State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2022

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STATE OF THE PHYSICAL, BIOLOGICAL AND SELECTED FISHERY RESOURCES OF PACIFIC CANADIAN MARINE ECOSYSTEMS IN 2022

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Abstract

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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 there is strong seasonality in coastal upwelling and downwelling, considerable freshwater influence, and variability from coupling with events and conditions in the tropical and North Pacific Ocean. The region supports ecologically and economically important resident and migratory populations of invertebrates, groundfish, pelagic fishes, marine mammals and seabirds.

Since 1999 an annual State of the Pacific Ocean meeting has been convened by DFO to bring together the marine science community in the Pacific Region and present the results of the most recent year's monitoring in the context of previous observations and expected future conditions. The workshop to review ecosystem conditions in 2022 was a hybrid meeting, convened both in-person in Victoria, B.C. and virtually, March 9-10, 2023. This technical report includes submissions based on presentations given at the meeting and poster summaries.

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

Résumé

Boldt, J.L., Joyce, E., Tucker, S., and Gauthier, S. (Eds.). 2023. State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2022. Can. Tech. Rep. Fish. Aquat. Sci. 3542: viii + 312 p.

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

Depuis 1999, une réunion annuelle sur l’État de l’océan Pacifique est organisée par le MPO afin de réunir la communauté scientifique dans la région du Pacifique et de présenter les résultats de la dernière année de surveillance dans le contexte d’observations précédentes, ainsi que les conditions futures attendues. L’atelier organisé du 9 au 10 mars 2023 pour examiner les conditions de l’écosystème en 2022 était un évènement hybride avec une rencontre en personne à Victoria avec option virtuelle. Le présent rapport technique comprend des soumissions basées sur les présentations données durant l’atelier et des résumés d’affiches.

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

Highlights, Introduction, and Overview

1. HIGHLIGHTS

1. Despite strong negative Pacific Decadal Oscillation and La Niña conditions in 2022, which should have led to an abnormally cool year, temperatures were near normal in the NE Pacific. There is a long-term trend of increasing sea surface temperatures in B.C. waters.
2. In 2022, daily mean air temperatures were above average and precipitation was below average in B.C. Snowpack was above-average well into June over most of B.C. and, in autumn, there was severe drought in northeast and southwest B.C.
3. By the end of summer, dissolved oxygen concentrations off the West coast of Vancouver Island (WCVI) were very low, but not as extreme as in 2021. In the Strait of Georgia (SOG), there has been a 24-year trend of decreasing oxygen at all depths.
4. Surface waters in the NE Pacific were anomalously fresh in 2022, similar to the last six years. In the SOG, there has been a trend to lower salinities in surface waters and higher salinities at depth.
5. In the central coast, the pH of deep water has been slightly less corrosive since 2019 and, in the Northern Salish Sea, has been slightly less corrosive since 2020.
6. Off the coast of B.C. and neighbouring U.S. States (45°N-60°N), the 2022 spring transition timing of upwelling was late, as was the fall downwelling, and the magnitude of summer upwelling was below average, resulting in an expectation of below-average productivity.
7. Indices of both the phytoplankton and zooplankton community composition have generally returned to average following the 2014-16 marine heatwave, with a few exceptions in some areas. In the SOG, model results indicate 2022 was an average year for spring bloom timing while *in situ* observations detected two spring blooms, and observed zooplankton biomass was above average.
8. Relative abundance of Olympia Oysters has remained stable at most Vancouver Island index sites between 2010 and 2022.
9. Coastwide Pacific Herring spawning biomass has been increasing since 2010. In 2022, it varied among assessed stocks with more than 50% of the total biomass occurring in the SOG. Herring weight-at-age continued to remain unchanged or increased.
10. Fraser River Eulachon spawning biomass was the lowest of the time series since 1995; whereas, off the WCVI, Eulachon biomass, of mixed ages and stocks, was moderately high relative to other surveyed years since 2000.
11. Generally, there were low returns of Chinook and Chum Salmon; whereas there were strong returns of Sockeye Salmon in several areas except the Fraser River (below average). The size of Fraser River Sockeye and Pink Salmon has decreased.
12. There was an increase in the biomass of shelf rockfish, some slope rockfish, and many flatfish species in the recent 5-10 years; whereas Arrowtooth Flounder and Pacific Spiny Dogfish biomass declined.
13. Marine Aquatic Invasive Species are increasing in both range and abundance in B.C. There has been a recent expansion of European Green Crab around Haida Gwaii, the Salish Sea, and southern Alaska. Bay Barnacle appears to be increasing on the WCVI.
14. The population of Harbour Seals is considered stable or slightly declining. The abundance of California Sea Lions in 2020-21 was a threefold increase since 2009-10, but there has not been a significant increase since 2017.
15. Sei Whale sightings in Canada's Exclusive Economic Zone have increased, indicating increasing abundance or changing distribution patterns, and/or increasing observation efforts in offshore waters.

2. INTRODUCTION

Fisheries and Oceans Canada (DFO), Pacific Region, facilitates and assembles an annual overview of the physical, chemical and biological conditions in the ocean off Canada's west coast. This compilation helps to develop a picture of how the ocean is changing and provides advance identification of important changes which may potentially impact human uses, activities, and benefits from the ocean. There is a concerted effort to include information that summarizes important climate, oceanographic, and biological components at different trophic levels for as many marine ecosystems in B.C. as possible. The highlights, overview, and summary sections of this report synthesize and emphasize ecosystem information that SOPO meeting participants discussed as important for communicating to science and fisheries management. This is done in a two or three day meeting, usually held in February or March of the year subsequent to the year being considered. The first meeting was held in 2000 to assess conditions in 1999; reports from these reviews are available at the following link (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 2022 (for conditions in 2021) is available at

https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/41067113.pdf

The 24th DFO State of the Pacific Ocean meeting, to review conditions in the NE Pacific and B.C. coastal waters in 2022, was a hybrid meeting, convened both in-person in Victoria, B.C. and virtually, March 9-10, 2023. Due to the hybrid platform, the meeting reached a broad audience; this year's meeting was attended by 366 researchers from 68 organizations, including the federal and B.C. governments, First Nations and Indigenous organizations, academia, national and international partners, and the private sector. For example, attendees included scientists from Fisheries and Oceans Canada, Parks Canada, Environment and Climate Change Canada, Transport Canada, and 17 different First Nation and Indigenous organizations, such as the Council of the Haida Nation, Toquaht Nation Government, Seabird Island Band, Heiltsuk Nation and the Tsawout, Namgis, Ucluelet, Huuayaht, and Ka:'yu:'k't'h'/Che:k'tles7et'h' First Nations, among others. Other

attendees included the Province of B.C., Hakai Institute, University of British Columbia, University of Victoria, Ocean Networks Canada, North Pacific Marine Science Organization, Grieg Seafood, T Buck Suzuki Foundation, and the Pacific Salmon Foundation, among others. These annual meetings represent a unique opportunity for scientists from different disciplines to highlight preliminary results of atmospheric, oceanographic, and marine species observations in 2022 in the context of historical observations.

Councillor Jackie Albany from the Songhees First Nation was scheduled to provide opening remarks, but, unfortunately, had to cancel at the last minute. Regional Director of Science, Andy Thomson, provided opening remarks, including his appreciation for the SOPO meeting and report. He noted that it is only through these types of collaborative processes that we can bring together different types of knowledge to gain a better understanding of how ecosystems are changing and to identify actions for DFO and future studies in Science. He noted that there are opportunities to address Science questions in the upcoming years with DFO's Pacific Salmon Science Initiative.

Regional Director of Science, Andy Thomson, provided opening remarks.

At the meeting 40 talks and 18 posters were presented. Topics ranged from annual precipitation to large-scale atmospheric and physical oceanographic conditions, to species composition of the phytoplankton and zooplankton communities, to fish and marine mammal stock status, to ocean noise, and everything in between. For the last couple of years, the organizing team has taken a proactive approach and also invited all First Nations and Indigenous organizations in B.C. to participate in the meeting. This resulted in 27 individual registrants from 17 different First Nations and Indigenous organizations. An invitation was also extended to all First Nations and Indigenous organizations to present or co-present at this and future meetings. There were 3 co-presentations: 1) on Day 1, collaborators from DFO, Gwaii Haanas Parks Canada, the Council of the Haida Nation, and the Hakai Institute gave a joint presentation on "2022 oceanographic conditions in and around Gwaii Haanas, Haida Gwaii, in relation to past observations"; 2) on Day 2, collaborators from DFO and the Council of the Haida Nation gave a joint presentation titled "Update on the distribution of aquatic invasive species and monitoring activities in the Pacific region, with details on Haida Gwaii efforts"; 3) collaborators from the Council of the Haida Nation and DFO gave a poster presentation titled: "Monitoring SG̲aan K̲inghlas–Bowie Seamount Marine Protected Area".

Poster summaries are presented in Appendix 1, the meeting agenda is presented in Appendix 2, and the meeting participants are listed in Appendix 3. The meeting was co-chaired by Jennifer Boldt (Pacific Biological Station), Strahan Tucker (Pacific Biological Station), Stéphane Gauthier (Institute of Ocean Sciences), and organized by Elizabeth Joyce. In addition to helping with meeting organization, all technical aspects of the virtual meeting were run by Stephen Page (Institute of Ocean Sciences), with support from Lucius Perreault (Institute of Ocean Sciences) and Lindsay Mazzei (Institute of Ocean Sciences). Convening this large-scale hybrid meeting involved planning and organization above and beyond the requirements for past SOPO meetings and was made possible with the skills and hard work of Elizabeth, Stephen, Lucius, and Lindsay.

2023 SOPO meeting organizers (left to right), Stephen Page, Jennifer Boldt, Elizabeth Joyce, Strahan Tucker, Stéphane Gauthier, Lindsay Mazzei, and Lucius Perreault.

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, results, and interpretations as of the date of this meeting. For use of, or reference to these individual presentations, please contact individual authors.

3. OVERVIEW AND SUMMARY

Climate change continues to be a dominant pressure acting on Northeast (NE) Pacific marine ecosystems, as 2022 was the fifth or sixth warmest year on record globally (depending on climatology used). B.C. air temperatures continued to increase (1950-2022) as daily mean air temperatures were above average (Curry et al., Section 6). Precipitation was below average in

B.C., while snowpack was above-average well into June over most of B.C. In autumn, severe drought conditions were experienced nearly everywhere in B.C. accompanied by near-record warm temperatures (Curry et al., Section 6). In 2022, river discharge in southern B.C. was less than normal, but was close to average in northern B.C. (Curry et al, Section 6; Donnet, Section 33). Despite strong negative PDO and La Niña conditions throughout 2022 which should have led to an abnormally cool year, temperatures were near normal in the NE Pacific (Ross and Robert, Section 7). The relatively normal temperatures observed in the NE Pacific were likely due to the juxtaposition of cool climate oscillations on a background of long-term climate warming (Ross and Robert, Section 7; Figures 3-1 and 3-2). The 2022 average annual SST, collected at shore stations along the B.C. coast, was marginally cooler than 2021 and close to the mean calculated over the 1992-2020 period (Donnet et al., Section 10). Coast-wide SST in 2022 was much lower than conditions observed in 2015 during the marine heatwave (MHW) known as "the Blob" and perhaps signaling an end of the warm period that started in 2014 (Donnet et al., Section 10). Overlying multi-year oscillations in the annual SST, there is a long-term trend towards rising ocean temperatures of 0.9°C over the last 100 years (Figure 3-3; Donnet et al., Section 10). Surface waters in the NE Pacific were anomalously fresh in 2022 but slightly less than 2021; this continues a freshening trend observed for the last six years (Ross and Robert, Section 7). Increasing CO_2 in the atmosphere has increased the acidification of the ocean, which will continue to intensify with the rise of anthropogenic carbon levels in the atmosphere (Evans, Section 36). In spring 2022, marine CO_2 conditions on the central B.C. coast and in the northern Salish Sea slightly improved compared to 2019-2020, but returned to more corrosive and low pH conditions for the remainder of the year (Evans, Section 36).

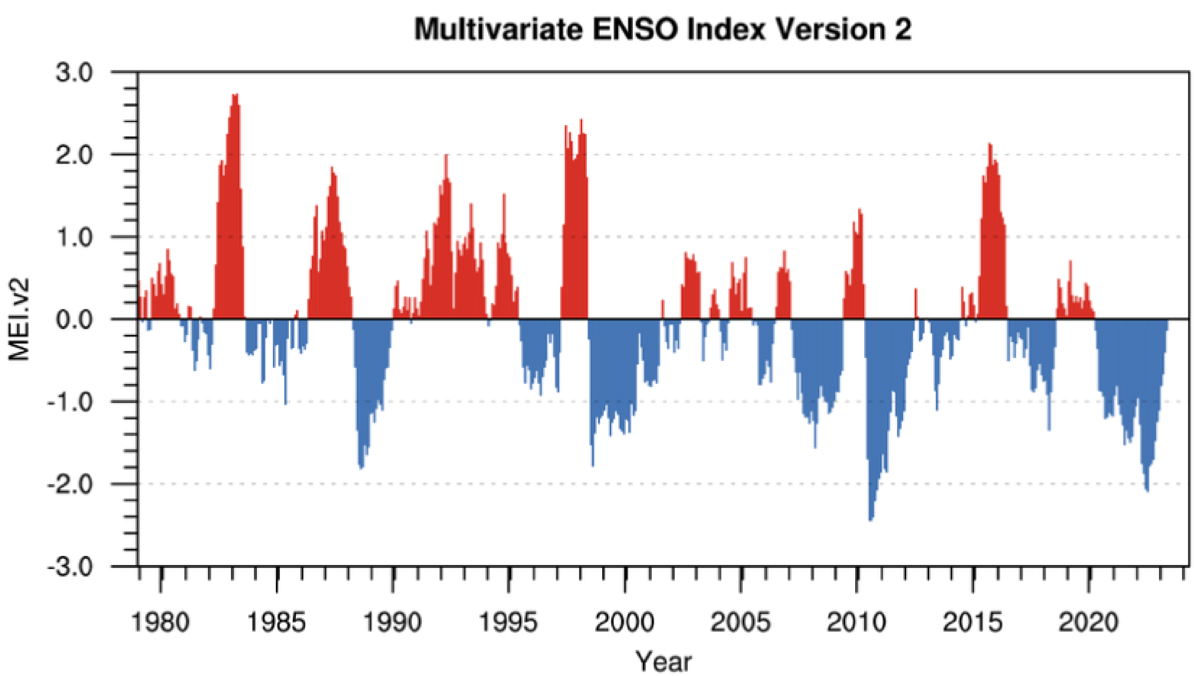

Figure 3-1. The multivariate ENSO Index. Data source: NOAA/ESRL/Physical Sciences Division – University of Colorado at Boulder/CIRES; https://psl.noaa.gov/enso/mei/

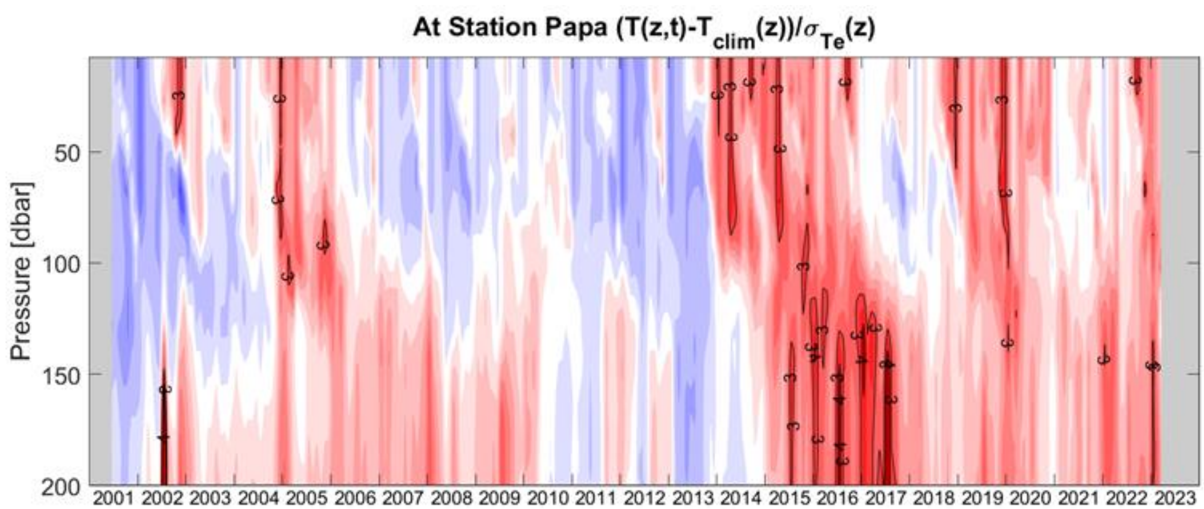

Figure 3-2. Plot of temperature, as observed by Argo floats near Ocean Station Papa, with anomalies calculated relative to the 1991-2020 seasonally-corrected mean and standard deviation (from the Line P time series). Cool colours indicate cooler than average temperatures and warm colours indicate warmer that average temperatures. Dark colours indicate anomalies that are large compared with standard deviations from the climatology. The black lines highlight regions with anomalies that are 3 and 4 standard deviations above the mean. Source: Ross and Robert, Section 7.

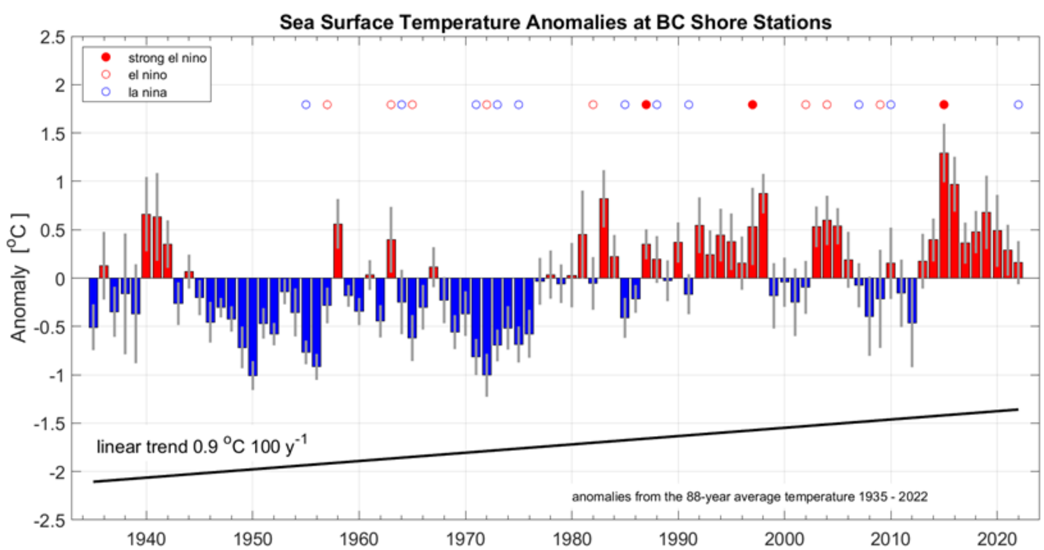

Figure 3-3. Trend in annual Sea Surface Temperature based on the observations of all lighthouses (black line). The bars represent the anomalies averaged over all stations (a coast wide indicator), (red – above average, blue – below average), the vertical grey lines show the variability (standard deviations) in the lighthouse data for each year (1935-2022). Important El Niño Southern Oscillation (ENSO) phases are indicated above as red (El Niño warm anomaly) and blue (La Niña cold anomaly) circles and dots (strong phase). Source: Donnet et al., Section 10.

Multiple marine heatwaves (MHWs) were identified in the NE Pacific in 2022; the largest MHW areas remained offshore in the open ocean for the first half of the year (Hilborn et al., Section 11). Beginning in late August most of the B.C. Exclusive Economic Zone (EEZ) fell under MHW status with varying intensity until late October (Hilborn et al., Section 11). The size, intensity, and frequency of MHWs in the NE Pacific is increasing (Hilborn et al., Section 11).

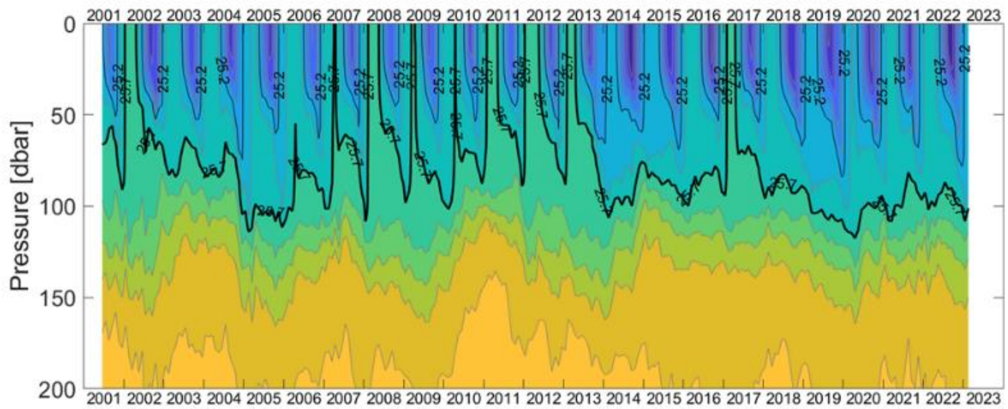

Figure 3-4. Coloured contour plot of density as observed by Argo floats near Station Papa (P26: 50º N, 145º W). The colours indicate potential density (yellow is denser and blue lighter). The black lines highlight the σ□=25.2 kg/m^3 (thin) and 25.7 kg/ m^3 (thick) isopycnals. Source: Ross and Robert,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

MHWs are associated with reduced vertical mixing, which causes increased winter stratification. This results in decreased nutrient supply from deep to surface offshore waters. The winter stratification was similar in 2021/22 and 2020/21, and both were stronger than during the 2007-2013 period preceding the first big MHW of the last decade (i.e. the ‘Blob’), but not as strong as the 2018/19 and 2019/20 winters which showed extremely low winter mixing. Thus, the mixing of nutrients to the surface was likely normal in 2021/22 (Figure 3-4; Ross and Robert, Section 7).

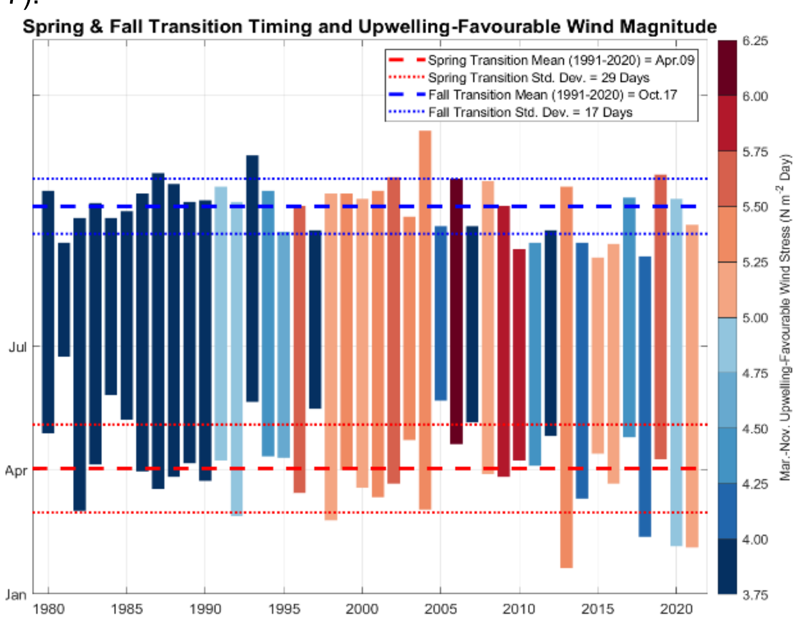

Figure 3-5. Annual spring and fall transition timing and March-November upwelling-favourable wind stress magnitude, 1980-2021. Bold dashed lines indicate the average spring (red) and fall (blue) transition dates. Light-dashed lines indicate standard deviations of the spring (red) and fall (blue) transition dates. Source: Hourston and Thomson, Section 8.

The timing and magnitude of upwelling of deep, nutrient-rich water off the west coast of Vancouver Island (WCVI) is an indicator of marine coastal productivity across trophic levels from plankton to fish to birds. Variability in the upwelling index corresponds with variations in the strength and/or longitudinal position of the Aleutian low-pressure system in the Gulf of Alaska. The 2022 spring transition timing of upwelling was very late relative to the 1991-2020 mean and the magnitude of summer upwelling was below the long-term average, resulting in an expectation of below-average upwelling-based coastal productivity (Hourston and Thomson, Section 8; Dewey et al., Section 38; Figure 3-5). After a late (June) start to upwelling, persistent upwelling, particularly along the southern Vancouver Island continental slope, brought California undercurrent source waters onto the shelf, supplying nutrients and saline water to surface waters and extending deep, oxygen-poor waters over the shelf eastward (Sastri et al., Section 15; Dewey et al., Section 38).

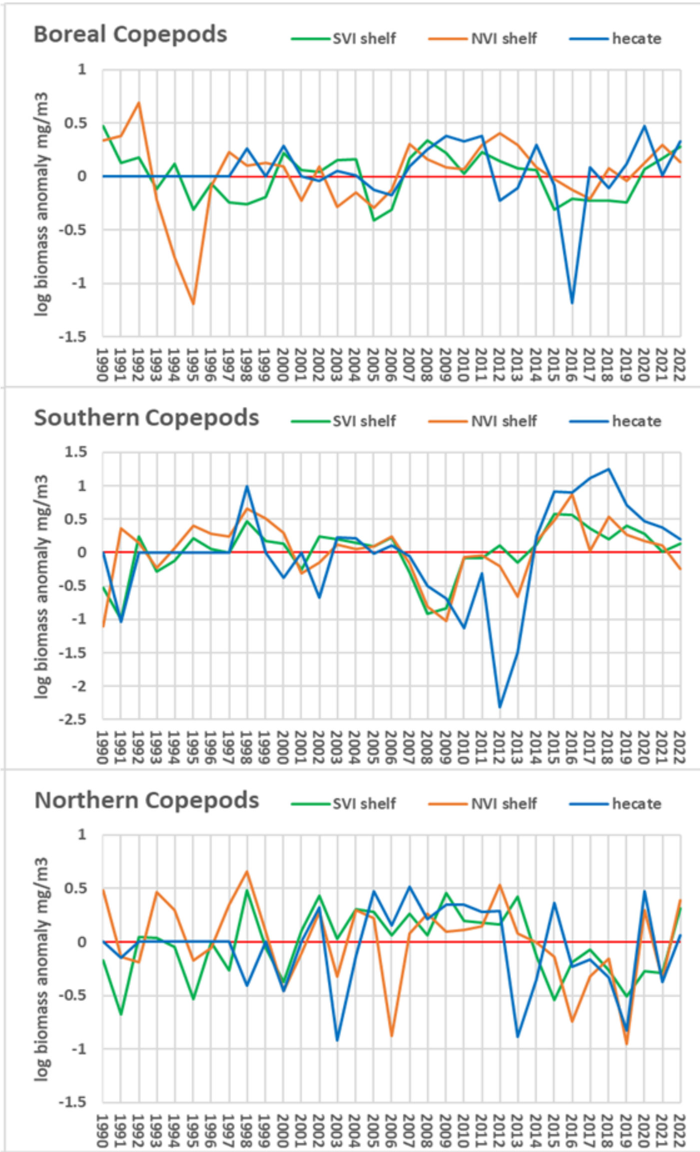

Figure 3-6. Zooplankton species-group anomaly time series. Line graphs are annual log scale anomalies. Southern Vancouver Island (SVI) green; Northern Vancouver Island (NVI) orange; Hecate Strait blue. Blank years mean no samples were collected. Source: Galbraith and Young, Section 20.

Phytoplankton and zooplankton communities appear to be returning to average status after the MHW (2014-2016) in the shelf region (Ostle and Batten, Section 21; Galbraith and Young, Section 20). In 2022, southern copepod species continued to decline in abundance compared to MHW years (Ostle and Batten, Section 21; Galbraith and Young, Section 20). Southern copepods were more prevalent in offshore compared to shelf waters of the south Vancouver Island and Hecate Strait regions (Figure 3-6). Boreal shelf and subarctic copepod biomass was above or near- average in all areas (Galbraith and Young, Section 20). Large subarctic and boreal copepods are more favourable for fish growth than small, southern copepod species.

Changes to the physical environment, phytoplankton, and zooplankton communities can have impacts on higher trophic levels. Extreme heat events, such as the atmospheric heat dome of 2021, may have a long-term effect on Olympia Oyster survival and reproduction; however, no evidence of decrease in density was observed at index sites in 2022 (Herder and Bureau, Section 22). There was an increase in the biomass of shelf rockfish, some slope rockfish, and many flatfish species in the recent 5-10 years. In contrast, Arrowtooth Flounder and Pacific Spiny Dogfish biomass declined (Anderson et al., Section 29).

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). As in 2021, the representation of *N. cristatus* in Cassin's auklet nestling diets on Triangle Island in 2022 was well below what would be expected based on PDO conditions (Hipfner, Section 30). Diets fed to nestling Rhinoceros Auklets on Pine and Lucy islands included normal amounts of Pacific Sand Lance and Pacific Herring in 2022, continuing the trend towards favourable conditions that existed prior to the Blob (Hipfner, Section 30).

Several populations of marine mammals have shown strong recovery trends (notably humpback whales) after commercial whaling ended in 1967, and are once again important components of marine ecosystems, resulting in increased overlap with human activities and potential conflicts with fisheries and marine traffic. Sei Whale sightings in Canada's EEZ have increased, indicating increasing abundance or changing distribution patterns, and/or increasing observation efforts in offshore waters (Doniol-Valcroze et al., Section 32). The population of Harbour Seals is considered stable or slightly declining, while the abundance of California Sea Lions in 2020-21 was a threefold increase since 2009-10, with no significant increase since 2017 (Tucker et al., Section 31).

In the Salish Sea, there are trends of increasing temperature and decreasing oxygen at all depths, and waters are generally becoming fresher at surface and saltier at depth (Donnet and Chandler, Section 37). During the spring of 2022, conditions were cooler, saltier, and less oxygenated than normal. These conditions continued through the summer at depth but surface waters were warmer, fresher and more oxygenated than normal. Thus, stronger than normal summer stratification occurred in 2022. In the fall, conditions were notably warmer at the surface, as well as saltier (Juan de Fuca) and less oxygenated than normal at most depths. In 2022, the Fraser River annual discharge was near-normal overall but below normal in the fall; the peak discharge was late (~1 month; Donnet and Chandler, Section 37; Figure 3-7).

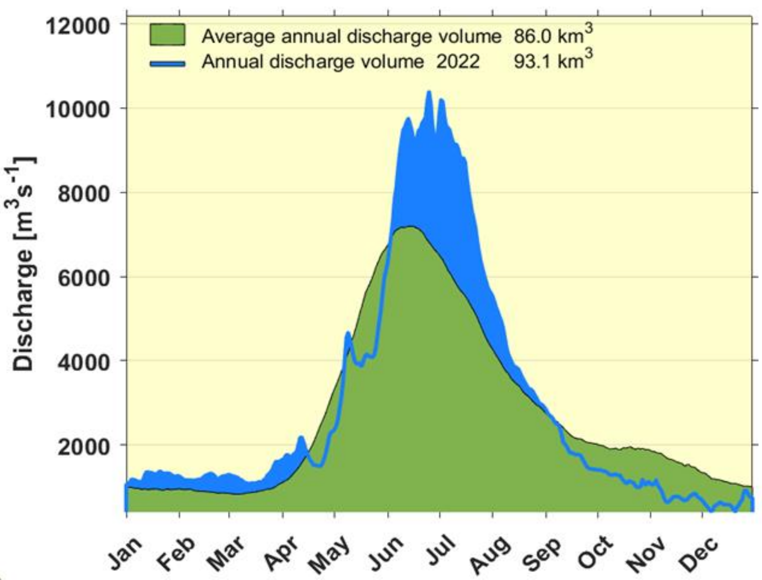

Figure 3-7. Fraser River discharge at Hope B.C.; 2022 (blue), 111 year average (green). Extracted from the Environment and Climate Change Canada Real-time Hydrometric Data web site, station number 08MF005, "FRASER RIVER AT HOPE" (https://wateroffice.ec.gc.ca/mainmenu/real_time_data_index_e.html) on 30 Jan 2023. Source: Donnet and Chandler, Section 37.

In the Strait of Georgia (SOG), 2022 was the first year since 2015 when all five harmful algal bloom taxa formed dense but localized blooms. In summer, there were dense blooms of *Heterosigma akashiwo, Dictyocha, Noctiluca scintillans, Rhizosolenia setigera,* and *Pseudo-nitzschia* in some areas (Esenkulova et al., Section 42). Harmful algal blooms can cause finfish and shellfish mortalities, impacts to human health, and economic losses. Marine Aquatic Invasive Species (AIS) are increasing in both range and abundance in B.C. For example, there has been an expansion of European Green Crab around Haida Gwaii and the Salish Sea (Gale et al., Section 48). This high-impact invader that negatively affects eelgrass, an important fish habitat, was detected for the first time on Haida Gwaii in July 2020 (Gale et al., Section 48). Preventing the spread of AIS requires management and monitoring of anthropogenic pathways and vectors as early detection of AIS can inform management and policy. Other anthropogenic stressors include oil spills, vessel traffic and underwater noise. For example, in 2022, there were 1054 oil spills reported to DFO; the most significant was the Fishing Vessel Aleutian Isle which sank with 15000 L of diesel on the U.S. side of the Juan de Fuca Strait (Herborg et al., Section 34).

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 early compared to the long-term average (Allen and Latornell, Section 40; Dewey et al., Section 38; Esenkulova et al., Section 42). In fact two spring blooms occurred, one in February followed by another one in April (Esenkulova et al., Section 42); the implications for feeding conditions for juvenile fish are unclear. In 2022, the SOG zooplankton biomass decreased but was still higher than the time series average since 1996 (Young et al., Section 43). Medium and large-sized copepods, important juvenile salmon prey, dominated the biomass (Young et al., Section 43).

Coastwide Pacific Herring biomass has been increasing since 2010, dominated by the SOG stock; however, in some assessed areas, such as Haida Gwaii, there have been prolonged periods of low biomass (Cleary et al., Section 24; Figure 3-8).

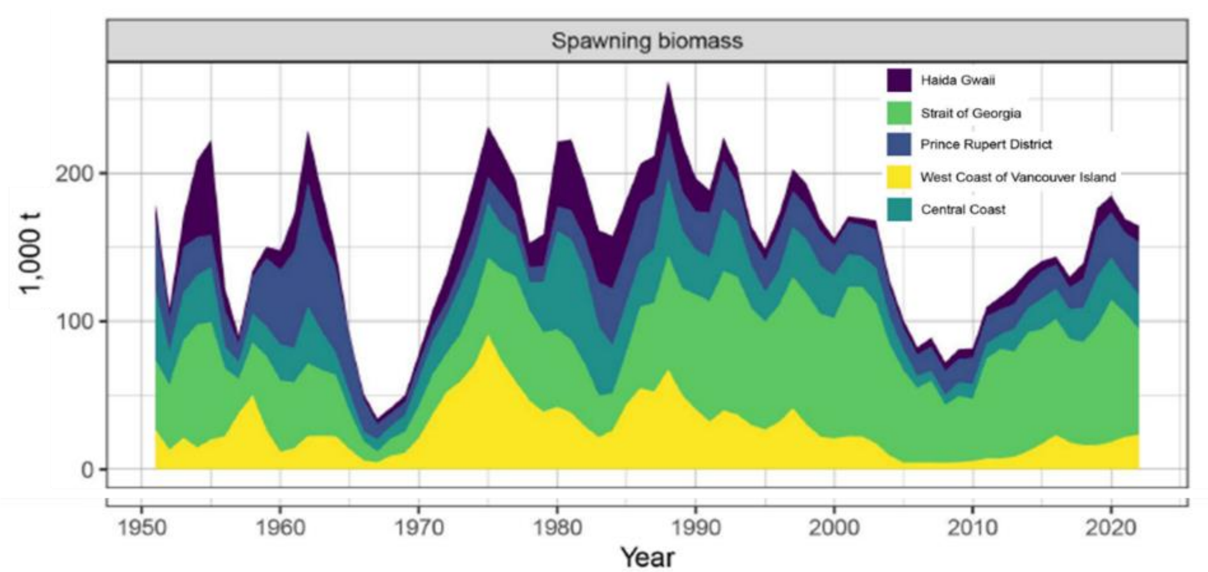

Figure 3-8. Pacific Herring spawning biomass of five assessed areas, 1951- 2022. Source: Cleary et al., Section 24.

In summer 2022, Pacific Herring biomass and CPUE in continental shelf waters off the WCVI (mixed stocks) were the highest in the 2006-2022 time series (Boldt et al., Section 25). In the SOG in the fall of 2022, the relative biomass of age-0 Pacific Herring was higher than that observed in 2021, but still below the time series mean; a very low biomass estimate of age-0 may indicate low recruitment to the adult SOG population (Boldt et al., Section 44). In 2022, Northern Anchovy were present in 48% of the SOG age-0 Pacific Herring survey sets; this is the third highest percentage in the time series (Boldt et al., Section 44). In 2022, the index of Fraser River Eulachon spawning stock biomass was estimated to be one of the lowest in the time series (~10 tonnes; Flostrand and Ens, Section 23). However, mean Eulachon catch per unit effort from a WCVI multispecies bottom trawl survey was moderately high (Flostrand and Ens, Section 23).

In the fall of 2022 in the SOG, juvenile salmon survey index of Coho Salmon abundance (catch per unit effort) was above average, Chinook Salmon was average, Sockeye and Chum Salmon were below average, while Pink Salmon was the highest observed since 2010 (Neville, Section 45). Also, juvenile Coho Salmon remained bigger than average (Neville, Section 45). Chum and Pink Salmon were the dominant juvenile salmon species encountered in summer and fall on the continental shelf of the northern and western coast of Vancouver Island (King et al, Section 25). Chum Salmon relative abundance in summer was below average. Pink Salmon relative abundance in fall was above average. These juvenile salmon, and those caught in summer, were in better condition than usual.

Many Canadian populations of Pacific salmon have exhibited significant declines in abundance coinciding with global climate change in the freshwater and marine ecosystems salmon inhabit (MacDonald et al., Section 27; Figure 3-9). The marine survival of B.C. Sockeye Salmon indicator stocks were generally below or near the long-term average for 2022; return abundances were below average for most populations except Francois and Osoyoos lakes, which had average to above average returns (Bailey and Freshwater, Section 28). Chinook Salmon returns in 2022 continued their trend of low abundances in many areas, with exceptions (examples: WCVI hatchery returns, east coast of Vancouver Island Fall returns). In 2022, Pink Salmon returns were average to above average in northern B.C. and on the east coast of Vancouver Island, and below average on the central coast and mainland inlets. Chum Salmon returns in 2022 were generally poor to extremely poor with some exceptions: Nass, enhanced Bella Coola, and lower SOG Chum Salmon. Coho Salmon returns to many systems were near average, while others were mixed (MacDonald et al., Section 27).

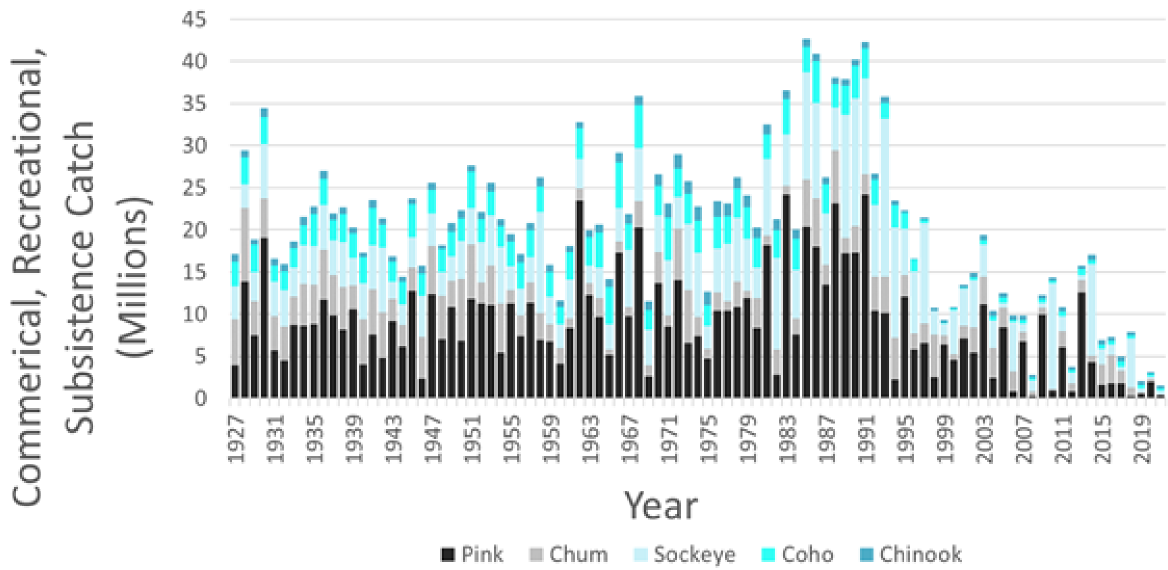

Figure 3-9. Commercial, recreational and Indigenous subsistence catch of Canadian Pink, Chum, Sockeye, Coho and Chinook Salmon (Grant et al. 2019; NPAFC statistics: https://npafc.org/statistics/). Average catch from 1925-1993 was 24.2 million, and from 1994-2014 was 13.4 million. Catch since 2015 has averaged 4.8 million, with the lowest catch on record occurring in 2021 (1.6 million). Source: Grant et al., Section 27.

4. REFERENCES

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5. ACKNOWLEDGMENTS

The authors and contributors to this Technical Report wish to thank all the officers and crews 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 2022

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6.1. Highlights

- In 2022, B.C. experienced above-normal daily temperatures and well below-normal daily precipitation.
- Above-normal snowpack persisted well into June over most of B.C. due to slightly cooler spring temperatures and above-normal precipitation in most regions.
- Near-record warm temperatures occurred in summer.
- In autumn, severe drought conditions were experienced nearly everywhere in B.C. accompanied by near-record warm temperatures.
- The trend in annual mean temperature in B.C. is positive and can be distinguished from natural variability over the analyzed period, 1950-2022. Annual total precipitation, however, exhibits no significant trend over that period.

6.2. Introduction

The seasonal conditions that transpire on land have impacts on nearby coastal waters through discharge, temperatures and nutrient input from rivers and streams. Wildfire events can also impact ocean waters via changes in river sediment transport. As part of a holistic approach to describing the state of the Pacific Ocean, this section will describe the evolution of seasonal weather and snowpack conditions relevant to the coastal waters of B.C. The particular records that are described are monthly temperature and precipitation pseudo-observations from a global atmospheric reanalysis and monthly measurements of water equivalent snowpack from provincial and private weather observing networks.

6.3. Description of the time series

6.3.1. Temperature and Precipitation

Observations of temperature and precipitation made at B.C. weather stations have been compiled on an ongoing basis since 2010 under the Climate Related Monitoring Program (CRMP). The dataset consists of observations from the CRMP 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, spans the years 1872 to present. Due to a combination of factors (staffing changes at PCIC and unanticipated delays in the transfer of data from certain networks), the spatial coverage of the station dataset for 2022 was insufficient for its exclusive use in this year's analysis. Instead, we made use of the fifth generation European Centre for Medium-range Weather Forecasting Atmospheric Reanalysis Product (ERA5), which offers a gridded representation of the historical climate spanning 1950-present at a horizontal resolution of approximately 30 km x 30 km over the globe. To the extent possible, we compared the results derived from ERA5 with those available from CRMP for 2022, noting an overall consistency between the two datasets.

Long-term records of mean monthly temperature and precipitation were used to calculate 30-year climate normals for each month of the year during the 1981–2010 reference period.

Anomalies in monthly temperature and precipitation were then calculated relative to these normals for the entire 1950-2022 time series covering B.C. The time series of gridded anomalies were then spatially divided among the B.C. River Forecast Centre's 23 Snow Index Basin regions. Spatial averages were taken across each region to form a monthly time series of regional anomalies that was used to rank individual years. The monthly data were 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 seasonal anomaly data is shown in Figure 6-1 for monthly mean temperature (left panel) and 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 over the 73-year period of 1950-2022 and the highest percentile as the coldest/driest that corresponds to a ranking of 73 for the period. 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, 10th – 1st, and 1st.

6.3.2. Snow

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

6.4. Status and trends

6.4.1. Temperature and Precipitation

In 2022, average annual temperature was higher than normal across B.C. as a whole when compared with the long-term (1950 – 2022) record. Averages for daily mean temperature were among the top 13 for the northern basins, and in the upper third of the distribution everywhere else except the East Kootenay. Precipitation anomalies across the province were below normal over the southern two-thirds of the province, with the exception of the Skeena-Nass and Nechako basins, which were near-normal. Annual precipitation in the Stikine was above-normal, and well above-normal in the Northwest, ranking as the 2nd wettest in the entire record in that basin.

On seasonal and monthly timescales, winter (December 2021-February 2022) and spring temperatures were near normal across B.C. The most notable temperature anomalies occurred in summer and fall. Summer mean temperature anomalies were the 2nd warmest on record over B.C. as a whole (Figure 6-1, left), with record temperatures achieved in the Northeast basins (Liard and Peace) and near-record warmth recorded in Skeena-Nass, Stikine, Nechako and Upper Fraser West. All B.C. basins experienced summer heat ranking among the top 10 warmest in the record. Above-normal temperatures persisted into the fall throughout the province, remaining well above-normal in the North and South and ranking amongst the top 10 warmest in half of the basins. The period of extended warmth led to widespread autumn drought conditions over much of B.C. Very warm summer temperatures and below-normal precipitation during summer and autumn resulted in severe drought conditions between July and November throughout most of B.C.

At the start of 2022, precipitation patterns varied considerably over the province, with abnormally wet conditions in the north (the 2nd wettest winter on record in Liard) and anomalously dry conditions in the southwest (8th driest winter on Vancouver Island). Precipitation was above-normal in most B.C. basins during spring, below-normal in the Stikine, and normal elsewhere in the northwest and southeast. A near-reversal of this pattern occurred by the summer, with the Okanagan, Similkameen (3rd driest on record), and Kootenays experiencing well below-normal precipitation, and northwest B.C. wetter than normal. The meteorological drought persisted and intensified into autumn, with nearly all B.C. basins receiving well below or below-normal rainfall conditions. B.C. as a whole, Vancouver Island and the South Coast marked their 2nd driest autumn on record (Figure 6-1, right). According to the Canadian Drought Monitor (CDM, 2023), by the end of November, eighty-two percent of B.C. was considered Abnormally Dry or in Moderate to Extreme Drought, including ninety-nine percent of the region's agricultural landscape. Autumn rains on the central and southwest coast were delayed by a month or more, leading to depleted river flows and heightened fire risk throughout southern B.C. In contrast, northwestern B.C. experienced normal to well above-normal precipitation for the remainder of the year.

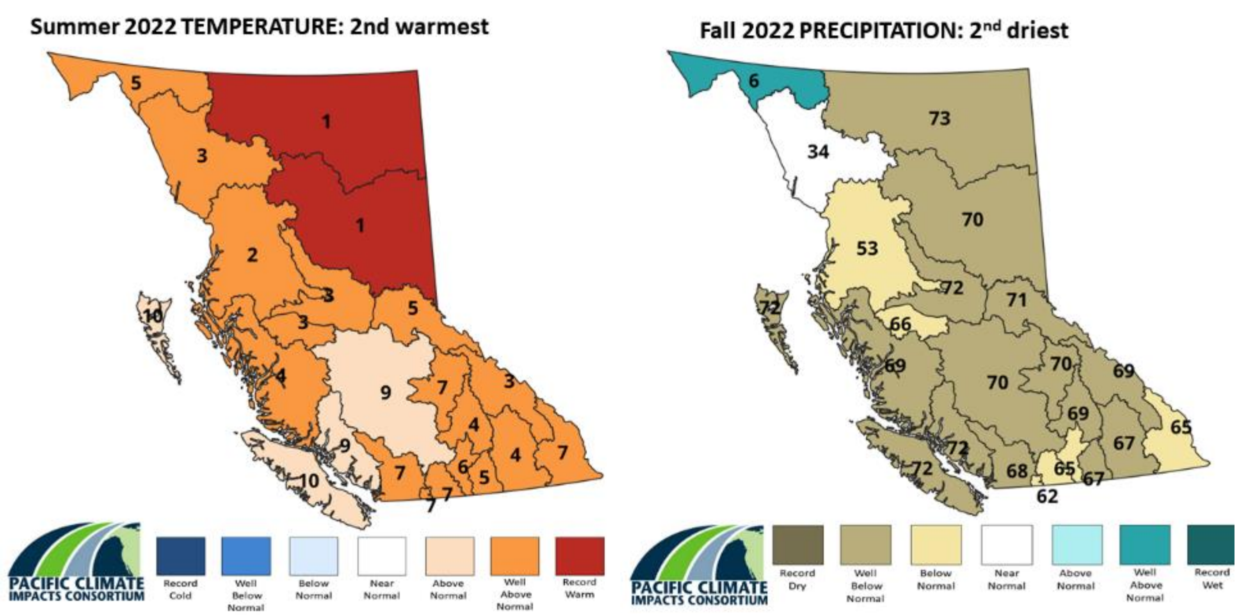

Figure 6-1. Seasonal anomalies in summer (JJA) average daily mean temperature (left panel) and fall (SON) total precipitation (right panel) for 2022 in B.C. Quantiles defining the colour scale are given in the text. Numbers on the map correspond to ranking (from high to low) in the 73 observation years from 1950 through 2022. Results are based on the ERA5 Reanalysis product from ECMWF, accessed via the KNMI Climate Explorer [*https://climexp.knmi.nl/*](https://climexp.knmi.nl/)

Using the seasonal and annual temperature and precipitation anomalies, province-wide trends are calculated for the full ERA5 record spanning 1950 through 2022. Temperature trends are more easily detected due to the smaller spatial and interannual variability of temperature compared to precipitation data. The trends in mean daily temperature are positive and statistically significant ($p < 0.05$) annually and in all seasons (Table 6-1). The trends in precipitation are not statistically different from zero, except for a small decreasing trend in winter.

Table 6-1. Linear trends in seasonal and annual daily mean temperature and total precipitation based on ERA5, spatially averaged over B.C. Only trends that are significant at the 5% significance level are shown.

Trends over 1950-2022	ANN	MAM	JJA	SON	DJF
Mean Temperature (°C decade^{-1})	+0.36	+0.35	+0.34	+0.25	+0.46
Precipitation (mm decade^{-1})	−	−	−	−	−23

6.4.2. Snow

The evolution of B.C.’s snowpack in most basins was near normal during the winter of 2021-2022. Snow accumulation was 72% to 134% of normal at the end of March with lower values found in the West Road-Chilcotin, Okanagan and Vancouver Island basins and the highest values recorded in the Northwest, Liard, Upper Fraser East and Upper Columbia basins (Figure 6-2, left). Cool spring temperatures in some basins accompanied by above-normal precipitation nearly everywhere in B.C. prompted continued snow accumulation well into spring. Snowmelt was significantly delayed in most areas (by 2-4 weeks; River Forecast Centre, 2022) resulting in well above-normal May and June snowpack levels (> 140% of normal; Figure 6-2, right) and below-normal streamflow until mid-June.

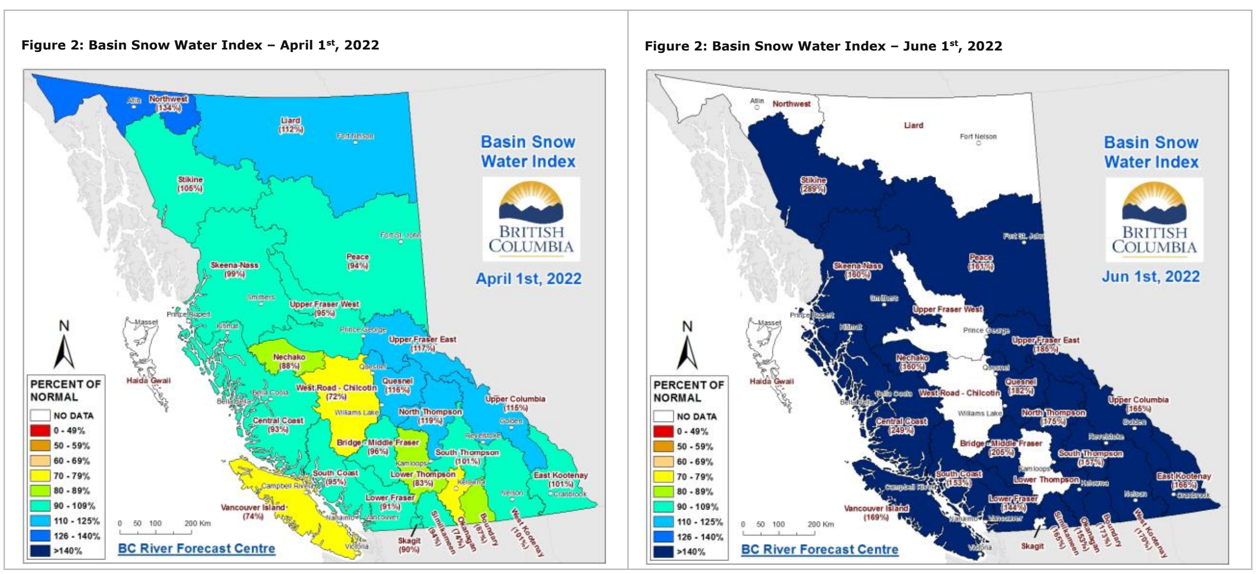

Figure 6-2. Anomalies in B.C. snowpack for April (left) and June (right), 2022. Maps are produced by the B.C. Ministry of Forests Lands and Natural Resource Operations and Rural Development’s River Forecast Centre (River Forecast Centre 2021).

6.5. Factors causing trends and implications

Overall, 2022 in B.C. was warmer and drier than normal. Daily mean temperatures were well above-normal in summer and fall throughout B.C., with record-breaking temperatures in the northeast in summer. Precipitation swung from above-normal in winter and spring to well below-normal over most of the province in summer and fall, leading to drought conditions that persisted into November.

The observed anomalous temperatures in 2022 are consistent with ongoing warming in B.C., as indicated by trend analysis of the 1950-2022 record. Annual mean temperatures in B.C. have risen by 0.34 ^{o}C $decade^{-1}$ on average over the last 73 years. Globally, 2022 was the 5^{th} or 6^{th} warmest year on record (depending on climatology used), while it ranked as the 15^{th} warmest in North America (Copernicus Climate Bulletin, 2023).

A La Niña pattern of ocean temperatures that formed in late 2020 and persisted throughout 2022 may have contributed to the above average precipitation and delayed snowmelt in late spring, as La Niña conditions are associated with cooler than normal temperatures and above average precipitation. However, the impact of the El Niño Southern Oscillation (ENSO) on B.C. weather is typically weak during summer and early fall, consistent with the warm and dry conditions experienced during those months. The latest available sea surface temperature measurements in the tropical Pacific Ocean (March 2023) indicate that ENSO has now entered its neutral phase.

6.6. References

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7. MARINE HEATWAVE MAKES A BRIEF APPEARANCE DESPITE STRONG LA NIÑA CONDITIONS

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7.1. Highlights

- Despite strong negative PDO and La Niña conditions throughout 2022 which should have led to an abnormally cool year, temperatures were near normal in the NE Pacific.
- Surface waters in the NE Pacific were anomalously fresh in 2022 but slightly less anomalous as compared to 2021.
- The mixing in the winter of 2021/22 was near normal relative to the 2001-2023 Argo timeseries for Ocean Station Papa.

7.2. Description of the time series

Sea surface temperatures (SSTs) were collated from the NOAA Physical Science Laboratory website (NOAA Extended SST v4 http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl). Pacific climate indices examined in this report include the Oceanic Niño Index (ONI; http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml), North Pacific Index (NPI; https://climatedataguide.ucar.edu/sites/default/ files/cas_data_files/asphilli/npindex_monthly.txt) Pacific Decadal Oscillation (PDO; http://research.jisao.washington.edu/pdo/), Southern Oscillation Index (SOI; www.cpc.ncep.noaa.gov/data/indices/soi), and North Pacific Gyre Oscillation (NPGO; http://www.o3d.org/npgo/); please see section 7.6. for details.

Sub-surface profiles of temperature and salinity were obtained from the Line P time series and Argo float data. Line P is an oceanographic survey line extending from the mouth of the Juan de Fuca Strait to Station Papa at 50°N and 145°W in the middle of the Gulf of Alaska (originally the location of a Weather Ship; Freeland 2007). Routine sampling started at Station Papa in 1956, but in 1959 sampling was started along the ship's track between the coast and the weather ship location. Nowadays there are typically three cruises per year, in Feb/Mar, May/Jun and Aug/Sep. Each gives specific information: the Feb/Mar cruise tells us the depth of the winter mixed layer (MLD) or how deep the waters are well mixed with constant temperature and density, as well as how stratified the ocean is; both are key to understanding delivery of nutrients into surface waters to fuel primary productivity (the rate at which phytoplankton convert sunlight to usable energy which is then moved up the food chain by zooplankton). The May/Jun cruise allows us to see how much nutrients were consumed by phytoplankton during spring and exactly how much nutrients are still available for summer primary production, and the Aug/Sep cruise tells us how much of those nutrients have been used and how good the primary production was for that summer. Herein we focus on the physical data collected by the Line P program, CTD observations of Temperature, Salinity (Conductivity), and Depth (Pressure).

Argo float data are also used to create a synthetic Line P section for each calendar month. Argo floats typically profile from 2000 decibars to the surface every 10 days, reporting temperature and salinity in near real-time (Wong et al. 2020). Since mid-2001, the Gulf of Alaska has supported an array of Argo floats and their observations were used to interpolate temperature and salinity profiles at each Line P station. Argo temperature and salinity data were accepted into the computation from a wide area of the Northeast Pacific, but the interpolation was carried out using a Gaussian covariance function with a 300 km e-folding scale. For each month, the mean profile is centered on the 15th and data are accepted into the interpolation with a time window of ±15 days. Since the Argo record is short as compared to the Line P timeseries, these Argo-based synthetic Line P data are sometimes plotted as anomalies referenced to a seasonally-corrected mean of temperature or salinity based on the ship data.

7.3. Status and trends

Based on NOAA's land and sea surface temperature data dating back to 1880, 2022 was the sixth warmest year on record globally (NOAA State of the Climate 2022). This is consistent with the recent trend, wherein 9 of the ten warmest years globally are in the last decade. In ranked order, the ten warmest years are 2016, 2020, 2019, 2015, 2017, 2022, 2021, 2018, 2014, and 2010. Sea surface temperatures (SSTs) in the Northeast Pacific (NE Pacific) were only slightly warm in 2022; i.e. less than 1°C above the average for the 1991-2020 base period (www.ncdc.noaa.gov/sotc/ service/global/map-blended-mntp/202201-202212.png).

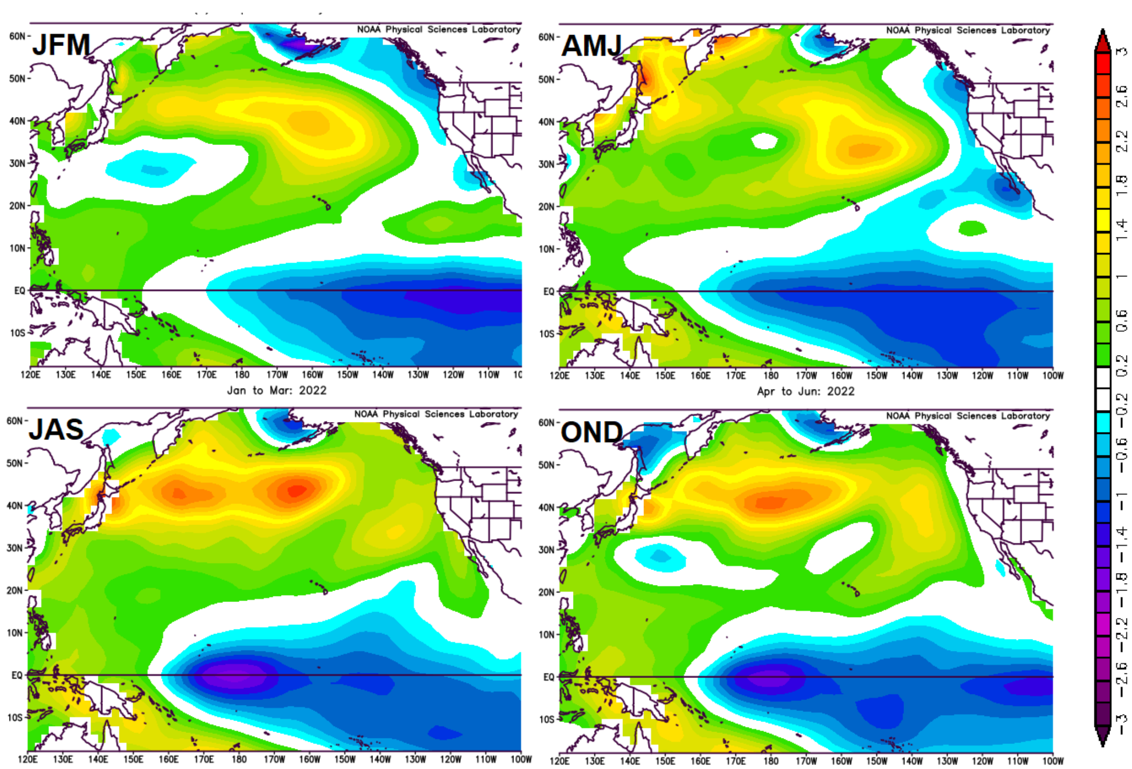

Figure 7-1. Seasonal maps of temperature anomalies in the Pacific Ocean for each quarter in 2022 (labelled by month groupings). The colour bar on the right, showing the temperature anomaly in °C, applies to all panels. Anomalies are relative to 1991-2020 base period. Source: NOAA Extended SST v4 http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl.

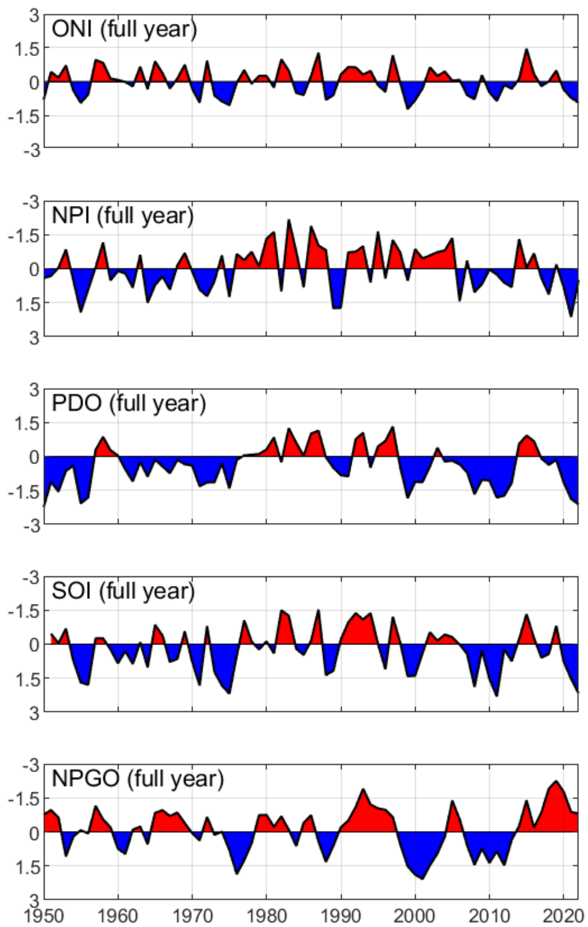

Figure 7-2. Time series of yearly-averaged Pacific climate indices. Some series are reversed so that series are red when coastal B.C. waters tend to be warm.

In the NE Pacific, the average SSTs were close to average throughout 2022, however the first half of the year was slightly cool and the second half slightly warm (Figure 7-1). Also notable in Figure 7-1 is the below average SSTs near the equator, indicative of the strong La Niña conditions present throughout 2022 (Figure 7-2). La Niña typically decreases SST in the NE Pacific, thus it is likely that the sustained La Niña conditions kept annual-mean SSTs near the 1991-2020 climatological mean, despite a marine heatwave in the fall of 2022 (Figure 7-3).

Looking at the climate indices collectively (Figure 7-2; see section 7.6. for details), they suggest that 2022 should have been a very cool year in the NE Pacific. While all the indices point in the same direction as in 2020 and 2021, most indices point to cooler condition in 2022 (i.e. the cool indices have larger amplitude except for the North Pacific Index; NPI). The North Pacific Gyre Oscillation (NPGO) continued to be the lone index indicating a warmer period, but had lower amplitude than in 2020 and 2021.

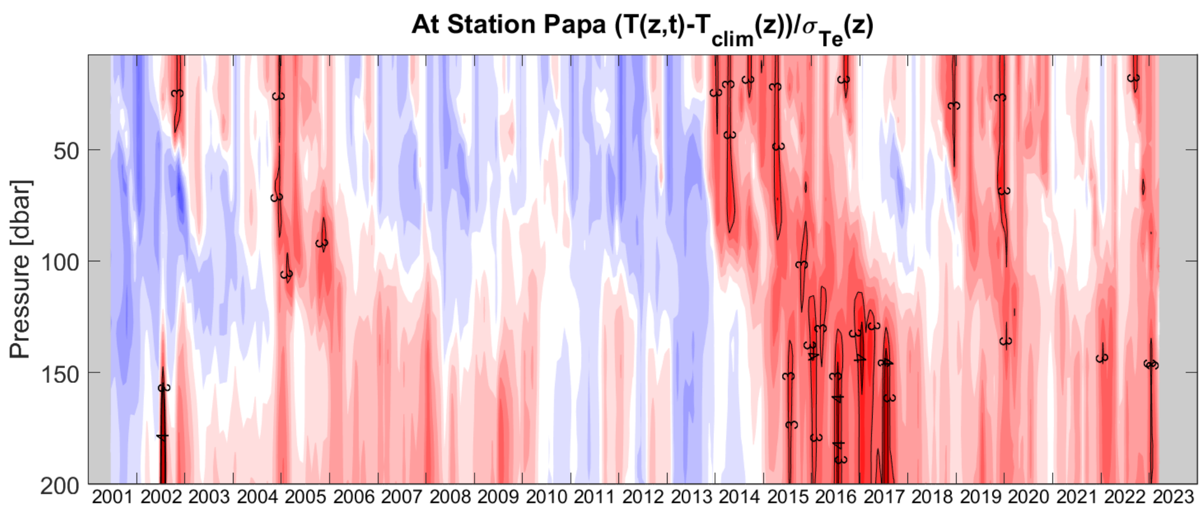

Figure 7-3. Plot of temperature, as observed by Argo floats near Ocean Station Papa, with anomalies calculated relative to the 1991-2020 seasonally-corrected mean and standard deviation (from the Line P time series). Cool colours indicate cooler than average temperatures and warm colours indicate warmer that average temperatures. Dark colours indicate anomalies that are large compared with standard deviations from the climatology. The black lines highlight regions with anomalies that are 3 and 4 standard deviations above the

Temperatures were slightly warmer than the 1991-2020 mean at Ocean Station Papa (OSP) in 2022 (Figure 7-3). Additionally, there continued to be significant salinity anomalies in the near-surface waters across the NE Pacific (Figure 7-4). This fresh anomaly wasn't stronger than in 2021, suggesting a weakening of the freshening trend in the NE Pacific. Sea surface salinity anomaly maps based on satellite data (Melnichenko et al. 2016; https://salinity.oceansciences.org/oi-anomaly.htm) show that these fresh anomalies stretch across much of the NE Pacific in 2022. The salinity anomaly timeseries at Station Papa show that these recent salinity anomalies are large relative to the 1991-2020 Line P climatology, with anomalies 3 standard deviations above the typical variability, but with lower anomalies in 2021 and 2022 relative to 2019 and 2020 (Figure 7-5).

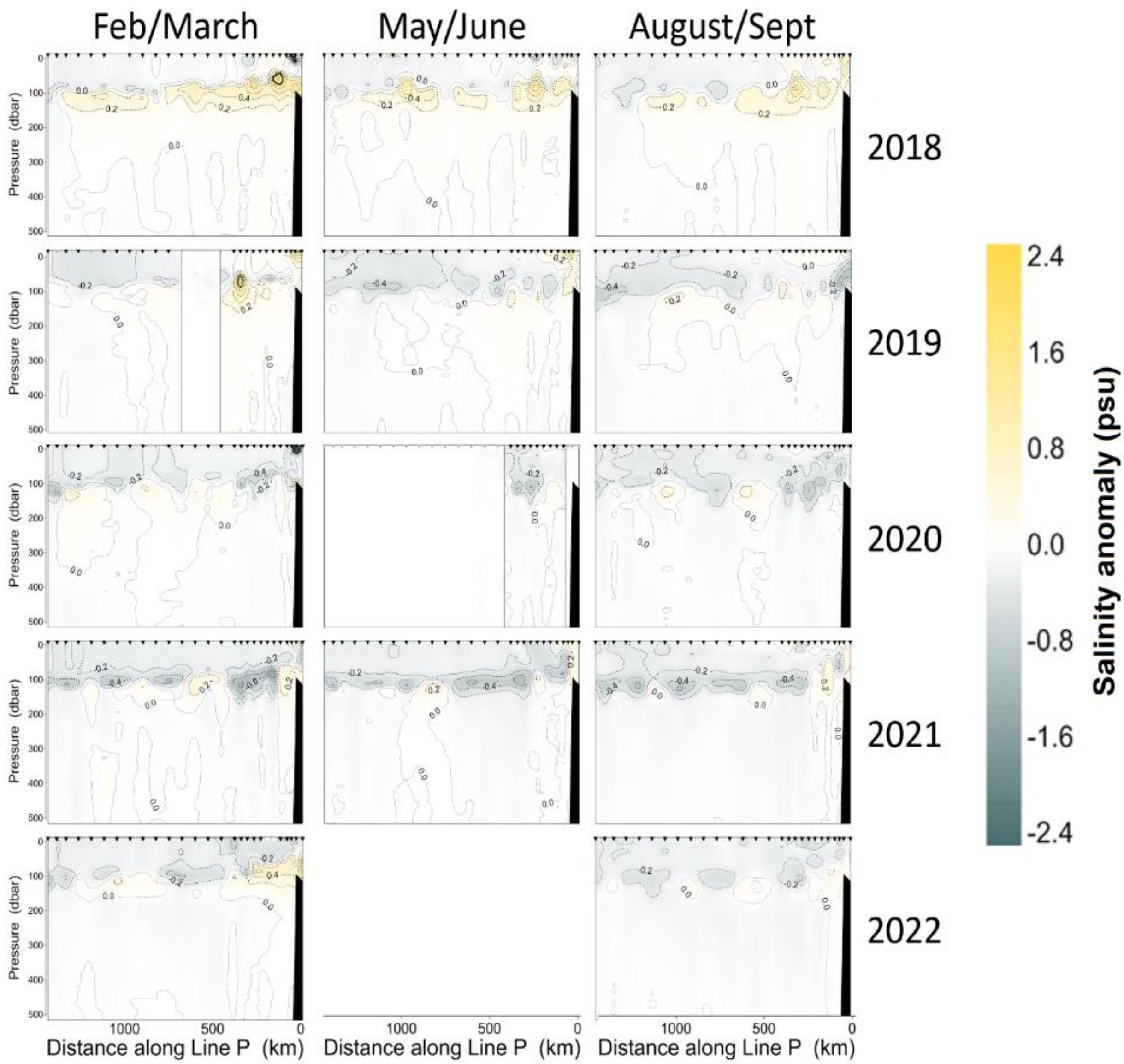

Figure 7-4. Salinity anomalies (psu) along Line P from 2018 to 2022 with respect to the 1981-2010 mean.

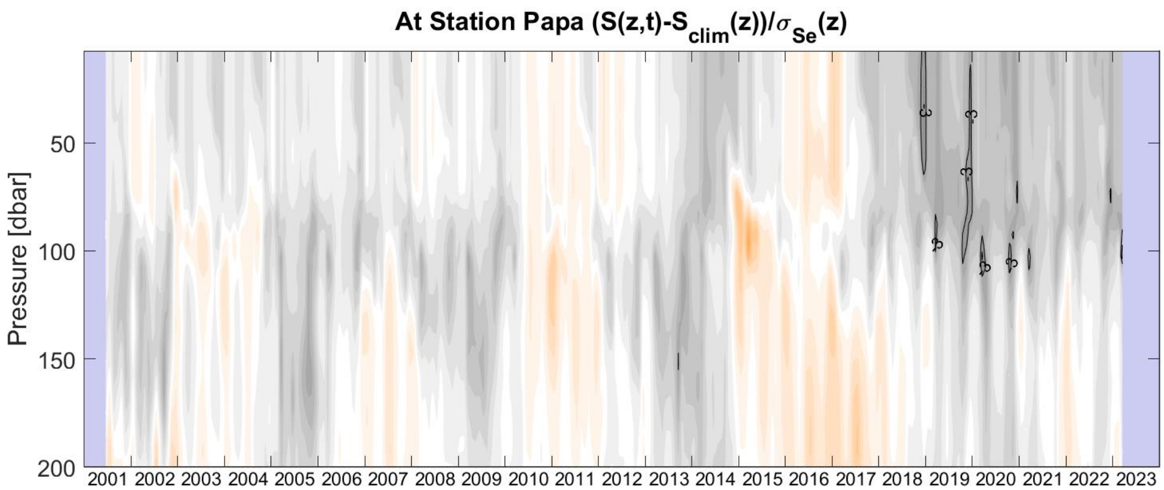

Figure 7-5. Plot of salinity anomalies as observed by Argo floats near Ocean Station Papa, with anomalies calculated relative to the 1991-2020 seasonally-corrected mean and standard deviation (from the Line P time series). The grey indicates fresher than average and orange indicates saltier than average. Dark colours indicate anomalies that are large compared with standard deviations from the climatology. The black lines highlight regions with anomalies that are 3 and 4 standard deviations below the mean.

The winter stratification was similar in 2021/22 and 2020/21 (Figure 7-6) and both were stronger than during the 2007-2013 period preceding the first big marine heatwave of the last decade (i.e. the ‘Blob’), but not as strong as the 2018/19 and 2019/20 winters which showed extremely low winter mixing. Thus, the mixing of nutrients to the surface was likely normal in 2021/22.

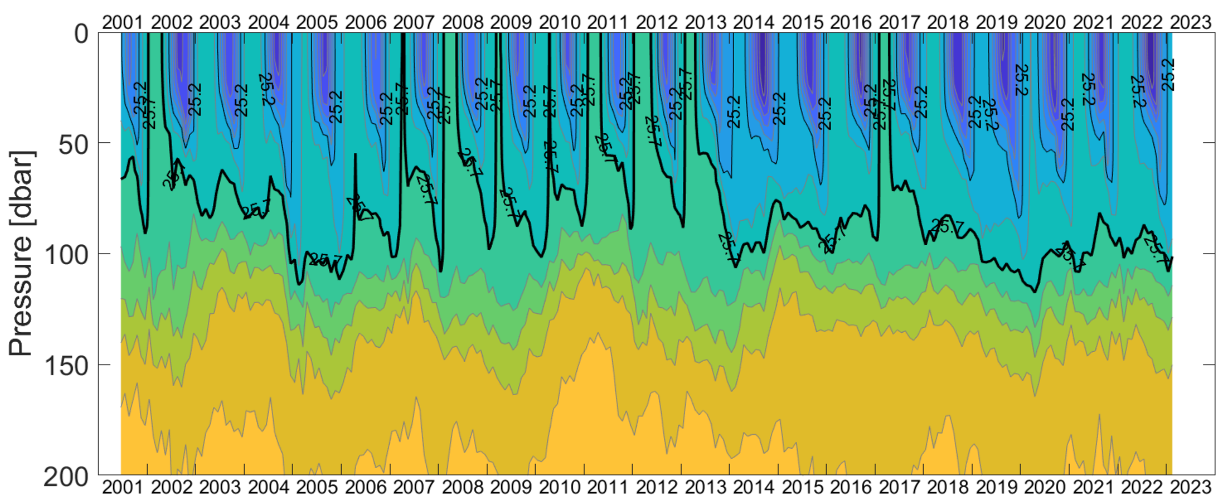

Figure 7-6. Coloured contour plot of density as observed by Argo floats near Station Papa (P26: 50º N, 145º W). The colours indicate potential density (yellow is denser and blue lighter). The black lines highlight the σ_θ=25.2 kg/m^3 (thin) and 25.7 kg/ m^3 (thick) isopycnals.

7.4. Factors influencing trends

The relatively normal temperatures observed in the NE Pacific are likely due to the juxtaposition of cool climate oscillations on a background of long-term climate warming. The salinity trend, i.e.

freshening of the surface waters in the NE Pacific, has been most strongly linked to amplification in the water cycle for pre-2017 freshening trends (Yu et al. 2020) but could also be related to increased river discharge due to accelerated glacial melt.

7.5. Implications of those trends

With climate indices suggesting a sustained cool period, it is likely that 2022/23 will experience stronger winter mixing, though this may be tempered by the anomalously fresh surface waters. Additionally, with the climate oscillations in a cool phase and the temperatures near normal, it is likely that during the next El Niño and/or positive PDO, the NE Pacific will be extremely warm.

The 'Blob' and the 2019-20 marine heatwave reduced winter mixing (Freeland 2015; Ross and Robert 2021), have led to surface nutrients among the lowest on record in the summer of 2019 (Peña and Nemcek 2020). The history of the σ_θ=25.7 kg/m^3 isopycnal (highlighted with a thick black line in Figure 7-6) illustrates this nicely. It remained very deep throughout the 2014-2016 marine heatwave, deeper even than much of the 2003-2005 warm period, while in 2017-2018 mixing was similar to 2007-2013 and it shoaled during the winter. Mixing decreased again during 2019-20 and it has not shoaled again. This weaker mixing suggests that nutrient supply from deep waters should have been weaker and therefore early spring nutrient levels should be on the low side in the spring of 2023, but not quite as low as in 2019 or 2020.

7.6. Description of Climate Indices

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

The **North Pacific Index (NPI)** is the area-weighted sea level pressure over the North Pacific Ocean from 30° N to 65° N and 160° E to 140° W. This index, like the Aleutian Low Pressure Index (ALPI; Surry and King 2015) reported in previous years, is a useful indicator of the intensity and a real extent of the Aleutian Low Pressure system. The NPI was generally positive (blue) from 1950 to 1976, and generally negative (red) from 1977 to 2008; a change than can be attributed to the strengthening of the Aleutian Low Pressure system after 1977. From 2008 to present, the NPI was mostly positive, due to weaker Aleutian Lows. The NPI anomaly, plotted in Figure 7-2, was calculated from the NPI by removing the 1950-2018 mean. Monthly time series of the NPI are provided by the Climate Analysis Section, NCAR at Boulder, Colorado and based on Trenberth and Hurrell 1994: https://climatedataguide.ucar.edu/sites/default/ files/cas_data_files/asphilli/npindex_monthly.txt.

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

The **Southern Oscillation Index (SOI)** is the anomaly in the sea level pressure difference between Tahiti (17°40′ S 149°25′ W) and Darwin, Australia (12°27′0″ S 130°50′0″ E). It is a measure of the large-scale fluctuations in air pressure occurring between the western and eastern tropical Pacific (i.e. the state of the Southern Oscillation) and, as it represents the changes in winds that set up El Niño/La Niña events, the ONI follows it quite closely. SOI is provided by the NOAA's National Weather Service National Centers for Environmental Prediction CPC and is available from: www.cpc.ncep.noaa.gov/data/indices/soi.

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

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

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8.1. Highlights

- Based on the timing of alongshore currents and wind stress, the 2022 Spring Transition timing was very late relative to the 1991-2020 mean. Late timing is associated with below-average upwelling-based coastal productivity.
- Stronger-than-average summer-time upwelling-favourable winds are generally associated with increased coastal productivity. Between 45° and 60° N, the magnitude of upwelling-favourable winds in 2022 was below the 1991-2020 average during the warm season. This also favoured below-average upwelling-based coastal productivity in 2022.
- The winter of 2021-2022 was characterized by below-average downwelling-favourable winds, indicating that winter storm activity was below-normal over the winter overall. Weaker winter storm activity implies weaker surface mixing, stronger stratification, possibly lower productivity, and has been associated with marine heat waves the following summer.

8.2. Description of time series

Spring and fall transition timing: 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 moorings A1 and E03 (Figures 8-1 and 8-2; Folkes et al. 2017; Thomson et al. 2013).

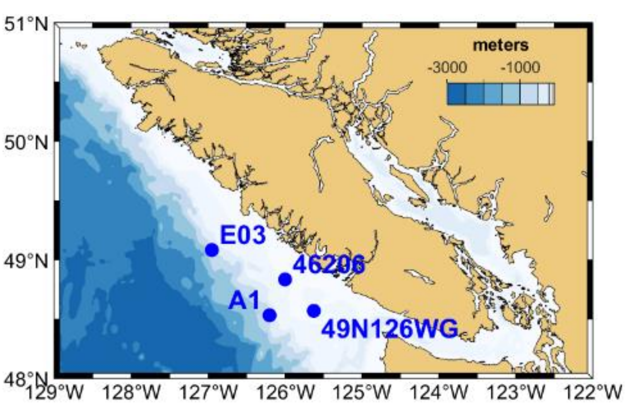

Figure 8-1. Map of mooring locations.

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., 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°to 60° N latitude

(Figure 8-3) using the NCEP/NCAR Reanalysis-1 analyses (Kistler et al. 2001) and subtracted the 1991-2020 mean to derive the Upwelling Index.

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 8-4). Because this is typically stronger in winter as a result of storms tracking eastward across the North Pacific, this index can reflect the strength of storms hitting the B.C. coast, a shift of storm tracks closer or further away from the coast, a longer or shorter storm season, or some combination of all three. The index also reflects the strength/weakness of wintertime vertical mixing of the surface water column near the coast.

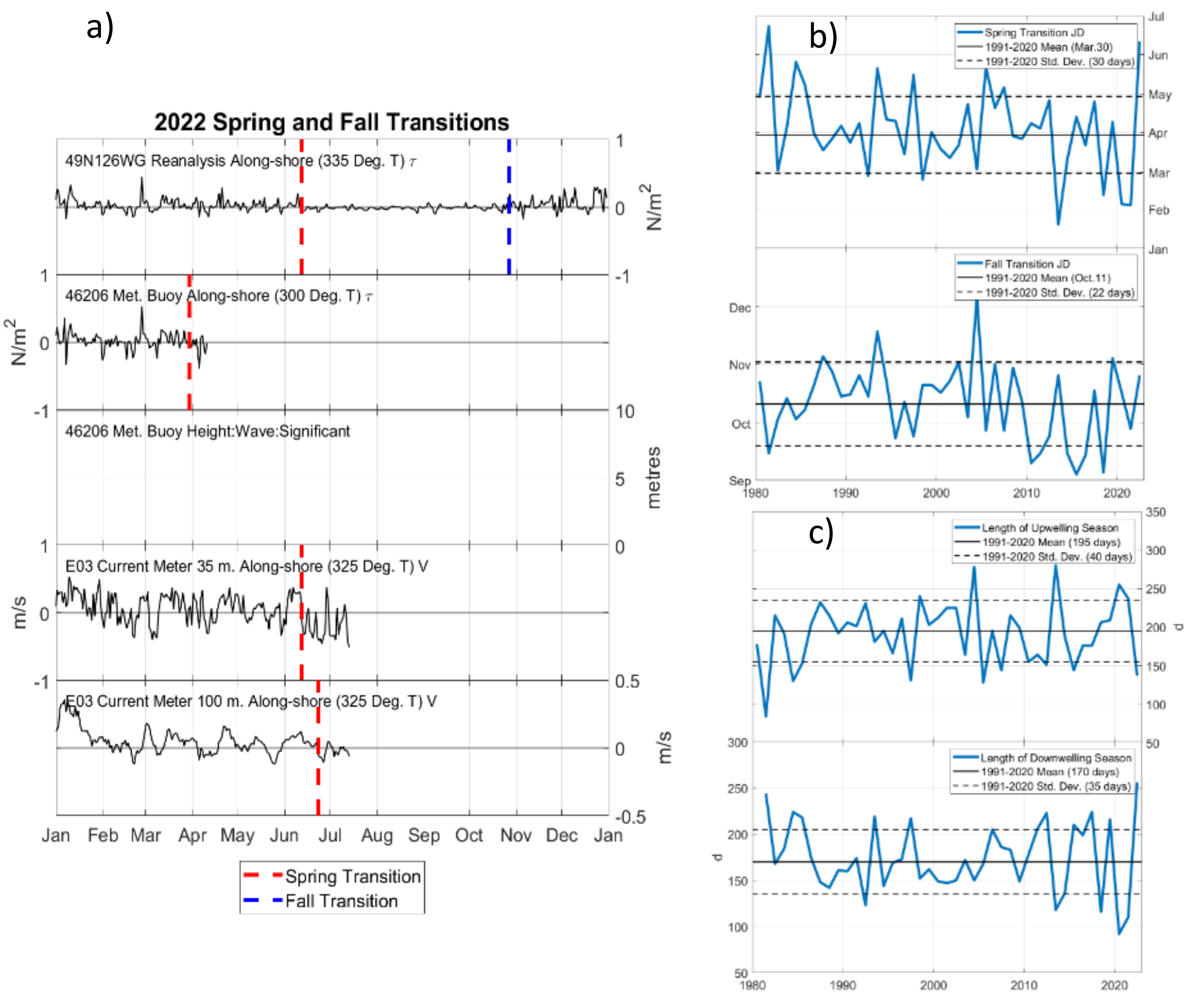

Figure 8-2. (a) Time series depicting the Spring and Fall Transitions off the West coast of Vancouver Island in 2022. Wind stress at Reanalysis-1 grid point 49°N 126°W and meteorological buoy 46206; significant wave height at 46206; along-shore current velocity at 35 and 100 m depth at mooring E03 (Folkes 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). (b) The annual Spring and Fall Transitions derived from time series in panel a. (c) The length of the upwelling and downwelling seasons derived from the time series in panel b.

8.3. Status and trends

8.3.1. Spring and Fall Transition timing

In 2022, the Spring Transition timing was very late compared to the 1991-2020 mean (Figures 8-2 and 8-5), and the second latest since 1981. The 2022 Fall Transition appears near average, although the lack of subsurface current data gives this assessment less confidence. Late Spring Transitions are associated with below average productivity in plankton, fish, and birds, as was particularly the case in 2005 (DFO 2006).

Over 2014-2020 the Fall Transition was trending later, such that the upwelling season was getting longer – and the downwelling (storm) season was getting shorter (Figures 8-2(b) and (c)). However, the late Spring Transition in 2022 resulted in a dramatic reset of the length of upwelling and downwelling seasons.

8.3.2. Upwelling Magnitude: The Upwelling Index

The Upwelling Index time series indicates that upwelling-favourable wind stress was below average over the 45°to 60° N latitude range over the 2022 warm season (Figures 8-3 and 8-5). In contrast, February upwelling-favourable winds were much higher than average. No trends in upwelling-favourable winds since 2013 are evident in Figure 8-3.

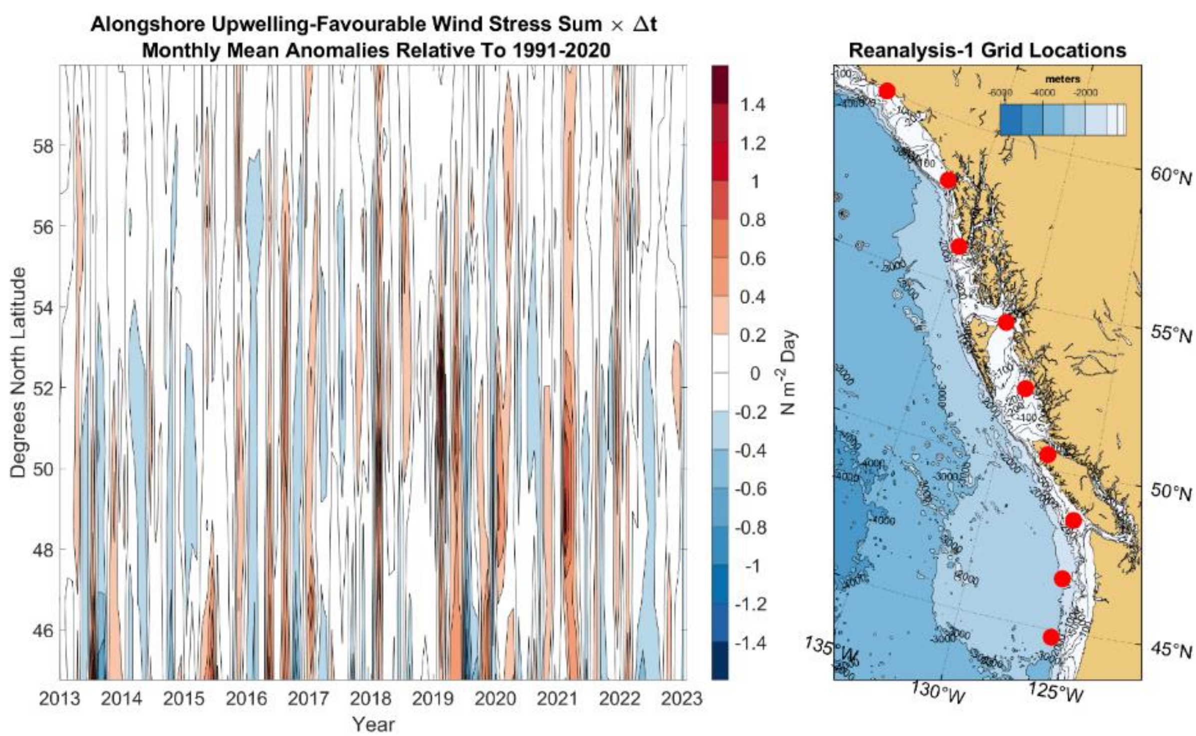

Figure 8-3. Recent (2013 to 2022) monthly mean anomalies (relative to 1991-2020) of monthly sums of alongshore upwelling-favourable (equatorward) wind stress from the NCEP/NCAR Reanalysis-1 coastal surface wind stress grid locations, 45-60° N.

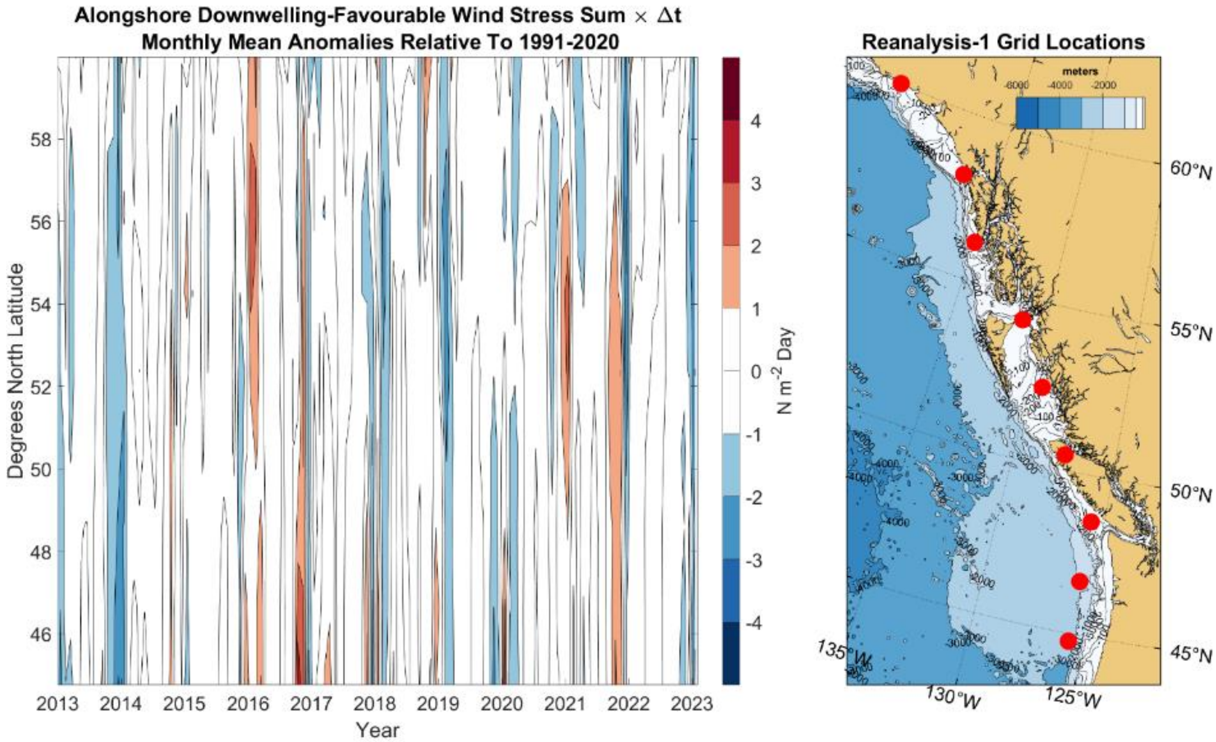

Figure 8-4. Recent (2013 to 2022) monthly mean anomalies (relative to 1991-2020) of monthly sums of alongshore downwelling-favourable (poleward) wind stress from the NCEP/NCAR Reanalysis-1 coastal surface wind stress grid locations, 45-60° N.

8.3.3. Downwelling Magnitude: The Downwelling Index

Over the previous four winters from 2017-2018 to 2020-2021, the Downwelling Index was lower than average, like the winter of 2013-2014, but not quite as low (Figure 8-4). This indicates reduced wintertime surface mixing near the coast and is usually associated with higher surface temperatures the following summer, such as the marine heatwave conditions observed in 2014 and 2019. Over winter 2021-2022, the index was again below average, and was followed by higher than average sea surface temperatures in summer 2022. So far over the winter of 2022-2023, the index has again been lower than average through January 2023, except for being slightly positive in December 2022.

8.4. Factors influencing trends

The reason why the Fall Transition may be occurring later over the last 10 years is unknown. While the Upwelling and Downwelling indices were higher than average over the ten year period 2000-2010 (indicating a period of consistently both stronger summertime and wintertime winds), the Downwelling Index had been lower than average over the period 2012-2020 and 2022 north of 50° N, excluding 2015-2016. This indicates weaker winter storms, or a shorter winter storm season, or winter storms that are tracking further to the northwest, away from the B.C. coast, or some combination of these three factors. The significantly weaker-than-average Downwelling Index in the winter of 2013-2014 was an accurate indicator of the weaker than average wintertime winds associated with the marine heatwave that year (Bond et al. 2015), and is likely also the case for 2019, 2020, and possibly 2021.

