State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2023

Jennifer L. Boldt, Elizabeth Joyce, Strahan Tucker, Stéphane Gauthier, and Hayley Dosser (Editors)

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STATE OF THE PHYSICAL, BIOLOGICAL AND SELECTED FISHERY RESOURCES OF PACIFIC CANADIAN MARINE ECOSYSTEMS IN 2023

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Abstract

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Fisheries and Oceans Canada is responsible for the management and protection of marine resources along the Pacific coast of Canada. 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 2023 was a hybrid meeting, convened both in-person in Nanaimo, B.C. and virtually, March 6-7, 2024. 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., Gauthier, S., and Dosser, H. (Eds.). 2023. State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2022. Can. Tech. Rep. Fish. Aquat. Sci. 3598: viii + 315 p.

Pêches et Océans Canada est chargé de la gestion et de la protection des ressources maritimes le long de la côte Pacifique du Canada. 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 6 au 7 mars 2024 pour examiner les conditions de l'écosystème en 2023 était un évènement hybride avec une rencontre en personne à Nanaimo 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. Overall, the northeast Pacific Ocean experienced surprisingly average sea surface temperatures during Earth's hottest year on record.
2. Most areas in the province of B.C., however, experienced severe late summer to fall drought and a record-setting wildfire season.
3. Following the development of a moderately strong El Niño, marine heatwaves were widespread in surface waters offshore and in Canada's EEZ in July, August and November-December.
4. There is a long-term trend of increasing sea surface temperatures of 0.85ºC over the last century.
5. Surface waters were anomalously fresh at Ocean Station Papa.
6. In the Strait of Georgia (SOG), 25-year trends show increasing temperature and decreasing oxygen throughout most of the system at all depths.
7. Substantial hypoxia events occurred in southern Queen Charlotte Sound in summer and in the La Perouse area, Line P, and Juan Perez Sound in fall.
8. The annual Fraser River discharge was the 2nd lowest in the 101-year record, with historically low discharge in June and July.
9. In spring, marine CO_2 conditions on the central B.C. coast and in the northern Salish Sea improved slightly compared to 2019-2020, but these returned to more corrosive and low pH conditions for the remainder of the year.
10. The transition to spring upwelling was late, and the magnitude of upwelling-favourable winds was below the long-term average, 1991-2020, resulting in an expectation of below-average upwelling-based coastal productivity.
11. Phytoplankton biomass was similar to that of previous years along Line P, the shelf, and offshore areas of B.C.
12. The abundance of southern copepods increased, whereas, boreal shelf and subarctic copepods decreased or were near average abundance off the west coast of Vancouver Island and Hecate Strait. SOG zooplankton biomass increased and was higher than the time series average since 1996.
13. Coastwide Pacific Herring biomass leveled off in 2021-2023. In the SOG, age-0 Pacific Herring abundance was the highest it has been since 2010 and above the time series mean, 1992-2023.
14. The Fraser River Eulachon spawning stock biomass index was estimated to be one of the lowest in the 1995-2023 time series.
15. The fall, SOG juvenile Coho Salmon abundance index was the highest on record for over 25 years. In summer and fall, the west coast of Vancouver Island juvenile Chum Salmon abundance indices were the highest on record.
16. The marine survival of B.C. Sockeye Salmon indicator stocks (except two) was generally below or near the long-term average.
17. Pink Salmon returning to the Fraser River had the 2nd lowest average weight observed in a century.
18. There was a continued increase in the biomass of shelf rockfish, several slope rockfish, and many flatfish species in the most recent 5-10 years. In contrast, Arrowtooth Flounder and Pacific Spiny Dogfish biomass declined over this time period.
19. Pacific Hake survey biomass off the west coast of North America was the 3rd lowest recorded; the proportion of the stock and biomass in Canada were the lowest ever recorded.
20. There is an ongoing expansion of invasive European Green Crab, as their presence was confirmed in the Prince Rupert/Skeena River area.

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. 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 online (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 2023 (for conditions in 2022) is available online (https://www.dfo-mpo.gc.ca/oceans/publications/soto-rceo/2022/pac-technical-report-rapport-technique-eng.html).

The 25th DFO State of the Pacific Ocean meeting, to review conditions in the northeast (NE) Pacific and B.C. coastal waters in 2023 (Figure 2-1), was a hybrid meeting, convened both in-person in Nanaimo, B.C. and virtually, March 6-7, 2024. Due to the hybrid platform, the meeting reached a broad audience; this year's meeting was attended by 463 researchers from 82 organizations, an increase of 26% and 21% from 2023. Organizations included 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 First Nation and Indigenous organizations, such as the Musqueam Indian Band, Mamalilikulla First Nation, Tsawout First Nation, T'Sou-ke First Nation, Seabird Island Band, Tsawwassen First Nation, Cowichan Tribes and the Council of the Haida Nation, 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. These annual meetings represent a unique opportunity for scientists from different disciplines to highlight preliminary results of atmospheric, oceanographic, and marine species observations in 2023 in the context of historical observations.

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

Elder Stephanie Thomas from the Snuneymuxw First Nation provided opening remarks to start the meeting. Regional Director of Science, Andy Thomson, also 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 needs in Science. An initial morning session on the 1st day provided a retrospective on 25 years of SOPO and its significance to the reported science and scientific community. The SOPO report provides a summary of scientific results from many DFO field operations outlined in [DFO's Fieldnotes](). SOPO reports inform DFO's National Initiatives, including: 1) the State of the Ocean Reporting to develop Canada's Oceans Now reports, and 2) the Ecosystem Approaches to Fisheries Management (EAFM) to integrate environmental variables into single species stock assessments and fisheries management decisions. SOPO reports are also used for Regional DFO initiatives, such as State of the Salmon reporting.

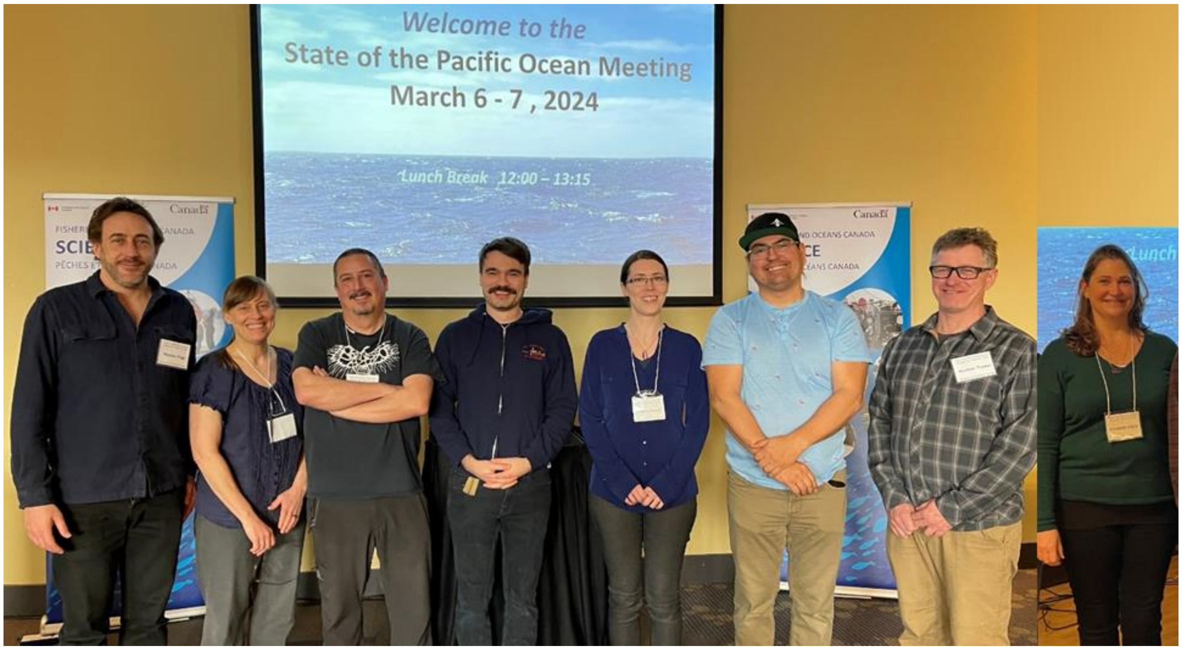
Elder Stephanie Thomas, from the Snuneymuxw First Nation. provided opening remarks.

DFO's Regional Director of Science, Andy Thomson, provided opening remarks.

At the meeting, 44 talks and 15 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, providing a comprehensive overview of conditions in the Pacific Region in 2023. Meeting invitations were circulated to individuals (First Nations, federal and provincial government, academia, and non-government organizations) that had participated or attended previous State of the Pacific Ocean meetings. For the last few 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. Compared to 2023, this resulted in a 2.5 fold increase in individual registrants (69) and over twice the number (35) of 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 2 co-presentations: 1) on Day 1 , collaborators from DFO and the Council of the Haida Nation gave a joint poster presentation titled "Monitoring SG̱áan Ḵinghlas–Bowie Seamount Marine Protected Area", and 2) on Day 2, collaborators from DFO, Gwaii Haanas Parks Canada, the Council of the Haida Nation, and the Hakai Institute gave a joint presentation on "2023 Ocean conditions in Gwaii Haanas and Haida Gwaii Chaan sḵ'ada gud ahl hlg̱unggulaa | Tang.g̱wan g̱an gud ad hlg̱ang.gulx̱a".

2024 SOPO meeting and poster session participants.

The agenda for the meeting is presented in Appendix 1, poster summaries are presented in Appendix 2, and the meeting participants are listed in Appendix 3. The meeting was co-chaired by Jennifer Boldt (Pacific Biological Station), Hayley Dosser (Institute of Ocean Sciences), 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.



2024 SOPO meeting organizers (left to right), Stephen Page, Jennifer Boldt, Stéphane Gauthier, Lindsay Mazzei, Hayley Dosser, Lucius Perreault, Strahan Tucker, Elizabeth Joyce.

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.

MARKING 25 YEARS OF SOPO

There were 3 presentations that provided an overview of 1) how the SOPO report supports individuals' work, 2) how the meeting and report have changed over time, and 3) SOPO meeting and report successes and ideas for future consideration. Current co-chair Strahan Tucker first presented a summary of post-2023 meeting survey results focusing on the question "what the significance of SOPO might be, if anything, for your work". Two primary themes emerged from the responses. The first was that SOPO provides critical context and reference for the participant's work, placing individual fields of study within the broader North Pacific ecosystem. The second revolved around relationships, where SOPO was seen as a key event providing an opportunity to confer and network with colleagues and develop important collaborations. 75% of respondents elaborated on at least one of these two themes.

Next, current co-chair Jennifer Boldt gave a more formal perspective on the history and significance of SOPO in 1) providing a picture of how the ocean is changing, 2) informing fisheries management, and 3) providing a communication opportunity among scientists and for reaching out to the public (see Section 5). An overview was provided on SOPO's beginnings, those involved in organizing both the meeting and report and meeting attendance trends. SOPO was then discussed within a broader context as a key source for the national State of the Oceans (SOTO) initiative, national EAFM initiatives and a key source for initiatives within the Pacific Region. Finally, the presentation looked ahead to how SOPO might evolve to address emerging objectives and needs in developing synthetic indicators, enhancing its relevance for EAFM and continued development of communications tools.

Finally, former co-chair Bill Crawford presented a retrospective on key scientific observations documented through SOPO over its 25 years (see Section 6). State of the Pacific Ocean meetings have helped to build an understanding of the increasingly complex relationships between geophysical and chemical changes and biological responses in the NE Pacific. Large El Niño and La Niña events only one year apart were observed during 1997-1999. These major ENSO events were likely factors that led managers and scientists to begin hosting annual State of the Ocean Meetings in the Pacific region. Developments included the incorporation of ENSO events in Sockeye Salmon return forecast models, resulting in increased forecasting skills. Subsequently, there was a recognition that other physical (e.g., marine heatwaves) and chemical processes (e.g., iron fertilization from volcanic eruptions) impact the biological communities in the Pacific.

3. OVERVIEW AND SUMMARY

Climate change continues to be a dominant pressure acting on NE Pacific marine ecosystems. In 2023, global land and ocean temperatures were the warmest on record (Ross and Robert, Section 8). Record warm average annual temperatures were observed across B.C. relative to the 1950 to 2023 time series (Curry et al., Section 7). Precipitation was well below average in B.C., while snowpack was generally below-normal through the winter, rapidly decreasing to well below-normal by June 1, due to early snowmelt across the province as record warm temperatures occurred in summer and fall (Curry et al., Section 7). In late summer and fall, severe drought conditions were experienced nearly everywhere in B.C., coinciding with record warm temperatures and below-normal precipitation, leading to a record wildfire year. Despite warmer air temperatures, sea surface temperatures (SSTs) were near average in the northeast Pacific (Ross and Robert, Section 8). The Pacific Decadal Oscillation (PDO) was strongly negative, which led to record warm SSTs in the northwest Pacific, but did not result in a cool year for the northeast Pacific because it occurred on a background of steadily rising temperatures due to climate change. The year finished with above average SSTs reflecting the onset of El Niño (Figures 3-1 and 3-2; Ross and Robert, Section 8). The 2023 average annual SST, at shore stations along the B.C. coast, was generally warmer than in 2022, with a coast-wide average increase of 0.4ºC (Hourston et al., Section 11). 2023 was a continuation of a warm period that started in 2013. This 11-year span of above-normal annual SST is the longest warm period in the shore station records (1935-2023) (Hourston et al., Section 11). Overlying multi-year oscillations in the annual SST, there is a long-term trend with ocean temperatures rising at a rate of 0.85ºC per 100 years, up from 0.63ºC per 100 years estimated a decade ago (Figure 3-3; Hourston et al., Section 11). Surface waters in the NE Pacific continued to be anomalously fresh in 2023 but strong anomalies were only seen at Ocean Station Papa (not throughout Line P); this continues a freshening trend observed for the last seven years (Ross and Robert, Section 8). 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 18). In spring 2023, marine CO_2 conditions on the central B.C. coast and in the northern Salish Sea improved slightly compared to 2019-2020, but these returned to more corrosive and low pH conditions for the remainder of the year (Evans, Section 18).

