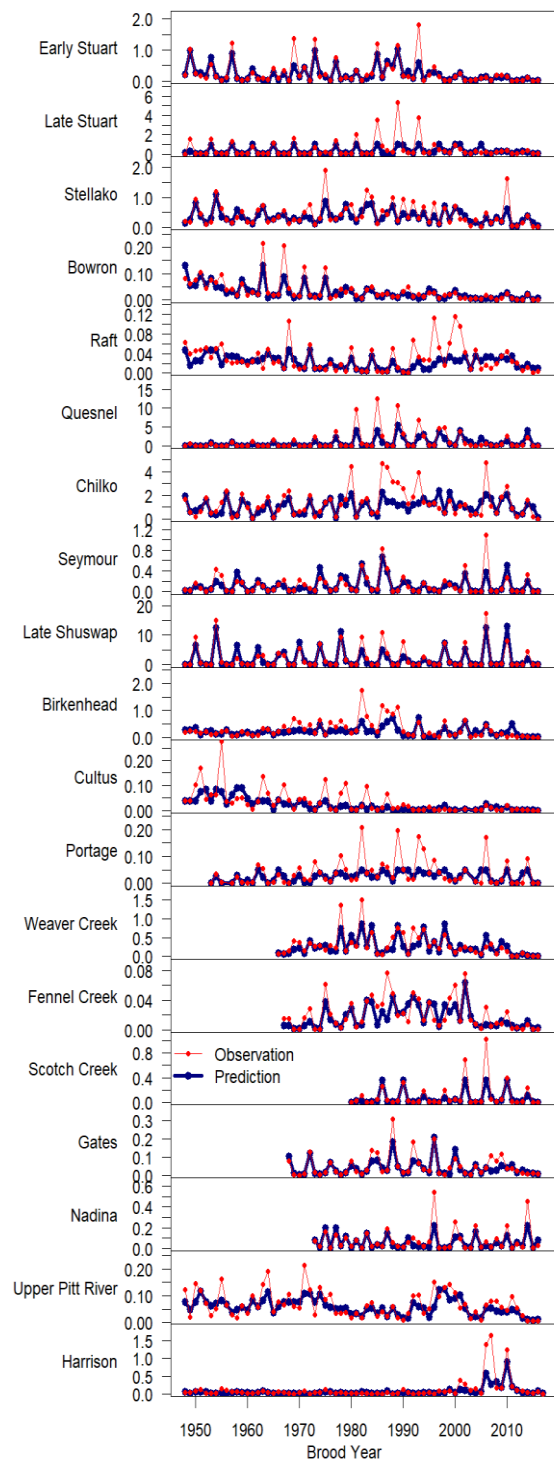
Since the late 1990s, most Fraser River Sockeye Salmon stocks have experienced low recruitment. In general, the BRT model fit was able to explain a large proportion of the variability in the recruitment time series (Figure 47-2) with the Quesnel stock achieving the highest level (93.7 %). For the majority of stocks, the BRT model was able to predict the general recruitment trends, although missing some extremes in the observed values, which in turn was reflected in the relatively small standard deviations in the predictions.

47.4. Factors influencing trends

For most Fraser River Sockeye Salmon stocks, the BRT models identified EFS or JUV as the important contributor(s) that had the highest relative influence (%) for predicting Sockeye Salmon recruitment (Figure 47-3). For all stocks (except for Weaver Creek which showed a stepwise increase relationship) predicted recruitment showed a Beverton-Holt-like relationship with EFS or JUV, and the relative influences varied from 14-91 % among different stocks. While the relationship between recruitment and the top biological factor (EFS or JUV) was shown as Beverton-Holt-like, the relationships between recruitment and the dominant environmental factor were diverse in shapes. Environmental factors explained less than 30% of the total recruitment variance. For stocks where a dominant environmental factor was identified as the top contributor (i.e., the Stellako, Birkenhead, Weaver Creek and Harrison stocks), the dominant environmental factor showed a smaller contribution (with lower relative influence) compared to a top biological factor in other stocks.

