State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2019

Jennifer L. Boldt, Ania Javorski and Peter C. Chandler (Editors)

Fisheries and Oceans Canada
Institute of Ocean Sciences
9860 West Saanich Road
Sidney, B.C. V8L 4B2

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Jennifer L. Boldt[1], Ania Javorski[2] and Peter C. Chandler [3] (Editors)

[1]Fisheries & Oceans Canada
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, B.C. V9T 6N7
Canada
Jennifer.Boldt@dfo-mpo.gc.ca

[2]Environmental Research & Consulting
103 Berkeley Place
Nanaimo, B.C. V9T 1L5
Canada
aniakjavorski@gmail.com

[3]Fisheries & Oceans Canada
Institute of Ocean Sciences
9860 West Saanich Road
Sidney, B.C. V8L 4B2
Canada
Peter.Chandler@dfo-mpo.gc.ca

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Fisheries and Oceans Canada is responsible for the management and protection of marine resources on the Pacific coast of Canada. Oceanographically this area is a transition zone between coastal upwelling (California Current) and downwelling (Alaskan Coastal Current) regions. There is strong seasonality and considerable freshwater influence, and an added 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 scientists in the Pacific Region to 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 2019 was held March 10-11, 2020 at the Vancouver Island Conference Centre, Nanaimo, BC. This technical report includes submissions based on presentations and posters given at the meeting.

Climate change continues to be a dominant pressure acting on NE Pacific marine ecosystems. Globally, land and ocean temperatures in 2019 were the second warmest on record and the occurrence of marine heatwaves (MHWs) in the NE Pacific is increasing. The upwelling-favourable winds along the west coast of Vancouver Island started at an average spring date with above average intensity, implying average to above average upwelling of nutrient-rich waters and, hence, productivity. In the spring and summer of 2019, surface nutrient concentrations along Line P were among the lowest on record. Anomalously warm ocean temperatures have resulted in changes to the phytoplankton community offshore and to the zooplankton community on the shelf. Changes at higher trophic levels have also been observed. For example, the returns and productivity of Fraser River Sockeye Salmon were the lowest on record, Smooth Pink Shrimp biomass on the west coast of Vancouver Island was among the lowest on record, and growth rates of Cassin's auklet nestlings on Triangle Island (north of Vancouver Island) were below the long-term average.

In the Strait of Georgia, the spring bloom timing was similar to the long-term average – which implies good feeding conditions for juvenile fish. Zooplankton biomass was above the long-term average with positive biomass anomalies of important zooplankton prey for juvenile salmon and forage fish. Forage fish have shown varying trends; for example, Pacific Herring biomass decreased in the Strait of Georgia and multiple sizes of Northern Anchovy continued to be present in survey catches. There has been a coast-wide decline in the returns of most Chinook, Sockeye, and Chum Salmon stocks in B.C., and declines of Coho Salmon stocks in southern B.C.; whereas, some Pink salmon stocks have had good returns.

A special session focused on physical and biological consequences of MHWs and climate change. There were five presentations given by DFO and ECCC scientists that examined the

characteristics and occurrences of recent MHWs, defining MHWs, zooplankton responses to MHWs, and the effects of MHWs on seabirds and Pacific Salmon.

Résumé

Boldt, J.L., Javorski, A., et Chandler, P.C. (Eds.). (2020). State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2019. Can. Tech. Rep. Fish. Aquat. Sci. 3377: x + 288 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 océanographique, cette aire est une zone de transition entre les régions côtières de montée des eaux (courant de la Californie) et de plongée des eaux (courant côtier de l'Alaska). Cette région est assujettie à une forte saisonnalité et une forte incidence des eaux douces, et une variabilité supplémentaire provenant des phénomènes et des conditions des tropiques et de l'océan du 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 tenue par les scientifiques du MPO dans la région du Pacifique pour présenter les résultats de la dernière année de surveillance dans le contexte d'observations précédentes, ainsi que les conditions futures escomptées. L'atelier tenu pour examiner les conditions de l'écosystème en 2019 a eu lieu les 10 et 11 mars 2020 au centre de conférence de l'île de Vancouver, à Nanaimo, en Colombie-Britannique. Ce rapport technique comprend des soumissions basées sur les présentations et les affiches distribuées à la réunion.

Les changements climatiques continuent de constituer une pression dominante qui agit sur les écosystèmes marins du Pacifique nord-est. Mondialement, les températures terrestres et des océans en 2019 étaient les deuxièmes plus chaudes jamais enregistrées et les vagues de chaleur marines dans le Pacifique nord-est surviennent plus fréquemment. Les vents favorables à la montée des eaux le long de la côte ouest de l'île de Vancouver ont commencé à une date moyenne au printemps, mais à une intensité supérieure à la moyenne, ce qui suggère que la montée des eaux riches en nutriments, et, en conséquence, la productivité, seront moyennes ou supérieures à la moyenne. Au printemps et à l'été de 2019, les concentrations de surface en nutriments le long de la ligne P étaient parmi les plus faibles jamais enregistrées. Des températures océaniques anormalement chaudes ont entraîné des changements dans les communautés de phytoplancton au large des côtes et dans les communautés de zooplancton sur la plateforme. On a également observé des changements à des niveaux trophiques supérieurs. Par exemple, la montaison et la productivité du saumon rouge du Fraser étaient les plus faibles jamais enregistrés, la biomasse de la crevette océanique sur la côte ouest de l'île de Vancouver était parmi les plus faibles enregistrées, et le taux de croissance des oiseaux niais du starique de Cassin sur l'île Triangle (au nord de l'île de Vancouver) était inférieur à la moyenne à long terme.

Dans le détroit de Géorgie, l'éclosion de printemps a eu lieu aux environs de la moyenne à long terme – ce qui suggère de bonnes conditions d'alimentation pour les poissons juvéniles. La biomasse du zooplancton était supérieure à la moyenne à long terme et comportait des anomalies de biomasse positives de proies importantes de zooplancton pour le saumon juvénile et le poisson-fourrageur. Les poissons-fourrageurs ont montré des tendances variées; par

exemple, la biomasse du hareng du Pacifique a diminué dans le détroit de Géorgie et différentes tailles d'anchois du Pacifique ont continué d'être présentes dans les prises de levé. On a observé une baisse sur toute la côte de la montaison de la plupart des stocks de saumon quinnat, rouge et kéta en Colombie-Britannique, et une baisse des stocks de saumon coho dans le sud de la C.-B. Dans le même temps, certains stocks de saumon rose ont eu une bonne montaison.

Une séance spéciale portait sur les conséquences physiques et biologiques des vagues de chaleur marines et des changements climatiques. Cinq présentations données par des scientifiques du MPO et d'ECCC examinaient les caractéristiques et les occurrences des récentes vagues de chaleur marines, en définissaient les vagues de chaleur marines, ainsi que les réponses du zooplancton, et les effets de ces vagues de chaleur sur les oiseaux de mer et le saumon du Pacifique.

Highlights, Introduction, and Overview

1. HIGHLIGHTS

1. Climate change continues to be a dominant pressure acting on NE Pacific marine ecosystems. Globally, land and ocean temperatures in 2019 were the second warmest on record.
2. The occurrence of marine heatwaves (MHWs) in the NE Pacific is increasing; 'normal' or cold years have not been observed since 2013, and this span of seven warm years has been observed only once in 80 years (from 1992-1998).
3. Acidification will continue to intensify as anthropogenic carbon input increases. In the northern Strait of Georgia during 2019, nearly all instances of sub-surface corrosive conditions for the mineral calcite, which is used by many shell-forming animals, were due to the buildup of anthropogenic carbon.
4. The NE Pacific is staying warm due to a lack of fall and winter cooling, resulting in increased stratification and reduced vertical mixing; as a result there are reduced levels of nutrients in offshore surface waters.
5. Surface nutrient concentrations in the offshore NE Pacific in 2019 were among the lowest on record. In particular, summer mixed layer nitrate was depleted at Ocean Station Papa for the first time in 60 years of observations.
6. Spring upwelling of cool nutrient rich waters along the west coast of Vancouver Island (WCVI) in 2019 had an average start time in spring; south of 50° N (Brooks Peninsula) the intensity of upwelling-favourable winds were above average, favourable to productivity and fish growth, north of 50° N upwelling-favourable winds were average to below-average.
7. Anomalously warm ocean temperatures have resulted in changes to the offshore phytoplankton community that affect not only the food web, but also the oxygen levels and biogeochemistry of the ocean.
8. Warm ocean temperatures have resulted in changes to the zooplankton community. On the WCVI there was a reduced biomass of subarctic, lipid-rich copepods and increased biomass of warm-water, lipid-poor copepods and gelatinous zooplankton. These changes negatively impacted fish (e.g., Pacific Salmon species) and seabirds (e.g., die-offs of Cassin's Auklets). In the SoG, however, there were positive biomass anomalies of preferred fish prey (hyperiid amphipods, decapods, and euphausiids).
9. The timing of the SoG spring bloom in 2019, was consistent with previous years – which implies good feeding conditions for juvenile fish.
10. Since the 'Blob' marine heatwave of 2014-2016, there have been fewer Pacific Sand Lance in Rhinoceros Auklet diets at Triangle Island and Pine Island, and fewer *Neocalanus cristatus*, a sub-arctic copepod, in Cassin's Auklet diets at Triangle Island. These observations suggest that there has been no bounce back in these important forage species since the 'Blob'.
11. There has been a coast-wide decline in the returns of most Chinook, Sockeye, and Chum Salmon stocks in B.C., and declines of Coho Salmon stocks in southern B.C.;

whereas, some Pink Salmon stocks have had good returns. The returns and productivity of the Fraser River Sockeye Salmon were the lowest on record

12. In 2019, the biomass of Pacific Herring showed modest increases in Prince Rupert District, Central Coast, WCVI, remained low in Haida Gwaii, and decreased in the SoG. Herring weight-at-age continued to increase in all stocks, following a 30 year declining trend from approximately 1980 to 2010.

13. Since the cessation of human harvesting and culling of marine mammals, the population of Harbour Seals in the SoG has increased and remained at about 40,000 since the 1990s. The abundance of Steller Sea Lions in B.C. increased in the 1990s to 2000s and, in 2017, was at ~40,000, unchanged since 2013.

14. While the population of southern resident Killer Whales remains low, the populations of the northern resident Killer Whales, Bigg's (transient) Killer Whales, and Humpback Whales have been increasing.

2. INTRODUCTION

Fisheries and Oceans Canada (DFO), Pacific Region, conducts an annual review of the physical, chemical and biological conditions in the ocean, 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 2019 (for conditions in 2018) is available at

https://www.dfo-mpo.gc.ca/oceans/publications/soto-rceo/2018/index-eng.html

In 2020, the meeting on conditions observed on the west coast of Canada (Figure 2-1) in 2019 took place on March 10 and 11 at the Vancouver Island Conference Centre, Nanaimo, B.C. Over 200 people participated in person or by web-conference. Participants included scientists from the federal and provincial government, First Nations / Indigenous-led organizations, academia, non-profits, industry and private companies. A trend over the past few years has been the increased participation and presentations by non-DFO scientists. This has provided a broader perspective of the science being done on Canada's Pacific coast, and the audiences who are interested in this science.

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

Snuneymuxw Elder James Johnny provided a meeting welcome and closing ceremony. The DFO Pacific Regional Director of Science, Dr. Carmel Lowe provided a welcome and introduction to the SOPO meeting. The session included 41 oral presentations and 19 posters covering a range of observations from 2019. One of the oral presentations was given by Kat Middleton (DFO), who is leading DFO's national state of the ocean reporting initiative. She highlighted the national synthesis report titled "Canada's Oceans Now" and showcased the completed Atlantic and Arctic regional reports, online information, and infographics. These will serve as examples for the national level state of the Pacific Ocean report that will be written in 2020/21. Aroha Miller (Ocean Watch and Ocean Wise Research Institute) presented an update on the state of local coastal ocean reporting for Howe Sound and B.C.: Integrating Indigenous Knowledge, Western Science, and Citizen Science. Laís Chaves (Haida Nation) and Cherisse DuPreez (DFO) gave a joint presentation describing the SGaan Kinghlas – Bowie Seamount MPA Monitoring plan.

At each annual SOPO meeting there is a special session. At this year's meeting the focus was the physical and biological consequences of marine heatwaves (MHWs) and climate change. There were five presentations given by DFO and ECCC scientists that examined the characteristics and occurrences of recent MHWs, defining MHWs, zooplankton responses to MHWs, and the effects of MHWs on seabirds and Pacific Salmon.

At the end of the first day a poster session was held with support from Ocean Networks Canada; nineteen posters were presented in the Vancouver Island Conference Centre. A poster on unusual marine events in 2019 provided space for participants to add their own observations. The agenda for the meeting is presented in Appendix 1, Poster abstracts are 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), and organized by Ania Javorski.

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.

2019 meeting attendees hear opening remarks from DFO's Regional Director of Science, Carmel Lowe (top and bottom right), and Snuneymuxw Elder, James Johnny (bottom left); Stephen Page coordinates comments from webinar participants and the evening poster session generates much discussion (bottom middle).

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 2019 were the second warmest on record. In B.C., anomalously warm air temperatures peaked in the spring forcing the early and rapid melt of a near-normal winter snowpack (Anslow, Section 6). The long-term record of sea surface temperatures (SSTs) collected at lighthouses along the B.C. coast showed that 2019 was 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: 0.86 °C over the last 100 years (Figure 3-1; Chandler, Section 10). Increasing CO_2 in the atmosphere has led to ocean acidification, which will continue to intensify as anthropogenic carbon content further increases (Evans, Section 35).

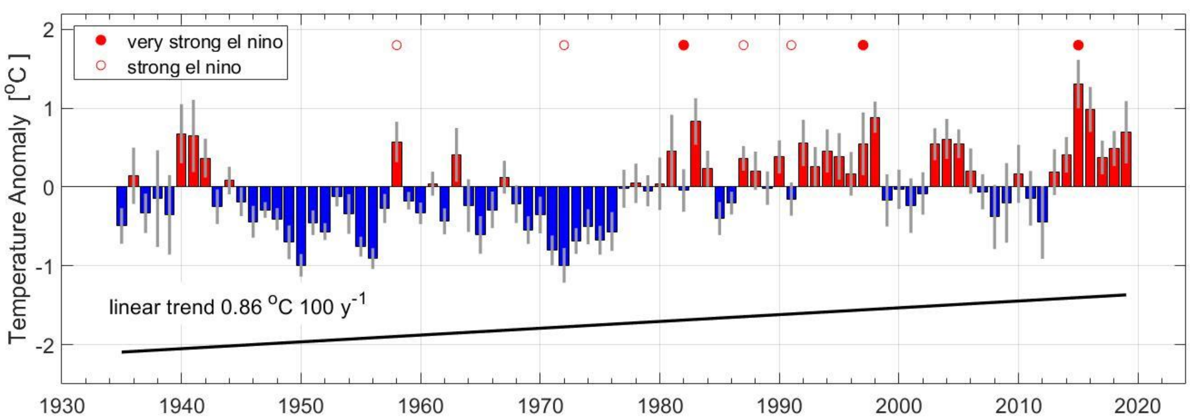

Figure 3-1. The trend in the annual temperature based on the observations of all lighthouses. The data shown are the anomalies from the long-term average temperature (1935-2017). The bars represent the anomalies averaged over all stations (a coast-wide indicator), (red – above average, blue – below average), the vertical grey lines show the variability in the lighthouse data for each year. Source: Chandler, Section 10.

In 2019, the NE Pacific experienced a moderate El Niño and a marine heatwave (MHW). The El Niño was weak in the first half of 2019 and neutral for the latter half of the year, so it had little effect on SSTs (Figure 3-2). The MHW resulted in record-breaking SST anomalies in both surface and subsurface waters (Figure 3-3; Ross and Robert, Section 7; Sastri, Section 13; Hannah et al., Section 48). The occurrence of MHWs in the NE Pacific is increasing, with MHWs observed in 2014-2016, 2018, and 2019; this span of seven warm years has been observed only once before in the last 80 years (during 1992-1998; Chandler, Section 49).

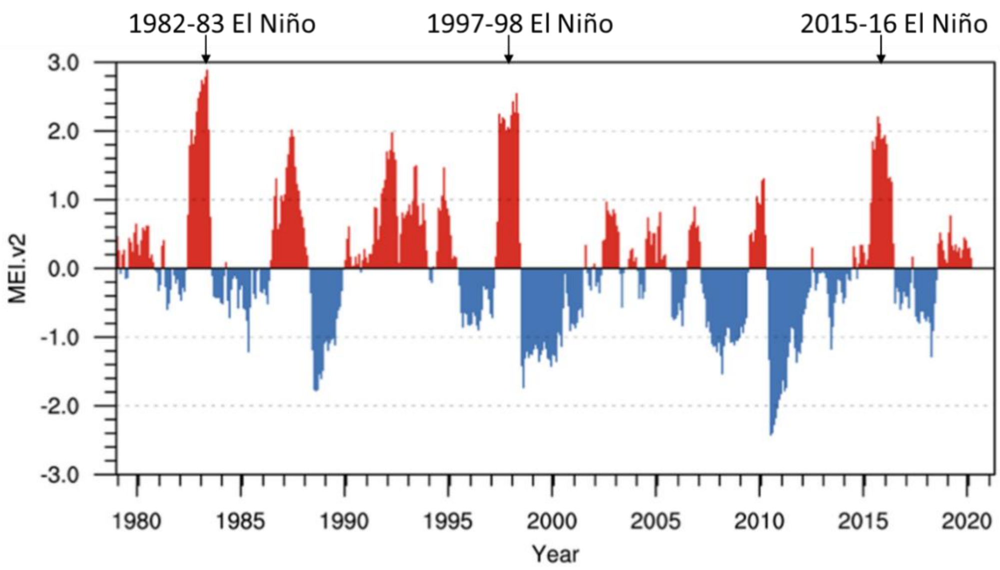

Figure 3-2. The multivariate ENSO Index. Data source: NOAA/ESRL/Physical Sciences Division – University of Colorado at Boulder/CIRES; https://psl.noaa.gov/enso/mei/

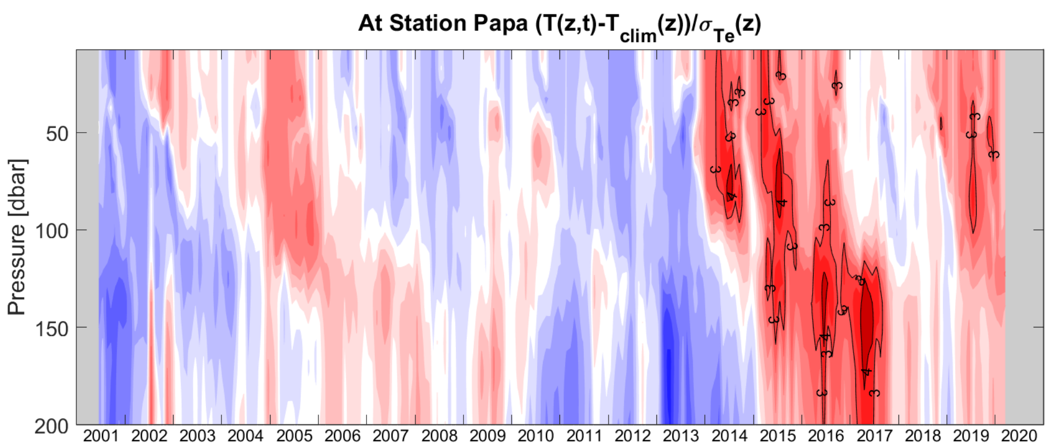

Figure 3-3. Plot of temperature anomalies relative to the 1956-2012 seasonally-corrected mean and standard deviation (from the Line P time series), as observed by Argo floats near Station Papa (P26: 50°N, 145°W). The cool colours indicate cooler than average temperatures and warm colours indicate warmer that average temperatures. Dark colours indicate anomalies 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. For five of the last six winters the strength of winter mixing was weak and stratification was strong (Figure 3-4; 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 16; Perry et al., Section 50), 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 51) due to prolonged drought in northern B.C. (Anslow, Section 6).

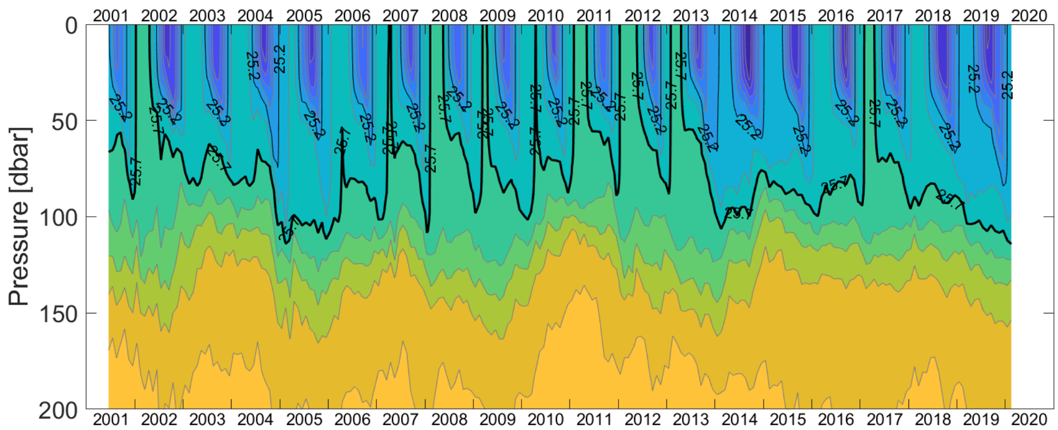

Figure 3-4. Coloured contour plot of density as observed by Argo floats near Station Papa (50°N, 145°W). The colours indicate potential density (yellow is denser and blue lighter). The black lines highlight the σ_θ=25.2 kg/m^3 (thin) and 25.7 kg/ m^3 (thick) isopycnals. Source: Ross and Robert, Section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

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. The average to above average intensity of the upwelling in 2019 was associated with average to above average upwelling-based productivity (Hourston and Thomson, Section 8; Dewey et al., Section 37). The timing of the transition to upwelling was average, favouring average upwelling-based coastal productivity (Hourston and Thomson, Section 8; Figure 3-5).

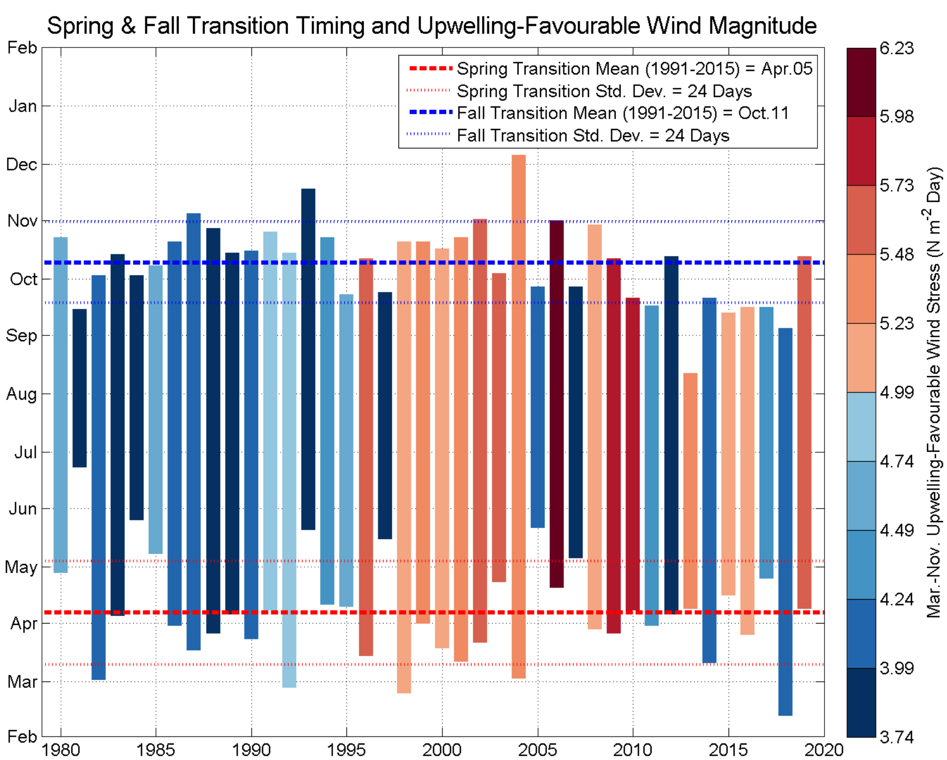

Figure 3-5. The upwelling index for the west coast of British Columbia. Bar plot showing Spring and Fall transitions and upwelling-favourable wind stress magnitude. The length of the bar corresponds to the duration of the upwelling season, coloured by the intensity of the upwelling (red indicates intense 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, DFO.

In the spring and summer 2019, surface nutrient concentrations along Line P were among the lowest on record (Peña and Nemcek, Section 14). In particular, the summer mixed layer nitrate was depleted at Ocean Station Papa for the first time in 60 years of observations. In 2019, on the west coast of B.C., the phytoplankton biomass was within the range of past values. The phytoplankton community composition in spring 2019 was similar to that of 2018 but different from years prior to 2018, with diatoms dominating phytoplankton biomass at several open-ocean stations (Peña and Nemcek, Section 14; Batten and Ostle, Section 15).

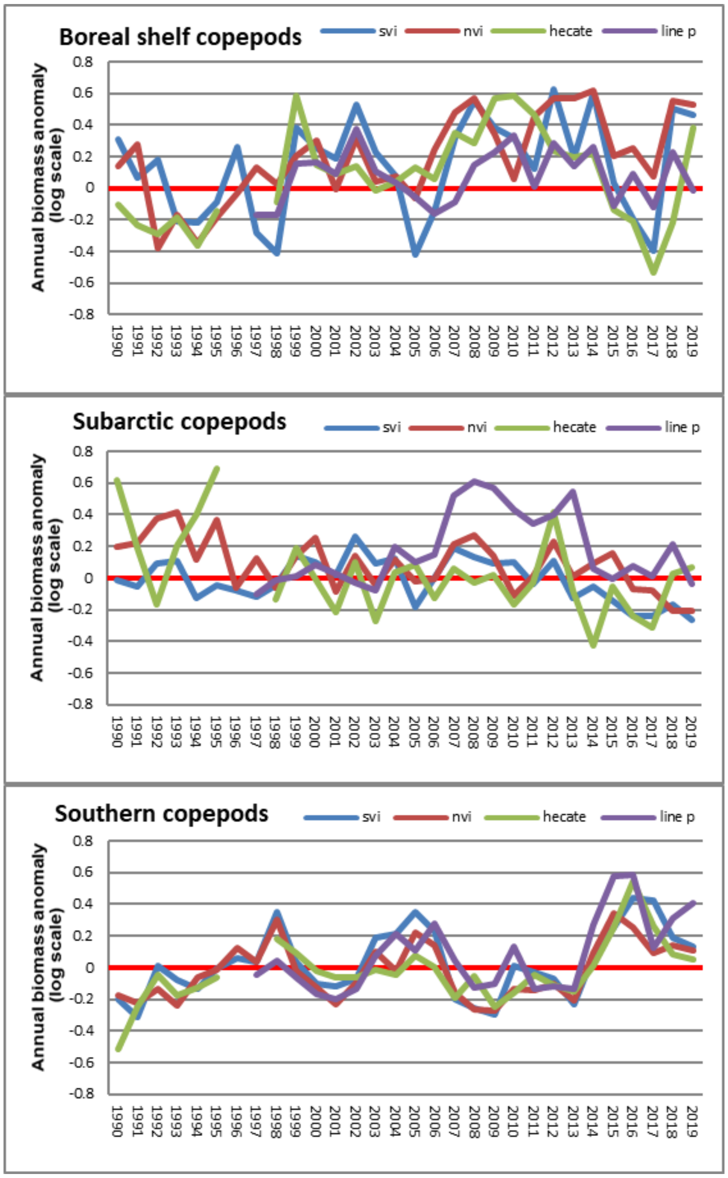

Figure 3-6. Zooplankton species-group anomaly time series for the regions shown in Figure 1. Line graphs are annual log scale anomalies. Southern Vancouver Island (SVI) blue; Northern Vancouver Island (NVI) red; Hecate Strait (HEC) green; Line P – purple for all graphs. Blank years mean no samples were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

The zooplankton community off the WCVI continues to reflect warm water conditions, with higher abundances of gelatinous and lower abundances of crustacean taxa (Galbraith and Young, Section 16) and, on the shelf, a dominance of small-sized copepod species (Batten and Ostle, Section 15). Large subarctic and boreal copepods are more favourable for fish growth than small, southern copepod species. In 2019, biomass anomalies of boreal copepods increased on the shelf; whereas, subarctic copepods anomalies decreased or were low in all areas except Hecate Strait (Galbraith and Young, Section 16; Figure 3-6). Southern copepod anomalies were positive in all regions in 2019 (Figure 3-6). The colonial tunicate, *Pyrosoma atlanticum*, that first appeared in B.C. waters in 2017, and was found in lower abundances along the shelf break in 2018, was absent from B.C. waters in 2019 (Galbraith and Young, Section 16).

Changes to the physical environment, and phytoplankton and zooplankton communities can have impacts on higher trophic levels. In 2019, the WCVI Smooth Pink Shrimp biomass, which is negatively correlated with SST (lagged 1 year), was among the lowest on record; anomalies have been below the climatological mean for the last four years (Perry et al., Section 23). During warm ocean conditions, Pacific Hake migrate north to Canadian waters;

however, in 2019, only a relatively small proportion of the stock was observed in Canadian waters, despite warm ocean conditions and total stock biomass being ~20% above the time series median (Gauthier et al., Section 25). In the 2019 Hecate Strait and Queen Charlotte Sound synoptic bottom trawl surveys, biomass indices increased for several Rockfish species (including Redbanded, Bocaccio, and Silvergray Rockfish), increased for North Pacific Spiny Dogfish, leveled off for Sablefish, Pacific Cod and Shortspine Thornyhead, but showed decadal-scale decreases for Arrowtooth Flounder and Spotted Ratfish (English et al., Section 24). Albacore tuna annual catch-per-unit-effort (CPUE) increased in 2018 and 2019 (Zhang, Section 69).

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 2019, growth rates of Cassin's auklet nestlings on Triangle Island were below the long-term average (Hipfner, Section 29). Marine mammal populations are also linked to their primary prey and while the population of southern resident Killer Whales remains low, the populations of the northern resident Killer Whales, Bigg's (transient) Killer Whales, and Humpback Whales have been increasing (Doniol-Valcroze et al., Section 27). The abundance of Steller sea lions in B.C. increased in the 1990s to 2000s and, in 2017, was at ~40,000, unchanged since 2013 (Tucker and Majewski, Section 26).

During 2019 in the Strait of Georgia (SoG), water temperatures were again generally above-normal (Chandler, Section 36). Following below-normal oxygen concentrations in 2018, a transition to near-normal oxygen concentrations has been observed throughout the system in 2019, and above-normal oxygen concentrations in the deep water of Haro Strait (Chandler, Section 36). Fraser River discharge was below normal in 2019 (although the long-term trend is for increasing annual discharge), with a relatively low discharge period in mid-summer. Normal, and above-normal flows were observed during the spring salmon outmigration period, and the fall spawning period (Figure 3-7).

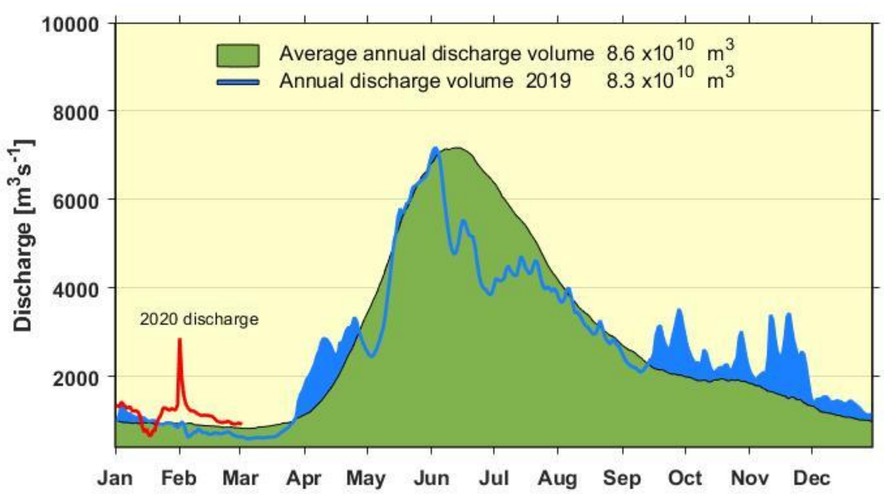

Figure 3-7. Fraser River discharge at Hope B.C.; 2019 (blue), 107 year average (green). The red line shows the above normal discharge in early 2020. Data source: Extracted from the Environment and Climate Change Canada Real-time Hydrometric Data web site (https://wateroffice.ec.gc.ca/mainmenu/real_time_data_index_e.html) on 2 Mar 2020.

In 2019 in the SoG, there were fewer dense Harmful Algal Blooms (HABs) than in 2018, but more than in 2015-2017 (Esenkulova et al., Section 40). On the WCVI, several fish farms experienced mortality events due to blooms of non-toxic, mechanically harmful diatoms *C. convolutus* and *C. concavicornis* (Esenkulova et al., Section 40). European Green Crab, an Aquatic Invasive Species that was first observed in Canadian waters during the 1997/98 El Niño, are widespread along the WCVI and have been found in low numbers in North and Central B.C. and the northern Salish Sea (Howard and Therriault, Section 46). More recently, this high-impact invader that negatively affects eelgrass, an important fish habitat, has been detected in the southern Salish Sea (Howard and Therriault, Section 46).

There has been no long-term trend in total primary productivity in the SoG over the last 100 years (Johannessen et al., Section 41); however, 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 38; Dewey et al., Section 37) – which implies good feeding conditions for juvenile fish.

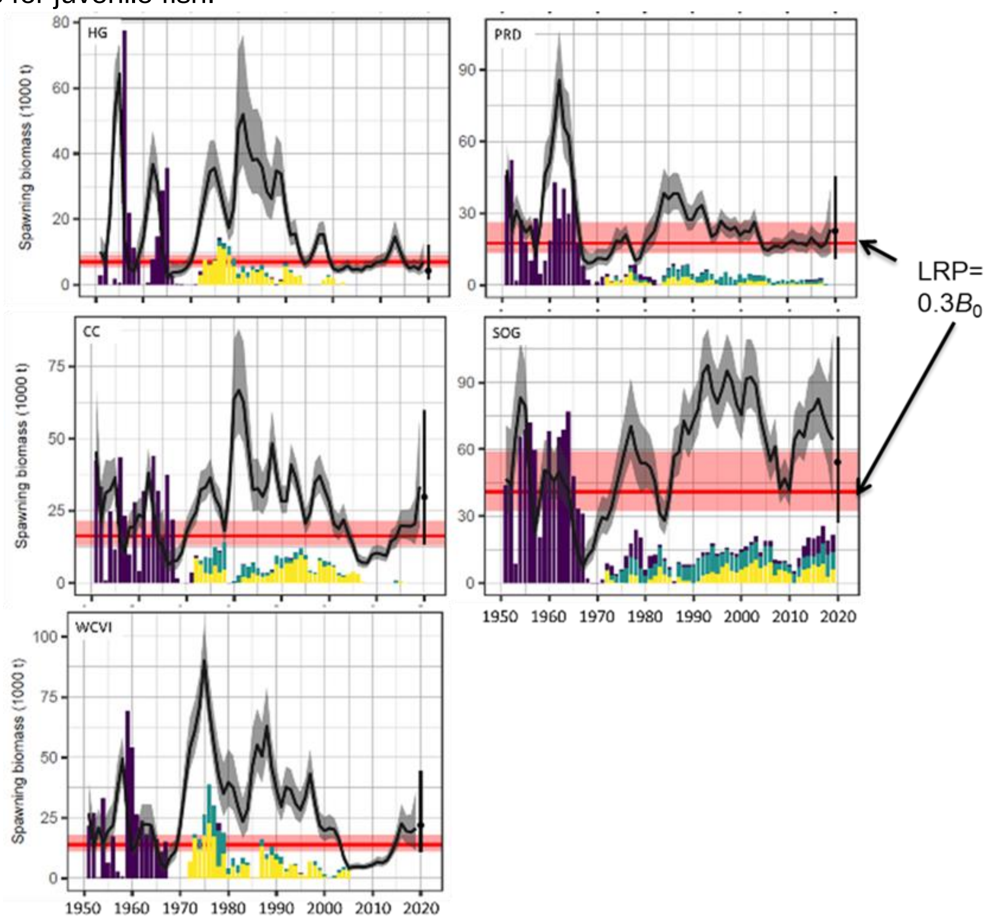

Figure 3-8. Summary of the dynamics of the five Pacific Herring stocks from 1951 to 2019, where solid lines with surrounding grey envelopes, represent medians and 5-95% credible intervals. Also shown is the reconstruction of spawning biomass (SBt) for each year t, with unfished values shown at far left (solid circle and vertical lines) and the projected spawning biomass given zero catch (SB_{2019}) 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 2020). LRP= limit reference point ($0.3B_0$). B_0 = unfished biomass. Figure adapted from DFO (2020).

In 2019, SoG zooplankton biomass was above the long-term average but the summer peak was later in the season than previous years (Young et al., Section 42). There were positive biomass anomalies of hyperiid amphipods, decapods, and euphausiids, which are important zooplankton prey for juvenile salmon and forage fish (Young et al., Section 42). Pacific Herring biomass decreased in the SoG, remained low for Haida Gwaii, and showed modest increases in Prince Rupert District, Central Coast, and WCVI (Cleary et al., Section 18; Figure 3-8). In 2019, multiple sizes of Northern Anchovy continued to be present in survey catches (Boldt et al., Section 43, Neville, Section 44). An index of Eulachon spawning stock biomass in the Fraser River was relatively low in 2019 (similar to 2004-2014; Flostrand, Section 17).

In the SoG, juvenile Coho and Chinook Salmon survey catch-per-unit-effort (CPUE) was average or above average and, in the fall survey, CPUE of juvenile Chum Salmon was the second highest in the time series (Neville, Section 44). In summer 2019, off the WCVI, however, the catch per unit effort (CPUE) of all juvenile Pacific Salmon was low (Anderson et al., Section 20). Adult Sockeye, Chinook, Chum, and Coho (southern latitudes) Salmon returns in 2019 were generally poor (Grant et al., Section 21). Pink Salmon have generally had better returns than most species in recent years. In 2019, returns of B.C.'s Sockeye Salmon 'index stocks' (Transboundary, North Coast, Central Coast, WCVI, Fraser, and Okanagan) were below average (Hyatt et al. Section 22) and returns and productivity of the Fraser River Sockeye Salmon aggregate were the lowest on record (Figure 3-9, Grant at el., Section 21). Poor salmon returns to the Fraser River watershed were compounded by the Big Bar landslide, which blocked upstream migration of many salmon populations (Grant et al., Section 21; Hyatt et al., Section 22).

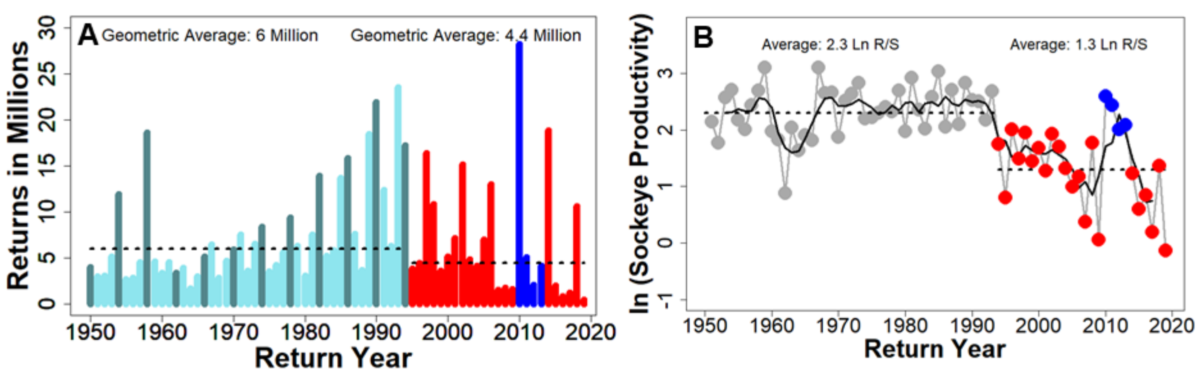

Figure 3-9. (A) Total Fraser Sockeye annual returns (dark blue vertical bars for the 2018 cycle and light blue vertical bars for the three other cycles) (B) Total Fraser Sockeye productivity (loge (returns/total spawner)) is presented up to the 2019 return year. The grey dots and lines represent annual productivity estimates. For both figures, the dashed line is the time series average. Productivity and returns have declined in recent decades, highlighted red, with the exception of four years from 2010-2013, which were closer to average, highlighted blue. Source: Grant et al., Section 21.

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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 2019

Faron Anslow, Pacific Climate Impacts Consortium, Victoria, BC, fanslow@uvic.ca

6.1. Highlights

- A moderate El Niño likely contributed to a slightly warmer than normal year in B.C.
- Anomalous warmth peaked in spring forcing rapid melt of a near-normal winter snowpack.
- Precipitation in summer and fall was above to much-above normal across B.C.
- Trends in temperature were positive for the period 1950 – 2019 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 0.5º x 0.5º grid covering British Columbia. The time series of gridded anomalies is then spatially subset by 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 is 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 120 for 2019. 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 on a monthly basis. Snowpack in regions are 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

We first discuss temperature and precipitation averaged over the year. Temperatures were higher than normal across British Columbia as a whole when compared with the long-term (1900 – 2019) record. Vancouver Island, Haida Gwaii and NW B.C. saw average daily minimum temperatures ranking in the top 10 among years in the long-term record. The rest of the province saw average daily minimum temperature ranking from 38th warmest to 15th warmest. 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 north and westernmost regions where rankings reached the tenth percentile. Precipitation anomalies across the province were mixed. Dry conditions extended along the west coast and into NW B.C. with anomalies ranking from 82nd to 113th wettest. Central and southern B.C. were near normal while northeast B.C. saw above normal precipitation with ranking from 38th to 33rd wettest.

On seasonal and monthly timescales, the primary anomalies were a very warm spring with very dry conditions. Seasonal anomalies for T_{max} were greater than those for T_{min} with anomalies much above normal in western and northern B.C. and above normal along the Rocky Mountains and in the Kootenay region. Seasonal temperatures peaked in May, with a mean of daily minimum temperatures that was amongst the hottest 10% of such values in the historical record. Average daily maximum temperatures were less extreme and followed a gradient from west (warmest) to east. In southeast B.C. the mean of daily maximum temperature was near normal. Precipitation in spring was much below normal to below normal everywhere in B.C. with driest conditions in western B.C.

A second notable aspect of the seasonal anomalies was the above normal to much above normal precipitation amount recorded from June through November. Although some regions experienced month-long dry spells, the overall regional anomalies were wet. The summer precipitation anomalies were much above normal across most of B.C. while fall anomalies were less extreme, but wetter than normal east of the Coast Mountains and near normal along the Coast Mountains and on the coast.

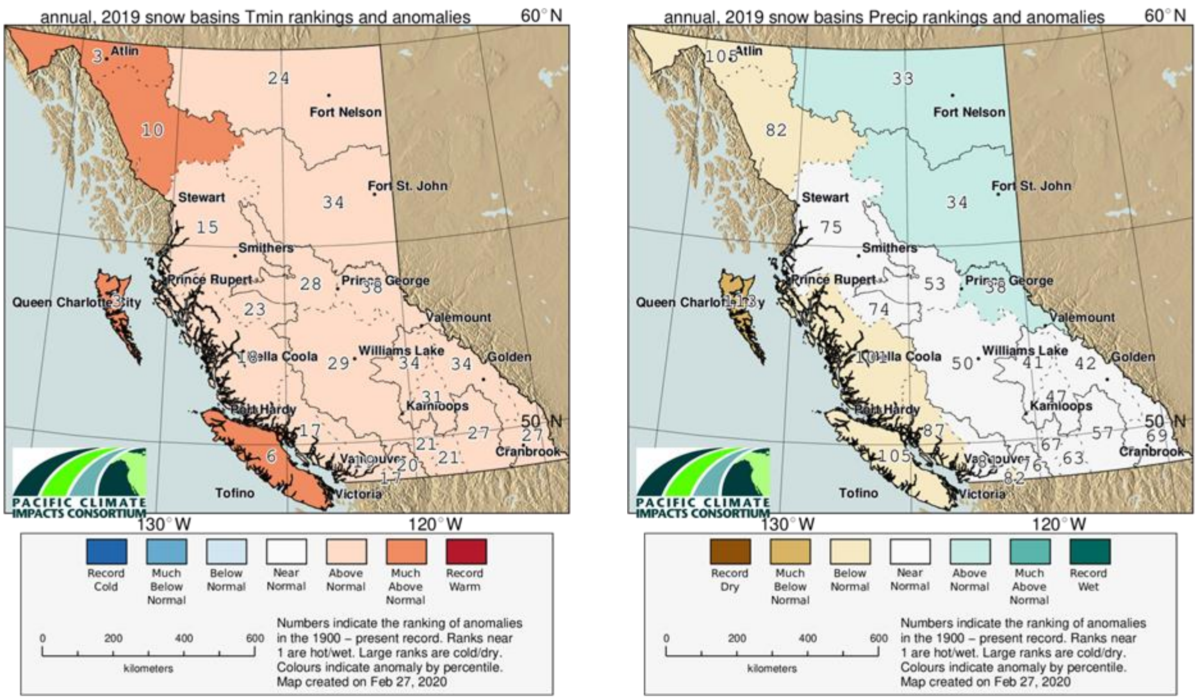

Figure 6-1. Annual anomalies in average daily minimum temperature (left panel) and total annual precipitation (right panel) for 2019 in British Columbia. Quantiles defining the colour scale are given in the text. Numbers on the map correspond to ranking in the 120 observation years from 1900 through 2019.

Using the province-wide seasonal and annual temperature and precipitation anomalies, trends are calculated for the full record spanning from 1900 through 2019 and for the period 1950 through 2019. Note that precipitation data early in the record are sparse and of 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 – 2019 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 are 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 – 2019 and 1950 – 2019. 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 – 2019*	*1950 – 2019*
Tmax (°C yr^{-1})	**0.008**	**0.021**
Tmin (°C yr^{-1})	**0.022**	**0.030**
Precip. (% yr^{-1})		0.069

6.4.2. Snow

The evolution of B.C.'s snowpack during the winter of 2018/2019 was mostly typical until punctuated by the warm, dry conditions of spring. Snow accumulation was 80% – 110% of normal at the end of April east of the Coast Mountains and north of the Okanagan (Figure 6-2). Elsewhere, the snowpack was lower than normal at 60% – 80% with extremely low values in the Skagit drainage and in NW B.C. The situation evolved rapidly over the subsequent month. By the end of May, the snowpack had dropped to half of normal throughout most of B.C. with the exception of the central Rocky Mountains and Kootenay (Figure 6-2). The rapid transition from near normal amounts of snow to extremely low snowpack suggests rapid melting and an earlier than normal spring freshet. The dry conditions and much above normal temperatures in May throughout B.C. drove this rapid transition. Although this report doesn't track trends in early snowpack decline, the transition to earlier loss of seasonal snow agrees with climate projections for B.C. (ul Islam et al. 2017).

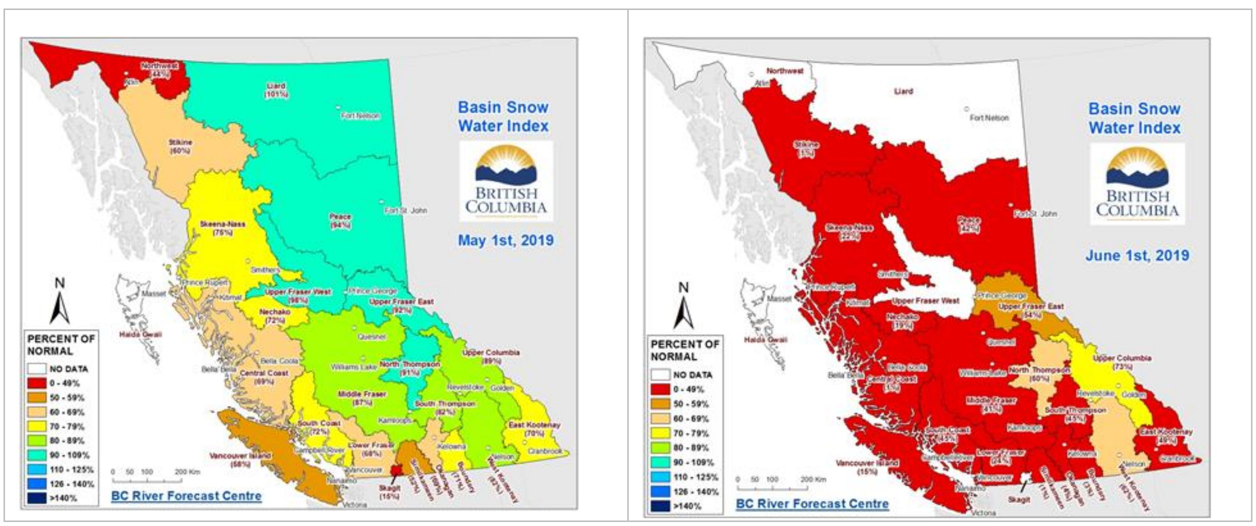

Figure 6-2: Anomalies in B.C. snowpack for May (left) and June (right), 2019. Maps are produced by the BC Ministry of Forests Lands and Natural Resource Operations and Rural Development's River Forecast Centre (River Forecast Centre 2019).

6.5. Discussion

2019 in British Columbia was slightly warmer than normal with the highest temperatures in May. Precipitation was lower than normal over coastal B.C. and higher than normal over eastern B.C. with a dry spring and wet late summer and fall period. The warm spring temperatures and low precipitation conspired to produce early melt of the winter snowpack and earlier than normal peaks in streamflow.

The observed anomalous conditions are likely due in part to ongoing warming in B.C. and ENSO activity. There was a weak El Niño during the winter of 2018/2019 and such events correspond to warmer than normal conditions in B.C. especially in late-winter and spring. El Niño events are typically accompanied by warm annual average temperatures as well (Stahl et al. 2006). Winter temperature was near normal, but spring was warm, so we suspect that El Niño may have helped induce the observed warm spring and the overall warm annual average temperature in B.C.

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7. ARE MARINE HEATWAVES THE NEW NORMAL FOR THE NORTHEAST PACIFIC OCEAN?

Tetjana Ross and Marie Robert, Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Tetjana.Ross@dfo-mpo.gc.ca, Marie.Robert@dfo-mpo.gc.ca

7.1. Highlights

- For most of 2019, the NE Pacific was in marine heatwave conditions for both surface and subsurface waters.
- The mixing in the winter of 2018/19 was very low, suggesting lower than normal surface nutrient levels in the spring of 2019.
- Climate indices suggest that 2020 will be less warm than 2019, but given that marine heatwave conditions appear to be the new normal, 2020 is likely to be a warm year.

7.2. Summary

Based on NOAA land and sea surface temperature data dating back to 1880, 2019 was the second warmest year on record globally (NOAA State of the Climate 2019). This is consistent with the recent trend, wherein 8 of the ten warmest years are in the last decade. In ranked order, the ten warmest years are 2016, 2019, 2015, 2017, 2018, 2014, 2010, 2013, 2005, and 1998. Sea surface temperatures (SSTs) in the Northeast Pacific (NE Pacific) were 1-2ºC above the average for the 1981-2010 base period (www.ncdc.noaa.gov/sotc/service/global/map-blended-mntp/201901-201912.png).

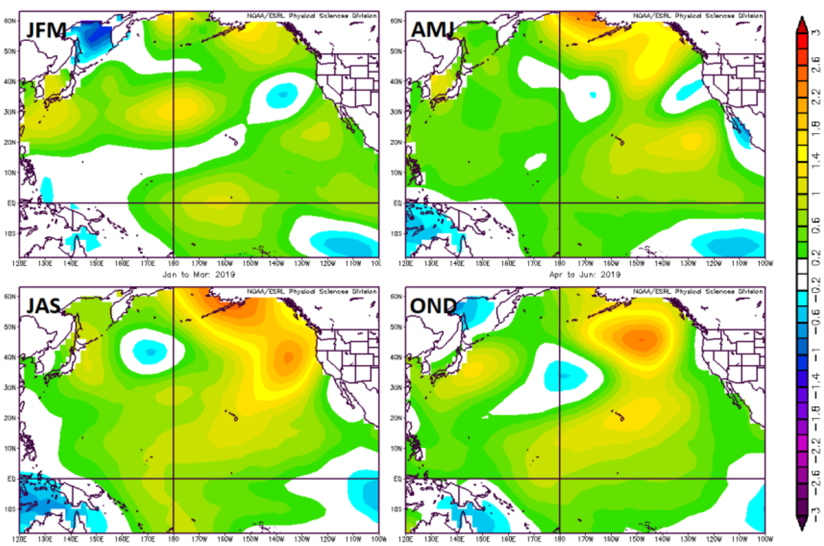

Figure 7-1. Seasonal maps of temperature anomalies in the Pacific Ocean for 2019. The colour bar on the right, showing the temperature anomaly in ºC, applies to all panels. Source: NOAA Extended SST v4 http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl. Anomalies are relative to 1981-2010 base period.

In the NE Pacific, the SSTs were warm throughout 2019 (Figure 7-1). In fact, the SSTs were so warm that the NE Pacific was in marine heatwave conditions through most of the year. This marine heatwave received a fair amount of press (see Hannah et al., Section 48 and Amaya et al. 2020 for details) and was so strong in the western NE Pacific to have record breaking yearly SST anomalies (NOAA; www.ncdc.noaa.gov/sotc/service/global/map-percentile-mntp/201901-201912.png). Unlike previous years, El Niño Southern Oscillation (ENSO) had little effect on the SSTs in the NE

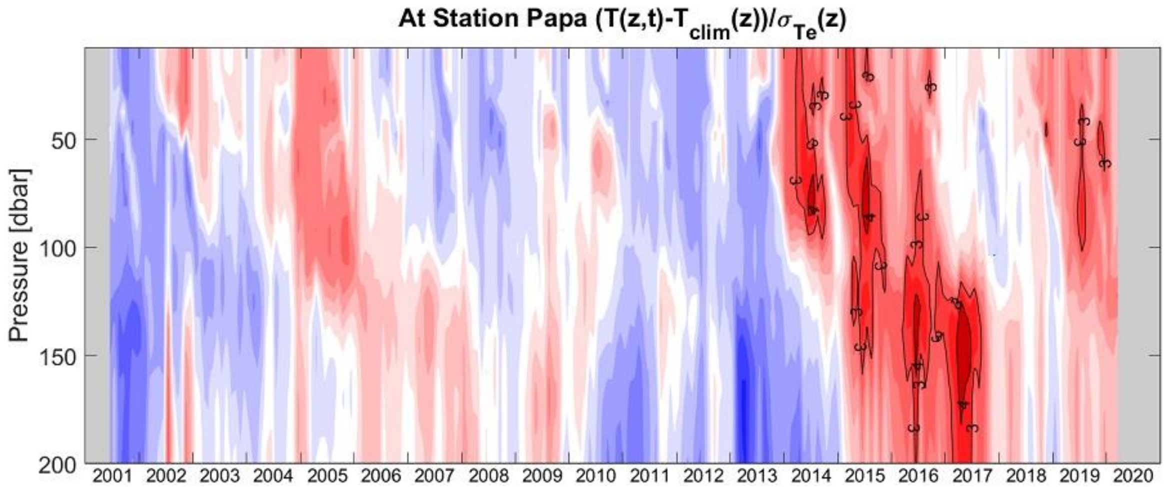

Figure 7-2. Plot of temperature anomalies relative to the 1956-2012 seasonally-corrected mean and standard deviation (from the Line P time series), as observed by Argo floats near Station Papa (P26: 50° N, 145° W).The cool colours indicate cooler than average temperatures and warm colours indicate warmer that 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.

Pacific in 2019. The above average SSTs might have been aided by the weak El Niño conditions in the first half of the year, but the warm anomalies increased in the latter half of the year during ENSO-neutral conditions.

Above average temperatures (relative to both the 1981-2010 (Figure 7-1 and 7-3) and 1956-2012 (Figure 7-2) 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 7-2), showed above average subsurface temperatures at Station Papa throughout 2019. This is in contrast to 2018, where subsurface temperatures were near-normal. The strongest anomalies (reaching 3 standard deviations above the mean) were at about 100 m depth, just above the permanent pycnocline. The marine heatwave was also observed across the entire line in the 2019 Line

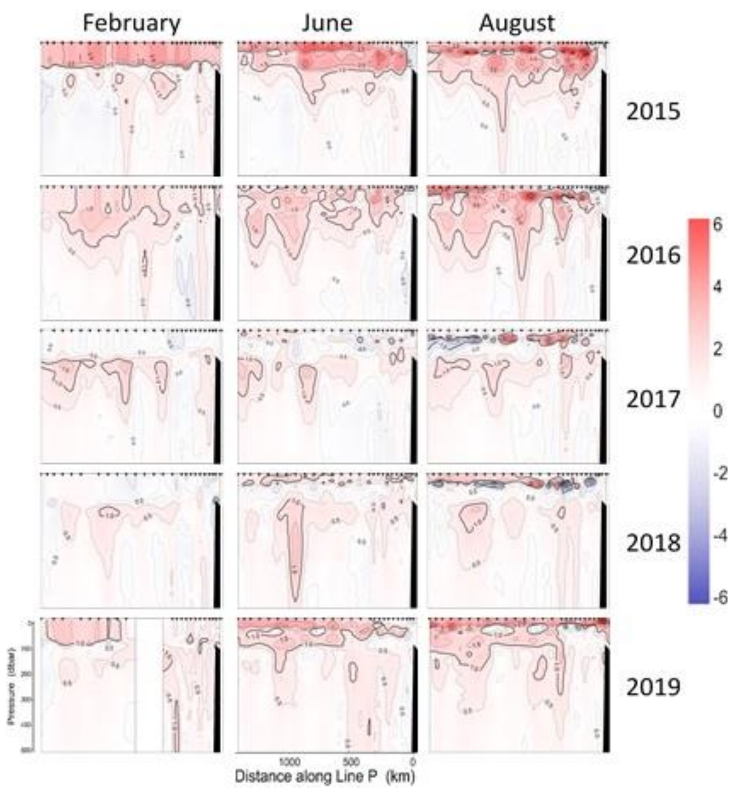

Figure 7-3. Temperature anomalies (°C) along Line P from 2015 to 2019 with respect to the 1981-2010 average.

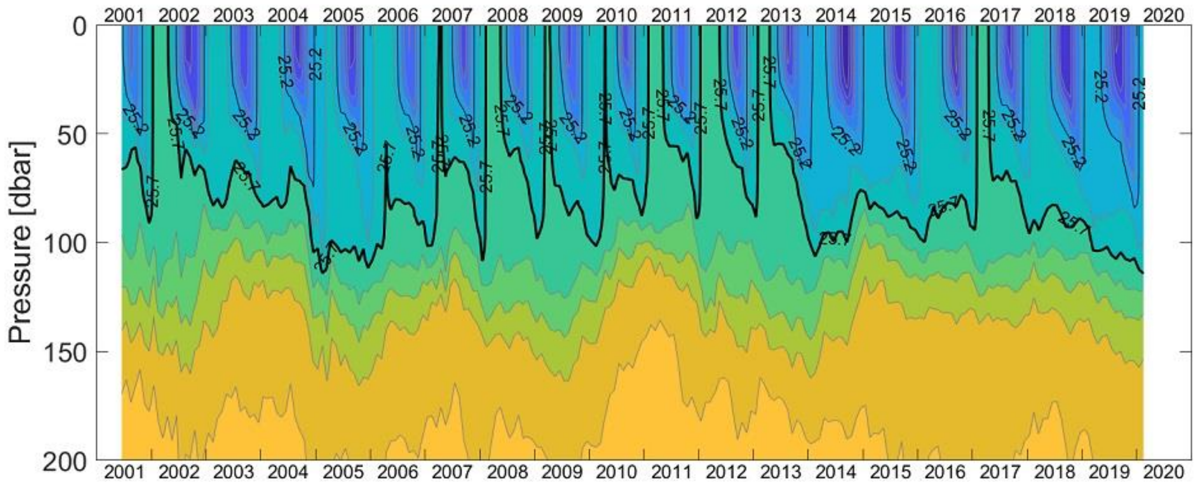

Figure 7-4. Coloured contour plot of density as observed by Argo floats near Station Papa (P26: 50º N, 145 º W). The colours indicate potential density (yellow is denser and blue lighter). The black lines highlight the σ_θ=25.2 kg/m^3 (thin) and 25.7 kg/ m^3 (thick) isopycnals.

P data (Figure 7-3); most strongly in the August 2019 data, which resembles August 2016.

The winter stratification was stronger in 2018/19 than in either of 2017/18 and 2016/17, more similar to the winters during the 'Blob' years (2013/14, 2014/15; Freeland 2015). In 2017 and 2018, it appeared that winter mixing had returned to normal. The history of the σ_Θ=25.7 kg/m^3 isopycnal (highlighted with a thick black line in Figure 7-4) illustrates this nicely. It remained very deep throughout the 2013-2015 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 2019. With the current marine heatwave condition, it is likely that 2019/20 will also have weaker than normal winter mixing.

Looking at the climate indices collectively (Figure 7-5), they indicated that 2019 should have been a fairly normal year; most indicated a slightly warm period, the NPGO suggested

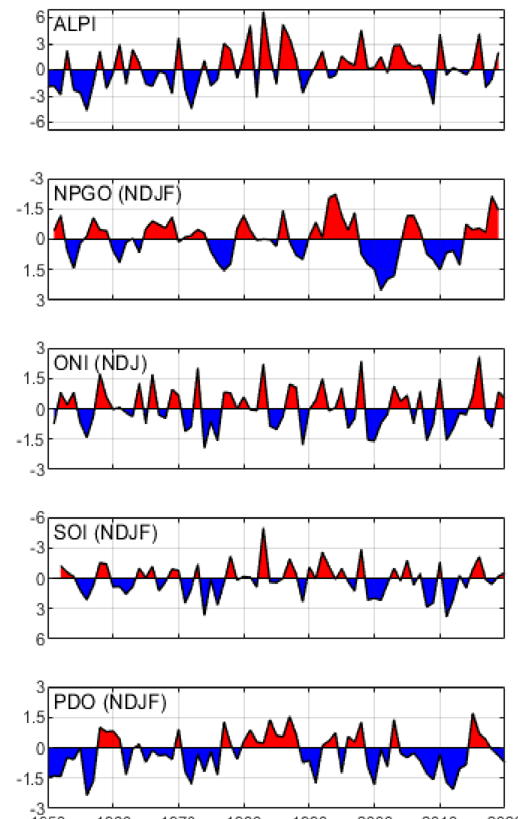

Figure 7-5. Time series of Pacific Ocean climate indices. Each of the monthly indices were averaged over the months indicated and plotted for the year in Jan. Some series are inverted (negative values are above the axes) so that all series are red when coastal B.C. temperatures are anomalously warm.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

very warm, and the PDO suggested cold, so, in sum, nothing extreme. However, the NE Pacific experienced an extreme year with marine heatwave conditions throughout most of the year. This may indicate there is a new normal, that is no longer well represented by the 30- or 60-year means. What is considered a marine heatwave based on these historical distributions may be the new normal. And only when the climate is driving temperatures down (as in 2017 and 2018), do we observe normal temperatures based on the historical climatology. Looking ahead the climate indices are suggesting that 2020 should be less warm than 2019.

7.3. Climate Indices

Aleutian Low Pressure Index (ALPI) is a yearly index that measures the relative intensity of the Aleutian Low pressure system of the north Pacific (December through March). It is calculated as the mean area (in km^2) that has sea level pressure less than or equal to 100.5 kPa and is expressed as an anomaly from the 1950-1997 mean (Surry and King 2015). A positive index value reflects a relatively strong, or intense, Aleutian Low. ALPI is provided by DFO Pacific (PBS) and is available from: http://www.dfo-mpo.gc.ca/science/data-donnees/climatology-climatologie/index-eng.html.

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 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 **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 (5º N-5º S, 120º-170º 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 **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 **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

Roy A.S. Hourston and Richard E. Thomson, Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Roy.Hourston@dfo-mpo.gc.ca, Richard.Thomson@dfo-mpo.gc.ca

8.1. Highlights

- Based on the timing of upwelling-favourable winds and alongshore currents, the 2019 Spring Transition timing was average relative to the 1991-2015 mean which is associated with average upwelling-based coastal productivity.
- Above-average upwelling-favourable winds are generally associated with increased coastal productivity. Between 45°-50° N, the upwelling-favourabe winds were above the 1991-2015 average in the early Spring and Summer and below-average from July to September; from 50°-60° N, the upwelling-favourable winds were below-average for most of the year.
- 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, shifted eastward offshore, or both. These conditions are associated with marine heatwaves, as in 2013-2014.

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).

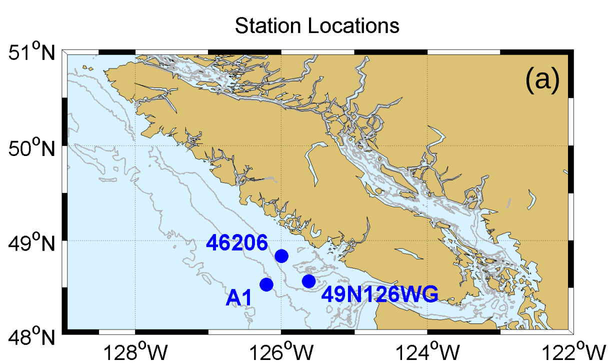

Figure 8-1. (a) Locations of observations delineating historical Spring and Fall Transitions.

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).

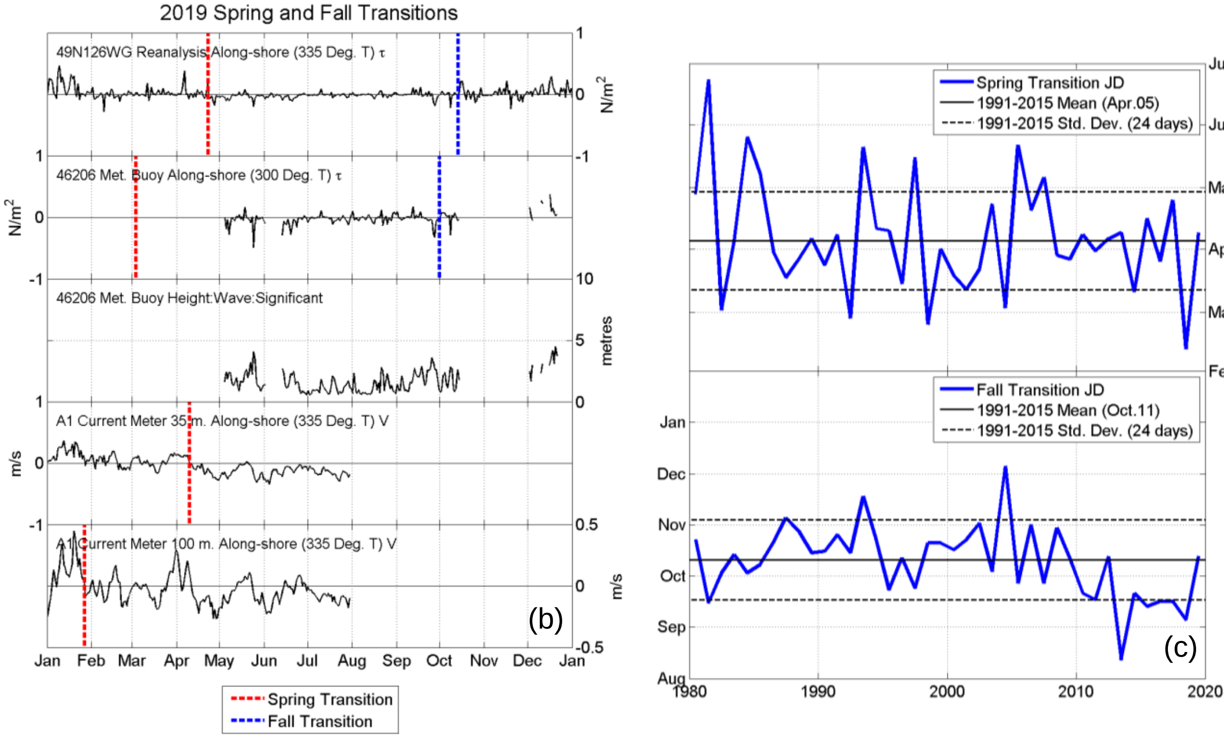

Figure 8-1. (b) Time series depicting the Spring and Fall Transitions off the west coast of Vancouver Island in 2019. Wind stress at Reanalysis-1 grid point 49N126W and meteorological buoy 46206; significant wave height at 46206; along-shore current velocity at 35 and 100 m depth at mooring A1 (Folkes 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 2019, the Spring Transition timing was average compared to the 1991-2015 mean (Figure 8-1 and Figure 8-4). Since 2005, however, it appears to have been generally getting earlier. 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 getting earlier, but not longer.

8.4. 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 1991-2015 mean to derive the Upwelling Index.

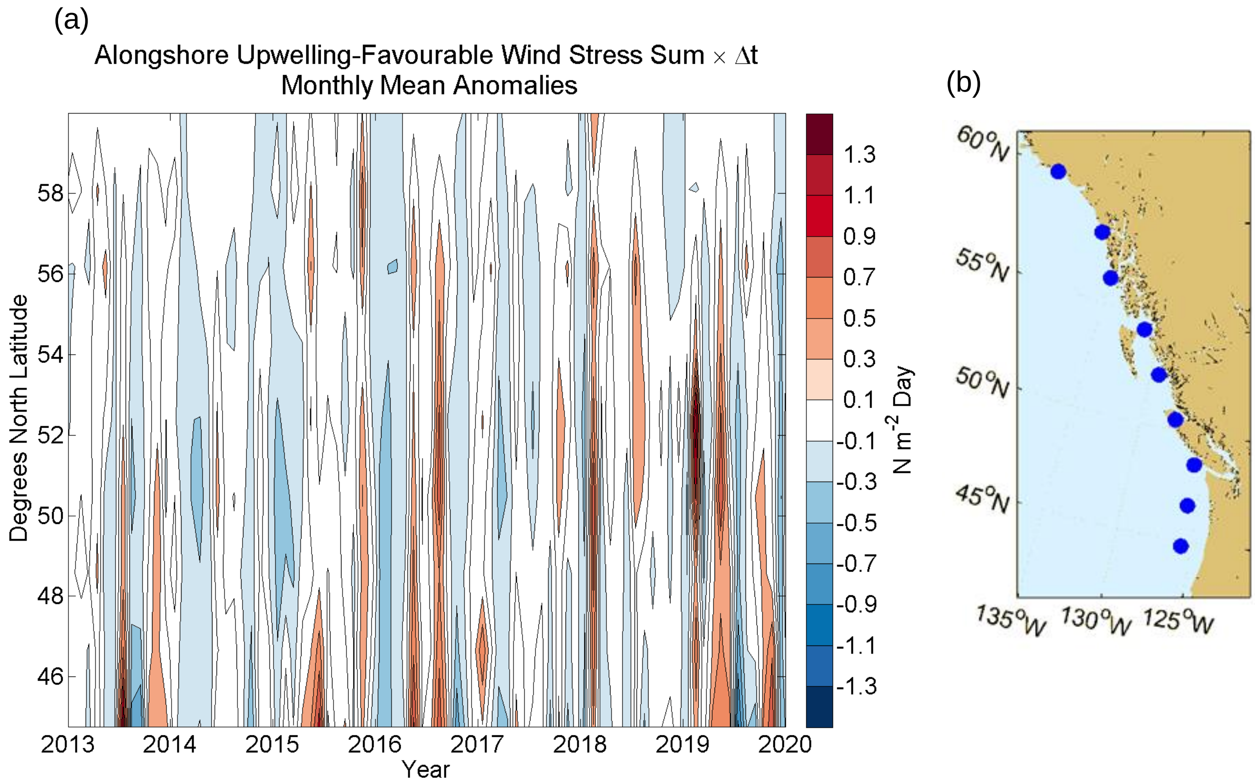

Figure 8-2. Recent (2013 to 2019) monthly mean anomalies (relative to 1991-2015) of monthly sums of alongshore upwelling-favourable (equatorward) wind stress (a) from the NCEP/NCAR Reanalysis-1 coastal surface wind stress grid locations, 45-60° N (b).

8.5. Status and trends

The Upwelling Index time series (Figure 8-2) indicates that upwelling-favourable wind stress was highly variable over the 45°-60° N latitude range in 2019 compared to recent years, with months of both positive and negative anomalies relative to the 1991-2015 average. The Upwelling Index was higher than average overall in 2019. This is in contrast 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.

8.6. Downwelling Magnitude: The Downwelling Index

Analogous to the Upwelling Index, the Downwelling Index is derived in the same way but by 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, or a shift of storm tracks closer or further away from the coast, or both. The index also reflects the strength/weakness of wintertime vertical mixing of the surface water column near the coast.

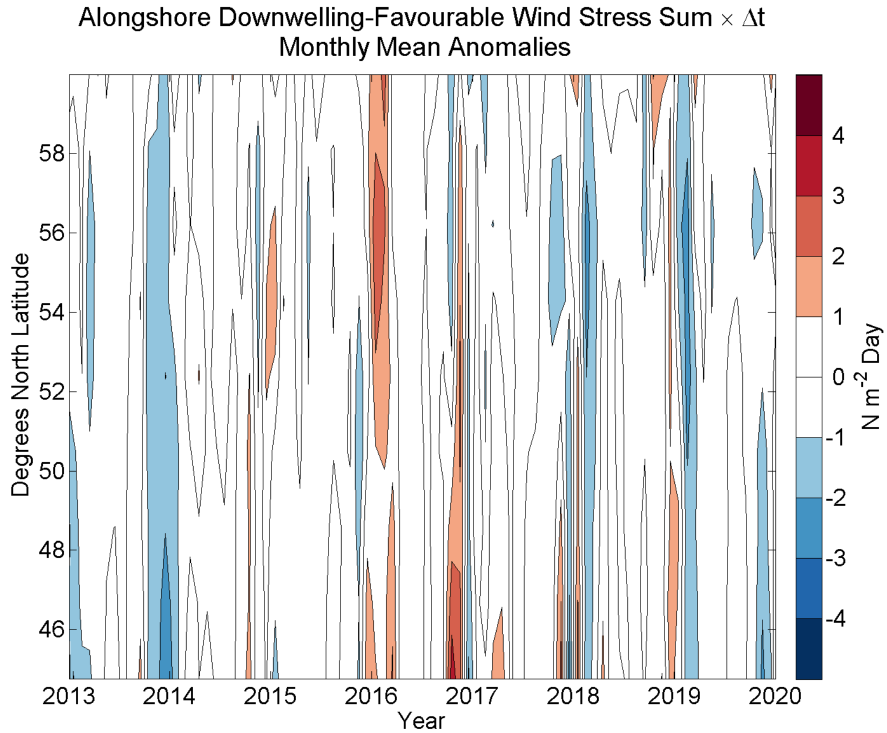

Figure 8-3. Recent (2013 to 2019) monthly mean anomalies (relative to 1991-2015) of monthly sums of alongshore downwelling-favourable (polarward) wind stress from the NCEP/NCAR Reanalysis-1 coastal surface wind stress grid locations, 45-60° N in Figure 8-2(b).

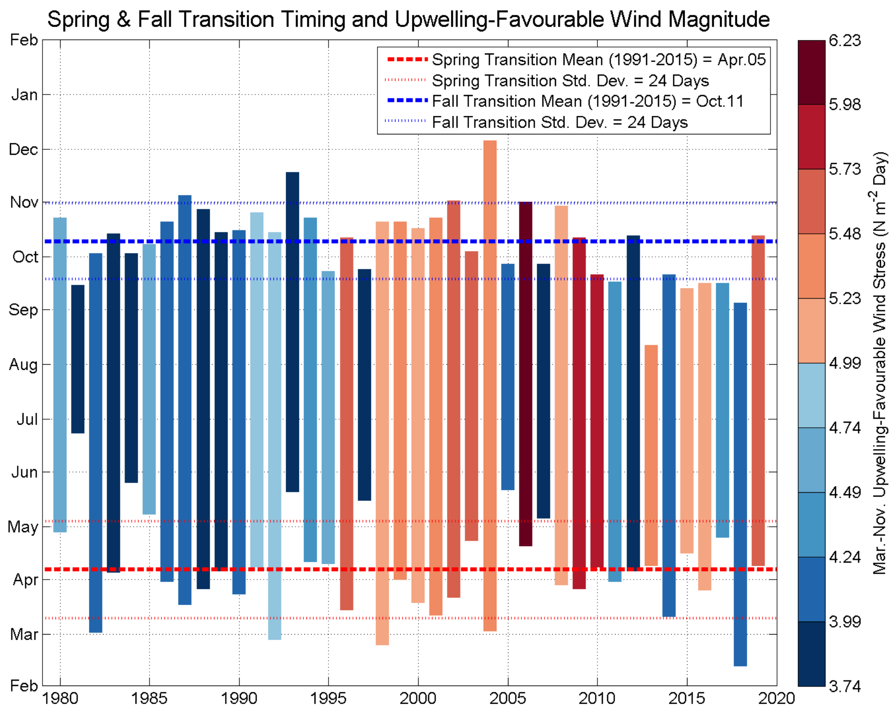

Figure 8-4. Annual Spring and Fall Transition Timing and March-November upwelling-favourable wind stress magnitude, 1980-2019.

8.7. Status and trends

Over the past three winters (2017-2018, 2018-2019, and 2019-2020) the Downwelling Index has been lower than average, as with the winter of 2013-2014, but not quite as low. Like those past years, it is indicative of the observed higher than average temperatures (Hourston and Thomson, Section 9, Figure 9-2(b)) and the marine heatwave conditions in 2019.

8.8. Factors influencing trends

Although the Spring Transition Index for 2019 was about average relative to 1991-2015, the reason for it possibly becoming 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), there have been no apparent trends over the last ten years. However, the significantly weaker-than-average Downwelling Index in 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.

8.9. 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 and Downwelling Indices are not readily apparent.

8.10. 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

Roy A.S. Hourston and Richard E. Thomson, Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Roy.Hourston@dfo-mpo.gc.ca, Richard.Thomson@dfo-mpo.gc.ca

9.1. Highlights

- In the summer of 2019, record high sea surface temperatures were recorded at weather buoy 46206 on the west coast of Vancouver Island. In early 2019 at nearby mooring A1 the temperature at 175 m was higher than twice the 25 year standard deviation over 1991-2015 for several consecutive days (Figure 9-2).
- Alongshore flow in 2019 was anomalously equatorward (upwelling-favourable) in February.
- Over the long-term, the west coast shelf-break wind stress and surface and subsurface currents have returned to near-average conditions after 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 over the last three years, but remain high at depth.

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.

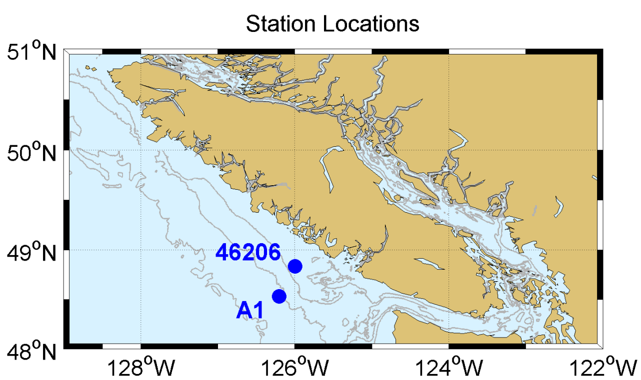

Figure 9-1. Locations of mooring A1 and meteorological buoy 46206.

9.3. Status and trends

At the beginning of 2019, temperatures at 175 m depth were significantly higher than the 1991-2015 average (Figure 9-2, left). This may have been the case at other depths, however there were no data at the surface (buoy failed) and 35 and 100 m (mooring hit and instruments lost). Temperatures were also significantly higher at the surface in July-September but again there are no data at depth (that mooring deployment will be recovered in summer, 2020). These conditions likely reflect continuing marine heatwave conditions.

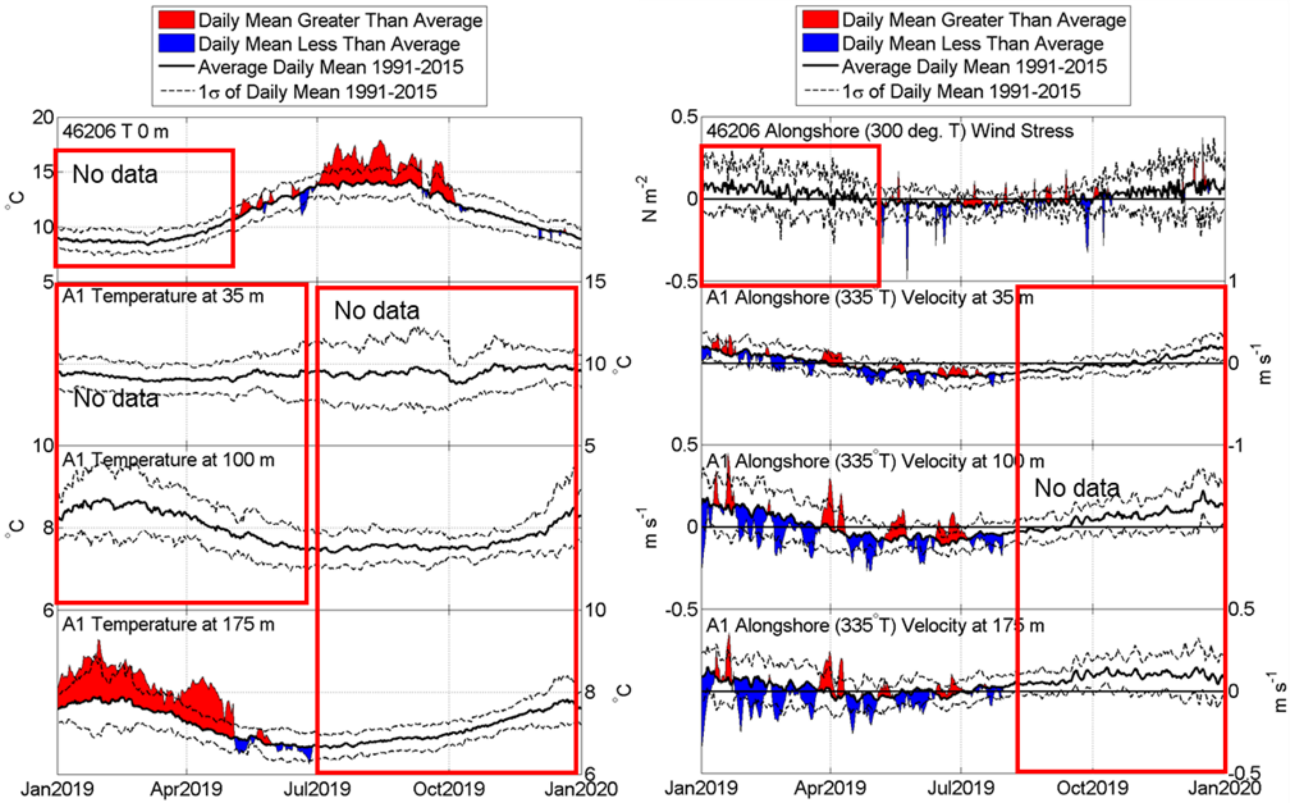

Figure 9-2. Daily means. Temperature (left panels) and alongshore wind stress/ocean current (right panels) at the surface, 35 m, 100 m, and 175 m depth from meteorological buoy 46206 and mooring A1. Angle in brackets (°T) is the principal direction of the wind or current vector in degrees true compass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

Alongshore surface winds and currents were generally near 1991-2015 average conditions (Figure 9-2, right). However, flow was consistently and anomalously equatorward (upwelling-favourable) in February-March. There are no data at the beginning of the year at the surface (buoy failed) and subsurface after July (that mooring deployment will be recovered in summer, 2020).

Figure 9-3 shows monthly mean temperature values for 2010-2019. Most evident are the positive temperature anomalies associated with the marine heatwave and El Niño over 2014-2016, The positive temperature anomalies have reappeared in 2019 at the surface and continued at 175 m depth. 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 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.

Higher temperatures and enhanced poleward flow were also observed during the previous strong El Niño in 1997-1998 (Figure 9-4). While flow has generally returned to long-term average conditions, observed temperature anomalies are still highly positive.

9.4. Factors influencing trends

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 and equatorward flow in summer, both of which were evident.

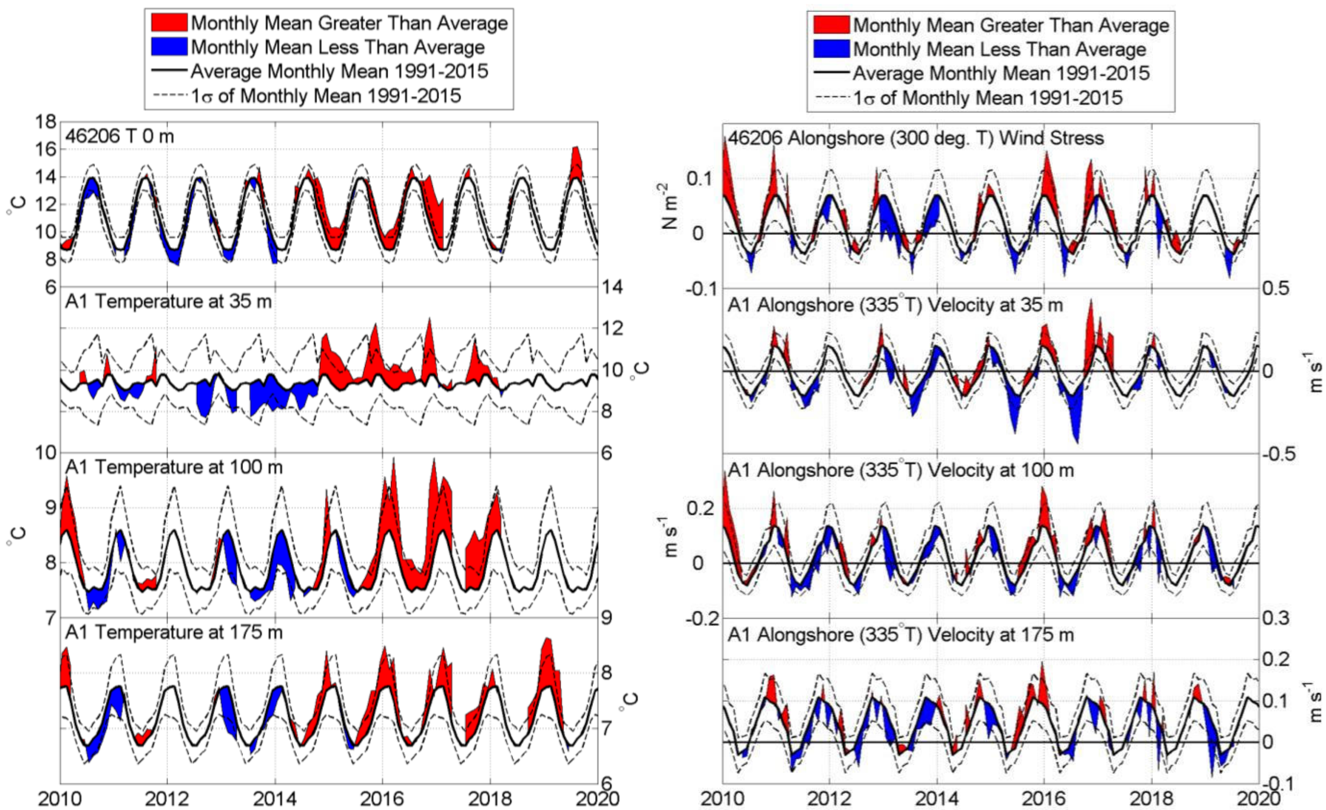

Figure 9-3. Monthly means. Temperature (left panels) and alongshore wind stress/ocean current (right panels) at the surface, 35 m, 100 m, and 175 m depth from meteorological buoy 46206 and mooring A1. Angle in brackets (ºT) is the principal direction of the wind or current vector in degrees true compass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

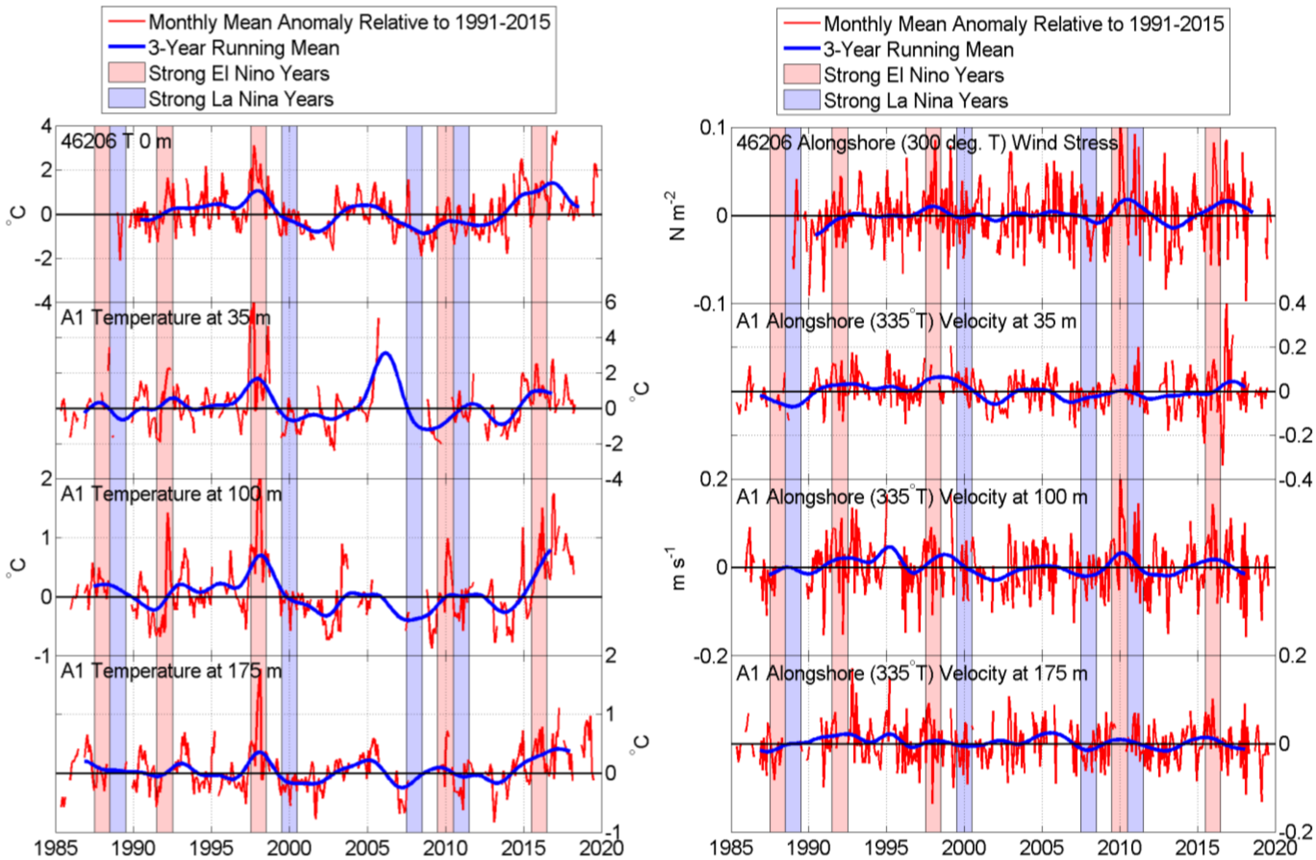

Figure 9-4. Monthly anomalies. Temperature (left panels) and alongshore wind stress/ocean current (right panels) at the surface, 35 m, 100 m, and 175 m depth from meteorological buoy 46206 and mooring A1. Angle in brackets (°T) is the principal direction of the wind or current vector in degrees true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

10. SEA SURFACE TEMPERATURE AND SALINITY OBSERVED AT SHORE STATIONS AND WEATHER BUOYS IN BRITISH COLUMBIA, 2019

Peter Chandler, Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Peter.Chandler@dfo-mpo.gc.ca

10.1. Highlights

- The average annual sea surface temperature (SST) from the 12 contributing shore stations in 2019 (10.83 °C) was generally warmer than in 2018 with a coast-wide average annual increase in SST of 0.16°C.
- Seven of the 12 coastal weather buoys provided sufficient data in 2019 for statistical analysis. The average annual SST from the seven coastal wave buoys in 2019 (11.11 °C) was generally warmer than in 2018 with a coast-wide average annual increase in SST of 0.10°C.
- Anomalies from the long-term average (1935-2019) SST record show periodic warm and cold periods with durations of several years; 2019 is a continuation of a warm period starting in 2014. This span of above normal annual SST is tied with the longest warm period on record (seven years from 1992-1998).
- The long-term data from the shore stations shows a linear trend to warmer coastal SSTs of 0.86 °C over 100 years.
- Annual salinity observations showed a decrease at six of 12 stations with an average coast-wide decrease of 0.13 (standard deviation of 0.07).