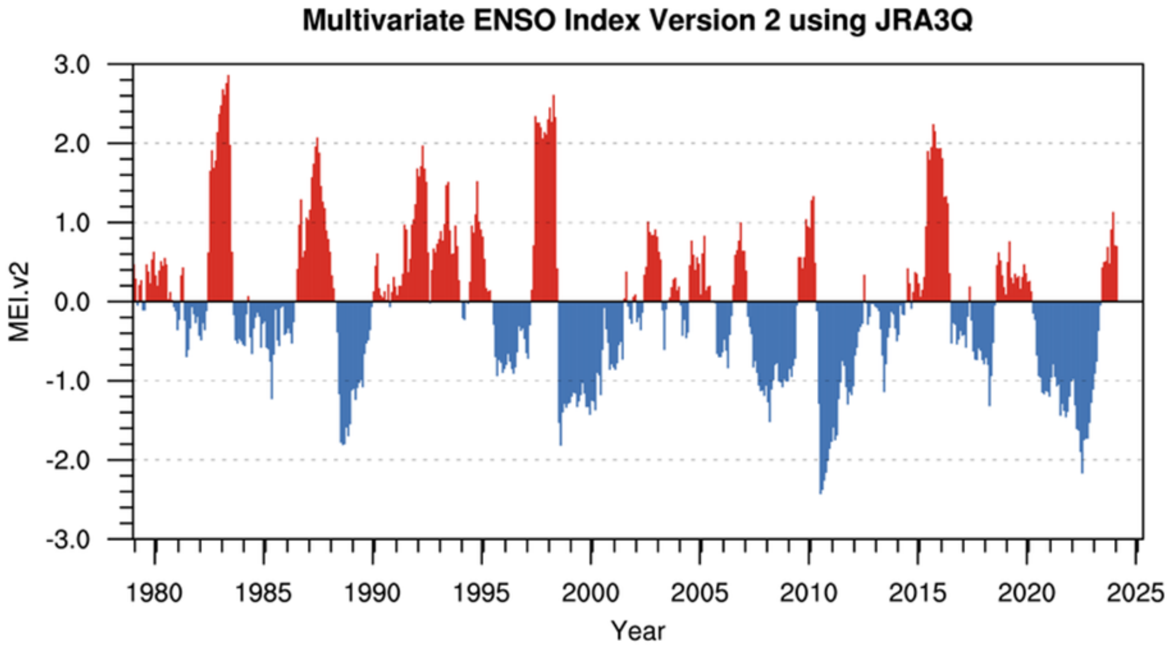


Figure 3-1. The multivariate ENSO Index. Data source: NOAA/ESRL/Physical Sciences Division – University of Colorado at Boulder/CIRES; https://psl.noaa.gov/enso/mei/

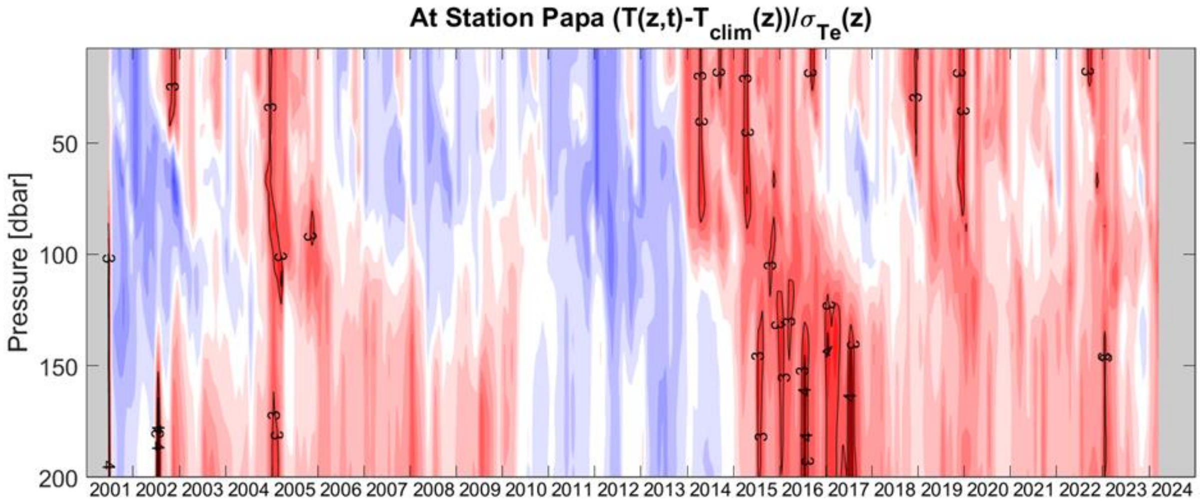


Figure 3-2. Temperature anomalies, as observed by Argo floats near Ocean Station Papa. Anomalies are calculated relative to the 1991-2020 seasonally-corrected mean and standard deviation (from the Line P time series). Cool colours indicate cooler than average temperatures and warm colours indicate warmer 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 8.

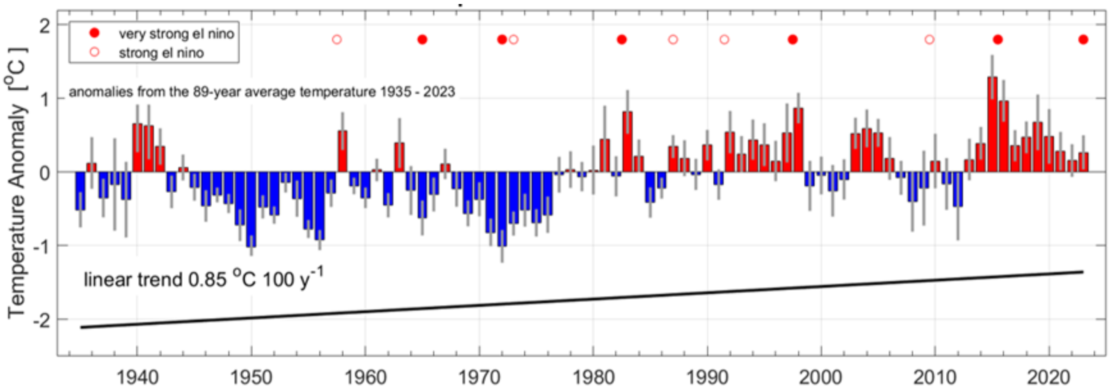


Figure 3-3. Annual-average temperature trend based on the observations from all shore stations for 1935-2023 (black line). The bars represent the anomalies over all the stations (a coast-wide indicator), (red – above average, blue – below average), the vertical grey lines show the variability in the shore station data for each year. Strong and very strong El Niño years using the NOAA ONI index are indicated by the red open and solid dots along the top of the plot. Source: Hourston et al., Section 11.

Marine Heatwaves (MHW) were widespread in surface waters offshore and in Canada's Exclusive Economic Zone (EEZ) after April 2023, with the largest extent in late July and early August (Hilborn et al., Section 19). The proportion of the B.C. EEZ in MHW status increased through the spring to >90% at its maximum at the beginning of August. However, while MHW conditions were present throughout the year, a number of cool events occurred, particularly in the Southern Shelf Bioregion and surrounding Vancouver Island. By the end of 2023, MHW conditions were present along the continental shelf and in coastal waters, with approximately one third of the B.C. EEZ in MHW status. The size, intensity, and frequency of MHWs in the NE Pacific is increasing (Hilborn et al., Section 19).

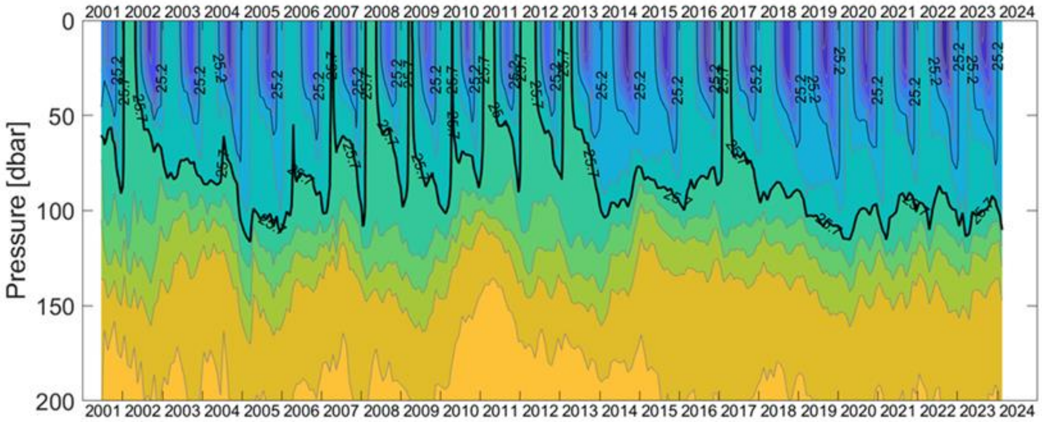


Figure 3-4. Coloured contour plot of density as observed by Argo floats near Station Papa (P26: 50° N, 145° W). The colours indicate potential density (yellow is denser and blue lighter). The black lines highlight the σ=25.2 kg/m³ (thin) and 25.7 kg/ m³ (thick) isopycnals. Source: Ross and Robert, Section 8.

MHWs are associated with reduced vertical mixing, which causes increased winter stratification. This results in decreased nutrient supply from deep to surface offshore waters. Winter stratification was stronger in 2022/23 relative to 2021/22 and 2020/21, therefore mixing of nutrients to the surface was likely weaker in 2022/23, but still fairly normal (Figure 3-4; Ross and

Robert, Section 8). Multiple hypoxia events were observed in B.C.'s waters in 2023. There were sustained hypoxia events in southern Queen Charlotte Sound in summer 2023, with similar events observed in summer 2022. Intense wintertime upwelling in Queen Charlotte Sound drove a hypoxia event in February 2023 (Hannah et al., Section 12). In September 2023, waters below ~100 m were hypoxic in Juan Perez Sound for the first time since annual sampling began in summer 2017 (Jackson et al., Section 16). In fall, hypoxic waters came within 50 m of the surface in the La Perouse area (off southwest Vancouver Island), but the spatial extent of the hypoxia was smaller than in 2021 and 2022 (Dosser et al., Section 13).

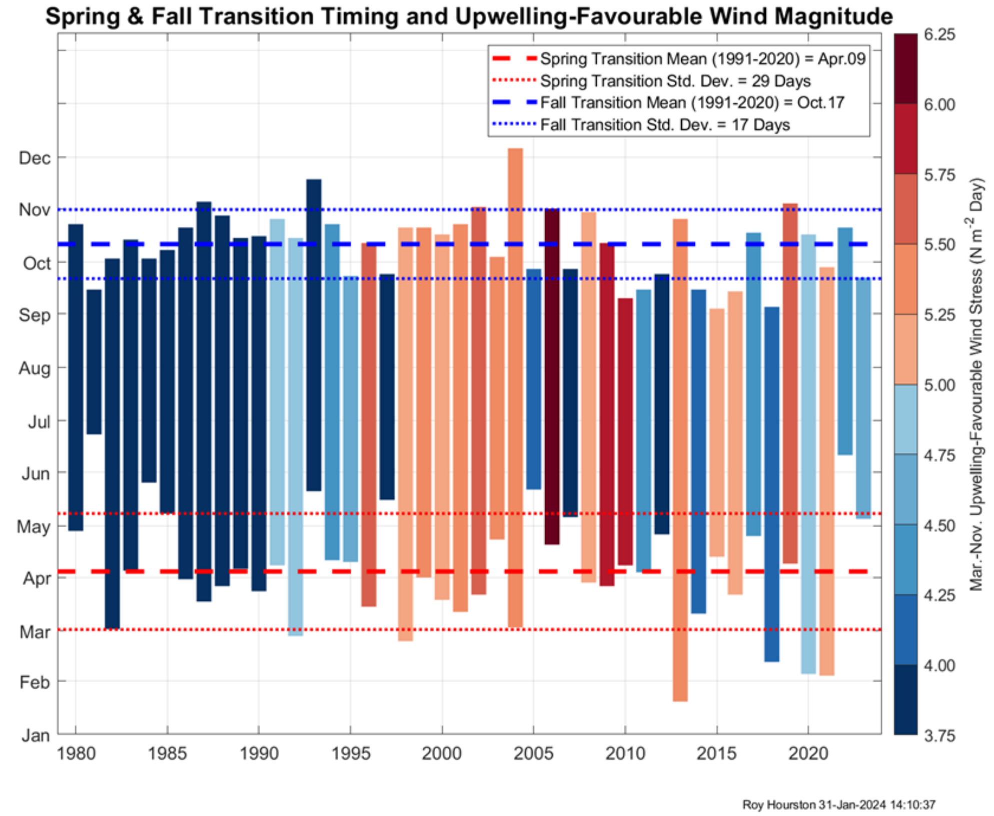


Figure 3-5. Annual spring and fall transition timing and March-November upwelling-favourable wind stress magnitude, 1980-2023. Bold dashed lines indicate the average spring (red) and fall (blue) transition dates. Light-dashed lines indicate standard deviations of the spring (red) and fall (blue) transition dates. Source: Hourston and Thomson, Section 9.

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 sea 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 2023 transition timing of spring upwelling was late (early May) relative to the 1991-2020 mean, and the magnitude of warm season upwelling-favourable winds was below the long-term average, resulting in an expectation of below-average upwelling-based coastal productivity (Figure 3-5; Hourston and Thomson, Section 9). In contrast, February upwelling-favourable winds were much higher than average for the sixth consecutive year (Hourston and

Thomson, Section 9). Persistent upwelling, particularly along the southern Vancouver Island continental slope, brings 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 toward the coast (Dosser et al., Section 13).

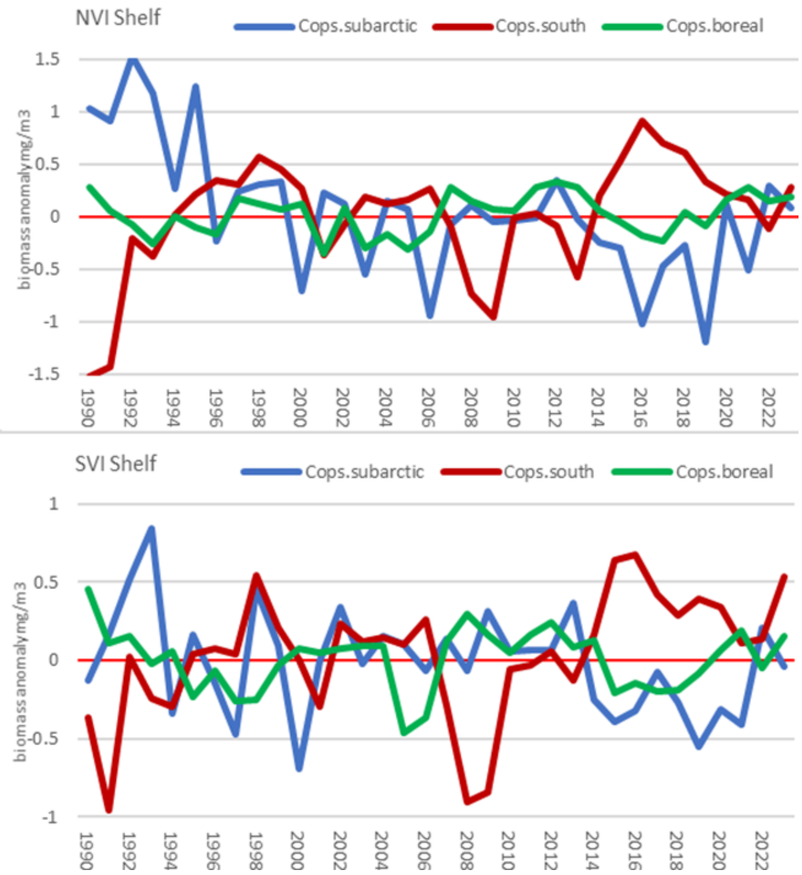


Figure 3.6. Zooplankton species-group anomaly time series, 1990-2023. Line graphs are annual log scale anomalies. Northern Vancouver Island (NVI; top panel) shelf; Southern Vancouver Island (SVI; bottom panel) shelf; subarctic copepods blue; southern copepods red; boreal copepods green. Blank years mean no samples were collected. Source: Galbraith and Young, Section 22.