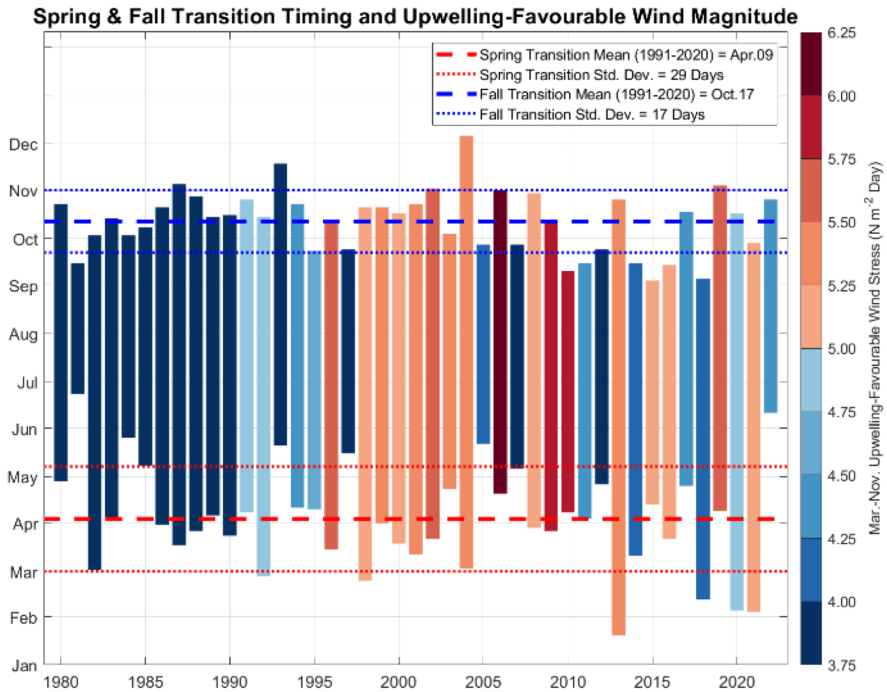

Figure 8-5. Annual Spring and Fall Transition Timing and March-November upwelling-favourable wind stress magnitude for the period 1980-2022.

8.5. Implications of those trends

The onset of seasonal upwelling that accompanies the Spring Transition varies from year to year (Thomson et al. 2014). This interannual variability may have implications related to the amount of winter ocean surface mixing, increased stratification, and productivity. 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 B.C.). The 2022 Spring Transition timing was very late, favouring below-average upwelling-based coastal productivity. Between 45°and 60° N, the magnitude of upwelling-favourable winds in 2022 was below average, also favouring below-average upwelling-based coastal productivity. Recent years of a weaker-than-average Downwelling Index are associated with, and may be precursors to, future marine heatwave events.

8.6. Acknowledgements

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

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

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9.1. Highlights

- Water temperatures were below average through early 2022 at the surface at weather buoy 46206 and at depth at mooring E03 off the west coast of Vancouver Island. There were no temperature data from the weather buoy and mooring for the remainder of the year.
- Alongshore flow at mooring E03 in 2022 was anomalous and strongly equatorward (upwelling-favourable) in February and March for the fifth year in a row. This was concurrent with below-average equatorward wind stress at buoy 46206 and lower than average water levels at Tofino arising from a weaker than normal Aleutian Low pressure system in the Gulf of Alaska.
- In June 2022, a weaker than average North Pacific High surface pressure system led to significantly higher than average coastal water levels as well as significantly more poleward than average shelf-break wind stress and subsurface currents.

9.2. Description of the time series

Subsurface temperatures and current velocities at the shelf break have been observed at mooring E03 (water depth ~400 m; Figure 9-1) since 1990, although there is a data gap between 2006-2020. Nearby meteorological buoy 46206 has provided sea surface temperature at 80 cm depth and wind velocity time series at 5 m elevation since 1988. Water level has been observed at Tofino since 1963. We have combined these series to obtain the vertical structure of water level, temperature, and flow through the water column.

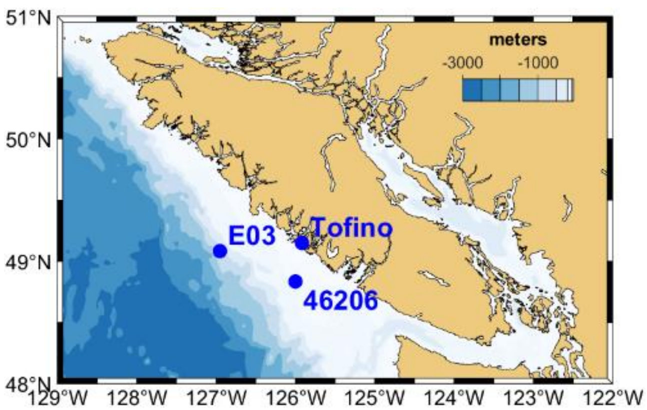

Figure 9-1. Locations of mooring E03, meteorological buoy 46206, and water level at Tofino.

9.3. Status and trends

Water temperatures at the surface were below average through early 2022, until buoy 46206 failed in April (Figure 9-2, left). Subsurface temperature data are only available from mooring E03 at 400 m depth and they were also below average early in the year, although not more than one standard deviation below the long-term mean. There are no data at depth after July 2022 until the mooring is recovered in summer 2023.

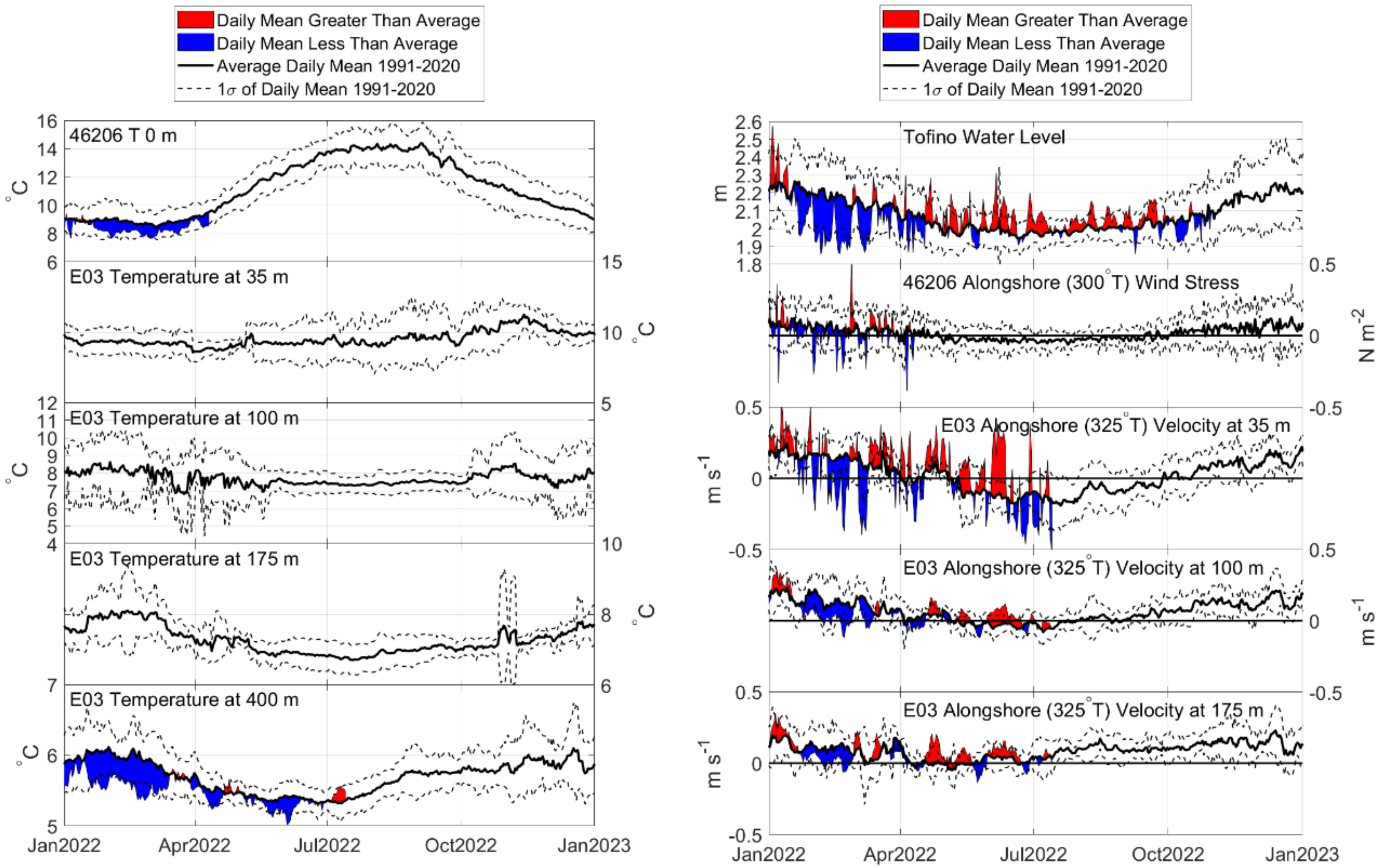

Figure 9-2. Daily mean values of temperature (left panels) and water level and alongshore wind stress/ocean current (right panels) at the surface, 35 m, 100 m, and 175 m depth from meteorological buoy 46206 and mooring E03. Angle in brackets (°T) is the principal direction of the wind or current vector in degrees true compass bearing.

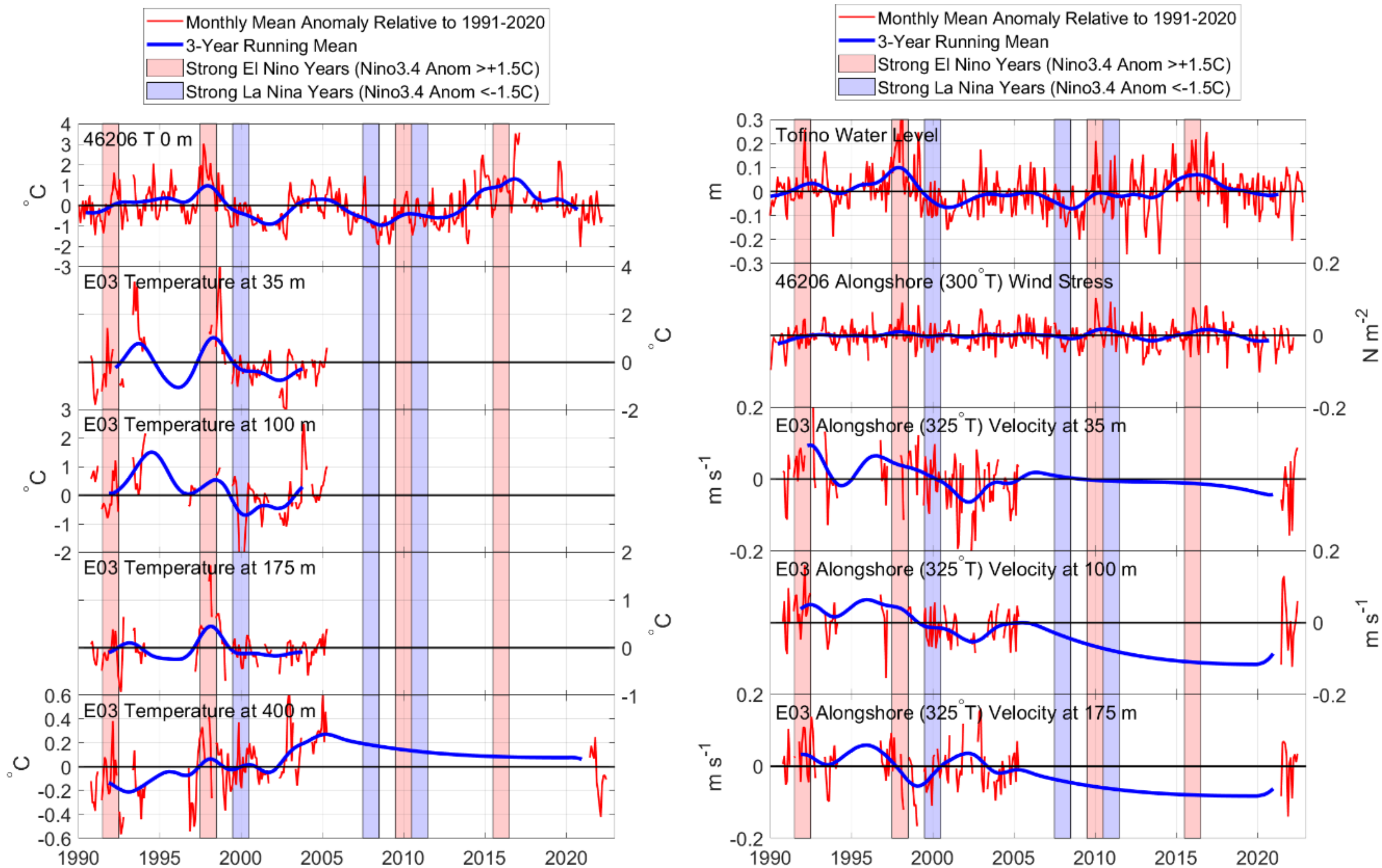

Figure 9-3. Monthly anomalies of temperature (left panels) and water level and alongshore wind stress/ocean current (right panels) at the surface, 35 m, 100 m, and 175 m depth from meteorological buoy 46206 and mooring E03. Angle in brackets (°T) is the principal direction of the wind or current vector in degrees true compass bearing.

The monthly mean water levels, alongshore surface winds and currents were generally near average (Figure 9-2, right). However, flow was consistently and anomalously strongly equatorward (upwelling-favourable) in February-March for the fifth straight year. Lower than average water levels were associated with southward flow early in the year. In June water levels and flow were significantly higher and the current more poleward than average due to a weaker North Pacific High surface pressure system. There are no weather buoy data after April due to equipment failure and no subsurface mooring data after July until the mooring is recovered in summer 2023.

Temperature anomalies were positive during the marine heatwave and El Niño over 2014-2016 (Figure 9-3). Positive temperature anomalies reappeared in 2019 at the surface but there were no data at other depths. For water level and alongshore flow, positive anomalies have typically occurred during El Niño years (Figure 9-3). This is likely due to stronger large-scale surface atmospheric circulation features (Aleutian Low and North Pacific High) associated with El Niño events. Stronger poleward flow may also have been due to an eastward shift of winter storm tracks toward the coast. For the fifth year in a row, conditions along the coast in 2022 consisted of anomalously strong equatorward (upwelling-favourable) flow in February/March. This reflected a recurring stronger and more northward-shifted North Pacific High atmospheric circulation system early in these years (2018-2022). Why this is recurring is unknown.

Higher temperatures and water levels, as well as enhanced poleward flow were also observed during the strong 1997-1998 El Niño (Figure 9-3). While flow now appears to be more equatorward (or weaker poleward) than average, temperature anomalies are near average at the surface compared to recent years. A lack of recent observed subsurface temperature anomalies prevents their assessment. Water level appears to be near the long-term average at time of writing.

There do not appear to be long-term trends in surface and subsurface temperatures and currents on the shelf or shelf break on the west coast of Vancouver Island over 1990-2022, but the recent large gap in subsurface data make that assessment for subsurface conditions uncertain at best. Mean water levels at Tofino also do not appear to exhibit a long-term trend.

9.4. Factors influencing trends

Although long-term trends do not appear evident, the strong El Niño of 2015-16 and recent years with increased occurrences of marine heatwaves are reflected in higher-than-average ocean temperatures at the surface and at depth (Hourston and Thomson, 2022). Weaker than average poleward flow in winter is also associated with marine heatwaves. This in turn reflects weaker storm activity and/or storm activity shifting westward and/or a stronger winter North Pacific High. Strong El Niños like that of 2015-2016 are associated with enhanced poleward flow in winter which was evident over the 2015-2016 winter (Hourston and Thomson, 2022).

9.5. Implications of those trends

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

9.6. References

Hourston, R.A.S., and Thomson, R.E. 2022. Vancouver Island West Coast Shelf Break Currents, Temperatures, And Wind Stress, p.37-41, in Boldt, J.L., Joyce, E., Tucker, S., and Gauthier, S. (Eds.). 2022. State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2021. Can. Tech. Rep. Fish. Aquat. Sci. 3482: vii + 242 p

10. SEA SURFACE TEMPERATURE AND SALINITY OBSERVED ALONG THE B.C. COAST IN 2022

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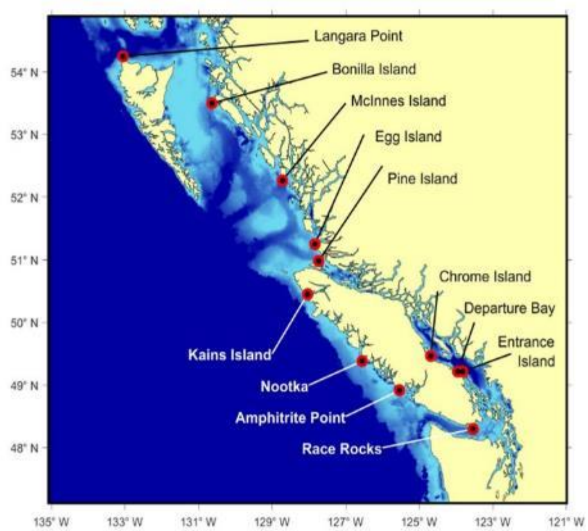
10.1. Highlights

- Sea surface temperatures were marginally lower in 2022 than in 2021 (-0.1°C) coast-wide and significantly lower than in 2015 (-1.2°C).
- The number of marine heat waves experienced were similar to 2021 in the Salish Sea (4) and West Coast (1) but might have been higher along the North Coast (3 vs. 0 observed at one station). Overall, a warm late summer and fall occurred in 2022 while 2021 had warmer spring and early summer.
- Sea surface temperatures show a continued long-term warming trend of 0.9°C / 100y with the last ten years all above the long-term mean.
- Annual mean sea surface salinity observations showed no change from 2021 to 2022 coast-wide (28.4).
- Over the long-term, a coast-wide freshening in the order of 0.2 / 100y was found. However, there is important year-to-year variability, as well as variability across regions.

10.2. Description of the time series



Station	Years of data	% good All time	% good 2022
Departure Bay	108	87	86
Race Rocks	101	97	98
Nootka	88	58	36
Amphitrite	88	96	96
Kains	87	95	25
Langara	86	91	87
Entrance	86	96	82
Pine Island	85	95	80
McInnes	68	94	92
Bonilla	62	98	99
Chrome	61	97	75
Egg Island	52	90	66
AVERAGE	**81**	**91**	**77**

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

As part of the British Columbia Shore Station Oceanographic Program, sea surface temperature (SST) and sea surface salinity (SSS) are measured daily at 12 shore stations, with the sampling taken at the first daylight high tide. Most stations are at lighthouses (Figure 10-1) with observations made by lighthouse keepers using a handheld electronic instrument (YSI Pro 30).

Records have been collected at two-thirds of the stations for over 80 years and for at least 50 years at the remaining stations, making this dataset particularly valuable to the study of long-term trends, as well as climate variability and changes. These datasets are amongst the longest series of this kind worldwide. Data coverage is over 90% on average but varies from year to year and site to site. There was, however, below average data collected during 2022, mostly due to poor coverage at two of the 12 stations. There was an instrument failure that could not be addressed quickly (Nootka) and a staffing issue at one lighthouse (Kains). For the others, most of the missing data was due to poor weather conditions and/or poor data quality. Overall, the average coverage for 2022 was 77% with only 3 stations above the 95% mark.

10.3. Status and trends

The observations show that the annual average daily SST at all stations was marginally cooler in 2022 than in 2021, with a coast-wide mean decrease of 0.1°C (10.4°C vs 10.5°C, respectively). Overall, annual temperatures observed at each station in 2022 and 2021 were close to each other as well as to the mean calculated over the 1991-2020 period (Figure 10-2, upper panel). The coast-wide SST in 2022 was therefore much lower than conditions observed in 2015 during the marine heatwave known as “the Blob” (11.6°C, annual average coast-wide). Regionally, the Salish Sea stations exhibited warmer temperatures than the West coast stations (11.8°C vs. 10.6°C in 2022), which in turn were warmer than the North coast stations (10.6°C vs. 9.6°C in 2022).

With respect to salinity (Figure 10-2, lower panel), the 2022 coast-wide annual average was found to be the same as in 2021 with a value of 28.4 based on the stations with sufficient data coverage during these last two years (a 66% minimum coverage per year and per station was used). This is markedly lower than the annual mean of 29.4 calculated over 1991-2020. An important part of this difference can be attributed to the absence of five stations which did not pass the coverage criteria and which are all (Race Rocks, Kains, Pine and Langara) but one (Nootka), located in areas of relatively high SSS. These annual means are, therefore, skewed towards lower SSS values. Race Rocks and Pine stations stand out from the 1991-2020 observed range in 2022; the former being slightly saltier than the annual maximum observed while the latter was slightly fresher. Regionally, two of the three stations located in the Salish sea showed fresher conditions in 2022 than in 2021 (Departure and Entrance) while Chrome reported saltier conditions. Along the West Coast, only one station reported enough observations and experienced an increase in SSS of 0.7 between 2021 and 2022 (from 28.1 to 28.8). Along the North Coast, three stations showed little difference between 2022 and 2021 and the normal; Langara, however, the northernmost station located offshore the mainland, reported notably saltier SSS conditions than normal for both 2021 and 2022.

Assuming a linear change over the entire data record (1935-present) the time series of temperature at all of the shore stations (combined) indicate a warming trend in the order of 0.9˚C over 100 years (Figure 10-3). Similarly, a coast-wide freshening in the order of 0.2 per 100 years was found based on combining all of the shore station (Figure 10-4). These estimates vary from site to site and are very sensitive to the period used for the analysis.

Cummins and Masson (2014, henceforth CM14) analyzed trends for 8 of the 12 stations. This analysis has been revisited with the benefit of an additional 10 years of data. Least-squares trends are presented in Tables 10-1 and 10-2 for SST and SSS, respectively. In addition, independent estimates of trends are given based on the Thiel-Sen estimator. For comparison, previous results from CM14 are included as well in the tables. Confidence intervals were calculated using a Monte Carlo method based on the auto-covariance of the de-trended SST and SSS records (see Appendix A of Cummins and Ross 2020).

The linear fits to SST indicated warming trends at each of the eight stations, consistent with the previous results. All these trends were statistically significant at the 95% confidence level, a finding not seen in the earlier analysis. Trends of remarkably similar magnitude (approx. 0.8 - 0.9 °C/century) were found at the four stations most exposed to the open Pacific (Race Rock, Amphitrite, Kains, Langara). Stations located in more protected waters, particularly those within the Strait of Georgia (Entrance and Chrome), displayed larger trends, as also found in CM14. The very large trend at Chrome was an artifact of the shorter record available at this station; comparable results were obtained for Entrance (2.1±1.1°C/century) with the analysis period restricted to 1961-2022. Lastly, it should be noted that trends from the Thiel-Sen estimator are similar to those based on least-squares fits, indicating that the results are robust with respect to the methodology applied to estimate trends.

In contrast to temperature, trends in surface salinity were not consistent across all the stations. There was a statistically significant freshening trend at Amphitrite, as found previously by CM14 and Freeland (2013), and also at Pine. The record of salinity at Langara was not considered in CM14 as its time series was considered suspect due to the dominance of a pronounced low frequency variability unlike any seen at the other stations. It is unclear if this reflects true ocean variability or if it is an artifact of the sampling location. Salinity records for the two stations in the Strait of Georgia were highly correlated with the discharge of the Fraser River (CM14), and displayed no significant trend.

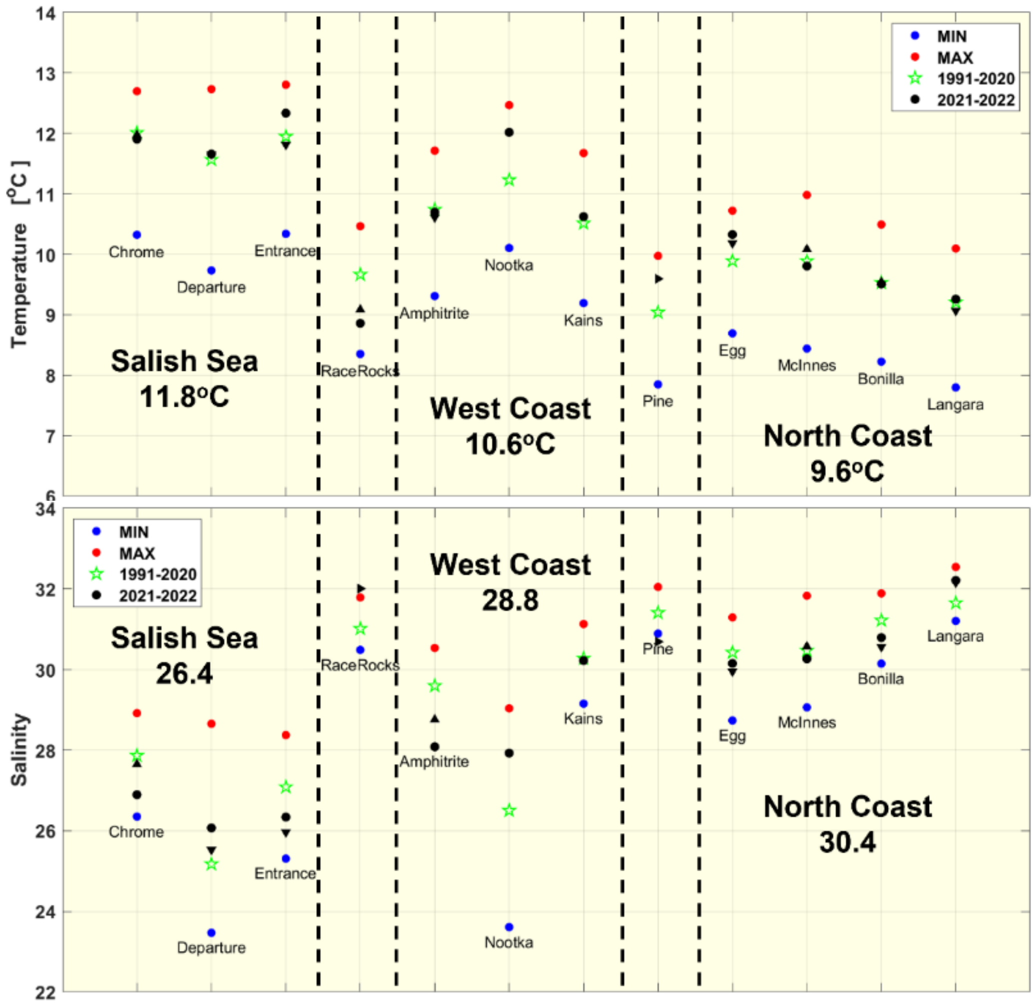


Figure 10-2. Upper panel. Annual average SST in 2021 (black dots) and 2022 (black triangles) from daily observations at shore stations along the west coast of Canada. The area is divided in three, geographycally distinct, regions (Salish Sea, West Coast and North Coast). Two stations lie at the periphery of these regions: Race Rocks and Pine and may be subject to distinct oceanographic regimes. The green stars represent the new climatological mean computed over the 1991-2020 period (30 years). Blue and red dots represent the minimum and maximum annual means observed within this climatology, respectivelly. Lower panel illustrate similar statistics using SSS data.

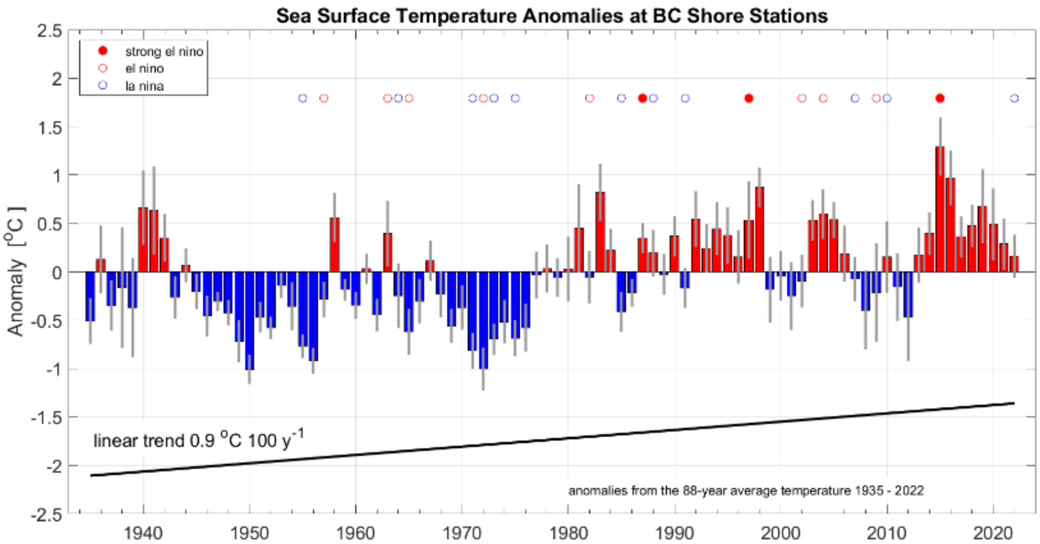


Figure 10-3. Trend in annual SST based on the observations of all lighthouses (black line). The bars represent the anomalies averaged over all stations (a coast wide indicator), (red – above average, blue – below average), the vertical grey lines show the variability (standard deviations) in the lighthouse data for each year (1935-2022). Important El Niño Southern Oscillation (ENSO) phases are indicated above as red (El Niño warm anomaly) and blue (La Niña cold anomaly) circles and dots (strong phase).

Table 10-1. SST trends based from Cummins & Masson (2014) and updated analysis. To allow comparison with Amphitrite and Kains, the trend at Race Rocks was given for the period 1935-2022. The least-squares trend for the entire record (Feb 1921 – Apr 2022) was 0.81 °C/century. To avoid a 30-month data gap (Sept 1937 - Feb 1940), the 95% confidence interval was calculated based on the abridged record, Mar 1940 - Apr 2022. The least-squares trend for this abridged record was 0.88 °C/century, similar to that of the entire record (0.86 °C/century). To avoid the extended data gaps occurring near the end of record, the 95% confidence interval was based on an abridged record, May 1936 - Dec 2019. The least-squares trend for the abridged record was 1.28 °C/century, similar to that of the entire record (1.29 °C/century).

	Cummins & Masson (2014) results		Updated analysis	
Station	C&M analysis period	Least-squares trend in °C/century	Analysis time period	Least-squares (Thiel-Sen) trend in °C/century
Race Rocks	Jan 1942 - Dec 2012	1.39 ± 0.68	Jan 1935 - Apr 2022[1]	0.87 (0.92) ± 0.58
Amphitrite Point	Jan 1935 - Dec 2012	0.71 ± 0.53	Jan 1935 - Apr 2022	0.89 (0.90) ± 0.36
Kains Island	Jan 1935 - Dec 2012	0.43 ± 0.74	Jan 1935 - Apr 2022	0.78 (0.79) ± 0.62
Langara Island	Jan 1940 - Dec 2012	0.75 ± 0.86	Oct 1936 - Mar 2022[2]	0.86 (0.86) ± 0.64
Entrance Island	Jan 1937 - Dec 2012	1.32 ± 0.96	May 1936 - Mar 2022[3]	1.29 (1.28) ± 0.87
Chrome Island	Jan 1963 - Dec 2012	3.38 ± 0.91	Apr 1961 - Apr 2022	2.62 (2.59) ± 1.01
Pine Island	Jan 1937 - Dec 2012	0.74 ± 0.81	Jan 1937 - Apr 2022	1.27 (1.18) ± 0.70
Bonilla Island	Jan 1960 - Dec 2012	0.72 ± 0.95	Apr 1960 - Apr 2022	1.09 (1.00) ± 0.56

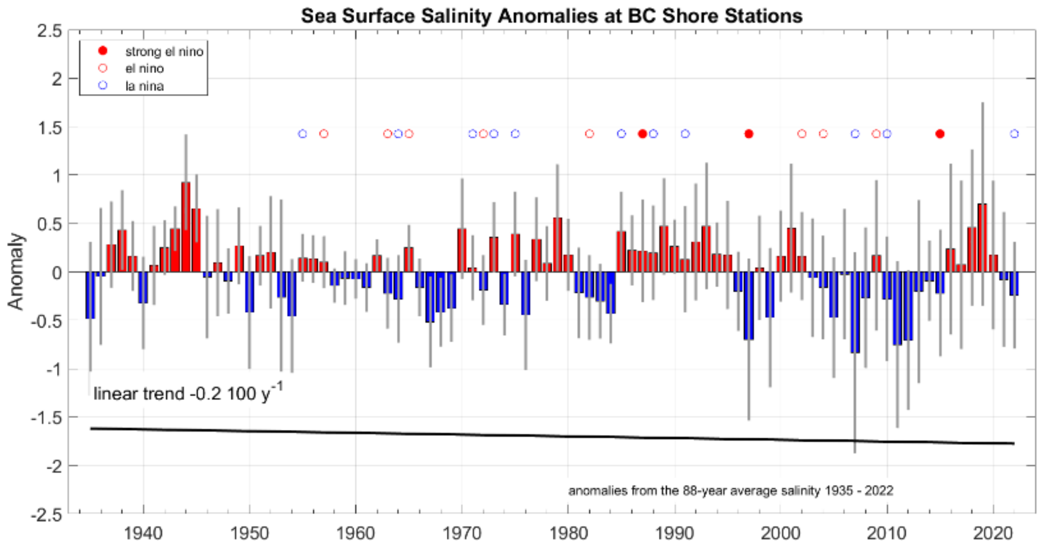


Figure 10-4. Trend in annual SSS based on the observations of all lighthouses (black line). The bars represent the anomalies averaged over all stations (a coast wide indicator), (red – above average, blue – below average), the vertical grey lines show the variability (standard deviations) in the lighthouse data for each year (1935-2022). Important El Niño Southern Oscillation (ENSO) phases are indicated above as red (El Niño warm anomaly) and blue (La Niña cold anomaly) circles and dots (strong phase).

Table 10-2. SSS trends based from Cummins & Masson (2014) and updated analysis. To avoid the extended data gaps occurring near the end of record, the 95% confidence interval was based on an abridged record, May 1936 - Dec 2019. The least-squares trend for both the abridged record and the entire record was 0.44 century^{-1}.

	Cummins & Masson (2014) results		Updated analysis	
Station	C&M analysis period	Least-squares trend in century^{-1}	Analysis time period	Least-squares (Thiel-Sen) trend in century^{-1}
Race Rocks	Jan 1942 - Dec 2012	-0.38 ± 0.53	Jan 1942 - Feb 2022	-0.19 (-0.20) ± 0.38
Amphitrite Point	Jan 1935 - Dec 2012	-0.82 ± 0.57	Aug 1934 - Apr 2022	-0.69 (-0.64) ± 0.48
Kains Island	Jan 1935 - Dec 2012	-0.47 ± 0.54	Jan 1935 - Apr 2022	-0.29 (-0.30) ± 0.52
Entrance Island	Jan 1937 - Dec 2012	0.70 ± 1.38	May 1936 - Mar 2022[1]	0.44 (0.49) ± 1.40
Chrome Island	Jan 1963 - Dec 2012	0.43 ± 1.56	Apr 1961 - Apr 2022	0.02 (0.03) ± 1.26
Pine Island	Jan 1937 - Dec 2012	-0.66 ± 0.42	Jan 1937 - Apr 2022	-0.52 (-0.53) ± 0.43
Bonilla Island	Jan 1960 - Dec 2012	0.14 ± 0.76	Apr 1960 - Apr 2022	-0.18 (-0.05) ± 0.72

10.4. Factors influencing trends

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

Although SSTs were notably warmer during the marine heatwave of 2014-16, conditions in 2022 continue the period of warmer than normal water (where normal is defined as the average on the long-term SST record starting in 1935). This warm water period has lasted for ten years, the longest span of above normal temperature in the time series. While the record shows multi-year and multi-decadal oscillations in the annual SST, there remains a long-term trend towards rising ocean temperatures.

The long-term salinity records show a trend to fresher conditions at most stations along the B.C. Coast. However, in comparison with temperature, salinity trends have greater uncertainty due to higher spatial and temporal variability. Variability in the salinity signal along the Pacific Coast is governed by the integrated effects of atmospheric forcing and local coastal precipitation; the Strait of Georgia is strongly influenced by the discharge from the Fraser River (CM14).

10.5. Implications of those trends

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

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11. SATELLITE MONITORING OF SEA SURFACE TEMPERATURE AND CHLOROPHYLL-A IN 2022

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11.1. Highlights

- Satellite sea surface temperature (SST) throughout the study regions within the B.C. EEZ was lower than usual during the spring of 2022. Peak summer temperatures were delayed to September, a month later than typical. Cooling was delayed in late summer and autumn, particularly during the month of October, coinciding with an extensive Marine Heatwave in the Northeast Pacific.
- More than half of the examined regions exhibited seasonally increasing SST trends during summer. The large offshore Area of Interest (TḥT) had the highest magnitude, and a location in eastern Hecate Strait had the lowest.
- Satellite-measured chlorophyll-a concentration (Chl-a) and its monthly variability were higher than usual in regions on the continental shelf during the late summer and fall. Many on-shelf regions had elevated Chl-a in spring that occurred a month earlier than is typical in the climatology.

11.2. Description of the time series

Satellite-measured sea surface temperature (SST, °C) and chlorophyll-a (Chl-a, a proxy used to estimate phytoplankton biomass in mg m^{-3}) were retrieved for the period 2003 through 2022 from the MODerate Resolution Imaging Spectroradiometer (MODIS-Aqua) at 4 km pixel resolution. The NASA Ocean Biology Processing Group (OBPG, https://oceancolor.gsfc.nasa.gov/) standard products were used, where night-time SST was calculated from the 11 and 12 micron bands (https://oceancolor.gsfc.nasa.gov/atbd/sst/), and Chl-a was calculated using the combined blue-green band ratio and Colour Index algorithms (https://oceancolor.gsfc.nasa.gov/atbd/chlor_a/). SST was also retrieved from the NOAA Advanced Very High Resolution Radiometer (AVHRR) Pathfinder series, which extends back to late 1981 (v5.3; https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.nodc:AVHRR_Pathfinder-NCEI-L3C-v5.3).

Temporal statistics were extracted for regions of interest in the British Columbia Exclusive Economic Zone (B.C. EEZ) and are summarized in Figure 11-1 a. and Table 11-1. These regions include Oceans Act marine protected areas (MPAs): Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs (with the northern section presented here; SRN), SG̲aan K̲inghlas-Bowie Seamount (SK-B), and the recently announced Tang.ɢwan – ḥačxʷiqak – Tsigis (TḥT; https://www.dfo-mpo.gc.ca/oceans/aoi-si/tht-eng.html). Other areas included Scott Islands marine National Wildlife Area (SI), Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve and Haida Heritage Site (the western and eastern sections; GHW and GHE). Three oceanographic stations, Mason53, E01 and A1, were also included, where data were extracted for a 5x5 pixel box centered on the location. Statistics for other significant regions, including the Endeavour Hydrothermal Vents MPA, are not presented here but are located online at https://ios-osd-dpg.github.io/ SST_Chla_Report.html.

For all areas, time series for each month and season (e.g. winter constituting the months of January, February and March) were extracted, along with the monthly climatological values. For SST, the mean, standard deviation and upper and lower 10 percentiles are presented, using the 1991-2020 climate normals period for climatology. For Chl-a, the geometric mean and standard deviation are presented to more accurately represent the average, using the shorter period 2003-2021 for the climatology. November, December and January images were excluded from the Chl-a dataset due to the low sun angle causing higher uncertainty in the measurements and limiting the spatial data coverage. Finally, a linear model and significance of fit were retained for the regional seasonally averaged SSTs.

11.3. Status and trends

Chl-a has been low climatologically, as well as in 2022, in the regions off the continental shelf (Figure 11-1 c.). Of the on-shelf regions, E01 demonstrated the most dynamic inter-annual variations in Chl-a; Chl-a at A1 was typically much lower, though it is located < 100 km to the southeast. A characteristic of 2022 throughout the regions and stations was higher autumn Chl-a occurring later than usual, particularly compared to 2021, which more closely followed the climatological means. For example, Chl-a in 2022 was 1 standard deviation higher in SRN during September, and similarly elevated nearby in GHE during September and October. In addition, multiple areas, including Mason53 and GHE, showed high variation of Chl-a in April rather than May, suggesting that the phytoplankton spring bloom occurred earlier than usual. However, Chl-a measures from April 2022 have higher associated uncertainty due to a MODIS-Aqua data outage from April 1st to 17th. A similar pattern was observed at E01 and A1, where the Chl-a and its standard deviation were higher in March instead of the usual April. This supports the idea that the bloom was early.

Overall SSTs were cooler than usual in the winter and spring, particularly in the regions on the southern continental shelf (e.g. TḥT, E01 and A1), then anomalously warm in the autumn (Figure 11-1 c.). Typically, warmest temperatures are reached in August throughout the regions examined, but the seasonality was delayed in 2022 with the majority (SK-B, GHW, ThT, E01 and A1) reaching their warmest monthly temperatures in September. October was a very unusual month, with SSTs exceeding the 90th percentile of the climatology in many areas, coinciding with an extensive Marine Heatwave (MHW) in the NEP. GHE (one of the stations that did not have unusually high October SST) had higher than usual SSTs during August. Maps showed that the spatial extent of high SSTs (> 2^{o}C anomaly) was largely constrained along the east coast of Haida Gwaii between Sandspit at the north and Laskeek Bay at the south end.

Seasonal trend analysis revealed statistically significant increases in SST in many regions during summer. The magnitudes varied but were typically larger in the satellite data record compared to SST trends seen at lighthouses along the B.C. coast (Chandler 2015), so will be examined further in future work. The largest trends occured in the TḥT region, while GHE, Mason53, E01 and A1 did not exhibit trend in any season.

11.4. Factors influencing trends

A characteristic of 2022 was the presence of sustained offshore Marine Heatwaves (MHWs) in the Northeast Pacific, causing SST in many regions (Mason53, GHW, SI, and TḥT) to exceed the upper 90th percentile of their climatological SSTs during the month of October. As detailed in the California Current Marine Heatwave Tracker (https://oceanview.pfeg.noaa.gov/projects/mhw/latest), a large offshore MHW formed in late January, followed by a secondary MHW in late August. The area under MHW status (typically defined as SSTs above the 90th percentile / 1.29 standard deviations in a normal distribution; Hobday et al. 2016) remained outside the B.C. EEZ for much of the first half of 2022, where the waters throughout were generally cooler than usual. Beginning in late August most of the B.C. EEZ fell under MHW status with varying intensity until late October. This was reflected in the satellite SSTs, as well as surface temperature measurements from buoys and lighthouse station data (see also: Donnet et al. Section 10, and https://github.com/IOS-OSD-DPG/Pacific_SST_NRT_Monitoring).

11.5. Implications of those trends.

Recently, Tanaka and Houtan (2022) demonstrated that > ½ of the North Pacific has been in MHW status in the last decade; similarly, the frequency, duration and intensity of MHWs globally are increasing due to anthropogenic climate change (Laufkötter et al. 2020; Hobday et al. 2018). In B.C., warming of the surface ocean has been observed in the long-term (Chandler 2015; Cummins and Masson 2014). Recent years have been under La Niña conditions, which tend to be cooler (as mentioned further in Section 12). The El Niño Southern Oscillation (ENSO) is forecasted to transition to neutral conditions during spring and summer of 2023, with significantly rising probabilities of transitioning to El Niño conditions following March 2023 (https://iri.columbia.edu/our-expertise/climate/forecasts/enso/current/?enso_tab=enso-cpc_plume). Given this information, we expect SSTs on the B.C. shelf will likely follow climatological values for winter and spring of 2023, but there is an increasing probability of warmer conditions later in the year. In the offshore portion of the B.C. EEZ the return of MHWs in 2023 is highly likely given the persistently warm water in the NEP outside the EEZ.

Warmer SSTs add pressures to the ecosystem; in terms of phytoplankton, MHWs can lower primary production, and contribute to Harmful Algae Bloom events (Crozier 2015). Ongoing monitoring of the timing and magnitude of phytoplankton blooms is an important part of understanding changes to the ecosystem and impacts of climate change.

Table 11-1. Region and station names and abbreviations, with statistically significant summer trends indicated as decadal values with slope standard error.

Region	ID	Summer SST Trend (°C per decade)
A1	A1	-
E01	E01	-
Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve and Haida Heritage Site *(West and East regions)*	GHW *(West)*	0.25 ± 0.12
	GHE *(East)*	-
Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs Marine Protected Area *(North region only)*	SRN *(North)*	0.23 ± 0.10
Mason53	Mason53	-
Scott Islands marine National Wildlife Area	SI	0.29 ± 0.09
SG̲aan K̲inghlas-Bowie Seamount Marine Protected Area	SK-B	0.27 ± 0.13
Tang.ɢwan – ḥačxwiqak – Tsig̱is Marine Protected Area	TḥT	0.36 ± 0.10

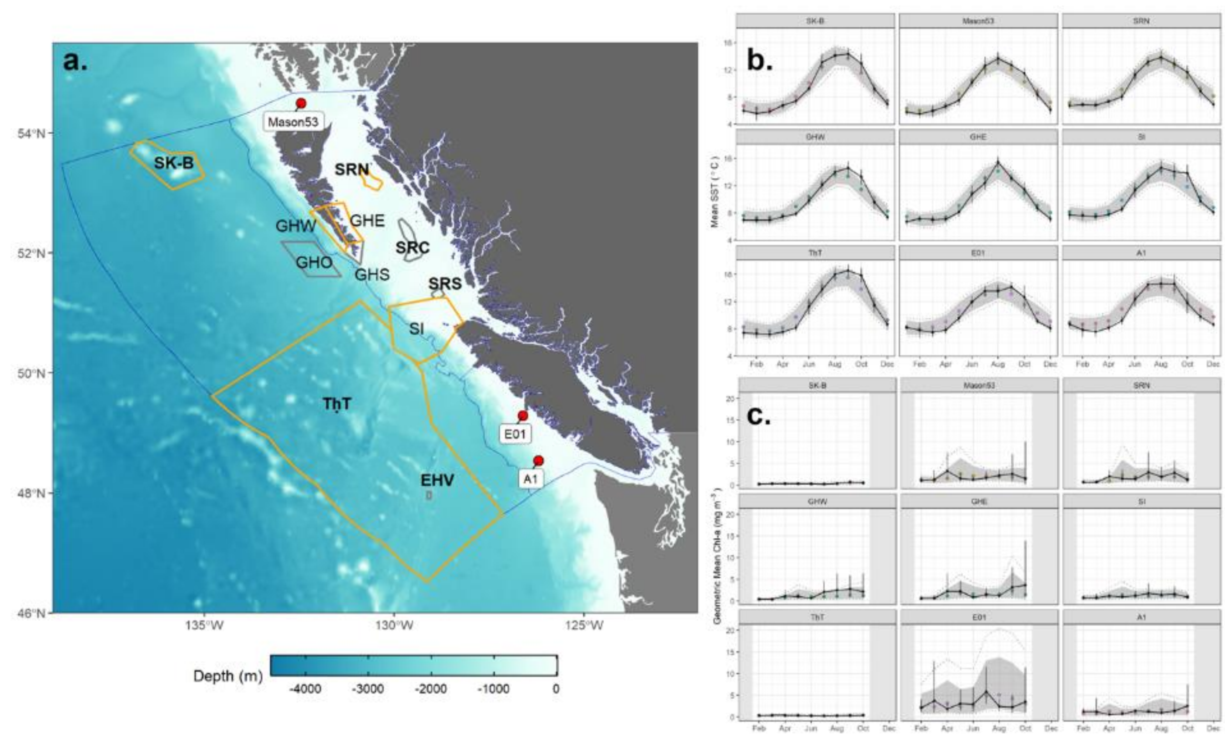

Figure 11-1. ***a.*** *Map of the stations (red points) and regions (orange outlines included in this report) used within the B.C. EEZ.* ***b.*** *SST climatology of the regions, with 2022 plotted on top (black points with bars indicating standard deviation).* ***c.*** *Chl-a climatology indicated in the same manner as SST, but with geometric mean and geometric standard deviation ranges. Dotted lines indicate upper and lower 10-percentiles.*

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12. SUBSURFACE OCEAN CONDITIONS ON THE B.C. SHELF: THE B.C. SHELF MOORING PROGRAM

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12.1. Highlights

- The B.C. Shelf Mooring Program has maintained 8-12 instrumented moorings on the B.C. shelf since 2016. It also maintains a 30+ year mooring record on the inner Vancouver Island shelf.
- With moorings in 3 marine protected areas in the northern shelf bioregion, the program could be the backbone of a monitoring programme for the region's MPA Network.
- The B.C. shelf has been recovering from the Blob (2014-2016) since about 2018, with decreasing subsurface temperatures at most locations (40 m and 100 m depth). This cooling may have ended in 2022.
- The oxygen concentration of the annual minimum at 40 m depth in the mouth of Queen Charlotte Sound has been increasing since the fall of 2017.
- On an annual cycle, the water column becomes largely isothermal down to at least 75-100 m over most of the shelf by winter (Dec/Jan/Feb). Thus satellite sea surface temperature (SST) can provide information about subsurface temperatures for a few months of the year. December 2022 was colder than the 30-year climatological averages across the entire shelf, with the largest anomalies of about 1-2 °C in Hecate Strait and the central coast.

12.2. Description of the time series

The B.C. Shelf Mooring Program has maintained an expanding array of instrumented moorings along the B.C. continental shelf starting in 2016 (Figure 12-1). Measurements at all locations include temperature, salinity, dissolved oxygen at multiple depths, and water velocity through the water column. Measurements of marine sound are available at some mooring locations. Moorings are recovered and redeployed on an annual basis.

The goal is to maintain an array of moorings from Juan de Fuca Strait to Dixon Entrance, subject to operational constraints. A keystone mooring, Scott2, has been kept in 300 m of water north of the Scott Islands since 2016. Other moorings of note are E01 (Estevan Point), Hak1 (Hakai Pass), SRN1 (Sponge Reef North), Juan2 (Juan Perez Sound), and Chat3 (Chatham Sound). The program inherited the long time series (30+ years) at EO1 and A1 at the southwest corner of the Vancouver Island shelf (Figure 12-1). EO1 continues to be maintained. A1 was abandoned in 2021 after the mooring was hit and cut by mid-water trawls three times in four years. E03 is a temporary replacement location until a plan to re-establish A1 is developed.

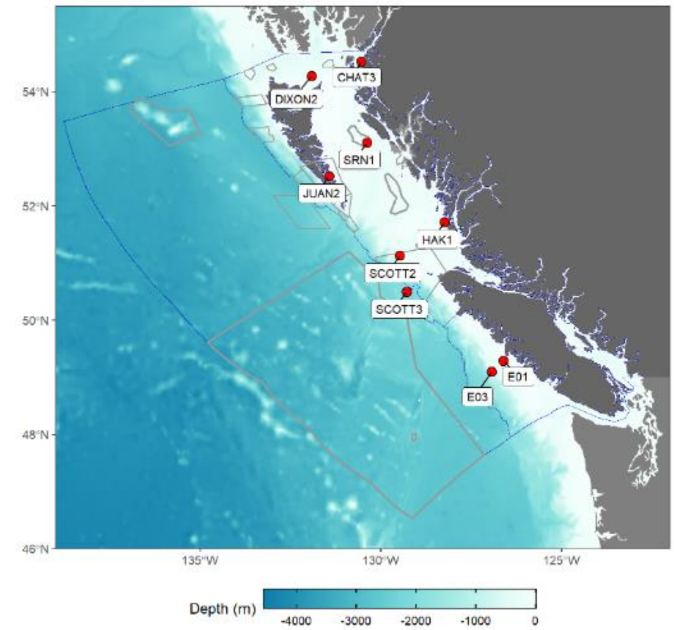

Figure 12-1. The location of the moored instrumentation for the period July 2022 to July 2023. The Canadian Exclusive Economic Zone is shown in blue, along with the various existing and proposed Marine Protected Areas in grey.

12.3. Status and trends

The longest mooring record is at E01 (Estevan Point) on the inner Vancouver Island shelf where data goes back to the 1980s. Figure 12-2 shows the temperature at four depths from July 2009 to July 2022. The Blob (2014-2016) is evident in the warm satellite sea surface temperatures in the fall and winter of 2014-15 and 2015-16 by the increase in the annual minimum SST. The annual minimum at 35 m increased in the winter/spring of 2016. The annual minimum near the bottom (75 m and 90 m) appeared to increase in winter 2017/18. There were instrument problems that year, which created data gaps. From 2018 to 2021, there was a decrease in the annual maximum and minimum temperature in the water column. The big increase observed in the annual maximum temperature in the fall of 2021 seems to signal the end of the declining trends.

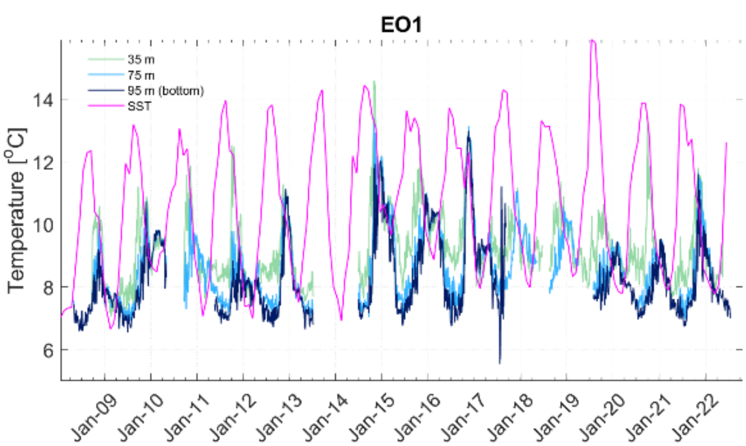

Figure 12-2. Temperature time series at E01 mooring for different depths: the surface (satellite SST), 35 m, 75, and 95 m.

The declining trend in the annual maximum temperature at 40 m is evident more broadly across the shelf (Figure 12-3). The data also suggest a decline in the annual maximum and minimum at 100 m (Figure 12-3), but the limited data before July 2019 precludes definitive statements.

Our longest dissolved oxygen time series are at the Scott2 mooring. Figure 12-4 shows the time series at 40 m and 280 m depth. The notable feature is the annual minimum concentration increase observed at 40 m depth between 2017 and 2022. This trend is also present for dissolved oxygen saturation. Thus, this trend is not simply a function of the decreasing annual minimum temperature. Near the bottom, at 280 m, the oxygen time series has a substantial seasonal cycle with a typical peak-to-trough range of 1 ml/l. In the summer, the oxygen often drops below the hypoxia limit of 1.4 ml/l. In the spring and summer of 2022, the deep oxygen went much lower than in previous years. The CTD calibration cast during mooring recovery showed near-bottom oxygen values of about 1.35 ml/l, which is low but not as low as the moored instrument value. Further investigation is required to determine whether the very low values are signal or instrument error.

The winter and fall storms lead to isothermal conditions down 75 or 100 m at most shelf locations– for example, the data at E01 in Figure 12-2. Therefore, the satellite SST can be a valuable proxy to assess subsurface temperature conditions during the winter months. The data is available back to 1982. January 2022 was colder than average by typically less than 0.5 °C. December 2022 was also colder than usual, with 1-2 °C anomalies in Hecate Strait, along the central coast and the Vancouver Island shelf (Figure 12-5). SST anomalies off the north end of Vancouver Island were between 0.5-1 °C.

12.4. Factors influencing trends

In the open northeast Pacific, the Blob (Bond et al. 2015) disappeared as a surface feature in 2106 but persisted at depth into 2018 (Ross et al. 2023). On the shelf, the warm water from the Blob was evident in Rivers Inlet until at least June

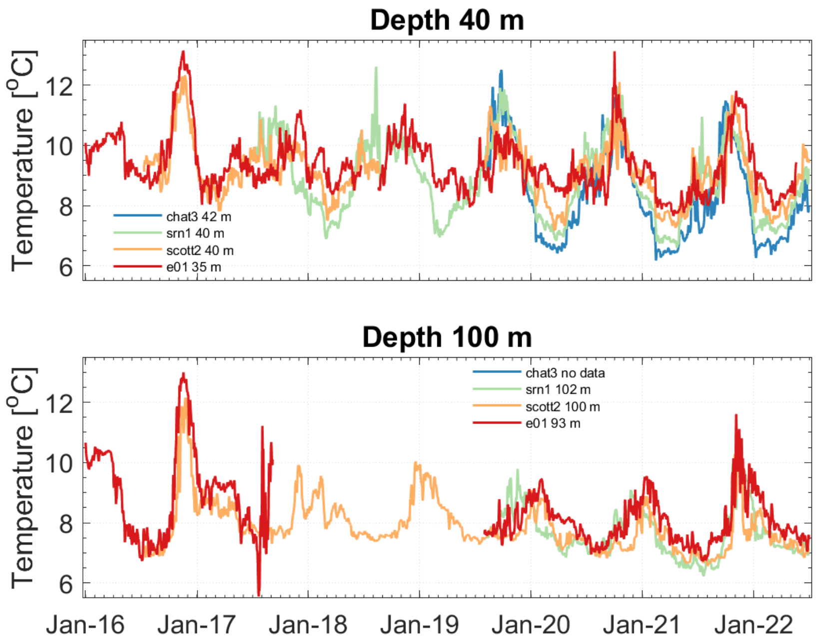

Figure 12-3. Subsurface temperature (40 m and 100 m) at four locations, E01, Scott2, SRN1, and Chat3, along the B.C. continental shelf. Notable features include the decline in annual maximum and minimum temperatures at 100 m from Jan 2018 to July 2021 and the decline in annual minimum temperatures at 40 m over the same period.

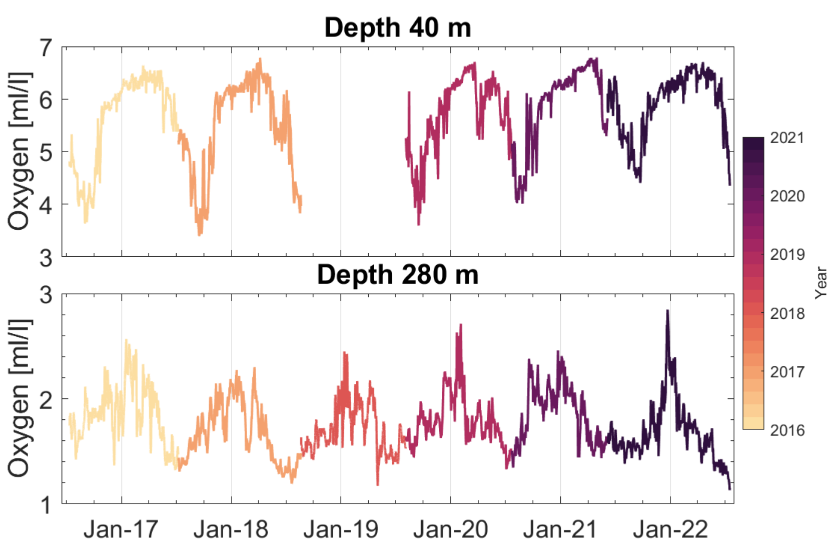

Figure 12-4. Dissolved oxygen time series at Scott2 mooring. The notable feature is the annual minimum concentration increase at 40 m depth from the fall of 2017 to the fall of 2022. This trend is also present for dissolved oxygen saturation. Thus, this trend is not simply a function of the decreasing annual minimum temperature.

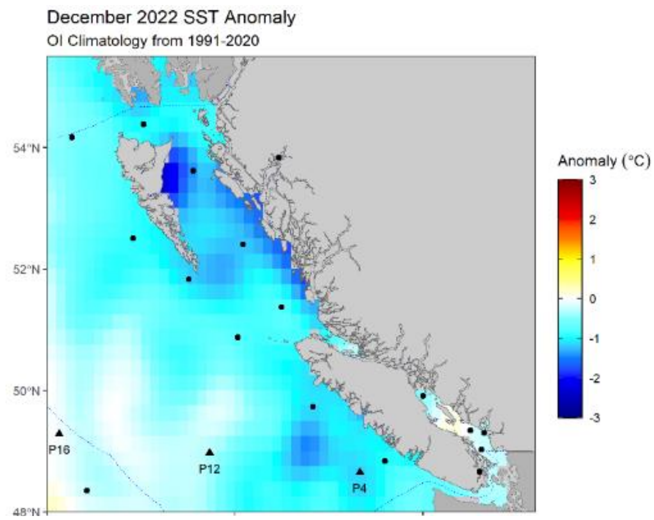

Figure 12-5. Satellite SST anomaly for December 2022, which can serve as a proxy for subsurface SST (down to 75-100 m).

2018 (Jackson et al. 2018). We interpret the declining temperatures from 2017 through 2021 as the signature of the recovery from the Blob (2014-2016), aided by consecutive La Niña winters (2020/21, 2021/22), which are generally expected to be cooler than normal.

It is important to remember that the water on the B.C. shelf is not stagnant. Even a very small monthly mean current of 1 cm/s implies a transit of 30 km that month. Thus the water is not staying in one place for a year or more. As such declining temperatures over multiple years are likely a sign of cooling over a broad area of the B.C. shelf and the NE Pacific.

We are uncertain about the increasing trend in the annual oxygen minimum at 40 m at Scott2. One possible explanation is an increase in the strength of summer storms in Queen Charlotte Sound since the Blob ended in 2016. We don't have consistent oxygen records at 40 m at the other mooring locations to assess whether the trend is local or shelf wide.

The anomalously low temperatures along the Central Coast in December 2022 may be the result of cold air outflow events from the fjords along that portion of the coast.

12.5. Implications of those trends.

The NOAA ENSO (El Niño Southern Oscillation) forecast for February 2023 indicates that La Niña conditions may be ending with a transition to ENSO neutral conditions by spring or early summer 2023. There is the potential for El Niño conditions by the fall of 2023. A return to El Niño conditions may lead to warmer ocean conditions. We note, however, that forecasts made in spring have the least predictive power. Overall it is reasonable to expect that the subsurface cooling event on the B.C. shelf has ended.

12.6. References

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13. OXYGEN AND CARBON IN 2022 ALONG LINE P AND IN QUEEN CHARLOTTE SOUND FROM OCEAN GLIDER DATA

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13.1. Highlights

- Ocean glider data captured high-resolution spatial variations in dissolved oxygen concentration, including a subthermocline eddy, along Line P.
- Anomalously low oxygen concentrations were observed in the intermediate water at Ocean Station Papa (OSP) in August and, in part, related to high spatial variability.
- Hypoxic conditions were present on the continental shelf between Tofino and Station P4 from August to at least mid-September.

13.2. Description of the time series

C-PROOF, the Canadian-Pacific Robotic Ocean Observing Facility, operates a fleet of autonomous ocean gliders equipped with sensors for high-resolution measurements of temperature, salinity, dissolved oxygen concentration, chlorophyll, CDOM, and backscatter, collected between the surface and 1,000 m depth. C-PROOF has maintained two glider monitoring lines since 2019 (Figure 13-1): the Calvert Line, which crosses Queen Charlotte Sound from Calvert Island to beyond the shelf break, and Line P, with the glider crossing the shelf near Tofino to station P4, then transiting to Ocean Station Papa (OSP). Glider sampling along these lines occurs during both the outbound and return trips.

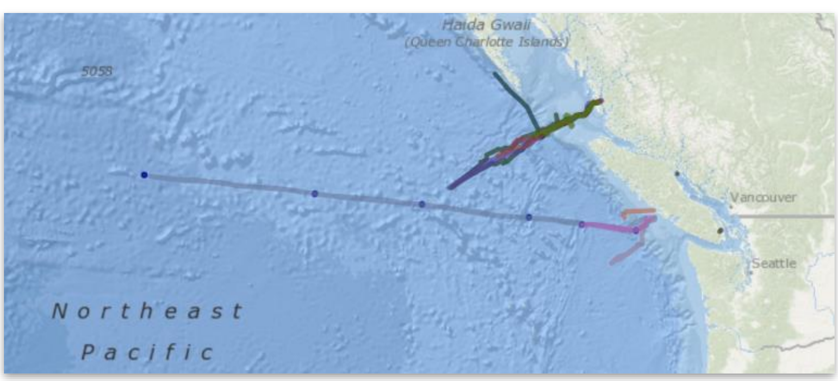

Figure 13-1. Ocean glider tracks for all thirteen glider surveys conducted in 2022 (coloured lines). Dots along Line P indicate key stations (P4, P8, P16, P20, OSP). Credit: cproof.uvic.ca

Ocean glider data resolve the small spatial and temporal scales important to upper ocean physical and biological processes, and capture variability that may be missed by hydrographic sampling cruises. The dissolved oxygen data are fully processed and corrected using Winkler titrated bottle samples collected by the Hakai Institute out of Calvert Island and by DFO during Line P cruises. On the Calvert Line, there were seven glider surveys between May and December 2022, while on Line P there were two glider surveys from May 31 to September 15, 2022 and from August 3 to October 31, 2022. The second Line P survey was atypical, with seven passes between stations P4 and P8, rather than sampling to OSP.

13.3. Status and trends

On the Calvert Line, 2022 was the first year with glider data collected in December. There was high seasonal variability in oxygen concentration in Queen Charlotte Sound, and a clear transition from coastal to open-ocean waters. Similar small-scale features to those observed in 2021 were present. Overall, conditions appeared similar to previous years.

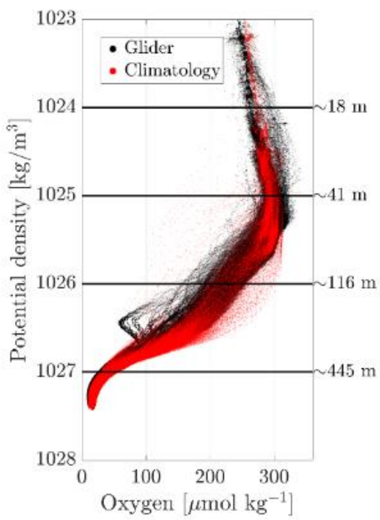

Figure 13-2. Ocean glider oxygen concentrations along Line P from P4 to OSP between May and September 2022 (black dots) as a function of potential density, compared to a climatology linearly interpolated to the same sampling locations and days of year (red dots). Average isopycnal depths are indicated.

Along Line P, oxygen concentration was evaluated relative to a 1991 to 2020 climatology created using Line P hydrographic station data with linear interpolation between stations and months, noting that it was heavily interpolated in some months due to the typical triannual cruise frequency. Oxygen values along Line P were lower in 2022 than the climatological average for a range of densities associated with intermediate water masses (about 100-300 m depth; Figure 13-2).

A low oxygen feature, observed near P12 on June 18, 2022, was consistent with a subthermocline eddy (Pelland et al. 2013). It was spicy (warm and saline) and hypoxic in its core (Figures 13-2-13-4). This feature, or a similar one, was observed again on July 12, 2022 by an Ocean Observatories Initiative glider ~200 km to the southeast (Peter Brickley, pers. comm.).

Apart from this eddy, the oxygen anomalies were largest at OSP (Figure 13-3), which had anomalously low oxygen for densities of ~1025.5 to 1027.5 kg/m^3. The low anomaly was -40 µmol/kg at OSP on the 1026.7 kg/m^3 isopycnal, which is associated with North Pacific Intermediate Water (NPIW) or possibly Gulf of Alaska Intermediate Water (GAIW) along Line P (You 2010). The anomaly also extended much deeper, into the oxygen minimum zone (OMZ). At stations P12 and P16, there were small positive anomalies for densities below ~1026 kg/m^3 and small negative anomalies for denser water. However, an examination of oxygen anomalies along the full Line P transect showed high spatial variability, with transitions between negative and positive anomalies occurring over 100-150 km scales (e.g., mesoscale) on a given isopycnal (Figure 13-3).

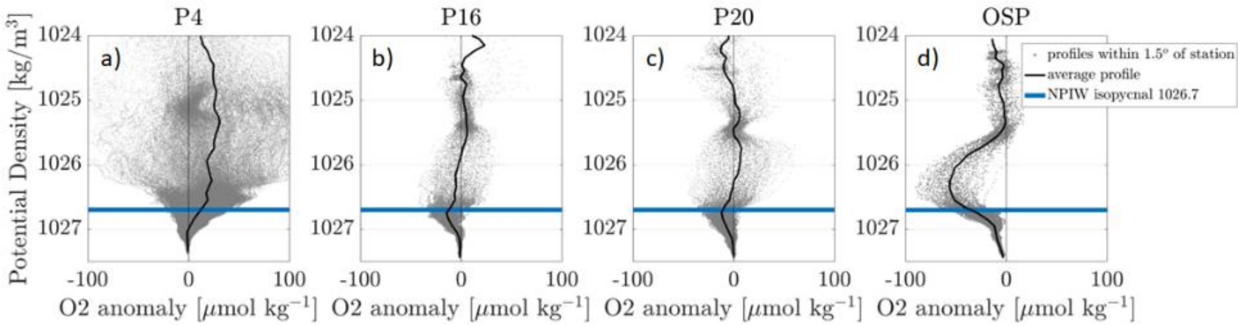

Figure 13-3. Oxygen anomaly (glider data minus climatology) as a function of potential density at Line P stations, P04 (a), P16 (b), P20 (c) and OSP (d). Gray dots show all ocean glider data from profiles collected within 1.5º longitude of the station, while the black line gives the average of these data. The blue line indicates the 1026.7 kg/m3 isopycnal, most strongly associated with NPIW.

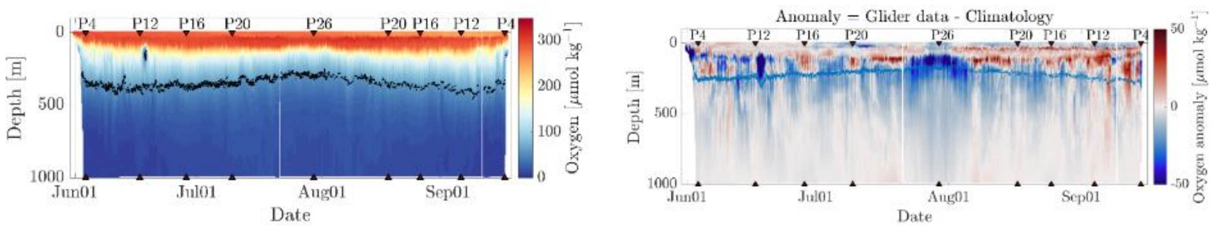

Figure 13-4. Transect of ocean glider oxygen concentration along Line P from P4 to OSP between May and September 2022 as a function of depth and time (left). The black dots show the 60 μmol/kg surface, indicating the hypoxic boundary and the approximate top of the OMZ. Oxygen anomaly along the same transect (right). The blue dots show the location of the 1026.7 kg/m^3 isopycnal.

On the continental shelf between Tofino, B.C. and Station P4, the gliders identified hypoxic conditions during mid-September 2022 over a limited spatial region on the deep shelf. Hypoxia was more widespread across the shelf in early August, and was absent in early June.

13.4. Factors influencing trends

Oxygen concentration has large decadal variability at OSP, with linear trends of -0.4 to -0.7 μmol/kg per year on the 1026.5, 1026.7, and 1026.9 kg/m^3 isopycnal surfaces (Crawford and Peña 2016; Cummins and Ross 2020; Whitney et al. 2007). Changes in solubility explain only a small part of the observed declines on these subsurface isopycnals. One other potential cause is warming and freshening in the Sea of Okhotsk driving reduced dense water formation.

Based on these reported trends, we expect a low oxygen anomaly of -7 to -10 μmol/kg relative to our 30-year climatological average, which is four to six times smaller than the observed anomaly at OSP. However, *intra*-decadal variability at OSP is also high, sometimes exceeding 50 μmol/kg (Crawford and Peña 2016). Furthermore, the ocean glider data suggests that oxygen concentration in intermediate water masses along Line P may be variable on spatial scales smaller than the spacing of Line P stations, thus not properly resolved by ship sampling.

Low oxygen values are commonly deep on the continental shelf in the summer southwest of Vancouver Island, caused by upwelling of low oxygen water and increased remineralization of shelf blooms (Crawford and Peña 2013). It is more unusual to observe hypoxic waters on the shelf near Tofino in mid-September, although the extent of the hypoxic water in 2022 was significantly less than during the 2021 low oxygen event. The spatial extent of this hypoxic water is described in more detail in section 15 (Sastri et al., Section 15).

13.5. Implications of those trends.

If spatial variability is partially responsible for the large low oxygen anomaly observed at OSP in the intermediate waters, uncertainties in previously reported trends may need to be re-evaluated. Our results suggest that quantifying spatial variability is a key next step, along with determining the cause(s) of the small-scale variability reported. Differences in oxygen between OSP and the rest of Line P further suggest that the processes affecting dissolved oxygen concentration at OSP may differ from those affecting other stations along Line P.

In Queen Charlotte Sound and along Line P, ocean glider data from 2019 to 2022 provides a high-resolution observational record that can be used to quantify spatiotemporal variability, improve existing climatologies, and enable comparisons with future years. Such comparisons are increasingly valuable, as oxygen is projected to decline due to shoaling of the OMZ and increased upwelling, with more frequent and severe hypoxia events on the continental shelf (Holdsworth et al. 2021) and detrimental consequences for ecosystems (Ross et al. 2020).

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14. WATER CURRENTS AND TRANSPORT OFF THE B.C. COAST

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14.1. Highlights

- In 2022, satellite altimetry indicated that the equatorward shelf-edge surface current at a west Vancouver Island transect was weaker than normal in summer and the year-round poleward surface current at a Queen Charlotte Sound transect was weaker than normal.
- Model hindcasts showed that in 2022 the water transport associated with the Vancouver Island Coastal Current was close to normal.

14.2. Description of the time series

Geostrophic surface currents were calculated at two transects (Figure 14-1) by using 10-day interval along-track satellite altimetry sea surface height data from October 1992 to December 2022, following the method outlined in Han et al. (2014) and Han and Chen (2022). One transect was located off the West Coast of Vancouver Island (WCVI) and the other was located at the mouth of Queen Charlotte Sound (QCS). The geostrophic surface currents were in the direction normal to the transect (positive poleward) and approximately represented the longshore flow. The calculated geostrophic surface currents were further averaged both seasonally and over-transect. At the WCVI transect (Figure 14-2, upper panel) the winter surface current was poleward and the summer surface current was equatorward, with the long-term mean surface current close to zero. At the Queen Charlotte Sound transect (Figure 14-2, lower panel), the climatological seasonal-mean surface current was poleward year-round; stronger in winter and weaker in summer.

Water transport at transects off Vancouver Island (Figure 14-1) was calculated for the inshore current (to represent the Vancouver Island Coastal Current), based on the model output from a 1/36° Northeast Pacific Ocean Model (NEPOM). The annual mean water transport of the model Vancouver Island Coastal Current was poleward (Figure 14-3).

14.3. Status and trends

There was no apparent long-term trend in the altimetric surface current over 1992-2022. Interannual variations were evident. In summer 2022, the altimetric equatorward surface current at the WCVI transect was weaker than normal. The altimetric poleward surface current at the QCS transect was weaker than normal in winter 2022.

There were substantial interannual variations in the modelled water transport. The annual-mean water transport of the modelled Vancouver Island Coastal Current was close to normal in 2022.

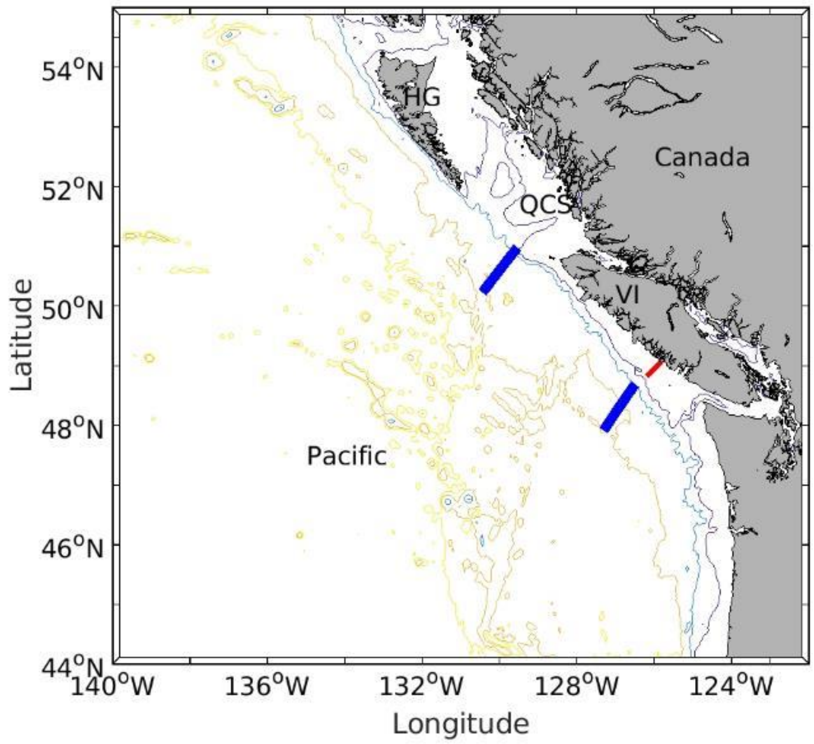

Figure 14-1. The study area showing the location of two altimetry transects (blue), bathymetry (200-, 1000-, 2000- and 3000-m isobaths) and a transect (red) for calculating the water transport associated with the Vancouver Island Coastal Current. HG: Haida Gwaii. QCS: Queen Charlotte Sound. VI: Vancouver Island.

14.4. Factors influencing trends

Stronger surface currents at the WCVI transect have occurred in El Niño and La Niña years, consistent with Hourston and Thompson's (2020) results from *in situ* measurements. The surface currents could also be influenced by the Pacific Decadal Oscillation, possibly via its impacts on regional wind patterns.

The Vancouver Island Coastal Current may be linked to buoyancy forcing associated with the fresher outflow from the Juan de Fuca Strait and longshore surface winds (Masson and Cummins 1998). Therefore, the Vancouver Island Coastal Current may be linked to large-scale climate processes such as El Niño, La Niña, and Pacific Decadal Oscillation.

In 2022 there was a moderate La Niña and a cool phase of the Pacific Decadal Oscillation (see Ross and Robert, Section 7).

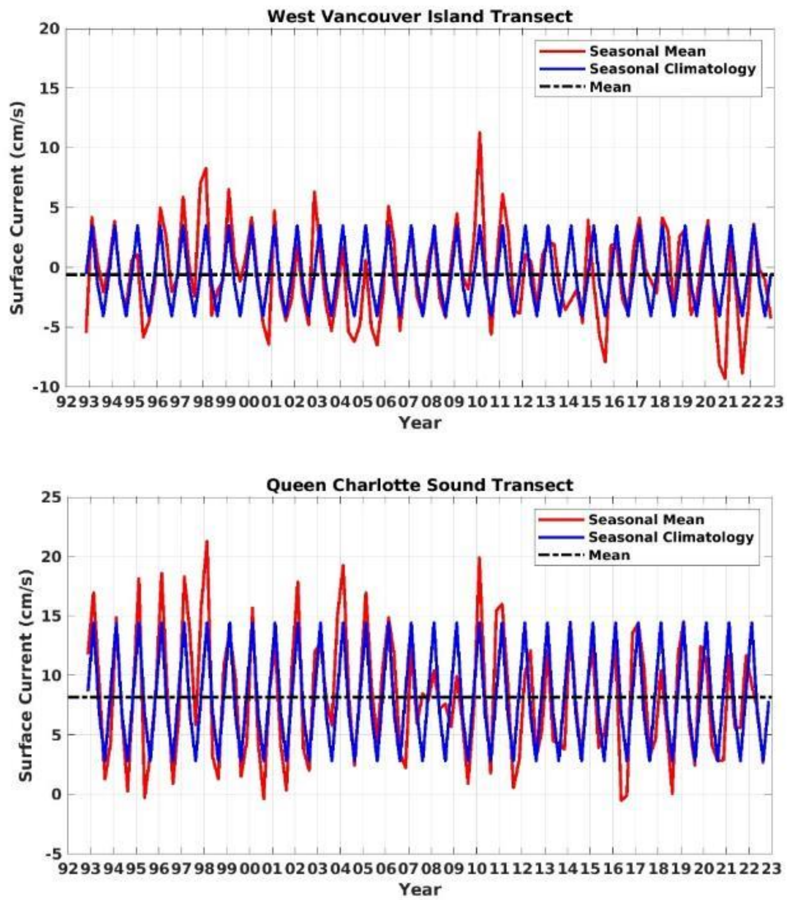

Figure 14-2. Seasonal-mean geostrophic surface currents (positive poleward) at the two transects located off the west coast of Vancouver Island (WCVI) (upper panel) and at the mouth of Queen Charlotte Sound (QCS) (lower panel). Note that the current is the averaged over the transect of about 110 km wide.

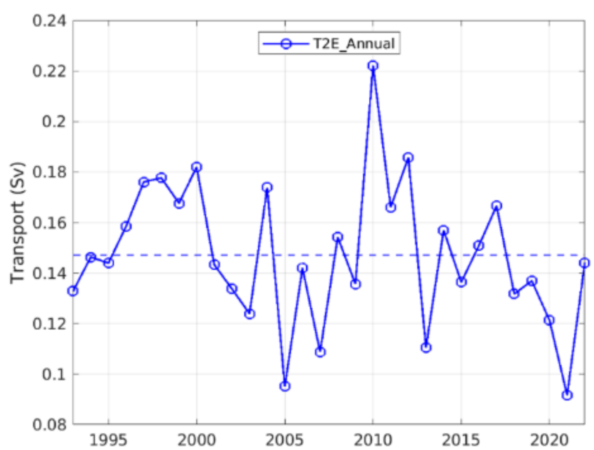

Figure 14-3. Annual-mean water transport (positive poleward) associated with the Vancouver Island Coastal Current. The dashed line is the mean transport averaged over 1993-2022. 1 $S_v = 10^6$ m^3/s.

14.5. Implications of those trends

These currents can affect water properties such as temperature, salinity, nutrients, dissolved oxygen off the B.C. coast. They can also impact transport and distribution of fish eggs and larvae. Folkes et al. (2018) showed that surface currents can be a useful predictor for the return timing and northern diversion rate of Fraser sockeye salmon.

14.6. References

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15. OCEANOGRAPHIC CONDITIONS OFF THE WEST COAST OF VANCOUVER ISLAND: 2022

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15.1. Highlights

- In May, the upper water column (< 50 m) along the west coast of Vancouver Island (WCVI) shelf and offshore was cooler (-0.5 to -0.7 °C) and much fresher (1.4 psu) than average over the shelf.
- Upper water column conditions in late-summer 2022 were still fresher but shifted to warmer than average for the southern WCVI shelf stations, remaining cooler than average for the shelf break/offshore stations.
- The northern WCVI surface mixed layer was generally warmer than average for both shelf and offshore stations in September.
- Dissolved oxygen concentrations at 125 m depth on the outer southern shelf were > 1.4 ml/l in May but dropped to 0.79 ml/L by the end of summer (very low but not as extreme as in 2021).

15.2. Description of the time series

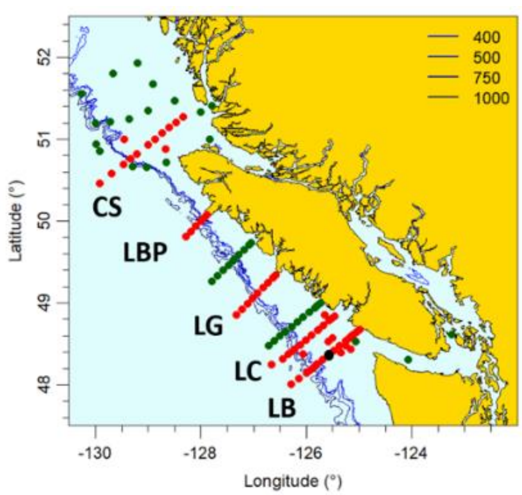

Figure 15-1. Map of the La Perouse-west coast of Vancouver standard survey stations. Stations for each of the survey lines (labelled) discussed in this report are identified with red symbols. Black symbol on LB line represents station LB08. Bathymetric contours indicate the shelf break and contour-specific depths (m) and are identified in the legend.

The zooplankton survey of the WCVI continental margin has been carried out since 1979 for southern WCVI, and since 1990 for northern WCVI. The La Perouse/WCVI survey generally takes place in May and September each year and provides synoptic snapshots of physical, chemical, and biological patterns at shelf, slope, and offshore stations. Each of the biannual surveys is 11-13 days in duration and generally falls within the annual upwelling period. The May survey typically occurs within 30 days of the onset of upwelling positive winds (Hourston and Thomson, Section 8; Dewey et al., Section 38). Transition timing from upwelling to downwelling varies with latitude; however, the September survey generally precedes this transition along southern WCVI. This report focuses on the most regularly sampled lines (red symbols in Figure 15-1): 1) LB, LC, and LG lines for southern WCVI; and 2) LBP and CS lines for northern WCVI. The time series average for all lines was estimated as the average temperature or salinity for each station-specific pressure-bin for the annual cycle (days of the year 100-300) for the 1991-2020 period. Anomalies were then calculated as the difference in temperature and salinity for each 2022 survey station-specific pressure bin and its corresponding time-series average interpolated to day of the year. Here we continue some of the long-term (1979-present) subsurface dissolved oxygen (ml/l) observations previously reported by Crawford and Peña (2013 and 2021). Section plots of oxygen for the LB line rely on sensor-based (SBE 43) measurements and the 125 m time-series observations for station LB08 rely on oxygen titrations of discrete seawater samples. Note that the May survey was cancelled in 2022, however, a modified survey of the southern lines, LB, LC, LD, and LG was carried out as part of another program in the survey area.

15.3. Status and trends

Upper ocean salinity and temperature 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 first biannual survey took place May 3-12, 2022. Salinity anomalies over the southern shelf were all negative (i.e. fresher than the long-term average) and line-specific averages were -0.37, -0.59, and -1.38 psu for LG, LC, and LB lines, respectively (Figure 15-2). Surface mixed layer salinity for southern slope and offshore stations were all slightly negative relative to time series averages (Figure 15-2).

Surface mixed layer temperatures were cooler than the long-term late-May-period average for most of the shelf and slope/offshore stations surveyed in the southern WCVI regions (Figure 15-3). Mean May temperatures in the surface mixed layer over the southern shelf varied between 8.74 and 10.74 °C, with temperature cooling across the shelf from inshore. Surface mixed layer temperatures along the southern lines were 0.47 °C cooler than average with progressively larger negative anomalies from north (LG line) to south (LB line).

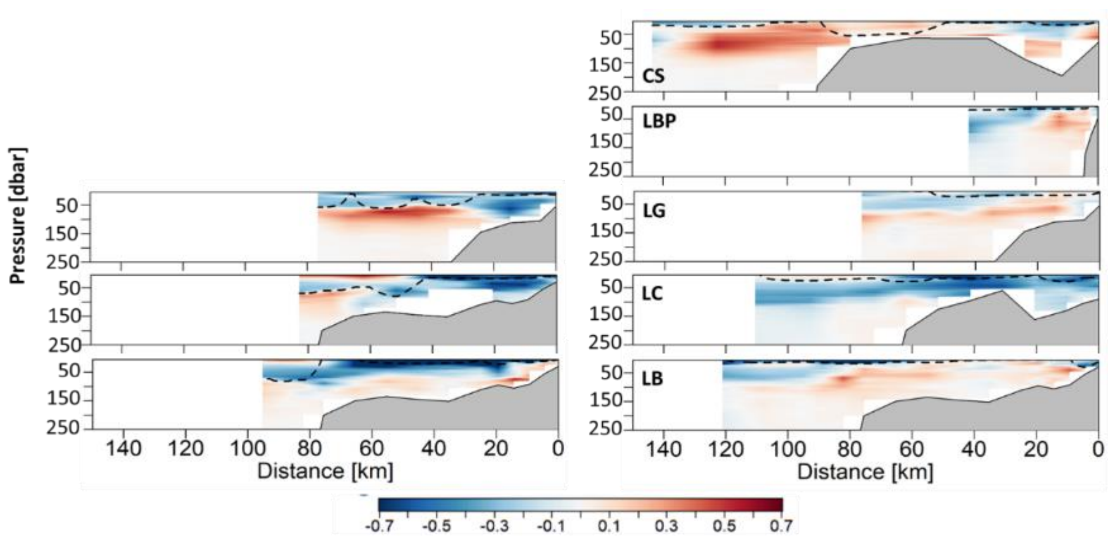

Figure 15-2. Salinity anomaly (psu) section plots across each sampling line. Maximum depth set at 250 dbar. Top to bottom represents northern to southern lines (see Figure 15-1). Left and right represent May and September surveys, respectively. The time series average for all lines was estimated as the average salinity for each station-specific pressure-bin for 1991-2020 and the annual period corresponding to each survey. Anomalies were calculated as the difference in salinity for each 2022 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. Dashed lines represent depth of the maximum buoyancy frequency squared (N^2) used here as a proxy for the base of the surface mixed layer.

The second annual survey took place August 26 - September, 2022. Consistent with seasonal expectation, the average surface mixed layer depths for all five survey lines were between 12-30 m. However, outer shelf CS line surface mixed layer depths were ~55 m deep. Average salinity over the shelf for CS and LBP lines was fresher (-0.28 and -0.16 psu) than the seasonal long-term averages and 0.3 and 0.25 psu fresher than average for CS and LBP slope/offshore stations, respectively. Surface mixed layer depths for the southern WCVI were generally shallower relative to the northern WCVI. As per May, the average salinity anomaly for all three southern lines in September (*see* Fig. 15-1) was fresher (0.34 psu) than the time series seasonal average for the shelf stations and 0.27 psu fresher for the slope/offshore stations.

The start of the September survey corresponded to the greatest influence of the 2022 NEP Marine Heatwave on WCVI, particularly in the north (Hilborn et al., Section 11). With the exception of the LBP line narrow shelf stations (-0.86 °C cooler than average); the surface mixed layer for all shelf stations along the WCVI were ~0.5 °C warmer, on average, than the seasonal average. There were no obvious north-south trends, but both CS and LBP lines were 1.5 and 0.66 °C warmer than average for slope/offshore stations respectively; whereas upper water column temperature was consistently cooler than average for the southern, LG, LC, and LB stations over the slope/offshore.

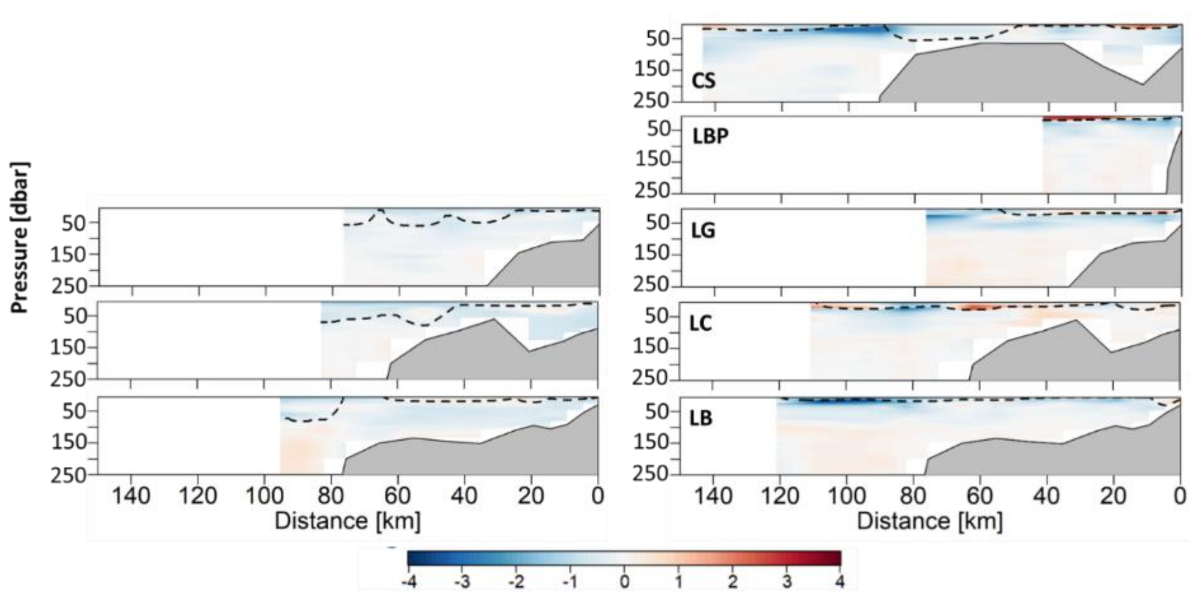

Figure 15-3. Temperature anomaly (°C) section plots across each sampling line. Maximum depth set at 250 dbar. Top to bottom represents northern to southern lines (Figure 15-1). Left to right represent May and September survey sections, respectively. The time series average for all lines was estimated as the average temperature for each station-specific pressure-bin for 1991-2020 and the annual period corresponding to each survey. Anomalies were calculated as the difference in temperature for each 2022 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. Dashed lines represent depth of the greatest buoyancy frequency squared (N^2) used here as a proxy for the base of the surface mixed layer.

The California undercurrent flows poleward along the WCVI slope and its core (200-300 m depth) is characterized by low oxygen associated with the 1.4 and 2.1 ml/l oxygen contours in both May and September (Figure 15-4). Seasonal upwelling, particularly along the southern shelf, extends these contours over the shelf. The lowest dissolved oxygen concentration on the shelf in May 2022 was centered ~10 km east of station LB08 (red symbol in Figure 15-4). This was also the case in September, however, the depth of the 1.4 ml/l oxygen contour had shoaled to ~90 m below the surface. Discrete bottle-based measurements of dissolved oxygen were 1.85 and 0.79 ml/l for May and September, respectively (Figure 15-5). The values are not as extreme as those measured in May and September 2021, however, September 2022 does rank among the lowest observed values for the time series. The oxygen-nitrate ratio decreased following the May survey and the September 2022 estimates (at 125 m for LB08) was among the lowest for the time series, suggesting that respiration of organic material at depth was not high early in the summer, but the rate of oxidation increased following the first survey, perhaps due to surface production associated with the late transition to upwelling in June (Hourston and Thomson, Section 8).