10.2. Description of the time series

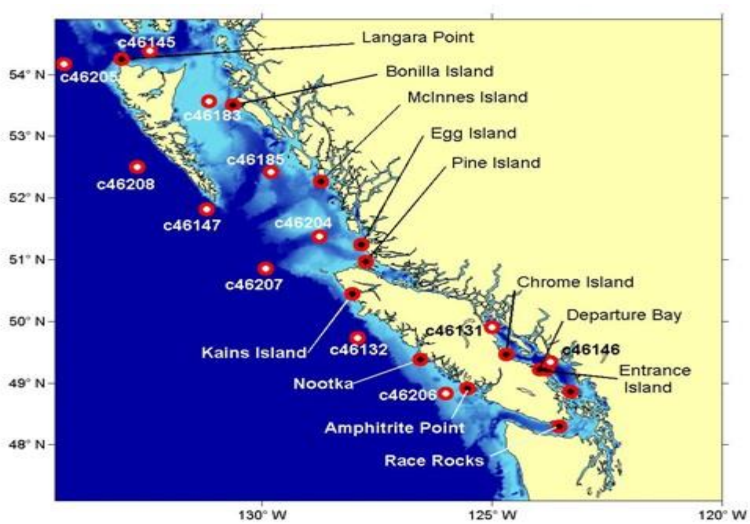

Figure 10-1. Red dots with black centers show the locations of 12 shore stations. Red dots with white centers show the locations of 12 weather buoys. See table below for details.

Station	Years of data
Departure Bay	104
Race Rocks	97
Nootka	52
Amphitrite	83
Kains I	83
Langara	82
Entrance I	83
Pine Island	82
McInnes	64
Bonilla	58
Chrome I	57
Egg Island	48

Buoy ID	Buoy Location	Years of data
c46146	Halibut Bank	27
c46131	Sentry Shoal	27
c46206	La Perouse	30
c46132	South Brooks	25
c46207	East Dellwood	30
c46147	South Moresby	26
c46208	West Moresby	29
c46205	West Dixon	31
c46145	Central Dixon	28
c46204	West Sea Otter	30
c46185	South Hecate	28
c46183	North Hecate	28

Two sources of data are used to describe changes in sea surface conditions in the coastal waters of B.C. in 2019. As part of the DFO 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 SST 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 warmer in 2019 than in 2018 (mean increase of 0.16 °C). There was a cluster of stations around northern Vancouver Island (Nootka, Kains and Pine) that showed higher SST increases in 2019 than observed at other stations (mean increase of 0.60 °C). The weather buoys data show an annual average increase in daily SST from last year of 0.18 °C (excluding stations with high uncertainty due to missing data or sensor accuracy, e.g. Laperouse and North Hecate).The coast-wide SST in 2019 was 0.66 °C lower compared to conditions in 2015 during the marine heatwave known as “the Blob”, but still 0.47 °C and 0.57 °C warmer than the 30 year climatology for the shore station data (1981-2010) and weather buoy data (1991 – 2018), respectively.

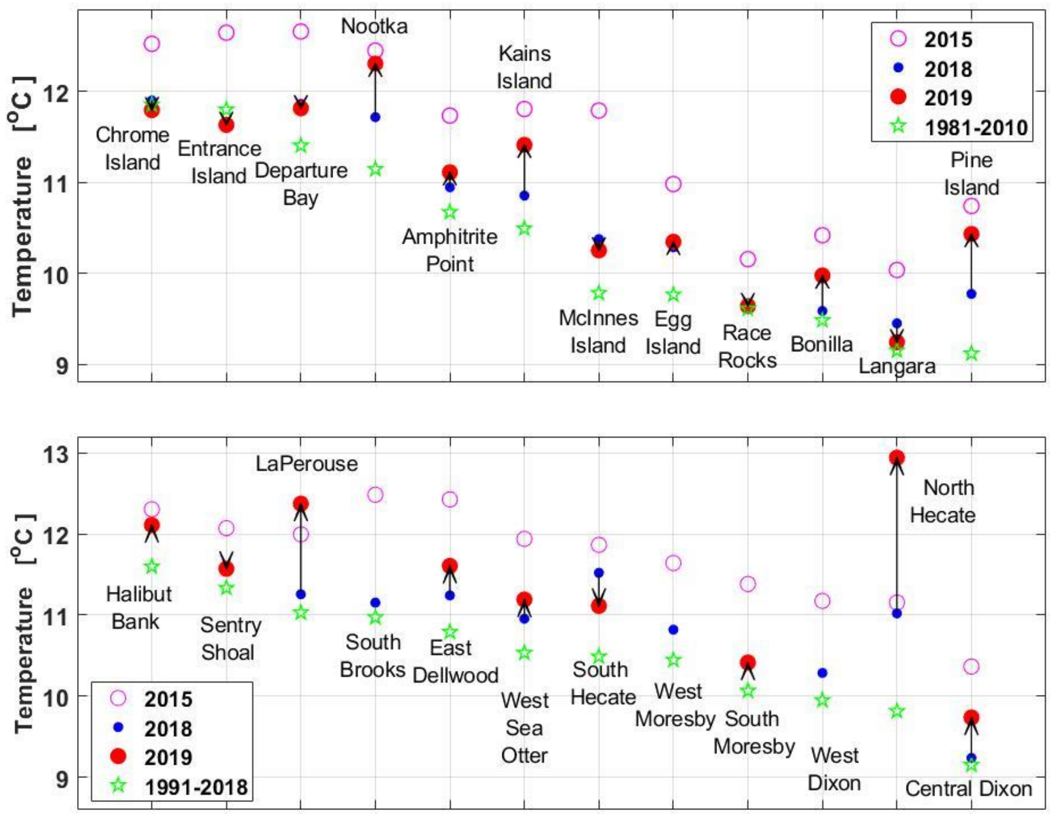

Figure 10-2. Upper panel. The average SST in 2018 (dark blue dots), and 2019 (red dots) from daily observations at shore stations along the west coast of Canada. Lower panel. The average SST from hourly observations at weather buoys along the west coast of Canada. The open circles show conditions in 2015 when SST was significantly higher than normal, the stars represent the climatological mean annual temperature.

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 0.86 °C over 100 years.

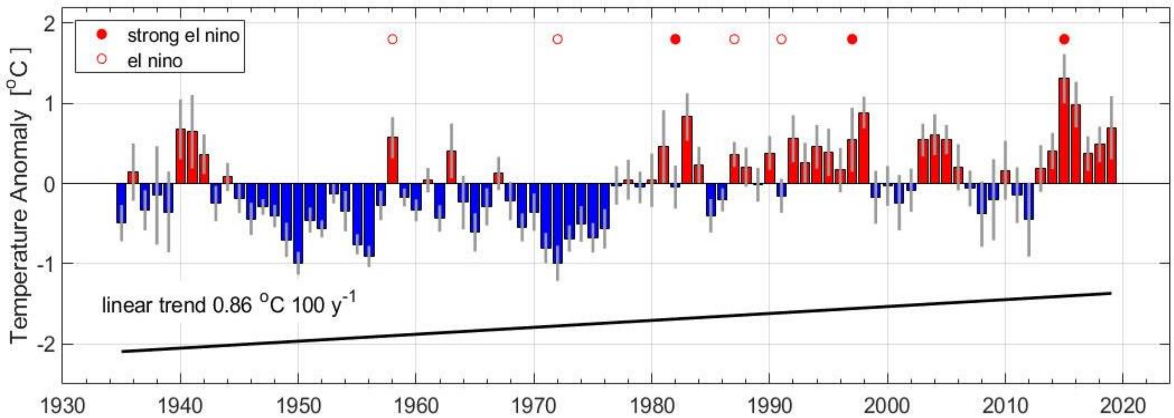

Figure 10-3. The trend in the annual temperature based on the observations of all lighthouses. The data shown are the anomalies from the long-term average temperature (1935-2017). The bars represent the anomalies averaged over all stations (a coast-wide indicator), (red – above average, blue – below average), the vertical grey lines show the variability in the lighthouse data for each year.

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 although recent years show more saline conditions.

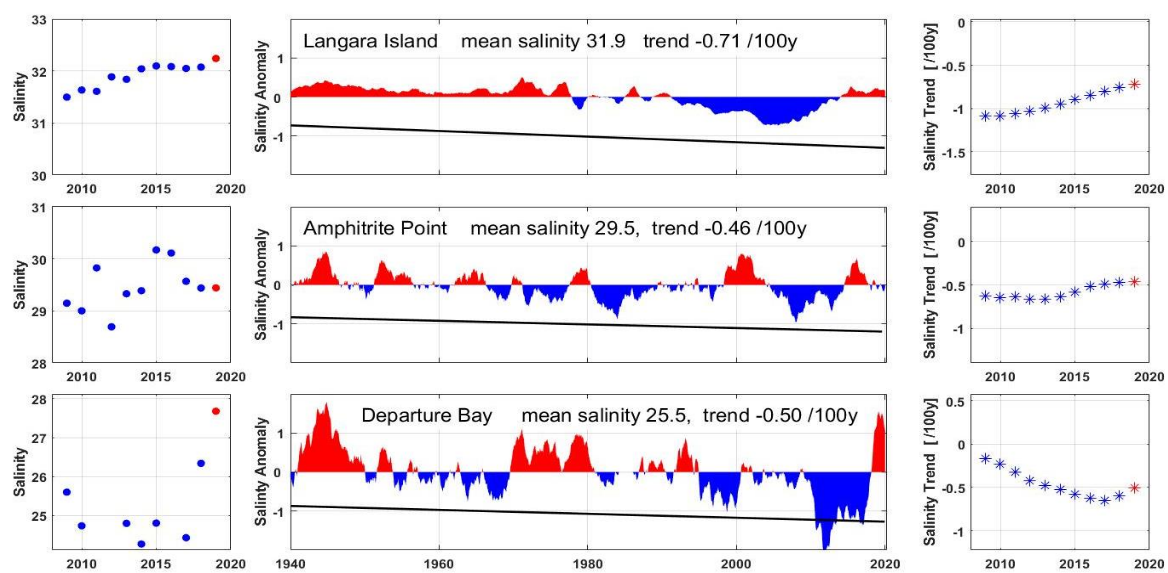

Figure 10-4. Time series of daily salinity observations, averaged over 12 months, at stations representing the North Coast, West Coast of Vancouver Island and Strait of Georgia. Positive anomalies from the average temperature of the entire record are shown in red, negative in blue. The left panel shows the annual mean SST 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

Although SSTs were warmer during the marine heatwave of 2014-16 the SSTs in 2019 continue the period of warmer than normal water. This warm water period started late in 2013 and its duration matches the record warm water episode (seven years from 1991 – 1998).

The marine heatwave activity observed further offshore (Ross and Robert, Section 7) in the satellite data was not evident in the near shore data in 2019, with the exception of the North Hecate weather buoy (note: the North Hecate data are under review as the SST signal is much larger than expected).

The long-term (80 year) temperature record shows that when overlying the 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

SST and salinity are fundamental water properties defining the habitat of organisms that live in the upper waters of the ocean. The impacts of these changes to the water properties 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 Galbraith and Young (Section 16), and Hyatt et al. (Section 22).

10.6. References

Cummins, P.F., and Masson, D. 2014. Climatic variability and trends in the surface waters of coastal British Columbia. Progress in Oceanography 120: 279–290.

11. OXYGEN CONCENTRATION IN SUBSURFACE WATERS

Bill Crawford and Angelica Peña, Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Bill.Crawford@dfo-mpo.gc.ca, Angelica.Pena@dfo-mpo.gc.ca

11.1. Highlights

- In late summer the concentration of dissolved oxygen (O_2) in the subsurface waters on the continental shelf of southwest Vancouver Island is generally low. Observations in 2019 showed normal (based on 40 years of data) O_2 levels on the northern shelf but a record low level (0.63 ml/L) at the southern station LB08.
- O_2 has been monitored along Line P for over 60 years. O_2 continued its 60-year decline seaward of 700 km along Line P. Little overall change has been observed at constant depths from the continental slope to 700 km along Line P.
- Lower O_2 in subsurface water on the continental shelf and slope in the past 30 years is generally associated with warmer, saltier water that flows from the south, whereas higher O_2 is found in cooler, fresher water that advects from the west.

11.2. O_2 on the continental shelf

A plot of historical near-bottom O_2 in summer is presented in Figure 11-1. Symbols reveal locations where hypoxia was observed. (Hypoxia is defined as O_2 less than 1.4 ml/L or 60 µmol/kg.) Many of these symbols are in inlets where deep seawater is naturally hypoxic due to low rates of water inflow from outside regions.

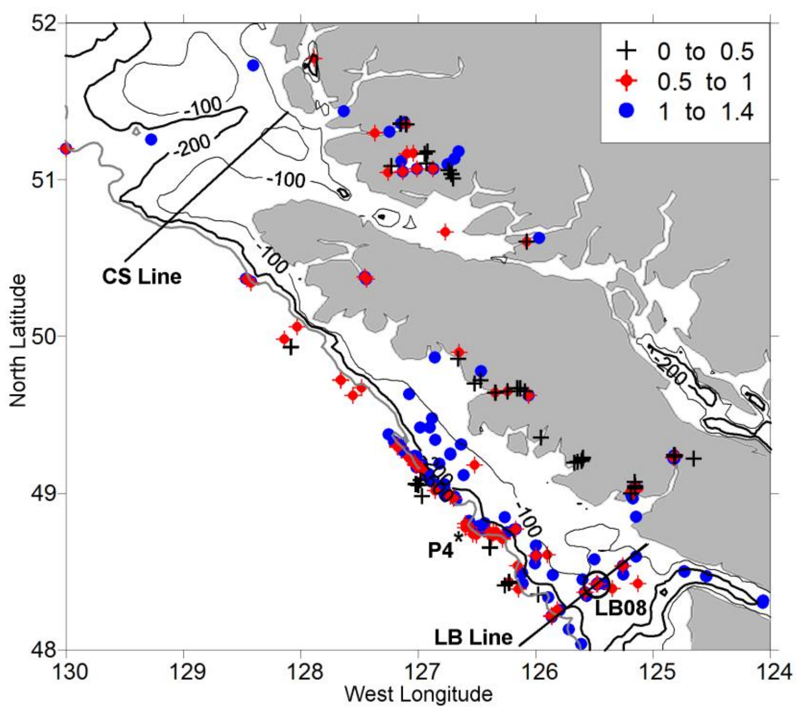

Figure 11-1. Oxygen concentration (O_2, ml/L) in summer within 20 metres of the ocean bottom for regions of the continental shelf and slope where bottom depth is less than 1000 metres. (1 ml/L = 43 µmol/kg) Each symbol represents a measurement by DFO research programs. Only observations with O_2 less than 1.4 ml/L (60 µmol/kg) are plotted. The symbol ***O*** *denotes the location of Station LB08, where O_2 has been monitored since 1979. LB Line is indicated by a black line through LB08. CS Line is north of Vancouver Island. 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 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.

The annual cycle of O_2 off SW Vancouver Island is presented in Figure 11-2. This graph shows that O_2 is usually lowest between mid-August and early October (days 230 to 280). One can see a general decrease in late summer from higher O_2 in 1979 - 2005 to lower O_2 in 2006 - 2019, excluding 2015.

Based on preliminary data the lowest O_2 concentrations on record (0.63 ml/L, 28 µmol/kg) were observed in 2019. O_2 concentrations in 2017 and 2018 were 0.80 and 0.86 ml/L (35 and 37 µmol/kg), respectively, very close to the record low in 2019. 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 Boldt et al. (2019).

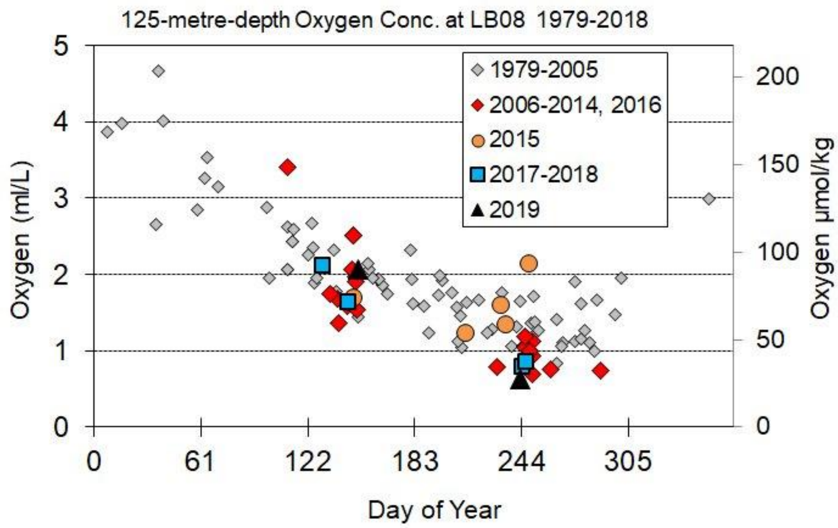

Figure 11-2. Oxygen concentration (O_2) *at 125 metres below the ocean surface at Station LB08. Symbols represent observations plotted on the day of the year the sample was collected. Day 244 is 1 Sept. The depth of ocean bottom here is 145 metres. Figure is based on Crawford and Peña (2013).*

The low O_2 at LB08 in late summer tends to be observed in denser, saltier water possibly due to an increase in northward flow of upwelled Pacific Equatorial water along the continental slope. Highest O_2 is usually found in fresher water that flows from the west. Therefore, much of the variability is due to different blends of these two water types. In addition, some of the low O_2 in 2017 to 2019 is likely due to increased upwelling and biological respiration in near-bottom waters.

Figure 11-3a shows cross-shelf contours of O_2 along LB Line averaged for the period of 2006 to 2018 (excluding 2015) corresponding to the recent era of low O_2 at LB08 shown in Figure 11-2. Lowest O_2 near bottom in Figure 11-3a is at LB08, at about 40 km from Station LB01, which itself is close to Vancouver Island. O_2 is higher at stations shoreward of about 40 km due to the oxygen-rich Vancouver Island Coastal Current that flows to the northwest here. The doming of O_2 contours is due to the proximity to the core of the Juan de Fuca Eddy. Figure 11-3b shows O_2 in late summer 2019 when O_2 was the lowest ever measured at 125 metres depth at LB08.

In 2019 low levels of O_2 in near-bottom waters extended along line LB 20 to 60 km from LB01. Further offshore O_2 was higher than the 2006 to 2018 average at most depths.

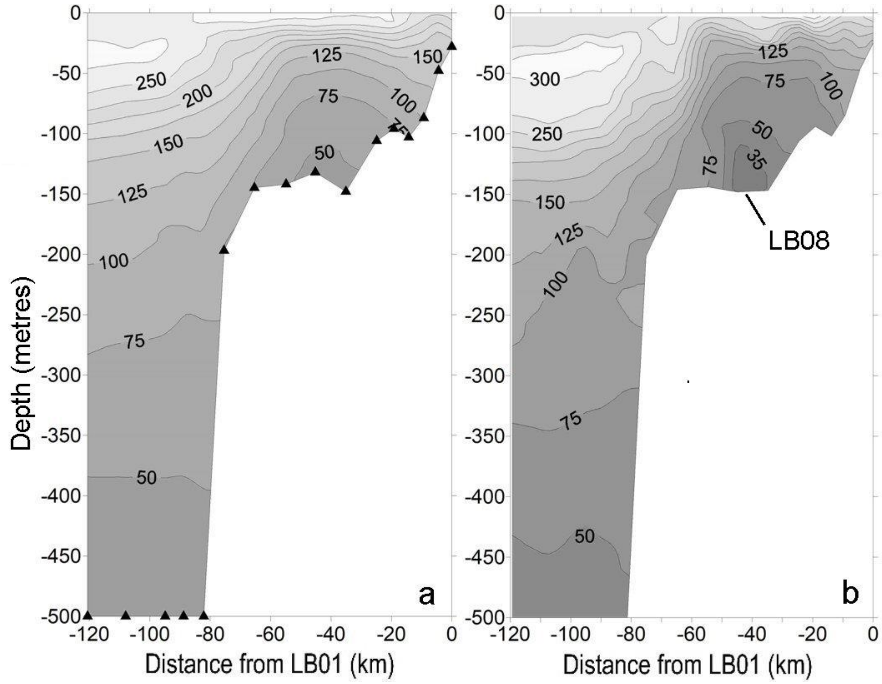

Figure 11-3. Oxygen concentration (µmol/kg) on the continental shelf and slope along LB Line of DFO sampling stations of southwest Vancouver Island. Contours show concentration in late summer for (a) average of years 2006 to 2018 (excluding 2015), and (b) 2019. LB01 is at the shoreward end of LB Line. See Figure 11-1 for location of LB Line.

Farther north along CS Line (see Figure 11-1 for location) O_2 in 2019 was close to the average observed over the period 2005 – 2018 (excluding 2015), so the extreme low in O_2 along LB line in 2019 does not represent this region.

11.3. Oxygen concentration in continental slope and offshore waters

There are few stations in 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 archives. Details of this process and results to 2011 are described by Crawford and Peña (2016). We present updates for Ocean Station P (OSP) and for Station P4 in Figure 11-4 below. OSP lies about 1400 km seaward along Line P in 4300 metres of water. P4 is on the continental slope in 1300 metres of water (Figure 11-1).

Seaward of the continental shelf, the dynamic height of subsurface waters moves up and down with the seasons and even with changes in local winds, creating a noisy record of O_2 at absolute depths. To suppress this noise, we calculate O_2 on constant-density surfaces rather than at constant depth. Observations of O_2 on constant- density surfaces are presented in Figure 11-4.

There is a general decrease in O_2 at OSP since 1956 (Figure 11-4a), modulated by an oscillation that fits the 18.6-year lunar nodal cycle (black dotted line); a feature first noted by Whitney, Freeland and Robert (2007). O_2 at constant depths have also decreased in this period (Cummins and Ross, in press).

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 27.9 density surfaces (Figure 11-4b). O_2 at P4 has increased somewhat since 2012, but concentrations were still below the peak in the 1980s. This overall decrease is generally compensated by increasing depths of the same constant-density surfaces, so that O_2 at constant depths in recent years is about the same as in 1980.

(a) *(b)*

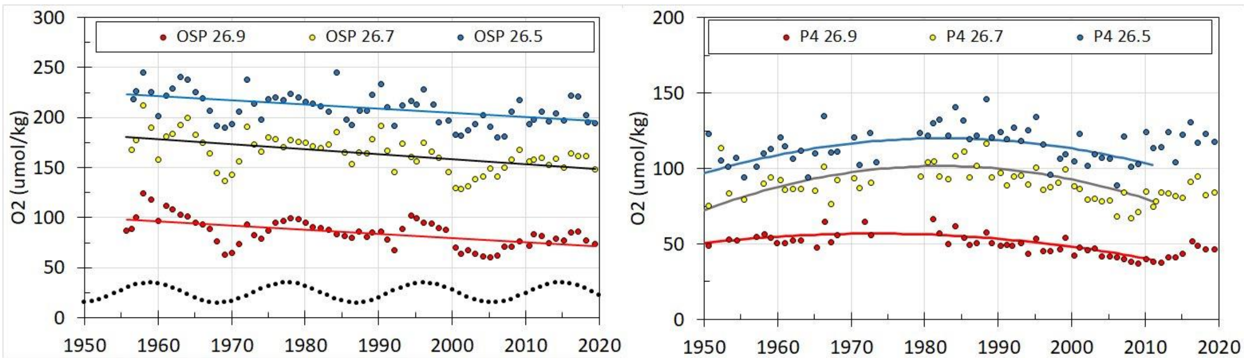

Figure 11-4. Annual average oxygen concentration (O_2) at (a) Ocean Station P (OSP) in offshore region, and (b) Station P4 on the continental slope. O_2 has been interpolated onto the constant-density surfaces 26.5, 26.7, and 26.9, representing potential densities of 1026.5 to 1026.9 kg/m^3. Typical depths of these density surfaces are 130, 170 and 300 m at OSP, and 180, 280 and 490 at P4. Trends at OSP are -0.4 µmol kg^{-1} y^{-1} on the 26.5 and 26.9 surfaces, and -0.5 µmol kg^{-1} y^{-1} on the 26.7 surface. Figure is based on Crawford and Peña (2016) and Whitney et al. (2007).

11.4. References

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11.5. Acknowledgements

We acknowledge Nick Bolingbroke, Marie Robert, Akash Sastri, Germaine Gatien, Di Wan of DFO, the Marine Environmental Data Service of DFO Ottawa, and NOAA National Centers for Environmental Information.

12. SATELLITE OBSERVATIONS OF B.C. WATERS

Jim Gower, Fisheries and Oceans Canada, Institute of Ocean Sciences, North Saanich, BC, jim.gower@dfo-mpo.gc.ca

12.1. Highlights

- Global indicators show accelerating climate change. The Keeling Curve representing global carbon dioxide concentration, the global average sea level and the global average SST all show continuing, exponential increases.
- Differences between the Keeling curve and an exponential model (Figure 12-1) show the effect of major volcanic eruptions in causing short, but significant reductions in CO_2 concentration by fertilizing the ocean with iron. So far, the only direct observation of this effect from a volcano is in waters near Station Papa in 2008 (Hamme et al. 2010).
- The spring bloom in the Strait of Georgia started on about 8 March 2019 in the central Strait, preceded by blooms in Sechelt Inlet and Malaspina Strait.
- A bright bloom, assumed to be Coccolithophores, was observed in Hecate Strait from 15 to 23 July 2019.
- A bloom whose signature in satellite imagery suggests *Heterosigma*, was observed in and off Barkley Sound in September 2019.

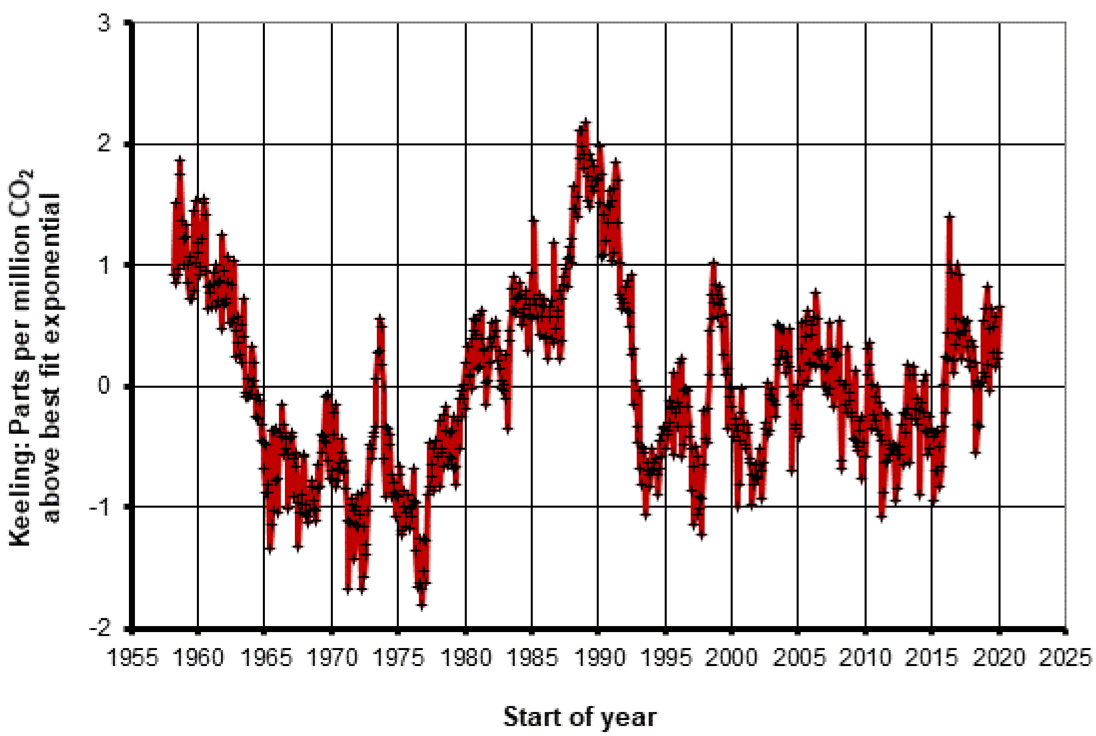

Figure 12-1. Concentration of carbon dioxide in the earth's atmosphere after removing the annual cycle and the exponentially increasing "business as usual" trend. The residual drops after eruption of Mt Agung (1964) and Pinatubo (1991) and following the El Niños in 1973, 1998 and 2016. Difference from continuing exponential growth has been mostly less than 1ppm in spite of efforts to reduce emissions.

12.2. Description of the time series

The "Keeling curve" (ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_mm_mlo.txt) shows carbon dioxide concentrations in the earth's atmosphere since 1957. The data now suggest an exponential increase: $CO_2(ppmv) = 257.5 + 111.5 \times 10^{(0.0164(year-2000))}$. In response, the global average sea level measured by satellite altimetry from 1993 to 2020 (https://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/mean-sea-level.html), and the average sea surface temperature anomaly measured from 1850 to 2020 (https://www.metoffice.gov.uk/hadobs/hadsst3/) are rising exponentially as:

$sea\ level = 15.25\ \times 10^{(0.0194(year-2000))}$ and $SST_{av} anomaly\ (C) = 0.64 \times 10^{(0.0195(year-2000))}$,

respectively.

In the past the timing of the spring bloom in the Strait of Georgia has been determined from MODIS and Sentinel 3 satellite imagery (Figure 12-2), with in-situ fluorometers mounted on B.C. ferries along ferry routes from Nanaimo to Tsawwassen and Horseshoe Bay by Oceans Networks Canada, and fluorescence data at two surface weather buoys. Only one ferry route recorded data in 2019 and the weather buoys are no longer equipped with fluorometers, but a Viking buoy deployed in 2018 in the northern Strait is being regularly serviced and recorded data up to 6 Feb 2020.

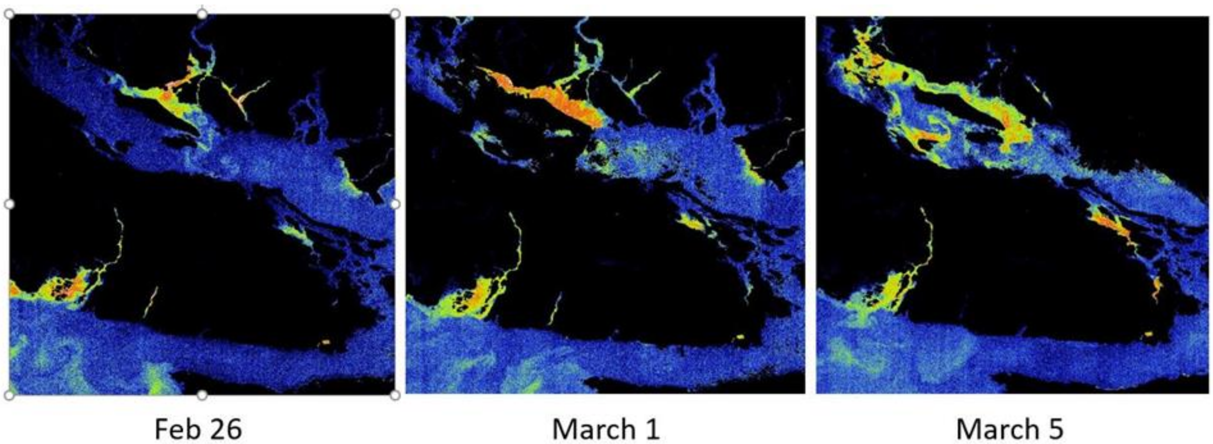

Figure 12-2. OLCI FLH images of the start of the spring bloom in the Strait of Georgia in 2019 (300 m resolution). As in 2018, the 2019 SoG spring bloom started after a bloom in Sechelt Inlet (before Feb 26), which spread and covered Malaspina Strait (March 1). This is another example of the "Malaspina Dragon" seeding which led to early spring blooms in 2005, 2008 and 2009.

Bright, Coccolithophore, blooms give a strong signal measured by many satellite imaging systems. NASA's Worldview (https://worldview.earthdata.nasa.gov/) provides a convenient daily display from MODIS and VIIRS instruments and showed bright water in Hecate Strait July 15 to 23, 2019 (Figure 12-3).

The *Heterosigma*-like bloom was detected in the September and October monthly global composite images that have been computed by the European Space Agency (Gower et al. 2008) from image data collected by MERIS (2002 to 2012) and Ocean and Land Colour

Instrument (OLCI; since 2016). These two instruments are the only global systems providing measurements in the 709nm spectral band where surface slicks of *Heterosigma* give a characteristic peak signal, measured by the MCI (Maximum Chlorophyll Index). The image in Figure 12-4 is derived from the full 300 m resolution image data of OLCI.

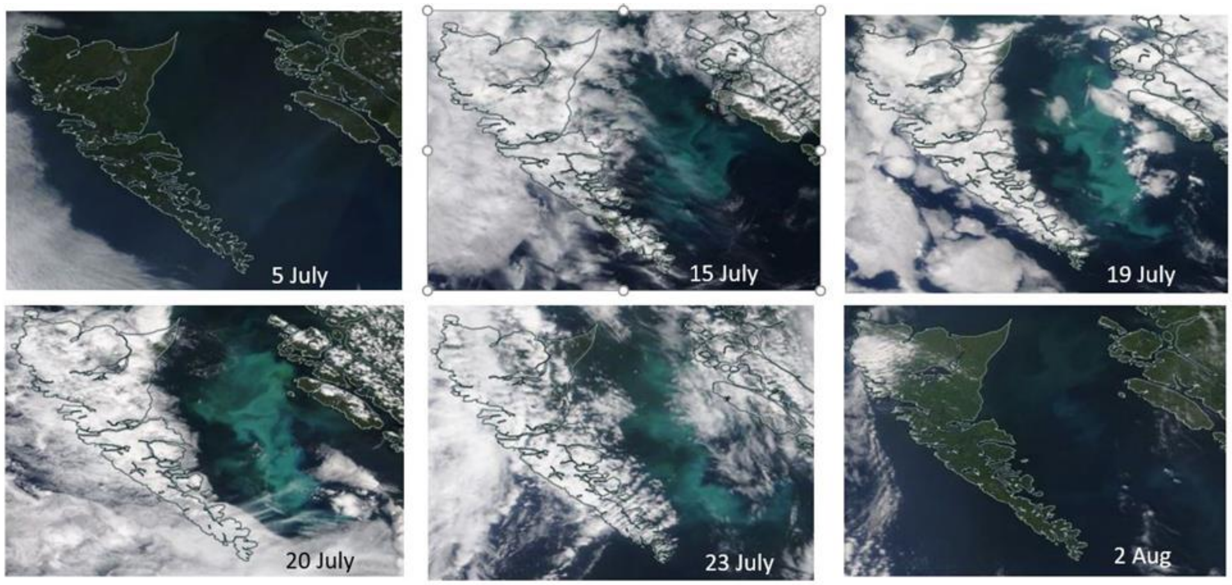

Figure 12-3. MODIS-T images at 250 m spatial resolution showing bright water in Hecate Strait from 15 to 23 July 2019.

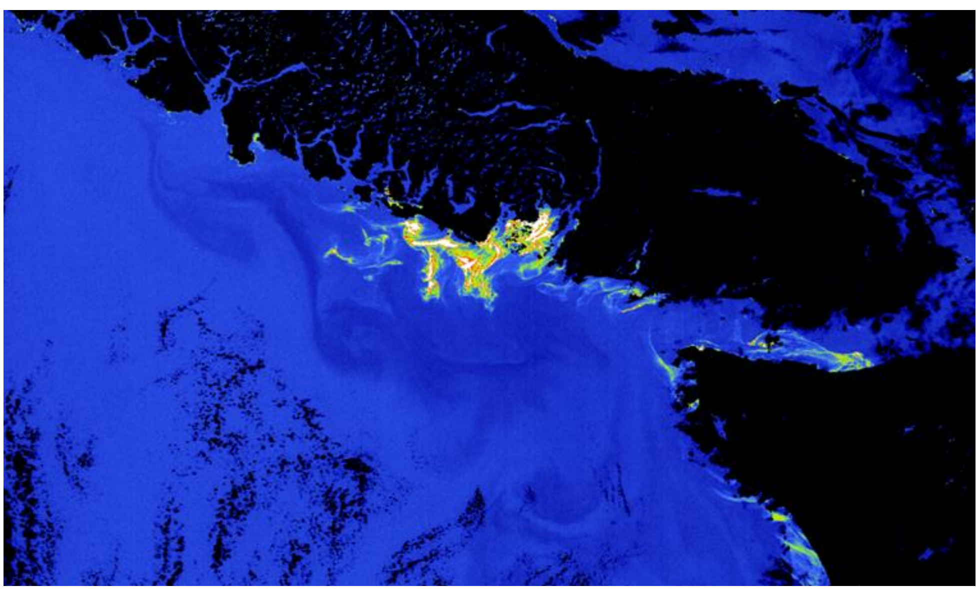

Figure 12-4. OLCI image at 300 m spatial resolution, showing water with high MCI signal in and near Barkley Sound on 18 August 2019.

12.3. Status and trends

In 2019, the Keeling measurements of the carbon dioxide concentration suggest that an exponential increase model best fit the data, in spite of global plans for emission reductions.

Residual differences from the long-term model (Figure 12-1) show the effects of volcanic eruptions (Agung in 1964, Pinatubo in 1991) and of El Niños (1971, 1998 and 2016). In response to the exponential rise in CO_2, global average sea level and sea surface temperature both show exponentially rising trends which would result in 40 cm of rise and 1.6 ^{o}C of warming by 2050, and 110 cm of rise and 4 ^{o}C of warming by 2100.

Near surface chlorophyll concentrations in the Strait of Georgia were monitored in 2019 by satellites and fluorometers on ferries and weather buoys. Images showed the pre-cursor blooms in Sechelt Inlet and Malaspina Strait (Figure 12-2). Satellite images and in-situ instruments gave a consistent start date for the start of the spring bloom, 8 March 2019.

In 2019, the only significant Coccolithophore bloom on the B.C. coast was observed in July in Hecate Strait. Similar blooms were noted along the B.C. coast in 2018, but were less intense and in fewer inlets than in 2016, the recent peak year.

The bright, *Heterosigma*-like bloom in 2019 was first observed in Sentinel 3a satellite imagery using the MCI index, spreading from the waters of Barkley Sound on 18 September 2019 (Figure 12-4), and extending further along the outer coast of Vancouver Island to the northwest by 30 September. Species reported in the area were *Ceratium* and *Heterosigma*.

12.4. Factors influencing trends

Emissions from burning fossil fuels have raised carbon dioxide levels in the atmosphere from 280 ppmv in pre-industrial times (before about the year 1850) to over 410 today, with doubling expected by about the year 2060. The resulting sea level rise will soon have dramatic effects in many parts of the world. Warming is starting to cause significant problems, with increasing forest and brush fires on land and impacts on fisheries in fresh water, coastal seas and oceans.

The spring bloom in the Strait of Georgia was again relatively early, with blooms in Sechelt Inlet and Malaspina Strait that may have seeded the start of the main bloom (Gower et al. 2013).

Factors leading to bright blooms in B.C. coastal waters are not well understood. Such blooms are common offshore in the Gulf of Alaska.

The September *Heterosigma*/*Ceratium* bloom in 2019 is not known to have caused significant harm to farmed salmon. An increase in frequency of such blooms would affect the economics of aquaculture, perhaps leading to a shift towards farms on land.

12.5. Implications of those trends.

Climate change is a global problem which is accelerating in the absence of concerted action to reduce carbon emissions. The change affects almost all aspects of the present SOPO report. Sea level rise is resulting in increased coastal erosion in many areas locally, and warming is expected to have an increasing effect on almost all fisheries.

Timing of the spring bloom in the Strait of Georgia is known to be important for migrating juvenile salmon. The importance of seeding from blooms in inlets in affecting this date is still undetermined, but blooms in Sechelt Inlet and Malaspina Strait appear to be associated with early spring blooms.

Coccolithophore blooms do not themselves cause harm, but they provide an indication of bloom activity in ocean and coastal waters. Any change implies a change in water properties, perhaps associated with global climate change, which needs to be understood.

Blooms, harmful and otherwise, are expected to become more common as ocean temperatures warm and nutrient flow into coastal waters continues to increase.

12.6. References

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13. OCEANOGRAPHIC CONDITIONS OFF THE WEST COAST OF VANCOUVER ISLAND: 2019

Akash Sastri, Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Akash.Sastri@dfo-mpo.gc.ca

13.1. Highlights

- Positive temperature anomalies (up to 1 °C) in the surface mixed layer at most sampling stations during the May survey (21 May – 2 June, 2019); anomalies were greater offshore than over the shelf and moderately positive at depth.
- Positive temperature anomalies (0.8 – 3.1 °C) in the surface mixed layer at most sampling stations during the September survey (29 August – 10 September, 2019); with no consistent horizontal pattern.
- The upper water column (< 100 m) was saltier and fresher than average during the May and September surveys, respectively.
- Conditions in September 2019 were similar to peak 'Blob' conditions in September 2015.

13.2. Description of the time series

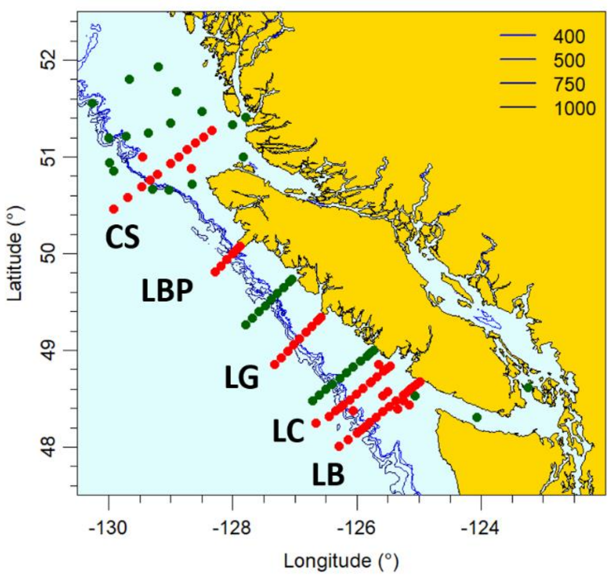

Figure 13-1. Map of the La Perouse-West Coast of Vancouver standard survey stations. Stations for each of the survey lines (labelled) discussed in this report are identified with red symbols. Bathymetric contours on the line indicate the shelf break and contour-specific depths (m) are identified in the 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 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 37). 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 13-1): 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 2019 survey station-specific pressure bin and its corresponding time-series average.

13.3. 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 each of the May time series tend to be cooler along the northern lines (9.75 °C) relative to southern lines (10.6 °C) with only moderate differences between shelf (<200 m) 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 (~13.6 °C) relative to shelf (~12.0 °C) stations for all 5 lines extending off of the west coast of Vancouver Island.

In May 2019, mean mixed layer depths for LB, LC, LG, and LBP lines varied between 14 and 19 m for shelf stations. The mean mixed layer depth at CS shelf stations was 31 m. Offshore, mean mixed layer depth was deeper and ranged from 24 to 40 m at each line. Temperatures at shelf stations for CS and LBP lines in May 2019 were 0.71°C and 0.36 °C warmer than average. Offshore, CS and LBP lines were 0.95 and 0.58 °C warmer than their respective time series averages. Temperatures at depth (>200 m) were moderately warmer than average offshore for LBP line but typical for CS line stations. Mixed layer temperature anomalies for the southern LG and LB shelf stations were moderately warmer than average (0.10 and 0.75 °C, respectively) and LC shelf stations were ~1.6 °C warmer than average. Offshore southern stations were also warmer than average with LG, LC, and LB mixed layer temperature anomalies of 0.33, 0.78, and 0.99 °C. Temperature anomalies extending from below the mixed layer to 100 m were slightly cooler than average, whereas, temperatures > 100 m were moderately warmer (~0.5 °C) warmer than average for stations along all three southern lines.

The period (July and August) following the May survey and leading to the September survey was characterized by below-average intensity upwelling positive winds (Hourston and Thomson, Section 8; Dewey et al. 2020). SST anomalies (see Ross and Robert, Section 7; Chandler, Section 10; Hannah et al., Section 48) were high (> 1.5 °C) along the west coast of Vancouver Island.

Observations during the September survey reflected the reduced upwelling conditions coupled with surface heating during this June-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 18 and 22 m at shelf stations along LB, LC, LG, and LBP lines. The mean mixed layer depth at CS shelf stations was 9 m. Offshore, mean mixed layer depths were similar to the May survey, ranging between 23 and 31 m. Surface mixed layer temperatures for shelf stations along the southern lines, LG, LC, and LB, were 2.9, 0.8, and 1.4 °C warmer than their respective time series averages. Offshore station mixed layer temperatures for LG, LC, and LB, were 2.6, 3.2, and 2.5 °C warmer than average. The mixed layer for LBP line (off of Brooks Peninsula) shelf and offshore stations was 3.1 and 2.3 °C warmer than the time series average. These September survey mixed layer temperature anomalies were comparable to similarly high values during the peak of the anomalously warm period in September 2016. Temperature anomalies for shelf and offshore CS line stations were 1.6 and 1.1 °C warmer than the time series average. Water column temperature below the mixed layer for all five lines was moderately warmer than average (< 0.5 °C) down to 200 m and at or slightly below average at depths > 200 m; indicating that the anomalously warm water conditions along the west coast of Vancouver Island were largely limited to the surface (see right-hand panel Figure 13-2). This anomalously warm mixed layer water was also anomalously fresh (see right-hand panel Figure 13-3.) Saltier than average surface water (< 10 m) sat immediately above the fresher than average water extending down to ~125 m for all lines in September; below which, salinity was not appreciably different from each time-series average. This is in contrast to May 2019 (left-hand panel Figure 13-3.), when surface waters (< 125 m) were generally saltier than each time-series average and this was especially pronounced at shelf stations along the 3 southern Vancouver Island lines.

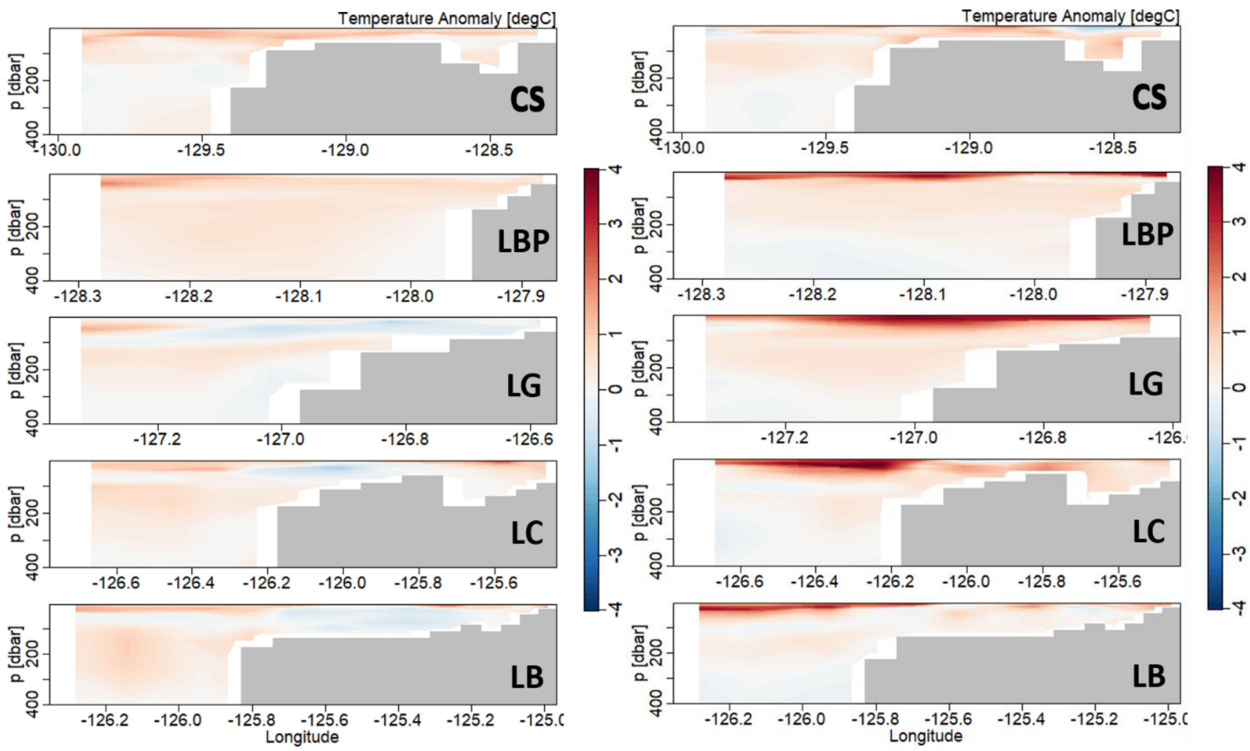

Figure 13-2. Temperature anomaly (°C) section plots across each sampling line. Maximum depth set at 400 dbar. Top to bottom represents northern to southern lines (see Figure 13-1). Left to right represent May and September survey sections, respectively. The time series average for CS and LBP lines was 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 2019 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.

13.4. Factors influencing trends

The broad-scale temporal and spatial patterns describing the evolution of the 2019 warm water anomaly are discussed by Ross and Robert (2019) and Ross and Robert (Section 7). Sea surface temperatures throughout the Gulf of Alaska and along the west coast of Vancouver Island were warmer than average (1-2 °C) during April 2019 and during the transition from downwelling to upwelling (see Hourston and Thomson, Section 8; Dewey et al., Section 37).

The May La Perouse survey (May 21 – June 2, 2019) followed a period of active upwelling which continued into early June, however (as noted above) upwelling favourable winds following the May survey and leading into the September survey were very low and the extremely warm temperature anomalies (up to ~3°C) observed in the mixed layer were in part associated with limited upwelling of cooler deep water onto the shelf.

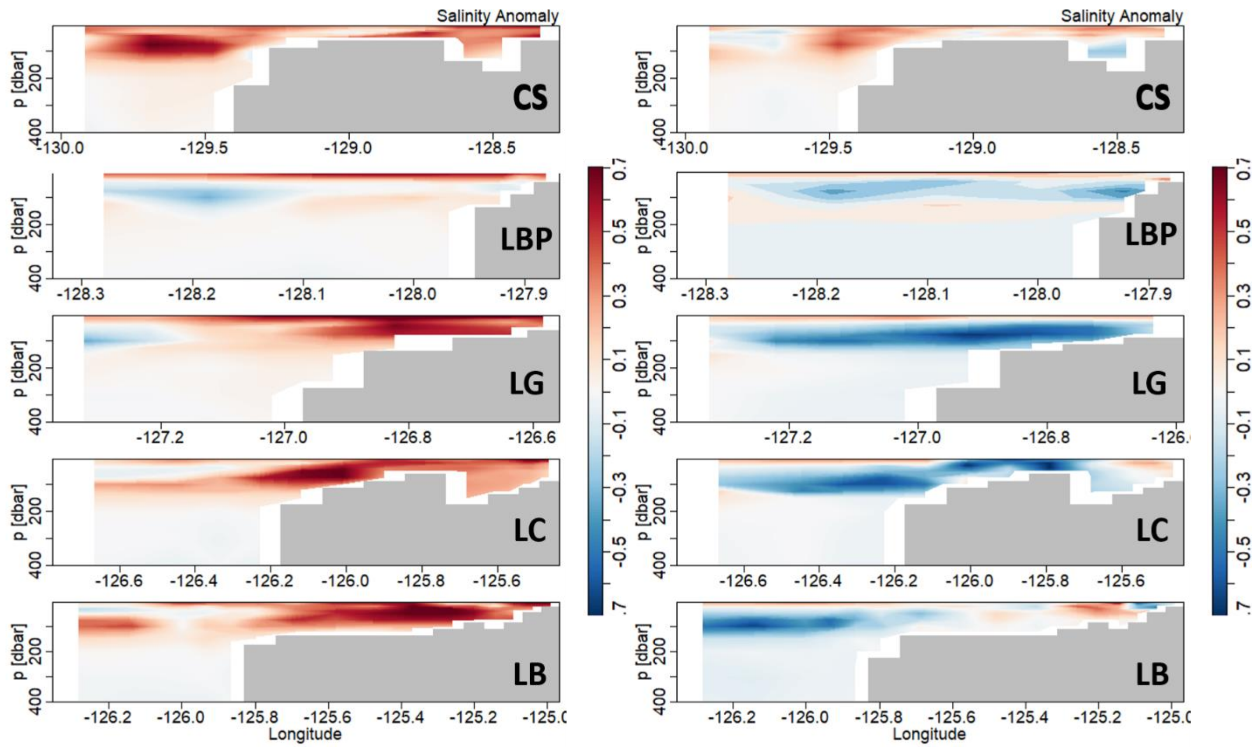

Figure 13-3. Salinity anomaly (psu) section plots across each sampling line. Maximum depth set at 400 dbar. Top to bottom represents northern to southern lines (see Figure 13-1). Left and right represent May and September surveys, respectively. The time series average for CS and LBP lines was estimated 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 2019 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.

13.5. 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 (see Perry et al., Section 50; Galbraith and Young, Section 16). 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).

13.6. References

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14. NUTRIENTS AND PHYTOPLANKTON ALONG LINE P AND WEST COAST OF VANCOUVER ISLAND

Angelica Peña and Nina Nemcek, Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Angelica.Pena@dfo-mpo.gc.ca, Nina.Nemcek@dfo-mpo.gc.ca

14.1. Highlights

- Surface nutrient concentrations along Line P in 2019 were among the lowest on record. In particular, summer mixed layer nitrate was depleted at Ocean Station Papa (OSP) for the first time in 60 years of observations.
- Phytoplankton community composition along Line P in spring of 2019 was similar to that of 2018 but different from previous years, with diatoms dominating phytoplankton biomass at several open-ocean stations.
- On the continental shelf of the west coast of Vancouver Island, nitrate concentrations and phytoplankton biomass in May and September 2019 were within the range of values from previous years.

14.2. 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 measured on DFO cruises three time a year in February, June, and August/September along Line P in the northeast subarctic Pacific and twice a year in May/June and early September on the La Perouse cruise off the west coast of Vancouver Island. Sampling for phytoplankton composition has been carried out at most of the stations along Line P (Figure 14-1a) since June 2010. Phytoplankton sampling along a series of transects on the west coast of Vancouver Island (Figure 14-1b) has been carried out since 2011. Sampling along the west coast was extended farther north in 2017.

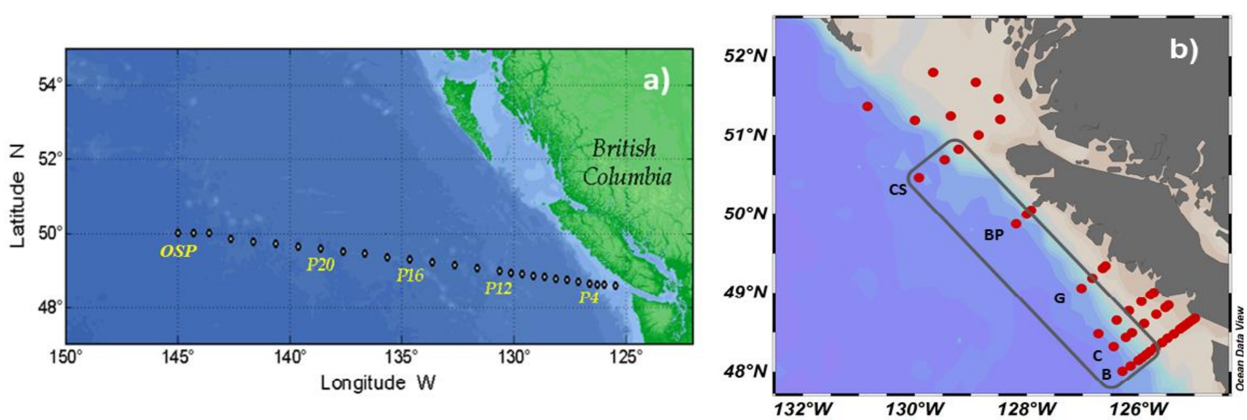

Figure 14-1. Location of sampling stations: a) along Line P, and b) on the west coast of Vancouver Island showing the outer coast stations (inside the grey rectangle) and continental shelf stations.

The abundance and composition of phytoplankton are determined from 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). Phytoplankton pigments were sampled along the west coast of Vancouver Island in 2019, but these samples have not been processed yet so phytoplankton composition data are not included in this report.

14.3. Status and trends

Line P extends from the southwest corner of Vancouver Island to OSP (Figure 14-1a) in the high-nutrient low-chlorophyll (HNLC) region where surface nutrient concentrations are usually high (>5 mmol m^{-3}) and Chl-a concentrations are low (<0.5 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 2018/19, nutrient renewal from vertical transport was restricted due to increased stratification, similar to that observed in winter 2014/15 during “the Blob”. As a result, surface nitrate and silicate values in 2019 were among the lowest on record at most stations along Line P (Figure 14-2). In particular, summer mixed layer nitrate was depleted in the HNLC region for the first time since sampling started 60 years ago in 1969. Higher Chl-a concentrations were observed at these offshore stations than in the transition region of Line P in spring and summer of 2019 (Figure 14-2).

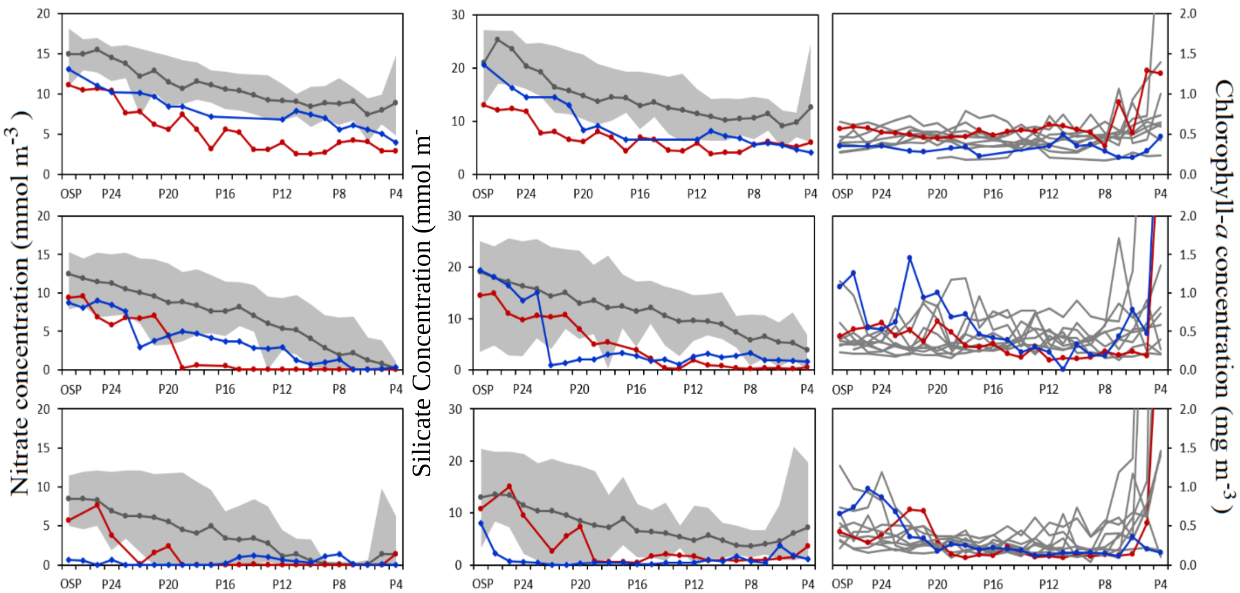

Figure 14-2. Nitrate (left panels, mmol m^{-3}), silicate (center panels, mmol m^{-3}), and chlorophyll-a (right panels, mg m^{-3}) in surface waters along Line P from P4 to OSP in winter (top panels), spring (middle panels) and summer (bottom panels). The left and center panels show the average (grey line) and range (shaded area) of nutrient concentrations in 2000-2014. The right panel shows all values in 2009-2019. In all panels, data for 2019 are shown in blue and for 2015 in red.

Phytoplankton assemblage composition along Line P shows an increase in the relative abundance of diatoms at several stations (~P15 to P22) in June 2019, similar to that observed in 2018, and consistent with the decrease in silicate concentration in this region. By August 2019, diatoms were more abundant farther offshore whereas phytoplankton composition was in general similar to that observed in previous years at other stations, with haptophytes dominating phytoplankton biomass (Figure 14-3).

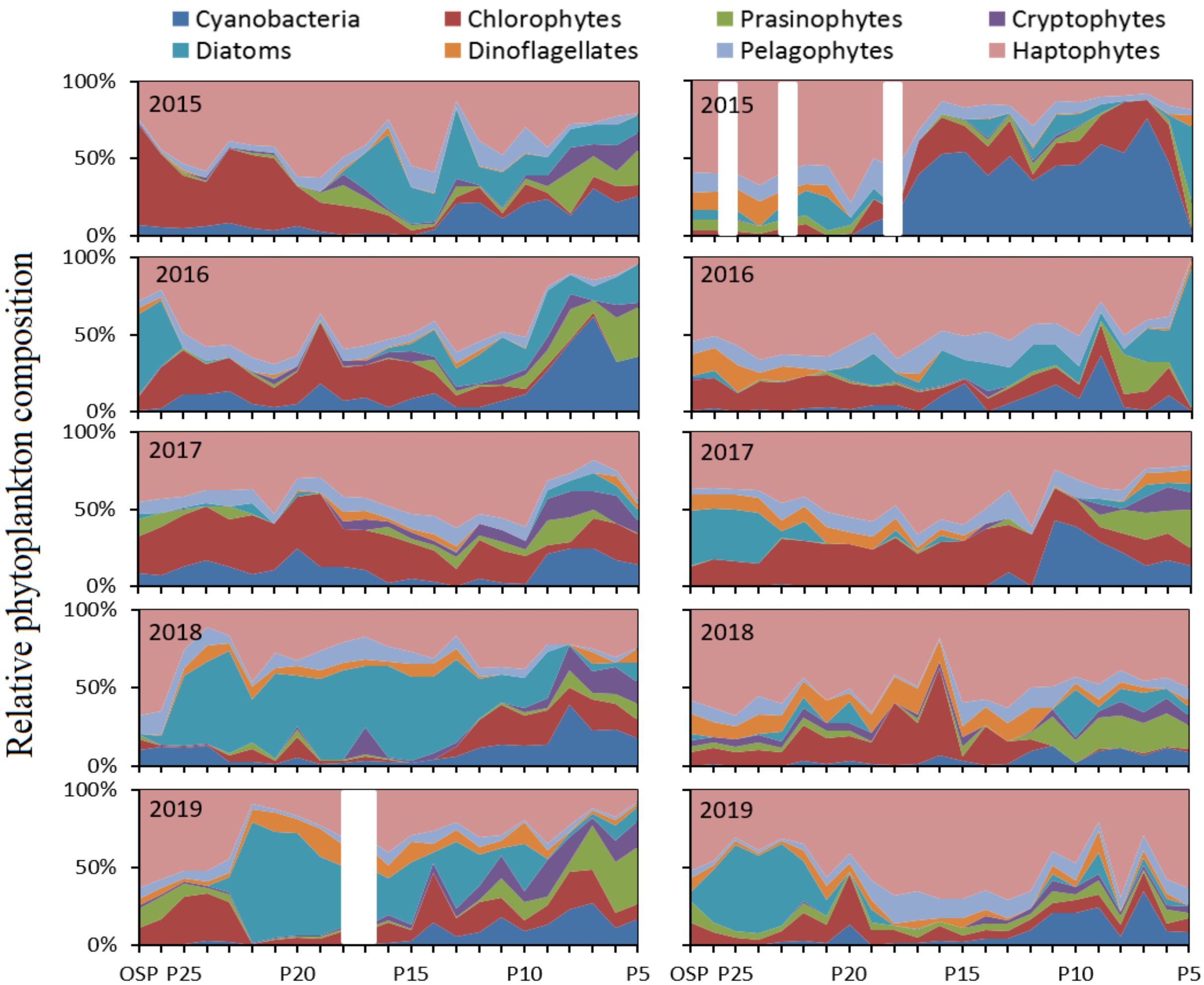

Figure 14-3. Relative phytoplankton composition in the upper layer at stations along Line P (see Figure 14-1) in June (left panels) and Aug./Sept. (right panels) of 2015 to 2019. Blank spaces indicate no data were collected.

Nitrate and Chl-a concentrations are highly variable in surface waters off the west coast of Vancouver Island (Figure 14-4). On the continental shelf, surface nutrient concentrations are usually lower in May compared to September. Chl-a is usually high (>5 mg m^{-3}) on the continental shelf off southern Vancouver Island where blooms of phytoplankton (>20 mg m^{-3} Chl-a) are often observed in May and/or September. At stations beyond the continental shelf, Chl-a and nutrient concentrations are usually lower than on the continental shelf. In 2019, nitrate concentrations in May and September were within the range of values observed in previous years (Figure 14-4) and show highest concentrations off southern Vancouver Island in September. Phytoplankton blooms were not observed in May and September of 2019 but Chl-a concentrations were within the range of values observed in previous years (Figure 14-4).

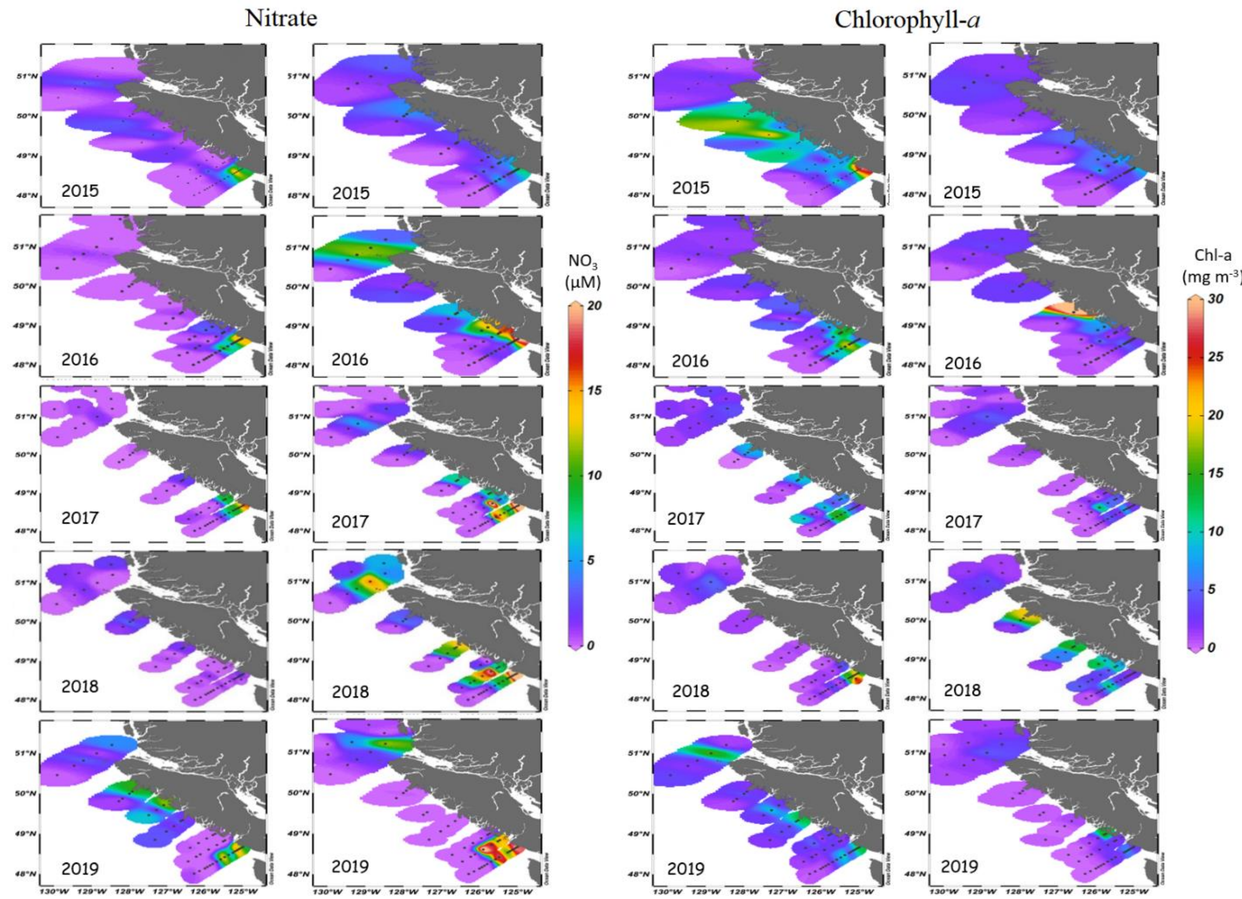

Figure 14-4. Nitrate (left panel, mmol m^{-3}) and chlorophyll-a (right panel, mg m^{-3}) at 5 m depth over the study area in May/June (left column) and September (right column) of 2015 to 2019.

14.4. Factors influencing trends

Several environmental factors including temperature, irradiance and nutrient availability, as well as grazing pressure, determine phytoplankton abundance and community composition. The observed changes in phytoplankton abundance and composition along Line P during the Blob in 2015 were 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 sporadic increases in diatom abundance in the transition region of Line P in June of 2018 and 2019 and at the most offshore stations of Line P in September of 2017 and 2019, as well as 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. These changes could be due to an increase in phytoplankton Fe availability or to anomalous transport of nutrient-depleted waters into the region. In coastal regions, such as the west coast of Vancouver Island where environmental conditions fluctuate rapidly, our sampling frequency (twice a year) is not adequate to study year-to-year variability in phytoplankton since the observed differences in Chl-a concentrations and phytoplankton composition could be as much due to intra-seasonal as to inter-annual variability.

To be able to compare among years, frequent (daily to bi-weekly) observations would be necessary depending on the time of year.

14.5. 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.

14.6. References

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15. LOWER TROPHIC LEVELS IN THE NORTHEAST PACIFIC

Sonia Batten[1] and Clare Ostle[2],

[1]Marine Biological Association, UK, c/o Nanaimo, BC, Sonia.Batten@mba.ac.uk
[2]Marine Biological Association, The Laboratory, Plymouth, UK. claost@mba.ac.uk

15.1. Highlights

- Diatoms and zooplankton organisms were relatively abundant in spring 2019.
- The offshore copepod community was close to an average mix of small and large species, while the shelf copepod community was dominated by small species.
- Phytoplankton and zooplankton were both biased towards communities indicating warmer waters for the sixth successive year.

15.2. Sampling

Sampling from commercial ships towing a Continuous Plankton Recorder (CPR) occurred approximately monthly, 6-9 times per year between March and October in the NE Pacific (Figure 15-1) continuing a time series 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. Data to June 2019 have been finalized at the time of writing while data for July to September 2019 (where shown) are provisional and likely to change.

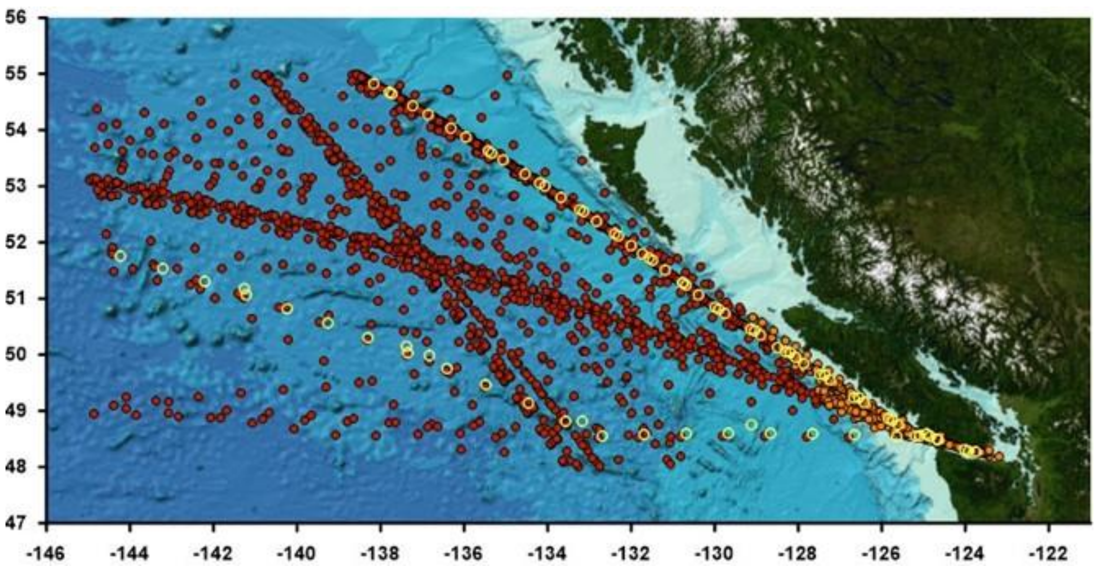

Figure 15-1. Map showing the location of historic CPR samples (2000-2018) red = offshore, orange = shelf. Overlaid yellow circles are the location of the 2019 samples used in this report.

Sea Surface Temperature (SST) data from 2000 to 2019 were 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 as spring means (April – June) to characterize the physical environment.

15.3. Description of the Plankton Time Series.

15.3.1. 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 in spring (March to June), iii) mean annual (April to June) 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).

15.3.2. 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. iii) Annual mean CTI for all the zooplankton taxa (again, April to June) for each region (calculated as described above for the phytoplankton CTI).

15.4. Status and Trends

15.4.1. Phytoplankton.

Diatom abundance in the offshore were close to average in spring 2019 and likely below average in autumn while on the shelf, numbers were higher than average in spring and close to, or above, average in autumn (Figure 15-2). The 2019 phytoplankton community composition was similar to 2016-17 (offshore) and 2015-2018 (shelf) with a relatively high proportion of rod-like diatoms and dinoflagellates (compared to the mean) and somewhat lower proportions of round diatoms (Figure 15-3). This is consistent with warmer conditions which generally result in nutrient/water column stability regimes that are more favourable for these groups.

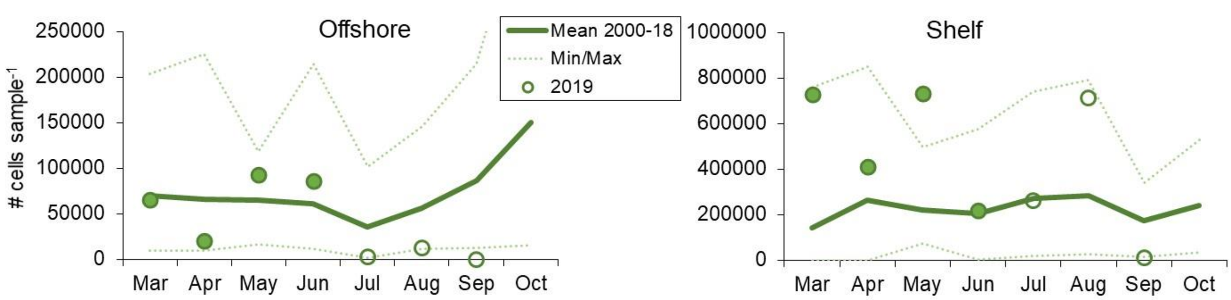

Figure 15-2. Monthly mean Diatom abundances for 2019 (circles) overlaid on historical means (2000-2018, solid line) and minima/maxima (dotted line) offshore (left) and on the shelf (right). Filled circles are finalised data, unfilled are provisional.

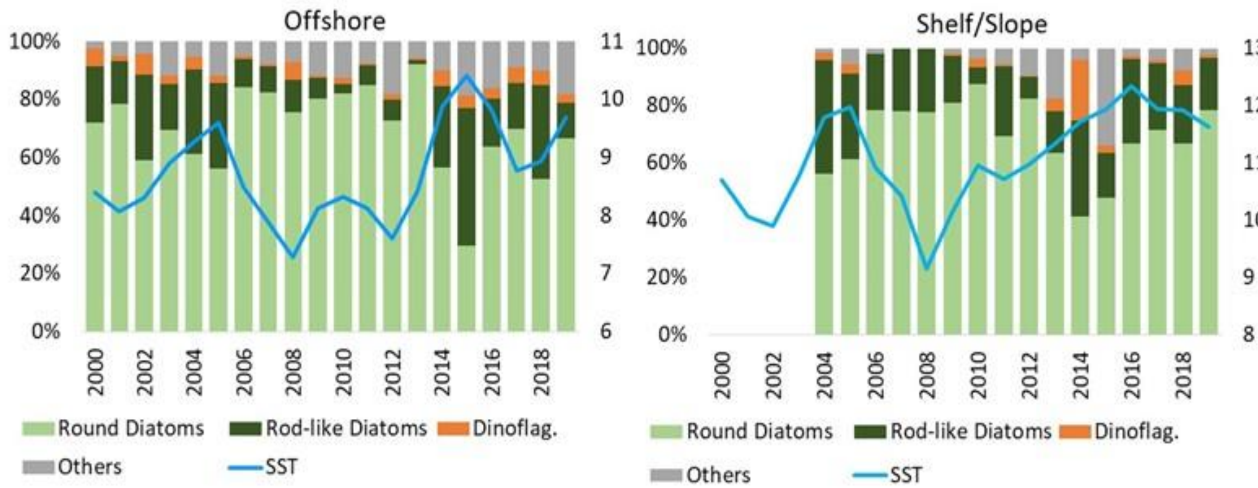

Figure 15-3. Contribution of each group to the mean March-June phytoplankton community offshore (left) and on the shelf (right). On the shelf, only June was sampled until 2004 so early years have been excluded, Spring SST is shown in blue (right-hand axis, °C).

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 15-4). The values for 2019 are closer to average than recent years have been, although still higher than prior to 2014.

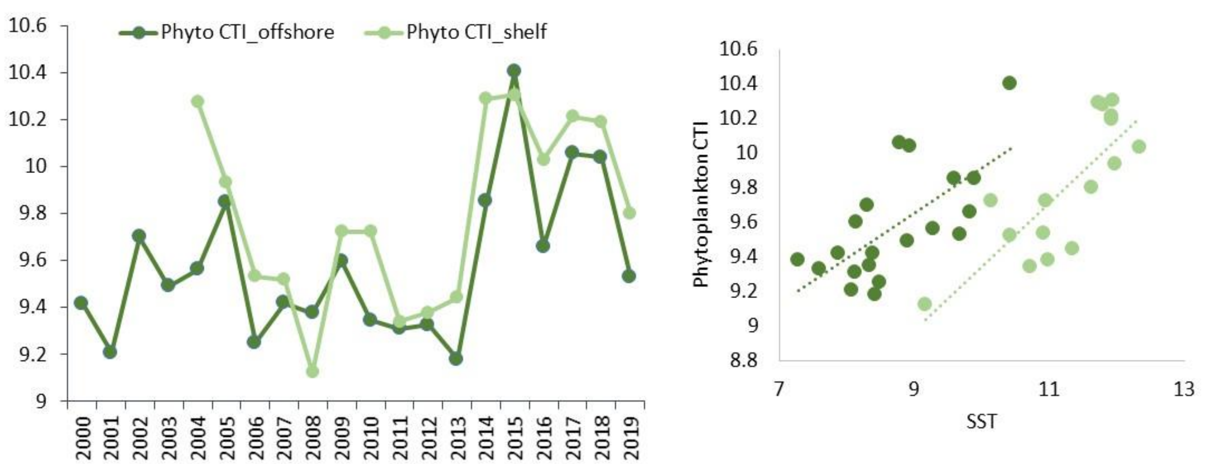

Figure 15-4. The mean annual phytoplankton Community Temperature Index (Apr-June) for each region (left) and the relationship between SST and CTI (right).

15.4.2. Zooplankton

Zooplankton abundance was above average in spring 2019 but 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 much smaller species than average throughout the year (Figure 15-5).

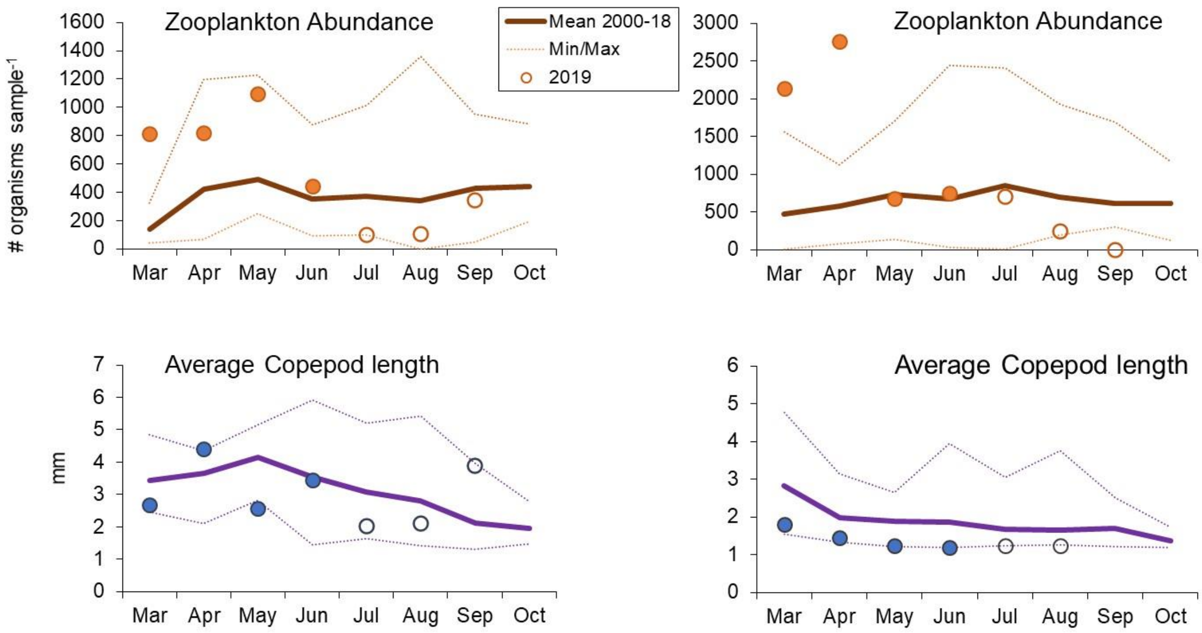

Figure 15-5. Monthly mean (solid line) zooplankton abundance in 2019, (top) and mean copepod size (lower) for the offshore (left) and shelf (right) regions. Filled circles show finalised data, unfilled circles provisional data. Minimum and maximum values shown (dotted lines).

Shelf zooplankton communities were generally comprised of warm water taxa compared to the offshore (Figure 15-6). Values for 2019 were higher than average in both regions, though not exceptional.

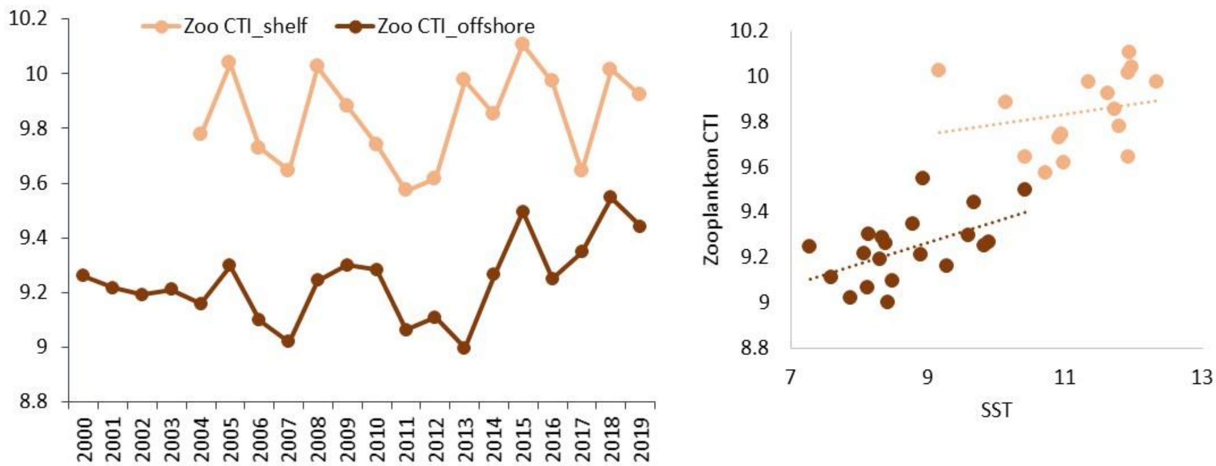

Figure 15-6. The mean annual zooplankton Community Temperature Index (Apr-June) for each region (left) and the relationship between SST and CTI (right).

15.5. Factors Influencing the trends

Whether 2019 saw continued warmth from the marine heatwave of 2014-2016 (DiLorenzo and Mantua 2016) or was in fact part of a second discrete heatwave, ocean temperatures were still relatively high in spring 2019 (Figure 15-3) and the lower trophic levels were still impacted. Increased stratification and lower nutrients 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.

15.6. 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 than average CTI values for both phytoplankton and zooplankton communities. Such communities may apparently persist for several years after a heat-wave event, especially if waters remain warm, and this report describes a sixth successive year of lower trophic levels that reflect warm conditions. The reduction in large copepod abundance on the shelf will influence the food web functioning here and likely have nutritional impacts on zooplankton predators since these copepods store more lipids (e.g. fish and some seabirds). 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.

15.7. References

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16. WEST COAST BRITISH COLUMBIA ZOOPLANKTON BIOMASS ANOMALIES 2019

Moira Galbraith and Kelly Young, Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Moira.Galbraith@dfo-mpo.gc.ca, Kelly.Young@dfo-mpo.gc.ca

16.1. Highlights

- Consecutive years of warm water intrusions from the south are effectively making the west coast of Vancouver Island like the nearshore California Current, with a high abundance of gelatinous taxa and low abundance of crustaceans.
- No *Pyrosoma atlanticum* colonies were detected in 2019.
- 2019 was very much like 2017-18 but still not an "average" boreal/subarctic zooplankton community.

16.2. 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 1990 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 16-1). 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.

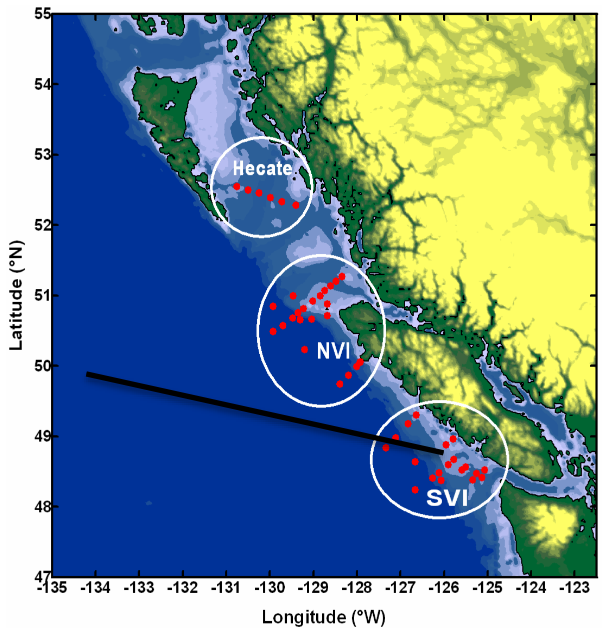

Figure 16-1. Zooplankton time series sampling locations (red dots; Line P – black line) in B.C. marine waters. Data are averaged for samples within each area. There are more samples included in the analysis than shown in figure.

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 anomaly time series. For a more detailed description see earlier reports (Mackas 1992; Mackas et al. 2001).

Zooplankton species on the west coast 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. 2013; Irvine and Crawford 2013). All data presented here are very preliminary as analysis is on-going; numbers will change but directions of trends usually do not change.

16.3. Status and trends

The biomass anomaly time series for copepod species groups and representative chaetognaths and euphausiids in the SVI, NVI, Line P and Hecate statistical areas are shown in Figures 16-2 and 16-3. Cool years tend to favour endemic ‘northern’ taxa; whereas warm years favour colonization by ‘southern’ taxa. See earlier State of the Ocean reports for pre-1990 anomalies, and descriptions on how to interpret the anomaly patterns.