47.5. Run size forecasts and implication of the BRT modelling method

The BRT model produced forecasts of Sockeye Salmon run size for 19 major stocks (Figure 47-4) totaling around 2 million in 2021. The Late Stuart (907K), Quesnel (281K) and Chilko (720K) stocks dominate the run size and represent 90 % of the forecasted total of all stocks combined. However, for both Late Stuart and Chilko stocks, the explained variance of BRT model is relatively low (less than 70%), which indicates higher uncertainties of the forecast. A full evaluation of uncertainties will be provided in the near future.



In contrast, all other stocks (Early Stuart, Stellako, Bowron, Raft, Seymour, Late Shuswap, Birkenhead, Cultus, Portage, Weaver Creek, Fennel Creek, Scotch Creek, Gates stocks, Upper Pitt River and Harrison) are predicted to have less than 75,000 recruits; this is the abundance threshold guideline for determining whether high precision spawning escapement methods (e.g. sonar, mark-recapture) should be planned for the upcoming year. These stock-specific results provide useful and timely information to both harvest managers and stock assessment operations for the upcoming 2021 summer/fall enumeration surveys.

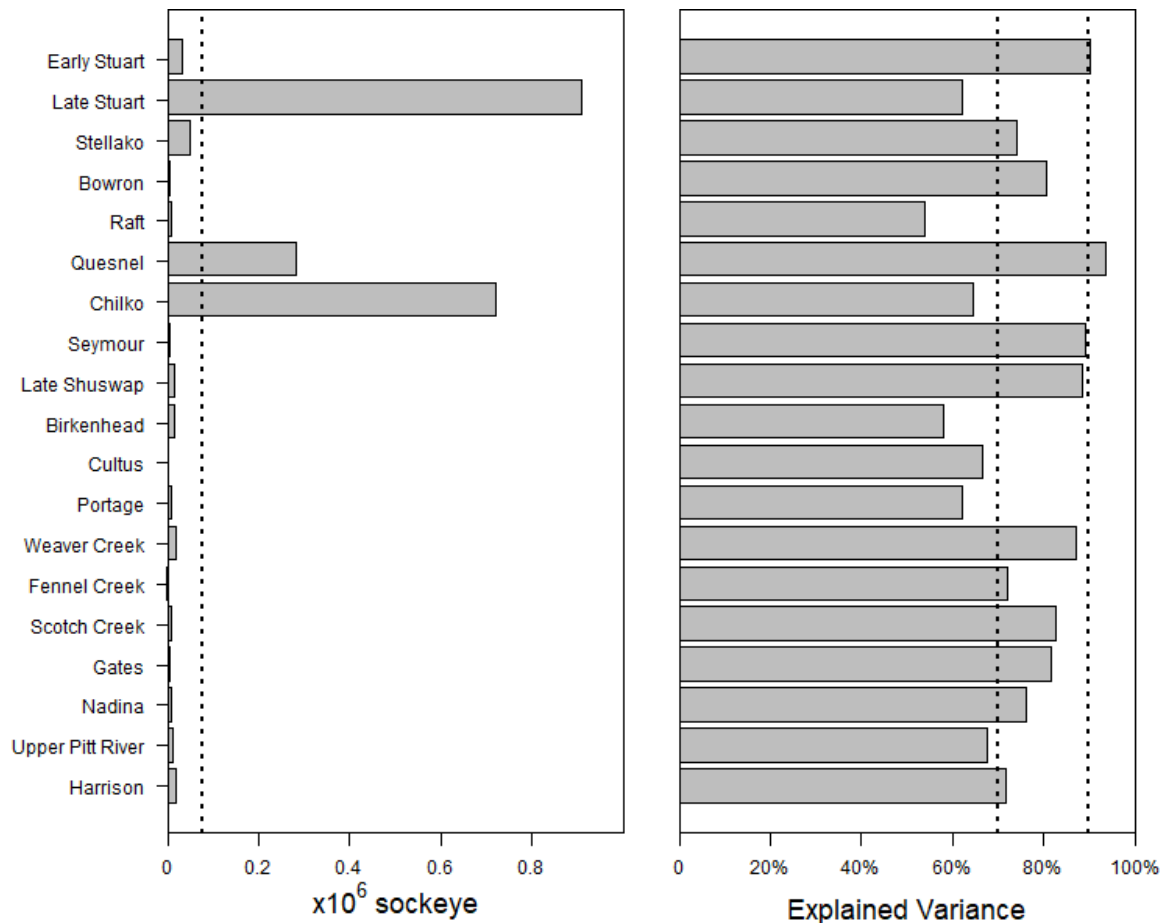


Figure 47-4. Left: The Boosted Regression Trees model run size forecasts of 19 Fraser River Sockeye Salmon stocks in 2020 (dash line is 75,000 fish). Right: The explained variance by Boosted Regression Tree model (dash lines are 70% and 90%).

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Appendix 2 - Meeting Agenda

SOPO DAY 1 - Tuesday March 2, 2021		
P#	Name	Title
1	Chandler	Introduction
2	Joe Seward	FN Welcome
3	Carmel Lowe	Welcome from DFO
4	Faron Anslow	Land temperature and hydrological conditions in 2020