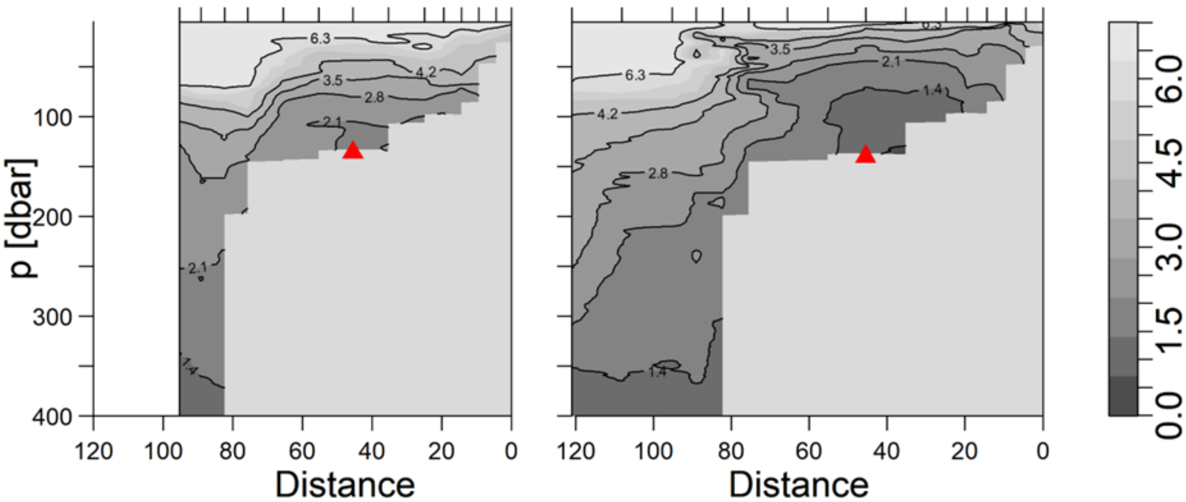

Figure 15-4. Section plots of dissolved oxygen (ml /l) along LB line (Figure 15-1) in May 2022 (left panel) and late August 2022 (right panel). Note that outer LB line stations were not sampled in May. The red triangle shows the location of the station LB08.

15.4. Factors influencing trends

La Niña conditions, beginning in late 2020 and persisting through to the September 2022 survey, were accompanied by cooler than average water column temperatures along the outer B.C. coast (Donnet, Section 10). Upwelling started later (June) than average and was near constant throughout the remainder of the summer and leading up to September 2022 survey (Hourston and Thomson, Section 8; Dewey et al, Section 38). After the May survey, persistent upwelling, particularly along the southern WCVI continental slope, brought California undercurrent source waters onto the shelf supplying nutrient and salt-rich water to the surface and extending deep oxygen-poor waters further inshore over the shelf. The very low seasonal oxygen to nitrate ratios at LB08 in September suggest high rates of respiration of organic material, perhaps enhanced by high seasonal production of phytoplankton in the surface. The development and expansion of a marine heatwave to the WCVI region (Hilborn et al., Section 11) may have contributed to the dramatic shift from cooler than average surface mixed layer temperatures in May to warmer than average surface mixed layer temperatures observed along most of the WCVI shelf in late summer.

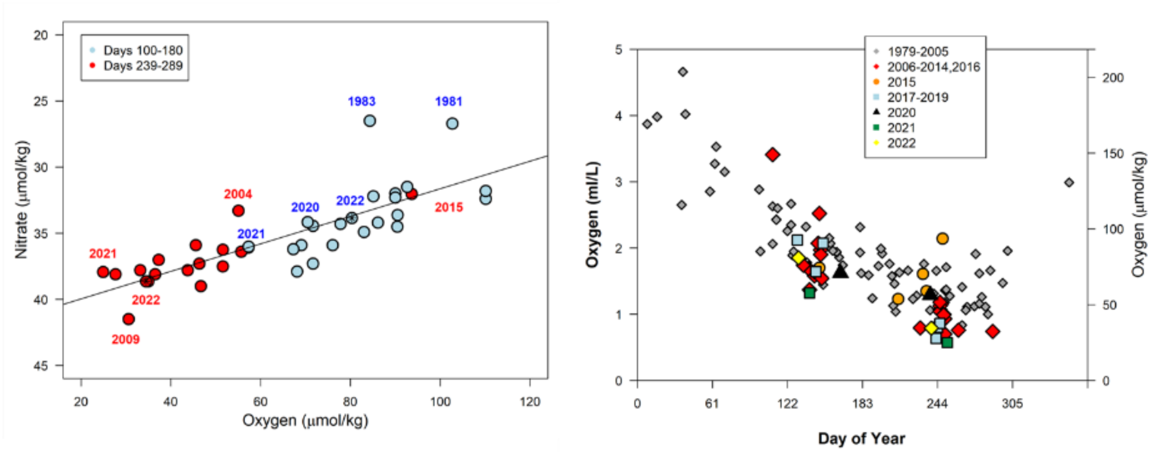

Figure 15-5. Annual cycle of 125 m dissolved oxygen concentration (ml/l and μmol/kg) at station LB08 highlighting time series extremes (left panel). Yellow symbols identify the 2022 low oxygen extremes for this time series (1979-2022). Interannual and seasonal variation of 125 m oxygen-to-nitrate ratios at station LB08 (1979-2022; right panel). Low oxygen to nitrate indicates greater oxidation of organic material with typical seasonal ratios in early 2022 but more extreme in late summer relative to long term measurements.

15.5. Implications of those trends

Warmer than average mixed layer temperatures along the WCVI are often associated with a greater abundance and biomass of smaller, less lipid-rich zooplankton relative to the larger, lipid-rich, boreal and subarctic groups which tend to dominate under cooler conditions (Galbraith, Section 20). Spring and early 2022 were characterized by cooler than average conditions which have been linked to seasonally average timing and normal to high biomass for larger subarctic and boreal zooplankton assumed to support productivity of pelagic fish and seabirds (Mackas et al. 2007; Hipfner et al. 2020); whereas the late summer was characterized by warmer than average temperatures more amenable to small lipid-poor zooplankton. Lower than average, hypoxic and/or anoxic subsurface oxygen concentrations pose particular risk to sessile benthic organisms and may limit the distribution of fish (e.g. Pacific Hake) which normally migrate through and feed in WCVI shelf waters.

15.6. References

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16. 2022 OCEANOGRAPHIC CONDITIONS IN AND AROUND GWAII HAANAS, HAIDA GWAII, IN RELATION TO PAST OBSERVATIONS

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16.1. Highlights

- In Juan Perez Sound, waters were cooler in 2021 and 2022 compared to the period from 2017 to 2020.
- Satellite sea surface temperature (SST) showed temperatures were in the colder ranges in spring and in the warmer ranges in summer and fall compared to the 1991 to 2020 time series.
- In general, oxygen concentrations in Juan Perez Sound are higher than in northern Queen Charlotte Sound/southern Hecate Strait.
- Satellite chlorophyll-a (chl-a) showed that concentrations were higher in Juan Perez Sound than southern Hecate Strait; a large fall bloom occurred in 2022.

16.2. Description of the time series

For this work, we examined data that were collected in northern Queen Charlotte Sound (QCS), southern Hecate Strait (HS), and Juan Perez Sound (JPS) in Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve, and Haida Heritage Site (GH; 51.25°N to 53.5°N and 128.5°W to 132°W; Figures 16-1 – 16-3). Temperature, salinity, and oxygen data were collected from both shipboard sampling and by moorings. Satellite-measured chl-a, a proxy for phytoplankton biomass in the upper optical depth of the ocean, and SST were also examined using the standard products provided by the NASA Ocean Biology Processing Group (https://oceancolor.gsfc.nasa.gov/) at 4 km pixel resolution for 2003-2022. SST from the Advanced Very High Resolution Radiometer (AVHRR) at corresponding resolution was also acquired for the period 1981-2022. GH was divided into east, west and southern sections (referred to as GHE, GHW and GHS, respectively; Figure 16-3), and monthly time series and climatological statistics were retrieved for each area (Hilborn, Guan and Hannah, Section 11).

In situ CTD and oxygen data were collected on annual cruises at multiple stations by Fisheries and Oceans Canada (DFO; summers 2015 & 2016, Oct 2020) in collaboration with Parks Canada Gwaii Haanas (GH; summers 2017 to 2022) and with both GH and Council of the Haida Nation (CHN; Jun-Jul 2019, Sep 2022). Data were generally collected in summer (Jun, Jul, Aug) or fall (Sep, Oct) months. Data collected in QCS and HS were examined from 2015 to 2022; samples collected in JPS started later from 2017 to 2022. Data from September 2022 were not yet available for inclusion in this summary.

Three moorings - two in Juan Perez Sound (Juan1 and Juan2) and one in Hecate Strait (SRN) - were deployed annually by the Institute of Ocean Sciences (DFO) in collaboration with GH in JPS. Juan1 (52.518°N, 131.480°W) was deployed twice from 2017–2019. The location slightly shifted for Juan2 (52.520°N, 131.431°W) deployments spanning 2019–2022. SRN (53.109°N, 130.388°W) was deployed from 2017-2022. At Juan2 moorings were equipped with two (2018–2019), three (2020–2021; 2021–2022) or four (2017–2018; 2019–2020) Seabird CTD sensors along the mooring line. The two deepest CTD instruments during each mooring deployment also collected dissolved oxygen (DO) data.

16.3. Status and trends

Average profiles of temperature and oxygen were created for the northern QCS/southern HS region (QCS/HS; Figure 16-1) and the JPS region (Figure 16-2). To minimize the impact of seasonal variability when examining interannual differences, data were examined by month.

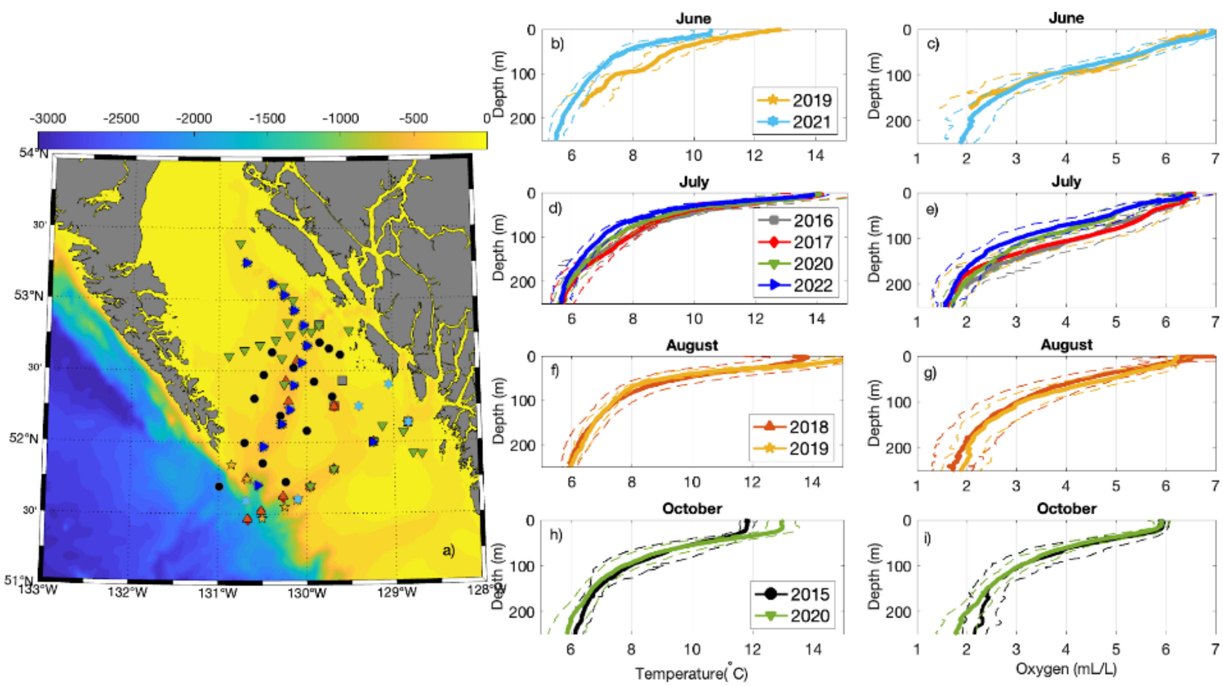

Figure 16-1. Average profiles of temperature (left column) and oxygen (right column) for data collected in QCS/HS from 2015 to 2022. Station locations are indicated on the map (left), with colours and symbols listed in the left column figures. To minimize seasonal variation, data were plotted by month: Jun, Jul, Aug and Oct.

In QCS/HS, surface waters (defined as above 50 m depth) were warmest in July and August and coldest in June and October. Of the years examined, warmest surface waters were observed in August 2018 and coldest surface waters were observed in June 2021. In July 2022, ocean temperature was similar to previous years (2016, 2017, and 2020). Oxygen concentrations were similar amongst the years and months, though we note that oxygen in July 2022 was lower than observed in 2016, 2017, and 2020.

Similar to QCS/HS, waters in JPS were coldest in June 2020 and warmest in August 2018. In July 2022, waters were the second coldest observed in the time series. Oxygen concentrations were higher in JPS relative to the surrounding region and had more interannual variability (though less spatial variability). The highest oxygen concentrations were observed in July 2017 and the lowest were observed in October 2020. In July 2022, oxygen concentrations were lower than both July 2017 and July 2020.

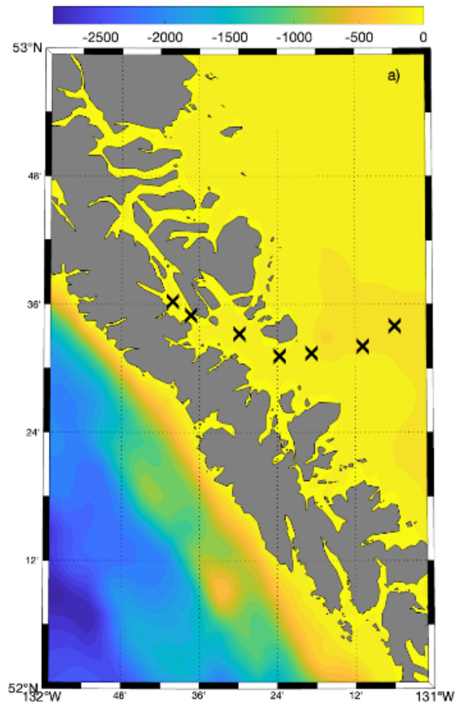

Figure 16-2. As in Figure 16-1, focused on the waters in JPS, Gwaii Haanas, with data collected from 2017 to 2022. All seven stations (black x on map), were sampled each year.

Monthly chl-a patterns differed between the three GH regions. Chl-a was highest overall and had the most seasonal variation in GHE, with both a pronounced spring and fall bloom. The phenology was similar in GHW and GHS, where chl-a was typically elevated in April and later in September. In 2022, the spring bloom started a month earlier (April) and lasted a month longer compared to the climatological data. Further, the fall bloom was larger and more sustained compared to the climatology. GHW also showed an extended fall bloom lasting for about 4 months in 2022. GHS had less pronounced spring and fall blooms, where 2022 was similar to previous years.

Peak SSTs are typically reached in August in all three regions. However, in 2022 SST increased until September and cooling was delayed, coinciding with a large Marine Heat Wave (MHW) event seen throughout the BC EEZ (Ross and Robert 2022). SST anomalies in October were particularly large, exceeding the upper 90th percentile of observations over the climatological period 1991-2020. GHE and GHS were excluded from this pattern, though GHE was anomalously warm a couple months earlier in August.

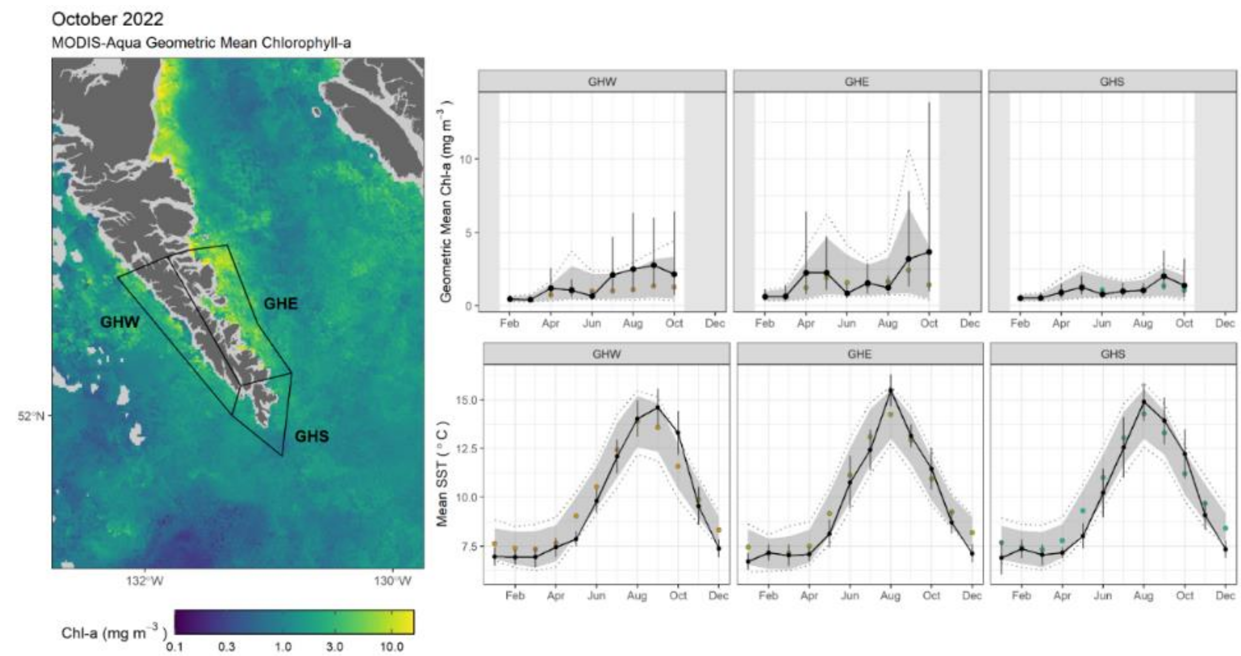

Figure 16-3. The three Gwaii Haanas regions (east, west, south) identified on a chl-a monthly composite of October 2022 (left). The chl-a and SST climatological means from (1991-2020 for SST, and 2003-2021 for chl-a as this dataset spans a shorter length of time) are indicated (right, top and bottom respectively) with coloured points, and standard deviation shaded in grey; dotted lines indicate upper and lower 10 percentiles. The 2022 monthly values are indicated in black with standard deviation bars.

16.4. Factors influencing trends

The 2014-2016 MHW lingered in B.C. deep waters until 2020 (Jackson et al. 2021). The termination of the deep water MHW resulted in coastal deep water cooling that started in the fall of 2020 (Jackson 2022). The cooling in JPS in 2021 and 2022 follows the trend observed in other central and northern coast regions (Jackson 2022). Oxygen concentrations are complex in JPS and further investigation is needed to determine the cause of the differences between JPS and QCS/HS.

SST could be one factor influencing chl-a trends. There's potential that the anomalously high SST in August could have shifted the fall bloom later into the year and decreased its magnitude. More research will need to go into whether this is causation or coincidence by looking at more historical data.

16.5. Implications of those trends.

Warm temperatures and low oxygen concentrations can have negative impacts on marine ecosystems (e.g. Smith et al. 2022; Hipfner et al. 2020). It is possible that the return to colder waters will result in a higher abundance of subarctic zooplankton species, which are more nutritious for many species including juvenile salmon, some marine seabirds, and forage fish.

Ongoing analysis of sea surface chl-a is important for monitoring shifts in the timing, extent, and magnitude of phytoplankton blooms, which may have cascading effects on other trophic levels.

Similarly, operational monitoring of SST and temperature and oxygen profiles by depth is critical for understanding the extent and impact of MHWs and anomalous events that can negatively impact marine species.

16.6. References

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17. CONSERVATION OF MARINE HABITATS IN THE SCOTT ISLANDS MARINE NATIONAL WILDLIFE AREA

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17.1. Highlights

- The seasonal decline in sea-surface temperatures (SSTs) was delayed in the fall of 2022. The SSTs were 2ºC warmer than normal in October in the Scott Islands Marine National Wildlife Area (NWA). SSTs returned to normal in November.
- Analysis of drifters deployed in 2022 showed for the first time surface currents exiting Hecate Strait and northern Queen Charlotte Sound (QCS) southward, appearing to go around the shallow banks in central QCS.
- Generally, drifters show a strong tendency to enter the NWA from the east, northeast, or the south. In 2022 some drifters entered the NWA from the open ocean to the west.
- From March through August it took drifters between 1-15 days to reach the NWA from the mouth of Queen Charlotte Strait (east of the NWA), which is a major transportation corridor. During September through February it took drifters between 1-9 days to reach the NWA from QCS, and from 0.5 to 4 days to reach the NWA from the latitude of Brooks Peninsula (to the south).

17.2. Description of the time series

The Scott Islands Marine National Wildlife Area (NWA) was established by the Government of Canada in 2018. In 2015, the Canadian Wildlife Service (CWS) of Environment and Climate Change Canada (ECCC), and Ocean Sciences Division (OSD) of Department of Fisheries and Oceans Canada developed a Collaborative Agreement (MOU), recently renewed to 2025-2026. The Scott Islands project is part of the long-term ocean monitoring to understand causes and effects of changes in the ocean environment on the marine ecosystem and resources. The monitoring program and its goals are described in detail in Jones et al. (2021, 2022).

Satellite monitoring, in particular of SST and Chlorophyll-a (Chl-a, a proxy for phytoplankton biomass), are valuable for monitoring trends and patterns in the upper ocean at high temporal frequency (Figure 17-1). For example, satellite SST facilitates monitoring the presence and strength of marine heatwaves, and the mean Chl-a concentration during April has been shown to correlate with Rhinoceros Auklet (*Ptychoramphus aleuticus*) fledgling success (Borstad et al. 2011). Satellite data from the Pathfinder Advanced Very High Resolution Radiometer (AVHRR, v5.3), distributed by NOAA, has been utilized to monitor SST in the NWA since 1981. SST and Chl-a from recent decades (2003 to present) are also acquired from the MODerate Resolution Imaging Spectroradiometer (MODIS-Aqua) with products distributed by the NASA Ocean Biology Processing Group (OBPG). These datasets were averaged for the NWA on a monthly basis to produce time series of monthly mean and climatological monthly mean values. November, December, and January were excluded from the Chl-a dataset.

The variability of the subsurface temperature, and dissolved oxygen in the NWA is reported by Hannah et al., Section 12.

GPS drifters reveal potential for anthropogenic items and natural living or inorganic substances on the ocean surface to be transported to a given location or area. These results assist management agencies to develop plans to respond to incidents, including search and rescue as well as handling substance releases. There is wide variation in the life span of the drifters used by OSD. Prior to 2022, the mean life span was about 9 days before the drifters stopped transmitting, with some lasting over 2 weeks. Most transmitted data to satellite at 5 or 10 minute intervals, some at 30 minutes (Hourston et al. 2021, R.A.S. Hourston, DFO, pers. comm.). In 2022 many drifters were set to provide locations at 30 minute intervals, facilitating longer periods of transmitting, and many lasted over 40 days (R.A.S. Hourston, DFO, pers. comm.).

The large number of drifters released coast-wide annually since 2014 provide substantial amounts of data (Figure 17-2). The combined data set is too large to handle visually, so analysis by area, and year and month, is required to describe surface currents.

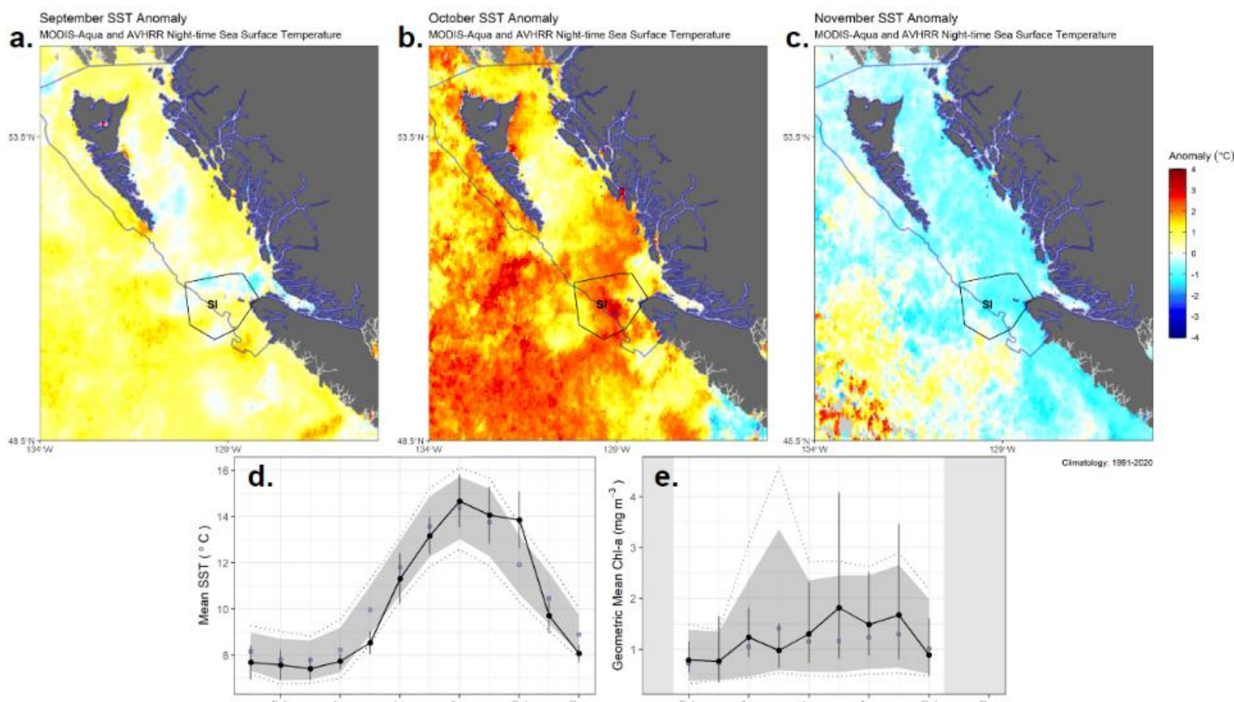

Figure 17-1. Monthly sea-surface temperature (SST) near the Scott Islands NWA for 2022 (a., b. and c.). Scott Islands NWA is indicated in black with the Northern Shelf Bioregion outline in blue. d. Satellite SST in Scott Islands NWA, where grey shading and coloured points indicated standard deviation and climatological mean respectively. 10th and 90th percentiles indicated with dashed lines. 2022 mean and standard deviation values are indicated in black points and bars. e. Satellite chlorophyll-a with similar information, but geometric standard deviation and geometric mean.

17.3. Status and trends

Satellite Chl-a in the NWA in 2022 was higher than usual later in the summer (July through September; Figure 17-1). Chl-a in April, known to be correlated with fledgling success of Rhinoceros Auklets, was slightly higher than the climatology, though an outage occurred for the MODIS-Aqua instrument leading to a total loss of data from the 1^{st} to 17^{th} of the month, which lowers the confidence of this month's average Chl-a. There was greater deviation from climatological values in the satellite-observed SST, with winter and spring values being slightly cooler than usual; May in particular was > 1 standard deviation below the 1991-2020 climatology for the month. Beginning in July, SSTs switched to being warmer than usual, with the October average being a full 2°C higher than the climatological mean of 11.8°C. Seasonal SST averages in the NWA overall showed a warming trend during summer (July, August and September), similar to other regions in the B.C. EEZ.

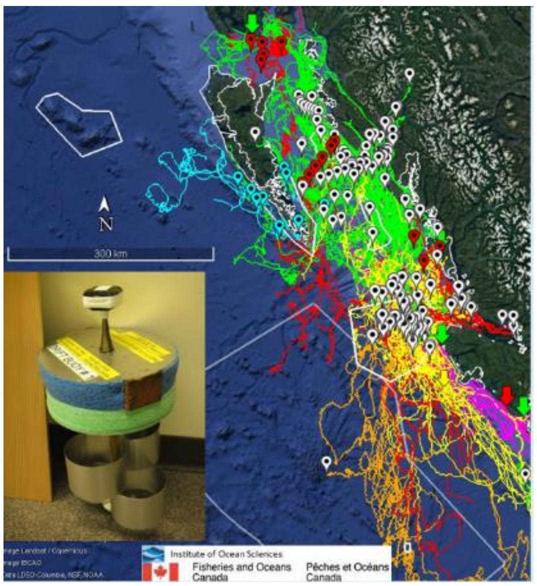

Figure 17-2. Drifters deployed 2014 – 2022. Deployments, except those between Vancouver Island and mainland B.C. n=353. Colours represent different months, years and locations of deployments.

Two clear features of accumulated data from drifters are the southward drift out of southern Queen Charlotte Sound (QCS), and the very limited westward drift out of the mouth of QCS. The drifters provide useful information even after the batteries die and the tracking stops. Drifters used in this project have been found on shorelines from Oregon to Alaska (not shown).

Visual assessment of the 2022 data has shown two areas which appear to have reduced transit of drifters compared to most of Hecate Strait and QCS (not shown). These correspond to areas of anti-cyclonic currents over the two shallow banks in the center of QCS (Hannah et al. in prep). This drift around banks likely reduces movement of surface waters, and any materials with them, northward from the NWA, or southward into it.

Assessment of drifters released in Hecate Strait and northern QCS showed very limited movement southward from 2014-2021. Drifters released in July 2022 demonstrated, for the first time, lengthy movements southward out of these areas into or near the NWA (Figure 17-3). Additionally, September 2022 was the first time drifters were deployed on the west side of Gwaii Haanas. These moved generally northward parallel to the shore, then trended westward (Figure 17-3).

The information from drifters accumulated through 2022 has allowed subjective evaluation of probability of surface carried materials to enter the NWA. Overall, the probability ratings are "high" or "moderate". These subjective ratings consider variability of seasonal movement patterns and sample sizes of drifters released. Given the proven variability of currents over time, this report does not identify areas or time periods as "low" or "nil" probability of drifters entering the NWA.

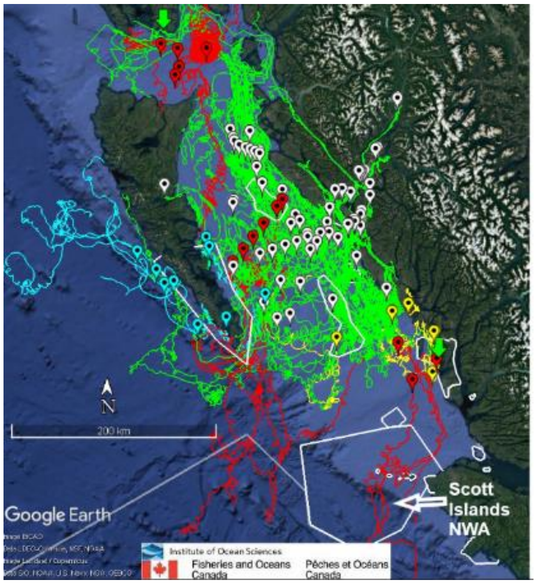

Figure 17-3. New drift patterns in 2022. Drifters deployed in Hecate Strait, northern Queen Charlotte Sound, or west coast of Gwaii Haanas. The red drifters were deployed in July 2022; n=17 [11 Hecate Strait or Queen Charlotte Sound, 6 Dixon Entrance]. The blue ones in September 2022; n=9 [6 west coast of Gwaii Haanas, 3 Hecate Strait]. The green drifters were deployed March – November 2014 – 2022; Hecate Strait; n=157 [excludes July and September 2022]. Bright white polygons: Federal and Provincial protected areas. Faded polygon: Area of Interest

Results of drifters deployed from September to February, 2017-2022, suggest high probability of southward, westward or northward, entry into the NWA. Eastward entry is assessed as moderate probability. Drifters took 1-9 days to reach the NWA from the southeast entrance to QSC. Those moving northward from the vicinity of Brooks Peninsula took ½ to 4 days to reach the NWA (Figure 17-4).

In the March to August period, 2016-2022, accumulated data from drifters indicates high probability of westward and southward entry into the NWA, and moderate probability of northward and eastward entry. Drifters took 1-15 days to reach the NWA from the southeast entrance to QCS (Figure 17-4). Prior to 2022, there was very limited information on probability of eastward movement into the NWA, leaving an information gap to support response planning. Some drifters released west of the NWA in 2022, subsequently moved eastward into it, supporting the moderate rating. Summer currents south of the NWA are generally southward (Freeland et al. 1984). Some drifters deployed in summer exited the NWA southward, then turned northward re-entering the NWA, supporting the moderate rating.

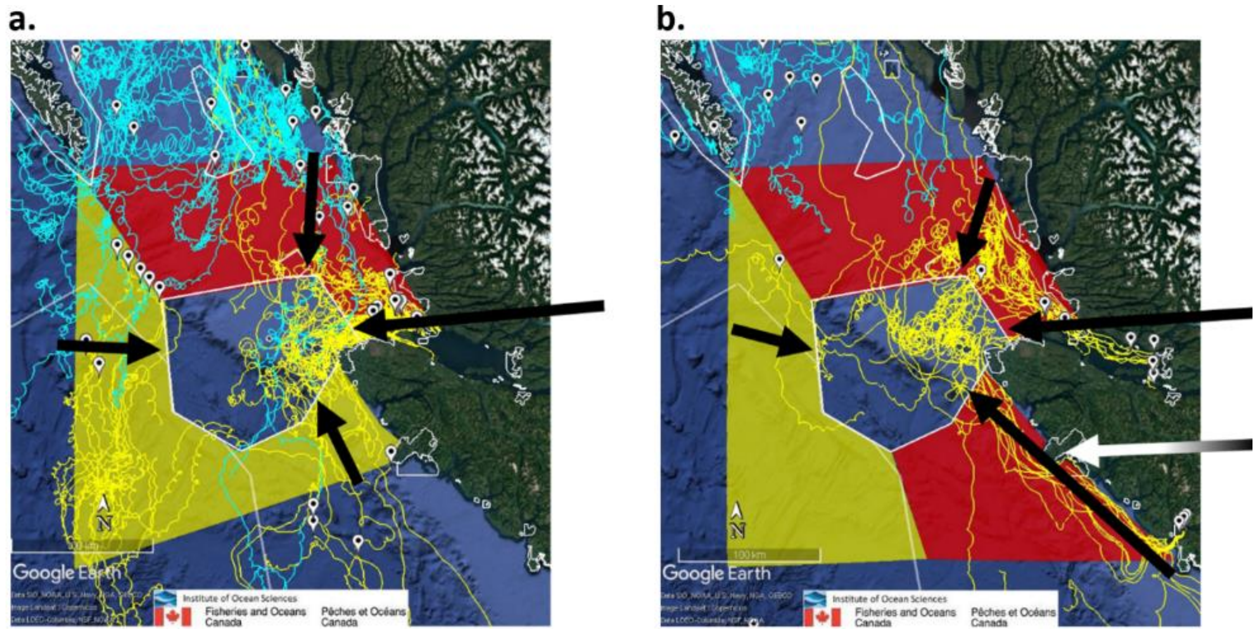

Figure 17-4. Subjective risk of substances entering the Scott Islands NWA. a. March – August, 2016 - 2022. b. September – February, 2017 - 2022. Red: High probability. Yellow: Moderate probability. Black arrows: direction entering the NWA. White arrow: Vicinity of Brooks Peninsula.

17.4. Factors influencing trends

The warm, anomalous SSTs in the NWA occurring in late summer into autumn corresponded to the development of a marine heatwave (MHW) in August. Satellite observations show that it entered the B.C. EEZ in late August and persisted until late October (detailed further in the NOAA heatwave tracker (Ross et al. 2023): (https://www.integratedecosystemassessment.noaa.gov/regions/california-current/cc-projects-blobtracker).

Review of drifter deployments from 2014 through 2022 has shown high variability of the surface drift patterns between seasons and years. As such it is not possible to provide precise estimates of movement from a given location into the NWA. The drifter data can be used to assess the subjective probability of entry into the NWA from different locations.

17.5. Implications of those trends

Marine heatwaves may have significant deleterious ecosystem effects. In recent years, MHWs have caused large mortality events for Cassin's Auklet (*Ptychoramphus aleuticus*) (Jones et al. 2018); therefore tracking them is an integral part of monitoring for the NWA, particularly due to its significance for seabirds.

Given the wide inter-annual variation of results from drifters, it is essential to continue annual deployments. Continuation will provide new information to better support development of incident response plans for the NWA. Continuance over time may also improve understanding of effects of climate change, and normal variability, on habitat suitability for seabirds and other marine predators including fish and marine mammals.

The NWA, as with all designated areas, will always be influenced by the wider marine environment, so it is essential to continue annual oceanographic assessments on an ecosystem basis.

The broad nature of the activities under the MOU between OSD and ECCC provides precedents to help design similar programs for other MPAs or designations.

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18. 2022 CHS PACIFIC HYDROGRAPHIC SURVEY UPDATE

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18.1. Highlights

- 63 multibeam surveys and 12 laser scanner survey were completed.
- 1,864 hrs of survey time.
- 17,741 km of survey lines.
- 3,544 km^2 surveyed.

18.2. Description

The Canadian Hydrographic Service's 2022-23 survey priorities were defined following extensive client consultation regarding multibeam, laser scanner, and backscatter data requirements. Ongoing challenges posed by the COVID-19 pandemic required CHS to continue to take precautionary measures to ensure the safety of its employees and any population potentially impacted by survey work during such unprecedented times. As some restrictions were lifted, CHS was able to return surveys to a full crew compliment on most survey platforms.

The priority areas on the south coast of B.C. (Figure 18-1) were identified as Barkley Sound, Nitinat Narrows, the Sombrio Faultline, the Gulf Island Anchorages, Discovery fish farms, Knight Inlet, Winchelsea Island, Esquimalt Harbour, Sand Heads, and Bute Inlet, as well as B.C. Ferry terminals at Little River, Whaletown, Sointula and Bear Cove. These areas were selected in support of charting priorities (especially charts 3670, 3671), and in support of NRCAN-SASIMA, Ocean Sciences Division, Ecosystems Sciences Division, Transport Canada, DND, CCG, RPSS, and Parks Canada priorities. These survey operations were carried out by the CCGS *Vector,* the CCGS *Otter Bay*, CSL *Shoal Seeker,* CSL *Kalman L. Czotter and by contract (portion of Barkley Sound).*

The priority areas on the central and north coast of B.C. (Figure 18-2) included Queen Charlotte Sound, the Scott Islands marine National Wildlife Area, Kitimat Terminals, Dean Channel and Burke Channel. Due to COVID-19 all nearshore survey work around Haida Gwaii and Gwaii Haanas Park continues to be suspended. The priority areas were selected based on continuing and completing efforts from the 2021 survey season, as well as in support of charting priorities, ECCC-DAS, ECCC-CWS and NRCAN-PNCIMA priorities. These survey operations were carried out by the CCGS *Vector* and the CSL *Shoal Seeker*.

All hydrographic surveys were carried out following the guidelines as stated in the ISO 9001:2015 Standard, Quality Manual for CHS, the 1001 series, *Data to Validated Databases*, *CHS Standards for Hydrographic Surveys*, *Hydrographic Survey Management Guidelines* and the *CUBE bathymetric Data Processing and Analysis* documents referenced by this ISO documentation. This includes meeting or exceeding Order 1, and adhering to appropriate reference, administration and safety manuals, relevant marine regulations, and departmental policies (Cloutier et al. 2022).

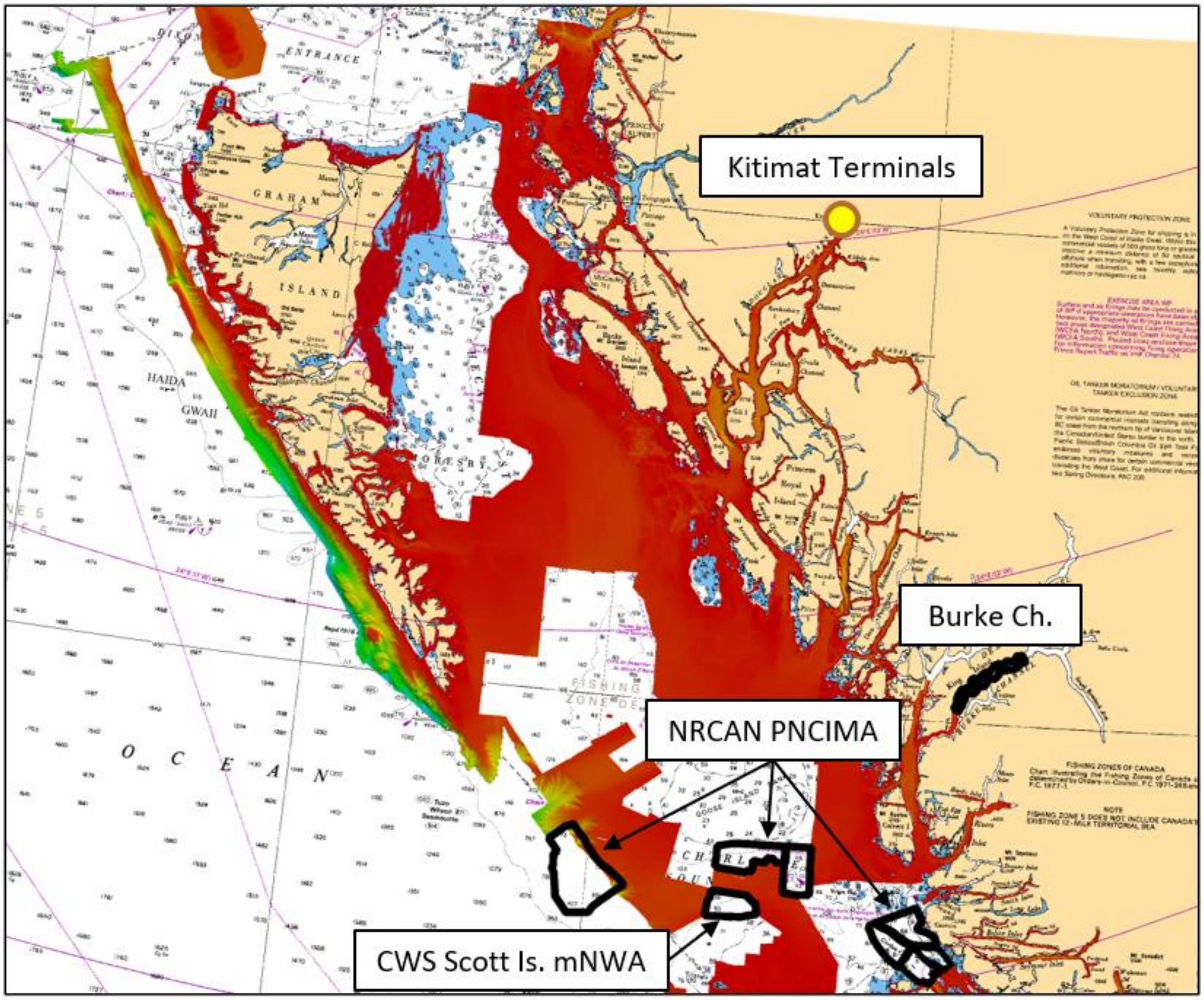

Figure 18-1. Overview of areas surveyed by CHS/CCG vessels on the Central and North Coast in 2022.

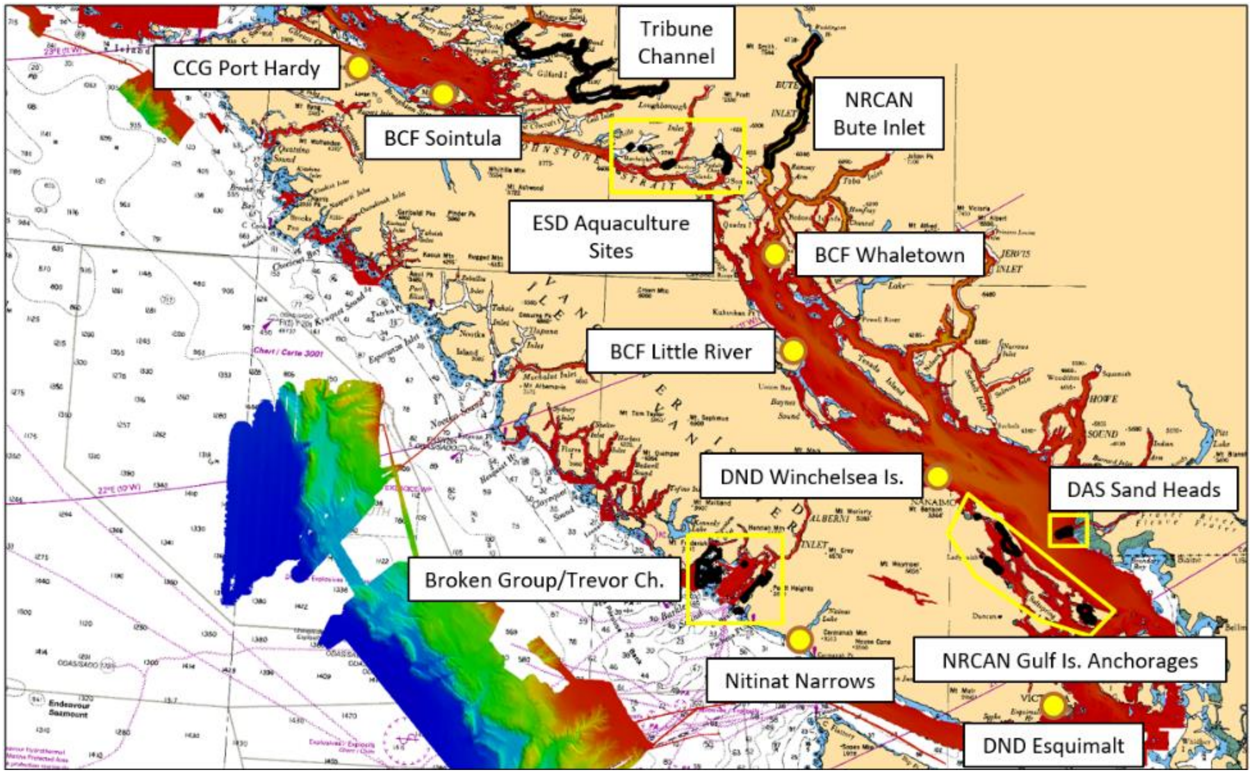

Figure 18-2. Overview of areas surveyed by CHS/CCG vessels on the South Coast in 2022.

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19. NUTRIENTS AND PHYTOPLANKTON ALONG LINE P

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19.1. Highlights

- Winter and summer nutrient concentrations in surface waters along Line P in 2022 were as high or higher than the average concentrations of previous years (2010-2021).
- Surface water nitrate anomalies have increased in recent years mostly due to stronger negative anomalies during the Marine Heat Waves (MHWs) in 2014-2015 and 2019-2020 that restricted winter nutrient renewal from vertical transport due to increased stratification.
- Phytoplankton biomass and community composition in 2022 were similar to those of previous years along Line P, except for an increase in the abundance of prasinophytes and cryptophytes at nearshore stations.

19.2. Description of the time series

Monitoring changes in nutrients, phytoplankton biomass, and community composition is important for the evaluation of ecosystem function and status, as well as for the study of biogeochemical cycles. Phytoplankton community composition, chlorophyll-a (“Chl-a”, an indicator of phytoplankton biomass) and nutrients are normally measured on DFO cruises along Line P (Figure 19-1) in the northeast subarctic Pacific Ocean three times a year in winter (February-March), spring (May-June), and summer (August-September). Nutrients were measured during 1969-1981 and from 1988 to the present, whereas sampling for phytoplankton composition has been carried out at most of the stations along Line P since June 2010. In 2022, sampling occurred in winter and summer but not in spring since the scheduled June cruise was cancelled.

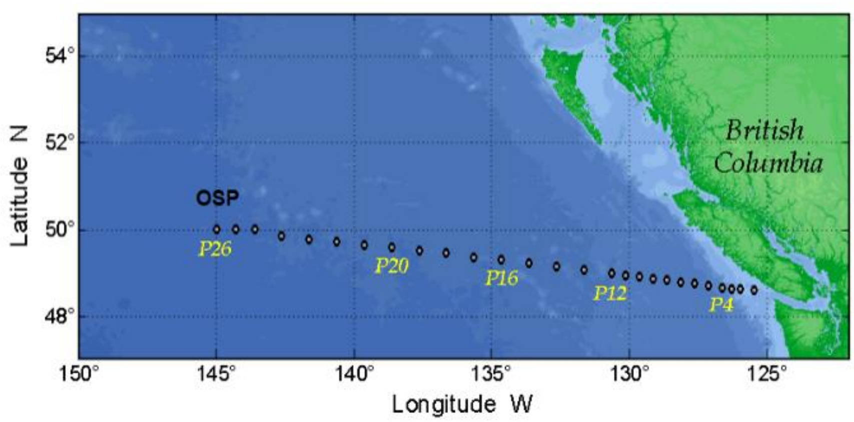

Figure 19-1. Location of sampling stations along Line P (P26 is Ocean Station Papa (OSP)).

The abundance and composition of phytoplankton are determined using a chemotaxonomic approach based on phytoplankton pigments (chlorophylls and carotenoids) analyzed by high performance liquid chromatography (HPLC) as described in Nemcek and Peña (2014). The HPLC pigment data are processed using a factorization matrix program (CHEMTAX) to estimate the contribution of the main taxonomic groups of phytoplankton to total Chl-a (Mackey et al. 1996).

19.3. Status and trends

Line P extends from the southwest corner of Vancouver Island to Ocean Station Papa (OSP, Figure 19-1) 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 (<0.8 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 in the Fe-rich waters of the continental shelf and slope there is high seasonal variability in nutrient concentrations, phytoplankton biomass and composition. In 2022, winter and summer surface nutrient concentrations (Figure 19-2) were as high or higher than the average concentrations from previous years (2010-2021). In particular, summer nitrate and silicate concentrations in surface waters offshore of P12 were higher than those observed during and after the Marine Heat Wave (MHW) of 2014/2015 and significantly higher than those observed in 2019 when nitrate depletion extended for the first time to OSP.

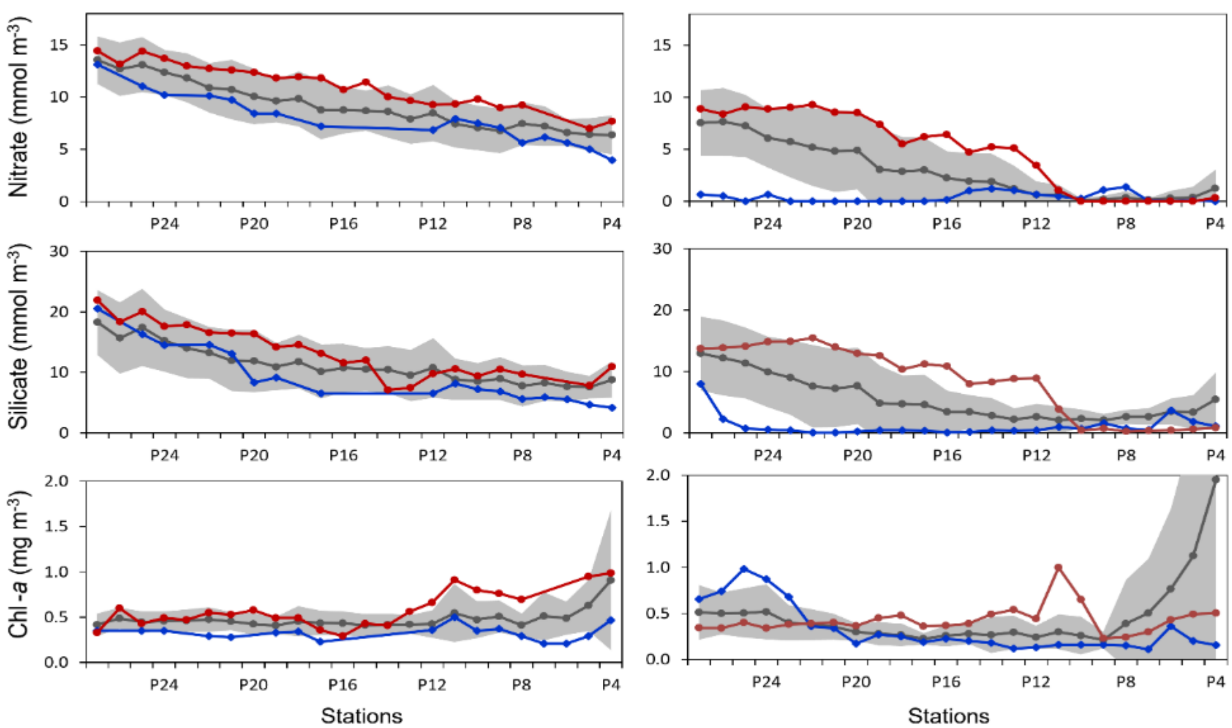

Figure 19-2. Concentrations of nitrate (top panels, mmol m^{-3}), silicate (middle panels, mmol m^{-3}), and chlorophyll-a (bottom panels, mgl m^{-3}) in surface waters along Line P from P4 to OSP in winter (left panels) and summer (right panels). All panels show the average (grey line) and standard deviation (shaded area) of concentrations in 2010-2021, data for 2019 (blue line), and for 2022 (red line).

Long time series of nitrate concentrations in surface waters along Line P have shown marked interannual variability (Peña and Varela 2007; Di Lorenzo et al. 2009). The strength of the nitrate anomalies (Figure 19-3) has increased in recent years. Stronger negative anomalies were observed during the MHWs in 2014-2015 and 2019-2020 that restricted winter nutrient renewal from vertical transport due to increased stratification.

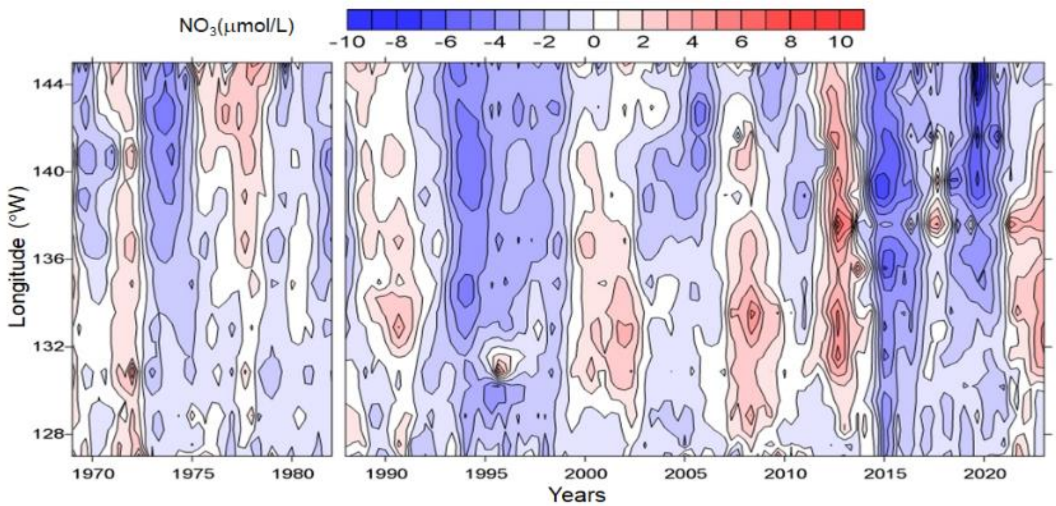

Figure 19-3. Hövemoller plot of surface mixed-layer nitrate concentration anomalies (µmol/L) along Line P from 1964 to 1981 and from 1988 to 2022.

Chl-a concentrations in 2022 were in general similar to those observed in previous years, except for a peak in the summer at P10 and P11 (Figure 19-2). Similarly, haptophytes dominated phytoplankton biomass at most stations along Line P in 2022 and phytoplankton composition was similar to previous years (Figure 19-4), except for an increase in the abundance of prasinophytes and cryptophytes at nearshore stations in winter.

19.4. Factors influencing trends

Several environmental factors including temperature, irradiance, and nutrient availability, as well as grazing pressure, determine phytoplankton abundance and community composition. During and right after the MHWs of recent years, significant fluctuations in nutrient concentration, phytoplankton biomass and diatom abundance were observed in the NE subarctic Pacific likely in response to the increase in surface temperature and changes in nutrient availability (Peña et al. 2019). These include the unprecedented depletion of mixed-layer nitrate, and to a lesser degree of silicate, in the HNLC region of Line P in the summer of 2019, as well as sporadic increases in diatom abundance at the most offshore stations of Line P in September of 2017 and 2019. In 2022, nutrient concentrations and phytoplankton biomass and composition have largely returned to pre-MHW conditions.

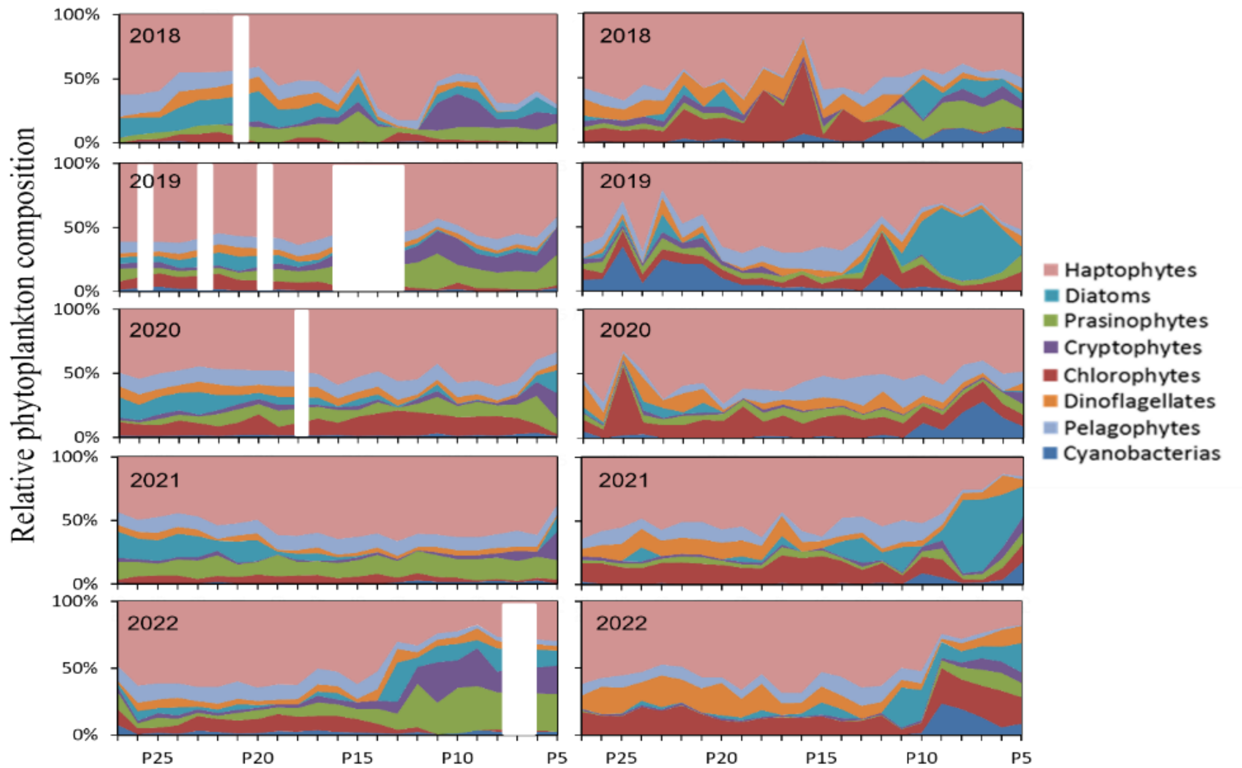

Figure 19-4. Relative phytoplankton composition in the upper layer at stations along Line P (see Figure 19-1) in February (left panels) and Aug./Sept. (right panels) of 2018 to 2022. Blank spaces indicate no data were collected.

19.5. 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.

19.6. References

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20. WEST COAST BRITISH COLUMBIA ZOOPLANKTON BIOMASS ANOMALIES 2022

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20.1. Highlights

- Sub-arctic and boreal copepods dominated the zooplankton communities from late spring into early summer, replaced by southern copepods in the fall.
- There was an increase in gelatinous zooplankton biomass across shelf areas, mainly due to an increase in hydromedusae and ctenophores through late summer and into fall.
- Southern chaetognaths disappeared from all areas which may be due to the cooling effect of La Niña.

20.2. Description of the time series

Zooplankton catch time-series are available for Southern Vancouver Island (SVI; 1979-present), Northern Vancouver Island (NVI; 1990-present), Line P (1996-present), and Hecate Strait (1990-present), 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. The ‘standard’ sampling locations are averaged within the SVI, NVI, Line P and Hecate regions (Figure 20-1). Additional locations are included in averages when they are available. See Mackas et al. 2001 for methodology of zooplankton surveys along the West Coast.

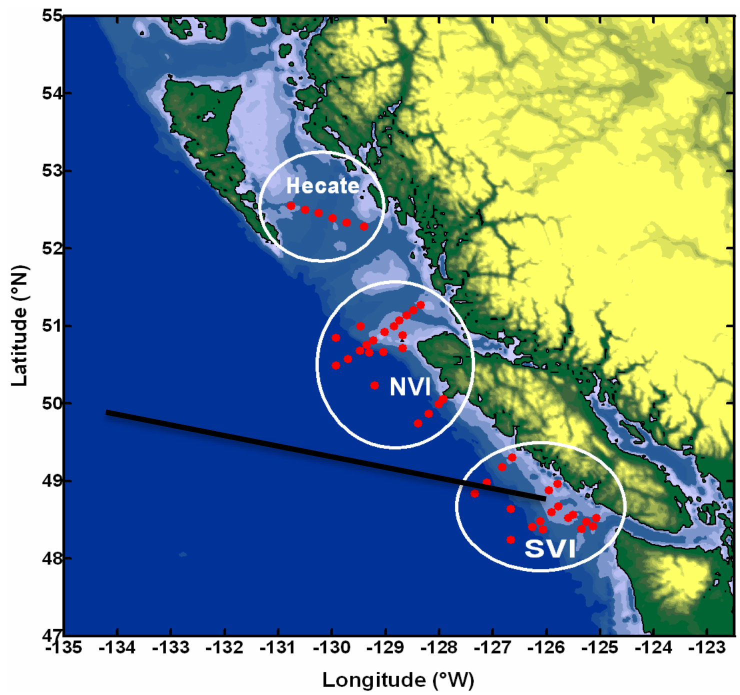

Figure 20-1. Zooplankton time series sampling locations (red dots; Line P – black line) in B.C. marine waters. Data are averaged for samples within each area. There are more samples included in the analysis than shown in figure.

The zooplankton climatology was estimated for each region, using the data from 1990 through to 2020 as a baseline, and compared to monthly conditions during any single year to produce a biomass anomaly time series. This is a change from previous State of the Pacific Reports of west coast Vancouver Island zooplankton anomaly series. For a more detailed description of the previous biomass anomaly series, see published articles Mackas 1992, Mackas et al. 2001 and Mackas et al. 2013b. The new method follows ICES protocol (O’Brian, 2022: see https://wgze.net/) with log 10 transformed biomass anomaly. The main difference between earlier and present methodology is the climatology baseline update to 2020 in addition to the treatment of zero values. The new method closely replicates the previous version of anomaly calculation in pattern of positive/negative values: range above and below average; but extremes are attenuated overall.

Zooplankton species (see Table 20-1 for species breakdown of groups) from the west coast of B.C. with similar zoogeographic ranges and ecological niches usually have a 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 (Galbraith and Young 2017; Mackas et al. 2013a; Irvine and Crawford 2013). All data presented here are very preliminary as sample identification and enumeration continues; numbers will change as analysis is completed but directions of trends *usually* do not change.

20.3. Status and trends

The biomass anomaly time series for copepod species groups 'southern', 'subarctic' and 'boreal shelf' focus on SVI and NVI shelf/offshore, stations P4-P12 on Line P, and Hecate Strait regions (Figure 20-2). Cool years tend to favour endemic 'northern' taxa; whereas warm years favour colonization by 'southern' taxa. See Mackas et al. (2013b) for pre-1995 anomalies, and descriptions on how to interpret the anomaly patterns.

Table 20-1. Zooplankton groups described in the time series in Figure 20-2.

Zooplankton group	Species	Comments
Southern copepods	*Acartia danae, A. arbruta, Clausocalanus spp., Calocalanus spp., Ctenocalanus vanus, Eucalanus californicus, Mesocalanus tenuicornis*, *Paracalanus spp.*	Centered about 1000 kilometers south of our study areas (either in the California Current and/or further offshore in the North Pacific Central Gyre)
Boreal shelf copepods	*Calanus marshallae, Pseudocalanus spp., Acartia longiremis*	Southern Oregon to the Bering Sea
Subarctic oceanic copepods	*Neocalanus plumchrus*, *N. cristatus*, *N. flemingeri*, *Eucalanus bungii, Metridia pacifica*	Inhabit deeper areas of the subarctic Pacific and Bering Sea from North America to Asia
Euphausiids	*Euphausia pacifica, Thysanoessa spinifera*	Centered off west coast of N. America; euphausiid biomass corrected for day/night tows.
Southern chaetognaths	*Mesosagitta minima, Serratosagitta bierii, Parasagitta euneritica*	Centered off California/Mexico
Northern chaetognath	*Parasagitta elegans, Eukrohnia hamata*	Boreal Pacific into the Arctic

In 2022, southern copepod species were more prevalent in the SVI offshore and Hecate regions than on the shelf and continued to decline in abundance in all areas, by comparison to previous years, particularly NVI shelf and offshore (Figure 20-2). Boreal shelf and subarctic copepods increased or were near average in biomass across all areas. The dip in the subarctic copepods in 2021, in the shelf area, may be a result of high numbers in the early summer (cooler waters) to the almost complete absence in the late summer/early fall (much warmer waters).

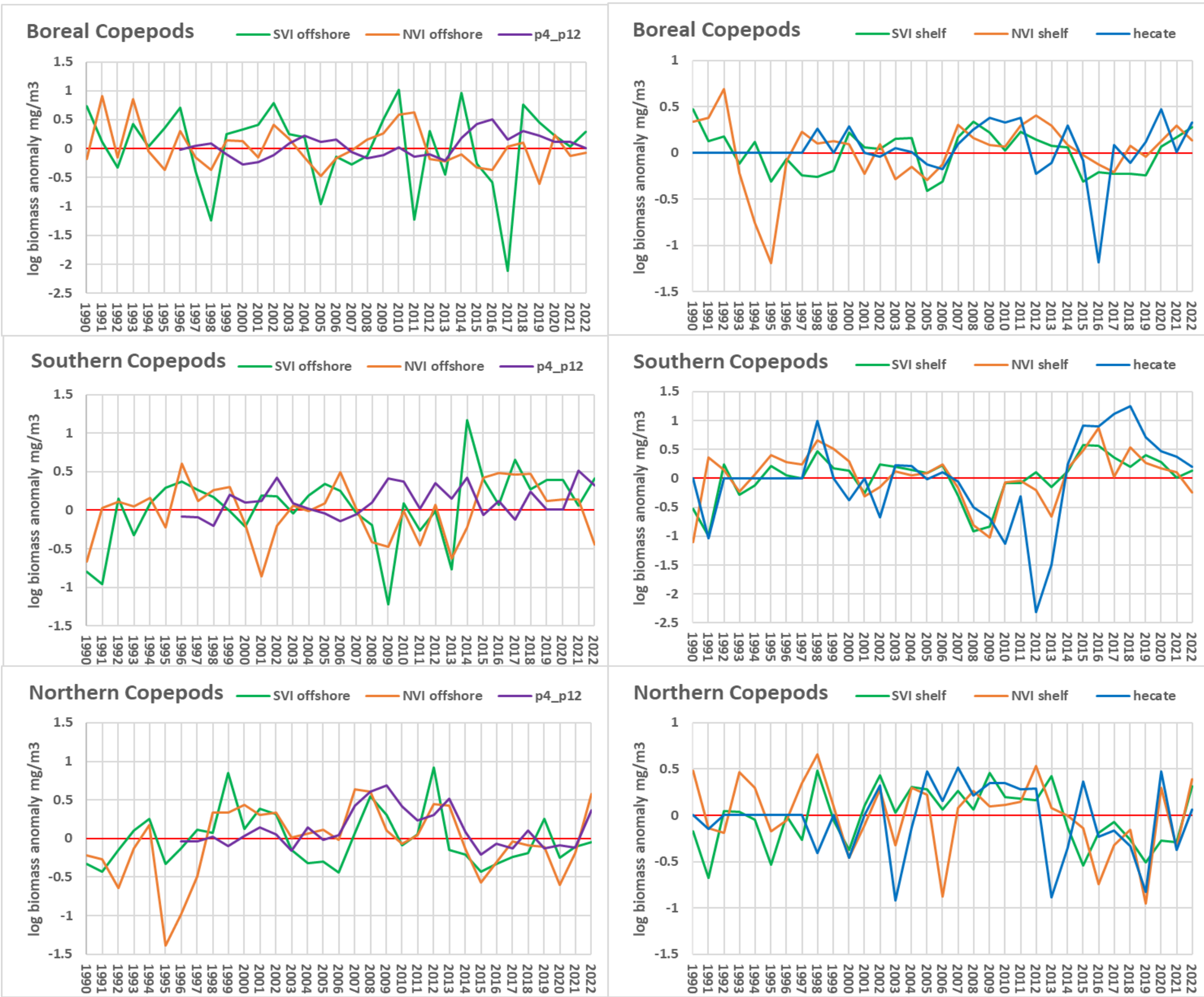

Figure 20-2. Zooplankton species-group anomaly time series for the regions shown in Figure 20-1. Southern Vancouver Island (SVI) green; Northern Vancouver Island (NVI) orange; Hecate Strait blue; Line P purple - shelf areas on left and offshore areas on right panels. Blank years mean no samples were collected.

Euphausiid biomass peaks are mainly in the NVI shelf area (Figure 20-3) and the SVI offshore region. The majority of the changes in biomass for the euphausiids are a result of growth; early in the year most are larval and as the year progresses, they grow to juvenile or adult stages. This may bias the annual anomaly but the overall picture is an increase in biomass except for the SVI shelf, NVI offshore and Hecate Strait area, and around average along inner Line P.

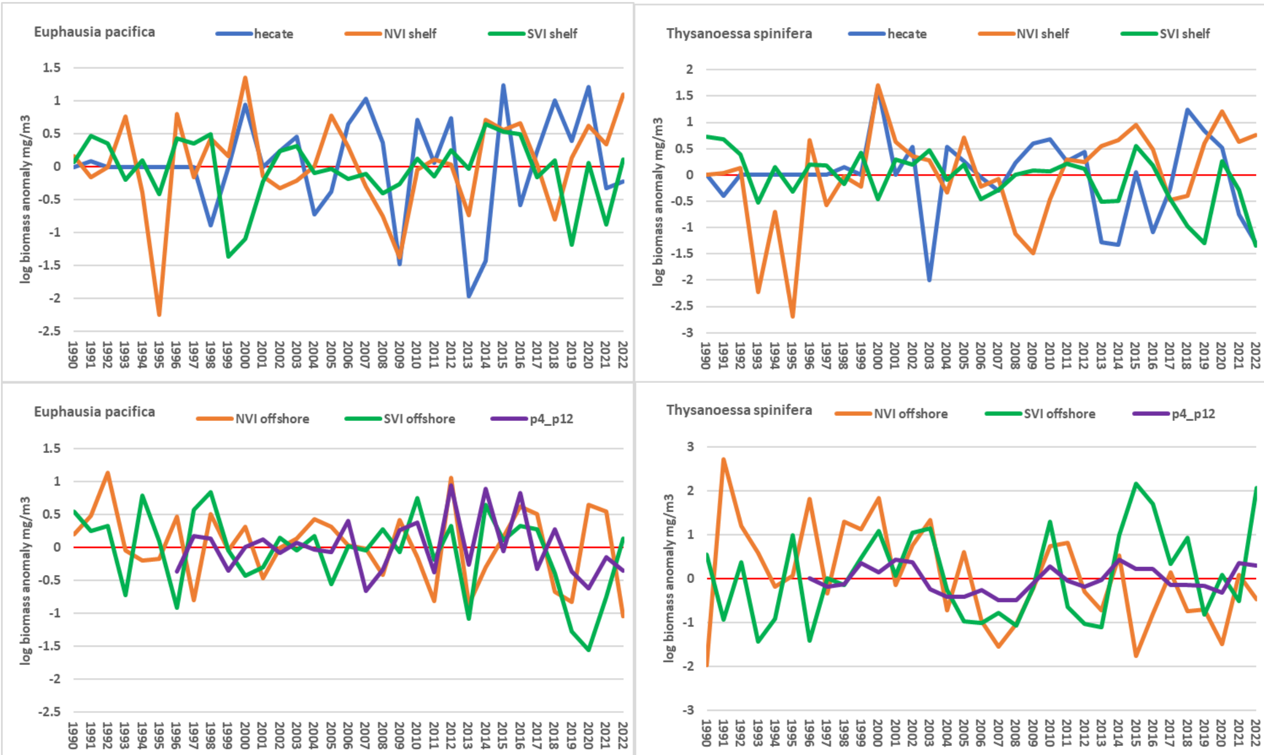

Figure 20-3. Euphausiid species comparison: Euphausia pacifica (left panel) and Thysanoessa spinifera (right panel) Vancouver Island shelf and offshore areas.

Larvaceans, siphonophores, and hydromedusae biomass anomalies continued to be positive for 2022 in all regions and were the main contributors to the gelatinous group. There was a sharp decrease in doliolid biomass across all regions, beginning in 2020 and continuing into 2022, with almost near absence in all areas. Salps, with very high numbers in 2021 were absent along the whole coast in 2022. This had a moderating effect on the CSIndex or “Crunchies (crustacean): Squishies (gelatinous)” Index (see Galbraith and Young 2019 for detailed explanation) through the averaging of regional data. The regions that had increases in gelatinous biomass contained mainly large numbers of *Pleurobrachia* and *Mitrocoma*. This represents the first year in a long time that the local gelatinous community were truly represented, without southern influence.

Shelf areas showed positive gelatinous biomass anomalies; whereas, the offshore areas were negative (Figure 20-4). Crustaceans were only positive in the NVI shelf and SVI offshore regions which may reflect the increase in *Neocalanus* biomass in those areas. The index reflects a return to average biomass which would imply lower biomass overall for 2021 and 2022 in comparison to previous years (which were all above average).

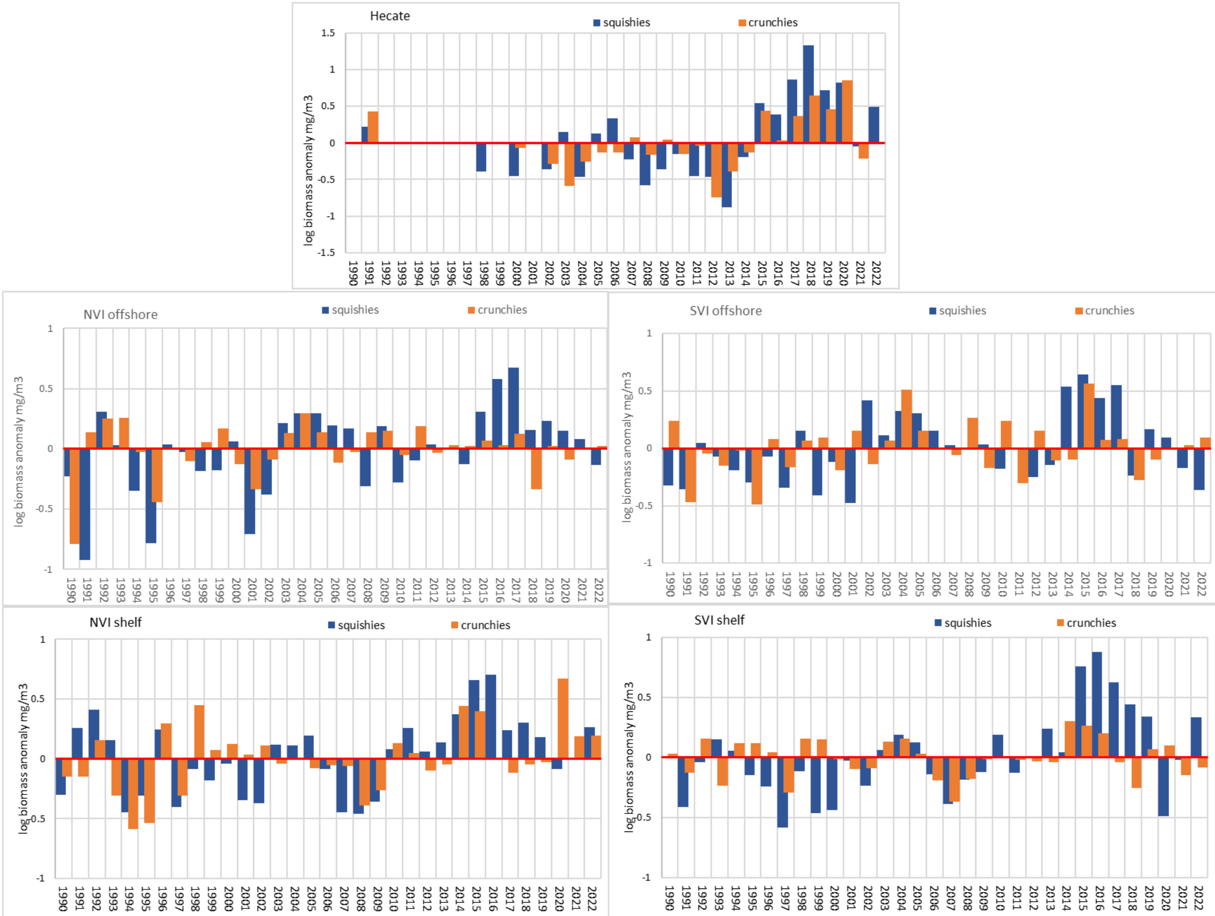

Figure 20-4. Biomass anomalies for selected crustaceans (orange: Crunchies) and gelatinous (blue: Squishies).

Along with the northern/southern copepod groupings, the chaetognaths show a strong correspondence to warm water intrusions, northern species give way readily to the southern community (Figure 20-5). The southern chaetognaths are very sensitive to cold water and when surface water temperatures cool during La Niña conditions, they are no longer found in samples collected from the Canadian west coast. The last couple of years have seen a steady drop in southern chaetognath biomass and a corresponding increase in northern chaetognath biomass, mainly *Parasagitta elegans*.

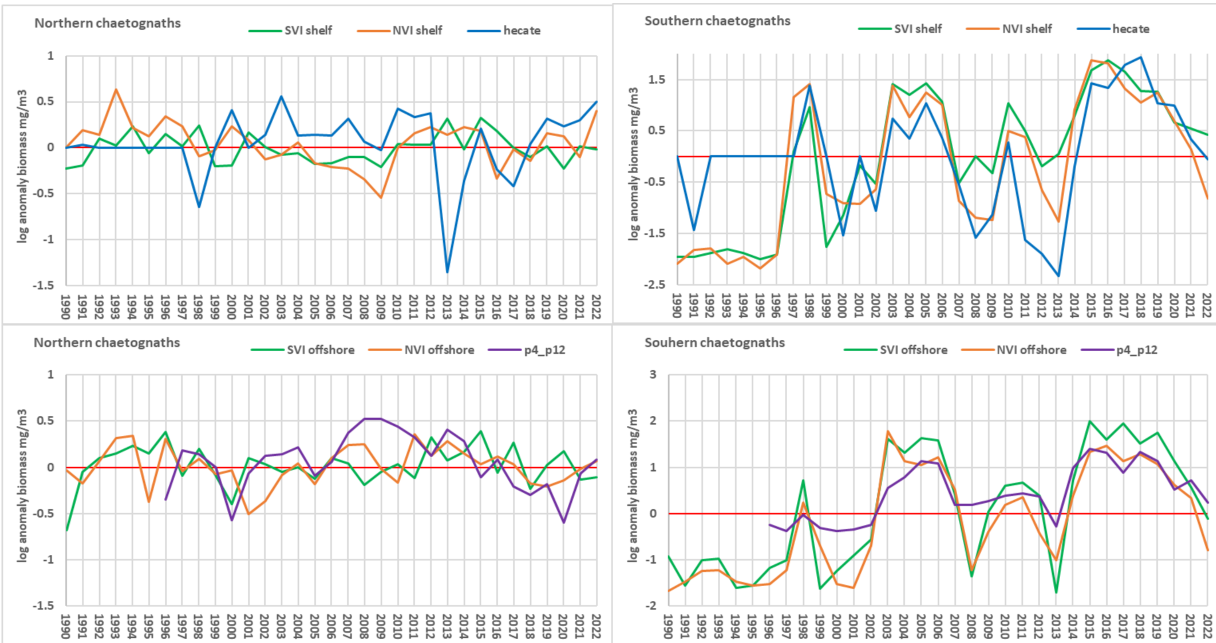

Figure 20-5. Northern chaetognaths (left panel) and Southern chaetognaths (right panel) biomass anomalies for selected areas.

20.4. Implications of those trends

Overall, 2022 saw a return to near-average biomass for crustaceans and gelatinous animals of the boreal/subarctic community in most regions. The above average euphausiid biomass anomalies in the SVI regions and NVI shelf, coupled with the spring/early summer increase of subarctic and boreal copepods (with high lipid content) may have provided good feeding conditions for larval fish, juvenile fish (especially out-migrating salmon smolts), and planktivorous seabirds feeding in the spring.

20.5. References

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21. LOWER TROPHIC LEVELS IN THE NORTHEAST PACIFIC

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21.1. Highlights

- In 2022, the mean copepod size, an index of community composition, appeared to have returned to average following the marine heatwaves that started in 2014, and copepods typically associated with warmer waters have declined in abundance, in both the offshore and shelf regions around B.C.
- Phytoplankton community indicators appeared to have returned to values of pre-heatwave (2014-2016) conditions in the offshore region.

21.2. Sampling

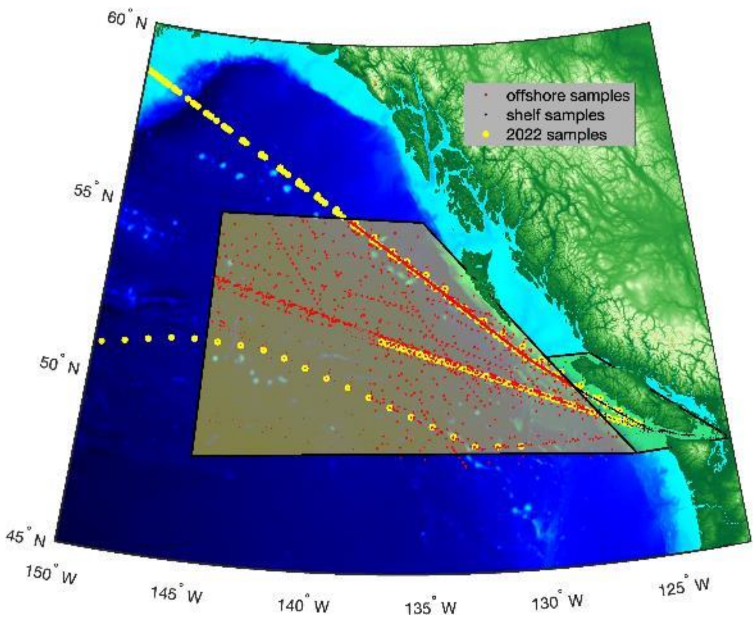

Figure 21-1. Map showing the location of historic CPR samples (2002-2021) red = offshore, black = shelf. Yellow circles are the location of the 2022 samples, note some 2022 samples are not yet analysed so are not shown.

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 21-1) continuing a time series that began 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. 2022 CPR data presented within this report are provisional and only include the months March-June and October, as the rest of the samples are still being analyzed.

All 2022 tows were completed as scheduled (Figure 21-1, see yellow circles). 2022 data have not yet been finalized (where shown) and are therefore provisional and likely to change.

Sea Surface Temperature (SST) data from 2000 to 2022 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 to characterize the physical environment.

21.3. Description of the Plankton Time Series

21.3.1. Phytoplankton

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

21.3.2. Zooplankton

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

21.4. Status and Trends

21.4.1. Phytoplankton

In the offshore region SST was similar to what it has been in recent warm years, whereas in the shelf region it was cooler than it has been during heatwave years. The phytoplankton community composition had higher numbers of round diatoms than heatwave years, reflecting numbers that were closer to years prior to the heatwave in 2015 (Figure 21-2).

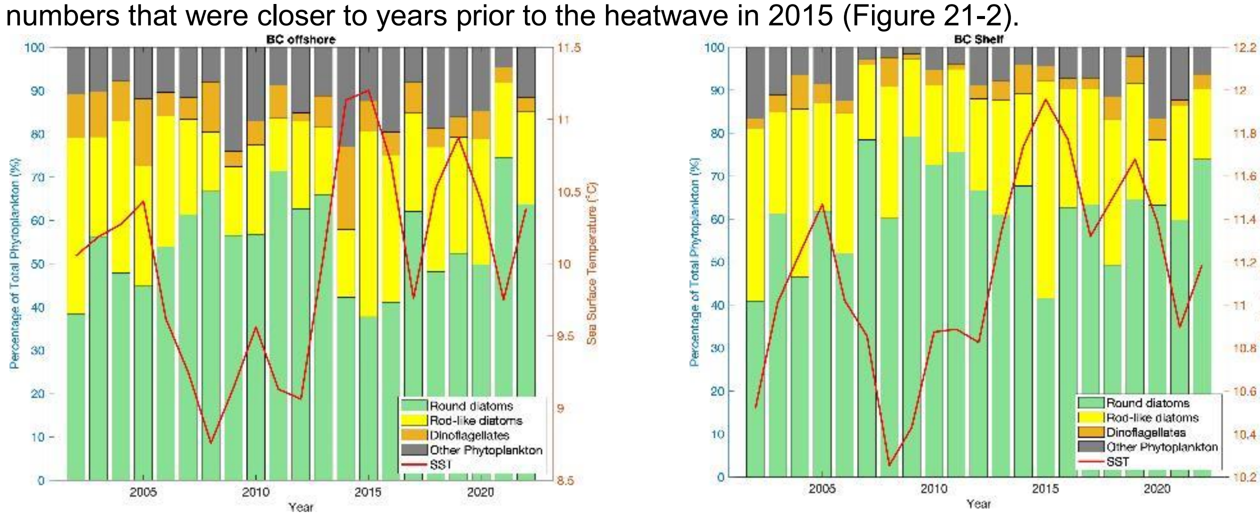

Figure 21-2. Contribution of each group to the mean annual phytoplankton community offshore (left) and on the shelf (right). SST is shown in red (right-hand axis, °C). Note: 2022 CPR data are provisional.

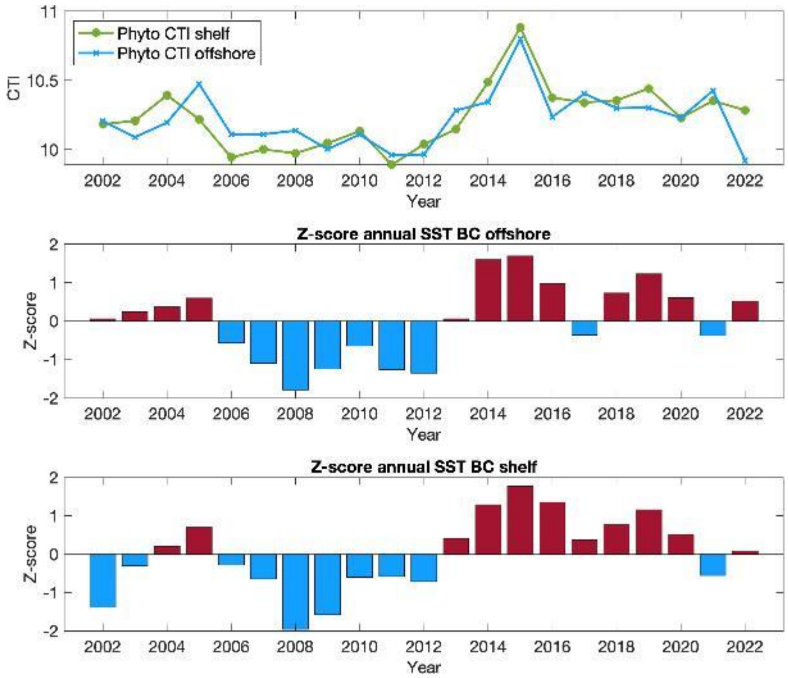

Figure 21-3. The mean annual phytoplankton Community Temperature Index for each region (top subplot) and the annual standardized z-score for Sea Surface Temperature in the offshore (middle subplot) and shelf (bottom subplot) region. Note: 2022 CPR data are provisional.

Both offshore and shelf regions show similar trends in phytoplankton CTI which correlate with observed SST; warmer communities in the early-2000s, cooler communities in the 2006 to 2013 period before reaching a maximum in 2015 (Figure 21-3) and a warm period following. The phytoplankton CTI values for the offshore region in 2022 are lower than they have been since 2012, whereas the shelf region have a phytoplankton CTI that is still elevated and similar to recent warm years.

21.4.2. Zooplankton

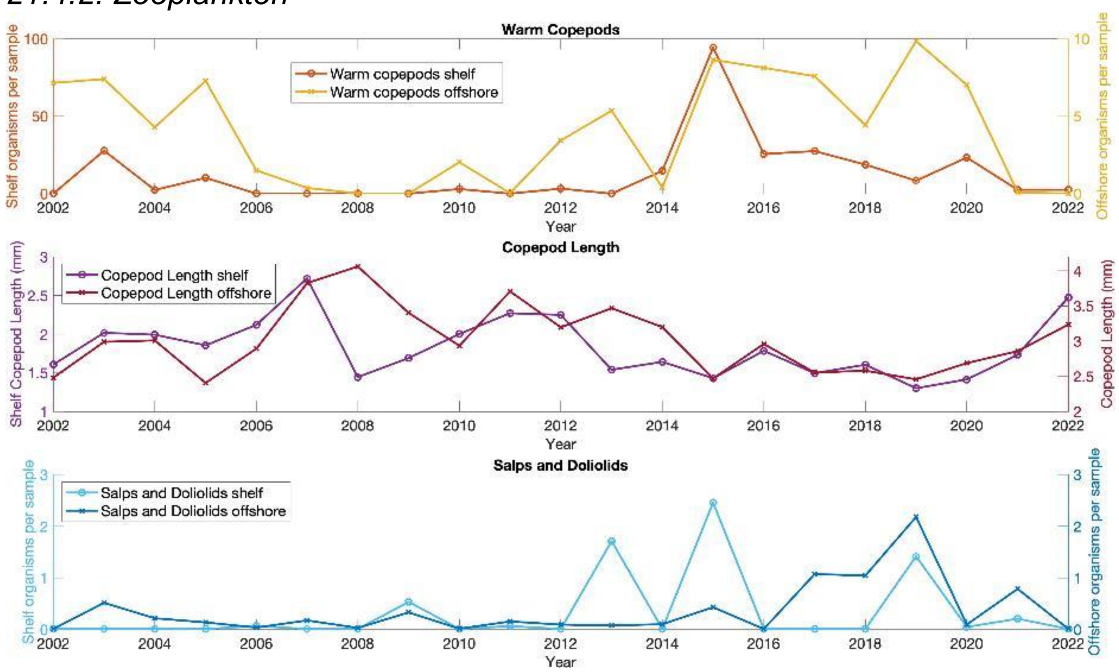

Figure 21-4. The mean annual abundance of warm water copepods (top), copepod length (middle), and salp and doliolid abundance (bottom) for both the shelf (left axis) and offshore (right axis) regions of B.C. Note: The CPR only captures small or fragments of salps and doliolids. Note: 2022 data are provisional.

The numbers of copepods typically associated with warm waters were low and the mean size of copepods increased in both regions in 2022 (Figure 21-4). Numbers of salps and doliolids (gelatinous plankton) also decreased in 2022 in both regions.

21.5. Factors Influencing the trends

In 2022, ocean temperatures in both the shelf and offshore regions around B.C. were higher than the mean, 2002-2022 (Figure 21-3), however the plankton communities appeared to be returning to average values following the marine heatwaves of 2014-2016 (DiLorenzo and Mantua 2016) and 2019 (Amaya et al. 2020). The phytoplankton associated with warmer waters were lower in abundance in the offshore region, reducing the community temperature index there relative to the shelf region (Figure 21-3), and the copepods associated with warmer waters were lower in numbers in both regions in 2022 (Figure 21-4). Anomalously warm surface waters can increase stratification thereby reducing nutrient availability. Lower nutrients can affect the phytoplankton composition by promoting growth of smaller and narrower cells because of a relatively larger surface area over which to absorb nutrients. In turn, the size and composition of the phytoplankton will impact the zooplankton that are able to feed on them, and so the effects pass up the food chain.

21.6. Implication of these trends

Warmer waters favour certain (often smaller) taxa over others, as seen by the fact that warmer water taxa are more prevalent and there are higher CTI values during warm years. Such communities may apparently persist for several years after a heatwave event, especially if waters remain warm, however it appears that after 8 years of warmer than average conditions, the plankton recorded in 2022 were returning to more typical sub-arctic/temperate communities. The return of average values of large copepod abundance on the shelf and offshore regions could influence food web functioning, since these copepods store more lipids to overwinter. While we cannot be certain how changing taxonomic composition of the prey affects predators via nutritional contributions to their diet, there could be some benefits of plankton communities returning to average.

21.7. References

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22. SURVEYS FOR OLYMPIA OYSTERS (*OSTREA LURIDA* CARPENTER, 1864) AT SIX INDEX SITES IN BRITISH COLUMBIA, 2010-2022

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22.1. Highlights

- Relative abundance of Olympia Oysters has remained stable at most index sites between 2010 and 2022.
- Density trends varied between the east and west coast of Vancouver Island. Density in 2022 was lower than in 2021 at sites in Barkley Sound while density remained stable at east coast sites.
- Extreme heat events, such as the heat dome of 2021, may have long-term effects on Olympia Oyster survival and reproduction. However, no evidence of decrease in density was observed at east coast index sites in 2022 suggesting that the heat dome did not affect Olympia Oyster survival at these sites in the short term.

22.2. Description of the time series

Thirteen locations around Vancouver Island were chosen as Olympia Oyster index sites in 2009 (DFO 2009). Between 2009 and 2017, each index site was surveyed two to four times (Norgard et al. 2018). The number of index sites was reduced to six in 2018 so that each site could be sampled annually (there are a limited number of very low tides (< 0.2 m) when surveys can occur each year). Annual surveys would more rapidly identify abundance trends and provide a better understanding of population dynamics. The six sites selected are: 1) Swy-a-lana Lagoon, Nanaimo, 2) Transfer Beach, Ladysmith, 3) Joes Bay, Barkley Sound, 4) Hillier Island, Barkley Sound, 5) Harris Point, Barkley Sound, and 6) Port Eliza, Nootka Sound. Each of these sites has been surveyed annually since 2018, except in 2020 when the COVID-19 pandemic halted survey activities. Surveys were conducted during the lowest tides of the month (typically < 0.1 m tides) and took 1-2 days to complete. Olympia Oyster index site surveys followed a stratified two-stage survey design (Gillespie and Kronlund 1999; Norgard et al. 2010) which ensured that sampling was distributed over the entire survey area. Counts of Olympia Oysters were split into two size categories: >15 mm (large) and ≤15 mm (small) since it is difficult to distinguish between Olympia Oysters and Pacific Oysters when they are ≤15 mm shell length.