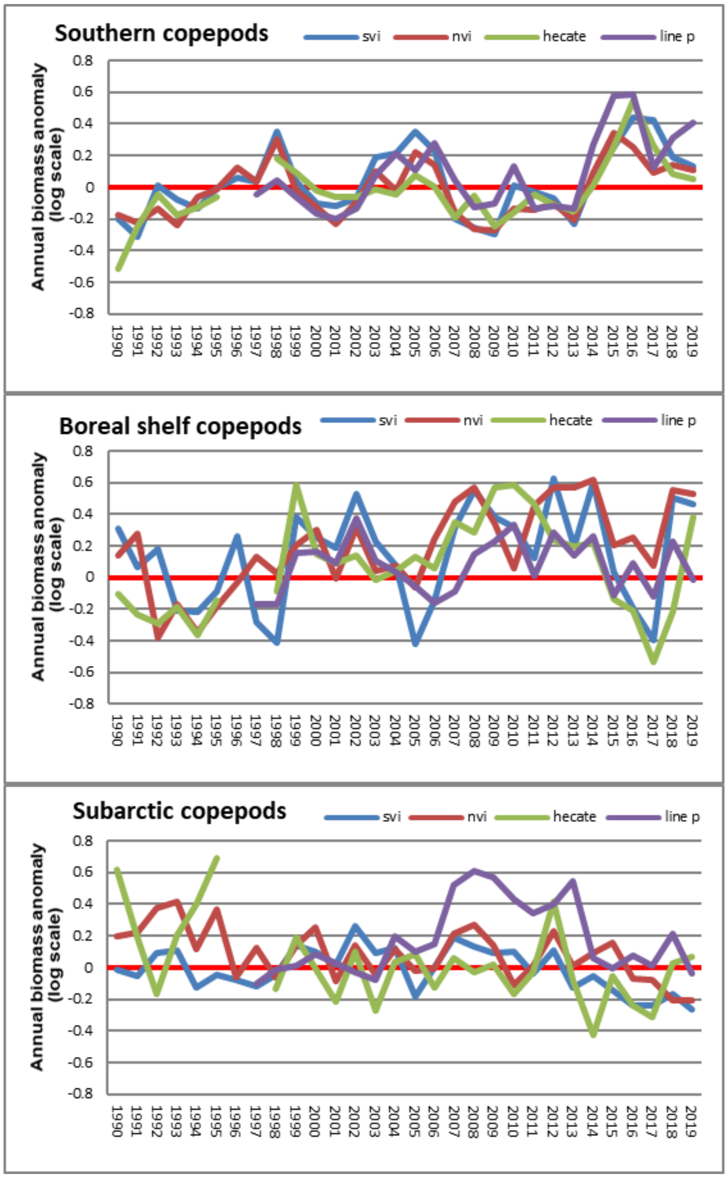

Figure 16-2. Zooplankton species-group anomaly time series for the regions shown in Figure 16-1. Line graphs are annual log scale anomalies. Southern Vancouver Island (SVI) blue; Northern Vancouver Island (NVI) red; Hecate Strait (HEC) green; Line P – purple for all graphs. Blank years mean no samples were collected.

In both the near shore and offshore regions of Vancouver Island, there were positive anomalies for southern copepods (Figure 16-2), chaetognaths (Figure 16-3), 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 2019 anomaly was not as strong as in 2016 (a year with a previous marine heatwave). By June, the whole continental margin of B.C. was inundated with large masses of gelatinous animals; mainly *Mitrocoma* on the shelf, doliolids in along the shelf break and offshore with other hydromedusae, and larvaceans increasing across all shelf areas.

Boreal copepods continued an upward trend along the shelf, whereas subarctic copepods decreased on Line P and SVI, but not in the Hecate shelf break area. Southern copepod anomalies were positive in all regions, but not as strong as in 2015-16 and appeared to be leveling off in 2019 (Figure 16-2).

Southern chaetognaths were prevalent in all areas with a slight increase off SVI. Their biomass anomaly has not returned to average but also has not increased in abundance as in the previous couple of years (Figure 16-3 top). *Parasagitta elegans* (northern chaetognaths) biomass increased to average values along Line P and in HS and above average values in NVI, but it decreased in SVI (Figure 16-3, bottom).

Euphausiids had trended positive over the last five years off the west coast of Vancouver Island but in 2019 there was a reversion to average biomass; there were different trends in other regions (Figure 16-4). The warming events since 2015 tended to favour *E. pacifica* over *T. spinifera* off the B.C. coast. In Hecate Strait and SVI shelf, there was generally a decrease in *T. spinifera* biomass after 2015, an increase in 2018 and average values in 2019. The euphausiid biomass anomaly along Line P showed no trend which may be a result of averaging data from nearshore with oceanic stations. Euphausiid species whose distribution centres off Oregon/California and south (*Thysanoessa gregaria* and *Nematocelis difficilis*) continue to be found along the Vancouver Island shelf edge and at Line P nearshore stations (data not shown).

Larvaceans, doliolids, siphonophores and hydromedusae biomass anomalies were positive for 2019 in the SVI shelf area, shelf break of NVI, and throughout Hecate Strait. There has been a sharp decrease in ctenophore biomass across all regions in 2019 and this has a moderating effect on the CSIndex (see below), through 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 influxes of salps were at the outer stations (P20 and P26). Doliolids and salps also added to the increasing trend (since 2014) in the gelatinous community in Hecate Strait (Figure 16-5).

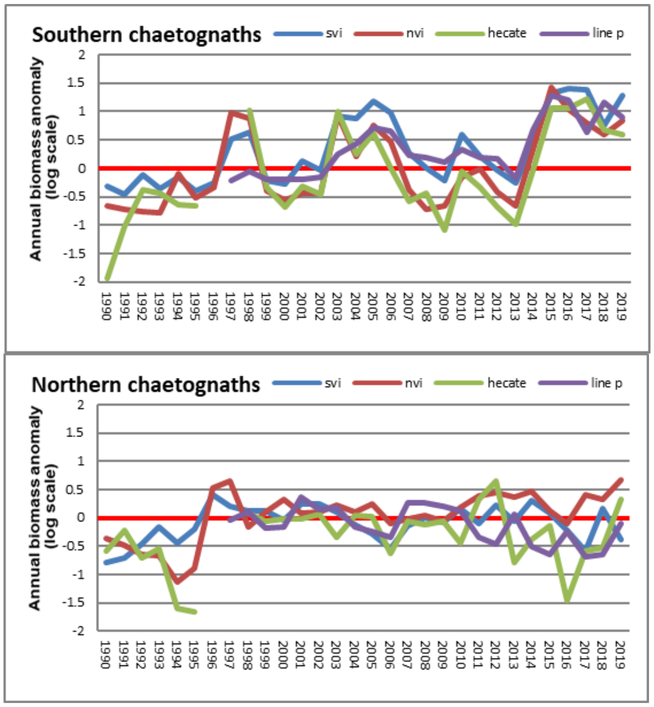

Figure 16-3. Chaetognath anomaly time series (vs climatological baseline) for all the regions. Chaetognaths divided into southern (Figure 16-3 - top) and northern (Figure16-3 - bottom) species groups; blank years mean no samples were collected.

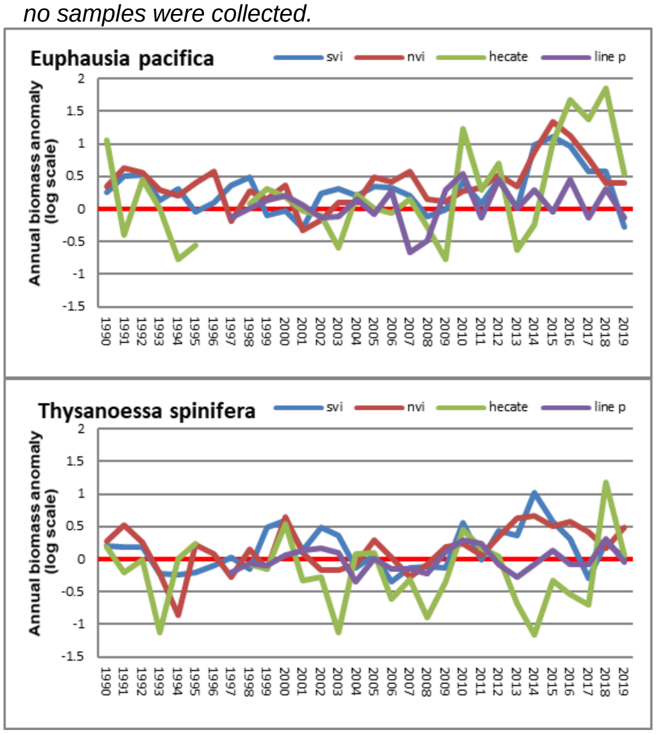

Figure 16-4. Euphausiid biomass anomaly time series (vs climatological baseline) for all the regions shown in Figure 16-1. Euphausiid biomass corrected for day/night sampling; blank years mean no samples were collected.

To summarize and simplify, all the material presented here has been condensed into a CSIndex, or “Crunchie: Squishy” Index (see previous SOPO reports). All show positive biomass anomalies except for Line P in 2019 (Figure 16-5).

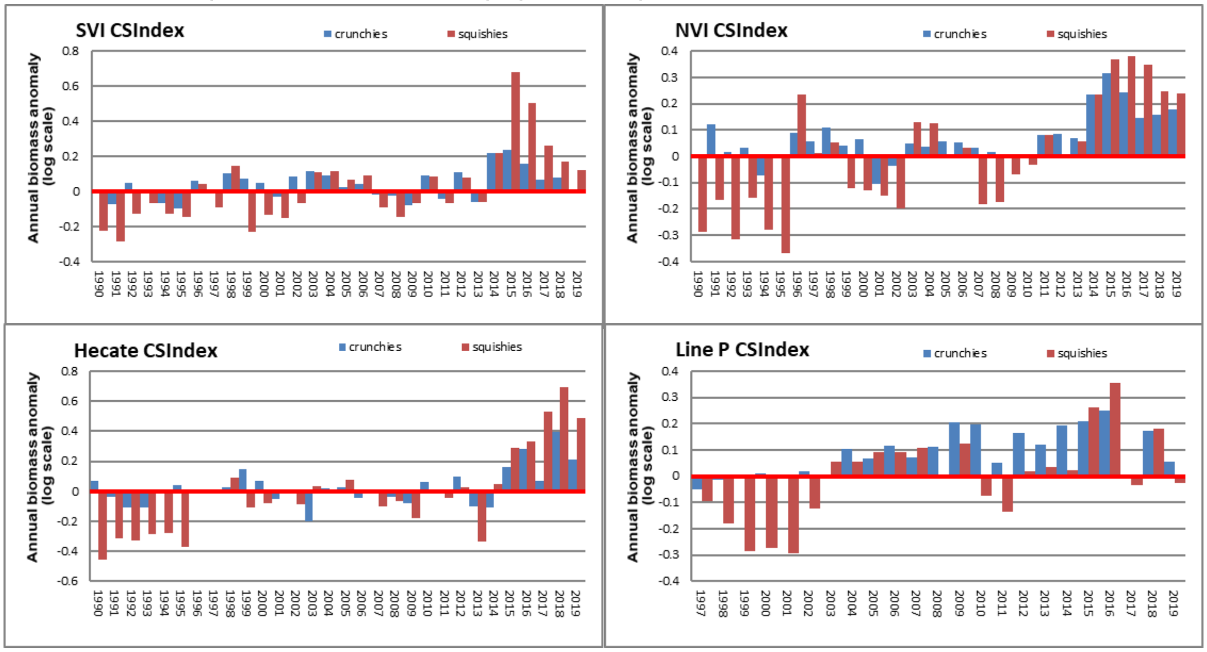

Figure 16-5. CS-Index: Comparing the gelatinous zooplankton (i.e. squishies) versus arthropod taxa (i.e. crunchies, ignoring meroplankton and removing southern crustacean species) biomass anomalies, within grouping and then by area. Be aware of axis change for Hecate.

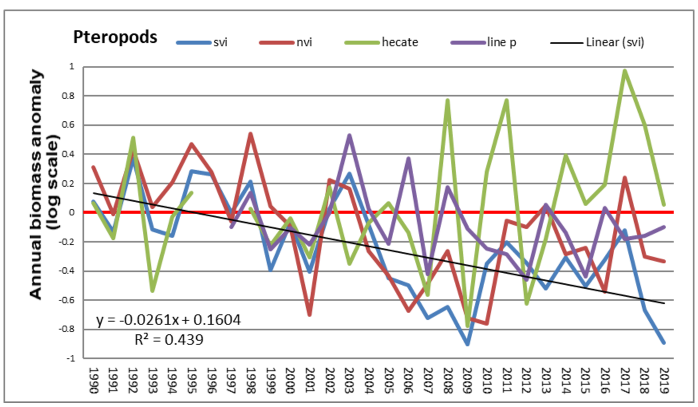

Figure 16-6. Pteropods, mainly Limacina helicina, biomass anomalies, by area; linear regression shown for SVI.

Thecosomatous pteropods (e.g. *Limacina 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. This year, trends in these pteropods were examined separately, as they appear to be declining over all areas, except Hecate (Figure 16-6). Pteropods may be reacting to different physical parameter(s) whereas, the CSIndex basically tracks changes in community structure due to oceanic sea surface temperatures.

16.4. Implications of those trends

Overall, 2019 saw movement towards historical average biomass for all areas, with gelatinous animals still being more abundant than crustaceans. The Hecate region had a negative euphausiid anomaly after the large increase in 2018. This, coupled with the decline in boreal copepods, the inundation of southern species, and the huge increase in gelatinous taxa along the outer coast and into Hecate Strait, may be of concern for larval fish, juvenile fish (especially outmigrating juvenile salmon), and planktivorous sea birds. The low and/or sporadic sampling effort in Hecate Strait made it difficult to summarize those data but the pattern is generally similar to that of the NVI shelf. The 2019 pattern of the high gelatinous biomass relative to crustacean biomass showed that something unusual is ongoing in Hecate Strait. Temperature was elevated in 2015/16 for the whole west coast of British Columbia (Yelland and Robert 2017) and this continued into 2019 after a brief cooling in the spring (Chandler, Section 10; Sastri, Section 13; Ross and Robert, Section 7). In times of warming events: 1997/98, 2003/04, 2014-2016 (Ross 2017) the SVI shelf and offshore area were inundated with low nutrient gelatinous animals (Figure 16-5). This makes foraging for food more arduous (calorie consuming travel) and risky (more exposure to predators) for the animals that rely on the spring and summer bonanza of crustaceans in the shelf areas. Expectations are that years when gelatinous zooplankton are more abundant equate to poor survival of juvenile fish and seabirds. As with the long-term trend in the copepod species groups, the net effect results in a zooplankton community off B.C. that is more like the community found in nearshore parts of the southern California Current System: high biomass of gelatinous zooplankton and low biomass of lipid rich large copepods. The status in 2019 continues the seventh year of this pattern.

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Yelland, D., and Robert, M. 2017. 2016 oceanographic conditions along Line P and the coast of Vancouver Island. In: Chandler, P.C., King, S.A., and Boldt, J. (Eds.). State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2016. Can. Tech. Rep. Fish. Aquat. Sci. 3225: 243 + vi p.

17. EULACHON STATUS AND TRENDS IN SOUTHERN B.C.

Linnea Flostrand, Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, Linnea.Flostrand@dfo-mpo.gc.ca

17.1. Highlights

- In 2019, the index of Eulachon spawning stock biomass in the Fraser River was estimated to be relatively low (~108 tonnes), similar to or higher than most years from 2004-2017 but lower than estimates for 2015 and 2018.
- Mean Eulachon catch per unit effort estimates from an annual spring west coast of Vancouver Island multispecies bottom trawl survey show a moderate increase in 2019 from relatively low levels in 2016 to 2018.
- In the 2019 spring multispecies bottom trawl survey, Eulachon standard lengths appeared to have a bi-modal distribution.

17.2. Description of indices

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

1) Annual Fraser River Eulachon egg and larval surveys (1995 to 2019) 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); and in the Columbia River (1888-2010 and 2014-2015); and from standardized gillnet surveys in the Fraser River (1995-2004; 2017-2019 not available).

17.3. Status and trends

Eulachon have experienced long-term declines in many rivers throughout their distribution from California to Alaska. The *Committee on the Status of Endangered Wildlife in Canada* (COSEWIC) assessed Eulachon in British Columbia as three designatable units (DUs): 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). Information in support of Eulachon recovery potential assessments in Canada are reported in Levesque and Therriault (2011) and Schweigert et al. (2012).

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 2019 (DFO 2020). Eulachon has also been caught as part of mixed-species marine catches from trawl fisheries and research surveys. There was an active commercial fishery for Eulachon in the Fraser River for over 96 years until a closure in 1997, followed by temporary openings in 2002 and 2004. Commercial fishing for Eulachon in the Fraser River has been closed since 2004 (DFO 2020).

Eulachon trends can vary considerably between years and survey indices. In 2019, the index of Eulachon spawning stock biomass in the Fraser River was estimated to be relatively low (~108 tonnes), similar to or higher than most years from 2004-2017 (e.g. 4-120 tonnes) but lower than estimates for 2015 and 2018 (317 and 408 tonnes, respectively) (Figure 17-1). In 2019, the mean Eulachon catch per unit effort (CPUE) from the spring WCVI multispecies trawl survey showed a moderate increase in 2019 from relatively low levels in 2016 to 2018 (Figure 17-2). In the 2019 spring multispecies bottom trawl survey, Eulachon standard lengths appeared to have a bi-modal distribution with peaks within the ranges of 9-11 cm and 14-17 cm (Figure 17-3).

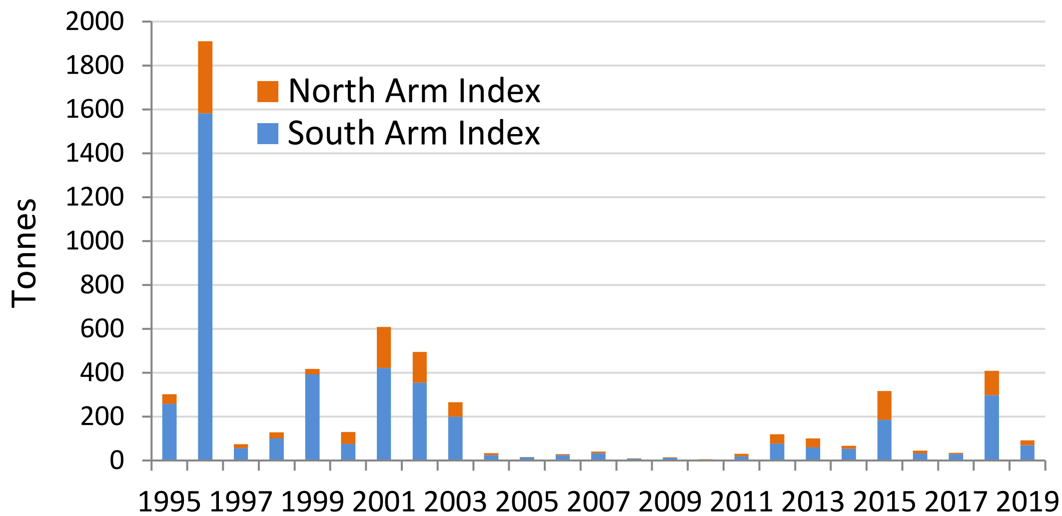

Figure 17-1. Estimated spawning stock biomass (SSB in tonnes) of Eulachon in the Fraser River, 1995-2019, comprised of sampling observations from the South and North Arms combined.

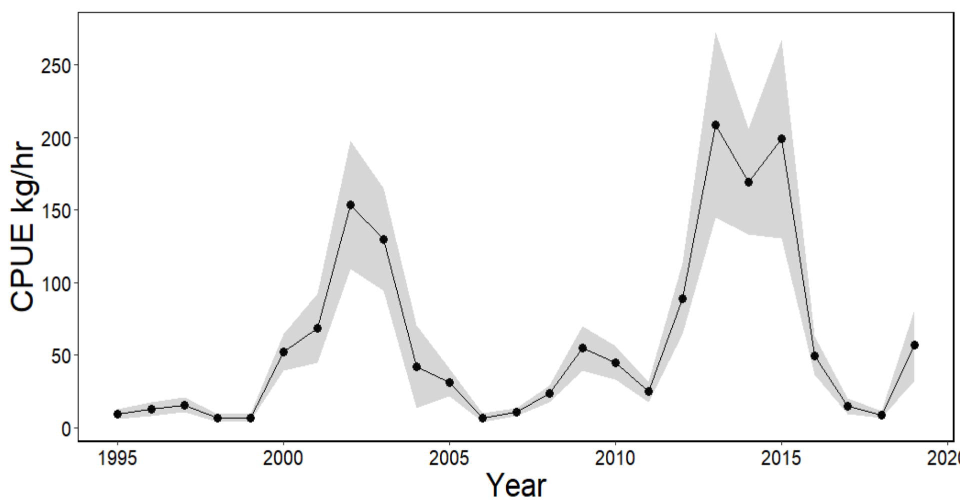

Figure 17-2. Eulachon mean catch per unit effort observations from spring WCVI multispecies trawl surveys (1987-2019). Mean 95% confidence intervals are enveloped in grey.

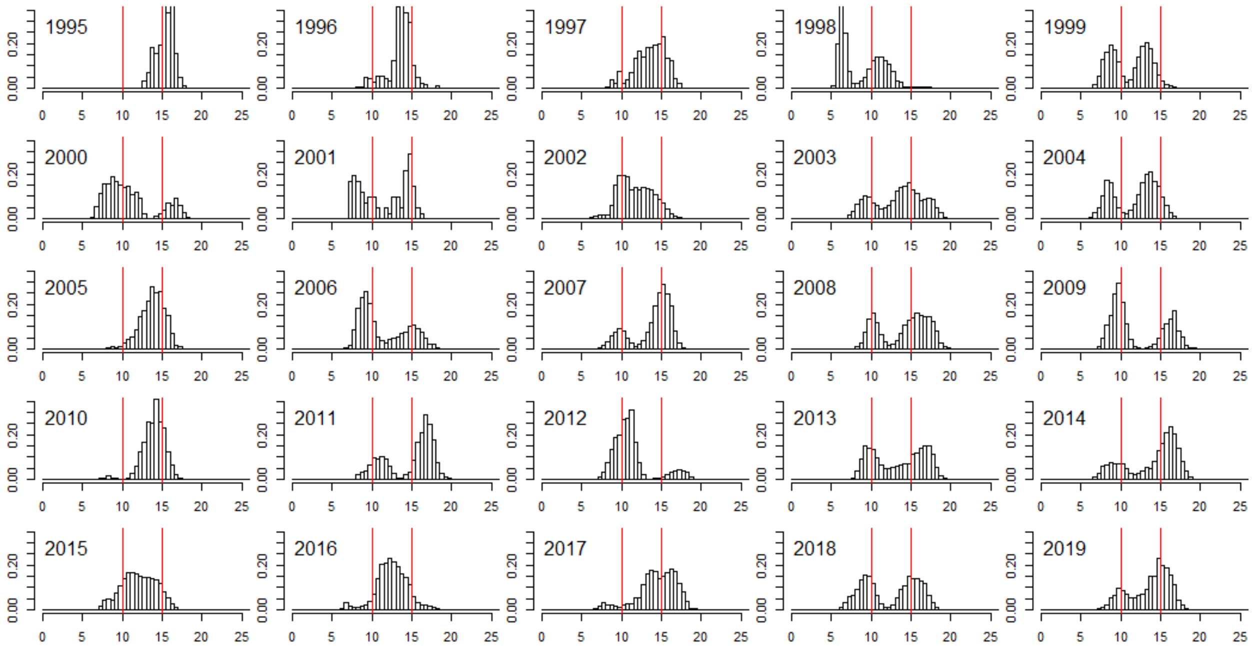

Figure 17-3. Density histograms of Eulachon standard lengths (in cm) from pooling sample data by year from WCVI survey samples 1995-2019. Red vertical lines are visual markers at 10 cm and 15 cm to assist comparisons between positions and shapes of annual length distributions.

17.4. Factors causing those trends

There are uncertainties associated with the ecology and biology of Eulachon stocks as well as the factors affecting Eulachon recruitment and survival. For example, it is uncertain what age range comprises the spawning stock each year, the composition of ages by cohort group, and to what degree spawning stocks and cohorts may mix on the spawning grounds and in different areas and seasons of the marine environment. Also it is believed that most Eulachon die after spawning but there is some evidence to suggest that some females may repeat spawn.

As for factors affecting Eulachon survival, Schweigert et al. (2012) state 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 coast-wide 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.”

17.5. Implications of those trends

Reduced biomass of Eulachon has negative implications for First Nations, commercial and recreational fishers (DFO 2020). Eulachon are socially and culturally significant to First Nations and are harvested by First Nations at low levels. Commercial and recreational fisheries are currently closed.

Reduced Eulachon abundance also likely has negative impacts on their predators. Important predators of Eulachon include: marine mammals (particularly seals and sea lions in the 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.

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18. PACIFIC HERRING IN BRITISH COLUMBIA, 2019

Jaclyn Cleary*, Sarah Hawkshaw, Matt Grinnell, Chris Grandin, Kristen Daniel, and Matt Thompson, Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, *Jaclyn.Cleary@dfo-mpo.gc.ca

18.1. Highlights

- Estimated spawning biomass varies among assessed areas. For example, in 2019, herring biomass remained low for Haida Gwaii, showed modest increases in Prince Rupert District, Central Coast, and West Coast of Vancouver Island, and decreased in the Strait of Georgia.
- Factors contributing to changes in biomass and stock status include changes in recruitment, natural mortality, mean weight-at-age, and model fits to the spawn index.
- There has been a continued increase of weight-at-age in all stocks, following a declining trend during approximately 1980 to 2010.

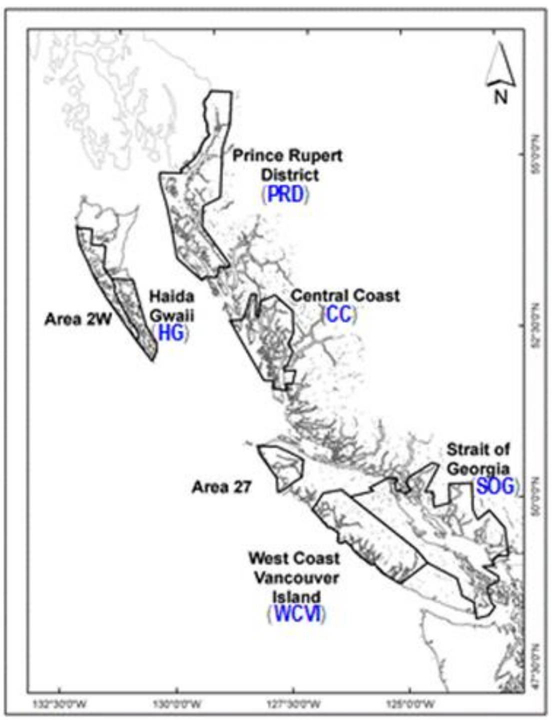

Figure 18-1. Location of the five major (Strait of Georgia, West Coast of Vancouver Island, Prince Rupert District, Haida Gwaii, and Central Coast) as well as two minor (Area 2W, and Area 27) Pacific Herring stocks in B.C.

18.2. 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 2020; Figure 18-1). 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 2019, the model was used to provide (in part) estimates of Pacific Herring spawning biomass and age-2 recruit abundances (DFO 2020). 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. Readers are referred to DFO (2020) for important additional information regarding the status of B.C. Pacific Herring stocks.

18.3. 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 18-2). Since 2000, the HG stock has been in a low biomass state (DFO 2020). The most recent data show that biomass remains very low due to very high estimated natural mortality rates.

The estimated stock biomass for PRD has shown minimal trend from 2005 to 2018, with a modest increase in 2019. In the CC in 2019 there was an increase in estimated spawning biomass, and in the SOG spawning biomass declined. The estimated spawning biomass for the WCVI stock has been stable the last three years (Figure 18-3).

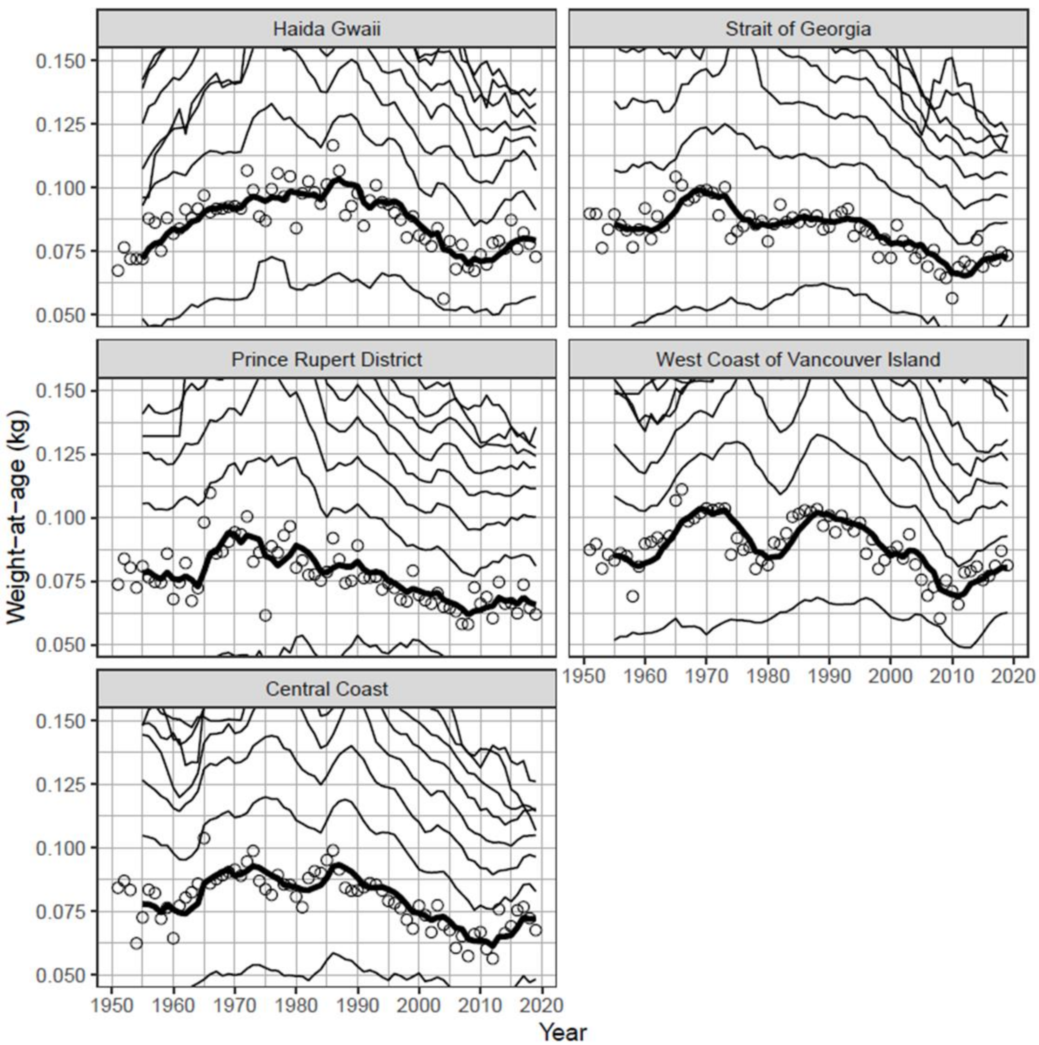

Figure 18-2. Time series of observed weight-at-age 3 (circles) and five-year running mean weight-at-age 3 (dark line) for major Pacific herring stocks, 1951 to 2019. Thinner black lines represent five-year running mean weight-at-age 2 (lowest) and ages 4-10+ (incrementing higher from age 3). Figure adapted from DFO (2020).

18.4. 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).

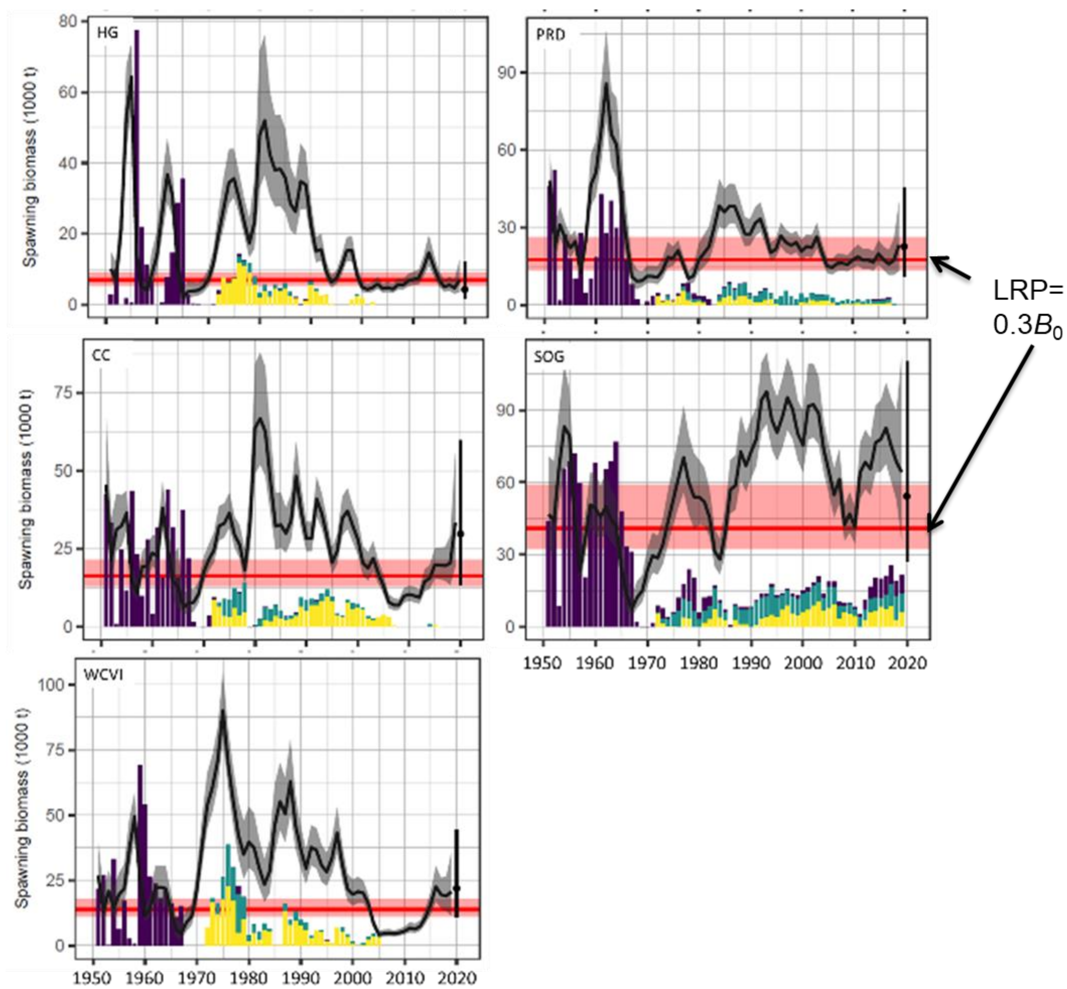

Figure 18-3. Summary of the dynamics of the five Pacific Herring stocks from 1951 to 2019, where solid lines with surrounding grey envelopes, represent medians and 5-95% credible intervals. Also shown is the reconstruction of spawning biomass (SBt) for each year t, with unfished values shown at far left (solid circle and vertical lines) and the projected spawning biomass given zero catch (SB_{2019}) 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 2020). LRP= limit reference point ($0.3B_0$). B_0 = unfished biomass. Figure adapted from DFO (2020).

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). In addition, Tanasichuk (2012) related increased WCVI herring recruitment to a higher biomass of euphausiids.

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). Herring recruitment has been correlated with piscivorous hake biomass (piscivorous hake are those hake that are large enough to consume herring), suggesting that predation may be an important factor influencing WCVI herring recruitment (Tanasichuk 2012). 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).

18.5. 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 LRPs), 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.

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19. PACIFIC HERRING SUMMER DISTRIBUTION AND ABUNDANCE ON THE VANCOUVER ISLAND CONTINENTAL SHELF

Jennifer Boldt*, Hilari Dennis-Bohm, Jackie King, Erika Anderson, and Tyler Zubkowski,
Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC,
*Jennifer.Boldt@dfo-mpo.gc.ca

19.1. Highlights

- Pacific Herring were less broadly distributed in 2019, compared to 2018 and 2017.
- Fewer Pacific Herring were caught north of Scott Islands or offshore of Clayoquot Sound.
- Pacific Herring biomass was higher in 2019 and 2017 compared to 2018.

19.2. Description of the time series

The Integrated Pelagic Ecosystem survey is part of an integrated project designed to study the structure and function of the pelagic ecosystem on the Vancouver Island Continental Shelf (< 200 m bottom depth) during summer. The main goal of the survey is to understand factors affecting the distribution, abundance, and food web linkages of pelagic fish species such as Pacific Herring. Survey objectives are to: 1) examine species distribution, composition, and abundance; 2) collect morphometric data, diet data, and biological samples; and 3) examine the prey environment by sampling zooplankton (vertical bongo net hauls) and conducting oceanographic monitoring (temperature, salinity, fluorescence, and dissolved oxygen). This is a random stratified trawl survey with 8 strata defined by depth and biological communities. A subset of 4x4 km blocks was randomly selected (allocated by strata sizes). Midwater trawl nets were used to sample fish (2017: CanTrawl 250; 2018 and 2019: LFS 7742; see Anderson et al. 2019) at randomly assigned depths (surface or 15 m). Pacific Herring exhibit diel vertical migration, generally ascending at night into upper waters; therefore, night time catches are reported. Catches were sorted into species and weighed. Catch per unit effort (CPUE) was calculated by dividing herring catch weights by the swept volume (product of net mouth opening height, width, and distance towed). Herring biomass was estimated for the survey region using methods in King et al. (2019) and Boldt et al. (2020). The survey was conducted during July 6-August 2, 2017, July 5-29, 2018 and, June 15-July 15, 2019. In 2019, acoustic data were collected along standardized transects during daylight hours using a SIMRAD EK60 scientific echo sounder operating at 38 kHz and 120 kHz, however the acoustic data have yet to be analyzed.

19.3. Status and trends

As in previous years, Pacific Herring were the species most frequently caught on the survey (Boldt et al. 2020). Pacific Herring are typically broadly distributed on the Vancouver Island continental shelf in the upper ~45 m of the water column during night time hours. In 2019, the herring were again widely distributed on the continental shelf but with some spatial differences compared to previous years (Figure 19-1). Areas of higher CPUE were located off the northwest and southwest coasts of Vancouver Island, specifically in the La Perouse area. Pacific Herring were not as broadly distributed in 2019 compared to previous years; there were several trawl hauls in which no Pacific Herring were caught north of Scott Islands and offshore of Clayoquot Sound. Anecdotally, in 2019, acoustic echograms showed dense echosign characteristic of small pelagic fish at depth during nighttime hours, unlike previous years when small pelagics moved up into the upper water column at night. In 2019, the total estimated biomass of Pacific Herring (98,217 t, SE= 6,966 t) was comparable to the biomass in 2017 (92,174 t, SE= 4,717 t) but almost 3 times higher than that in 2018 (34,652 t, SE= 1,667 t) (Figure 19-1; King et al. 2019; Boldt et al. 2020).

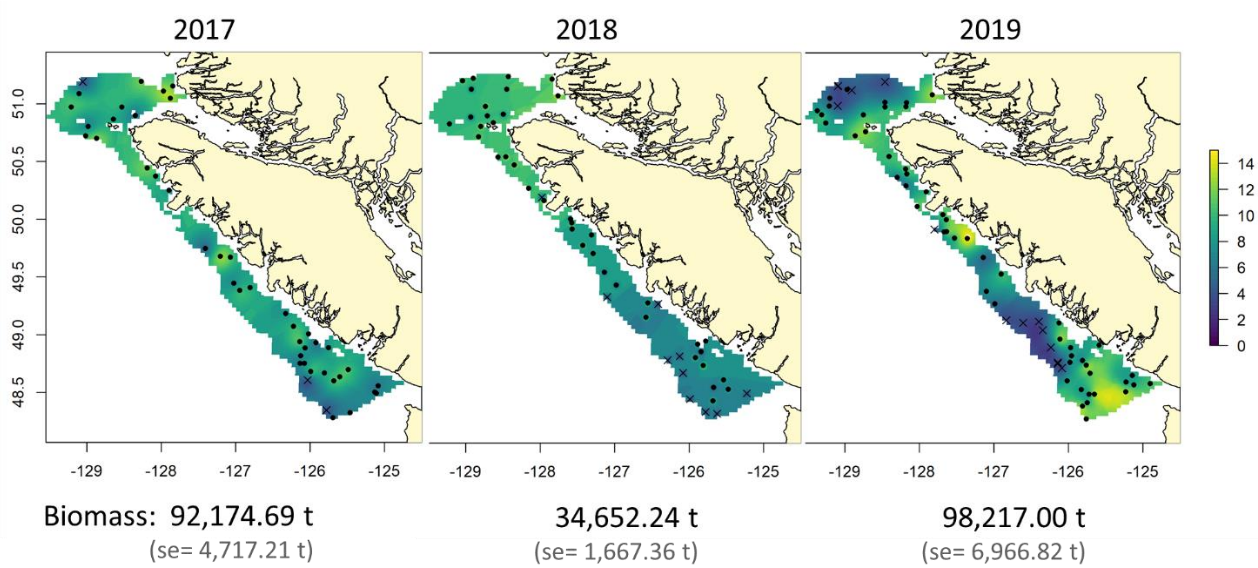

Figure 19-1. Integrated Pelagic Ecosystem Survey on the Vancouver Island Continental shelf (<200 m bottom depth). Catch per unit effort (kg/km^3) of Pacific Herring in night time trawl hauls, 2017-2019. Catch per unit effort values were spatially interpolated using kriging. Black dots indicate stations where herring were caught; black X's indicate stations where a trawl was conducted but no herring were caught. Total biomass (tonnes) estimates are indicated with standard error values. These are preliminary results and may change with additional analyses.

19.4. Factors influencing trends

Environmental variables, such as temperature, are known to affect Pacific Herring recruitment and survival (Tester 1948; Ware 1991). Bottom-up control of production can also influence fish abundance (Ware and Thompson 2005; Perry and Schweigert 2008; Schweigert et al. 2013; Boldt et al. 2018). Pacific Herring are zooplanktivorous, consuming primarily euphausiids 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 northward flowing current could result in the presence of California Current waters off the West coast of Vancouver Island (WCVI), bringing warm-water 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, Pacific 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, Pacific Herring recruitment has been negatively correlated with piscivorous Pacific Hake biomass (i.e., Pacific Hake that are large enough to consume herring), suggesting predation may be an important factor influencing WCVI Pacific Herring recruitment (Tanasichuk 2012). Godefroid et al. (2019) found that the strongest drivers of Pacific Herring summer distribution and density likely include: 1) Pacific Hake (predator), 2) Pacific Sardine (potential competitor when present; currently not abundant in B.C.), and 3) zooplankton (prey).

19.5. Implications of those trends

One of the many types of data collected on this survey is a time series of Pacific Herring abundance and distribution during their summer foraging period. Stock assessments for Pacific Herring indicate temporal changes in natural mortality – the causes of which are unknown. This survey examines Pacific Herring abundance and distribution in the summer, providing an improved understanding of factors affecting their mortality. Spatial data from this survey supports the hypothesis that Pacific Hake predation is an important factor to consider in estimating Pacific Herring mortality (Boldt et al. 2019; Godefroid et al. 2019). Pacific Herring aggregations along the west coast of Vancouver Island are also informative when determining variability in seabird and marine mammal distributions. Mismatch between Pacific Herring aggregations and seabird or marine mammal foraging areas could translate into decreased growth or survival of those predators. This time series provides an indicator of ecosystem productivity and the availability of Pacific Herring to their predators.

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20. 2019 JUVENILE SALMON SURVEYS ON THE VANCOUVER ISLAND CONTINENTAL SHELF

Erika Anderson[1], Jackie King, Jennifer Boldt, Tyler Zubkowski, Cameron Freshwater, Hilari Dennis-Bohm, Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC,
[1]Erika.Anderson@dfo-mpo.gc.ca

20.1. Highlights

- Low catch per unit effort (CPUE) of all juvenile Pacific Salmon on the west coast of Vancouver Island in June and July 2019.
- Juvenile Coho Salmon condition was above average, juvenile Chinook and Chum Salmon condition was average, and juvenile Sockeye Salmon condition was slightly below average in 2019.
- Energy density of juvenile Chinook and Coho Salmon was similar between 2019, 2018, 2002, and 1999.

20.2. Description of the time series

Juvenile salmon catch per unit effort (CPUE) anomalies were estimated from surface trawl surveys conducted by Fisheries and Oceans Canada on the continental shelf of Vancouver Island. From 1998 to 2015 High Seas Salmon Surveys were conducted along standard transects and included opportunistic sampling. Since 2017, the Integrated Pelagic Ecosystem Survey (IPES) used a random stratified survey design based on depth and biological communities (King et al. 2019; Boldt et al. 2020). Every effort has been made to minimize the influence of survey design, (i.e., incorporating only daytime tows, in the same survey area, with similar tow depths); however, comparisons between survey periods should be made with caution. Annual CPUE anomalies were calculated as the mean of natural log-transformed (plus one) catch counts per volume swept, and expressed as standardized anomalies.

20.3. Status and trends

CPUE anomalies for all juvenile salmon were low in 2019 (Figure 20-1). Juvenile Chum Salmon had the largest biomass compared to other Pacific Salmon. There were no juvenile Pink Salmon caught during daylight tows in 2019. This was not unusual given the two-year cyclic nature of Pink Salmon with odd brood years dominating southern B.C..

The region immediately north of Brooks Peninsula was a hotspot for juvenile Pacific Salmon (Figure 20-2). Juvenile Chinook Salmon were widespread in the study area in lower abundance. Juvenile Chum Salmon were caught in higher abundances in localized tows. Juvenile Coho Salmon were higher in the southern and inshore areas. Finally, juvenile Sockeye Salmon were caught in Queen Charlotte Strait.

The length to weight relationship indicated that juvenile Coho Salmon condition was above average, juvenile Chinook and Chum Salmon condition was average and juvenile Sockeye Salmon condition was slightly below average in 2019 (Figure 20-3).

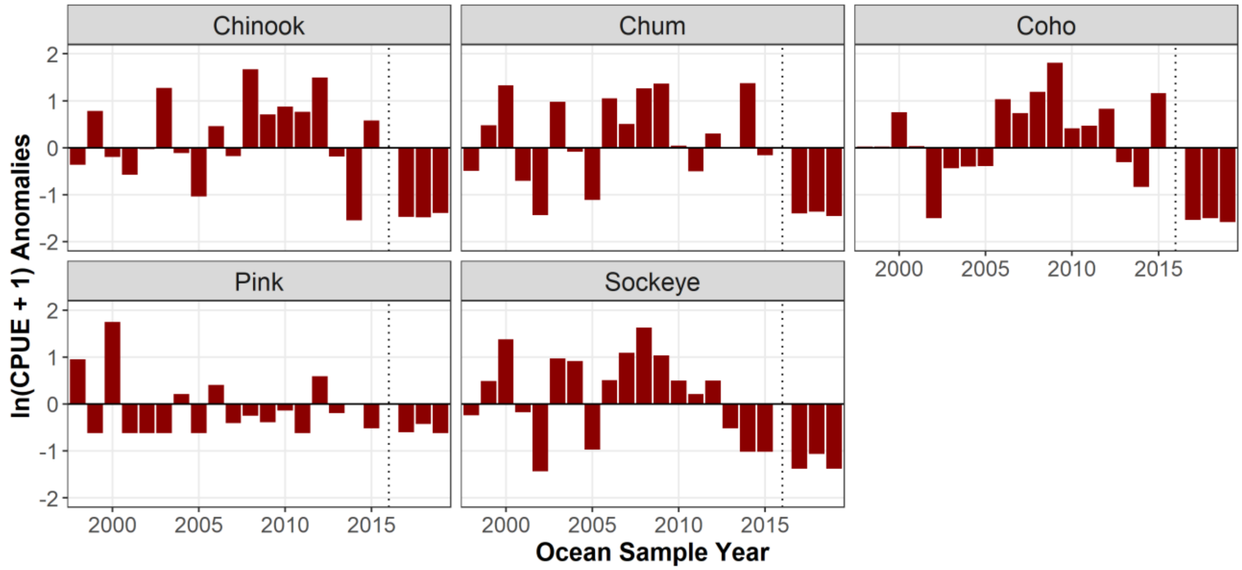

Figure 20-1. Annual catch per unit effort (CPUE) anomalies in June and July from 1998-2019 for juvenile Pacific Salmon off the west coast of Vancouver Island. Positive anomalies represent above average abundance; negative anomalies represent below average abundance. The vertical dotted line indicates that there were no surveys in 2016.

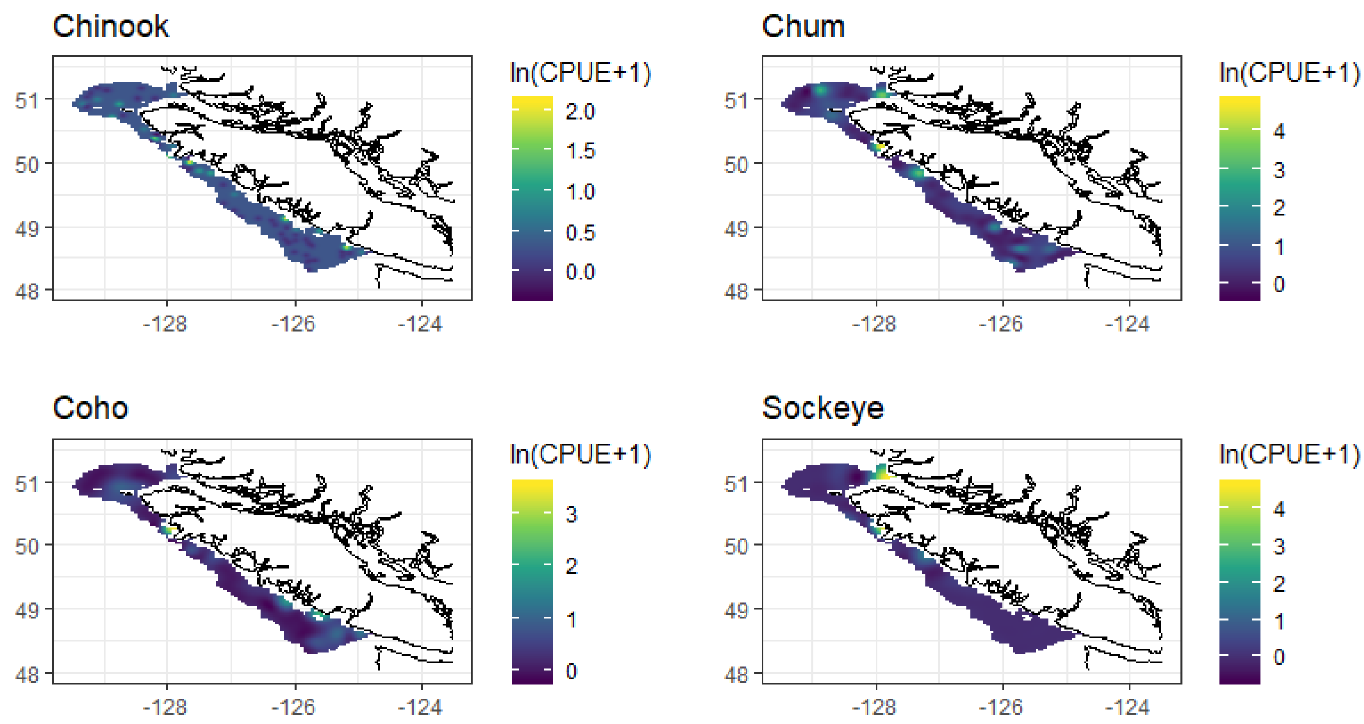

Figure 20-2. Kriging interpolation of catch per unit effort, ln(CPUE + 1), of juvenile Pacific Salmon off the west coast of Vancouver Island in 2019. Yellow indicates a higher CPUE, whereas dark blue indicates lower CPUE. The surfaces include tows with zero catch.

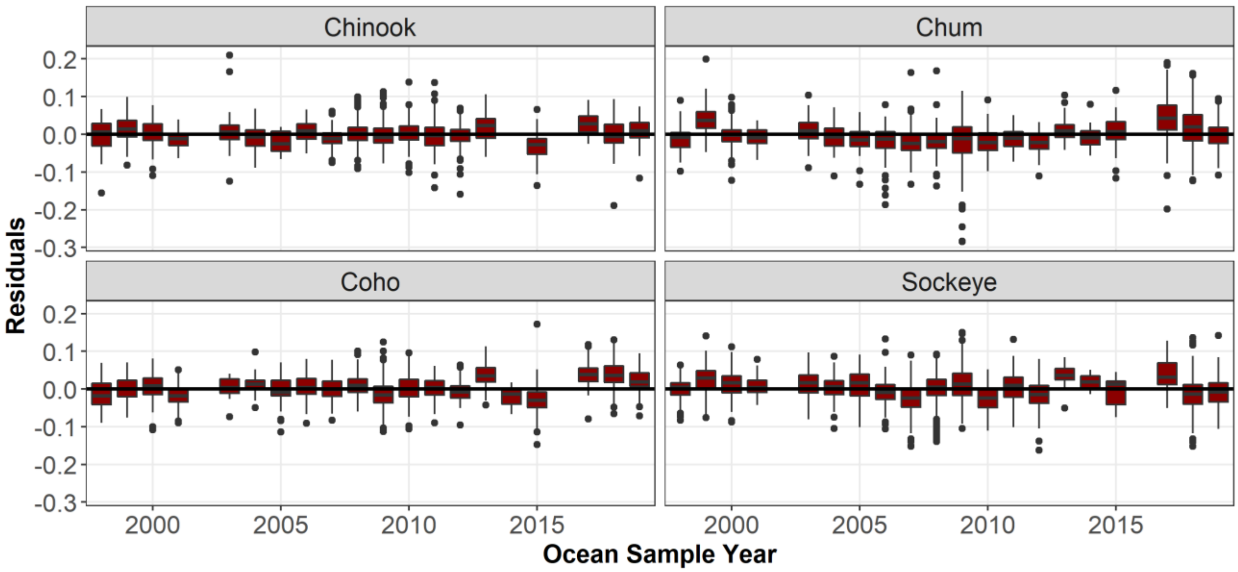

Figure 20-3. Juvenile salmon condition as measured by residuals from the log length to log weight relationship by species from 1998 to 2019. The boxes represent the lower quantile and upper quantile, the mean is the black line within the box, and outliers are dots.

A more precise measure of fish condition is energy density, as estimated with a calorimeter. The energy density of juvenile Chinook and Coho Salmon in 2018 and 2019 was comparable to that from historic (1999 and 2002) samples. Energy density values were also comparable between 2018 and 2019 for juvenile Chum and Sockeye Salmon. Future research will estimate stock-specific condition.

20.4. Factors influencing trends

The relative abundance of juvenile 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. The continued low juvenile salmon abundance observed in these surveys off the west coast of Vancouver Island (WCVI) provides some support for the concept of a new ecosystem base-line in this region following the 2015 marine heatwave. Juvenile salmon survey catch rate anomalies throughout the northeastern Pacific and the Bering Sea continue to exhibit highly variable responses across regions after the 2015 marine heatwave (King et al. 2020).

20.5. Implications of those trends

Below average relative indices of abundance (CPUE) suggests below average returns for the stocks typically encountered in these surveys. The majority of Sockeye Salmon encountered on the continental shelf of northern Vancouver Island originate from the Fraser River, and those on the WCVI originate from local stocks, predominantly Barkley Sound; the majority of Chinook and Coho Salmon captured along the Vancouver Island continental shelf originate from Columbia River, Puget Sound, Vancouver Island, and Oregon stocks in order of dominance. Genetic stock identification for Chum and Pink Salmon were not yet available for these surveys. The juvenile Pacific Salmon encountered in these surveys will return to spawn at varying times, but generally these catch rates apply to Pink and Coho Salmon returning in 2020, Sockeye and Chinook Salmon returning in 2021, and Chum Salmon returning in 2022.

20.6. References

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21. STATE OF CANADIAN PACIFIC SALMON IN 2019

Sue C.H. Grant[1], Bronwyn L. MacDonald[1], & Catherine G.J. Michielsens[2]

[1]State of Salmon Program, Fisheries and Oceans Canada, Regional Headquarters, Vancouver, BC, Sue.Grant@dfo-mpo.gc.ca, Bronwyn.MacDonald@dfo-mpo.gc.ca,
[2]Pacific Salmon Commission, Vancouver, BC, Michielsens@psc.org

21.1. Highlights

- Sockeye and Chinook returns in 2019 were generally poor. This is a continuation of recent trends for these species, where low returns have been observed, particularly at southern latitudes.
- Chum salmon returns in 2019 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 2019 were mixed. Pink salmon have generally had better returns than most species in recent years, while Coho have exhibited poor returns, particularly in southern latitudes.
- 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.
- Poor salmon returns to the Fraser watershed in 2019 were compounded by the Big Bar landslide, which blocked upstream migration of many salmon populations. Work is on-going to attempt to mitigate this blockage for 2020 spawning migrations.

21.2. 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 data are currently available up to 2017. Although in-season salmon catch data are available to manage particular fisheries, there is generally a lag of a few years to finalize and integrate these data into a standardized format available through the NPAFC. Therefore, 2018 and 2019 data points are unavailable currently.

Most salmon return information for 2019 is only available qualitatively at the time of this report. Qualitative input on 2019 returns was provided by various DFO Area leads: Northern B.C.-Alaska transboundary updates: A. Foos; Yukon: M. Folkes & C. Carli; Inside Chum: P. Van Will; North Coast all species: C. Carr-Harris; Fraser Chinook: R. Bailey; South Coast: W. Luedke. Quantitative returns in 2019 are available for key Sockeye populations, and are presented in Hyatt et al. (Section 22). Further details on 2019 returns and productivity are available for the 18 key Fraser River sockeye populations (Grant et al. 2019a, 2019b). These are provided by S. Latham, from the Pacific Salmon Commission (PSC), and S. Decker & B. Leaf, from DFO.

21.3. Canadian Pacific Salmon status and trends

21.3.1. Trends in salmon catch

Commercial catch for all five DFO-managed Pacific Salmon species has declined in the past decade (Figure 21-1). 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. 2019c). Although integrated catch data are not yet available for 2019, commercial fisheries were extremely curtailed for this year, due to generally low expected returns for most populations.

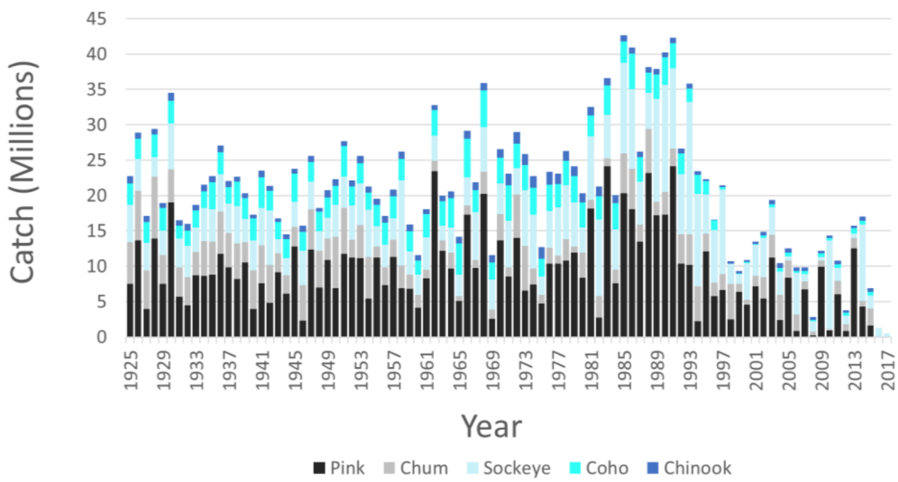

Figure 21-1. Commercial catch of Canadian Pink, Chum, Sockeye, Coho and Chinook Salmon (Grant et al. 2019c; NPAFC statitics: https://npafc.org/statistics/). Average catch from 1925-1993 was 30 million, and from 1994-2017 was 15 million.

21.3.2. Qualitative Canadian Pacific Salmon returns in 2019

Total returns of Chinook in 2019 were poor, which continued the recent trend of generally low abundances (Grant et al. 2019c). Some local area exceptions in 2019 included Fraser summer ocean-type Chinook, East and West Coast of Vancouver Island ocean-type, and Alsek River Chinook in the Northern B.C.-Alaska transboundary region. Sockeye returns in 2019 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. 2019c; Hyatt et al. 2019). Populations in the Alsek and Taku Rivers of the Northern B.C.-Alaska transboundary region were exceptions to the Sockeye trend in 2019. Coho returns in 2019 were mixed, where populations in Northern B.C. and the West Coast of Vancouver Island had below average returns, and the Interior Fraser and Northern B.C.-Alaska transboundary populations had average returns. Pink returns in 2019 were also mixed, and similar to Chum salmon in recent years, were generally better than other species. Chum salmon generally exhibited poor returns in 2019, in contrast with their recent trend of better returns (Grant et al. 2019c). In the Fraser River, a major landslide located at the Big Bar ferry north of Lillooet further negatively impacted salmon populations above the slide. This landslide further reduced the number of spawners able to reach upstream spawning grounds (Government of B.C. et al. 2019).

21.3.3. Canadian Sockeye Salmon in 2019

Sockeye Salmon are the one species where return data for 2019 are available in time for this report. Returns of Sockeye were generally poor for most key populations presented by Hyatt et al. (Section 22).

Returns and productivity for the Fraser Sockeye aggregate were the lowest on record in 2019, which corresponds to the 2015 brood year (Figure 21-2). Additionally, productivities were synchronously low across all 18 key Fraser Sockeye populations (Figure 21-3), and were lower than those associated with the 2009 return year, which led to the Cohen Inquiry (Cohen 2012a, 2012b).

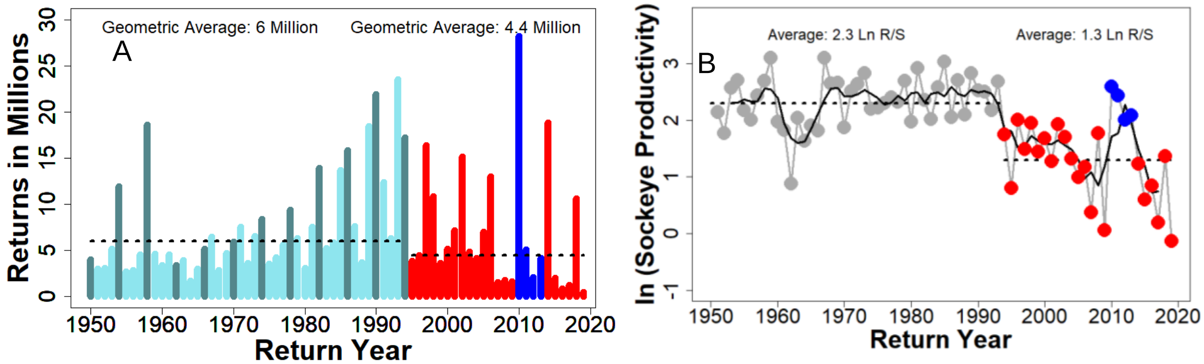

Figure 21-2. (A) Total Fraser Sockeye annual returns (dark blue vertical bars for the 2018 cycle and light blue vertical bars for the three other cycles) and (B) total Fraser Sockeye productivity (log_e (returns/total spawner)) is presented up to the 2019 return year. The grey dots and lines represent annual productivity estimates. For both figures, the dashed line is the time series average. Productivity and returns have declined in recent decades, highlighted red, with the exception of four years from 2010-2013, which were closer to average, highlighted blue.

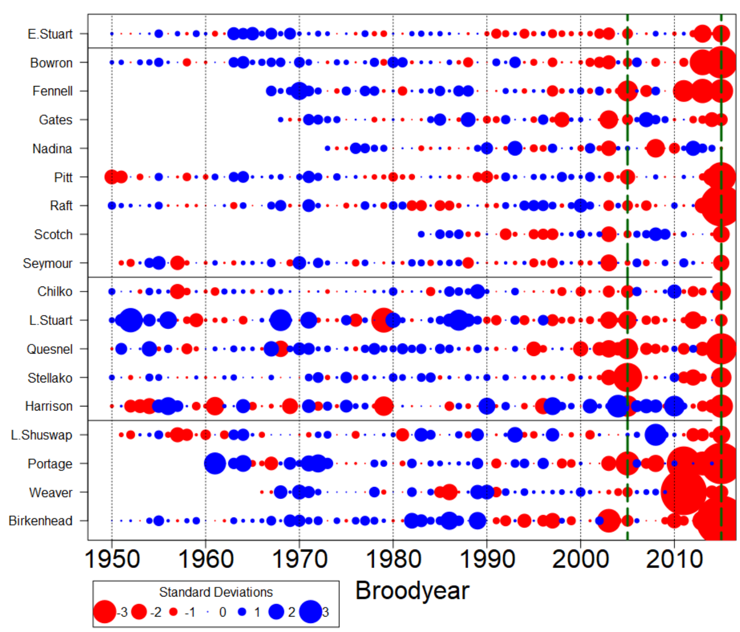

Figure 21-3. Four year old Fraser Sockeye productivity (Ricker model residuals for all populations except Scotch, Seymour and Late Shuswap, which are Larkin residuals) up to the 2015 brood year (2019 return year) across 18 key populations. Both freshwater and marine factors contribute to the observed productivities. 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 2015 brood years (2009 and 2019 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.

21.4. 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. 2019c). These marine and freshwater ecosystem changes are impacting Pacific Salmon at every stage of their life-cycle.

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 (see Table 16-2 in Galbraith and Young 2019). 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. 2019). 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 2019).

British Columbia and Yukon air and water temperatures are increasing, and precipitation patterns are changing, altering freshwater habitats (Grant et al. 2019c). 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.

21.5. 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. 2019c; Crozier et al. 2019). 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 recently 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. 2019c).

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22. COAST-WIDE SOCKEYE SALMON PERFORMANCE INDICATORS, REGIONAL OVERVIEW OF TRENDS, 2019 RETURNS, AND 2020-2021 OUTLOOK

Kim Hyatt*, Howard Stiff, and Margot Stockwell, Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, *Kim.Hyatt@dfo-mpo.gc.ca

22.1. Highlights

- Returns of B.C.'s Transboundary, North Coast, Central Coast, WCVI, Fraser, and Okanagan Sockeye Salmon 'index stocks' in 2019 were below median management forecasts and all-year average return estimates.
- Large returns of Sockeye Salmon to Bristol Bay Alaska 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 and maturation in the Gulf of Alaska (GOA) in 2018, displayed sub-average returns in 2019. By contrast, Bristol Bay Sockeye, with sea-entry north of the Aleutians and maturation in the Bering Sea, experienced survival-favourable conditions and exhibited near record returns in 2019.

22.2. Time Series – Annual Returns of Coast-wide Sockeye "Indicator Stocks"

Hyatt et al. (2019) have briefly described sources of salmon population data comprising a *de facto* international network of coast-wide Sockeye Salmon performance indicators (Figure 22-1) from which inferences about trends in geographic patterns of abundance and biological traits may be made. Sockeye return data are comprised of 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.

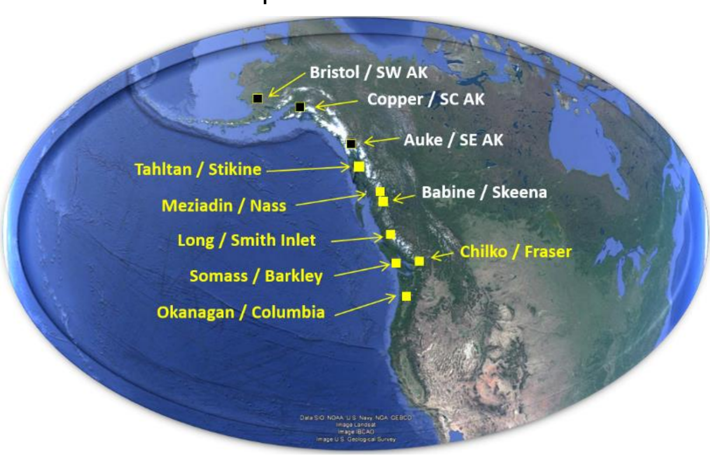

Figure 22-1. Coast-wide Sockeye Performance Indicator Stocks. Approximate points of sea entry for a network of relatively data-rich Sockeye stocks monitored by DFO (yellow) and ADFG (black) on an annual basis for biological traits (age-at-return, size-at-return, return timing etc.) and total returns (catch plus escapement) relative to predicted returns.

Production trends of “data-rich” Sockeye populations or stock aggregates (i.e. “indicator stocks”) are assumed to represent other populations 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 22-2).

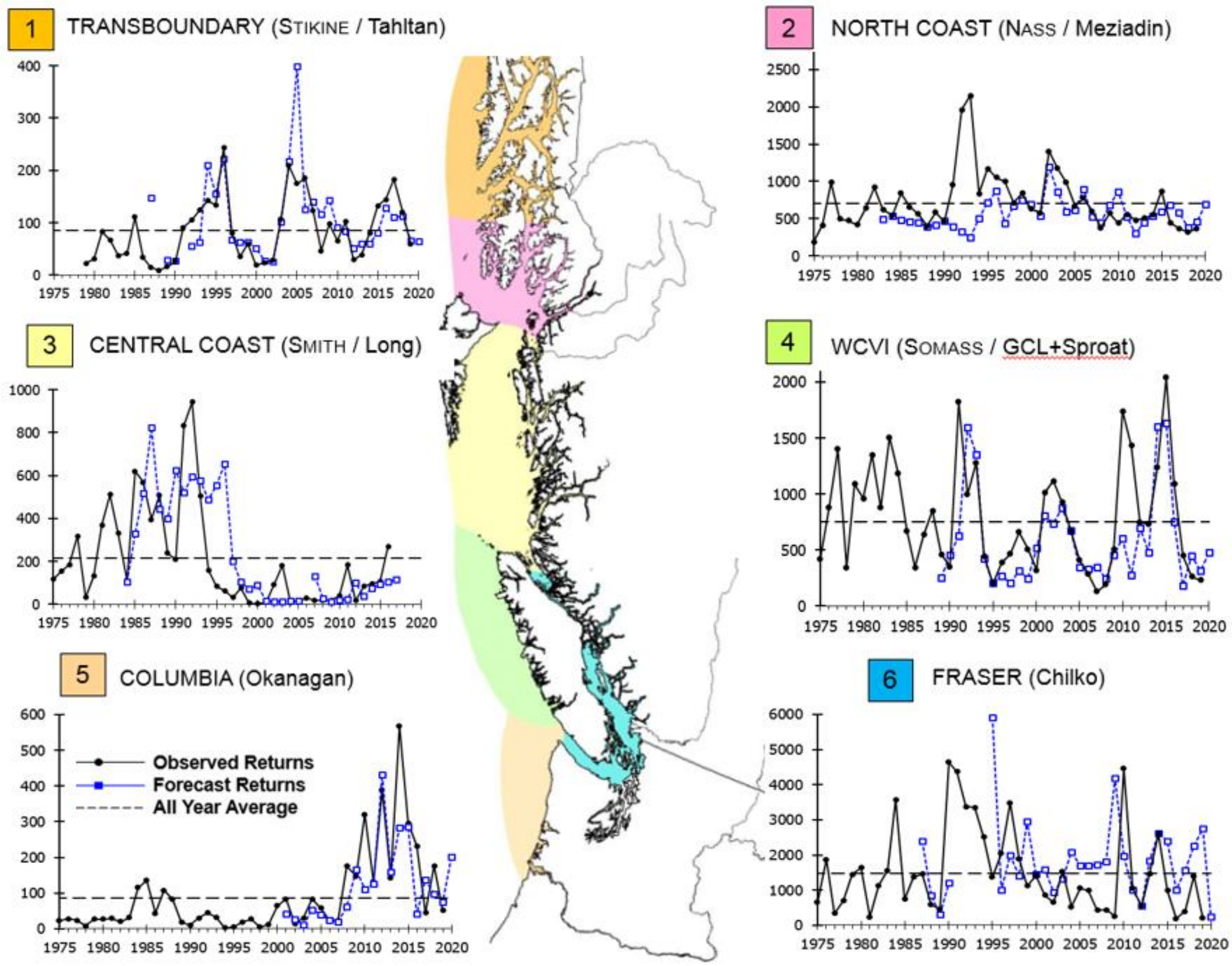

Figure 22-2. Trends in the total annual returns (thousands of fish; black line) and management forecasts (blue line) for British Columbia Sockeye index stocks, by DOMAIN: (1) Tahltan (TRANSBOUNDARY); (2) Meziadin (NORTH COAST); (3) Long (CENTRAL COAST); (4) Somass (WCVI); (5) Okanagan (COLUMBIA) and (6) Chilko (FRASER).

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

In 2019, B.C. index stocks generally exhibited returns below to far below their 40 year average (Figure 22-2). Escapement goals were not met for most stocks, and Sockeye fisheries were closed or highly restricted in Canadian waters.[1] By contrast, Bristol Bay (Alaska) Sockeye achieved record returns in 2018 and 2019 (62 million and 56 million fish respectively; ADFG

[1] An estimated 45,000 Nass Sockeye were intercepted by U.S. commercial fisheries in Alaska in 2019 compared to ~21,000 pieces by (principally) the Area C gillnet fleet (NFWD 2019).

2019). Exceptional returns to Bristol Bay and weak returns to southeast Alaska 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). Environmental conditions in freshwater and marine ecosystems for the past 3-4 years have not favoured improved survival at multiple salmonid life stages (Hyatt et al. 2018, Section 51; MacDonald et al. 2018). Consequently, declining returns to B.C. systems in 2019 relative to larger returns during 2014-2016 were generally anticipated by forecasting routines (i.e. forecast errors were 32% for Okanagan, 25% for Somass, 20% for Nass, 13% for Tahltan, but 92% for Chilko for which returns reached a record low, Figure 22-2).

22.4. 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 2019, 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 and 2016[2], in conjunction with a marine heatwave in the Northeast Pacific from late 2013 to autumn 2016, and the strongest El Niño event in the past 70 years in late 2015 through early 2016. Freshwater temperature anomalies during egg-incubation ranged 1-2°C above normal, potentially impacting hatch timing and growth.[3] Early snowmelt and high discharge levels likely promoted scour events in rearing habitat, reducing egg-to-fry survival.

While physical ocean conditions reverted towards normal in 2017, biological conditions encountered by Sockeye smolts making sea-entry in 2016 and 2017 “continued to reflect a warmer ocean” (DFO 2020, p. 54), 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 affect sub-adult growth and survival.

The ENSO index[4], 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)[5] (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:

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[2] Pacific Climate Impacts Consortium Seasonal Anomaly Maps (downloaded: March 2020)

[3] High winter- and spring temperatures likely contributed to high in-lake over-winter mortality rates (>80%) for Somass Sockeye pre-smolts from brood year 2014 (Hyatt et al. Section 51).

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

[5] However, see Hyatt et al. (Section 51) 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) were associated with sub-average returns for many stocks, most evidently for those entering directly into the CCS. The strong El Niño event in 2015/16 has been followed by declines in the majority of Sockeye stocks to below-average returns from 2017 to 2019.

22.5. Implications and Outlook for Returns in 2020-2022

Across the life-history of B.C. Sockeye populations returning in 2020, 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 – associated with a return of B.C. outer coast (but not Salish Sea) temperatures close to the climatological mean in 2018 (Chandler 2019) – signals some potential for improvement in survival for juvenile Sockeye at sea entry in 2018. However any moderate improvement is likely to be outweighed by several negative events, including:

- Extremely warm, wet November 2016 (2-5°C above normal) in many parts of the province, with numerous scour-inducing storm events leading to flooding on Vancouver Island, and South and Central Coast during the salmon egg incubation period.
- Sub-average snow packs in 2017[6] in Central Coast, North Coast, the Stikine, and Vancouver Island regions in 2018, followed by above-average May temperatures, early freshets, and late summer to fall drought, potentially affecting returns in 2020 and 2021.
- A coast-wide 2019 spring drought associated with an intense marine heatwave that developed and persisted from June 2019 to January 2020 (NEP19; NOAA 2016) with potential for negative impacts in freshwater and marine systems (e.g. see Hyatt et al., Section 51) on juvenile and sub-adult salmon supporting adult returns in 2020-2022.
- In the Fraser River system, the impact of the Big Bar rock-slide is expected to have large negative impacts on survival and production of all upstream salmon species starting with the 2019 brood year and going forward.

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23. WCVI SMALL-MESH MULTI-SPECIES BOTTOM TRAWL SURVEYS (TARGET SPECIES: SMOOTH PINK SHRIMP): UPDATE TO 2019

R. Ian Perry[1,2], Ken Fong[1], Shaun MacNeil[1], Brenda Waddell[1]

[1]Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, Ian.Perry@dfo-mpo.gc.ca, Ken.Fong@dfo-mpo.gc.ca
[2]Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC

23.1. Highlights

- Smooth Pink Shrimp biomass in Areas 124-125 off the west coast of Vancouver Island in 2019 continued to be among the lowest of the time series, with anomalies well below the climatological mean.
- A statistically significant relationship exists between the sea surface temperature (SST) at Amphitrite Point in Year i - 1, the biomass of Smooth Pink Shrimp in Year i - 1, and the observed biomass of Smooth Pink Shrimp in Year i.
- Using this relationship, the Amphitrite Point SST in 2019 and the observed Pink Shrimp biomass in 2019 project continued very low Smooth Pink Shrimp biomass for 2020.
- Among the well-sampled finfish taxa, Lingcod and Eulachon continued to have negative biomass anomalies in 2019; biomass anomalies for all other well-sampled finfish taxa remained positive, with biomass peaks in 2019 for several flatfish species: Petrale Sole, Rex Sole, Dover Sole, Flathead Sole, Slender Sole.
- Based on biomass composition of the "well-sampled" taxa, 2017, 2018 and 2019 were similar, but were different from the biomass composition during 2009-2015.

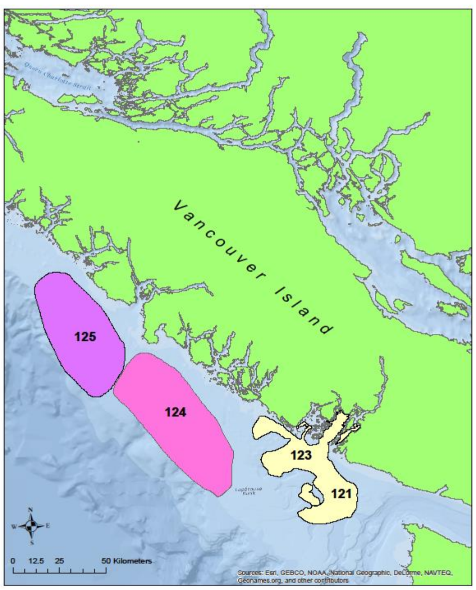

Figure 23-1. Map showing the three main Smooth Pink shrimp (Pandalus jordani) fishing grounds and survey areas off Vancouver Island. The Nootka (Area 125) and Tofino (Area 124) Grounds have been surveyed since 1973. The area off Barkley Sound (Areas 23, 121 and 123) has been surveyed since 1996.

23.2. Description of the time series

Fishery-independent bottom trawl surveys using a small-mesh net (targeting the Smooth Pink Shrimp *Pandalus jordani*) have been conducted during May since 1973 in two regions, and since 1996 in three regions, off the west coast of Vancouver Island (Figure 23-1). The survey masks for these regions, over which the total biomass of each species has been estimated, generally occur between the 100 m and 200 m isobaths for Areas 124 and 125. A different vessel was used for the survey in 2017, 2018, and 2019 compared with previous years.

This small-mesh multi-species bottom trawl survey was designed to target Smooth Pink Shrimp on the shrimp fishing grounds in a relatively small area off the west coast of Vancouver Island (Figure 23-1). The interannual variability of biomass estimates of other taxa caught along with Smooth Pink Shrimp depend on whether these other taxa are highly mobile in and out of the survey area or are highly patchy in their distribution. An autocorrelation analysis was used to identify 13 “well-sampled” taxa (i.e. which have positive autocorrelations of at least a one year lag; Table 23-1) out of the 34 taxa that have been regularly sampled and identified to species on this survey. Data are calculated as the total biomass over the survey area and are presented as standardised (by the standard deviation) $\log_{10}$-scaled species anomalies from the climatological period 1981-2010.

Table 23-1. List of ‘core’ species which have been sampled and identified routinely during these small mesh surveys since 1973 and for which annual biomass estimates are calculated. Taxa in blue are those with significant (p<0.05) autocorrelations and which are therefore considered to be “well-sampled” by this survey.

Pelagics	Demersals		Benthics
Pacific Hake	Silvergrey Rockfish	Pacific Cod	Sea Mouse
American Shad	Darkblotch Rockfish	Sablefish	Heart Urchin
Pacific Herring	Green Rockfish	Lingcod	Sea Urchins
Eulachon	Yellowtail Rockfish	Ratfish	Sea Cucumber
Dogfish	Boccacio	Smooth Pink Shrimp	
Walleye Pollock	Canary Rockfish	Dover Sole	
	Redstripe Rockfish	Pacific Sanddab	
	Pacific Ocean Perch	Petrale Sole	
	Arrowtooth Flounder	Rex Sole	
	English Sole	Flathead Sole	
	Pacific Halibut	Slender Sole	
	Yelloweye Rockfish	Spot Prawn	

23.3. Status and Trends

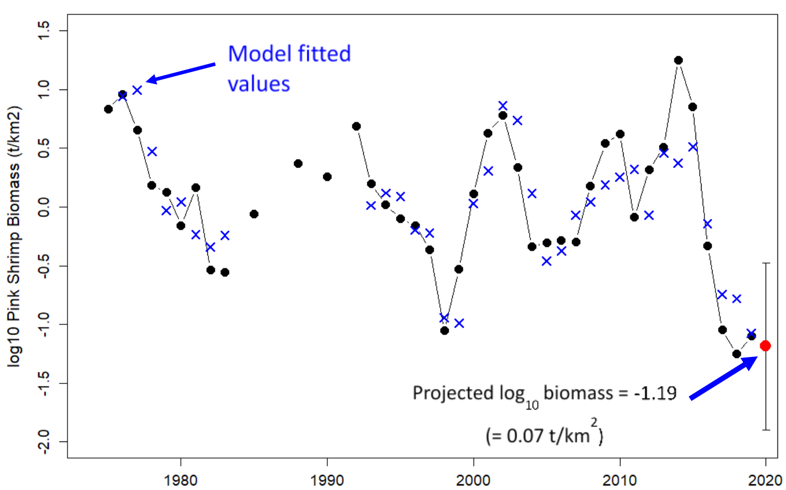

Figure 23-2. Annual biomass of Smooth Pink Shrimp in Areas 124+125 off the west coast of Vancouver Island as determined by these surveys (black dots and line). The blue crosses are model fits. Red dot and 95% confidence interval (vertical line) at 2020 represents the biomass predicted from the new multiple regression.

A statistical model was constructed with the $\log_{10}$ biomass of Smooth Pink Shrimp as the response variable and the annual mean sea surface temperature (SST) at Amphitrite Point along the west coast of Vancouver Island two years previously as the explanatory variable (e.g. Perry et al. 2019). This model was updated to take into account the significant autocorrelation at lag 1 of the current pink shrimp biomass on the biomass in the previous year, and also includes the mean annual SST at Amphitrite Point in the previous year. This new model has very good statistical fits to the data ($_{adjusted}R^2$ = 0.72, P << 0.001), and has very good prediction skill (derived from 5 repeat 5-fold cross-validation, R^2 = 0.75) (Figure 23-2).

The survey in May 2019 shows the biomass of *Pandalus jordani* shrimp off central Vancouver Island continued to decline from the record high level observed in 2014, and was now a substantial negative anomaly (although slightly higher than in 2018; Figure 23-3). Only three other taxa had negative or near zero biomass anomalies in recent years: Lingcod, Eulachon, and sea cucumber (not shown). The biomass anomalies of most of the flatfish species considered to be well-sampled have been at or near maximum biomass anomalies (Figures 23-4, 23-5), with the exception of Arrowtooth Flounder which has declined to be near its mean biomass over the period 1981 to 2010 (Figure 23-4). Cumulative anomalies and the annual average anomaly illustrates that anomalies for most species were negative from 1973 to 1999, and have been mostly positive since 2000 with a slight negative period from 2006-2008. The year 2019 had the 5th highest annual average anomaly since 1973. Negative biomass anomalies in 2019 occurred for Smooth Pink Shrimp, Eulachon and Sea Cucumber.

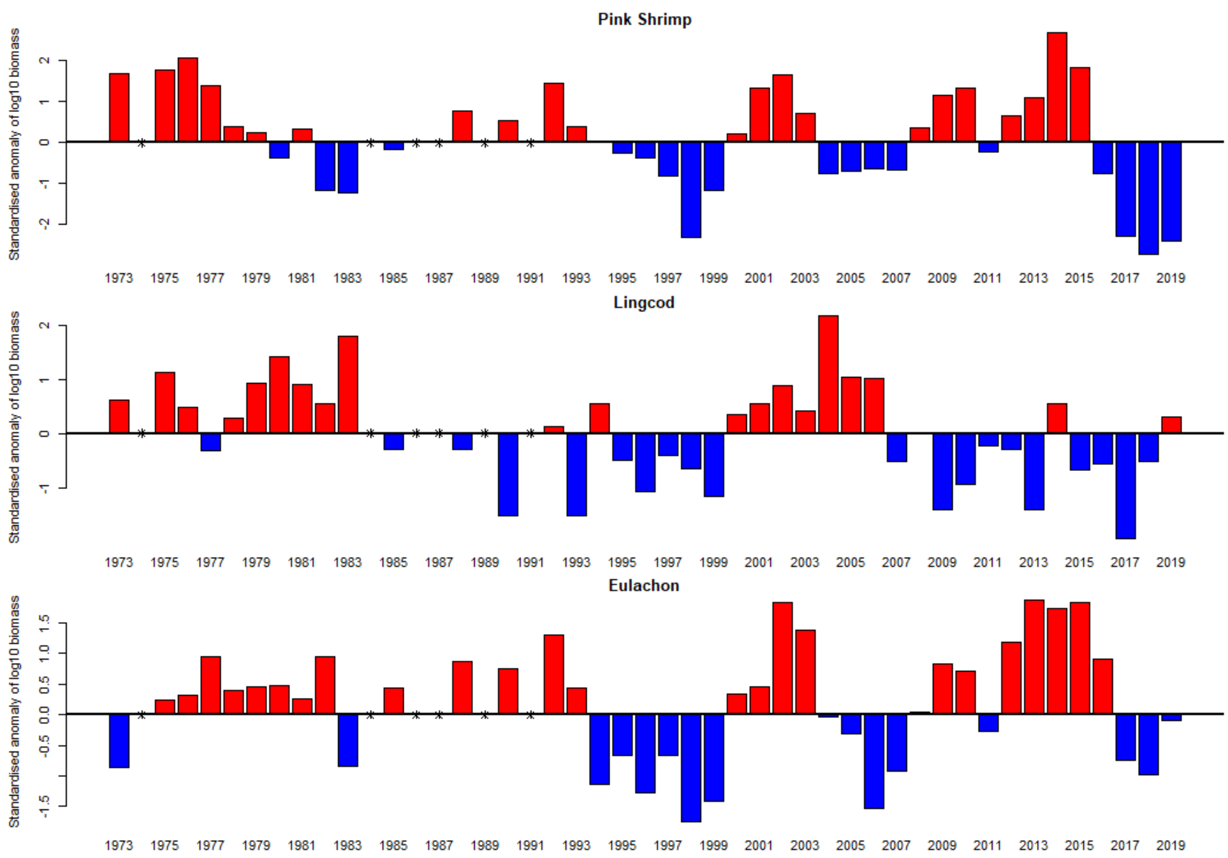

Figure 23-3. Standardised (by the standard deviation) anomalies of log_{10} species biomass for Smooth Pink Shrimp, Lingcod, and Eulachon. Climatology period is 1981-2010.

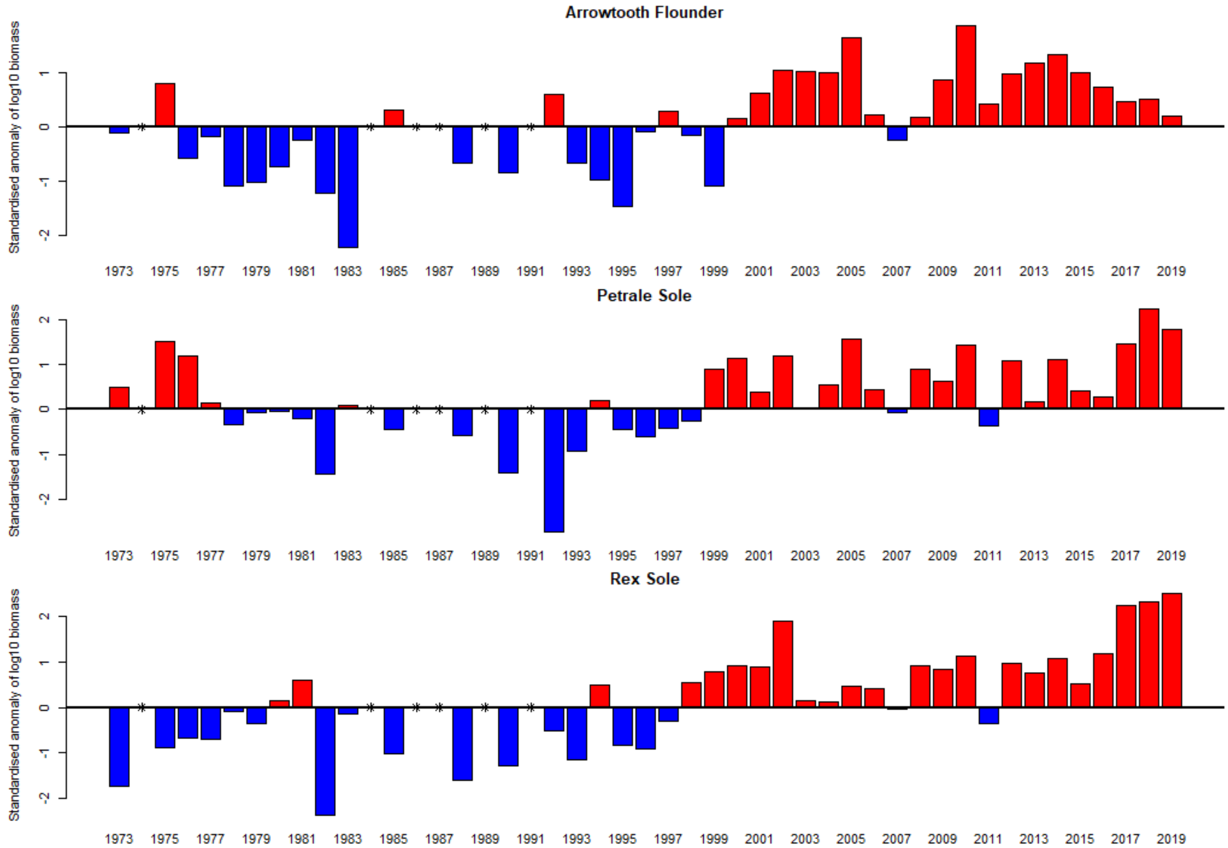

Figure 23-4. Standardised (by the standard deviation) anomalies of $\log_{10}$ species biomass for Arrowtooth Flounder, Petrale Sole, and Rex Sole. Climatology period is 1981-2010.