Phytoplankton biomass in 2023 was similar to that of previous years along Line P (although there was an increase in one area during spring; Peña, Section 17) and along the Continuous Plankton Recorder transect (shelf and offshore; Ostle et al., Section 50). Sub-arctic and boreal copepods (favourable for fish growth) dominated the zooplankton communities from late spring into early summer but were replaced by southern copepods (less favourable for fish growth) in the late summer/fall (Galbraith et al., Section 22; Ostle et al., Section 51). There had been a steady decline in abundance of southern copepods in all areas since 2015, but that trend switched in 2023, especially in the southern shelf region (Figure 3-6; Galbraith et al., Section 22). Boreal shelf and subarctic copepods decreased or were near average biomass across all areas. An increase in gelatinous zooplankton biomass across shelf areas was observed in 2023, mainly due to an increase in salps and doliolids through late summer and into fall. Euphausiid biomass in 2023 was average to above average (Galbraith et al., Section 22).

Changes to the physical environment, phytoplankton, and zooplankton communities can have impacts on higher trophic levels. There was a continued increase in the biomass of shelf rockfish, several slope rockfish, and many flatfish species in the most recent 5-10 years (Anderson et al., Section 29). In contrast, Arrowtooth Flounder and Pacific Spiny Dogfish biomass declined in recent years. Dogfish stocks experienced the steepest declines with a particularly precipitous decrease in outside Vancouver Island waters (Anderson et al., Section 29). The 2023 total survey biomass estimate of Pacific Hake off the west coasts of Canada and the U.S. was the third lowest in the time series, only slightly higher than the lows of 2001 and 2011 (Gauthier and Stanley, Section 32). Less than 3% of this estimated survey biomass was encountered in Canadian waters, the lowest of the survey time series, and was confined to the west coast of Vancouver Island. 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 2023 (Herder and Bureau, Section 22).

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, Section 23). As in 2021 and 2022, the representation of *N. cristatus* in Cassin's Auklet nestling diets on Triangle Island in 2023 was well below what would be expected based on PDO conditions (Hipfner, Section 23). The fish-based diets fed to nestling Rhinoceros Auklets are also affected by prey availability, with nestling auklets growing more quickly in years in which their diets include more Pacific Sand Lance. Diets fed to nestling Rhinoceros Auklets on Protection Island in the Salish Sea and Lucy Island in Chatham Sound included normal amounts of Pacific Sand Lance and Pacific Herring, but diets were very low in Sand Lance at Pine Island in southern Queen Charlotte Sound (Hipfner, Section 23). Systematic cetacean surveys conducted from 2020 - 2023 have provided the first season-specific abundance estimates for Humpback Whales, Harbour Porpoises, and Dall's Porpoises for Canadian portions of the southern Salish Sea and Swiftsure Bank. All three species are present in the area year-round, though distribution and abundance vary seasonally. Quantifying the return of Humpback Whales and Harbour Porpoises to the southern Salish Sea provides evidence of this ecosystem's capability to support recovering populations of marine mammals (McMillan et al., Section 33).

In the Salish Sea, trends of increasing temperature and decreasing oxygen were observed at all depths, except at depths > 75 m in the northern Strait of Georgia (SOG), and waters were generally trending fresher at the surface and saltier at depth (Dosser et al., Section 33). During summer 2023, conditions were cooler, more saline, and more oxygenated than average in the subsurface waters of the SOG, with warm, more saline, less-oxygenated waters in Juan de Fuca Strait. During fall, warm, saline, and less oxygenated water occurred throughout much of the system, with a layer of less oxygenated water in Juan de Fuca Strait at depths of around 100 m. The annual Fraser River discharge was the 2nd lowest in the 101-year record, with historically low discharge in June and July (Figure 3-7; Dosser et al., Section 33; Wang et al., Section 38).

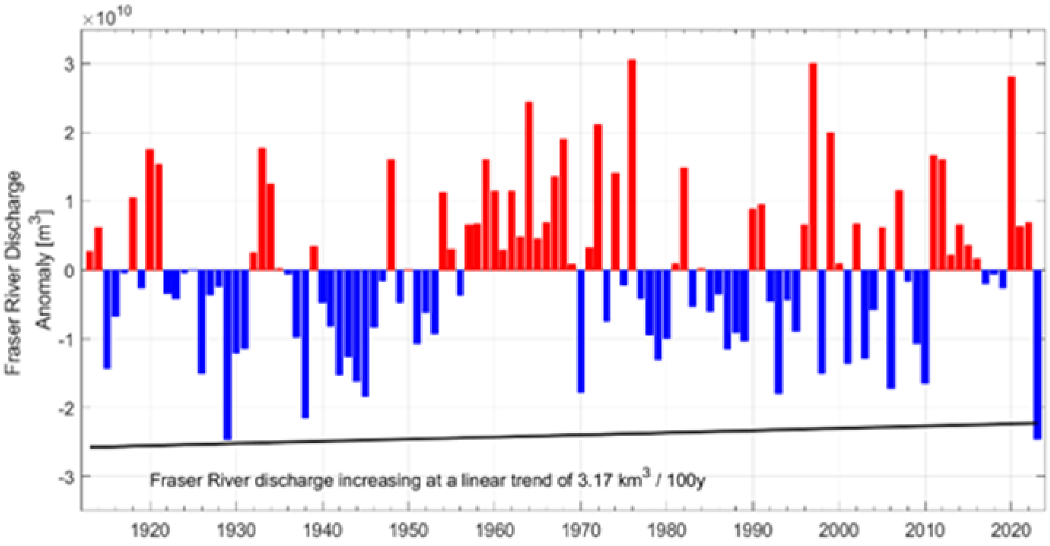


Figure 3-7. Time series of the annual Fraser River discharge anomaly and linear trend. Data extracted from the Environment and Climate Change Canada Real-time Hydrometric Data web site (https://wateroffice.ec.gc.ca/mainmenu/real_time_data_index_e.html) on 28 Feb 2023. Source: Dosser et al, Section 33.

In the SOG, 2023 and 2022 were the only two years in the 2015-2023 time series when all five Harmful Algal Blooms taxa formed dense (>100 cells per mL) blooms (Esenkulova et al., Section 42). In summer, there were widespread, very dense blooms of *Noctiluca scintillans* and dense but localized blooms of *Heterosigma akashiwo* and *Dictyocha*; a few local blooms of *Rhizosolenia setigera*, and *Pseudo-nitzschia* were seen in late summer and spring respectively; *Alexandrium* (Paralytic Shellfish Poison causing taxa) occurrence was noticeably lower than usual while *Dinophysis* (Diarrhetic Shellfish Poison causing taxa) was close to average (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 including new detections near Prince Rupert and the Skeena River estuary (Howard et al., Section 35). This high-impact invader that negatively affects eelgrass, an important fish habitat, was detected for the first time on Haida Gwaii in July 2020 (Howard et al., Section 35). 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 pressures include oil spills, vessel traffic, and underwater noise. For example, in 2023, there were 1137 oil spills reported to the Canadian Coast Guard and DFO Spill Response was activated for 53 spills; the most significant spills were the MV Maipo River spill in Nanaimo, the Fraser River Fuel Barge spill, and the overboard Fuel Truck incident in Chancellor Channel (Herborg et al., Section 36).

Annual variation in spring bloom timing and community composition may affect the food web through a temporal match or mismatch between prey and predators. In 2023, the SOG spring bloom timing was typical compared to the long-term average (Allen and Latornell, Section 40; Esenkulova et al., Section 42). Model estimates indicate that the 2023 summer diatom biomass was low compared to the long term average and the diets of zooplankton were more nanoflagellate-based than the long term mean (Suchy and Allen, Section 41). In 2023, the SOG total zooplankton biomass (averaged over the year) increased from 2022 and was higher than the time series average since 1996 (Young et al., Section 43). Medium and large-sized copepods, euphausiids, and amphipods (important juvenile salmon prey) dominated the biomass; however, the euphausiid biomass was low in the summer of 2023 (Young et al., Section 43).

Coastwide Pacific Herring biomass increased during 2010-2020 and leveled off in 2021-2023, dominated by the SOG stock; however, in some assessed areas, such as Haida Gwaii, there have been prolonged periods of low biomass (Figure 3-8; Cleary et al., Section 24).

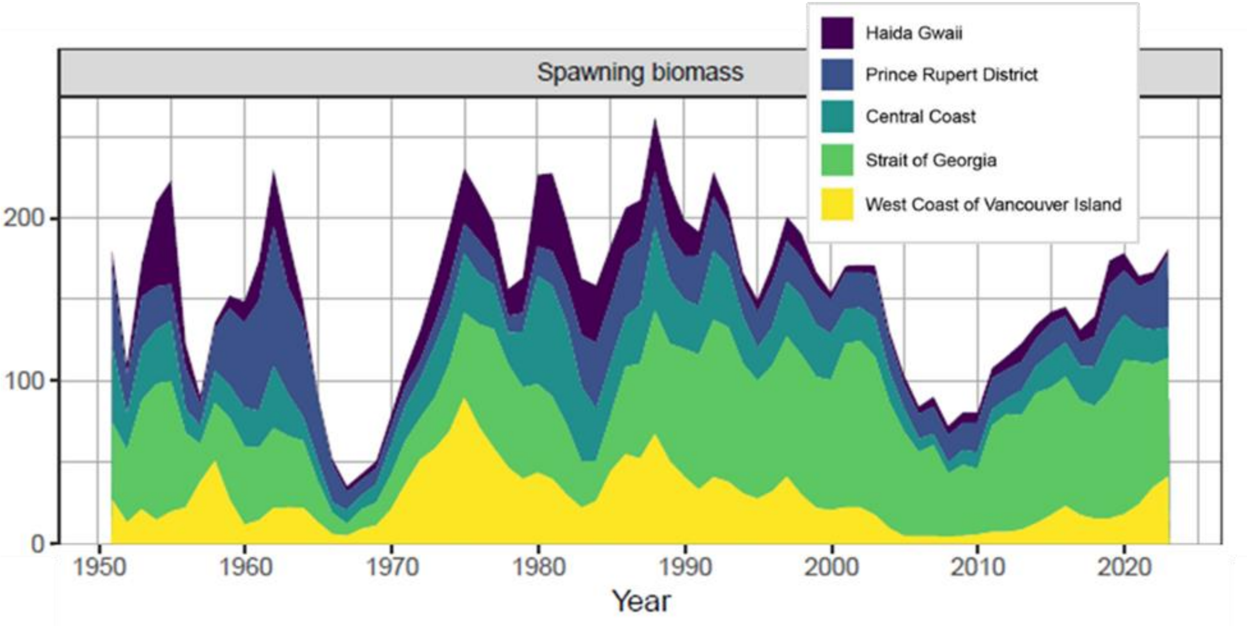


Figure 3-8. Pacific Herring spawning biomass of five assessed areas, 1951- 2023. Source: Cleary et al., Section 27.

In summer 2023, Pacific Herring biomass in continental shelf waters off the WCVI (mixed stocks) was the 2nd highest in the 2006-2023 time series with CPUE particularly high off the southwest coast of Vancouver Island (Boldt et al., Section 25). In the SOG in 2023, the relative biomass of age-0 Pacific Herring was the highest it has been since 2010 and above the time series mean, since 1992 (Boldt et al., Section 44). Age-0 herring were smaller than average, but their condition was above average. In 2023, Northern Anchovy were present in 24% of the SOG age-0 Pacific Herring survey sets; half the value observed in 2022 (Boldt et al., Section 44). In 2023, the index of Fraser River Eulachon spawning stock biomass was estimated to be one of the lowest in the time series, 1995-2023 (~10 tonnes; Flostrand et al., Section 46) at a level comparable to 2022. However, mean Eulachon catch per unit effort from a WCVI multispecies bottom trawl survey was moderately high with a slight reduction in average catch weight from 2022, but an increase in the total number of eulachon caught (Flostrand et al., Section 46).

In the fall of 2023 in the SOG, the juvenile Coho Salmon survey abundance index was the highest on record for over 25 years and continued an upward trend that started in 2010. Chinook, Sockeye, and Chum Salmon were below average, while Pink Salmon was low, which is typical for an odd-numbered year (Neville, Section 47). On the continental shelf of the northern and western coast of Vancouver Island, Chum Salmon was the dominant juvenile salmon species encountered in summer and fall, where index values were the highest in both time series (King et al, Section 29). Fall caught juvenile Coho Salmon were also above average. All other species were close to the time series average although the juvenile Sockeye Salmon index, while only average, increased substantially from the historic low summer index values estimated for 2021 and 2022. All juvenile salmon species except Chum Salmon had above average condition (King et al., Section 29). Marine survival estimates of B.C. Sockeye Salmon indicator stocks were generally below or near the long-term average for 2023, except for Chilko and Tahltan Lakes, which showed longer-term negative trends (Bailey and Freshwater, Section 30). Freshwater productivity was variable with several stocks showing above average productivity (Chilko, Osoyoos, Quesnel, Tahltan, Tatsamenie) while Sproat and Wenatchee Lakes showed below average productivity in recent years (Bailey and Freshwater, Section 30). Fraser River Sockeye Salmon lengths in 2023 were ranked 17th and 6th smallest, for ocean age-2 and ocean age-3 fish, respectively, out of 30 odd-numbered years since 1964. This is consistent with documented recent decreases in body size, particularly for older fish. Fraser River Pink Salmon body size in 2023 was the 2nd smallest since estimates began in 1927 (Latham et al., Section 48).

4. ACKNOWLEDGEMENTS

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.

5. THE 25TH ANNIVERSARY OF THE STATE OF THE PACIFIC OCEAN MEETING

Jennifer Boldt, Strahan Tucker, Stéphane Gauthier, Hayley Dosser, R. Ian Perry, Bill Crawford
DFO

The 2024 SOPO meeting was the 25th annual meeting – an accomplishment made possible by meeting organizers, participants, report contributors, and support from DFO leadership over the past years. The current co-chairs, on behalf of DFO, wish to thank all past and present meeting and report participants and contributors, as well as the originators of the report for making SOPO a continuing success.

Motivated by the major 1997/98 El Niño and 1998/99 La Niña, Dr. John Garrett (head of Ocean Physics, IOS) initiated efforts in 1999 to report on ocean physics; the mandate was to review recent ocean conditions and make the results available at stock assessment meetings. In 2000, the first meeting was convened to report on conditions up to 1999, with a focus on ocean and marine life conditions in the year under review, relative to the context of available time series. This has continued through to 2024, with an ever-growing and changing SOPO organizing team (Figure 5-1), and expanding and increasingly diverse group of participants and contributors (Figure 5-2).