22.3. Status and trends

Olympia Oyster was designated as a species of Special Concern in 2003 under the *Species at Risk Act* (SARA). A management plan was developed for Olympia Oyster in 2009. One of the objectives of the management plan is to ensure the maintenance of the relative abundance of Olympia Oysters at index sites. Since the start of the time series in 2010, the large size class (> 15 mm) of Olympia Oysters at index sites have shown varying long-term trends (Figure 22-1).

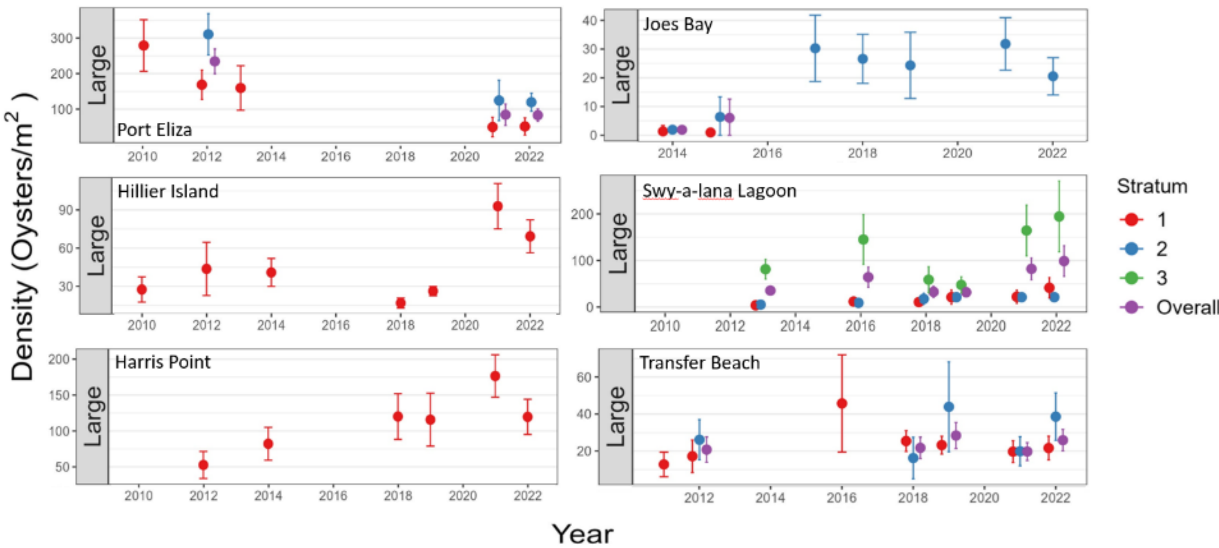

Figure 22-1. Density of large (>15mm shell length) Olympia Oyster, between 2010 and 2022, at index sites located around Vancouver Island (Herder et al. 2022).

Port Eliza, Nootka Sound: Despite high densities overall, the density of Olympia Oysters in the large size class has declined since the start of the time series; from 278.9 ± 73.5 oysters m^{-2} in 2010 to 82.9 ± 17.2 oysters m^{-2} in 2022.

Hillier Island, Barkley Sound: Density of Olympia Oysters generally increased over the time series. In 2010, density of large Olympia Oysters was 27.5 ± 9.7 oysters m^{-2}. Density increased to 43.7 ± 20.5 oysters m^{-2} in 2012, decreased to 16.9 ± 3.9 oysters m^{-2} by 2018 and increased again to 93.0 ± 17.6 oysters m^{-2} in 2021, the highest in the time series. In 2022, density declined to 69.3 ± 12.7 oysters m^{-2}.

Harris Point, Barkley Sound: Density of Olympia Oysters (large size class) increased steadily from 52.7 ± 18.4 oysters m^{-2} in 2012 to 176.6 ± 28.9 oysters m^{-2} in 2021 (highest value of the time series). In 2022, density declined to 119.7 ± 24.0. In 2010 small and large Olympia Oysters were not distinguished from each other, however, density of the small and large size classes combined was 47.0 ± 10.9 oysters m^{-2}.

Joes Bay, Barkley Sound: Only results from Stratum 2 are discussed (Stratum 1 is very small and was only surveyed in 2014 and 2015). Density of large Olympia Oysters in Stratum 2 increased from 1.9 ± 1.2 Olympia Oysters m^{-2} in 2014 to 30.3 ± 11.3 Olympia Oysters m^{-2} in 2017. Density has remained relatively stable since 2017. Density was highest in the time series in 2021 (31.8 ± 9.0 oysters m^{-2}). In 2022, density declined to 20.5 ± 6.4 oysters m^{-2}.

Swy-a-lana Lagoon, Nanaimo: Small and large Olympia Oysters were not distinguished in 2010. Between 2013 and 2021 density of large Olympia Oysters fluctuated. In 2013, density was 35.3 ± 8.4 oysters m^{-2}. Density increased, decreased and increased again to 98.7 ± 32.1 oysters m^{-2} in 2022; the highest value in the time series.

Transfer Beach, Ladysmith: Density of large Olympia Oysters remained fairly constant at this site over the time series, with density ranging between a low of 19.8 ± 4.7 oysters m^{-2} in 2021 and a high of 28.4 ± 6.9 oysters m^{-2} in 2019. Density in 2022 also fell within this range at 25.9

oysters m^{-2} observed (in 2011 and 2016 only one stratum was surveyed so these data were not included in the density range reported here).

22.4. Factors influencing trends

Location and size of survey strata at some sites were inconsistent in the early years (e.g. Port Eliza, Joes Bay, Transfer Beach), the number of strata surveyed at some sites varied from year to year with some strata being dropped from the sampling plans, and gaps of several years between surveys at some sites makes interpretation of trends difficult. The data from 2018 onward followed a consistent sampling design and should allow us to determine trends of abundance over time more reliably. Found in the low intertidal zone, Olympia Oyster survival and reproduction is affected by extreme fluctuations in temperature (DFO 2009). The heat dome of June 2021 occurred when the lowest tides of the year occurred in the afternoon which led to long exposures of oysters out of the water at the time of day when the heat was most intense. The heat dome did not appear to affect Olympia Oyster survival at sites in the Strait of Georgia as no declines in density of Olympia Oyster were observed at Swy-a-lana Lagoon or Transfer Beach in 2022. Swy-a-lana Lagoon is a unique site in that oysters are found in terraced pools and are never out of the water. Olympia Oysters at this site would have been less impacted by the heat dome compared to the Transfer Beach site. On the west coast of Vancouver Island, it is less clear whether the heat dome affected oyster densities. Olympia Oyster density declined at sites in Barkley Sound but in 2021 they were surveyed after the heat dome. However, Olympia Oyster density at Port Eliza remained similar in 2021 and 2022 but Port Eliza was surveyed before the heat dome.

22.5. Implications of those trends

Olympia Oyster density varied across Vancouver Island as did density trends, suggesting that different factors may influence populations dynamics at each index site. In 2010, Port Eliza had the highest density of all sites in the time series (278.9 ± 73.5 oysters m^{-2}). Despite a large decrease in density since 2010, Port Eliza remains a relatively high-density site. Density at the three sites located in Barkley Sound declined slightly in 2022 after showing their highest respective densities in 2021. Density at the two sites in the Strait of Georgia has remained relatively stable over the time series. These results suggest that the management objective of maintaining density at the index sites is being achieved.

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

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23.1. Highlights

- In 2022, the Fraser River Eulachon egg and larval survey index of spawning stock biomass was low (~10 tonnes), at a level comparable to the lowest estimates in the time series since 1995.
- Mean Eulachon catch per unit effort estimates from an annual spring west coast of Vancouver Island multispecies bottom trawl survey in 2022 had moderately high estimates of catch weight per unit effort (similar to 2021 observations) and a reduction in estimated numbers of Eulachon catch per unit effort from 2021, especially for smaller Eulachon (up to 12.5 cm standard length).

23.2. Description of indices

Indices of Eulachon (*Thaleichthys pacificus)* used to monitor population dynamics over time are based on:

1) An annual springtime Fraser River Eulachon egg and larval survey (1995 to 2022) 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, 2021-2022) and in the Queen Charlotte Sound (QCS, 1998-2012, 2016),
3) In-river catches of spawning Eulachon from past commercial fishing in the Fraser River (1900-2004), in the Columbia River (1888-2010 and 2014-2015), and from standardized gillnet surveys in the Fraser River (1995-2004 and; 2017-2022; not reported here).

23.3. Status and trends

Long-term declines of spawning Eulachon have been observed in many rivers throughout their distribution from California to Alaska in the past 2-4 decades. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed Eulachon in B.C. as three designatable unit (DUs) populations in 2011. The Fraser River and Central Pacific Coast DUs were assessed as endangered, and the Nass/Skeena DU was assessed as a species of special concern (COSEWIC 2011, 2013).

Eulachon is an important First Nations fishery resource and in-river Eulachon Food, Social and Ceremonial fisheries have occurred in years up until and including 2022 (DFO 2022). Commercial fishing for Eulachon has been closed since 2004 but there was an active commercial fishery for Eulachon in the Fraser River for over 90 years until a closure in 1997, followed by temporary openings in 2002 and 2004 (DFO 2022).

In 2022, the index of Eulachon spawning stock biomass in the Fraser River was estimated to be low (~10 tonnes), comparable to the lowest estimates in the Fraser Eulachon egg and larval survey time series since 1995, such as for years 2004-2011, 2016 and 2017 (Figure 23-1).

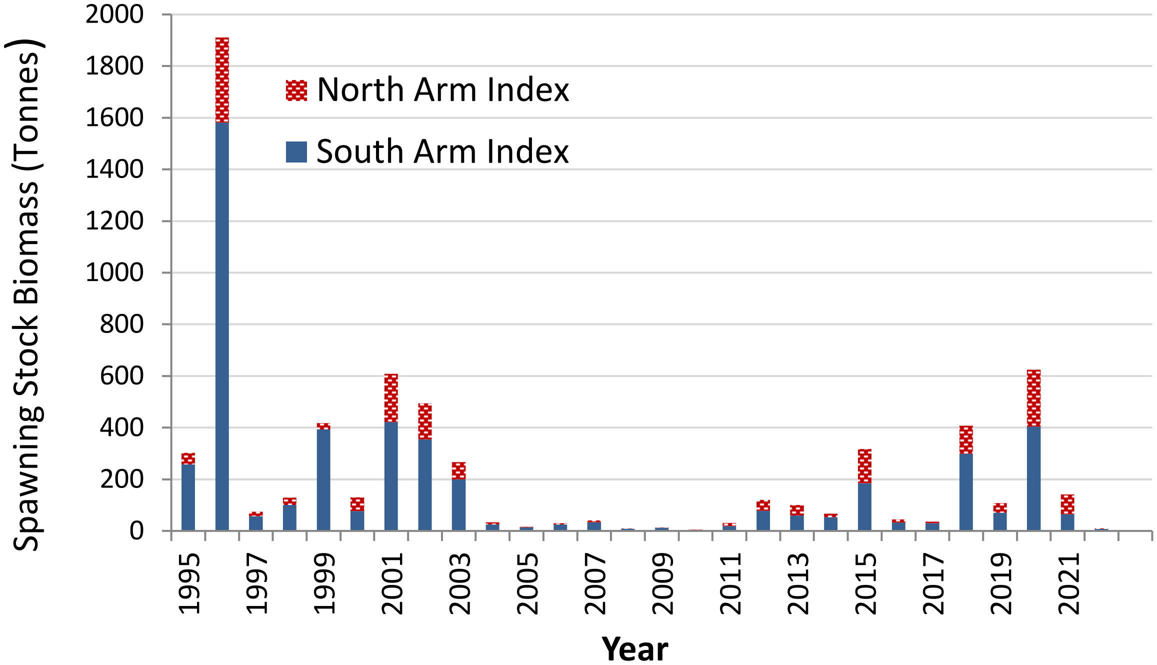

Figure 23-1. Estimated spawning stock biomass indices (SSB in tonnes) of Eulachon from the South and North Arms of the Fraser River, 1995-2022.

In 2022, mean Eulachon catch per unit effort (CPUE) observations from the spring WCVI multispecies trawl survey showed moderately high estimates of catch weight per unit effort (similar to 2021 observations) and a reduction in estimated numbers of Eulachon catch per unit effort from 2021, especially for smaller Eulachon (up to 12.5 cm standard length; Figure 23-2).

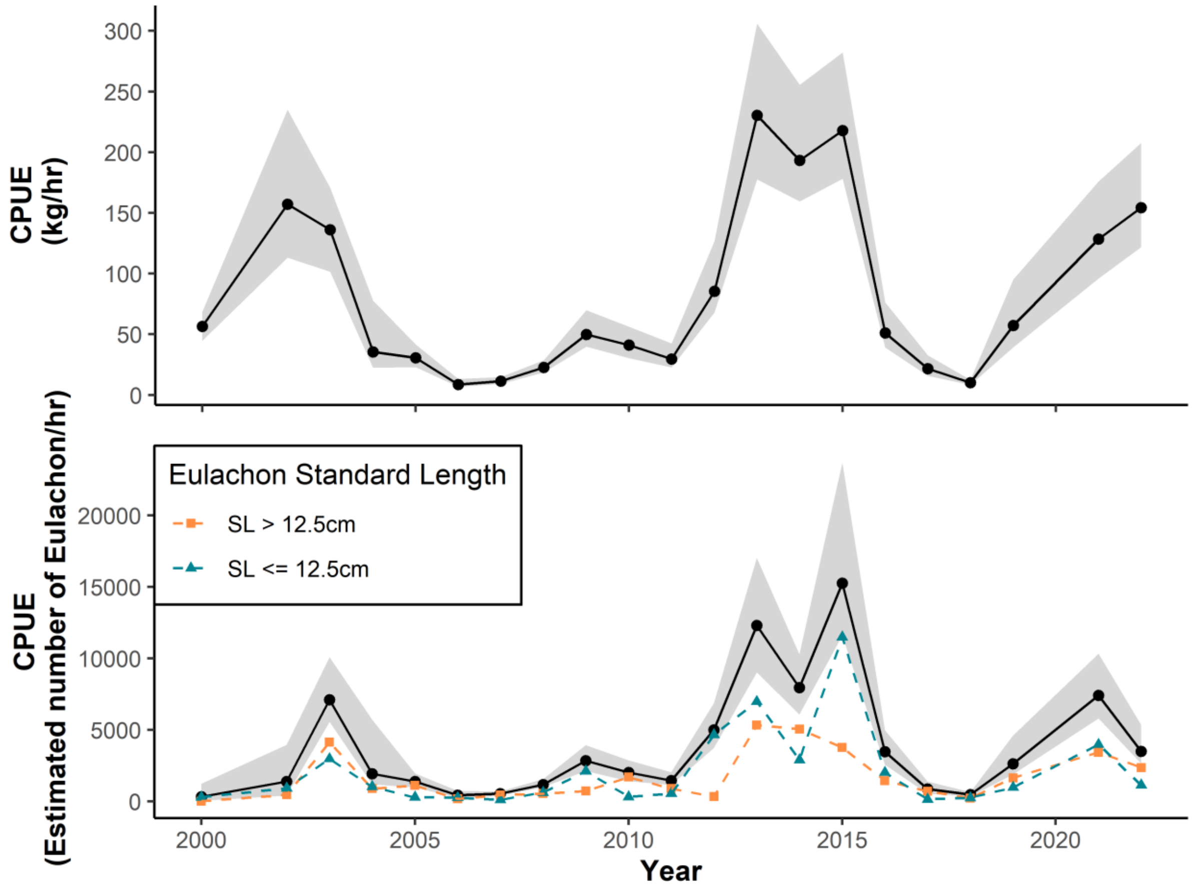

Figure 23-2. Eulachon mean CPUE from spring WCVI multispecies trawl surveys (2000- 2022, no survey in 2020) and 95% studentized bootstrap confidence intervals (gray envelopes), as catch weight per trawl tow duration (kg/hour, top panel) and number of fish per tow duration (bottom panel). Dashed lines represent mean catch number per unit effort of Eulachon greater than 12.5 cm standard length (orange) or less than or equal to 12.5 cm standard length (blue).

In 2022, Eulachon standard length observations from the spring WCVI multispecies trawl survey appeared to have a bi-modal distribution with peaks within the ranges of 7-10 cm and 13-17 cm but the relative amount of smaller fish was lower than in 2021 (Figure 23-3). Annual Eulachon standard length frequency distributions are represented in two ways. One way shows statistically unweighted standard length frequency histograms (Figure 23-3, right panel) where fish length observations were pooled across all fishing events (therefore each fish specimen observation has equal statistical weight). The other way shows standard length frequency histograms where samples of fish length observations were statistically weighted by the estimated total number of Eulachon caught in each fishing event and standardized by the fishing duration (in hours) of each fishing event (Figure 23-3, left panel). The weighting method resulted in reducing the number of fish under 5 cm observed in the 2022 sampling efforts.

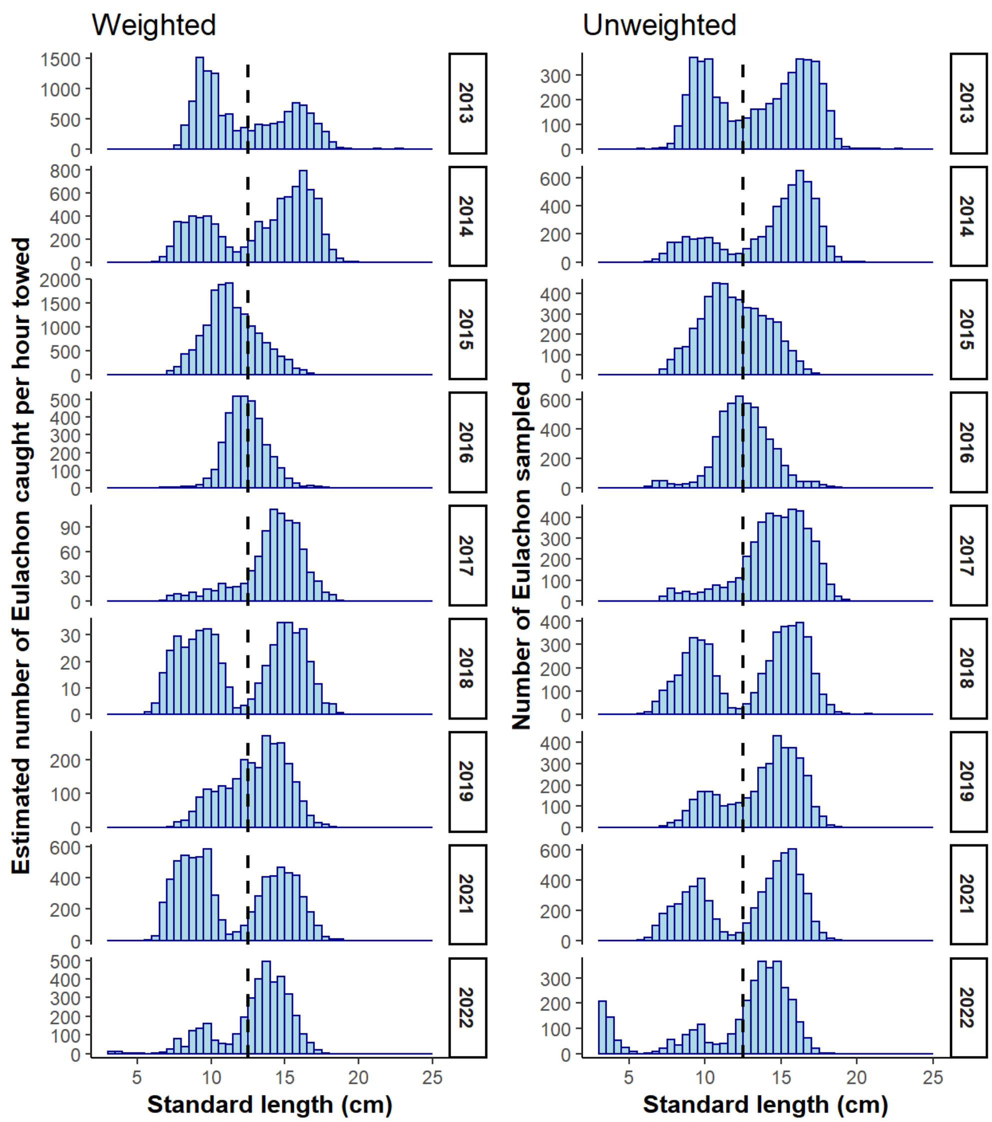

Figure 23-3. Eulachon standard length frequency histograms (in cm) from 2013-2022 WCVI survey samples, from statistically weighting by the estimated total number of Eulachon caught in each fishing event and standardizing by the fishing duration (left panel) and from pooling sample data by year (right panel). Dashed vertical lines are visual markers at 12.5 cm to assist comparisons between positions and shapes of length distributions.

23.4. Factors causing those trends

There is considerable uncertainty associated with the ecology and stock dynamics of Eulachon. The reasons for the large interannual variation in Fraser Eulachon spawner index observations in recent years is not well understood. The low 2022 index was not anticipated, especially given the moderately high marine WCVI CPUE trends in 2021 and 2022 and that Eulachon abundance trends for the Columbia River had 2022 as one of the highest levels over the last 20 years. It is uncertain what age range and composition comprise the Fraser Eulachon spawning stock each year and to what degree spawning stocks and cohorts may mix and be under metapopulation influences. It is generally believed that most Eulachon die after spawning but there is some evidence to suggest that some individuals (especially females) may repeat spawn (Dealy and Hodes 2019).

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

23.5. Implications of those trends

Reduced biomass of Eulachon has negative implications for First Nations, commercial and recreational fishers. Eulachon are socially and culturally significant to many First Nations who have been harvesting Eulachon at low levels. Commercial and recreational fisheries targeting Eulachon have been closed for over a decade (DFO 2022). Incidental capture of Eulachon in the marine environment has negative implications on trawl fisheries targeting other species, as trawl fisheries may be subject to area closures or reduced fishing effort to reduce Eulachon mortality.

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

23.6. References

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24. PACIFIC HERRING IN BRITISH COLUMBIA, 2022

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24.1. Highlights

- In recent years, following a declining trend from approximately 1980 to 2010, weight-at-age for all B.C. stocks of Pacific Herring have either remained unchanged or have increased.
- Total B.C. coastwide spawning biomass summed across the 5 major stocks has been increasing since 2010. The estimated herring spawning biomass varied among the assessed stocks with more than 50% of the total biomass of herring in B.C. occurring in the Strait of Georgia (SOG).

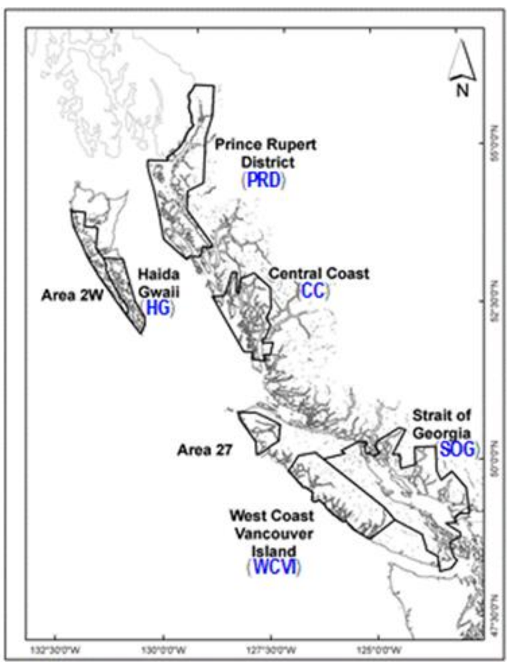

Figure 24-1. Location of the five major (Strait of Georgia, West Coast of Vancouver Island, Prince Rupert District, Haida Gwaii, and Central Coast) as well as two minor (Area 2W, and Area 27) Pacific Herring stocks in B.C.

24.2. Summary

In B.C., Pacific Herring are managed as five major stocks (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 2022; Figure 24-1). For each stock, herring population trends are based on stock-specific model estimates of 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 (DFO 2022).

24.3. Status and trends

In all five major herring stocks there was a declining trend in weight-at-age from the 1980s through to 2010, with a leveling off or increase in recent years (Figure 24-2). Since 2000, the HG stock has been in a low biomass state and below the limit reference point (LRP) for most years between 2000-2017, with a small increase in 2020 and 2021 (DFO 2022). The estimated stock biomass for PRD is above the LRP and increased in 2019-2022. The CC survey biomass is above the LRP and shows an increasing trend from 2015-2020, however it declined in 2021 and 2022. The SOG spawning biomass varies extensively over the time series and is estimated to have been above the LRP in all years since 2010. Biomass decreased in 2021 but remains above the LRP and is still relatively high compared to historic estimates (Figure 24-3). WCVI stock biomass has slowly increased since 2012 and is currently above the LRP (DFO 2021; Figure 24-3).

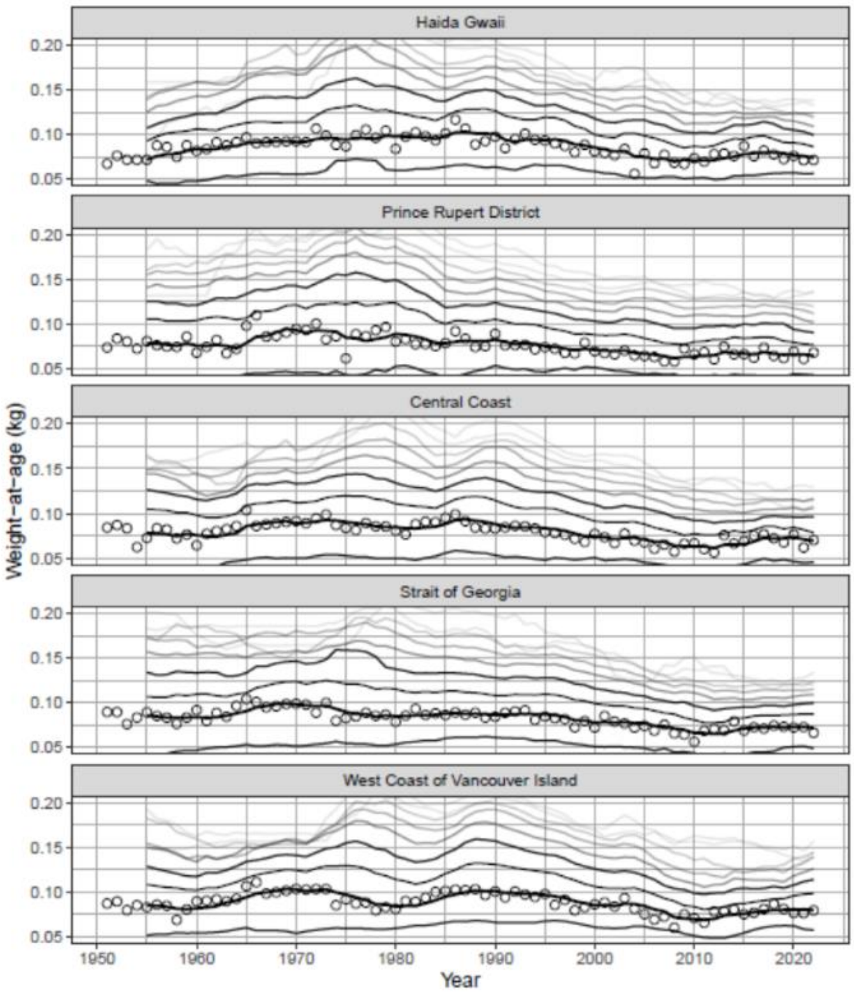

Figure 24-2. Observed weight-at-age 3 (circles) and five-year running mean weight-at-age 3 (dark line) for major Pacific Herring stocks, 1951 to 2022. Thinner black lines represent five-year running mean weight-at-age 2 (lowest) and ages 4-10+ (incrementing higher from age 3). Figure from DFO (2022).

24.4. Factors influencing trends in herring biomass

Common trends in herring weight-at-age observed for all B.C. stocks suggests that large-scale factors may be influencing herring growth. 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).

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 results in the presence of California current waters off the WCVI and may bring southern zooplankton species that have a lower energetic value, creating poorer feeding conditions for herring (Schweigert et al. 2010; Mackas et al. 2004).

There are a wide variety of herring predators, including Pacific Hake, Lingcod, Spiny Dogfish, Pacific Cod, Sablefish, Arrowtooth Flounder, Pacific Halibut, Steller Sea Lions, Northern Fur Seals, Harbour Seals, California Sea Lions, and Humpback Whales (Schweigert et al. 2010). Herring – predator interactions have been studied off of the WCVI, where the abundance of most marine mammal predators has increased (Olesiuk 2010; DFO 2021; Wright et al. 2021). 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).

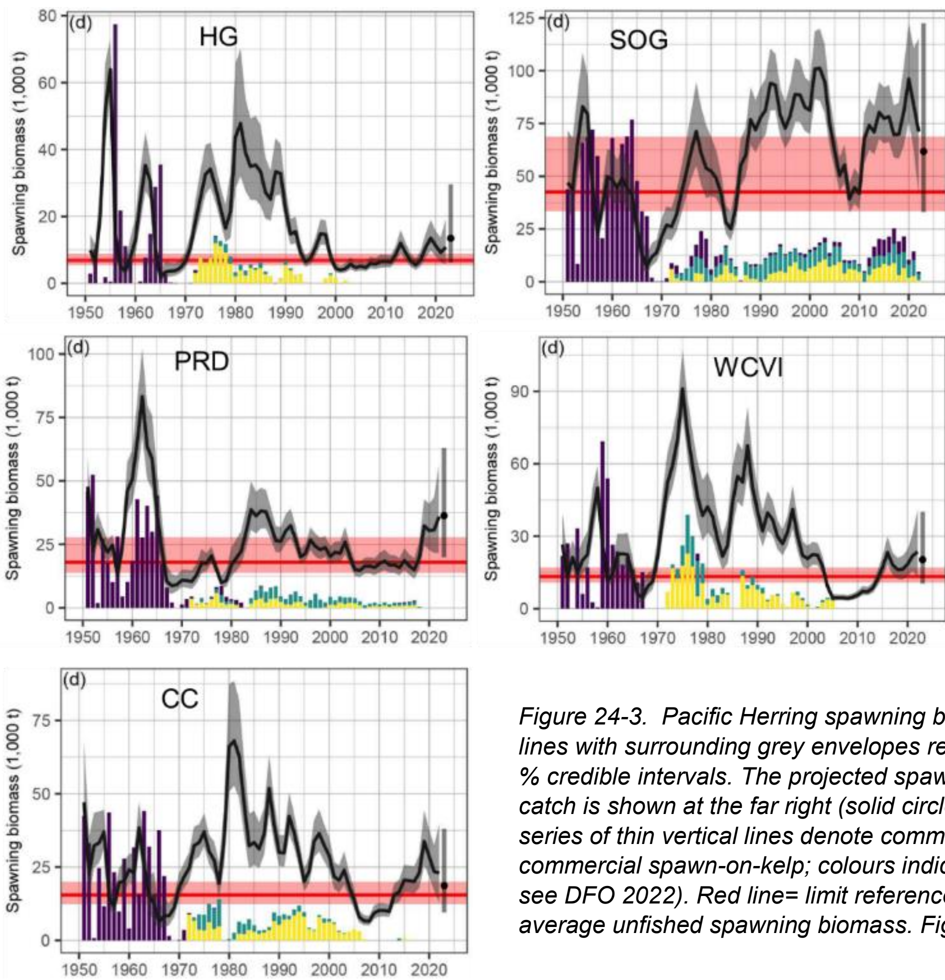

Figure 24-3. Pacific Herring spawning biomass, 1951- 2022. Black lines with surrounding grey envelopes represent medians and 5-95 % credible intervals. The projected spawning biomass given zero catch is shown at the far right (solid circle and vertical lines). Time series of thin vertical lines denote commercial catch (excluding commercial spawn-on-kelp; colours indicate different gear types; see DFO 2022). Red line= limit reference point ($0.3B_0$). B_0 = average unfished spawning biomass. Figure from DFO (2022).

24.5. Implications of trends

Trends in herring biomass have implications for both fisheries and predators. Pacific Herring are an important component of commercial fisheries in B.C. Harvest options (total allowable catch, TAC) considered by Fisheries Management reflect application of simulation tested management procedures (MP) to one-year forecasts of herring biomass. All TAC options reflect MPs that meet the conservation objective of avoiding the LRP with a minimum 75% probability.

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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25. PACIFIC HERRING SUMMER DISTRIBUTION AND ABUNDANCE OFF THE VANCOUVER ISLAND CONTINENTAL SHELF

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25.1. Highlights

- In July 2022, Pacific Herring biomass off the west coast of Vancouver Island was the highest in the time series (2006-2022).
- In July 2022, Pacific Herring were generally higher in all survey areas along the west coast of Vancouver Island compared to most other years in the time series.

25.2. Description of the time series

The Integrated Pelagic Ecosystem Science (IPES) 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 (see King et al. 2019; Boldt et al. 2020). The survey was conducted during July 5-31, 2022. The 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). This is a random stratified trawl survey with 8 strata defined by depth and biological communities. A subset of blocks was randomly selected (allocated by strata sizes). Midwater trawl nets were used to sample fish (2017: CanTrawl 250; 2018-present: LFS 7742; see Anderson et al. 2019) at randomly assigned depths (0 or 15 m). Catch per unit effort (CPUE) was estimated as species' catch weights divided by swept volume (product of net mouth opening height, width, and distance towed). Herring biomass was estimated using a spatio-temporal model (Anderson et al. 2022) that combined IPES data with historic night-pelagics survey data (see Flostrand et al. 2014), while accounting for important variables, such as daytime or nighttime trawl sets and gear depth.

25.3. Status and trends

As seen in previous years Pacific Herring were the species most frequently caught during 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. CPUE was roughly twice as high in nighttime tows as daytime tows and highest near the surface as expected given their diel behaviour (Figure 25-1). In 2022, herring biomass was the highest in the time series (with a high variance estimate) (Figure 25-1). Areas of highest CPUE were located off the southwest coast of Vancouver Island. However, CPUE was generally higher along most of the west coast of Vancouver Island survey area in 2022 compared to most other years in the time series (Figure 25-1). In 2022, the total estimated biomass of Pacific Herring was 241,126 t.

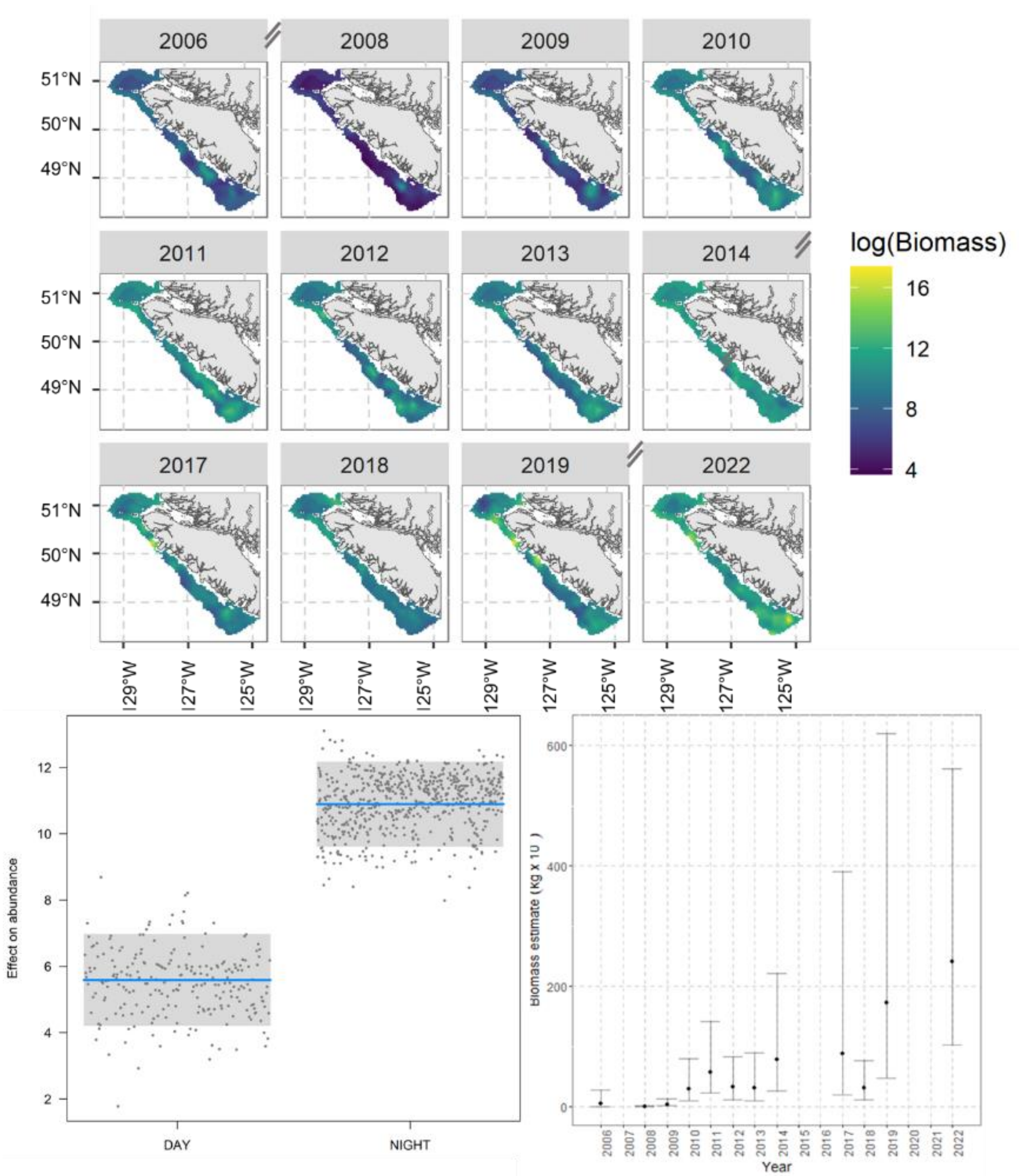

Figure 25-1. Pacific Herring biomass, as estimated with a spatio-temporal model, in the night pelagics (2006-2014) and Integrated Pelagic Ecosystem Science surveys (2017-2022) (top panel), effect of day vs night on abundance estimates (bottom, left panel), and total biomass estimates, 2006-2022 (bottom, right panel).

25.4. 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, types, and quality of prey available. For example, a northerly current direction could bring warm-water, low-lipid copepods to the west coast of Vancouver Island, 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). At the margins of Pacific Hake and Pacific Herring distributions, consumption of Pacific Herring by Pacific Hake may be high (Ware & McFarlane 1986; 1995). In areas where Pacific Hake densities are high, Pacific Herring may have to trade off predation risk against finding prey (e.g., euphausiids; Godefroid et al. 2019).

25.5. 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 are driven by spring egg dive surveys to estimate spawning stock biomass; however, stock assessments 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 include 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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26. 2022 JUVENILE SALMON SURVEYS ON THE CONTINTENTAL SHELF OF VANCOUVER ISLAND

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26.1. Highlights

- Chum and Pink Salmon were the dominant juvenile salmon species encountered in summer and fall.
- Chum Salmon relative abundance in summer and fall were below average. Summer juvenile Chum Salmon are usually dominated by west coast Vancouver Island stocks (summer) and by Strait of Georgia stocks (fall) returning in 2025. The juvenile Chum Salmon in fall were in better condition than usual.
- Pink Salmon relative abundance in fall was above average; these salmon will return to spawn in 2023. These juvenile salmon, and those caught in summer, were in better condition than usual.
- Sockeye Salmon relative abundance in summer and fall was below average. These juvenile salmon are typically dominated by west coast Vancouver Island (summer) and Strait of Georgia (fall) stocks returning in 2024.
- Chinook Salmon relative abundance in fall was above average, and these fish are usually dominated by west coast Vancouver Island stocks ocean-type cycles that will return in 2025.
- Coho Salmon in fall were in better condition than usual; these fish originate from southern B.C. and Puget Sound and will return in 2023.

26.2. Description of the time series

Summer Integrated Pelagic Ecosystem Survey on the continental shelf of Vancouver Island

Since 1998, daytime juvenile salmon surveys have been conducted on the continental shelf of the northern and western coast of Vancouver Island (WCVI) during summer, typically late-June to early-August. For 1998-2016 surveys, tows were conducted at headrope depths of surface, 15 m or 30 m using mid-water trawl gear (CanTrawl 250) along standard transects that sometimes extended from coastal inlets to beyond the shelf-break. In 2017, the survey design was switched to a stratified, random design (King et al. 2019) which continued in 2018 (July 5-29). The survey area was portioned into 8 strata based on depth contours (50-100 m; 100-200 m) and known biological communities. Each strata was gridded into 4 x 4 km blocks, from which a random set of blocks were selected in proportion to the relative area of each strata to the whole survey area. Since 2017, each tow location is fished in day and again at night. Fishing was conducted with the same historical trawl gear in 2017 and with a replacement mid-water trawl net (LFS 7742) in 2018. In 2022, trawling was limited to headrope depths of surface and 15 m. Gear calibration between the historic CanTrawl 250 and the replacement LFS 7742 nets indicate that catch-per-unit effort (CPUE) calculated with swept volume (km^3) are comparable (Anderson et al. 2019).

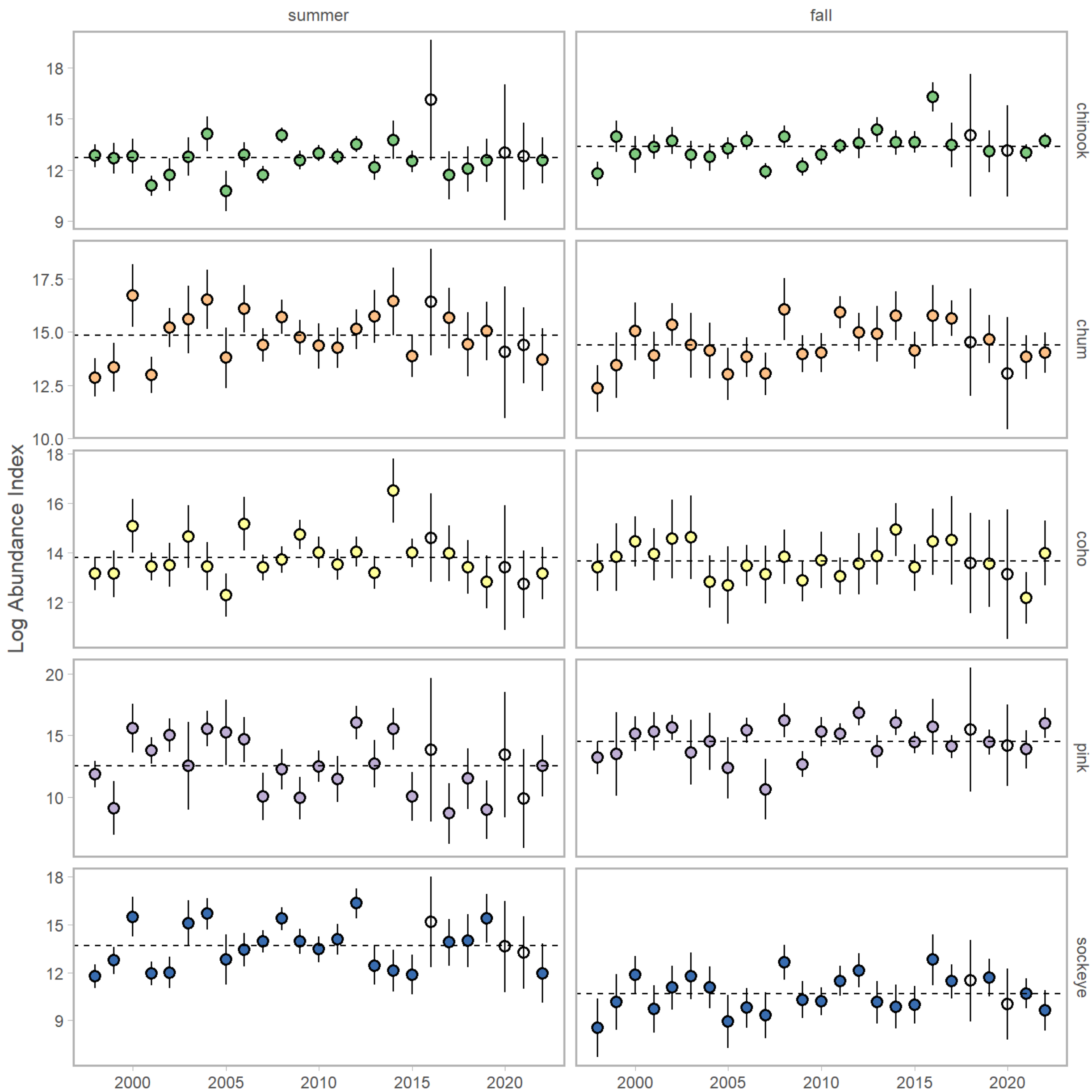

Figure 26.1. Annual (log) Abundance Index estimated from geostatistical models for juvenile Chinook, Chum, Coho, Pink and Sockeye Salmon caught in summer on the continental shelf of Vancouver Island and in fall on the continental shelf and inlets of Vancouver Island. Open circles denote years without a survey in that season; index values for missing years estimated from both annual autocorrelation and the other season if available. See Freshwater et al. (in press) for estimation methods.

<u>Fall Juvenile Salmon Survey on the continental shelf and inlets of Vancouver Island</u>

Fall surveys for juvenile salmon have also been conducted on the continental shelf, and inlets of Vancouver Island since 1998, albeit more intermittently. Tows are conducted at standard stations along the coast and within inlets. Similar trawl gear to summer surveys was used. In 2022, daytime trawling was randomly conducted at headrope depths of surface and 15 m.

For both survey time series, changes in survey design as well as survey timing and location, along with factors such as headrope depth, or time of day for fishing have impacts on the estimation of relative abundance indices, such as catch per unit effort. We now estimate an Abundance Index from geostatistical models that account for changes in survey locations, and includes impacts such as sample timing, headrope depth, diurnal vs. nocturnal sampling, and changes in summer survey design (Freshwater et al. in press). Length and weight data were used to estimate species-specific length-weight regressions across years with annual weight residuals presented to represent condition.

26.3. Status and trends

Relative abundance

The Abundance Indices (log) derived from seasonal and species-specific geostatistical models (Figure 26-1) indicate Chum and Pink Salmon were the most abundant species encountered in both summer and fall. The 95% confidence intervals associated with the 2022 Abundance Index for summer caught Sockeye Salmon were below average; those for summer and fall caught Chum Salmon were also below average, but the intervals marginally included the average values (Figure 26-1). Conversely, fall caught Chinook Salmon and Pink Salmon were above average (Figure 26-1). All other Abundance Indices were close to average (Figure 26-1).

Condition

The 2022 summer median and quartile ranges of weight residuals for Coho Salmon were above average (Figure 26-2). Similarly in fall, the median weight residuals for Chum Salmon and Pink Salmon were also above average, but the lower quartile range marginally includes zero (Figure 26-2). While the residuals for Sockeye Salmon in summer were well below average, too few samples were collected these results should not be considered.

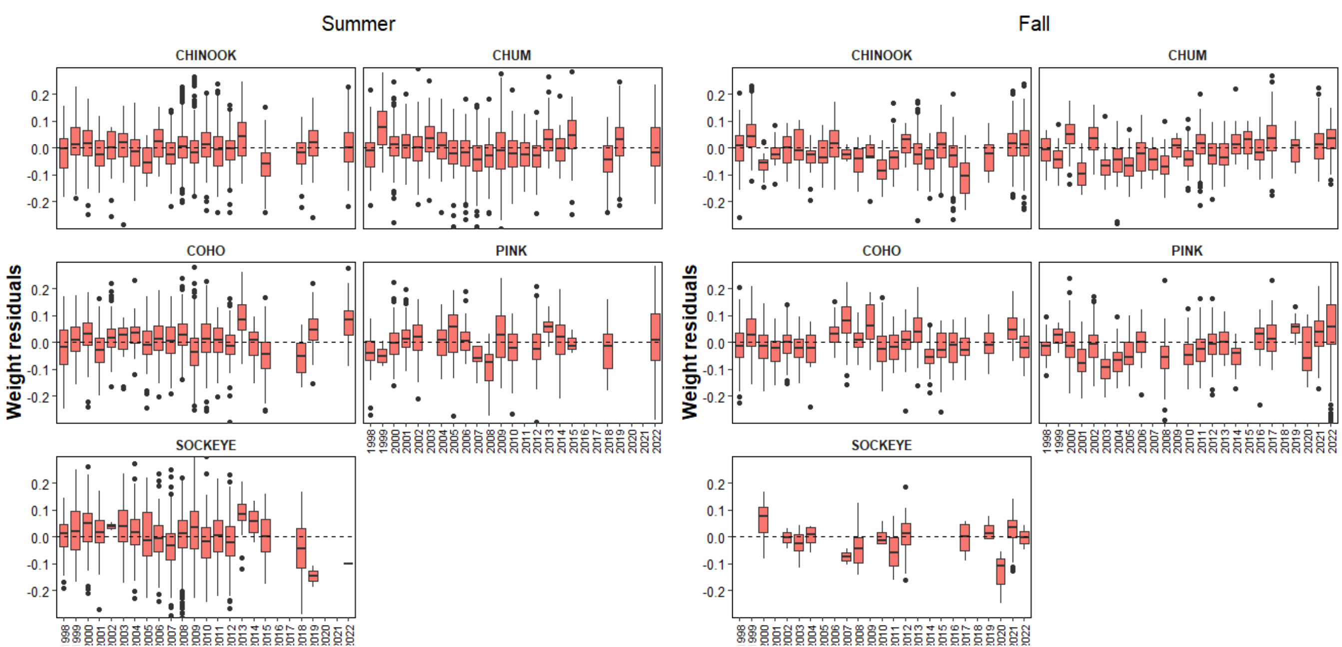

Figure 26-2. Box plots of weight residuals calculated from species-specific length-weight regressions (all years and seasons combined) for juvenile Chinook, Chum, Coho, Pink and Sockeye Salmon caught in summer on the continental shelf of Vancouver Island in fall on the continental shelf and inlets of Vancouver Island.

26.4. 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. Prey quality and availability can also influence condition. In 2022, summer Coho Salmon and fall Pink Salmon were fatter than normal and both species' diets had large proportions of crabs and euphausiids. Chum Salmon however did not consume large proportions of these prey items, highlighting that other factors such as size-selective mortality (i.e. smaller, skinnier fish) may influence condition trends.

26.5. Implications of those trends

The juvenile Pacific salmon encountered in these surveys will return to spawn at varying times, but generally these Abundance Indices and condition apply to: Coho and Pink Salmon returning in 2023; stream-type Chinook and Sockeye Salmon returning in 2024; and ocean-type Chinook, Chum and Harrison Sockeye Salmon returning in 2025. Genetic stock identification from previous surveys provide general indication of regional origins of the salmon encountered. The continued below average Abundance Index in summer and fall for Chum Salmon apply predominately to west coast Vancouver Island stocks (summer) and Strait of Georgia stocks (fall) returning in 2025. The below average Abundance Index in summer and fall for Sockeye Salmon apply predominately to west coast Vancouver Island stocks (summer) and Strait of Georgia stocks (fall) returning in 2024. The above average Chinook salmon fall Abundance Index most likely apply to west coast Vancouver Island stocks ocean-type cycles that will return in 2025. There are insufficient genetic stock identification results from previous surveys to indicate the dominant region of origin for Pink Salmon encountered in fall.

26.6. References

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27. STATE OF CANADIAN PACIFIC SALMON IN 2022

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27.1. Highlights

- Many Canadian populations of Pacific salmon have exhibited significant declines in abundance, coinciding with global climate change responses in freshwater and marine ecosystems.
- Chinook Salmon returns in 2022 continued their trend of low abundances in many areas, with exceptions (examples: WCVI hatchery returns, ECVI Fall returns).
- Sockeye Salmon returns in 2022 were strong in several areas (example: Skeena, Nass, Northern Transboundary, WCVI), but were below average for the Fraser Sockeye aggregate.
- Even-year Pink Salmon returns in 2022 were average to above average in northern B.C. and on the east coast of Vancouver Island, and below average on the central coast and mainland inlets.
- Chum Salmon returns in 2022 were generally poor to extremely poor with some exceptions: Nass Chum, enhanced Bella Coola Chum, and lower Strait of Georgia.
- Coho Salmon returns to many systems in 2022 were near average, while others were mixed.

27.2. Description of the Canadian Pacific salmon time series

Catch data are available up to 2021 for the five Pacific salmon species managed by DFO (Sockeye, Chinook, Coho, Pink and Chum; NPAFC: https://npafc.org/statistics/).

Most information on returning abundances of Pacific salmon in 2022 is available only in qualitative form at the time of this report. Qualitative input on 2022 returns was provided through DFO staff.

Wild Salmon Policy (WSP) rapid statuses are available for 69 Pacific salmon Conservation Units (CUs), within DFO's Pacific Salmon Status Scanner (The Scanner), an interactive data visualization tool for salmon experts (Pestal et al. 2023a, 2023b). The WSP rapid status approach uses an algorithm and expert review process to approximate the results of labour-intensive WSP integrated status assessments (Holt 2009; Holt et al. 2009; Grant et al. 2011, 2020; Grant and Pestal 2012; DFO 2015, 2016; Brown et al. in press; Pestal et al. 2023b, 2023a). Briefly, to generate WSP rapid statuses, escapement data up to 2019 were obtained from DFO Stock Assessment biologists (see Pestal et al. 2023b, 2023a). Processing steps, including data quality filtering, site selection, and infilling, were applied to escapement estimates to arrive at a quality-controlled aggregate escapement time series for each CU (Pestal et al. 2023a). In collaboration with species experts, Wild Salmon Policy metrics were calculated for each CU, where appropriate, and the WSP rapid status algorithm was applied to generate WSP rapid statuses (Pestal et al. 2023a).

27.3. Canadian Pacific salmon status and trends

27.3.1. Trends in salmon catch

Aggregated catch of the five DFO-managed Pacific salmon species has declined in recent decades (Figure 27-1). This is due to declines in target salmon population abundances, and constraints placed on mixed-stock fisheries to protect co-migrating salmon populations in poor status (Grant et al. 2019). Low returns from 2019 to 2021 led to extremely low Canadian catch, averaging 2.3 million.

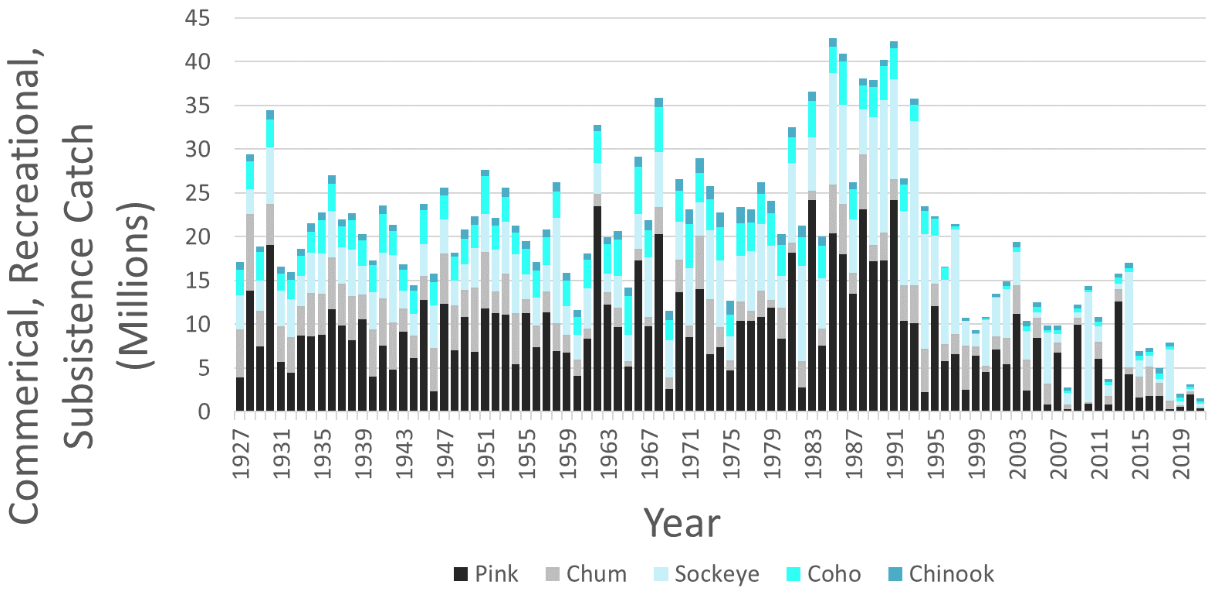

Figure 27-1. Commercial, recreational and Indigenous subsistence catch of Canadian Pink, Chum, Sockeye, Coho and Chinook Salmon (Grant et al. 2019; NPAFC statistics: https://npafc.org/statistics/). Average catch from 1925-1993 was 24.2 million, and from 1994-2014 was 13.4 million. Catch since 2015 has averaged 4.8 million, with the lowest catch on record occurring in 2021 (1.6 million).

27.3.2. Qualitative Canadian Pacific salmon returns in 2022

Chinook Salmon returns in 2022 continued a trend of low abundances in many areas. For example, Yukon River Chinook returns in 2022 were the lowest on record. Some exceptions include west coast Vancouver Island hatchery Chinook, and Fall returns on the east coast of Vancouver Island. Return information for Fraser River Chinook is not yet available, but escapements were average or above average depending on the Stock Management Unit. Sockeye Salmon abundances have generally been declining (Grant et al. 2019; Hyatt et al. 2020). In 2022, Sockeye returns were strong in several areas, including the north coast of B.C. (Skeena/Nass), the Northern Transboundary systems, and the west coast of Vancouver Island. Returns to the Fraser River were below average for the 2022 cycle line due to an extremely low return of the Late Run Stock Management Unit.

Coho Salmon returns to many systems in 2022 were near average, while others were mixed. Returns in the Strait of Georgia were below average in the northern systems and above average for mid-Vancouver Island. Returns are not yet available for Interior Fraser Coho, but preliminary escapement estimates are average to above average.

Even-year Pink Salmon have exhibited declining abundances in some areas, including southern B.C. (Grant et al. 2019). In 2022, Pink returns were above average on the east coast of Vancouver Island and in the Skeena and Nass Rivers. The central coast and mainland Inlets saw below average returns.

Chum Salmon have recently exhibited declines (Grant et al. 2019), though some populations, including Skeena and Nass Chum, began to decline earlier (NPAFC in review; Grant et al. 2019). Chum returns in 2022 were generally poor to extremely poor. There were exceptions, including Nass Chum, enhanced Bella Coola Chum, and some southern populations including southeast Vancouver Island and the Fraser River.

27.3.3. Canadian Pacific salmon statuses and trends using the Pacific Salmon Status Scanner

Red status CUs increased from 19% in 1995 to 47% in 2019 out of all CUs that can be assigned a WSP rapid status in the Scanner (Figure 27-2) (Pestal et al. 2023a). Green status CUs decreased during this timeframe, from 42% in 1995 to 11% in 2019. This pattern is driven by Sockeye and Chinook CUs, which dominate the assessed CUs.

Rapid statuses of more than half of the assessable Fraser Chinook CUs (8 of 15) were relatively stable between 2010 and 2019, though many were in the lowest status zone (Figure 27-3). Four CUs declined in rapid status over time, while the remaining three CUs fluctuated between Amber and Red over the rapid status time series (Figure 27-3). Almost all (13 of 15) of the assessable Fraser Chinook CUs were Red status in the most recently assessed year, 2019.

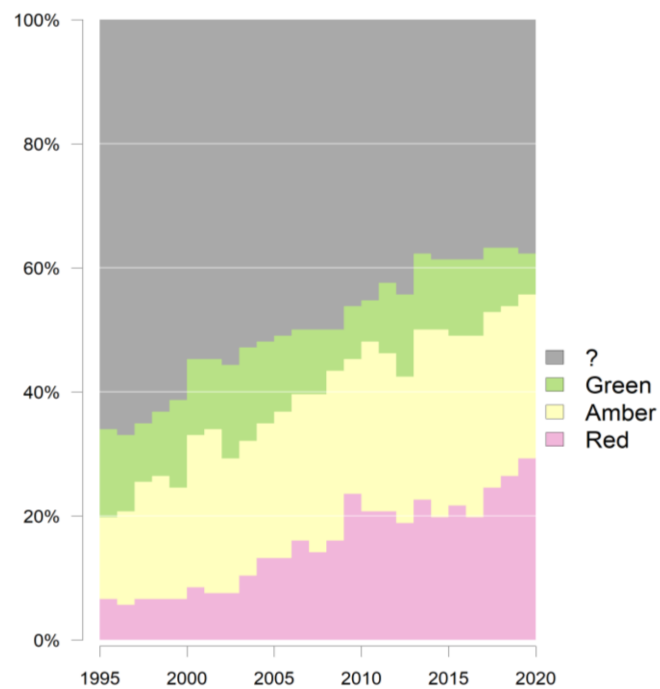

Figure 27-2. Percentage of CUs assigned to each status category in the Pacific Salmon Status Scanner. Current data include Fraser Sockeye, Southern B.C. Chinook (CUs outside the Fraser under review), Interior Fraser Coho, Fraser Chum, Fraser Pink, and preliminary Skeena/Nass Sockeye data (under review). Coloured areas show the annual composition of rapid status results, including data-deficient cases where no status could be assigned (in grey). Figure reproduced from Pestal et al. (2023a).

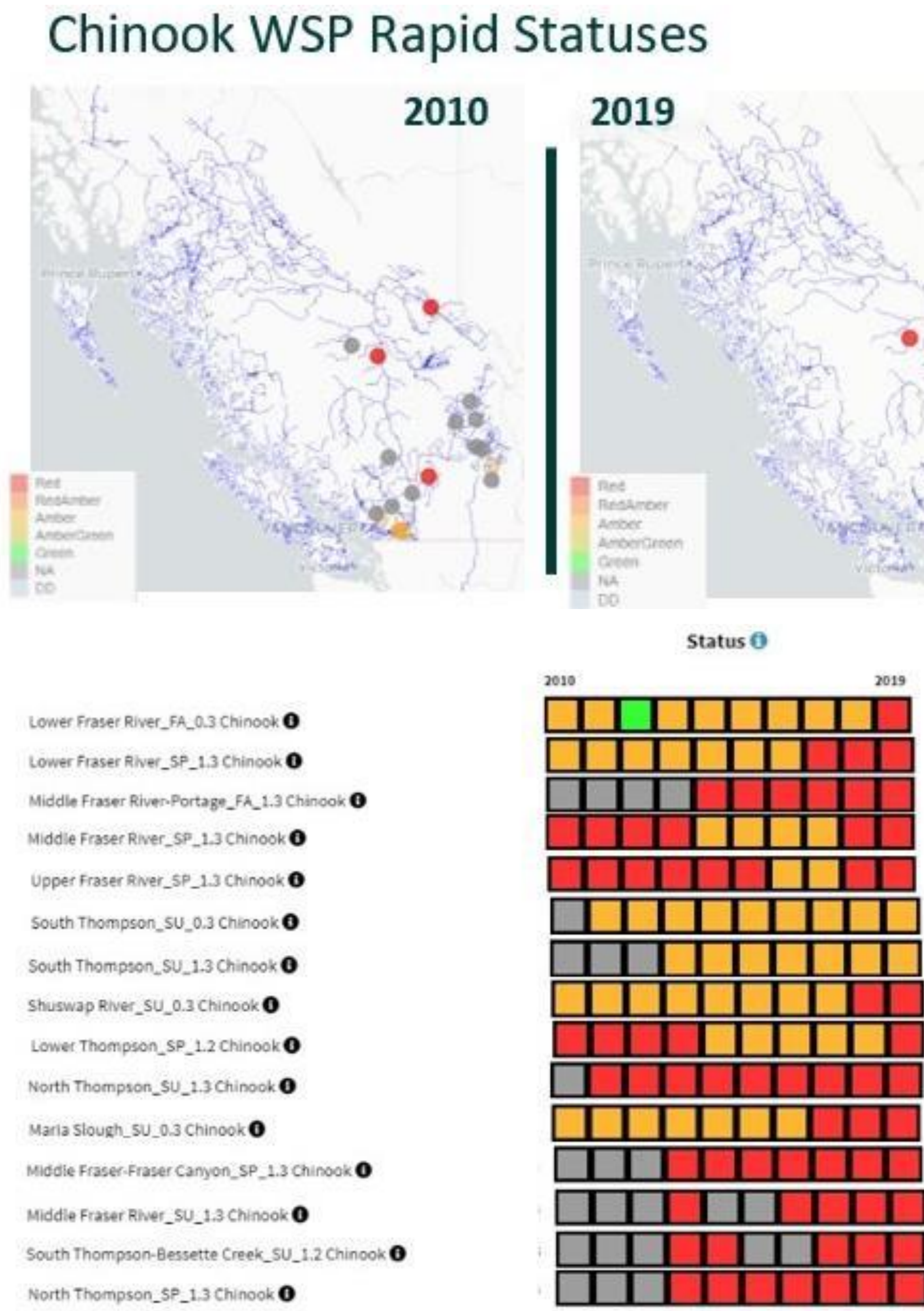

Figure 27-3. WSP rapid statuses of Fraser Chinook CUs in 2010 compared to 2019. Each circle on the maps represents a Fraser Chinook Conservation Unit (CU). Circles are coloured according to the CU rapid status for the indicated year. The accompanying table shows the timeline of rapid statuses for each year between 2010 and 2019 for the CUs labelled.

Almost half of the Fraser Sockeye CUs (10 of 22) were stable between 2010 and 2019, though many stable CUs were in the Red status zone throughout the time period (Figure 27-4). Rapid statuses of seven other CUs deteriorated, while two improved overall. In the most recent year of data (2019), more than half of the assessed CUs were in the Red status zone (12 of 22).

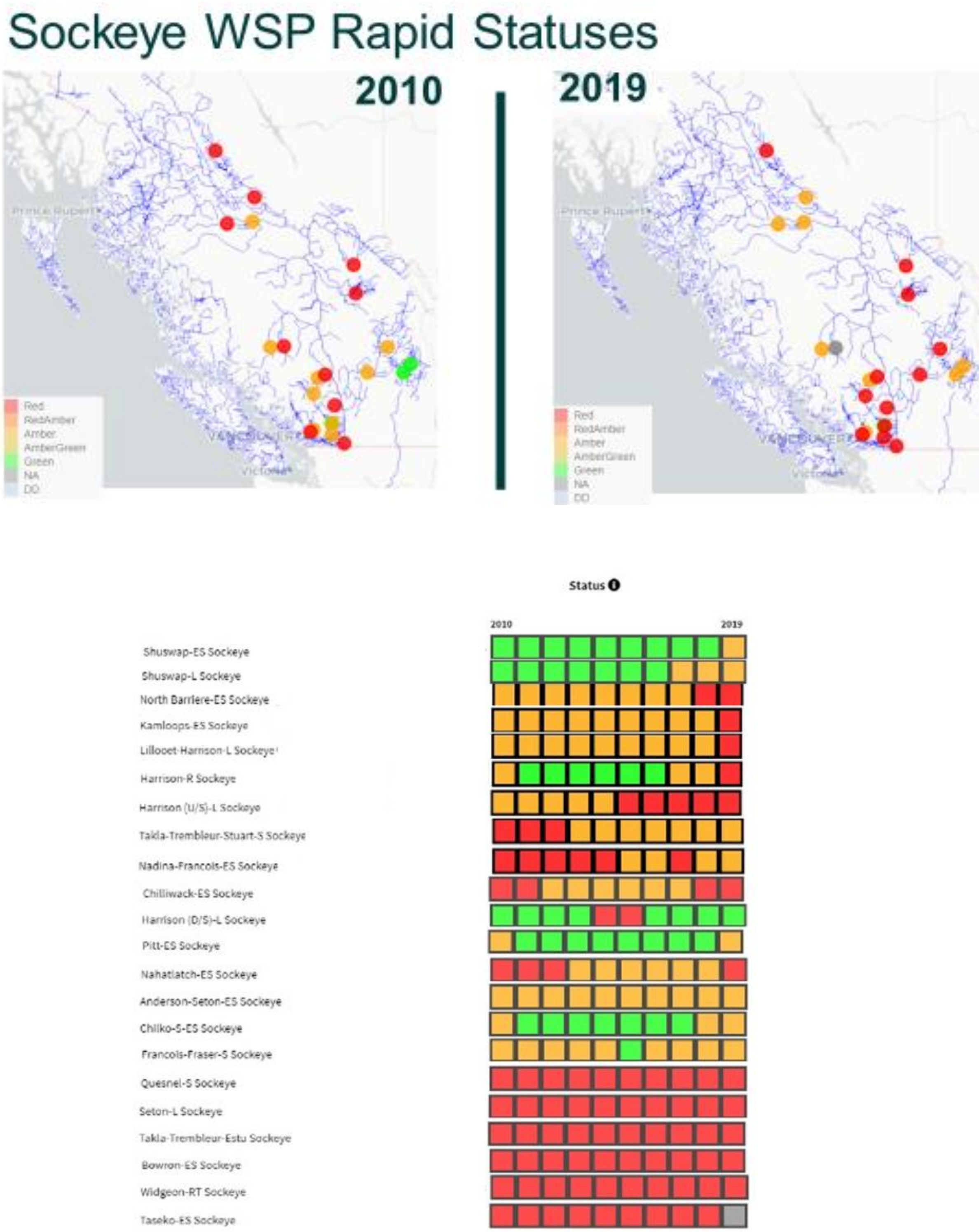

Figure 27-4. WSP rapid statuses of Fraser Sockeye CUs in 2010 compared to 2019. Each circle on the maps represents a Fraser Sockeye Conservation Unit (CU). Circles are coloured according to the CU rapid status for the indicated year. The accompanying table shows the timeline of rapid statuses for each year between 2010 and 2019 for the CUs labelled.

Rapid statuses of four Interior Fraser Coho CUs were relatively stable over time, remaining mostly Amber status. North Thompson Coho was also mostly Amber, though status periodically improved to Green, including in the most recently assessed year (2019).

Fraser Pink Salmon could only be assessed for status in the most recent five cycle years (odd years only). Rapid status of Fraser Pink fluctuated between Amber and Red, and was Amber in the most recently assessed year (2019). Rapid status of Fraser Chum could only be assessed for one year (2019) and was Amber.

27.4. Factors Influencing Pacific Salmon Trends

Canadian Pacific salmon ecosystems are responding to climate and landscape change, and those changes are impacting Pacific salmon throughout their life-cycle (Grant et al. 2019). B.C. and Yukon air and freshwater temperatures are increasing, and precipitation patterns are changing, altering freshwater habitats (Grant et al. 2019). The effects of climate change in freshwater are compounded by natural and human-caused landscape change, which can lead to changes in hydrology, sediment loads, and frequencies of landslides. Warming in the Northeast Pacific Ocean, and marine heatwaves like “The Blob” are affecting ocean food webs. Shifts in zooplankton species composition were observed in waters along the west and north coast of Vancouver Island, and broadly in the NE Pacific during and after “The Blob” (Boldt et al. 2020; Galbraith and Young 2020). Southern zooplankton species, typically centred 1,000 km south of the southern British Columbia coast, dominated lower levels of the salmon food web (Galbraith and Young 2020). Southern species are considered poorer quality food for salmon.

27.5. Implications of those trends

Recent trends in salmon abundances yield a growing, but still incomplete, view of Pacific salmon vulnerability to climate change. Improving that understanding will help us adapt to change, through ensuring that fisheries management, salmon enhancement, and habitat restoration activities are aligned to future salmon production and biodiversity (Nelitz et al. 2007; Hunter and Wade 2015; Hunter et al. 2015; Grant et al. 2019; Crozier et al. 2019, 2021). Continued tracking of salmon statuses and trends as they respond to climate change and other threats is important to support this work. Tracking salmon responses to management actions is also essential. Such tasks can now be facilitated through continued expansion of the Pacific Salmon Status Scanner.

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28. SOCKEYE SALMON INDICATOR POPULATIONS ACROSS B.C.: SMOLT ABUNDANCE, MARINE SURVIVAL AND ADULT RECRUITMENT

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28.1. Highlights

- B.C. Sockeye Salmon smolt abundances were variable but generally close to their long-term averages for most populations.
- Marine survival was generally below or near the long-term average, except for Chilko Lake, which was below average with a long-term negative trend.
- Recruit abundance was variable, but below average for most populations; Francois and Osoyoos Lakes were exceptions in recent years with average to above average returns.

28.2. Time Series – Annual Abundance and Marine Survival of Sockeye Salmon "Indicator Stocks"

The time series' shown were sourced from/produced by various stock assessment programs across B.C., Washington, and Alaska (Figure 28-1). Methods for estimating smolt, pre-smolt, and fry abundances (Figure 28-2) were monitored using a combination of fish fences and hydroacoustic surveys. Recruit abundance (i.e. the number of fish that arrived at the estuary of a given watershed; Figures 28-3 and 28-4) involved summing estimates of harvest (through catch monitoring), spawner escapement (from mark recapture programs, spawner and deadpitch surveys, and fish fences), and upstream migration mortality. Recruit age composition was estimated from scale or otolith analyses, or smolt-to-adult pit-tag recaptures. Marine survival (Figure 28-5) was calculated as the number of recruits from the same smolt year (based on ocean age) divided by the number of juveniles (smolts or fry) on a given smolt year.

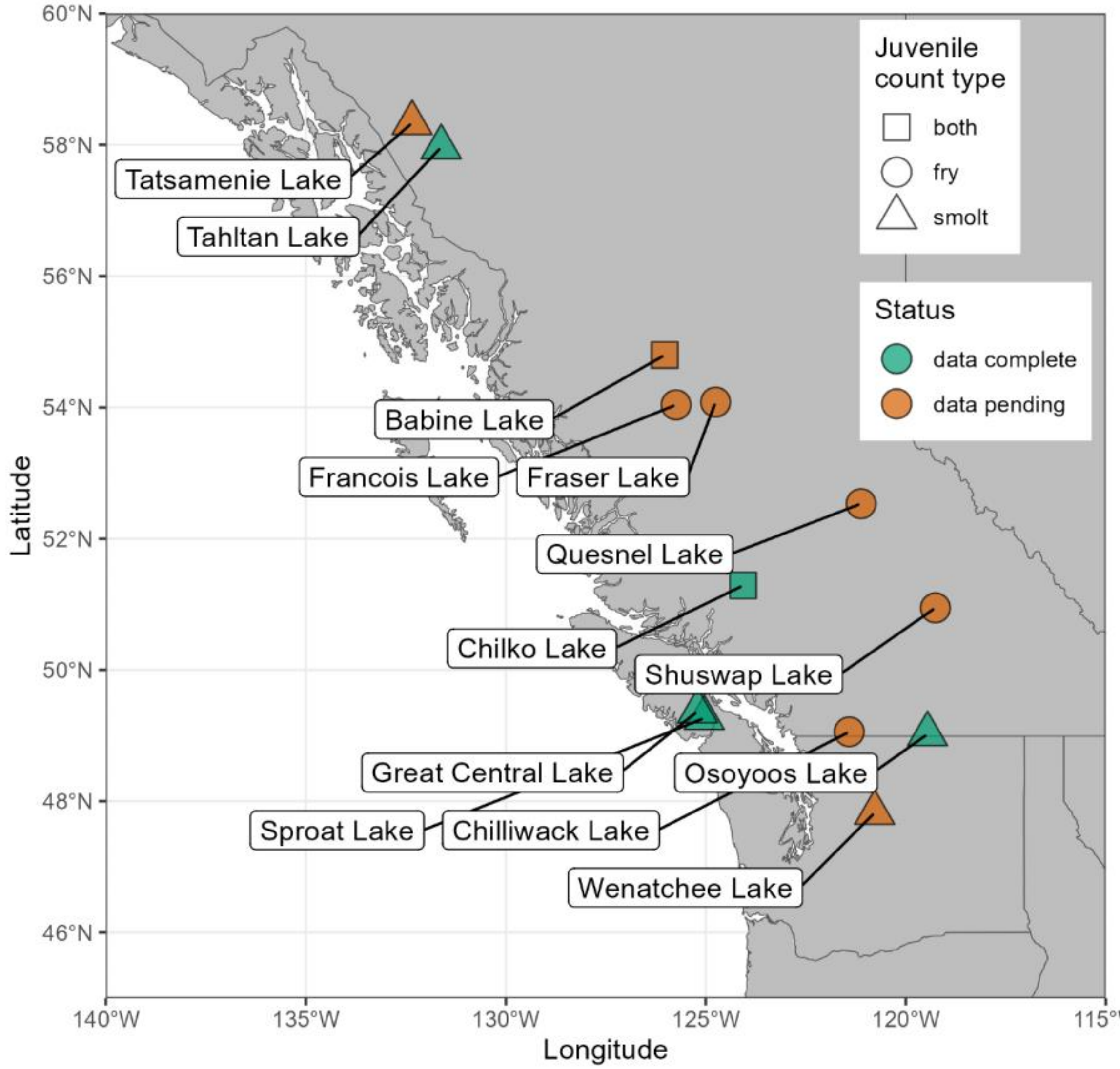

Figure 28-1. Locations, juvenile count type, and general data status (including juveniles and adults) of Sockeye Salmon "indicator populations". Squares represent populations with fry and smolt estimates, circles for fry hydroacoustic surveys only, and triangles for smolt estimates only. Green points indicate datasets that are complete, and orange points indicate data that have either not been received or have been received but require additional QA/QC.

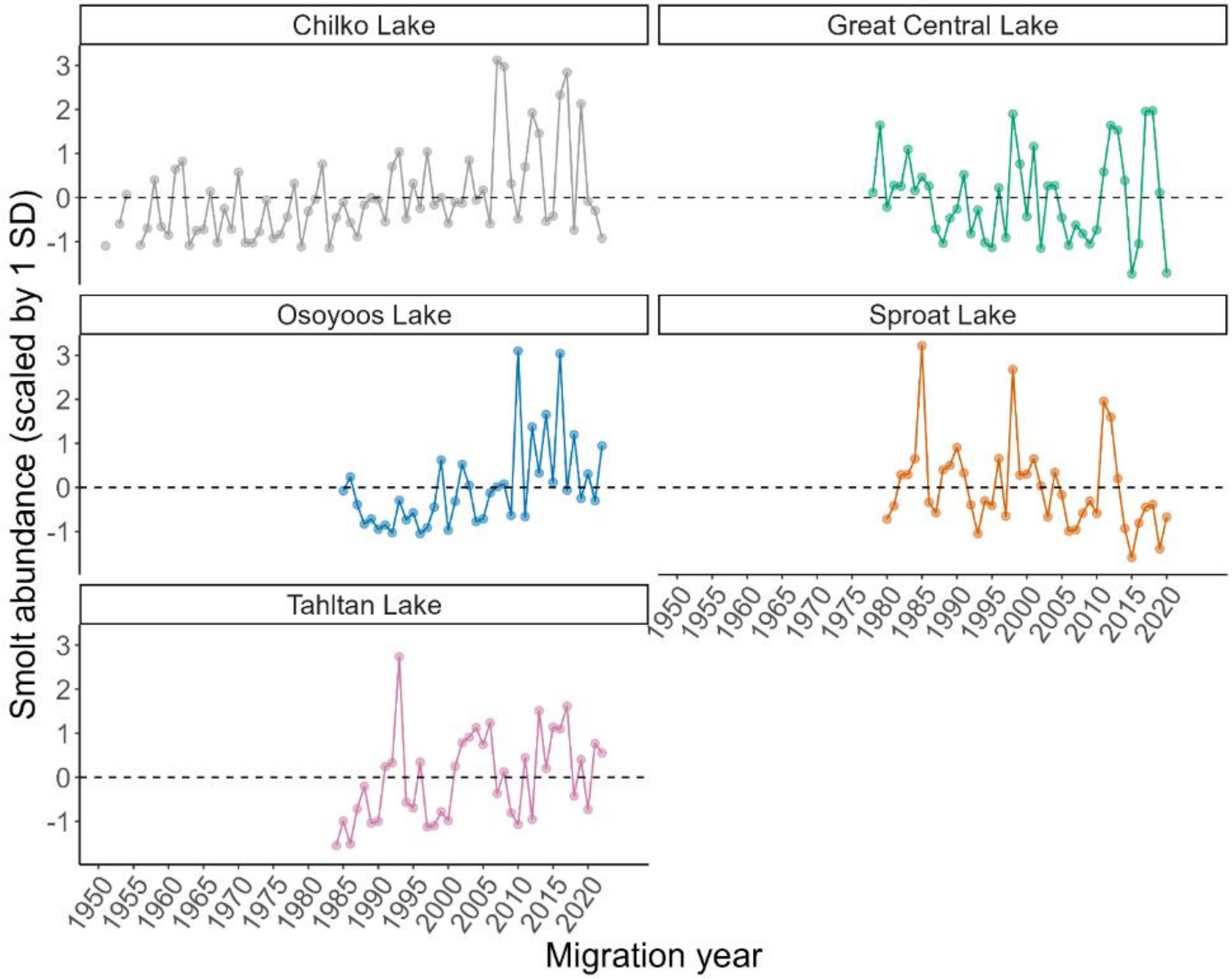

Figure 28-2. Standardized smolt abundance (centred and scaled by 1 SD) for Sockeye Salmon indicator populations with complete datasets (i.e., populations with green points in Figure 28-1). The dashed black lines represent the long-term mean smolt abundance for each population. Smolt abundances were counted using a full river fish fence for Chilko and Tahltan Lakes, while pre-smolt abundance was estimated for Sproat, Great Central, and Osoyoos Lakes using hydroacoustic trawl surveys.

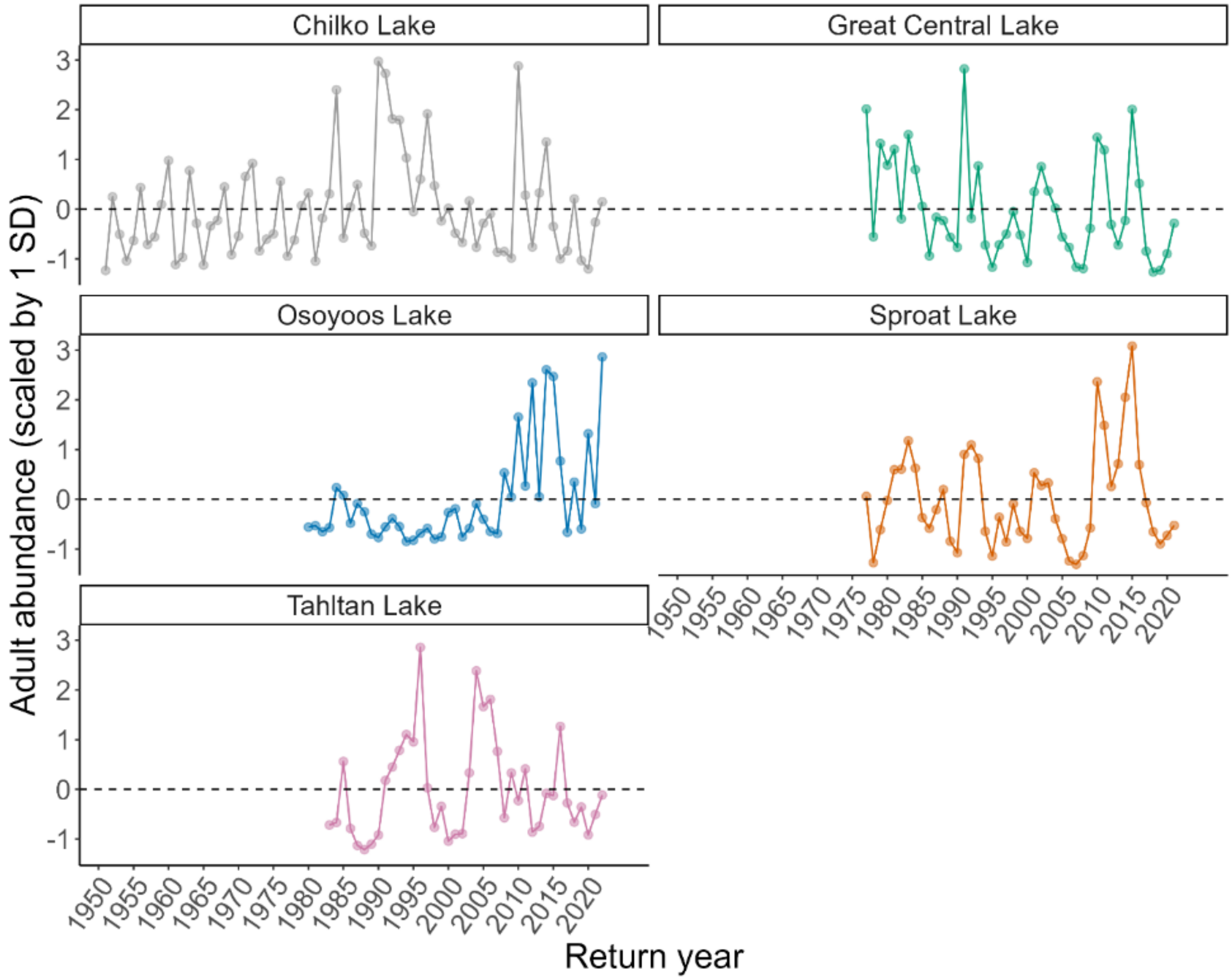

Figure 28-3. Standardized adult recruit abundance (centred and scaled by 1 SD) for Sockeye Salmon indicator populations with complete datasets (i.e., populations with green points in Figure 28-1). The dashed black lines represent the long-term mean adult recruitment abundance for each population.

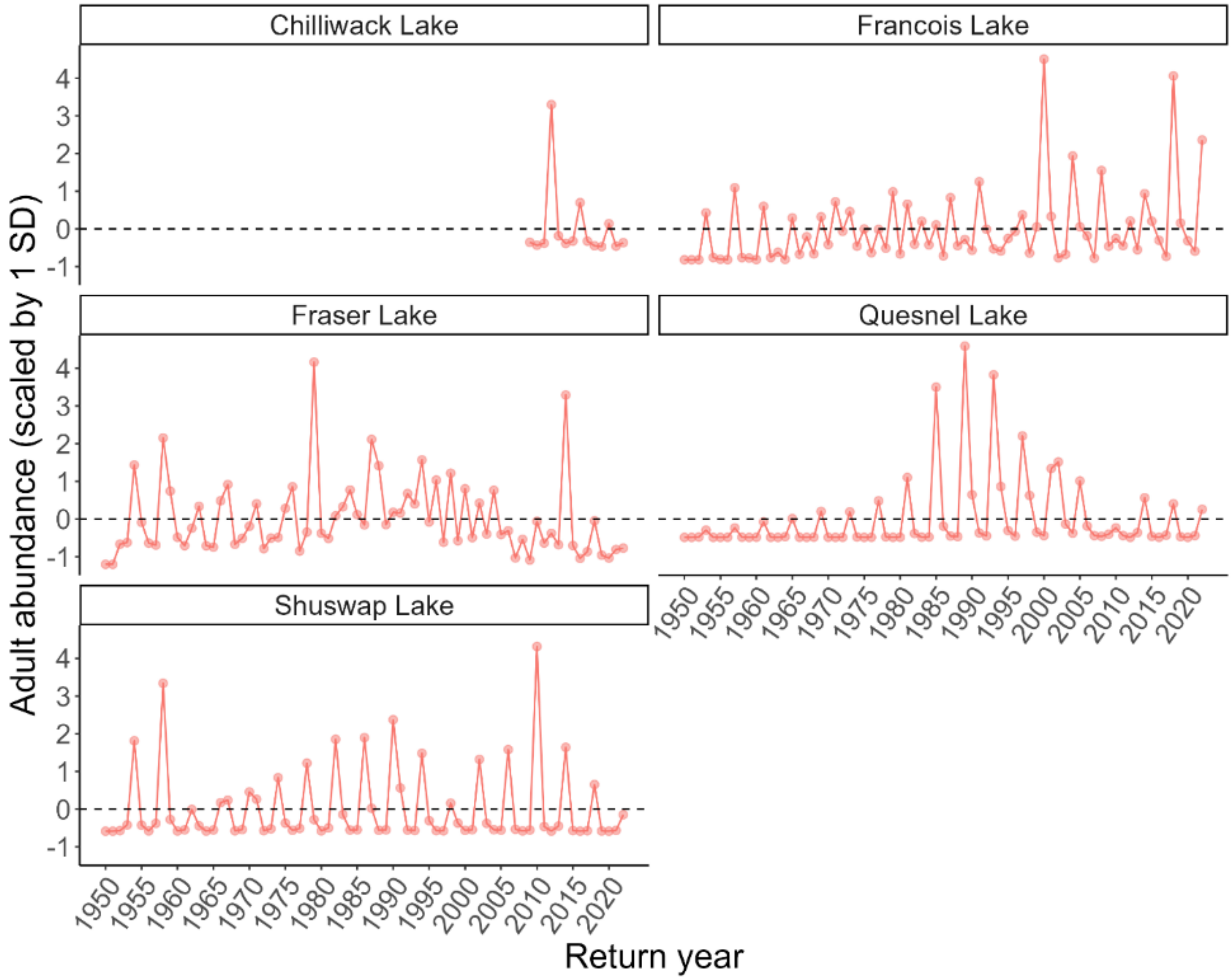

Figure 28-4. Standardized adult recruitment abundance (centred and scaled by 1 SD) for Sockeye Salmon indicator populations with partially complete datasets (i.e., populations with orange points in Figure 28-1). The dashed black lines represent the long-term mean adult recruitment abundance for each population.

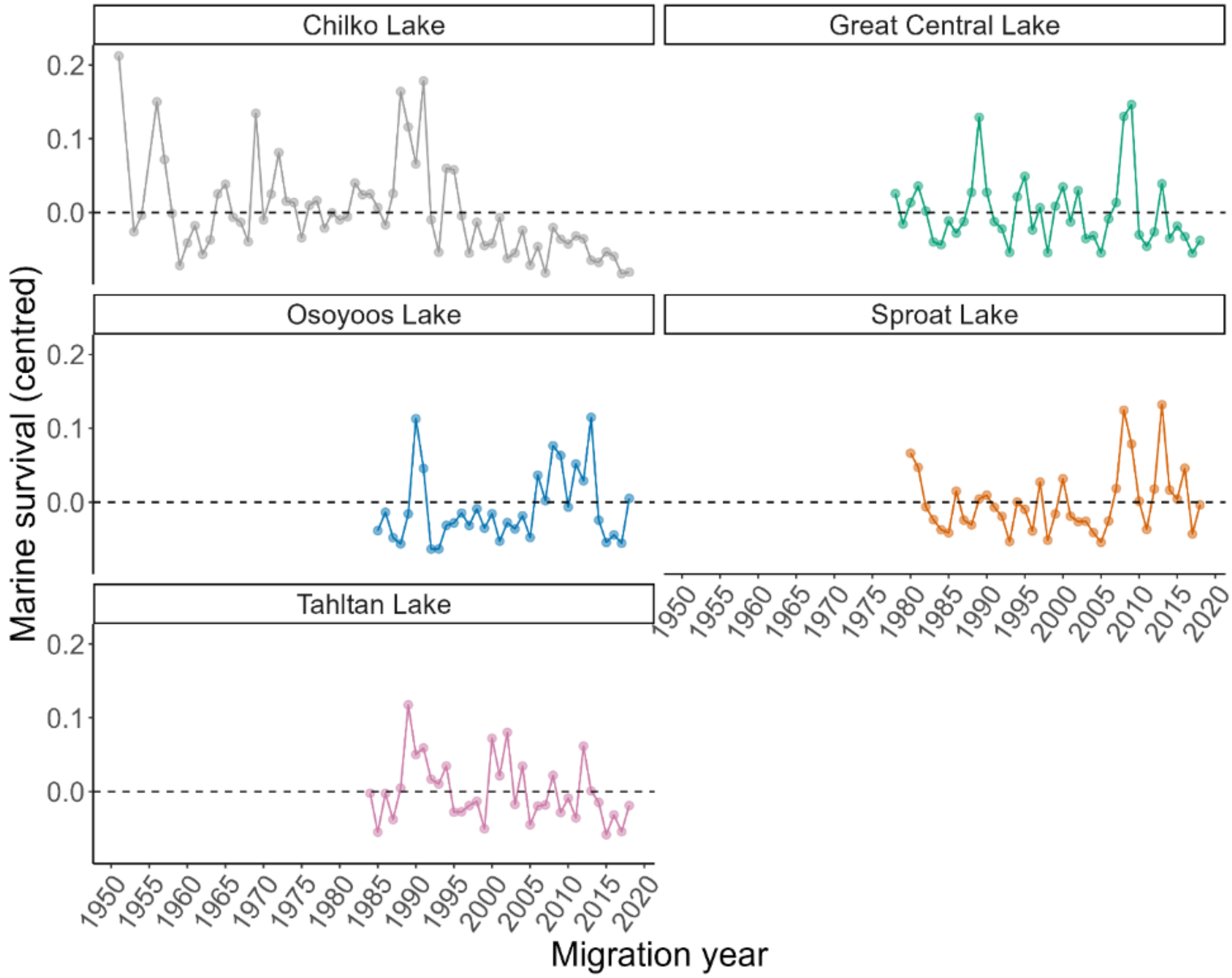

Figure 28-5. Centred marine survival for Sockeye Salmon indicator populations with complete datasets (i.e., populations with green points in Figure 28-1). The dashed black lines represent the long-term mean marine survival for each population.

28.3. Status and trends

Through time, smolt abundances at each nursery lake have been highly variable and without a general trend across populations (Figure 28-2). Notably however, Sproat Lake appeared to be in a consistent smolt production slump since 2014 (below long term average).

Across the timeseries, adult recruit abundance has been variable and nearing or under the long-term averages for most populations (Figures 28-3 and 28-4). It should be noted that many Fraser River Sockeye Salmon systems are highly cyclical (Chilko Lake in Figure 28-3 and all populations in Figure 28-4). Osoyoos Lake has entered a phase of much higher recruit abundance since approximately 2010.

The marine survival timeseries again showed high variability, but with below average to average marine survival in recent years (Figure 28-5). Chilko Lake was particularly poor with below average and declining marine survival since the mid 1990s.

28.4. Factors influencing trends

While there have been many attempts to uncover the environmental drivers of Sockeye Salmon abundance and marine survival, drivers remain poorly understood and many hypotheses are still being explored (e.g., Irvine and Akenhead 2013; Walters et al. 2020; McKinnell and Irvine 2021; etc.). However, density-dependent spawner-to-juvenile production relationships are well-documented in freshwater (e.g., Schindler et al. 2005), and it is generally accepted that marine heatwaves such as the “Blob” reduce Sockeye Salmon marine survival and production at the southern portion of the species range (Cheung and Frölicher 2020; Connors et al. 2020).