5	Tetjana Ross	Review of temperature, salinity and density of the North Eastern Pacific in 2020 using Argo, glider, satellite and Line P data
6	Roy Hourston	Wind-driven upwelling along the Northwest coast of North America: timing and magnitude
7	Peter Chandler	Sea surface temperature and salinity observed on the British Columbia coast in 2020
8	Anne Ballantyne	Sea Level in British Columbia 1910-2020
Lunch		
9	Bill Crawford	Oxygen trends in subsurface waters on the BC shelf and Gulf of Alaska
10	Guoqi Han	Surface currents along the shelf edge and continental slope off the British Columbia coast
11	Jennifer Jackson	Interdecadal oceanographic trends in Rivers and Bute Inlet, BC
12	Wiley Evans	Coastal CO2 observations from Fitz Hugh Sound and Northern salish sea in 2020
13	Akash Sastri	Oceanographic conditions off the West Coast of Vancouver Island: 2020
14	Angelica Peña	Phytoplankton monitoring along Line P
15	Moira Galbraith	West coast zooplankton: annual anomaly time series
16	Chandler/Boldt	Summary discussion
SOPO DAY 2 - Wednesday March 3, 2021		
17	Chandler/Boldt	Summary
18	Clare Ostle	Lower Trophic Levels in the Northeast Pacific, from CPR sampling
19	Jennifer Boldt	Pelagic fish: an update on status and trends
20	Erika Anderson	2020 Fall Juvenile Salmon Trawl Survey on the North Coast of BC
21	Sue Grant	State of Canadian Pacific Salmon in 2020
22	Howard Stiff/Kim Hyatt	Sockeye salmon recruitment variations, ocean state changes, year 2020 performance and 2021 "outlook"
23	Steve Latham	Size and age trends of mature Fraser River sockeye and pink salmon through 2020
24	Sean Anderson	Trends in Pacific Canadian groundfish stock status
Lunch		
25	Zane Zhang	North Pacific albacore tuna abundance and trends in the Canadian and the U.S. EEZs