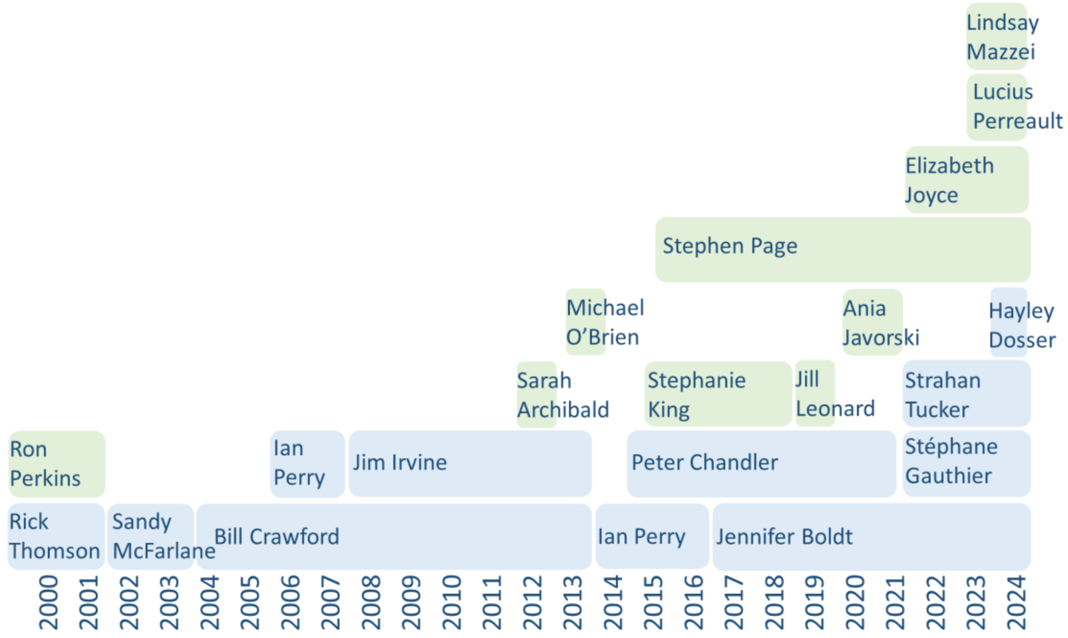


Figure 5-1. The State of the Pacific Ocean meeting and report Team (blue shaded = meeting co-chairs and report editors; green-shaded = meeting and report organization), 2000-2024.

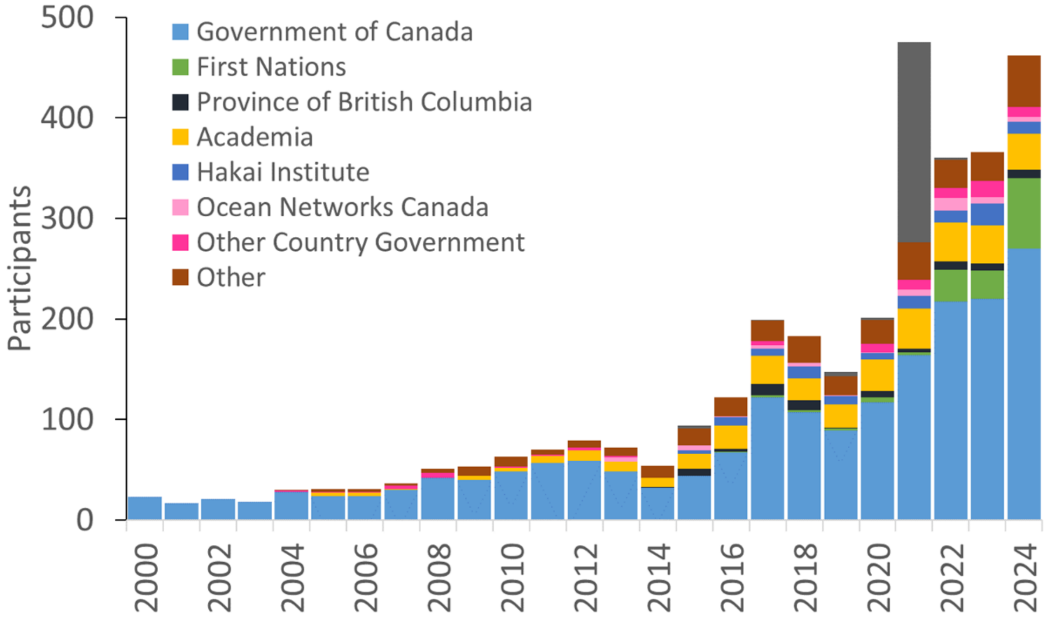


Figure 5-2. State of the Pacific Ocean meeting participants and report contributors, 2000-2024 (note that meeting participation was not recorded in early years).

The SOPO report contains summaries of many DFO research and monitoring programs, which are outlined in DFO's Fieldnotes. These summaries are used to develop an overall synthesis of the state of the ocean and are utilized for several national and regional DFO initiatives. For example, SOPO reports are a key source for DFO's National State of the Ocean reporting initiative, Canada's Oceans Now reports, the goal of which is to inform Canadian citizens. The Canada's Oceans Now reports are completed on a 4-year cycle, rotating between the Pacific, Atlantic, and Arctic regions with a fourth national roll-up year. The SOPO reports are also a key resource for DFO's national Ecosystem Approach to Fisheries Management (EAFM) initiative, the goal of which is to integrate environmental variables into stock assessments and fisheries management decisions. Within the EAFM initiative, a case study utilized SOPO reports as a resource to incorporate supplemental ecosystem information into stock assessment advice on Haida Gwaii Pacific Herring. SOPO reports are also utilized in regional initiatives, such as State of Canadian Pacific Salmon reporting (e.g, Grant et al. 2019, MacDonald et al. 2020).

The SOPO report and meeting 1) provides a picture of how the ocean is changing, 2) informs fisheries management, and 3) provides communication opportunities among scientists. In the future, it is hoped that the SOPO meeting and report will continue to deliver a synthesis that scientists can use to place their research within a broader context both spatially and temporally, as well as to inform other initiatives, such as EAFM. Future developments might evolve to develop and report on synthetic ecosystem indicators (e.g., proportion of large or predatory fish), enhance the availability of SOPO time series for use in ecosystem considerations of single species stock assessments (e.g., R package PACEA, developed by Andrew Edwards and Travis Tai, Section 55), and continue to develop tools to communicate SOPO information to a broad audience.

5.1. References

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6. MAJOR ENVIRONMENTAL EVENTS OVER THE 25 YEARS OF STATE OF THE PACIFIC OCEAN MEETINGS

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6.1. Highlights

- State of the Pacific Ocean meetings have become the main annual event for in-person networking among government, First Nations, academic, industrial, and NGO scientists.
- State of the Pacific Ocean meetings have helped to understand the increasingly complex relationships between geophysical and chemical changes and biological responses in the NE Pacific.

6.2. Major events during the past 25 years of State of the Pacific Ocean reports

In 2000, at the first Fisheries and Oceans Canada State of the Pacific Ocean (SOPO) meeting, the major environmental events in NE Pacific were believed largely related to El Niño – Southern Oscillation (ENSO) events, and to the Pacific Decadal Oscillation (a western – eastern North Pacific pattern of ocean-atmosphere climate variability most evident in sea surface temperatures). For example, Kim Hyatt (DFO, Pacific Biological Station, Nanaimo) and colleagues developed a model in which lagged El Niño and La Niña events increased their forecasting skill for Barkley Sound Sockeye Salmon returns (1970-2015). Specifically, cooler ocean conditions (La Niña) tended to produce better Sockeye Salmon fry recruitment, whereas warmer ocean conditions (El Niño) produced poorer Sockeye Salmon fry recruitment. These oscillations were due to a complex set of processes of fry survival in their early months at sea as a result of prey and predator conditions.

However, over the course of SOPO meetings, participants soon recognized that many other ocean physical and chemical processes and events were impacting and changing ocean biology (Figure 6-1). One of the strongest (which was also first recognized by Howard Freeland of DFO at the SOPO meeting in 2014 for conditions in 2013), was the marine heat wave in the NE Pacific which has subsequently become known as “The Blob”. It has also been noted over the years that geophysical events, such as volcanic eruptions which fertilise the NE Pacific with iron, and earthquakes such as the Great Tohoku earthquake in Japan in 2011, can have important impacts on ocean biology (e.g., Hamme et al. 2010; Therriault et al. 2018).

All SOPO reports can be found with an internet search for “State Ocean Pacific Region”.

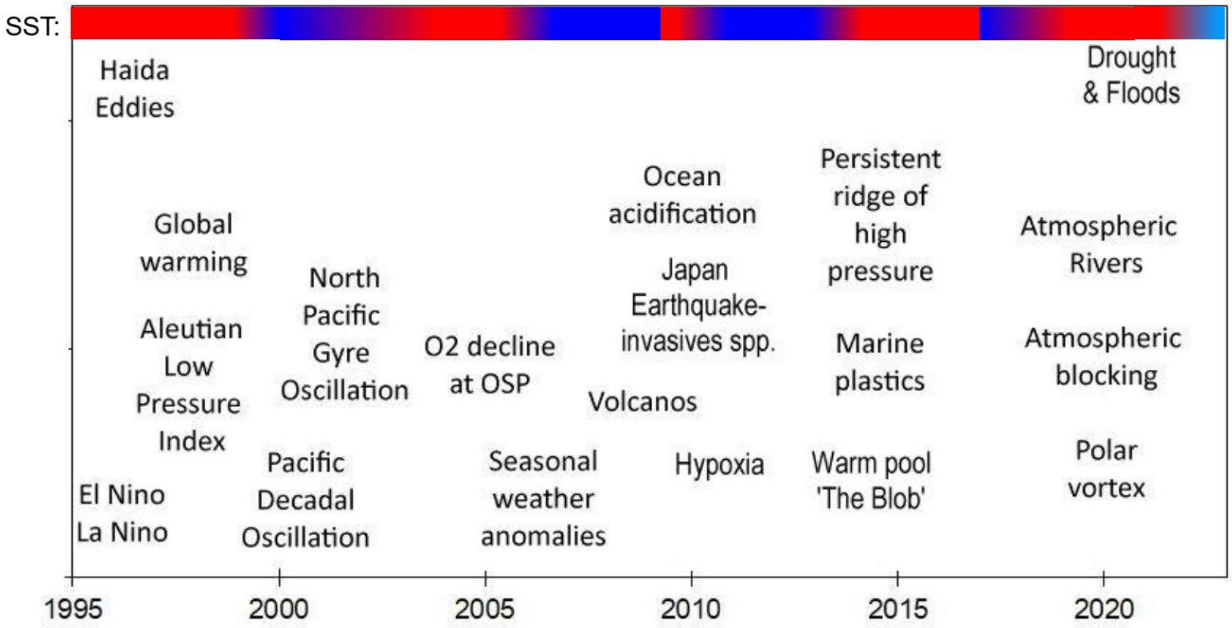

Figure 6-1. Example of physical, chemical and geophysical events in the NE Pacific that impact ocean biology, and the approximate year (along the X-axis) when they were noted. Coloured bar along the top represents sea surface temperatures (blue = cool, red = warm).

Other major physical events and associated environmental conditions are presented in Table 6-1 along with their notable impacts to ocean biology. In some cases, it was not uncommon to see impacts in biology first, which produced much excitement and research energy to identify their connections with physical and/or chemical processes. One prime example is the return of far fewer Fraser River Sockeye Salmon in 2009 than was expected (possibly due to delayed upwelling and warmer spring conditions in 2007), followed by a huge return in 2010. The former event was the motivation for the creation of the Cohen Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River, in 2009. Its goal was to investigate the decline of Sockeye Salmon stocks and provide recommendations. The Commission's final report (Ottawa, 2012) included 75 recommendations on a range of issues, including the need to incorporate more environmental and ecosystem information.

The number of times that significant terms were mentioned in each report also provides an indication of when various processes and topics were recognized and examined more closely during the meetings (i.e., when terms were mentioned more frequently; Figure 6-2). However, there can also be a 'researcher' effect depending on how many people were working on a topic and when they may have retired.

Table 6-1. Summary of selected important physical and biological events in NE Pacific over past 25 years.

Year	Physical/chemical conditions	Biological conditions
1999	Conditions near normal after years of El Niño events	Improved plankton, salmon, herring, Pacific Cod populations over next few years compared with previous ENSO conditions
2003	Recognized much of the variability in B.C. waters is related to prevailing winter winds; stronger winds from south lead to stronger coastal flows to the north and warmer conditions	More southern zooplankton, Pacific Sardine, Pacific Hake in B.C. waters
2004	Warm conditions throughout B.C. waters	Increase in warm water taxa (plankton, hake); decline of cold water species (shrimp); Humboldt Squid (from Mexico) very abundant
2005	Warm conditions persist, reduced vertical nutrient supply in offshore waters, late Spring transition (April)	Increase in warm water migratory taxa (Pacific Hake, Pacific Sardine); lower zooplankton biomass, more southern zooplankton species; poor year for seabirds; poor juvenile Coho Salmon growth
2007	Cool La Niña conditions; colder winter but warmer summer temps	Zooplankton return to ‘cool ocean’ conditions; low Sockeye Salmon returns
2008	Coolest NE Pacific Ocean in 50 years; hypoxia spreading in deep waters; iron-rich volcanic dust in NE Pacific	Volcanic dust stimulates high plankton abundances in NE Pacific; good survival of juvenile Sockeye Salmon, seabirds, sablefish, but Pacific Sardine, Pacific Herring decline
2009	Cool early in year, warmer late in year	Return of far fewer Fraser River Sockeye Salmon than expected (possibly due to spring conditions in 2007) leads to establishment of the Cohen Commission Inquiry; Humboldt Squid very abundant
2010	El Niño event early in year, but La Niña late in year, with cool conditions persisting to 2012; lowest bottom water O2 concentrations	Near-record high number of Fraser River Sockeye Salmon returns; no Humboldt Squid observed
2013	A “year of transition”: Cool in 1st half, warm in 2nd half; weak winds in NE Pacific led to weak downwelling, resulting in ‘The Blob’	Biological responses to these changes were muted: more warm water zooplankton in fall; improving numbers of Sockeye Salmon; no Pacific Sardine; two North Pacific Right Whales observed (first time in 62 years)

Year	Physical/chemical conditions	Biological conditions
2014	Full marine heatwave conditions	Many occurrences of warm water taxa; southern zooplankton species common; high northern diversion of Fraser Sockeye Salmon; mass mortalities of juvenile Cassin's Auklets
2015	Marine heatwave continued; transition to El Niño late in year	Widespread and persistent (toxic) phytoplankton bloom; very high abundances gelatinous plankton; warmer water fish common; no widespread salmon recruitment failures, but changes in return timing and size-at-age
2017	Return to more typical cool ocean conditions	Unusual and very high abundances of gelatinous zooplankton (pyrosomes, salps); coastwide declines of Sockeye Salmon indicator stock returns (likely due to previous 'Blob' conditions)
2018 - 2022	Direct effects of 2014-2016 diminished, but ocean remained warm; Global temperatures among highest recorded, which kept NE Pacific conditions warm Marine heatwaves oscillated with El Niño and La Niña conditions, but long term warming trend continued. 2021: Summer 'heat dome', Fall floods; extreme low O2 at some locations WCVI 2022: surface temperatures near-normal	Anomalous warm conditions 2018-2021 resulted in changes to phytoplankton and zooplankton communities, although returned to normal by 2022 with cooler conditions Changes at higher trophic levels also observed (e.g., low Fraser Sockeye Salmon returns and productivity, low Smooth Pink Shrimp biomass of WCVI, low growth rates Cassin's Auklet nestlings) 2021 'heat dome' along southern B.C. coast created thermal barriers, migration delays, and increased mortalities of Sockeye Salmon in some south coast rivers; high mortalities of coastal shellfish