23.4. Factors influencing these trends

Potential causes for the observed trends are under investigation. Climate and environmental factors are expected to be the main drivers of trends over this length of time. The regression relationship between Smooth Pink Shrimp biomass in the present year with its biomass and SST in the year previous is consistent with its 2-3 year life span, its recruitment to this survey year mostly by age 2, and the influence of Sea Surface Temperature while the juveniles were growing in the previous year. Temperature may have a direct effect on the survival of larval shrimp (with cooler temperatures being favoured) and/or temperature may serve as a proxy for other processes (e.g. example, increased abundances of predators on larval shrimp when conditions are warmer).

23.5. Implications of these trends

Many of the species considered to be “well-sampled” by this survey are of commercial interest. Considered collectively, biomass anomalies of many of these taxa have been largely positive since 2000, compared to the reference period of 1981-2010. The implication is that groundfish biomass off the west coast of Vancouver may also have increased compared with the 1980s and 1990s, at least for these selected species in these small areas surveyed with sandy bottom types that are the preferred habitat for Smooth Pink Shrimp. This is under investigation.

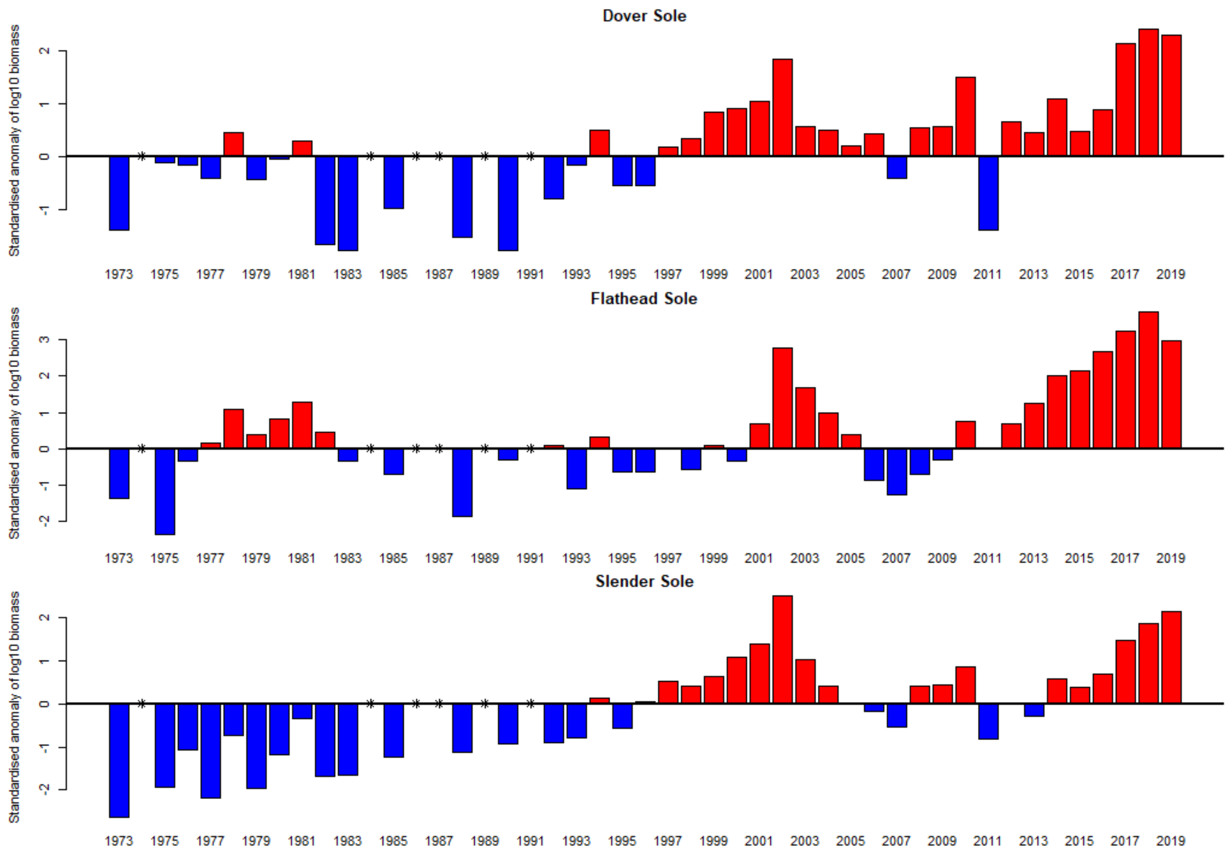

Figure 23-5. Standardised (by the standard deviation) anomalies of $\log_{10}$ species biomass for Dover Sole, Flathead Sole, and Slender Sole. Climatology period is 1981-2010.

23.6. References

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24. A REVIEW OF GROUNDFISH SURVEYS IN 2019

Philina A. English, Sean C. Anderson, and Greg D. Workman, Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, Philina.English@dfo-mpo.gc.ca, Sean.Anderson@dfo-mpo.gc.ca, Greg.Workman@dfo-mpo.gc.ca

24.1. Highlights

- The top five species by weight from this year's trawl survey in Hecate Strait were Spotted Ratfish, Arrowtooth Flounder, Rex Sole, Dover Sole, and English Sole. In Queen Charlotte Sound dominant species were Sablefish, Pacific Ocean Perch, Arrowtooth Flounder, Silvergray Rockfish, and Pacific Hake.
- Notable trends across both surveys in the last two years included increases in biomass indices for several Rockfish species including Bocaccio and Redbanded; an apparent reversal of a longer-term declining trend for North Pacific Spiny Dogfish; leveling off of trends for Sablefish, Pacific Cod, and Shortspine Thornyhead; and decadal-scale decreases in Arrowtooth Flounder and Spotted Ratfish indices.
- Immature fish biomass indices have increased more sharply than mature fish biomass indices for Sablefish, Petrale Sole, Lingcod, Slender Sole, and Yelloweye Rockfish.

24.2. Fisheries-independent groundfish time series

The Fisheries and Oceans Canada (DFO) Groundfish Section conducts a suite of randomized surveys using bottom trawl, longline hook, and longline trap gear that, in aggregate, provide coverage for all offshore waters of Canada's Pacific Coast. Surveys in Queen Charlotte Sound (QCS) and Hecate Strait (HS) are conducted in odd numbered years (Figure 24-1) and the West Coast of Vancouver Island and the West Coast of Haida Gwaii surveys are conducted in even numbered years. In addition to the bottom trawl surveys, two Hard Bottom Longline surveys are conducted, one in "inside" waters (east of Vancouver Island) and in "outside" waters (everything else). Each year the surveys alternate between northern and southern areas (the northern areas were surveyed in 2019). Lastly, a coast-wide longline trap survey targeting sablefish (Sablefish Research and Assessment Survey) is conducted every year. In addition to the random depth-stratified surveys, the Groundfish Section collects additional information from a DFO Small-Mesh Multi-species Bottom Trawl Survey (fixed-station survey of commercially important shrimp grounds off the West Coast of Vancouver Island and eastern Queen Charlotte Sound) and the International Pacific Halibut Commission (IPHC) Setline Survey.

The randomized surveys follow depth-stratified designs and have in common full enumeration of the catches (all catch sorted to the lowest taxon possible), size and sex composition sampling for most species, and more detailed biological sampling of selected species. Most of the surveys are conducted in collaboration with the commercial fishing industry under the authorities of various collaborative agreements. Trends and results of biological sampling from all of these surveys are now reported in "a reproducible data synopsis for over 100 species of British Columbia groundfish" (Anderson et al. 2019); only results from the synoptic bottom trawl are currently updated to include 2019 and are reported here.

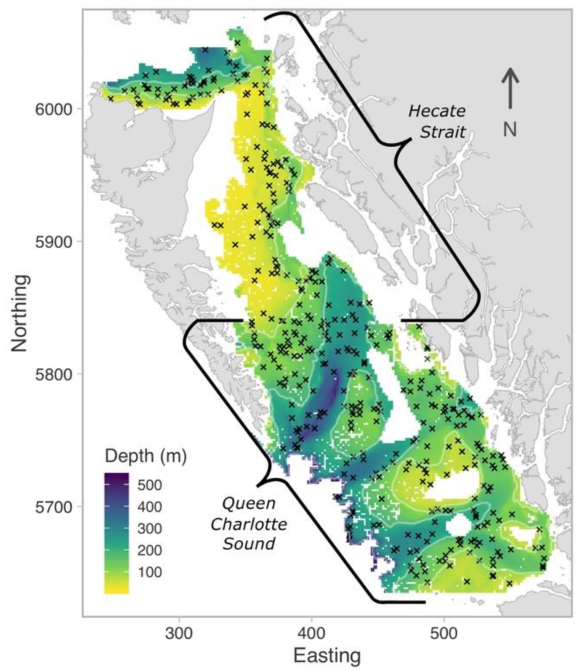

Figure 24-1. Locations of 378 successful tows conducted during the 2019 synoptic bottom trawl surveys in Hecate Strait (May – June) and Queen Charlotte Sound (July).

The trends reported here are geostatistical spatiotemporal biomass index trends as described in Anderson et al. (2019), except that data for both 2019 survey areas have been combined, while biomass densities have been split by the proportion of mature versus immature fish whenever such data was collected. To do this, we used the biological samples collected during these same surveys to estimate the length at which 5% of individuals were mature (defined by gonadal development stages of immature or maturing vs. mature, ripe, or spent) using ogives fit as sex-specific logistic regressions to individual specimens. When sufficient samples were available in all years, a random effect of year was included to allow for temporal change in size at maturity and these year specific thresholds were used to split observed catches. The summed weight of all measured fish that exceeded the length threshold was divided by the total weight of all measured fish, and multiplied by the swept area biomass estimates for each tow. This provided the estimate of mature (or nearly mature) fish biomass, while the remainder of the catch density was classified as immature. For small catches, where individual-level measurements were not collected, we applied the mean ratio from all measured tows to estimate maturity-specific biomass. We then predicted biomass densities separately for adult and immature fish across the entire combined survey area and plotted trends in the estimated total biomass each year with uncertainty. While the units are presented as metric tonnes of fish biomass, these estimates assume the estimated biomass can be projected well from the sampled locations to the full survey domain and that the survey catchability is 1, so these values are more appropriately considered a unitless index of relative biomass.

The use of model-based indices allowed adjacent trawl surveys to be stitched together for more wholistic trend estimation, while the splitting of survey catches by maturity might help to identify species where climate change may be impacting reproductive success, either positively or negatively. Furthermore, maps of these predicted biomass densities can be used to identify potentially important habitat and changes in distribution.

24.3. Status and trends

The total catch weight of all fish caught during both bottom trawl surveys was 196.4 metric tonnes representing 108 species (or distinct taxonomic groups). The average catch per tow was 355 kg in HS versus 612 kg in QCS. The top species by mass in HS were Spotted Ratfish (*Hydrolagus colliei*, 10 000 kg), Arrowtooth Flounder (*Atheresthes stomias*, 6,700 kg), Rex Sole

(*Glyptocephalus zachirus*, 4,800 kg), Dover Sole (*Microstomus pacificus,* 4,100 kg), and English Sole (*Parophrys vetulus,* 3,000 kg). In QCS the dominant species were Sablefish (*Anoplopoma fimbria*, 20,600 kg), Pacific Ocean Perch (*Sebastes alutus,* 18,900 kg), Arrowtooth Flounder (*Atheresthes stomias*, 16,000 kg), Silvergray Rockfish (*Sebastes brevispinis*, 12,900 kg) and Pacific Hake (*Merluccius productus*, 11,800 kg).

Notable trends in mature fish biomass indices across both surveys included: sharp increases for several Rockfish species including Redbanded (*Sebastes babcocki*) and Bocaccio (*Sebastes paucispinis*), an apparent reversal of a longer-term declining trend for North Pacific Spiny Dogfish (*Squalus suckleyi*), leveling off of trends for Sablefish, Pacific Cod (*Gadus macrocephalus*) and Shortspine Thornyhead (*Sebastolobus alascanus*), and decadal-scale decreases in Arrowtooth Flounder and Spotted Ratfish (Figure 24-2). Also, in a number of cases, immature biomass indices appear to have increased more sharply than mature biomass indices: Sablefish, Petrale Sole (*Eopsetta jordani*), Lingcod (*Ophiodon elongatus*), Slender Sole (*Lyopsetta exilis*), and Yelloweye Rockfish (*Sebastes ruberrimus*). Finally, 2019 catch accounted for 82% and 92% of the total catch weight across all years for Chilipepper (*Sebastes goodei*) and Shortbelly Rockfish (*Sebastes jordani*) respectively, suggesting recent range expansions north of Vancouver Island.

24.4. Factors influencing trends

There are many potential causes for observed trends including the direct impacts from fishery removals and climate change. A more comprehensive analysis than is presented here is required to tease apart the various influences on survey trends; however, other work underway does suggest that local changes in abundance for many of these species are correlated with trends in temperature and dissolved oxygen availability.

24.5. Implications of those trends

While there do appear to be persistent trends for some species, they cannot be taken to represent stock status on their own. These indices must be incorporated into comprehensive stock assessment analyses before conclusions can be drawn about stock status.

24.6. References

Anderson, S.C., Keppel, E.A., and Edwards, A.M. 2019. A reproducible data synopsis for over 100 species of British Columbia groundfish. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/041. vii + 321 p.

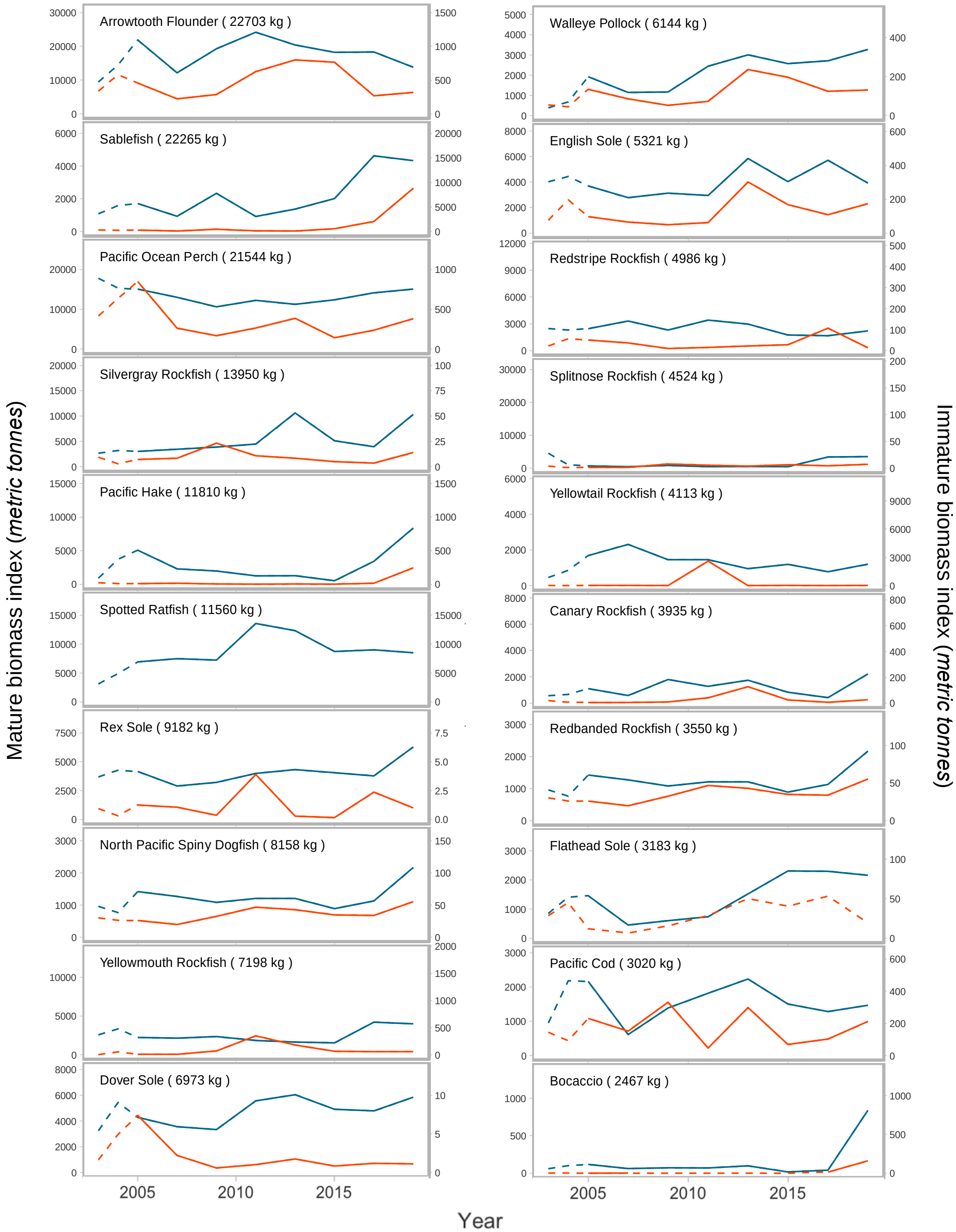

Figure 24-2. Model-based biomass indices for 20 species with the largest combined catches (ordered by decreasing total catch) on the 2019 Synoptic Bottom Trawl Surveys (estimated total biomass for full survey grid with 95% CI). Blue lines (left axis) represent total mature fish biomass (or overall biomass, when sufficient maturity data was not collected). Orange lines (right axis) represent immature fish biomass (see text for definitions). Dashed lines indicate unreliable estimates due to the model not converging, very low catches, or spatial bias in pre-2005 estimates (QCS starts in 2003 and HS in 2005).

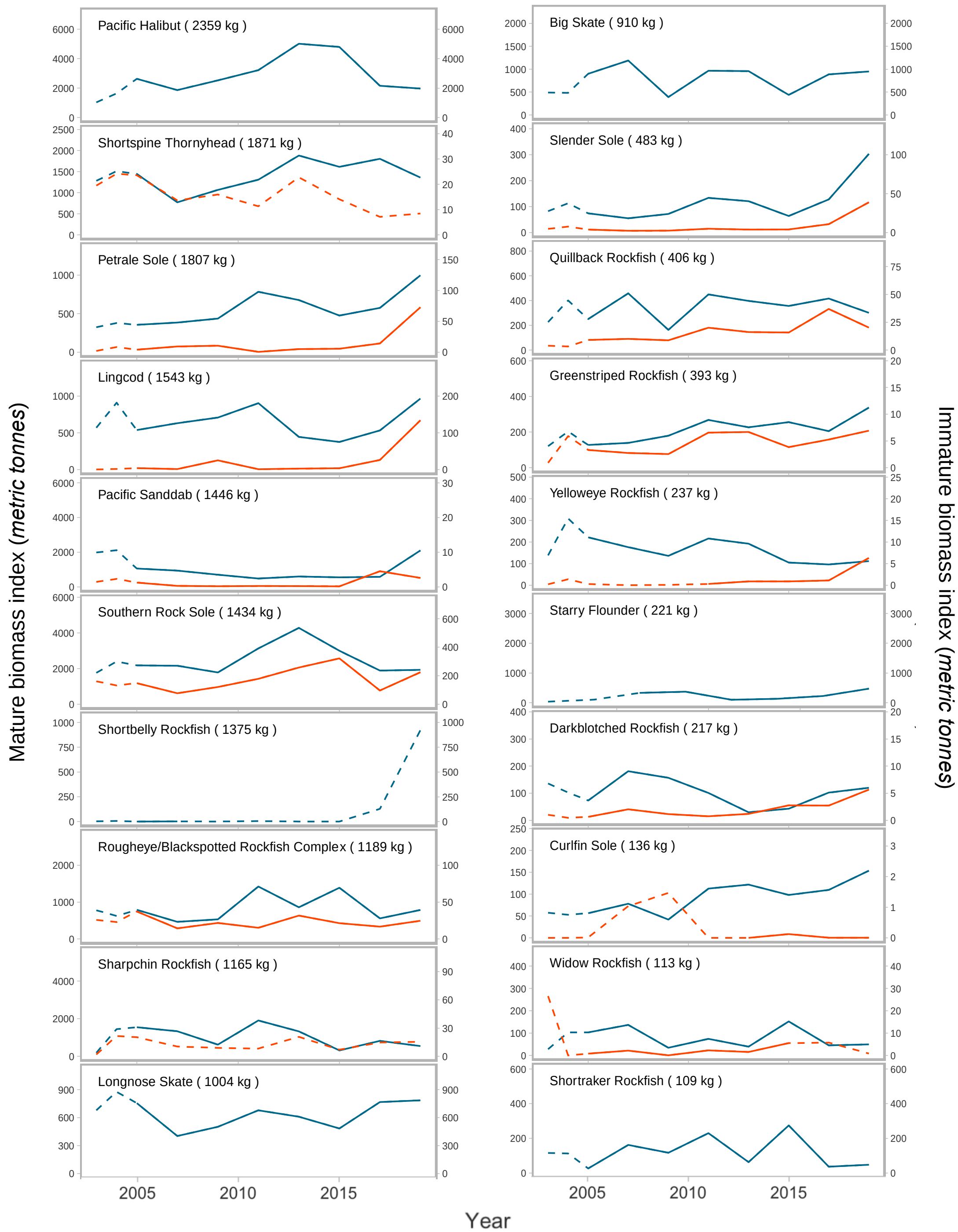

Figure 24-2. continued.

25. 2019 DISTRIBUTION AND ABUNDANCE OF PACIFIC HAKE (*MERLUCCIUS PRODUCTUS*)

Stéphane Gauthier[1], Chelsea Stanley[1], and Julia Clemons[2]

[1] Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Stephane.Gauthier@dfo-mpo.gc.ca
[2] Northwest Fisheries Science Center, Seattle, WA, Julia.Clemons@noaa.gov

25.1. Highlights

- The 2019 estimate of Pacific Hake of 1.723 million t was 20% above the median of the time series, higher than the estimate of 2017, but lower than the two previous surveys of 2013 and 2015.
- Only about 11% of the total estimated survey biomass was encountered in Canadian waters, and the distribution of hake did not extend further north than Goose Bank, off the Northern tip of Vancouver Island.

25.2. Description of the time series

Pacific Hake ranges from southern California to northern British Columbia (25-55° N). It is a migratory species that is thought to spawn off of the southern to central California coast during January to March (Saunders and McFarlane 1997). Adult hake then migrate north in the spring and by the summer can be detected in large aggregations from Northern California to the northern end of British Columbia, with distributions sometimes exceeding these boundaries. Size and age generally increase with increasing latitude during the migratory season. The populations of Pacific Hake found in the Strait of Georgia and Puget Sound are genetically distinct and not included in this survey (Iwamoto et al. 2004; King et al. 2012).

The Pacific Hake fishery is one of the largest fisheries on the west coast of the U.S. and Canada. This requires monitoring and management of the population on both sides of the border. Hake has been managed in Canada since 1992, with Canada joining the U.S. in their hake research program that had previously been in place since 1975. The joint U.S. and Canadian integrated acoustic-trawl survey is the primary fishery-independent tool used to assess the distribution, abundance and biology of the Pacific Hake population. The survey was completed on a triennial basis until 2003, when the decision to switch to a biennial basis was made. In 2004, the U.S. enacted a treaty that detailed an agreement with Canada on the joint management of Pacific Hake. This treaty dictated a joint survey on a triennial basis, however the survey has continued on a biennial (or annual) basis since 2003. The treaty also divides the annual quota between the two countries, giving 73.88% of the quota to the U.S., leaving 26.12% to the Canadian fishery.

The 2019 survey effort included parallel transects that were run from southern California to southern Alaska (Figure 25-1). Transects were 10-20 nmi apart and spanned from the 50 m isobath to the 1500 m isobath along each transect. Transects would extend beyond the 1500 m isobath if there was still obvious hake signal to ensure the offshore extent of the population was properly covered. Acoustic marks were targeted with a midwater trawl to assess species composition, length distribution, and other biological parameters. Backscatter assigned to

Pacific Hake was interpolated between transects to obtain an overall estimate of abundance for the entire coast. Using the biological information gained from the midwater trawls, the backscatter was scaled to biomass using the fish length to target strength (TS) relationship (Traynor 1996).

25.3. Status and trends

The distribution of hake has been variable over the history of the survey, with the widest distribution seen in 1998 (Figure 25-1). In 2019, distribution of hake did not extend further than Goose Bank off the northern tip of Vancouver Island (Figure 25-1 and Figure 25-2). The 2019 estimated total biomass of 1.723 million t was higher than in 2017, but lower than the previous two surveys (2013, 2015, Figure 25-3). Catch data from the survey indicated a dominance of the 2016, 2014 and 2010 year classes. No age-1 (nor age-0) hake were observed in Canada. While age-1 Hake is not used in the biomass estimate, it is used in the stock assessment model as an indicator of recruitment. Only 11% of the estimated biomass of adult hake (age-2+) from the survey was observed in Canadian waters.

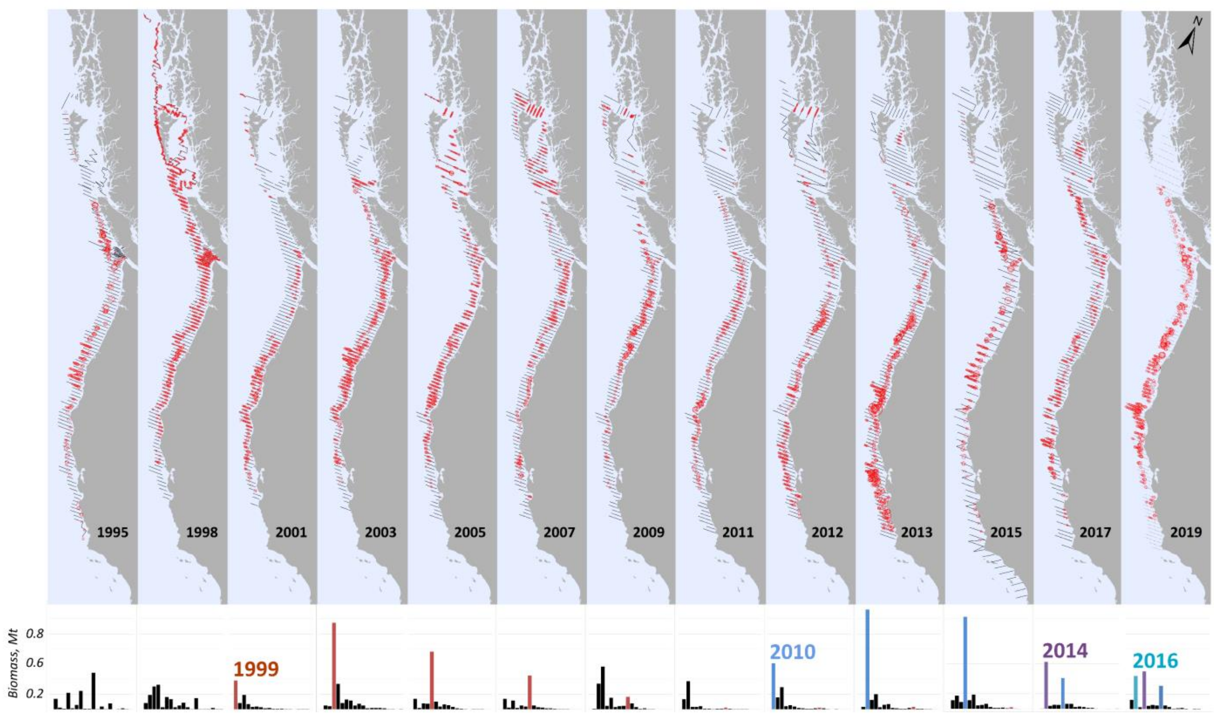

Figure 25-1. Northeast Pacific distribution of Pacific Hake from 1995-present. The biomass by age barplot below the map highlights the dominant year classes in the time series.

25.4. Factors influencing trends

It has been observed that during warm ocean conditions (such as the 1998 El Niño event) a larger proportion of the stock migrates into Canadian waters, apparently due to intensified northward transport (Agostini et al. 2006). This was also observed in 2015 (with the so-called warm ”Blob”), although the distribution did not extend much beyond the northern tip of Vancouver Island. The proportion of Pacific Hake that migrated into Canadian waters in 2017 was over 27% and the largest observed since 2005, while in 2019 the proportion in Canada was only of 11%. This was also the first time in the time series where no aggregations of hake were observed north of Goose Bank. There are some indications that temperatures in northern Hecate Strait were unusually high in 2019. We also observed less acoustic signs attributable to fish species (e.g. Pacific herring, walleye pollock, rockfish) in Hecate Strait than in previous surveys. These trends and observations emphasize the need for more research into the links between environmental variables and the distribution and migration of Pacific Hake and associated fauna.

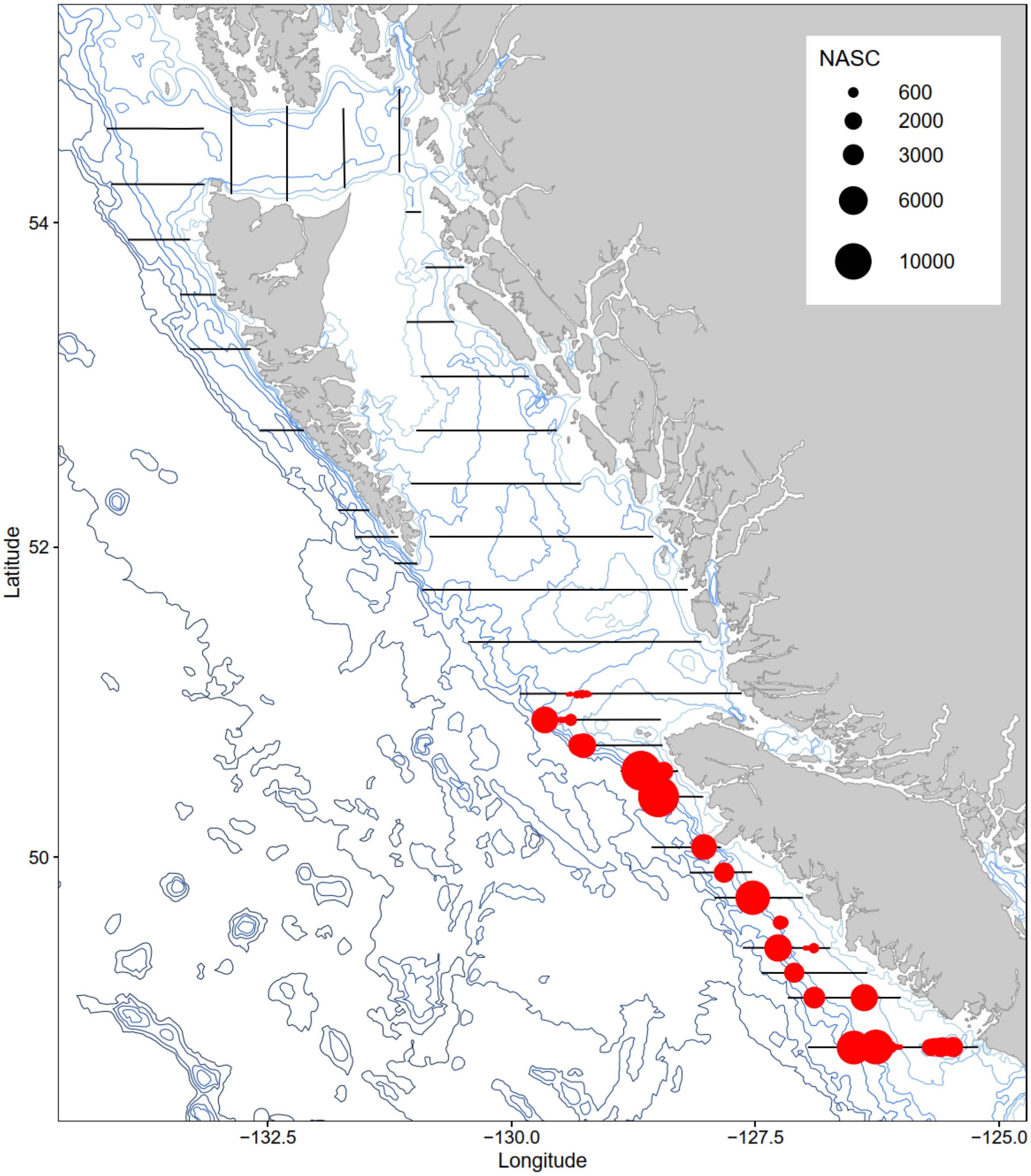

Figure 25-2. Distribution of adult Pacific Hake in Canadian waters in 2019. Red circles represent Nautical Area Scattering Coefficients (NASC, $m^2 nmi^{-2}$).

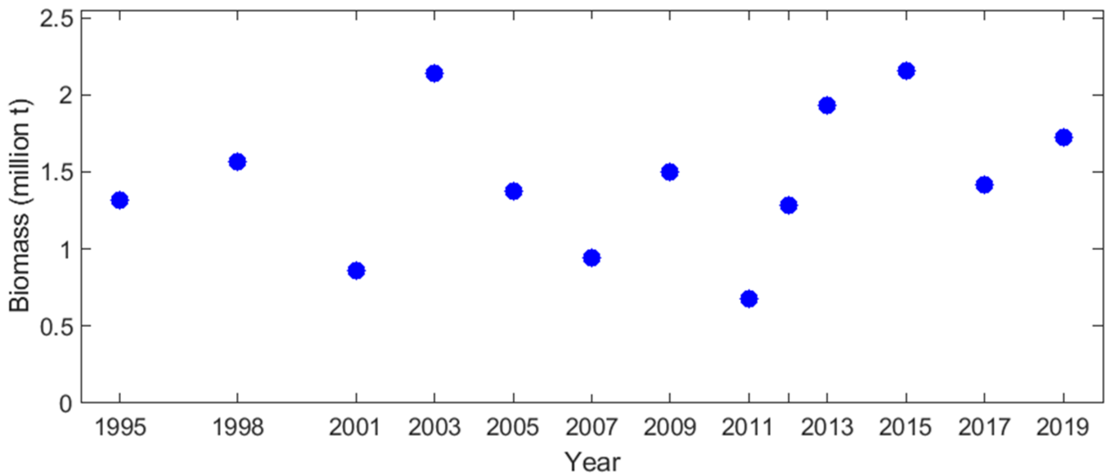

Figure 25-3. Time-series of coast-wide Pacific Hake biomass estimates from the joint DFO-NOAA surveys.

25.5. Implications of those trends

During the strong El Niño of 1998, hake extended well into Alaska, but during recent warming events the distribution was retracted and confined mostly to the West Coast of Vancouver Island. These trends suggest that temperature alone may not be a good predictor of hake northward migration extent, but that other mechanisms (such as the source and onset of the warming conditions) have differential effects on poleward currents, distribution and availability of prey, or other factors influencing the distribution of these fish. This is however speculative at best, and points to the need for more research on Pacific Hake movements. Efforts focusing on these topics are currently underway.

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26. TRENDS IN ABUNDANCE & DISTRIBUTION OF PINNIPEDS IN B.C.

Strahan Tucker and Sheena Majewski, Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, strahan.tucker@dfo-mpo.gc.ca, sheena.majewski@dfo-mpo.gc.ca

26.1. Highlights

- The Strait of Georgia (SOG) supports the highest density of Harbour Seals on the B.C. coast and has been the primary index site for population surveys. The 2014 population abundance of 38,900 (95% CI 34,810 to 42,250) is consistent with estimates dating back to the mid-1990s. However, there was evidence of continuing redistribution among areas and between sites.
- 2017 counts of Steller Sea Lions indicate a possible slowing in the annual rate of increase in pup production since 2013, but not in the rate of growth in the non-pup component of the population. The adjusted 2017 breeding season population in B.C. estimate was 42,770 (95% CI of 38,200 to 47,700). This represents no significant change from the last estimate in 2013.

26.2. Description of the time series

Since the early 1970s, DFO has undertaken standardized, aerial breeding-season surveys to monitor populations of Harbour Seals (*Phoca vitulina*) and Steller Sea Lions (*Eumetopias jubatus*) in B.C. Specific survey parameters are outlined by Olesiuk (2010 and 2018) for harbour seals and Steller sea lions, respectively. These surveys have provided time series of trends in counts; estimates of the total population size are obtained by applying a correction factor to account for animals that were at sea and missed during surveys. Correction factors have been derived by tracking haulout patterns of individual animals through satellite telemetry.

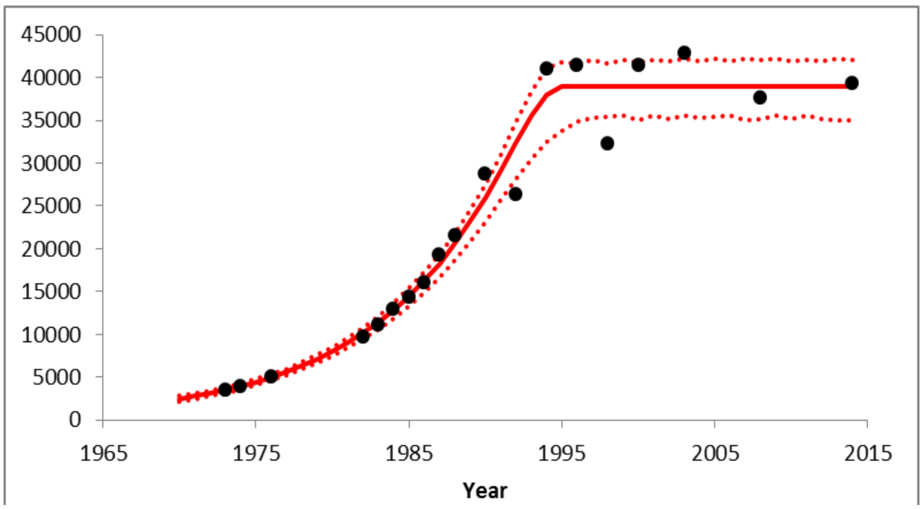

Figure 26-1. Population trend of harbour seals in the Strait of Georgia. The solid line show the generalized logistic model fitted by maximum likelihood, the dotted lines show the 95% Confidence Intervals and the black dots show estimated abundance (Majewski and Ellis, in review).

26.3. Status and trends

26.3.1. Harbour Seals

The SOG supports the highest density of Harbour Seals on the B.C. coast and has been the primary index site for population surveys since the protection of the species in 1973. There were an estimated

~39,100 Harbour Seals in the SOG as of 2008, representing 37% of the total B.C. population (Olesiuk 2010).

For the last SOG survey in 2014 (Majewski and Ellis, *in review*), the modeled abundance was estimated at 38,900 (95% CI 34,810 to 42,250). This represents no significant change from the previous estimated SOG population in 2010. In fact, the abundance of seals in the SOG has remained relatively constant since the mid-1990s (Figure 26-1). However, there was evidence of continuing redistribution among areas and between sites, with further increases in the proportion of animals in the north and south of SOG (Majewski and Ellis, *in review*).

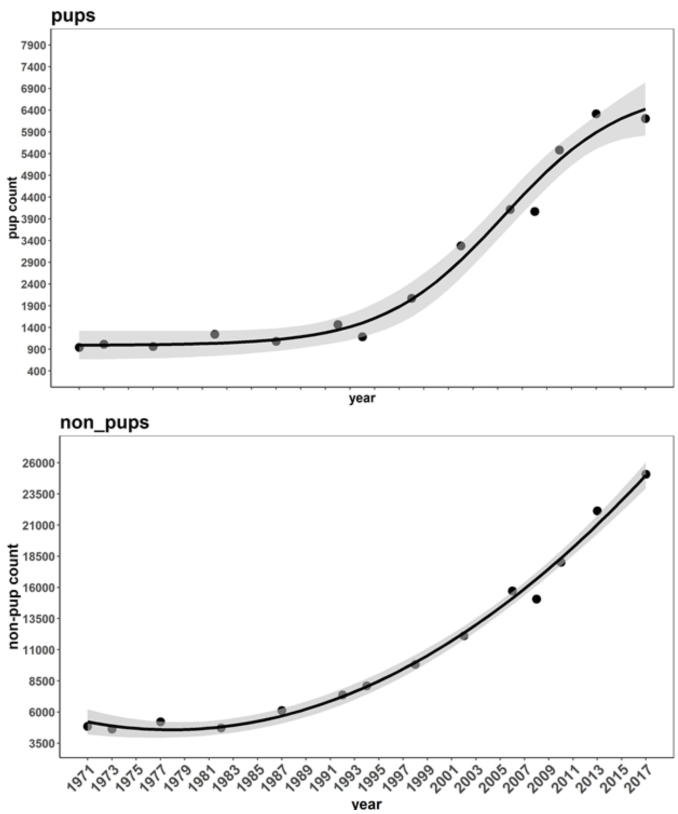

Figure 26-2. Trends in the number of pups (top panel) and non-pups (bottom panel) based on breeding season aerial surveys, 1971-2017. Black lines and shading denote the logistic model fit to pup counts (top panel) and the polynomial model fit for non-pup counts (bottom panel). Grey shading denotes 95% confidence intervals. (Majewski et al. in review).

26.3.2. Steller Sea Lions

Steller Sea Lions reside year-round and breed in Canadian waters as part of its pan-Pacific range. Steller Sea Lions occur throughout the coastal water of British Columbia (B.C.). Animals are highly aggregated at rookery and outer coast year-round haulout sites during the summer breeding season with dispersal to other areas of the coast for foraging through fall and winter.

In 2017, a total of 6,200 pups and 25,136 non-pups were counted. Models fit to the counts indicate a possible slowing in the annual rate of increase in pup production since 2013, but not in the rate of growth in the non-pup component of the population (Figure 26-2). The adjusted 2017 breeding season population estimate was 42,770 (95% CI of 38,200 to 47,700). This represents no significant change from the last estimate of 39,200 (95% CI 33,600 to 44,800) in 2013 (Olesiuk 2018).

26.4. Factors influencing trends

The specific factors regulating population trends of pinnipeds in B.C. remain unclear. In general, because pinnipeds are relatively long lived, they have evolved to maintain relatively stable population sizes at or near the carrying capacity of the environment, despite the potential for large fluctuations in survival (particularly pups) and fecundity from year to year (Wade 2018). Globally, we are currently witnessing the return of many pinniped populations to levels limited by their carrying capacity following overexploitation. Concurrently, increasing attention is being paid to the role of top predators (i.e. killer whales) on population dynamics as they themselves recover.

Harbour Seal populations in B.C. have remained stable in the SOG for the past 25 years. It is presently unclear what is driving any re-distribution within the SOG, but both prey availability and predator avoidance are key considerations.

While a preliminary observation, it is possible that a reduction in pup production in Steller Sea Lions is due to the emergence of pressures of density dependence. Alternatively, this may be due to environmental variability affecting vital rates that directly influence population trends.

26.5. Implications of those trends.

Both Harbour Seals and Steller Sea Lions have been identified as primary prey species of threatened Bigg's (aka West Coast Transient) Killer Whales along the coast of British Columbia. It is suspected that the recovery of pinniped populations has contributed to the increasing population of Bigg's Killer Whales as well as the increased observations of Bigg's Killer Whales in the SOG in recent years. The Recovery Strategy for Bigg's Killer Whales identifies the need to determine the quantity, quality and distribution of the prey necessary to sustain or increase the current population level (DFO 2007). In support of this recovery objective, updated assessments for breeding populations of pinniped abundance and distribution are provided by DFO.

In addition to supporting recovery of the Bigg's Killer Whale population, information on pinniped abundance and distribution is routinely required for responding to support ecosystem based management. This includes environmental assessments, siting of finfish and shellfish aquaculture facilities, evaluating impacts of marine mammal populations on fishery resources as well as potential competition with Resident Killer Whale for critical food resources, and, evaluating the potential impacts of changing ocean conditions.

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27. RECOVERY TRENDS IN MARINE MAMMAL POPULATIONS: RECENT EXAMPLES IN PACIFIC CANADIAN WATERS AND POTENTIAL ECOSYSTEM INTERACTIONS

Thomas Doniol-Valcroze, Linda Nichol, Robin Abernethy, James Pilkington, Lisa Spaven, Eva Stredulinsky, Jared Towers and Brianna Wright, Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, thomas.doniol-valcroze@dfo-mpo.gc.ca

27.1. Highlights

- Several marine mammal populations in Canadian Pacific waters have shown strong recovery trends and are once again important components of marine ecosystems.
- Sightings of Bigg's Killer Whales have increased in the Salish Sea coincidentally with an increase in their main prey, Harbour Seals. A population subset of 349 individuals most often found in coastal waters has grown at an average annual rate of 4.1% since 2012.
- A coast-wide ship survey showed that Humpback Whales have continued to recover from past exploitation and have reoccupied their former habitat in British Columbia, where their summer abundance was estimated at 12,500 (95% CI 8,500 – 18,600) in 2018.
- Abundance of Sea Otters in British Columbia was estimated at 8,100 in 2017. The annual rate of increase across B.C. was 5.2% per year for the period 2013 to 2017, but growth rates are lower in areas that have been occupied for longer periods of time.

27.2. Description of the time series

Bigg's Killer Whales (*Orcinus orca*) were encountered and photo-identified in British Columbia from 1975 to 2019 during dedicated and opportunistic research excursions. Thousands of photos from 1958 to present have also been submitted by numerous contributors from California to Alaska, making this one of the largest and longest running cetacean photo-identification datasets in existence. Images of killer whale dorsal fins and saddle patches were used to create a catalogue of individuals and to document sighting histories (Towers et al. 2019).

Systematic line transect surveys were conducted by non-government researchers in B.C.'s coastal waters during 2004 – 2008, to estimate abundance of ten marine mammal species, including Humpback Whales (*Megaptera novaeangliae*, Best et al. 2015). Until recently, no other information was available to estimate coast-wide trends. The Pacific Region International Survey of Marine Megafauna (PRISMM), a multi-species, ship-based, systematic line transect survey, was conducted between July 4 and September 5, 2018 to estimate the abundance and distribution of cetacean species in Canadian Pacific waters.

Sea Otters (*Enhydra lutris*) endemic to British Columbia were extirpated by 1931. Canada's current Sea Otter population is comprised of descendants of animals from Alaska reintroduced to Checleset Bay on the west coast of Vancouver Island during three translocation efforts in 1969, 1970 and 1972. The B.C. Sea Otter population has been surveyed at 1-3 year intervals since 1977. Counts from surveys provide an index of abundance and a report of range expansion (Nichol et al. 2015).

27.3. Status and trends

A total of 766 unique Bigg's Killer Whale individuals were identified during the 1958-2018 period. To identify the subset of this population showing the most fidelity to coastal waters, criteria were developed based on their rates of occurrence. A total of 206 mature individuals that were alive in 2018 were encountered at least once since 2014 and were documented during at least seven years or >10 encounters during the study period. Their offspring and other inferred maternally related kin include an additional 143 individuals. This population subset of 349 individuals has grown at an observed average annual rate of 4.1% since 2012 due to relatively low mortality and the birth of over 100 calves during this time period (Towers et al. 2019).

The total abundance estimate for Humpback Whales in 2018 in Pacific Canadian waters was 12,500 (95% CI 8,500 – 18,600). This includes the offshore area (8,700 whales) for which no previous abundance estimate was available, and where the vast majority of sightings were made on the continental shelf off the west coast of Vancouver Island (Figure 27-1). The abundance for the central coast was 3,360, which can be compared to the earlier estimate of 1,540 in the same strata based on survey data collected between 2004-2008 (Best et al. 2015), which shows that Humpback Whales have continued to reoccupy and expand their range within B.C. waters. Moreover, earlier systematic surveys did not detect any Humpback Whales in the Salish Sea whereas 2018 abundance was estimated at 430 in that region, indicating that Humpback Whales have expanded into an area from which they were still largely absent in the early 2000's.

The Sea Otter population in B.C. has continued to grow in numbers and range in recent years, following patterns that are typical of other recovering Sea Otter populations (e.g., Tinker et al. 2019). Abundance of Sea Otters in British Columbia was estimated at 8,100 in 2017. The annual rate of increase across the whole B.C. region was 5.2% per year for the period 2013 to 2017, but growth rates are lower in areas that have been occupied for longer periods of time.

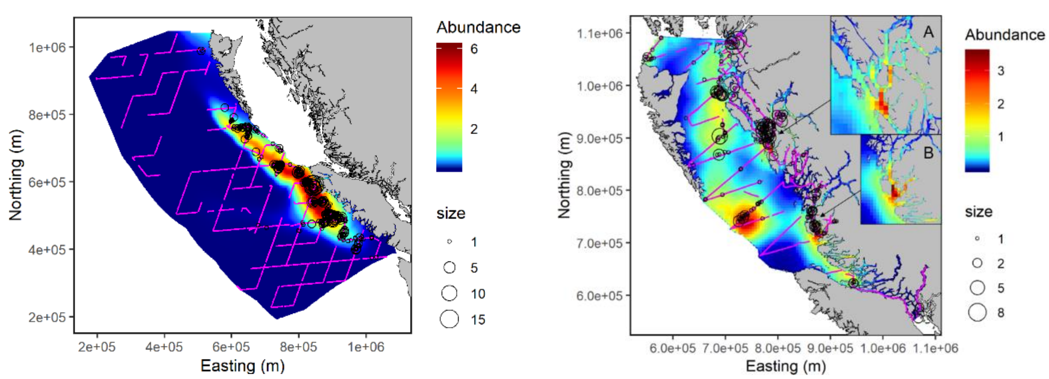

Figure 27-1. Estimated densities (fill colour indicates the number of individuals per 25 km² grid cell) of Humpback Whales in the offshore (left) and inshore (right) blocks in 2018.

27.4. Factors influencing trends

The increase in the number of Bigg's Killer Whale sightings in coastal B.C. waters was likely linked to the high abundance of their main prey item, Harbour Seals (*Phoca vitulina*), which have recovered rapidly since the end of commercial exploitation in the 1970s.

Humpback Whales were depleted by commercial whaling in the North Pacific over the period 1870 – 1967. Following its protection from exploitation, the population has increased at rates of 8% per year. This increase in numbers and the reoccupation of historical habitat likely underlie the dramatic increase of Humpback Whale sightings in B.C. waters over the last twenty years.

Immediately following their reintroduction in B.C. in 1969, Sea Otters increased rapidly in numbers at rates near the species' physiological maximum. This rapid exponential growth was likely the result of their protected status and of abundant invertebrate prey, which had increased in the absence of Sea Otters (Estes 1990). Over time, region-wide population growth has slowed in response to density-dependent processes, linked to food availability. Sea Otters occupy small home ranges and exhibit limited dispersal with the result that growth trends vary geographically across the population, with lower growth rates in areas that are approaching carrying capacity.

27.5. Implications of those trends.

Several populations of marine mammal in Canadian Pacific waters have shown strong recovery trends and are once again important components of marine ecosystems, resulting in increased overlap with human activities and potential conflicts with fisheries. The return of these predators to habitats from which they were previously extirpated (or at low numbers) has important ecosystem-level implications. Predation pressure by Bigg's Killer Whales likely affected the Harbor Seal population and may in time affect the distribution and behaviour of other prey species. Humpback Whales consume large amounts of biomass (zooplankton and forage fish) and may have impacts on fish populations. Sea Otters exert a strong top-down pressure on invertebrate prey items, which in turn has a positive effect on kelp forests and fish abundance.

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28. SEABIRD AND GREY WHALE POPULATION TRENDS IN PACIFIC RIM NATIONAL PARK RESERVE OF CANADA

Yuri Zharikov and Jennifer Yakimishyn, Pacific Rim National Park Reserve, Parks Canada, Ucluelet, BC, yuri.zharikov@canada.ca, jennifer.yakimishyn@canada.ca

28.1. Highlights

- Demersal fish-feeding species (guillemot and cormorants) displayed a steady increase across the entire time series (1999-2019).
- 2019 was a favourable year for both pelagic fish-feeding seabirds (Common Murre, Rhinoceros Auklet and Marbled Murrelet) and Grey Whale populations in coastal waters of Pacific Rim National Park Reserve.
- Pelagic fish-feeding seabirds abundance, Marbled Murrelets in particular, and Grey Whale abundance followed similar patterns and may reflect similar oceanographic conditions favouring zooplankton prey.
- Overall, the seabird community displayed a decadal-like fluctuation pattern in abundance.

28.2. Description of the time series

We reviewed abundance trends in several common seabirds (1999-2019) and grey whales (2003-2019) based on at-sea counts in the coastal waters of Pacific Rim National Park Reserve (PRNPR). Counts were conducted biweekly in May – August along three transects for seabirds (two in the Broken Group Islands and one along the West Coast Trail), and only counts along the West Coast Trail were considered for Grey Whales (Figure 28-1). For seabirds we calculated species-specific population trends using the package *rtrim* (Bogaart et al. 2018; R Core Team 2019). *Rtrim* is an implementation in R of the TRIM program (Pannekoek and van Strien 2004) – the standard trend analysis tool used in the Pan-European Common Bird Monitoring Scheme (Gregory et al. 2005). The *rtrim* statistical model is based on Poisson log-linear regression, estimating site and year effects on species abundance (counts) as well as an overall linear trend (on the log-scale). The basic model is: expected count = year + site, where both year and site are fixed effects, estimated using maximum likelihood and generalized estimating equations to handle overdispersion and serial autocorrelation.

To assess the overall trends in coastal seabird populations we calculated a multi-species indicator (MSI) according to Gregory et al. (2005), where the index for each year is the geometric mean of the TRIM indices of the contributing bird species. We applied a Monte Carlo method to account for sampling error in trend estimation in the MSI using the MSI-tool in R available at: https://www.cbs.nl/en-gb/society/nature-and-environment/indices-and-trends-trim-/msi-tool (Soldaat et al. 2017).

Grey Whale (*Eschrichtius robustus*) abundance in a given year reflects the Pacific Coast Feeding Group (PCFG), a population of Grey Whales that show strong maternal site fidelity to summer feeding grounds (Calambokidis et al. 2017; Frasier et al. 2011). Overall, trend in the time series was assessed using Ordinary Least Squares (OLS) regression. Abundance data from each survey were analysed using a one-factor analysis of variance, where year was the independent factor, and subsequent Tukey's test was performed to determine which years differed.

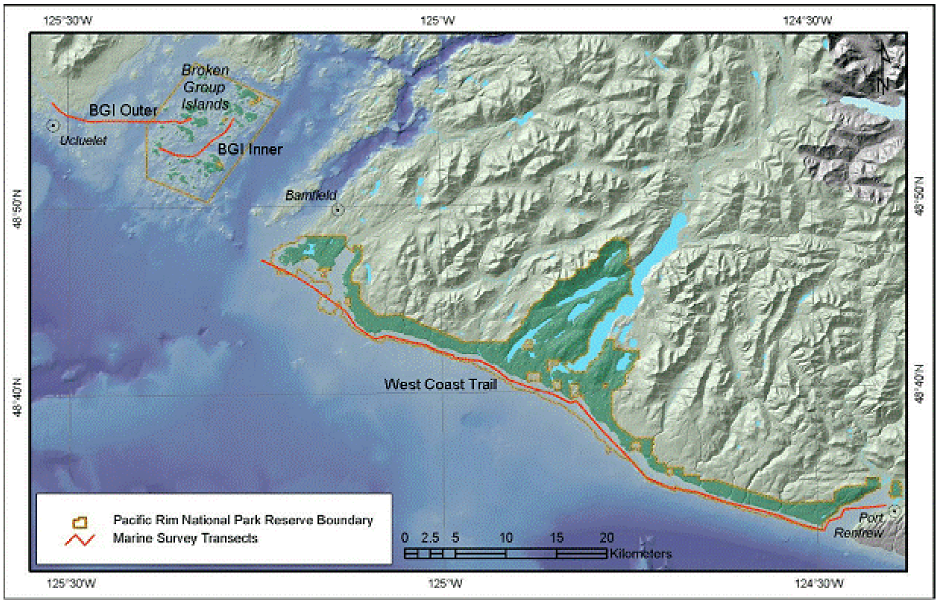

Figure 28-1. At-sea seabird and marine mammal transects in the waters of Pacific Rim National Park Reserve. The Broken Group Islands unit of the Park Reserve is in the top left corner.

28.3. Status and trends

Seabirds: The results are presented for five taxa that comprise ~90% of all individuals counted. All five species displayed stable to strongly positive trends over the past twenty years (Table 28-1). For all seabird species combined, there was a declining trend in 1999 – 2008, an increase in 2008 – 2014 and an apparent decline afterwards (Figure 28-2), resembling a decadal fluctuation pattern. In 2019, abundance was above the long-term average for all species covered in this analysis except for Rhinoceros Auklet. In 2014-2016, all species had a particularly high abundance.

*Table 28-1. Seabird population trends (additive annual trend and se) in the coastal waters of Pacific Rim National Park Reserve, Canada modelled in rtrim. Table includes overdispersion (Overdisp) and goodness-of-fit (GoF) statistics. CORM refers to **combined** counts of pelagic cormorants, Brandt's Cormorants and counts where cormorant species could not be identified. Trend significance is adjusted for overdispersion.*

Species (1999-2019)	Trend	SE	p	Interpretation	Overdisp	GoF
Common Murre (*Uria aalge*)	0.023	0.011	0.050	Stable	6.72	0.000
Marbled Murrelet (*Brachyramphus marmoratus*)	0.030	0.006	0.000	Moderate increase	11.05	0.000
Pelagic Cormorant (*Phalacrocorax pelagicus*)	0.112	0.005	0.000	Strong increase	0.82	0.002
Pigeon Guillemot (*Cepphus columba*)	0.077	0.008	0.000	Strong increase	1.08	0.328
Rhinoceros Auklet (*Cerorhinca monocerata*)	0.029	0.011	0.013	Moderate increase	2.68	0.000
CORM	0.025	0.005	0.000	Moderate increase	1.75	0.001

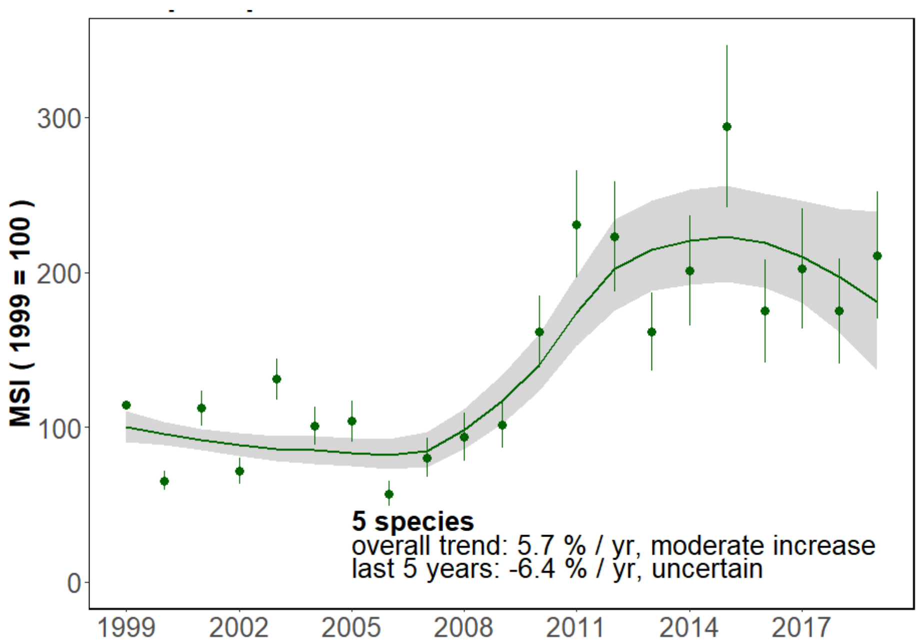

Figure 28-2. Annual trend in the Multi-species indicator (MSI) for five seabird species (see Table 28-1) in the coastal waters of Pacific Rim National Park Reserve. MSI in the start year (1999) is set at 100. Standard deviation bars are based on 1,000 Monte Carlo simulations for each year. Grey band is the 95% confidence interval of the smoothed MSI trend.

Grey Whales: There was no trend in grey whale abundance between 2003 to 2019 (OLS, $F_{1,15}$ = 0.01, p=0.92), however abundance varied among years (Figure 28-3; ANOVA, F = 4.83, p < 0.001; Tukey-Kramer Multiple Comparison test, 2003> 2007, 2009, 2017, 2018; 2015 > all years except 2003, 2010, 2012, 2016 and 2019). Grey Whale abundance was high in 2003 and 2015 and low in 2007, 2017 and 2018 (Figure 28-3).

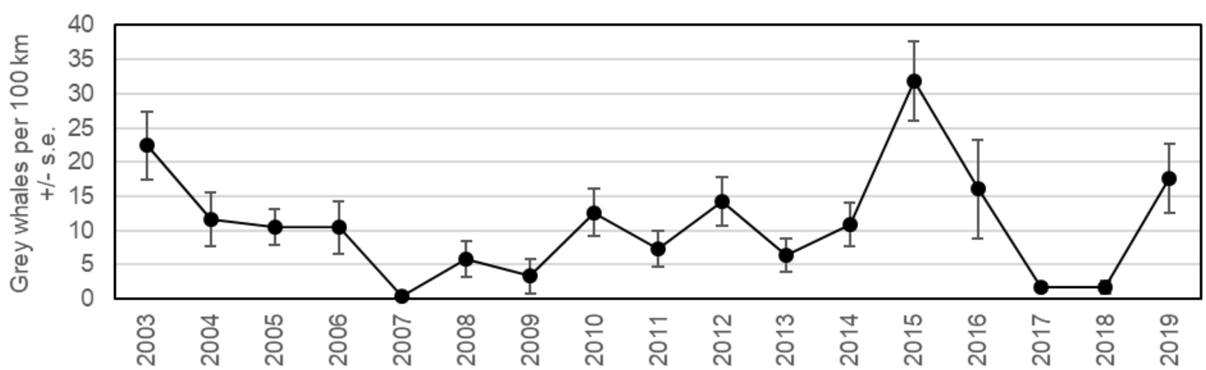

Figure 28-3. Mean annual Grey Whale abundance observed during surveys (May to August) along the West Coast Trail unit of Pacific Rim National Park Reserve.

28.4. Factors influencing trends

Trends in seabirds and Grey Whales likely reflected an improving food base. Grey Whales forage on coastal zooplankton and invertebrates, and in feeding areas off coastal British Columbia, targeting mysid shrimp, amphipods, ghost shrimps and porcelain crab larva (Dunham and Duffus 2001). Forage fish, prey of pelagic fish feeding seabirds, are also zooplantivores feeding mainly on crustaceans, such as copepods and euphausiids (Hipfner and Galbraith 2013). Pelagic fish-feeding seabirds abundance, Marbled Murrelets in particular, and Grey Whale abundance followed similar patterns and may reflect similar oceanographic conditions favouring zooplankton prey. In addition, Marbled Murrelets and Grey Whales often congregate in the same areas along the West Coast of Vancouver Island (WCVI) and this pattern was consistent between years (Collyer et al. 2008).

28.5. Implications of those trends

Increases in seabirds and Grey Whales suggest that ocean conditions support breeding populations (murrelets, cormorants and guillemot) and attract foraging seabirds (murres and auklets) from a broader area. In addition, foraging conditions for Grey Whales were likely more favourable than previous years, notably in 2017 and 2018. Grey Whales do not appear to be in competition with seabirds for food resources in the area (cf. Ainley and Hyrenback 2010).

An earlier (1996-2006) study of seabirds along Line P reported positive population trends for a suite of species including Common Murres and Rhinoceros Auklets (Thompson et al. 2012). While we do not have more recent information on regional trends for all of the species covered in this report, a recent US publication on Marbled Murrelet (McIver et al. 2019) suggests a significant annual decline in 2001 - 2018 in the coastal waters of Washington State (-3.9%) and significant increases in Oregon (2.2%) and California (4.6%). Given the geographic proximity between Washington and WCVI one could entertain a possibility that some Washington Marbled Murrelets have emigrated to or forage in WCVI waters. This hypothesis would require individual telemetry data to be thoroughly tested.

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29. SEABIRD OBSERVATIONS ON THE OUTER B.C. COAST IN 2019

Mark Hipfner, Environment and Climate Change Canada, Wildlife Research Division, Pacific Wildlife Research Centre, Delta, BC, Mark.Hipfner@canada.ca

29.1. Highlights

- Cassin's Auklets had a below-average breeding season in 2019 relative to the 1996-2018 baseline on the world's largest colony on Triangle Island, as expected from the weakly negative state of the Pacific Decadal Oscillation.
- There was little juvenile salmon in diets fed to nestling Rhinoceros Auklets on Pine, Triangle and Protection islands in 2019 (and none at Cleland Island or S'Gang Gwaay). In contrast, amounts at Lucy Island were among the highest in thirteen years of study. Juvenile salmon are a secondary prey type for these birds.

29.2. Description of the time series

Annually since 1996, on Triangle Island, the mean mass at 25 d of Cassin's Auklet nestlings is derived and estimated as a proxy for growth rate; this is an indicator of survival as well as zooplankton prey availability (Hipfner et al. 2020).

Annually, scientists with Environment Canada and Fisheries and Oceans Canada have been quantifying predation by Rhinoceros Auklets on salmon smolts since 2006 as an indicator of salmon mortality and seabird feeding success (Tucker et al. 2016). Nestling diets were quantified at Pine, Lucy, Triangle, Cleland, and S'Gang Gwaay Islands, and in the U.S., collaborators quantified diets on Protection Island.

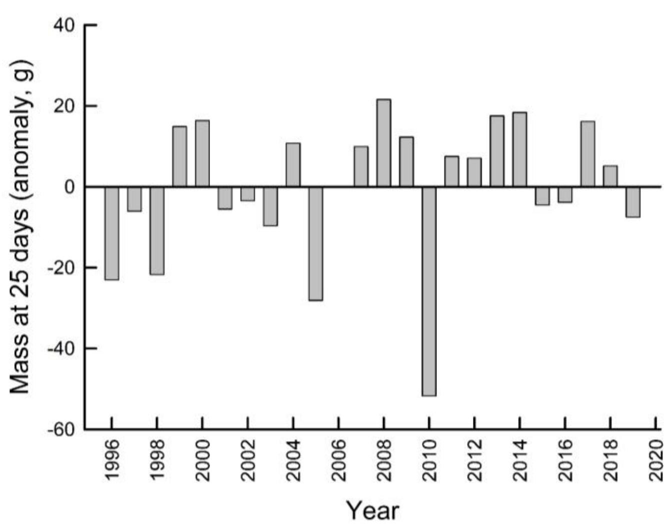

Figure 29-1. Yearly anomaly of the mean 25-day-mass (a proxy for growth rate) of nestling Cassin's Auklets on Triangle Island, BC, in 2019 relative to the 1996-2018 baseline.

29.3. Status and Trends

In 2019, Cassin's Auklet growth rates were below the long-term (1996-2018) average (Figure 29-1). The 25-day mass of nestlings was the 6th lowest in the time series.

There is marked temporal and spatial variation in the importance, and species and stock composition of salmon in Rhinoceros Auklet nestling diets. In general, salmon is most important at Pine Island; in 2019, the amount of salmon in diets there was low (Figure 29-2), despite the fact that the amount of the birds' primary prey, Pacific Sand Lance (*Ammodytes personatus*), was

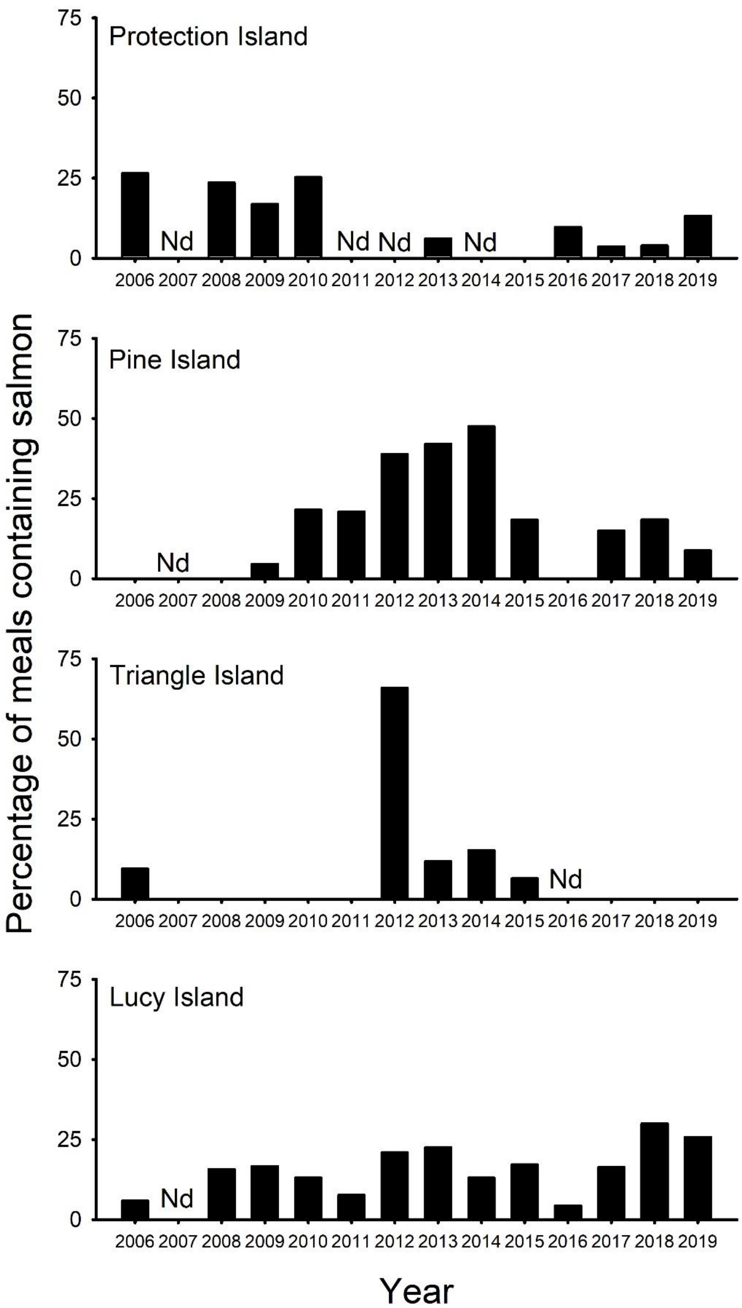

Figure 29-2. Percentage of meals delivered to nestling Rhinoceros Auklets that included one or more salmon (Pink, Chum, or Sockeye) on 3 colonies in B.C., Triangle, Pine and Lucy islands, and on Protection Island, WA, in 2006-2019. None was delivered at Cleland Island or S'Gang Gwaay.

also low. Salmon has generally been less important overall, and less variable, in diets at Lucy Island, but the amount present in 2019 was among the highest of any year through the study period. Salmon was an important component of auklet nestling diets at Triangle Island only in 2012 (largely Fraser River Sockeye Salmon), and was absent altogether in 2018 sampling. Our collaborators in Washington State have been tracking diets of Rhinoceros Auklets at Protection Island over the same time period, and salmon was uncommon in auklet nestling diets there in 2019.

29.4. Factors influencing trends

Like other breeding parameters, growth rates of nestling Cassin's Auklets (*Ptychoramphus aleuticus*) are affected very strongly by oceanographic conditions, which have a profound influence on seasonal patterns of prey availability. In general, nestling auklets grow more quickly on Triangle Island, the world's largest breeding colony, in cold-water, PDO-negative years when the subarctic copepod *Neocalanus cristatus* is abundant in offshore waters and persists in their diets through the bulk of the provisioning period from mid-May to late June (Hipfner et al. 2020). Below average growth rates in the 2019 were expected given the weakly positive state of the PDO over the preceding winter and spring (Figure 29-1).

The main prey species fed to nestlings is Pacific sand lance (*Ammodytes personatus*), and the birds respond positively to variation in the abundance of this prey (Bertram and Kaiser 1993). Secondary prey species, including salmon smolts, Pacific Herring (*Clupea pallasii*), and juvenile rockfish (*Sebastes* spp.), make up larger proportions of the diet in years when sand lance is less available. However, understanding of the role of other factors that determine representation of salmon in diets, especially physical environmental variation, remains poor.

29.5. Implications of those trends

Low growth rates of Cassin's Auklets nestlings will translate to low survival of nestlings and lower population growth. The low growth rate also indicates that warm ocean conditions continue to affect zooplankton and those effects are transferred to top predators.

Mortality rates during the marine phase of the life cycle of Pacific Salmon generally exceed 90%, and it is widely believed that most mortality is due to predation in the first few weeks to months following ocean entry (Beamish and Mankhen 2001). On their northerly seaward migration, the vast majority of Pink Salmon (*O. gorbuscha*), Chum Salmon (*O. keta*) and Sockeye Salmon (*O. nerka*) smolts from stocks in southern and central British Columbia funnel past aggregations of hundreds of thousands of Rhinoceros Auklets (*Cerorhinca monocerata*) breeding on colonies scattered along the province's Central and North coasts. The auklets are wing-propelled, pursuit-diving seabirds that forage mainly in the top 5-10 m of the water column and within ~90 km of their breeding colonies. The smolts' migration occurs in June and July, coinciding with the period when the auklets are delivering whole and intact fish, including salmon smolts, to their nestlings. These predators could potentially have an impact on salmon survival.

29.6. References

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30. ECOSYSTEM STATUS AND TRENDS - WEST COAST VANCOUVER ISLAND INDICATORS

Jennifer L. Boldt*, Caihong Fu, and R. Ian Perry, Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, *Jennifer.Boldt@dfo-mpo.gc.ca

30.1. Highlights

- Status and trends of selected environment, human, and ecosystem indicators can be simplified to a few important trends.
- Most pressure-response relationships are linear; three nonlinear cases may provide leading indicators with thresholds.
- Top pressures include both human and environmental pressures.

30.2. Description of indices

The objectives of this study were to identify indicators for the West Coast of Vancouver Island (WCVI) and: 1) document the status and trends of the ecosystem, 2) examine the pressure-response relationships of both human and environmental drivers, 3) identify any non-linear relationships between ecosystem pressures and responses, and 4) identify thresholds that may help determine, target or limit reference points.

For previously identified ecosystem objectives (listed in Table 30-1), indicators of environment, human, and ecosystem pressures and responses were selected based on indicator selection criteria and frameworks (e.g., Bundy et al. 2017; Drivers, pressures, status, indicators, responses (DPSIRS) approach; Table 30-1) and core indicators identified by previous studies (e.g., Shin et al. 2010a, 2010b; Link et al. 2010; Fu et al. 2019; Boldt et al. 2014). Indicator time series were assembled for 1986-2017 (Table 30-1 and Figure 30-1). Multivariate Dynamic Factor Analyses (DFA; Holmes et al. 2012) were used to identify common trends among the different sets of environment, human, and ecosystem indicators. Gradient forest analyses (Ellis et al. 2012) were used to identify ecosystem responses to environmental and human pressures and thresholds. Single pressure-response relationships were examined for nonlinearities (following methods of Samhouri et al. 2017), and General Additive Models (GAMs; Hastie and Tibshirani 1990; Large et al. 2013) were used to examine nonlinear relationships and thresholds. This is a work-in-progress, one goal of which is to introduce synthesis-type indicators, such as trophic level of the surveyed community and trends from DFA, into the State of the Ocean Report.

30.3. Status and trends

Ecosystem indicators for the WCVI show varying trends during 1986-2017 (Figure 30-1); the most notable trends were increases in small mesh multispecies survey biomass, total landings, and Steller Sea Lions over the time series, as well as declines in subarctic copepods since the 1990s, and declines in the trophic level of the catch and the ratio of released to landings from the early 2000s to approximately 2012 (Figure 30-1). Multivariate DFA reduced these to five trends: one for environmental, one for human, and three for ecosystem indicators (Figure 30-1). Gradient forest analysis highlighted three important pressures (both human and environmental) that may be associated with ecosystem thresholds (nonlinearities): PDO, ratio of released to landings, and spring transition timing (Figure 30-2). Most pressure-response relationships were linear (or linear with autocorrelation); three nonlinear cases were identified using GAMs. Nonlinearities were between the proportion of predatory fish and the PDO, the abundance of southern copepods and the PDO, and the abundance of boreal copepods and spring transition timing (Figure 30-3).

Table 30-1. Indicators of environment and human pressures (A); ecosystem objectives, ecosystem pressures and responses (B), abbreviations, and data sources.

(A)

Component	Pressure	Indicator	Source
Environment	SST change	Pacific Decadal Oscillation (PDO_Annual)	a
	Water source	North Pacific Gyre Oscillation (NPGO)	b
	SST change	Multivariate ENSO Index Version 2 (MEI_Annual)	c
	SST change	Local sea surface temperature (SST_satellite)	d
	Nutrient availability	Upwelling magnitude	e
	Nutrient availability	Spring transition timing	e
Human	Fishery removals (landings)	Total landings (Tot_Landings)	f
	Fishery removals (discards)	Ratio of released to landings (Released_DivBy_Landings)	f
	Ecosystem function change	Trophic level of landings (TL_Landings)	g
	Ecosystem function change	Catch of foraging groups: benthivores, planktivores, zoopiscivores, piscivores	f
	Ecosystem function change	Catch of habitat groups: demersals, pelagics	f
	Ecosystem function change	Intrinsic vulnerability index (IVI)	g

(B)

Component	Objective	Indicator	Source
Ecosystem	Maintain structure and function	Zooplankton crunchy (Zoopl_SVI_Crunchy)	h
	Maintain structure and function	Zooplankton squishy	h
	Maintain structure and function	Copepods southern	h
	Maintain structure and function	Copepods boreal	h
	Maintain structure and function	Copepods subarctic	h
	Maintain structure and function	Trophic level of surveyed species (TL_SurveyedComm)	i
	Maintain structure and function	Steller sea lion abundance	j
	Maintain structure and function	Mean length (Mean_Len)	g
	Maintain stability and resistance	Mean lifespan	g
	Conserve biodiversity	Proportion predatory fish (Prop_PredFish)	i
	Maintain resource potential	Biomass of surveyed species (Tot_B_Survey)	i
	Maintain resource potential, structure, function	Survey biomass of foraging groups: benthivores, planktivores, zoopiscivores, piscivores	i
	Maintain resource potential, structure, function	Survey biomass of habitats groups: pelagics, demersals	i

a. http://research.jisao.washington.edu/pdo/PDO.latest.txt; Mantua et al. 1997
b. Di Lorenzo et al. 2008
c. National Center for Atmospheric Research Staff (Eds). Last modified 20 Aug 2013. "The Climate Data Guide: Multivariate ENSO Index." Retrieved from https://climatedataguide.ucar.edu/climate-data/multivariate-enso-index.
d. "https://www.ncdc.noaa.gov/oisst. Dataset Citation: Banzon et al. 2016, Reynolds et al. 2007.
e. Hourston and Thomson 2019
f. Maria Surry, Shelee Hamilton, Leslie Barton, Mary Thiess (DFO)
g. Caihong Fu (DFO)
h. Moira Galbraith, Kelly Young, Ian Perry (DFO); Galbraith and Young (2018)
i. Brenda Waddell, Ian Perry, small mesh multispecies survey (DFO)
j. Olesiuk 2018

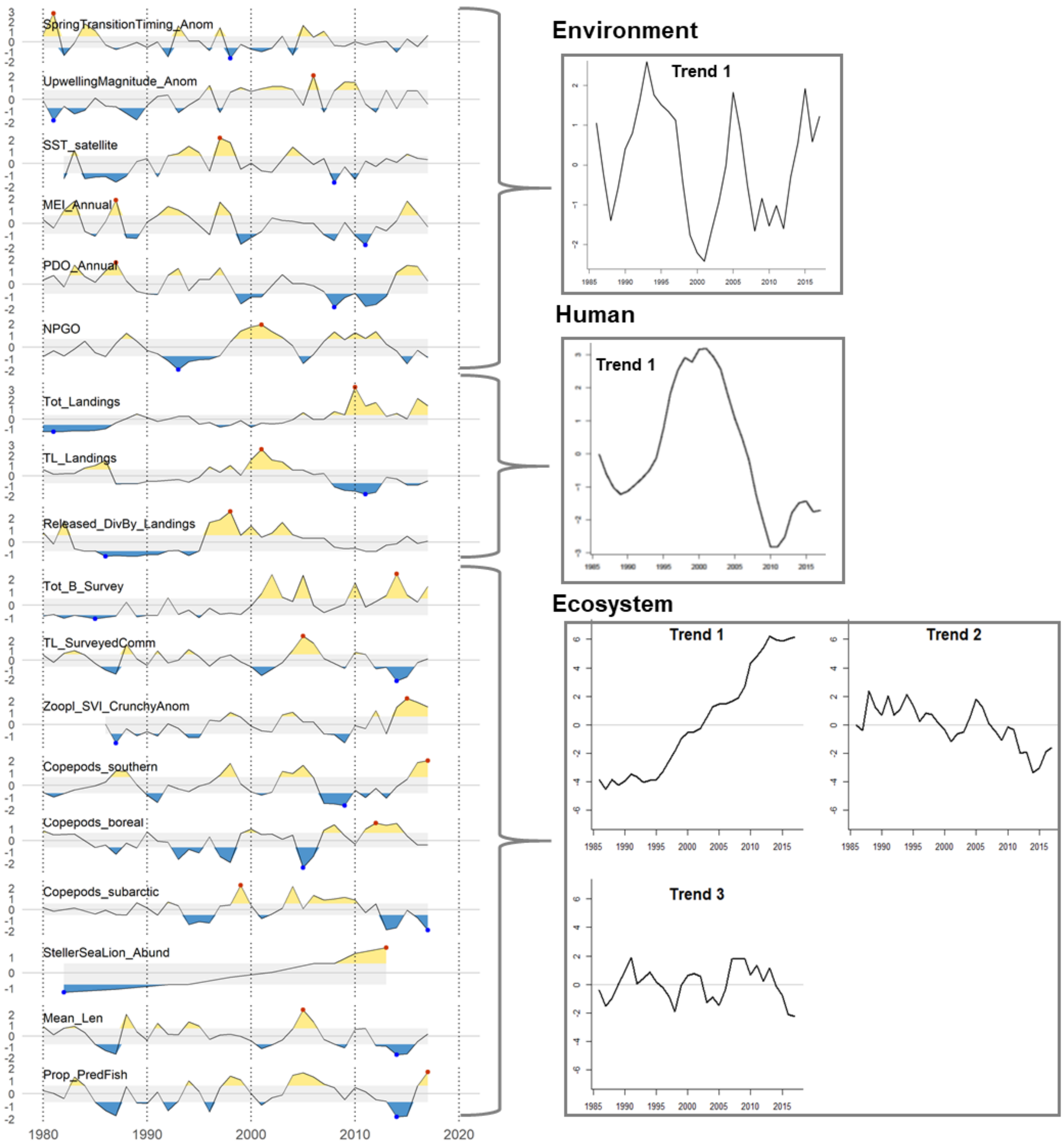

Figure 30-1. Time series anomalies of indicators of environment and human pressures, and ecosystem responses (left column) and trends identified from these indicators with Multivariate Dynamic Factor Analyses (right column), for the west coast of Vancouver Island. See Table 30-1 for indicator abbreviations. The blue dot is the minimum value and the orange dot is the maximum value for the time series anomalies. Grey shaded area represents the 25th and 75th quartiles.

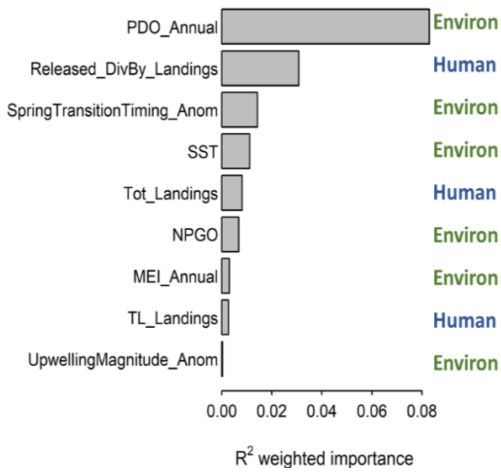

Figure 30-2. Important environmental and human drivers of ecosystem responses identified with gradient forest analysis.

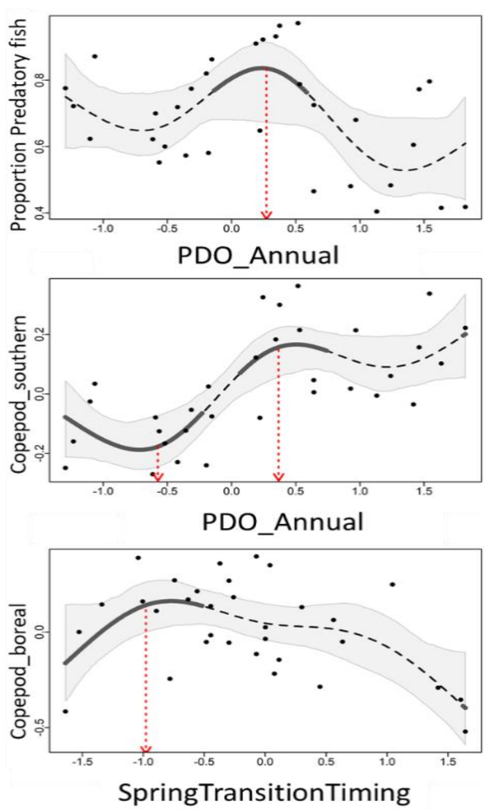

Figure 30-3. Three nonlinear relationships between environmental pressures and ecosystem responses identified with General Additive Models (GAMs). Dashed line is the GAM smoother, gray shaded area is the 95% CI, points are raw data, the thick solid line is the threshold range where the 95% CI of the second derivative of the GAM smoother line does not include 0, red dotted arrow indicates the best estimate of the threshold locations.

30.4. Factors causing trends

Factors causing trends in several of the individual indicator time series are discussed elsewhere in this report (e.g., Galbraith and Young, Section 16, Perry et al., Section 23). Trends in landings, trophic level of landings, and the ratio of released to landings were driven in part by changes in biomass but also by management actions. Further exploration of results from DFA (e.g., relationships among trends) and gradient forest analyses will clarify important pressure-response relationships. Thresholds for nonlinear responses can be identified through GAM analyses. In future analyses, non-stationarity of relationships will have to be considered.

30.5. Implications of trends

Sound fisheries management requires consideration of broad factors that influence marine ecosystems. Given DFO's National Initiative towards an Ecosystem Approach to Fisheries Management, there is a growing interest in the status of marine ecosystems. Multiple pressures can impact marine structure and function. Nonlinear ecosystem responses to climate and anthropogenic drivers and pressures can indicate thresholds, where small pressure changes can cause large ecosystem responses. Identification of nonlinear relationships and thresholds can provide leading indicators of ecosystem change.

30.6. Acknowledgments

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31. MOVING TOWARDS A MONITORING PLAN FOR THE SGAAN KINGHLAS-BOWIE SEAMOUNT MARINE PROTECTED AREA

Laís Chaves[1], Cherisse DuPreez[2], Tammy Norgard[2], Molly Clarkson[1], Jacinthe Amyot[2]

[1]Council of the Haida Nation, Haida Gwaii, BC, lais.chaves@haidanation.com; molly.clarkson@haidanation.com
[2]Fisheries and Oceans Canada, Pacific Region, BC, cherisse.dupreez@dfo-mpo.gc.ca; tammy.norgard@dfo-mpo.gc.ca; jacinthe.amyot@dfo-mpo.gc.ca

31.1. Highlight

- The development of a monitoring plan is a priority for the implementation of the SGaan Kinghlas-Bowie Seamount Marine Protected Area (SK-B MPA) management plan. The technical team responsible for overseeing the implementation of the Management Plan for the Marine Protected Area (MPA) is currently seeking potential partnerships to support long-term monitoring activities within the MPA.

31.2. 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 an 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 MPA namesake seamount, SK-B, is a large, uniquely shallow seamount, rising to within 24 m of the sea surface, supporting animals and kelp usually restricted to the coast. It's ecological significance and protection is of interest to a global community.

31.3. Conservation Goal and Strategic and Operational Objectives

The management framework for the SK-B MPA management plan establishes one conservation and four management goals. The strategic objectives and operational objectives related to these goals are described in the plan. These objectives will ultimately inform the development of indicators and reference points to be identified in the MPA monitoring plan.

31.4. The management plan implementation and priorities

The CHN and DFO are committed to the collaborative implementation of the SK-B MPA management plan and will follow SK-B guiding principles, mandates, priorities and capacities for ocean management. Development and implementation of a monitoring plan 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.

The plan (see Table 31-1), including its goals and objectives, will be collaboratively reviewed and updated every five years to consider emerging management needs and priorities, as well as results from monitoring reports and annual work plans (Table 31-1).

Table 31-1. Break-down of strategic and operational Objectives related to the Conservation Goal of the SK-B MPA management plan (Goal 1). The unique biodiversity, structural habitat and ecosystem function of the SK-B MPA are protected and conserved.

STRATEGIC OBJECTIVES	OPERATIONAL OBJECTIVES
1.1 Populations of rare, localized, endemic and vulnerable species are protected and conserved.	**a.** The condition and abundance of cold-water coral and sponges are within a range of the natural state.
	b. The condition and abundance of other invertebrates are within a range of the natural state.
	c. The condition and abundance of fishes (e.g. Blackspotted/ Rougheye rockfish, Bocaccio, Yelloweye rockfish, Sablefish, Prowfish) are within a range of the natural state.
1.2 Habitats that are essential for life history phases of species within the MPA are protected and conserved.	**a.** Sensitive benthic habitats are within a range of the natural state.
	b. Pelagic and sea surface conditions are within a range of the natural state.
1.3 Ecosystem food webs are protected and conserved.	**a.** Ecosystem function and trophic structure are within a range of the natural state.

31.5. Brief history of research conducted in the SK-B MPA and next steps

Sporadic surveys have taken place on SK-B Seamount since the 1940s for geological, biological, and naval purposes, making it one of the better studied seamounts in the world. Information on fish, benthic and mobile invertebrate species, and benthic habitats is available from commercial fishery records and from surveys carried out by SCUBA and submersible vehicles. More recently (2011-2017), data related to coral and sponge distribution were collected in partnership with the sablefish trap fishery, as well as vessel traffic using hydrophones. In 2018, a collaborative (CHN, DFO, Oceana Canada, Ocean Networks Canada) research expedition to SK-B seamount completed additional seafloor mapping, recorded videos, and collected species, as well as placed markers in areas identified to conduct long-term monitoring. Preliminary findings include the discovery of species new to science and the identification of new deep-sea coral habitats more abundant and diverse than previously recorded. More information from this expedition will be released in the coming years

The Management Board supports research and monitoring activities within the SK-B MPA, as long as these activities do not compromise the protection and conservation of the MPA, and impacts are minimized as necessary. In order to conduct scientific research or monitoring activities in the SK-B MPA, researchers must submit an activity plan to DFO. The management Board reviews activity plans for consistency with the goals and objectives outlined in the Management Plan and makes a recommendation to the CHN and DFO. Researchers are encouraged to propose research activities and work with the technical team to identify gaps and address monitoring needs.

31.6. Factors influencing future trends

Due to its remoteness, regulations, and other factors, there are limited activities taking place in the SK-B MPA (e.g., no commercial fishing, limited tourism) relative to coastal MPAs. Under this perspective, the SK-B MPA is a potential sentinel site to detect environmental changes at a larger scale (i.e. effects of climate change, underwater noise) and their effects on deepsea environments.