26	Brett Howard	Recent range expansions of invasive marine invertebrates in the Pacific region
27	Cherisse Du Preez & Laís Chaves	SGaan Kinghlas-Bowie Seamount MPA
28	Stéphane Gauthier	Scientific surveys on the CCG vessel Franklin: successes, challenges, solutions
29	Peter Chandler	Strait of Georgia and Juan de Fuca Strait Water Properties - 2020
30	Richard Dewey	Deep and sea surface water properties in the Strait of Georgia 2020: Cabled and Ferry Systems
31	Susan Allen	Spring phytoplankton bloom timing, interannual summer productivity in the Strait of Georgia
32	Chandler/Boldt	Summary discussion
SOPO DAY 3 - Thursday March 4, 2021		
33	Chandler/Boldt	Summary
34	Svetlana Esenkulova	Harmful algal blooms in the Salish Sea in 2020
35	Ian Perry	Domoic Acid Surveillance in Pacific Canadian Waters: 2016 – 2020
36	Kelly Young	Zooplankton status and trends in the central Strait of Georgia, 2020
37	Chrys Neville	Juvenile salmon in the SoG on the Franklin
38	Linnea Flostrand	Eulachon status and trends in southern B.C. and Lower Fraser River Didymo observations
39	Will Duguid	Adult Chinook Salmon diets as an indicator of spatial and temporal variation in coastal food webs
40	Jim Irvine	Were Disastrously Low Salmon Returns in 2020 the Consequence of Interactions with Abundant Pink Salmon?
Break		
41	Jackson Chu	The Saanich Inlet Transect 2020: Using ROVs to monitor the vulnerability of benthic biodiversity to major climate stressors
42	Charles Hannah	Assessing ocean habitat for seabirds - Scott Islands Marine National Wildlife Area
43	Patrick O'Hara	Recent trends in marine traffic and associated threats in the Salish Sea based on Automatic Identification System for Ships (AIS) and novel traffic data collection techniques
44	Jennifer Boldt	Unusual occurrences in 2020
45	Kat Middleton	Canada's Oceans Now, 2020 - State of Canada's Oceans
46	Chandler/Boldt	Summary highlights discussion

Appendix 3 - Meeting Participants (Zoom Sign-in names)

12505146067	Ania Javorski	Carmel Lowe
ABATTY	Anne Ballantyne	Caroline Fox
Adam S	Anneka Vanderpas	Caroline Graham
Adrienne Murphy	Ariel Lenske	Carolyn
AFacundo	Aroha Miller Ocean Wise	Carrie Holt
agelab	Arthur Bass	Carrie Robb DFO Science
Aidan Sackmann	Ashley	Catherine Michielsens
Akash Sastri	Aswea Porter	Cathryn Murray
Al Magnan	Athena Ogden	Cecilia Wong
Alana Closs	Barbara Sobota (CWS Pacific)	Charles H Gilbert (Skip)
Alex Hare	BassettS	Charles Hannah
Alice	BaxterB	Charmaine
Alice Bui	Bea Proudfoot	Chelsea Ashbrook
Alice Kobayashi	BeltonM	Chelsea Rothkop
Alicia Andersen	Ben	Chelsea Stanley
Aline Isabelle	Ben O'Connor	Cherisse
Alisa Preston	Ben Snow	Cheryl
Alyssa Gehman	Benji Spagat (ECCC)	Cheryl L. Greengrove
Amanda	BertramD	Chris
Amanda Timmerman	BethElLee Herrmann (UW)	Christian
Amanda Winans	Bill Crawford	Christina Cann
Amber Dearden	Brad Butler	Christine K
Amber Holdsworth	Braemon Conville	Christopher Krembs (Ecology)
amclaskey	Brandon Sackmann	Chrys Neville
amh	Brendan Connors	Chuck Parken
Amy Tabata	Brett Howard - DFO	Cindy Wright
Ana C. Franco	Brett Johnson	Claire Dawson (Ocean Wise)
Ana Pozas	Brian Hunt	Claire O'Brien
Andrea Hilborn	Brian Kingzett	Clare Ostle
Andrea Locke	Brian Leaf	ClarkeC
Andrea Moore	Brian Riddell (PSF)	CLARKEM
Andrew Baylis	Bridget Ferriss	CLKR
Andrew Chin	Bronwyn MacDonald	Colette Wabnitz
Andrew Edwards	Brooke Davis (DFO)	Colleen Kellogg
Andrew Leising	Brooke Hackett	Dan Baker
Andrew Margolin	Bruce Nairn	Dan Doutaz
Andrew Ross	Chris Rooper	Dana Haggarty
Andy Lin	Cailyn Siider	Daniel Labbe
Angela S.	Cameron Freshwater	Danielle Lacasse
Anh Tran	Candy J	David Angus (FLNRORD)