The increase in Osoyoos Lake Sockeye Salmon production that occurred around 2010 coincided with the implementation of the Fish Water Management Tools program and the reintroduction of anadromous Sockeye to Skaha Lake (the next lake upstream of Osoyoos Lake in the Okanagan watershed). Anecdotal evidence suggests that the Fish Water Management Tools program, which aimed to reduce the frequency and duration of egg-scouring events and extreme low-water events, may have contributed to increased productivity, but formal analyses are ongoing.

Beyond monitoring and simple comparison, the purpose of gathering these Sockeye Salmon timeseries is to analyze them for shared trends in freshwater and marine productivity using Multivariate Auto Regressive State Space (MARSS; Holmes et al. 2012) models. Depending on which Sockeye Salmon populations have the greatest covariance in stage-specific productivity, we can identify plausible environmental drivers for variability in survival. For example, if populations in close geographic proximity display the greatest covariance, we may hypothesize that productivity is predominantly associated with local environmental influences rather than basin-scale processes.

28.5. Implications

The implications of these timeseries (both long term and latest data considered) suggest that Sockeye Salmon productivity may be constrained by marine conditions. Marine survival has been below average for several stocks despite the recent cooler La Niña phase. The likely transition to a warmer El Niño phase may result in further declines in survival. More promising, however, was the Osoyoos Lake timeseries, which suggested that increased freshwater productivity may offset the impacts of poor marine conditions. Understanding what drives production in both freshwater and marine life-stages may allow us to maintain higher smolt production to offset poor marine survival, while understanding drivers of marine survival will improve our ability to forecast returns and sustainably manage fisheries.

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29. TRENDS IN PACIFIC CANADIAN GROUNDFISH STOCK STATUS AND SURVEYS

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29.1. Highlights

- Average groundfish stock status declined from 1950 to around 2000, and following management changes, has remained relatively stable since then.
- In 2022, assessments were updated for four stocks (Sablefish, Canary Rockfish, Arrowtooth Flounder, inside Quillback Rockfish). The first three were estimated to be above their Limit Reference Point (LRP) with very high (>95%) probability; the latter with high (75–95%) probability. Sablefish and Canary Rockfish were estimated to be above their Upper Stock Reference (USR) with very high probability; the latter two stocks with ~50% probability.
- Over the last two decades, survey indices increased for ~70% of stocks, remained neutral for ~15%, and declined for ~15% stocks.
- All assessed shelf rockfish (Bocaccio, Canary, Redstripe, Silvergray, Widow, Yellowtail) and several slope rockfish increased in surveyed biomass over the last 5–7 years; surveyed biomass also increased for several flatfish (Petrale, English, Rex, and Dover Sole) but declined for Arrowtooth Flounder over the last 5–10 years.
- Survey indices for North Pacific Spiny Dogfish stocks had the steepest declines across all stocks—particularly for the outside stock, which excludes inside Vancouver Island waters—despite low fishing pressure compared to historical levels.

29.2. Introduction

DFO conducts a suite of randomized surveys using bottom trawl, longline hook, and longline trap gear that, in aggregate, cover Canada's Pacific Coast (Anderson et al. 2019). Synoptic trawl surveys in Queen Charlotte Sound (Areas 5A and 5B) and Hecate Strait (Areas 5C and 5D) are conducted in odd numbered years, while the West Coast of Vancouver Island (WCVI; Areas 3C and 3D) and the West Coast of Haida Gwaii (WCHG; Area 5E) surveys are conducted in even numbered years. In addition, four biennial Hard Bottom Longline (HBLL) surveys are conducted, two in "inside" waters (east of Vancouver Island; Area 4B) and two in "outside" waters (everywhere else). Lastly, a coast-wide longline trap survey targeting Sablefish is conducted every year and DFO collects biological information from the International Pacific Halibut Commission (IPHC) Setline Survey. In 2022, the HBLL outside south, HBLL inside south, synoptic WCHG, synoptic WCVI, Sablefish surveys were run.

Assessment scientists conduct stock assessments for major fish stocks in B.C. These assessments combine fishery-dependent data (such as commercial catches) with fishery-independent data (data from scientific surveys) to estimate quantities such as spawning stock biomass, growth, and maturity, and to derive measures of fishing intensity and stock status. Stock status is typically assessed with respect to two reference points: (1) the Limit Reference

Point (LRP), a “status below which serious harm is occurring to the stock”; and (2) the Upper Stock Reference Point (USR), which represents the “threshold below which removals must be progressively reduced in order to avoid reaching the LRP” (DFO 2009). While stock assessments represent the gold-standard of estimated trends in population status, assessments are time and labour intensive and therefore frequently lag behind high quality datasets such as indices of abundance from scientific surveys, which often closely reflect population trends from assessments. Geostatistical spatiotemporal models allow spatially adjacent areas surveyed in various years to be combined into single annual indices that can help track changes in surveyed abundance between assessments.

Here, we explore population trends for groundfish stocks using two methods: (1) we update a hierarchical Bayesian state-space time-series model (Anderson et al. 2021) to explore trends until the year 2022, and (2) we develop model-based indices from relevant surveys for all assessed stocks, as well as stocks with outstanding requests for Science Advice.

29.3. Description of the time series

We gathered Bayesian posterior distributions of estimated biomass from assessments for 25 stocks, including four updated assessments (coastwide Sablefish, Canary Rockfish, and Arrowtooth Flounder; inside Quillback Rockfish). From these distributions, we modelled overall (i.e., all stocks combined) mean log stock status as a latent random walk with individual stocks assumed to have an auto-regressive observation model with their ‘true’ status drawn from their stock-assessed posterior distribution. The approach is an extension of a model in Hilborn et al. 2020, that includes uncertainty on stock status and is implemented in Stan (Carpenter et al. 2017); details are available in Anderson et al. (2021).

For these 25 stocks, as well as stocks with outstanding requests for Science Advice, and stocks with assessments that lacked the necessary posterior distributions for inclusion in the above model, we selected the relevant surveys (40 total stocks). We combined regional surveys that used the same gear and protocols (selecting among longline surveys or combinations of synoptic trawl surveys). We then fit geostatistical models to abundance or biomass density with the R package sdmTMB (Anderson et al. 2022). These models accounted for latent spatial factors with a constant spatial Gaussian random field and allowed spatiotemporal deviations to evolve as a Guassian random field random walk. For each stock–survey type combination, we fit both Tweedie and delta-gamma (binomial and gamma) observation error models and reported the model that produced the most precise index estimates on average; for most stocks (~80%), this was the delta-gamma model. We then predicted and summed biomass or abundance density across the appropriate 2 x 2 km survey grid(s) (e.g., Anderson et al. 2019) and scaled the survey index to the existing stock assessment biomass trend based on the geometric mean in overlapping years. Data and code to reproduce our analysis are available at https://github.com/pbs-assess/gftrends.

29.4. Status and trends

Across all stocks, there was a decline in average stock status until approximately 2000 (Figure 29-1). The late 1990s and early 2000s marked the beginning of a relatively stable average status. We estimated the overall mean B/LRP (biomass divided by the LRP) in 2022 to be 3.6 (95% CI: 2.9–4.3). The overall mean B/USR and B/B_{MSY} (biomass divided by biomass at maximum sustainable yield) in 2022 was 1.7 (95% CI: 1.4–2.1) and 1.6 (95% CI: 1.3–2.0), respectively (Figure 29-1, 29-2). Despite the overall pattern in the average biological status, there was considerable variation within and across individual stocks, especially when recent survey trends are also considered (Figure 29-3).

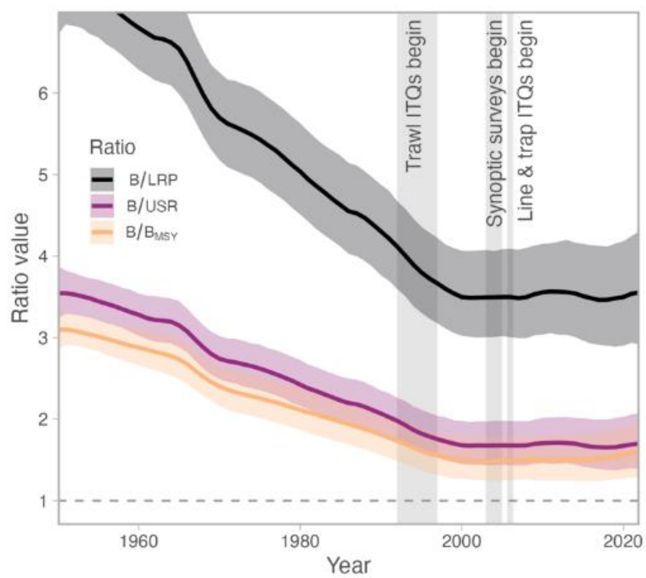

Figure 29-1. Overall mean biomass status across all stocks for B/LRP, B/USR, and B/B_{MSY} (see text for definitions) from the hierarchical time-series model. Dark lines represent the posterior median and shaded ribbons represent 95% quantile credible intervals. ITQ= individual transferable quota.

Estimated biomass was above the LRP and USR for most stocks as of the most recent assessment (Figure 29-2). Of the stocks with full posterior distributions available, inside (4B) Lingcod and Quillback Rockfish were the only stocks with $>$ 5% posterior density below their LRP as of their most recent assessments (Figure 29-2). Coastwide Bocaccio had $>$ 5% posterior density below its LRP in 2020 (DFO 2020a) but effectively 0% by 2021 after a large recruitment cohort in 2016 (DFO 2022a). Quillback Rockfish in the outside waters also had $>$ 5% posterior density below its LRP as of the 2011 assessment, but the full posterior distribution was not available (quantiles shown in Figure 29-3; an updated assessment to be reviewed in 2023). Pacific Cod in 3CD had a 0.02 probability B $<$ LRP in 2020; the 2021 and 2022 survey values remained low. Considering the USR instead of the LRP, 8/25 of the stocks in Figure 29-2 had > 25% probability of being below their USR as of their most recent assessment.

When we used survey indices to explore more recent changes across species, additional patterns emerged. Survey indices for all assessed shelf rockfish (Bocaccio, Canary, Redstripe, Silvergray, Widow, Yellowtail), and some slope rockfish (e.g., Yellowmouth) increased in the past ~5–7 years (Figure 29-3). The survey indices also allowed us to explore surveyed population trends of species that have not yet received full assessments, such as many flatfish and Chondrichthyans. Most of the included flatfish (soles: Petrale, English, Rex, Dover) appeared to increase in survey biomass over the last 5–10 years. However, the trawl survey index and stock assessment indicate that Arrowtooth Flounder have declined over the same time span (Figure 29-3). Trends among the skates generally appeared stable or positive. North Pacific Spiny Dogfish (herein ‘dogfish’) stocks, however, experienced the steepest declines of all stocks (Figure 29-3), with a particularly steep decline in outside Vancouver Island waters.

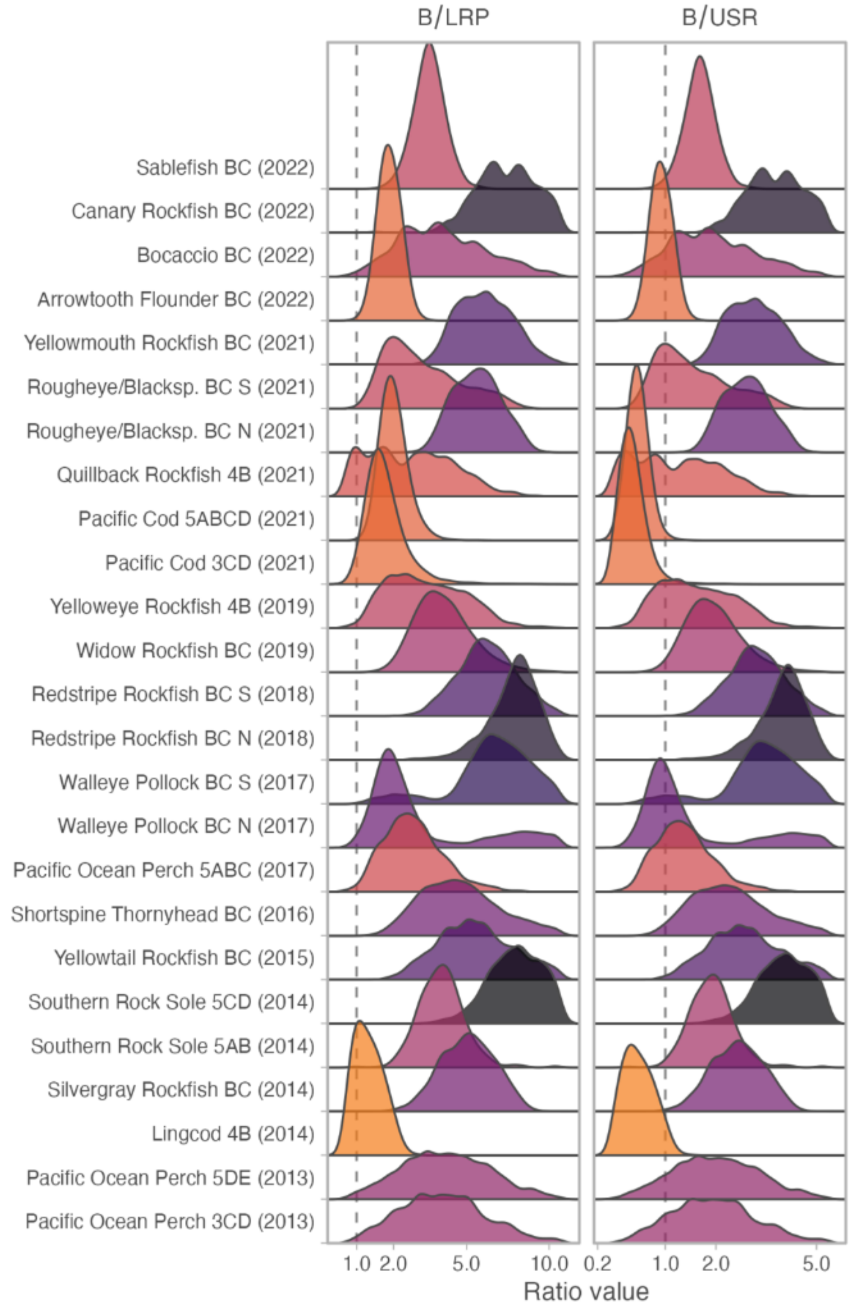

Figure 29-2. Posterior distribution of the two measures of stock status for 25 stocks (Edwards et al. 2011, 2013; Edwards et al. 2014; DFO 2015, 2019, 2020a, 2020b, 2020c, 2020d, 2022b; Holt et al. 2016a, 2016b; Starr et al. 2016; Starr and Haigh 2017, 2021a; DFO 2021; Starr and Haigh 2021b; Grandin et al. 2023; Starr and Haigh 2023; DFO 2023a; DFO 2023b; Huynh et al. 2023). Stocks are arranged in order of assessment with the most recent assessments at the top; years in the first column indicate the year the status represents. Colours represent the mean B/LRP value such that black is highest and orange is lowest. Vertical dashed lines are at values of 1.0 in all columns. The x-axis has been square-root transformed to slightly compress high ratio values for visualization. The full posterior was not available for the outside Quillback stock, which is shown in Figure 29-3 (Yamanaka et al. 2011). Years shown in parentheses indicate the year in which the assessment focused on biomass status, which is usually the year of the assessment and usually one year beyond the last year of data.

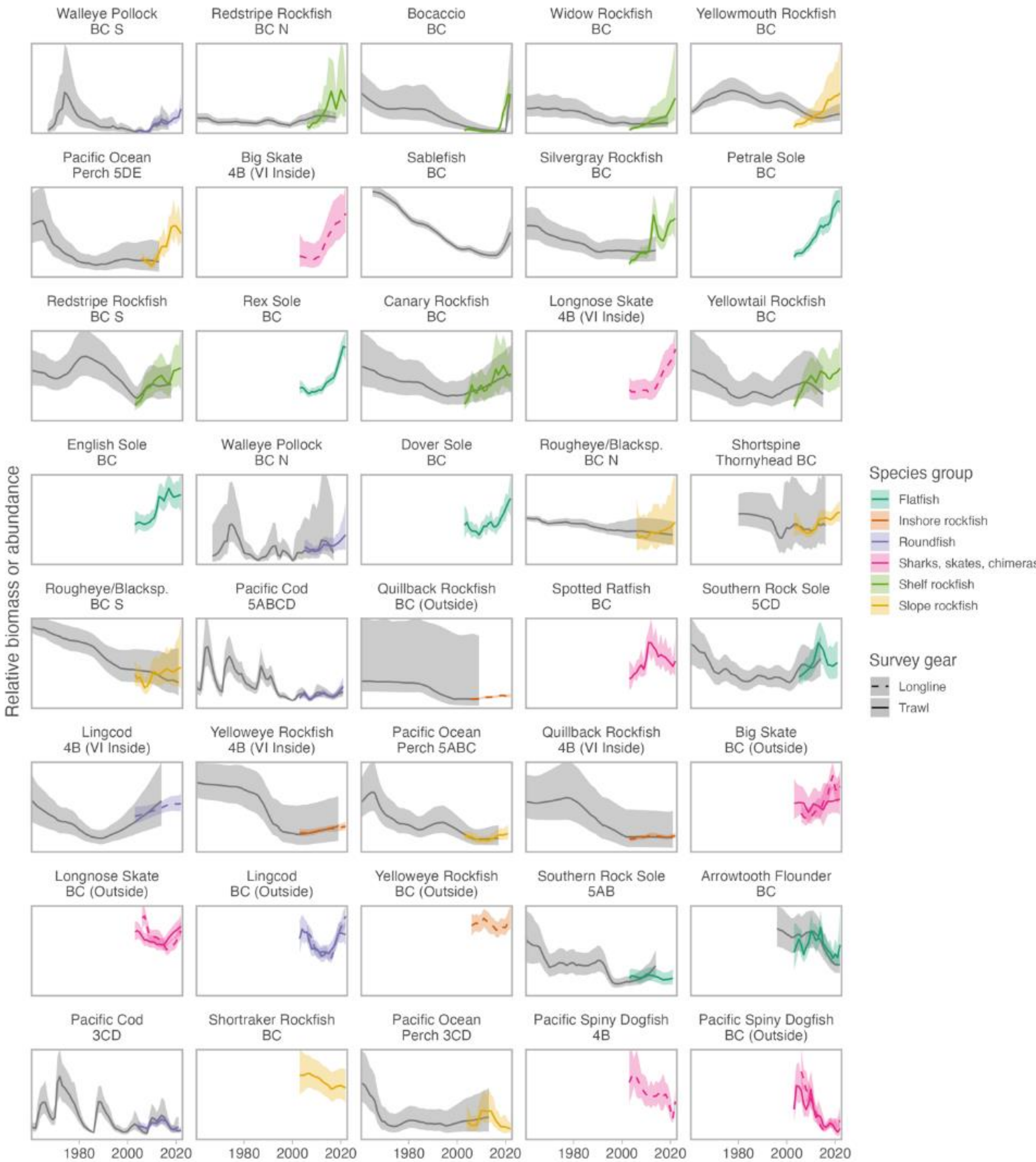

Figure 29-3. Trends for 40 B.C. groundfish stocks with assessments in the last ~15 years or outstanding requests for Science Advice. Dark grey lines and ribbons represent output from stock assessments: trajectories of median B/LRP 95% quantile credible intervals (see citations in Figure 29-2 caption). Coloured lines and ribbons represent model-based indices for the most relevant survey(s) for each stock. Survey trends are scaled to existing assessments based on the geometric mean in overlapping years to account for survey catchability. Sablefish are indexed through a trap survey, which is not modelled here; however; the assessed biomass extends to 2022.

29.5. Factors influencing trends

The long term overall groundfish trend is likely to have been primarily influenced by fishery removals and management interventions. The transition from declining average B/LRP and B/USR to a relatively stable trajectory coincided with the implementation of individual transferable quotas (ITQs) for the trawl fleet, the introduction of 100% at-sea observer coverage over the period 1992–1997 (Turris 2000), and the initiation of the current synoptic trawl surveys in 2003. Furthermore, ITQs and electronic at-sea monitoring were introduced into the longline and trap fisheries in 2006 (Stanley et al. 2015).

Other patterns may be driven by species interactions and climatic effects. For example, dogfish are not currently heavily affected by any fishery, so the cause of their survey declines is unknown. One possibility is that climate change is driving a northward range shift or that seasonal distribution patterns have changed as seen in the northwest Pacific Ocean (Kanamori et al. 2022). For several species, there is evidence that temperature velocity—the pace a fish would have to move to maintain consistent temperature—may be related to a fine-scale redistribution of population density in Canadian Pacific waters (English et al. 2022). Effects of recent oceanographic conditions on spawning habitat are hypothesized to have led to years of low recruitment in some groundfish (e.g., Pacific Cod in nearby Alaskan waters, Laurel and Rogers 2020). On the other hand, after decades of consistently low recruitment, recent increases in several shelf rockfishe species—most notably Bocaccio—may in part be driven by transient availability of oxygen-rich water at depth during gestation (Schroeder et al. 2019; DFO 2022a).

29.6. Implications of those trends

The Sustainable Fisheries Framework and the Fish Stocks provisions of the *Fisheries Act* require that major fish stocks be maintained above their LRP with high probability (≥75% if subject to the Fish Stocks provisions). Two stocks had $>$ 5% probability of being below their LRP as of their last assessment and neither is currently a Major Stock. Roughly one-third of assessed stocks had $>$ 25% probability of being in the cautious zone where removals should be progressively reduced to avoid reaching the LRP. Rebuilding and precautionary management of stocks in the critical and cautious zones, respectively, should help ensure stock status improves over time in response to reduced fishing pressure and favourable environmental conditions if and when they occur.

29.7. Acknowledgements

We thank Rowan Haigh, Brendan Connors, Robyn Forrest, Chris Grandin, Dana Haggarty, and Kendra Holt for providing stock assessment output data and contributing to the initial version of the time series model (Anderson et al. 2021). We thank all those involved in coordinating and conducting the synoptic and longline surveys (especially Malcolm Wyeth, Norm Olsen, Maria Cornthwaite, and Dana Haggarty) as well as the many others who have contributed to the collection of survey data that make analyses such as these possible.

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30. SEABIRD OBSERVATIONS ON THE B.C. COAST IN 2022

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30.1. Highlights

- As in 2021, diets fed to nestling Cassin's Auklets on Triangle Island in 2022 included substantially less of the subarctic copepod *Neocalanus cristatus*, their most important prey, than expected from the strongly negative PDO in the 6 months preceding the breeding season.
- Diets fed to nestling Rhinoceros Auklets on Pine Island and Lucy Island included normal amounts of Pacific Sand Lance and Pacific Herring in 2022, continuing the trend towards favourable conditions that existed prior to the Blob.

30.2. Description of the time series

Annually since 1996, Environment Canada and Fisheries and Oceans Canada has monitored the diets fed to Cassin's Auklet (*Ptychoramphus aleuticus*) nestlings on Triangle Island as indicator of survival as well as zooplankton prey availability (Hipfner et al. 2020). Analyses include only data collected in late June in all years.

In addition, scientists have been annually quantifying predation by Rhinoceros Auklets (*Ptychoramphus aleuticus*) on fish, including salmon smolts, since 2006 as an indicator of seabird feeding success and salmon mortality (Tucker et al. 2016). Nestling diets in 2022 were quantified at Pine, Lucy, Triangle, and Cleland islands, and in the U.S., collaborators quantified diets on Protection Island.

30.3. Status and Trends

Diets fed to Cassin's Auklet nestlings

In 2022, the representation of the subarctic copepod *N. cristatus* in Cassin's Auklet nestling diets was well below what would be expected from the strongly negative PDO based on the existing relationship for 1996-2021 (Figure 30-1). This prey item also occurred at much lower than expected levels in 2021.

Diets fed to Rhinoceros Auklet nestlings

In 2022, diets fed to nestling Rhinoceros Auklets on two colonies in B.C., Pine Island (in southern Queen Charlotte Sound) and Lucy Island (in Chatham Sound), included near normal amounts of Pacific Sand Lance (*Ammodytes personatus)* and Pacific Herring (*Clupea pallasii*) (Figure 30-2). Comparison with an existing time series (2006-2021) indicates a continuing trend to more favourable, pre-Blob conditions for these birds. Salmon were present at unusually high levels in diets at Lucy Island in 2022. Diets over the time series have tended to be much less variable at Protection Island, WA, in the Salish Sea.

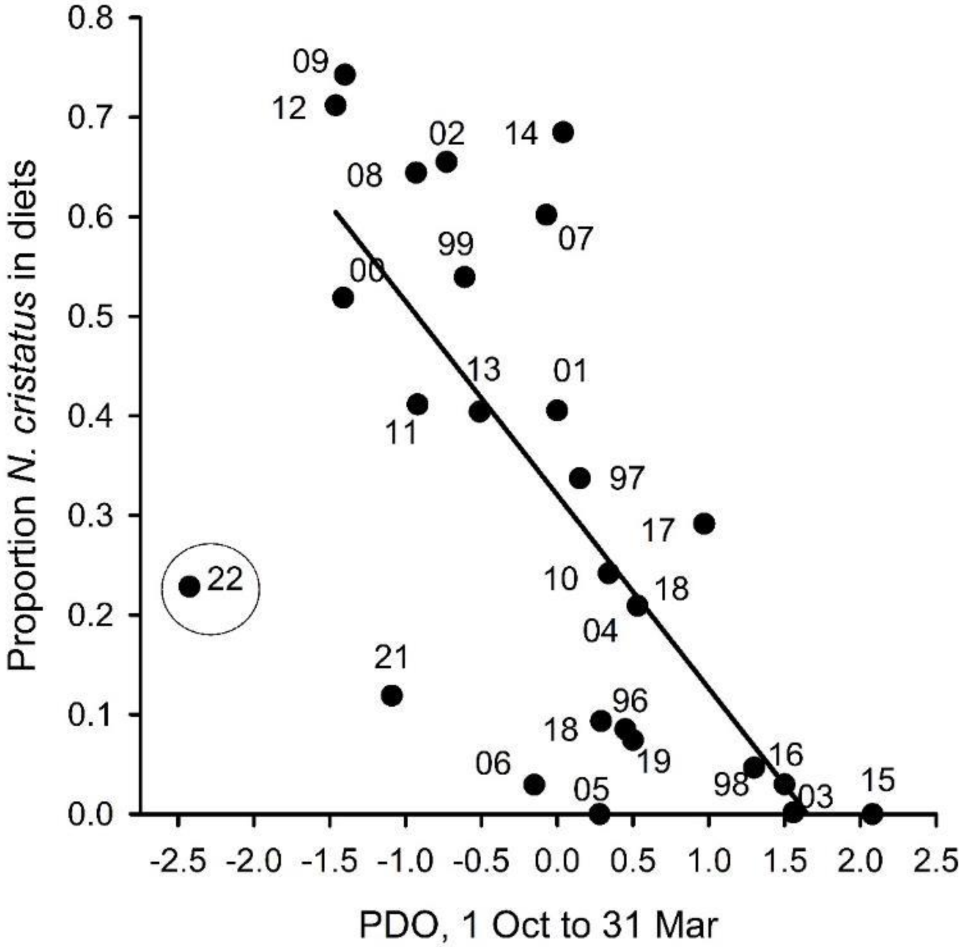

Figure 30-1. Proportion of Neocalanus cristatus in diets fed to nestling Cassin's Auklets in late June as a function of the PDO,1996 to 2022.

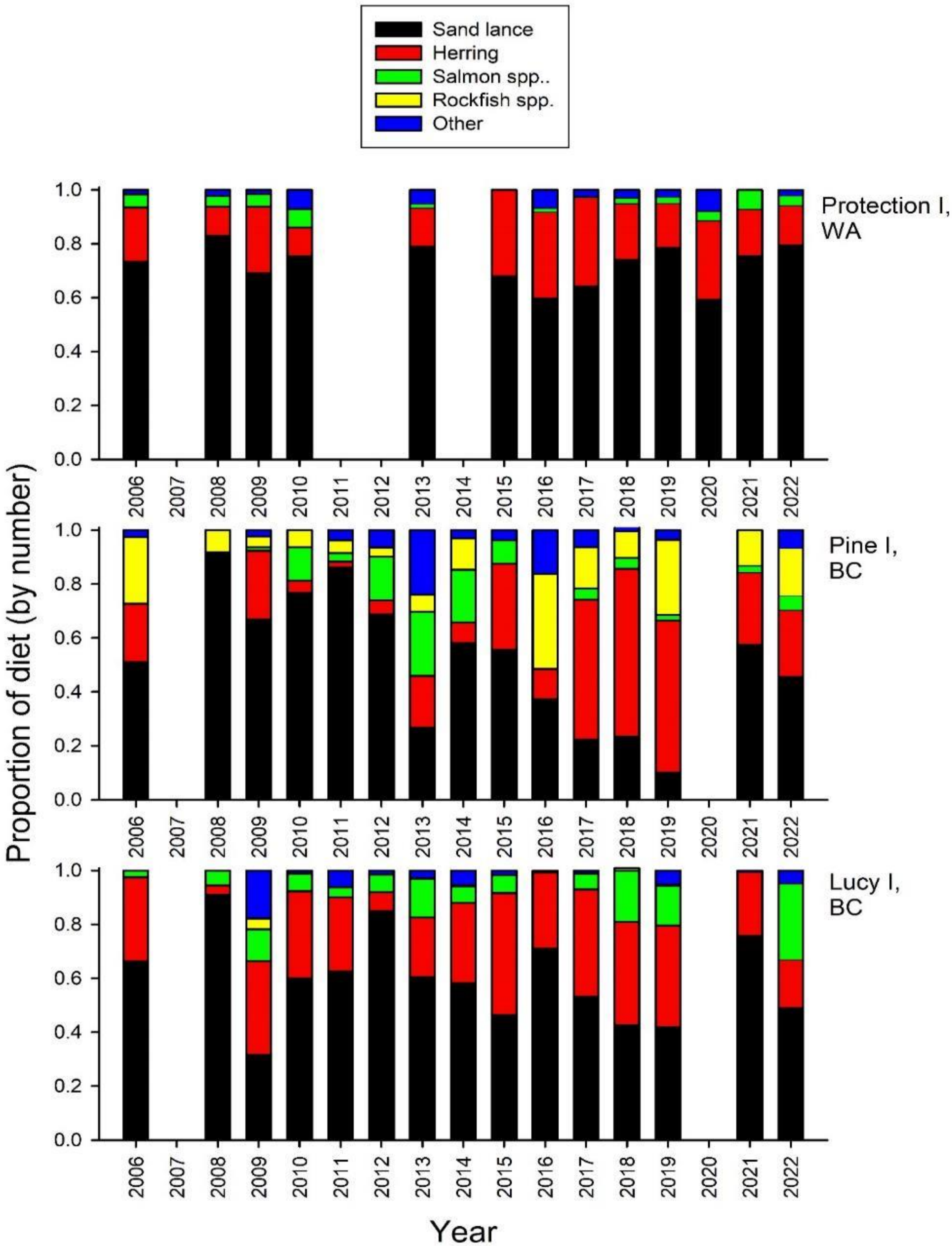

Figure 30-2. Species composition (by number) of the diets delivered to nestling Rhinoceros Auklets on 2 colonies in B.C. and 1 in WA in 2006-2022.

30.4. Factors influencing trends

The zooplankton-based diets fed to nestling Cassin's Auklets on Triangle Island, the world's largest breeding colony, 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 in cold-water, PDO-negative years when the subarctic copepod *N. 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).

The fish-based diets fed to nestling Rhinoceros Auklets on colonies in B.C. are also affected by oceanographic conditions (Thayer et al. 2008). In general, nestling auklets grow more quickly in years in which their diets include more Pacific Sand Lance, a small forage fish (Borstad et al. 2011).

30.5. Implications of those trends

Lower proportions of the subarctic copepod *N. cristatus* in diets of Cassin's Auklet nestlings may result in lower growth rates. Low growth rates of nestlings will translate to low survival and lower population growth.

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 B.C. funnel past aggregations of hundreds of thousands of Rhinoceros Auklets 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, although the birds tend to take small, poor condition smolts (Miller et al. 2013; Tucker et al. 2016).

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31. UPDATE TO PINNIPED ABUNDANCE TRENDS IN B.C.

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31.1. Highlights

- A mean abundance of 13,600 (95% CI 11,300-16,300) California Sea Lions overwintering in B.C. was estimated in 2020-21. This represents a threefold increase since 2009-10 and no significant increase since 2017.
- The abundance of B.C. Harbour Seals increased from a low of approximately 10,000 in the 1960s to over 100,000 in the early 2000s and is now stable or slightly declining; in 2015-2019, their abundance was 85,400 (95% CI 82,000-88,900).

31.2. Description of the time series

Since the early 1970's, DFO has undertaken standardized, aerial breeding-season surveys to monitor populations of Harbour Seals in B.C. Although California Sea Lions have been periodically counted in winter surveys for Steller Sea Lions, 2020-2021 marked the first year with a survey dedicated to this species in particular. Specific survey parameters are outlined by Olesiuk (2010 and 2018) for Harbour Seals and sea lions, respectively.

Given the vast area to cover during a coast-wide survey, an assessment of Harbour Seals represents a compilation of surveys of regions conducted over several years, and consequently, is not a synoptic view of the stock. Abundance estimates are compiled from counts within each subregion, applying the appropriate corrections, then summing to the regional level or for the entire B.C. coast. For Harbour Seals, aerial surveys were conducted during 2015-2019, achieving the highest compilation of survey coverage (90% of the B.C. coast) to date (DFO 2022).

California Sea Lions breed at rookery sites in southern California and Mexico during May-June, after which sub-adult and adult males typically migrate northward over the fall and winter to sites in Oregon, Washington, and B.C. with a limited number of sightings in southern Alaska. Animals start arriving in coastal B.C. as early as August with a departure by May. A series of five standardized aerial surveys of southern B.C. sea lion haulout sites was completed from November 2020 through March 2021 (DFO 2023). As California Sea Lions are considered to be highly transitory, the replicate surveys allowed for an exploration of the temporal variation in counts and abundance in B.C. over the winter period.

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 are derived by tracking haulout patterns of individual animals through satellite telemetry. To estimate the proportion of pinnipeds hauled out during survey conditions, satellite tags were deployed on 30 Harbour Seals in the Strait of Georgia during 2019-2021. To account for sea lions at sea, monthly correction factors derived from satellite tags deployed on sea lions in nearby Puget Sound (Washington, U.S.A.) between 2014-16, were applied (DFO 2023).

31.3. Status and trends

Taking the sum of the regional estimates in the years surveyed (2015-2019), we estimated stock size to be 84,500 (95% CI 81,200-88,000) Harbour Seals in B.C. Projecting regional trends to 2019 for regions that were surveyed in the earlier years of the compilation of surveys, we obtained a slightly higher but statistically similar estimate at 85,400 (95% CI 82,000-88,900) seals (Figure 31-1). This is similar to the 2003-2008 estimate of 105,000 seals (95% CI of 90,900-118,900; Olesiuk 2010). Given the uncertainty in the regional estimates, the stock in 2015-2019 is either stable or has declined slightly relative to the 2003-2008 assessment. However, abundance, density and trends varied regionally. Fourty-two percent of the stock resides in the Strait of Georgia.

In 2020-21, the monthly winter population estimates for California Sea Lions in B.C ranged from 12,800 to 14,600 individuals, leading to an average total abundance of 13,600 (95% CI 11,300-16,300) individuals (Figure 31-2a). While abundance remained consistent across monthly surveys in 2020-21, there was a redistribution of animals. This represents a three-fold increase from winter 2009-10, and no significant increase since the estimate in 2017 (Figure 31-2b).

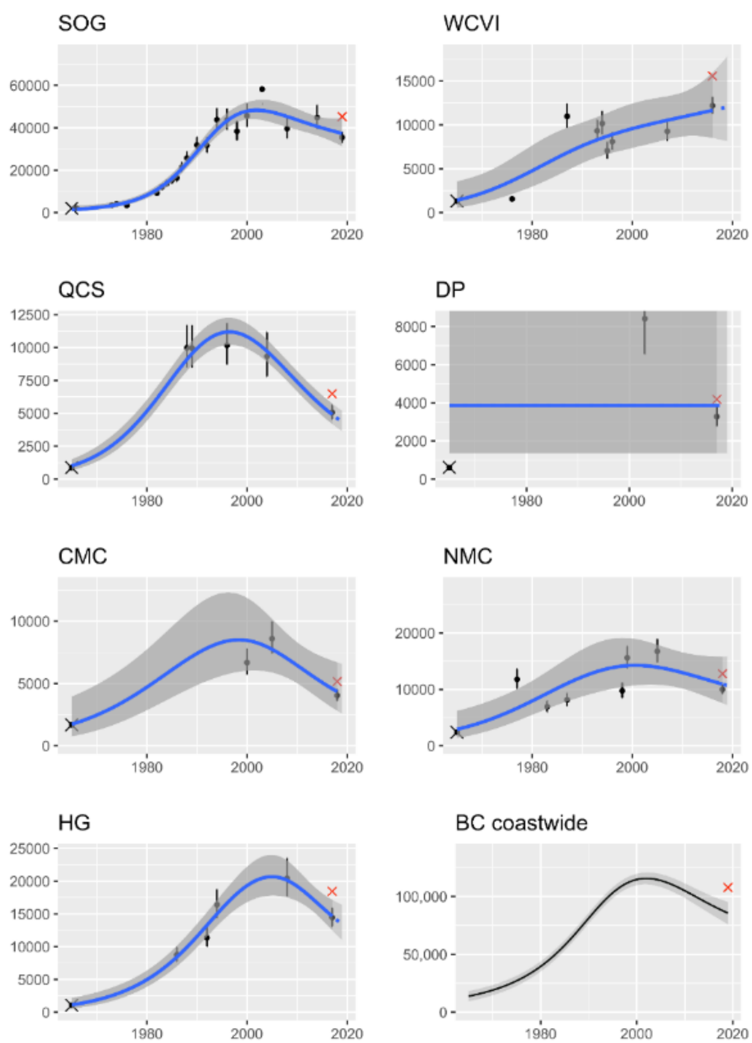

Figure 31-1. Harbour Seal abundance estimates (black dots) with 95% CI (black vertical bar) and trends for all seven regions and the B.C. composite. The black "x" is the reconstructed abundance estimate for 1965. The red "x" indicates the abundance estimate that would have been obtained using the old correction factor for the proportion of seals hauled out. Lines with shading represent the mean trends in abundance and standard errors based on model output. Blue dots are the projected abundances to 2019. Regions are: Strait of Georgia (SOG), west coast of Vancouver Island (WCVI), Queen Charlotte Strait (QCS), Discovery Passage (DP), central mainland coast (CMC), northern mainland coast (NMC), Haida Gwaii (HG).

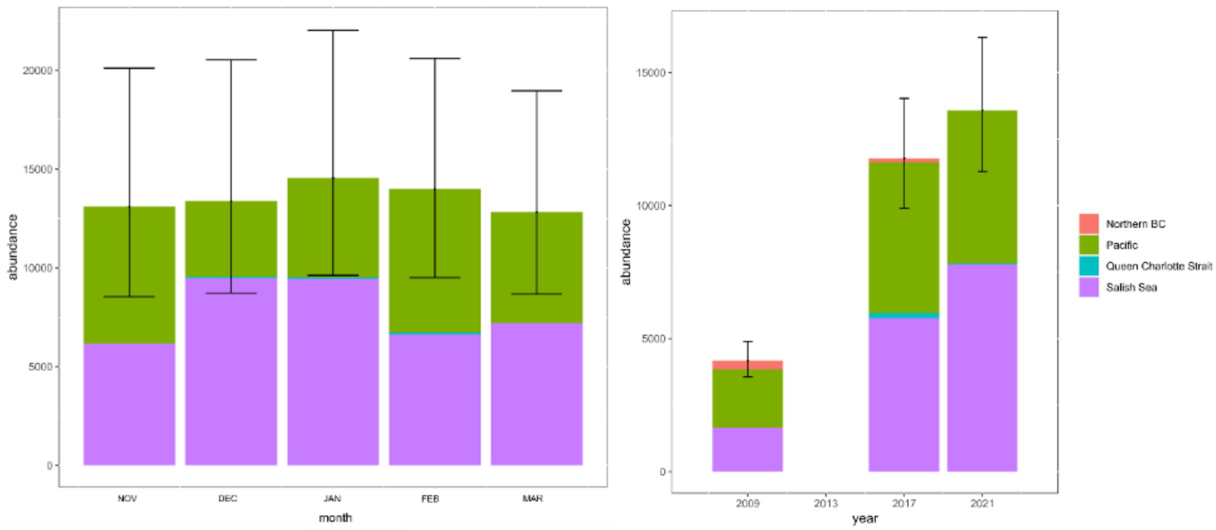

Figure 31-2. Average estimated abundance with 95% Confidence Intervals (CI) of California Sea Lions hauled out during a) monthly 2020-2021 winter surveys (November-March) and b) 2009-2021 winter surveys.

31.4. Factors influencing trends

Potential causes for observed trends and current status

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.

The abundance of B.C. Harbour Seals increased from a low of approximately 10,000 seals in the 1960's, to over 100,000 in the early 2000's, and is now stable or slightly declining. It appears that abundance has declined by 2,000-10,000 animals in the Strait of Georgia, for the first time in 30 years. One hypothesis is Bigg's Killer Whale predation.

The threefold increase in California Sea Lions overwintering in Canadian Pacific waters since 2009-10 cannot be solely explained by an increase in the overall U.S.A. population of California Sea Lions, which appears to have stabilized in recent years. A redistribution/increase in the proportion of males overwintering in coastal B.C. may be linked to changes in prey availability in other parts of the range.

31.5. Implications of those trends.

Pinnipeds have been identified as primary prey species of threatened Bigg's (aka West Coast Transient) Killer Whales along the coast of B.C. 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 Salish Sea 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 Whales for critical food resources, and, evaluating the potential impacts of changing ocean conditions.

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32. SEI AGAIN? NEW INFORMATION ON THE RECOVERY OF SEI WHALES (*BALAENOPTERA BOREALIS*) IN PACIFIC CANADIAN WATERS FROM SYSTEMATIC SURVEYS IN 2018-2022

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32.1. Highlights

- In systematic surveys of the Canadian Exclusive Economic Zone, sightings of 5 Sei Whales (*Balaenoptera borealis*) were made in 2018, 93 in 2021 and 48 in 2022, while none were observed in 2019.
- Most sightings were made in an area characterized by the presence of large seamounts.
- These results may indicate increasing abundance or changing distribution patterns, but also likely reflect increasing survey efforts in offshore waters. Differences across years are reminiscent of observations from whalers that Sei Whales could abruptly appear or disappear from certain areas.

32.2. Description of the time series

Over 30 non-systematic ship surveys were conducted by Fisheries and Oceans Canada (DFO) off the Pacific coast of Canada in the years 2003-2017, in all seasons, mostly in coastal and shelf waters from southern Vancouver Island to north of Haida Gwaii but only occasionally beyond the shelf edge. No Sei Whales were ever sighted during any of these surveys (Ford et al. 2010, DFO unpublished data). Systematic surveys were conducted by non-government researchers in inshore coastal waters of B.C. during the summers of 2004 and 2005 and one Sei Whale was seen (Williams and Thomas 2007). However, none of these surveys covered a significant proportion of the offshore waters within the Canadian Exclusive Economic Zone (EEZ). In 2012, a survey for a program of the International Whaling Commission observed 2 groups comprising 4 individual Sei Whales within the Canadian EEZ (Matsuoka et al. 2013).

Starting in 2018, DFO ship-based, multi-species systematic surveys were conducted to estimate abundance and density of cetaceans in Pacific Canadian waters onboard the 69-m Canadian Coast Guard Ship John P. Tully. In 2018, the study area included an offshore stratum that extended from Vancouver Island and Haida Gwaii to the boundaries of the Canadian EEZ and the survey followed a grid design using sets of parallel systematic transect lines separated by 60 km (Figure 32-1). In 2019, 2021 and 2022, zig-zag transects were conducted at higher intensity (i.e., lower spacing) within smaller box-shaped strata corresponding to areas of specific interest.

The ship travelled along survey transects at a speed of approximately 18.5 km h^{-1} when on-effort. Visual survey effort took place during daylight hours and was halted when seas were greater than sea state 4 on the Beaufort scale (swell height > 2 m and wind > 16 kts), or when visibility was less than 3 nm. Most of the survey was conducted in passing mode, during which the ship did not divert from the trackline when detections were made. Closing mode was only used when deemed necessary (e.g., for sample collection).

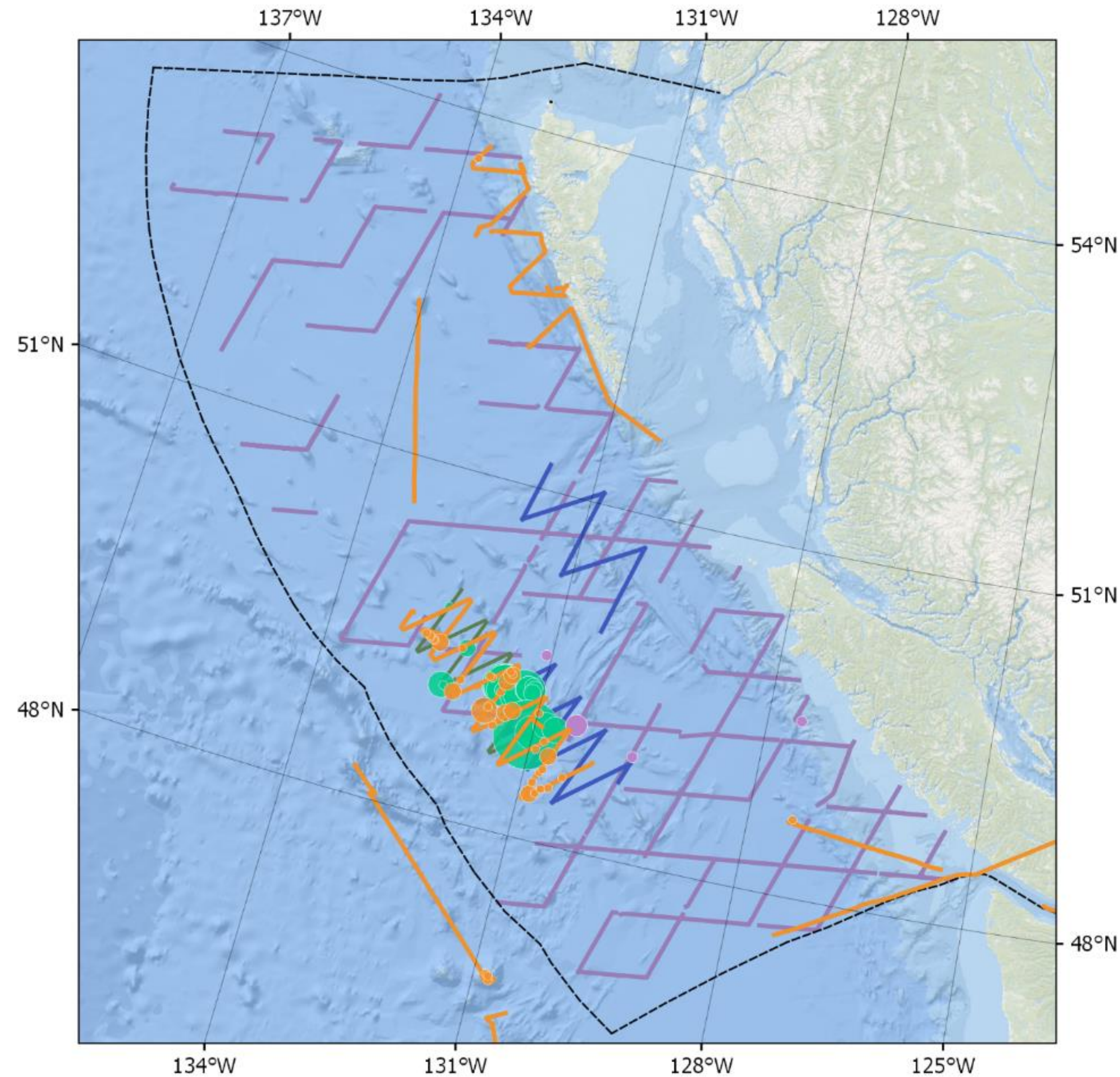

Figure 32-1. Systematic survey effort (solid lines) and Sei Whale sightings (circles) in the Canadian EEZ (dashed line). Purple: 2018. Blue: 2019 (no sightings). Green: 2021. Orange: 2022. Circle radius represents group size (from 1 to 5).

32.3. Status and trends

Many cetacean species were depleted in Canadian Pacific waters by commercial whaling, which ended in 1967. Although some populations have since shown evidence of recovery (e.g., Humpback Whales), much less is known about the current abundance of species distributed in difficult-to-survey offshore regions. In particular, little information has been available on Sei Whales since the end of whaling in B.C. Sei Whales dominated the catches at the Coal Harbour land station from 1962 to 1966, but the population off Canada was considered depleted by 1967 and is classified as *Endangered* under the Species-at-Risk Act. Analysis of whaling data showed that the vast majority of catches made by Canadian whalers occurred beyond the continental shelf break and in deeper water than other balaenopterids (Gregr 2000, Nichol et al. 2002).

In 2018, visual effort in offshore waters totaled 5,440 km and 4 sightings of Sei Whales (5 individuals) were made (Figure 32-1). In 2019, visual effort in two smaller offshore strata totalled 1,050 km and no Sei Whale were observed. In 2021, visual effort was restricted to one offshore stratum and 37 sightings were made for a total of 93 individuals. At one point in 2021, the ship went into closing mode towards a distant sighting and found a large aggregation of 25-30 Sei Whales. The 38 sightings made in 2022 were more scattered geographically and showed smaller group sizes (total of 48 individuals). An additional 3 sightings were made opportunistically in September 2022 on the Cobb seamount during a survey outside of the EEZ.

32.4. Factors influencing trends

It is difficult to know if these recent observations of Sei Whales in the Canadian EEZ reflect the recovery of the population (i.e., increasing abundance), a larger amount of survey effort in offshore waters, or a change in distribution of Sei Whales from outside the EEZ.

The vast majority of sightings made in 2018-2022 were made in the same offshore area, a region characterized by complex underwater bathymetry and the presence of large seamounts. Weather conditions in 2019, 2021 and 2022 were similar and particularly favourable to cetacean detections (good visibility and calm seas), as shown by numerous detections of smaller or more cryptic species (e.g. Dall's Porpoises and Beaked Whales). Yet, within the area of overlap among the three years, and with comparable effort, the 2019 survey had no Sei Whale sightings while the 2021 and 2022 cruises yielded an unprecedented number of detections. The reasons for this extreme inter-annual variability are unknown, but this pattern is similar to observations from whalers that Sei Whales could abruptly disappear from occupied areas or appear in places from which they had long been absent (Ford 2014).

32.5. Implications of those trends.

Several populations of marine mammals in Canada 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. Almost no information had been available until now to assess the recovery potential of Sei Whales in Pacific Canadian waters, but recent survey efforts by DFO have provided new insights into the distribution, habitat and density of this species. Next steps will include estimation of abundance from the survey data, investigation of seasonality from passive acoustic monitoring, consideration of environmental covariates to explain variation in density across years, and genetic analyses of skin samples collected on two individuals in 2021.

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33. THE STATUS OF THE GULF OF ALASKA 2022

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33.1. Highlights

- The Gulf of Alaska (GOA) shelf marine ecosystem continues an ongoing transition from a marine community responding to previous marine heatwaves (2014–2016 and 2019), to one potentially characterized by cooler ocean temperatures (Figure 33-1).
- The past year (2022) was the most consistently productive year since the last year dominated by marine heatwave conditions (2019). The productivity was consistent spatially, across the GOA, and across numerous ecosystem metrics.
- Despite the generally productive year, some concerns persist around thermal and foraging conditions for adult groundfish along the shelf edge and upper slope. There are additional concerns regarding the potential impact of warm, summer and fall, ocean surface temperatures on juvenile groundfish overwinter survival in 2023.
- The past year (2022) was an 'off' year in the alternating GOA schedule of NOAA's bottom trawl, summer acoustic, and spring ecosystem surveys, limiting available information related to groundfish ecosystem conditions, especially in the western GOA.

33.2. Description of time series

The NOAA Fisheries' 2022 Status of the Gulf of Alaska Ecosystem Status Report (Ferriss and Zador 2022) is part of the Groundfish Stock Assessment and Fisheries Evaluation Report. The purpose of this annual report is to inform the North Pacific Fisheries Management Council in setting harvest specifications for groundfish fisheries. The Ecosystem Assessment section is copied below. All reports can be found online https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands) and through the following QR code.

33.3. Status and trends, Factors influencing trends, and Implications of trends

Western Gulf of Alaska Shelf 2022

The western GOA experienced a third consecutive year of non-persistent marine heatwave conditions and experienced a mixture of cooler and warmer than average conditions throughout the year. Cooler winter and early spring surface temperatures coincided with a productive start to the year. Summer and fall temperatures (as of November 1) were above average, at surface and at depth. Warming in the second half of the year has the potential to negatively impact growth and lipid storage for groundfish, especially important for survival of juveniles entering their first winter. Surface temperatures are predicted to be cooler than average in the upcoming winter (2023).

The winter and spring ocean temperatures were cooler than average, coinciding with generally average to above-average forage conditions, with the exception of zooplankton around the Semidi Islands. Moving from west to east within the western GOA, zooplankton biomass was potentially below average southwest of Kodiak, as indicated by parakeet auklet reproductive success on the Semidi Islands. Spring biomasses of copepods and euphausiids were close to the survey average (1998-2022) along the shelf, offshore of Seward. These generally favourable prey conditions east of Kodiak were reflected in average to above-average planktivorous seabird reproduction (observed in colonies on E. Amatuli and Middleton Islands). Forage fish appeared relatively abundant and available to predators across the western GOA, based on above-average reproductive success in fish-eating seabirds (at the Semidi Islands, Middleton Island, and mixed trends on Amatuli Island). Seabird chicks on Middleton Island were fed a variety of herring, sandlance, age-0 Sablefish, and other forage fish (but low levels of Capelin), reflecting the presence of key forage species in the adult foraging range. Fish-eating and zooplankton-eating seabirds were also observed in higher densities above the middle shelf of the Seward Line in 2022. This expansion follows a period of concentration in the nearshore regions after the 2014-2016 and 2019 marine heatwave periods, and indicates greater forage opportunities across the shelf.

Longer-lived species at higher trophic levels may still be impacted by marine heatwave impacts. The endangered western distinct population segment of Steller Sea Lions have experienced declines of non-pup counts in the GOA regions from 2017-2021, likely associated with the 2014–2016 marine heatwave in the GOA. This decline follows an increasing trend since the early 2000's. Potential mechanisms for this decline include reduced prey availability (Walleye Pollock and Pacific Cod are key prey species), and reduced reproductive success and juvenile survival.

The frequency and intensity of harmful algal blooms were minimal this year, and appear not to have increased in response to the warmer-than-average summer temperatures.

Eastern Gulf of Alaska Shelf 2022

The eastern GOA shelf had similar trends in thermal conditions and productivity at lower trophic levels as the western GOA. The region experienced a cooler-than-average winter and early spring. Summer and fall temperatures (as of November 1) were above average at the surface, including a brief but widespread marine heatwave in July and a more prolonged marine heatwave period through the month of October (and continuing as of November 1). Warm summer and fall ocean temperatures can negatively impact growth and lipid storage for overwinter survival of groundfish, especially juveniles entering their first winter.

The cooler winter and spring ocean temperatures coincided with an above-average zooplankton and forage fish prey base. Total zooplankton density in Icy Strait (driven by calanoid copepods and euphausiids) was greater than one standard deviation above average. These positive zooplankton forage conditions were reflected on the shelf, offshore from Sitka, by above-average reproductive success of zooplankton-eating seabirds on St. Lazaria Island. Reproductive success of fish-eating seabirds at the same location was also above average, presumably reflecting the availability of nutritious forage fish. Herring populations in Sitka Sound and Cross Sound continue to be relatively abundant (supported by a strong 2016 year class), and numerous young Sablefish cohorts appear to be in the GOA system, including age-0's that appeared in Middleton Island seabird chick diets and presumably traveling from eastern GOA nursery habitat to within foraging range of the Middleton Island seabirds. Some metrics of forage fish in the eastern GOA are below average, including Eulachon population estimates and some juvenile salmon CPUE and smolt productivity in southeast Alaska.

Commercial harvest of salmon in southeastern Alaska has been below average (1997–2022) since 2017 (Sockeye and Chinook Salmon), 2018 (Coho and Pink Salmon), and 2019 (Chum Salmon). Juvenile salmon CPUE from Icy Strait, southeastern Alaska, have been consistently below or near average for all species since 2016 (Chinook Salmon), 2017 (Chum, Pink, and Sockeye Salmon) and 2018 (Coho Salmon). Explanations of these low indicators of juvenile salmon abundance vary by species and life history, but reflect a combination of spawner abundance (Pink Salmon), marine survival (Chum Salmon), and freshwater and early marine survival (Chinook, Sockeye, and Coho Salmon). Average fork length and energy densities of these juvenile salmon were all at or above average in 2022, with the exception of Chum salmon, reflecting foraging success.

Marine mammals are experiencing continued impacts of the 2014–2016 and 2019 marine heatwaves. The eastern distinct population segment of Steller Sea Lions (removed from the threatened listing under the Endangered Species Act in 2013) have experienced declines of non-pup and pup counts in the GOA regions from 2017–2021, likely associated with the 2014–2016 marine heatwave. Potential mechanisms for this decline include adult movement out of the region, reduced prey availability (Walleye Pollock and Pacific Cod are key prey species) and reduced reproductive success and juvenile survival.

Glacier Bay, Humpback Whale calf production declined since 2020 and 2021, and the 2019–2022 crude birth rate has not recovered to the pre-2014 mean. Humpback Whales in Prince William Sound are not considered to have returned to pre-2014 levels, although 2022 encounter rates of Humpback Whales increased from recent years. The decline in Prince William Sound Humpback Whales is surprising given the return of Prince William Sound herring biomass, a key prey species, to pre-marine heatwave levels.

The frequency and intensity of harmful algal blooms was minimal this year, and appear not to have increased in response to the warmer-than-average summer temperatures. Invasive Green Crabs were detected in Alaska for the first time in July, 2022. They are known to expand their range northward in summers following warm winters, so their potential range expansion will be important to monitor if warm temperatures persist in the eastern GOA. However, surface temperatures are predicted to be cooler than average in the winter (2023).

GOA Shelf/Upper Slope 2022

The GOA shelf edge and upper slope demersal/benthic habitat is an area characterized by limited ecosystem data, but includes some indicators of increased concern. This is habitat for numerous managed groundfish species, including Sablefish, rockfish (e.g., Shortraker Rockfish, Rougheye/Blackspotted Rockfish, Thornyhead Rockfish, Pacific Ocean Perch), and flatfish (deepwater flatfish complex, including Dover Sole). A number of these species migrate onto the shelf to spawn (e.g., Sablefish, Pacific Ocean Perch) and others are capable of changing depths in response to environmental conditions (Yang et al. 2019), so their ability to mitigate unfavourable habitat and forage conditions may be greater than some shelf groundfish. However, given the data-poor aspect of this habitat, it is important to highlight declining trends in relevant indicators when they arise. For example, temperatures around 250 m depth, along the shelf edge, have been consistently above average since 2016. Also, structural epifauna (primarily sponges), which are important habitat for rockfish, have experienced a multi-year decline in the western GOA.

In addition, adult female Sablefish had below-average condition in 2022, potentially indicating that they experienced challenging forage conditions, despite their characterization as opportunistic predators. We have no data on biomass trends on benthic infaunal prey (polychaetes and clams) or invertebrates on or near the bottom (amphipods and other small crustaceans, shrimp, and brittlestars), which are primary prey for numerous flatfish in this region.

The Gulf of Alaska: Multi-Year Trends

The upcoming winter is predicted to be a third consecutive La Niña, which, coupled with a negative Pacific Decadal Oscillation (PDO) and non-persistent marine heatwave conditions, has been associated with a three year period of cooling on the GOA shelf. A triple La Niña would be the third such event to occur in the past 50 years, yet there are numerous reasons to assume the ecological response to the current period will not follow past trends. Differences include: (1) the current La Niña period beginning in warm ocean thermal conditions throughout the water column, following the 2014–2016 and 2019 cumulative marine heatwave period, (2) a marine community in transition from that warm period, (3) the documented weakening of relationships between various climate indices and GOA community responses due in part to a weak Aleutian Low (Litzow et al. 2018), and (4) the continued long-term warming of the GOA shifting the definition of warming and cooling as they relate to species' temperature thresholds and responses.

Previous triple La Niña periods occurred from 1973–1976 and from 1998–2001. The PDO shifted from a previous cool regime (negative index) to a warm regime (positive index) in 1977, which, along with a strong Aleutian low, induced a regime shift from a GOA community dominated by flatfish and crustaceans (as well as increased seabird and Steller Sea Lion populations) to one dominated by gadids and rockfish (Chavez 2003; Mueter and Norcross 2000; Anderson and Piatt 1999). The second triple La Niña (1998–2001) was characterized as a cool thermal period in the GOA, with a suite of more temporary community responses, including strong 1999 year classes of Walleye Pollock and Pacific Cod, increased shrimp biomass, and increased presence of Capelin in seabird diets (Boldt 2005; Hatch 2013). The past two La Niña/ negative PDO years (2020, 2021) have coincided with ocean temperatures cooling from initial warmer-than-average thermal conditions throughout the GOA shelf water column to approximately average temperatures, with extended cooler-than-average temperatures for the first half of 2022. Given the residual heat in the system, the productive, cooler-water affiliated communities, as observed in the 1998–2001 period, took multiple years to materialize in the current period, or still remain elusive. For example, localized large phytoplankton blooms were observed in 2021 and 2022 but not consistently across the GOA. Zooplankton productivity has remained patchy across the GOA, but has been the most spatially consistent and highest biomass in 2022. Capelin populations remain relatively low, and there are mixed trends in the productivity of certain groundfish species (e.g., Pacific Cod has not yet recovered).

If the PDO remains negative in upcoming years, and if there is an absence of persistent marine heatwaves, the GOA could remain in a cooler state, but would not be expected to return to the same ecological community as the pre-70's regime shift. A return to that period is unlikely as there are more than two potential states of the GOA marine system, and there have been multiple ecological and oceanographic shifts, and climate-induced changes since then. However, recently-observed trends may indicate the direction in which the GOA marine community is transitioning. Total apex biomass of groundfish remains low (as of 2021) and groundfish surplus production metrics indicate potentially lower productivity (as of 2019). GOA groundfish biomass remains dominated by Arrowtooth Flounder, Walleye Pollock, Pacific Ocean perch, and increasingly Sablefish. However, the composition of this group is shifting. Pacific Cod has not recovered from the severe decline during the marine heatwave period and Arrowtooth Flounder has been declining since 2008, while Pacific Ocean Perch has steadily increased over many years and Sablefish has been increasing since 2016. Other isolated indicators that show differences potentially reflective of community transitions include: (1) the 2022 Papa Trajectory Index (an indicator of winter surface transport) had the second most southerly endpoint since the 1970's, (2) Tanner Crab and shrimp CPUE around Kodiak continue to increase, and (3) commercial catches of certain GOA salmon stocks, particularly in southeastern Alaska, remain below-average. Another year (2023) of similar ocean conditions would be informative as to the relative persistence of these trends.

Figure 33-1. A visual summary of ecosystem trends in the Gulf of Alaska in 2022. Figure and additional details can be found in the Gulf of Alaska In Brief (2022) (https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands). The symbols include: Tanner Crab, Sablefish, Pacific Herring, winter and early spring surface temperatures, summer and fall temperatures, harmful algal blooms, forage fish, Capelin, juvenile salmon, Eulachon, herring, Steller Sea Lions, Humpback Whale, temperatures, structural epifauna (primarily sponges), groundfish species, Sablefish, Pacific Ocean Perch, flatfish, and Green Crab.

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34. A REVIEW OF 5 YEARS OF MARINE OIL SPILLS IN B.C.

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34.1. Highlights

- In 2022, there were 1054 oil spills reported to DFO; a DFO response was activated for 25.
- The most significant was the Fishing Vessel Aleutian Isle which sank with 15000 L of diesel just across the international border in Juan de Fuca Strait.

34.2. Summary

The DFO spill response program, operating since 2017, has collected five years of data on reported marine oil spills as well as the associated responses. On average 1100 spills per year are reported in the Pacific Region through the Canadian Coast Guard (CCG) Regional Operations Centre, as required by the Canada Shipping Act. These reports vary greatly in type of fuel, amount, actual spill vs potential spill by a vessel in distress, and even reports of lost containers or marine debris that fall outside of the mandate of the marine oil spills program. In order to make the data more useful and accessible, a trial ArcGIS dashboard was developed that allows the user to select spills by time frame, type and area in order to identify hotspots or possibly determine cumulative impacts.

A yearly summary of the responses for which DFO was activated, based on CCG requests, varied from 19 to 32 per year, with 25 in 2022. It is noteworthy that the effort associated with 'activation' can involve as little as a notification email to DFO management to ensure that they are aware of the incident and know who, within DFO, is the contact in case questions or concerns arise. On the other end of the spectrum is a 7 month full-time response for several staff members with subsequent fieldwork, such as in case of the historic shipwreck of the MV Schiedyk near Bligh Island.

In 2022, there were four cases of fishing vessels that sunk or struck the seafloor and released some quantity of fuel. The most significant was the Fishing Vessel Aleutian Isle which sank with 15000 L of diesel just across the international border in Juan de Fuca Strait and triggered a prolonged international response, lead by US agencies.

35. UNUSUAL EVENTS IN CANADA'S PACIFIC MARINE WATERS IN 2022

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35.1. 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 2022 that were reported include: in southern B.C., both hot and cold air temperature records were broken, record numbers of Bigg's Killer Whales and Humpback Whales were observed in the Salish Sea, rare species were observed, such as an Arctic amphipod and a deep water scyphozoan, and more.

35.2. 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 2022 that have been reported to or noted by DFO Science staff. Some of these events may be included in other reports in this document, whereas other observations may not be presented in detail or at all. In addition, participants were invited to provide their own observations of unusual events during the State of the Pacific Ocean meeting, which are included in this report.

35.3. Status and trends

Observations in 2022 that were reported to DFO by participants at the 2023 State of the Pacific Ocean workshop are presented in Table 35-1. For example, debris from the MV Zim Kingston continues to wash ashore, in southern B.C., both hot and cold air temperature records were broken, and the Navy live-fire testing resumed in the Juan de Fuca Strait. There were record numbers of Bigg's Killer Whales and Humpback Whales observed in the Salish Sea, but there were also dead whales that washed ashore and at least one whale observed to be tangled in fishing gear. There were observations of rare interactions (i.e., a Harbour Porpoise calf swimming with a Northern Resident Killer Whale matriline) and rare species, such as an Arctic amphipod (*Themisto libellula*), deep water scyphozoan (*Deepstaria reticulum*), and a sunfish (*Mola tecta*). Other unusual occurrences are listed in Table 35-1.

Table 35-1. Observations of weird, wonderful and/or unusual marine events reported during 2022 or reported at the 2023 State of the Pacific Ocean meeting.

Event	Where	When	Reported by	Details
MV Zim Kingston Debris	Juan de Fuca, B.C. shores	Oct. 2021-present	Chek News	Debris still washing ashore in B.C.
Drought kills returning salmon	Central and Southern B.C.	Oct. 5, 2022	Victoria News	Drought in salmon-bearing rivers caused mortality of returning salmon
Record number Bigg's Killer Whales and Humpback Whales	Salish Sea	2022	Chek News	The most frequently spotted whale species in the Salish Sea in 2022
Dead whales on shore	a. Sunshine coast b. Haida Gwaii	a. Mar. 25, b. Nov. 13, 2022	a. Chek News b. Chek News	a. 3-metre-long Fin Whale probably died in mid-March before it washed ashore near Pender Harbour b. Dead Humpback Whale on Haida Gwaii shoreline
Grey Whale tangled in fishing gear	Tofino	Mar. 25, 2022	CTV News	Grey Whale tangled in fishing gear off Tofino prompts search by DFO

Hot and cold air temperature records broken	South B.C., Vancouver Is.	2022	CTV News	Feb. 11: record warm temperatures Feb. 24: record cold temperatures July 30: record warm temperatures
Rare sunfish species *Mola tecta* spotted	Alert Bay	Oct. 25, 2022	Chek News	Few sightings in the northern hemisphere since 2019
Porpoise calf hanging out with Killer Whales	Caamano Sound	Jul. 8, 2022	Brianna Wright, DFO	Harbour Porpoise calf swimming with a Northern Resident Killer Whale matriline
Arctic hyperiid amphipod species	Dixon Entrance	July 20, 2022	Moira Galbratith, DFO	*Themisto libellula*, an Arctic species, collected. Not clear if advected south or from glaciation-remnant population
Deep water scyphozoan	Offshore Cape Scott, 1000-1500 m depth	Sept., 2022	Moira Galbraith, Kelly Young, DFO	*Deepstaria reticulum*, a rare scyphozoan cnidarian that has only previously been seen by ROV, and never before found this far north
Navy live-fire testing re-started	Juan de Fuca area, 'Whiskey Hotel'	Jan. 2023	CTV News	Resumed after 3- year break (since 2019)

35.4. Factors influencing trends

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

35.5. References

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

36. COASTAL CO_2 OBSERVATIONS IN BRITISH COLUMBIA DURING 2022

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36.1. Highlights

- Time series on the central B.C. coast and in the northern Salish Sea showed declines in surface seawater pCO_2 / increases in Ω_{arag} between mid-February and early March due to reduced downwelling and increased phytoplankton productivity.
- Downwelling / stormy conditions re-initiated in March and reversed the trends seen earlier in the month.
- Large contributions of freshwater were evident during summer in both regions, with implications for Ω_{arag}
- Ω conditions at depth at both sites showed slightly improved conditions compared to 2019-2020, and this appeared to be correlated with the North Pacific Gyre Oscillation (NPGO) but the exact mechanisms are yet to be determined.

36.2. Description of the time series

Marine carbon dioxide (CO_2) system time series are presented from two regions: the central B.C. coast in the area of Fitz Hugh Sound, and the northern Salish Sea. Data from Fitz Hugh Sound were collected from an oceanographic station (KC10; 51.650396°N, 127.9508157°W) on a near monthly frequency and from the Kwakshua Channel (KC) buoy. Samples from KC10 were collected every month at 9 depths from the surface to 325 m, and only aragonite and calcite saturation state (Ω_{arag} and Ω_{cal}, respectively) derived from seawater CO_2 partial pressure (pCO_2) and dissolved inorganic carbon (DIC) measurements are shown here. Seawater data were collected hourly from the buoy with instruments sampling at 1 m. The buoy seawater data presented here are measurements of xCO_2 (CO_2 mole fractions in dry air, nominally equivalent to pCO_2), salinity, and chlorophyll. Atmospheric xCO_2 is also shown here and measured on the buoy every 3 hours. Data from the northern Salish Sea were collected at an oceanographic station (QU39; 50.03044358°N, 125.1052797°W) and from a seawater stream drawn from 1-m depth in Hyacinthe Bay into the Flow Through Laboratory at the Hakai Institute's Quadra Island Field Station (QIFS, Evans et al. 2019). Samples from QU39 were collected every 2 weeks from 12 depths from the surface to 260 m, and only Ω_{arag}, Ω_{cal}, and pH (on the total scale), derived from pCO_2 and DIC data, are shown here. Only Ω_{arag} and salinity are shown from the QIFS, and a subset of oxygen data (presented as a difference from saturated values, ΔO_2) from a 1-m instrument package on a nearby test mooring, are also included. Derivation of Ω_{arag}, Ω_{cal}, and pH using these data, along with their associated uncertainties, is described in Evans et al. (2019) and Evans et al. (2022).

36.3. Patterns in marine CO2

36.3.1. Surface water conditions

A number of environmental conditions drove similar surface CO_2 patterns between sites on the central B.C. coast (Figure 36-1) and the northern Salish Sea (Figure 36-2). These included relaxed downwelling / stormy conditions between mid-February and early March, followed by the return to stormy conditions into April, large seasonal increases in freshwater content through summer, and finally quiescent atmospheric conditions into late October. Early relaxation in downwelling / stormy conditions resulted in a large increase in surface chlorophyll and drawdown in seawater pCO_2 at KC10 and the KC buoy beginning March 11 (Figure 36-1). In the northern Salish Sea, the earliest seawater CO_2 drawdown and Ω_{arag} increase in the QIFS record was observed (Figure 36-2, February 16 in 2022 versus February 27 in 2015). These conditions were short-lived, lasting ~2 weeks at both locations before downwelling / stormy conditions drove a reversal back to winter-like levels.

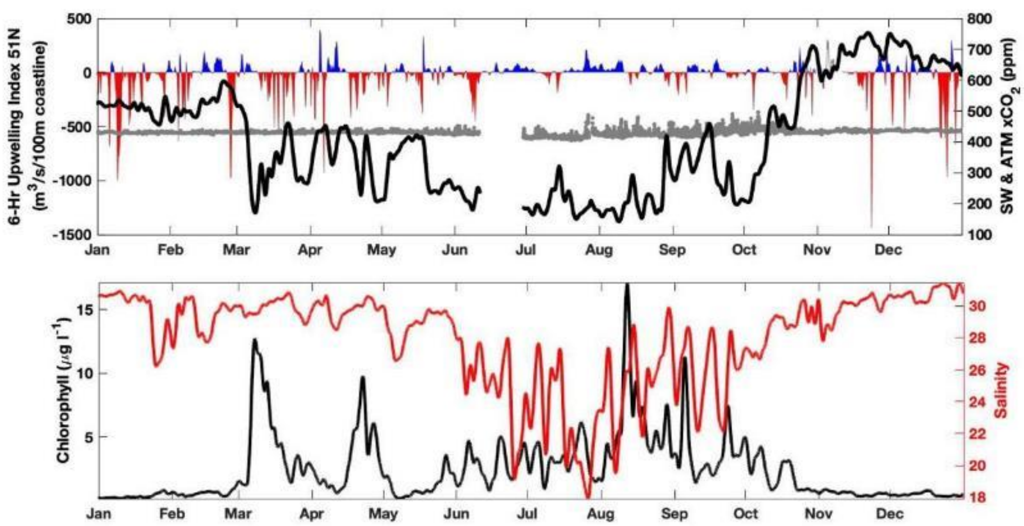

Figure 36-1. Top panel is seawater xCO_2 (black, ppm) and atmospheric xCO_2 (gray, ppm) with the 6-Hr Upwelling Index for 51°N ($m^3/s/100$ m coastline) from NOAA. The bottom panel is chlorophyll content (µg l^{-1}) and salinity (reported on PSS-78) from the KC buoy.

Large (~10 unit) summer reductions in salinity occurred at both locations due to high freshwater content (Figures 36-1 and 36-2). Summer freshwater content was higher at both sites compared to previous years (data not shown). While undersaturated pCO_2 conditions with respect to the atmosphere were maintained at KC10 in addition to higher but variable chlorophyll (Figure 36-1), Ω_{arag} was suppressed at QIFS during the period of greatest freshwater content (Figure 36-2).

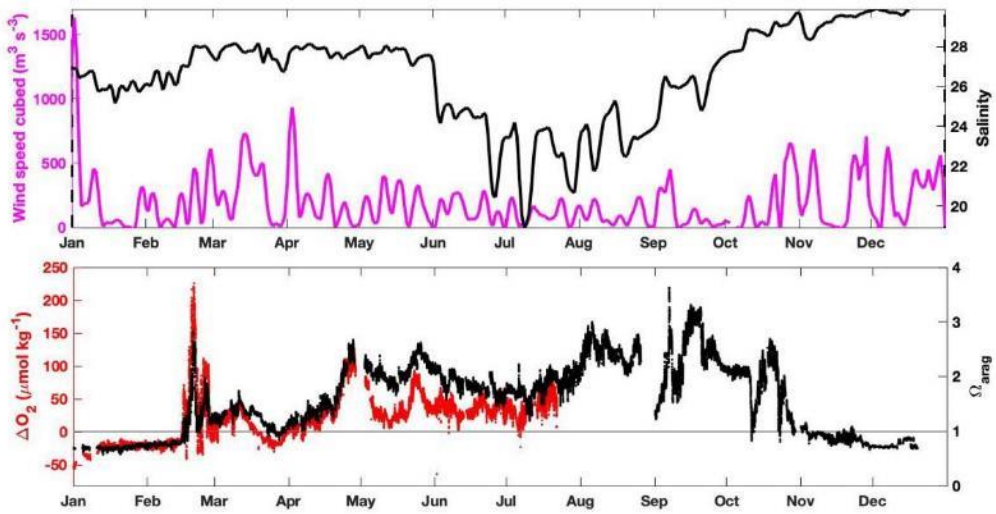

Figure 36-2. Top panel is wind speed cubed (magenta, m^3 s^{-3}) from the ECCC Sentry Shoal mooring and salinity from the QIFS. The bottom panel is ΔO_2 (µmol kg^{-1}) from an instrument package located on our test mooring in Hyacinthe Bay at 1 m depth, and Ω_{arag} if from the QIFS.

Following the minima in summer salinity at both sites, a quiescent period of wind conditions coincided with reduced seawater pCO_2 at the KC buoy (Figure 36-1) and elevated Ω_{arag} at the QIFS prior to the arrival of stormy conditions in late October. These marine CO_2 conditions reflect the presence of autumn phytoplankton blooms. Elevated chlorophyll content at KC10 provides further evidence that appreciable phytoplankton biomass persisted into mid-October.

36.3.2. Deep water conditions

Figures 36-3 and 36-4 show patterns in Ω_{arag} and Ω_{cal} through the water columns at KC10 and QU39. Undersaturated conditions that would be corrosive to the biominerals aragonite and calcite were evident at depth at both locations throughout each time series. At QU39, calcite undersaturation also coincides with periods of very low pH (values < 7.55). Notably, both sites have exhibited slightly improved Ω conditions since 2020. The vertical and temporal extent of severely corrosive conditions has declined, as has the magnitude of severely corrosive conditions (Figures 36-3 and 36-4). This shift in conditions is counter to the expected changes due to increasing anthropogenic CO_2 content (Evans et al. 2022; Evans et al. 2019).

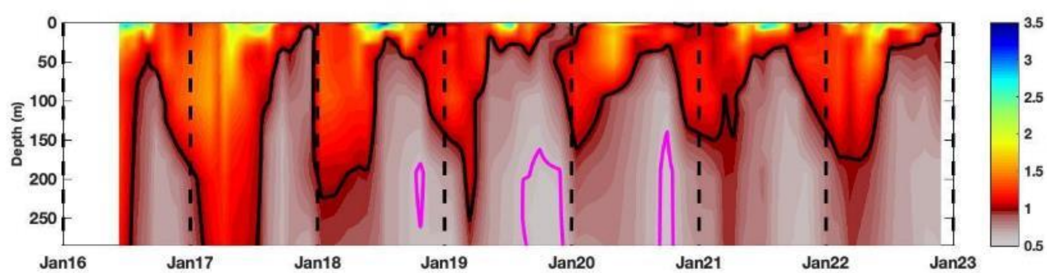

Figure 36-3. Ω_{arag} through the water column at KC10 beginning June 9, 2016 and ending November 26, 2022. The black line denotes Ω_{arag} equal to 1, with deeper waters exhibiting lower Ω_{arag} values that are corrosive to aragonite. The magenta line marks seawater with Ω_{cal} equal to 1. Calcite undersaturation (Ω_{cal} < 1) was evident at this site in 2018, 2019, and 2020, although the levels of corrosive conditions have decreased since 2020.

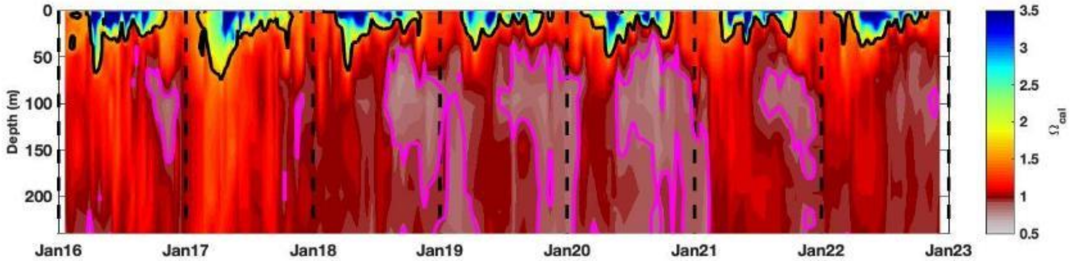

Figure 36-4. Ω_{cal} through the water column at QU39 beginning January 19, 2016 and ending December 6, 2022. The black line denotes Ω_{arag} equal to 1, with deeper waters exhibiting lower Ω_{arag} values that are corrosive to aragonite. The magenta line marks seawater pH equal to 7.55. Extremely low pH (values < 7.55) and calcite undersaturation have been observed every year, although the vertical and temporal extent of these conditions has decreased since 2020.

36.4. Factors influencing trends

The most surprising trend in these time series is the reduction in severely corrosive conditions at depth at KC10 and QU39. It is known that interannual variability can modulate patterns in long-term trends (Crawford and Peña 2016; Hauri et al. 2021), and Figure 36-5 suggests that NPGO might play a role in explaining the reduction in severely corrosive conditions at these sites. However, the mechanisms are not clear. NPGO reflects inter-annual variations in wind-driven upwelling and horizontal advection across the Pacific basin (Di Lorenzo et al. 2008), but the factors influencing these trends likely go beyond the strength of upwelling and the character of deep source water entering these nearshore zones.

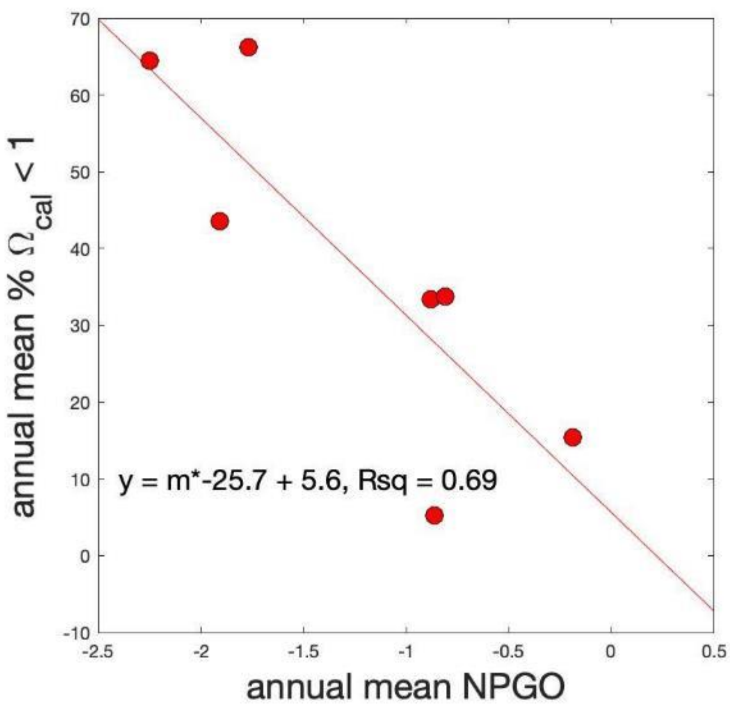

Figure 36-5. Annual mean NPGO versus the annual mean percentage of the water column at QU39 with Ω_{cal} < 1.

36.5. Implications of those trends

Variations in surface seawater conditions at these nearshore locations have implications for vulnerable life stages of species impacted by ocean acidification. Transitions back to winter-like conditions following early season phytoplankton blooms potentially lead to adverse, but yet undetermined, effects on spawning species during spring. The reductions in Ω_{arag} that coincide with large declines in salinity during summer may have similar effects.

The recent trends in deep water Ω_{arag} and Ω_{cal} reflect modulation by inter-annual variability. This variability is currently dampening ocean acidification trends, however, a return to conditions that favor more corrosive Ω_{arag} and Ω_{cal} levels may magnify those trends such that extreme temporal and spatial extents of severely corrosive conditions manifest. Continued observations are essential to track these conditions and determine the underlying mechanisms.

36.6. References

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37. SALISH SEA TEMPERATURE, SALINITY AND OXYGEN OBSERVATIONS IN 2022

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37.1. Highlights

- 2022 spring conditions were generally cooler, saltier and less oxygenated than normal (1999-2022) in the Salish Sea.
- 2022 summer conditions were warmer, fresher and more oxygenated than normal near the surface but colder, saltier and less oxygenated than normal below. Thus, stronger summer stratification than normal occurred in 2022, overall.
- 2022 fall conditions were notably warmer at the surface (Strait of Georgia in particular), as well as saltier (Juan de Fuca) and less oxygenated overall (most depths) than normal.
- The 24 year (1999-2022) trends indicate increasing temperature and decreasing oxygen throughout the system at all depths and salinity is generally trending towards fresher conditions at the surface and saltier conditions at depth.
- The Fraser River annual discharge was near-normal in 2022 but with a late peak (~1 month) and below normal fall conditions. The long-term trend is positive, i.e. increasing discharge over time (1912-2022).

37.2. Description of the time series

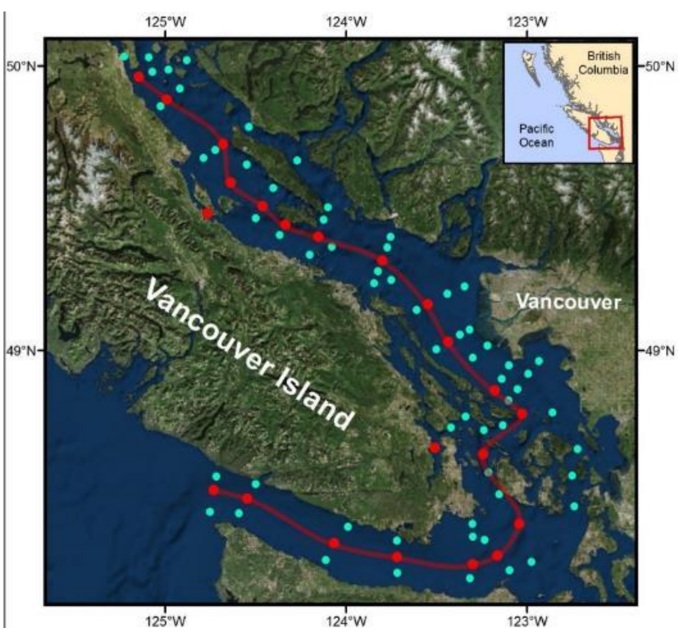

Figure 37-1. Dots show the locations of stations sampled during the water properties surveys. The thalweg is shown as the red line joining the deepest stations along the centerline of the straits.

Changes in the water properties of the Strait of Georgia and Juan de Fuca Strait have been monitored regularly since 1999 via a seasonal survey occurring 3-4 times a year. Conductivity-Temperature-Depth (CTD) profiles and bottle samples using a SeaBird 911 CTD installed on a rosette are collected during those surveys at about 80 stations (25 with bottles; Figure 37-1). These profiles and samples can then be used to study the physical, chemical and biological conditions of the area. The latest conditions and evolution of three parameters, taken along the main thalweg, are presented in this document: temperature, salinity and dissolved oxygen. Data collected are used to calculate long-term averages and identify the 2022 anomalies from these average conditions (defined as “normal”).

In 2022, surveys were carried out April 1-6, June 23-29, and October 5-11.

37.3. Status and trends

Observations of temperature, salinity and oxygen made in 2022 are compared to the 1999-2022 averages (24-year climatology) and shown as anomalies in Figures 37-2 to 37-4. During the April survey, temperature conditions were generally cooler than normal all along the thalweg except towards the northern end where it started to reach above normal conditions. Conditions were clearly saltier within the Juan de Fuca but fresher in the Boundary Pass (an area subject to strong vertical mixing). In the Strait of Georgia, salinity conditions were slightly saltier than normal. With respect to oxygen, spring conditions were mostly below normal, particularly within the Juan de Fuca strait. In the Strait of Georgia, some patches of higher than normal oxygen concentration occurred, potentially related to local (and patchy) areas of active primary production.

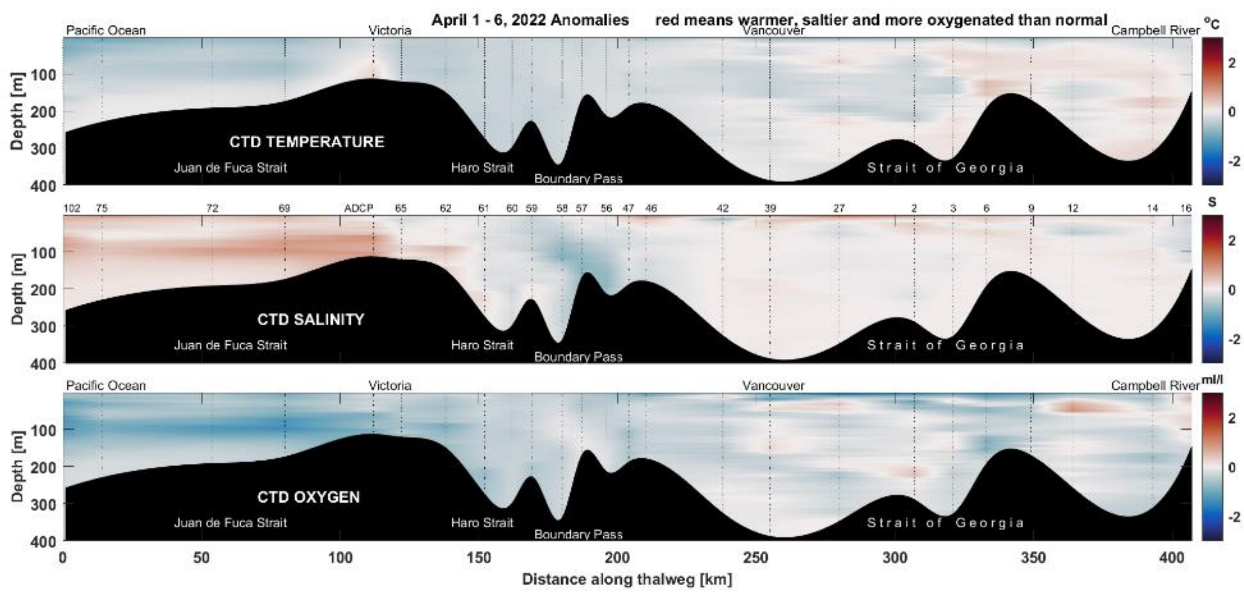

Figure 37-2. Temperature (°C), salinity (S) and oxygen (mL/L) anomalies along the thalweg observed in the spring of 2022.

In June, surface waters were warmer and fresher than normal along most of the transect, particularly to the north of the Boundary Pass. Below this surface layer, varying in depth (thicker in the Juan de Fuca and thinner in Strait of Georgia), waters were colder and saltier (up to and including the Boundary Pass); suggesting stronger than normal stratification. In the Strait of Georgia, sub-surface salinities were largely near-normal. In the Juan de Fuca and Haro Strait, dissolved oxygen patterns resembled that of temperature: low concentration associated with cold temperatures and vice-versa. This is contrary to oxygen natural dissolution (lower in warmer waters) and reflect the effect of deep and cold Pacific water of low oxygen concentration advection to the Salish Sea during the upwelling season (Masson 2006).

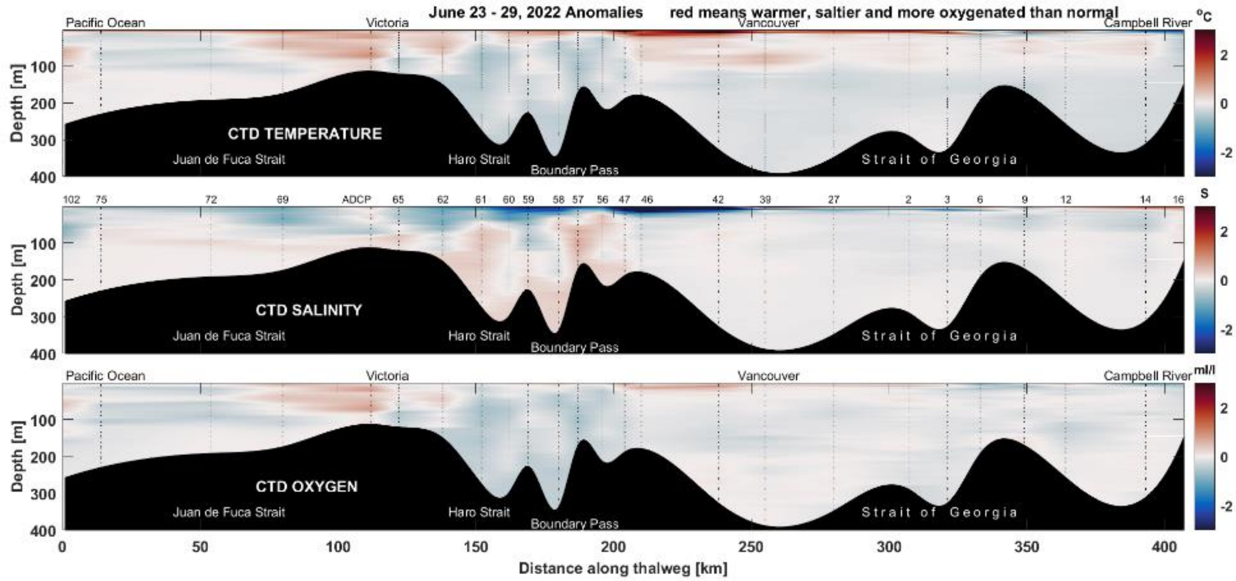

Figure 37-3. Temperature, salinity and oxygen anomalies along the thalweg observed in the summer of 2022.

In October, the warm surface anomaly was still well-present and had even extended through the water column in Haro Strait and Boundary Pass. It was also thicker and stronger in the Strait of Georgia. Stronger, subsurface cold anomaly was also present in Juan de Fuca, indicating a lasting effect of the upwelling season (and/or estuarine circulation). This was also reflected by the low oxygen concentration present in the area. Lower than normal oxygen concentration was also present through the remaining part of the transect, although to a lesser degree. One can also note the presence of a strong signal of a nearly vertically homogeneous positive anomaly of temperature and negative anomaly of salinity at station 58 (Boundary Pass); possibly due to a strong mixing event.