31.7. Reference

CHN and DFO 2019. SGaan Kinghlas–Bowie Seamount Gin siigee tl’a damaan kinggangs gin k’aalaagangs Marine Protected Area Management Plan 2019. 45 p.

32. UNUSUAL EVENTS IN CANADA'S PACIFIC MARINE WATERS IN 2019

Jennifer L. Boldt[1], R. Ian Perry[1], Peter C. Chandler[2]

[1] Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, Jennifer.Boldt@dfo-mpo.gc.ca
[2] Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC

32.1. 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 2019 that were reported include: the planet's hottest July on record (land and air), increased grey whale strandings, krill die-offs, appearance of an Olive Ridley sea turtle and a spotted porcupine fish.

32.2. 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 2019 that have been reported to 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, viewers of this poster 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.

32.3. Status and trends

Observations in 2019 that were reported to DFO by participants at the 2020 State of the Pacific Ocean workshop are presented in Table 1-1. The hottest July on record was observed in 2019, with global land and air temperatures 0.95 ºC warmer than the 20th century average for July. Climate change has prompted thousands of scientists from 156 countries to declare a climate emergency (Ripple et al. 2020, https://scientistswarning.forestry.oregonstate.edu/). In Northeast Pacific waters, there was an increase in Grey Whale strandings; near record numbers of dead Grey Whales were recorded off California and Oregon coasts in addition to 11 that came ashore in Washington. In B.C., two euphausiid (krill) die-offs were observed, and dense harmful algal blooms (HABs) were observed in Howe Sound and the northern Strait of Georgia, causing water discoloration. HABs near Binns Island, Bawden Point, and Ross Pass in Herbert Inlet, near

Tofino, resulted in fish mortality events at three fish farms in November. Unusual species sighted in B.C. include an Olive Ridley Sea Turtle in Alberni Inlet and a Spotted Porcupine Fish off the west coast of Vancouver Island (WCVI), near Jordan River.

Table 32-1. 2019 Observations of weird, wonderful and/or unusual marine events reported during 2019 or reported at the 2020 State of the Pacific Ocean meeting.

Event	Where	When	Reported by	(Brief) Details
Krill die-off	Beach Gardens Resort and Marina, Powel River	March 27, 2019	Darlene Williams; mypowellrivernow.com	-appeared to be female krill in the process of mating, or having recently mated. -could be linked to an earlier bloom and resulting anoxic, or very low oxygen, conditions, or bacterial infection
Krill die-off	Sea plane dock, Masset, Haida Gwaii	April 4, 2019	Leila (citizen)	“extremely large amounts of deceased baby shrimp floating in the water around the dock.”
Grey Whale strandings	North Saanich beach	May 1, 2019	DFO; Chek News	-Near record numbers dead Grey Whales off California and Oregon in addition to 11 that have come ashore in Washington. - due to starvation? Solar storms (Granger et al. 2020)?
Hottest July on record	Earth	July 2019	NOAA; Chek News	Global land and air temperatures were 0.95 degrees Celsius warmer than 20th century average for July
Dense HABs, causing water discoloration	Howe Sound, North SoG, Vancouver	July 2019	Citizen Science of SoG, PSF; North shore news	-Very dense red/orange blooms caused by dinoflagellate *Noctiluca scintillans* and possibly *Mesodinium rubrum*
Olive Ridley Sea Turtle	Alberni Inlet	Sept. 30, 2019	Citizen; Chek News; Vancouver Aquarium	- “Berni” was the fourth of his species to turn up in B.C. waters
Large bloom of dinoflagellates, predominately *Ceratium divericatum*	Canadian side of the west entrance of Juan de Fuca Strait	Oct 1, 2019	Nina Nemcek during the fall Salish Sea water properties survey	1000’s of birds, schooling fish and lots of feeding whales observed

Spotted Porcupine Fish	WCVI, near Jordan R.	October 28, 2019	Citizen; Chek News	-possible pet trade animal thrown overboard off fishing boat? -swam here with a warmer waters?
Scientists Declare A Climate Emergency	Earth	November 5, 2019	Ripple et al. 2020; HuffPost	13,422 scientists from 156 countries have declared a climate emergency, warning in a new report that “untold human suffering” is “unavoidable” without drastic action
HABs at fish farms	Binns Island, Bawden Point and Ross Pass in the area of Herbert Inlet, near Tofino	November 20, 2019	Cermaq Canada; Chek News	-fish deaths at three farms because of harmful algae bloom -Chaetoceros concavicornis and C. convolutes – which are both native

32.4. Factors influencing trends

Potential factors influencing these events include a changing climate, natural population explosions and anthropogenic pressures. Disease is a potential factor causing mortality, but is often overlooked or 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. For example, the Olive Ridley Sea Turtle, named Berni, was the fourth of his species to turn up in B.C. waters. The Spotted Porcupine Fish may have arrived with warmer waters or it might have been a pet trade animal thrown overboard off of a fishing boat. The 2019 HABs involved native species of algae. The Grey Whale strandings were thought to be due to starvation and/or solar storms (Granger et al. 2020).

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33. CANADA'S OCEANS NOW: ANNUAL REPORTS ON THE STATE OF CANADA'S OCEANS

Katherine Middleton, Fisheries and Oceans Canada, Ottawa, ON, katherine.middleton@dfo-mpo.gc.ca

- Canada's State of the Ocean reports are annual summaries of the current status and trends of marine ecosystems in Canada's three oceans.
- An ongoing reporting cycle presents information on one of Canada's oceans per year; followed by a national report being undertaken in the fourth year.
- State of the Ocean products for each ocean region include a technical report, a plain-language public report entitled Canada's Oceans Now and accompanying communication products such as infographics, videos and social media posts.
- The State of the Pacific Ocean products, including the SOPO technical report, a public report and communication products will be released in the 2020-2021 cycle. The public-facing content may include plain language science writing, case studies, infographics and engaging visuals for social media and outreach.

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 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.

In 2021 the State of the Pacific Ocean summary report and communication products will be produced based on peer review information presented at the March 2020 SOPO meeting. Alongside the annual technical report will be a plain-language public report, infographics and other engaging science communication products.

The public report on the State of the Atlantic Ocean was released in April 2019 on a new SOTO website. DFO Science launched State of the Atlantic Ocean products including a technical report (*State of the Atlantic ocean synthesis report, 2018*), public report (*Canada's Oceans Now: Atlantic Ecosystems, 2018*), 12 key message infographics, an interactive e-book, and a frequently asked questions page. Together with the Atlantic report release came additional digital content which summarized key findings from the 2016 State of the Pacific Ocean meeting.

The State of the Arctic Ocean and associated products has also been released. This includes the first technical report on the State of Canada's Arctic seas, a public report featuring engaging infographics translated into French, Inuktitut and Inuinnaqtun, a case study document and accompanying social media content (https://www.dfo-mpo.gc.ca/oceans/soto-rceo/arctic-arctique/index-eng.html).

The National State of the Ocean report will also be released later in 2020. This report will be a high level summary document communicating the state of all three of Canada's oceans using engaging infographics and plain language science writing. Additional communication and outreach products will be produced to accompany the release.

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

34. RIVERS AND BUTE INLET WATER PROPERTIES IN 2019 COMPARED TO A 1951 TO 2010 TIME SERIES

Jennifer Jackson, Hakai Institute, Victoria, BC, jennifer.jackson@hakai.org

34.1. Highlights

- In both Rivers Inlet and Bute Inlet, intermediate and deep waters in 2019 were warmer and saltier than the 1951 to 2010 average.
- In both Rivers Inlet and Bute Inlet, surface waters were freshest in May and June 2019, suggesting an early freshet.
- In both Rivers Inlet and Bute Inlet, deep water had less oxygen in 2019 than the 1951 to 2010 average.

34.2. 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 34-1). As of February 2020, 161 temperature and salinity profiles and 132 oxygen profiles have been collected at DFO2, with more than 96% of the data collected since 2001. As of February 2020, 118 temperature and salinity profiles and 104 oxygen profiles have been collected at BU4, with 23% if the data collected since 2001.

Following water type definitions in fjords (Farmer and Freeland 1983), 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 dwarfs interannual variation. To compare 2019 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 2019 was calculated.

Figure 34-1. 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), which 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.

34.3. Status and trends

34.3.1. Rivers Inlet

Comparing the long-term times series to 2019 for the surface water (Figure 34-2) shows that the surface was warmer and had less oxygen than the 1951 to 2010 average. The coldest surface temperature (7.4°C) was observed in February and the warmest surface water (13.2°C) was observed in May. The freshest surface water (17.6) was observed in May, approximately 1 month earlier than the typical June freshest (Wolfe et al. 2015) and the June salinity minimum (Tommasi et al. 2013) observed from 2006 to 2010.

In 2019, both intermediate (Figure 34-3) and deep (Figure 34-4) water were warmer, saltier, and less oxygenated than the long-term average. These results suggest the continued impact of the 2014 to 2016 marine heatwave on coastal waters and suggest that anomalous heat continues to linger in British Columbia fjords (Jackson et al. 2018). Increased salinity in intermediate and deep water could be caused by enhanced upwelling of offshore waters from depths around 140 m (Jackson et al. 2018) or because increased salinity is needed to balance out the increased temperature and keep the density the same. Further research is needed to determine how much of decreased oxygen is caused by warmer waters.

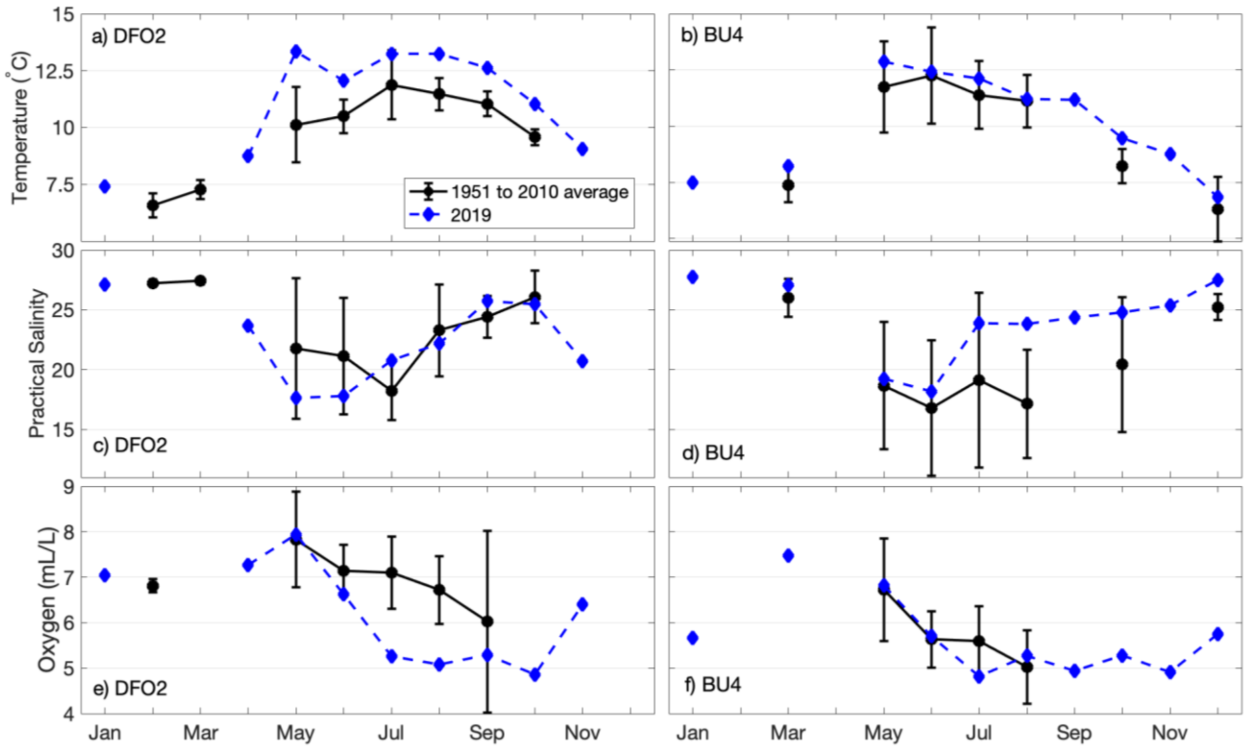

Figure 34-2. The monthly average surface (defined as water fresher than 1022 kgm^{-3}) conditions for (top) temperature, (middle) practical salinity, and bottom (oxygen) at stations DFO2 in Rivers Inlet (panels a), c) and e)) and BU4 in Bute Inlet (panels b), d), and f)). The solid black line denotes the monthly average from 1951 to 2010 and the dashed blue line shows the 2019 monthly average. Error bars represent the standard deviation of the 1951 to 2010 time series and only months that were sampled on at least 3 different years were shown.

34.3.2. Bute Inlet

Comparing the long-term times series to 2019 for the surface water (Figure 34-2) shows that the surface was warmer and had less oxygen than the 1951 to 2010 average. The coldest surface temperature (6.8°C) was observed in December and the warmest surface water (12.8°C) was observed in May. The freshest surface water (17.3) was observed in June.

In 2019, both intermediate (Figure 34-3) and deep (Figure 34-4) water were warmer, saltier, and less oxygenated than the long-term average. Similar to Rivers Inlet, these results show a long-term, year-round change to British Columbia central coast inlets. In Bute Inlet, these changes may be associated with the 2014 to 2016 marine heatwave but the limited sampling between 2000 and 2017 makes the impact of the heatwave difficult to interpret. Further research is needed to determine how much of decreased oxygen is caused by warmer waters.

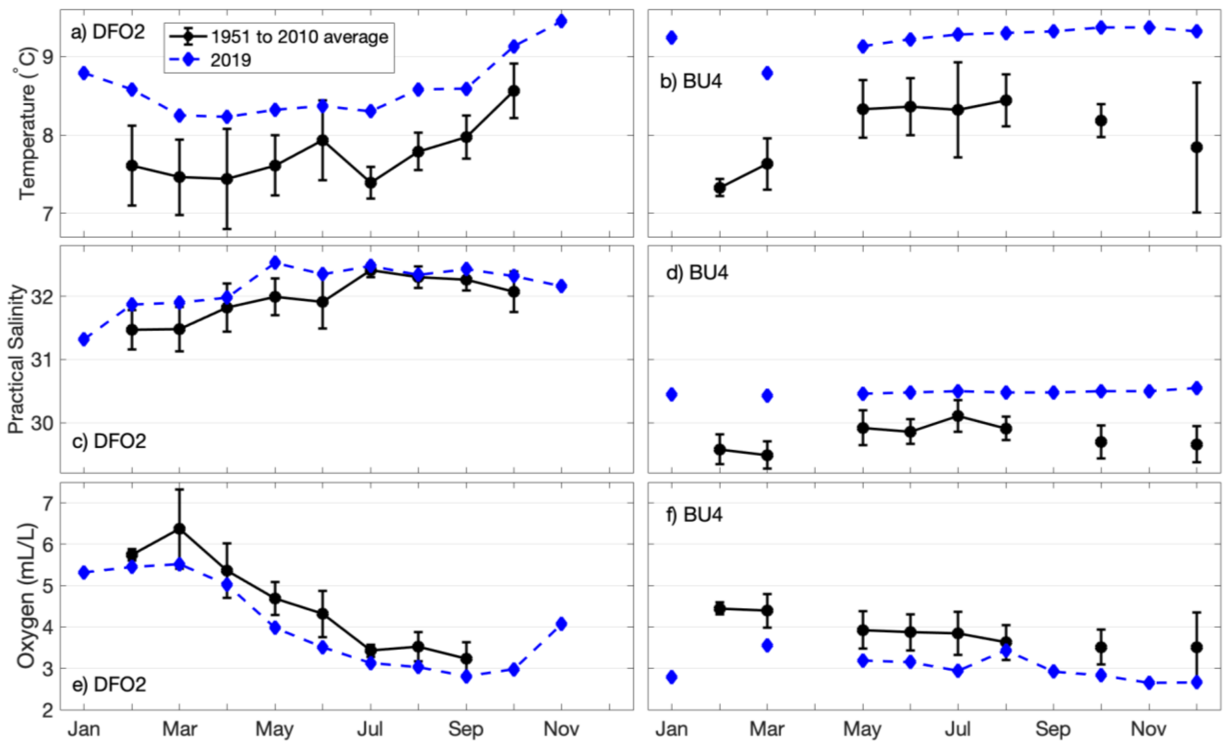

Figure 34-3. As in Figure 34-2 but for intermediate water, which was defined as water between the base of the surface layer and the 140 m sill depth for DFO2 (Rivers Inlet) and from the base of the surface layer to 355 m for BU4 (Bute Inlet).

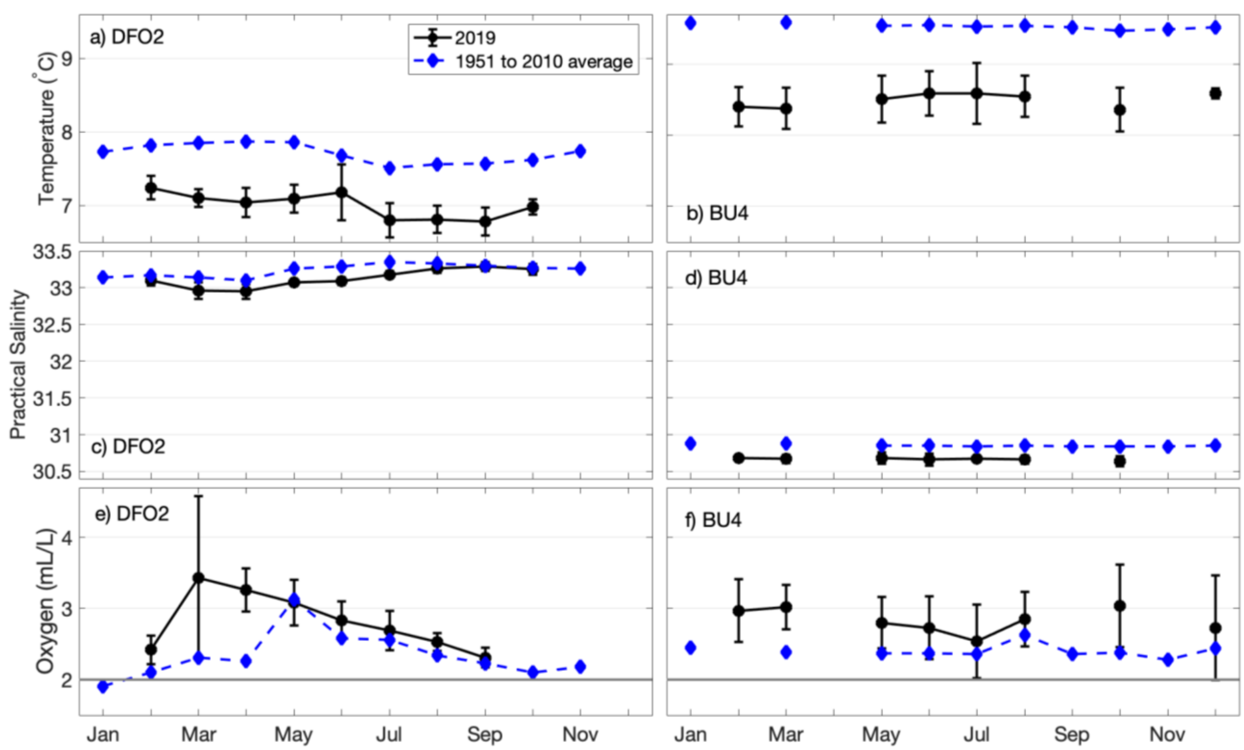

Figure 34-4. As in Figure 34-2 but for deep water, defined as water between the sill depth of 140 m and the bottom (334 m) in Rivers Inlet and between the sill depth of 355 m and the bottom (632 m) in Bute Inlet. The horizontal grey line in the bottom panel indicates 2 mL/L of oxygen, or hypoxic water.

34.4. 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 2019 inlet conditions were likely associated with reduced salmon growth during the 2019 outmigration. The warm intermediate and deep water in Rivers and Bute Inlet since 2015 means that five different salmon year-classes have experienced anomalously warm marine water conditions when the juvenile salmon enter the fjords.

Deep water in the Strait of Georgia also had decreased oxygen (Chandler, Section 36), suggesting that processes that brought low oxygen into Rivers and Bute Inlet influenced a large region of the B.C. coast. Research from Saanich Inlet (Chu et al., Section 45) shows that the biodiversity changes with different oxygen concentrations and this suggests that the hypoxic water observed in Rivers and Bute Inlet may have a significant impact on the local ecosystem.

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35. COASTAL CO_2 OBSERVATIONS: 2019

Wiley Evans, Hakai Institute, Heriot Bay, BC, wiley.evans@hakai.org

35.1. Highlights

- Along-coast surface pCO_2 variability has been detailed by multiple years of ferry observations.
- Warm sea surface temperature had a pronounced impact on pCO_2 variability in late 2019 on the northern B.C. coast and in southeast Alaska.
- Datasets from the central B.C. coast revealed inter-annual to sub-seasonal variability with increased sub-surface pCO_2 at depth in late 2018 and 2019 relative to previous years.
- Observations from the northern Salish Sea showed nearly sustained under-saturation of calcite in the mid-water column since July 2018.
- High pCO_2, low pH, and corrosive conditions for calcium carbonate bio-minerals will continue to intensify as the anthropogenic carbon content further increases in the ocean.

35.2. Description of CO_2 datasets

Coastal CO_2 datasets described in this report come from a collection of mobile and stationary platforms as well as discrete seawater samples collected at key hydrographic stations. These datasets span 3 spatial domains: coast-wide near-shore surface water, more detailed surface and through-water column observations on the B.C. central coast, and the same for the northern Salish Sea. The coast-wide surface observations were collected from the Alaska Marine Highway System (AMHS) ferry *Columbia* as it transited twice per week between southeast Alaska and the Salish Sea. More detailed observations on the B.C. central coast consisted of surface measurements from the Kwakshua Channel (KC) buoy on the central coast (http://www.ipacoa.org/Explorer?action=oiw:fixed_platform:HAKAI_KCBuoy:observations:H1_CO2) and discrete seawater samples collected through the water column at a hydrographic station adjacent to the buoy (station KC10). In the northern Salish Sea, surface observations made at the Hakai Institute's Quadra Island Field Station (http://www.ipacoa.org/Explorer?action=oiw:fixed_platform:HAKAI_Quadra1:observations:H2_CO2) track those from a nearby hydrographic station (station QU39) where discrete seawater samples are collected through the water column.

35.3. Patterns in CO_2 Datasets

Coast-wide observations from the AMHS ferry *Columbia* revealed highly variable surface pCO_2 conditions along the coast from the Salish Sea to southeast Alaska (Figure 35-1). High pCO_2 conditions with respect to the atmosphere were observed during winter and in tidally-mixed zones. Areas with pCO_2 roughly two times the atmospheric concentration (~800 µatm) also exhibited corrosive conditions for the calcium carbonate bio-mineral aragonite. Johnstone Strait in particular was a persistent high CO_2 zone due to tidal mixing that also exhibited low surface oxygen content. From spring to early autumn, pCO_2 is reduced in areas that experience high rates of primary production and in areas influenced by glacial melt (*i.e.* southeast Alaska). The spring bloom is evident in these data as the starting point of pCO_2 under-saturation with respect to the atmosphere each year. In 2019, the spring bloom pCO_2 drawdown appeared to be stronger and more extensive than in 2018, albeit was curtailed in the Salish Sea during April by the occurrence of stormy weather conditions. The majority of pCO_2 variability across this domain is driven by changes in total inorganic carbon (TCO_2), total alkalinity (TA), and salinity, however, the temperature influence was assessed following Takahashi et al. (2002) to evaluate the potential influence of warm conditions in 2019. Seasonal cooling and warming drives positive and negative changes in pCO_2 on the order of 100 µatm during winter and summer, respectively. In 2018, sea surface temperature (SST) cooled from the seasonal maximal in August through September such that the influence of warmer temperature on pCO_2 variability decreased. In 2019, warm SST persisted into September, particularly in southeast Alaska and on the north coast of B.C., such that the temperature influence on pCO_2 variability was maintained causing elevated late season surface pCO_2 during this year. In 2019, the influence of warmer temperatures in the late season was also detected in the other surface datasets described in this report, but not to the extent that was seen in the northern region of the ferry transit.

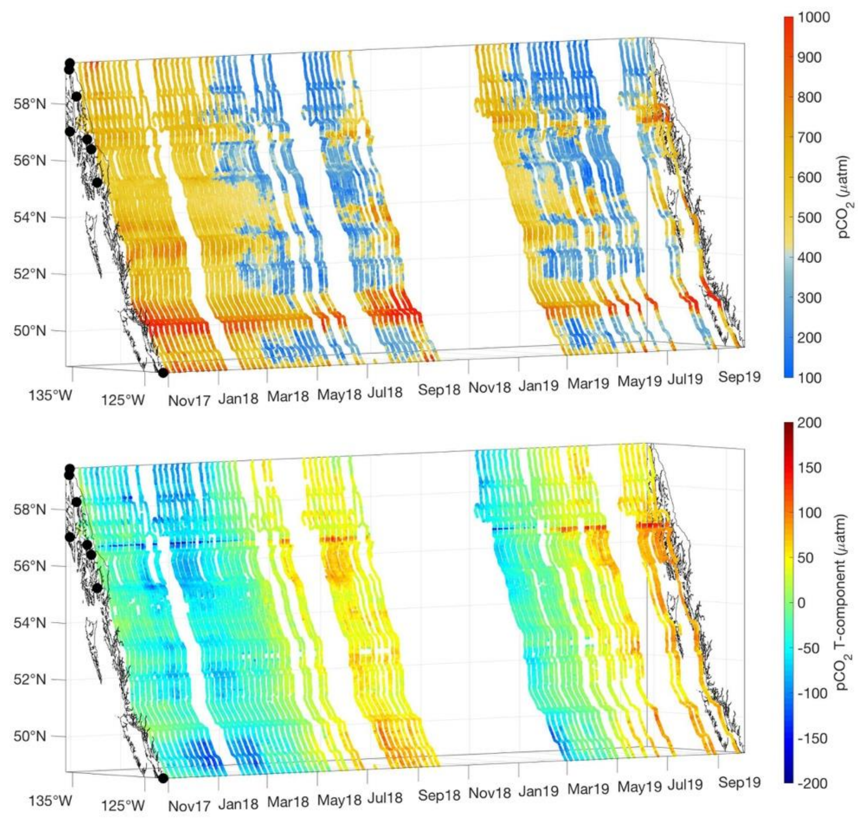

Figure 35-1. The top panel is surface water pCO_2 (µatm) measured from the AMHS ferry Columbia on transits between Washington State and southeast Alaska. X-, Y-, and Z-axes are latitude, longitude, and time, respectively. The coastline is shown for reference with the black dots marking the ferry terminals. The lower panel is the temperature effect on the pCO_2 variability (µatm).

The KC buoy record on the central coast of B.C. began in May of 2018, and therefore has only captured two summer and winter seasons. However, the higher resolution measurements from the buoy show short time scale variability not observed in the data from the underway system aboard the *Columbia*. For example, the April 2019 breakdown of under-saturated surface conditions with respect to atmospheric pCO_2 seen in the Salish Sea from the *Columbia* was short-lived on the central B.C. coast as captured by the buoy. Such fine detail structure of pCO_2 variability in the buoy record is currently being examined. The KC buoy data also revealed summer minima in pCO_2 content that was lower in 2018 than seen in 2019, potentially indicated more intense rates of primary production during the summer of 2018. Discrete measurements collected approximately monthly from a hydrographic station near the buoy (KC10) showed increased sub-surface pCO_2 from roughly July to January each year, with slightly higher and longer lasting conditions seen in 2018 and 2019. Instances of calcite under-saturation, the most insoluble form of calcium carbonate, were also observed during these periods of higher sub-surface pCO_2.

Over five years of continuous surface pCO_2 measurements have now been made from the Quadra Island Field Station in the northern Salish Sea. These data show winter conditions exhibit high but stable pCO_2 relative to the much lower but at times highly variable summer conditions. In 2019, summer pCO_2 variability was low relative to that was seen in 2015 and 2016, indicating that the last 3 years had relatively stable summer conditions. Measurements through the water column at the nearby hydrographic station QU39, which began in January 2016, indicated that sub-surface pCO_2 typically increases late in the year and most noticeably at 100 m. Winter mixing beginning in November re-oxygenates this zone of the water column and breaks down the seasonally high pCO_2 conditions. During 2018 and 2019, late season pCO_2 maxima appeared early in the year, covered a greater proportion of the water column, reached higher concentrations, and lasted longer into the preceding year. These high pCO_2 conditions co-occurred with calcite under-saturation in the northern Salish Sea water column. Sustained under-saturated conditions for calcite have been observed in the mid water column since July 2018 (Figure 35-2). The anthropogenic CO_2 content was estimated using the approach described in Evans et al. (2019) with an additional correction to account for the age of the water mass (last contact with the atmosphere). Estimated anthropogenic CO_2 content follows other estimates for the Salish Sea and Northeast Pacific coastal water (Feely et al. 2010; Carter et al. 2019), and showed seasonality and variability with depth. Estimated anthropogenic CO_2 content was subtracted from the TCO_2, and then this adjusted TCO_2 was used to re-compute the marine CO_2 system. The comparison between observed and re-computed calcite saturation states reveal that the majority of calcite under-saturation is driven by the buildup of anthropogenic CO_2.

35.4. Implications of CO_2 patterns

Continued buildup of anthropogenic CO_2 content will intensify high pCO_2, low pH, and corrosive conditions for calcium carbonate bio-minerals (*e.g.*, increase in magnitude, increase in duration of exposure, increase in frequency of exposure). The biological implications will be heightened stress for vulnerable organisms with potentially high energetic costs (Waldbusser et al. 2013; Bednarsek et al. 2017; Gimenez et al. 2018). The corrosive conditions for calcite in the sub-surface northern Salish Sea imply all forms of calcium carbonate are thermodynamically unstable and will tend to dissolve. The Salish Sea serves as an example of the extreme sensitivity of regions with weakly-buffered seawater to increasing anthropogenic CO_2 content.

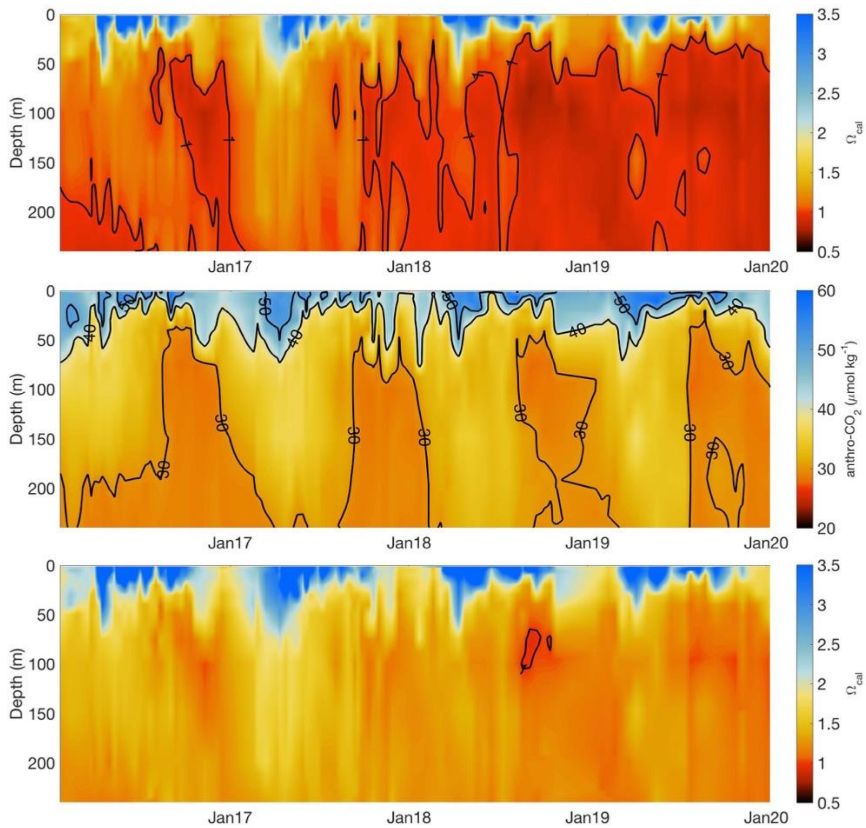

Figure 35-2. The top panel is calcite saturation state (Ω_{cal}) through the water column from January 2016 to January 2020 at station QU39 in the northern Salish Sea. The second panel is estimated anthropogenic CO_2 content (µmol kg^{-1}) at this site. The third panel is calcite saturation state re-computed with the anthropogenic CO_2 contribution to the total inorganic carbon content removed. Note that nearly all occurrences of calcite under-saturation are no longer present after accounting for the anthropogenic CO_2 contribution.

35.5. Data Availability and Acknowledgements

Newly released datasets described in this report can be found at the below links.

KC buoy: https://www.nodc.noaa.gov/ocads/data/0208810.xml

Quadra Island Field Station: https://www.nodc.noaa.gov/ocads/data/0208638.xml

AMHS ferry *Columbia*: https://www.nodc.noaa.gov/ocads/data/0209049.xml

Discrete sample datasets are being prepared for release through the Hakai Institute: https://hecate.hakai.org/geonetwork/srv/eng/catalog.search#/home. I am grateful for contributions from Jennifer Jackson, Alex, Hare, Katie Pocock, Carrie Weekes, Shawn Hateley, Jessy Barrette, Chris O'Sullivan, Chris Mackenzie, Emma Myers, Bryne Fedje, Eva Jordison Justin Belluz, Christy Harrington, Geoff Lebon, and Adrienne Sutton that have kept these datasets going. I am also grateful for the support from the Alaska Marine Highway System, Alaska Ocean Observing System, Alaska Coastal Rainforest Center, and the Tula Foundation.

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36. SALISH SEA TEMPERATURE, SALINITY AND OXYGEN OBSERVATIONS IN 2019

Peter Chandler, Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Peter.Chandler@dfo-mpo.gc.ca

36.1. Highlights

- Salish Sea water temperatures were generally above-normal in 2019, with the exception of near-normal temperatures in the mid-depth waters of the central Strait of Georgia in spring and summer.
- Following below-normal oxygen concentrations in 2018, 2019 has seen a transition to near-normal oxygen concentrations throughout the system, with the exception of above-normal oxygen concentrations in the deep water of Haro Strait.
- The Fraser River discharge was below normal in 2019 (although the long-term trend is for increasing annual discharge), with a relatively low discharge period in mid-summer. Normal, and above-normal flows were observed during the spring salmon outmigration period, and the fall spawning period.

36.2. 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 36-1). In 2019, surveys were carried out April 6-13, June 2-8, and in the fall (Sep 30-Oct 6). The second dataset is provided by the Department of National Defence from the 73 temperature and salinity profiles collected in 2019 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 2019 anomalies from these average conditions.

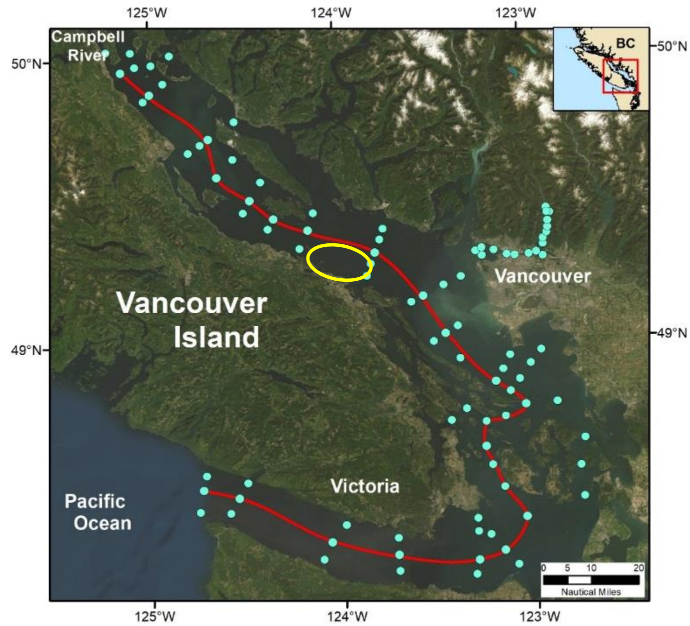

Figure 36-1. Dots show the locations of stations sampled during the water properties surveys. The thalweg is shown as the red line joining the deepest stations along the centerline of the Straits. The yellow ellipse marks the CFMETR data collection area.

36.3. Status and trends

Observations of temperature and oxygen made in 2019 are compared to the 1999-2019 averages and shown as anomalies in Figure 36-2. The Salish Sea was generally warmer than normal throughout 2019, especially in the fall. The Strait of Georgia mid-depth temperatures in spring were just slightly above normal and near-normal in summer.

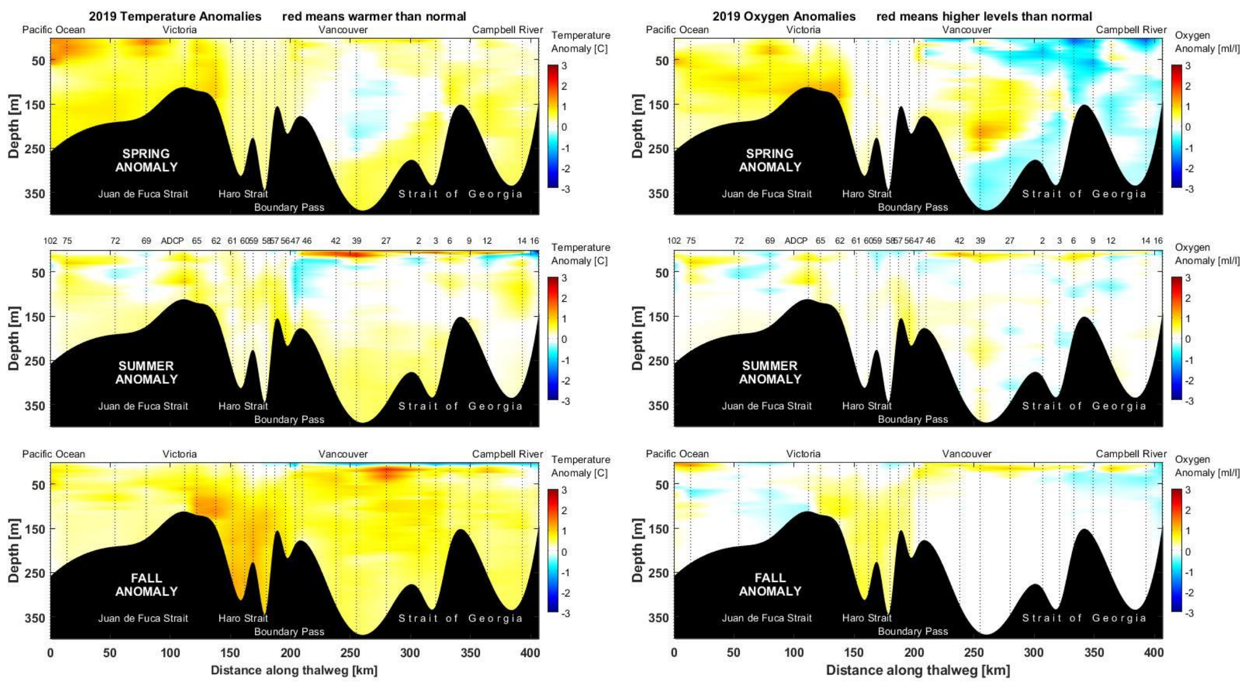

Figure 36-2. Temperature (left column) and oxygen (right column) anomalies along the thalweg observed in spring (top row), summer (middle row), and fall (bottom row) 2019.

Salinity anomalies (not shown) show fresher than normal conditions at mid-depth in Juan de Fuca Strait during the spring, and in the deep waters of Haro Strait in the fall. The Strait of Georgia salinity was near-normal for most of the year, with a shallow surface layer of saline water in the summer, likely due to the reduced precipitation and Fraser river runoff in early summer.

Following 2018 when oxygen levels in the Salish Sea were lower than normal, 2019 showed a return to near-normal levels by summer. Above-normal oxygen levels were observed in Juan de Fuca Strait in the spring, and in the deep water of Haro Strait in the fall.
The interannual variations in the temperature collected near Nanoose (Figure 36-3, upper panel) show depth averaged temperatures in 2018 at levels consistent with the long-term average, and temperature with depth conditions very similar to those in 2017, and 2004-2006.

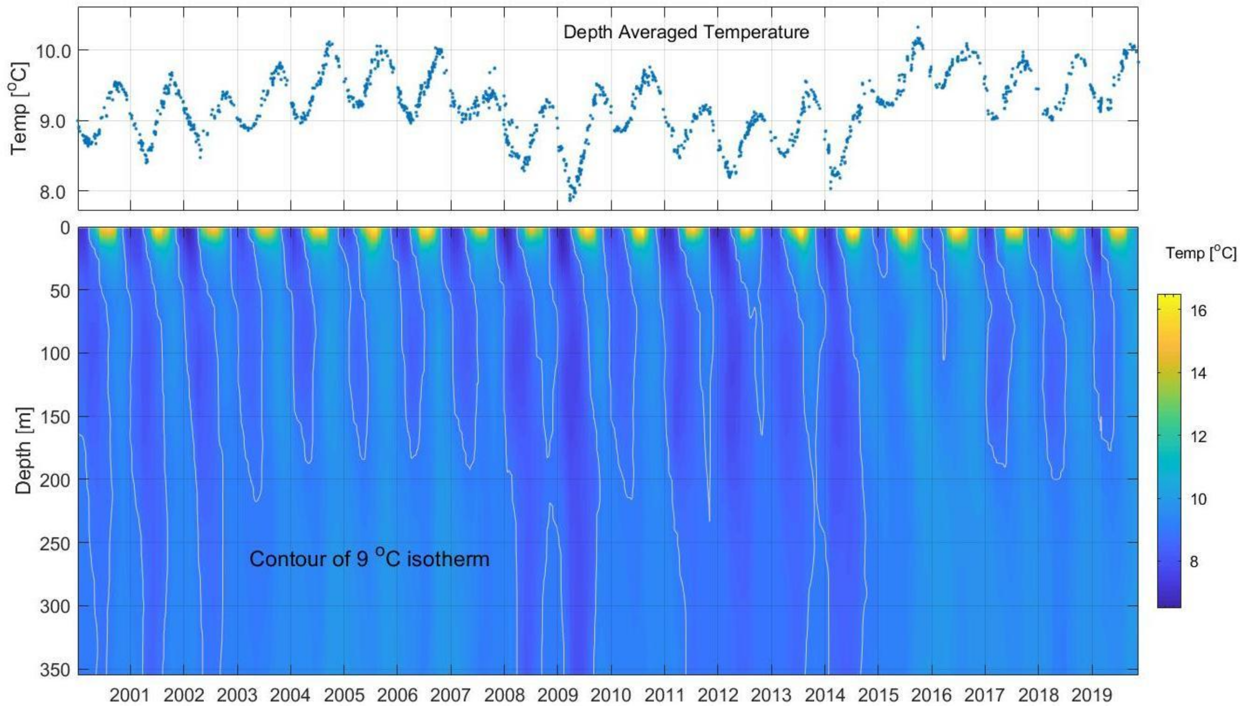

Figure 36-3. The time series of depth averaged temperature collected near Nanoose in the central Strait of Georgia (upper); the vertical distribution of these data (lower).

The influence of the Fraser River discharge is particularly evident in the salinity of the surface waters of the central and southern Strait of Georgia. While the 2019 annual discharge of the Fraser River measured at Hope, B.C. (see Figure 36-4) was slightly less than the 107 year average there was a higher than average discharge in the spring and fall of the year, resulting in a median annual discharge 8 days later than normal, but a peak discharge date 10 days earlier than the long-term average.

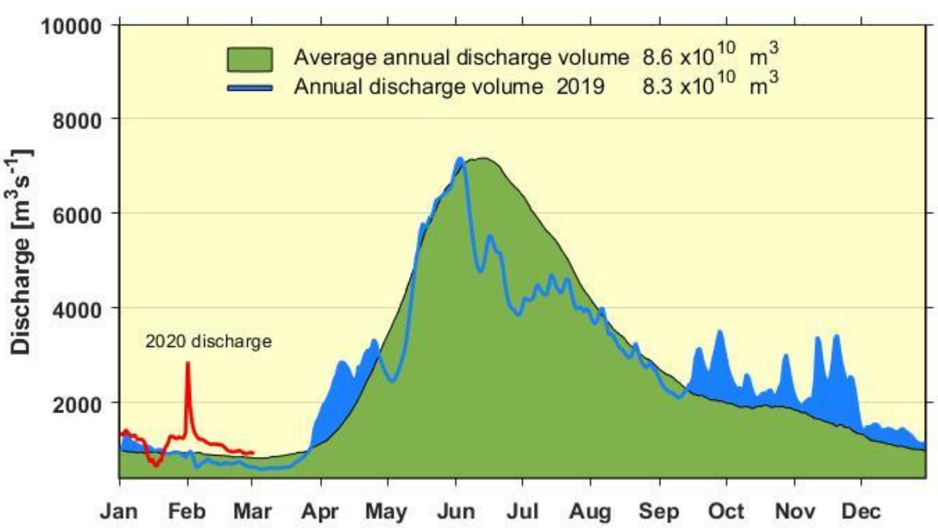

Figure 36-4. Fraser River discharge at Hope B.C.; 2019 (blue), 107 year average (green). The red line shows the above normal discharge in early 2020. Extracted from the Environment and Climate Change Canada Real-time Hydrometric Data web site (https://wateroffice.ec.gc.ca/mainmenu/real_time_data_index_e.html) on 2 Mar 2020.

36.4. Factors influencing trends

Water properties in the Salish Sea are primarily influenced by ocean conditions at the western entrance of the Strait of Juan de Fuca, and the freshwater discharge of 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 in the Salish Sea water properties, and the trend of increased discharge of the Fraser River is reflected in the freshening trend of the surface layer. 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).

36.5. References

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37. DEEP WATER AND SEA SURFACE PROPERTIES IN THE SALISH SEA DURING 2019: CABLED INSTRUMENTS AND FERRIES

Richard Dewey[1], Mike Morley[1], Steve Mihaly[1], and Rich Pawlowicz[2]

[1]Ocean Networks Canada, University of Victoria, Victoria, BC, rdewey@uvic.ca, rdevey@uvic.ca, mmorley@uvic.ca
[2]University of British Columbia, Vancouver, BC, rich@eos.ubc.ca

37.1. Highlights

- Moderate (average) upwelling was recorded off the southern coast of B.C. (48°N 125°W) between April 8 and Sept. 9, 2019.
- Downwelling prior to April 8 and after Sept. 9 was weak when compared to data extending back to 1957.
- Seasonal patterns of temperature at the Ocean Networks Canada (ONC) coastal sites: Folger Passage (98 m); Saanich Inlet (96 m); Strait of Georgia (SoG) East (170 m); and SoG Central (300 m), were similar to 2018 and generally warmer than conditions prior to 2015.
- Ocean conditions in the deeper waters of the Salish Sea remain about 0.5 ºC warmer than prior to 2015.
- Deep water renewal into the deep waters (>300 m) of the SoG, as record at the SoG Central site extended from early June to mid December, the latest renewal event in the past dozen years.
- The 2019 SoG spring phytoplankton bloom as recorded on the BC Ferries thermosalinograph system started on or about March 8, 2019, similar to 2018.

37.2. 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 Central Strait of Georgia (SoG Central). 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 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 takes the daily average along-shore wind stress component and scales it (with *f*, the Coriolis parameter) to arrive at a volume estimate of the amount of ocean transported off (positive - upwelling) or on-shore (negative - downwelling) per 100 m of coastline.

2. ONC's Folger Passage Deep (100 m) 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 inner shelf at the mouth of Barkley Sound, and the time series discussed here started Sept. 2009. This time series provides an indicator of the near shore, mid-depth water properties (T, S, O_2) that are strongly influenced by local up- and down-welling conditions.
3. ONC's SoG Central (300 m) site is a fixed cabled installation at 49° 2.4' N and 123° 25.6' W. The instrument platform sits on the bottom in the southern central Strait, along the eastern side of the thalweg, a conduit for dense water renewal flows coming from the south. The platform was installed in Sept. 2008. This time series provides an indicator of the deep water properties (T, S, O_2) in the southern Strait, that are strongly influenced by deep water renewal events.
4. ONC has instruments installed on the BC Ferry 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, O_2, Chl) across the southern Strait, that are strongly influenced by the Fraser River.

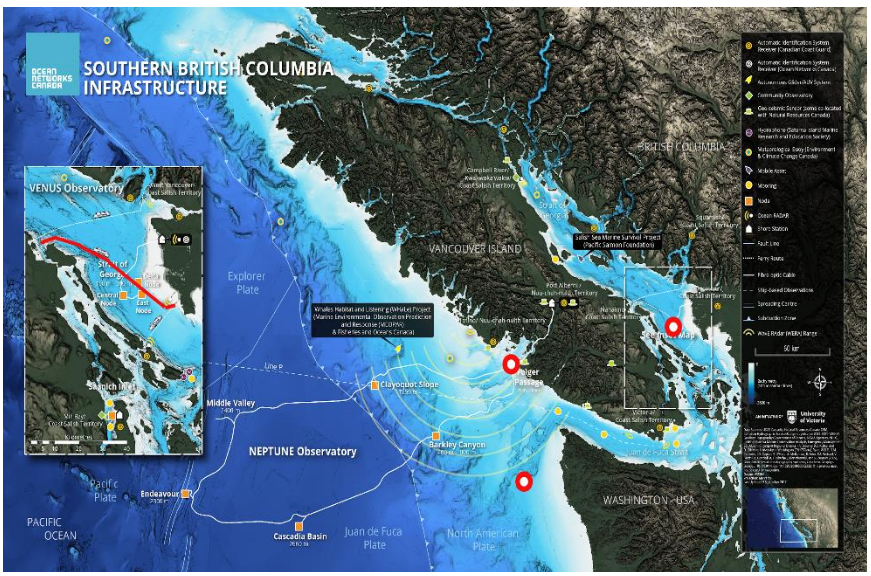

Figure 37-1. Southern coast of B.C., showing ONC's installed and instrumented assets. Sites where data will be shown have been highlighted with red/white circles (NOAA Buoy, west of Washington State, Folger Passage, near the entrance to Barkley Sound, and SoG Central, within the Salish Sea) and the Queen of Alberni Ferry route (red line in map inset).

37.3. Status and Trends – 2019

37.3.1. Upwelling

The coastal waters of B.C. and the Salish Sea are strongly influenced by upwelling conditions along the west coast of North America. For the Salish Sea, this includes the region near the entrance to Juan de Fuca Strait. 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 37-1).

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 downwelling conditions affecting the coastal waters of southern B.C. (Figure 37-2). The winds of 2019 show a few critical characteristics. First, there were strong northward blowing winds only in early 2019 (January), revealed by a sharp downward trend in the cumulative index (black line Figure 37-2). After this early windy period, the downwelling winds were weaker, and the transition to upwelling winds occurred on or about April 8, 2019. Upwelling conditions in 2019 (strength and duration) were rather typical, ending on or about Sept 9. After this date, the downwelling winds remained weak for the remainder of the year (with few fall storms), ending with less net downwelling than the long-term average (Figure 37-2, blue curve).

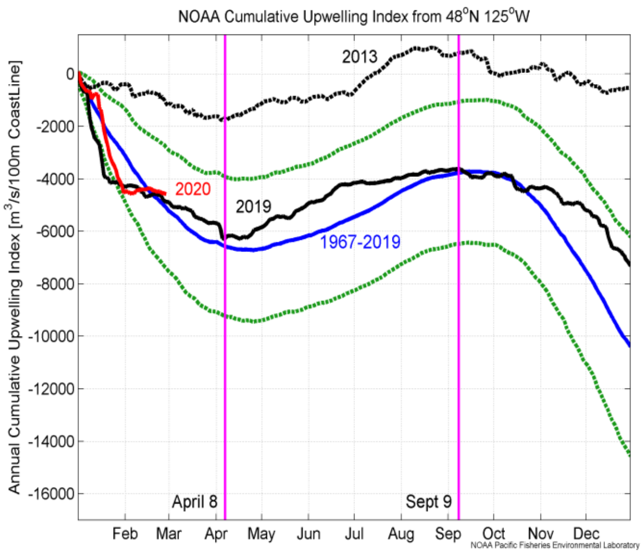

Figure 37-2. The cumulative upwelling index from along shore winds recorded at 48°N 125°W, west of Washington State (Figure 37-1). Downward (downwelling) trends occur during northward winds (winds from the south) and upward (upwelling) trends occur during southward winds (winds from the north). 2019 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 downwelling year on record, contributing to the development of the warm Blob in the Northeast Pacific.

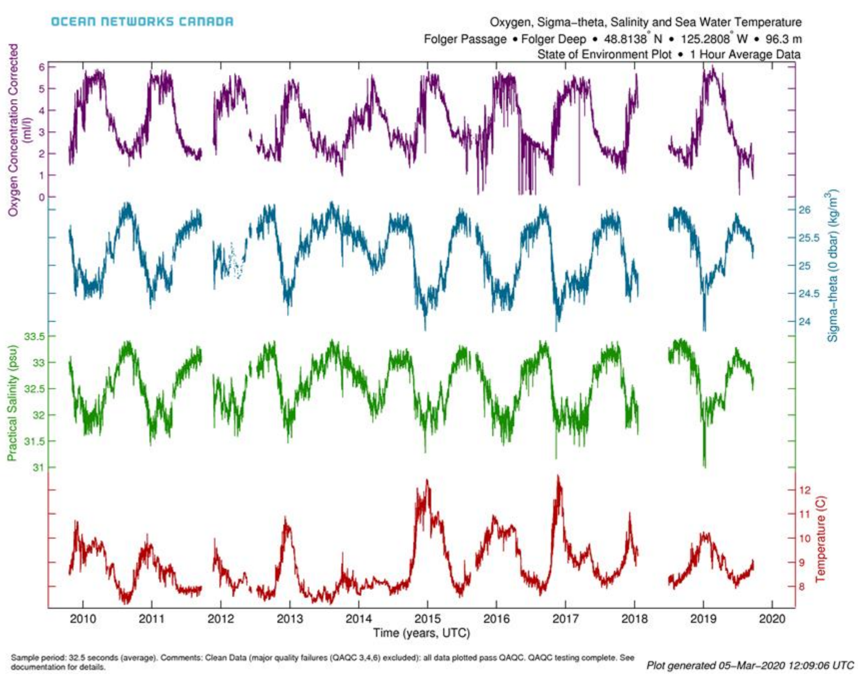

Figure 37-3. Time series of water properties from the cabled station at Folger Passage (100 m) located near the entrance to Barkley Sound along the west coast of Vancouver Island (Figure 37-1). Shown are (top to bottom): Oxygen (magenta), Density σ_t (blue), Salinity (green), and Temperature (red). Instrument failures in early 2018 and late 2019 have introduced data gaps.

37.3.2. Folger Passage

ONC maintains numerous stations in the Salish Sea (in-shore, formally VENUS) and off the west coast of Vancouver Island (off-shore, formally NEPTUNE). Along the west coast of Vancouver Island, the off-shore cable has a station at Folger Passage (Figure 37-1) near the entrance to Barkley Sound. This station has a fixed platform at a depth of 100 m. Shown in Figure 37-3 are the CTD and oxygen records for Folger Passage (100 m). 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, surface waters are pushed eastward up along the shore, causing the seawater to be fresher and warmer. During the up-welling season, cooler salty water is entrained into the coastal waters.

Several signals are noteworthy. The absence of a down-welling (warm peak) during the winter of 2013-14 is indicative of warm water staying off-shore and forming the “Blob” in early 2014. When down-welling resumed in late 2014, the peak temperature in late 2014 and early 2015 were the warmest in this record. While late 2019 is truncated from September 23 due to an instrument failure, both the down-welling (warm peak of 10 ºC) and up-welling (colder period, down to 8 ºC) are generally unremarkable.

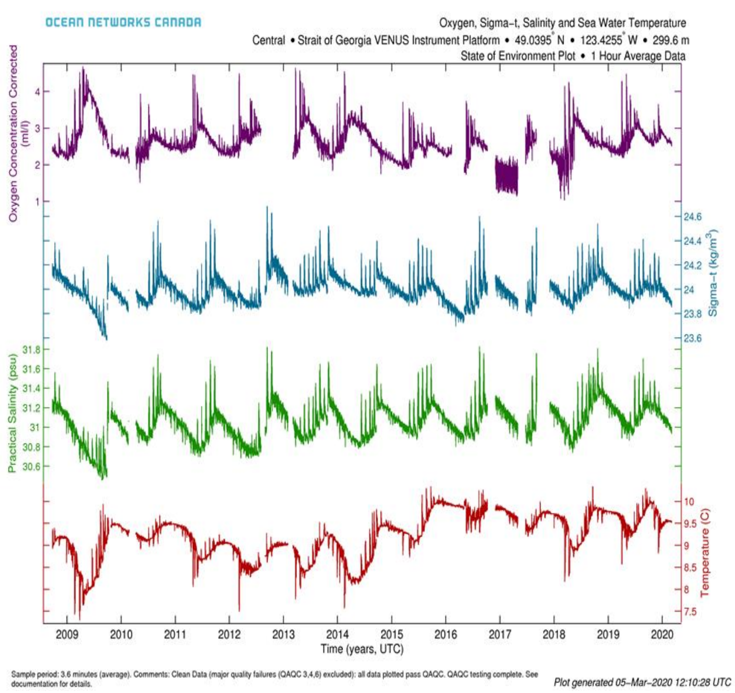

Figure 37-4. Seawater properties from the ONC SoG Central (300 m) cabled station, showing (top to bottom): Oxygen, Density (σ_t), Salinity, and Temperature. Of note is the baseline step up in temperatures during the intrusion of the Northeast Pacific Blob in late 2014 and early 2015. From 2015 onward, the entire deep basin of the SoG is on average over 0.7 ºC warmer than prior to 2015. Spikes are real and associated with (in temperature): downward - cold ventilation events (winter), and upward - salty deep water renewal events (summer).

37.3.3. Strait of Georgia Deep Waters

In the Salish Sea, the time series is from the SoG Central location (Figure 37-1), located in the south-central region at a depth of 300 m. This site is located along the right-hand (east) side of the thalweg, between the shallow southern Strait and the deep central basin, with maximum depths exceeding 400 m. Shown in Figure 37-4 are the CTD and oxygen records, starting in 2008. Apart from a few data gaps associated with sensor failures and plugged conductivity cells, the data reveal several key features of the deep 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. 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, and is replenished during the winter months by deep (top-down) ventilation from the surface, which are also revealed to be cold intrusions. These patterns are consistent with the findings of LeBlond et al. (1991) and Masson (2002).

A closer look at the 2019 deep water SoG time series will highlight these important trends and events. Shown in Figure 37-5 are the water property time series for 2019. On top of the general seasonal variations are the pronounced renewal events, associated with top-down ventilation (oxygen spikes in April - June) and the dense deep water renewal events (Salinity spikes form June - December). Following Griffin and LeBlond (1990) the deep water renewal events can be linked to tidal mixing rates within the Jan Juan and Gulf Islands, which are lowest once per-month and align with the deep water renewal events (Figure 37-5).

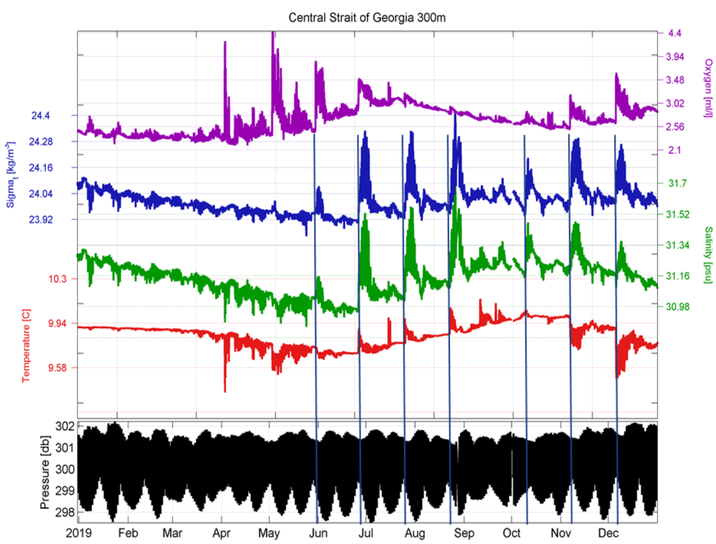

Figure 37-5. The times series from the SoG Central (300 m) station, showing, top-to-bottom: Oxygen, Density (σ_t), Salinity, Temperature, and Pressure (tide height). Of note are the intrusive events associated with: a) winter top-down ventilation events (both cooling and re-oxygenation) and b) tidal modulated deep water renewal events during the summer up-welling season (events associated with higher salinity). Unique in 2019 are the late year (November and December) renewal events when there is still salty water entering the system but the surface cooling/ventilation has also started.

Unique to 2019 are some late season deep water renewal events. Figure 37-5 reveals 2 - 3 late season (Oct - Dec) events identified by higher/spikes in salinity. By this late in the season, regional temperatures are cooling, and surface waters (high in oxygen) are becoming colder. A dry fall reduced the amount of surface fresh water, allowing the persistence of deep salty conditions in the approaching Straits (Juan de Fuca and Haro Straits).

37.3.4. *Surface Waters Properties from BC Ferries*

ONC also maintains a thermosalinograph (TSG) system on the Queen of Alberni Ferry, which runs from Duke Point to Tsawwassen (Figure 37-1, inset). This system is equipped with oxygen and Chlorophyll fluorometer sensors, which can identify the spring phytoplankton bloom. Shown in Figure 37-6 are column space-time series. The spring phytoplankton bloom is perhaps most identifiable in the fourth column, Chl-a (log), with a clear transition to higher chorophyll a concentrations. For reference, the spring bloom starts about March 8 in this record.

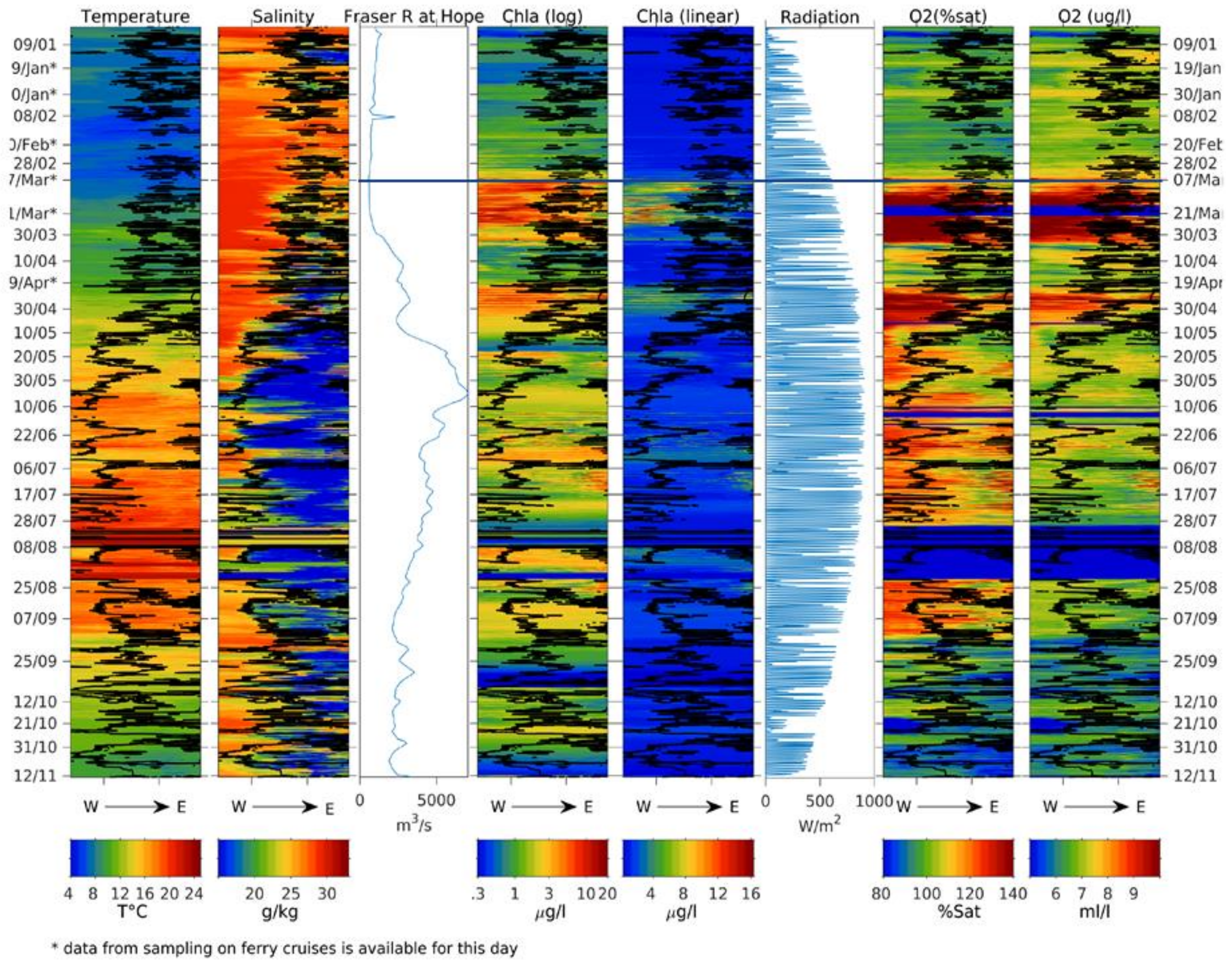

Figure 37-6. Time and Space times series from sensors mounted on the Queen of Alberni Ferry, with time progressing top-to-bottom and space from left (west, Duke Point) to right (east, Tsawwassen). Columns are (from left to right): Sea-surface Temperature, Salinity, Fraser River Discharge (at Hope), Chlorophyll a in both log and linear scaling, solar radiation, and dissolved oxygen, in both % saturation and µgm/l.

37.4. Summary

Assessment of the 2019 marine conditions along the southwest coast of Vancouver Island, both off-shore and in-shore, reveal several characteristics:

- The down-welling and up-welling seasons were not remarkable. There was only one strong down-welling period early in the year (January 2019), followed by relatively weak down-welling (through to early April), weak up-welling (through to early September), and weak down-welling (through to December).
- Up-welling signals on the shelf of southwest Vancouver Island were unremarkable.

- Deep water properties within the Salish Sea remained warm following the intrusion of Blob water in 2015. Temperatures in deep waters remains between 0.5 and 0.7 ºC above pre-Blob conditions.
- Deep water renewal events into the SoG occur during the summer up-welling season from mid-June through to mid-December, the latest renewal season recorded.
- Surface conditions in the SoG as revealed by the sensors on the Queen of Alberni reveal a spring phytoplankton bloom starting on or about March 8, 2019, similar to the long-term records.

37.5. References

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Masson, D. 2002. Deep Water Renewal in the Strait of Georgia Estuarine, Coastal and Shelf Science 54: 115-126.

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

Susan Allen, Doug Latornell and Elise Olson, Earth, Ocean and Atmospheric Sciences, University of British Columbia, Vancouver, BC, sallen@eoas.ubc.ca, dlatornell@eoas.ubc.ca, eolson@eoas.ubc.ca

38.1. Highlights

- The timing of the Spring Bloom in 2019 was average. The timing of the 2020 spring bloom is predicted to be average.
- The spring bloom timing has changed little between consecutive years since 2006, unlike the 10 years previous.
- The contribution of diatoms to summer phytoplankton productivity in 2019 was low compared to the 2007-2019 mean.

38.2. Description of the time series

Using the regions of the Strait of Georgia (SoG) defined by DFO based on hydrographic and plankton characteristics (unpublished, Perry and Galbraith, Fisheries and Oceans, Canada), the one-dimensional model results here pertain to the Central SoG. From the three dimensional model we show results from the Southern, Central and Northern SoG.

38.2.1. One-dimensional Biophysical Model: SOG: for Spring Bloom

SOG is a vertical one-dimensional physical mixing model coupled to a Nitrate-Diatom biological model (Collins et al. 2009). All two-dimensional oceanographic processes not resolved by the model are parameterized. The model location, STRATOGEM station S3, is on the Tsawwassen to Duke Point ferry route. The model is forced by winds measured at Sand Heads, clouds and temperature measured at YVR (Vancouver) airport and river flow measurements at Hope (representing the snow melt dominated part of the Fraser River) and in the Englishman River (representing all other rivers and the rainfall dominated part of the Fraser River). Using these data sources, we produced a time series of spring bloom time back to 1967 (Allen and Wolfe 2013).

38.2.2. Three-dimensional biophysical Model: SalishSeaCast: for Summer Productivity

SalishSeaCast is a three-dimensional coupled bio-physical model of the Salish Sea. The physical model is based on NEMO (Madec et al. 2012), with grid resolutions of about 500 m in the horizontal and 1–22 m in the vertical (Soontiens et al. 2016). Resolution is higher near the surface. It is forced by realistic winds from Environment and Climate Change, Canada (2019), and river input 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 based on the 3 nutrients, 3 phytoplankton, 2 zooplankton, 3 detritus model (Olson et al. 2020). The time series is a 13 year run from 2007 to 2019.

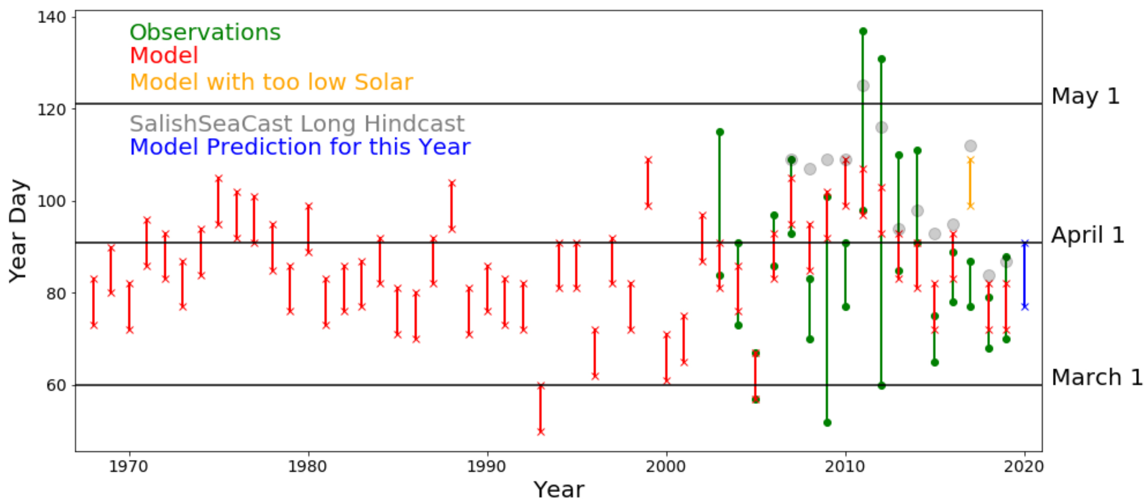

Figure 38-1: Time series of the timing of the peak of the Spring Phytoplankton Bloom. Green- observations from ferry systems. Red – SOG model. Orange – SOG model with too little solar radiation (see Allen et al. 2018), Blue – SOG model prediction for 2020 and Grey – SalishSeaCast (all late).

38.3. Status and trends

38.3.1. Spring Bloom

The 2019 spring bloom happened between March 13 – March 23, 2019 according the SOG model (Figure 38-1). The ferry observations give ½ peak height to ½ peak height bloom timing of March 11 – March 29, 2019 (Figure 38-1). For details on the ferry observations see Dewey et al., Section 37. This timing agrees with the satellite observations (Gower et al., Section 12). The 2020 spring bloom is predicted to peak between March 17 – April 1, 2020.

These blooms have typical timing. The mean of the SOG timeseries is March 26 with a standard deviation of 11 days. Of note, since 2011, the spring bloom timing has not varied strongly between years. This is similar to the time series before 1993 and very different from the large swings seen between 1993 and 2006.

38.3.2. Summer Productivity

Summer productivity (Figure 38-2, top left panel) shows the northern and southern SoG are more productive than the central region. Throughout the Strait, except in some inlets, summer productivity in 2019 was lower than the thirteen-year mean by about 5-10%. The model includes three broad classes of photosynthesizers: diatoms, *Mesodinium rubrum,* and flagellates. In 2019, a larger fraction of the photosynthesis was done by flagellates compared to diatoms. The ciliate, *Mesodinium rubrum,* only contributes a small amount. The variation of primary productivity between phytoplankton classes is much larger than the variation of total primary productivity. In 2019, up to 40% more of the productivity was done by the flagellates.

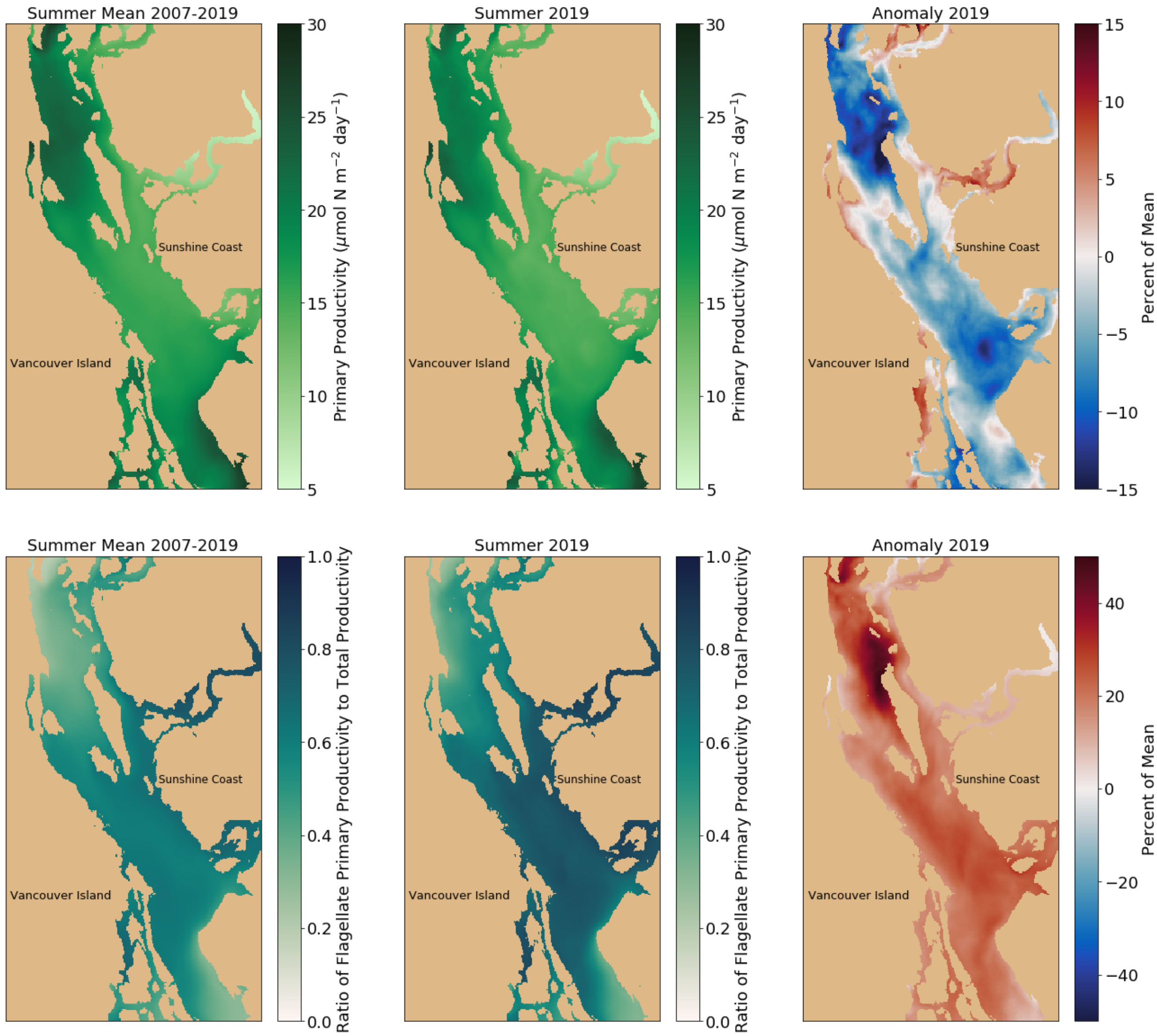

Figure 38-2: Summer productivity in the Strait of Georgia and its variation in 2019 compared to mean over 2007-2019. Values are averaged over June, July and August and integrated through the top 30-m of the water column. Only water depths greater than 35 m are shown. Top row: primary productivity in the model. Bottom row: ratio of flagellate primary productivity compared to total. Left column: mean over thirteen years. Middle column: 2019, Right column, anomalies from the mean for 2019 in percent.

38.4. Factors influencing trends

38.4.1. Spring Bloom

According to the SOG model, the 2019 spring bloom commenced in late February as winds were weak and there were fewer clouds than typical (Figure 38-3). The bloom was strongly interrupted by a large storm in early March. Thereafter the bloom was quick and peaked on March 18.

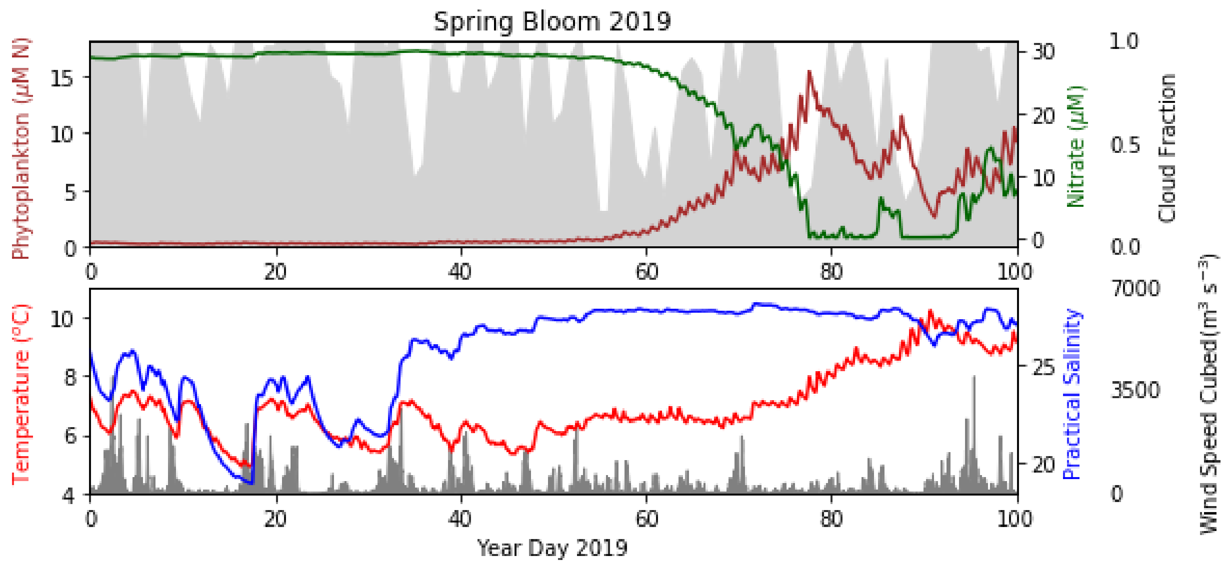

Figure 38-3: Hindcast of the 2019 spring bloom and related conditions in the Strait of Georgia. The lower panel shows temperature (in red) and salinity (in blue) averaged over the upper 3 m of the water column; in grey is the wind-speed cubed which is directly related to the strength of the mixing. The top panel shows phytoplankton biomass (in dark red) and nitrate (in green); in grey is the cloud fraction averaged over the day. The 2019 spring bloom was March 18 plus or minus 5 days. Plots span the period January 1, 2019 to April 11, 2019.

38.5. 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 2019 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 amount of primary productivity should help define bottom-up food availability for higher trophic levels. The SalishSeaCast model is still being evaluated but it appears that the gross food availability is fairly stable (± 10%) between years. The phytoplankton groups responsible for the summer primary productivity appear to vary more strongly.

38.6. References

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39. SEASONAL DYNAMICS OF THE PHYTOPLANKTON COMMUNITY IN THE SALISH SEA FROM HPLC MEASUREMENTS 2015-2019

Nina Nemcek, Melissa Hennekes, and Ian Perry, Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, nina.nemcek@dfo-mpo.gc.ca, melissa.hennekes@dfo-mpo.gc.ca, ian.perry@dfo-mpo.gc.ca

39.1. Highlights

- As in previous years, centric diatoms comprised the bulk of the phytoplankton community in April despite much lower Chl-*a* biomass during the 2019 survey.
- A large bloom of the dinoflagellate *Ceratium diveracatum* was observed in Juan de Fuca Strait in early October.
- On average, biomass was lower during spring, summer and fall surveys in 2019 compared to previous years, but this was at least partially due to survey timing missing the spring bloom.

39.2. Description of the time series

Monitoring the seasonal and interannual variability in phytoplankton biomass and community composition is important for understanding ecosystem function, particularly as it relates to food availability for higher trophic levels (zooplankton and fish). While chlorophyll a (Chl-a) biomass gives an indication of the amount of available food, elucidating the composition of the phytoplankton community is important for considerations of both food quality and food web structure. Fluorometric measurements of Chl-a have taken place on the Strait of Georgia (SoG) surveys since 1999 when the time series began; high performance liquid chromatography (HPLC) measurements for determining community composition were added in 2004 with a hiatus between 2012-2014. The time series in its present form was re-initiated in 2015 and presented herein.

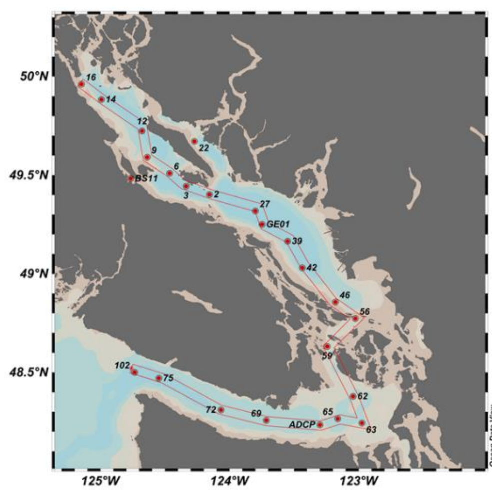

Figure 39-1. Map of sampling locations in the Salish Sea with the thalweg highlighted.

Cruises take place on the Canadian Coast Guard Ship (*CCGS) Vector* at least 3 times per year in April, June and Sept/Oct with water sampling occurring at stations along the thalweg (Figure 39-1). Since 2018 additional surveys on the *CCGS Neocaligus* and *CCGS John P Tully* have helped provide a more complete picture of the seasonal progression of the phytoplankton community. The biomass and composition of the phytoplankton community was determined from pigment concentrations measured by HPLC as described in Nemcek and Peña (2014). A factorization matrix program (CHEMTAX) was used to estimate the contribution of the various phytoplankton groups to total Chl-a (Mackey et al. 1996), and outputs were ground truthed by comparison to microscopic analysis of Lugol's preserved samples.

39.3. Status and trends

Phytoplankton community composition during the April surveys was similar in all 5 years across the survey region (Figure 39-2). The central SoG showed the most consistent phytoplankton community with more interannual variability observed in the north and in Juan de Fuca Strait. Centric diatoms (diatoms-1) were the main component of the spring bloom and comprised ~90-100% of the phytoplankton community in areas where biomass was highest (Figure 39-2) with *Thalassiosira spp*., *Chaetoceros spp*. and *Skeletonema costatum* being the most common species observed. In 2019, April biomass was much lower across the entire survey area due to stormy weather at the start of the survey that dispersed any phytoplankton blooms (Figure 39-2). Phytoplankton composition in the northern SoG resembled that observed in 2015 with a higher proportion of haptophytes than in the interim years.

Groups such as raphidophytes, dinoflagellates and cyanobacteria that were virtually absent in spring contributed more significantly to the community in June (Figure 39-2). Summer biomass was much lower across the survey region than in spring as expected, but particularly low in 2019 compared to the previous 4 years. In all years, the lowest summer biomass was consistently observed in the north and this was also the region with the most diverse phytoplankton community (Figure 39-2). Diatoms were virtually absent by June in the northern SoG and smaller flagellates took over. Community composition in the north in 2019 was very similar to 2015 and 2016 with almost no diatoms present and haptophytes comprising the majority of the phytoplankton community. This particular composition may represent a later stage in the succession from spring conditions than observed in 2017 and 2018 and may thus be a function of survey timing rather than interannual differences in phytoplankton composition. In the central SoG, summer diatom biomass was much lower in 2018 and 2019 compared to the previous 3 years which may be related to survey timing as above. Although the raphidophyte *Heterosigma akashiwo* was present in summer of 2019, large blooms like those that occurred in summer of 2018 were not observed.

In the fall, phytoplankton biomass is higher than in summer with smaller episodic blooms than those observed in the spring. Diversity is generally highest during this season across the region. In 2019, biomass in the SoG was the lowest of the past 5 years with prasinophytes dominating the phytoplankton community in both the central and northern Strait (Figure 39-2). The most striking feature of the 2019 surveys was the large bloom of dinoflagellates observed in Juan de Fuca Strait (Figure 39-2). Microscopic analysis revealed this to be a bloom of *Ceratium divericatum*. Although blooms of dinoflagellates have not been observed over the past 5 years of surveys and this group is typically a minor contributor to biomass in the SoG year round, late summer and fall blooms of dinoflagellates have previously been observed in Juan de Fuca Strait, particularly near the mouth in the vicinity of the Juan de Fuca eddy. This bloom appeared to be supporting an active food web as thousands of seabirds as well as Humpback Whales were observed feeding in the vicinity during this sampling.

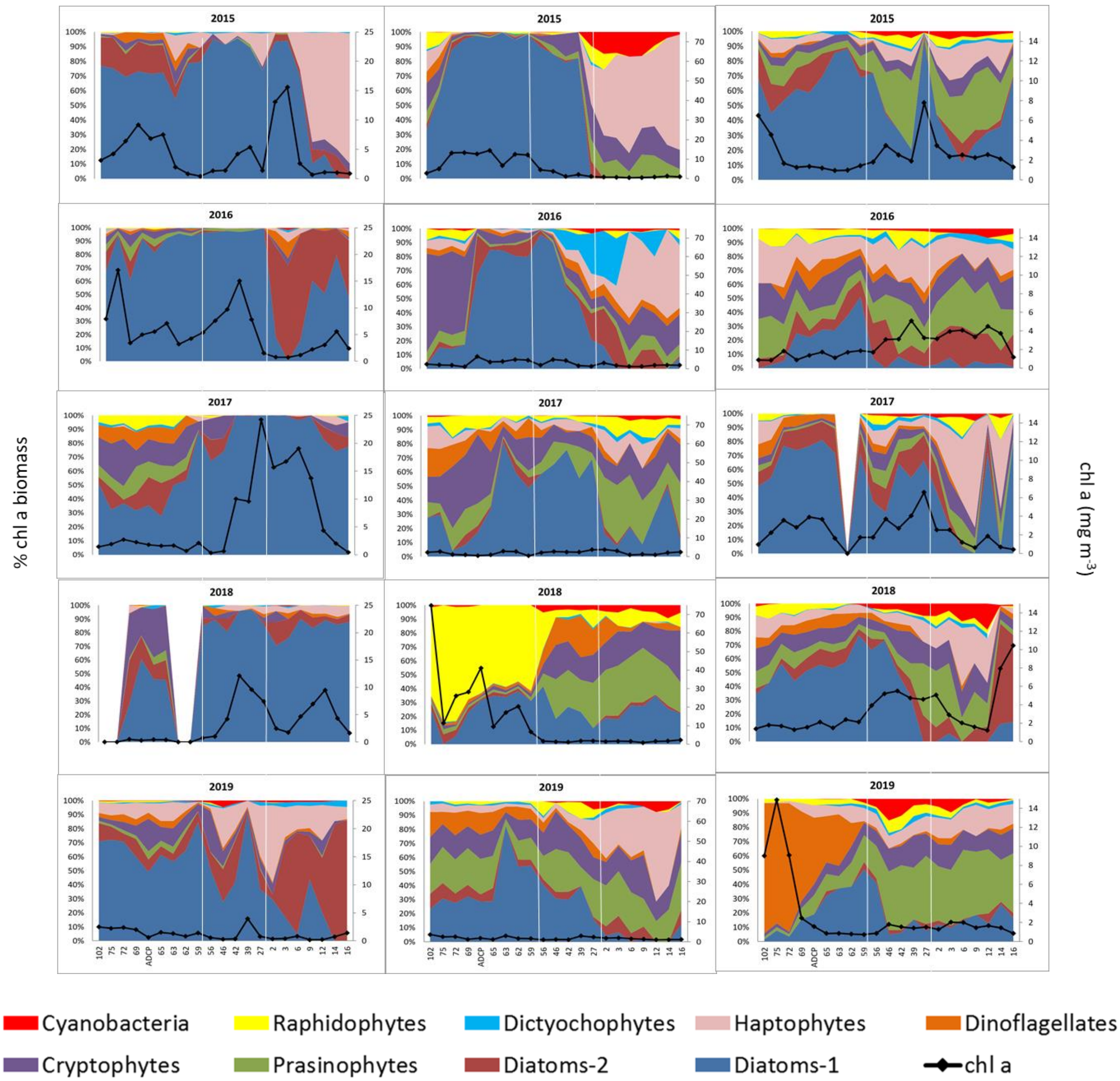

Figure 39-2. CHEMTAX outputs by station (see Figure 39-1) showing the relative contribution of each phytoplankton group to total Chl-a biomass (left axes) for each year and season; April, June and Sept/Oct in the left panel, center panel and right panel, respectively. Diatoms-1 represent centric diatoms whereas Diatoms-2 approximate pennate diatoms. Absolute Chl-a values (black lines) are plotted on the right axes. Note the different scales for each season. White lines designate the approximate boundaries (left to right) of Juan de Fuca Strait, and central and northern SoG.