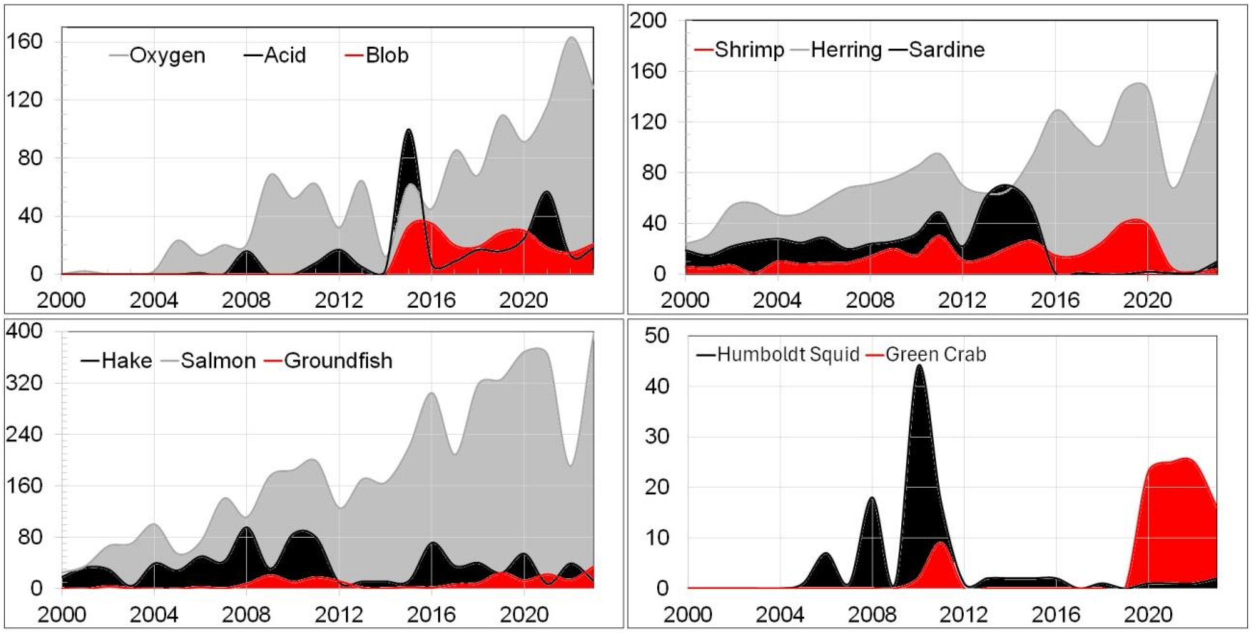

Figure 6-2. Number of times in each annual State of the Pacific Ocean report that specific terms were mentioned. This reflects their interest among participants and also when various processes (e.g., 'Blob') or taxa (e.g., Salmon) were noticed and deemed to be of interest or importance. Humboldt Squid and Green Crab are representative of warm water or invasive species, respectively.

6.3. Reflections

Having been involved in SOPO meetings (and in some cases co-chairs of the process), the authors of this report have several reflections. Foremost is that participants want to attend and present their recent findings – the meetings are the main annual (Pacific) event for in-person networking among government, academic, industrial, NGO and First Nations researchers. Participants find the meetings important for understanding what has been happening in the NE Pacific recently and how their research fits with other activities. In addition, the style developed by SOPO has set a pattern for similar reporting in other DFO Regions and Washington State.

Since the presentations are not polished and completed scientific analyses (rather they represent quick looks at the results from the most recent surveys and experiments), State of the Pacific Ocean meetings have been good opportunities for recognizing unusual events early and spreading the news among scientists and organizations. Unusual events often occur with a 'sharp' physical signal, but biological responses can be attenuated in amplitude and expanded in duration, the extents of which depend in part on trophic level. This is, in part, why it continues to be difficult to point to 'single' physical events as the cause of observed biological phenomena, especially when there may be several 'sharp' physical events in succession.

6.4. Conclusions

We conclude with insights offered by Andrew Bakun at a PICES meeting in 2017 (Bakun 2017) (modified from a comment by Ron O'Dor of Dalhousie University): "Chemistry and physics make the laws; Organisms exploit the loopholes in the laws. As a result, marine ecosystems continually evolve their dynamics in response to a variety of stresses." State of the Pacific

Ocean meetings have been a key resource and process for identifying these ‘laws’ as they apply to the NE Pacific, and how the biological ‘lawyers’ exploit the loopholes in these laws.

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

7. LAND TEMPERATURE AND HYDROLOGICAL CONDITIONS OVER B.C. IN 2023

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7.1. Highlights

- In 2023, B.C. experienced record warm annual, summer and fall temperatures and well below-normal annual precipitation.
- Snowpack was generally below-normal through the winter, rapidly decreasing to well below-normal by June 1st due to early snowmelt across the province.
- In late summer and fall, severe drought conditions were experienced nearly everywhere in B.C., coinciding with record warm temperatures and below-normal precipitation.
- The trend in annual mean temperature in B.C. is positive and can be distinguished from natural variability over the analyzed period, 1950-2023. Annual precipitation, however, exhibits no significant trend over that period.

7.2. Introduction

Temperature and precipitation can provide valuable insight into seasonal conditions in B.C. that have important impacts on B.C.'s coastal waters in the Pacific Ocean. This section describes the seasonal evolution of weather and snowpack conditions across B.C. in 2023 to help complement information from coastal and oceanic data analyses. In this effort, we use monthly temperature and precipitation pseudo-observations from a global atmospheric reanalysis and both manual and automated monthly measurements of snow water equivalent from the B.C. River Forecast Center.

7.3. Description of the data

7.3.1. 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 dataset 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 2023 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 to present at a horizontal resolution of approximately 30 km x 30 km over the globe.

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 to 2010 reference period. Anomalies in monthly temperature and precipitation were then computed relative to these normals for the entire 1950 to 2023 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 then taken across each region to form a monthly time series of regional anomalies. 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 by year. An example of the resulting annual anomaly data is shown in Figure 7-1 for annual mean temperature (left panel) and precipitation (right panel). The temperature and precipitation anomalies are expressed as percentiles among the number of observed seasons or years in the sample. We define the first percentile and number 1 ranking as the warmest/wettest over the 74-year period of 1950 to 2023 and the highest percentile as the coldest/driest with a ranking of 74. 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 to 90th, 90th to 66th, 66th to 33rd, 33rd to 10th, 10th to 1st, and 1st.

7.3.2. Snow

Monthly measurements of snowpack are made by the Ministry of Environment and Climate Change Strategy and BC Hydro through manual snow surveys and automated snow weather stations across the province. In addition, the Ministry of Forests River Forecast Centre compiles monthly snowpack data from early January through June. Snowpack in regions is compared with data from previous years to determine how the current year's accumulated snow amount compares with historical expectations. Historical data are available from 1997-2023. This is important because in most basins, early spring snowpack dictates the added potential (or lack thereof) for riverine flooding during the late spring melt season.

7.4. Status and trends

7.4.1. Temperature and Precipitation

In 2023, average annual temperature was record warm across B.C. relative to the 1950 to 2023 record (Figure 7-1, left). All basins ranked in the top 5, with most basins ranking as the warmest year since 1950. Annual precipitation anomalies were well below normal, especially in the south, with the province ranking 4th driest in the entire record (Figure 7-1, right). The Upper Fraser West, Nechako, and Skagit basins all experienced their record driest year since 1950. The Northwest was the only basin that had above normal annual precipitation.

Winter was the only season that had near normal temperature for B.C. Temperatures increased throughout the year, reaching above normal in the spring and record warm in the summer and fall. The Liard and Peace basins experienced their warmest summer on record, while all other basins ranked within the top 7 warmest summers. In the fall, most basins continued to rank in the top 7 warmest years, but a few basins in southern B.C. were slightly less warm with above normal temperature anomalies. Record warm temperatures and below normal precipitation throughout summer and fall prompted severe drought conditions over much of B.C. (see below).

Over the winter of 2022-2023, precipitation patterns were largely near normal over the province, with above normal precipitation seen in the Liard and North Thompson basins. Precipitation was below normal on Vancouver Island and the South Coast, and in most of the basins bordering the United States. By spring, most of the province was characterized by below normal precipitation: the Nechako, in particular, experienced its 4th driest spring on record. While most of the basins bordering the United States were normal, the Northwest was unusually wet. Precipitation remained below normal for most of B.C. into the summer of 2023. The northwestern and southeastern basins bordering Alberta were normal, while Vancouver Island (4th driest), Haida Gwaii, and the Central Coast were well below normal. By fall, dry conditions spread to nearly all basins, with the exception of Haida Gwaii and Stikine (near-normal) and the Northwest which was anomalously wet (10th wettest). Eight basins recorded their 7th driest or drier fall season since 1950. Areas bordering the United States and Southern Alberta were slightly less dry, as were Vancouver Island and Skeena-Nass.

By the end of July, 84% of B.C. was rated Abnormally Dry or in Moderate to Exceptional Drought (Canadian Drought Monitor, 2023). This included 98% of B.C.'s agricultural lands. Moderate to Exceptional droughts persisted and increased to cover 88% of B.C. by the end of November. Most of the province experienced extreme low streamflow, low soil moisture, and a record-breaking wildfire season (Canadian Drought Monitor, 2023; BC Wildfire Service, 2023).

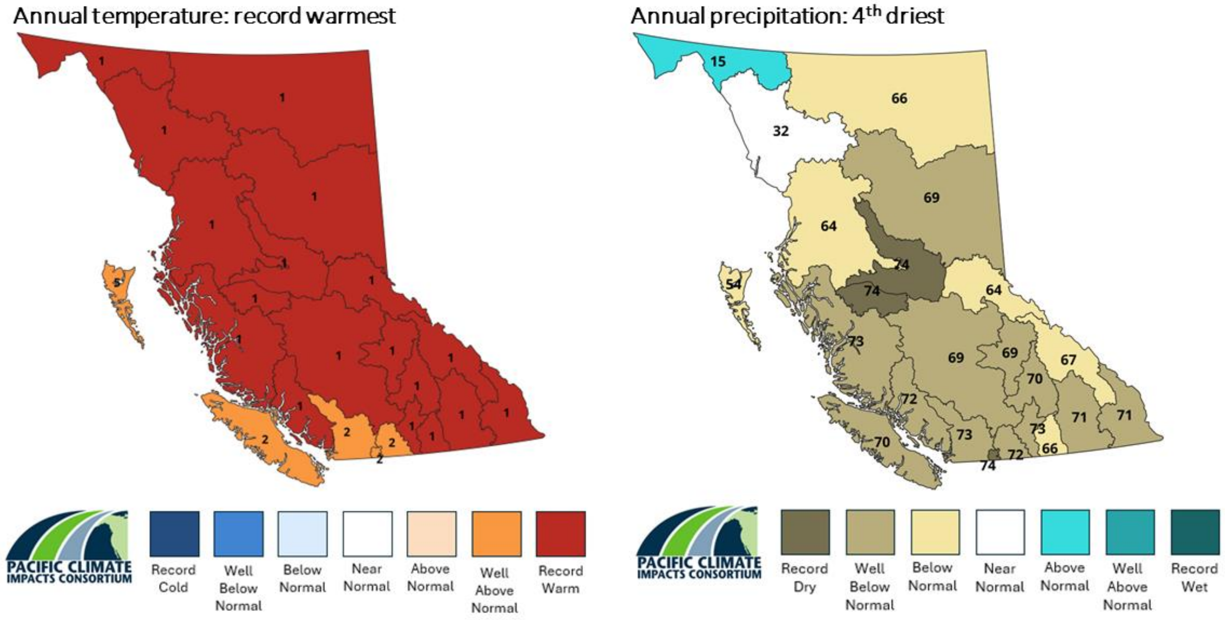

Figure 7-1. Annual anomalies for average daily mean temperature (left panel) and total precipitation (right panel) for 2023 in B.C. Colour scale is based on percentiles as provided in the text. Labels on the map refer to ranking by year (1950 – 2023) with 1 being the warmest/wettest year and 74 being the coldest/driest year. Results are based on the ERA5 Reanalysis product from ECMWF, accessed via the KNMI Climate Explorer 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 2023. 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 7-1). The trends in precipitation are not statistically different from zero, except for a small decreasing trend in winter.

Table 7-1. 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 1950-2023	ANN	MAM	JJA	SON	DJF
Mean Temperature (°C decade-1)	+0.37	+0.35	+0.35	+0.26	+0.45
Precipitation (mm decade-1)	–	–	–	–	−22

7.4.2. Snow

B.C.'s snowpack was below normal during the winter of 2022-2023, except at the end of the season when snowpack returned to near normal (March 1 was at 90-109% of normal). The Okanagan, Boundary, and Lower Thompson basins had above normal snowpack all winter (>110%; January 1st to May 1st), then rapidly decreased to < 50% of normal snowpack by June 1st. Due to above normal temperatures and below normal precipitation in the spring followed by record warm temperatures in the summer, early snowmelt occurred province wide. This led to an early melt freshet at the Fraser River at Shelley in the southern Peace Basin (M. Schnorbus, private communication) and high flows and flooding in the Central and Southern interior in May (River Forecast Center, 2023).

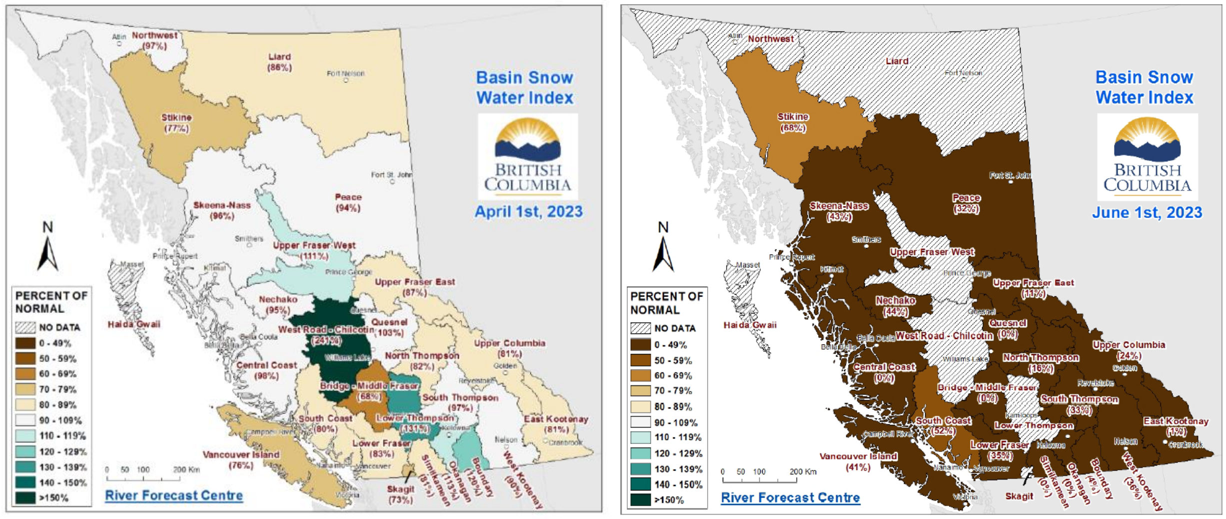

Figure 7-2. Anomalies in B.C. snowpack for April (left) and June (right), 2023. Maps are produced by the B.C. Ministry of Forests River Forecast Centre (River Forecast Centre 2023).