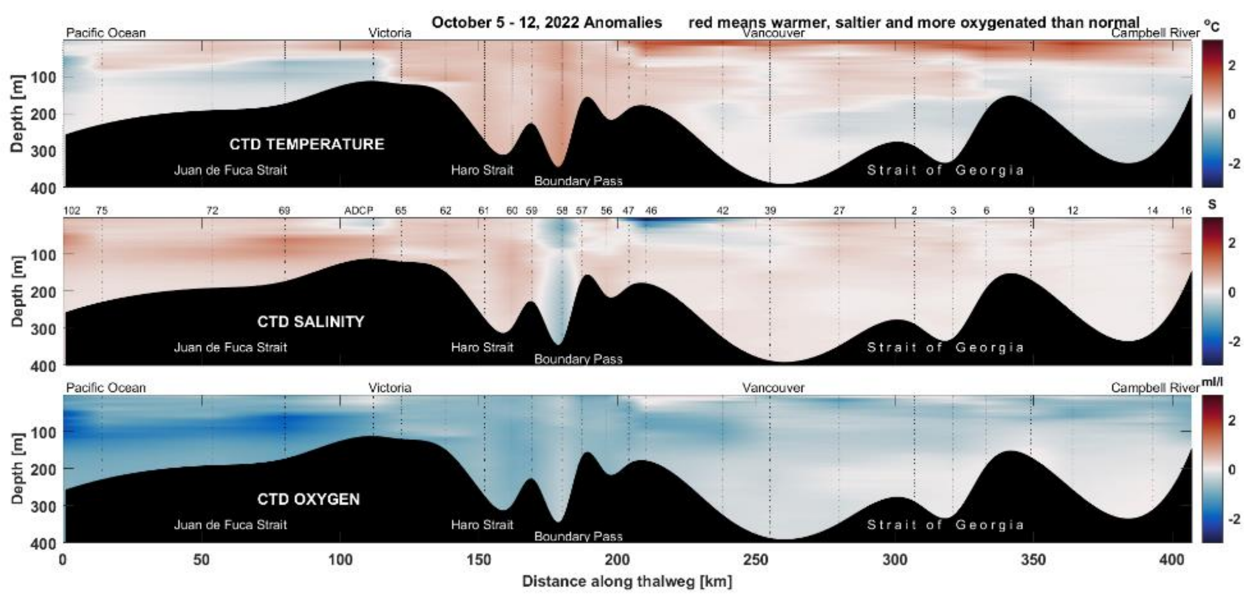

Figure 37-4. Temperature, salinity and oxygen anomalies along the thalweg observed in the fall of 2022.

The Fraser River discharge influences the salinity of the surface waters of the central and southern Strait of Georgia, and is a driving force for the Vancouver Island buoyancy current that flows northwards along the west coast of Vancouver Island. The 2022 annual discharge of the Fraser River measured at Hope, B.C. (see Figure 37-5) was slightly above average (93.1 km^3 vs. 86.0 km^3; an 8% increase) and the annual discharge of the Fraser River is increasing at a rate of 4.49 $x10^9$ m^3 per 100 years.

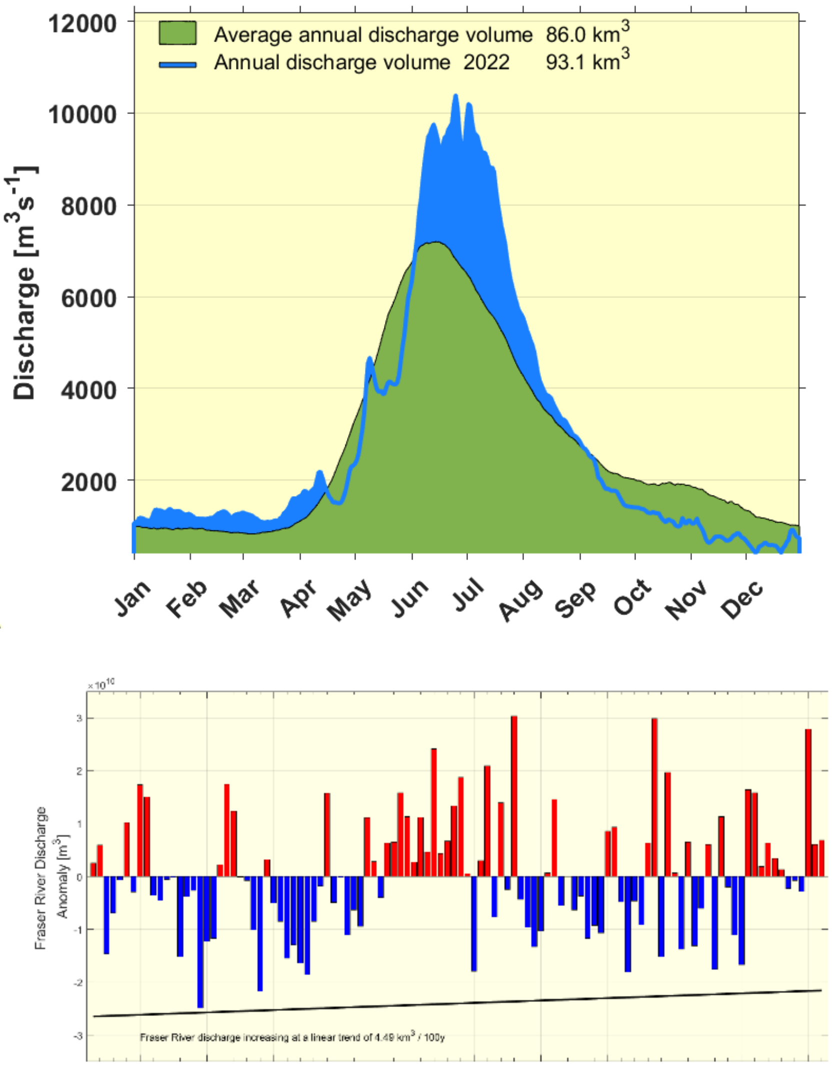

Figure 37-5. (Upper panel) Fraser River discharge at Hope B.C.; 2022 (blue), 111 year average (green). (Lower panel) The time series of the annual Fraser River discharge anomaly. Extracted from the Environment and Climate Change Canada Real-time Hydrometric Data web site, station number 08MF005, "FRASER RIVER AT HOPE" (https://wateroffice.ec.gc.ca/mainmenu/real_time_data_index_e.html) on 30 Jan 2023.

37.4. Factors influencing trends

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

37.5. References

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38. OCEAN OBSERVATORY CONTRIBUTIONS TO ASSESSING 2022 SOUTHERN B.C. COASTAL CONDITIONS

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38.1. Highlights

- Winds of southern Vancouver Island were light in February 2022, perhaps contributing to an early phytoplankton bloom in the Strait of Georgia (Esenkulova et al., Section 42).
- The spring transition to upwelling winds was 50 days later than usual (June 10, 2022).
- The fall transition to down-welling was late (October 14, 2022).
- A cool weather outbreak in May delayed the Fraser River freshet by 3 weeks.
- The deep water renewal season for the Salish Sea was late to start and extended well into the fall (late October).
- CODAR data coverage was poor during the large and delayed Fraser River discharge.

38.2. Description of the Time Series

Here we report on several time series recorded from a number of permanent installations, including upwelling winds west of Cape Flattery, cabled platforms in the Strait of Georgia, Fraser River discharge (Hope), and the High-Frequency CODAR Radar derived surface currents (Figure 38-1).

1. NOAA Reanalysis Upwelling Index (48°N 125°W), the Bakun Upwelling index, is available from the NOAA Pacific Fisheries Environmental Laboratory website:

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

   The derived Bakun Upwelling Index takes the daily average scaled (by f) along-shore wind stress component derived from reanalysis (re-constructed surface pressure fields) resulting in a volume estimate of the amount of ocean transported off (positive - upwelling) or on-shore (negative – down-welling) per 100m of coastline. The daily upwelling indices are summed cumulatively for each year, revealing the winter/fall down-welling, summer upwelling strength and seasons (spring and winter transitions).
2. Fraser River discharge (m^3/s) measured at Hope is available from the Water Office of Environment Canada (https://wateroffice.ec.gc.ca/index_e.html). Data from 1912 to 2022 has been obtained and used in the following analysis.
3. Ocean Network Canada's (ONC's) Strait of Georgia Central cabled observatory platform (300m) at 48° 59.6'N 123° 2.75'W includes a CTD & O_2 record extending back to 2008. Data were used to detect deep water renewal events, which were linked to weak mixing periods associated with neap tides (Soetaert et al. 2022)

4. CODAR (HF Radar) data from the southern Strait of Georgia provided wide regional coverage of ocean surface currents throughout 2022 from four shore-based antennae at: Pt Atkinson, Iona, West Port, and Georgia Pt.

Figure 38-1. Southern coast of B.C., showing ONC's installed and instrumented ocean observing assets. Sites where data will be shown have been highlighted with red circles (NOAA Upwelling [48°N 125°W], CTDs and CODAR in southern Strait of Georgia.

38.3. Status and Trends

38.3.1. Upwelling

The coastal waters of B.C. and the Salish Sea are strongly influenced by upwelling conditions along the West Coast. For the Salish Sea, this includes the region near the southern continental shelf and entrance to Juan de Fuca Strait. Prevailing summer winds blow towards the south, are associated with the development of the North Pacific High-pressure zone off the west coast of North America, and are upwelling-favourable. North bound winds are generally associated with winter and stormier conditions (pineapple express), the establishment of the Aleutian Low in the Gulf of Alaska, and are down-welling-favourable. Summer upwelling winds push surface (warm and fresh) waters off-shore, bringing deeper off-shore (salty nutrient rich) waters closer to shore at depth, and into the Juan de Fuca Canyon and Strait. During down-welling (winter) conditions, warmer, fresher surface waters are pushed towards the coast, pushing down the deeper salty, nutrient rich waters. For the cumulative upwelling plot (Figure 38-2), downward trending segments indicate down-welling (negative index) conditions and upward trending segments indicate upwelling (positive index) conditions.

Early in 2022, the typical southerly down-welling winter winds were weak from mid-January to late February. It is possible these February light wind conditions may have resulted in some in-shore phytoplankton blooms. Steady but weak down-welling favourable winds prevailed from March through to early June, and local weather remained cool until mid-June (Victoria had one of the coldest Mays on record). The northerly wind, upwelling season (**spring transition**) was late, starting (at this Cape Flattery location) on **June 10** (57 year average start is April 26). Upwelling winds were not strong (only 60% of the average net upwelling), but steady all the way through to early October, when down-welling winds returned after **Oct 14** (average end is Sept 16). As such, for the southern coast of B.C., the upwelling season was relatively late (by 50 days) and prolonged.

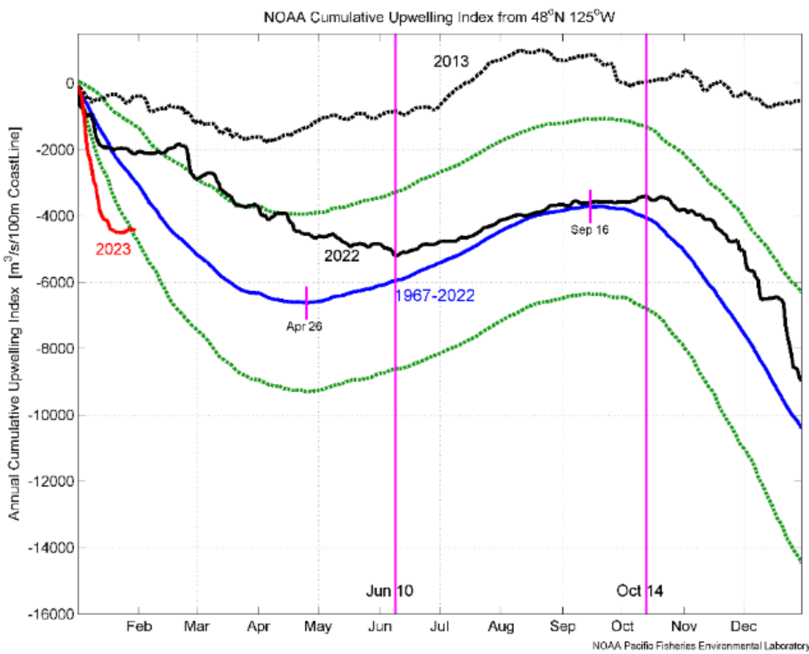

Figure 38-2. The cumulative daily upwelling index from reanalysis wind stress at 48°N 125°W, west of Washington State (Figure 38-1). Downward (down-welling, negative indices) trends occur during northward winds (winds from the south) and upward (upwelling, positive indices) trends occur during southward winds (winds from the north). 2022 is shown in a solid black line. The blue curve is the long-term (57 year) average, with plus and minus one standard deviations (green dashed curves). 2013 is shown as the weakest down-welling year on record, contributing to the development of the warm blob in the Northeast Pacific. The vertical lines indicate the late beginning (June 10) and delayed end (Oct 14) of the 2022 upwelling season.

38.3.2. Estuarine Circulation and Deep Water Renewal

Shown in Figure 38-3 are 2022 temperature and salinity records from ONC's Strait of Georgia (SoG) Central station at 300m depth (Figure 38-1). Temperatures generally decline in winter from surface cooling and increase during the summer from surface heating. Salinity declines in the winter from rainfall and increases in the summer during the upwelling season. These general trends are punctuated by cool/fresh (dense) intrusions in the winter (when temperature is dictating density) and warm/salty (dense) intrusions in the summer (when salinity is dictating density). The intrusions are a result of vertical (top-to-bottom) mixing by tides. In the winter, the surface waters are cool and fresh (and oxygenated, not shown). While in the summer, surface waters are warm (and oxygenated), and deep upwelled waters are salty (and rich in nutrients). Both sets (seasons) of intrusions represent dense seawater passing by the SoG Central station, in transit to deeper depths. Biologically, the cold winter intrusions (March, April, and May) bring higher oxygen levels (ventilation), while the salty summer intrusions (June– Oct) bring nutrients. Both of these deep water renewal seasons represent means of maintaining the general health of the Salish Sea.

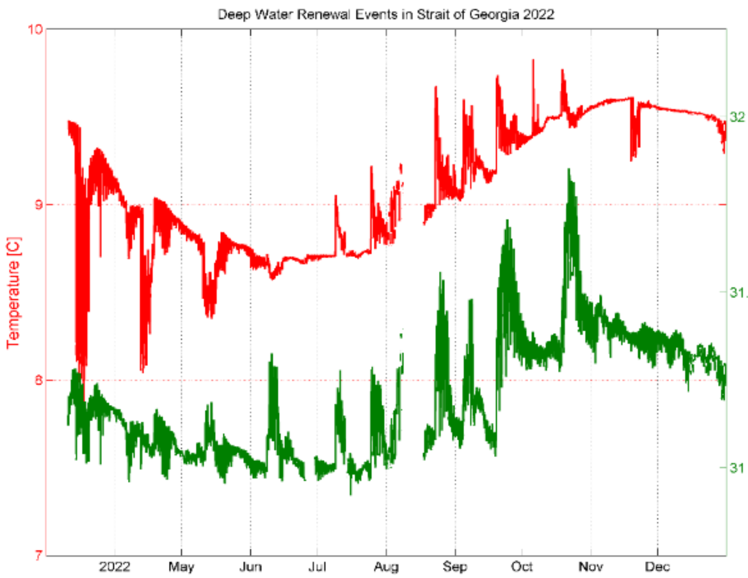

Figure 38-3. 2022 (March through December) time series of temperature (red) and salinity (green) from the cabled station at Strait of Georgia Central (300m) located in the central southern strait (Figure 38-1). Temperatures generally decline in winter from surface cooling and increase during the summer from surface heating. Salinity declines in the winter from rain fall and increases in the summer during the upwelling season. These general trends are punctuated by cool/fresh intrusions in the winter and warm/salty intrusions in the summer. (see text for an explanation)

38.3.3. Fraser River Discharge

Dictated by large-scale atmospheric conditions, the cool spring in 2022 and later summer also caused a later than usual freshet from the Fraser River. Shown in Figure 38-4 is a plot of the historical Fraser River discharge in m^3/s at Hope, averaged into three decade climate periods, and the discharge for 2022 (in red). While early discharge seems to be on track to be increasing in mid-May, a cool weather outbreak in mid-May delayed the freshet by about 3 weeks (Figure 38-4). When combined with the later onset of coastal upwelling along the west coast, there is a cumulative impact of a late or delayed deep water renewal season for the Salish Sea.

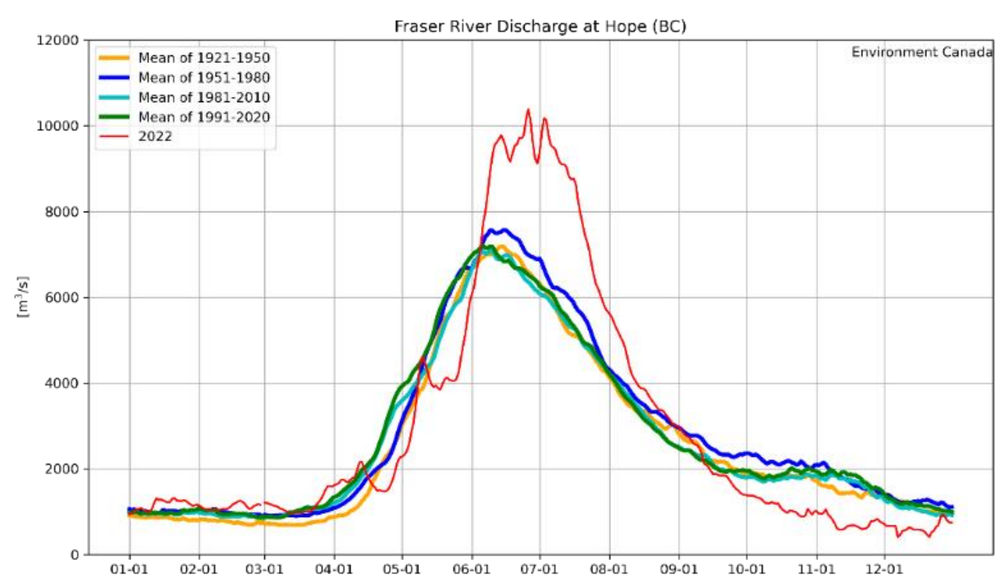

Figure 38-4. Fraser River discharge (m^3/s) at Hope as reported by Environment Canada. Shown are three 30 year climate averages and the discharge curve for 2022 (red). A three week cooling period in May 2022 delayed the freshet, which then peaked in late June (rather than early June) at relatively high levels (10,000 m^3/s).

38.3.4. Deep Water Renewal Season in the Salish Sea

The combination of a late spring upwelling transition and a late Fraser River freshet resulted in a late, yet prolonged deep water renewal season (Masson 2002) in the 2022. Shown in Figure 38-5 are the start and end periods of the deep water renewal seasons as recorded by dense salty intrusions at the cabled observatory installations in both Saanich Inlet and the Strait of Georgia. In all cases, the deep water renewal events are aligned with the weaker neap tides that occur each month (Masson 2002; Soetaert et al. 2022; Masoud and Pawlowicz 2023). As such, the temporal resolution of the "deep water renewal season" (Figure 38-5) is a week. The deep water renewal season in 2022 was relatively late, second week in June (but not as late as 2021), and ended the last week in October, the latest end in this 17 year record. Also shown (Figure 38-5) is the average deep water renewal season (red), with minus and plus one standard deviation for the start and end weeks, respectively (red).

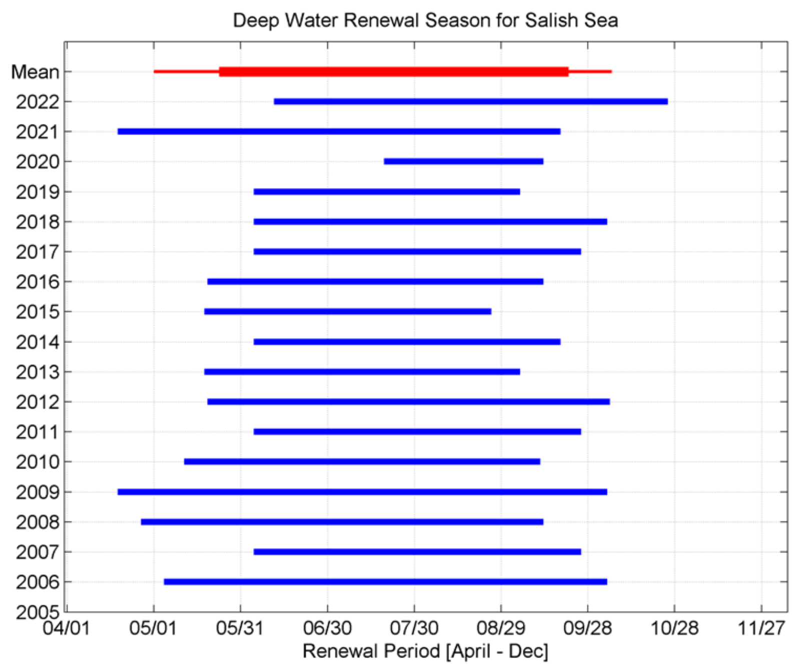

Figure 38-5. The deep water renewal season as revealed by the ONC Salish Sea (Saanich Inlet and Strait of Georgia) CTD & O_2 time series. Deep water renewals can occur during the weakest neap tides of each month (e.g. Soetaert et al. 2022) from early summer to early fall. 2022 was one of the latest and longest renewal seasons for the 17 year ONC record (since 2006).

38.3.5. CODAR Surface Currents

ONC's Strait of Georgia CODAR (HF Radar) surface currents produces hourly maps of the surface currents throughout the southern central Strait of Georgia. The system consists of four shore-based CODAR stations (Figure 38-1) that transmit high frequency radar signals and determine Doppler velocities from the Bragg-enhanced back-scattered signal. This technology can generally “see” over the horizon, since the electromagnetic waves couple with the salty (conductive) seawater. However, during the Fraser River freshet, the surface waters of the Strait experience a significant reduction in salinities, with large regions experiencing values typically below 20 g/kg, and at times below 10 g/kg. When salinities drop below 15 g/kg, HF radar signals de-couple from the surface, and there is poor or no CODAR backscatter. Shown in Figure 38-6 is a plot showing the timing and volume of the Fraser River discharge (top panel) and the percent good (% of cells with valid data) of CODAR surface current data. Due to the late discharge, poor CODAR data was evident from late June through to August, 2022.

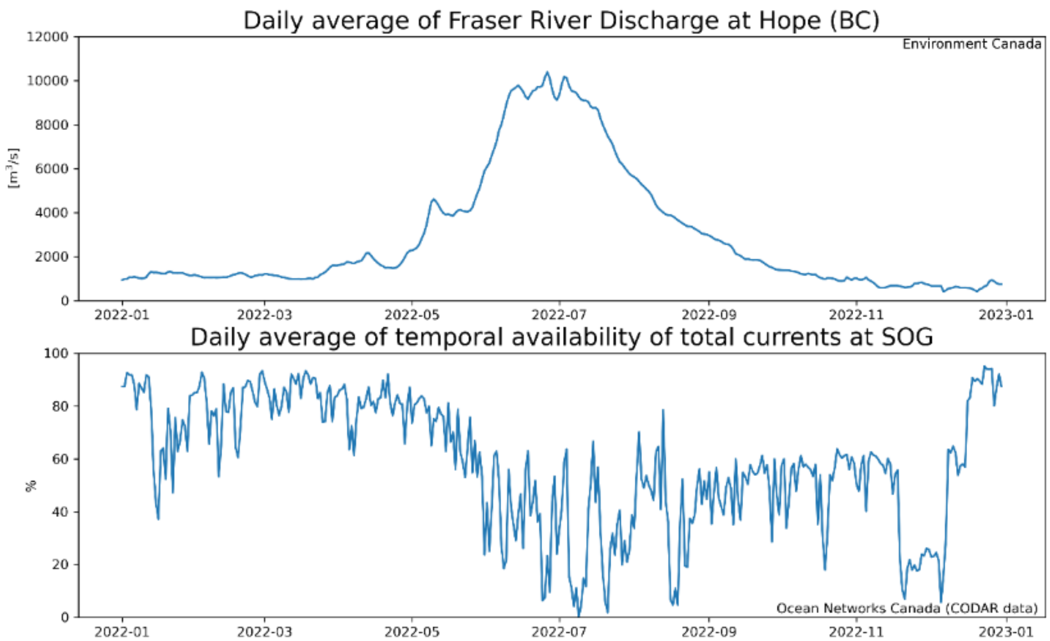

Figure 38-6. The Fraser River discharge [m^3/s] at Hope (top) and the percent good (# of cells returning good daily data) CODAR data for the Strait of Georgia. The slightly late freshet, resulted in a drop in CODAR data coverage from late June through into August.

38.4. Factors affecting trends

It is worth noting some basic water property sources, as we attempt to interpret variations in the Salish Sea. As a large estuary, salinity (salt concentration) can only increase with input from the Pacific Ocean, and generally from greater depths, either through direct transport or wind or tidally induced vertical mixing (upward). Similarly, surface salinities are generally lower, so a decrease in salinity occurs when surface waters are either advected to a site or mixed downward. Linked with the higher salinity deep Pacific waters are higher nutrient concentrations, as the fresh water (river discharges) is relatively low in most core oceanographic nutrients (Nitrate and Phosphate). Increases in salinity can therefore be a proxy for an increase in nutrients. Throughout the Salish Sea, salinities usually decline during the rainy winter months at nearly all depths, and expect for the near river mouths, increase during the summer upwelling season.

For temperature, there are also simple sources and seasonal variations. Warmer temperatures can usually only come from near surface waters heated by solar radiation (in the summer/early fall). Colder temperatures come from winter surface cooling (ventilation), or in the summer from cooler upwelled deep Pacific waters.

While not a conserved quantity, oxygen concentration has a few processes that cause observed variations. Oxygen is infused (increases) only in the upper layers of the ocean, either by in-gassing from the atmosphere or from phytoplankton primary production. Deep waters are never a source for increasing oxygen levels. Below the surface layers, oxygen will steadily decline as a result of respiration, either from higher trophic levels or microbial and bacteria remineralization processes.

Tidal generated turbulence provides a mechanism for mixing water properties vertically. For every unit of surface waters mixed downwards, an equal unit of deep water is mixed upwards. In other words for every kg of fresher surface water mixed downward, a kg of saltier water is mixed upward. If the surface waters are cold (winter), then tidal mixing causes deeper waters to cool. If the surface waters are warm (summer), tidal mixing causes deeper waters to warm. While properties are mixed uniformly, seawater density is a non-linear equation of temperature and salinity. For most of the Salish Sea, salinity variations dominate the density differences, very cold temperatures can dominate seawater density in the late winter.

The Salish Sea is a large estuary, with a sustained estuarine circulation driven by rain run-off from coastal rivers in the winter and snow melt and the freshet of the Fraser River in the summer. For a typical year, fresh water discharge into the Salish Sea across the seasons is relatively uniform. While snow packs were high in the winter of 2022, rain in the summer and fall were well below normal. When combined with coastal upwelling along the West Coast in the summer months, the exchange flow of the estuarine circulation brings deeper Pacific Ocean waters in through Juan de Fuca into the Salish Sea. This water is characterized by elevated salinities and high nutrient content. Tidal turbulence in the constricted passageways in the Gulf and San Juan Islands introduces vertical mixing of the fresher surface waters with the deeper saltier waters. Spring-neap variations over a month, modulate this mixing (strong during spring tides, weak during neap tides) and therefore modulates the surface and deep water properties.

The spring-neap modulated mixing establishes variations in the water properties of the estuarine exchange flows exiting and entering the Salish Sea (Masson 2002). During spring tides, the turbulence and associated mixing is sufficiently vigorous as to nearly homogenize the vertical distributions of heat and salt. This results in an estuarine circulation with slightly saltier water at the surface (exiting) and slightly fresher water (entering) at depth. During the neap tides, when turbulence is weaker and the vertical mixing rates are reduced, the out-going surface waters remain fresher, and the deep inbound waters remain saltier. The large salinity gradients tend to dictate the seawater density, and as such, deep water renewal events tend to occur when the highest density (saltiest) waters flow into the deep basins of the Salish Sea, during, or just after, the neap tides. This is well represented in two recent papers by Soetaert et al (2022) and Masoud and Pawlowicz (2023) on deep water renewals into Saanich Inlet and the Strait of Georgia, respectively.

38.5. Implications of trends

In 2022, the major characteristics recorded by ONC for the southwest coast of Vancouver Island included a late and prolonged upwelling season, of moderate (60%) net strength. The Fraser River freshet was also delayed by cooler temperatures in May 2022. This combination may have contributed to a late and sustained deep water renewal season for the Salish Sea.

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39. THE SMALL AND SMALLER: TIME SERIES OF PHYTOPLANKTON AND PROKARYOPLANKTON FROM THE CENTRAL COAST AND NORTHERN SALISH SEA WITH A FOCUS ON 2022 AND LINKS TO PHYSICOCHEMICAL VARIABILITY

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39.1. Highlights

- The earliest spring blooms of the Hakai Institute northern Salish Sea (QU39) and central coast (KC10) monitoring sites (monitored since 2015) were observed in 2022.
- Station QU39 showed moderate positive diatom anomalies during autumn blooms in September and November. Station KC10 showed a large diatom and dinoflagellate bloom in August during nutrient depleted, warm and high stratification conditions.
- Late in 2021 to early 2022, there was a decline in several groups of chemoautotrophic prokaryoplankton except Marinimicrobia, key in nitrogen and sulfur cycling, which maintained a positive anomaly throughout much of 2022.

39.2. Description of the time series

Figure 39-1. Study area map showing the location of the central coast (KC10) and northern Salish Sea (QU39) sampling locations. Coordinates are provided within the text. Sampling at KC10 was performed monthly and at QU39 weekly.

Phytoplankton pigment and biomolecular time series were analyzed from two stations (QU39 and KC10) that are maintained by the Hakai Institute (Figure 39-1). For pigment analysis, filtered water samples (1 L onto 47 mm GF/F filters) from 5m depth were measured using high performance liquid chromatography (HPLC) at the University of South Carolina Baruch Institute using the USC method (Hooker et al. 2005). Chemotaxonomic (CHEMTAX) analysis was then used to derive estimates of phytoplankton functional group contributions (in terms of total chlorophyll *a* - TChla, mg m^{-3}) (Mackey et al. 1996). Analysis and input pigment ratios were the same as Del Bel Belluz et al. (2021), with the addition of the raphidophytes group for the KC10 data based on microscopic observations.

Biomolecular samples (2 L) were collected from 0, 5, 30, 100 m and near bottom from QU39 and KC10, filtered onto a 0.22-µm Sterivex filter, then stored at -70°C until extraction. DNA was extracted using enzymatic lysis followed by phenol:chloroform extraction and purification using Amicon filter columns (Hawley et al. 2017). Microbial community structure (prokaryotes and photosynthetic eukaryotes) was interrogated through Illumina amplicon sequencing of the V4-V5 region of the 16S rRNA gene (McNichol et al. 2021) using a fusion primer approach (Comeau et al. 2017). Resulting sequences were denoised using dada2 and annotated using the Silva 138 (prokaryotes) or PR2 (photosynthetic protists) reference sequence databases using the Naïve-bayes classifier as implemented in QIIME2. All sequencing was done at the Hakai Institute Quadra Island Ecological Observatory.

Physicochemical data were used to investigate trends in phytoplankton biomass and community composition. Salinity, temperature, density (used to derive stratification via $\Delta\rho_{30\text{-}3m}$) and freshwater content (FWC) were derived from Hakai CTD data. Nutrients were analyzed at the University of British Columbia (see Del Bel Belluz et al. 2021). For the QU39 phytoplankton pigment and microbial sequence data, monthly standardized anomalies were calculated following the methods used in Suchy et al. (2019) with ±1 representing moderate anomalies and ± 2 representing strong anomalies.

39.3. Status and Trends

39.3.1. Phytoplankton time series

In 2022, phytoplankton in the northern Salish Sea (NSS) generally followed expected seasonal trends with relatively small monthly TChla and diatom anomalies through much of the year (Figure 39-2). Of note, 2022 saw the earliest spring bloom onset of the time series (Feb. 18, 2022, TChla = 8.70 mg m^{-3}), developing after a period of sunny and calm wind conditions and increased stratification (Figure 39-3). Yet, this bloom was ultimately short-lived and terminated by wind mixing. As winds subsided, diatoms made a resurgence in April drawing nutrients to limiting conditions on May 3rd ($NO_3^- + NO_2^-$ = 0.12 μmol L^{-1}). In June, stratification and FWC increased ($\Delta\rho$ > 2.0 and FWC > 0.8) and this transition coincided with the succession to a high diversity of phytoflagellates. Similar to previous years in the time series, August nutrient renewal and drawdown events, associated with breaks in stratification, were not met with high TChla conditions. In September, a small autumn diatom bloom developed on September 20th (TChla = 4.29 mg m^{-3}) resulting in a moderate positive monthly diatom anomaly. Of note, diatoms resurged in November resulting in a moderate positive diatom anomaly for this month.

Similar to the NSS, 2022 showed one of the earliest (March 8, 2022, TChla = 19.35 mg m^{-3}) and strongest spring diatom blooms of the KC10 time series. The early spring bloom was observed during increases in stratification following a brief period of calm and sunny conditions (Figure 39-4). In addition, a large August dinoflagellate bloom, dominated by *Ceratium fusus*, was observed when the water column was highly stratified. High dinoflagellate contributions have only occurred in the last two years of the four-year CHEMTAX time series.

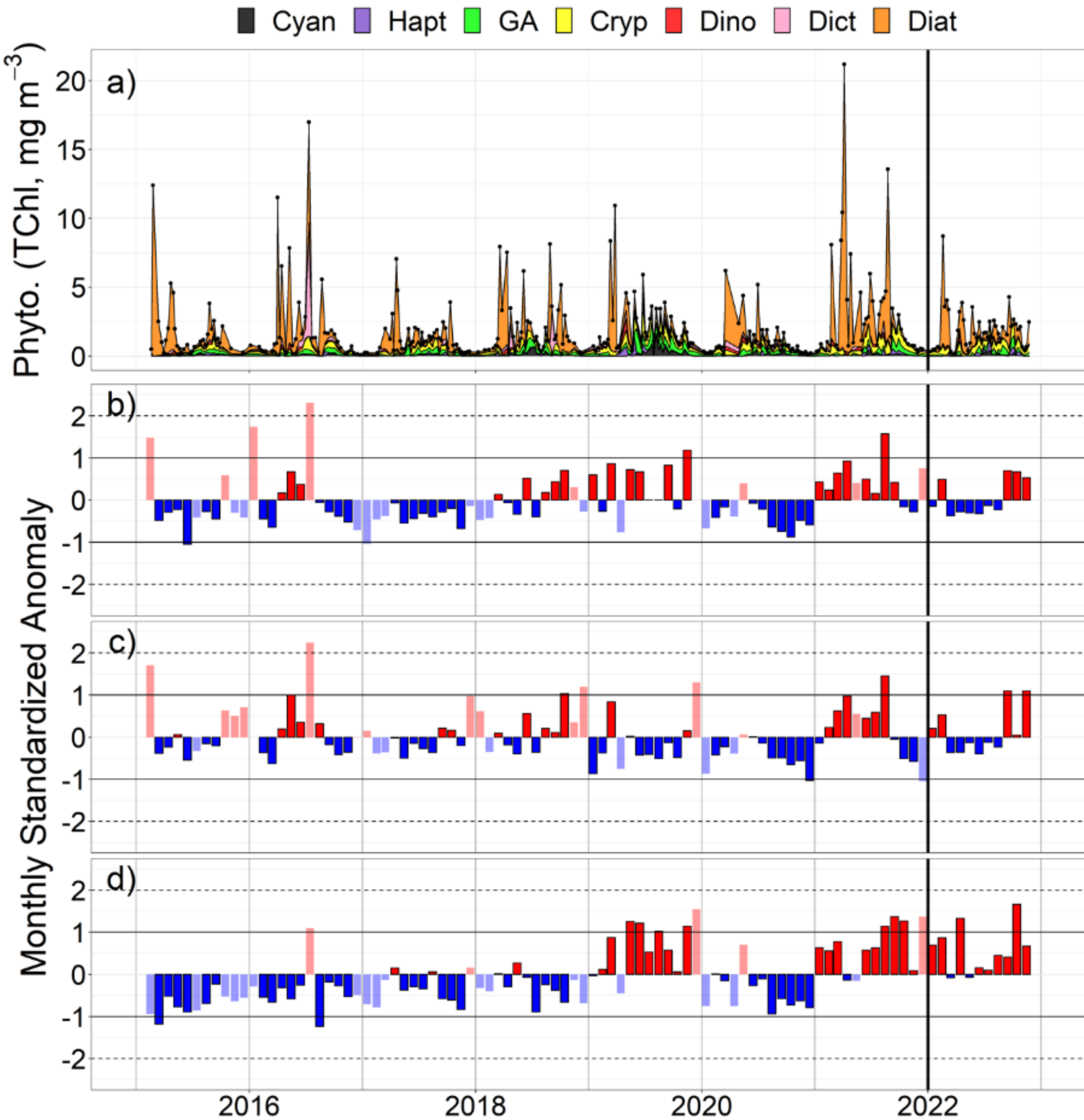

Figure 39-2. Station QU39 (northern Salish Sea) 5m depth 2015 - 2022 time series of a) CHEMTAX phytoplankton functional group contributions (TChla mg m^{-3}) and monthly standardized anomalies for b) TChla; c) Diatoms (Diat) and; d) Cryptophytes (Cryp). The groups shown in the CHEMTAX plot represent cyanobacteria (Cyan, black), haptophytes (Hapt, purple), green algae (GA, green), cryptophytes (Cryp, yellow), dinoflagellates (Dino, red), dictyochophytes (Dict, pink) and diatoms (Diat, orange). Monthly standardized anomalies were calculated following Suchy et al. (2019) with ± 1 (dashed horizontal lines) and ± 2 (solid horizontal lines) representing moderate and high deviations from the time series mean, respectively. Shaded bars represent months where < 3 samples were collected and may not represent robust monthly means. The solid vertical line delineates the start of 2022.

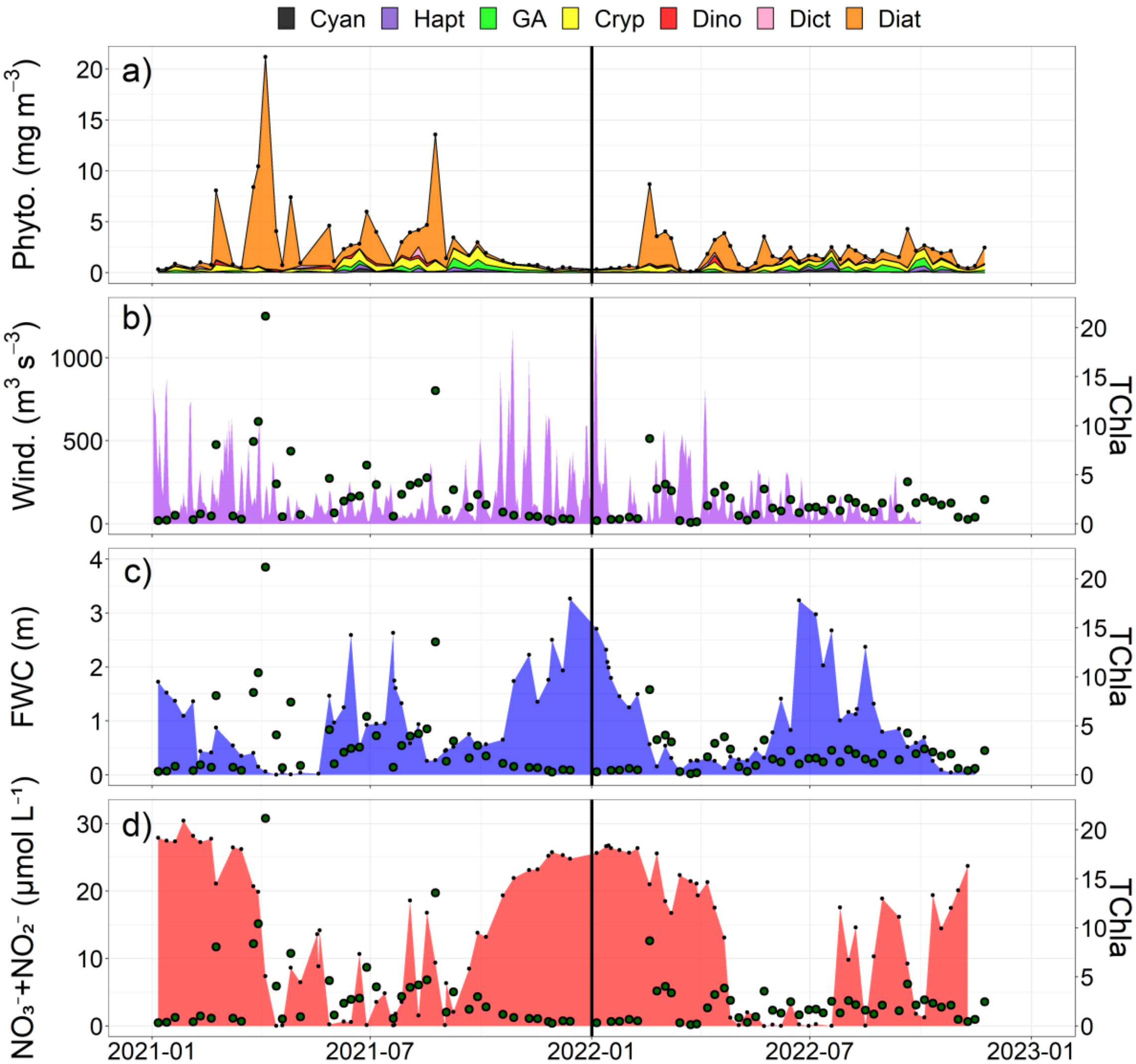

Figure 39-3. Station QU39 (northern Salish Sea) 2021 - 2022 time series of a) 5m depth CHEMTAX phytoplankton functional group contributions (TChla mg m^{-3}); b) wind speed cubed (m^3 s^{-3}) from the environment Canada Sentry Shoal Buoy; c) FWC calculated from Hakai CTD data and d) 5m depth $NO_3^- + NO_2^-$ (μmol L^{-1}). The right-y axis of b-d represents TChla and corresponds to the green dots. The solid vertical line represents the start of 2022. Phytoplankton group abbreviations and colours are described in Figure 39-2.

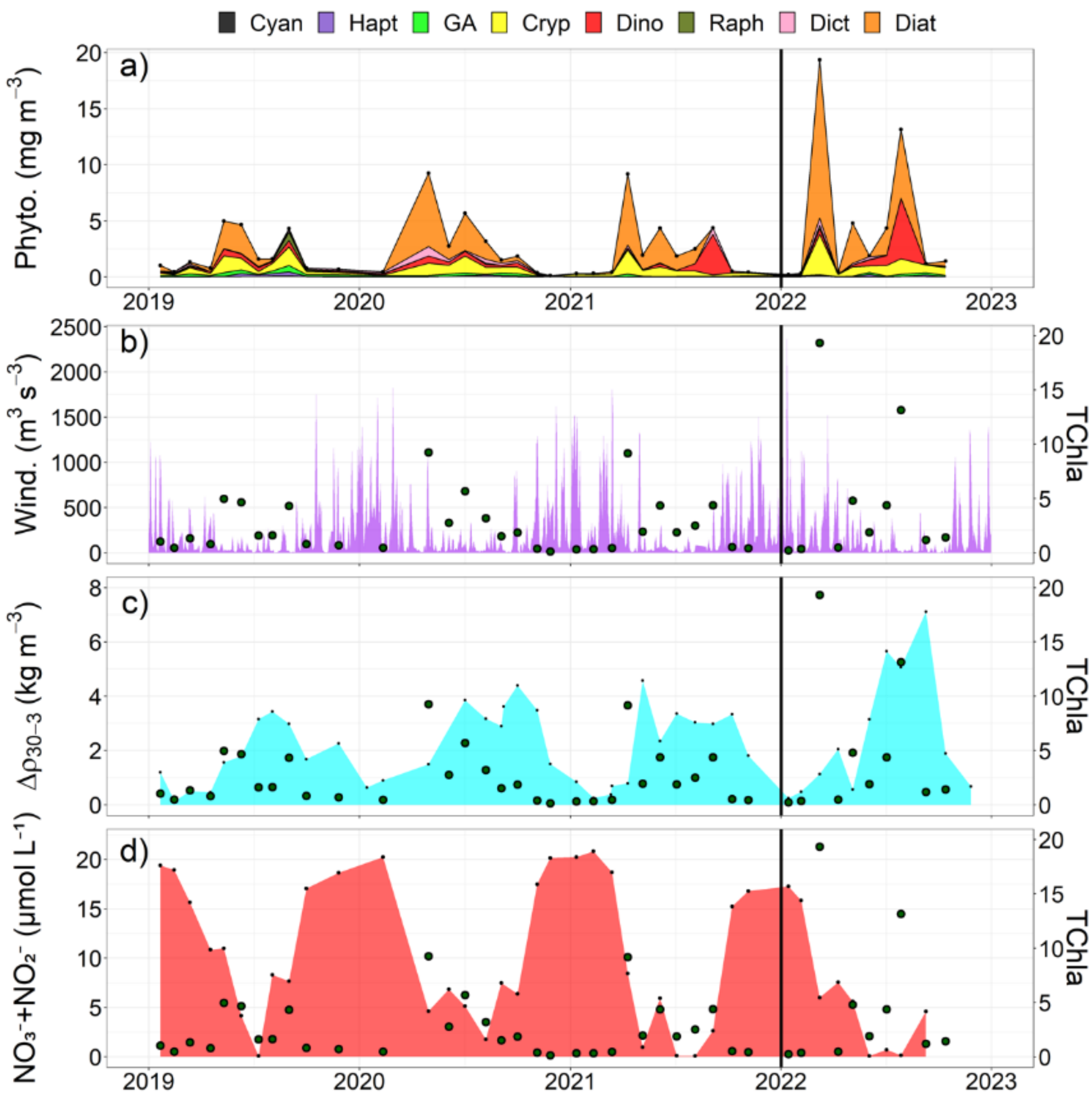

Figure 39-4. Station KC10 (central coast) 2019 - 2022 time series of a) monthly 5m depth CHEMTAX phytoplankton functional group contributions (TChla mg m^{-3}); b) wind speed cubed (m^3 s^{-3}) from the "Lookout" Hakai weather station; c) Δρ (kg m^{-3}) representing the difference in density between 30m and 3m depth and; d) 5m depth $NO_3^- + NO_2^-$ (µmol L^{-1}). The right-y axis of b-d represents TChla and corresponds to the green dots. The solid vertical line represents the start of 2022. Phytoplankton group abbreviations and colours are described in Figure 39-2 with exception the addition of the raphidophyte group (Raph, dark green) for this time series.

39.3.2. Biomolecular time series

Highlighting our findings in the intermediate waters at QU39, we observed that early in the time series temperature was on average warmer, the water fresher, with a larger range in dissolved oxygen, and generally lower pCO_2 concentrations. These conditions favored a larger contribution of a cosmopolitan group of bacteria, SAR11 (Figure 39-5). This oligotrophic group is known for its metabolism of simple carbon compounds and, in lower oxygen zones, has been found to reduce nitrate. Early in 2018 there was then a shift, with intermediate waters becoming colder, saltier, and having higher pCO_2. These conditions favored nitrifying and sulfur oxidizing microbial groups. Late in 2021 and into 2022, there was another shift in the intermediate waters that brought about a decline in these groups of chemoautotrophic bacteria that are key in nutrient regeneration and biogeochemical cycling in mesopelagic waters. An exception was Marinimicrobia, a metabolically diverse group of bacteria that are important in nitrogen and sulfur cycling, which continued to be important. Ultimately, what happens in these deeper waters may impact nutrient availability shallower in the water column, and thus phytoplankton productivity.

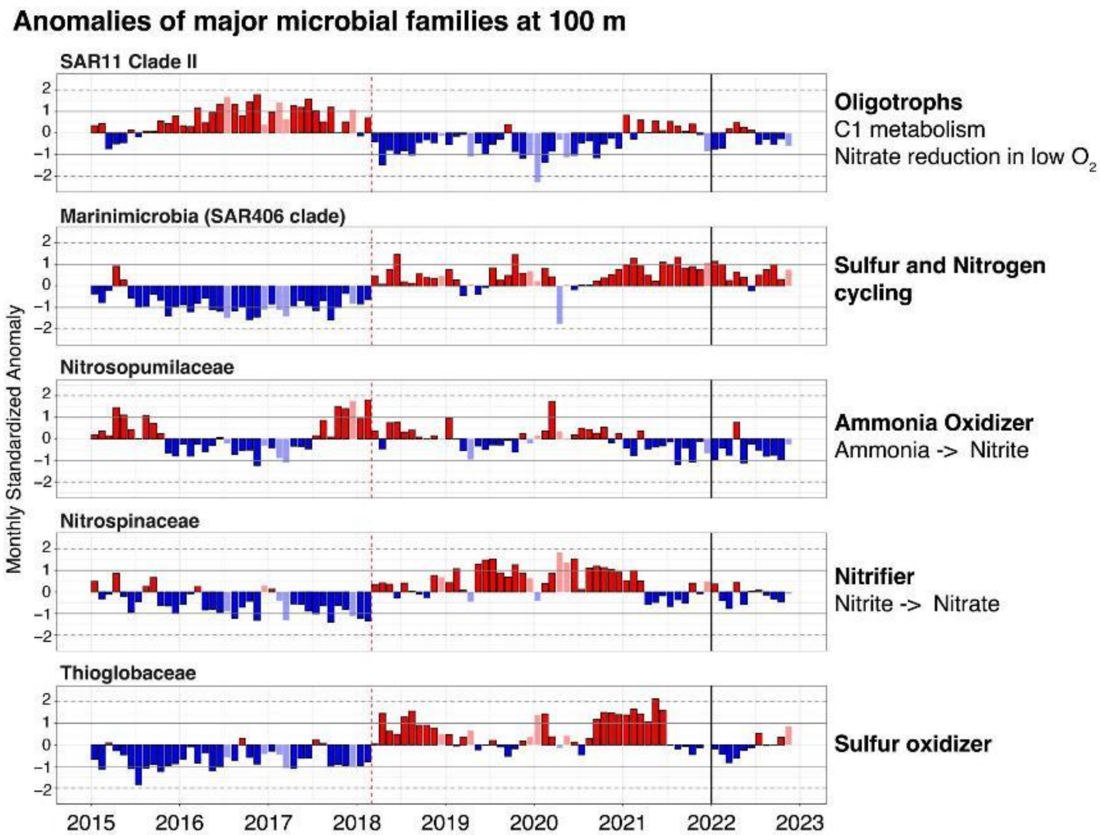

Figure 39-5. Monthly standardized anomalies for 5 microbial groups derived via biomolecular methods from 100m depth at station QU39. Anomalies were calculated in the same way as those shown and described in Figure 39-2. The dominant role of each group in biogeochemical cycling is specified to the right of each row. The bold vertical line represents the start of 2022.

39.4. Factors influencing those trends

The early spring bloom observed in the NSS (QU39) coincided with early season wind reductions and increased incoming PAR and stratification. Regionally, these drivers have been shown to combine to lift light limitation to phytoplankton in the surface layer (Collins et al. 2009; Allen and Wolfe 2013). Trends prior to the early spring bloom on the Central Coast (KC10) were not as clear, although increased stratification, likely tied to rainfall, and wind reductions were observed. Similar observations were made in Douglas Channel where rainfall induced stratification was linked to an unexpected winter diatom bloom (Johannessen et al. 2019). Furthermore, early season upwelling-favourable winds were observed in 2022 (Evans, Section 36; Hourston, Section 8), possibly driving the early bloom.

At station QU39, spring and summer FWC may influence diatom biomass. For example, 2021 was a high diatom biomass and low FWC year and during spring and summer, nutrient renewal appeared to be inversely correlated to FWC and diatom contributions increased following renewal events (Figure 39-3). In turn, 2022 had higher FWC, lower nutrients and normal to low diatom biomass. It is possible that in 2021, lower FWC allowed for easier mixing of the summer water column and subsequent nutrient renewal creating more favorable conditions for diatom blooms. It is important to note that grazing was not measured here but likely plays a key role in phytoplankton dynamics.

Freshwater and resulting stratification may also be an important driver of summer phytoplankton community composition on the Central Coast, at station KC10. For instance, the development of the large August dinoflagellate bloom was observed during high regional freshwater discharge and stratification. In both 2021 and 2022, dinoflagellate blooms were dominated by *Ceratium fusus*, which has been linked to the development of stratification following freshwater events (Baek et al. 2007).

Finally, in intermediate waters in the NSS (QU39), microbial communities in the intermediate and deep waters were tightly linked to physicochemical parameters, particularly salinity (+), inorganic nutrients (+), and oxygen (-). Therefore, these communities were likely driven in part by renewal events and the influence of oceanic waters on the coastal shelf.

39.5. Implications of those trends

Drivers of spring bloom timing within the Salish Sea are well documented and it is projected that a warming climate will result in increased interannual fluctuations in bloom timing and the amount of early blooms (Allen and Wolfe 2013). On the central coast of B.C., drivers of bloom timing are comparatively less well understood; however, climate change is projected to have large regional impacts on precipitation, freshwater discharge and storm events, each having strong influences on bloom timing, duration, and composition. Within River's Inlet (nearby station KC10), mismatches between bloom timing and zooplankton development have been linked to changes in zooplankton composition and reductions in biomass having deleterious effects on higher trophic levels such as Sockeye Salmon (Tomassi et al. 2013; Wolfe et al. 2015). While providing crucial insight on bloom timing and drivers, the time series presented here also suggest strong links between freshwater and summer phytoplankton community composition both on the central coast and in the northern Salish Sea. Impacts of climatic changes, both on land and at sea, will likely have profound impacts on primary productivity and phytoplankton community structure with cascading effects on the food web in this coastal margin system. The Hakai Institute's time series provide valuable information on phytoplankton and microbial community dynamics and their drivers at an unprecedented temporal resolution and are essential for resolving how changing ocean conditions influence ocean biology.

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40. SPRING PHYTOPLANKTON BLOOM TIMING IN THE STRAIT OF GEORGIA

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40.1. Highlights

- The timing of the spring bloom in 2022 was typical. The spring bloom timing changed significantly compared to 2021 which was a late bloom.
- The timing of the 2023 spring bloom is predicted to be average to late.

40.2. Description of the time series

Here we use a numerical model to show interannual variations in the phytoplankton in the Strait of Georgia (SoG). As described in previous reports, SOG is a vertical one-dimensional physical model coupled to a Nitrate-Diatom biological model (Collins et al. 2009). All lateral oceanographic processes not resolved by the model are parameterized. The model location, STRATOGEM station S3, is on the Tsawwassen to Duke Point ferry route in central SoG (Perry et al. 2021). The model is forced by winds measured at Sand Heads, clouds and temperature measured at YVR (Vancouver) airport and river flow measurements at Hope and the Englishman River or Nanaimo River when the Englishman is not available (e.g., 2021, 2022). The flow at Hope represents the snow melt dominated part of the Fraser River while the Englishman River or Nanaimo River represents all other rivers and the rainfall dominated part of the Fraser River. We have produced a time series of spring bloom time back to 1967 (Allen and Wolfe 2013).

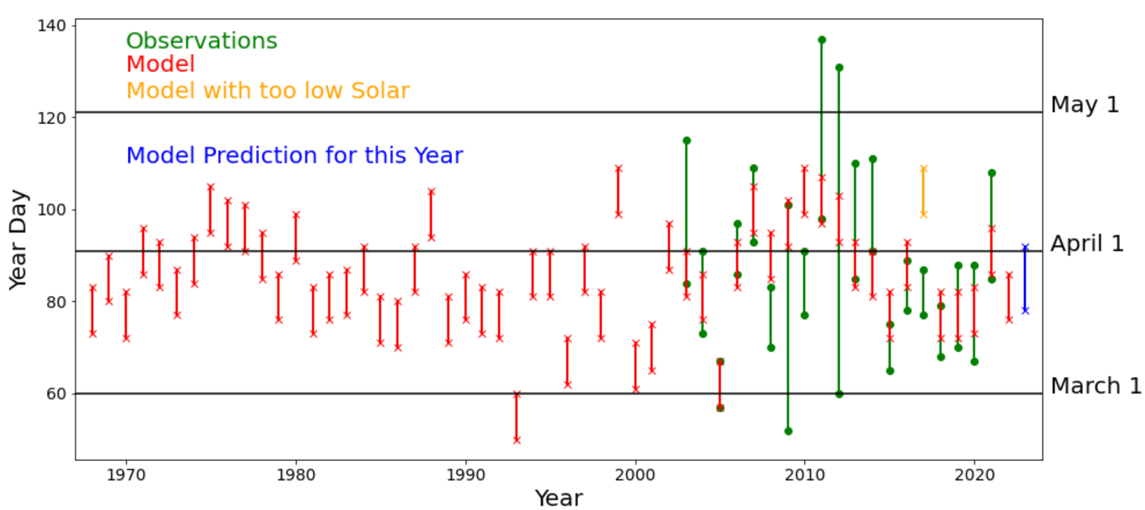

Figure 40-1. Time series of the timing of the peak of the spring phytoplankton bloom. Green- observations from observation systems, see Esenkulova et al., Section 42. Red – SOG model. Orange – SOG model with too little solar radiation (see Allen et al. 2018). Blue –SOG prediction for 2023 as of Mar 18, 2023.

40.3. Status and trends

The 2022 spring bloom happened between March 17 – March 27, 2022 according the SOG model (Figure 40-1). Ferry data is unfortunately not available for 2022. The Pacific Salmon Foundation's Citizen Science program observations showed a preliminary bloom in late February, that did not deplete the nitrate. A hint of such of bloom is in the model results around day 55 (Figure 40-2). The observations in March did not show strong productivity, and a nitrate depleting bloom was not observed until mid-April (Esenkulova et al., Section 42). There are two possibilities for the discrepancies between the model and the observations: 1) although observations were taken about every second week in March in the region, the observations could have missed a March bloom. 2) the model is wrong. One possibility is that the 40-m depth temperature forcing needs to be updated.

As of March 18, 2023, the 2023 spring bloom is predicted to peak between March 19 – April 2, 2023.

According to the model, the 2022 spring bloom had near median timing. The mean/median of the SOG timeseries is March 26/27 with the first quartile on March 18 and the third quartile on April 1. As noted last year, from 2011 – 2020, the spring bloom timing did not vary strongly between years. However, 2021 marked a significant shift to a later spring bloom. Then 2022 was a shift back.

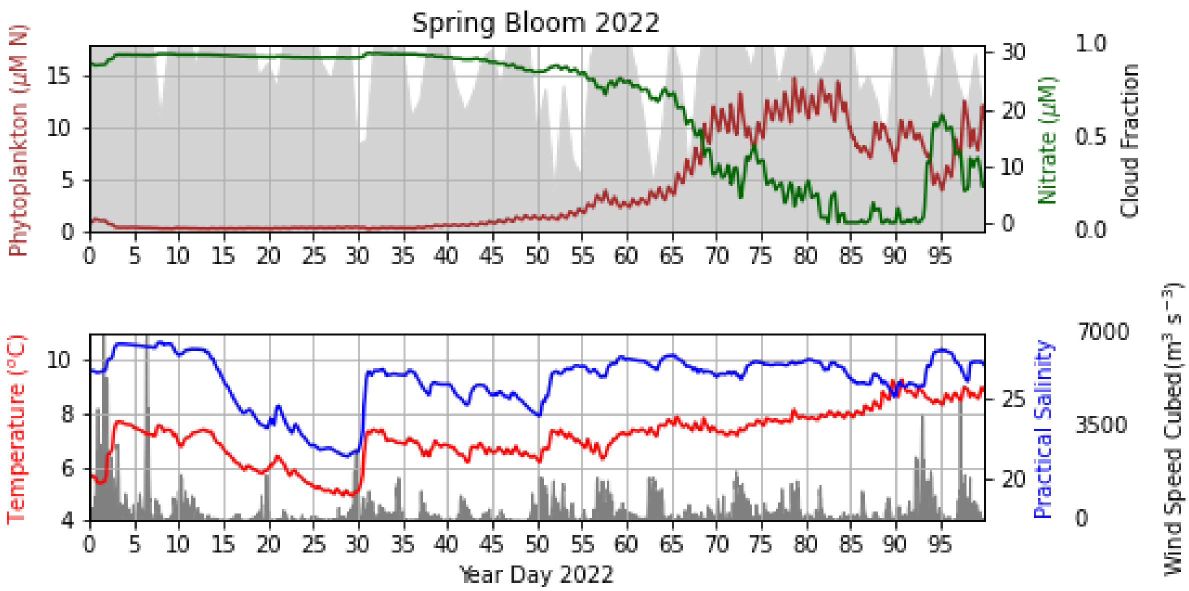

Figure 40-2. Hindcast of the 2022 spring bloom and related conditions in the Strait of Georgia. The lower panel shows temperature (in red) and salinity (in blue) averaged over the upper 3 m of the water column; in grey is the wind-speed cubed which is directly related to the strength of the mixing. The top panel shows phytoplankton biomass (in dark red) and nitrate (in green); in grey is the cloud fraction averaged over the day. The 2022 spring bloom was March 22 plus or minus 5 days. Plots span the period January 1, 2022 to April 10, 2022.

40.4. Factors influencing trends

According to the SOG model, the 2022 spring bloom commenced in late February to early March as clouds decreased (Figure 40-2). However, from March 10 through 25th, the cloud cover was high again and multiple wind events suppressed growth. The bloom was extended and peaked on March 22.

40.5. 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). Extreme shifts of timing have led to poor zooplankton growth (e.g., Sastri and Dower 2009) and late spring blooms are also associated with fewer large and medium copepods (Perry et al. 2021). With the 2022 spring bloom typical and with an only one-week shift in timing, one would expect a good zooplankton year, particularly for large and medium copepods, and good age-0 herring abundance. Observations support this expectation (Galbraith et al., Section 20; Boldt et al., Section 44)

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41. INTERANNUAL SUMMER PRODUCTIVITY IN THE STRAIT OF GEORGIA

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41.1. Highlights

- Summer diatom biomass in 2022 was low compared to the long term average.
- Zooplankton summer diet was more flagellate-based than the long term mean.
- The NPGO was in its warm phase in summer 2022, consistent with the observed productivity.

41.2. Description of the time series

Here we use a numerical model to estimate interannual variations in the phytoplankton and zooplankton in the Strait of Georgia (SoG). SalishSeaCast is a three-dimensional coupled bio-chemical-physical model of the Salish Sea (Figure 41-1). The physical model is based on NEMO (Madec et al. 2015). Grid resolutions are about 500 m in the horizontal and 1–22 m in the vertical, with higher resolution near the surface (Soontiens et al. 2016). It is forced by realistic winds and solar radiation from Environment and Climate Change, Canada's HRDPS 2.5 km model (Milbrandt et al. 2016). River input is based on a climatology (Morrison et al. 2011), or in the case of the Fraser River, on observations at Hope. The biological model, SMELT, is a 3 nutrient, 3 phytoplankton, 2 zooplankton, 3 detritus class model (Olson et al. 2020). The two most important phytoplankton boxes are diatoms: representing both pennate and centric diatoms, and flagellates: representing primarily haptophytes, cryptophytes and prasinophytes. Here we present summer phytoplankton dynamics in the Central SoG (Figure 41-1) based on the current version of the model (v201905), for which we have a 16-year time series (2007-2022).

Figure 41-1. Domain of the SalishSeaCast model showing Central Strait of Georgia Box used for analysis.

Zooplankton biomass anomalies in the SoG have been linked to both the North Pacific Gyre Oscillation (NPGO, Mackas et al. 2013) and the Pacific Decadal Oscillation (PDO, Perry et al. 2021) over a time period when it was correlated with the NPGO. Warm-phase events may result in a mismatch between phytoplankton and large, energy-rich crustaceans in the Central SoG, resulting in lower abundances of the latter (Suchy et al. 2022). SalishSeaCast replicates the linkage between the NPGO (Di Lorenzo et al. 2008) and the food available to zooplankton in the SoG (Figure 41-2).

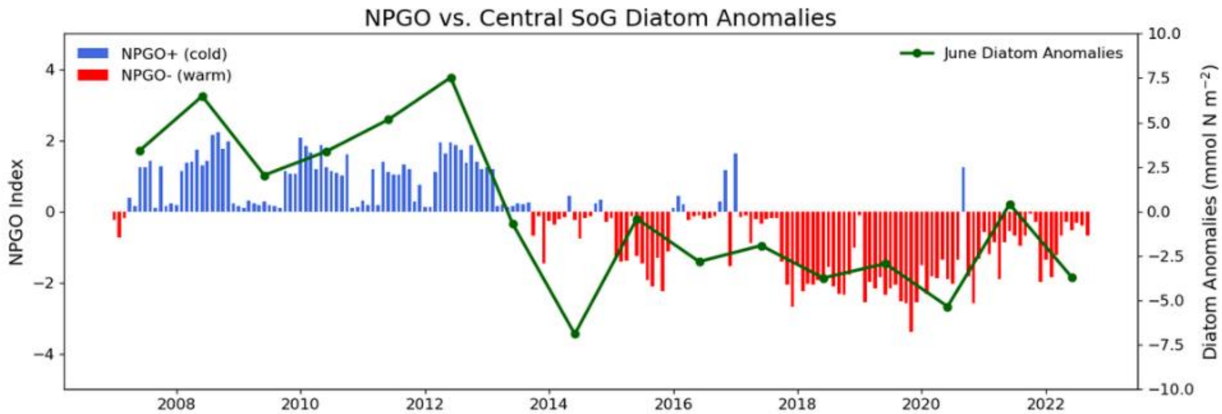

Figure 41-2. NGPO time series (bars) versus diatom biomass anomalies (line) in the Central SoG in June. Note the strong correlation.

41.3. Status and trends

Diatom and flagellate biomass in the model Central SoG box (Figure 41-1) was integrated over the top 100 m and then averaged over the month. June diatom biomass anomalies (Figure 41-2) were higher in years with positive (cold) NPGO than those with negative (warm) NPGO. Like the decade before, 2022 was a negative NPGO year and a low diatom biomass year.

In years with warm-phase conditions (negative NPGO), the summer phytoplankton consisted of fewer diatoms and more flagellates (Figure 41-3).

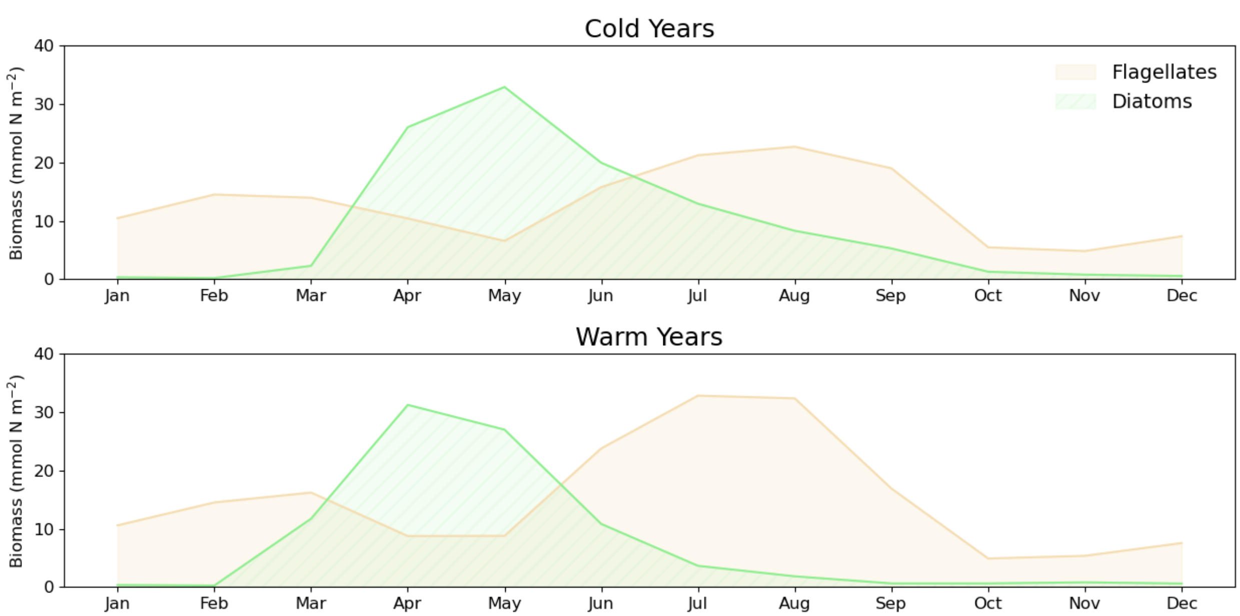

Figure 41-3. For the four highest NPGO years in the time series (Cold Years) and the four lowest NPGO years in the time series (Warm Years) the mean monthly flagellate and diatom biomass.

41.4. Factors influencing trends

The NPGO affects the Salish Sea in multiple ways (Suchy et al., pers. comm.) including impacting the end of winter nitrate levels, the timing of the spring bloom and the strength of wind upwelling pulses in the summer (Moore-Maley and Allen, 2022). As 2022 was a warm phase NPGO, summer diatoms were low and flagellates were an important part of the zooplankton diet (Figure 41-4).

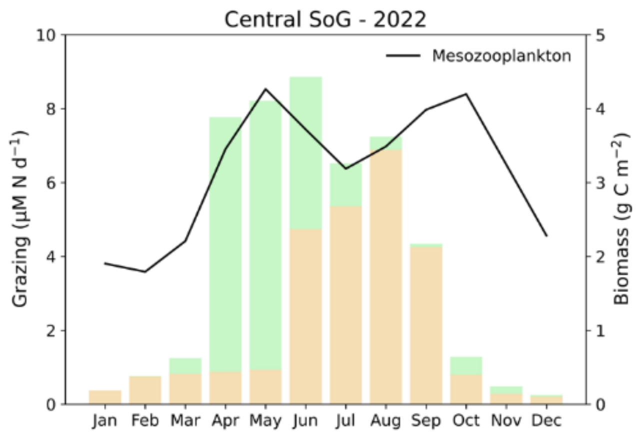

Figure 41-4. The mesozooplankton grazing and biomass in 2022 in the Central SoG on diatoms (green) and flagellates (orange). Flagellate grazing was high and diatom grazing was low from July through September.

41.5. Implications of those trends.

Given the link between zooplankton biomass and the NPGO in the observations, it appears that the diet of zooplankton is significantly impacted by warm-phase vs. cold-phase conditions. The current warm phase of the NPGO has led to low summer diatom biomass in the model, a shift to a flagellate-dominated zooplankton diet, and lower zooplankton biomass compared to what is observed during cold years.

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42. OCEANOGRAPHIC CONDITIONS AND HARMFUL ALGAL BLOOMS IN THE STRAIT OF GEORGIA 2022

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42.1. Highlights

- Surface waters were slightly cooler in summer and slightly saltier in fall compared to previous years. Deep waters were cooler than last few years.
- Two spring blooms occurred, one in February and another in April; surface silicate values in summer were among the highest seen since 2015.
- In summer, there were dense blooms of *Heterosigma akashiwo, Dictyocha, Noctiluca scintillans, Rhizosolenia setigera,* and *Pseudo-nitzschia* in some areas.
- *Alexandrium* and *Dinophysis* (PSP and DSP causing taxa) were abundant; *P. reticulatum* (yessotoxin producer) was unusually abundant in July-August.

42.2. Citizen Science Program

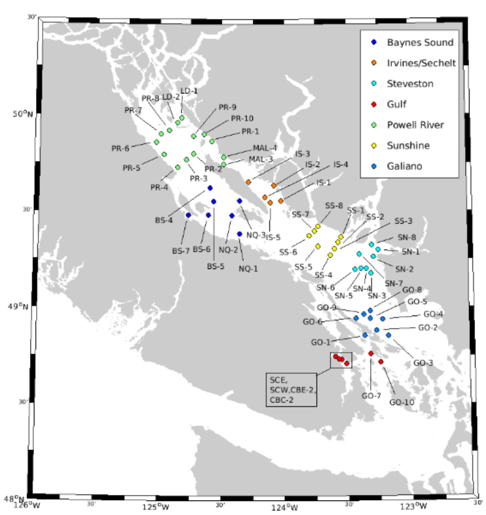

Figure 42-1. Map of the Strait of Georgia with CitSci program sampling locations in 2022. Different colours represent different patrols.

A Citizen Science (CitSc) oceanography program has been operated by the Pacific Salmon Foundation (PSF) since 2015. This program includes several dozen trained citizens organized into crews working on 7-10 vessels. Technical support is provided by PSF, as well as its partners at Ocean Networks Canada (ONC), Fisheries and Oceans Canada (DFO), and the Universities of Victoria and British Columbia (UBC). Surveys are undertaken across the Strait of Georgia (SoG) on a regular schedule, about 20 times a year. See the CitSci program and data here: marinescience.ca/wp-content/uploads/2023/01/2022PSF-CitizenScience-info-flyer.pdf), "Atlas of oceanographic conditions in the Strait of Georgia" (sogdatacentre.ca/atlas), and (facebook.com/CitizenSciencePhytoplankton).

42.3. Description of the time series

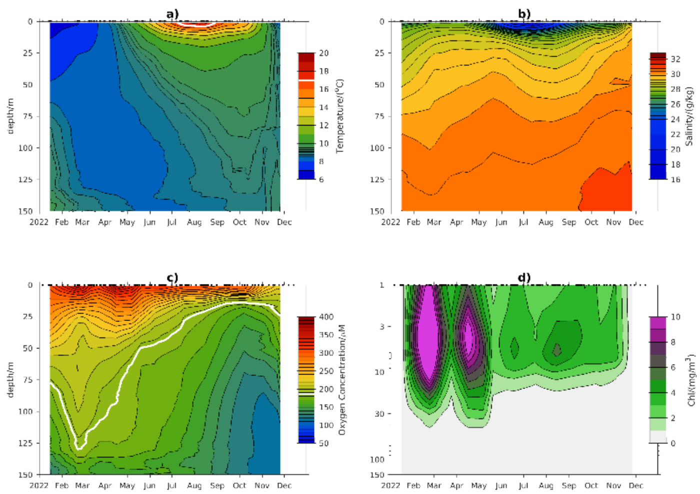

Figure 42-2. Annual cycle for water properties in the Strait of Georgia in 2022. White lines mark conservative physiological boundaries for salmonids (warmest temperature 17C, lowest O_2 6ppm or 187 uM.

In 2022, CitSci sampling occurred at ~55 sites (Figure 42-1) 2 to 3 times a month between February and October with some additional, once a month “winter” sampling. Conductivity, temperature, depth, dissolved oxygen, chlorophyl fluorescence (CTD/O_2/Fl) profiles to 150 m depth were collected at all stations for a total of 774 profiles. Raw data were archived and processed by ONC (community fishers web app). Nutrient samples were collected at two depths (0 and 20 m) at ~30 stations (645 samples in total), phytoplankton samples at the surface at all stations and additional 5, 10, and 20 m at ~30 stations (~1150 samples). Surface seawater and filter samples were also collected at four stations for biotoxin analysis (> 100 samples). Sample/measurement processing and analysis was done at the PSF, UBC, ONC, and DFO. Phytoplankton samples were analyzed on a Sedgewick-Rafter slide; specimens were identified to the lowest taxonomic level possible and enumerated (cells mL^{-1}) for dominant species or groups and species known or suspected to have negative effects on aquaculture in B.C. (Haigh et al. 2004).

42.4. Status and trends

In 2022, Strait of Georgia conditions were typical with the coldest deeper waters in spring, followed by a warmer, more saline, and oxygen-deficient deep waters in summer/fall (Figure 42-2). This seasonal cycle was similar to conditions in most years (Figure 42-3). However, the Strait of Georgia below 100 m continued a trend seen over the last several years, getting a little colder and fresher, and a little less oxygenated (although not outside of the range of variability seen since 2015). Surface temperatures were slightly colder in 2022 compared to last year, but surface salinities maintained the low summer values seen in the 2 previous years, matching the above-average summer Fraser inflow of the last 3 years (Figure 42-4).

Dissolved oxygen levels were less than 6 ppm or 187 uM in waters deeper than about 20 m depth in late summer (Figure 42-2). For salmonids in particular, studies found avoidance behaviors at concentrations of 4.5 to 6 ppm (BCMECCS 1997b), with B.C. Water Quality Guidelines suggesting an acceptable instantaneous oxygen threshold of 5 ppm to prevent harm to all life stages of aquatic life (BCMECCS 1997a). Based on expert recommendations, we highlight a slightly more conservative upper limit of 6 ppm (or 187 μM) in our figures. Similarly, temperatures greater than about 17 °C are thought to cause physiological stress in salmonids

(US EPA 2003) and the upper 6 m of the water column were warmer than this in July and August.

Based on Chlorophyll observations, there was an unusual appearance of two distinct spring blooms. The first occurred in mid-February, and had higher "peak" values, with maximums at depths of about 5 m. The second bloom occurred in mid-April, and lasted longer, into May, but with lower peak values relative to the February peak. Based on surface water samples, algae cell concentrations reached up to 10,000 cells per mL in February and up to 5,000 cells per mL in April. The first spring bloom was more pronounced in northern SoG and comprised *Skeletonema costatum* (similar to 2015 spring bloom) whereas second bloom comprised several diatom species, similar to 2016-2021. The first bloom did not exhaust nutrients. The second bloom also did not end with nutrient exhaustion, although surface nitrate levels finally reached very low values in June. Although the summer had low nitrate conditions, silicate levels remained relatively high, almost reaching levels seen in 2020.

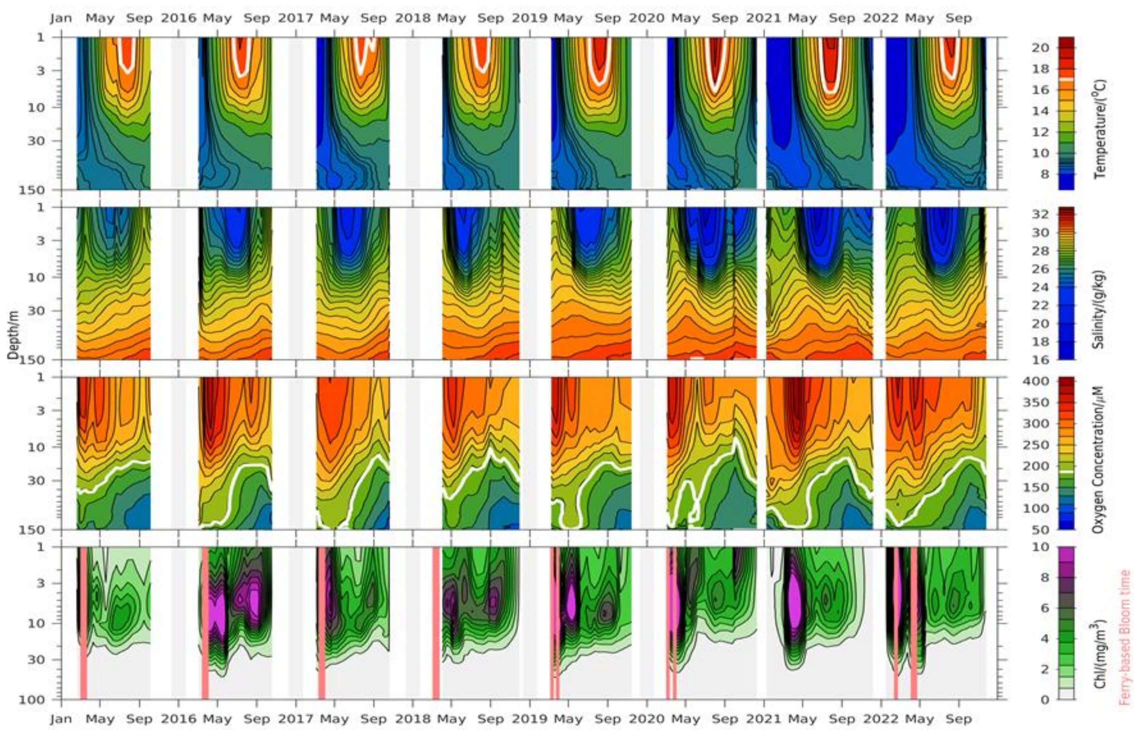

Figure 42-3. Strait-wide trends in water properties from 2015-2022. Note that depth axis is logarithmically scaled so that near-surface variations are emphasized.

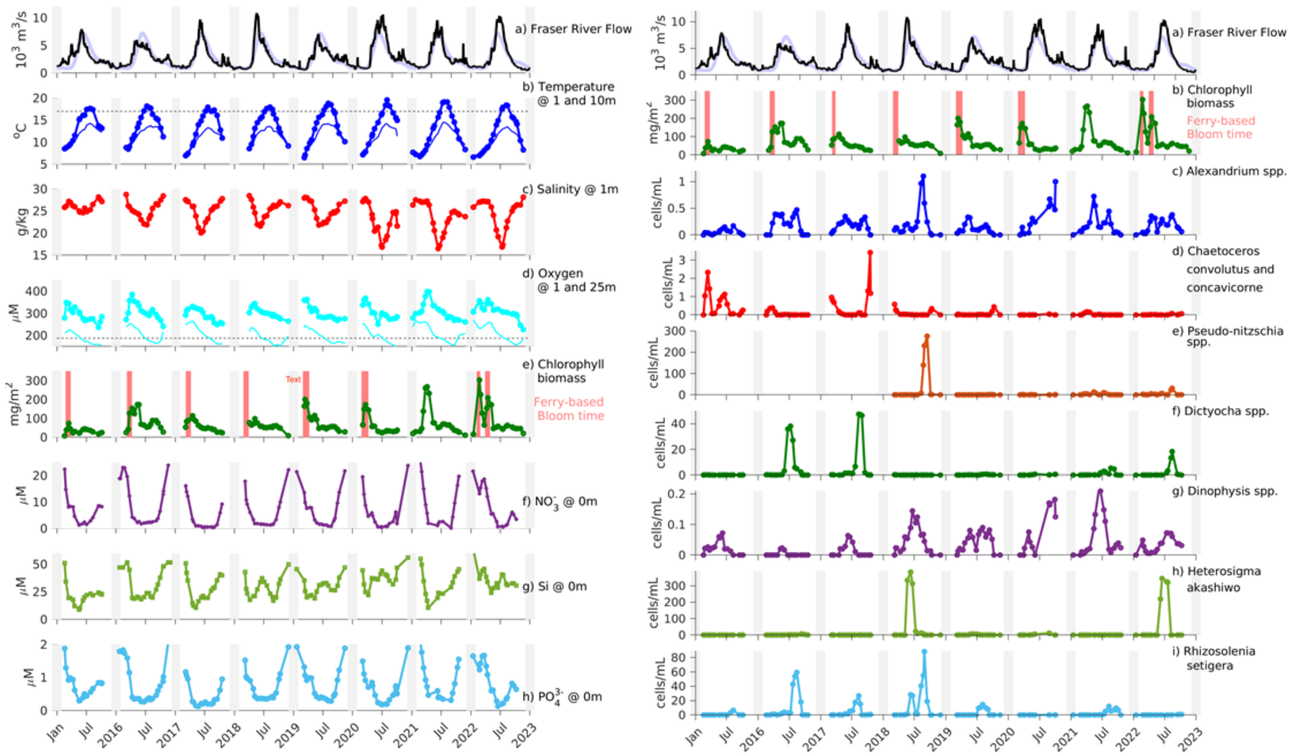

Figure 42-4. Strait-wide trends in average surface properties (left) and average harmful algae (right).

2022 was the first year since 2015 when all five HAB taxa formed dense (>100 cells per mL) blooms (Table 42-1). Blooms were localized. There were thick, vivid orange blooms of *Noctiluca scintillans* (up to 1000 cells per mL) at the beginning of August at a few coastal areas (*e.g.* Mill Bay, Burrard Inlet) (Figure 42-5). Ichthyotoxic raphidophyte, *Heterosigma akashiwo*, formed localized dense blooms from mid-June to mid-July in Steveston, Irvine's Sechelt and Cowichan Bay sampling areas. Later on, from mid-July to mid-August, there were blooms of silicoflagellate *Dictyocha* in the same areas. In mid-August and at the beginning of October, there were blooms of diatoms *Rhizosolenia setigera* and *Pseudo-nitzschia* spp. in numerous areas (Nanaimo, Galiano, Irvine's, Baynes Sound and Powell River).

*Table 42-1. Maximum concentrations (cell per mL) observed in PSF Citizen Science monitoring program samples. Notes: *Noctiluca maximum cell counts are from opportunistic samples obtained directly from the bloom; **routine Pseudo-nitzschia enumeration started in 2018, in 2015-2017 it was enumerated only if it was a dominant taxa in a sample.*

HAB taxa	2015	2016	2017	2018	2019	2020	2021	2022
*Noctiluca scintillans**	1	2	3	3000	800	1	3200	1000
Heterosigma akashiwo	6	150	20	11000	25000	7000	10	15000
Dictyocha spp.	5	700	400	10	10	50	150	140
Rhizosolenia setigera	250	800	1800	4000	500	5	500	400
Pseudo-nitzschia spp.**	40	150	1800	4500	30	70	1800	2000

Figure 42-5. Noctiluca scintillans bloom in Mill Bay, August 3, 2022. Photo by N. Christiansen, PSF (left panel) and a cell under the microscope (right panel). Photo by S. Esenkulova, PSF.

Some algae cause harmful effects at non-bloom densities as they produce toxins which can be harmful at very low concentrations. Species from *Alexandrium* and *Dinophysis* genera produce toxins that cause shellfish poisoning (PSP and DSP), while *Protoperidinium reticulatum* produce yessotoxin; the health risks of yessotoxin are not well understood. Overall, *Alexandrium* was abundant in SoG and seen in about 20% of May-September samples. Its summer abundance was comparable with 2016-2018, 2020 and 2021; in 2015 and 2019 it was noticeably (~1/4) lower. *Dinophysis* was present in about 6% of May-September samples, which is close to the eight year average, however unlike *Alexandrium*, *Dinophysis* abundance differs about ten-fold between years. *P. reticulatum* was unusually abundant in July-August samples, with concentrations of 10-90 cells per mL seen in all monitored areas in August. Maximum concentrations seen in previous years did not exceed 4 cell per mL, with the exception of 2018 when *P. reticulatum* reached 45 cell per mL, in August in Irvine's Sechelt area. In-situ algae observations for *Alexandrium, Dinophysis*, and *P. reticulatum* were in agreement with biotoxins observations (for details refer to Ross at al. Section 7).

42.5. Factors influencing trends

Phytoplankton dynamics are directly governed by environmental factors. Harmful algae concentrations in SoG are linked to environmental parameters (e.g. temperature, salinity, nutrients, and stratification) and exhibit strong inter-annual and spatial differences (Esenkulova et al. 2021). Variations in oceanographic conditions and phytoplankton influence higher trophic levels (zooplankton and fish), however these links in SoG are not yet fully understood.

42.6. Implications of those trends

Salmonids are vulnerable to warm waters and hypoxia. The SoG was warm and approached the DO limits for salmonids in several areas at the end of summer 2021, although this is not different than in most years. Blooms of *Heterosigma* in SoG cause multimillion dollar losses to aquaculture industry every year (Haigh and Esenkulova 2014) and have been linked to poor salmon returns (Rensel et al. 2010). Subsequently, several indications were found that wild juvenile salmon in SoG may be directly affected by algal blooms (Esenkulova et al. 2022). A study based on four years of CitSc data found that ichthyotoxic blooms were associated with negative impacts at the finfish farms and high abundance of *Alexandrium* and *Dinophysis* were associated with high PSP and DSP toxin concentrations in shellfish (Esenkulova et al. 2021). Studies on impact of HABs on food web dynamics and potential outcomes for finfish and shellfish are needed.

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43. ZOOPLANKTON STATUS AND TRENDS IN THE CENTRAL AND NORTHERN STRAIT OF GEORGIA, 2022

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43.1. Highlights

- 2022 zooplankton biomass peaked in July, estimated at 174 mg m^{-3} (sd 76 mg m^{-3}).
- Small copepods dominated by numbers (abundance), but ‘fish food’ plankton (medium-large calanoids, euphausiids and amphipods) had a higher contribution by biomass.
- 2022 zooplankton biomass trended down but was still higher than the average biomass overall (preliminary).

43.2. Description of the time series

Zooplankton samples have been collected at approximately 20 standardized stations monthly from February to October since 2015, with historic (but sporadic sampling effort) data going back to 1995.

For this report, we described current trends of abundance (m^{-3}) and biomass (mg m^{-3}) as monthly averages of all samples processed in 2022 in the deep (bottom depths greater than 50 m, and vertical net haul samples which covered over 70% of the water column) central and northern Strait of Georgia (averaged together, Figure 43-1). 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 the results are preliminary.

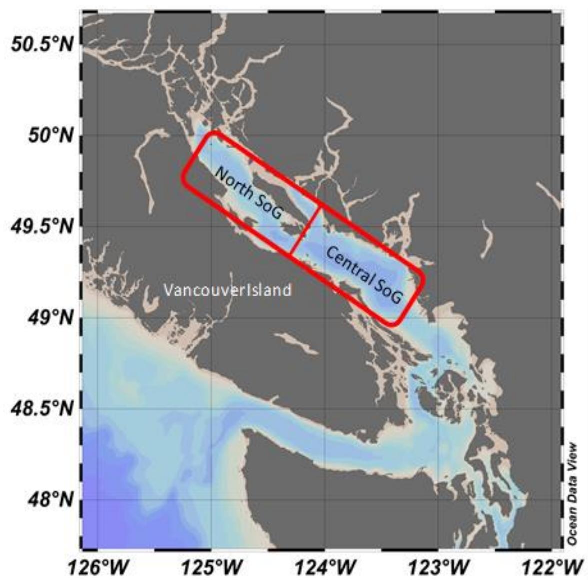

Figure 43-1. The central and northern Strait of Georgia (SoG) shown by the red boxes.

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

43.3. Status and trends

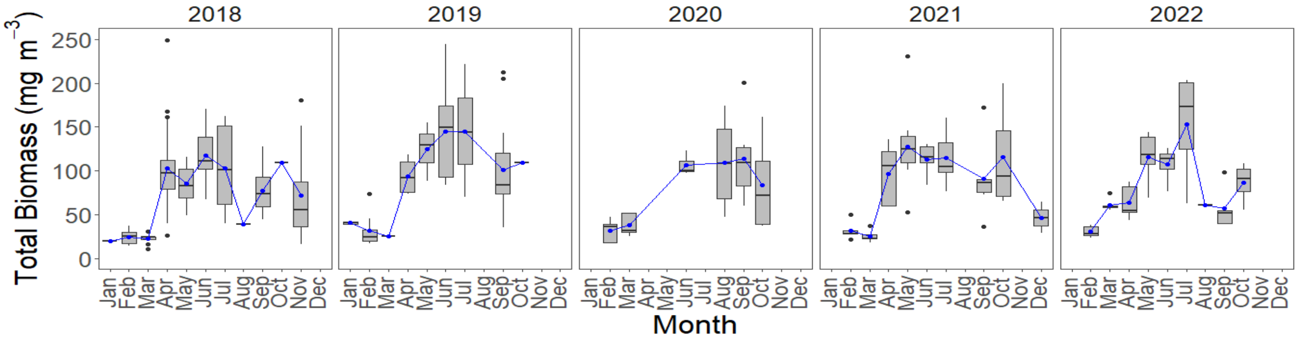

Figure 43-2. Average total biomass (mg m^{-3}) of zooplankton by month in the north and central (averaged together) Strait of Georgia for 2018-2022. Boxplots show median and spread of data, blue dot and line follows the mean biomass.

The total zooplankton biomass in 2022 ranged from 23.7- 313.5 mg m^{-3}, with the lowest biomass occurring in the winter (Feb) and peaking in July (mean 174 mg m^{-3} sd 76 mg m^{-3}; Figure 43-2). The July 2022 peak was similar to 2019 and was higher than 2020-21. Overall, total biomass was above average in 2022, but lower than 2021 (Figure 43-3).

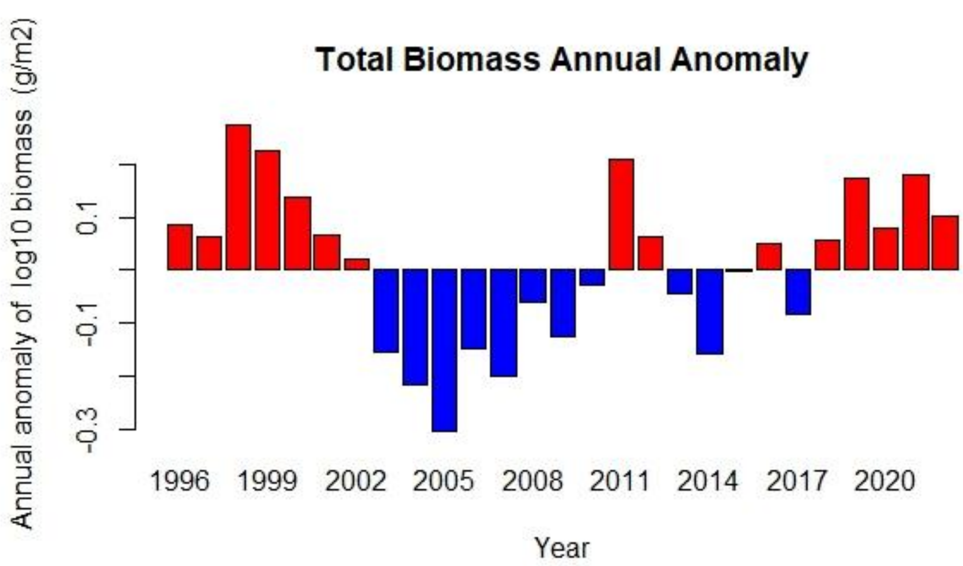

Figure 43-3. Annual biomass anomalies of total zooplankton biomass in the deep waters of the central and northern Strait of Georgia, 1996-2022.