The seasonal progression of the phytoplankton community at three stations representing central and northern SoG as well as Haro Strait is shown in Figure 39-3 (Juan de Fuca Strait was only sampled 3 times per year as in Figure 39-2). Chlorophyll a biomass was generally low during all 2019 surveys with only the late April/early May survey showing signs of a phytoplankton bloom in the central SoG (Figure 39-3a). Nitrate concentrations indicate that the spring bloom started

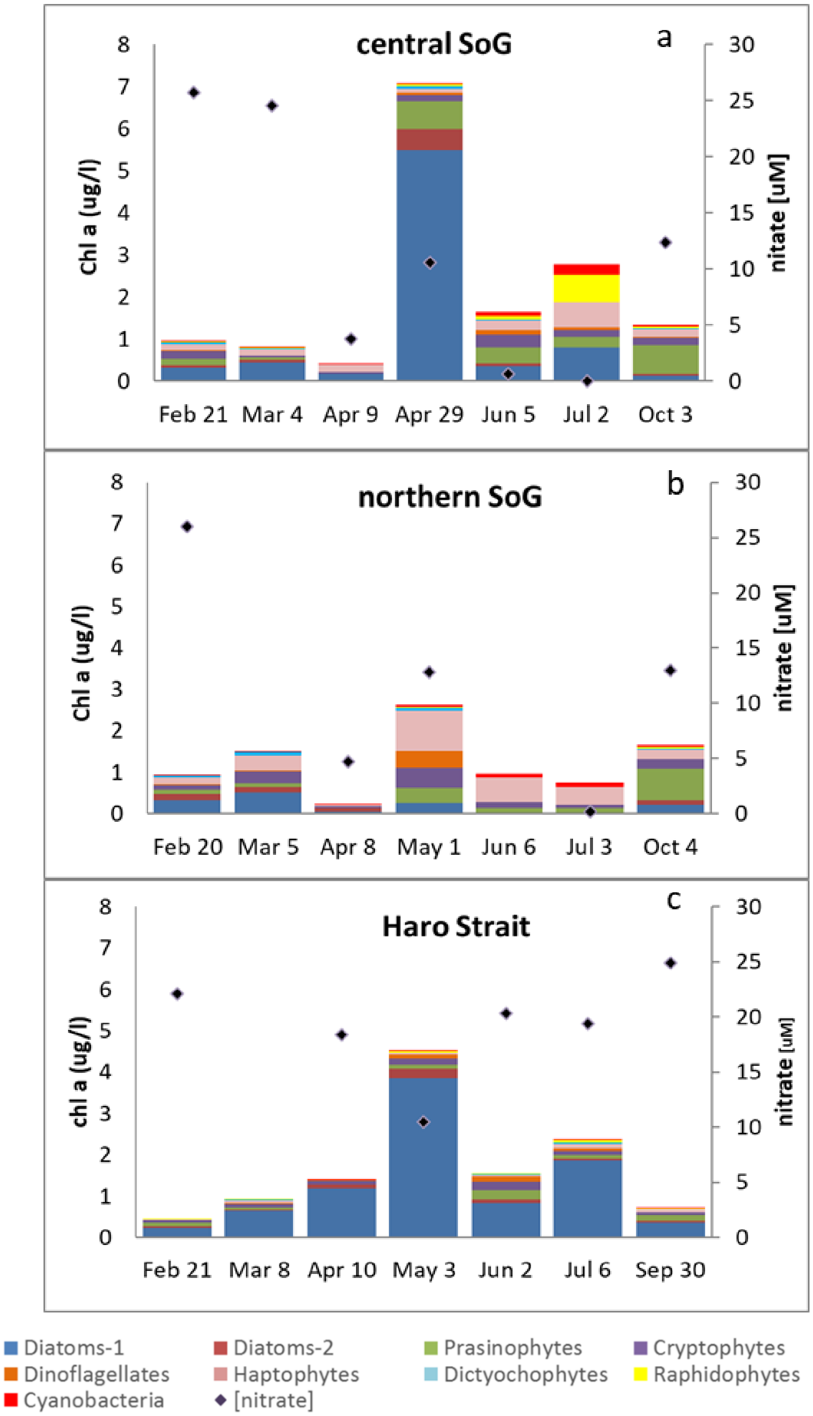

Figure 39-3: Seasonal changes in the phytoplankton community at 3 stations: a) GEO1, b) stn 12 and c) stn 59. Each phytoplankton group is shown as absolute biomass equivalents of Chl-a as determined by CHEMTAX (left axes) with corresponding nitrate concentrations (right axes). Note that nitrate concentrations were not measured on all dates.

sometime after March 4th in the central SoG as there is strong nitrate drawdown evident between this date and the following survey in early April (Figure 39-3a). It is likely that our March sampling missed the spring bloom in the central SoG by only a few days as satellite imagery (Gower, Section 12), underway chlorophyll a fluorescence from ferries (Dewey et al., Section 37), and model predictions (Allen et al., Section 38) indicate it began around March 6-8th. Underway pCO_2 data from a ferry transiting the SoG also showed intense pCO_2 drawdown indicative of rapidly growing phytoplankton throughout the month of March (Evans, Section 35), that relaxed significantly with the stormy weather in early April and remained elevated throughout most of April until bloom conditions resumed at the end of April (Figure 39-3a). All of these data sources indicate a strong, pronounced bloom in the central SoG throughout the month of March that was bracketed on either end by our ship-based sampling.

The evolution of the phytoplankton community in the central and northern SoG exhibited different patterns following the spring bloom. From February through to early April community structure and nutrient levels were similar in both areas (Figure 39-3a-b). However in late April/May the central SoG was characterized by a diatom dominated bloom whereas further north a shift to a mixed flagellate community largely comprised of haptophytes had already occurred despite very similar nitrate levels in both regions (Figure 39-3a-b). This is similar to observations from 2018 where the shift to a mixed flagellate community occurred about a month earlier in the northern SoG compared to the central region (Nemcek et al. 2019). By early October, community structure in both parts of the Strait was similar once again with a mixed flagellate composition dominated by prasinophytes (Figure 39-3a-b). Despite increased nitrate levels in fall from renewed mixing, the flagellate community did not shift back to diatoms in either part of the SoG. In contrast, in Haro Strait, tidal mixing kept nitrate levels high throughout the year and centric diatoms were the main component of the phytoplankton community year round (Figure 39-3c).

39.4. Factors influencing trends

A number of environmental factors control phytoplankton growth and community composition with the two most important being nutrient and light availability. In the winter, nutrient concentrations are high but deep mixing and low irradiance prevents phytoplankton from thriving. Once the water column stabilizes, the spring bloom can begin and nutrient drawdown follows. In the SoG we observed a shift in the phytoplankton community from mostly diatoms to mostly flagellates once surface nitrate was depleted (silicate concentrations were never limiting). Due to their larger surface area to volume ratios, the smaller flagellate cells have a competitive advantage compared to the much larger diatoms when nutrients are low. This shift happened earlier in the northern SoG compared to the central SoG.

39.5. Implications of those trends

Phytoplankton are the base of all marine food webs so their biomass and composition will determine both the quality and abundance of food available to higher trophic levels. Diatom based food chains are thought to be shorter with fewer trophic levels as energy is passed from phytoplankton to zooplankton to fish more efficiently, whereas flagellate based food webs rely on nutrient recycling and have more linkages and thus more losses as energy is passed to higher trophic levels. Furthermore, varying fatty acid profiles mean diatoms and flagellates have different nutritional values to their consumers. The Strait of Georgia, Haro Strait and Juan de Fuca Strait showed very different phytoplankton community compositions due to differences in the oceanography

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40. HARMFUL ALGAL BLOOMS IN THE SALISH SEA 2019

Svetlana Esenkulova, Nicole Frederickson, and Isobel Pearsall, Pacific Salmon Foundation (PSF), Vancouver, BC, svesen@uvic.ca, nicolehfrederickson@gmail.com, pearsalli@shaw.ca

40.1. Highlights

- Based on data collected as part of the PSF Citizen Science oceanography program, there were prominent harmful algae blooms (HABs) in the Strait of Georgia (SoG) in 2019, however they were not as widespread as in 2018; there were more HABs in 2019 than in 2015-2017.
- There were bright orange *Noctiluca scintillans* blooms in northeast inlets in late July 2019.
- There were strong but localized *Heterosigma akashiwo* blooms in August 2019.

40.2. Citizen Science Program

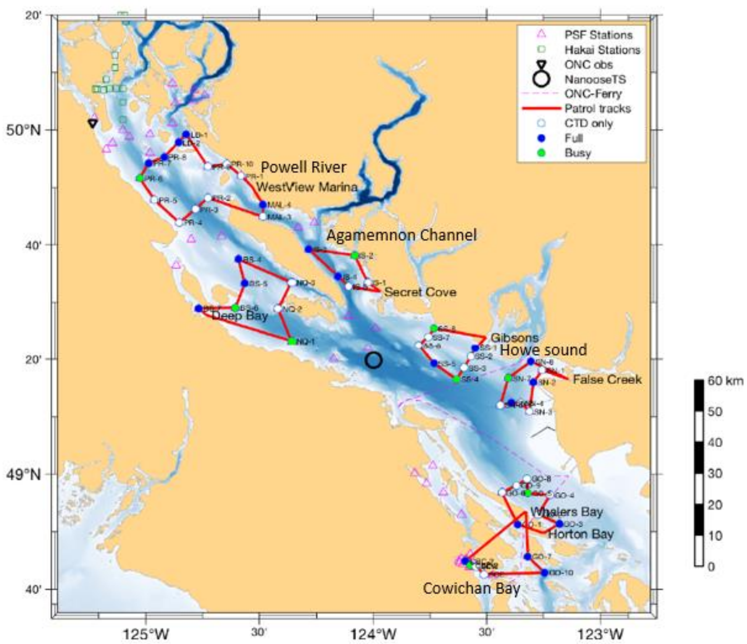

Figure 40-1. Map of the SoG with Citizen Science Program sampling locations 2019.

The Citizen Science Program was initially proposed by Dr. Eddy Carmack, DFO. He envisioned a 'mosquito fleet' of private boats collecting data for science everywhere in the SoG at once. The Program was funded for 2015-2020 through the Pacific Salmon Foundation. Trained members of the local communities collected information in the SoG 2 to 3 times a month between February and October. In 2019 the number of sampling stations was approximately ~55 sites (Figure 40-1), a slight decrease from ~70 sites sampled in 2015-2018. Conductivity-temperature-depth (CTD) profiles were collected at all stations (data available through the Strait of Georgia Data Centre http://sogdatacentre.ca), nutrient samples 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. The Citizen Science Program provided unique data for the entire Strait at a resolution that had not been possible before.

40.3. Description of the time series

Phytoplankton samples were collected 2 to 3 times a month between February and October; at the surface (0 m) at ~55 sites and at depths of 5, 10, and 20 m at ~10 sites. Phytoplankton samples were analyzed on a Sedgewick-Rafter slide; the identification of specimens is done to the lowest taxonomic level possible; 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 ~800 samples (~70% of the total number of samples collected in 2019).

40.4. Status and trends

After the annual spring bloom (comprised mostly of *Thalassiosira, Skeletonema,* and *Chaetoceros,* as in 2016-2018 but not 2015), several harmful algal blooms were noted. Blooms of the dinoflagellate *Noctiluca Scintillans* (Figures 40-2 - 40-4) were seen in inlets north of Vancouver in late July.

Figure 40-2. Noctiluca Scintillans under microscope. Photo by S. Esenkulova.

Figure 40-3. Aerial photo of the Noctiluca Scintillans bloom in the Howe Sound, July 25, 2019. Photo by M. Bahrey.

Figure 40-4. Photo of dense Noctiluca Scintillans bloom in Agamemnon Channel, July 26, 2019. Photo by T. Woodard.

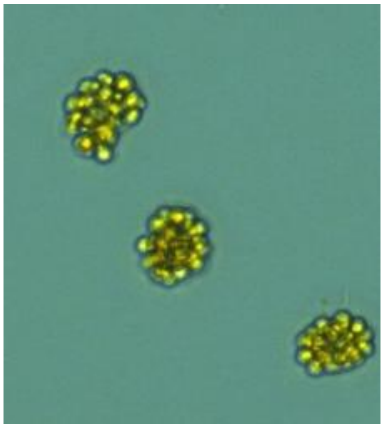

Figure 40-5. Cells of Heterosigma akashiwo. Photo by S. Esenkulova.

There were blooms of ichthyotoxic raphidophytes - *Heterosigma akashiwo* (Figure 40-5) with several cells (<100 cell mL^{-1}) occurring in early May-July samples in Cowichan Bay, Irvine’s/Sechelt, Powell River and Sunshine Coast areas. Very dense blooms with maximum concentrations reaching 25,000 cell mL^{-1} were seen in Cowichan Bay on August 20, 2019.

Figure 40-6. Photo of dense Ceratium spp. bloom at the Long Beach, September 21 and cells of Ceratium spp. from the same water sample. Photos by J. Pudota.

On the West coast of Vancouver Island (not Citizen Science data) there were strong blooms of dinoflagellate *Ceratium* spp. (J. Pudota, HAMP, personal communication; Figure 40-6) and *Alexandrium* spp. in the fall. Strong *Alexandrium* blooms led to PSP toxins concentration in shellfish up to 250 times higher than Canadian Food Inspection Agency limits and a partial paralysis of 15 people, who harvested shellfish from the closed by DFO beaches (Vancouver Sun, 2019).

Overall, our preliminary results indicate that SoG HABs dynamics in 2019 were somewhat closer to 2018 relative to 2015-2017.

40.5. Factors influencing trends

Phytoplankton dynamics are directly governed by primary environmental factors. High resolution 2015-2019 oceanographic data based on the Citizen Science Program is summarized by Dr. R. Pawlowicz (Pawlowicz et al. 2020). Multiyear database of harmful algae concentrations and environmental parameters enables an analysis of the links between HABs and environmental characteristics in the SoG.

40.6. Implications of those trends.

Noctiluca blooms can increase ammonia levels, cause hypoxia, and disrupt classic diatom-based energy transfer. Blooms of *Heterosigma* in the coastal waters of B.C. are the largest cause of direct farmed salmon losses (Haigh and Esenkulova 2014). HAB effects on marine life in the Salish Sea are unknown.

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41. HAS PRIMARY PRODUCTIVITY DECLINED IN THE SALISH SEA?

Sophia Johannessen[1], Robie W. Macdonald[1] and Jonathan E. Strivens[2]

[1]Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, sophia.johannessen@dfo-mpo.gc.ca, robie.macdonald@dfo-mpo.gc.ca
[2]Pacific Northwest National Laboratory, Seattle, WA, jonathan.strivens@pnnl.gov

41.1. Highlights

- Total primary productivity has neither increased nor decreased in the Strait of Georgia or Puget Sound over the last 100 years.
- The decline in populations of Coho and Chinook Salmon in the Salish Sea over the last 30 years cannot be attributed to a decline in primary productivity.

41.2. Description of the time series

Marine sediments maintain a continuous record of conditions in the overlying water. We analyzed 17 sediment cores collected in the Strait of Georgia from 2002 to 2018, together with four cores collected in Puget Sound in 2007 (Brandenberger et al. 2011). Organic carbon, total nitrogen and stables isotopes of organic carbon and nitrogen were measured in all the cores. From the isotopic data, we determined contributions of marine-derived and terrigenous organic matter over time following Johannessen et al. (2005).

The results of the sediment core analysis were combined with those of a previously-published regional nitrogen budget (Sutton et al. 2013).

41.3. Status and trends

There was no trend in the flux of marine-derived organic matter to the sediments of the Strait of Georgia or Puget Sound over the last 100 years. An apparent increase in the marine flux in recent years is due to remineralization of organic matter in the surface sediments.

In contrast, the flux of terrigenous organic matter has increased over the last century in the Strait of Georgia, while in Puget Sound, terrigenous flux peaked in the mid-twentieth century.

The independent estimate of primary productivity provided by the Sutton et al. (2013) nitrogen budget, compared with an estimate from 30 years earlier (Harrison et al. 1983) supports the conclusion that there has been no change in total primary productivity over that timeframe.

41.4. Factors influencing trends

We were able to distinguish between in situ remineralization of marine-derived organic matter and a true increase in the flux of terrigenous matter: the total increase in apparent organic flux toward the sediment surface depended on the time in the case of terrigenous flux, but was independent of time for the marine flux (Figure 41-1).

The increase in terrigenous flux has likely resulted from changes in land use in the Georgia Basin (forestry, agriculture, urbanization) over the last century (e.g. Tunnicliffe 2000).

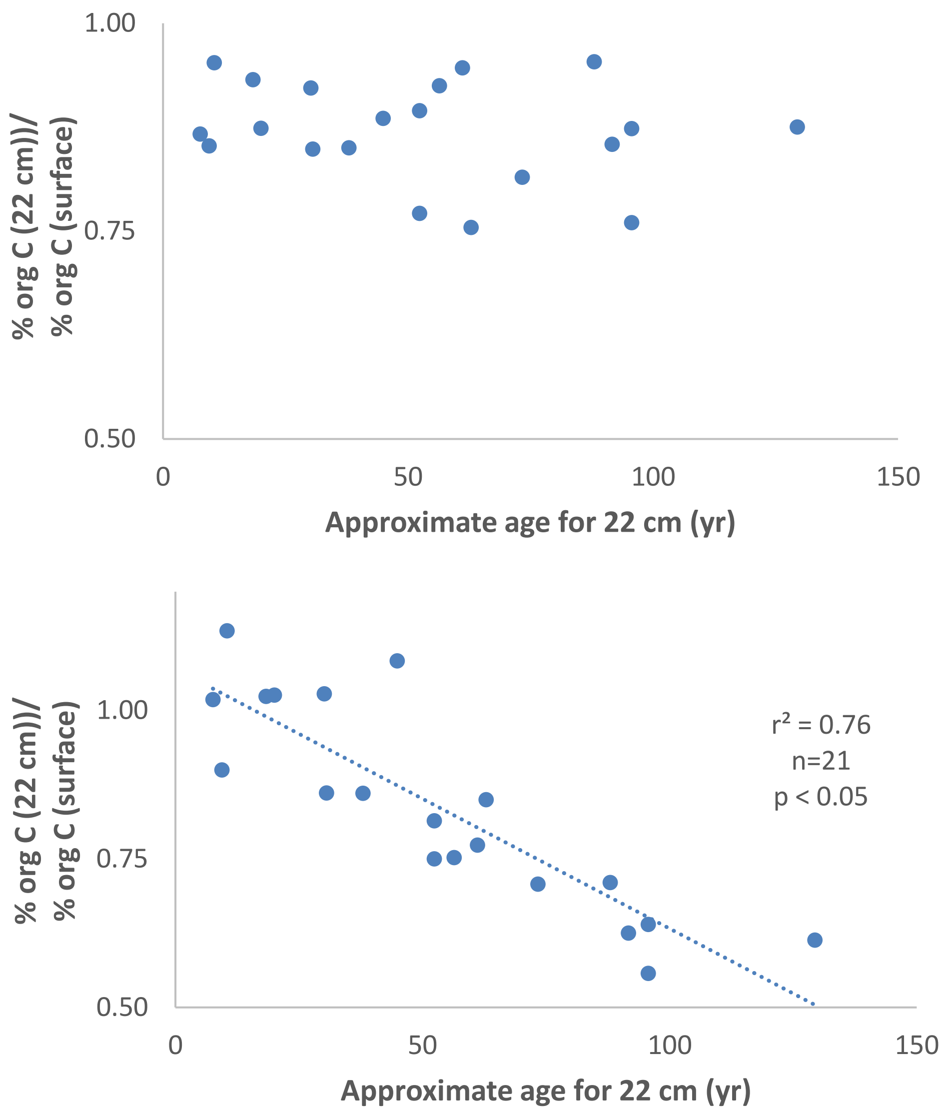

Figure 41-1. The ratio of organic flux at 22 cm depth (below the deepest mixed layer in the sample set) to that at the surface vs. the approximate number of years required to accumulate 22 cm of sediment in each core. The flux ratio for terrigenous organic matter depends on time (bottom panel), while that for marine-derived organic matter does not (top panel).

41.5. Implications of observed trends

A decline in productivity at the base of the food web has been proposed as an explanation for the observed decline in populations of Chinook and Coho Salmon (e.g. Preikshot et al. 2013).The sediment time series and the water column nutrient budget indicate that total primary productivity in the Salish Sea has not changed over the last 30 years or even over the last century. Consequently, the decline in salmon populations was not due to declining primary productivity.

This conclusion helps to narrow the range of explanations for the decline in salmon, which will help to support effective fisheries management in the future.

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42. ZOOPLANKTON STATUS AND TRENDS IN THE CENTRAL AND NORTHERN STRAIT OF GEORGIA, 2019

Kelly Young[1], Moira Galbraith[1] and Ian Perry[2]

[1]Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Kelly.Young@dfo-mpo.gc.ca, Moira.Galbraith@dfo-mpo.gc.ca
[2]Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC and Pacific Biological Station, Nanaimo, BC, Ian.Perry@dfo-mpo.gc.ca

42.1. Highlights

- In 2019, zooplankton biomass was highest in the summer (June-July), slightly later than previous years based on the monthly surveys conducted in 2016-2019.
- The magnitude of the biomass peak in 2019 was lower than last year, but a higher-than-average biomass persisted longer through the year.
- Overall zooplankton biomass has been trending up, with 2019 having a higher than average biomass (preliminary).

42.2. Description of the time series

Since the late 1960s, zooplankton sampling within the Strait of Georgia (SoG) has been sporadic, with little coordination among short term sampling programs. Sampling improved in the late 1990s; however, prior to 2014, zooplankton sampling did not follow consistent sampling protocols.

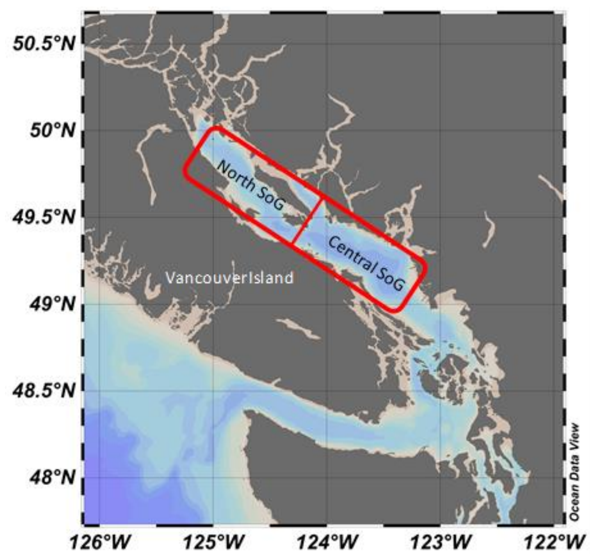

Figure 42-1. The central and northern Strait of Georgia (SoG) shown by the red boxes.

During 2015-2017, zooplankton samples were collected at approximately 20 standardized stations every 2-3 weeks from February to October as part of the Salish Sea Marine Survival of Salmon Program (supported in part by the Pacific Salmon Foundation). For 2018-2019, the time-series was continued with monthly sampling at these same stations. The three main objectives of the zooplankton sampling program were to investigate: the seasonal and inter-annual patterns of the zooplankton community; the possible causes of any changes; and 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 collected in 2019 in the deep (bottom depths greater than 80 m, and vertical net haul samples which covered over 70% of the water column, or which were >150 m day or night) central and northern Strait of Georgia (averaged together; Figure 42-1). 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-year (1996-2019) 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).

42.3. Status and trends

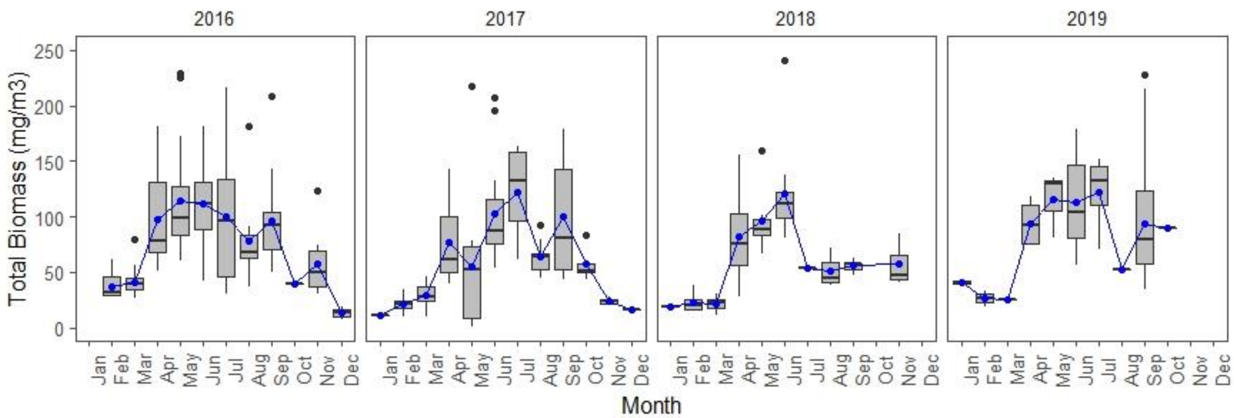

Figure 42-2. Average total biomass (mg m^{-3}) of zooplankton by month in the north and central (averaged together) Strait of Georgia for 2016-2019. Boxplots show median and spread of data, blue dot and line follows the mean biomass.

The total zooplankton biomass in 2019 ranged from 19.15 - 227.64 mg m^{-3}, with the lowest biomass occurring in the winter and peaking in the summer (June-July; Figure 42-2). The summer peak was later in season than in previous years (Figure 42-2). Overall, total biomass was above average in 2019 (Figure 42-3).

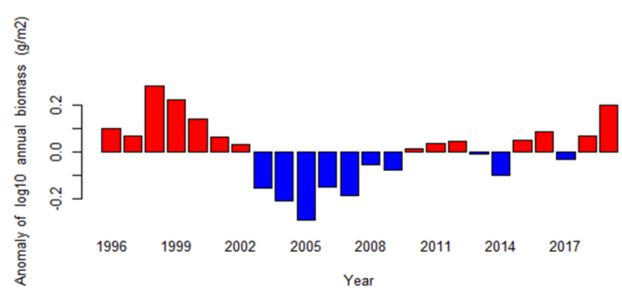

Figure 42-3. Annual biomass anomalies of total zooplankton biomass in the deep waters of the central and northern Strait of Georgia, 1996-2019.

Copepods, in particular calanoid copepods, dominated the zooplankton by abundance (Figure 42-4, left). Medium- and large-body calanoid copepods and the larger crustaceans (euphausiids and amphipods) dominated by biomass (Figure 42-4, right).

Within the copepods, small copepods (such as *Pseudocalanus* spp. and cyclopoid-type copepods) were very abundant, but they contributed little to the overall biomass (Figure 42-5). Of the larger copepods, the copepod *Eucalanus bungii* made up the majority of the large copepod biomass in the Strait during the spring (Figure 42-5) representing a change from the typical spring dominant large copepod *Neocalanus plumchrus* (Figure 42-6).

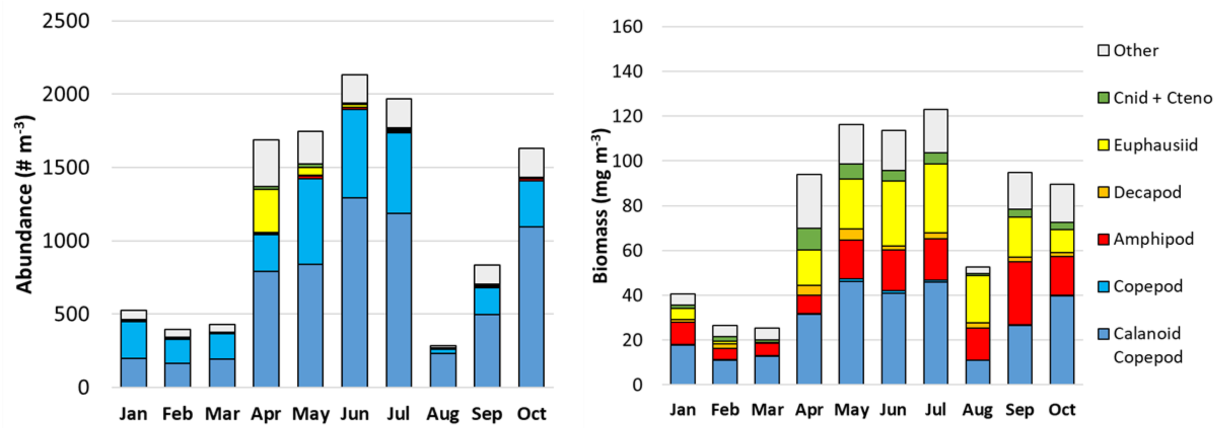

Figure 42-4. Taxonomic composition of zooplankton from northern and central Strait of Georgia in 2019, averaged by month. Left: abundance (m^{-3}); Right: biomass (mg m^{-3}). Legend: Calanoid copepod – all calanoid copepods; Copepod – all other copepods; Amphipods – all amphipods (hyperiid and gammarid); Decapod – all decapods (shrimp, crab larvae); Euphausiid – all euphausiids (eggs, larvae and adults); Cnid + Cteno – all Cnidarian (medusa and siphonophores) and Ctenophores; Other – everything else: Molluscs, Polychaetes, Chaetognaths, Ichthyoplankton, Larvaceans, etc.

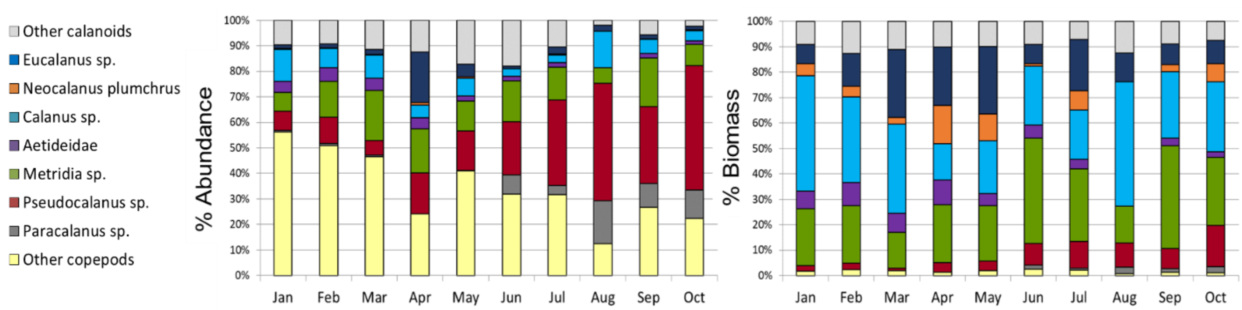

Figure 42-5. Relative abundance (left) and relative biomass (right) of all copepods collected from northern and central Strait of Georgia in 2019, averaged by month. Legend: Other copepods – all non-calanoid copepods; Paracalanus sp. – P. indicus and P. parvus; Pseudocalanus sp. – mix of P. minutus, 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.

The peak timing of the abundance and biomass of the zooplankton in the SoG varied by species (Figure 42-4). Within the crustacean groups considered as preferred food for juvenile salmon ('fish food'), euphausiid abundance peaked in spring, mostly due to large numbers of eggs and larval stages (Figure 42-4). In comparison to the June peak in 2018, euphausiid biomass peaked in July of 2019 and was almost half of the 2018 maximum of 56.8 mg m^{-3} (Young et al. 2019). Decapod (crab and shrimp) larval abundance and biomass for 2019 was similar to 2018; abundance peaked in the spring, but their biomass dropped through the spring/summer as they transitioned from planktonic larvae to benthic adults. In 2019, amphipod abundance and biomass increased in the summer, and peaked in September. For all three groups, the biomass remained high for a longer period of time than seen in 2018 (Figure 42-4, right).

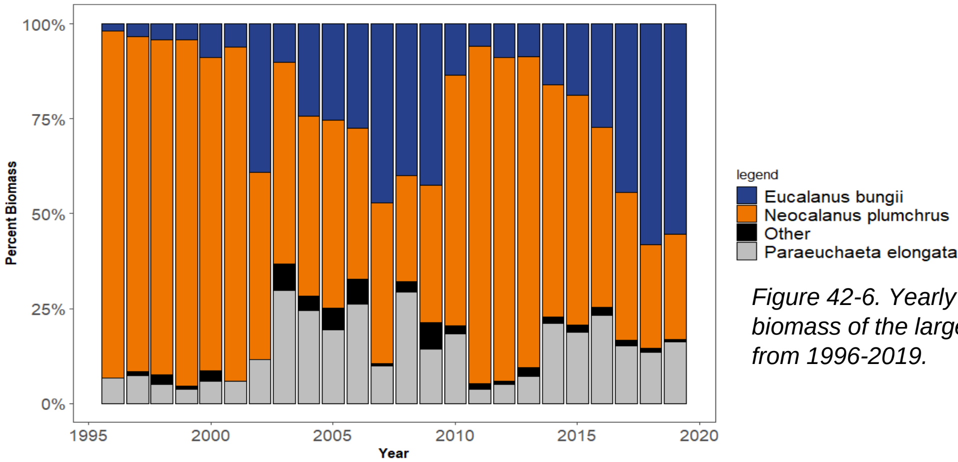

Figure 42-6. Yearly averaged percent biomass of the large calanoid copepods from 1996-2019.

For 2019 ichthyoplankton, Gadiformes, mainly Hake (*Merluccius productus*) abundance and biomass peaked in April. Osmerid, mainly Northern Smoothtongue (*Leuroglossus schmidti*), biomass increased slightly through the spring and peaked in the summer and was present in similar amounts compared to 2018 (Young et al. 2019). In 2019, Clupeiformes biomass increased in April, predominately Pacific Herring (*Clupea pallasii*) larvae, as well as in September, from Northern Anchovy (*Engraulis mordax*) larvae.

42.4. Factors influencing trends

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

42.5. Implications of those trends.

Large changes in the zooplankton were documented in the West Coast of Vancouver Island zooplankton in 2019 (Galbraith and Young, Section 16); however, those negative changes haven't been seen in the SoG zooplankton communities to date. 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). Responses in the SoG zooplankton have been shown to be up to 12 months delayed compared to the offshore (Mackas et al. 2013), so it is expected conditions in 2020 may start showing a transition to lower productivity with increasing temperature if conditions in the SoG become similar to conditions off the WCVI. There is the potential that conditions in the marine environment have shifted to a ‘new normal’ (such as temperature/salinity anomalies; see Ross and Robert, Section 7; Chandler, Section 36) and the associated community responses currently happening are out of phase with what was expected (e.g., see Perry et al., Section 50). 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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43. STRAIT OF GEORGIA JUVENILE HERRING SURVEY

Jennifer L. Boldt[1*], Matt Thompson[1], Hilari Dennis-Bohm[1], Matthew H. Grinnell[1], Jaclyn Cleary[1], Chris Rooper[1], Jake Schweigert[2], Doug Hay[2]

[1]Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, [*]Jennifer.Boldt@dfo-mpo.gc.ca
[2]Emeritus, Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC

43.1. Highlights

- In 2019, an index of the relative biomass of juvenile (age-0) herring was the same general magnitude as observed since 2013; it was higher than in 2018, but with higher variance.
- In 2019, age-0 herring lengths and weights were similar to those measured in 2018; their condition was slightly lower than measured in 2018 but still above average.
- In 2019, Northern Anchovy continued to be present in catches, but the proportion of sets with anchovy was lower than observed during 2016-2018.

43.2. Description of indices

The Strait of Georgia (SoG) juvenile (age-0) Pacific Herring survey is a monitoring program that samples the nearshore pelagic fish community, the zooplankton community, and physical water column properties (e.g. temperature, salinity, oxygen). A goal of the survey is to estimate an index of the relative biomass (abundance) of age-0 herring as a potential predictor of the abundance of age-3 herring recruits estimated in the annual stock assessment model. This index may also represent trends in potential prey availability to Coho and Chinook Salmon and other predators.

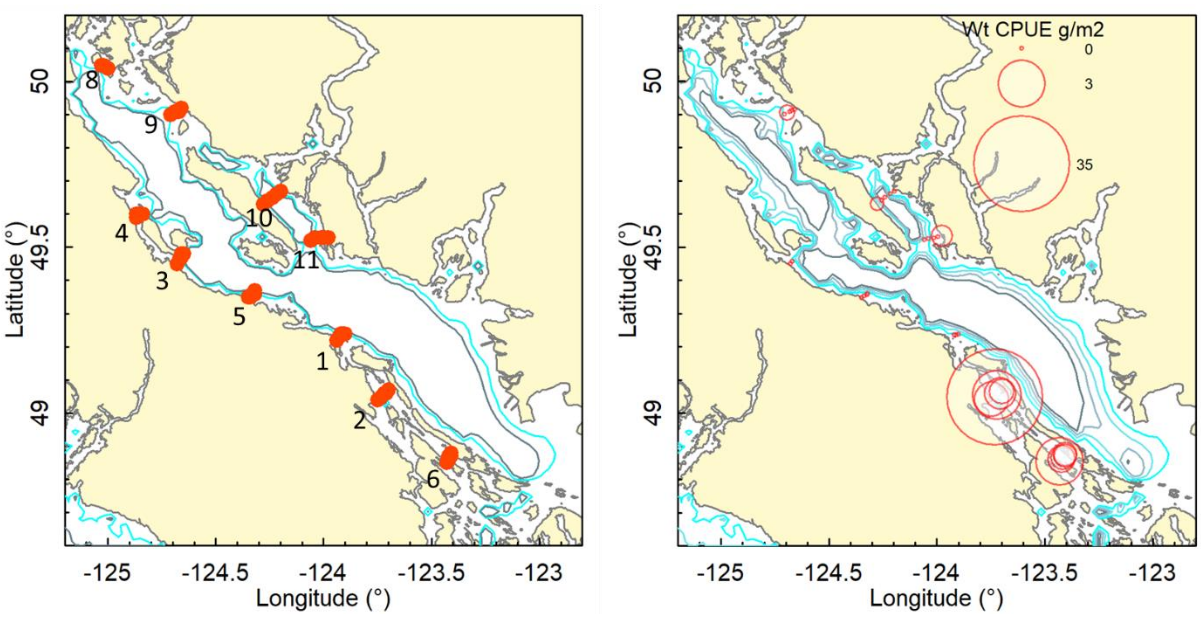

Figure 43-1. Core stations along the 10 core transects of the Strait of Georgia juvenile herring survey (left panel; there is no transect #7) and catch weight per unit effort of age-0 herring sampled in 2019 (right panel).

Ten core transects, each with three to five core stations (total 48 core stations), distributed around the perimeter of the SoG, have been sampled consistently during September-October since 1992 (except 1995; Thompson et al. 2013; see Thompson et al. 2003 and Boldt et al. 2015 for detailed survey design and methods; Figure 43-1). Sampling was conducted after dusk when herring were near the surface with purse seine sets at predetermined stations. Species' catch weights were estimated and, in the laboratory, fish were sorted to species, weighed, and measured (nearest mm). Herring were between 54 and 125 mm (standard length) long in all years sampled. The age-0 herring index of catch weight per-unit-effort (CPUE and associated variance) was calculated using Thompson's (1992) two-stage (transect, station) method and variance estimator (see Boldt et al. 2015). In addition, herring condition was calculated as residuals from a double-log-transformed length-weight regression (Boldt et al. 2019).

43.3. Status and trends

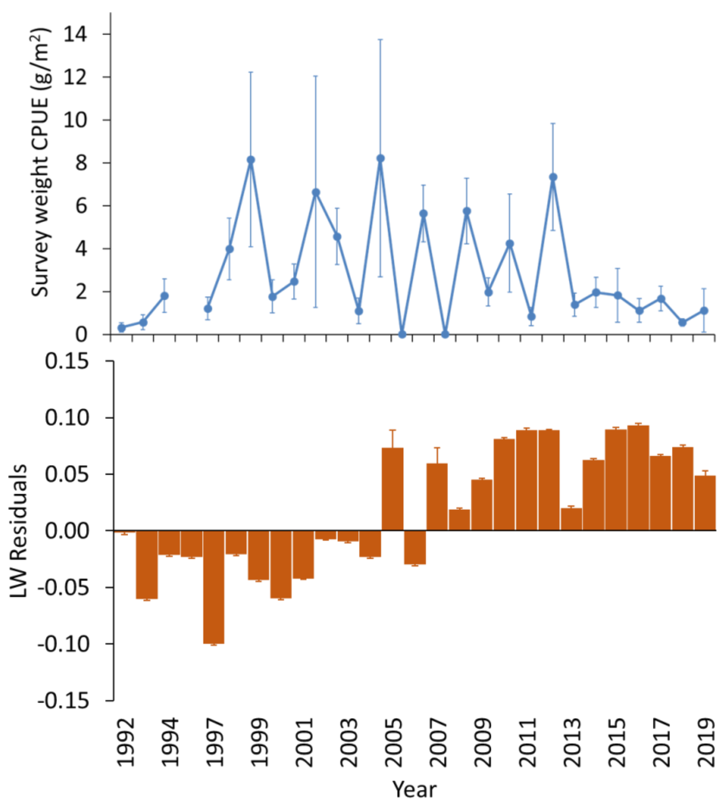

Figure 43-2. Mean catch weight per-unit-effort (CPUE; top panel) and mean condition (residuals from a double log-transformed length-weight regression; bottom panel) of age-0 Pacific Herring caught in the Strait of Georgia juvenile herring survey at core transects and stations during 1992-2019 (no survey in 1995; Boldt et al. 2015). Standard error bars are shown.

In 2019, 34 of the 48 core stations were sampled; several stations could not be sampled due to weather or gear issues. Transects #4 and #8 were not sampled; three of five and two of five core stations were sampled on transects #1 and #3, respectively. Age-0 herring were sampled in 13 of 24 stations, with one very large catch on Transect 2 (Figure 43-1). Estimates of age-0 catch weight CPUE (the index) varied annually, with no overall linear trend during 1992-2019 (Figure 43-2). The age-0 herring index tended to peak every two or three years, with the peaks occurring in even years during 2004-2012. During 2013-2019, the index was intermediate-low compared to the peaks in the time series.

In 2019, an index of the relative biomass of age-0 herring was of the same general magnitude observed since 2013; it was higher than in 2018, but with higher variance (likely because, in part, not all core stations could be sampled). High estimates of variability are associated with peak estimates; the survey coefficient of variation (CV) was 0.48.

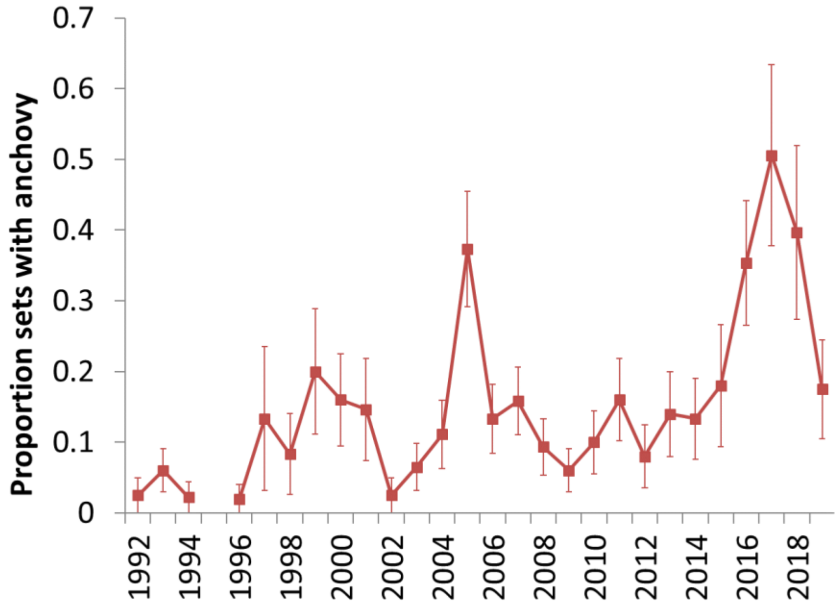

Figure 43-3. Proportion of purse seine sets that contained Northern Anchovy, 1992-2019 (no survey in 1995). Time series updated from Duguid, et al. (2018). Standard error bars are shown.

Age-0 herring length-weight residuals increased during 1997-2012, and were positive in 2005 and 2007-2019 (Figure 43-2). In 2019, Northern Anchovy were caught at 7 of 34 stations (Figure 43-3), which was a lower proportion of sets with anchovy than that observed during 2016-2018.

43.4. Factors causing trends

Bottom-up processes (prey-driven) are the main factors affecting the interannual variability in age-0 herring abundance and condition (Boldt et al. 2018). Bottom-up factors include zooplankton prey availability, herring spawn biomass, temperature, and the date when most herring spawn relative to the spring bloom date. The timing or match-mismatch between spawning herring and the subsequent availability of prey to juveniles appears to be important in determining abundance of age-0 herring in the fall (Schweigert et al. 2013; Boldt et al. 2018). No negative effects of the competitors or predators examined (i.e., juvenile salmon) were detected on age-0 herring abundance (Boldt et al. 2018), implying that when conditions are good for age-0 herring, they are also good for juvenile salmon species. There is some evidence that top-down (predator-driven; e.g., juvenile Coho and Chinook Salmon) processes may negatively affect age-0 herring condition (but not age-0 herring abundance; Boldt et al. 2018). Herring recruitment and survival has also been linked to water temperatures (Tester 1948; Ware 1991) and bottom-up control of production (Ware and Thompson 2005; Perry and Schweigert 2008; Schweigert et al. 2013).

43.5. Implications of trends

Analyses show that age-0 herring survey indices are correlated with the abundance of age-3 recruits (2.5 years later) as estimated by the age-structured stock assessment model (Hay et al. 2003; Schweigert et al. 2009; Boldt et al. 2018). This correlation is heavily reliant on two years with both low age-0 and low age-3 recruit abundances (e.g. 2005 and 2007). The age-0 herring survey may therefore provide a leading indicator of low recruitment years.

Pacific Herring are prey for piscivorous fish, marine mammals, and seabirds and are important commercial species in British Columbia’s coastal waters. Changes in herring abundance may affect availability to commercial fisheries as well as the survival of predators, such as Coho and Chinook Salmon. Age-0 herring in better condition may be more energy dense (Paul et al.

1998; Boldt and Rooper 2009). Fish that have a higher energy density have an improved chance at surviving reduced feeding opportunities during winter (Paul et al. 1998; Foy and Paul 1999) and they present a more energy-rich prey for predators. Understanding trends in the populations of small pelagic fish species and factors that affect their abundance and condition requires long-term monitoring of the nearshore pelagic ecosystem.

43.6. Acknowledgments

In memory of and with thanks to Doug Henderson for many years of hard work and good cheer as skipper and to Dr. Terrance J. Quinn II for his support with initial analyses.

The 2019 Strait of Georgia juvenile herring survey was funded by the Department of Fisheries and Oceans; some previous surveys were partially funded by the Herring Conservation and Research Society and the Pacific Salmon Foundation. Thank-you to skipper Phil Dupuis for helping with the survey this year.

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44. JUVENILE SALMON IN THE STRAIT OF GEORGIA 2019

Chrys Neville, Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, Chrys.Neville@dfo-mpo.gc.ca

44.1. Highlights

- In September, Coho Salmon continued to be in high abundance and were large in size, similar to the trend observed over the past few years.
- Chum Salmon numbers in September were the second highest in the time series and over 30X greater than the CPUE in September 2017.
- Northern Anchovy were observed in diets of all ages of Chinook and Coho Salmon. Additionally, Northern Anchovy caught in the survey were of mixed size classes.

44.2. Introduction

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 2019, juvenile salmon were sampled during two trawl surveys (June 18 – July 6 and September 10 – 28). Fishing was conducted using the commercial charter vessel FV *Sea Crest*, the same vessel as the previous two years. Surveys were conducted within the time frame required and trawl sets were completed on the standard track lines that have been fished since 1998, following the protocol in Beamish et al. (2000) and Sweeting et al. (2003). In addition, some sets were completed in Desolation Sound, Discovery Islands, Gulf Islands, and Juan de Fuca Strait.

44.3. Description of the time series

Catch-per-unit-effort (CPUE) for each survey is calculated using trawl sets conducted on the 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 < 300 mm in summer survey and < 350 mm in September survey. This 22-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.

44.4. Status and trends

In summer, Coho and Chinook Salmon CPUE was average or above average (Figure 44-1). In summer, Chinook Salmon CPUE was similar to values observed since 2010. Chum and Sockeye Salmon CPUE was low during the summer months although the size and condition of juveniles caught was good. The CPUE of Sockeye Salmon was similar to observations in 2007 which resulted in the poor 2009 return. In the fall, Chum Salmon CPUE was the second highest observed in the time series and Coho salmon CPUE continued a trend observed over the past 8 years. The size of both Chum and Coho was above average. In the fall, Chinook Salmon

CPUE was average and Sockeye Salmon CPUE was below average, similar to the low CPUEs over the past 5 years.

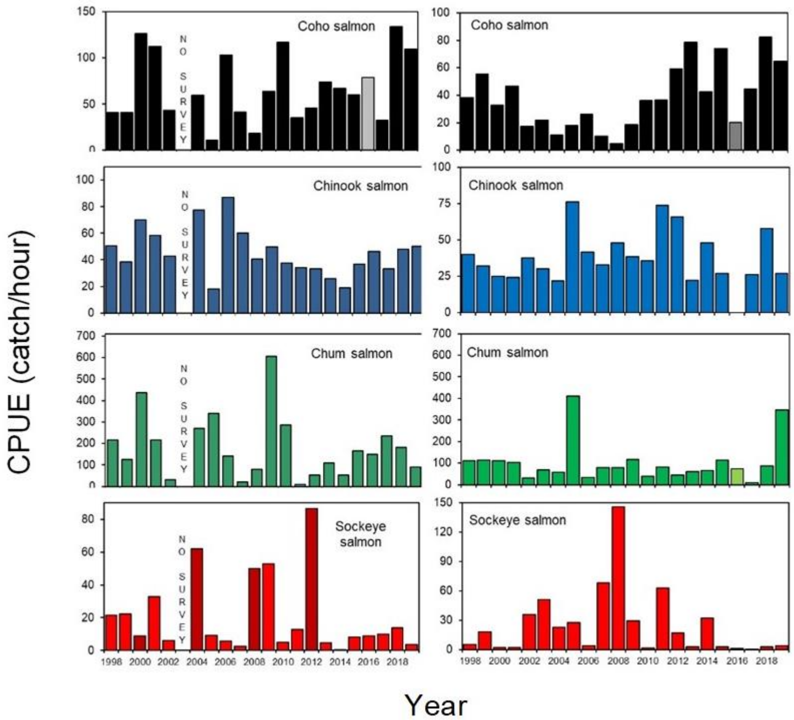

Figure 44-1. CPUE of salmon in early summer (left) and fall (right) from 1998-2019.

Northern Anchovy were caught in several areas of the SoG with the largest catches in the fall in mainland inlets (Desolation Sound, Jervis Inlet). During the summer months, Northern Anchovy catches were smaller but they were observed in a higher proportion of sets. The bimodal length frequency in catch and the presence of larval Northern Anchovy in the diets of Chinook and Coho Salmon suggest multiple age classes and successful spawning in the SoG during 2019.

44.5. Factors influencing trends

Several observations suggest good conditions for juvenile salmon rearing in the Strait of Georgia in 2019. The increase in size of juvenile salmon, especially Coho Salmon, suggests good early marine growth within the SoG. The low proportion of empty stomachs in Coho and Chinook salmon is also an indication that the prey in this region was good. The primary diet items of the juvenile salmon has not shifted but the change in size of the individuals suggests that more of their food is able to support growth over other physiological and survival needs.

44.6. 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. Beamish et al. (2010) have demonstrated that the abundance of juvenile Coho in September was related to total returns for the period prior to 2010. More recent research has indicated that, although this continues to be true, there are also shifts in productivity that change this relationship. The ability to understand the drivers of this change and identify them may provide an ability to identify shifts in productivity for species and stocks early in their marine residence.

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45. THE SAANICH INLET TRANSECT 2019: SLOW RECOVERY OF A COLD-WATER CORAL POPULATION INDICATES VULNERABILITY TO A MAJOR CLIMATE STRESSOR

Jackson W. F. Chu[1], Benjamin M. Grupe[2], Ryan Gasbarro[3], Janelle Curtis[4]

[1]Memorial University of Newfoundland, St. John's, NL, jwfchu@gmail.com
[2]University of Victoria, Victoria, BC, bengrupe@uvic.ca
[3]Temple University, Philadelphia, PA, USA, rgasbarro1@gmail.com
[4]Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, Janelle.curtis@dfo-mpo.gc.ca

45.1. Highlights

- In Saanich Inlet, biologically-relevant hypoxia exposure could not be calculated for the first time since ONC-VENUS monitoring began because of a 4-month data gap in the ONC-VENUS array, but appears synoptically similar to 2018.
- Density of commercial shrimp (e.g. Spot Prawn *Pandalus platyceros*) has recovered to the benchmark period.
- Sustained, low-level populations of new species (*Armina californica* and *Pentamera cf. pseudocalcigera*) remain in the community.
- Recruitment of Sea Whip (*Halipteris willemoesi*) is the first indication of their potential to recover after a severe hypoxia-induced population crash, although they are still <8% of the population that existed before the benchmark period (2006-2013).
- Recovery rate of the cold-water corals is substantially slower than the recovery of the habitat oxygen regime and the mobile species assemblage which have mostly returned to levels comparable to the benchmark period (2006-2013).

45.2. Description of the time series

Since 2006, remotely-operated vehicles (ROVs) with an onboard CTD and dissolved oxygen (DO) sensor package and high-definition video cameras have repeated the same benthic transect (n=16) in Patricia Bay, Saanich Inlet, B.C (Chu and Tunnicliffe 2015a; Gasbarro et al. 2019a). This near-annual survey (except for 2014-2015) is the longest-running time-series in Canada designed to monitor benthic biodiversity using standardized ROV methods. The transect begins in the deep basin and traverses from 180-40 m bottom depths while transitioning through zones of low-to-high oxygen over a gradual soft-bottom slope. This ecological 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 intervals since 2006. The ONC-VENUS instrument platform is approximately mid-way 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 2015a) and 2016 (Gasbarro et al. 2019a), Spring 2017, Fall 2018, and Spring 2019. Standard protocols (Chu and Tunnicliffe 2015a) were modified to use a CTD and DO sensor package (RBR Concerto3 CTD with a Rinko DO optode) was used with a Phantom ROV platform operated by DFO while maintaining the data integrity of the time-series.

Under the ecological context of this time-series, hypoxia has been empirically defined by the oxygen requirements of several key species present, which generally range from 0.3-1.1 ml L^{-1} (Chu and Tunnicliffe 2015a; Chu and Gale 2017). The study design allows for direct comparisons of hypoxia-induced shifts in epibenthic animal distributions over time. Of the documented species, we used 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.

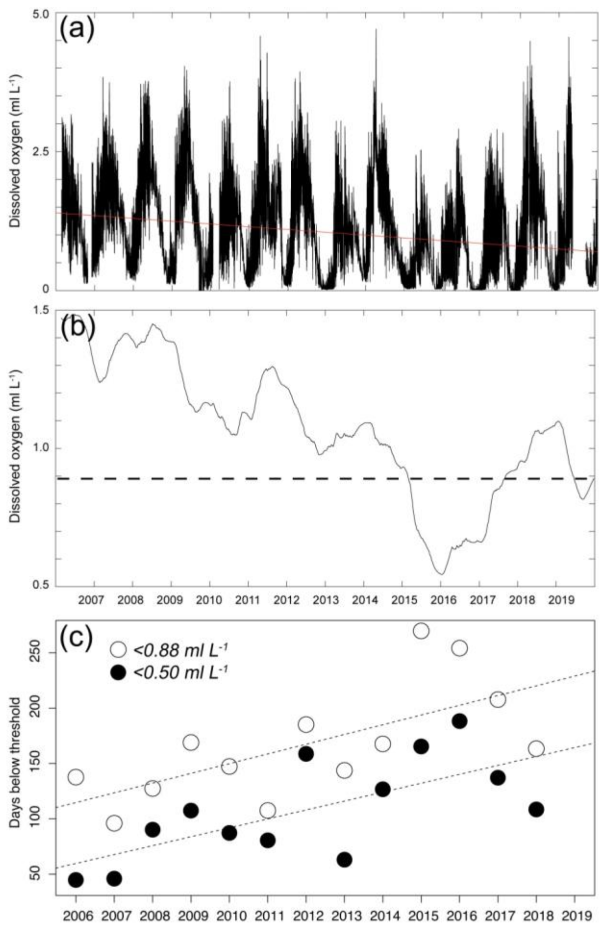

Figure 45-1. The 14-year continuous ONC-VENUS dissolved oxygen (DO) records measured per-minute at 96 m in Patricia Bay, Saanich Inlet. (a) Long-term DO decline (dashed line). (b) One-year running mean of panel-a. Dashed line is the 0.88 ml L^{-1} East Pacific hypoxia threshold. (c) The cumulative annual days below hypoxia thresholds for 2019 could not be calculated because of the four-month data gap in the ONC-VENUS records.

45.3. Status and trends

A four-month data gap (between May and September) in the 2019 ONC-VENUS records prevented the annual hypoxia exposure metrics from being calculated. Environmental oxygen trends can only be qualitatively reported and cautiously interpreted given this notable data gap. The annual, mean oxygen level declined annually since 2006. As of December 2019, the annual rate of decline remained at -0.05 ml L^{-1} $year^{-1}$ compared to 2018 (Figure 45-1a, data from Feb 2006-Dec 2019) (Figure 45-1b). The annual duration of hypoxia at this site has been increasing over time (Figure 45-1c). From 2006-2018, 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 $year^{-1}$. 2019 was the first year since 2006 where duration of hypoxic exposure could not be calculated. At the time of our survey on May 28, 2019, the habitat showed signs of recovering from the sustained oxygen depletion, with annual oxygen levels at ONC-VENUS having recovered just above the 0.88 ml L^{-1} severe hypoxia threshold. Oxygen measured at ONC-VENUS was still far from recovering to 2006-2013 baseline levels (1.0-1.5 ml L^{-1}). However, the 2019-Spring ROV-measured oxygen profile appeared more similar to Spring profiles from the 2006-2013 benchmark period, a recovery from the severe shoaling of hypoxic waters observed in 2016 (Figure 45-2).

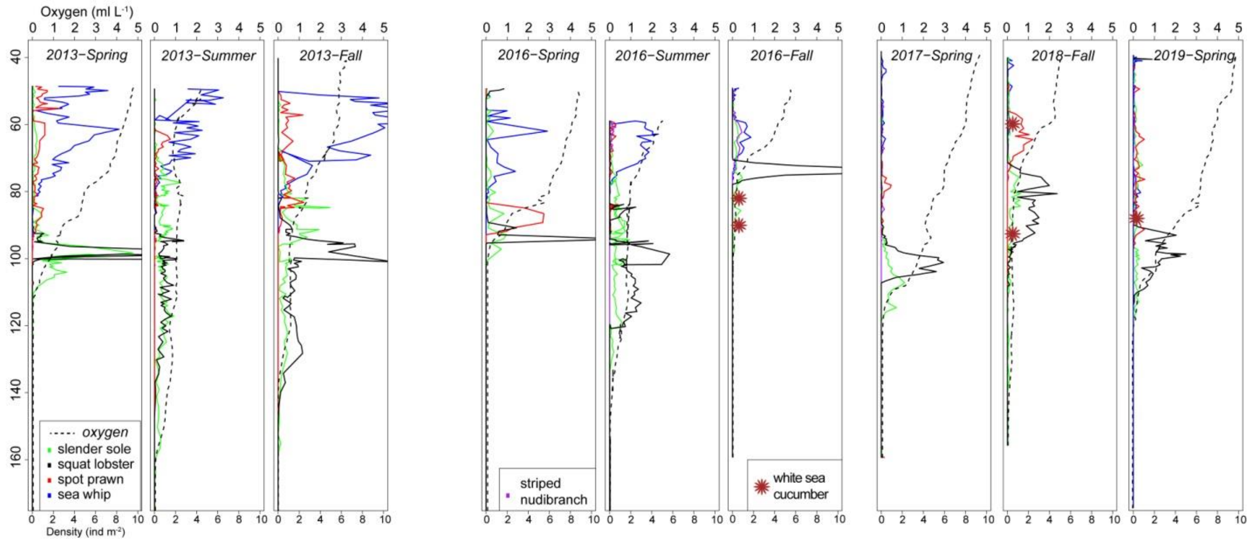

Figure 45-2. Surveys of key species depth-based densities in Patricia Bay, Saanich Inlet relative to DO gradient (dashed line) in 2013 (n=3), 2016 (n=3), 2017 (n=1), 2018 (n=1), 2019 (n=1). No surveys were conducted in 2014-2015.

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 2015-2017 (Gasbarro 2017; Chu et al. 2018; Gasbarro et al. 2019a). 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. 2019a), 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. 2019a).

In 2019, the epibenthic community continued to show successional stages of recovery. Hypoxia-tolerant species (Slender Sole and Squat Lobster) were distributed at typical depths and had normal abundances. Spot Prawn in 2019 had densities and depth distributions somewhat similar to 2013 (Figures 45-2 and 45-3). The species that first appeared in the system in 2016 remain present in low numbers as of Spring of 2019 (Figure 45-3). The observed number of Sea Whips (n=191) was triple the number observed in 2018, (n=66, Chu et al. 2019) as a consequence of many juveniles having recruited over the past year.

45.4. Implications of these trends

Following the sustained period of hypoxia from 2015-2017, seafloor oxygen levels in Saanich Inlet have continued to measure above the severe hypoxia threshold for over a year. Based on abundance, most populations of key mobile fauna appear to have recovered from this extreme climate event. Predictably, species that normally thrive in hypoxic waters (Slender Sole, Squat Lobsters) were negligibly impacted and recovered quickly followed by the mobile species with higher hypoxia sensitivity (e.g. pandalid shrimp), which recovered after about two years.

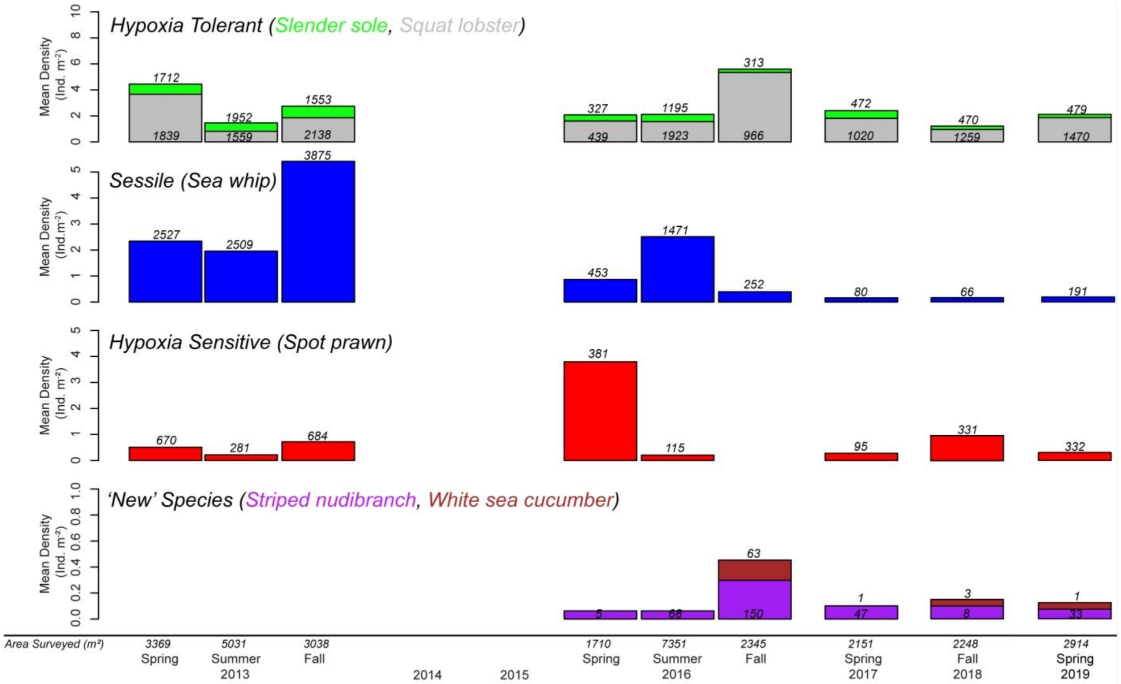

Figure 45-3. Average densities per survey for each key species presented. Total counts are indicated on each bar. Total area surveyed (m²) for each year is indicated on the x-axis. Differences in area surveyed among years is primarily attributable to truncation of the deeper portion of the transect and varying field performance among different ROV platforms. No surveys were performed in 2014-2015. 'New species' (striped Striped nudibranchNudibranch, white White sea Sea cucumberCucumber) 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. 2013 data are from Chu and Tunnicliffe (2015a). 2016 data are from Gasbarro et al. (2019b) Earlier surveys (2006-2012) are not presented but are published in Chu and Tunnicliffe (2015b).

Juvenile recruitment is the first sign of recovery of the Sea Whip population, which also indicates that sessile species assemblage recovery is the last successional stage after a community-shift induced by an extreme climate event. Although this shows there is the potential for a population of cold-water coral to recover after a substantial population-level die-off; the population is still <8% of the total observed during the benchmark period. The rate of population-level recovery of sea whip is notably lagging behind that of the mobile species assemblage which appears to have stabilized over the past two years. Assuming a general, linear net population growth of 100 sea whip yr^{-1}, it will take several decades for the Sea Whip population to return to benchmark abundance levels (n > 2000). Ecosystem functioning will likely take much longer to recover because growth rates are typically slow in cold-water corals (Neves et al. 2015). Whether the continued pressure of the Sea Whip predator in the system is slowing the population growth rate requires dedicated research to substantiate. 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 prior to baseline shifts induced by the extreme climate event.

45.5. Acknowledgements

Continuation of this time-series was made possible by the support of DFO who donated ship time, use of their Phantom ROV, and purchased sensors for the 2019 field season. We appreciate support from Tammy Norgard, Stephanie Kraft-Archer, Ben Snow, Jackie Detering, Henrik Kreiberg and others who made the 2019 survey possible.

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46. RECENT RANGE EXPANSIONS OF INVASIVE MARINE INVERTEBRATES IN THE PACIFIC REGION

Brett R. Howard and Thomas W. Therriault, Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, Brett.Howard@dfo-mpo.gc.ca, Thomas.Therriault@dfo-mpo.gc.ca

46.1. Highlights

- Marine Aquatic Invasive Species (AIS) continue to spread in B.C.
- Early detection of AIS can inform management and policy.
- Management of AIS should focus on anthropogenic pathways and vectors.

46.2. Description of indices - Monitoring aquatic invasive species in the Pacific Region

Marine Aquatic Invasive Species (AIS) are increasingly common throughout the Pacific Region. 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 46-1). These monitoring programs have improved our understanding of anthropogenic pathways, aided early detection efforts, and resulted in productive partnerships with First Nations and stakeholders.

46.2.1. Settlement Plate Program

Since 2014, the standardized method for monitoring fouling AIS in the Pacific Region has been weighted PVC tiles plates (14 cm^2) deployed from floating docks. The plates are scanned for 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 useful 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).

46.2.2. European Green Crab Trapping Program

Green crabs have been monitored in the Pacific Region 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 mean low water using baited Fukui fish traps.

The dataset generated by the trapping program has been useful for understanding the ongoing spread of Green Crabs 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.

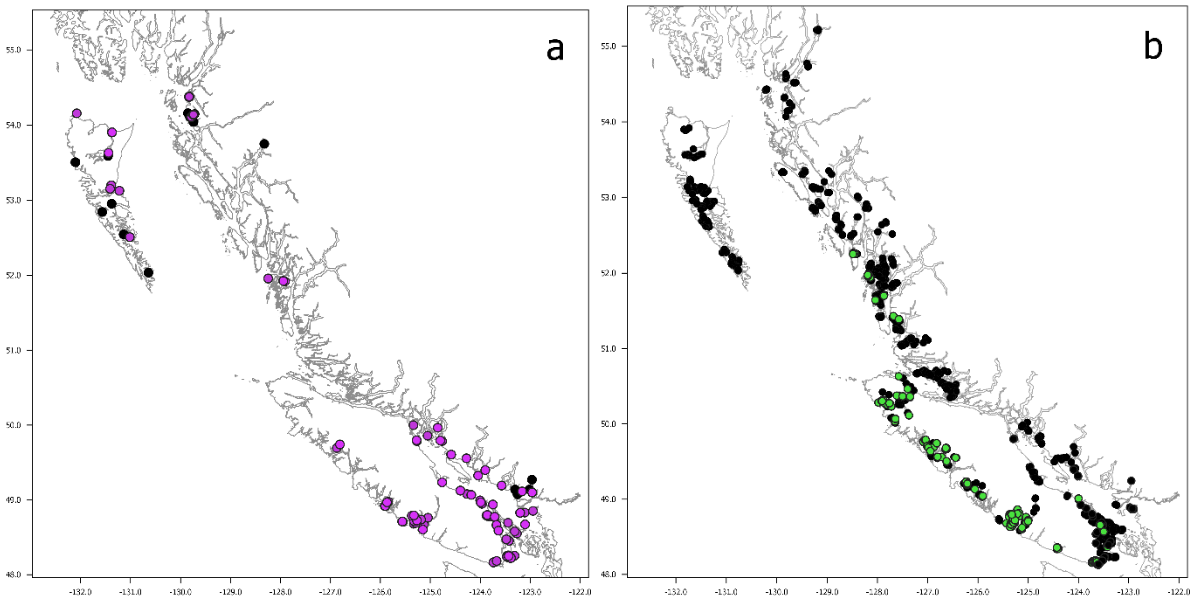

Figure 46-1. a) All settlement plate deployment sites between 2006 and 2019. To demonstrate the range of some species of interest, points indicate whether invasive botryllid tunicates (B. violaceus and B. schlosseri) have been detected (purple) or not detected (black). b) All locations trapped for European Green Crabs by DFO or partners between 2006 and 2019. Points show whether Green Crabs have been detected (green) or not detected (black).

46.3. 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 46-2). Of the focal fouling AIS monitored, four have been detected region-wide, including on Haida Gwaii: *Botrylloides violaceus* and *Botryllus schlosseri* (colonial tunicates), and *Schizoporella japonica* and *Cryptosula pallasiana* (encrusting bryozoans). However, spread at smaller scales is still being observed. The first detection of *B. violaceus* and *B. schlosseri* on the North Coast was in Lax Kw'alaams territory in 2018, and localized spread to Prince Rupert was observed in 2019.

Although the thermal and salinity tolerances of Green Crab suggest the species can occur throughout much of the region, the invasion has been largely restricted to the West Coast of Vancouver Island until recently (Figure 46-3). Range expansions are now being observed along the coastal mainland, including the detection of Green Crab larvae in Prince Rupert in 2019, and into the Salish Sea (Figure 46-1b). While the CPUE of Green Crabs in these new areas remain low currently, catches on Vancouver Island demonstrate the potential for this species to become hyper-abundant under favourable conditions (Figure 46-3).

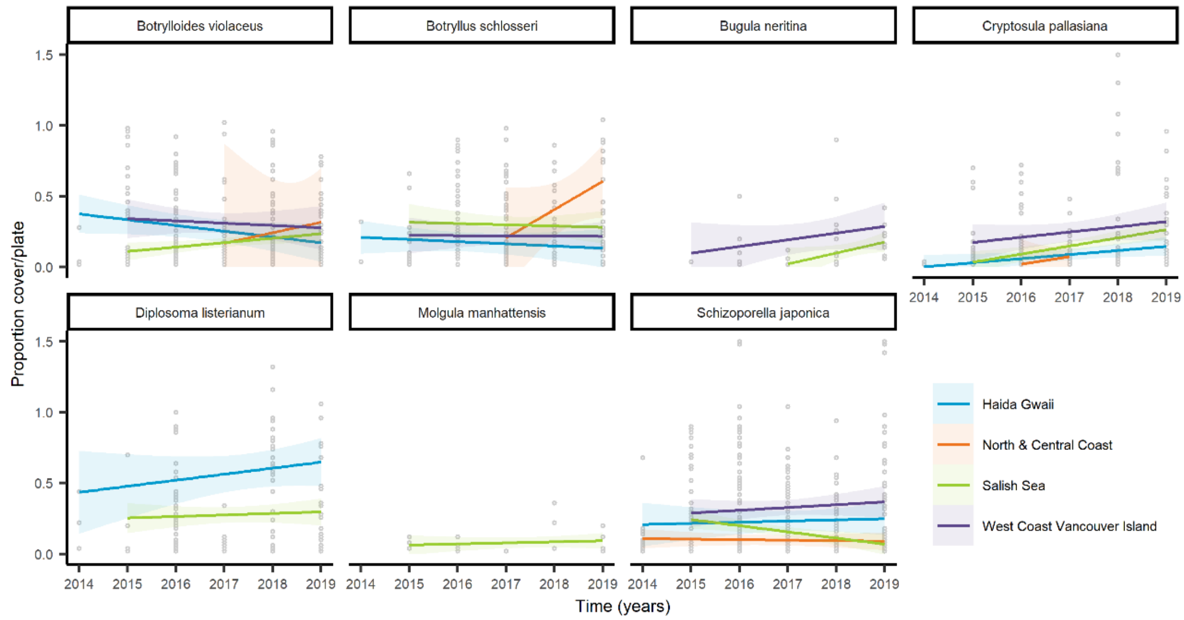

Figure 46-2. Change in abundance of some AIS found on settlement plates in each of four areas, presented as the smoothed conditional mean of the proportion of the plates covered (±95% CI), by each species, per area. Grey points are proportion AIS cover for individual plates (raw data). Proportions can be greater than 1.0 due to species growing in layers, such that more than one occurrence of AIS may be recorded per point.

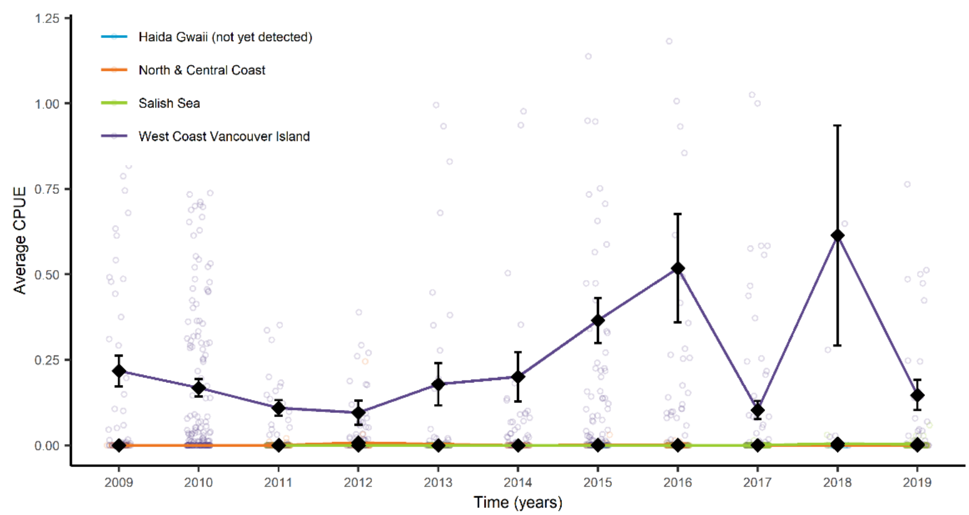

Figure 46-3. Annual average catch per unit effort (CPUE) for European Green Crabs (± SE) for all traps set in each of four areas of the coast. Coloured points indicate individual trapping events within each area. Note all raw data are plotted, but most CPUEs are too small for points to be visible.

46.4. Factors influencing spread and abundance of AIS

For the Pacific Region, climate change is likely to permit the survival of AIS currently restricted to more southern locations. This is of particular concern for Haida Gwaii (Howard et al. 2018). It is also likely that periods of significant warming, like the 2014/16 El Niño, will facilitate population spikes and long-range larval dispersal events for species such as Green Crab (Gillespie et al. 2007; Brasseale et al. 2019). The potential for spread of AIS via infested vessels, structures, and equipment will continue to be a primary vector for both existing (known) and novel AIS around the region, potentially increasing as isolated areas of the coast open up to vessel traffic over time.

46.5. 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. Education and outreach that target changing human behaviour, such as the Clean, Drain, Dry decontamination procedures, can reduce the likelihood of inadvertent movement of AIS. By focussing management on key transport vectors, there is a better chance of reducing spread of both established AIS and newly introduced or undetected fouling species whose impacts are not yet known.

European Green Crabs are known to have significant negative impacts on bivalve populations, especially clams, and on eelgrass habitat (Howard et al. 2019). The trend in increasing abundance and spread of this species into the Salish Sea 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. In compliance with this action plan, Fish and Fish Habitat Protection Program (FFHPP) maintains a dedicated early detection and eradication program for green crabs.

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47. AN UPDATE ON THE STATE OF LOCAL COASTAL OCEAN REPORTING: INTEGRATING INDIGENOUS KNOWLEDGE, WESTERN SCIENCE, AND CITIZEN SCIENCE

Aroha Miller, Jennifer Chapman and Amber Dearden, Ocean Watch, Ocean Wise Research Institute, Vancouver, BC, aroha.miller@ocean.org

47.1. Highlights

- Local coastal ocean reporting integrates science-based evidence, community knowledge, and Indigenous knowledge, which drives unified conservation actions.
- Key issues impeding coastal ocean health were identified; an action plan was created to address these issues.
- The community formed a task force to advance recommended actions.
- Communities are integral to creating meaningful conservation tools and bridging the science – action gap.

47.2. Community-driven Conservation

Ocean Watch, a part of Ocean Wise Conservation Association, produces reports on the state of coastal ocean health. Two reports have been released to date – the Ocean Watch: Howe Sound Edition (OWHS 2017), and the Ocean Watch: BC Coast Edition (OWBC 2018). Both reports use a non-technical, storytelling style of communication with simplified graphics, which has been very popular. Community-driven conservation successes have been achieved since these reports were released.

Here, we focus on the OWHS 2017 report because it is a narrow geographic location with high community interest and participation; a number of successful conservation actions have been taken; and the update to this first report is due for release in summer 2020.

Figure 47-1. Átl'ḵa7tsem/Txwnéwu7ts/Howe Sound, with red dots representing major communities. Inset: Location in relation to Vancouver, B.C.

Located north of Vancouver, Átl'ḵa7tsem/Txwnéwu7ts/Howe Sound is an inlet of the Salish Sea, carved by glacial ice into the surrounding mountains to form a fjord (Figure 47-1). It is the traditional, unceded territory of the Sḵwx̱wú7mesh Úxwumixw/Squamish Nation.

OWHS 2017 presented 32 ocean health topics (e.g., rockfish, outdoor learning, ocean warming) arranged into seven themes (Figure 47-2). Each article provided current available knowledge using a combination of Western science, citizen science and community knowledge, and Traditional Indigenous knowledge. Where applicable, the connection to First Nations was included. We provided a list of recommended actions that individuals, organizations, and governments (all levels) could take to improve the health of the local marine environment.

A health rating was assigned to each article, where applicable, based on the availability and trend indicated by data presented, and how high risk or vulnerable an issue or topic was. Key issues impeding improvement towards a "healthy" rating were identified, many of which had cross-cutting themes (e.g., limited monitoring and baseline data; loss of habitat and contamination due to industrialization; governance by more than ten different local government bodies). From the identification of key issues and the recommended actions in the articles, an action plan was created to guide communities in the Sound on how they could improve the overall health of their local coastal environment.

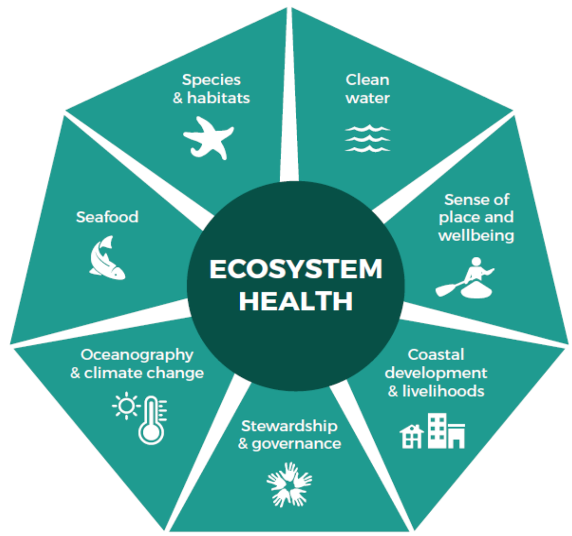

Figure 47-2. The seven themes into which all articles were grouped within the Ocean Watch: Howe Sound Edition (2017).

The release of OWHS 2017 provided new impetus to the many communities throughout Átl'ḵa7tsem/Txwnéwu7ts/Howe Sound, who were already working together to create a comprehensive plan to direct stewardship and sustainable growth. To implement the action plan from OWHS 2017, the Ocean Watch Task Force (OWTF) was formed – a sub-committee of the already existing Howe Sound Community Forum. The OWTF comprised members of local governments, First Nations, government representatives, planning staff, and NGOs. A key outcome was the creation of a strategic plan (OWHS 2019) to guide local governments in taking steps towards achieving healthy coastal environments in a coordinated, collaborative manner.

Several other important conservation tools were developed or are still in progress, for example:

- the Ocean Watch Rating Legend Assessment (OWHS 2017);
- the creation of the Atl'ḵa7tsem/Howe Sound Marine Conservation Assessment online map (Beaty et al. 2018);
- the Provincial Cumulative Effects Assessment (B.C. Govt 2019);
- the development of an Atl'ḵa7tsem/Howe Sound Marine Reference Guide (MRG 2019).

These are all important tools based on data collected from Western and/or citizen science, local knowledge and stories, with Sḵwx̱wú7mesh Úxwumixw/Squamish Nation knowledge. In addition, work continues towards the designation of Átl'ḵa7tsem/Txwnéwu7ts/Howe Sound as a United Nations Educational, Scientific, and Cultural Organization (UNESCO) biosphere region (HSBRI 2019).

OWHS 2017 provided an integrated source of different types of knowledge to the many communities throughout the Sound. Effective bridging of the science-action gap based on OWHS 2017 created demand for an updated report. The update is almost complete and due for release in summer 2020. The update has a strong focus on climate change impacts on the marine environment. We anticipate that it will continue to unify and motivate the communities in Atl'ḵa7tsem/Howe Sound to work towards successful conservation outcomes, especially in the face of uncertainty from climate change.

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Individual reports on the special session

48. THE MARINE HEATWAVES OF 2018 AND 2019

Charles Hannah, Peter Chandler, Stephen Page, Fisheries and Oceans Canada, Sidney, BC, Charles.Hannah@dfo-mpo.gc.ca, peter.chandfler@dfo-mpo.gc.ca , stephen.page@dfo-mpo.gc.ca

48.1. Highlights

- 2018 and 2019 were generally warmer than normal in the Northeast Pacific.
- In the fall of 2018 and again in 2019 there were marine heatwaves which were comparable to the Blob (2013-2016) in size and magnitude but not in duration.
- The sea surface temperature (SST) on the north coast of B.C. was generally warmer than normal from the summer of 2018 through the late fall of 2019. However the extreme marine heatwave (MHW) in northern Hecate Strat was likely an artifact of a misbehaving temperature sensor.
- Southern Vancouver Island (La Perouse weather buoy) was in a MHW state during the summer of 2019 (50 days at Category 1 and above) but not in the fall.

48.2. Description of the time series

The definition of a MHW (Hobday et al. 2016, 2018) is that it occurred 'if it lasts for 5 or more days, with temperatures warmer than the 90th percentile based on a 30 year historical period' (Hobday et al. 2016). Categories of MHW are defined based on the difference between the 90th percentile and the mean, where both resolve the annual cycle. A category 1 MHW has SST in excess of the 90th percentile for 5 consecutive days. Defining the difference between the 90% percentile and the mean as "the increment", a category 2 MHW is in excess of the 90th percentile plus 1 increment for 5 consecutive days, a category 3 MHW is in excess of the 90th percentile plus 2 increments, and so on.

The marine heatwave index is truly an extreme statistic. Given 30 years of daily data, only 3 days can exceed the 90th percentile and a MHW requires at least 5 of those days in a row. As such one should expect the calculations to be sensitive to the details of how the observations were made and how they were processed.

Numerous SST time series were used in this analysis

- SST and MHW statistics obtained from the Marine Heatwaves International Working Group at marineheatwaves.org. The data source is the NOAA 1/4° daily Optimum Interpolation Sea Surface Temperature (OISST) which is constructed by combining observations from satellites, ships, and buoys. The Climatology period is 1982-2011. An important point for this report is the OISST product is not independent of the weather buoy data.
- Weekly SST anomaly maps (global) were obtained from the National Centre for Environmental Prediction website http://www.emc.ncep.noaa.gov/research/cmb/sst_analysis/ under the weekly anomaly archive.
- The British Columbia weather buoy network of Axis 3 m buoys maintained by Environment and Climate Change Canada (Figure 48-1) measure SST about 80 cm

below the sea surface. The data are available from DFO at http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/waves-vagues/data-donnees/index-eng.asp. For this report we computed MHW Statistics for the Central Dixon Entrance (C46145), North Hecate (C46183), South Hecate (46185) and La Perouse Bank buoys (46206). For La Perouse the record starts in November 1988 so there is 30 years of data. The other records are a bit shorter (typically starting in 1991) we used the entire record to define the annual cycle and the 90th percentile at each location. The locations of the buoys are shown in Figure 9-2 of Hannah et al. (2019).

- The British Columbia Shore Station Oceanographic Program measures SST daily at many B.C. lighthouses. We used the data from Bonilla lighthouse which started in 1960, https://dfo-mpo.gc.ca/science/data-donnees/lightstations-phares/index-eng.html
- Monthly average maps of the 500 mb height anomalies are available from the International Research Institute for Climate and Society, Columbia University http://iridl.ldeo.columbia.edu/maproom/Global/Atm_Circulation/Monthly_Height_500hPa.html
- Monthly average satellite SST at 4 km resolution were provided by Dr. Emmanuel Devred at the Bedford Institute of Oceanography (BIO/DFO).

48.3. Status and trends

The wide range of time series examined all showed that both 2018 and 2019 were generally warmer than normal but not at all places at all times. There were also major MHWs in the northeast Pacific waters of 2018 and 2019 (Livingston 2018; NOAA 2019). On the shelf, what appeared to be a major MHW in northern Hecate Strait from the summer of 2018 through the fall of 2019 was in fact an artifact of a problematic thermometer on the north Hecate Weather buoy. This data then influenced the data used by the Marine Heatwave Tracker site. We think that the time series from Bonilla lighthouse (Figure 48-1) captures the conditions in northern Hecate Strait during this period – persistently warm but not a sustained MHW.

For southern Vancouver Island the temperature time series from Amphitrite lighthouse (Figure 48-2) shows that conditions were generally above normal in 2018 and 2019. There were sustained MHW conditions in the summer of 2019 and cool conditions in the fall of 2019. The results in the fall of 2019 seem to contradict the NOAA (2019) announcement of the major MHW, but careful consideration of the satellite SST imagery suggests that southern Vancouver Island was not warmer than normal. Note that the La Perouse weather buoy time series has large gaps in both 2018 and 2019 and could not be used in the analysis.

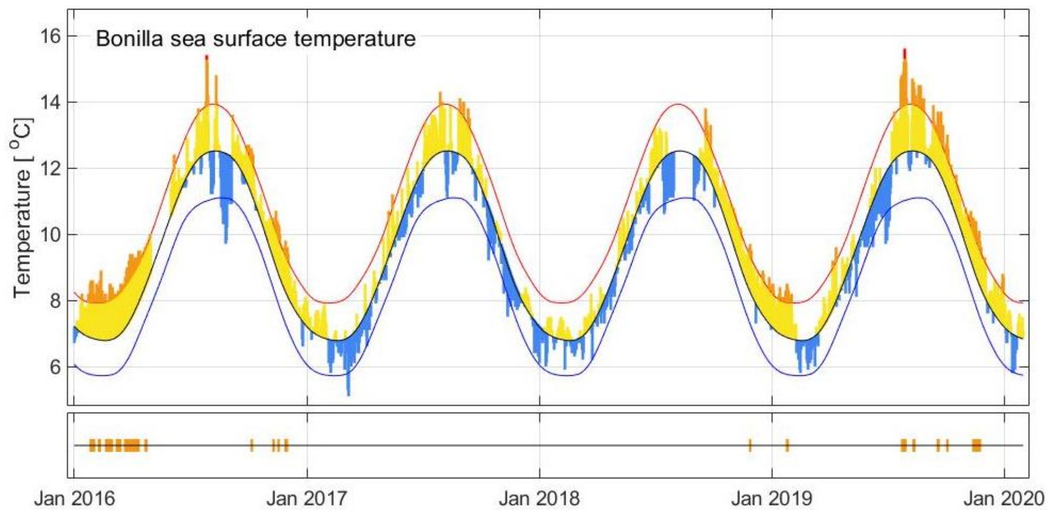

Figure 48-1. SST time series from Bonilla lighthouse for 2016 through the beginning of 2020. The climatological seasonal cycle (black), the 90th percentile (red), and 10th percentile (purple) are shown based on 30 years of data starting in 1990. Temperatures above normal and shown in yellow and below normal in blue. MHW events are shown in orange (Cat 1) and red (Cat2).

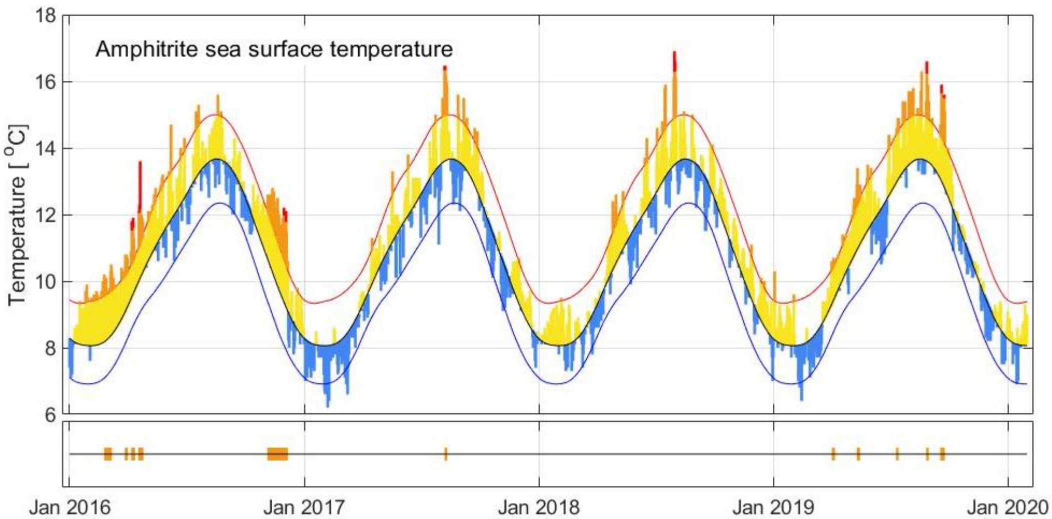

Figure 48-2. SST time series from Amphitrite lighthouse for 2016 through the beginning of 2020. The colour scheme is the same as Figure 48-1.

Figures 48-3 and 48-4 show the MHW statistics at the South Hecate and La Perouse weather buoys. These statistics show the dominance of the Blob and post-Blob period in the MHW statistics and the importance of the 1997/98 El Niño event. There was also a small event in 2004.

48.4. Factors influencing trends

The recent large MHWs (The Blob in 2013-15; 2018, 2019) seem to have their origin in the fall (Bond et al. 2015; Peterson et al. 2016; Britten 2018; Livingston 2018; NOAA 2019). One hypothesis is that high pressure ridges in the upper atmosphere (as indicated by the 500 mb height anomalies) prevent the fall storms from reaching B.C. This reduces the cooling of the upper ocean at a time when it usually cools at a rate of about 2 ºC per month. When the ridge disappears after 2 or 3 weeks, the surface ocean is 1-2 ºC warmer, and more strongly stratified than normal. The warm anomaly can persist for many months until the return of 'normal storms' re-establishes the normal cooling rate. A greater than normal cooling rate is required to remove the surface temperature anomaly. This hypothesis is untested.