David Blackburn	Hannah Stewart DFO	Jessica
David Welch	HannahL	Jessica Garzke
dean trethewey	harry nyce sr	Jessica Hutchinson
Debby Ianson	Hauke Blanken	Jessica Nephin
Di Wan	Hayleigh	Jessy Barrette
Diana McHugh	Hayley Dosser	Jill Campbell
Diana Varela	Hem Nalini Morzaria-Luna	Jim Irvine
Doug Hay	HigginsM	Jim McIsaac
Doug Latornell	Hilari Dennis-Bohm	joanne
Doug's iPad	hockers	Jocelyn Nelson
DOVERN	HolmesJ	Joe Needoba
Drew Snaffer	Hongsik Kim	Joe Seward
Eddy Kennedy DFO	Howard Freeland	Joe Tadey
Elise Olson	Howard Stiff (DFO)	Joel Filgate-Mcnabb
Emily Bishop	HUNTINGTONS	John Dower
Emily Rubidge	Hussein Alidina	John Nelson
Emma Hodgson	Ian Perry	Jon Chamberlain
Erika Anderson	Iris Kemp (LLTK Administrator)	Jonathan Kellogg
Erika Lok	Isobel Pearsall	Jonathan Martin
Erin Rechisky	Jackie Detering	joseph.kim
Erin Sowerby Greene	Jackie King	Julia Bos - Ecology
EVANSR	Jackson	Julian Smith
Evgeny Pakhomov	Jackson Chu	Julie E Keister
Faron Anslow	Jacob	Julie E. Masura
Faye Manning	Jacob Lerner	Julie Keister
Fiona Francis	Jacob W	Julie Merchel
Fiona Martens	Jade Shiller ECCC	Justin Del Bel Belluz
ForsterI	Jake Schweigert	Karalea Cantera
Francis Juanes	James P	Karen G
FuC	Jamey Selleck - NRC (Seattle)	Karianne Blank
Gabriela Hannach	Jan Buermans	Karin Mathias
GARNERG	Jane Healey	Karyn Suchy
GatienG	Janelle Curtis	Kat Middleton
Geoffrey Martynuik	Janet F-R	Katherine C
Glenn	Janet Mossman	Katherine Punis
Graham Sorenson	jason	Kathryn Sobocinski
Greg	JC (Janice Chan)	Katie
Greg Jones	Jeff Denison DFO	Katie Davidson
Greg McClelland	Jen Jackson	Katie Gale (DFO)
Greig Oldford	Jenna Cragg	Kayleigh (she/they)
Guoqi Han	Jennifer Boldt	Kaylyn Kwasnecha
Haley Andersen	Jennifer Yakimishyn	Keegan Flanagan