7.5. Factors causing trends and implications

In 2023, B.C. was record warm with well below normal annual precipitation. B.C. was warmer and drier than normal in all seasons except winter. Record-breaking temperatures occurred in the summer and fall for B.C. as a whole and specifically in the Liard (summer), Peace (summer), and Stikine (fall) basins. Precipitation was near normal in the winter and the province became drier throughout the year, with the most basins ranking well below normal in the fall. The combination of record-breaking temperatures and below normal precipitation led to severe drought conditions that persisted well into the fall. This coincided with a record-breaking wildfire season in 2023.

The observed anomalous temperatures in 2023 are consistent with ongoing warming in B.C., as indicated by trend analysis of the 1950 to 2023 record (Table 7-1). Annual mean temperatures in B.C. have risen by 0.37ºC decade^{-1} on average over the last 74 years. B.C. followed global temperature trends with 2023 being the warmest year on record (Copernicus Climate Bulletin, 2024).

In 2023, ocean temperatures transitioned from a La Niña pattern into what became a strong El Niño in March of 2023. As El Niño is associated with above average temperatures and below average precipitation in B.C., this state change may have contributed to the early snowmelt and the temperature and precipitation patterns seen throughout the spring, summer, and fall.

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8. NORTHEAST PACIFIC EXPERIENCES SURPRISINGLY NORMAL TEMPERATURES DURING EARTH'S HOTTEST YEAR ON RECORD

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8.1. Highlights

- 2023 was the warmest year on record globally, but sea surface temperatures (SSTs) were near average in the northeast Pacific.
- The PDO was strongly negative, which led to record warm SSTs in the northwest Pacific, but did not correlate with cool SSTs in the northeast Pacific.
- Surface waters in the northeast Pacific continued to be anomalously fresh in 2023 but strong anomalies were only seen at Ocean Station Papa (not throughout Line P section).

8.2. Description of the time series

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), North Pacific Index (NPI) Pacific Decadal Oscillation (PDO), Southern Oscillation Index (SOI), and North Pacific Gyre Oscillation (NPGO); please see section 8.6. 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 Ocean Station Papa (OSP) 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 OSP 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.

8.3. Status and trends

Based on NOAA's land and SST data dating back to 1880, 2023 was the warmest year on record globally (NOAA State of the Climate 2023). This is consistent with the recent trend, wherein all ten of the warmest years globally are in the last decade. In ranked order, the ten warmest years are 2023, 2016, 2020, 2019, 2015, 2017, 2022, 2021, 2018 and, 2014. Despite the record warm year globally, SSTs in the Northeast Pacific (NE Pacific) were only slightly warm in 2023; 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/202301-202312.png).

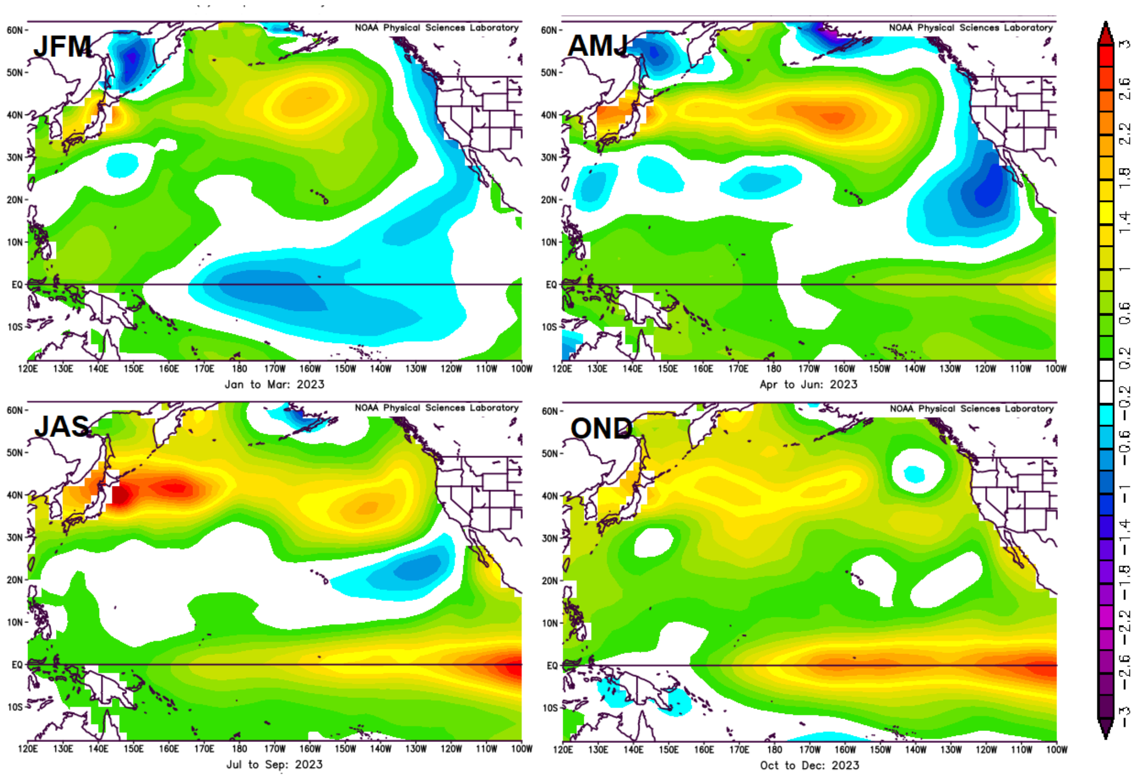

Figure 8-1. Seasonal maps of temperature anomalies in the Pacific Ocean for each quarter in 2023 (labelled by month groupings). The colour bar on the right, showing the temperature anomaly in °C, applies to all panels. Anomalies are relative to 1991-2020 base period. Source: NOAA Extended SST v4 http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl.

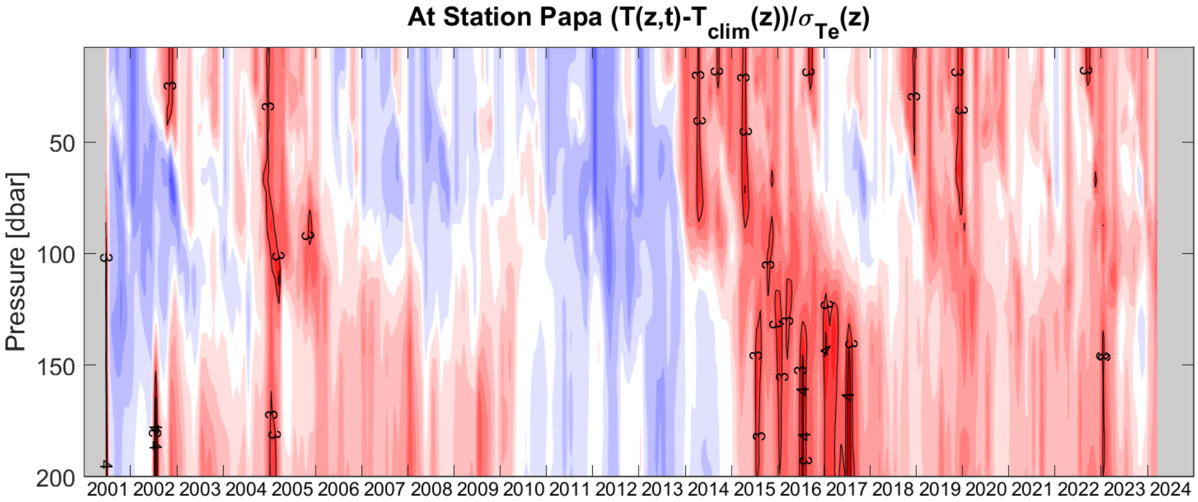

Figure 8-2. Plot of temperature anomalies, as observed by Argo floats near Ocean Station Papa. Anomalies are calculated relative to the 1991-2020 seasonally-corrected mean and standard deviation (from the Line P time series). Cool colours indicate cooler than average temperatures and warm colours indicate 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.

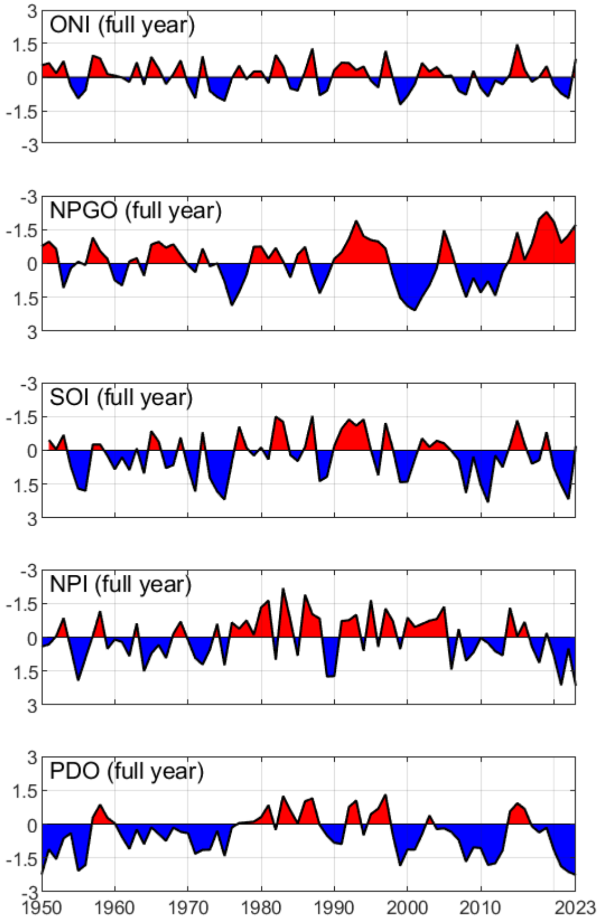

Figure 8-3. Time series of yearly-averaged Pacific climate indices. Some series are reversed so that series are red when coastal B.C. waters tend to be warm.

In the NE Pacific, the seasonally-averaged SSTs were close to the 1991-2020 climatological values throughout 2023. Coastal temperatures were cooler than average throughout the first half of the year and slightly warm in the second half (Figure 8-1). Also notable is the large change in SSTs near the equator from strongly below average at the beginning of the year to strongly above average at the end (Figure 8-1); i.e., the switch from the La Niña conditions present since 2021 to El Niño conditions in the latter part of 2023. El Niño typically increases SST in the NE Pacific, so the switch is consistent with the pattern of coastal SSTs. However, this mid-year change was not seen offshore; SSTs remained slightly warm, which is what we expect for an average year given climate change, throughout the year at Ocean Station Papa (OSP; 50N,145W; Figure 8-2).

There were strongly negative Pacific Decadal Oscillation (PDO) conditions throughout 2023 (Figure 8-3), but this did not result in a cool year for the NE Pacific

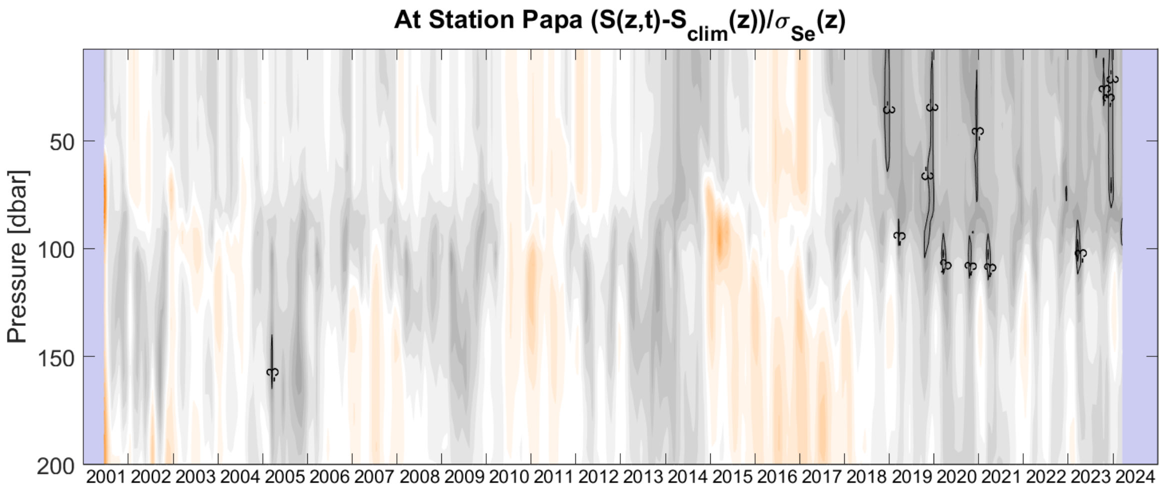

Figure 8-4. Plot of salinity anomalies as observed by Argo floats near Ocean Station Papa, with anomalies calculated relative to the 1991-2020 seasonally-corrected mean and standard deviation (from the Line P time series). The grey indicates fresher than average and orange indicates saltier than average. 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.

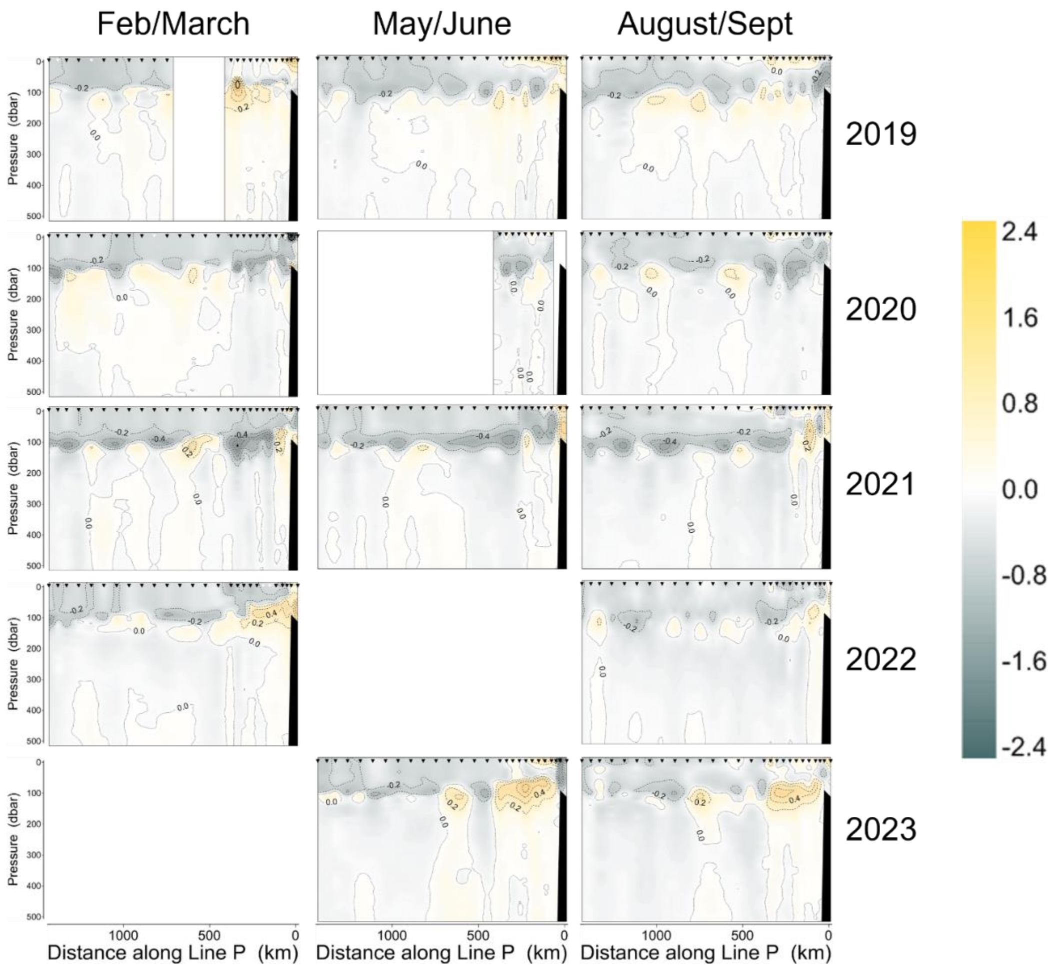

Figure 8-5. Salinity anomalies (psu) along Line P from 2019 to 2023 with respect to the 1991-2020 mean. Contour lines highlight labelled salinity anomlaly values. August 2023 data have not yet been quality controlled and adjusted.

because it occurred on a background of steadily rising temperatures due to climate change as well as the switch to El Niño. We can see how near-average temperatures in the NE Pacific can lead to a strongly negative PDO state by looking at how warm the northwest Pacific was in 2023 (Figure 8-2), particularly in Summer, but also Spring and Fall. This is because the PDO is a measure of the strength of a SST pattern with positive values when the NE Pacific is warm relative to the NW Pacific. With climate change, we can (and did) have a strong negative PDO without cool temperatures in the NE Pacific.