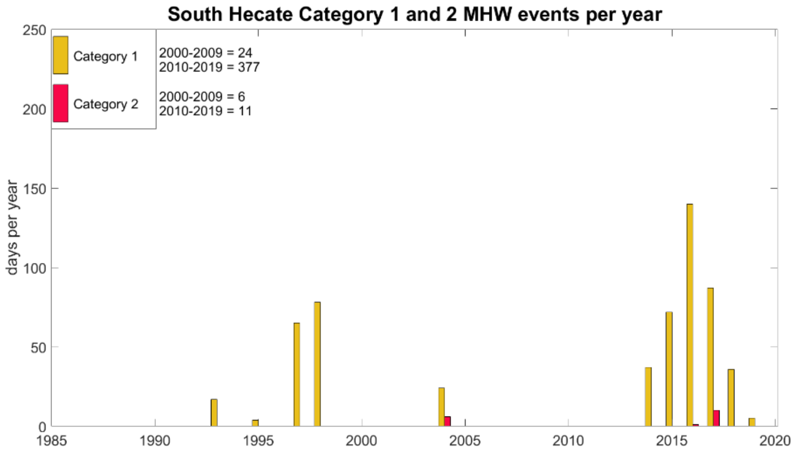

Figure 48-3. MHW statistics for SST at the South Hecate weather buoy. Category 1 refers to all MHW events of Category 1 strength and above; Category 2 refers to all MHW events of Category 2 strength and above.

48.5. Implications of those trends

The persistent drought in California from 2012-2015 has been attributed to the increased occurrence of high pressure ridges in the upper atmosphere (500 mb height anomaly centred over Victoria, BC; Swain 2015). The increased occurrence of these ridges has been linked to climate change (Swain et al. 2014, 2017; Wang et al. 2014). Therefore it is possible that the recent MHWs in the northeast Pacific are one of the mechanisms by which climate change will express itself in B.C. waters. It seems reasonable to think of these MHWs as part of our system (the climate) rather than anomalies.

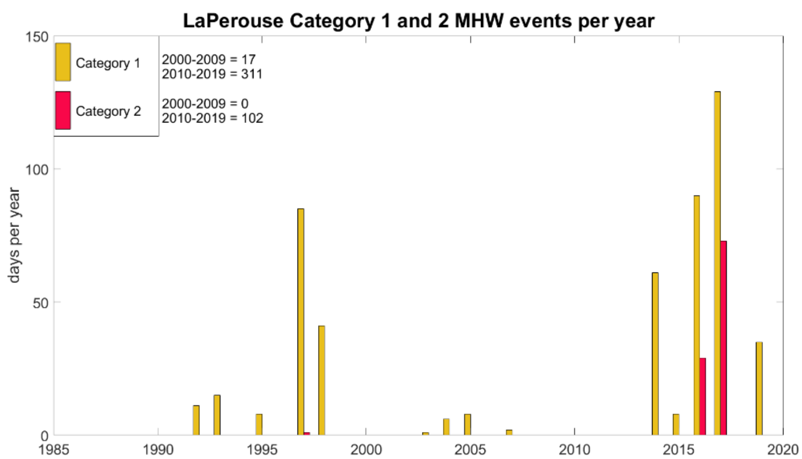

Figure 48-4. MHW statistics for SST at the La Perouse weather buoy. Category 1 refers to all MHW events of Category 1 strength and above; Category 2 refers to all MHW events of Category 2 strength and above. There are large gaps in the data coverage in the fall and winter of 2018/19 and the fall of 2019. The satellite SST indicates there were no sustained MHW events during those times.

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49. DEFINING MARINE HEATWAVES – ARE WE GETTING IT RIGHT?

Peter Chandler, Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Peter.Chandler@dfo-mpo.gc.ca

49.1. Highlights

- The global average marine heatwave frequency and duration is increasing, resulting in an increase in annual marine heatwave days globally.
- Marine heatwaves are extreme events and can have significantly negative impacts on regional marine ecosystems.
- For impact focussed ecosystem research on a regional scale, such as Canada's west coast, there is benefit to including additional defining factors specific to the region.

49.2. The global definition of marine heatwaves

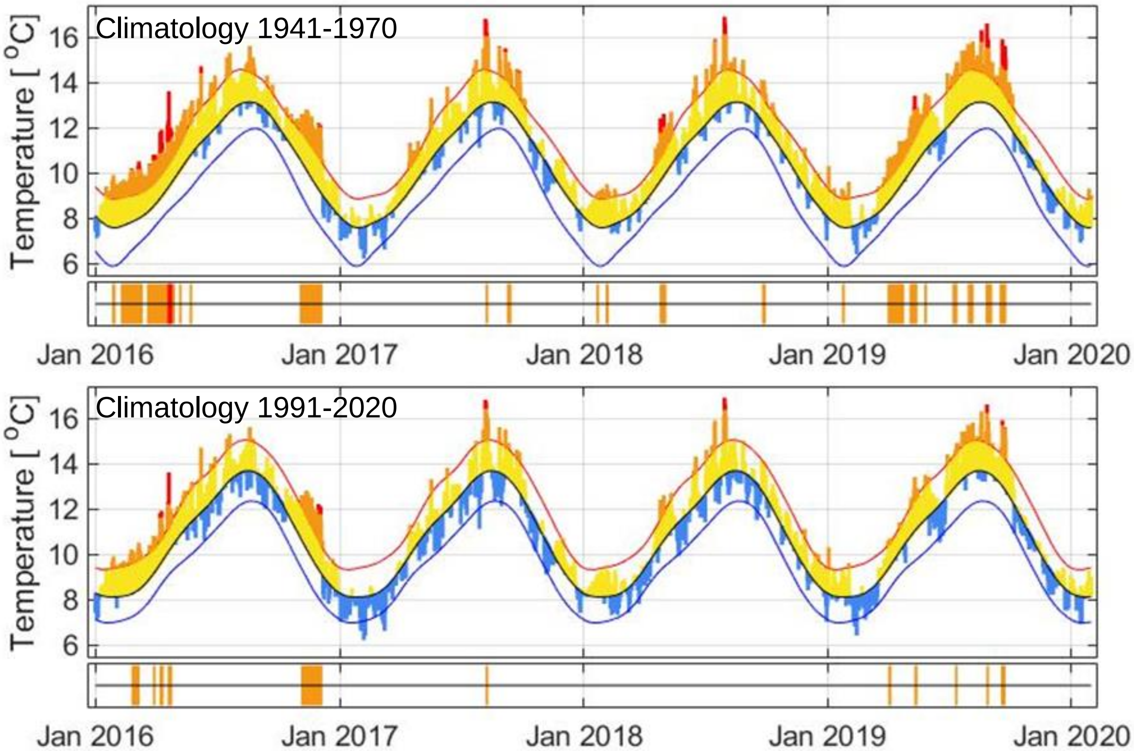
In addition to the long-term trend of a warming ocean, sea surface temperature (SST) data reveal anomalously warm water events (marine heatwaves, MHWs) occurring over several months and extending over hundreds to thousands of square kilometres. Hobday et al. (2016 and 2018) applied a definition based on the duration and intensity that the SST event exceeded a climatological temperature threshold; using this definition marine heatwave studies show that MWHs have doubled in frequency since 1982 and are increasing in intensity (IPCC 2019).

Using a common definition to define MWHs on a global scale provides an important and effective means of raising awareness of these extreme events to a range of audiences. This consistent definition is also helpful in planning research into the ecosystem impacts of MHWs, many of which are negative. While the global definition of MHWs is a necessary starting point, knowledge of the regional ecosystem being impacted leads to developing a more region specific MHW definition.

49.3. Regional factors affecting marine heatwaves on Canada's west coast

Marine heatwaves are defined as an event based on temperature data at the sea surface. During a MHW the warmer surface waters mix down to heat the subsurface ocean yet while the surface expression of the MHW may disappear there remains evidence of sustained positive subsurface temperature anomalies, as deep as 100 m (Ross and Robert, Section 7). This prolonged period of subsurface warming, with its ecosystem impact, is not captured in the global MHW definition and blurs the parameters of the MHWs duration and end date.

The satellite record provides an excellent database to examine the temporal and spatial changes of SSTs since the 1980s. The World Meteorological Organization recommended 30-year climate normals to be used to establish the climatological record critical to defining MHWs. The sensitivity of the climatological record used in the MHW analysis can be examined using longer term SST data records, such as the daily SST data collected at Amphitrite Point since 1935, which allows multiple 30-year normals to be used to identify MHWs. Figure 49-1 shows that using a climatology from 1991-2020 (when SST conditions were warmer) results in fewer and less intense MHWs that when a cooler 1941-1970 climatology is used. This sensitivity of the physical parameters of the MHW to the climatology may influence research that forecasts over many tens of years.



Climatology 1941-1970			**Climatology 1991-2020**		
Number of Cat1 MHWs	Duration (days)	Max intensity ºC	Number of Cat1 MHWs	Duration (days)	Max intensity ºC
20	**12.9 ± 11.5**	**2.6 ± 0.71**	**11**	**9.1 ± 8.2**	**2.5 ± 0.68**
Number of Cat2 MHWs			Number of Cat2 MHWs		
1	**8**	**4**	**-**	**-**	**-**

Figure 49-1. Upper panel: Time series of MHWs from Amphitrite Point daily (see Chandler section 10) SST based on a climatology of SST from 1941-1970 (yellow: above normal, orange: cat 1 MHW), red: Cat 2 MHW). Lower panel: The same MHW time series based on climatology of SST from1991-2020. The table gives the MHW statistics. Duration is the consecutive number of days the SST exceeds the climatology as a Cat1 MHW (exceed the 90 percentile threshold for 5 days), or as a Cat2 MHW (greater than the twice the 90th percentile for 5 consecutive days), the max intensity is the highest anomaly SST during the MHW.

A clearer picture of the impacts of a warming ocean on marine ecosystems can be determined by separating the effects of the long-term warming due to climate change, the periodic effects of climate variability, and the event effect of marine heatwaves. Canada's west coast is influenced by SST variability due to the El Niño Southern Oscillation (ENSO, as represented in the Oceanic Niño Index, ONI), and the Pacific Decadal Oscillation (PDO). Figure 49-2 shows the coincidence of MHWs in the Amphitrite Point daily SST record with the ONI and PDO. The ENSO events are associated with increased mean and variability of MHW duration in the northeast Pacific Ocean (Oliver et al. 2018), requiring an understanding of regional MHWs and climate variability.

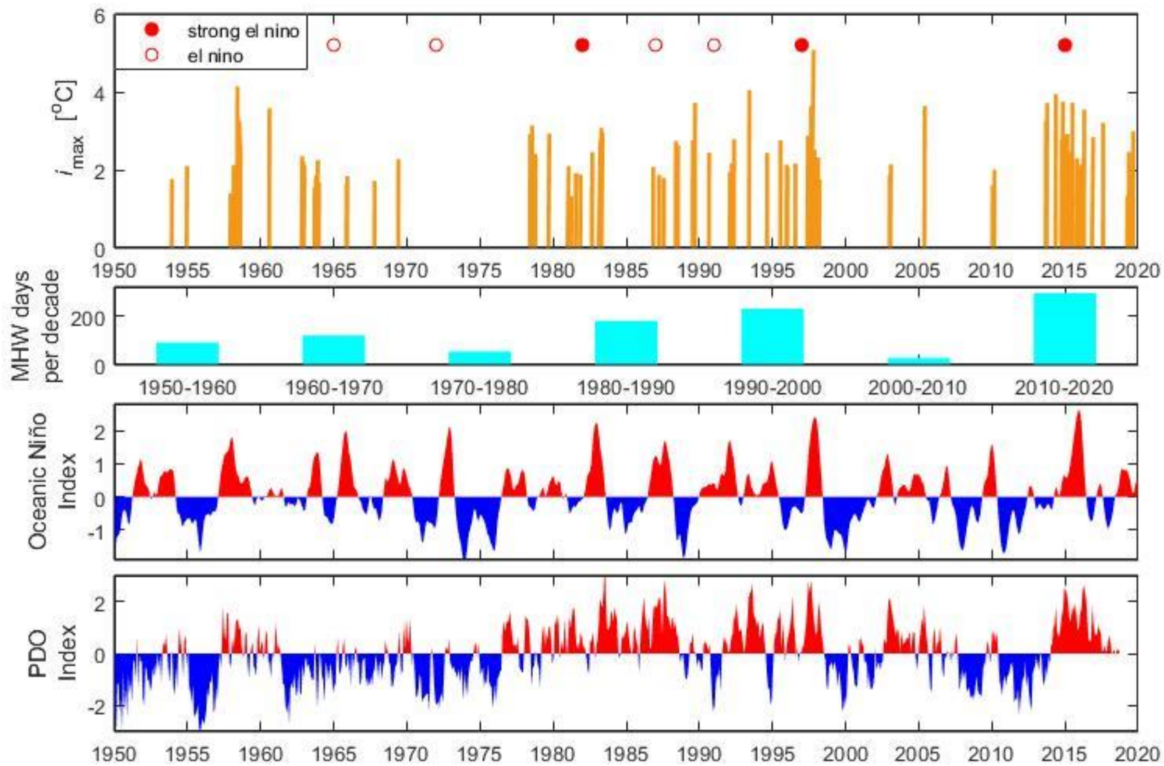


Figure 49-2. Time series of marine heatwaves at Amphitrite Point (top two panels) and ONI and PDO climate indices (lower two panels) known to effect SST off Canada's west coast.

49.4. Implications of an enhanced definition

As the world's oceans continue to warm, the likelihood of marine heatwave events continues to increase. Canada's west coast has experienced both a long-lasting marine heatwave ("the Blob" of 2014-2016), and recent shorter events in 2019. All MHWs have negative effects across a range of taxa and biological processes, particularly when there are high levels of biodiversity or species at the edges of their warm range (Smale et al. 2019). While the global definition of MHWs is important when comparing the physical attributes of these extreme events occurring around the world, there remains a need to enhance the definition for regional ecosystem impact research.

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50. ZOOPLANKTON RESPONSES ALONG THE WEST COAST OF VANCOUVER ISLAND TO THE NE PACIFIC MARINE HEATWAVE

R. Ian Perry[1,2], Moira Galbraith[2], Kelly Young[2], Akash Sastri[2]

[1]Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, Ian.Perry@dfo-mpo.gc.ca
[2]Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Moira.Galbraith@dfo-mpo.gc.ca, Kelly.Young@dfo-mpo.gc.ca, Akash.Sastri@dfo-mpo.gc.ca

50.1. Highlights

- Zooplankton responses to the 2015-2016 marine heatwave were similar to their responses to other warm events such as ENSO and delayed Spring transition;
- however, zooplankton responses were more intense (consistent with the more intense nature of this event) and more persistent (zooplankton impacts of previous warm events have lasted only 1-2 years).
- Total zooplankton biomass anomalies along the west coast of Vancouver Island were very high during the recent heatwave years.
- Biomass anomalies of crustacean and gelatinous zooplankton taxa were not out-of-phase as had been expected; both presented high anomalies during the heatwave years, but the crustaceans declined quickly afterwards (2017-2019).

50.2. Description of the marine heatwave in the NE Pacific

The marine heatwave in the NE Pacific formed during the fall of 2013, and expanded in areal extent through 2014, with upper layer water temperatures reaching over 3 ºC above climatological conditions (e.g. Bond et al. 2015; Di Lorenzo and Mantua 2016). By fall 2014, this large expanse of very warm water had been advected to the west coast of North America, where it persisted through 2015 and combined with an El Niño event at the end of 2015 and into the first half of 2016.

50.3. Status and Trends

Average annual surface water temperatures measured at Amphitrite Point along the west coast of Vancouver Island in 2015 were 1 ºC above the 1981-2010 climatological mean, which was the warmest over the period 1979 to 2019. Average annual sea surface temperatures at Amphitrite Point in 2016 were the third warmest over the period 1979-2019, after the El Niño events of 1997 and 1983 (Figure 50-1).

Annual anomalies of the zooplankton total biomass in the onshelf and offshelf areas of the southern and northern regions of the west coast of Vancouver Island were at a series low in 2008 compared to the 1981-2010 climatological mean, but increased steadily to reach a maximum during the marine heatwave years of 2015 and 2016. These zooplankton total biomass anomalies then declined to below the 1981-2010 mean biomass in 2017 and 2018 (Figure 50-1).

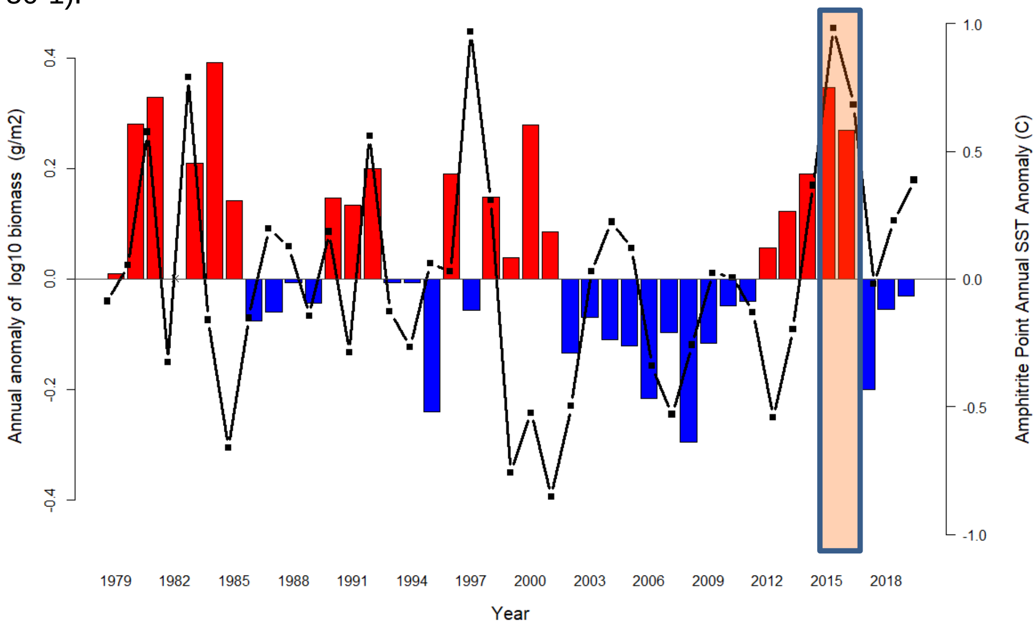

Figure 50-1. Amphitrite Point average annual sea surface temperature anomaly (SST, ºC; solid black dots and line; right y-axis), and zooplankton total biomass anomalies (based on the climatology from 1981-2010; bars, left y-axis). Orange vertical bar represents the years 2015 and 2016, which are defined as the marine heatwave years along the southwest coast of Vancouver Island.

Along the northwest coast of North America, it is known that zooplankton species composition changes with water temperature (e.g. Mackas et al. 2004). "Boreal" and "Subarctic" copepods occur typically in the northern (boreal) and deep-ocean (subarctic) regions of the NE Pacific. They are large and nutritious species which are good food for fish. Typically they have higher biomass anomalies when water temperatures are cooler. "Southern" copepods occur typically in regions south of British Columbia. They are generally small, poor quality species which are poor food for fish. They tend to have higher biomass anomalies with warmer water temperatures. Example species of these three groups are named in Table 50-1.

Table 50-1. Copepod species definitions for "Southern", "Boreal" and "Subarctic" taxa.

Southern-origin copepods	Boreal-origin copepods	Subarctic-origin copepods
Acartia danae	*Acartia longiremis*	*Eucalanus bungii*
Acartia tonsa	*Calanus marshallae*	*Neocalanus cristatus*
Calocalanus spp.	*Pseudocalanus* spp.	*Neocalanus flemingeri*
Clausocalanus spp.		*Neocalanus plumchrus*
Ctenocalanus vanus		
Mesocalanus tenuicornis		
Metridia pseudopacifica		
Paracalanus spp.		

Biomass anomalies of the Boreal and Southern taxa showed the expected alternation under warmer and cooler conditions, such that southern taxa had relatively higher biomass compared to their 1981-2010 average during warm years, and *vice versa* for the Boreal taxa during cold years (Figure 50-2). During the marine heatwave years (2015, 2016), however, the separation of these two time series was extreme, with record high positive biomass anomalies for the Southern taxa, but near-record low biomass anomalies for the Boreal taxa, consistent with the very warm nature of this heatwave event along the west coast of Vancouver Island.

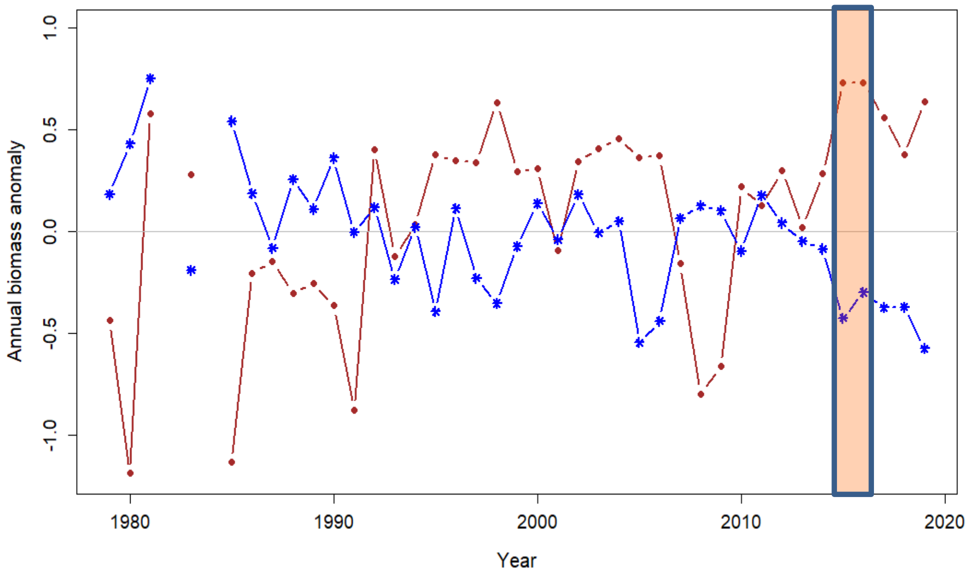

Figure 50-2. Annual biomass anomalies of the "Boreal" (blue line and stars) and "Southern" (brown line and dots) copepods, along the southern continental shelf of the west coast of Vancouver Island. Orange vertical bar represents the years 2015 and 2016, which are defined as the marine heatwave years along the southwest coast of Vancouver Island.

Table 50-2. Taxa defined in the "Crustacean", "Gelatinous", and "Other" categories.

"Crustaceans" (hard-bodied plankton)	"Gelatinous" (gelatinous plankton)	Other
Class Malacostraca (e.g. Euphausiids, Amphipods, Decapods)	Phylum Ctenophora	Phylum Chaetognatha
Class Maxillopoda (e.g. copepods)	Class Scyphozoa	Phylum Arthropoda (e.g. insects)
Class Ostracoda	Class Hydrozoa (excluding Siphonophores)	Phylum Chordata (e.g. fish)
Class Branchiopoda (e.g. cladocera)	Order Siphonophora	Phylum Cnidaria (e.g. anemones)
Infraclass Cirripedia (e.g. barnacles)	Class Thaliacea (e.g. salps, pyrosomes, doliolids)	Phylum Echinodermata
	Class Appendicularia (e.g. larvaceans)	Phylum Mollusca (e.g. squid, octopus)
	Pteropods (e.g. Limacina, Clione)	Class Polychaeta (e.g. worms)

There has been considerable discussion in the scientific literature about the potential for gelatinous plankton to replace crustacean plankton, and the possible consequences to the production of fish (e.g. Richardson et al. 2009; Bode et al. 2013). The potential for this alternation was examined for the west coast of Vancouver Island during these marine heatwave years. The taxa included in the definition of “Crustaceans” and “Gelatinous” plankton are shown in Table 50-2.

Annual anomalies of the biomass of “Crustaceans” and “Gelatinous” zooplankton in 2015 and 2016 were among the highest observed for both taxonomic groups. However, the biomass anomalies of the “Crustacean” zooplankton quickly turned negative after 2016, whereas the biomass anomalies of the “Gelatinous” zooplankton remained positive after 2016 (although at lower levels than the peak in 2015; Figure 50-3).

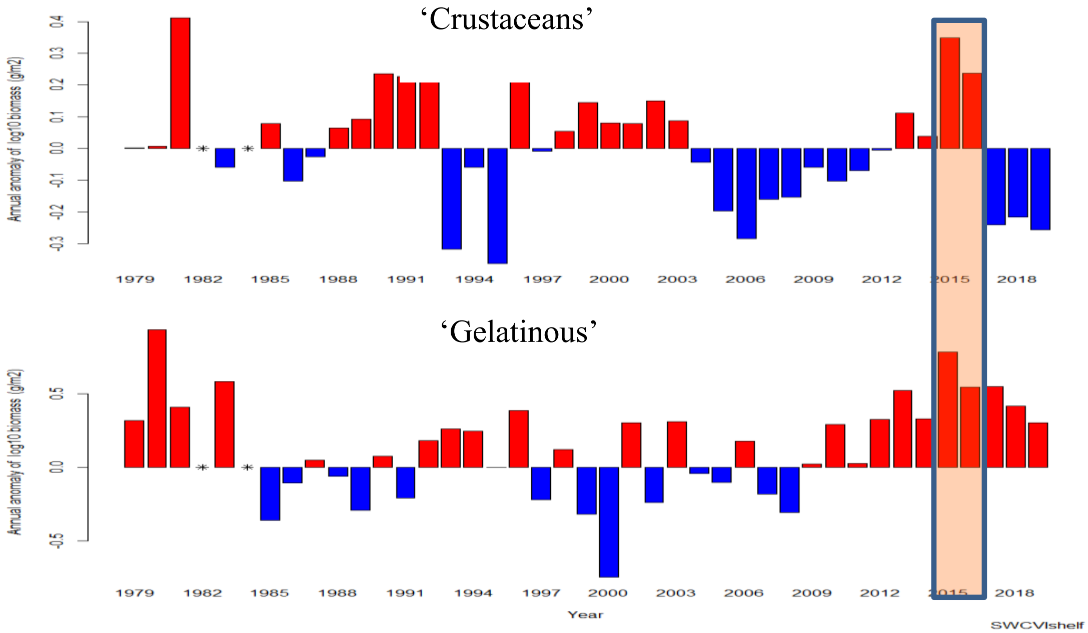

Figure 50-3. Annual biomass anomalies of the “Crustacean” and “Gelatinous” zooplankton along the southwestern continental shelf of Vancouver Island. The orange bar represents the marine heatwave years of 2015 and 2016.

Constrained (chronological) clustering of the zooplankton taxa included in the three taxonomic groups defined in Table 50-2 showed very close taxonomic similarity between 2015 and 2016, and somewhat similar with 2017, but a significant break between 2015 and previous years (Figure 50-4). This is consistent with the biomass anomalies presented in Figure 50-3.

50.4. Implications of these results

In general, zooplankton responses to the marine heatwave of 2015-2016 were similar to their responses to other warm events such as ENSO and a delayed Spring transition. However, the responses were more intense, consistent with the more intense nature of this event, i.e. deeper negative anomalies for boreal copepods, stronger positive anomalies for southern copepods. These responses were also more persistent, in that zooplankton impacts of previous warm events have lasted only 1-2 years after the event whereas we are still seeing changes/impacts in 2019 from 2015-2016. The observation that the total zooplankton biomass anomalies along the southwestern continental shelf of Vancouver Island were very high during these heatwave years was unexpected, but likely a result of more animals with predominantly southern origin being advected onto the Vancouver Island continental shelf. The observation that the biomass anomalies of ‘Crustacean’ and ‘Gelatinous’ zooplankton taxa were not out-of-phase during the heatwave years, as had been expected based on literature results from elsewhere, was surprising. Although both groups had high biomass anomalies during the heatwave years, the “Crustaceans” declined quickly afterwards (2017-2019), whereas the biomass anomalies of the ‘Gelatinous’ plankton showed a more modest decline. The extent to which these findings may be representative of future marine heatwaves along the Vancouver Island continental shelf are currently unknown, and are a subject of close observation and monitoring.

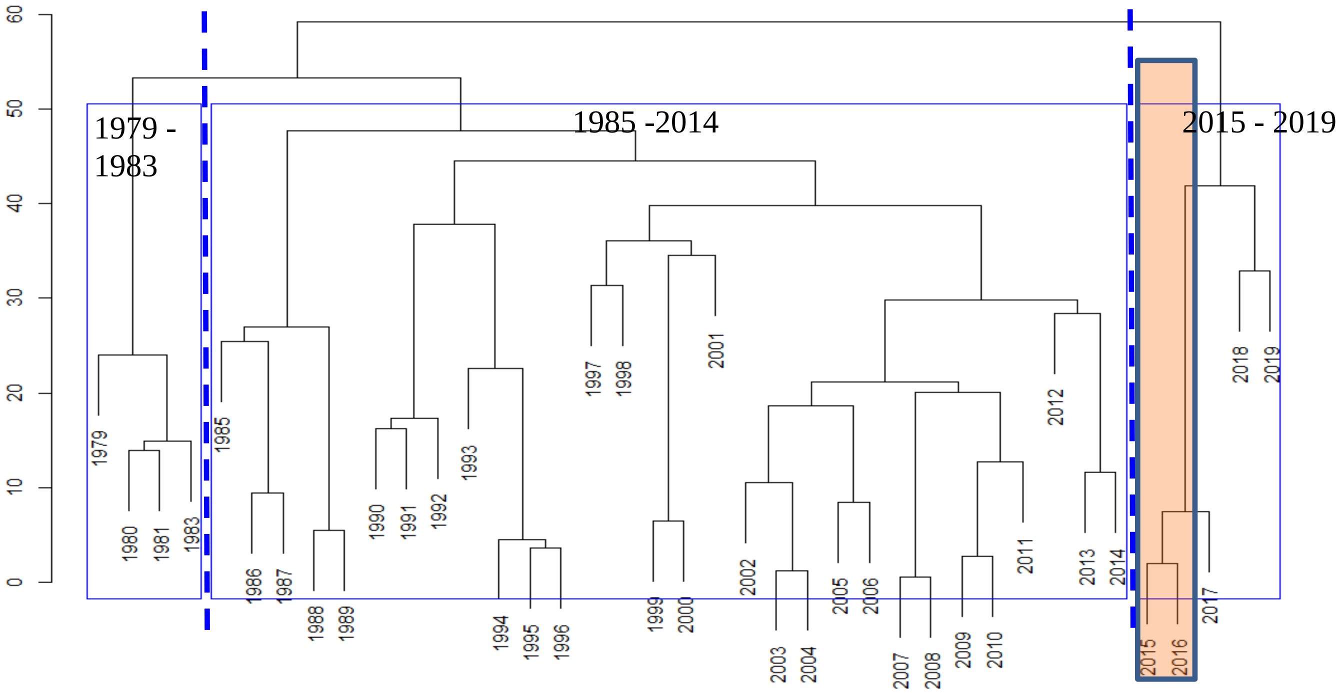

Figure 50-4. Constrained (chronological) clustering of zooplankton taxa (defined in Table 50-2) based on their biomass anomalies. Significant (P<0.05) breaks derived from a randomisation procedure are shown as blue dashed lines. The orange bar represents the marine heatwave years of 2015 and 2016.

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51. IMPACTS OF THE 2013-2016 MARINE HEATWAVE ON SOCKEYE SALMON

Kim Hyatt*, Howard Stiff, and Margot Stockwell, Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, *Kim.Hyatt@dfo-mpo.gc.ca

51.1. Highlights

- In northern waters from south-central Alaska (Cook Inlet) to the B.C. north Coast (Nass and Skeena rivers), adult salmon returning to freshwater in 2015-2017 exhibited sub-average size-at-age. Return timing to terminal marine fisheries for several stocks was 10-17 days later than average in association with exposure to anomalously high temperatures while rearing in the Gulf of Alaska in 2013-2016 (Hyatt et al. 2019a).
- In more southerly waters, total numbers and morphological traits (size-at-age, age-at-maturity) of Barkley Sound Sockeye adults returning from rearing in the Gulf of Alaska (GOA) during the NEP13 years of 2014-2016 were not affected in any exceptional way.
- Frequent, temperature-induced delays of entry to the Somass River by Barkley Sound adult Sockeye were observed in 2015 with resultant pooling of fish holding in Alberni Inlet and exposure to hypoxia (Stiff et al. 2016). Unusual straying occurred to non-natal systems up to 450 km away in 2015, but not in all MHW years (Hyatt et al. 2016b).
- Unprecedented mortality events (85-90%) for juvenile Sockeye overwintering in Great Central and Sproat lakes under anomalously warm conditions in 2014-2015 resulted in major reductions in adult Sockeye returns to Barkley Sound in 2017-2019.

51.2. Time Series of Annual Returns and Biological Attributes of Sockeye "Indicator Stocks"

Hyatt et al. (2019a) have briefly described sources of salmon population data comprising a *de facto* set of coast-wide Sockeye Salmon performance indicators. In addition, some populations are also sampled annually for biological attributes (e.g. size-at-age, freshwater run-timing, annual production of fry and/or smolts, smolt size, age and run timing) that permit assessment of whether annual variations in recruitment of adult salmon to terminal area fisheries are determined principally at freshwater or alternately marine life stages of a given parent-year of origin. Research programs that supplement adult catch and escapement data with other biological attribute observations on salmon also commonly monitor a variety of biophysical indices of environmental conditions or events likely to influence salmon. In a few cases, these programs have created decadal-scale time series observations that provide indices of average biophysical attributes of the fish and associated environments at specific life stages such that meaningful conclusions can be provided about whether traits or associated conditions may be regarded as truly anomalous. Documentation of methods and time series observations for Barkley Sound Sockeye and associated environmental conditions are available for: annual timing of adult entry into the Somass River (Hyatt et al. 2015), annual abundance and growth of Sockeye fry in Barkley nursery lakes (Hyatt et al. 2011), size-and-age of smolts at seaward migration (Hyatt et al. 2019c, 2019d), and subsequent returns of adults (Hyatt et al. 2019a, Section 22).

A single generation of Sockeye Salmon typically takes 4-6 years to complete its full life cycle. Consequently, compilation of results to examine the potential influence of NEP13 MHW year conditions on a broader range of life history events and biological traits for Barkley Sound Sockeye (e.g. marine survival) could not be completed before juvenile Sockeye that migrated seaward in the final MHW year of 2016 returned to reproduce as adults in the fall of 2019.

51.3. General Overview of Status and Trends of Sockeye Relative to the 2013-2016 Marine Heatwave

Hyatt et al. (2016a, 2019a) reported that:

- Above average returns have occurred in recent years for Alaska's Bristol Bay Sockeye, but many other stocks returning to waters from southeast to southcentral Alaska (AK) exhibited total returns well below expectation in 2017-2019. Return variations were associated with far above average temperatures and food-web changes experienced by juvenile salmon migrating seaward and assumed to have reared in the Gulf of Alaska (GOA) during MHW years of 2015-2016.
- Sockeye stocks from Bristol Bay through to northern B.C. all exhibited exceptional declines in average size in 2015-2018 due to either earlier ages-at-maturity or reduced size-at-age (Hyatt et al. 2019b). In addition, return timing to rivers of origin for northern B.C. Sockeye (Nass and Skeena rivers) was 10-17 days later than average in 2017-2018 (Steve Cox-Rogers, DFO pers. comm.).
- During the NEP13 MHW fisheries managers and scientists feared that biophysical changes might significantly alter marine survival and biological traits of southern Sockeye populations. However, preliminary observations suggested that, Sockeye returning to Barkley Sound and the Somass River in the south were well within the range of size-at-age variations observed over the past 15 years (Hyatt et al. 2019a, 2019b).

Time series information, supporting assessment of potential impacts of NEP13 MHW years on multiple life stages and parent years of origin for Barkley Sockeye, are now complete and support several conclusions regarding responses of this population as follows:

- Average production of Barkley Sound Sockeye smolts in freshwater during the 2014-2016 sea-entry years was less than 50% of the 35 year mean (22.0 versus 54.7 smolts per spawner; range 10-32 and 19-109 respectively) and reached a record low of 11 smolts per adult in spring 2015. The latter event was associated with exceptional surface water temperature elevations of 1-2 degrees Celsius during overwintering (Dec-March) by Sockeye fry in Great Central and Sproat lakes (Hyatt et al., unpublished data).
- Smolt production from freshwater was below average during NEP13 MHW years, but sizes at seaward migration were generally above the long-term mean (4.1 vs 3,2 g respectively for Great Central smolts). Condition factors (K) for migrating smolts were either near average (2015) or somewhat below average (2016) (Hyatt et al. 2019d).
- Productivity of Barkley Sound Sockeye, from smolt-to-adult returns (SAR) was close to the all-year average (SAR of 5.1 versus an all-year average of 5.6). This was surprising

given our previous observations that smolt-to-adult survival normally decreases in association with sea-entry years for which temperatures are above average.

- Major reductions in adult Sockeye returns to Barkley Sound did occur in 2017-2019 (Hyatt et al., Section 22). Observations reported here suggest these reductions were principally a consequence of life history events affecting juvenile salmon production in freshwater, under the influence of marine heatwave conditions in 2014-2016, rather than due primarily to impacts on marine life history events of salmon.
- Barkley Sound Sockeye adults returning in 2015-2018 arrived in numbers consistent with pre-season forecasts (Hyatt et al., Section 22) that routinely account for the effects of anomalous freshwater or ocean conditions (e.g. El Niño, PDO) on productivity of particular brood years (Hyatt et al. 2003, 2013) and exhibited biological traits (age-at-return, return timing) that suggest they were not affected while rearing in the GOA in any exceptional way by the NEP13 MHW.
- The 2013 sea entry smolt cohort set a new abundance record and subsequently a new record high of 2.2 million adult Sockeye returns as catch and escapement to Barkley Sound during the peak MHW year of 2015 (Hyatt et al. 2016). However, temperature-induced delays of adult salmon entry to the Somass River in 2015 and pooling of fish holding in Alberni Inlet, exposed them to hypoxia (Stiff et al. 2016). Subsequent straying of Somass Sockeye, verified via DNA analysis, was observed in non-natal rivers (Elwha R., Quinsam R.) more than 100 km away, in association with the 2015 MHW year. Previous observations of widespread straying by Sockeye Salmon into non-natal, rivers from northern CA to the northern tip of Vancouver Island in the 1997 MHW year (McKinnell et al. 1999) strongly implicate involvement of MHW conditions with this unusual behaviour.

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

The multi-year NEP13 MHW induced a higher than average frequency of anomalous biophysical events including: elevated seasonal temperature, multiyear flood and drought events, structural and productivity changes in aquatic ecosystems at lower trophic levels (see references in Chandler et al. 2016, 2018; Boldt et al. 2019).

The serial to sometimes simultaneous occurrence of anomalous environmental conditions in freshwater and marine ecosystems (see references in Chandler et al. 2016, 2018; Boldt et al. 2019), led Hyatt et al. (2016, 2019a, Section 22) to conclude that environmental anomalies were driving an emergent pattern for coast-wide declines in survival and total returns plus changes in biological traits (i.e. size-at-age, age-at-return and/or return timing) of Sockeye Index stocks distributed from south central AK in the north to the Columbia River in the south. These were stocks that reared in freshwater rivers and lakes south of the Aleutians in 2014-2018, migrated seaward in 2015-2019 and matured in the GOA to return to their rivers of origin in 2016-2019.

There appears to be a shared trend for common behavioural responses among many populations of returning adult Sockeye that, in one or more years of return between 2015-2019, have displayed extended delays of entry-to and straying-from their freshwater systems of origin due to high temperatures and/or insufficient flow (Somass - WCVI, Okanagan and Wenatchee –

Columbia R., Lake Washington – Salish Sea, Meziadin – Nass R. on the northern B.C. coast, Auke Creek – Juneau, AK etc.).

Several studies that have examined recruit per spawner (R/S) time series have identified temperature as the single dominant variable associated with production variations of the majority of Sockeye stocks (references in Peterman and Dorner 2012). Although R/S indices do not allow clear distinctions to be made regarding whether factors influencing overall survival variations originate in freshwater or marine ecosystems, most of these studies have concluded that the causal mechanism occurs in the ocean given a significant association between survival variations and sea surface temperature. However, it is also true that most of these studies identified an equivalent association between freshwater temperatures and subsequent R/S variations during the late winter prior to sea entry. Observations of Sproat and Great Central survival suppression during overwintering periods, characterized by above average temperatures, indicate that both freshwater and marine mechanisms are driving these broad patterns of Sockeye production variations.

51.5. Implications of NEP13 and Outlook from NEP19 Conditions

There is published anecdotal evidence that salmon recruitment failures involved a large number, and perhaps the majority, of salmon populations of several species in this same area between 2015 and 2019. Simultaneous recruitment failures among salmon populations originating from freshwater systems covering such a large geographic area are relatively uncommon, occurring perhaps one year in fifteen, among Sockeye Index stocks (Hyatt et al., Section 22).

The emergence of a marine heatwave in 2018-2019 (NEP19) was not an encouraging development from a salmon recovery perspective. Observations that NEP19 climate anomalies had largely dissipated by January of 2020 offer some hope that the associated disruptions to freshwater and marine ecosystems will not be as severe as appeared to be the case with NEP13 MHW. Improvements to understanding the extent and the nature of salmon life-history and climate interactions in freshwater and marine ecosystems that control salmon recruitment variations will require establishing a wider network of Index Stocks, similar to the Barkley Sockeye example, for which factors controlling recruitment success and biological attributes at several life-stages are carefully investigated.

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Appendix 1 - Poster Session Abstracts

52. MARINE DATA FOR B.C.: A COMPREHENSIVE DATA REPOSITORY AND INTERPRETIVE MAP CATALOGUE (HTTP://SOGDATACENTRE.CA)

Isobel Pearsall, Terry Curran and Benjamin Skinner, Pacific Salmon Foundation, Vancouver, BC, pearsalli@psf.ca

52.1. Description

The Strait of Georgia Data Centre is a collaborative program between the Pacific Salmon Foundation (PSF) and the Institute for the Oceans and Fisheries (IOF UBC), to build a secure data archive for marine ecosystem information on the Strait of Georgia. The freely-available data is held in the informatics cloud at the University of British Columbia, and is funded through the Sitka Foundation and PSF.

The data archive is fully compliant with all the international standards for data sharing and embraces the open source data management tools and techniques for low cost maintenance and utmost compatibility. The applications used are GeoNetwork for metadata management and online mapping, Geoserver for creation of data layers for downloading and geospatial information system (GIS) access, and a reliable PostgreSQL spatial database cluster to hold metadata and data. Basic principles are no data duplication and that data should be managed closest to origin, if the data is freely available and in “take-away” form elsewhere. Sometimes datasets are not instantly share-able, and in these cases the PSF is required to host a copy.

52.2. Status

During 2019, the number of indexed datasets increased from 502 to 663. There are currently two story maps and thirteen interpretive maps. Work is underway to enhance the website with a Marine Reference Guide.

52.3. Contributing partners

BC Ministry of Environment, Bird Studies Canada, BC Marine Conservation Analysis Program, Canadian Wildlife Service, Washington State Department of Ecology, Environment and Climate Change Canada, Fisheries and Oceans Canada, Living Oceans Society (for BCMCA), Ministry of Forests, Lands and Natural Resource Operations, Natural Resources Canada, Ocean Networks Canada, Underwater Harvesters Association, University of British Columbia, UVic Pacific Climate Impacts Consortium, Vancouver Island University, WWF Canada, and numerous citizen science groups.

53. PROTECTION BY PROXY: ASSESSING TIDAL CURRENT AS AN INDICATOR OF BIODIVERSITY

Sarah Dudas[1], Sharon Jeffery[2], Jessica Nephin[2]

[1]Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, Sarah.Dudas@dfo-mpo.gc.ca
[2]Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC

Canada's oceans support approximately 16,500 species along a 243,042 km coastline (Hutchings et al. 2012). Approximately 14% of Canada's marine and coastal areas are currently protected, with new Government of Canada goals of increasing protection to 20% by 2025 and 30% by 2030. The magnitude of Canada's coastal areas and the number of species it supports presents a challenge for scientists trying to determine species distribution and abundance, and to prioritize areas for protection. One way to address this is the development of proxies or indicators of biodiversity. The main goal of the work described here was to assess tidal current speed as an indicator of marine invertebrate biodiversity.

Two separate studies were conducted in subtidal habitat in high and low current sites over two depth ranges within the Strait of Georgia (SoG) to assess biodiversity (Figure 53-1):

1. For the deep water (50-260 m) surveys, low and high current areas were defined as areas with bottom tidal current speeds either greater or less than the 60th percentile of values in the SoG model (Soontiens et al. 2016). Remotely operated vehicle transects were conducted in several locations within the SoG. Transect locations were limited to areas predicted to have rocky substrate (where slope was greater than 5 degrees, ridge or mound features were present, and rugosity was relatively high). From many randomly selected transects in high and low current areas, a total of eight were completed, each approximately 500 m in length. Still images taken from the video were annotated, counting all benthic species, using Biigle (https://biigle.de/). Species counts were standardized by sampling effort estimated by transect distance multiplied by mean transect image area.

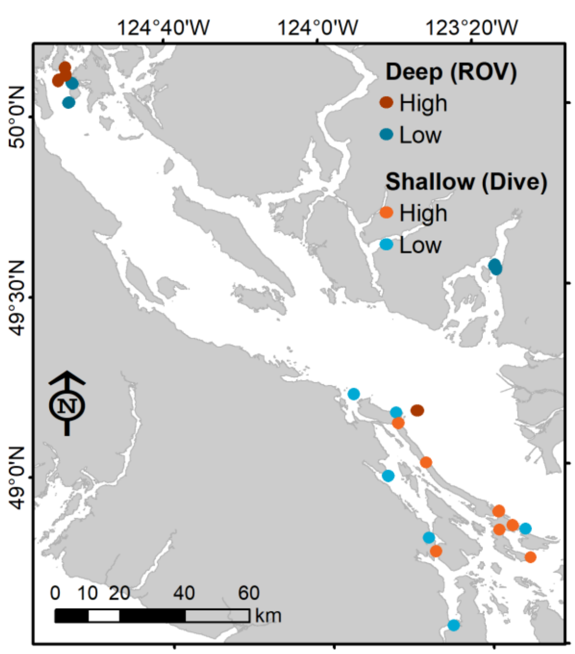

Figure 53-1. Map of high and low current study sites in the Strait of Georgia for deep water ROV (red – high, dark blue – low) and shallow water dive surveys (orange – high, blue – low). Some sites appear to overlap at this scale.

2. For the shallow water (3-15 m) surveys, high current sites were defined as those where divers were only able to enter the water safely at slack tide, and low current sites were safe to dive at any time in the tidal cycle. Sites were chosen in the southern Gulf islands using information from an extensive diving and species database and then refined in the field using *in situ*

observations of current speed. Invertebrates were surveyed by SCUBA within 1 m^2 quadrats at depths of 3, 9, 15 m, along three transects perpendicular to shore for each site. Species presence was recorded and total biomass of all invertebrates was estimated, for each quadrat. A total of 14 sites were surveyed. Subsequently, sites were filtered using *in-situ* bottom tidal current speed measurements. Only eight sites were retained for data analysis; the sites with the highest and lowest current speed (four of each).

High tidal current habitats support unique biological communities. Deep water surveys showed that community composition differed between high and low tidal current sites (NMDS, r^2=0.45, p-value=0.028, Figure 53-2); however, species richness did not. Further, the reef-building sponge area was greater in high current transects, with an average of 49.6 m^2 compared to 0.5 m^2 in low current transects (based on effort-corrected values). It is important to note that low current transects were conducted at shallower depths (mean of 106 m for low current versus 166 m for high current) and covered less rocky habitat (28% in high current and only 1% in low current). Shallow water SCUBA surveys showed that invertebrate species richness and biomass were significantly higher at high current sites (1.3 and 5X greater respectively) (Figure 53-3). Invertebrate community composition also differed between high and low current sites (ANOSIM, R=0.24, p=0.001).

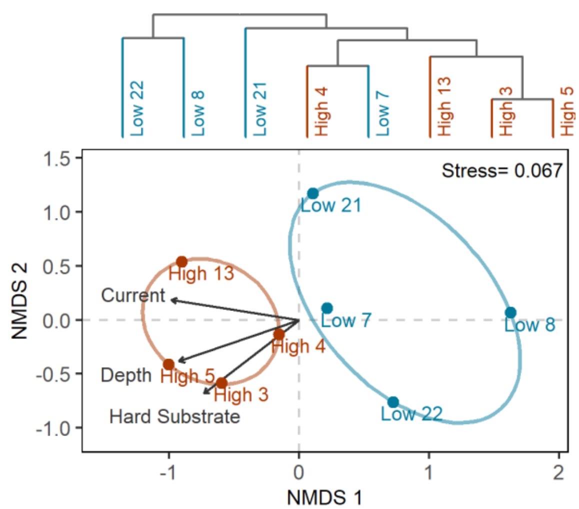

Figure 53-2. Cluster dendrogram and NMDS ordination based on Bray-Curtis distance for high and low current sites in deep water (50-260 m). Ordination displays transect and environmental vectors (arrows). Ellipses represent minimal area ellipsoids (for high and low).

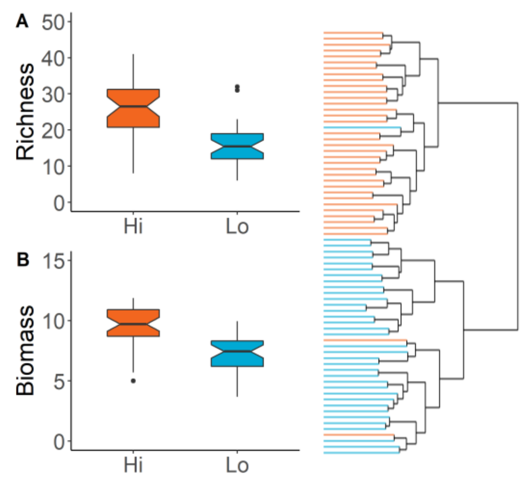

Figure 53-3. Invertebrate species richness (A) and biomass (B) and cluster dendrogram (right) for high and low current sites in shallow water (3-15 m). Cluster dendrogram based on jaccard distances (red lines indicate high current and blue indicates low current quadrats).

These studies provide some of the first empirical evidence on the influence of tidal current speed on biodiversity patterns, and support the recent proposal that, where information is sufficient, high tidal current areas should be considered Ecologically and Biologically Significant Areas (Rubidge et al., in press). High tidal current habitats appear to support different invertebrate communities with potentially higher biodiversity and biomass than low current areas, and may be a useful indicator of biodiversity for shallower habitats. Future work may include the addition of high and low current sites in other parts of the Pacific Bioregion. The application of this indicator in marine conservation is currently being explored.

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54. THE APPROACH TO OPEN GOVERNMENT FROM SCIENCE IN DFO'S PACIFIC REGION

Lu Guan[1] and Jason Parsley[2]
[1]Fisheries and Oceans Canada, Institute of Ocean Sciences, Victoria, BC, Lu.Guan@dfo-mpo.gc.ca
[2]Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, Jason.Parsley@dfo-mpo.gc.ca

The Government of Canada (GoC) produces a wide range of data (e.g. scientific, geospatial, oceanographic, fishery, etc.) to govern and direct its decisions. In recent years, proactive disclosure of government data and information represents the starting point of activities related to Open Government. According to the Directive on Open Government (https://www.tbs-sct.gc.ca/pol/doc-eng.aspx?id=28108), open data is defined as structured data that is machine-readable, freely shared, used, and built on without restrictions. Increased access to federal research data supports primary research in Canadian and international academic communities, as well as public sector and industry-based research communities, and also supports innovation in the private sector by reducing duplication and promoting reuse of existing resources.

A dataset published on the Open Data Portal is composed of four components: data files, dataset publication metadata, data dictionary, and supporting documents. Data files should be in a non-proprietary modifiable format (e.g. CSV, TEXT, XML, HTML, NetCDF, etc.). Dataset metadata describe the structure, significance, context and host systems of the dataset. A data dictionary is a file containing clear definitions for each heading (rows and columns). Supporting documentation, such as published reports, provides additional explanations to the dataset, and would help users to better understand, interpret and use the published data.

So far, DFO Pacific has published 56 datasets to Open Maps and Open Data Portal. For the 2019-2020 fiscal year, nine new datasets and thirteen published datasets have been published and updated, respectively. More specifically, the published new datasets are:

- Ocean Station "Papa" Detailed Zooplankton Data: 1956-1980
- The Strait of Georgia Ichthyoplankton Survey, 1979-1981
- Groundfish Synoptic Bottom Trawl Surveys
- Pacific Salmon Conservation Units, Sites & Status
- Standard Oceanographic Sampling Stations
- Sea Otter (*Enhydra lutris*) Population Counts, British Columbia, 1977-2013
- Aquatic Invasive Species European Green Crab (*Carcinus maenas*) Monitoring, British Columbia
- Herring biosample database

The updated datasets are:

- Chum Salmon Conservation Units, Sites & Status
- Southern B.C. Chinook Salmon Conservation Units, Sites & Status
- River Type Sockeye Salmon Conservation Units, Sites & Status
- Lake Type Sockeye Salmon Conservation Units, Sites & Status
- Even Year Pink Salmon Conservation Units, Sites & Status
- Odd Year Pink Salmon Conservation Units, Sites & Status
- Chinook Salmon Conservation Units, Sites & Status
- Coho Salmon Conservation Units, Sites & Status
- Pacific Region Commercial Salmon Fishery In-season Catch Estimates

- NuSEDS-New Salmon Escapement Database System (non-spatial)
- Herring Permanent Spawn Transects
- British Columbia Shore Station Sea Surface Temperature and Salinity Data (Pacific), 1914-present
- Pacific recreational Fishery Salmon Head Depots

55. ESTIMATING ECOLOGICAL VULNERABILITY TO CLIMATE CHANGE ACROSS HISTORIC PACIFIC FISHING GROUNDS

Karen L. Hunter[1], Joy Wade[2], Andrew McMillan[1], Miranda Smith[3], Danielle Perron[4], Mike Foreman[5]

[1]Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, karen.hunter@dfo-mpo.gc.ca, andrew.mcmillan@dfo-mpo.gc.ca
[2]Fundy Aqua Services, Nanaimo, BC, joywadefundyaqua@gmail.com
[3]MC Wright and Associates, Nanaimo, BC, miranda.smith@mcwrightonline.com
[4]Fisheries and Oceans Canada, Vancouver, BC, danielle.perron@dfo-mpo.gc.ca
[5]Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, mike.foreman@dfo-mpo.gc.ca

Marine species and communities respond to changing environments (Alabia et al. 2018; Kleisner et al. 2016; Pinsky et al. 2013). Depending on the severity and novelty, responses can range from no change, to distributional or migratory changes, to increased mortality or extirpation (Pecl et al. 2017; Ainsworth et al. 2011). In order for fisheries to thrive and provide dependable livelihoods, it is necessary to detect changes in climate within the fishery context.

We estimated relative ecological vulnerability for key commercial fisheries in Canada's Pacific waters by combining a thermal exposure analysis and an expert-derived sensitivity assessment. We estimated thermal limits for the adult life stage of selected species using two methods: extracting data from a physiological limits database (Steiner et al. 2018) and outputs of a Bayesian hierarchical species distribution model (McMillan et al. in review). Average seasonal thermal change was determined from the difference between contemporary (Masson and Fine 2012) and projected (Foreman et al. 2014; A2 (no abatement), AR4; 2060-70s) regional ocean model systems models (ROMS). The difference in temperature between time periods and across fishing footprints relative to each species thermal threshold was translated into an exposure index that accounted for the change in: 1) extent (entire fishing footprint), 2) magnitude (proportion of footprint with threshold met or exceeded), 3) frequency of threshold being met or exceeded, and 4) degree of threshold exceedance relative to each species' threshold (Figure 55-1). We re-ran the exposure assessment using thresholds adjusted by +1 °C and –1 °C to test the sensitivity of the assessment. Potential economic risk to fisheries from thermal change in British Columbia's Northern Shelf Bioregion was mapped by overlaying a Marxan-derived fisheries economic value distribution with cumulative frequency of thermal threshold exceedance for all assessed fisheries. We used climate sensitivity attributes developed in previous climate vulnerability studies to qualitatively score species' sensitivity to climate change (Hare et al. 2016; Stortini et al. 2015). Vulnerability rank was determined from the rank matrix based on the combination of exposure index and sensitivity scores (Figure 55-1).

Projected temperature change across historic fishing grounds may impact some important commercial fisheries with 11 of 15 assessed species determined to be in the high vulnerability category (rank 3 of 4). Pacific Herring was the only species to rank in the highest vulnerability category. Projected future temperature change (based on average seasonal maximum) resulting in thermal limits being exceeded across all assessed species ranged from 0 °C to 2.04

°C. The overlay of fisheries economic value and cumulative exposure index (i.e. thermal threshold met or exceeded) completed for the Northern Shelf Bioregion suggests fishing locations along the continental shelf break have the highest overlap but no area was categorized as both highest economic value and highest thermal exposure. For the 15 species considered in the assessment, sensitivity scores ranged from low to very high. Stock status and early life dispersal were on average the lowest scoring attributes, with population growth rate spawning cycle, and sensitivity to ocean acidification scoring the highest for individual species and cumulatively.

Vulnerability rank informs where new science and adaptation planning for fisheries management could be undertaken. Our spatial assessment of historic fishing grounds suggests that for the majority of species we studied, the projected shift in temperature for B.C. waters will expose a greater portion of the current fisheries distribution to thermal conditions that go above the majority of assessed species thresholds. In contrast, projected water temperatures will not exceed thermal thresholds for some species and may in fact increase suitable thermal habitat (i.e. Pacific Hake, North Pacific Spiny Dogfish, Geoduck). Accuracy of ocean model predictions at nearshore locations are less understood than coastal and offshore areas. Therefore, exposure scores of fisheries with a large proportion of harvest occurring nearshore including Geoduck, Spot Prawn, and Pacific Herring may be either over or underestimated. Future assessments could include additional environmental variables where threshold values are known and be re-run as new ocean model products and climate-sensitivity studies become available.

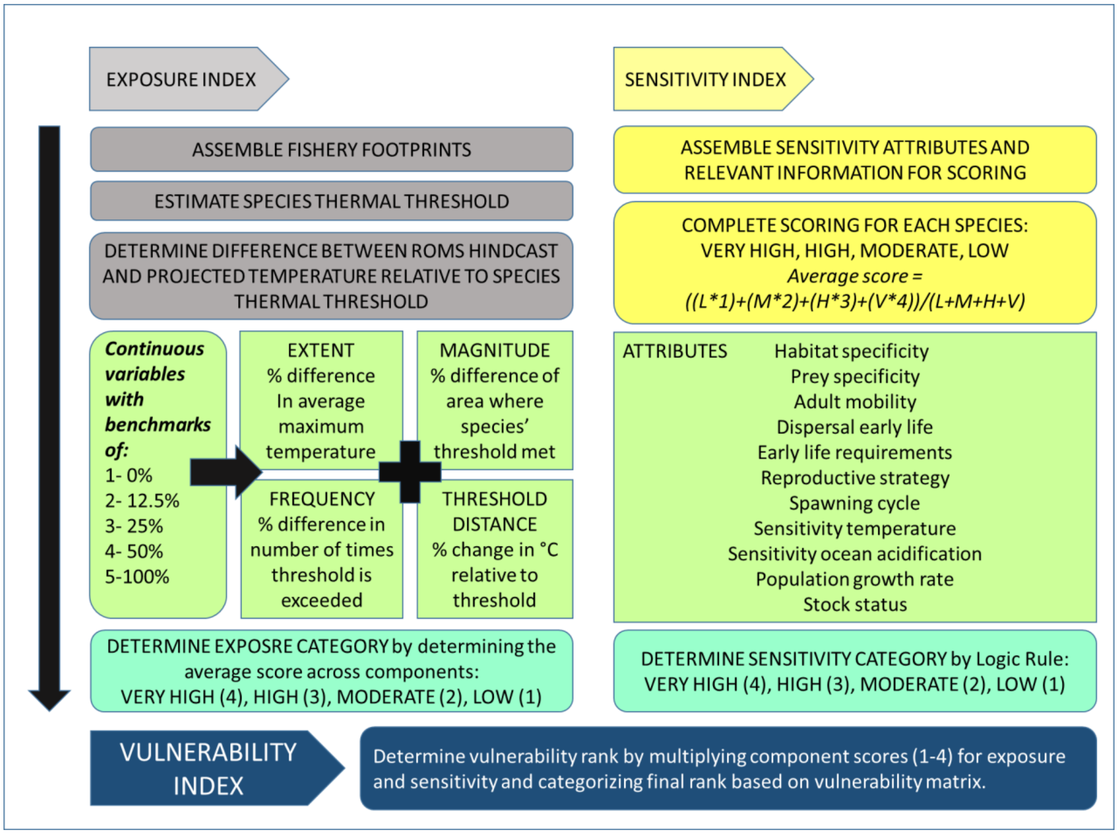

Figure 55-1. Workflow for the calculation of exposure and sensitivity indices, combining to produce a vulnerability index for fisheries off the coast of British Columbia.

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56. ADULT SALMON DIETS AS AN ECOSYSTEM MONITORING TOOL IN COASTAL BRITISH COLUMBIA

Katie Innes, Jessica Qualley, Micah Quindazzi, Nick Bohlender, Will Duguid*, and Francis Juanes, Fisheries Ecology and Marine Conservation Laboratory, University of Victoria, Victoria, BC, *willduguid@hotmail.com

Chinook and Coho Salmon are an important component of coastal ecosystems in the Northeast Pacific. Surprisingly, data on the diets of adult Salmon in British Columbia are sparse, with no published data since the 1960s and no publications on winter diets. Since 2017 we have been developing a low-cost, citizen science-based program to sample adult Chinook and Coho Salmon diets throughout the year in British Columbia. In the short term, we are seeking to characterize spatial and seasonal variation in adult salmon diets. Size data (including otolith dimensions) for individual prey items are allowing us to infer the seasonal importance of different life-history stages of important prey species. Our results to date suggest spatial and seasonal variation in diet within the Canadian Salish Sea. The mechanisms underlying this variation may have implications not only for growth and fecundity of adult Chinook Salmon, but also for growth and survival of juvenile Pacific Salmon and other species.

In the long-term we hope to develop this program as a method to monitor changes in the ecosystem from the perspective of the salmon themselves. To investigate interannual variation in the diet composition of Chinook Salmon within the Salish Sea we have developed preliminary ‘Salish Sea Partial Fullness Indices” (Figure 56-1). These indices track the mean gravimetric contribution of different prey categories to Chinook Salmon diets, with their sum providing an index of overall stomach fullness. To account for different numbers of samples in different areas and seasons across years, we calculate these indices as means of 100 random samples of diets drawn, with replacement, from our data. Each random sample (N = 141) is balanced with respect to Pacific Fishery Management Areas (PFMAs) and seasons (Spring, Summer, Winter) with sample sizes being defined as the minimum number of available samples in each PFMA/Season combination across years. Pacific Herring overwhelmingly dominate diets and Northern Anchovy appear to have decreased in importance in 2019. Overall, there is a slight decline in stomach fullness from 2017-2019. These results are preliminary, but as our time series develops, we hope to validate this approach through comparison with existing sampling programs. Adult salmon diet monitoring has the potential to complement existing and future fishery-independent surveys in elucidating natural and anthropogenic changes in the coastal ocean of British Columbia. It also offers the benefit of directly engaging participants in British Columbia’s public fishery in ecosystem science.

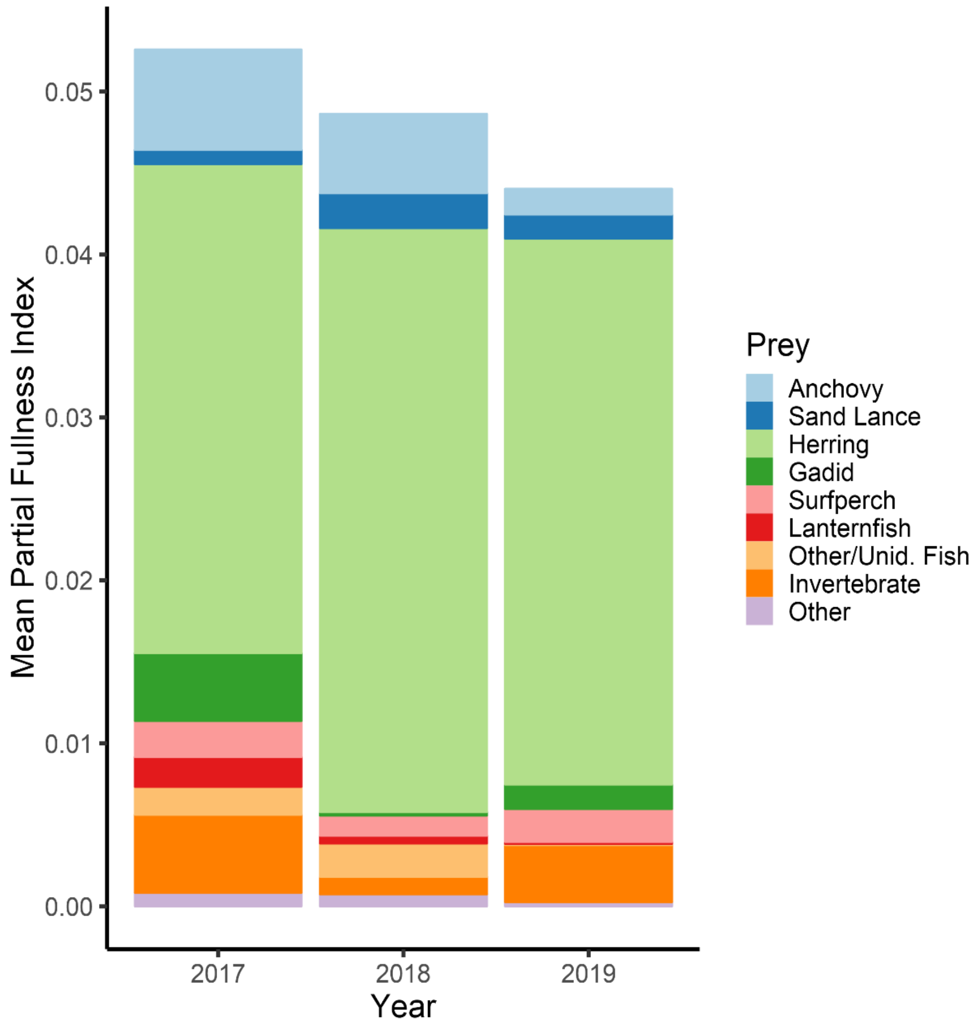

Figure 56-1. Index of mean partial fullness scores (~prey mass/predator length^3) for adult Chinook Salmon in the Salish Sea from 2017-2019. Values were derived by averaging 100 random samples (with replacement) of 141 adult Chinook Salmon diets in each year. Sample size for resampling was based on the minimum PFMA/Season sample size across years (aggregate N = 141; Spring (April-June) = 12, Summer (July-September) = 46, Winter (October-March) = 83; Northern Strait of Georgia = 29, Southern Strait of Georgia = 29, Gulf Islands/Haro Strait/Juan de Fuca Strait = 83; total N exposed to resampling = 980; number of samples averaged = 100).

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

Greg Jones and Charles Hannah, Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, reshook@shaw.ca, Charles.Hannah@dfo-mpo.gc.ca

57.1. 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, and deployment of GPS drifters (Figure 57-1). Satellite data are also used to complement the data sources listed.
- GPS drifters, carried by surface currents, demonstrate that the NWA is part of a larger marine ecosystem with the potential for substances to be transported long distances in relatively short time periods, and the potential for substances from distant major ship corridors to reach the NWA.
- Drifters in previous years showed that currents in summer could move surface waters into the NWA from over 100 km away. Drifters released in January 2019 (Figure 57-1) were the first to show such transport could also occur in winter, indicating that surface waters and substances may enter the NWA in any season.
- Reproduction of planktivorous seabirds improves with high availability of subarctic copepods, in particular *Neocalanus cristatus*, which occurs when cold water moves south into the region (Hipfner et al. 2020). Biomass of sub-arctic copepods has decreased on and off the shelf in recent years, with potential negative effects on planktivorous marine predators (Figure 57-2).
- Long-term monitoring of oxygen and other marine habitat parameters is essential to detect natural or anthropogenic trends. Hypoxia (< 1.4 mLO_2/L) has not been detected at the two mooring locations (example Figure 57-3), or on a cross section of the NWA in June 2019 (Figure 57-4).
- Data from a cross-shelf survey of the NWA in June 2019 show that dissolved oxygen below the surface mixed-layer is well stratified (Figure 57-4).
- Biologists in Environment and Climate Change Canada use results from this project to assess seabird populations in relation to trends in their forage supply and ocean habitats.

57.2. Description

The Scott Islands NWA was established by the Government of Canada in 2018 (Figure 57-1). 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 50% of the worlds Cassin's Auklet (*Ptychoramphus aleuticus*).

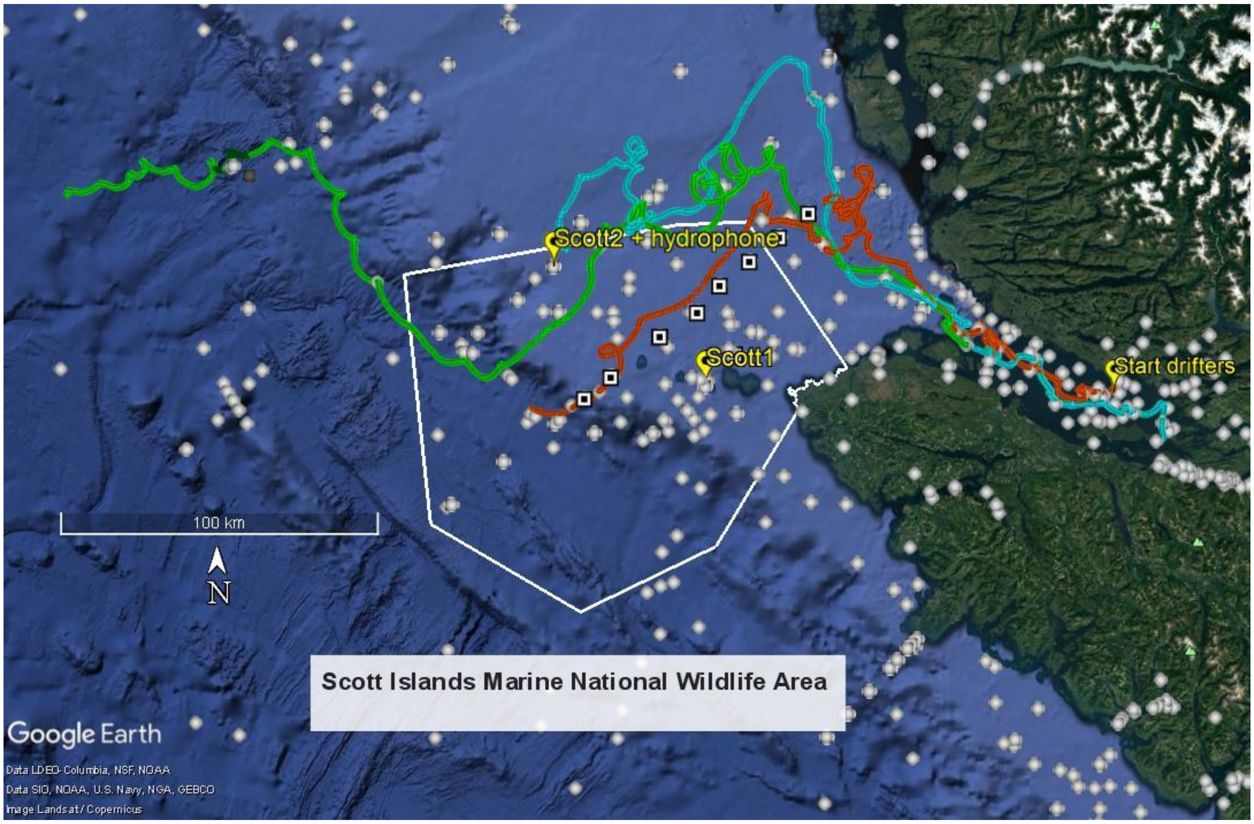

Figure 57-1. Scott Islands Marine National Wildlife Area. White line: NWA boundary. Black and White squares: Permanent sample sites with data on Figure 57-4. White dots: All locations sampled 2016 – 2019 on DFO monitoring cruises. Most sites were sampled several times, so there are more samples than dots on the map. Yellow Scott icons: Sub-surface mooring placements 2016 - 2019. Yellow Start icon: Example of GPS drifters deployed in January 2019. Three drifters released outside the NWA, drifted westerly into it, and one continued out with surface currents over 16 – 19 days (green, red and blue tracks).

- As part of the larger marine ecosystem the NWA can be negatively affected by the release of substances from distant locations in relatively short time periods, possibly in any season, including the potential for substances from distant major ship corridors to reach the NWA. The results are also consistent with previous results showing westward movement of nutrients into the NWA (Borstad et al. 2011).
- Seabirds are marine wildlife:
    - All their food comes from the ocean.
    - Ocean conditions influence seabird breeding through effects on forage species.
    - Seabirds are affected by ocean dynamics similar to other marine predators such as fish and marine mammals.
- In 2015 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. Results will assist in the understanding of marine habitats for all marine predators.

- 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. Any defined area is a part of the marine environment so an ecosystem approach is needed.
- Work under the Agreement was conducted on an ocean ecosystem basis, not the legal boundary of the NWA. The most important projects implemented in the NWA were:
  - Continuation of La Perouse oceanographic surveys in the NWA as part of the coast network, with particular emphasis on analysis of zooplankton due to their importance as forage species, and with emphasis on ocean conditions such as dissolved oxygen which is important to all marine life (Figures 57-1, 57-2, and 57-4).
  - Placing of two sub-surface oceanographic moorings, as part of a coast-wide network that is continuously recording ocean characteristics at various depths. (Figures 57-1 and 57-3). Approximately 10% of the coast mooring network is in the NWA. Either of the two NWA moorings may be moved at times to other locations within the NWA, to support improved understanding of the marine ecosystem. Scott2 includes a hydrophone to record natural and anthropogenic sounds.
  - The ocean surveys and moorings in the NWA collectively resulted in approximately 290 sample events, 2016 – 2019, producing thousands of data points (total of events as downloaded from Waterproperties.ca).
  - GPS drifters were released in the NWA, and drifters released elsewhere were carried by currents into it (Figure 57-1).
  - Satellite data were used to assess primary productivity using Chlorophyll *a* (NASA Giovanni), and to assess Sea Surface Temperature (NOAA), as both these parameters correlate with seabird populations by influencing forage species (Borstad et al. 2011).

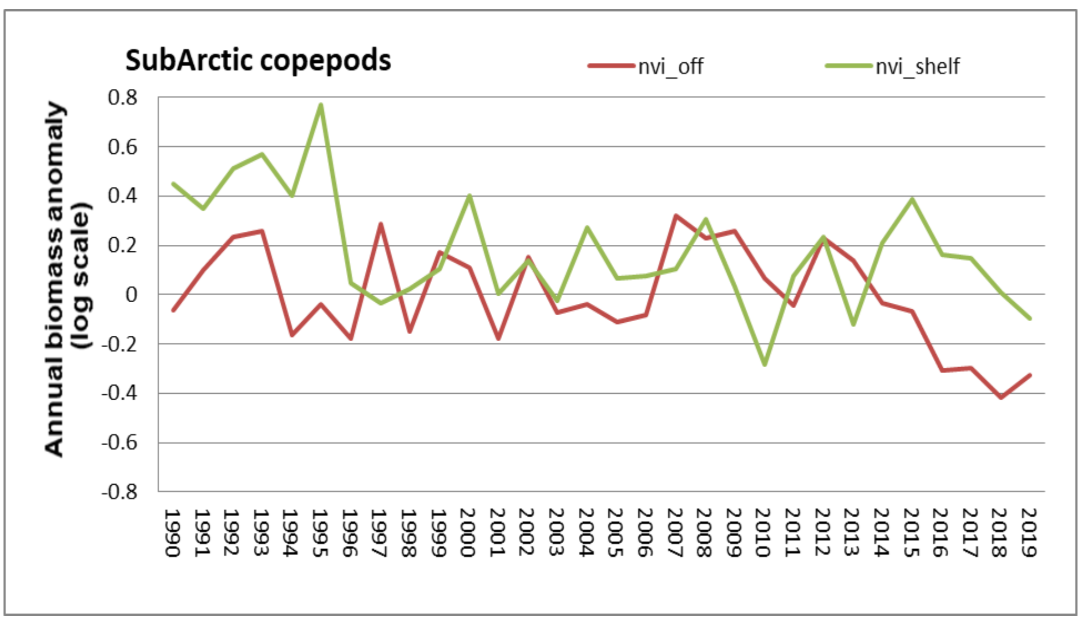

Figure 57-2. Zooplankton index in the Scott Islands ecosystem. North Vancouver Island (NVI) shelf and offshore zones include portions of the Scott Islands NWA (Moira Galbraith pers. comm. 2020).

- Zooplankton species composition and abundance varies with annual and seasonal ocean conditions. Reproduction of planktivorous seabirds is best with high availability of subarctic copepods, in particular *Neocalanus cristatus*, which occurs when the Pacific Decadal Oscillation is in negative phase during which cold water moves south into the region (Hipfner et al. 2020). Biomass of sub-arctic copepods has decreased on and off the shelf in recent years, with potential negative effects on planktivorous marine predators (Figure 57-2).

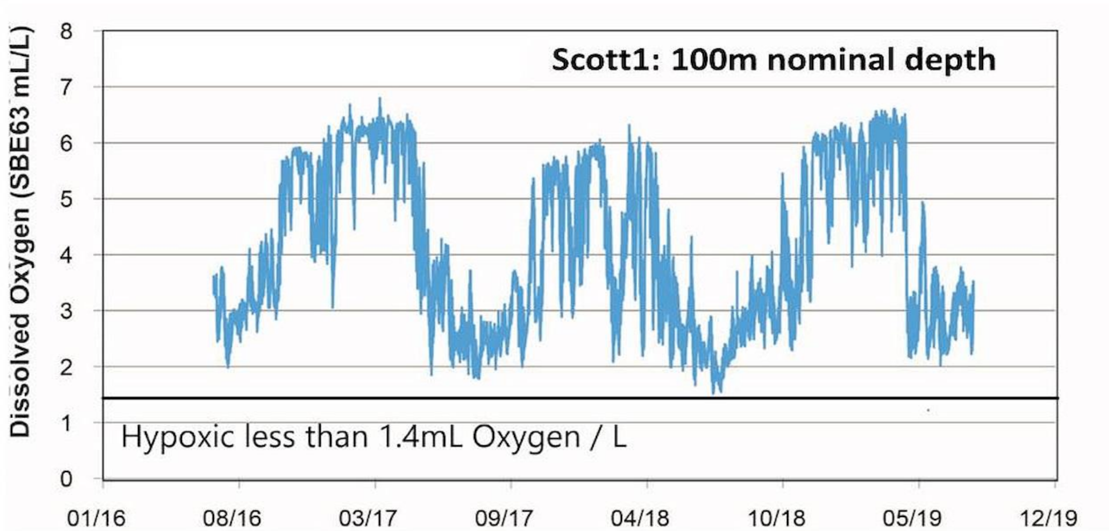

Figure 57-3. Dissolved Oxygen at ~100 m depth, sub-surface mooring at Scott1 in the Scott Islands NWA (Cindy Wright pers. comm. 2020). Location of Scott1 is shown in Figure 57-1.

- Dissolved Oxygen at ~100 m, near bottom, varies due to mixing of various depths, and is normally lower in summer, higher in other seasons. No hypoxia (< 1.4 mLO_2/L) has been detected at the mooring locations, or at the La Perouse sample sites shown (Figures 57-3 and 57-4). However, some species in other areas show sublethal effects at some of the observed oxygen levels above hypoxia (Ekau et al. 2010; Vaquer-Sunyer and Duarte 2008).

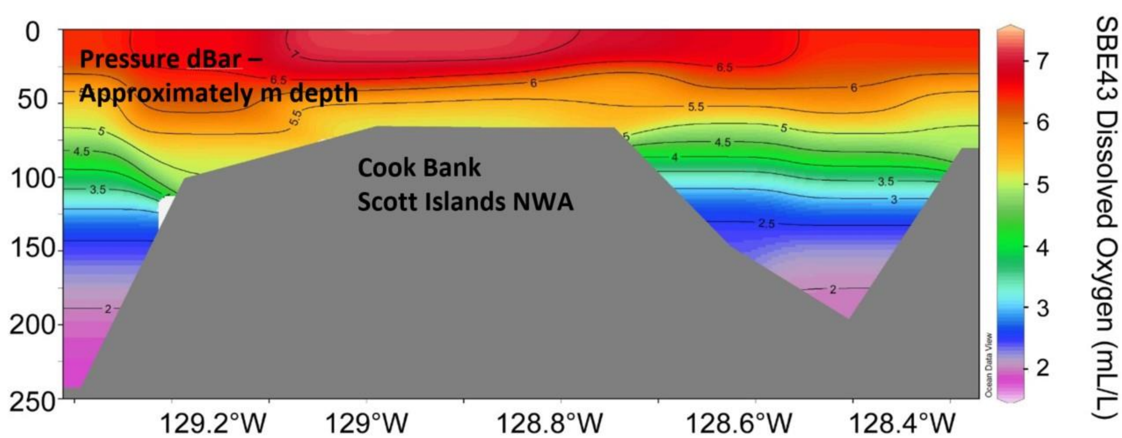

Figure 57-4. Dissolved Oxygen across the Scott Islands NWA, June 2019. Dissolved Oxygen across the NWA is typically stratified, with lower levels as depths increase. Data collected from permanent sample sites shown in Figure 57-1 (Cindy Wright pers. comm. 2020).

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58. MARINE MICROBIAL COMMUNITIES FROM THE STRAIT OF GEORGIA TO THE CENTRAL COAST OF BRITISH COLUMBIA

Colleen Kellogg[1], Carolyn Prentice[1], Rebecca Piercey[2], Justin Del Bel Belluz[1], Brian Hunt[1,3], Jennifer Jackson[1], and The Hakai Oceanography Team

[1]Hakai Institute, Heriot Bay, BC, colleen.kellogg@hakai.org, carolyn.prentice@hakai.org justin.belluz@hakai.org, b.hunt@ocean.ubc.ca, jennifer.jackson@hakai.org
[2]University of New South Wales, Sydney Australia
[3]University of British Columbia, Vancouver, BC

Microbes (Bacteria, Archaea, and Protists) play important roles in marine food webs. They are primary producers and food for higher trophic levels. They are carbon and nutrient cyclers, driving global biogeochemical cycles. Despite their integral roles in ocean chemistry and biology, we lack an understanding of their diversity and ecosystem function along the coast of British Columbia. Since 2014, we have been collecting samples as part of Hakai's oceanography program to monitor and understand drivers of change in microbial diversity along the B.C. coast, a region impacted by both changing ocean and terrestrial conditions. Sample collection details are summarized in Table 58-1.

Table 58-1. Details for Hakai Institute's oceanography time series stations from which microbial samples are collected. Other sites and depths are sampled by the oceanography program but are described here, as only sites sampled by the microbial oceanography component of Hakai's oceanography field program are shown.

Station	Latitude	Longitude	Sampling dates	Depths sampled (m)	Frequency
QU39	50.0307	-125.0092	Nov. 2014 (QU24), then QU39 from March 2015 to present	0, 5, 30, 100, 260	Weekly
QU43	50.3392104	-125.11764	May 2018 to present	0, 5, 30, 150, 500	Monthly
FZH01	51.6394	-127.8958	March 2016- Jan 2019	0, 5, 30, 100, 275	Monthly- 6 weeks
KC10	51.6505	-127.9516	Feb. 2019 to present	0, 5, 30, 100, 325	Monthly- 6 weeks
QCS01	51.705	-128.2384	March 2018 to present	0, 5, 30, 115	Monthly- 6 weeks
DFO2	51.5208	-127.5583	Jan 2019 to present	0, 5, 30, 100, 300	Monthly- 6 weeks

We use massively parallel amplicon sequencing to target via polymerase chain reaction (PCR) and sequence via Illumina MiSeq the V4V5 region of the 16S rRNA gene; a conserved genetic marker commonly used in biodiversity surveys of ocean microbes.

Thus far we have results from 2014 thru 2018 for QU39 and from sample collection initiation until late 2019 for all other sites. The prokaryotic (Bacteria and Archaea) community shows clear seasonality from surface to depth at all sites, with (not unexpectedly) Proteobacteria making up the largest fraction of sequences. We observed seasonal (spring-summer) increases in sequences belonging to the Bacteroidetes phylum, well-known to be skilled degraders of organic matter. From 100 m to 260 m, sequences related to Thaumarchaeota (ammonia-oxidizing Archaea) and other chemolithoautotrophic microbes (e.g. *Nitrospina sp*., *Marinimicrobia sp*.) make up a notable portion of the prokaryotic community. From 2014-2017, fluctuations in microbial community members was very predictable, but beginning in 2018, we observed potential changes between 100 m and bottom at QU39, with an increase in the proportion of sequences identified as *Thiomicrospirales sp*., and a decline in the proportion of sequences related to the cosmopolitan bacterial clade, SAR11. In comparing across regions, from the Strait of Georgia to the central coast, around Calvert Island, we see that *Thiomicrospirales sp.* sequences make up, on average, a greater fraction of sequences in samples from the central coast. What has brought about their increase in the deep waters of the Strait of Georgia? Will we see this trend continue when we complete analyses for 2019?

We can also assess the diversity of plastid DNA in our samples (and thus, phytoplankton) as chloroplast DNA is also amplified by our PCR primers. From this we observe that the dominant diatom taxa vary regionally, with sequences identified as *Thalassiosira sp*. being more abundant in the samples from the central coast. We observe a greater diversity of diatom taxa in the Strait of Georgia, with more interannual variability. Notable were high relative abundances of *Chaetoceros sp.* and *Rhizosolenia sp.* sequences, in addition to *Thalassiosira* sp. What drives this regional variability is a question we will address in the upcoming months. The duration of dominance of diatom-related sequences was short, especially in the Strait of Georgia, and the bulk of the plastid sequences during all other times of year were related to *Phaeocystis sp*., Cryptophytes, and several different picophytoplankton including *Bathycoccus sp*. and *Micromonas sp*. This highlights the importance of small phytoplankton in the Strait of Georgia. These small phytoplankton belonging to the Mamiellales order cannot be easily identified by microscopy and underscores the importance of coupling genomics-based tools to refine our understanding of phytoplankton dynamics in the waters of coastal British Columbia.

59. BIOGEOCHEMICAL REGIONALIZATION OF BRITISH COLUMBIA'S COASTAL OCEAN

Andrew R. Margolin[1*], Hayley V. Dosser[1], Jennifer M. Jackson[2], Patrick Pata[1], Stephanie Waterman[1], Brian P.V. Hunt[1,2]

[1]University of British Columbia, Vancouver, BC, [*] a.margolin@oceans.ubc.ca
[2]Hakai Institute, Victoria, BC

The coastal ocean of British Columbia (B.C.) is a highly complex environment influenced by diverse processes such as upwelling and downwelling, intense tidal mixing, and large volumes of freshwater/terrigenous input from the Pacific Coastal Temperate Rainforest. This region of the Northeast Pacific is further subject to the effects of large amplitude climate oscillations (e.g., Pacific Decadal Oscillation, El Niño–Southern Oscillation), and is increasingly impacted by marine heatwaves. This study aims to examine the biogeochemical regionalization, spatiotemporal variability, and trends of B.C.'s coastal ocean water properties through the analysis of a combination of historical and recent data. Physical and chemical observations from the past nine decades are utilized, including measurements of temperature, salinity, oxygen and nutrients. Observational data are obtained via the Canadian Integrated Ocean Observing System (CIOOS Pacific 2019a, 2019b), which is a nation-wide platform to integrate ocean data from various sources and facilitate data access for diverse end-users. Data are utilized to define and characterize regions of B.C.'s coastal ocean based on physical and chemical properties, using principal component and cluster analyses and considering short-term variability and long-term trends. The ocean's biogeochemical properties are foundational to ecosystem structure and function and this work establishes regional indicators that can be used to detect and predict the consequences of climate-driven changes. This regionalization of B.C.'s coastal waters will serve to improve spatial management of the province's marine resources, water quality and protected areas.

59.1. References

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CIOOS Pacific. 2019b. Institute of Ocean Sciences Rosette Bottle Data. Nov. 1930 - Jul. 2019, 46°N, 122°W; 60°N, 140°W. https://catalogue.cioospacific.ca/dataset/bf0ad274-c085-4fe0-b739-2821235464f1. Accessed 28 Feb. 2020.

60. FATTY ACID COMPOSITION OF PARTICULATE ORGANIC MATTER IN THE NORTHERN STRAIT OF GEORGIA

Anna K. McLaskey[1], Ian Forster[2], Jessica Garzke[1], and Brian P.V. Hunt[1]

[1]Institute for the Oceans and Fisheries, University of British Columbia, Vancouver, BC, a.mclaskey@oceans.ubc.ca, b.hunt@oceans.ubc.ca, j.garzke@oceans.ubc.ca
[2]Fisheries and Oceans Canada, West Vancouver, BC, Ian.Forster@dfo-mpo.gc.ca

60.1. Highlights

- Particulate organic matter collected approximately weekly from 2015 through 2018 at the Hakai Institute's station QU39 in the northern Strait of Georgia has been characterized for fatty acid composition.
- Fatty acid composition shows a strong seasonal cycle as well as interannual variability in nutritionally important fatty acids.

60.2. Description of the time series

This time series consists of particulate organic matter (POM) fatty acid (FA) composition sampled weekly since 2015 by the Hakai Institute at station QU39 near Quadra Island (50.0307 N, -125.099 W) in the northern Strait of Georgia (Figure 60-1). Seawater was collected with Niskin bottles at depths of 0, 5, 10, and 30 m, and 2.5 L from each depth (10 L total) was filtered onto a GF/F filter and stored at -80 °C until analysis.

FAs were measured as fatty acid methyl esters (FAMEs) quantified by gas chromatography. Lipid extraction and esterification were done in a single step following a modified protocol of Puttick et al. (2009). In brief, freeze-dried samples were extracted in 2 mL of 3M HCl in methanol and 0.5 mL of hexane, and incubated at 80 °C overnight. The following day, 2 mL of 0.9% NaCl solution and 1.5 mL of hexane were added, samples were centrifuged, and the hexane layer containing FAMEs was separated for analysis. FAMEs were analyzed using a gas chromatograph equipped with a flame ionization detector (SCION 436, hydrogen carrier gas), separated using an Agilent CP-Sil 88 column (50 m, 0.25 mm diameter), identified using FA standard mixtures (Nu-Chek Prep GLC-37, GLC-463) and comparisons with other labs, and quantified with the addition of a known amount of C19:0 added to each sample at the first extraction step.