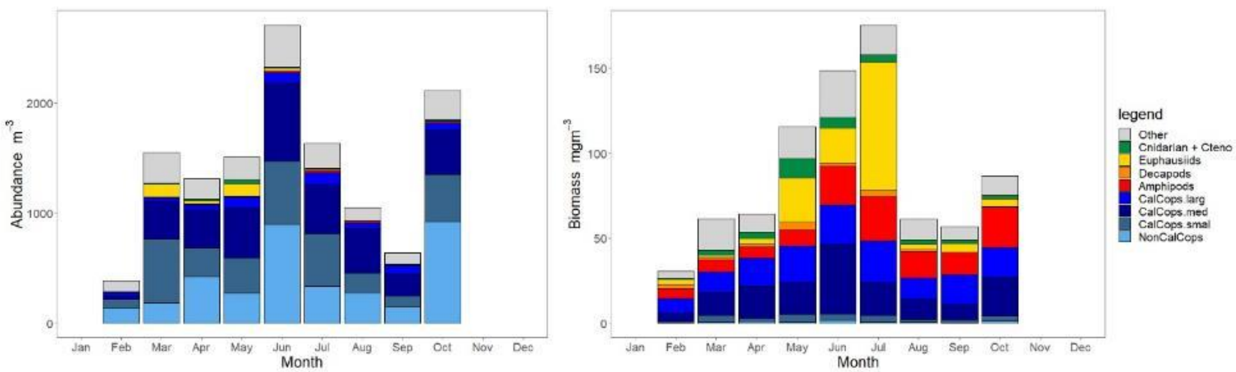

Figure 43-4. Taxonomic composition of zooplankton from northern and central Strait of Georgia in 2022, averaged by month. Left: abundance (m^{-3}); Right: biomass (mg m^{-3}). Legend: CalCops.larg – calanoid copepods, prosome length (PL)>3mm; CalCops.med – calanoid copepods PL 1-3mm; CalCops.smal – calanoid copepods PL <1mm; NonCalCops – all other copepods; Amphipods – all amphipods (hyperiid and gammarid); Decapod – all decapods (shrimp, crab larvae); Euphausiid – all euphausiids (eggs, larvae and adults); Cnidarian + Cteno – all Cnidarian (medusa and siphonophores) and Ctenophores; Other – everything else: Molluscs, Polychaetes, Chaetognaths, Ichthyoplankton, Larvaceans, etc.

The peak timing of the abundance and biomass of the zooplankton in the SoG varied by species (Figure 43-4), and followed similar trends as previous years (e.g. Young et al. 2020; 2021). Copepods, particularly calanoid copepods, dominated the zooplankton by abundance (Figure 43-4, left).

Medium- and large-body calanoid copepods and the larger crustaceans (euphausiids and amphipods) dominated the biomass (Figure 43-4, right). The composition of the medium and large-sized copepods was similar to 2020-21 with *Eucalanus bungii* and *Metridia pacifica* making up the majority of the copepod biomass (Figure 43-5).

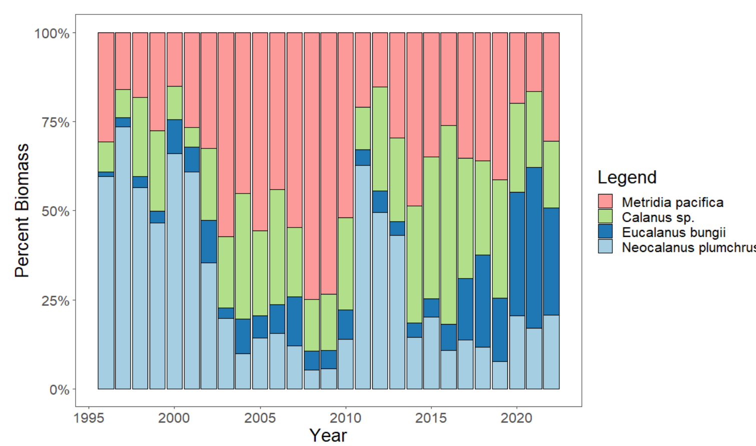

Figure 43-5. Yearly averaged percent biomass of the medium (M. pacifica and Calanus sp.) and large (E. bungii and N. plumchrus) calanoid copepods from 1996-2022.

Euphausiid biomass in 2022 was higher than average in summer and lower than average in the fall with an overall average biomass for the year.

43.4. Factors influencing trends

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

43.5. Implications of those trends.

Medium and large sized crustaceans (calanoid copepods, euphausiids and amphipods) make up the majority of the total biomass of zooplankton in the Strait, and variations in these groups over time have been shown to be important variables in the modeled marine survival of some Chinook and Coho Salmon populations that enter the Strait as juveniles (Araujo et al. 2013; Perry et al. 2021). A consistent zooplankton monitoring program in the Salish Sea can assist with projections of future abundances of juvenile salmon.

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44. STRAIT OF GEORGIA JUVENILE HERRING SURVEY

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44.1. Highlights

- In 2022, the index of the relative biomass of age-0 herring was higher than that observed in 2021, but still below the time series mean.
- Age-0 herring were smaller than average, but their condition was above average.
- In 2022, Northern Anchovy were present in 48% of the fishing sets; this is the third highest percentage in the time series.

44.2. Description of indices

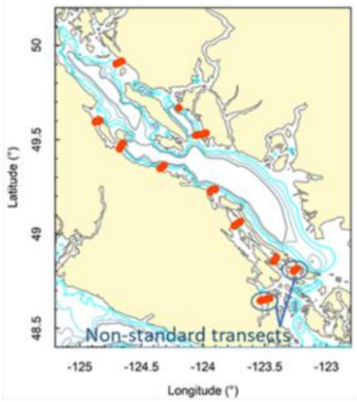
The Strait of Georgia (SoG) juvenile (age-0) Pacific Herring survey is a monitoring program that samples the nearshore pelagic fish community, the zooplankton community, and physical water column properties. A goal of the survey is to estimate an index of the relative biomass (abundance) of age-0 herring 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.

Ten standard transects, each with three to five stations (total 48 standard stations), distributed around the perimeter of the SoG, have been sampled consistently during September-October since 1992 (except 1995 and 2020; Thompson et al. 2013; Thompson et al. 2003; Boldt et al. 2015; Figure 44-1). Additional transects were sampled in 2021 (1) and 2022 (2; Figure 44-1). 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). The age-0 herring index of catch weight per-unit-effort (CPUE and associated variance) was calculated using standard transects and 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). In 2021 and 2022, scientific echosounder data were collected at standard transects to supplement the survey. These data and stereo-optic camera collections are being analyzed and will be published.

44.3. Status and trends

In 2022, 9 of 10 standard transects plus two additional transects were sampled. Weather prevented sampling of some stations. Age-0 herring were caught in 39 of the 48 stations sampled, and 31 of standard stations sampled. Estimates of mean catch weights (g), abundance, and CPUE (weight and abundance) of age-0 herring varied interannually with no significant linear trend during 1992-2022 (Figure 44-2). The age-0 herring indices tended to peak every two or three years, with the peaks occurring in even years during 2004-2012. During 2013-2022, the indices were intermediate-low compared to the peaks in the time series (Figure

44-1). In 2022, indices (using standard transects) were higher than those observed in 2021, but still below time series averages. High estimates of variability were associated with peak index values; the survey coefficient of variation (CV) was 0.48 (Figure 44-2).



Age-0 herring length-weight residuals increased during 1997-2012, and were positive in 2005 and 2007-2022 (Figure 44-2). In 2022, herring condition was above average; however, the average length, weight, and energy density of age-0 herring was low compared to time series average (Figure 44-2). In 2022, Northern Anchovy were caught in 17 of 40 standard stations sampled (Figure 44-3); this is similar to 2021 and a relatively high proportion in the time series (Figure 44-3). Northern Anchovy were not caught at the 8 non-standard stations sampled in 2022.

Figure 44-1. Stations sampled during the 2022 Strait of Georgia age-0 Pacific Herring survey.

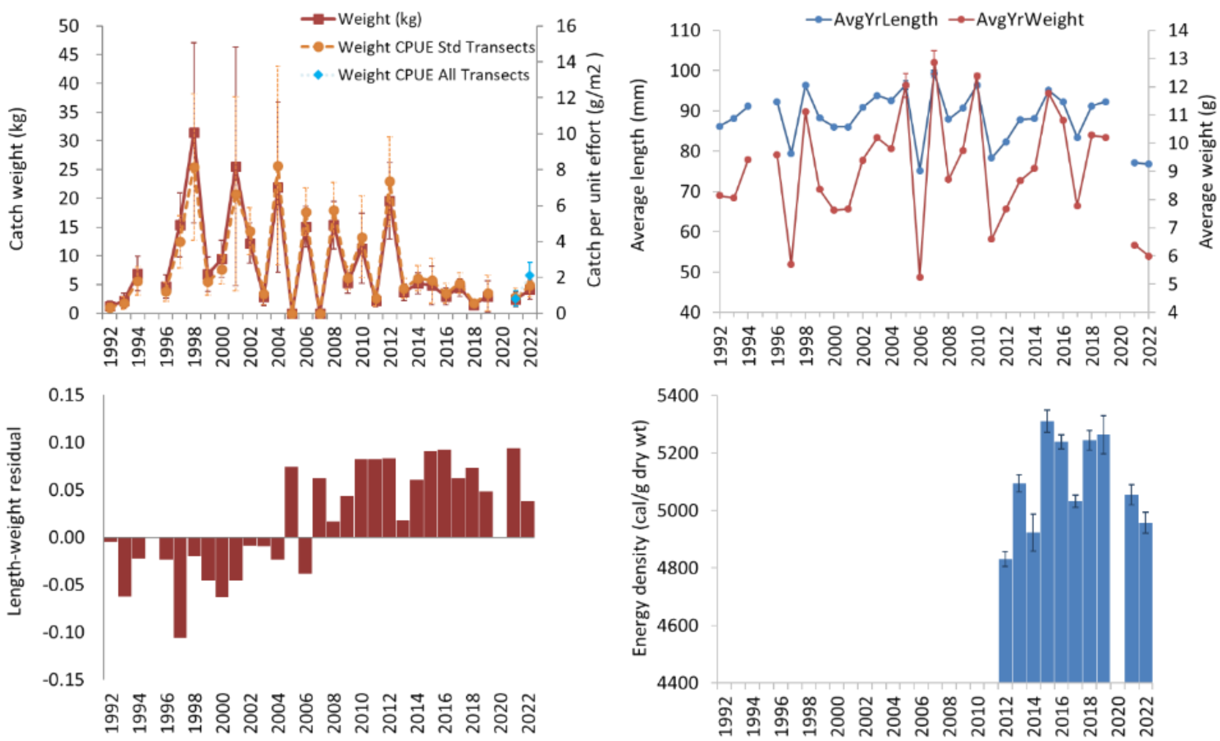


Figure 44-2. Mean catch weight (kg) and catch weight-per-unit-effort (weight CPUE; g/m^2; for standard stations and all stations sampled) (top, left panel); mean standard length (mm) and weight (g) (top, right panel); mean condition (residuals from a double log-transformed length-weight regression; bottom, left panel); and energy density (bottom, right panel) of age-0 Pacific Herring in the Strait of Georgia. Standard error bars are shown.

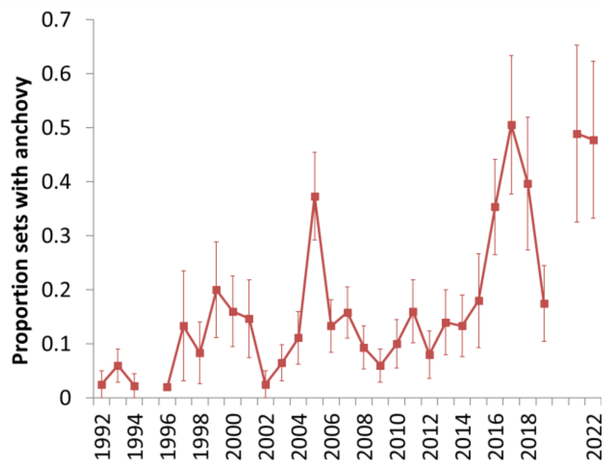


Figure 44-3. Proportion of purse seine sets at standard transects that contained Northern Anchovy, 1992-2022 (no survey in 1995 or 2020). Time series updated from Duguid et al. 2019. Standard error bars are shown.

44.4. 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 juvenile salmon competitors or predators 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. 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).

44.5. Implications of trends

Age-0 herring survey indices may provide a leading indicator of low recruitment years. In 2005 and 2007, there were low age-0 and subsequent low age-3 recruit abundances. Juvenile and adult Pacific Herring are prey for piscivorous fish, marine mammals, and seabirds and are important commercial species in B.C.'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.

44.6. 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 2022 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 in 2019-2022.

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45. JUVENILE SALMON IN THE STRAIT OF GEORGIA 2022

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45.1. Highlights

- In September 2022, the juvenile salmon survey was completed in the Strait of Georgia (SoG) and in additional areas of Desolation Sound and Bute Inlet.
- The CPUE of Coho Salmon was similar to high CPUEs observed since around 2010. The CPUE in combination with size of the juveniles indicated good early marine conditions for Coho Salmon in the SoG.
- A bi-modal length frequency of juvenile Chinook Salmon lengths in September suggests early marine growth for the late ocean entry South Thompson stock may not be as good as in years prior to 2020.

45.2. Description of the time series

Juvenile salmon generally enter the SoG from April to June and many may remain and rear in the SoG until the fall. The juvenile salmon trawl surveys are designed to sample juvenile salmon throughout the SoG during this first ocean summer and fall. In 2022, only the fall survey was completed due to staffing issue for the CCG vessel *Sir John Franklin* in June. To ensure the fall survey was not cancelled, the commercial fishing vessel *Nordic Pearl* was chartered to complete the survey. Using a charter vessel resulted in fewer fishing days and fewer science staff for the work but ensured the standard survey area was sampled. The survey was fished following standard survey protocol described in Beamish et al. (2000) and Sweeting et al. (2003). The net used in this survey was the LFS 7742 net that replaced the Cantrawl 350 net in 2019 (Anderson et al. 2019).

The survey in September 2022 completed sampling on the standard track line as well as sets in Desolation Sound and Bute Inlet. Catch-per-unit-effort (CPUE) was calculated using trawl sets conducted on this standard track line in the main basin of the SoG (Canadian waters) and for specified habitat depths (Chinook Salmon 0-60 m, Coho Salmon 0-45 m, Pink, Chum, and Sockeye Salmon 0-30 m) (Beamish et al. 2000; Sweeting et al. 2003). For the given sets, the total catch and area surveyed was used to calculate average catch per hour. This 24-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.

45.3. Status and trends

In the fall, the CPUE of Coho Salmon was similar to those observed since around 2010, when there was a shift in productivity resulting in higher CPUEs (Figure 45-1). Additionally, the size of the Coho Salmon remained above average; it has been above average since 2010 (Figure 45-2). The CPUE of Chinook Salmon in the fall survey was average for the entire time series. It is important to note that late ocean entry South Thompson stocks dominate the fall CPUE. The length frequency of the Chinook Salmon in the 2022 survey was bimodal (Figure 45-3). The lower mode of the distribution is expected to be South Thompson Chinook Salmon and by number, dominated the catch in 2022. However, the average size of these fish was smaller than observations from 2012 to 2019. Sockeye Salmon in the SoG in September are dominated by the ocean type Harrison stock. In 2022, the catch of these fish within the SoG remained low but was the highest since 2014. The CPUE of Chum Salmon in September was below average for the time series. Pink Salmon entering the SoG will be primarily Fraser River origin fish. The CPUE in September was the highest observed since 2010.

45.4. Factors influencing trends

The size and condition of Coho, Chum and Pink Salmon (not all shown), suggests good early marine growth for these species within the SoG. Beamish and Neville (2021) showed an increase in productivity for Coho Salmon in the SoG around 2008-2010 and demonstrated that within a productivity period there is a Beverton-Holt relationship between escapement and the CPUE in September two years later. This indicates that there is a carrying capacity for Coho Salmon in the SoG. Therefore, a combination of ocean conditions and a carrying capacity for this species are influencing current trends. The shifts in the length frequency of Chinook Salmon in September (started in 2020) suggest that these late ocean entry fish are not growing as quickly during

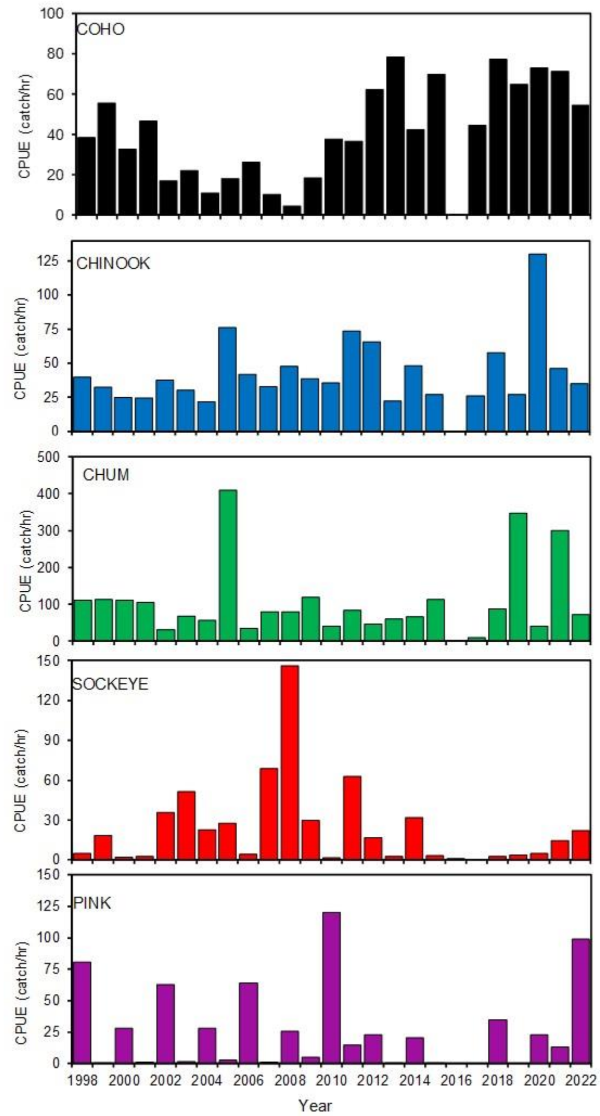

Figure 45-1. CPUE of ocean age 0 salmon in September/early October 1998-2022. The survey in 2016 was late and is not considered in time series. Note: y axes differ between species.

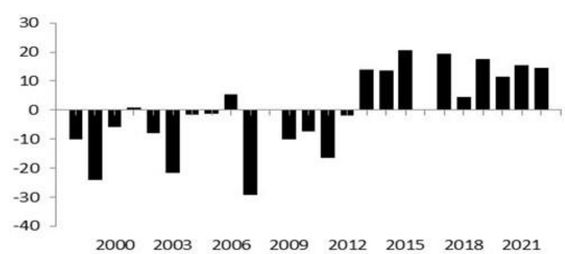

Figure 45-2. The length anomaly of Coho Salmon in the September surveys 1998-2022.

their early ocean residence as they did prior to 2020. The mechanisms that may be influencing this growth include changes in zooplankton production in August, increased competition between Chinook Salmon stocks or with other species, and changes in freshwater production in the South Thompson region. The poor returns of Chum Salmon to B.C. in the past few years should be of concern. The trend in CPUE of this species has been similar over the time series but the trend in the size of the juveniles is similar to juvenile Coho Salmon and suggests that within the SoG conditions have not declined for the juveniles and mechanisms regulating survival may be from the first marine winter onward.

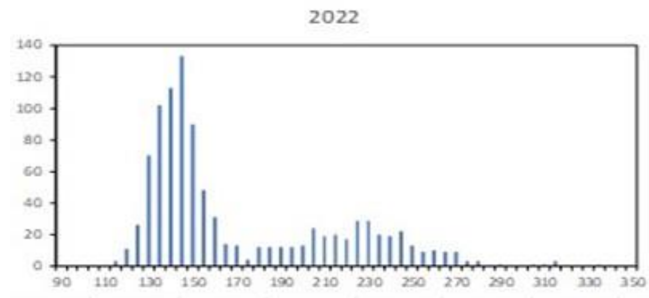

Figure 45-3 The (mm) frequency of Chinook Salmon in the September survey in 2022.

45.5. Implications of those trends.

Several hypotheses suggest that growth and energy storage during the first marine summer are related to the ability of fish to survive their first marine winter and affect their total marine survival. The Beverton-Holt relationship between the adult escapement and the CPUE of coho salmon in September two years later indicates that there is a threshold for the number of juvenile Coho Salmon that can rear in the SoG and once that threshold is reached, the addition of more juvenile salmon will not increase total returns. However, it also highlights that identifying productivity shifts is essential. The declining size of South Thompson Chinook Salmon may be an indication of poor early marine growth for these late ocean entry stocks and, if growth in the first marine summer is a driver, could negatively impact marine survival of these stocks. This could result in lower returns for the South Thompson starting in 2024. Understanding the mechanisms for this decline in size is therefore important and may provide further information to help identify mechanism regulating marine survival. Declines in returns of Chum Salmon are similar to declines of this species in Japan and indicate that ocean survival is a primary driver. Focus needs to be put on identifying the mechanisms regulating ocean survival of this species, one of B.C.'s most abundant salmon species. The ability to understand the drivers of changes in the marine survival of all salmon species may provide new tools to provide early forecasts early in the marine residence of these species but more importantly, tools to help ensure we manage to retain resiliency in the species over large-scale changes in climate.

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46. ADULT SALMON DIET MONITORING 2017-2022

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46.1. Highlights

- Pacific Herring remained important prey for Chinook Salmon in the Strait of Georgia and south and west coasts of Vancouver Island in both summer and winter 2022.
- Stomach fullness remained highest in the Strait of Georgia where herring overwhelmingly dominated diets in both seasons.
- Pacific Sardine were observed in (4) stomachs off the west coast Vancouver Island in August 2022.

46.2. Description of the time series

The Adult Salmon Diet Program (ASDP) is a citizen science initiative that has been investigating Chinook and Coho Salmon diets in B.C. since 2017 (Quindazzi et al. 2020). The program is run through the Juanes Lab at the University of Victoria and was supported by the Pacific Salmon Foundation and Fisheries and Oceans Canada in 2022. Predator diet sampling can provide insight into the fine-scale distribution and relative abundances of forage species (including the size and/or age classes present) that may complement or otherwise not be available through other sampling methods (Thayer 2008). The short-term objectives of the ASDP are to characterize spatial and seasonal trends in the diets of adult Chinook and Coho Salmon. In the long term, the project seeks to monitor change in forage species communities and assess implications for salmon trophic ecology. An additional objective is to foster dialogue between fishers and fisheries scientists through a citizen science framework.

Digestive tracts of Chinook and Coho Salmon that are captured in the recreational fishery are submitted by anglers and collected from cleaning stations on public docks and at derbies. Data collected include: species, capture location, capture date, adipose fish status, length and/or weight, and other observations. In the lab, prey items are identified and weighed (see Duguid et al. in review), and subsamples are measured, and otoliths are extracted and archived. This report focuses exclusively on diet data for Chinook Salmon.

To investigate the temporal variation in the diet composition and feeding intensity on prey species, mean “partial fullness scores” (Magnussen 2011) for prey categories were compared among regions, seasons, and years. These scores were calculated as 1000*prey category weight (g) divided by the cube of salmon length (cm). A length-based fullness index was used as the length of Chinook Salmon was more commonly available than weight. Winter was defined as October to March and Summer as April to October. To prevent splitting the winter season between years the months of October to December were shifted forward into the following calendar year. The periods April 1 to July 15 (Strait of Georgia (SOG)) and April 1 – July 31 (Haro Strait, Gulf Islands, Howe Sound, and Strait of Juan de Fuca) were excluded from analysis as retention of Chinook Salmon was partially or completely closed during these periods beginning in 2019. Regions for reporting were defined using a cluster analysis of a Bray-Curtis dissimilarity matrix of mean percent weight of prey categories pooled by Pacific Fishery Management Areas (PFMAs) in the Salish Sea from April to September (Greentree 2021). This resulted in 4 distinct regions within the Salish Sea: Gulf Islands/Haro Strait, SOG, Howe Sound, and Strait of Juan de Fuca (JDF) (Figure 46-1). Data from the West Coast Vancouver Island (WCVI) were not included in the cluster analysis, but all PFMAs from this region were aggregated into an arbitrary grouping. Of the 3848 Chinook Salmon samples processed to date by the program, 2676 were included in the time series presented here.

46.3. Status and Trends

Pacific Herring continued to be important in the diet of Chinook Salmon in summer and winter

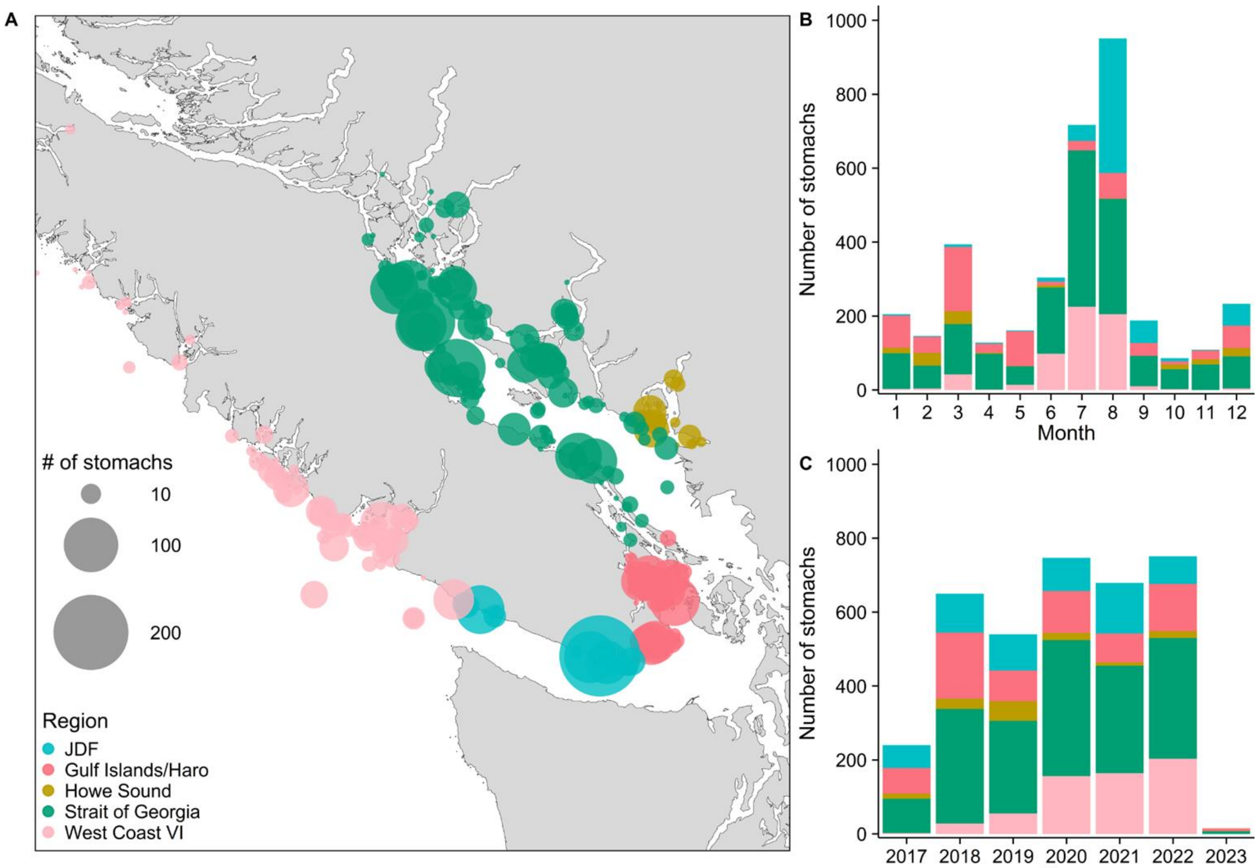

Figure 46-1. Distribution of adult Chinook Salmon diet samples in (A) space, and by (B) month and (C) year. Colours indicated the five regions used to spatially aggregates samples for this talk. JDF = Juan de Fuca; VI = Vancouver Island. This figure shows all samples processed by the program, not only those included in the time series reported here (see text).

across regions and were particularly dominant in the SOG (Figure 46-2). As seen in previous years, this region had the greatest overall stomach fullness in both summer and winter, with age-2+ herring (defined as ≥ 145mm standard length and otolith width to standard length regression). In 2022, age-2+ Pacific Herring made up 74.9% of the aggregate weight of herring in the SOG summer diets.

In all summers examined, Chinook Salmon in the Gulf Islands/Haro Strait, Juan de Fuca Strait, and the WCVI all exhibited considerably lower stomach fullness than in the SOG. In winter 2022, stomach fullness in the Gulf Islands/Haro Strait region returned to a level typical of the time series after elevated fullness driven by juvenile (age-0/1) Pacific Herring in winter 2021. There was also a potential increase in the importance of Pacific Sand Lance in the Gulf Islands/Haro Strait region in winter. It should be noted that April through July samples for this region have been removed from the time series to allow for comparison across years before and after regional closures. In years of the ASDP prior to these closures (2017-2018), Sand Lance were primarily encountered in stomachs from the Gulf Islands/Haro Region between April and July, therefore this time series underestimates the overall importance of Pacific Sand Lance in diets. The elevated importance of Sand Lance in this region in winter 2022 was likely at least partially driven by an elevated number of March samples from PFMA 19B collected at the Sidney Anglers' derby. As seen in previous years, herring and invertebrates, primarily squid, made up most of the diet on WCVI in the summer, however the overall fullness was low compared to 2021. Howe Sound continued to be the only region included in the time series where Northern Anchovy and Surfperch made an important contribution to diets. Beginning in 2021, parts of Jervis Inlet in PFMA 16 have been open to Chinook Salmon retention while other regions of the SOG remain closed in spring and early summer. While samples from this limited opening were not included in the time series, it is of note that 9 of 19 Chinook Salmon stomachs from Jervis inlet from April to June 2022 also contained anchovy (see Greentree et al., Section 67.

Pacific Sardine were identified in the stomachs of four fish from WCVI in August of 2022 (confirmed) and one sardine was identified (unconfirmed) in a stomach from Victoria Harbour in December 2022. These are the first confirmed Pacific Sardine encountered by the program. Given the similarity of diagnostic bones between sardine and herring, archived otoliths will be examined to ensure that sardine have not been missed in prior years.

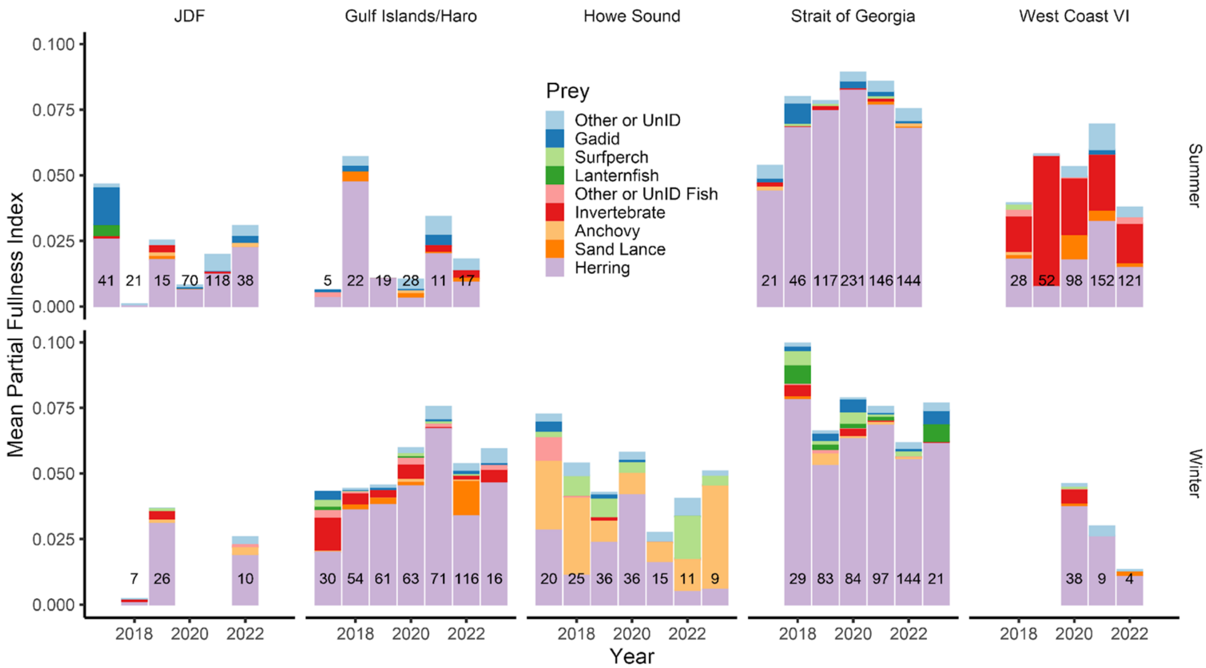

Figure 46-2. Mean Partial Fullness Index of adult Chinook Salmon diets in summer (April- September) and Winter (October-March) for five regions (Figure 46-1) of coastal B.C. from 2017 to 2023. Note that data for some periods and regions were removed for all years to account regional fisheries closures (see text for details), October-December were moved forward to the following calendar year to prevent splitting of a season. Only region/season combinations with more than 3 samples are shown. The sample size is overlaid for each year and region. JDF = Juan de Fuca; VI = Vancouver Island.

46.4. Factors Influencing those trends

As the program is limited to a 6-year window, trends in the data should be interpreted with caution. The consistently high fullness and contribution of age-2+ Pacific Herring to summer diets of Chinook Salmon in the SOG are of note. The SOG stock of Pacific Herring is considered migratory, with the majority of age-2+ fish leaving the Salish Sea in the summer to feed. The Pacific Herring spawning biomass has been above the limit reference point since 2010 (Cleary et al., Section 24). We currently lack an understanding of the factors that may control what proportion of age-2+ Pacific Herring remain in the SOG in the summer and regulate their availability to salmon and other predators. This is an important area for future research.

The abundance of Northern Anchovy in the Salish Sea was anomalously high during the warm conditions in 2015 and 2016 (Duguid et al. 2019). In 2021 and 2022, there was a relatively high occurrence of anchovy in the SOG age-0 herring survey sets (Boldt et al., Section 44). Chinook Salmon diets indicate that Northern Anchovy continues to be an important diet item in Howe Sound and perhaps other mainland inlets. Occurrence of Northern Anchovy in salmon diets likely lags conditions suitable for reproduction in the SOG by one to two years. As the SOG warms, Northern Anchovy may become more abundant and ecologically important within localized regions or within the SOG as a whole.

46.5. Implication of Trends

To date ASDP data have suggested relatively consistent regional patterns in fullness and diet composition among years. Going forward, data from this program will be able to quickly indicate major changes in forage fish community composition and implications for Chinook Salmon trophic ecology. The capacity to detect changes in the contribution of different herring age classes to summer diets in the SOG and the continuity of elevated stomach fullness in this region may be particularly valuable. The ASDP will also act as an indicator of abundance or range changes for other prey species including Northern Anchovy, Pacific Sand Lance, and Pacific Sardine as oceanographic and climatic conditions vary.

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47. MARINE BIOTOXIN MONITORING IN B.C. COASTAL WATERS

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47.1. Highlights

- Algal biotoxins including those responsible for amnesic, paralytic and diarrhetic shellfish poisoning are present in B.C. coastal waters.
- Biotoxin concentrations appear to be positively correlated with water temperature and the presence of associated harmful algae.
- Domoic acid (DA) concentrations were generally lower in 2022 than in 2021 when they approached levels associated with DA accumulation in shellfish during the spring.
- Saxitoxin and related hydrophilic biotoxins peaked later and at much higher concentrations than DA, particularly in Clayoquot Sound during summer 2022.
- The distribution and abundance of predominant hydrophobic biotoxins were similar in 2021 and 2022 except yessotoxin, which was relatively abundant during summer 2022.

47.2. Description of the time series

In 2015, an extraordinary phytoplankton bloom occurred along the continental shelf of Western North America, including B.C. The bloom contained species of the pennate diatom *Pseudo-nitzschia* (McCabe et al. 2016) that, under certain conditions, produce the neurotoxin domoic acid (DA). This algal biotoxin is responsible for amnesiac shellfish poisoning (ASP) in humans and has been associated with illness and mortality in marine mammals (Savage 2017; Moriarty et al. 2021). In 2016, DFO began a large-scale at-sea domoic acid surveillance program (Perry et al. 2021) to assess the presence and patterns of DA in Pacific Canadian waters, based upon the analysis of particulate filters by enzyme-linked immunosorbent assay (ELISA). In 2019, additional DFO funding was provided to study DA and other algal toxins including those responsible for paralytic (PSP) and diarrhetic shellfish poisoning (DSP) at nearshore aquaculture facilities in collaboration with B.C. salmon farmers (Ross et al. 2021). Since 2020, DFO has also been collaborating with Pacific Salmon Foundation (PSF) Citizen Science Oceanography Program (sogdatacentre.ca/atlas) to monitor algal biotoxins, phytoplankton taxonomy, and environmental conditions in the Salish Sea (Ross at al. 2022). In 2022, the program was extended to include samples collected by DFO during Salish Sea Biophysical Surveys in the Strait of Georgia (SoG). This report provides a summary of results obtained since 2020 as part of DFO's collaborative Marine Biotoxin Monitoring Program.

Surface seawater samples were collected from specific locations once or twice a month by B.C. salmon farmers and PSF citizen scientists (Figure 47-1) and two or three times a year from multiple locations during DFO surveys (Figure 47-1) along with taxonomic samples and environmental data. Samples for biotoxin analysis were obtained using a filter holder and vacuum pump to draw 1 L of seawater through a 0.45 um filter and collect the filtrate. The filters were then stored at -80 °C in 5 mL cryovials and the filtered seawater at -20 °C in 1 L plastic bottles. After thawing at room temperature, biotoxins were recovered from filters using solvent extraction and from filtrate samples using solid-phase extraction. The resulting extracts were analyzed for DA and PSP toxins using hydrophilic interaction chromatography (HILIC), and for DSP and other lipophilic toxins using reversed phase liquid chromatography (RPLC), combined with MS/MS. Filter and filtrate measurements were used to investigate the distribution of dissolved vs. particulate biotoxin, or combined to obtain the total concentration of biotoxin in seawater.

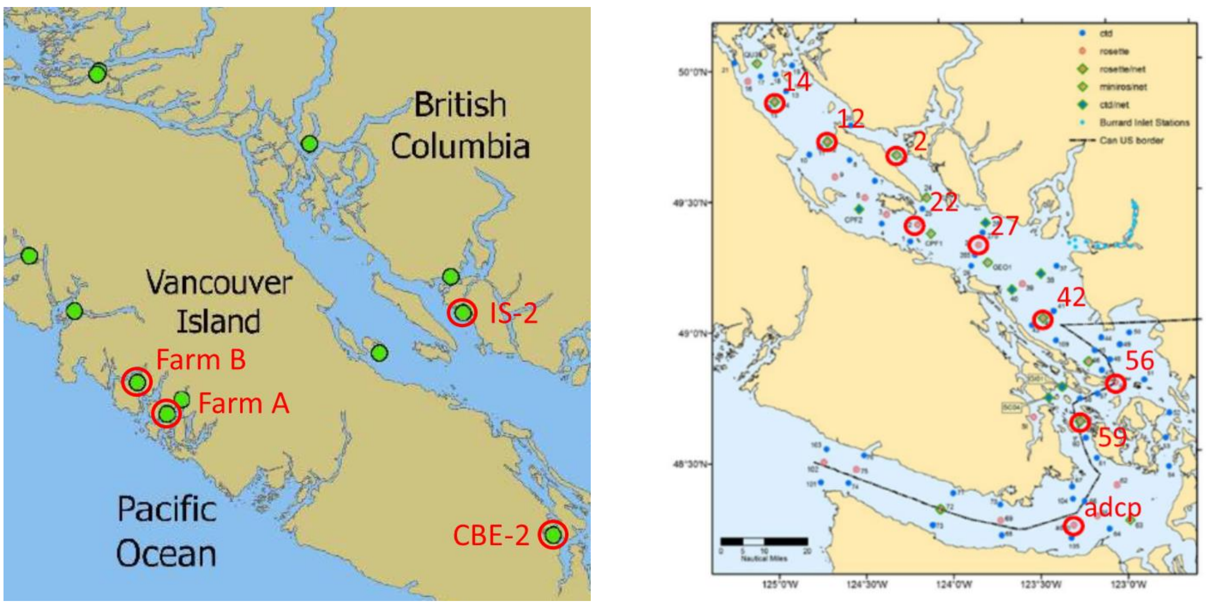

Figure 47-1. Long-term biotoxin monitoring locations near B.C. salmon farms (WCVI) and at PSF citizen science sites (SoG; left panel). Seasonal biotoxin sampling locations during DFO Salish Sea Biophysical Surveys (SoG; right panel).

47.3. Status and trends

Data collected at the WCVI farm sites between November 2020 and August 2022, show that total DA peaked earlier in 2021 than in 2022 and was greater at Farm A than at Farm B in 2021, approaching 100 ng/L in May and June (Figure 47-2). Particulate DA concentrations of around 100 ng/L, a threshold for potential DA accumulation in shellfish (Perry et al., 2021), were observed in some WCVI samples collected during the May 2021 La Perouse survey as part of DFO’s Domoic Acid Surveillance Program (which continues to operate in parallel with the Marine Biotoxin Monitoring Program). One isolated sample (LBP3) collected during the October 2021 La Perouse cruise reached 975 ng/L. However, all particulate DA concentrations measured in 2022 as part of the DA Surveillance Program were below 20 ng/L while total DA concentrations measured in 2022 were below 100 ng/L (Figure 47-2). Time series for the PSF citizen science sites (Figure 47-3) suggest that total DA peaked earlier at SoG than at WCVI farm sites. However, DA levels were generally lower in 2022 than in 2021.

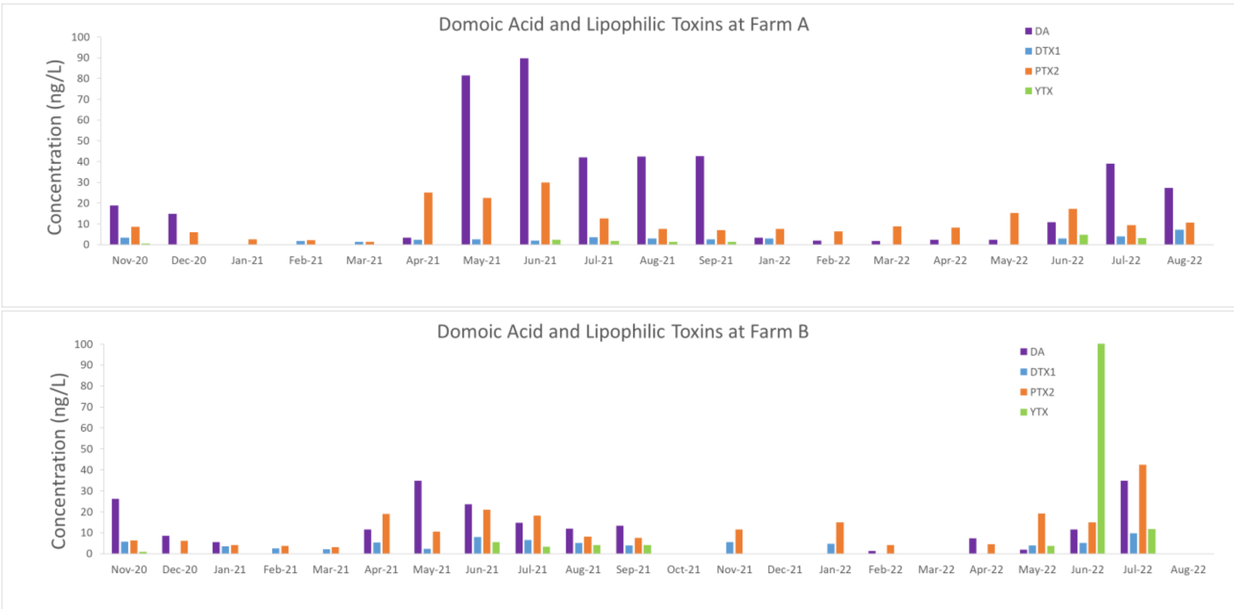

Figure 47-2. Time series of DA and Lipophilic Toxins at Farms A and B in Clayoquot Sound (Nov. 2020 to Aug. 2022).

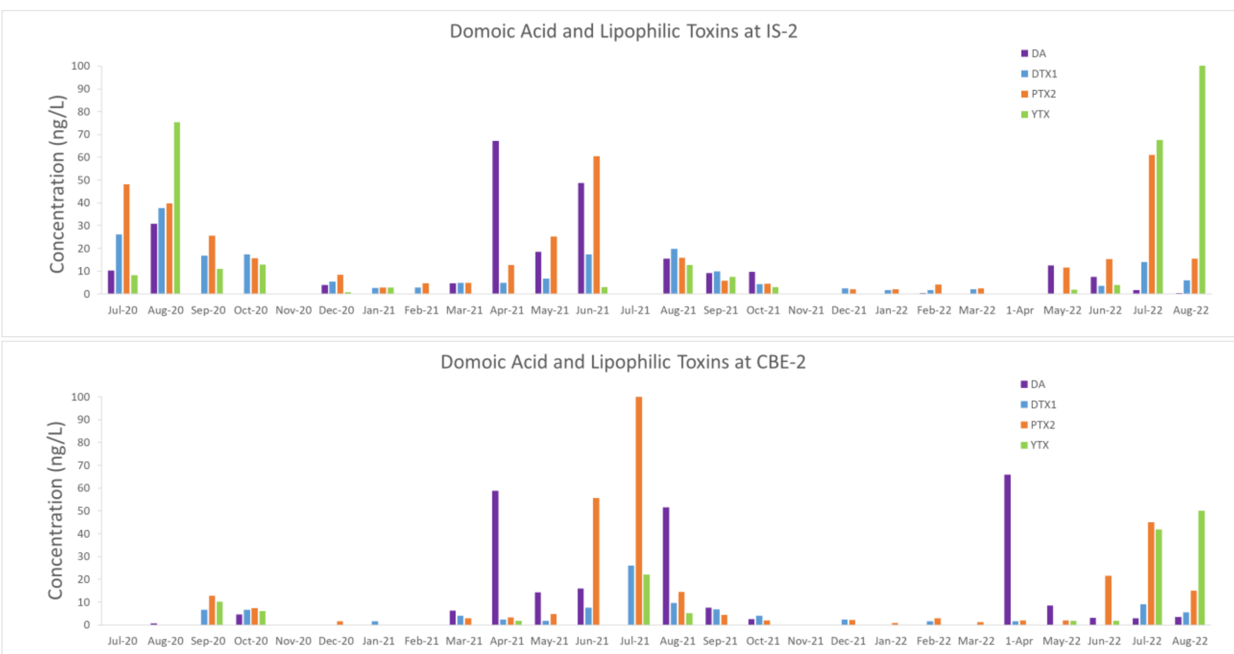

Figure 47-3. Time series of DA and Lipophilic Toxins in Malaspina Strait and Cowichan Bay (Jul. 2020 to Aug. 2022).

Dinophysistoxin-1 (DTX1) and pectenotoxin-2 (PTX2) which are produced by dinoflagellate species of the genus *Dinophysis* were present at similar concentrations in 2021 and 2022 whereas yessotoxin (YTX) which may be produced by dinoflagellate species of the genus

Protoceratium, *Lingulodinium* or *Gonyaulax* was relatively abundant in 2022 (Figures 47-2 and 47-3).

Of the 11 PSP toxins detected in B.C. coastal waters the most abundant were generally C2, C1, and saxitoxin (STX) to which other PSP toxins are structurally related. Time series for these PSP toxins (Figure 47-4) show that they tend to peak later and be more abundant than DA (Figure 47-2) at WCVI farm sites. Whereas C2 concentrations at Farm A were similar in 2021 and 2022, reaching over 200 ng/L in late-summer, those at Farm B were much higher in 2022, reaching over 4500 ng/L compared with a maximum of 820 ng/L in 2021.

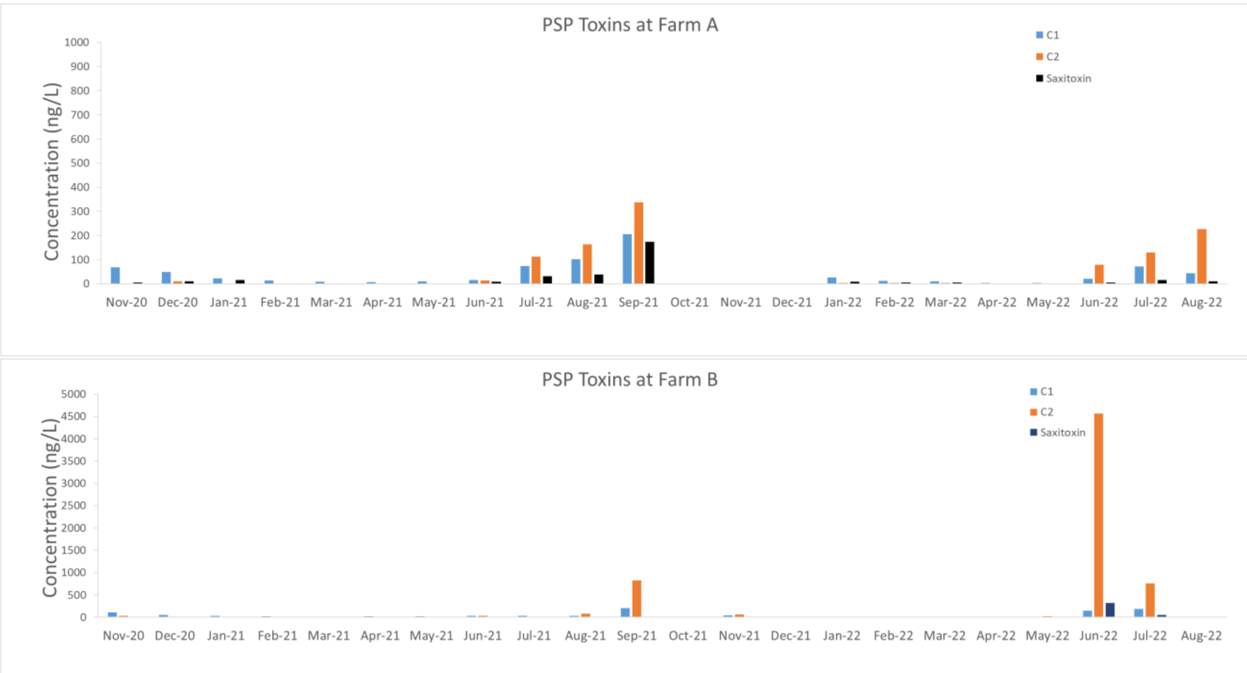

Figure 47-4. Time series of PSP Toxins at Farms A and B in Clayoquot Sound (Nov. 2020 to Aug. 2022).

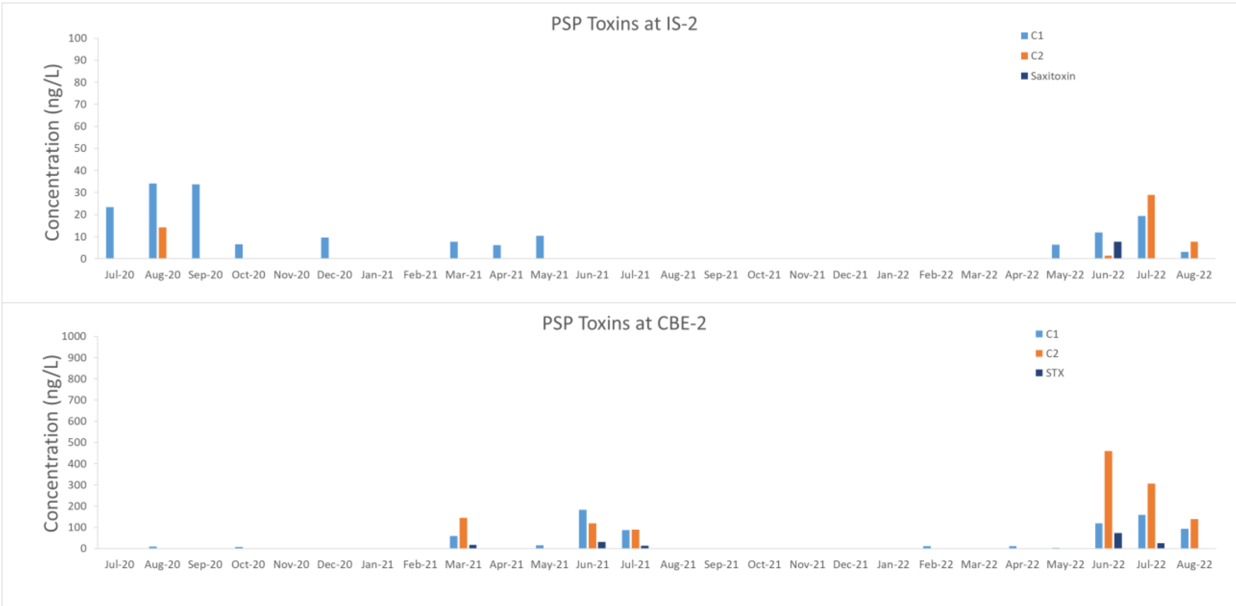

Figure 47-5. Time series of PSP Toxins in Malaspina Strait and Cowichan Bay (Jul. 2020 to Aug. 2022).

The same PSP toxins were also more abundant in 2022 at CBE-2 in Cowichan Bay, where C2 reaching a maximum of 460 ng/L compared with 145 ng/L in 2021 (Figure 47-5). In contrast, all PSP toxins remained below 40 ng/L at IS-2 in Malaspina Strait and were virtually absent in 2021. Other PSP toxins were detected but generally at much lower concentrations, notably at Farm B and IS-2 during summer 2022 and at Farm A and CBE-2 during summer 2020 and 2022. Production of these toxins at similar relative concentrations by a local strain of the dinoflagellate *Alexandrium tamarense* has been demonstrated during culture experiments.

Analysis of samples collected in spring, summer and fall 2022 during Salish Sea Biophysical Surveys show spatial and seasonal variations in biotoxin concentrations between the northern and southern SoG (Figure 47-6). The distribution of DA shifted from central and southern stations in the spring to northern and southern stations in the summer and fall, approaching 100 ng/L near the Juan de Fuca Strait (Stn. acdp) in summer 2022. The distribution of total PSP toxin abundance mirrored that of the parent and most toxic compound saxitoxin (not shown), peaking in summer but persisting into the fall and present at all stations in April, June and October 2022.

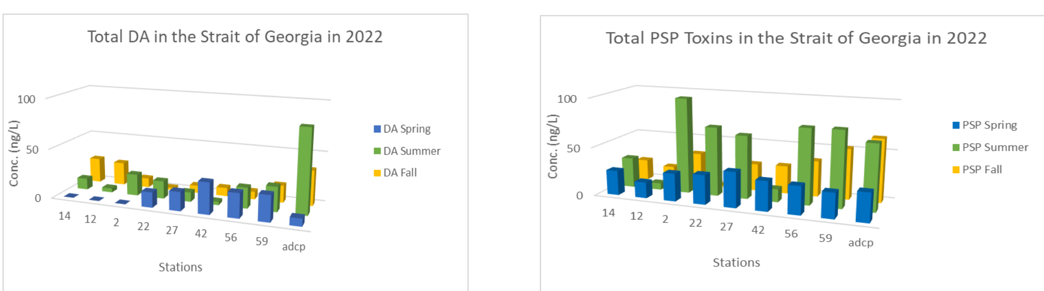

Figure 47-6. Seasonality in total DA and PSP toxins from the northern to southern SoG (Stns. 14 to adcp) in 2022.

Lipophilic toxins (Figure 47-7) were most abundant in the Malaspina Strait (Stn. 2) in June 2022 with total PTX2 reaching a maximum of 190 ng/L compared with 52 ng/L for PTX and 20 ng/L for DTX1 (not shown). These toxins were present at all stations in October 2022, with YTX being the most abundant, but were essentially absent from the SoG in April 2022.

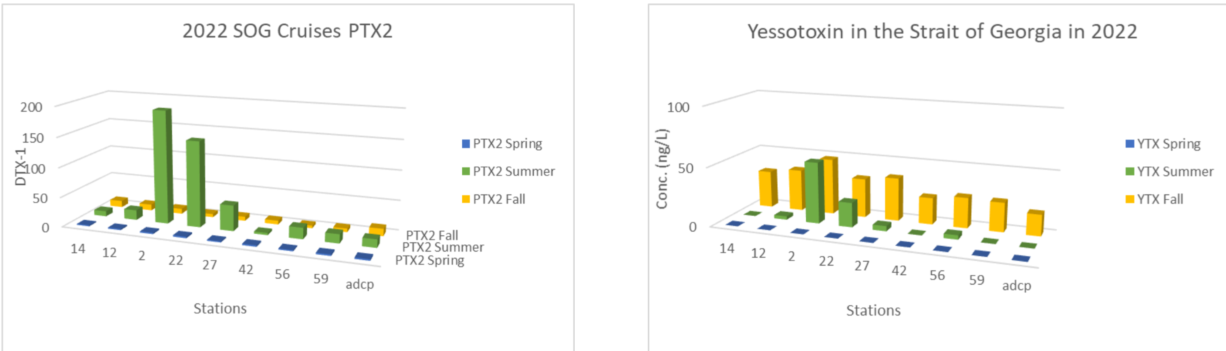

Figure 47-7. Seasonality in total PTX2 and YTX from the northern to southern SoG (Stns. 14 to adcp) in 2022.

47.4. Factors influencing trends

The occurrence and abundance of biotoxins in B.C. coastal waters appear to correlate with water temperature and/or the presence of associated harmful algae. For example, DA and DTX1 concentrations at Farm B between November 2020 and July 2021 are linearly correlated with water temperature (r^2 = 0.73 and 0.70, respectively) whereas PSP toxin C1 shows different linear correlations with temperature (r^2 = 0.91 and 0.90, respectively) before and after the spring 2021 bloom. In each case the extrapolated threshold temperature for biotoxin detection in seawater was ~8°C. Correlation of biotoxin concentrations in 2022 with temperature and other environmental factors is under way. Meanwhile, comparisons with taxonomic data suggest that biotoxin concentrations peak at the same time or shortly after the appearance of associated harmful algae but that some may persist following a bloom. These include PSP toxins which are relatively soluble and are sometimes detected in filtered seawater during the winter. Taxonomic data from the PSF Citizen Science Oceanography Program also suggests that relatively high concentrations of YTX during summer 2022 may be associated with higher than normal levels of *Protoceratium reticulatum* in the SoG.

47.5. Implications of those trends

Algal biotoxins are know to harm marine mammals and to be associated with illness and mortality in wild and farmed fish. Temporal trends in biotoxin concentration, as revealed by this monitoring program, can be used to predict when and where farmed and migrating salmon and marine mammals may be exposed to such chemicals, and to identify biotoxins that need to be assessed for their toxicity towards these species. Positive correlations between biotoxin concentration and water temperature also have implications for the potential impact of climate change on marine ecosystems in terms of how often and to what extent biotoxins may be produced by harmful algae in the future. Regular monitoring of biotoxins and environmental conditions in B.C. coastal waters provides information needed to help predict and manage the cumulative impacts of these and other stressors on living marine resources.

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48. UPDATE ON THE DISTRIBUTION OF AQUATIC INVASIVE SPECIES AND MONITORING ACTIVITIES IN THE PACIFIC REGION

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48.1. Highlights

- Marine Aquatic Invasive Species (AIS) continue to spread in B.C.
- European Green Crab (EGC; *Carcinus maenas*) continue to be found at sites throughout Haida Gwaii, following its discovery there in 2020.
- Early detection of AIS can inform management and policy, as demonstrated by the rapid response to EGC on Haida Gwaii.
- Preventing the spread of AIS requires management and monitoring of anthropogenic pathways and vectors.

48.2. Monitoring Aquatic Invasive Species in Pacific Region

Two long-term Marine Aquatic Invasive Species (AIS) monitoring programs led by DFO AIS Science are reported on here: the Settlement Plate Program, which monitors fouling AIS, and the European Green Crab Trapping Program, which targets the invasive European Green Crab (EGC; *Carcinus maenas*, Figure 48-1). We also report on efforts by the Council of Haida Nation to monitor and respond to the EGC invasion on Haida Gwaii.

48.2.1. Settlement Plate Program

Since 2014, the standardized method for monitoring fouling AIS in B.C. has been weighted PVC plates (14x14 cm) deployed from floating docks. Because this method detects fouling species most likely to establish in the upper water column and on anthropogenic structures, it is an effective method for understanding the risk of spread of fouling AIS by small vessels (Clarke Murray et al. 2011) and static structures like floating fishing lodges and docks (Iacarella et al. 2019).

In addition to the standard summer (May–Sep/Oct) settlement plates, a spring (Jan-May) deployment was added . Due to logistical constraints, sampling focused on sites in the ports of Prince Rupert (4 sites in spring, 6 in summer), Metro Vancouver (4 sites in spring, 11 sites in summer), and Nanaimo (1 spring and 1 summer) (Figure 48-1a). Presence/absence data for known AIS at each site was compiled for all plates (10 or 20 plates per site, depending on the location).

48.2.2. European Green Crab Trapping Programs

DFO Science

EGC have been monitored in B.C. since 2006, eight years after their introduction from the United States via natural larval dispersal (Gillespie et al. 2007). EGC are an intertidal species and are trapped at or above chart datum using baited Fukui fish traps. The dataset generated by the trapping program is useful for understanding the ongoing spread of EGC throughout coastal B.C., 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 EGC in new areas, including the Salish Sea and Haida Gwaii.

DFO AIS Science trapping work in 2022 covered five sites in Barkley Sound (West Coast Vancouver Island), which is limited compared to efforts in 2019 and 2021 (33 and 22 coastwide sites, respectively).

Council of the Haida Nation

EGC were first found on Haida Gwaii in July 2020. Following initial detection, the Council of the Haida Nation (CHN) utilized existing government partnerships to initiate a response program to understand and mitigate the impacts of the invasion. This program includes both detection trapping to understand the geographic extent of the invasion and depletion trapping at priority sites for population suppression. The program is also monitoring and mapping environmental variables likely to affect EGC, and monitoring native populations of bivalves, native shore crabs, and eelgrass that are likely to be impacted by the invasion. Data collected will be used to assess the effectiveness of depletion trapping, refine the response strategy, and inform local management decisions.

EGC are typically found in tidal flats, estuaries, salt marshes and beaches, and in more protected waters (Howard et al. 2022). However, on Haida Gwaii EGC have also been found on exposed, cobbly beaches with large wave action. This has introduced an additional barrier to trapping them effectively in dynamic, intertidal water.

The Haida Gwaii coastline was divided into 900 shore segments, which were determined based on geography and EGC suitability. The average segment is 5 km long and 60 ha in size. Shore segments were prioritized for detection trapping based on cultural and ecological importance as well as EGC suitability. Six priority sites were selected for depletion trapping based on cultural and ecological importance, and predicted sensitivity to impacts from EGC. These six sites were intensively trapped from Aug–Sep 2022, and the impact of this trapping on the EGC population was assessed.

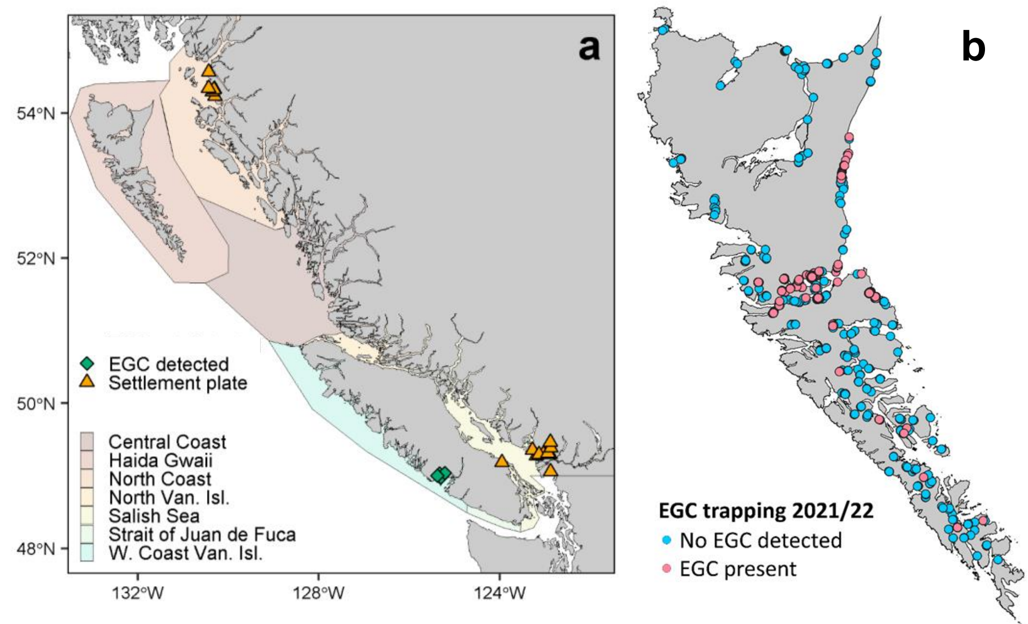

Figure 48-1. a) Locations of DFO Science European Green Crab (EGC) trapping and settlement plate deployment in 2022; b) Locations of Council of the Haida Nation EGC trapping in 2021/22.

48.3. Status and Trends

48.3.1. Settlement Plate Program

Results from the summer plate deployments are shown in Figure 48-2. No new species of biofouling AIS were detected in B.C. in 2022, although several local range expansions of known AIS were observed within Metro Vancouver. The violet tunicate *Botrylloides violaceus* was detected for the first time at Crescent Beach in Surrey, its first detection in Boundary Bay since 2008. Three AIS were detected in the spring, two of which were also recorded at their respective sites in the summer (the bryozoan *Cryptosula pallasiana* at Newcastle Marina, Nanaimo, and the tunicate *Botryllus schlosseri* at Coal Harbour, Vancouver). The third spring AIS, the barnacle *Amphibalanus improvisus,* was detected for the first time at Reed Point, Port Moody, although it has been previously found throughout western Burrard Inlet and Indian Arm. It was not detected at Reed Point on the summer plates. No AIS were found on spring plates in Prince Rupert.

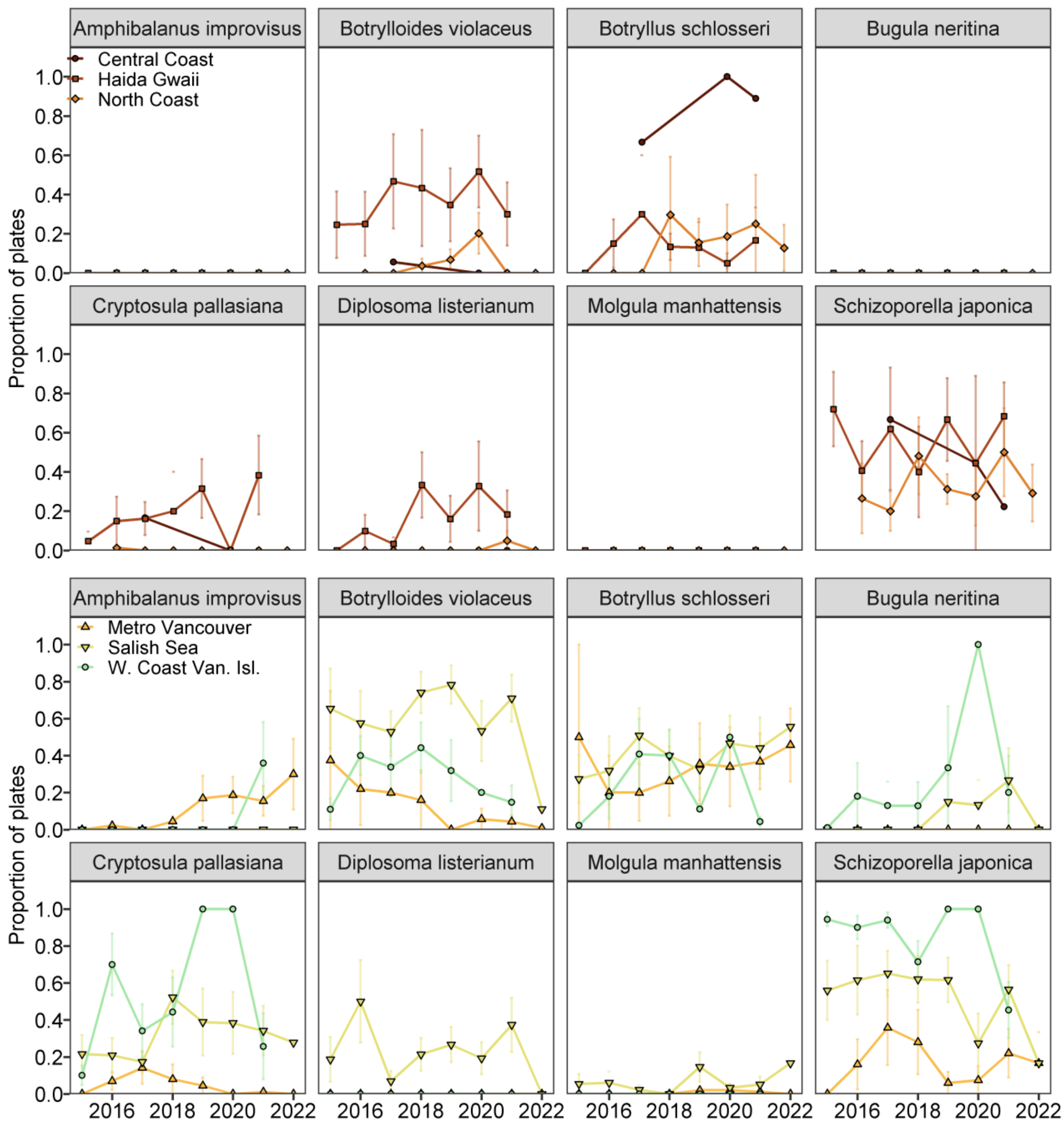

Figure 48-2. Change in prevalence of some AIS found on settlement plates in three areas in northern B.C. (top two rows) and southern B.C. (bottom two rows), presented as the proportion of plates at each site on which each species was found, averaged within regions. Only data from summer deployments (May–Sep/Oct) are shown. Note that in 2022, data were only collected in the North Coast (6 sites), Metro Vancouver (6 sites), and Salish Sea (1 site).

48.3.2. European Green Crab Trapping Program

DFO AIS Science catches of EGC in Barkley Sound increased slightly from 2021 (Figure 48-3), but continue to be low relative to historical levels for unknown reasons. Ongoing elimination trapping efforts in Clayoquot Sound, led by the Coastal Restoration Society, continue to catch substantial numbers of crabs, indicating that EGC population dynamics in Barkley Sound may not be representative of EGC population dynamics on the west coast of Vancouver Island.

In Haida Gwaii, CHN has trapped 18% of the shore segments as of the end of 2022, and EGC were detected at 24% of those (Figure 48-1b). In 2021, a total of 167 EGC were captured. Trapping effort was increased in 2022, and over 31,000 EGC were captured in Haida Gwaii waters from May–Nov. One goal of the detection trapping was to understand the spread of EGC from the proposed epicenter in Skidegate Inlet. The invasion has reached north to Cape Ball along East Beach, south to Ikeda Cove in Gwaii Haanas, and west to Dawson Inlet at the west end of Skidegate Channel (Figure 48-1b). So far EGC have not been detected on the north or west coasts of Haida Gwaii.

The priority site that was trapped most intensively (greatest number of traps/area) showed significant reduction in Catch Per Unit Effort (CPUE) over the period. There was also a significant reduction in the average size of crabs, and an increase in the percentage of females caught. The other priority sites were either larger or had less trapping effort dedicated to them, and therefore were trapped less intensively (fewer traps/area). None of these sites showed any decrease in CPUE over the trapping period. These sites either showed no change in average size or percentage of females, or showed an increase in average size and a decrease in percentage of females. These results suggest that depletion trapping requires a large number of traps relative to the size of the site to be effective.

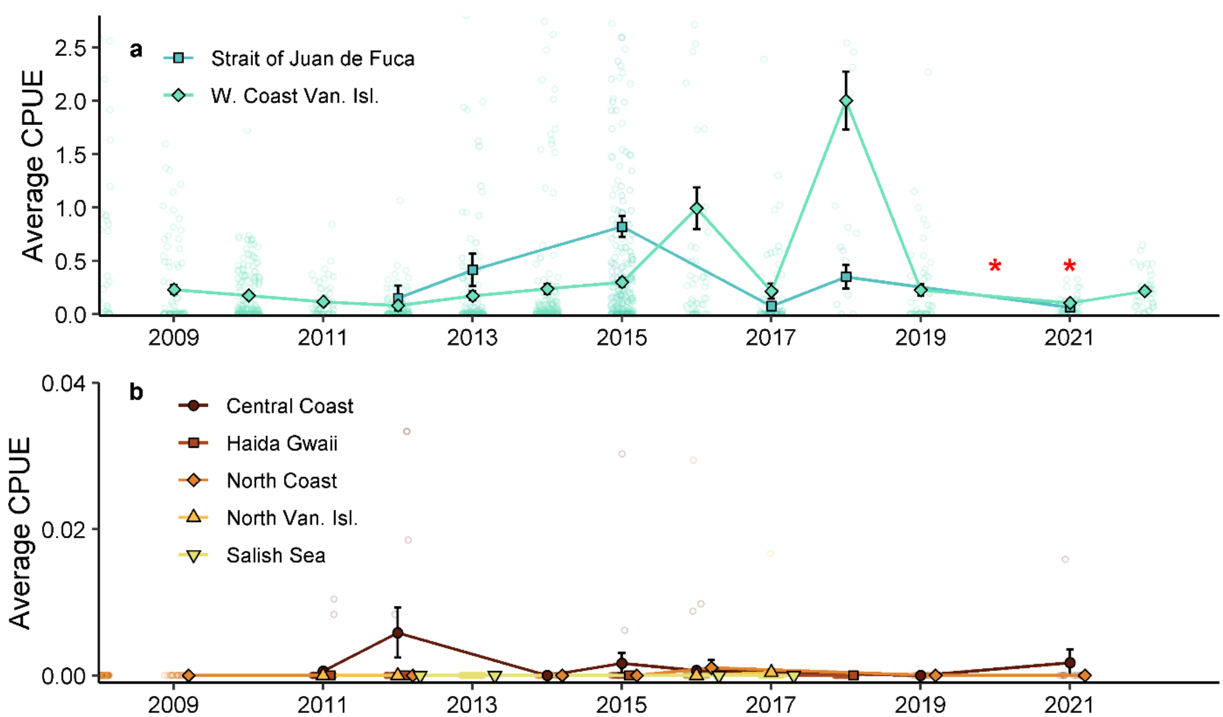

Figure 48-3. Annual CPUE (catch per unit effort) of European Green Crabs (mean ± SE of all trapping events within a region) from the DFO AIS Science trapping program on a) the West Coast of Vancouver Island and the Strait of Juan de Fuca, and b) elsewhere in B.C. (note scale differences). Empty points represent individual trapping events (6 traps per set). All raw data are plotted, but most CPUEs are too small for points to be visible. Red stars indicate caution when interpreting data in a) as the trapping program was interrupted in 2020 due to Covid-19, and the 2021

data includes surveys with anomalously low catches (see Gale et al. 2022). Note that some values have changed from last year's report (Gale et al. 2022) because this plot does not include partner data, only results from DFO AIS Science.

48.4. Implications and drivers of AIS range expansions in the Pacific Region

The potential for localized, anthropogenic spread of AIS combined with their increasing abundance and climate change 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 anthropogenic spread of AIS via infested vessels, structures, and equipment will continue to be a primary vector for both existing (known) and novel AIS in B.C. The Settlement Plate Program has been both a useful proxy for tracking dispersal of fouling AIS and a means of increasing public awareness of these species. By engaging with the public and focusing management on key vectors, there is a better chance of reducing spread of both established AIS and newly introduced or undetected ones whose impacts are not yet known.

EGC are known to have significant negative impacts on bivalve populations, especially clams, and on eelgrass habitats (Howard et al. 2019). The continued spread of this species has resulted in the Salish Sea Transboundary Action Plan for Invasive EGC (Drinkwin et al. 2019), a joint management plan between DFO and Washington State partners, and a dedicated early detection and eradication program managed by FFHPP. However, the arrival of EGC on Haida Gwaii and more recently, southern Alaska[1], has highlighted the need for similar multiagency management plans for other parts of B.C. in order to limit the ecosystem impacts of this invader.

The range expansions of EGC and early spring detections of fouling AIS also demonstrate the ongoing role of climate change in the spread and impacts of AIS in B.C. It is expected that periods of significant warming will facilitate population spikes and natural long-range larval dispersal events for AIS (Gillespie et al. 2007; Brasseale et al. 2019).

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49. WHAT OUR SOUNDSCAPE DESCRIPTIONS TELL US ABOUT ACOUSTIC DISTURBANCE FOR SOUTHERN RESIDENT KILLER WHALES

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49.1. Highlights

- Spatiotemporal patterns of noise additions from wind and vessels to ambient sound levels in the Salish Sea were considered for the potential impacts on Southern Resident Killer Whale (SRKW) acoustics use.
- Communication calls in the range of 1-40 kHz were the most impacted by both wind and vessel noise.
- Commercial vessel noise exceeded wind noise at almost all times and in all locations.

49.2. Description of the time series

Wind and vessel noise layers

Wind noise was estimated from wind speed data (Figure 49-1) from the SalishSeaCast model (Sootiens et al. 2016, Soontiens and Allen 2017) and converted to equivalent noise levels using available empirical relationships (Vagle et al. 1990). Vessel presence was characterised from Automatic Identification Systems (AIS) data differentiating Class A vessels, and used as an input for a vessel noise model (Aulanier et al. 2017) at 125 Hz. Class A vessels are commercial vessels mandated to carry the AIS transceivers. Examination of vessel noise as a function of depth through the water column was possible (Figure 49-2). The vessel noise model was ground-truthed using passive acoustic recordings made since 2018 from up to 12 sites throughout the Salish Sea (Figures 49-1- 49-5). Sound levels were examined over 3-month increments (January-March, April-June, July-September, October-December).

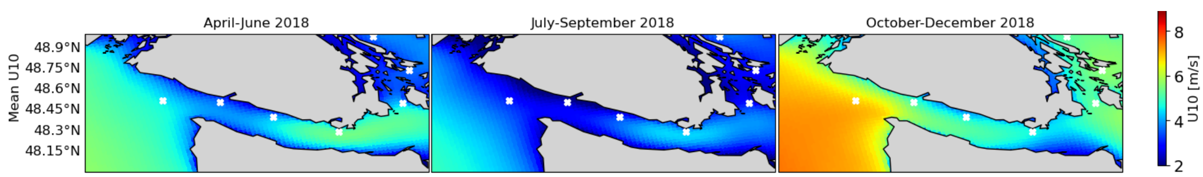

Figure 49-1. Three-month average wind speed from SalishSeaCast model. January to March were the same as October to December and so are not shown. Passive acoustic mooring locations indicated with white crosses.

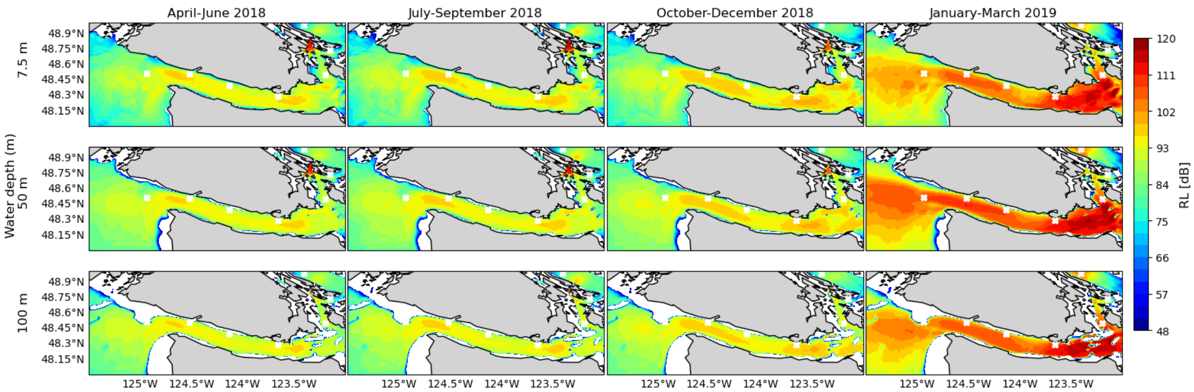

Figure 49-2. Vessel noise additions at 125 Hz for commercial Class A vessels transiting the study area as obtained from the shipping noise model. Comparisons were made for median noise levels (L_{50}) for 3-month periods, and for water depths 7.5 m, 50 m, 100 m.

<u>Sound levels in communication and echolocation frequencies</u>

The estimated wind and vessel noise was extrapolated into the frequencies representing the communication and echolocation ranges for SRKW. Communication calls like whistles and pulsed calls, were considered using the 1-40 kHz frequency range. Echolocation signals were characterised by using a 50 kHz candidate frequency, estimating the returns of these signals from an average Chinook salmon as its target, consistent with other similar works (see Au et al. 2004). The distance over which calls in these frequencies could be used effectively as a result of natural (Figure 49-3) and anthropogenic noise additions (Figure 49-4) were considered for the 3-month time periods. This was compared to times of 'minimum ambient' sound levels, when wind and vessel noise was absent. Call ranges estimated for the noise scenarios were expressed as proportions of the maximum call range possible under minimum ambient.

49.3. Implications for southern resident killer whales

Our work to describe the soundscape (Burnham et al. 2021) showed that wind noise increased in the offshore waters by Swiftsure Bank and western part of Juan de Fuca in the winter. It was here that we saw the greatest reductions in both communication call extent and echolocation range (Figure 49-3). At times and places where the wind noise was at its greatest the signal range would be reduced between 40-60% compared to minimum ambient conditions.

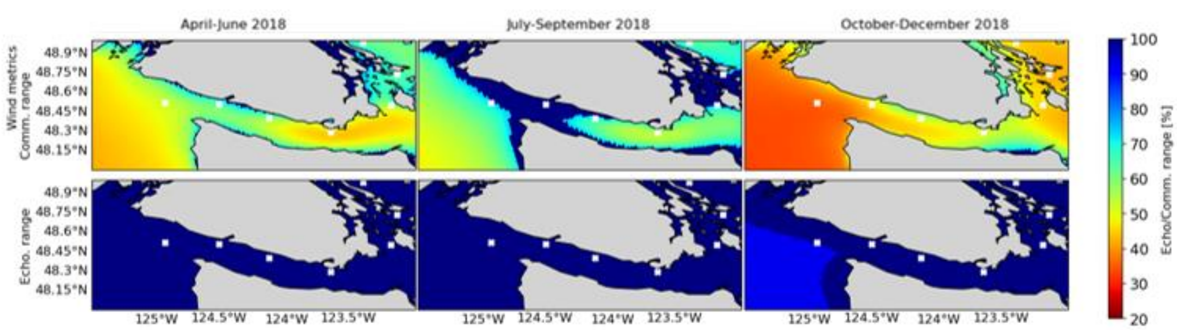

Figure 49-3. Proportional reductions seen for 1-40 kHz (Comm.) and 50 kHz (Echo.) signals from 'minimum ambient' conditions resulting from wind noise. January to March showed identical results to October to December and so are not depicted in a separate panel.

Shipping noise is a consistent component of the soundscape at Swiftsure Bank and through Juan de Fuca Strait. These areas were highlighted as the regions that would experience sufficient noise to reduce communication call and echolocation signal efficacy (Figure 49-4). Areas around Sooke and the entrance to Haro Strait were also highlighted. The passage rate of vessels was consistent throughout the year, therefore the greater reductions seen in the cooler months of October to March, up to 90% reduction from minimum ambient for communication calls (Figure 49-4), likely results from seasonally altered sound propagation properties (Vagle et al. 2021).

The limited propagation of higher frequencies resulted in the vessel noise additions at 50 kHz to be restricted to the shipping lanes through all times and depths considered (Figure 49-5). The model suggests that, in the shipping lanes themselves, echolocation signal returns may not exceed ambient noise levels, making these calls ineffective. This suggests that SRKW use of echolocation during foraging, as modeled, could be severely impacted.

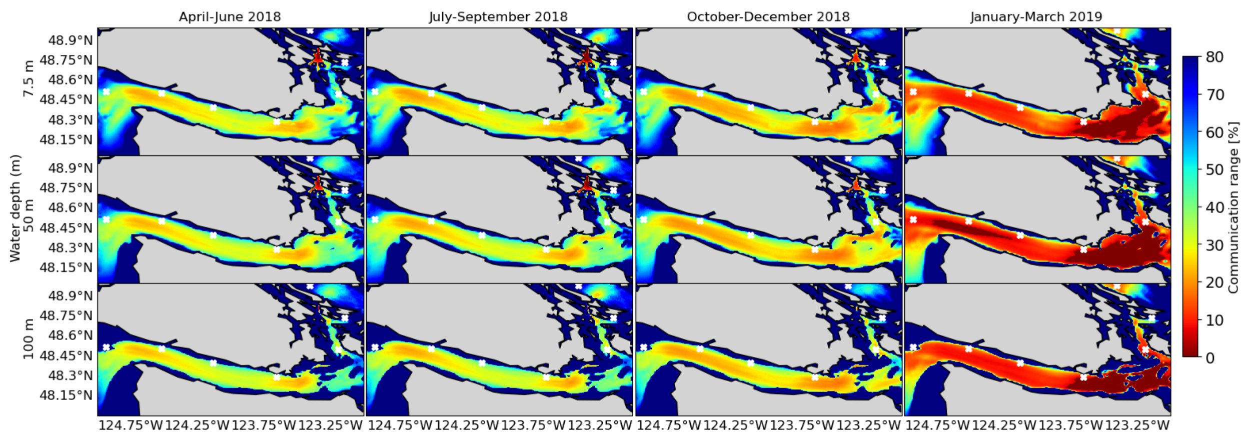

Figure 49-4. Proportional reduction, due to vessel noise, of 1-40 kHz band signal range from 'minimum ambient' conditions representing communication call use by SRKW. Comparisons were made for 3-month periods, at water depths 7.5 m, 50 m, 100 m. Mooring locations indicated as white crosses.

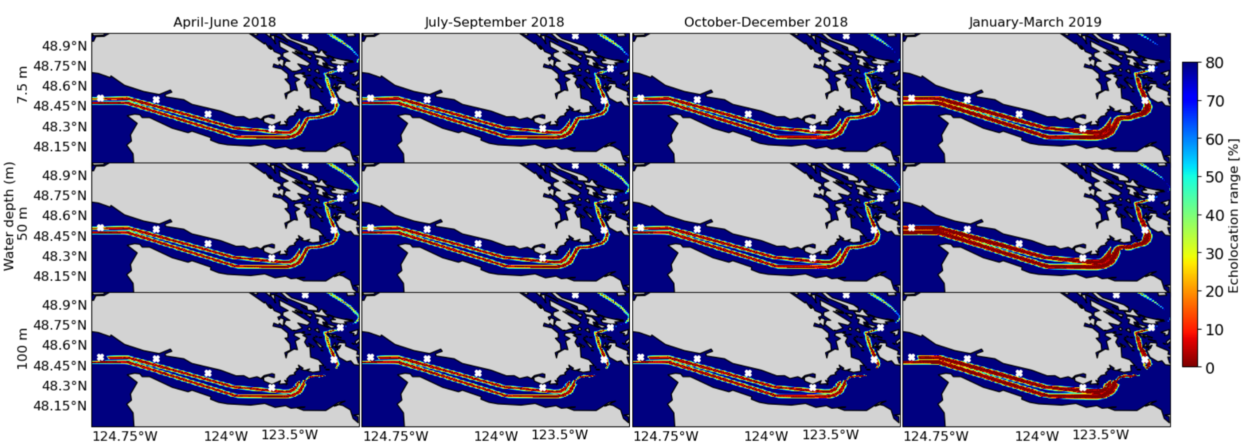

Figure 49-5. Proportional reduction, due to vessel noise, of 50 kHz signal range from 'minimum ambient' conditions representing echolocation use by SRKW. Comparisons were made for 3-month periods, with whale at 10 m echo-locating on Chinook salmon prey at depths of 7.5 m, 50 m, 100 m.

49.4. Applications

These models add to our work on soundscape descriptions and help evaluate the potential acoustic disturbance on SRKW (Burnham et al. 2023). In the future, it will be furthered to help make predictions for different soundscape scenarios, for example under altered vessel presence, speed, and/or routing.

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50. LAUNCHING PACEA: AN R PACKAGE TO AMALGAMATE PACIFIC DATA TO HELP OPERATIONALISE AN ECOSYSTEM APPROACH TO FISHERIES MANAGEMENT

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50.1. Highlights

- An Ecosystem Approach to Fisheries Management is a priority for DFO, given the legislative obligation (under the revised Fisheries Act) to take into account the environmental conditions affecting stocks when managing fisheries.
- Stock assessment scientists across DFO report that the biggest impediment to doing this is availability of environmental data.
- PACea is an R package that is amalgamating various sources of Pacific Region environmental data into a single product such the data can easily be utilised by assessment scientists and other interested users.

50.2. Motivation

Under the revised Fisheries Act, when implementing management measures to promote sustainability the Minister shall take into account the environmental conditions affecting a fish stock. However, just over half of DFO's stock assessments do not currently use environmental data, based on a survey of DFO assessment scientists for 212 stocks (Kulka et al. 2022).

The survey also found that the leading cause of not integrating environmental data into assessments was the availability of such data (Kulka et al. 2022). While some data may be available from colleagues or made public on Open Data platforms, it may still require some searching by the scientist and substantial data wrangling to make it usable for their analysis. For example, output from the Regional Ocean Modelling System (ROMS) for B.C. waters is shared by oceanographers, but it is in a format (i.e. netCDF) which is unfamiliar to most biologists. Extensive effort is then required to wrangle the data into a useful structure for analyses in R (the statistical programming language used by stock assessment scientists).

A related example is a DFO colleague who wanted to include sea surface temperature as an input into models of sightings of marine mammals (including humpback whales, fin whales, Dall's porpoises and harbour porpoises). While she found temperature data on the US Environmental Research Division's Data Access Program (ERDDAP) website, there was a choice of 339 datasets to download. Not being an oceanographer, it would have required a substantial effort to work out which dataset to use and then to convert it into a usable structure for the analyses, and there was not the time available.

50.3. Solution

The PACea R package (Edwards and Watson 2023) is being developed to facilitate the sharing of ecosystem data for ease of use by stock assessment scientists and other interested parties. It is motivated by a similar package developed for the Gulf of St. Lawrence (Duplisea et al. 2020). Datasets are being fully documented as to where they came from, including citations of original sources. Spatial data are efficiently saved on a grid covering the B.C. coast, and vignettes will show users how to extract, use, and map the data. Non-spatial time series are also being included. Data are stored at monthly or annual resolution, as appropriate.

Core datasets in the process of being incorporated include:

- ROMS output:
  - temperature at the sea surface and at various depths
  - oxygen at various depths
  - salinity at various depths
  - primary production
  - chlorophyll
  - pH at different depths
  - depth of aragonite saturation
- sea-surface temperature from satellite measurements (one of the ERDDAP datasets)
- lighthouse temperature time series
- oceanographic indices such as Pacific Decadal Oscillation, Oceanic Niño Index, Southern Oscillation Index.

Biological data will also be added, and it is envisioned that PACea will expand in response to requests from users. Sharing data in usable formats can have many benefits, as for the synopsis of visualisations of DFO data on 113 species of Pacific groundfish (Anderson et al. 2020; DFO 2022). For example, the synopsis turned raw data into interpretable graphics for parties (such as First Nations, fishery managers, and non-governmental organisations) who might lack the time, skills or institutional knowledge to access and correctly process Open Data. Similarly, PACea will eliminate the need for individual stock assessment scientists to figure out how to obtain and format data, while also reducing the number of individual requests to oceanographers for products such as ROMS output. Being written as a properly documented and formatted R package will ensure that it can be efficiently updated as newer data become available. This will help *operationalise* an Ecosystem Approach to Fisheries Management in DFO's Pacific Region.

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Appendix 1 - Poster Abstracts

51. SURVEYING AND MONITORING NEARSHORE FORAGE FISH IN THE SALISH SEA USING ACOUSTIC-OPTIC TECHNOLOGIES

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51.1. Highlights

- Acoustic arrays were deployed continuously at two sites in the Strait of Georgia from February 2022 – April 2023.
- Approximately monthly deployments of stereo-camera systems were also completed for 24-hour periods at the two sites throughout 2022 and early 2023.
- Age-0 Pacific herring appeared in late spring, but juveniles were in the nearshore throughout the year (although absent in December).
- Pollock appeared to be the other dominant small pelagic fish in the nearshore in the Salish Sea.
- Stereo cameras perceived similar size distributions as those captured in seine nets and the shipboard acoustics show similar spatial patterns in abundance to seine net catches.

51.2. Extended abstract

Forage fish comprise an important link between zooplankton and predatory fishes, birds and marine mammals. In the Salish Sea, Pacific Herring are the most abundant forage fish. Herring spawn in the spring and larvae hatch about 2 weeks later and juveniles are thought to occupy nearshore habitats in the following summer and fall. Since 1992, DFO has conducted a seine survey to estimate the relative abundance of juvenile herring in September. In 2021, we began using advanced sampling technologies (acoustics, optics and spatial modeling) to estimate herring abundance and to improve our understanding of juvenile herring residency nearshore. The main tools used in this work were stationary underwater stereo camera systems and moored acoustic arrays. Vessel mounted acoustics were also added to the September seine surveys. The two main forage fish species observed in the stationary cameras were herring and juvenile Pollock. In addition a number of predatory fish were observed (Dogfish, Lingcod, Copper Rockfish, Pacific Cod) and marine mammals (sea lions and Harbour Seals). Catches and acoustics showed similar patterns seasonally, with juvenile herring appearing in the spring in the nearshore and then moving out of the nearshore in the early winter (for the most part). Image analysis and acoustic analysis will be completed in the spring of 2023.

52. JOINT CANADA-USA INTERNATIONAL SEAMOUNT SURVEY

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52.1. Highlights

- In 2022, 5 seamounts in international waters were surveyed using underwater stereo video cameras.
- Fan-type corals and glass sponges occurred frequently (but at relatively low densities) on transects below 600 m on all seamounts. Demosponges were largely absent.
- Much of the substrate at deeper depths was rocky and volcanic (particularly on Brown Bear, Warwick and Eickelberg).
- Rockfish species were dominated by Shortspine Thornyhead (>600 m), Blackspotted Rockfish (200-600 m) and Rosethorn Rockfish (< 200 m), with clear evidence of historical fishing observed.

52.2. Extended abstract

The Joint Canada-USA International Seamount Survey (JCUISS) focussed on deep-sea coral and sponge communities on seamounts in international waters with a primary objective to generate spatially explicit data using underwater stereo video cameras that can be used to map the distribution of deep-sea corals and sponges at the seamounts, document their size structure, visible impacts of human activity, and their species associations. The survey used a stratified-random sampling design with depth strata on 5 seamounts and was carried out during a 14 day cruise (Sept. 6-20, 2022) aboard the Canadian Coast Guard Vessel John P. Tully. Seventy-seven stations were occupied at five seamounts at depths ranging from 100-850 m.

The main tool used in this work was the underwater stereo camera system. The visual survey was designed in a robust statistically sound method so that inferences about the deep-sea coral and sponge communities on seamounts can be made. Preliminary image analysis showed that corals were present at 57% of the transects occupied. Most of the corals occurred at depths below 400 m and corals were present at most transects on all seamounts below this depth (Figure 52-1). Discarded longline gear was observed at ~20% of transects and a single furrow believed to be indicative of bottom trawl gear was observed. Most of the fishing gear occurred on Cobb Seamount.