Looking at the climate indices collectively (Figure 8-3; see section 8.6. for details), they do not show a clear pattern. The Oceanic Niño Index (ONI) and North Pacific Gyre Oscillation (NPGO) pointed to a warm year in the NE Pacific in 2023. Meanwhile, the PDO and North Pacific Index (NPI) suggested the opposite. This mix is consistent with the near-normal water temperatures.

At OSP in the Alaskan Gyre, temperatures continued to be slightly warm and slightly fresh, consistent with the last 6 years. Temperatures in the upper 200 m were slightly warmer than the 1991-2020 mean in 2023 (Figure 8-2), but, unlike 2022, exhibited no strong anomalies due to marine heatwaves. The salinity anomaly timeseries shows that—at least in 2023—the recent salinity anomalies above 100 m depth were very large relative to the 1991-2020 Line P climatology, with anomalies 3 standard deviations above the typical variability (Figure 8-4). The section plots along Line P show that the salinity anomalies in the upper 100 meters stretch from OSP to the B.C. coast (Figure 8-5), but also suggest that, while the fresh anomaly was similar in strength to 2022, it was stronger further offshore, with some positive salinity anomalies near the coast. Sea surface salinity anomaly maps based on satellite data (Melnichenko et al. 2016; https://salinity.oceansciences.org/oi-anomaly.htm) show that these offshore fresh anomalies stretched across much of the NE Pacific in 2023 (as in 2021 and 2022).

The winter stratification was stronger in 2022/23 relative to 2021/22 and 2020/21 (Figure 8-6) suggesting less winter mixing than in the past 2 winters. For context, the 2022/23 winter stratification was similar to the 2019/20 winter, but not as strong as during the 'Blob' years. Thus, the mixing of nutrients to the surface was likely weaker in 2022/23 relative to 2021/22, but still fairly normal.

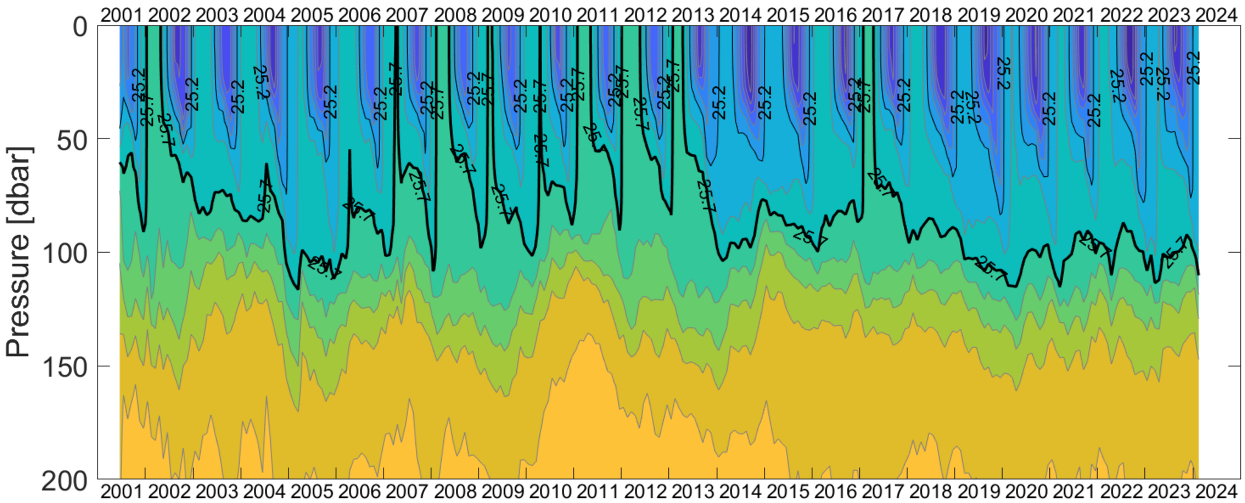

Figure 8-6. Coloured contour plot of density as observed by Argo floats near Ocean Station Papa (P26: 50º N, 145º W). The colours indicate potential density (yellow is denser and blue lighter). The black lines highlight the σ_θ=25.2 kg/m^3 (thin) and 25.7 kg/ m^3 (thick) isopycnals.

8.4. Factors influencing trends

The relatively normal temperatures observed in the NE Pacific are likely due to the juxtaposition of a cool PDO phase and the fact that the El Niño developed late in the year with a background of long-term climate warming. The salinity anomalies, i.e., freshening of the surface waters in the NE Pacific in the last 5 years, have 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 other mechanisms (e.g., increased river discharge due to accelerated glacial melt).

8.5. Implications of those trends

With the PDO in a cool phase and the temperatures near normal, it is likely that during the next 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), which 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/m3 isopycnal (highlighted with a thick black line in Figure 8-6) 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 lower and therefore early spring nutrient levels should be on the low side in the spring of 2024, but not quite as low as during the 'Blob'.

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

The North Pacific Index (NPI) is the area-weighted sea level pressure over the North Pacific Ocean from 30° N to 65° N and 160° E to 140° W. This index, like the Aleutian Low Pressure Index (ALPI; Surry and King 2015) reported in previous years, is a useful indicator of the intensity and 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 8-3, was calculated from the NPI by removing the 1950-2023 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 SST 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′ S 130°50′ 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). It is also negatively correlated with SST in coastal B.C. Monthly values of NPGO are available from: http://www.o3d.org/npgo/.

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

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9.1. Highlights

- The 2023 Spring Transition timing was late relative to the 1991-2020 mean. Late timing is associated with below-average upwelling-based coastal productivity.
- The length of the 2023 summer upwelling season, from Spring to Fall Transition, was shorter than average. This also favoured below-average upwelling-based coastal productivity.
- Between 45° and 60° N, the magnitude of upwelling-favourable winds in 2023 was below the 1991-2020 average during the warm season. This too favoured below-average upwelling-based coastal productivity in 2023.
- The winter of 2022-2023 was characterized by below-average downwelling-favourable winds, indicating that winter storm activity was below normal over the winter overall. The winter of 2023-24 also had below average downwelling winds as of January 2024, which favours another marine heat wave in 2024.

9.2. Description of the time series

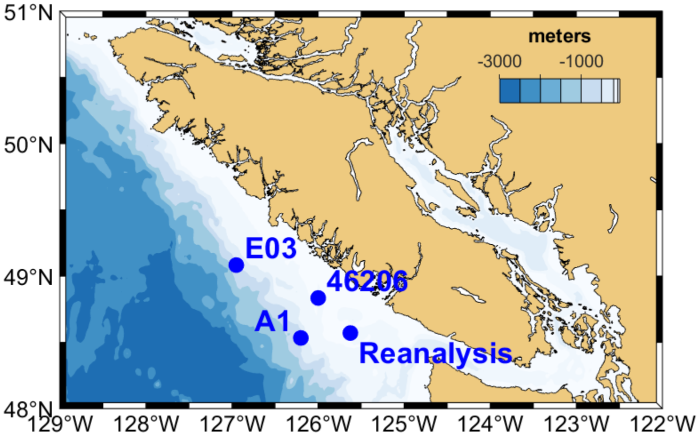

Figure 9-1. Locations of moorings A1 and E03 used for wind velocity, meteorological buoy 46206 used for wind stress, and Reanalysis 1 used for wind stress.

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 alongshore wind stress time series from NCEP/NCAR Reanalysis-1 (Kistler et al. 2001), alongshore wind velocity from the Environment and Climate Change Canada meteorological buoy, and the alongshore current velocity at 35 and 100 m depth at moorings A1 and E03 (Figures 9-1 and 9-2; Folkes et al. 2017; Thomson et al. 2013).

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 the upwelling-favourable-only wind stress by month along the West Coast of North America from 45°to 60° N latitude (Figure 9-3) 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 the poleward (downwelling-favourable) wind stress (Figure 9-4). 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 to 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.

9.3. Status and trends

9.3.1. Spring and Fall Transition timing

In 2023, the Spring Transition was late compared to the 1991-2020 mean (Figures 9-2 and 9-5). The 2023 Spring Transition date was taken as the mean of the transition to predominantly equatorward current flow at 35 and 100 m at station E03, and is close to that for the Reanalysis wind stress. Unfortunately, there were no data from meteorological buoy 46206 in 2023. Surface chlorophyll increased at the time of Spring Transition, indicating increased productivity upon the onset of upwelling. The timing of the 2023 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 the period 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 9-2(b) and (c)). However, the late Spring Transitions in 2022 and 2023 resulted in a dramatic reset of the length of upwelling and downwelling seasons making them shorter and longer than average, respectively. The shorter than average upwelling season favoured below-average productivity in 2023.

9.3.2. 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 2023 warm season (Figures 9-3 and 9-5). In contrast, February upwelling-favourable winds were much higher than average for the sixth consecutive year. No trends in upwelling-favourable winds since 2013 are evident in Figure 9-3.

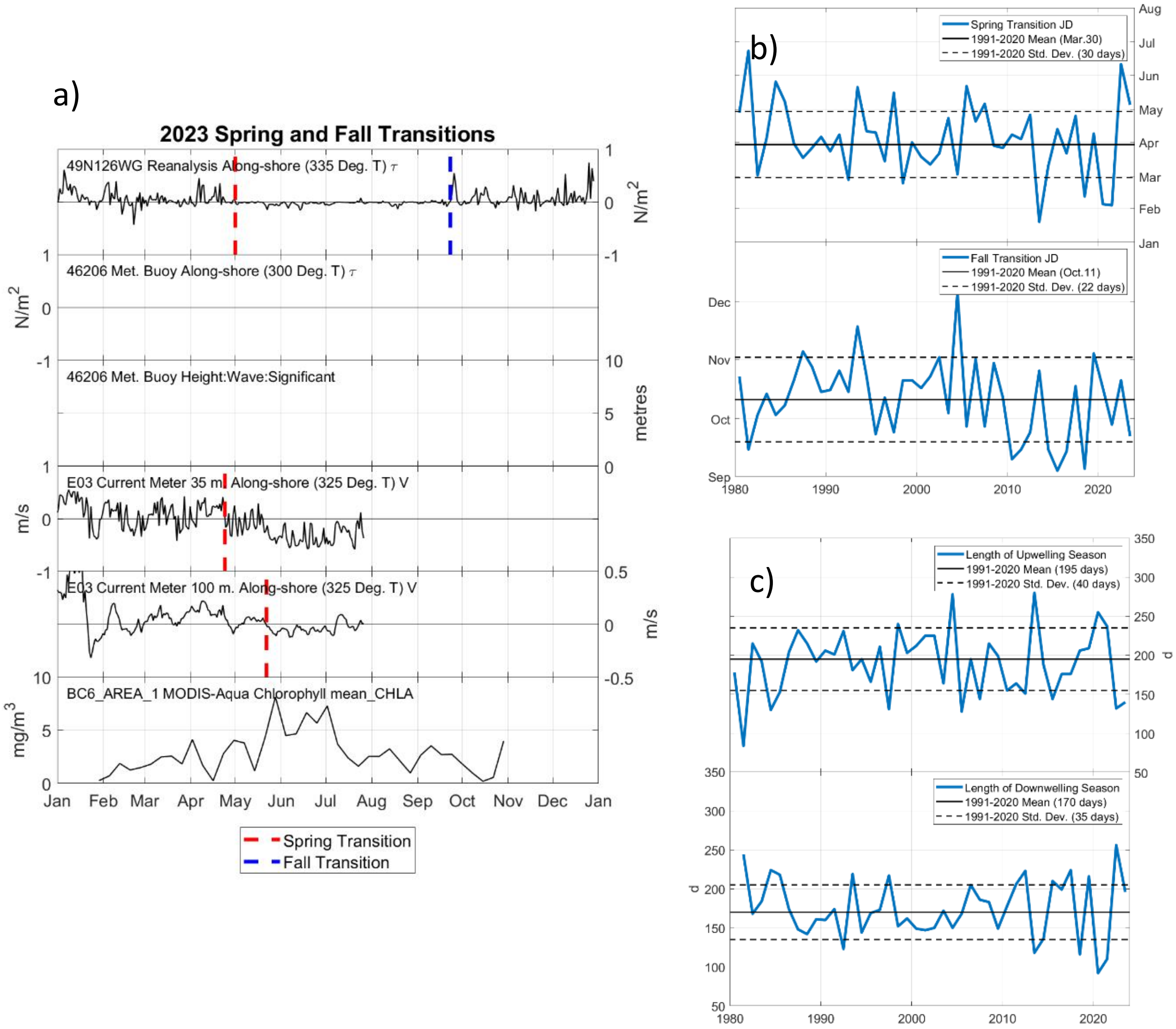

Figure 9-2. (a) Time series depicting the Spring and Fall Transitions off the West coast of Vancouver Island in 2023. Wind stress at Reanalysis-1 grid point 49°N 126°W and meteorological buoy 46206; significant wave height at 46206; alongshore current velocity at 35 and 100 m depth at mooring E03 (Folkes et al. 2017; Thomson et al. 2013) and MODIS-Aqua chlorophyll-a (A. Hilborn, pers. comm.). 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.