60.3. Status and trends

Across all four years, POM FAs follow a seasonal cycle with greater concentrations of total FA and nutritionally important polyunsaturated FAs (PUFAs) during the biologically productive season (Figure 60-2). In general, FA composition is characteristic of a diatom dominated community in the spring (March-April), and a complex mixed phytoplankton community, potentially comprised of cryptophytes, chlorophytes, and dinoflagellates during the late summer and fall (Sept-Oct). In the winter, POM is primarily composed of saturated FAs that are less labile than other FAs, and therefore represent a more degraded POM pool. This signal was particularly prominent during the winter of 2017-2018. In 2016, the diatom dominated

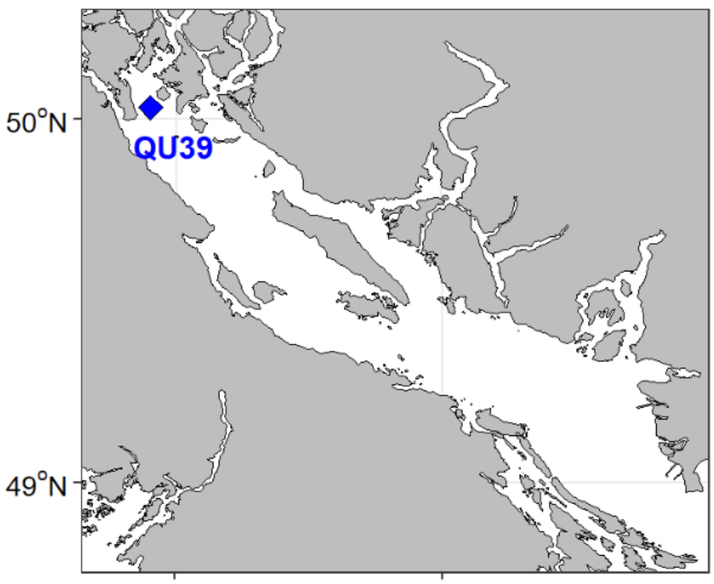

Figure 60-1. Location of station QU39 in the northern Strait of Georgia where the time series is sampled.

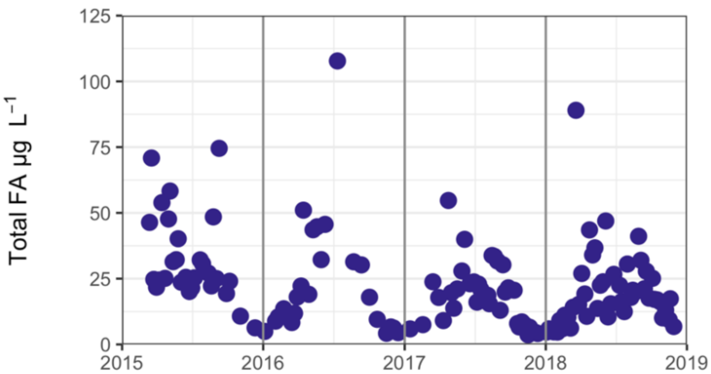

Figure 60-2. Timeseries of total FA (µg L^{-1}) of POM collected at QU39 from 2015 through 2018.

community persisted throughout the summer, while in summer 2015 and 2017 POM was mainly comprised of the complex mixed community. In 2018, both communities were present throughout the summer.

60.4. Implications of these trends

These data show interannual variability in the nutritional quality of POM that likely influence higher trophic levels. The year-to-year differences in POM FA composition are largely driven by changes in the essential FAs alpha-linolenic acid (C18:3n-3) and stearidonic acid (C18:4n-3), both of which are nutritionally important PUFAs and precursors of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). This work provides a basis to use FAs as food web tracers within the zooplankton community, which are also sampled at the same location, and has implications for the growth and survival of fish, including juvenile salmon.

60.5. References

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61. THE BROUGHTON AQUACULTURE TRANSITION INITIATIVE (BATI)

Thomas A. Okey, Director and First Nations Coordinator

Broughton Aquaculture Transition Initiative, *Kwikwasut'Inuxw Haxwa'mis First Nation*, *Mamalilikulla First Nation*, and *'Namgis First Nation*, Tom.Okey@namgis.bc.ca

61.1. Highlights

- Three First Nations in the Broughton Area have chosen a wild salmon future.
- Multiple agreements frame the Broughton Aquaculture Transition Initiative (BATI).
- The BATI is implementing three BC Salmon Restoration and Innovation Fund contribution agreements.
- Monitoring and assessment of watersheds and marine environments in the Broughton Area can be communicated publicly and used in Integrated Ecosystem Assessment.
- A wild salmon future will increase ecosystem health as well as sustenance, health, and prosperity for First Nations communities.

61.2. Summary

The *Mamalilikulla First Nation,* the *'Namgis First Nation,* and the *Kwikwasut'Inuxw Haxwa'mis First Nation* have led the development of government-to-government agreements, recommendations, and frameworks to activate and oversee the recovery of wild Pacific Salmon in their territories in the Broughton area. Recognizing that wild Pacific Salmon are harmed by multiple aspects of salmon farming including sea lice infestation, pathogens, and pollution, the agreements specify a schedule for salmon farm removals, and they provide frameworks and support for an Indigenous Monitoring and Inspection Plan (IMIP) to oversee and regulate salmon farm operations and decommissioning. The framing agreements also provide for the development of a BC First Nations genomics lab and a Wild Salmon Restoration Project that includes assessments, prioritization, and restoration of salmon habitat throughout the watersheds and estuaries of the territories of the three First Nations.

61.3. Framing Agreements

The following agreements involving the aforementioned First Nations, the government of British Columbia, the Government of Canada, and private aquaculture companies provide the framework for the Broughton Aquaculture Transition Initiative.

61.3.1. Letter of Understanding

- A Letter of Understanding between First Nations Governments and Provincial Governments (First Nations and BC 2018a) promulgated a process to address finfish aquaculture in the Broughton Area, including recommendations on Provincial tenure replacement.

61.3.2. Steering Committee Recommendations

- The Letter of Understanding created a Steering Committee to develop collaborative solutions for finfish aquaculture farms in the Broughton Area (First Nations and BC 2018b) includeing a schedule for salmon farm decommissioning

61.3.3. Indigenous Monitoring and Inspection Plan Framework Agreement

- The IMIP Framework Agreement between aquaculture companies Mowi West Canada and Cermaq Canada and the *Kwikwasut'Inuxw Haxwa'mis First Nation,* the *Mamalilikulla First Nation,* and the *'Namgis First Nation* is being implemented by the Broughton Aquaculture Transition Initiative and all involved parties (see Figure 61-1) (First Nations, Mowi, Cermaq 2019).

61.3.4. Contribution Agreements through BC SRIF

Three BC Salmon Restoration and Innovation Fund contributions are approved to support the following Broughton Aquaculture Transition Initiative projects:

- The Independent BC First Nations Genomics Lab Project
- The Broughton Wild Salmon Restoration Project
- The Broughton First Nations Indigenous Monitoring and Inspection Plan

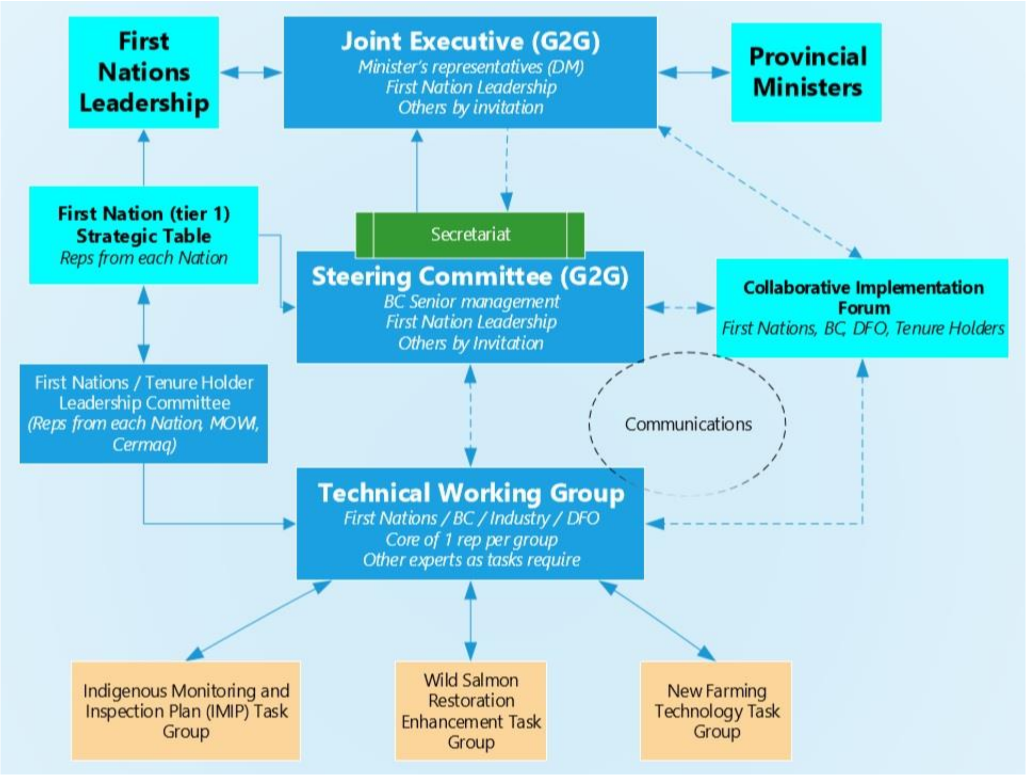

Figure 61-1. Governance and engagement structure for the Indigenous Monitoring and Inspection Plan (First Nations, BC, DFO, Cermaq, Mowi 2019).

61.4. Management Actions

One example of progress in the management of sea lice impacts in the Broughton Area during the transition to prioritizing wild salmon ecosystems is the proposal by the three First Nations to implement a zone-based total-louse approach to deriving farm-specific annual sea lice thresholds for Broughton Area salmon farms beginning in 2021. This science-based proposal assumes that such an approach would most effectively manage the exposure of out-migrating salmon to the concentrations of sea lice associated with salmon farms (see Figure 61-2).

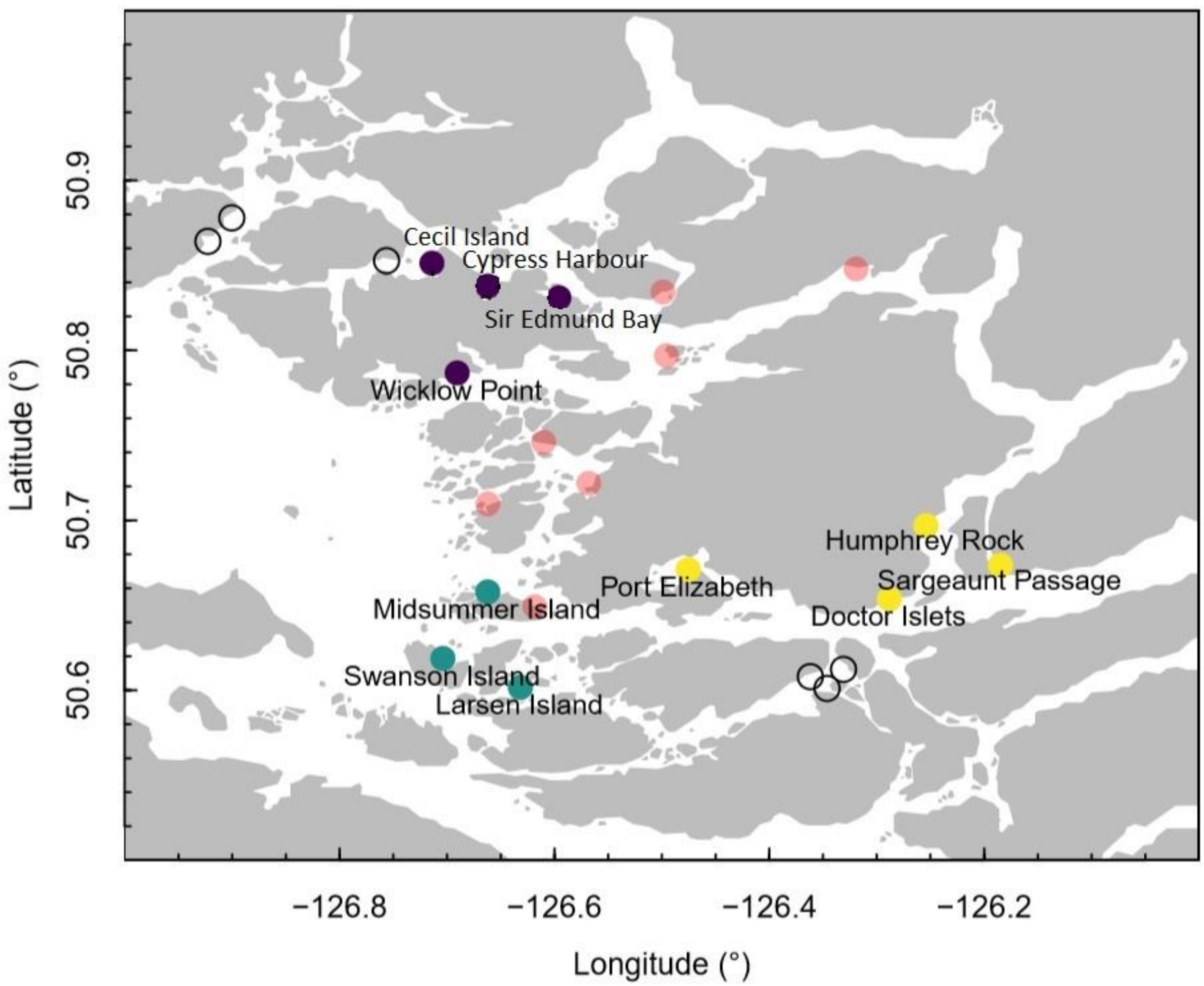

Figure 61-2. Remaining clusters of salmon farms in the Broughton Area (purple, green, and yellow dots). Pink dots denote recently removed salmon farms (Figure by Dr. Andrew Bateman for the present project).

61.5. Data Integration for Public Communication and Integrated Ecosystem Assessment

All parties with data time series relevant to the Broughton Area, such as Mowi, Cermaq, DFO, BC Ministries, ONC, First Nations, and US sources such as NOAA Fisheries could share datasets on online platforms such as the Data Plotting Tool developed by NOAA Fisheries (see Figure 61-3) (NOAA 2020) or other such indicators and data sharing platforms. This approach could also be applied to other marine areas of Canada's Pacific, or all of Canada's Pacific and Canada's other oceans. Information from the Broughton Aquaculture Transition Initiative and the Indigenous Monitoring and Inspection Plan, and DFO's State of the Pacific Ocean Reports, can all be incorporated into these platforms and considered the core of regional Integrated Ecosystem Assessments because it can inform management adaptively.

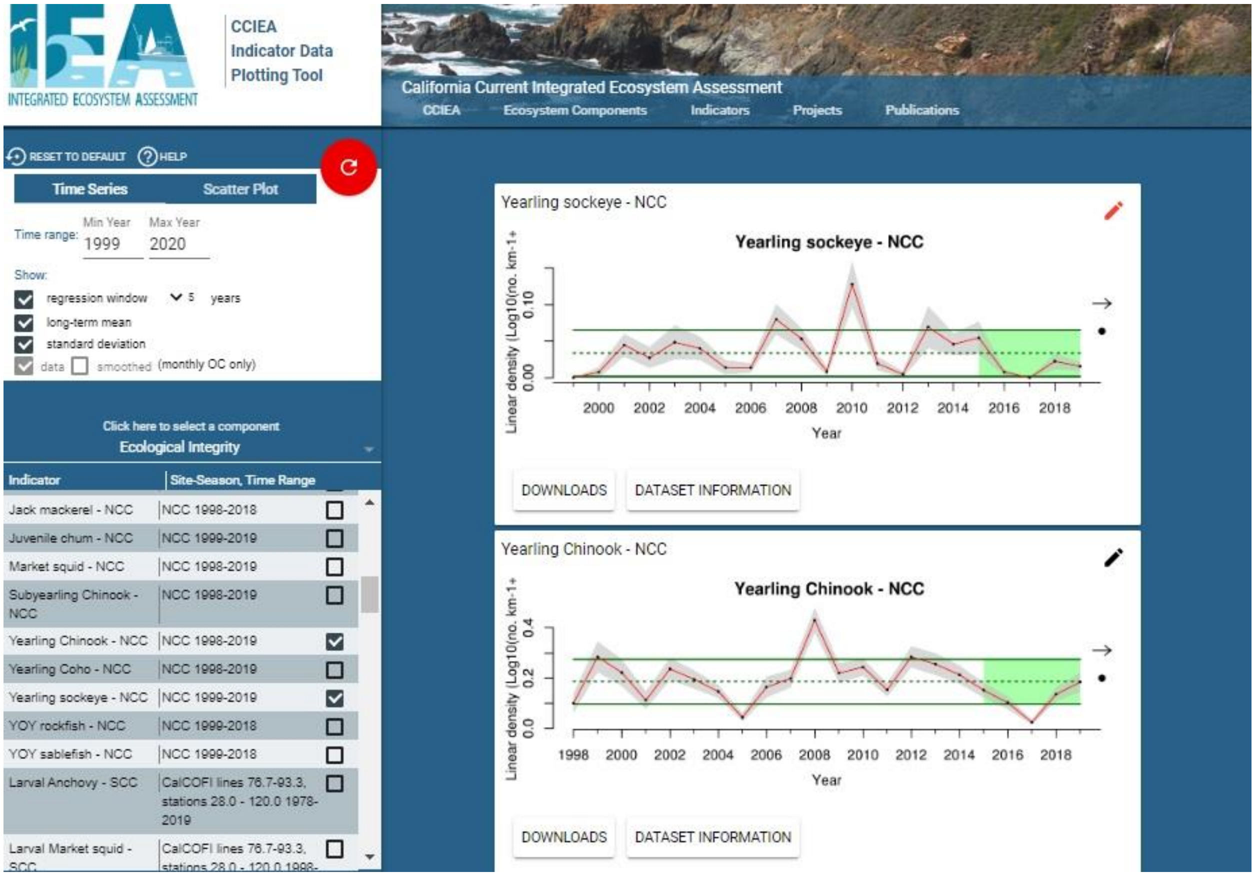

Figure 61-3. The Custom Data Plotting Tool found on the California Current Integrated Ecosystem Assessment website (NOAA 2020) displaying and serving time series datasets from the Northern California Current.

61.6. Conclusion

The Broughton Aquaculture Transition Initiative represents an opportunity for the aquaculture industry in British Columbia to transition to more sustainable practices and adjust to being overseen and regulated by the First Nations in whose territories they operate. It also represents an opportunity for the Province of British Columbia and the Government of Canada to acknowledge the primacy of First Nations conservation, stewardship, and management of natural resources in these territories, and to work together with indigenous communities for a healthier social-ecological future. Moreover, it represents an opportunity for First Nations individuals and communities to manifest their knowledge, skills, and primary authority in the conservation and management of natural resources in their territories. Recognizing that all things are connected, the three First Nations of the Broughton Aquaculture Transition Initiative is prioritizing the restoration and recovery of 'wild Pacific Salmon' populations with the knowledge that this will also aid the recovery of historical biodiversity and productivity in the region, in addition to other aspects of ecosystem and socio-cultural structures, functions, and values.

61.7. References

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62. ZOOPLANKTON BIOREGIONALIZATION OF THE BRITISH COLUMBIA COASTAL OCEAN

Patrick Pata[1,2], Andrew Margolin[1], Moira Galbraith[3], Kelly Young[3], Ian Perry[4], Brian P.V. Hunt[1,2,5]

[1]Institute for the Oceans and Fisheries, University of British Columbia, Vancouver, BC, p.pata@oceans.ubc.ca
[2]Department of Earth, Ocean and Atmospheric Sciences, University of British Columbia, Vancouver, BC
[3]Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC
[4]Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC
[5]Hakai Institute, Victoria, BC

The objective of the project is to develop a data-driven dynamic bioregionalization of the British Columbia coastal ocean based on zooplankton distributions. A subset of the Fisheries and Oceans Canada, Pacific Region zooplankton database was analyzed. This included 3,703 vertical net samples collected during spring and summer from 1995 to 2014, with 464 zooplankton taxa identified to the species or lowest possible taxonomic level. A principal coordinates analysis (PCoA) was performed on the Sorensen dissimilarity of the presence/absence matrix. The PCoA axes were correlated with sample metadata, in situ temperature and salinity integrated over the net tow depth and upper 0 to 50 m, and climate indices. Axis 1 (22.8% variance explained) represented the bathymetry gradient (deep to shallow) while axis 2 (10.1% variance explained) represented the salinity gradient (estuarine to oceanic). Axes 3 and 4 (9.7% variance explained) represented mixed temporal gradients of inter-annual to decadal variability. The first 16 PCoA axes, representing 75% of the total variance, were used in a k-means cluster analysis. Seven bioregions were identified (Figure 62-1) that represented zooplankton communities typical of (1) offshore north/west, (2) offshore south/east, (3) shelf deep, (4) shelf coastal cool, (5) shelf coastal warm, (6) estuarine deep, and (7) estuarine shallow waters. A closer look into the assignment of bioregions for frequently sampled research stations (Figure 62-1) showed a temporally dynamic component of intra-annual and inter-annual variability. The log-Chord transformed taxa abundances were correlated with the PCoA axes and were used in an indicator value analysis against the seven bioregions. This demonstrated species-level sensitivity to bioregionalization, and that the relative abundances of common zooplankton taxa were most indicative of the bioregions. Averaging of the biomass of all the samples in each bioregion showed regional differences in the total mesozooplankton biomass and community composition. The number of bioregions was selected based on producing qualitatively relevant patterns. Future work will involve using a quantitative and ecologically meaningful basis for delineating bioregions.

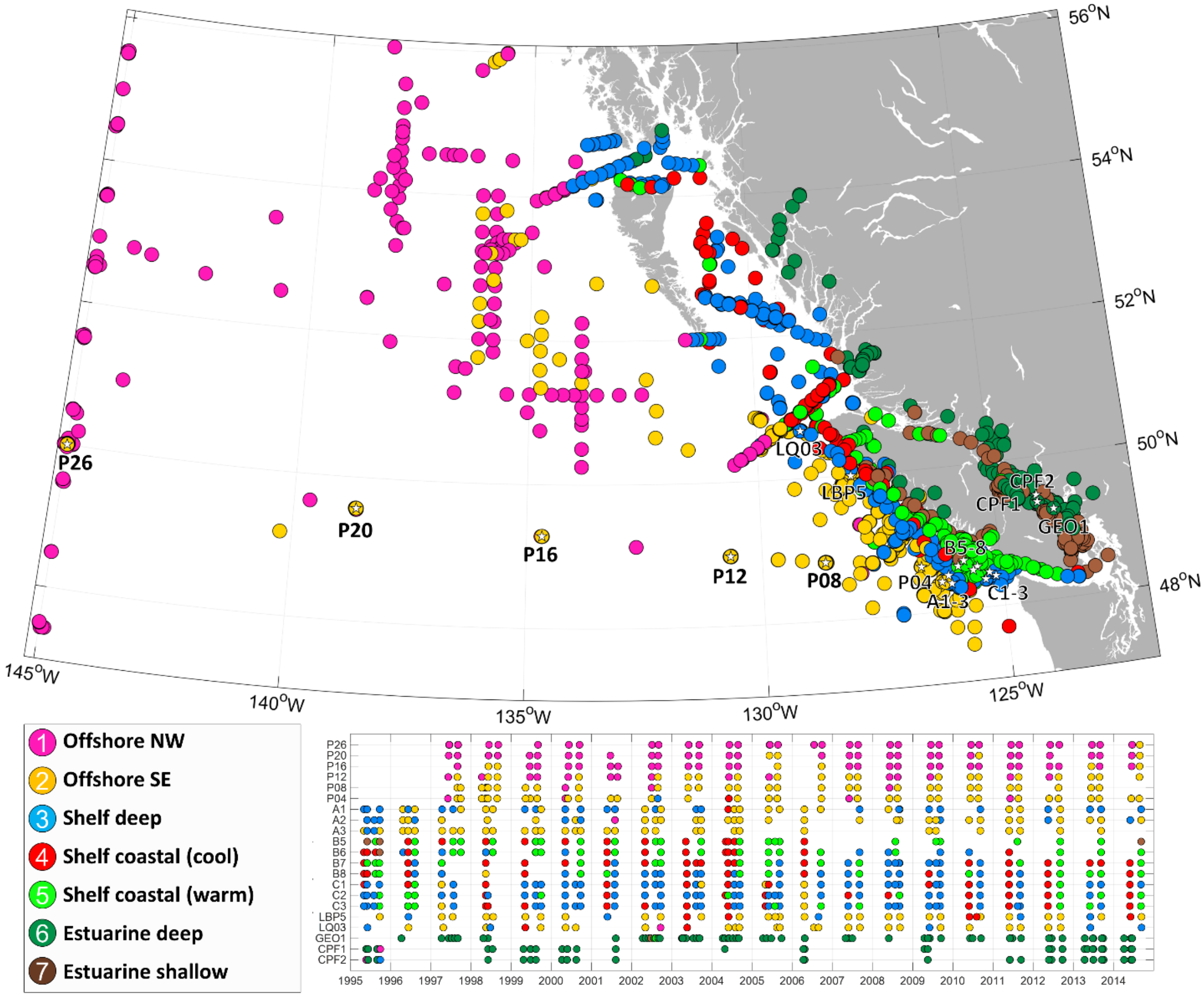

Figure 62-1. Upper figure shows the seven bioregions representing zooplankton communities. Legend in lower left. The most recent cluster is on top, because samples overlap in space. Lower right figure shows a time series of the most frequently sampled stations (marked on the map).

63. A CLIMATOLOGY OF THE STRAIT OF GEORGIA: THE PSF CITIZEN SCIENCE DATASET 2015-2019

Richard Pawlowicz[1], Isobel Pearsall[2], Svetlana Esenkulova[2], Sam Stevens[1], Ben Skinner[2], Ryan Flagg[3]

[1]Ocean Dynamics Laboratory, EOAS-UBC, Vancouver, BC, rpawlowicz@eoas.ubc.ca, sstevens@eoas.ubc.ca
[2]Pacific Salmon Foundation, Vancouver, BC, pearsalli@psf.ca, svesen@uvic.ca, bskinner@psf.ca
[3]Ocean Networks Canada, Victoria, BC, rmflagg@uvic.ca

63.1. Background

A "Citizen Science" program to collect hydrographic data was initially proposed by Dr. Eddy Carmack at Fisheries and Oceans Canada (DFO). He envisioned a 'mosquito fleet' of private boats collecting data from overlapping areas of the Strait of Georgia (SOG) on the same days throughout the year. Such a program has now been operating since 2015, funded and operated by the Pacific Salmon Foundation (PSF).

Key objectives of the program are as follows:

- To achieve oceanographic monitoring of the SOG at a temporal and spatial scale not achieved before.
- To examine how changes in ocean temperatures, oxygen content, salinity, and nutrients impact the food web moving up from phytoplankton to zooplankton and ultimately to Pacific Salmon.
- To determine the prevalence of harmful algal blooms throughout the SOG.
- To determine the timing and propagation of the spring bloom throughout the Strait.

To carry out this program, trained members from local communities collect information in the Strait of Georgia 1 to 3 times a month year-round at approximately 70 sites (Figure 63-1). Conductivity-temperature-depth (CTD) profiles, with additional information on chlorophyll fluorescence and dissolved oxygen content, are collected at all stations, along with secchi disk measurements and phytoplankton content. Nutrient samples at 0 and 20 m depth are collected at ~40 stations, filtered chlorophyll at a depth of 5 m at 9 stations, and zooplankton samples from net tows at three stations.

Logistical support, as well as processing and initial analysis of this field data, is carried out by groups at PSF, University of British Columbia, Ocean Networks Canada (ONC), Fisheries and Oceans Canada, and the University of Victoria. The electronic profile data is managed by ONC, who developed a smart phone application for data transfer so that profiles can be sent directly from the small boats to ONC, where it undergoes quality control and is then archived and made freely available over the internet. ONC also carries out instrument calibrations and provide engineering support.

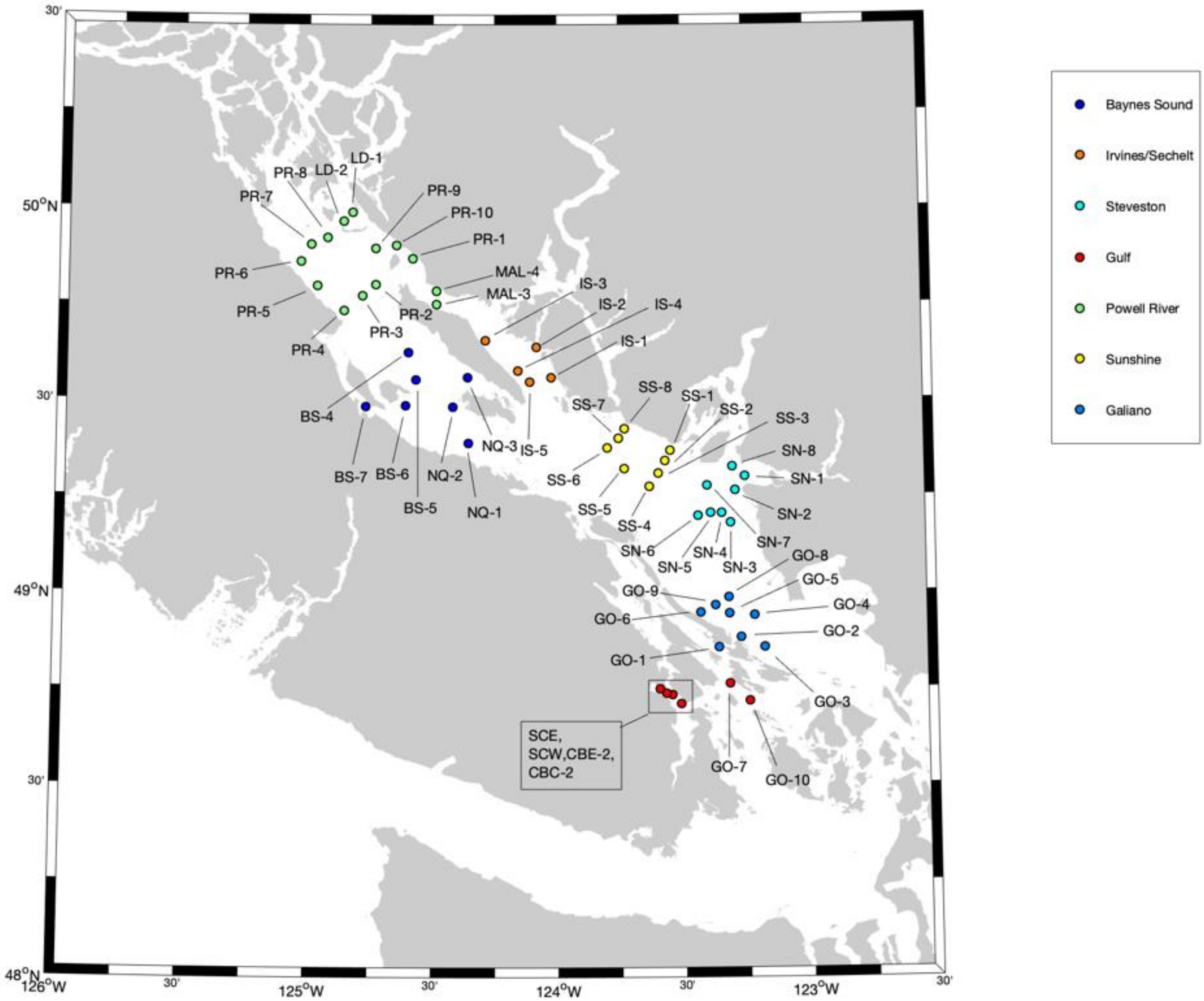

Figure 63-1. Map of the Strait of Georgia with 2019 Citizen Science Program sampling locations.

63.2. Description of the time series

A large number of samples were collected each year between 2015 and 2019 (Table 63-1). Data storage, quality control, calibrations carried out by ONC and UBC. All of the data are freely available in Oceans 2.0 and data, maps & animations are also freely available at the Strait of Georgia Data Centre www.sogdatacentre.ca. This includes CTD cast data, nutrients (nitrate+nitrite, silicate and phosphate), filtered Chlorophyll a, secchi depths, phytoplankton (including harmful algal blooms) and zooplankton abundance and biomass by species.

Currently, a climatological atlas is in preparation by Dr. Rich Pawlowicz and others at UBC. Figures 63-2 provides an example of the type of time series information that is being collated. The

Citizen Science Program provides unique data for the entire SOG at a resolution that has not been possible before.

Table 63-1. The number of samples collected each year between 2015 and 2019.

Sampling Years	Vessel Trips	CTD casts	Nutrients Collected	Phytoplankton Collected	Chlorophyll Collected	Secchi Recordings	Zooplankton Collected	Total Samples
2015	150	1,132	2,264	1,381	193	2,088	146	7,204
2016	199	1,445	1,587	2,064	349	2,825	60	8,330
2017	197	1,420	1,529	1,934	340	2,814	54	8,091
2018	205	1,160	1,621	2,037	362	2,903	69	8,152
2019	133	741	972	1,053	186	1,482	54	4,488
5 years	884	5,898	7,973	8,469	1,430	12,112	383	36,265

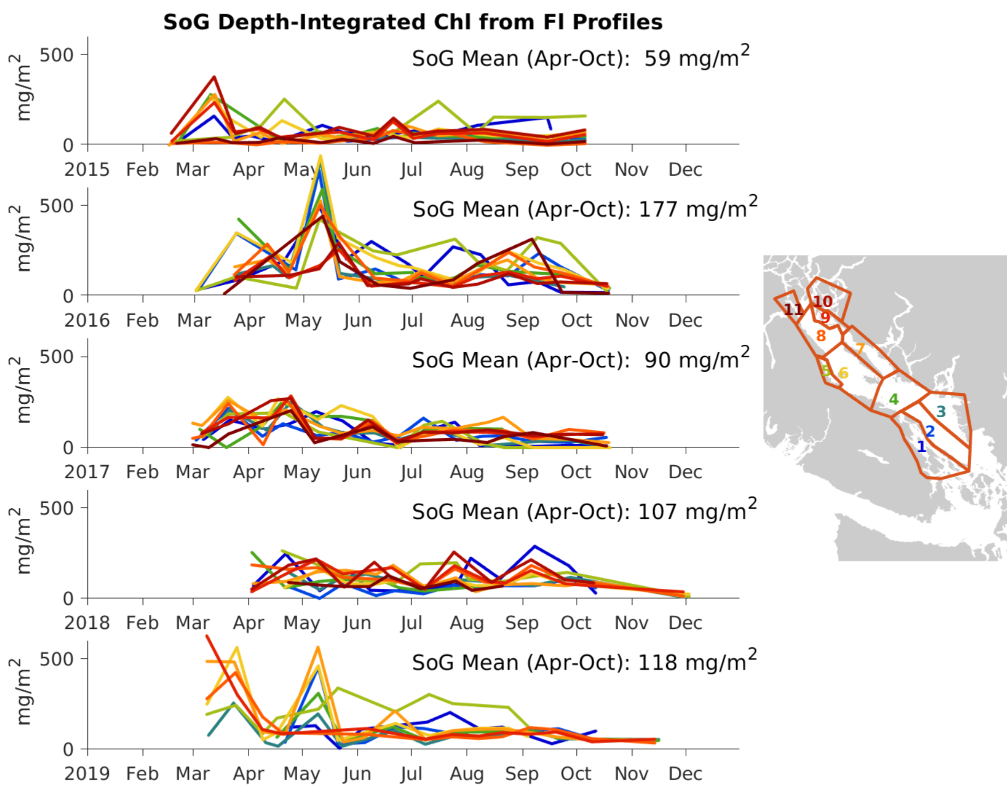

Figure 63-2. Depth integrated Chl-a from CTD fluorometer profiles in the Strait of Georgia 2015-2019 (i.e., top panel is 2015, bottom panel is 2019).

63.3. Acknowledgements

This project would not be possible without the hard work of many people, who we gratefully acknowledge. The logistical backbone of the project is managed by Nicole Frederickson (current) and Colin Novak (2015-2019), who also answered many questions. Scientists at DFO provided assistance in the initial planning and establishment of the program. Many people at ONC assisted in calibrations, app development, and QA/QC. Scientific evaluation of the data was carried out in the Pawlowicz lab at UBC, with the assistance of Janet Lam, Nicholas Larsen, Reese Chappel, and Trent Suzuki. Finally, this project would not have happened without the dedicated citizen scientists around the Strait of Georgia who actually go out to sea to make these measurements. And thank you to PSF for their continued funding of this important program.

64. MICROCYSTINS IN COASTAL WATERS OF SOUTHERN BRITISH COLUMBIA AND THEIR EFFECTS ON SALMON HEALTH

Ryan B. Shartau*[1], Lenora Turcotte[1], Albert Caballero Solares[2], Heinrich Snyman[3], Pearse McCarron[4], Julia C. Bradshaw[1], Matthew Rise[2], Stewart C. Johnson[1].

[1] Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, *Ryan.Shartau@dfo-mpo.gc.ca
[2] Ocean Sciences, Memorial University, St. John's, NL
[3] Laboratory Services Division, University of Guelph, Kemptville, ON
[4] National Research Council, Halifax, NS

Toxins produced by harmful algae negatively impact marine organisms, including wild and farmed salmon. In the coastal waters of southern British Columbia (B.C.), numerous mortality events attributed to exposure to algal toxins have been recorded at fish farms. In addition, histological analysis of wild salmon suggests that they are similarly exposed to algal toxins during their marine residency. One of the diseases attributed to algal toxin exposure in B.C. is Net Pen Liver Disease (NPLD), which is a toxicopathic liver disease first reported in Washington State and B.C. around 1990 (Kent 1990). In recent years, the incidence and severity of this disease has increased on B.C. salmon farms resulting in millions of dollars of lost production. This disease is characterized by loss of gross liver structure and histological changes that include prominent hepatic megalocytosis. Interestingly, similar lesions have been reported from wild and farmed Chinook Salmon collected in the Strait of Georgia and Oregon and Pink Salmon in the Broughton Archipelago (Kent et al. 1988; Stephen et al. 1993). This disease is attributed to exposure to microcystins (MC), which are a group of closely related hepatotoxins produced by Cyanobacteria (Andersen et al. 1993).

In this project we established a monitoring program for MC and other algal toxins, examined the role of MC in the development of NPLD, and compared the physiological processes (e.g. immune, endocrine, cardiac and metabolic) and cellular effects of sub-lethal environmentally relevant MCs exposure on Atlantic and Chinook Salmon.

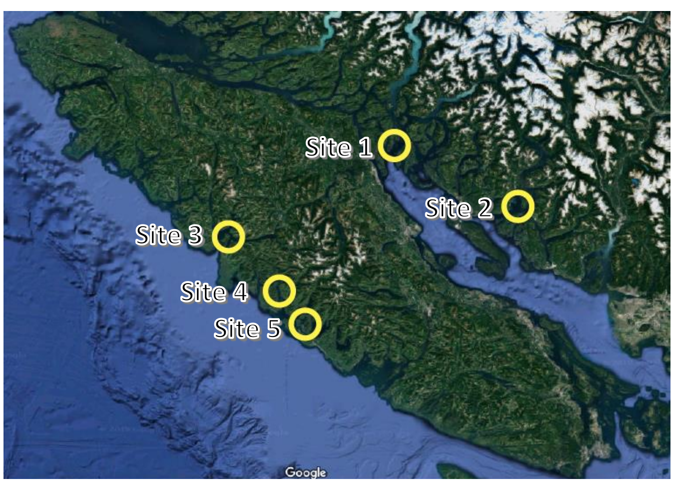

Figure 64-1. Sites in Southern British Columbia where sampling occurred for microcystin, okadaic acid, and domoic acid.

The presence of algal toxins was monitored using passive Solid Phase Adsorption Toxin Tracking (SPATT) and discrete water sampling at five fish farm sites from June 2017 to September 2019 (Figure 64-1). Samples were analyzed for the presence of MC, okadaic acid (OA) which has a similar mechanism of toxicity as MC, and domoic acid (DA) which is a toxin of potential concern to salmon producers. All three toxins were found at all sites over the two-year period in both SPATT and water samples. With respect to MC, the range in

SPATT samples across all sites was 0.04 – 6.70 ng MC g $SPATT^{-1}$ day^{-1} (Figure 64-2) while MC concentrations in water samples ranged from 0.15 – 2.26 ng MC L^{-1} across all sites; these values are comparable to marine environments in California where MC in coastal waters are a recognized environmental concern (Gibble et al. 2016; Peacock et al. 2018).

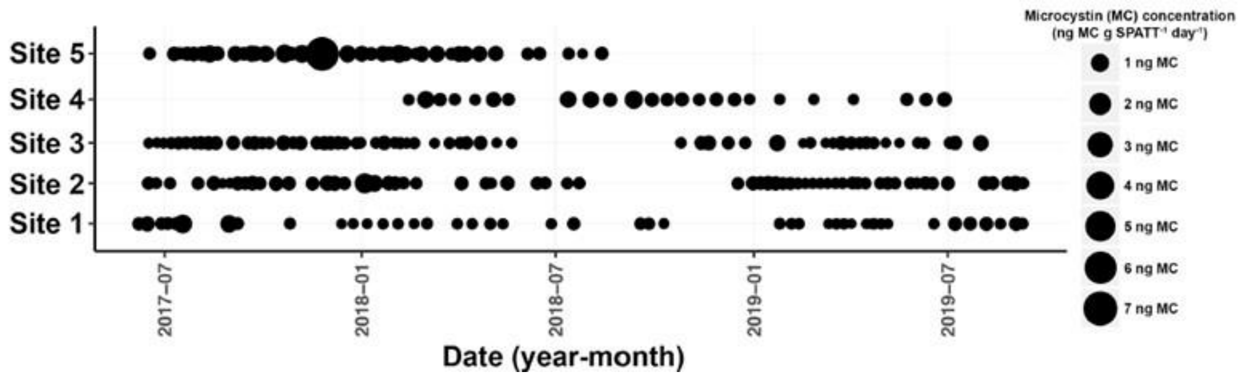

Figure 64-2. Concentration of microcystin in Solid Phase Adsorption Toxin Tracking (SPATT) samples (ng MC g $SPATT^{-1}$ day^{-1}) at five sites from June 2017 to September 2019 (see Figure 64-1 for map).

The effect of sub-lethal MC exposure on salmon was investigated by oral gavage of juvenile Atlantic and Chinook Salmon with different MC concentrations (1700, 2200, and 3200 μg kg^{-1}) of MC-producing cyanobacteria, non-toxic cyanobacteria, and saline. Fish were sampled at 5 time points post-gavage (6, 12, 24, 72h and 2 weeks) and tissues (liver, head kidney, and brain) were collected for histology and gene expression. Histopathology indicated that hepatic structural changes that included biliary preductular cell hyperplasia and hepatocellular hydropic degeneration occurred by 6h post-gavage in both species and persisted until 24h; lesions were largely resolved by 72h. Similarly, the expression of genes associated with liver function and health were upregulated at 6h and returned to control levels by 72h and 2 weeks post-gavage. Expression of genes in head kidney associated with immune and inflammatory responses changed similarly. Gavage of a single sub-lethal dose of MC did not produce hepatic megalocytosis, the defining characteristic of NPLD, however severe, but reversible, changes in liver histopathology occurred indicating that MC induced rapid structural changes. Gene expression demonstrated a transcriptional response due to MC exposure typical of toxin exposure as genes associated with inflammation, immunity, and stress responses were upregulated in liver and kidney, indicating MC exposure is stressful.

NPLD did not develop in Atlantic or Chinook Salmon following this environmentally-relevant MC exposure experiment. This suggests the development of NPLD in wild and farmed fish may require exposure to higher MC concentrations during blooms and/or through the ingestion of contaminated natural feeds, or longer term chronic exposure to MC (possibly in in conjunction with other toxins) through drinking of contaminated seawater or absorption through tissues such as gills. Additionally, OA, which co-occurs at much higher concentrations than MC in our samples, may be contributing to the development of NPLD as OA is a hepatotoxin with a similar mode of toxicity.

In zebrafish and medaka, sublethal MC exposure has been found to have effects on behaviour, reproduction, and the ability to tolerate other stressors in the absence of disease (Liu et al. 2014; Manach et al. 2018). The effects of environmentally relevant chronic exposure of salmon to MC and other algal toxins (individually or combined) has not been examined. We anticipate that salmon have some natural tolerance to the presence of toxins in the marine environment, however, changes in the frequency and/or magnitude of toxin exposure may occur due to climate change or other anthropogenic influences (Wells et al. 2015). It remains to be investigated what are the sub-lethal and lethal tolerance thresholds for salmon in response to algal toxin exposure, and how toxin exposure affects their ability to respond to naturally occurring environmental stressors (e.g. hypoxia, temperature change). Investigating the routes of exposure and the physiological impact of these toxins on salmon (and other marine organisms) will be an important part of understanding the ecosystem-level effects of harmful algal blooms in marine ecosystems, including their possible role in the decline of salmon populations (Noakes et al. 2000).

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65. USING SEASONALITY TO TRACE WATER MASSES IN A COASTAL OCEAN

Samuel W. Stevens, Rich Pawlowicz and Susan Allen, Department of Earth, Ocean and Atmospheric Sciences, University of British Columbia, Vancouver, BC, sstevens@eoas.ubc.ca, rpawlowicz@eoas.ubc.ca, sallen@eoas.ubc.ca

The Intermediate Water (IW) of the Strait of Georgia directly receives around half of Greater Vancouver's wastewater via a submarine outfall offshore of Iona Beach. However, the IW circulation that acts to disperse anthropogenic pollutants from this outfall throughout the strait is poorly understood. This study uses a synthesis of hydrography from various time-series programs- most prominently the Pacific Salmon Foundation Citizen Science program- to address this. Previously, studies in B.C. waters have exploited the spatially varying signal of seasonality from a handful of hydrographic stations to track subsurface ventilation signals (Leblond et al. 1991; Pawlowicz et al. 2007). We expand this analysis to a regional scale, using data from over 130 hydrographic stations in the Strait of Georgia to compare the phase difference and amplitude variability of the seasonal cycles of temperature to infer water mass age and mixing. We also use model outputs from SalishSeaCast- a baroclinic, three-dimensional, primitive equation model of the Salish Sea- to supplement these analyses. We find that the IW ventilation signal propagates northwards from Haro Strait with an average speed of 1.5 - 2.0 cm s^{-1}, though propagation speeds of up to 3 cm s^{-1} are observed in a boundary current on the eastern shores of the southern basin. The oldest IW, with an age of approximately 120 days, is found in the northwest of the region, where seasonal cycle amplitude damping of up to 85% suggests that a large percentage of the IW has been modified by mixing processes during its journey. A second renewal signal is identified within the upper IW emanating southwards from the Discovery Passage area, though it is not clear whether this represents a new input of water into the system or simply a manifestation of water mass transformation processes within Discovery Passage. Finally, we perform Lagrangian particle tracking experiments within SalishSeaCast to trace the pathways of the two ventilation inflows and use these virtual particles to calculate dispersion and residence time statistics for the region.

65.1. References

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66. ‘DATA HOLE’ IN MARINE PROTECTED AREAS

Di Wan, Pramod Thupaki, Roy Hourston, and Charles Hannah, Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Di.Wan@dfo-mpo.gc.ca

There are currently 14 Marine Protected Areas (MPAs) in Canada and three are in the Pacific Ocean: Endeavour Hydrothermal Vents, SGaan Kinghlas-Bowie Seamount, and Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs. MPAs are key to a healthy marine environment and provide a science based understanding of the coastal environment and communities. The data records at the Institute of Ocean Sciences, Fisheries and Oceans Canada, which hosts most of the data collected in the Pacific Region show that the data distribution in these three MPAs is not uniform in time or space (Figure 66-1). Endeavour Hydrothermal vents have more data than the other two MPAs but are concentrated between 1985 and 2008; the Hecate Strait Glass Sponge Reef site has samples since 1950s to the present with gaps in the middle; the SGaan Kinghlas-Bowie Seamount site only has a few discrete samples in some years. Continuous monitoring programs in MPAs are needed as they are important for understanding the long-term ecological and environmental trends and effectiveness of the MPA management tool.

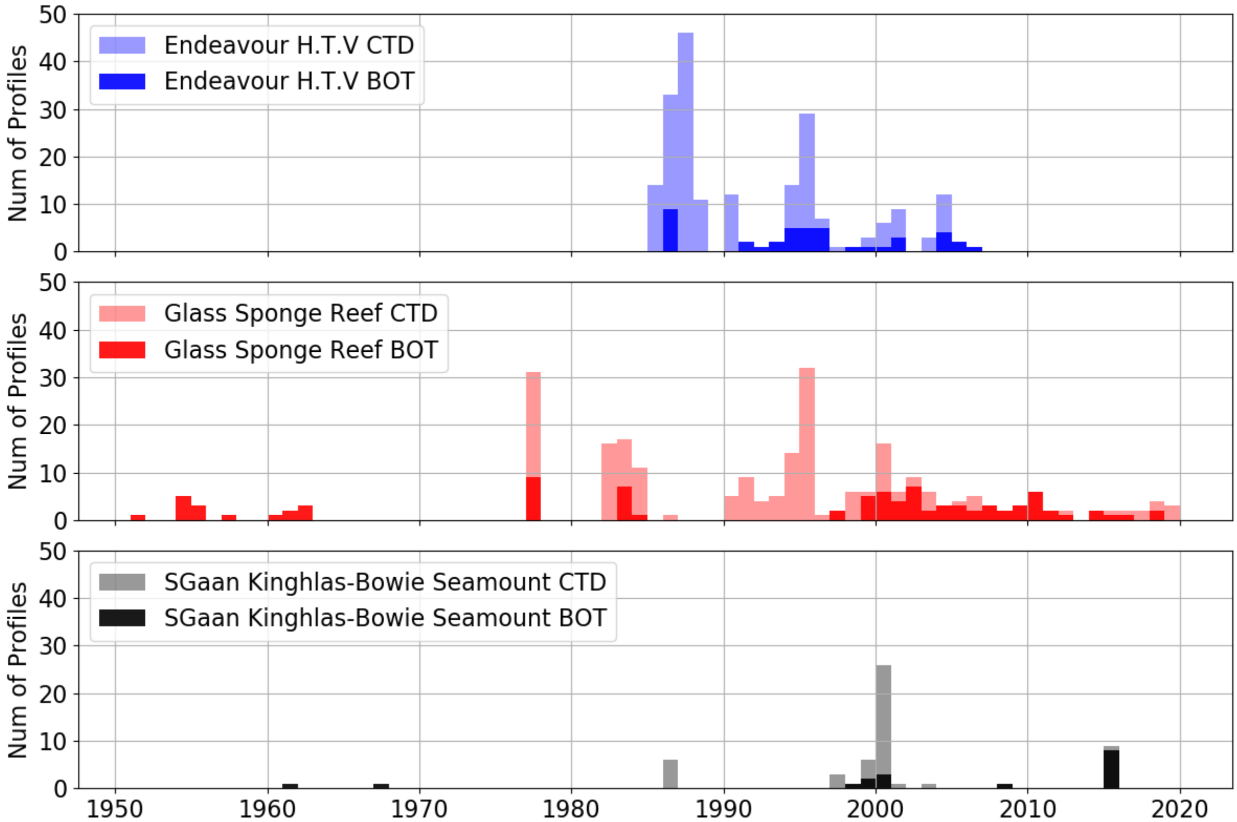

Figure 66-1. Detailed CTD (Conductivity, Temperature, and Depth) sample and bottle (BOT) water sample distribution in three MPAs over time. H.T.V. = hydrothermal vent.

66.1. Acknowledgements

All the data are compiled from Open Data Portal and Canadian Integrated Ocean Observing System (CIOOS) Pacific, which is a powerful open-access platform for sharing information about the state of our ocean.

- https://cioospacific.ca
- https://www.waterproperties.ca/data/
- https://open.canada.ca/data/en/dataset/a1e18963-25dd-4219-a33f-1a38c4971250
- https://www.dfo-mpo.gc.ca/oceans/mpa-zpm/index-eng.html

67. MOORING PANELS CONTRIBUTE TO OUR UNDERSTANDING OF MARINE DEBRIS AND INVASIVE SPECIES

Linsey Haram[1]*, Cathryn Murray[2], Cindy Wright[2], Greg Ruiz[1], and Jim Carlton[3]

[1]Smithsonian Environmental Research Center, Edgewater, MD, USA *HaramL@si.edu
[2]Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC
[3]Williams College, Williamstown, MA, USA

Man-made marine debris consists of 75% plastic material (Thompson and Maximenko 2016), and at least 8 million tons of plastic, ranging from large pieces to micro-beads and fibers, are estimated to enter the ocean every year (Jambeck et al. 2015). Findings from the 2011 Japan tsunami show how such debris acts as habitats on which more than 300 species travelled thousands of kilometres to arrive on distant coastlines (Carlton et al. 2017). The movement of marine debris across ocean basins mimics in distance, but not in kind, the extremely rare natural rafting events that have populated islands over geological time scales (Kay and Palumbi 1987). The extreme longevity of plastic as a substrate in the ocean and its rapidly increasing amounts suggest that plastic debris will play an increasing role as a vector of potentially invasive species, mediated by a "floating ecosystem" in the garbage patch (Barnes 2002; Gregory 2009).

Here we describe our investigation into the developing fouling community associated with the marine debris, particularly in the open ocean and the garbage patch. As a proxy for marine debris, we attached fouling panels to mooring structures in Canadian and US Pacific waters and present the results of the developing species diversity and community. Fouling panels are a low tech passive experimental device to identify and monitor fouling species in an ecosystem and their deployment on mooring structures in the open ocean is a unique and innovative application. Using the data from the mooring panel research to complement the larger project which aims to sample biological diversity on floating marine debris opportunistically in the garbage patch and model the movement of marine debris in the North Pacific we give new insight into the issue of marine debris and the interaction between two emergent stressors – marine debris and invasive species.

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68. ESTIMATING FRASER RIVER SOCKEYE SALMON RUN SIZE USING A MACHINE LEARNING METHOD

Yi Xu[1], Mike Hawkshaw[1], Caihong Fu[2], Roy Hourston[3], David Patterson[4], Peter Chandler[3]

[1]Fisheries and Oceans Canada, Fraser and Interior Area, Delta, BC, yi.xu2@dfo-mpo.gc.ca, mike.hawkshaw@dfo-mpo.gc.ca
[2]Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, caihong.fu@dfo-mpo.gc.ca
[3]Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, roy.hourston@dfo-mpo.gc.ca peter.chandler@dfo-mpo.gc.ca
[4]Fisheries and Oceans Canada, Science Branch, Pacific Region, School of Resource and Environmental Management, Simon Fraser University, Burnaby, BC, david.patterson@dfo-mpo.gc.ca

68.1. Highlights

- A Boosted Regression Trees model (BRT) was developed to study the mathematical relationships between Fraser River Sockeye Salmon recruitment and multiple environmental variables.
- In general, the BRT model is able to reproduce major variations observed and can explain over 50% of the variability in recruitment of all selected Sockeye Salmon stocks.
- The key environmental parameters that explain the variability vary among 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.

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

68.2.1. Fish Population Data

The Fraser Sockeye Salmon (*Oncorhynchus nerka*) recruitment time series (1948-2015) were provided by the Pacific Salmon Commission (PSC) and the time series of effective females spawners (EFS) and juvenile abundance (Juv) for the same period were provided by DFO for 19 major stocks (Figure 68-1). These data sets, detailed in Grant et al. (2011) were used to forecast Sockeye run size in 2019 (DFO 2019).

68.2.2. 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 68-1). 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 1950-2015 except for BI (from 1967-2013).

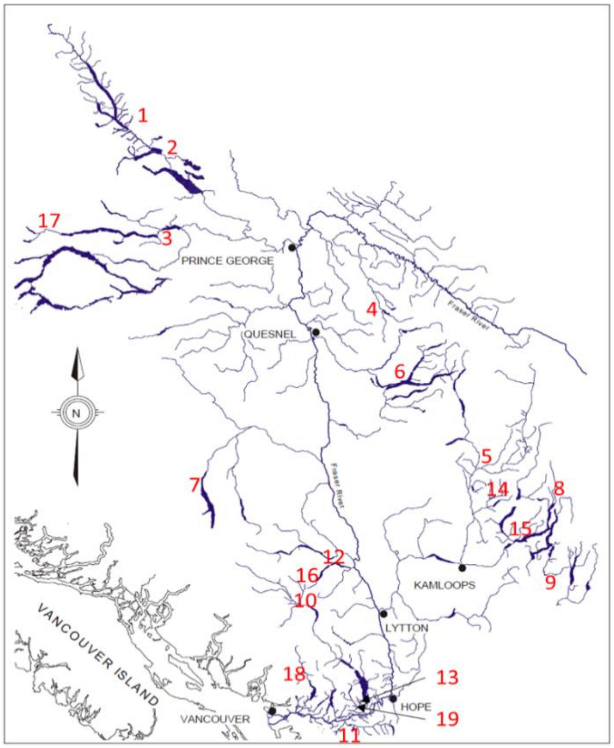

Figure 68-1. Locations of 19 major Fraser Sockeye salmon stocks where spawning data were collected.

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 68-1. Leading environmental factors identified by Boosted regression trees model.

Climate indices	Annual Pacific Decadal Oscillation (PDO) Summer PDO (Jun, Jul, Aug) Winter NPGO (Dec, Jan, Feb) Winter Northern Oscillation Index Bifurcation Index	pdo pdo.sum npgo.win noi.win BI
Regional sea surface temperature	Entrance Island April SST Entrance Island June SST Pine Island April SST Pine Island May SST Pine Island July SST Gulf of Alaska summer SST (Jun, Jul, Aug) Gulf of Alaska May SST	apesst jnesst appsst mapsst jlpsst ocean.sst.sum ocean.sst5
Wind stress	Summer upwelling-favoured at West Coast Vancouver Island Winter upwelling-favoured at West Coast Vancouver Island Annual upwelling-favoured at Central Coast Annual downwelling-favoured at Central Coast Winter downwelling-favoured at Prince Rupert District Annual upwelling-favoured at Prince Rupert District	wind.wcvi.up.sum wind.wcvi.up.win wind.cc.up.annual wind.cc.dn.annual wind.prd.dn.winter wind.prd.up.annual
Discharge	Fraser River discharge at Hope in April and June	aflow

68.2.3. Boosted regression trees model

A tree-based model (BRT, boosted regression trees; Elith et al. 2008) was developed to study the mathematical relationships between Sockeye recruitment and multiple environmental co-variates. 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 2019).

68.3. 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 68-2) with the Early Stuart stock achieving the highest level (85.9%). 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.

68.4. Factors influencing trends

For most Fraser River Sockeye Salmon stocks, the BRT models identified EFS or Juv as the top contributor that had the highest relative influence (%) for predicting Sockeye Salmon recruitment (Figure 68-3). For all stocks (except for the Weaver Creek), predicted recruitment showed a Beverton-Holt-like relationship with EFS or Juv, and the relative influences varied from 20-70% among different stocks. While the relationship between recruitment and the top biological factor (EFS or Juv) was shown as Beverton-Holt-like, the relationship between recruitment and the dominant environmental factor was diverse in shapes. For example, wind stress and BI showed complex nonlinear relationships, and warmer SSTs and a positive Pacific Decadal Oscillation (PDO) were negatively related to Sockeye Salmon recruitment. 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, and Weaver Creek stocks), the dominant environmental factor showed a smaller contribution (with lower relative influence) compared to a top biological factor in other stocks.

68.5. Run size forecasts and implication of the BRT modeling method

The BRT model produced forecasts of Sockeye Salmon run size for the year 2020 (Figure 68-4), totaling around 1.69 million and run size of the Chilko stock of about 580,000 – this is the largest among the 19 Fraser River Sockeye Salmon stocks and represents 34% of the forecasted total of all stocks combined. Other stocks including Stellako, Quesnel, Birkenhead, Weaver Creek and Nadina are predicted to have more than 75,000 recruits; this is the lower abundance threshold guideline for determining whether high precision spawning escapement methods (e.g. sonar, mark-recapture) should be planned for the upcoming year. Forecasted run sizes for Late Stuart and Harrison stocks are both near the cut-off, between 70,000 to 75,000, suggesting early in-season information on stock run-size could be crucial for last minute changes to spawning escapement field operations. In contrast, the remaining populations, Early Stuart, Bowron, Raft, Seymour, Late Shuswap, Cultus, Portage, Fennel Creek, Scotch Creek, Gates stocks, and Upper Pitt River are relatively small (<70,000 fish). These stock-specific results provide useful and timely information to both harvest managers and stock assessment operations for the upcoming 2020 summer/fall enumeration surveys.

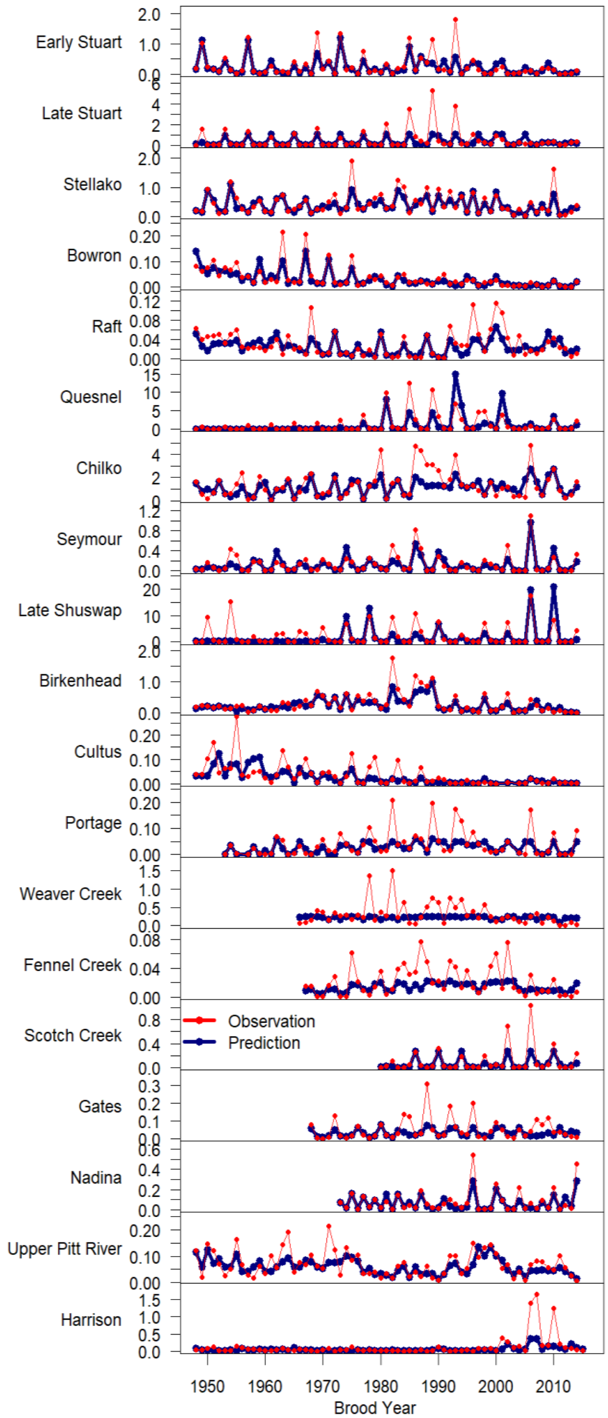

Figure 68-2. Observed and Boosted-Regression-Trees predicted recruitment (log scale) of 19 Fraser River Sockeye Salmon stocks.

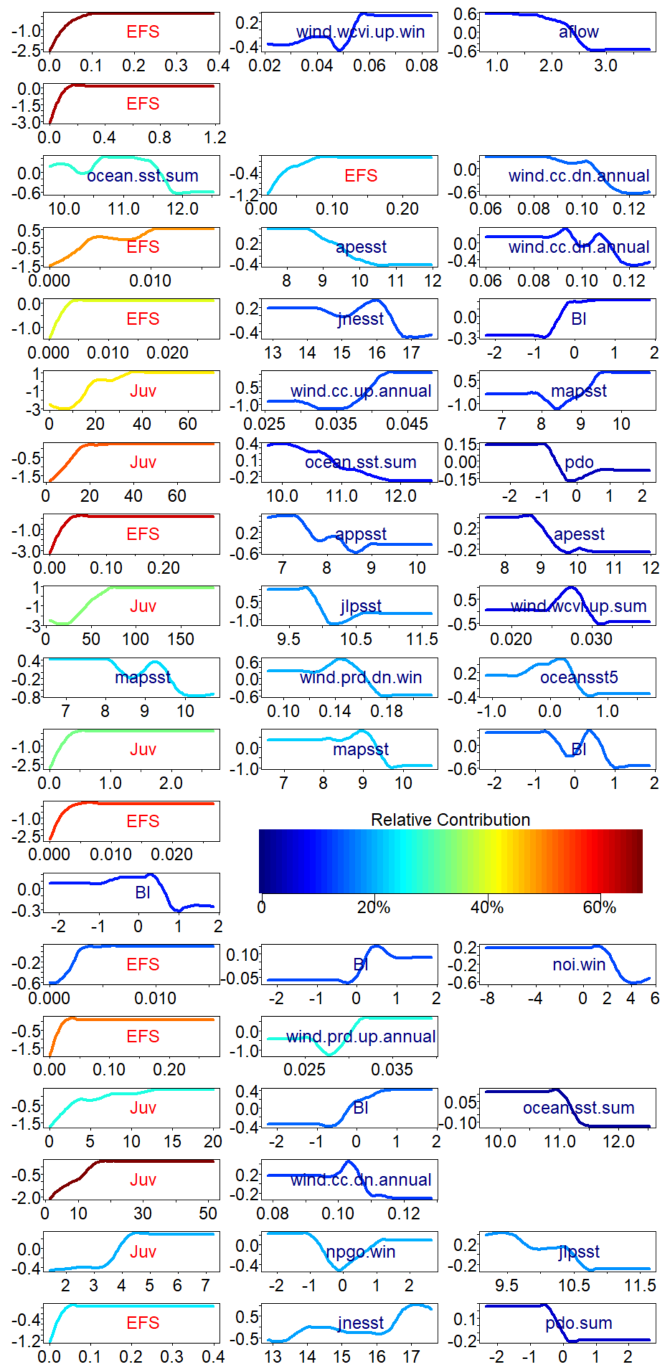

Figure 68-3. Fitted functions of top three predictors and relative contributions from the Boosted Regression Trees models (See Table 68-1 and text for acronym definitions).

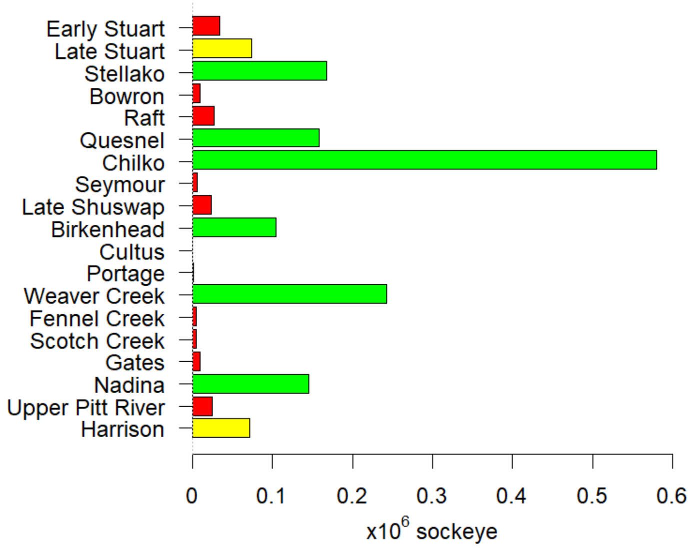

Figure 68-4. The Boosted Regression Trees model run size forecasts of 19 Fraser River Sockeye salmon stocks in 2020 (Red: <=70,000, Yellow: 70,000-75,000, Green: >=75,000).

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

Zane Zhang, Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, zane.zhang@dfo-mpo.gc.ca

69.1. 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 and 2019.
- In 2019, CPUE in the Pacific Canadian exclusive economic zone (EEZ) was similar to that in the U.S. EEZ; in most of the earlier years, CPUEs in Canada's EEZ were substantially lower than those in the U.S. EEZ.
- CPUEs are significantly and positively correlated with North Pacific Gyre Oscillation (NPGO) indices in both the Pacific Canadian and the U.S. EEZs.

69.2. 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 EEZ, 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 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 in the U.S. EEZ in 1995 by the Canadian fishery. No CPUE data exists in the U.S. EEZ in 2013, as no Canadian albacore fishing occurred there.

69.3. 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 were increasing in 2018 and 2019 following the drastic drop, exceeding the overall mean in 2019 (Figure 69-1A). Albacore CPUEs in the U.S. EEZ by the Canadian fishery showed a general increasing trend between 1996 and 2015. CPUEs decreased in 2016 and 2017, increased in 2018, and fell again in 2019 (Figure 69-1B). Ratios of CPUEs in the Canadian EEZ to CPUEs in the U.S. EEZ showed substantial variation between 1996 and 2019, although the ratios were all below one (Figure 69-2). This ratio was higher than 0.9 in 2019, as in 2002, 2005 and 2010.

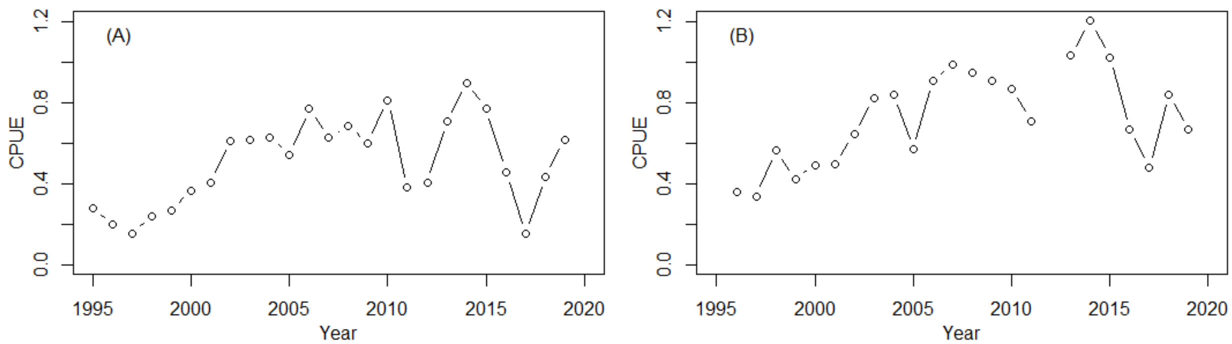

Figure 69-1. Annual Catch-per-unit-effort (CPUE) in the Canadian EEZ (A) and the U.S. EEZ (B) for the Canadian fishery.

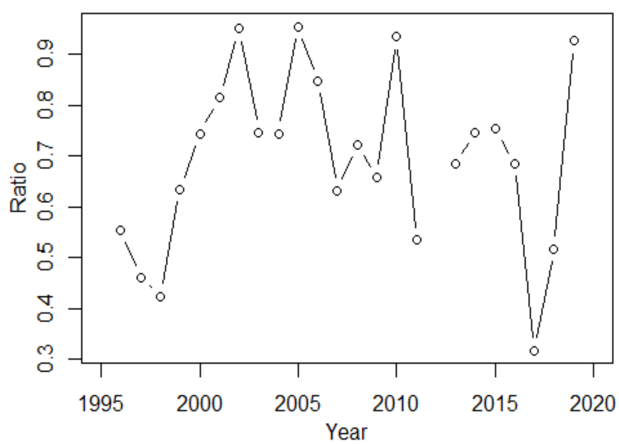

Figure 69-2. Ratio of annual CPUE in the Canadian EEZ to annual CPUE in the U.S. EEZ for the Canadian fishery.

69.4. 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 North Pacific Gyre Oscillation (NPGO) index. Figure 69-3 shows the relationships between CPUEs and the NPGO index four 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.

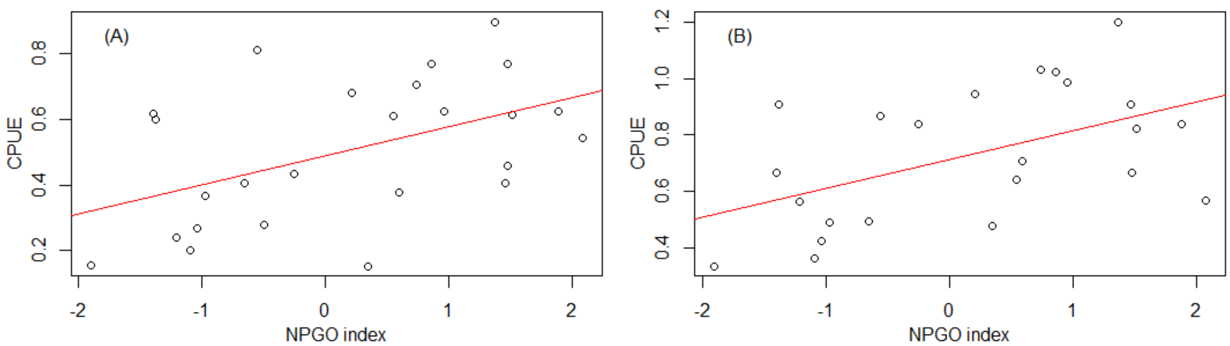

Figure 69-3. Correlation between annual means of NPGO indices four years earlier and CPUEs in the Canadian EEZ (A) and in the U.S. EEZ (B) for the Canadian fishery.

69.5. 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 two 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.

69.6. References

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Appendix 2 - Meeting Agenda

SOPO DAY 1 - Tuesday March 10, 2020		
P#	Name	Title
	Chandler/Boldt	Introduction
	James Johnny	Snuneymuxw Welcome
	Carmel Lowe	Welcome from DFO
1	Faron Anslow	Land temperature and hydrological conditions in 2019
2	Tetjana Ross	Temperature, salinity and density of the NE Pacific using Argo, satellite and Line P data
3	Roy Hourston	Wind-driven upwelling along the Northwest coast of North America: timing and magnitude
4	Peter Chandler	Sea surface temperature and salinity at B.C. lighthouses
5	Bill Crawford	Changes in Oxygen in subsurface waters of the B.C. shelf and Gulf of Alaska
6	Jim Gower	Satellite observations of B.C. waters
7	Jennifer Jackson	Interdecadal oceanographic trends in Rivers Inlet, BC
8	Wiley Evans	2019 Coastal Ocean Conditions Revealed by the Hakai Institute's Continuous CO2 Datasets
9	Akash Sastri	Oceanographic conditions off the West Coast of Vancouver Island: 2019
	Lunch	
10	Angelica Pena	Phytoplankton monitoring along Line P and off the west coast of Vancouver Island
11	Moira Galbraith	West coast zooplankton: annual anomaly time series
12	Sonia Batten	Lower trophic levels in shelf and offshore waters from CPR sampling
13	Ian Perry	West Coast of Vancouver Island small mesh multispecies bottom trawl survey (target species: smooth pink shrimp) – 2019 update
14	Jennifer Boldt	Pelagic fish: an update on status and trends
15	Philina English	A review of groundfish surveys
16	Stephane Gauthier	Updates from the 2019 joint DFO-NOAA acoustic survey of Pacific Hake (Merluccius productus)
	Break	
17	Erika Anderson	2019 Juvenile Salmon Surveys on the Continental Shelf of Vancouver Island
18	Sue Grant	State of Canadian Pacific Salmon in 2019
19	Howard Stiff	Sockeye salmon recruitment variations, ocean state changes, year 2019 performance and 2020 "outlook"
20	Strahan Tucker	Trends in abundance and distribution of pinnipeds in B.C.
21	Thomas Doniol-Valcroze	Recovery trends of marine mammal populations: recent examples in Pacific Canadian waters and potential ecosystem interactions
22	Jennifer Yakimishyn	Seabird and Grey Whale Population Trends in Pacific Rim National Park Reserve of Canada
23	Mark Hipfner	Observations on seabirds on the outer coast in 2019

24	Chandler/Boldt	Discussion
	Poster Session sponsored by Ocean Networks Canada	
SOPO DAY 2 - Wednesday March 11, 2020		
	Chandler/Boldt	Reflections and highlights on day 1
1	Kat Middleton	Canada's Oceans Now: Annual Reports on the State of Canada's Oceans
2	Chandler/Boldt	National SOTO discussion - Pacific Region; highlight reporting out
3	Brett Howard	Recent range expansions of invasive marine invertebrates in the Pacific region
4	Peter Chandler	The 2019 Strait of Georgia Water Properties Surveys
5	Richard Dewey	Deep and sea surface water properties in the Strait of Georgia 2019: Cabled and Ferry Systems
	Break	
6	Susan Allen	Spring bloom timing and interannual variations in primary productivity in the SoG
7	Nina Nemcek	Seasonal dynamics of the phytoplankton community in the Strait of Georgia
8	Nicole Frederickson	Harmful algal blooms in the Salish Sea in 2019
9	Sophie Johannessen	Has primary productivity declined in the Salish Sea?
10	Kelly Young	Zooplankton status and trends in the central Strait of Georgia, 2019
	James Johnny	Snuneymuxw Closing Ceremony
	Lunch	
11	Janelle Curtis	The Saanich Inlet transect 2019: Slow recovery of a cold-water coral population three years after a sustained hypoxia event indicates vilnerability to a major climate stressor
12	Cherisse Du Preez & Laís Chaves	Moving towards a monitoring plan for the **SGaan Kinghlas**-Bowie seamount MPA
13	Aroha Miller	An update on the state of local coastal ocean reporting: Integrating Indigenous Knowledge, Western Science, and Citizen Science
14	Jennifer Boldt & Caihong Fu	Ecosystem status and trends - West Coast Vancouver Island indicators
	Special Session	
15	Charles Hannah	The Marine Heatwaves of 2018 and 2019
	Break	
16	Peter Chandler	Defining Marine Heatwaves – are we getting it right?
17	Ian Perry	Zooplankton responses along the west coast of Vancouver Island to the NE Pacific marine heatwave
18	Doug Bertram	Marine heatwave effects on seabirds
19	Kim Hyatt	Marine heatwave effects on salmon
	Chandler/Boldt	Wrap up

Appendix 3 - Meeting Participants

Participant	Affiliation	Meeting or WebEx
Adam Batty	Government of British Columbia	WebEx
Akash Sastri	Fisheries and Oceans Canada	Meeting
Al Magnan	Fisheries and Oceans Canada	Meeting
Aleria Ladwig	Fisheries and Oceans Canada	WebEx
Alicia Andersen	UBC	WebEx
Allison Oliver	Skeena Fisheries Commission	Meeting
Amber Dearden	Ocean Wise	WebEx
Ana C. Franco	UBC	WebEx
Andrew Edwards	Fisheries and Oceans Canada	Meeting
Andrew Leising	Southwest Fisheries Science Centre, National Marine Fisheries Service	WebEx
Andrew Margolin	UBC	Meeting
Andrew McMillan	Fisheries and Oceans Canada	Meeting
Andrew Trites	UBC	WebEx
Andy Lin	ASL Environmental Sciences Inc.	Both
Angela Addison	North Coast Skeena First Nations Stewardship Society	Meeting
Angelica Peña	Fisheries and Oceans Canada	Meeting
Ania Javorski	Environmental Research & Consulting	Meeting
Anna McLaskey	UBC	Meeting
Anne Ballantyne	Fisheries and Oceans Canada	WebEx
Ann-Marie Huang	Fisheries and Oceans Canada	Meeting
Aroha Miller	Ocean Watch	Meeting
Art Bass	UBC	WebEx
Ashley Park	Fisheries and Oceans Canada	Meeting
Athena Ogden	Fisheries and Oceans Canada	WebEx
Bill Crawford	Fisheries and Oceans Canada	Meeting
Bill Sydeman	Farallon Institute	WebEx
Brett Howard	Fisheries and Oceans Canada	Meeting
Brianna Wright	Fisheries and Oceans Canada	Meeting
Brock Ramshaw	Fisheries and Oceans Canada	WebEx
Bronwyn MacDonald	Fisheries and Oceans Canada	WebEx
Bruce Baxter	Fisheries and Oceans Canada	WebEx
Bruce Nairn	King County	WebEx
Caihong Fu	Fisheries and Oceans Canada	Meeting
Cameron Freshwater	Fisheries and Oceans Canada	Meeting
Candice St. Germain	Fisheries and Oceans Canada	Meeting
Carl Walters	UBC	WebEx
Carly Taylor	Government of British Columbia	WebEx

Carmel Lowe	Fisheries and Oceans Canada	Meeting
Carolyn Gibson	Haida Nation	Meeting
Carrie Holt	Fisheries and Oceans Canada	WebEx
Cecilia Wong	Environment and Climate Change Canada / Gov of Canada	WebEx
Charles Hannah	Fisheries and Oceans Canada	Meeting
Chelsea Stanley	Fisheries and Oceans Canada	WebEx
Cherisse Du Preez	Fisheries and Oceans Canada	Meeting
Chris Harvey	Northwest Fisheries Science Centre, National Marine Fisheries Service	WebEx
Chris Rooper	Fisheries and Oceans Canada	Meeting
Chrissy Czembor	Fisheries and Oceans Canada	Meeting
Cindy Wright	Fisheries and Oceans Canada	Meeting
Claire Dawson	Ocean Wise	WebEx
Cliff Robinson	Fisheries and Oceans Canada	WebEx
Colleen Kellogg	Hakai Institute	Both
Dan Clark	Fisheries and Oceans Canada	Meeting
Darren Tuele		WebEx
David Blackbourn	Fisheries and Oceans Canada, Retired	Meeting
Di Wan	Fisheries and Oceans Canada	Meeting
Doug Bertram	Fisheries and Oceans Canada	WebEx
Doug Hay	Fisheries and Oceans Canada, Retired	Meeting
Doug Latornell	UBC	Meeting
Eddy Kennedy	Fisheries and Oceans Canada	Meeting
Elise Olson	UBC	WebEx
Erika Anderson	Fisheries and Oceans Canada	Meeting
Erika Lok	Environment and Climate Change Canada / Gov of Canada	Meeting
Erin Rechisky	Kintama Research Services	Both
Faron Anslow	Pacific Climate Impacts Consortium	Meeting
Florian Lüskow	UBC	WebEx
Gabriela Hannach	King County	WebEx
Greg Jones	Fisheries and Oceans Canada	Meeting
Greig Oldford	UBC	WebEx
Hana Hourston	Fisheries and Oceans Canada	WebEx
Hayleigh Rados	Fisheries and Oceans Canada	WebEx
Hilari Dennis-Bohm	Fisheries and Oceans Canada	Meeting
Holly McCullough	Fisheries and Oceans Canada	Meeting
Hongsik		WebEx
Howard Stiff	Fisheries and Oceans Canada	Both
Ian Perry	Fisheries and Oceans Canada	Meeting
Iselle Flores	UBC	WebEx
Isobel Pearsall	Pacific Salmon Foundation	WebEx
Jacinthe (Jazz) Amyot	Fisheries and Oceans Canada	Meeting

Jackie Detering	Fisheries and Oceans Canada	WebEx
Jackie King	Fisheries and Oceans Canada	Meeting
Jackson Joly	Environment and Climate Change Canada / Gov of Canada	WebEx
Jake Schweigert	Fisheries and Oceans Canada, Retired	Both
James Johnny	Snuneymuxw First Nation	Meeting
James Mortimor	Fisheries and Oceans Canada	Both
Jan Newton	University of Washington	WebEx
Janelle Curtis	Fisheries and Oceans Canada	Meeting
Jasmine Wietzke	Fisheries and Oceans Canada	WebEx
Jason Parsley	Fisheries and Oceans Canada	Meeting
Jay Pudota	Samudra Environmental Consulting	Meeting
Jen Chapman	Ocean Wise	WebEx
Jennifer Boldt	Fisheries and Oceans Canada	Meeting
Jennifer Jackson	Hakai Institute	Meeting
Jennifer Sandher	Fisheries and Oceans Canada	WebEx
Jennifer Yakimishyn	Parks Canada / Gov of Canada	Meeting
Jenny Ferone	Environment and Climate Change Canada / Gov of Canada	WebEx
Jessie Bell	Fisheries and Oceans Canada	WebEx
Jessy Barrette	Hakai Institute	Both
Jim Gower	Fisheries and Oceans Canada	Meeting
Jim McIsaac	T Buck Suzuki Foundation	WebEx
Jocelyn Nelson	Fisheries and Oceans Canada	Meeting
Johanna Fee	UBC	WebEx
Julia Bos	Western Washington University	WebEx
Julie Vandenbor	Vancouver Island University, Deep Bay Field Station	Meeting
Justin Del Bel Belluz	Hakai Institute	Both
Karen Hunter	Fisheries and Oceans Canada	Meeting
Karyn Suchy	University of Victoria	WebEx
Kate Schuler	UBC	Meeting
Katherine Middleton	Fisheries and Oceans Canada	Meeting
Katie Gale	Fisheries and Oceans Canada	Meeting
Katie Innes	University of Victoria	Meeting
Kayleigh Gillespie	Fisheries and Oceans Canada	WebEx
Kelly Young	Fisheries and Oceans Canada	Meeting
Keri Benner	Fisheries and Oceans Canada	WebEx
Kevin Romanin	Government of British Columbia	WebEx
Kilian Stehfest	David Suzuki Foundation	Meeting
Kim Hyatt	Fisheries and Oceans Canada	Meeting
Kimberle Stark	King County	WebEx
Kristin Gravelle	Fisheries and Oceans Canada	Both
Laís Chaves	Haida Nation	Meeting
Larry Neilson	Government of British Columbia	WebEx

Laura Tessier	North Pacific Anadromous Fish Commission	Meeting
Lauri Sadorus	International Pacific Halibut Commission	WebEx
Liam Krider	Fisheries and Oceans Canada	Meeting
Linnea Flostrand	Fisheries and Oceans Canada	Both
Lisa Setterington	Fisheries and Oceans Canada	WebEx
Lu Guan	Fisheries and Oceans Canada	Meeting
Lucie Hannah	Fisheries and Oceans Canada	WebEx
Lynn Lee	Gwaii Haanas National Park Reserve, Parks Canada	Meeting
Lyse Godbout	Fisheries and Oceans Canada	WebEx
March Klaver	Fisheries and Oceans Canada	Meeting
Margot Hessing-Lewis	Strait of Georgia Data Centre	WebEx
Margot Stockwell	Fisheries and Oceans Canada	WebEx
Mark Hipfner	Environment and Climate Change Canada / Gov of Canada	Meeting
Mark Potyrala	Fisheries and Oceans Canada	Meeting
Martin Nantel	Fisheries and Oceans Canada	Both
Meaghen McCord	Gulf Islands National Park Reserve, Parks Canada	Meeting
Melinda Scott	Fisheries and Oceans Canada	WebEx
Melissa Hennekes	Fisheries and Oceans Canada	Meeting
Michael Thom	Fisheries and Oceans Canada	WebEx
Michel Breton	Fisheries and Oceans Canada	Meeting
Midoli Bresch	Fisheries and Oceans Canada	Meeting
Moira Galbraith	Fisheries and Oceans Canada	Meeting
Nadine Templeman	Fisheries and Oceans Canada	WebEx
Natasha Salter	Fisheries and Oceans Canada	WebEx
Nicole Frederickson	Pacific Salmon Foundation	Meeting
Nina Nemcek	Fisheries and Oceans Canada	Meeting
Pam Allen	Fisheries and Oceans Canada	WebEx
Pasan Samarasin	Pacific Salmon Commission	WebEx
Patrick O'Hara	Environment and Climate Change Canada / Gov of Canada	Meeting
Patrick Pata	UBC	Both
Patrick Thompson	Fisheries and Oceans Canada	WebEx
Peter Chandler	Fisheries and Oceans Canada	Meeting
Philina English	Fisheries and Oceans Canada	Both
Pramod Thupaki	Fisheries and Oceans Canada	Meeting
Rachael Gravon	King County	WebEx
Rachel Chudnow	UBC	WebEx
Rebecca Wardle	Government of British Columbia	WebEx
Rhian Evans	Fisheries and Oceans Canada	Meeting
Richard Dewey	Ocean Networks Canada, University of Victoria	Meeting
Rick Page		WebEx
Robert Izett	UBC	Meeting
Roy Hourston	Fisheries and Oceans Canada	Meeting

Ryan Shartau	Fisheries and Oceans Canada	Meeting
Sahir Advani	UBC	WebEx
Sam Stevens	UBC	Meeting
Sarah Bartnik	Environment and Climate Change Canada / Gov of Canada	WebEx
Sarah Dudas	Fisheries and Oceans Canada	Meeting
Sarah Rosengard	UBC	WebEx
Scott Akenhead	Fisheries and Oceans Canada	Meeting
Scott Wallace	David Suzuki Foundation	Meeting
Sean MacConnachie	Fisheries and Oceans Canada	Meeting
Sean Tippett	Fisheries and Oceans Canada	Meeting
Selina Agbayani	Fisheries and Oceans Canada	WebEx
Shelley Jepps	Fisheries and Oceans Canada	Meeting
Sonia Batten	Marine Biological Association; North Pacific Marine Science Organization	Meeting
Sophie Johannessen	Fisheries and Oceans Canada	Meeting
Stephane Gauthier	Fisheries and Oceans Canada	Meeting
Stephanie King	Inwatertech	Meeting
Stephanie Taylor	North Pacific Anadromous Fish Commission	Meeting
Stephen Page	Fisheries and Oceans Canada	Meeting
Steve Latham	Pacific Salmon Commission	Meeting
Strahan Tucker	Fisheries and Oceans Canada	Meeting
Sue Grant	Fisheries and Oceans Canada	WebEx
Susan Allen	UBC	Meeting
Tamara Fraser	Fisheries and Oceans Canada	Meeting
Tammy Norgard	Fisheries and Oceans Canada	Meeting
Terry Curran	Pacific Salmon Foundation	Meeting
Tetjana Ross	Fisheries and Oceans Canada	Meeting
Thomas Doniol-Valcroze	Fisheries and Oceans Canada	Meeting
Tom Okey	Broughton Aquaculture Transition Initiative	Meeting
Tyson Carswell	Government of British Columbia	WebEx
Victoria Postlethwaite	Fisheries and Oceans Canada	Meeting
Villy Christensen	UBC	WebEx
Wafa Tafesh	King County	WebEx
Wayne Jacob	Hakai Institute	WebEx
Wendy Eash-Loucks	King County	WebEx
Wiley Evans	Tula Foundation - Hakai Institute	Meeting
Will Duguid	University of Victoria	WebEx
Yi Xu	Fisheries and Oceans Canada	Both
Zarah Zheng	UBC	WebEx
Ziwei Wang	University of Victoria	WebEx