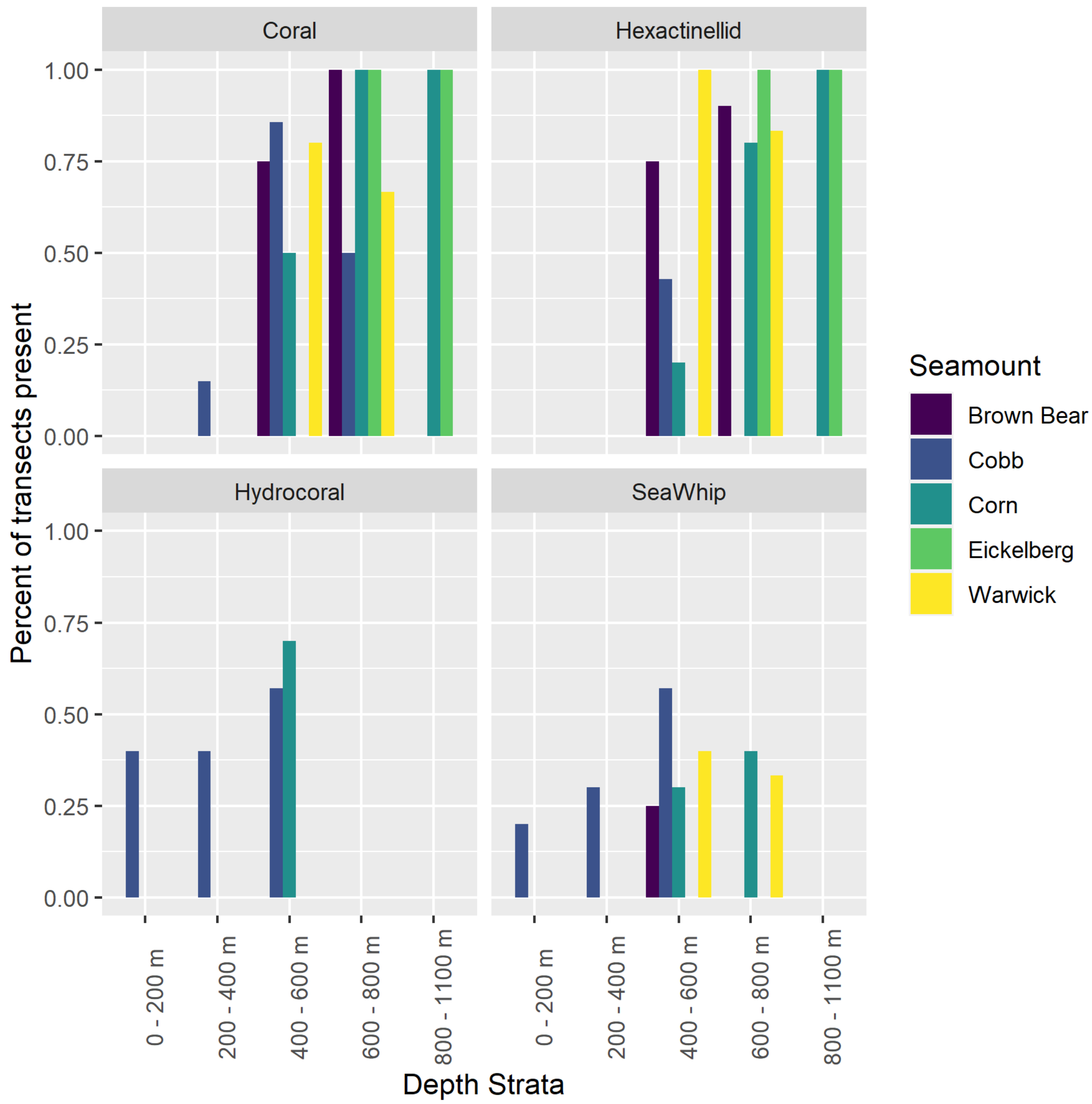

Figure 52-1. Percentages present for the four most common structure forming invertebrates at the five seamounts surveyed during the Joint Canada USA International Seamounts cruise.

53. OCEANOGRAPHY AT THE HAKAI INSTITUTE: 10 YEARS IN

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53.1. Highlights

- The oceanographic focus at the Hakai Institute has grown over the decade, becoming increasingly multi-disciplinary, to examine more deeply the roles of freshwater input and other physical forcings, and expanded to consider the impacts of emerging climate stressors in more regions along the northeast Pacific coast.
- Long-term observation and multi-disciplinary research are the pillars supporting the Hakai Institute's objective to understand climate stressors and their impacts on ecosystem dynamics along the northeast Pacific coastal margin.
- Oceanographic data is collected, analyzed, and distributed through a series of key partnerships.

53.2. Extended abstract

Oceanography at the Hakai Institute (HI), a division of the Tula Foundation, began on the central B.C. coast in the nearshore waters surrounding the Calvert Island Ecological Observatory in 2012. Early research pursued the interplay between terrestrial inputs, marine conditions and food web dynamics. Our oceanographic focus has grown over the decade, becoming increasingly multi-disciplinary, to examine more deeply the roles of freshwater input and other physical forcings, but also expanded to consider the impacts of emerging climate stressors (warming, de-oxygenation, and ocean acidification) in more regions along the northeast Pacific coast including waters surrounding our second field station within the Salish Sea, the Quadra Island Ecological Observatory, where operations began in 2015.

The region bounded by our field stations is centrally located within the Northeast Pacific Coastal Temperate Rainforest (Bidlack et al. 2021), and by virtue receives significant freshwater (Giesbrecht et al. 2022) making it a hot-spot for studying land-ocean connectivity (St. Pierre et al. 2020) due, in part, to high dissolved organic carbon fluxes to the coastal ocean (Oliver et al. 2017) that subsidize marine food webs (St. Pierre et al. 2021). Freshwater input to these fjords drives an estuarine circulation pattern, which, when combined with the remineralization of sinking organic matter of surface origin within intermediate waters and incoming low-oxygen deep ocean water, can create oxygen minimum zones that adversely impact marine organisms and are prone to be amplified by climate change (Jackson et al. 2021a). Organic matter produced in the surface layer largely consists of phytoplankton, which have populations and community structure that is highly variable and shaped by both physical processes and grazing pressure (Del Bel Belluz et al. 2021). Likewise, microbial community composition and function is tightly linked to physical and chemical conditions as well as organic matter sources in the region (Kellogg, pers. Comm.). Physical variability that shapes phytoplankton structure also influences zooplankton biomass (Mahara et al. 2021) and subsequently the condition of juvenile salmon migrating past our Quadra Island Ecological Observatory (James et al. 2020). These components of the marine food web are strongly influenced by climate change, and the manifestation of climate change signals, including warming, de-oxygenation, and even large-amplitude events such as marine heatwaves, within nearshore regions is likely shaped by connectivity to the deep ocean (Dosser et al. 2021; Hare et al. 2020; Jackson et al. 2021b). For instance, fjords with direct connection to the deep ocean may receive and retain signals from marine heatwaves longer than in other areas (Jackson et al. 2018), whereas fjords with a more convoluted connectivity to the deep ocean, such as Bute Inlet, may contain larger volumes of corrosive water for calcium carbonate due to generally weaker buffering (Hare et al. 2020). While such fjords may be hot-spots for corrosive seawater, it is clear that conditions can vary widely across a range of temporal and spatial scales (Evans et al. 2022; Evans et al. 2019).

Long-term observation and multi-disciplinary research are the pillars supporting the HI objective to understand climate stressors and their impacts on ecosystem dynamics along the northeast Pacific coastal margin. The foundation for these pillars is built from strong regional partnerships. HI ocean observing benefits from strong partnership with many government and academic partners, including, but not limited to, Fisheries and Oceans Canada, the Canadian Profiling Robotic Ocean Observing Facility, the University of British Columbia, and the Province of British Columbia. Our focus looking ahead is to strengthen these pillars in order to provide critical, timely, and actionable information that supports a path toward enhanced resiliency.

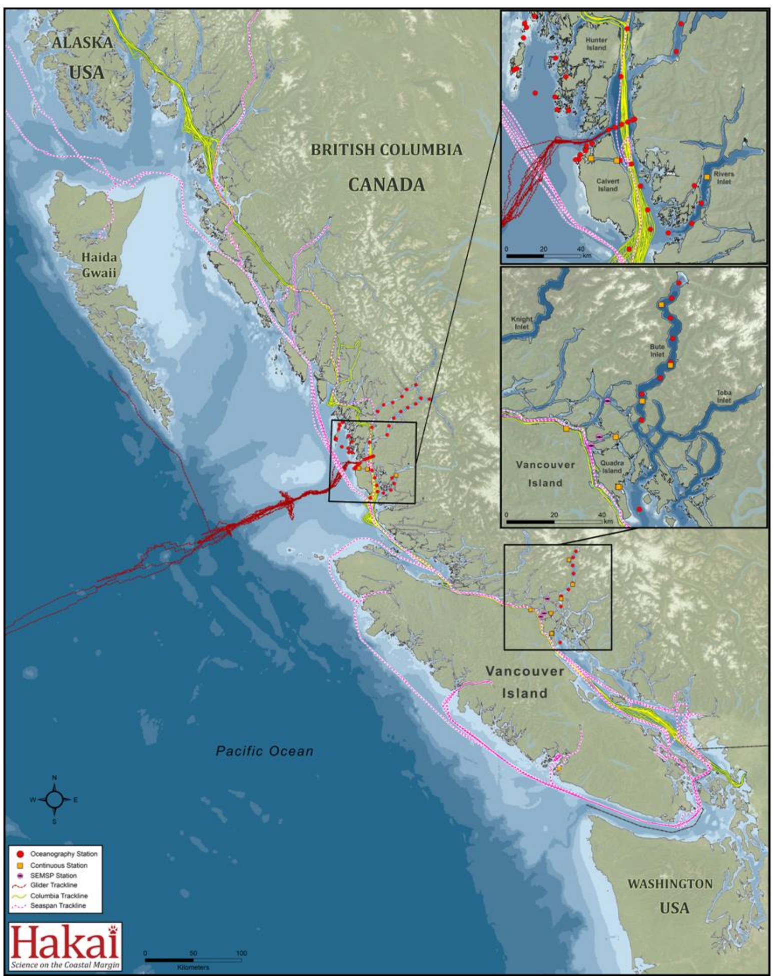

Figure 53-1. Map showing ocean observing efforts of the Hakai Institute and partners during 2022. Collaborative efforts include the CPROOF glider program, Sea Span underway measurements, Columbia Ferry underway measurements, BC Shellfish Growers Association monitoring of intake water, and various partnerships with UBC and other institutions.

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54. THE BIG FLUSH: SNOW AND ICE MELT DOMINATE SEASONAL SALINITY VARIATION ON THE CENTRAL B.C. COAST

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54.1. Highlights

- In July 2022, we observed high freshwater content from Dean Channel to Lama Passage, corresponding with the timing of runoff from the Snow Mountain and Glacierized Mountain watersheds.
- In late July, freshwater through Hakai Pass was mixed to ~30 psu by the time the water was advected to 55.5 km from the coast.
- The available streamflow gauges suggest 2022 was characterized by later and larger than normal meltwater runoff while fall flows were exceptionally low, except for some large events.

54.2. Extended abstract

Freshwater runoff is a key driver of physical, chemical, biological, and ecological processes along coastal margins. Mixing of riverine and ocean waters can create zones of high biological productivity and carbon fixation, while also affecting the cycling of nutrients and organic matter (St. Pierre et al. 2021, 2022). Most fjords in B.C. are dominated by mountainous watersheds with significant snow and glacier cover (Giesbrecht et al. 2022). However, these watersheds are increasingly susceptible to climate change, making it critical to understand the changes that are occurring in these environments.

The 2022 data we present were collected using two different observational strategies on the central B.C. coast (Figures 54-1 – 54-4). The first consisted of a transect from Dean Channel (52.45417°N, -127.2583°W) through Fitz Hugh Sound and into Rivers Inlet (51.6008°N, -127.5313°W) where CTD casts were conducted in 4 days time. The second consisted of two glider transects from the middle of Fitz Hugh Sound (51.72648°N, -128.04770°W) through Hakai Pass to just past the shelf break (50.88877°N, -130.44280°W). In the CTD transect time series, we found that the summer freshet from Dean Channel peaked in July, corresponding with the timing of runoff from the Snow Mountain and Glacierized Mountain watersheds. Glider data showed that the 2022 summer freshet was able to advect to ~55 km from the coast. In contrast to the channels and fjords, the freshwater that advected through and out of Hakai Pass was rich in chl-a, suggesting accretion of biomass over time.

With only two years of data in Burke and Dean Channels, we focused on data collected from 0 to 30 m at KC10 to gain a better understanding of how seasonal freshwater timing had contributed to biogeochemical processes. CTD casts from June 6, 2012 to February 11, 2023

have provided insight into the seasonal freshwater intrusions from the surrounding fjords into the surface layer. We repeatedly saw high ΔO_2 (μmol/kg) and high chlorophyll maxima from increased productivity sink below the low density layer in the summer season.

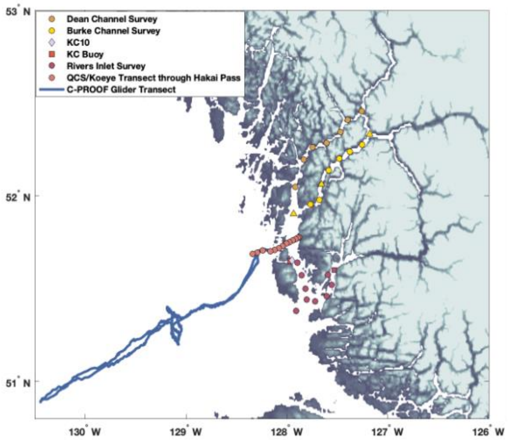

Figure 54-1. *Spatial coverage on the central B.C. coast from monthly surveys at Hakai Institute and the continuous C-PROOF glider transect. Triangles represent the stations sampled continuously from 2021 to 2022. The square represents KC Buoy mooring while the diamond represents station KC10.*

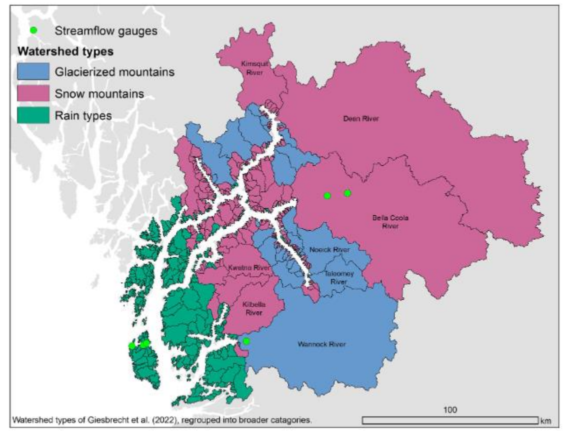

Figure 54-2. The study area has three broad types of watersheds, which vary in terms of runoff timing and the relative contribution of rain, snow, and glacial meltwater contributions to coastal waters.

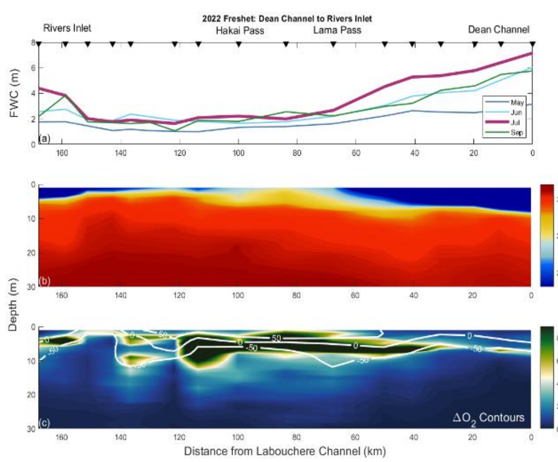

Figure 54-3. (a) Freshwater content computed using a reference salinity of 31.7 following the relationship from Proshutinsky et al. (2009), (b) Salinity from CTD data collected July 2-5, (c) Fluorometry chlorophyll collected July 2nd to 5th, with ΔO2 (μmol/kg) contours overlaid.

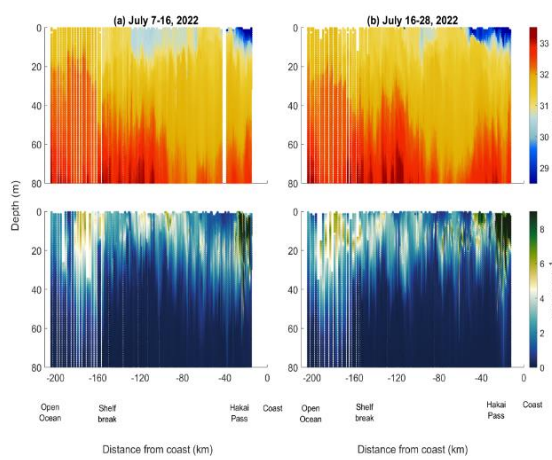

Figure 54-4. Glider salinity (top panels) and chlorophyll-a (bottom panels) transects from coast to open ocean for half surveys conducted in (a) July 7-16 and (b) July 16-28.

54.3. References

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St. Pierre, K.A., Hunt, B.P.V., Giesbrecht, I.J.W., Tank, S.E., Lertzman, K.P., Del Bel Belluz, J., Hessing-Lewis, M.L., Olson, A., and Froese, T. 2022. Seasonally and Spatially Variable Organic Matter Contributions From Watershed, Marine Macrophyte, and Pelagic Sources to the Northeast Pacific Ocean Margin. Front. Mar. Sci. 9:863209. doi: 10.3389/fmars.2022.863209

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55. CAN KELP FORESTS HELP TO MITIGATE OCEAN ACIDIFICATION? MAYBE NOT…

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55.1. Highlights

- The effects of kelp on surrounding water properties were not substantial enough to improve the overall pH conditions of the surrounding water, at least not in the studies shown here.
- Kelp is sensitive to extreme heat events and can at times have a negative effect on pH conditions thereby reducing its potential as an ocean acidification mitigation strategy.

55.2. Extended Abstract

The photosynthetic production of submerged aquatic vegetation (SAV) has been broadly categorized as a potential climate solution and method of local ocean acidification (OA) amelioration. The majority of studies thus far have focused on seagrasses and the combination of results show effects vary regionally, while kelp forests and particularly canopy forming kelps are relatively understudied and as such their capacity to ameliorate OA is not well known. Two case studies were conducted in which autonomous sensors measuring pH, salinity, temperature and (in some instances) dissolved oxygen in 30 minute intervals were deployed at 1-2 meters depth proximal to a kelp bed and at a distal reference site.

The first case study took place near Triquet Island where reference site pH conditions were at times 0.2 units above those measured in the kelp bed. This demonstrated that kelp beds are not always a pH refugia, and that reference sites may not always be a reliable 'control'. The second case study took place in Owen Bay near Redonda Island where summertime daily pH variability at the kelp site was characterized by daytime peaks at 1:00 PM and nighttime lows at 5:00 AM (Figure 55-1). Daily pH minima and maxima demonstrated that the increased pH amplitude at the kelp site was primarily a result of nighttime lows. In addition, severe effects were seen during the 2021 heat dome such that negative conditions persisted throughout the day with pH consistently lower at the kelp site for ~5 days. The negative effects during events such as this greatly offset the positive effects of the kelp on local water properties. This study demonstrates the sensitivity of kelp to extreme events and reduces its capacity as an OA mitigation strategy.

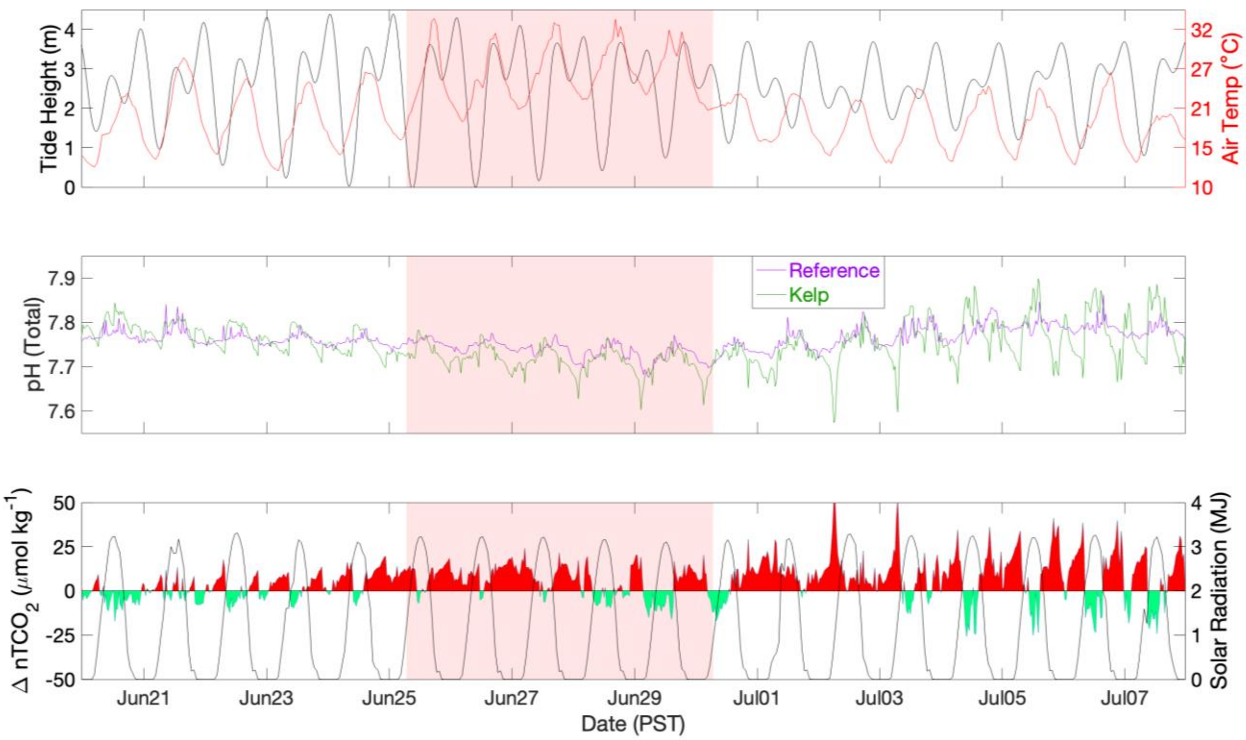

Figure 55-1. Top: Tide height in Owen Bay (m, black) and air temperature (ºC, red) from Quadra Island weather station. Middle: High frequency measurements of pH (total) from Owen bay kelp site (green) and Little Bear Bay reference site (purple). Bottom: ΔnTCO₂ (µmol/kg, colour) and solar radiation (MJ, black) from Quadra Island weather station. ΔnTCO₂ is salinity-normalized TCO₂ calculated from measured pH and regional TA(S) from the Owen Bay kelp site with the reference signal removed. Red bars indicate the dates of abnormally high air temperature described as the 2021 'heat dome'.

56. PROKARYOTIC AND PHOTOSYNTHETIC EUKARYOTE TIME SERIES IN B.C. FJORDS

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56.1. Highlights

- In three B.C. fjords, we observed greater variability and seasonality in phytoplankton (photosynthetic eukaryotes) relative to prokaryotic (Bacteria/Archaea) communities.
- Prokaryotic community composition varied with depth. Deeper communities (100-150m) reflect the low oxygen conditions present in the fjords (e.g., chemoautotrophic lifestyles).

56.2. Extended abstract

The B.C. coast is characterized by numerous fjords, many of which are undergoing rapid environmental changes, particularly at depth (Jackson et al. 2021). Little is known about the microbial communities that inhabit these fjords or how their composition may be influenced by changes in runoff, temperature, and oxygen. Seawater samples (2 L) were collected and filtered through 0.22 µm Sterivex filters at monthly intervals from three inlets over different time periods and depths (Table 56-1, Figures 56-1, 56-2). DNA was extracted from the filters and the 16S rRNA gene was amplified to examine prokaryotic (Bacteria/Archaea), as well as photosynthetic eukaryote communities using chloroplast sequences (Bennke et al. 2018). We examined the relative abundances of the top 10 prokaryote/phytoplankton groups through time in each inlet, and found that prokaryotic communities at 5 m depth exhibited some seasonality changes and were dominated by Proteobacteria and Bacteroidia. Deeper prokaryotic communities were more stable through time, and included chemoautotrophic taxa such as the ammonia oxidizing Nitrososphaeria and nitrifying Nitrospinia, reflecting the low oxygen conditions often present in deeper fjord waters. Phytoplankton communities exhibited greater temporal variability than prokaryotic communities, with diatoms (Bacillariophyta) often dominating in the spring and summer months, especially on the Central Coast (DFO2). Our next steps will be to examine environmental drivers (e.g. temperature, nutrients, salinity, oxygen) of prokaryotic and phytoplankton communities. These fjord time series provide a baseline against which to compare future change, and first insights into the key microbial taxa in fjord ecosystems. We will continue to sample station DFO2 on a monthly basis to provide an on-going, high resolution time series of microbial communities in fjord ecosystems.

Table 56-1. Details of time series of DNA sampling in B.C. fjords

Location	Station	Sampling Duration	Sampled Depths	Station coordinates (DD)
Rivers Inlet	DFO2	July 2018 - present (ongoing)	0, 5, 30, 100, 300 m	-127.558300, 51.520800
Bute Inlet	QU43	May 2018 - Nov. 2020	0, 5, 30, 150, 500 m	-125.117638, 50.339210
Toba Inlet	TO4A	Feb. 2021 - Jan 2022	0, 5, 30, 150, 350 m	-124.514790, 50.426440

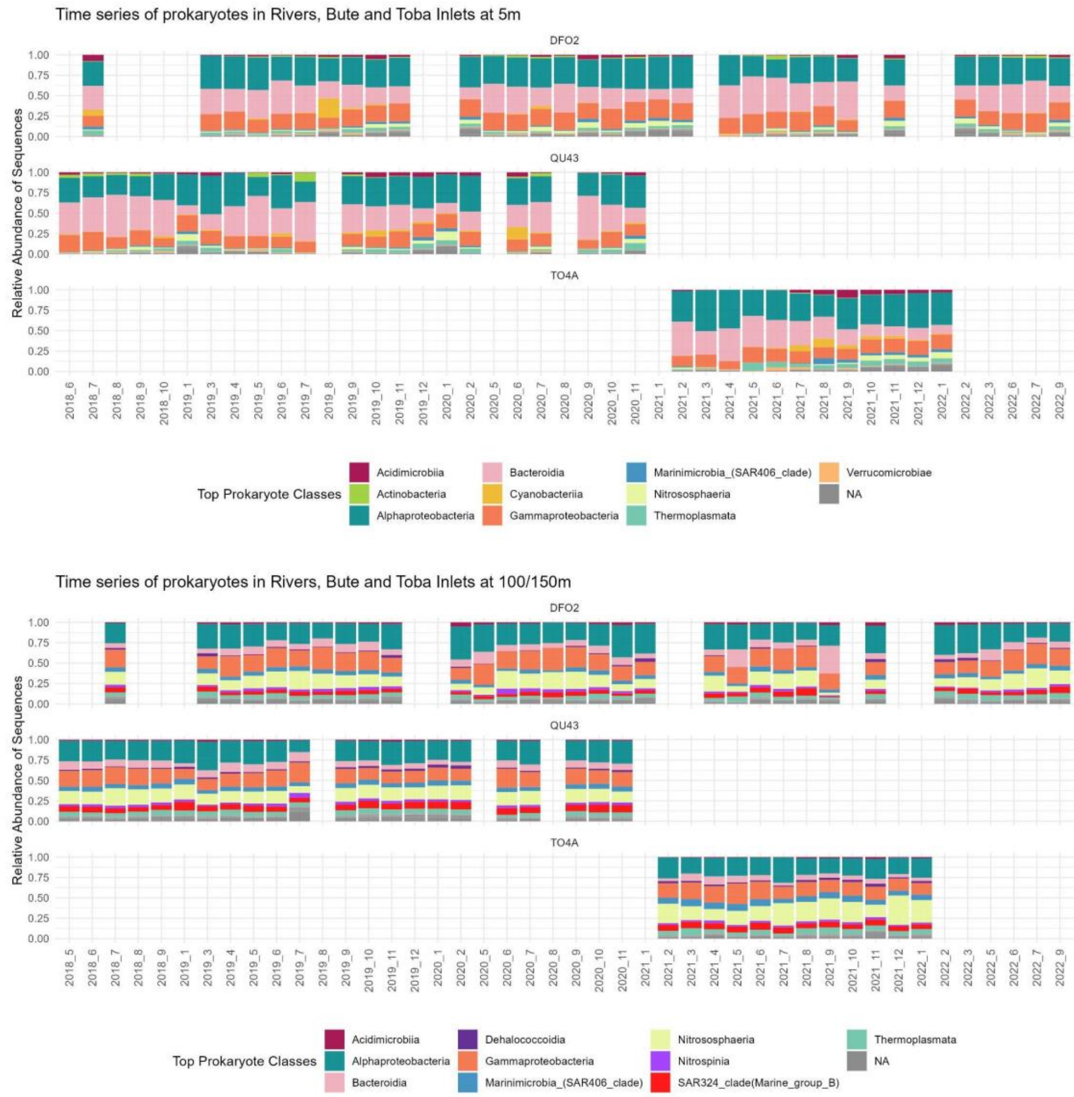

Figure 56-1. Time series of prokaryotes in Rivers, Bute and Toba inlets at 5 m (top panel) and 100/150 m (bottom panel).

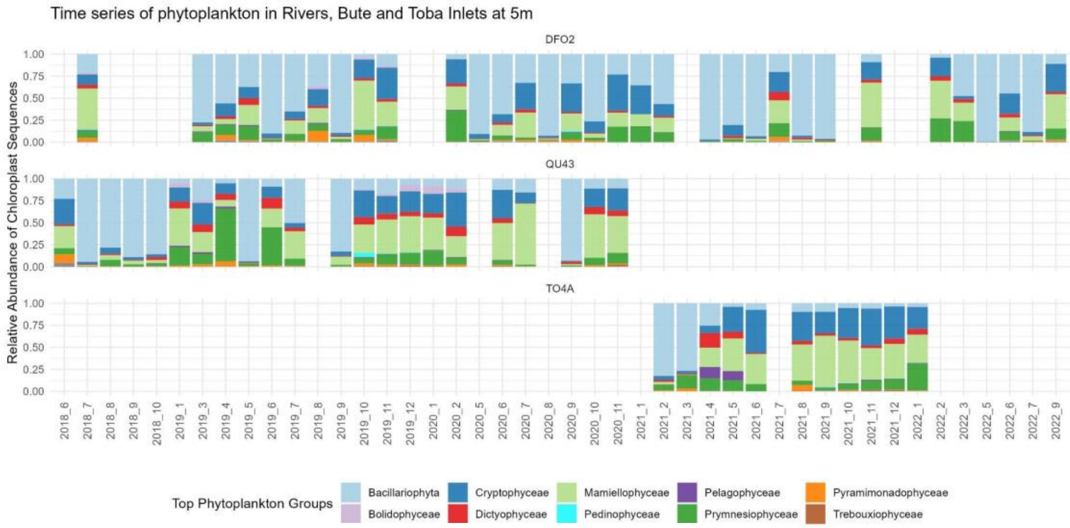

Figure 56-2. Time series of phytoplankton in Rivers, Bute and Toba inlets at 5 m.

56.3. References

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57. CANADA'S FORAGE FISH: AN IMPORTANT BUT POORLY UNDERSTOOD COMPONENT OF MARINE ECOSYSTEMS

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[5] Fisheries and Oceans Canada, Institute of Ocean Sciences
[6] Fisheries and Oceans Canada, Freshwater Institute
[7] Fisheries and Oceans Canada, Gulf Fisheries Centre

57.1. Highlights

- Forage fish knowledge gaps include: noncommercially exploited species, early life history stages, diets, migration, performance (e.g., swimming), survival, and the effects of some pressures (e.g., large-scale climate pressures).

57.2. Extended abstract

The abstract from Boldt et al. (2022) states: "Forage fish form a critical trophic link in marine ecosystems, and yet, for many species, there is limited information available. As nations move from single species stock assessments to ecosystem approaches to fisheries management (EAFMs), more information on forage fish will be required. In this study, 50 years of scientific literature were systematically mapped for 11 forage fish species in Canada's Arctic, Atlantic, and Pacific oceans. The objectives were to identify (1) knowledge clusters and gaps and (2) the pressures studied in relation to forage fish outcomes. Of the 2897 articles mapped, the majority studied adults and the distribution, productivity, growth, and life history of commercially fished species. Knowledge gaps were identified for forage fish: (1) that were noncommercially exploited; (2) egg and larval life history stages of most species and juveniles of noncommercial species; (3) diets of most species; (4) migration and performance for all species and survival of non-commercial species; and (5) the effects of some pressures (e.g., large-scale climate pressures). Addressing these knowledge gaps would improve the application of EAFMs."

57.3. References

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58. CANADA'S OCEANS NOW - STATE OF CANADA'S OCEANS

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58.1. Highlights

- Canada's State of the Ocean reports are annual summaries of the current status and trends of marine ecosystems in Canada's three oceans.
- The State of the Pacific Ocean public report and communication products were released in June 2022. The public-facing content includes plain language science writing, case studies, infographics and engaging visuals for social media and outreach.
- The public and technical reports alongside associated products for the State of the Atlantic Ocean were released in April 2019 followed by the State of the Arctic Ocean in April 2020 the National State of the Oceans report *Canada's Oceans Now, 2020* was released in March 2021. The National report is a high-level summary of status and trends in all three oceans highlighted through engaging infographics and plain language science writing.
- The next State of the Atlantic Ocean technical and public report content is being developed and is set to release in June 2023.

58.2. Summary

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

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

The State of the Pacific Ocean public report and communication products were released in June 2022. *Canada's Oceans Now: Pacific Ecosystems, 2021* is the fourth public report of the annual ocean series on the current status and trends of marine ecosystems in Canada. This report is based on key findings detailed in the Canadian Technical Report of Fisheries and Aquatic Sciences 3377 and 3434, *State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems* in 2019 and 2020. The public report was prepared by Fisheries and Oceans Canada with contributions from Environment and Climate Change Canada and the Government of British Columbia. The report gives an overview of the health of Canada's Pacific and shares our knowledge of the many influences that affect ocean systems. It also highlights the key challenges facing our ocean ecosystems, coastal communities, fisheries and other ocean economies, such as the effects of extreme warming events on species distribution and habitat, and how changes to the marine food web may impact the livelihoods and well-being of coastal communities. The next State of the Pacific Ocean public report is planned to be released in 2026.

The first SOTO report and accompanying products on the State of the Atlantic Ocean were released in April 2019 followed by the State of the Arctic Ocean and associated products in April 2020. In March 2021, the National State of the Oceans report *Canada's Oceans Now, 2020* was released alongside communication products. The public report is a high-level summary of status and trends from all three oceans with engaging infographics and plain language science writing.

The next State of the Atlantic Ocean technical and public report content is being developed and is set to release in June 2023.

59. OCEAN SCIENCES DIVISION OCEANOGRAPHIC DATA PRODUCTS

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59.1. Extended abstract

Sustained ocean observations are essential for understanding the state of the oceans and the changes in the oceans over time. The Ocean Sciences Division (OSD) has collected oceanographic data on a range of physical, chemical and biological features in Pacific and Arctic regions through various research and monitoring programs. The OSD data archive contains the holdings of oceanographic data generated by the Institute of Ocean Sciences and other agencies and laboratories, including the Institute of Oceanography at the University of British Columbia and the Pacific Biological Station. The main types of observational data in OSD data archive include:

- 78,000+ CTD profiles (1965-present)
- 450+ Moored CTD time series (2008-present)
- 43,000+ Niskin Bottle files (1930 -present)
- 370+ Moored Acoustic Doppler Current Profiler time series (1998-present)
- 3300+ Moored Current Meter files (1995-present)
- 1000+ Thermosalinograph data files (1998-present)
- 230+ Weather Station Anemometer data files (1967-present)
- 1700+ Surface Drifter files (2014-present, www.waterproperties.ca/drifters/)
- BC Lightstation Sea-Surface Temperature and Salinity data (1914-present)

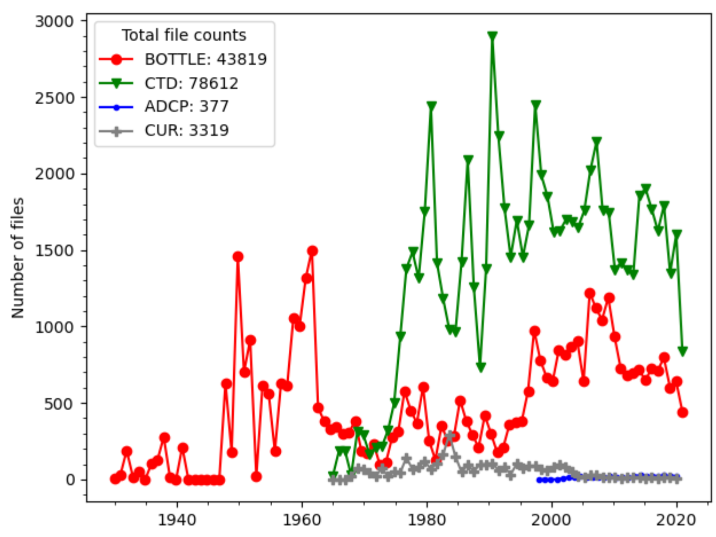

Figure 59-1. Time series of observations (Bottle, CTD, ADCP and CurrentMeter) in OSD data archive.

OSD also generates observational data such as glider data, Argo data, Viking buoy data, plankton data and hydroacoustic data which are managed under research programs.

OSD oceanographic data products are available for user access from:

- Water Properties website (core site, https://www.waterproperties.ca/data)
- Federal Geospatial platform (https://open.canada.ca/en/open-maps)
- Open Data Portal (https://open.canada.ca/en/open -data)
- Canadian Integrated Ocean Observing System (CIOOS; https://catalogue.cioospacific.ca/dataset)
- International Ocean Carbon Data system (OCADS)

OSD has been developing data pages to provide analyzed data and summarised results for regular monitoring programs, and developing DMApps for data search and visualization:

- Oceanographic status monitoring data pages (https://ios-osd-dpg.github.io)
    - Marine Heatwave Monitoring of the Northeast Pacific
    - Sea-surface Temperature and Chlorophyll-a Concentration Time Series
    - Deep Water Properties of B.C. Inlet

- Data Management Applications (https://dmapps.waterproperties.ca/en/)
    - IOS Satellite Sea Surface Temperature
    - IOS Satellite Sea Surface Chlorophyll
    - IOS Contaminants Database
    - IOS Acoustic Survey
    - IOS Drifters
    - IOS Moorings

60. IS EARLY MARINE GROWTH RELATED TO SURVIVAL IN CHILKO LAKE SOCKEYE SALMON?

Lyse Godbout[1], Carrie Holt[1], Cameron Freshwater[1], Michael O'Brien[1], Maxine Forest[2], Marc Trudel[3], Strahan Tucker[1], and Francis Juanes[4]
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60.1. Extended abstract

To assess the importance of early marine growth in determining survival for Sockeye Salmon in the Salish Sea, we compared the size at ocean entry and early marine growth in both the juveniles and returning adults in ocean entry years of contrasting survival of fish spawning in Chilko Lake. Smolt-to-adult survival of Sockeye Salmon returning to Chilko Lake was lower than average for the 77.1 million smolts that entered marine waters in 2007 (<0.25%), and high for the 71.9 million that entered he ocean in 2008 (6.7%). As recruitment dynamics of Pacific salmon are generally expected to be determined by growth during their early marine life, we tested three hypotheses about marine growth and size at ocean entry across these two years: (1) mean early marine growth is lower for the juveniles collected in 2007 compared to 2008, (2) within a cohort, size at ocean entry and mean early marine growth are higher in returning adults compared to juveniles as a result of size or growth-selectivity mortality, and (3) within a cohort, variance/range in size at ocean entry or early marine growth is lower in returning adults compared to juveniles.

We used daily growth increments from otoliths to determine how the early marine growth rates of juvenile (one-year smolt) and returning adult Chilko Lake Sockeye Salmon differed between years of low and high survival after ~ 40 days at sea, the period hypothesized to be critical for survival. Otolith radius at ocean entry was used as a proxy for size at ocean entry of both the juveniles and adults.

Our results supported our hypotheses, in part. First, mean early marine growth of juveniles in 2007, a year of poor survival, was smaller than early marine growth in 2008, a year of high survival.

Second, mean early marine growth, as measured from otoliths of juveniles entering the ocean in 2007, was significantly lower than the mean growth of individuals from the same cohort measured from the otoliths of spawners in 2009. However, size at ocean entry was not significantly different between juveniles and returning adults, supporting the hypothesis of mortality of slower growing fish. In addition, the early marine growth of adults in 2009 (2007 ocean entry year) was not significantly different than that of adults in 2010 (2008 ocean entry year), suggesting that only the fastest growing individuals survived.

Third, we found that the variance in early marine growth of adults returning in 2009 was lower than that of juveniles from the same cohort, but this was not the case for cohort of adults

returning in 2010 (and juveniles entering in 2008) a year of high survival. Combined these results suggest that only the faster growing individuals survived.

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

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61.1. Extended Abstract

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 have represented 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 Government Portal is composed of four components: data files, metadata, data dictionary, and supporting documents. Data files should be in a non-proprietary modifiable format (e.g. CSV, XLS, XML, HTML, SHP). Metadata describes the structure, significance, context, and host systems of the dataset, including the title and abstract/description. A data dictionary is a file containing clear definitions for each heading (rows and columns). Supporting documentation, such as published reports and journal articles, provides additional explanations to the dataset, and guides users to better understand, interpret and use the published data.

So far, DFO Pacific has published 168 datasets to Open Maps and Open Government Portal. For the 2022-2023 fiscal year, twelve new datasets and forty five published datasets have been published and updated, respectively. More specifically, the published new datasets are:

- Demersal (groundfish) community diversity and biomass metrics in the Northern and Southern shelf bioregions
- DFO Gridded Commercial Fishing Data – Various Years
- Fieldnotes 2020-2021: Pacific Science Field Operations
- Fieldnotes 2022-2023: Pacific Science Field Operations
- Fieldnotes: Pacific Science Field Operations
- Hecate Strait Multispecies Assemblage Bottom Trawl Survey
- Herring Roe fishery catch data
- Predicted distributions of 65 groundfish species in Canadian Pacific waters
- Sea lice mitigation events at B.C. marine finfish aquaculture sites
- Seasonal Salinity climatologies of the British Columbia Exclusive Economic Zone (2001-2020
- Seasonal Temperature climatologies of the British Columbia Exclusive Economic Zone (2001-2020)

- Spatial density models of cetaceans in the Canadian Pacific estimated from 2018 ship-based surveys

The updated datasets are:

- Aleutian Low Pressure Index
- Atmospheric Forcing Index (AFI)
- British Columbia Lightstation Sea-Surface Temperature and Salinity Data (Pacific), 1914-present
- British Columbia Spot Prawn (*Pandalus platyceros*) Spawner Index
- Carcass classification of cultured salmon at British Columbian aquaculture sites by facility, 2013 onwards
- Current valid British Columbia aquaculture licence holders
- DFO sea lice audits of B.C. marine finfish aquaculture sites
- Escapes of cultured marine finfish from B.C. aquaculture sites
- Fieldnotes 2021-2022: Pacific Science Field Operations
- Fish health events at British Columbia marine finfish aquaculture sites
- Fraser River Flows (FRF)
- Groundfish Hard Bottom Longline Surveys
- Groundfish Synoptic Bottom Trawl Surveys
- Harbour seal (*Phoca vitulina*) counts and haul out locations along B.C. coast
- Hecate Strait Synoptic Bottom Trawl Surveys
- Important Areas for Birds in Pacific North Coast Integrated Management Area
- Important Areas for Cetaceans in Strait of Georgia Ecoregion
- Incidental catch at B.C. marine finfish aquaculture sites
- Industry sea lice counts at B.C. marine finfish aquaculture sites
- Inside North Hard Bottom Longline Surveys
- Inside South Hard Bottom Longline Surveys
- Managing transfers and fish health at British Columbia salmon farms
- Marine mammal interactions at British Columbia marine finfish aquaculture sites
- Mortality events at British Columbia marine finfish aquaculture sites
- Nearshore Bottom Patches for Pacific Canada. Version 1.0
- NuSEDS-New Salmon Escapement Database System
- Outside North Hard Bottom Longline Surveys
- Outside South Hard Bottom Longline Surveys
- Pacific Circulation Index (Winter)
- Pacific Herring spawn index data
- Pacific Marine Ecological Classification System and its Application to the Northern and Southern Shelf Bioregions
- Pacific Recreational Fishery Salmon Head Depots
- Pacific Region Commercial Salmon Fishery In-season Catch Estimates
- Pacific Region Commercial Salmon Fishery Post-Season Catch Estimates
- Queen Charlotte Sound Synoptic Bottom Trawl Surveys

- Results of DFO benthic audits of British Columbia marine finfish aquaculture sites
- Results of DFO fish health audits of British Columbian marine finfish aquaculture sites, by facility
- Results of industry benthic monitoring of British Columbia marine finfish aquaculture sites, 2011 and ongoing
- Sea lice mitigation events at B.C. marine finfish aquaculture sites
- Sea Otter (*Enhydra lutris*) Population Counts, British Columbia, 1977-2013
- Seasonal Climatologies of the Northeast Pacific Ocean (1980-2010)
- Sponge Reef Areas of the Pacific Region
- Strait of Georgia Synoptic Bottom Trawl Surveys
- West Coast Haida Gwaii Synoptic Bottom Trawl Surveys
- West Coast Vancouver Island Synoptic Bottom Trawl Surveys

62. MONITORING SGAAN KINGHLAS-BOWIE SEAMOUNT MARINE PROTECTED AREA

Heidi Gartner[1], Skil Jáada (Vanessa Zahner)[2], Lindsay Clark[1,3], and Cherisse Du Preez[1,3]

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62.1. Highlights

- The CHN and DFO co-created an ecological Monitoring Framework.
- In 2022, CHN and DFO co-led a 2nd expedition to SGaan Kinghlas-Bowie Seamount Marine Protected Area (SK-B MPA) and observed worrisome changes at benthic monitoring sites.

62.2. Extended Abstract

SK-B and its two sister seamounts were designated by the Haida Nation as a **Xaads siigee tl'a damaan tl'a king giigangs** *Haida MPA* in 1997 and by the Canadian Government as an *Oceans Act MPA* in 2008. The management board completed the Management Plan in 2019 (CHN and DFO 2019) and our DFO and CHN science team co-created the ecological Monitoring Framework this year (Du Preez et al. in prep). The framework focuses on indicators, tools, and strategies for monitoring the six ecological operational objectives (e.g., proposes 15 biological, 16 environmental, and 5 stressor metrics).

In 2022, the team co-led its second expedition to SK-B MPA (first in 2018) and collected monitoring data for biological and environmental indicator ecosystem components using a remotely operated vehicle (ROV), ship-based multibeam bathymetry (pole-mounted to the CCGS J. P. Tully), and oceanographic equipment (e.g., deployed an Argo float to monitor a potential trapped Haida Eddy).

SK-B MPA seamounts were heavily fished with destructive bottom-contact gear for decades before the 2018 fisheries closure. While there is the potential for recovery, ongoing and future human pressures may still cause degradation (e.g., climate change). In 2018, we established 17 long-term benthic monitoring sites (Gartner et al. 2022) at depths identified as vulnerable to ongoing oxygen depletion (Ross et al. 2020). The 2022 expedition enabled the first repeat surveys of 6 sites in SK-B MPA (data: high-resolution photo mosaics, bathymetry, and CTD - conductivity, temperature, and depth, for each 10 m x 10 m sites). Ecological analyses are in progress for animal abundance and condition, including cold-water corals and sponges (e.g., Figure 62-1). These species are slow-growing, long-lived, and adapted to the remarkably stable conditions, which is why our preliminary observations of hundred-year-old+ colonies and branches dying within 4 years is surprising and very worrisome (some likely in response to climate change).

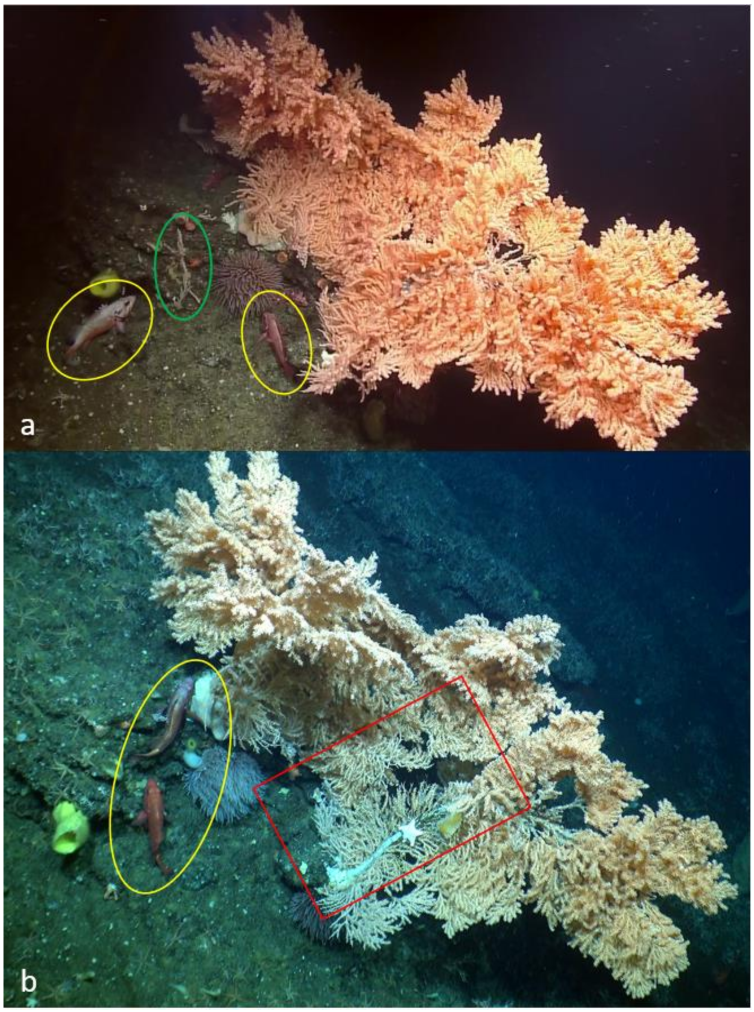

Figure 62-1. Comparison of cold-water corals within a benthic monitoring site in 2018 (a) and 2022 (b). Notable observations: incredible fidelity of rockfish to habitat-forming cold-water corals (yellow circles), loss of a small coral colony (green circle), and predation on the coral by a sea star (red rectangle).

62.3. References

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63. OPPORTUNISTIC SAMPLING FROM SMALL RESEARCH PROGRAMS INFORMS INTERNATIONAL SALMON FISHERIES MANAGEMENT

Stephen Latham, Catherine Michielsens, Pacific Salmon Commission, Vancouver, B.C., Latham@psc.org, Michielsens@psc.org.

63.1. Highlights

- Increased accessibility of DNA sampling benefits fisheries managers, e.g. the time series of juvenile Sockeye Salmon DNA was extended by small research programs in 2020 and played an important role in fisheries management of returning adults in 2022.
- Stock proportions estimated from these samples were used to provide an early, relatively precise, and useful update to the pre-season forecast. The success of this method has implications for understanding critical mortality periods during marine life history stages.

63.2. Extended Abstract

Several large DFO research projects collect biological information and samples from Fraser Sockeye Salmon (hereafter referred to as Sockeye) post-smolts during their migration to the north Pacific Ocean. These programs operate at various locations from the lower Fraser River to Queen Charlotte Sound (e.g., Mahoney et al. 2013; Neville et al. 2016) and are critical for understanding the life history of this species and for explaining variance in fisheries production. Standardized DNA analyses are conducted on Sockeye tissues (Beacham et al. 2004), yielding a time series of stock proportion estimates for outmigrating juveniles. These stock proportions have been found, for some stock components, to be similar to the relative abundances of adults returning two years later (Latham and Michielsens 2022). This has proved useful for fisheries planning purposes every four years (2014, 2018, …), when the commercially valuable Late Shuswap stock is dominant, and assessment of the Early Shuswap stock provides a timely signal of the Late Shuswap stock's survival.

The return strength of the Early Shuswap stock group can be well-estimated by mid-August, whereas the return strength of the Late Shuswap stock group is usually poorly known until a high proportion of the run has migrated upstream past hydroacoustic facilities in September (Michielsens and Martens 2022). Therefore, several weeks prior to upstream migration, and while Late Shuswap Sockeye occupy marine areas where significant international and domestic fisheries occur, a Smolt Method of Updating Run Forecasts (SMURF) makes use of the ratio among Late and Early components of post-smolt samples:

$$N_L = N_E \cdot ((1 - p_E)/p_E)$$

with N_L and N_E being the abundances of adult Late Shuswap and Early Shuswap Sockeye, respectively, and p_E being the proportion of sampled Shuswap juveniles belonging to early stocks. SMURF estimates rely on the assumption that the ratio between Late and Early Shuswap Sockeye in the cohort is stable from the time juveniles are sampled until the adults return to the Fraser River two years later (see Latham and Michielsens 2022).

In 2020, DFO's main post-smolt research projects did not operate due to COVID-19. The Hakai Institute Juvenile Salmon Program (Johnson et al. 2019) and Raincoast Research Society (Bateman et al. 2016) instead provided all 648 samples, with 325 of these being from relevant stocks (due to genetic similarity, "Early Shuswap" includes early-returning Sockeye that rear in Adams Lake and North Barriere Lake, and "Late Shuswap" includes late-returning Sockeye that rear in Seton Lake, although the numerically dominant stocks in each case are from Shuswap Lake). In contrast, over 6,000 juvenile genotypes were obtained in each of 2012 and 2016, of which approximately 4,300 and 2,500 belonged to relevant stocks, respectively (Figure 63-1). In each case, the juvenile samples were stratified into temporal and spatial clusters to estimate the uncertainty in the ratio of Late Shuswap to Early Shuswap fish. The estimated ratio was 5.3, 4.4, and 3.1 in 2012, 2016, and 2020, respectively (80% C.I.: 5.0-5.5, 4.1-4.8, and 2.6-3.7).

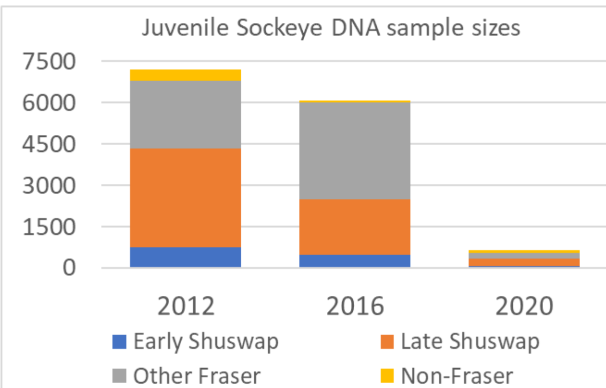

Figure 63-1. Sample size of post-smolt Sockeye Salmon genotypes in 2012, 2016, and 2020, attributed to Early Shuswap, Late Shuswap, other Fraser, and non-Fraser stocks.

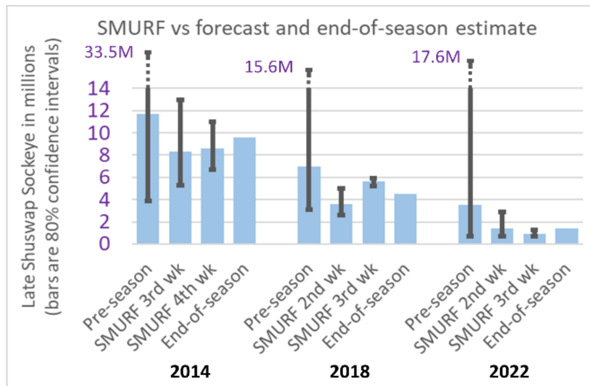

Figure 63-2. Late Shuswap run sizes, comparing SMURF estimates (using information from juvenile DNA samples) to other estimates. Black bars are 80% C.I. (not available for end-of-season estimates).

In 2022, as in 2014 and 2018, the pre-season forecast of Late Shuswap Sockeye was poorly constrained (Figure 63-2). When the Early Shuswap stock group was first estimated (August 12: 0.44 million; 80% C.I.: 0.22-0.89 million) the SMURF estimate of Late Shuswap was 1.40 million (80% C.I.: 0.68-2.87 million). One week later the Early Shuswap estimate became more precise (August 18: 0.29 million; 80% C.I.: 0.22-0.38 million), and the corresponding Late Shuswap estimate was 0.93 million (80% C.I.: 0.67-1.28 million). At the end of September, after the Sockeye migration into the Fraser River was essentially complete, the Late Shuswap run was estimated to be 1.40 million. Similar to 2018, the final Late Shuswap run size was outside the confidence interval of later SMURF estimates, but this approach has, nevertheless, been valuable for fisheries managers. Results imply substantial similarity (if not equality) of marine survival for early and late components of the Sockeye return to the Fraser River, which itself has implications for our understanding of the varying production of this resource.

As DNA sampling becomes more accessible (Latham and Brkic 2022), there is great potential to benefit from standardized results integrated across monitoring programs. This was demonstrated by augmentation of the growing time series of post-smolt Fraser Sockeye DNA samples in 2020. Research on post-smolt juveniles, including DNA collection from diverse samples, should continue to be prioritized.

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64. BODY SIZE OF MATURE FRASER SOCKEYE SALMON: DATA NOW ACCESSIBLE FOR ECOLOGICAL RESEARCH

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64.1. Highlights

- Fraser Sockeye Salmon were small again in 2022, with lengths ranked 10th and 6th smallest for 2-ocean and 3-ocean ages, respectively, since 1964. Among even-numbered years, lengths for both age classes were 2nd smallest behind 2020.

64.2. Description of the time series

Body size measurements of mature Sockeye Salmon (hereafter referred to as Sockeye) likely integrate both bottom-up and top-down effects. The first time series reported here includes Sockeye body size measurements of individuals caught during their return to the Fraser River (2003-2022). Samples are obtained from fisheries (gear types: variable mesh gillnet, purse seine, and reef net) in the lower Fraser River and marine approach areas. Post-orbital fork length (POF) and weight data are used to calculate condition factor on a stock-, age-, and sex-specific basis for these Sockeye. Fish were identified to stock using DNA, and stock-year combinations were only included if $n > 10$ matching weights and lengths were obtained for each sex. Due to low frequencies of other age classes in 2022, only 2-ocean ages were included in analyses. Anomalies were averaged for the sexes. Condition factor, K, was calculated using POF in mm, weight in kg, and a stock- and sex-specific exponent of the arithmetic form of the length-weight relationship (b) as $K = (\text{fish mass} \cdot 10^8)/\text{POF}^{\boldsymbol{b}}$ (Froese 2006). Anomalies were converted to percentages prior to averaging among sexes.

The second time series is average length (mm) of carcasses on spawning grounds (1964-2022). Using ages derived from otoliths and applying a minimum sample size threshold for each sex of each stock and year ($n = 20$ and $n = 10$ per year for 2-ocean and 3-ocean Sockeye, respectively), age- and sex-specific annual anomalies are calculated as the difference between year-specific average standard lengths and the average standard length across all years. These anomalies are averaged across the sexes. Only stocks that met threshold sample sizes in 2022 were analyzed. Several stocks were well represented across most decades – of 26 possible stocks, 16 and 6 stocks were analyzed for 2-ocean and 3-ocean ages, respectively.

64.3. Status and trends

64.3.1. Weight and condition factor of returning Fraser Sockeye Salmon

The lowest weights were observed in the most recent years and, in 2022, were 4th lowest in this time series and lowest among even-numbered years (Figure 64-1A). Body condition demonstrated a strong and possibly increasing biennial fluctuation, but no linear trend was seen in the time series. Average body condition in 2022 was higher than observed in odd-numbered years and also higher than observed in 2004, 2006, and 2016 (Figure 64-1B). On average, 2-ocean Sockeye caught during even-numbered years weighed 0.15 kg more ($p < 0.001$) and were nearly 5% higher in condition factor anomaly ($p < 0.001$) than those caught in odd-numbered years.

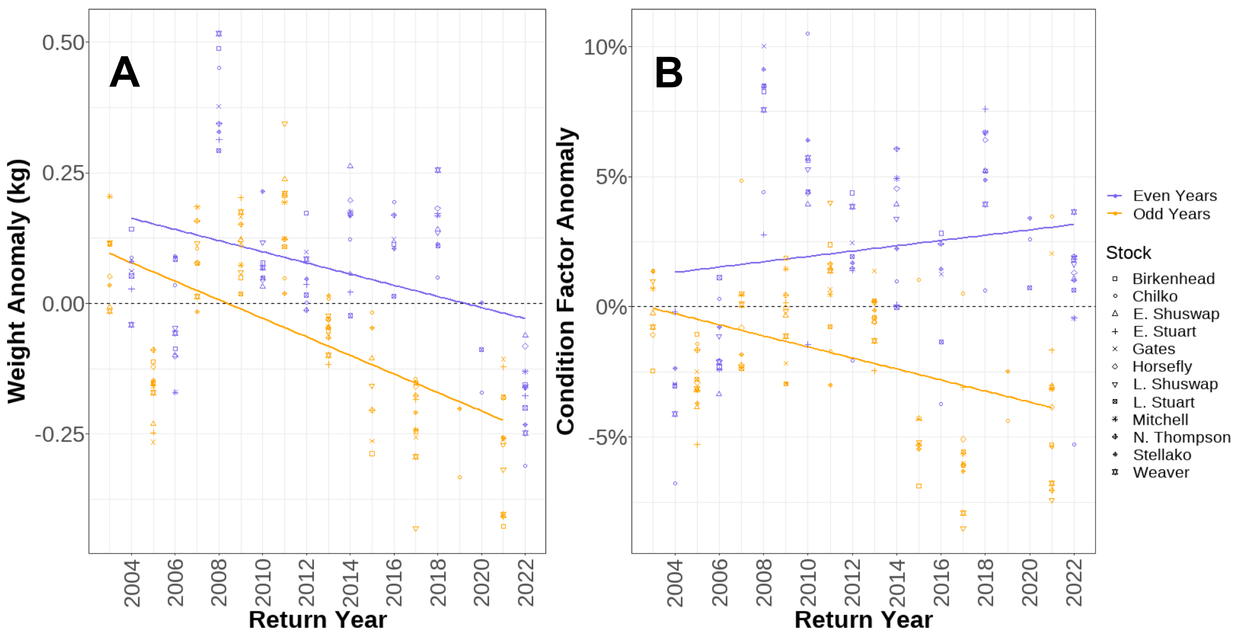

Figure 64-1. Average stock-specific weight anomalies (kg, panel A) and condition factor anomalies (%, panel B) of 2-ocean Fraser Sockeye Salmon in fisheries. Linear regressions were fit separately for odd- and even-numbered return years.

64.3.2. Spawning ground lengths of Fraser River Sockeye Salmon

Mature Fraser Sockeye tend to be shorter in odd-numbered years than in even-numbered years (Figure 64-2). A sharp decline in length occurred, across stocks and ages, from the 1970s to the 1990s. Since the 2000s, declines in average length have been more severe for 3-ocean Sockeye than for 2-ocean Sockeye, especially for Sockeye returning on odd-numbered years (Figure 64-2). Consistent with stock-specific average weights reported above, average lengths on the spawning grounds in 2022 were among the lowest on record for even-numbered years. The average anomaly across stocks ranked 10th lowest for 2-ocean Sockeye, but 2nd lowest on an even-numbered year, with 2020 being the only even-numbered year with a lower average length anomaly in the time series.

64.4. Factors influencing trends

These time series show historical and recent declines in overall size-at-age of Fraser Sockeye and a biennial fluctuation in which Sockeye tend to be shorter, lighter, and skinnier when returning in odd-numbered years. One hypothesis for these trends involves a mixture of direct and indirect effects of sea surface temperatures. Increased marine temperatures result in increased metabolic demands on Sockeye (Cox and Hinch 1997) and also reduce the abundance and/or quality of food resources (DFO 2020). These may negatively affect Fraser Sockeye even in the absence of competition with Pink Salmon, but increased temperatures may also result in exacerbated impacts from Pink Salmon, whose overall abundance throughout the North Pacific Ocean has benefitted from warming temperatures (Connors et al. 2020). Analyses to date have not revealed convincing explanatory relationships, however, in part because marine distributions of Sockeye and Pink Salmon are poorly known, and because size and abundance patterns of candidate Pink Salmon stocks have not matched simplistic expectations under this hypothesis (Latham et al. 2022). The PSC has begun to make data readily accessible on its website: https://psc1.shinyapps.io/BioDataApp/.

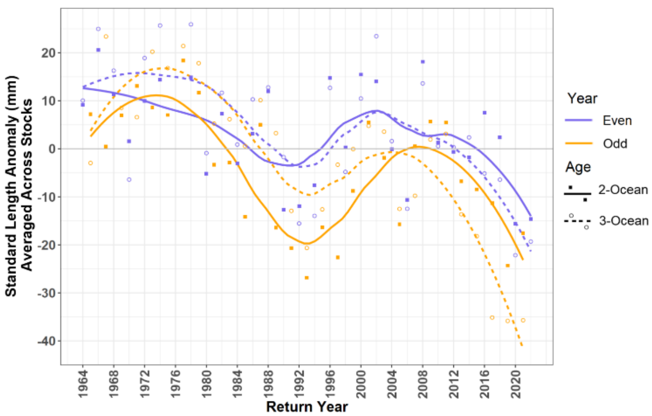

Figure 64- 2. Average standard lengths of Fraser Sockeye Salmon on their spawning grounds. Annual anomalies were calculated relative to long term averages and averaged across stocks. LOESS curves were fit to even- and odd-numbered years separately.

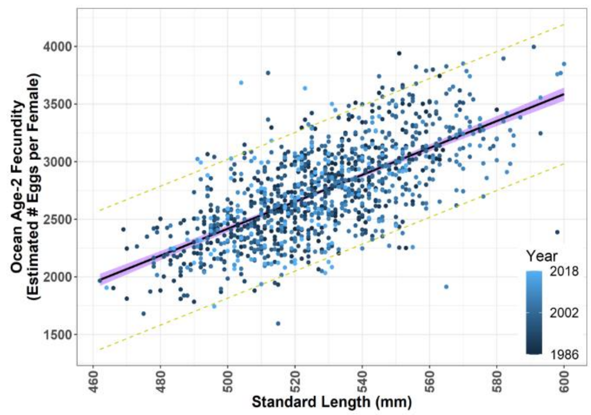

Figure 64-3. Estimated fecundity of female 2-ocean Chilko Sockeye Salmon (1986-2018). The purple band around the linear model (y= -3422 + 11.68x, R^2 =0.45) is the 95% C.I. while the yellow lines show the 95% prediction interval.

64.5. Implications of those trends

The size of salmon is directly tied to their value in fisheries, their transport of nutrients to natal habitats, and their fecundity. To illustrate the latter, we used historical fecundity data (Tracy Cone, DFO, unpublished data) in years with a minimum of 20 samples to plot the relationship between length and egg deposition of 2-ocean Chilko River Sockeye from 1986-2018 (Figure 64-3). Based on a simple linear relationship, every 2 cm decrease in fish size equates to approximately 230 fewer eggs. Size of maturing salmon may also influence marine survival, success of upriver migration, and effectiveness of nest construction. Spawning escapement targets and other fisheries management considerations for Fraser Sockeye do not currently consider trends in body size (e.g., DFO 2020) but probably should.

64.6. References

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65. IN-SEASON CATCH ESTIMATES OF COMMERCIAL SALMON

Yi Xu[1], Shelee Hamilton[2], Jason Parsley[1], and Zhipeng Wu[1]

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65.1. Highlights

- In-season estimated catch and catch-per-unit-effort (CPUE) of commercial salmon is summarized from 2005-2022.
- 2,116,000 Pacific salmon were caught by seine, gillnet and troll fisheries in 2022.
- Sockeye salmon experienced a dominant cycle with more catch and higher CPUE.
- No apparent up or down trends were observed in CPUE in the past 18 years.

65.2. Extended abstract

In 1998, the Commercial Salmon Logbook program was launched, and it became mandatory for all commercial salmon fishers to participate in the program by 2001. Under the program, fishers are required to maintain a harvest logbook, recording their daily catch and effort data, and submit it to DFO within specific deadlines via service providers.

The Department of Fisheries and Oceans Canada (DFO) uses the Fishery Operations System (FOS) as a centralized Oracle database to store commercial salmon fishery catch, effort, and biological data. Initially constructed in 2001, the FOS database remains the primary storage facility for all records related to DFO's Commercial Salmon Logbook program in the Pacific Region. Resource managers utilize the catch and effort data provided by the fishers, as well as information obtained from other sources such as overflights, to estimate the in-season commercial catch. This dataset is a fishery-dependent product under Integrated Fisheries Management Plans (IFMPs). IFMPs provide a broad context to the management of the Pacific salmon fishery http://www.pac.dfo-mpo.gc.ca/fm-gp/ifmp-eng.html.

In 2022, about 130K Chinook, 55K Chum, 117K Coho, 676K Pink and 1,138K Sockeye Salmon were caught by commercial fishermen. We found that the catch and CPUE vary widely across species, time and space. In general, 2022 was a good year with relative more catch and higher CPUE for Sockeye Salmon. CPUE time series showed coherent patterns in some areas, however, no apparent up or down trends were observed in CPUE for any salmon species in the past 18 years.

This dataset is published annually, for the most recent updates check the Open Data website (https://open.canada.ca/data/en/dataset/7ac5fe02-308d-4fff-b805-80194f8ddeb4).

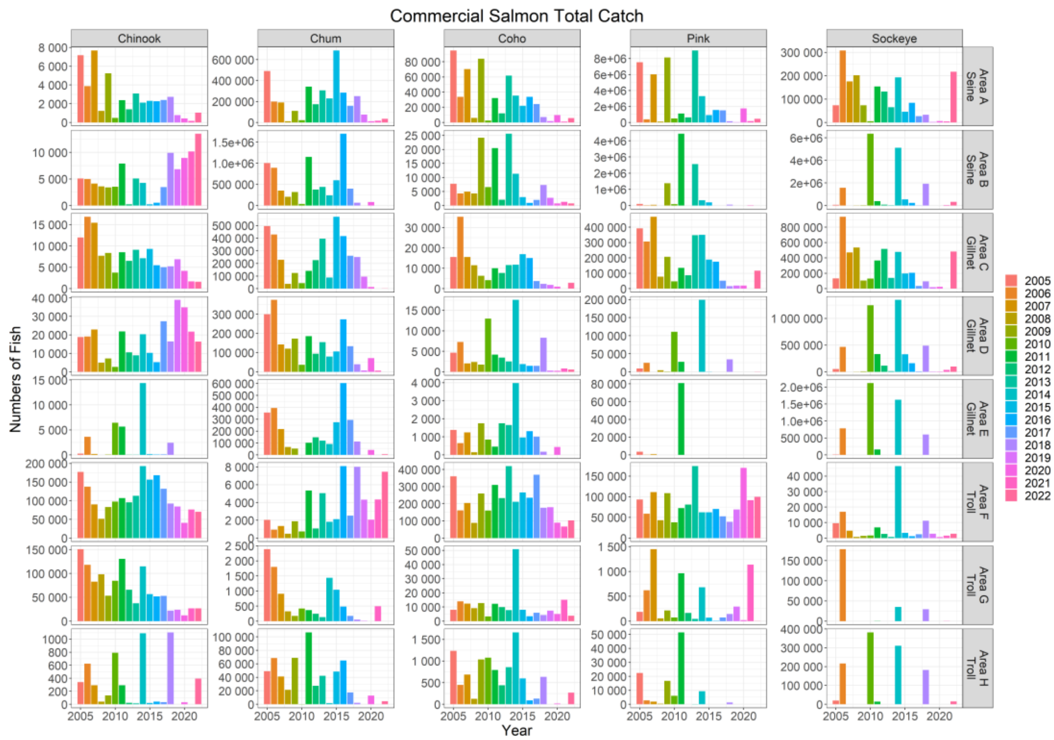

Figure 65-1. The catch of commercial salmon (numbers of fish) in licence areas (A-H) for seine, gillnet, troll fisheries from 2005-2022.

Figure 65-2. The catch per unit effort (CPUE) of commercial salmon (numbers of fish per boat days) in licence areas (A-H) for seine, gillnet, troll fisheries from 2005-2022.

65.3. Data disclaimer

- This data contains only commercial catch estimates and does not include test-fishing, recreational or First Nations data.
- The 2022 data are preliminary in-season catch estimates and are subject to change.
- Consult the applicable resource manager or biologist as to the status of particular catch estimates.
- All catch estimates are reported in pieces (numbers of fish).

65.4. Acknowledgements

The authors would like to thank all commercial fishermen, service providers, DFO resource managers and IT team who contributed to this dataset. Special thanks are given to recent contributors and collaborators in 2022-23: Brad Beaith, Heather Braun, Karen Burnett, Curtis Curkan, Fifi Esenam, Patrick Fairweather, Matt Jessop, Corey Martens, Christie Morrison, Justinas Savickas, Miranda Smith, Collin Thommasen, Jenn Toole, Yiwei Wang, Madeline Wanless, Teagan Wardrop and Mike Wright. We appreciate the SOPO meeting organizers for offering us an opportunity to present our work. This project is funded by Fisheries and Oceans Canada.

66. THE CONTINUOUS VERTICAL DATUM MODEL FOR CANADIAN WATERS—RECENT OPERATIONAL SURFACES

Michael G. Morley, Marlene Jeffries

Fisheries and Oceans Canada, Canadian Hydrographic Service, Institute of Ocean Sciences, Sidney, B.C. Mike.Morley@dfo-mpo.gc.ca

66.1. Highlights

- The Continuous Vertical Datum (CVD) model produced by the Canadian Hydrographic Service produces hydrographic vertical separation surfaces (HyVSEP) surfaces of chart datum with respect to geodetic datums of interest such as NAD83 (CSRS), CGVD28, and CGVD2013.
- The CVD model employs modeled separation elements such as: a geoid model, satellite altimetry, tidal oceanographic models, and relative sea-level rise to produce an integrated separation surface that is then warped to honour presently accepted chart datum at all CHS tide stations.
- The HyVSEPs can be applied to bathymetric sounding reduction, delineating intertidal/sub-tidal zones for ecological studies and land use, definition of coastline, flood mapping, storm surge and tsunami modeling, and infrastructure planning.
- CHS is developing a process to upload the HyVSEPs to the CHS Bathymetric Database (BDB) instance for future dissemination to the public through the NONNA (**NON-NA**vigational) bathymetric data portal: https://data.chs-shc.ca/login. For now, the current operational surface (2022v1) is available upon request.
- New realizations of the HyVSEPs are generated as new or improved water-level and GNSS observations, grid modifications, and input models come available (approximately annually).

66.2. Summary

The Canadian Hydrographic Service (CHS) has developed the CVD model that estimates HyVSEP with respect to ellipsoidal (NAD83 CSRS) and geodetic vertical datums. HyVSEPs integrate a number of modeled vertical separation elements: geoid model, satellite altimetry, tide heights and dynamic ocean topography estimated from numerical ocean models, and relative sea level rise (sea level rise and vertical crustal velocities) to determine ideal separations on high resolution (~100 m coastal resolution) spatially adaptive TIN working grids. Observed water levels combined with GNSS-derived geodetic datum heights at existing CHS water-level stations are used as guidance for the modeled separation elements to determine an ‘ideal’ surface, as well as to apply corrections to the surface in order to honour presently adopted chart datum (PACD) – the low-water datum recorded at water-level stations referenced by most CHS hydrographic data products. This corrected surface becomes the final operational HyVSEP surface used in the development of CHS hydrographic data products and available to the general public.

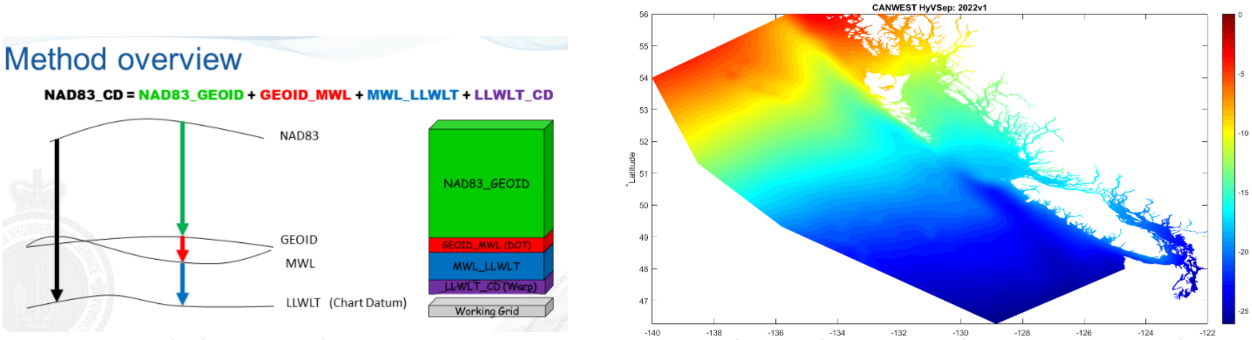

Figure 66-1. (left) Summary of vertical layers making up the NAD83-CD HyVSEP. (Right) Operational NAD83-CD HyVSEP surface for 2022.

67. SPATIAL VISUALIZATION OF THE FREQUENCY OF OCCURRENCE OF CHINOOK SALMON PREY IN SOUTHERN B.C.

Wesley Greentree, Will Duguid, Bridget Maher, Chloe Kraemer, Jessica Qualley, Micah Quindazzi, and Francis Juanes, University of Victoria, Victoria, B.C. wgreentree@outlook.com

67.1. Highlights

- Pacific Herring were dominant prey of adult Chinook Salmon in the Salish Sea and along the west coast of Vancouver Island. The importance of different Pacific Herring age classes varied spatially and seasonally.
- Other prey groups (e.g., Pacific Sand Lance, Northern Anchovy, squid, myctophids) are only important prey to Chinook Salmon in specific regions.

67.2. Extended abstract

The University of Victoria Adult Salmon Diet Program partners with the recreational fishery, conservation groups and First Nations to collect data on the diet composition of adult Chinook and Coho Salmon (Quindazzi et al. 2020). Since adult Chinook Salmon are opportunistic predators whose diets reflect prey availability (Mills et al. 2007; Thayer et al. 2014, 2020), their diet composition is a useful tool to monitor prey that are not always targeted by fishery-independent surveys (e.g., age 2+ Pacific Herring, Pacific Sand Lance, Northern Anchovy). We mapped the number of Chinook Salmon digestive tracts containing key prey groups at each catch site, as well as the total number of salmon sampled at each site. Separate maps were made for summer and winter. Pacific Herring were highly important prey in all regions and seasons, with age-2+ Pacific Herring especially key in the northern Strait of Georgia in summer (Figure 67-1). Other prey groups were only important in specific, often small, regions (Figure 67-1). Given the high spatiotemporal resolution of this time series, adult salmon diets will be a valuable tool to detect climate-driven changes in prey availability in coastal B.C. A temporal analysis of this time series is presented in this report (Maher et al. 2023, Section 46).

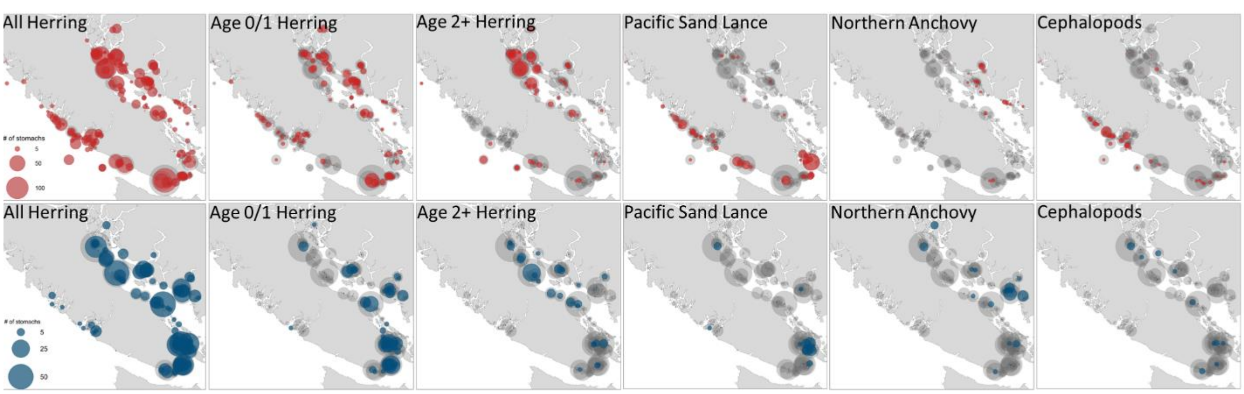

Figure 67-1. Distribution of select prey groups in the digestive tracts of adult Chinook Salmon in the Salish Sea and west coast of Vancouver Island, split by season (summer: red; winter: blue). Underlying grey circles indicate the total number of salmon sampled at each site per season.

67.3. References

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Appendix 2 - Meeting Agenda

Oral presentations							SOPO DAY 1 - Thursday March 9, 2023
P#	Length	Start time		End time	Name	Affiliation	Title
	0:10	9:00	-	9:10	Tucker/Gauthier/Boldt	DFO	Introduction
	0:15	9:10	-	9:25	Councillor Jackie Albany	Songhees Nation	Opening (cancelled)
	0:05	9:25	-	9:30	Andy Thomson	DFO	Welcome from DFO
1	0:15	9:30	-	9:45	Charles Curry	Pacific Climate Impacts Consortium, University of Victoria	Land temperature and hydrological conditions in 2022
2	0:15	9:45	-	10:00	Tetjana Ross	DFO	Review of temperature, salinity and density of the northeastern Pacific in 2022 using Argo, glider, satellite and Line P data
3	0:15	10:00	-	10:15	Roy Hourston	DFO	Wind-driven upwelling/downwelling along the northwest coast of North America: timing and magnitude
	0:15	10:15	-	10:30	Break		
4	0:15	10:30	-	10:45	Sebastien Donnet	DFO	Sea surface temperature and salinity observed along the BC coast in 2022
5	0:15	10:45	-	11:00	Andrea Hilborn/Lu Guan/Charles Hannah	DFO	Satellite monitoring of sea surface temperature and chlorophyll-a in 2022
6	0:15	11:00	-	11:15	Charles Hannah	DFO	Subsurface ocean conditions on the BC shelf: the BC shelf mooring program
7	0:15	11:15	-	11:30	Hayley Dosser	DFO	Oxygen and carbon in 2022 along Line P and in Queen Charlotte Sound from ocean glider data
8	0:15	11:30	-	11:45	Guoqi Han	DFO	Water currents and transport off the British Columbia coast
9	0:15	11:45	-	12:00	Duncan Havens	DFO	2022 Hydrographic Surveys
	1:15	12:00	-	13:15			Lunch
10	0:15	13:15	-	13:30	Akash Sastri	DFO	Oceanographic conditions and dissolved oxygen off the west coast of Vancouver Island: 2022
11	0:15	13:30	-	13:45	Lynn Lee & DFO, CHN & Hakai collaborators	DFO, Gwaii Haanas Parks Canada, Council of the Haida Nation, Hakai Institute	2022 oceanographic conditions in and around Gwaii Haanas, Haida Gwaii, in relation to past observations
12	0:15	13:45	-	14:00	Wiley Evans	Hakai Institute	Coastal CO_2 observations in British Columbia during 2022
13	0:15	14:00	-	14:15	Colleen Kellogg /Justin Belluz	Hakai Institute	The small and smaller: time series of phytoplankton and prokaryoplankton from the central coast and northern Salish Sea with a focus on 2022 and links to physicochemical variability
14	0:15	14:15	-	14:30	Angelica Pena	DFO	Nutrient and phytoplankton monitoring along Line P and the west coast of Vancouver Island
15	0:15	14:30	-	14:45	Moira Galbraith	DFO	West coast zooplankton: annual anomaly time series
	0:15	14:45	-	15:00	Break		
16	0:15	15:00	-	15:15	Maycira Costa/Sejal Pramlall	University of Victoria	Biorigionalization and phytoplankton phenology in the British Columbia and Southeast Alaska coast oceans
17	0:15	15:15	-	15:30	Greg Jones/Charles Hannah/Andrea Hilborn	DFO	Oceanographic conditions influencing seabird habitats in the Scott Islands Marine National Wildlife Area
18	0:15	15:30	-	15:45	Jennifer Boldt	DFO	Pelagic fish: an update on status and trends
19	0:15	15:45	-	16:00	Jackie King	DFO	2022 juvenile salmon surveys on the Vancouver Island continental shelf
20	0:15	16:00	-	16:15	Sue Grant	DFO	State of Canadian Pacific Salmon
21	0:15	16:15	-	16:30	Colin Bailey/Cameron Freshwater	DFO	Sockeye indicator populations across BC: smolt abundance, marine survival and adult recruitment
	0:15	16:30	-	16:45	Tucker/Gauthier/Boldt		Summary discussion
	2:00	17:00	-	19:00			POSTER SESSION +A9:HA1:H32

Oral presentations							SOPO DAY 2 - Friday March 10, 2023
P#	**Length**	**Start time**		**End time**	**Name**	**Affiliation**	**Title**
	0:15	9:00	-	9:15	Tucker/Gauthier/Boldt	DFO	Introduction
22	0:15	9:15	-	9:30	Clare Ostle	Marine Biology Association	Lower trophic levels in the Northeast Pacific, from continuous plankton recorder sampling
23	0:15	9:30	-	9:45	Sean Anderson	DFO	Trends in Pacific Canadian groundfish stock status and surveys
24	0:15	9:45	-	10:00	Doug Bertram for Mark Hipfner	ECCC	Observations on seabirds along the BC coast
25	0:15	10:00	-	10:15	Strahan Tucker	DFO	Update to pinniped abundance trends in BC
26	0:15	10:15	-	10:30	Thomas Doniol-Valcroze	DFO	Sei again? New information on the recovery of sei whales (*Balaenoptera borealis*) in Pacific Canadian waters from systematic surveys conducted in 2018-2022
	0:15	10:30		10:45	Break		
27	0:15	10:45	-	11:00	Bridget Ferriss	NOAA Fisheries	Ecosystem Status of the Gulf of Alaska in 2022
28	0:15	11:00	-	11:15	Erin Herder/Dominique Bureau	DFO	An update to Olympia Oyster index site monitoring around Vancouver Island
29	0:15	11:15	-	11:30	Katie Gale/Gin Kampen	DFO, Council of the Haida Nation	Update on the distribution of aquatic invasive species and monitoring activities in the Pacific region, with details on Haida Gwaii efforts
30	0:15	11:30	-	11:45	Matthias Herborg	DFO	A review of 5 years of marine oil spills in BC waters
31	0:15	11:45	-	12:00	Andrew Ross	DFO	Marine biotoxin monitoring in BC coastal waters
	1:15	12:00	-	13:15	**Lunch**		
32	0:15	13:15	-	13:30	Sebastien Donnet	DFO	Salish Sea temperature, salinity and oxygen observations in 2022
33	0:15	13:30	-	13:45	Richard Dewey/Steve Mihaly/Kohen Bauer	ONC	Ocean observatory contributions to assessing the 2022 southern BC coastal conditions
34	0:15	13:45	-	14:00	Susan Allen	UBC	Update to 2022 (and a look forward to 2023) for the timing of the spring phytoplankton bloom and the summer productivity in the Strait of Georgia
35	0:15	14:00	-	14:15	Svetlana Esenkulova/Rich Pawlowicz	Pacific Salmon Foundation	Oceanographic conditions and harmful algal blooms in the Strait of Georgia 2022
36	0:15	14:15	-	14:30	Kelly Young	DFO	Zooplankton status and trends in the central and northern Strait of Georgia, 2022
37	0:15	14:30	-	14:45	Linnea Flostrand	DFO	Eulachon status and trends in southern BC
	0:15	14:45	-	15:00	Break		
38	0:15	15:00	-	15:15	Chrys Neville	DFO	Changes/shifts/consistencies in the SOG small pelagic community in 2022
39	0:15	15:15	-	15:30	Bridget Maher	University of Victoria	Adult salmon diet monitoring 2017-2022
40	0:15	15:30	-	15:45	Rianna Burnham	DFO	What our soundscape descriptions tell us about acoustic disturbance for southern resident killer whales (2018-2022)
41	0:15	15:45	-	16:00	Andrew Edwards	DFO	Launching PACea: an R package to amalgamate Pacific data to help operationalise an ecosystem approach to fisheries management
	0:30	16:00	-	16:30	Tucker/Gauthier/Boldt		Summary discussion

Appendix 3 - Meeting Participants

First Name	Last Name	Organization
Selina	Agbayani	Fisheries and Oceans Canada
Hussein	Alidina	WWF-Canada
Susan	Allen	University of British Columbia
Sean	Anderson	Fisheries and Oceans Canada
Kurtis	Anstey	Fisheries and Oceans Canada
Mike	Atkins	West Coast Geoduck Research Corp.
Hannah	Avenant	Canadian Wildlife Service
Colin	Bailey	Fisheries and Oceans Canada
Sarah	Bartnik	Environment and Climate Change Canada
Leslie	Barton	Fisheries and Oceans Canada
Arthur	Bass	Fisheries and Oceans Canada
Sonia	Batten	North Pacific Marine Science Organization
Adam	Batty	Province of BC - LWRS
Kohen	Bauer	Ocean Networks Canada
Katie	Beach	Fisheries and Oceans Canada
Kim	Bedard	Hakai Institute
Mark	Belton	Fisheries and Oceans Canada
Jon	Bergshoeff	Hakai Institute
Kathryn	Berry	Fisheries and Oceans Canada
Douglas	Bertram	Environment and Climate Change Canada
Laura	Bianucci	Fisheries and Oceans Canada

Sherryl	Bisgrove	Simon Fraser University
Morgan	Black	University of Victoria
David	Blackbourn	Retired
Marjolaine	Blais	Fisheries and Oceans Canada
Cynthia	Bluteau	Fisheries and Oceans Canada
Jessy	Bokvist	Fisheries and Oceans Canada
Jennifer	Boldt	Fisheries and Oceans Canada
Julia	Bos	King County Department of Natural Resources and Parks
Rayne	Boyko	Council of the Haida Nation
Hannah	Bregulla	Council of the Haida Nation
Adam	Brennan	Fisheries and Oceans Canada
Emily	Brown	Institute for Oceans and Fisheries, UBC
Ainsley	Brown	Council of the Haida Nation
Tamara	Brown	Fisheries and Oceans Canada
Stephan	Brulot-Sawchyn	Department of National Defence
Alice	Bui	Oceans Network Canada
Christine	Bukta	Fisheries and Oceans Canada
Dominique	Bureau	Fisheries and Oceans Canada
Karen	Burnett	Fisheries and Oceans Canada
Rianna	Burnham	Fisheries and Oceans Canada
Wendy	Callendar	Fisheries and Oceans Canada
Nora	Carlson	University of Victoria
Aline	Carrier	Toquaht Nation Government
Hannah	Carter	Province of BC - LWRS
Rowshyra	Castaneda	Fisheries and Oceans Canada

Jon	Chamberlain	Fisheries and Oceans Canada
Michelle	Charbonneau	Fisheries and Oceans Canada
Lais	Chaves	Tsawout First Nation
Sean	Cheesman	Ministry of Agriculture and Food
Nancy	Chen	Fisheries and Oceans Canada
Alexis	Chittick	King County
Lindsay	Clark	Fisheries and Oceans Canada
Israyelle	Claxton	Parks Canada Agency
Sarina	clay-Smith	Pacific Salmon Foundation
Nik	Clyde	Environment and Climate Change Canada
Natalie	Coleman	Washington State Department of Ecology
Melanie	Collette	Fisheries and Oceans Canada
Sean	Collins	Fisheries and Oceans Canada
Rachel	Commandant	Grieg Seafood BC Ltd.
Brendan	Connors	Fisheries and Oceans Canada
Aurelie	Cosandey-Godin	Transport Canada
Paul	Covert	Fisheries and Oceans Canada
Kieran	Cox	Simon Fraser University
William	Crawford	Fisheries and Oceans Canada
Stuart	Crawford	Council of the Haida Nation
John	Cristiani	Fisheries and Oceans Canada
Rebecca	Croke	Fisheries and Oceans Canada
Jonquil	Crosby	Ucluelet First Nation
Octavio	Cruz	Pauquachin First Nation
Dylan	Cunningham	Fisheries and Oceans Canada

Terry	Curran	Pacific Salmon Foundation
Charles	Curry	Pacific Climate Impacts Consortium
Dan	Curtis	Fisheries and Oceans Canada
Christina (Chrissy)	Czembor	Fisheries and Oceans Canada
Neil	Dangerfield	Fisheries and Oceans Canada
Katie	Davidson	Fisheries and Oceans Canada
Shaun	Davies	Fisheries and Oceans Canada
Justin	Del Bel Belluz	Hakai Institute
Isabelle	Desmarais	Hakai Institute
Jackie	Detering	Fisheries and Oceans Canada
Richard	Dewey	Ocean Networks Canada
DAVID	DICK	WSANEC LEADERSHIP COUNCIL
Sean	Dimoff	Fisheries and Oceans Canada
Yoana	Dinkova	Environment and Climate Change Canada
Phillip	Dionne	Washington Department of Fish and Wildlife
Thomas	Doniol-Valcroze	Fisheries and Oceans Canada
Sebastien	Donnet	Fisheries and Oceans Canada
Jesse	Dool	Ocean Networks Canada
Hayley	Dosser	Fisheries and Oceans Canada
Cherisse	Du Preez	Fisheries and Oceans Canada
Sarah	Dudas	Fisheries and Oceans Canada
Will	Duguid	UVic and PSF
Jillian	Dunic	Fisheries and Oceans Canada
Michael	Dunphy	Fisheries and Oceans Canada
Wendy	Eash-Loucks	King County Department of Natural Resources and Parks

Andrew	Edwards	Fisheries and Oceans Canada
Svetlana	Esenkulova	Pacific Salmon Foundation
Jacob	Etzkorn	Hakai Institute
Wiley	Evans	Hakai Institute
Julia	Fast	University of British Columbia
Bryn	Fedje	Hakai institute
Rick	Ferguson	Fisheries and Oceans Canada
Bridget	Ferriss	NOAA Fisheries
Linnea	Flostrand	Fisheries and Oceans Canada
Kelsey	Flynn	Fisheries and Oceans Canada
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