Kelly Swan	Luke Warkentin	Monique Raap
Kelly Young	Lynda Ritchie DFO	James Mortimor
Ken Morgan	Lynn Lee	Nadine Parker
Kevin Pellett	Lyse Godbout	Natalie Benoit
Kevin Romanin	MAAAAT	Natasha Salter
Kiana Matwichuk	Mackenzie Beck	Nathan Duifhuis
KieranP	MACKENZIEC	Neil Dangerfield-DFO Science
Kim	Madeline Lavery	Nic Ens
Kim Bedard	MajewskiS	Nicholas Ens
Kim Lagimodiere	Mardy Johnson	Nick Bolingbroke
Kim Stark-King County	Margot Hessing-Lewis	Nick Brown
Kim-Ly Thompson	Maria Cornthwaite	Nicole
Kirstyn Nygren	Marie	Nicole Frederickson
KlaverM	marie-Hélène Gravel	Nicole McEwan
KM	Marina Wright	NicoletteWatson
KrassovskiM	Marisa Keefe	Niisii Guujaaw
Kristina Hick	Mark Saunders (IYS 1)	Nik Clyde
Kristine Sandhu	Marlene Jeffries	Nina
KS	Martin Nantel	Noriko Okamoto
Kyra St. Pierre	Matt Miller	Norm Olsen
LAFORGE B	Matt Townsend	OBRIENC
Lais Chaves	Matthew Asplin	Olivia Schaefer DFO
Langley zoom iPad	McCorquodaleB	Ovi Haque
Laura Bianucci	MCGOVARINS	PaigeY
Laura Tessier	Megan Kot	Patrick Duke
Lauren Girdler	MELANIE ANG	Patrick O'Hara
Lauren Krzus	Melissa Hennekes	Patrick Pata
Lauri Sadorus	Merlin Best	Patrick Thompson
LeggattR	Michael Arbeider	Patrick Whittaker Grieg Seafood
Li	Michael Folkes	Patrik Zetterberg
Liam Peck	Michael Foreman	PattisonV
liaoX	Michael Livingston	Paul Covert
Lindsay Davidson	Michaela Maier	Angelica Pena
Linnea Flostrand	Michel Breton	Pete
LIUQ	Mike Morley	Pete Wills
LNEILSON Ministry of Agriculture Food and Fisheries	Miki	Peter Chandler
Lorri Granum	Mina	Philina
Lu Guan	Mina Masoud	Phillip Dionne
Luc Bujold (DFO-MEDS)	Minje Choi	PORTEOUSN
Lucas Abruzzi	Miriam O - DFO Science	Pramod Thupaki
Luke Rogers	Moira	PunisK

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RAAPM	Selina Agbayani	Tereza Jarnikova
Rachel	SHANE	Tetjana Ross
RBurnham (BURBurnham)	Shannon Schmunk	Theresa Venello
Rebecca Beutel	Shea Wyatt	Thomas Smith
rhian evans	shuminli	Tim Hawkins
Rich Pawlowicz	Shyla	Tim Hewison - Grieg Seafood
Richard Banner	Simon Jones DFO	Tom Okey
Richard Chea	Simone Alin	TuckerS
Richard Dewey	Skip	Tyler Zhang
Rick Page	Skip McKinnell	Tyler Zubkowski
RiedelD	smihaly	Tyrel Froese
Roanna Leung	smith	Tyson Carswell - BC Agriculture Fisheries & Food
Rob S	SMITHJU	VanWillP
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Ron Tanasichuk	Stephen Page	Virginia
Rowan Fox	SpearD	Vishnu Perumthuruthil Suseelan
Roy Hourston	Stacey Verrin	Wafa Tafesh
Sahir Advani	Stef	wangziwei
Samuel Stevens	Stephane Gauthier	Wendy Callendar
Samuelle Simard-Provençal	Steve Baillie	Wendy Eash-Loucks
Sarah Bartnik	Steve Latham	Wendy Szaniszló
Sarah Dudas	Steve Pearce	Wiley Evans
Clare Mortimor	Steve Romaine	Will Duguid
Sarah Friesen	Steve Smith (DFO)	William Atlas
Sarah Hawkshaw	Stu Crawford Council of the Haida Nation	Williams Daniel
Sarah Hudson	Stuart LePage	Wintherlv
Sarah Zimmermann	Sue Grant	WINTHERT
Scott Akenhead	Susan Allen	wischniowski
Scott Decker	Svetlana Esenkulova	Yi Xu
Scott Toews	SweetenT	Zarah Zheng
Scott Wallace DSF	TalbotR	Zane Zhang
Sean Anderson	Tammy	Zhimin Ma (MEDS Canada)
Sean Boyd	Tanya Vivian	Zoe Crysler
Sean MacConnachie	Taylor Martin	