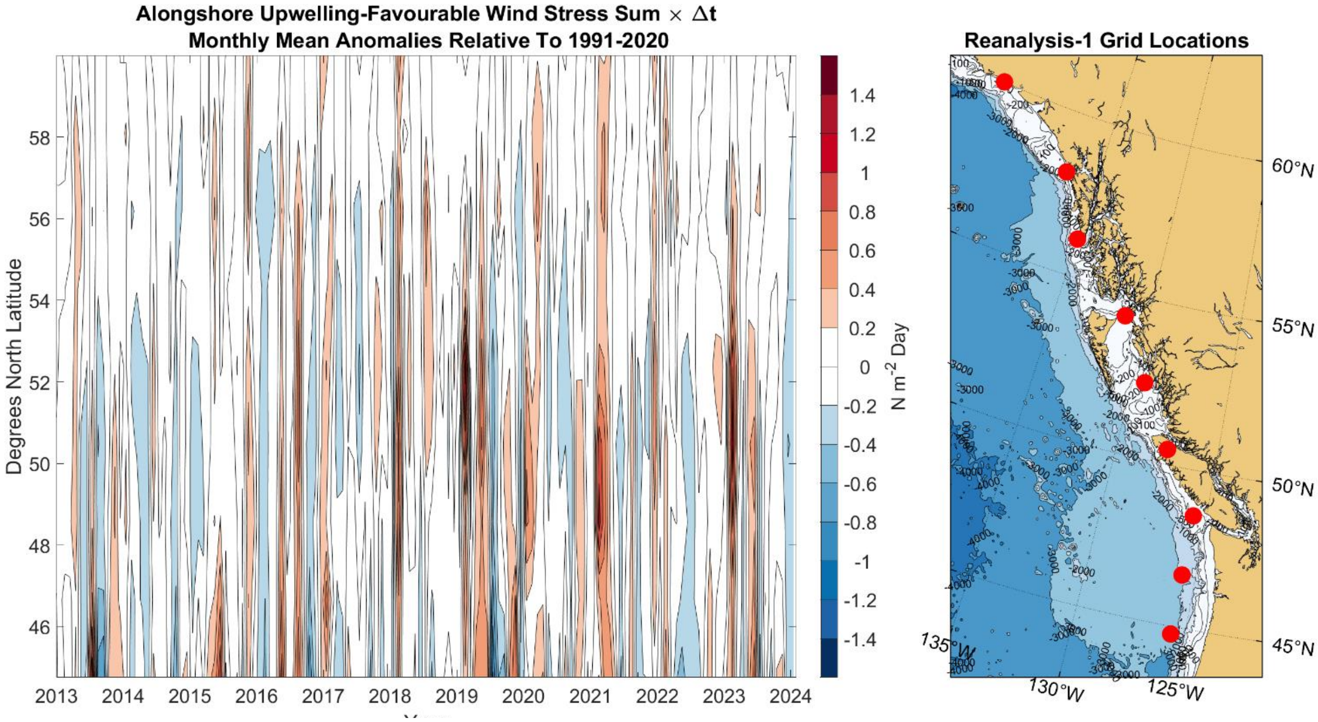

Figure 9-3. Recent (2013 to 2023) monthly mean anomalies (relative to 1991-2020) of monthly sums of alongshore upwelling-favourable (equatorward) wind stress from the NCEP/NCAR Reanalysis-1 coastal surface wind stress grid locations, 45-60° N.

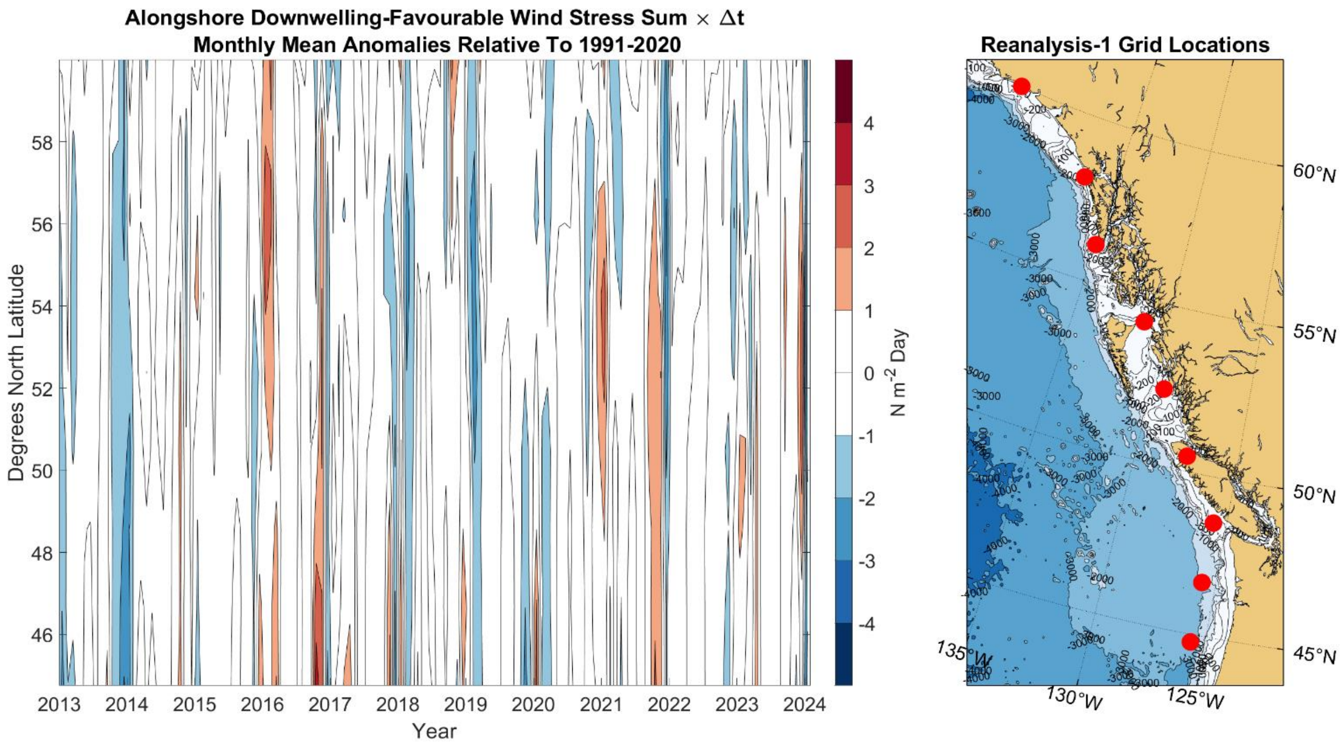

Figure 9-4. Recent (2013 to 2023) monthly mean anomalies (relative to 1991-2020) of monthly sums of alongshore downwelling-favourable (poleward) wind stress from the NCEP/NCAR Reanalysis-1 coastal surface wind stress grid locations, 45-60° N.

9.3.3. Downwelling Magnitude: The Downwelling Index

During four of five winters from 2017-2018 to 2021-2022 (excluding 2020-2021), the Downwelling Index was lower than average, like the winter of 2013-2014, but not quite as low (Figure 9-4). This indicates reduced wintertime surface mixing and shallower mixed layer depth 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 2022-2023, the index was again below average, and was followed by higher-than-average sea surface temperatures in summer 2023. So far over the winter of 2023-2024, the index has again been lower than average through January 2024, except for being slightly positive in December 2023. If it continues to be lower that would favour warmer than average surface temperatures for the summer of 2024.

9.4. Factors influencing trends

The reason 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 wintertime Downwelling Index had been lower than average over the period 2012-2020 and 2022 and 2023 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.

9.5. 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 degree of winter ocean surface mixing, the vertical extent of the surface mixed layer, and the level of upper ocean 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 2023 Spring Transition was late, favouring below-average upwelling-based coastal productivity.

Between 45°and 60° N, the magnitudes of warm season upwelling-favourable winds in 2023 were below average, also favouring below-average upwelling-based coastal productivity.

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 most of the winters since 2018-2019, as well as future marine heatwave events. In addition, the weaker winter storm activity associated with a weaker Downwelling Index implies weaker surface mixing, a shallower mixed layer depth, stronger stratification, and possibly lower productivity.

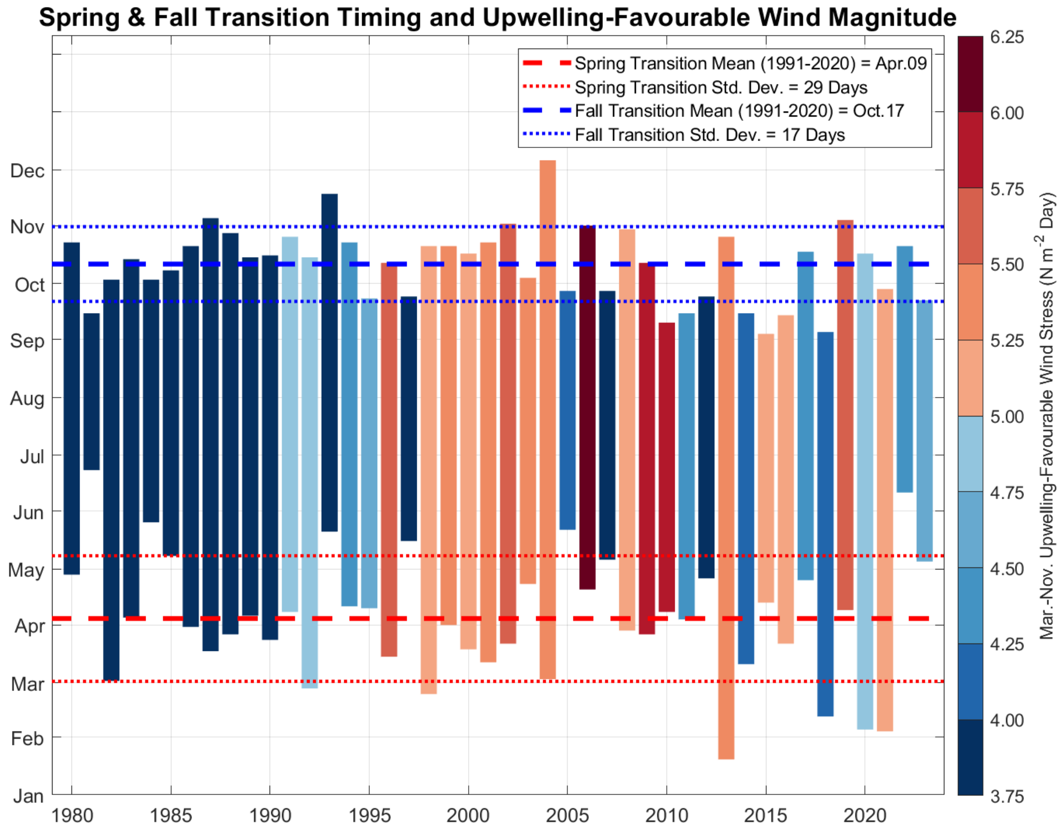

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Figure 9-5. Annual Spring and Fall Transition Timing and March-November upwelling-favourable wind stress magnitude for the period 1980-2023 for the region near the stations depicted in Figure 9-1.

9.6. Acknowledgements

Mooring ocean velocity and temperature data provided by the Institute of Ocean Sciences Data Archive, Ocean Sciences Division, Department of Fisheries and Oceans Canada. http://www.pac.dfo-mpo.gc.ca/science/oceans/data-donnees/index-eng.html.

NCEP-NCAR Reanalysis 1 wind stress data provided by the NOAA Physical Sciences Laboratory, Boulder, Colorado, USA, from their website https://psl.noaa.gov.

MODIS-Aqua chlorophyll-a data provided by Andrea Hilborn, Institute of Ocean Sciences, Ocean Sciences Division, Department of Fisheries and Oceans Canada.

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10. VANCOUVER ISLAND WEST COAST SHELF BREAK CURRENTS, TEMPERATURES, WIND STRESS, AND WATER LEVEL

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10.1. Highlights

- In January/February 2023, the speeds of alongshore currents at mooring E03 were anomalously high and strongly equatorward (upwelling-favourable) for the sixth year in a row. This was concurrent with stronger than average equatorward wind stress, lower than average water levels at Tofino, and was associated with below average water temperatures at depth and at the surface in February/March. These conditions arose from a weaker than average Aleutian Low pressure system in the Gulf of Alaska and a stronger than average North Pacific High, a scenario that may be becoming the new normal for February.
- In June 2023, a stronger than average North Pacific High surface pressure system led to stronger than average upwelling-favourable equatorward shelf-break wind stress and subsurface currents, and lower than average coastal water levels and surface temperatures.
- The year finished with above average surface temperatures reflecting the onset of El Niño.

10.2. 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 10-1) since 1990, with an extensive data gap between 2006-2020. Nearby alongshore wind velocity from the Environment and Climate Change Canada meteorological buoy 46206 has provided sea surface temperature at 80 cm depth and wind velocity time series at 5 m elevation (corrected to the standard height of 10 m) since 1988. Unfortunately, the buoy was out of service in 2023. In its place, we used sea surface temperature from the satellite/in situ NOAA Optimum Interpolation (OI) SST V2 High Resolution Dataset (Huang et al., 2021) and surface wind stress from NCEP-NCAR Reanalysis 1 (Kistler et al., 2001). Water level has been observed at Tofino by the Canadian Hydrographic Service since 1963. We have combined these series to obtain the vertical structure of

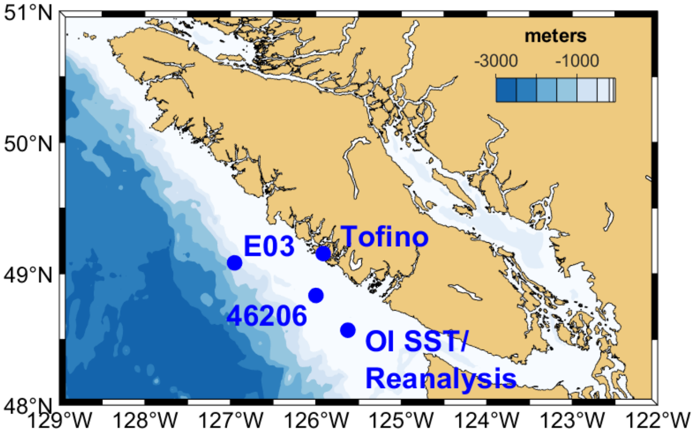

Figure 10-1. Locations of mooring E03 for temperature and velocity, meteorological buoy 46206 for temperature and wind stress, OI SST for temperature and Reanalysis 1 for wind stress, and Tofino for water level.

water level, temperature, and flow within the water column.

10.3. Status and trends

Water temperatures at the surface in early 2023 were average to below average through to April, were strongly below average in June, and finished the year above average reflecting the onset of El Niño (Figure 10-2, left). Subsurface temperatures were only available from mooring E03 at 400 m depth and they were above and then below average early in the year, and above average mid-year. Data recorded at depth after July 2023 will not be available until the mooring is recovered in summer 2024.

Alongshore winds and currents were more strongly poleward (downwelling-favourable) than average early in January (Figure 10-2, right) due to a stronger than average or eastward-shifted Aleutian Low pressure system at the time. This led to higher-than-average sea level and above average temperatures at the surface and at depth. In late January/February 2023, things reversed, with stronger than average equatorward flow and lower than average sea level. This resulted from a weaker than average Aleutian Low and stronger and more northward-shifted North Pacific High pressure system over the northeast Pacific. This is the sixth consecutive year this has happened in February and may signal new normal conditions for February. In June, there was a strong upwelling event indicated by lower than average surface temperatures, stronger than average equatorward near-surface currents, and a stronger than average North Pacific High.

Historically, temperature anomalies were positive during a marine heatwave and El Niño over 2014-2016 (Figure 10-3, left). 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 10-3). 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.

Higher temperatures and water levels, as well as enhanced poleward flow, were also observed during the strong 1997-1998 El Niño (Figure 10-3). This was also the case over the latter half of 2023 with the onset of another El Niño event.

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 1990-2023, 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 trend, 1990-2023.

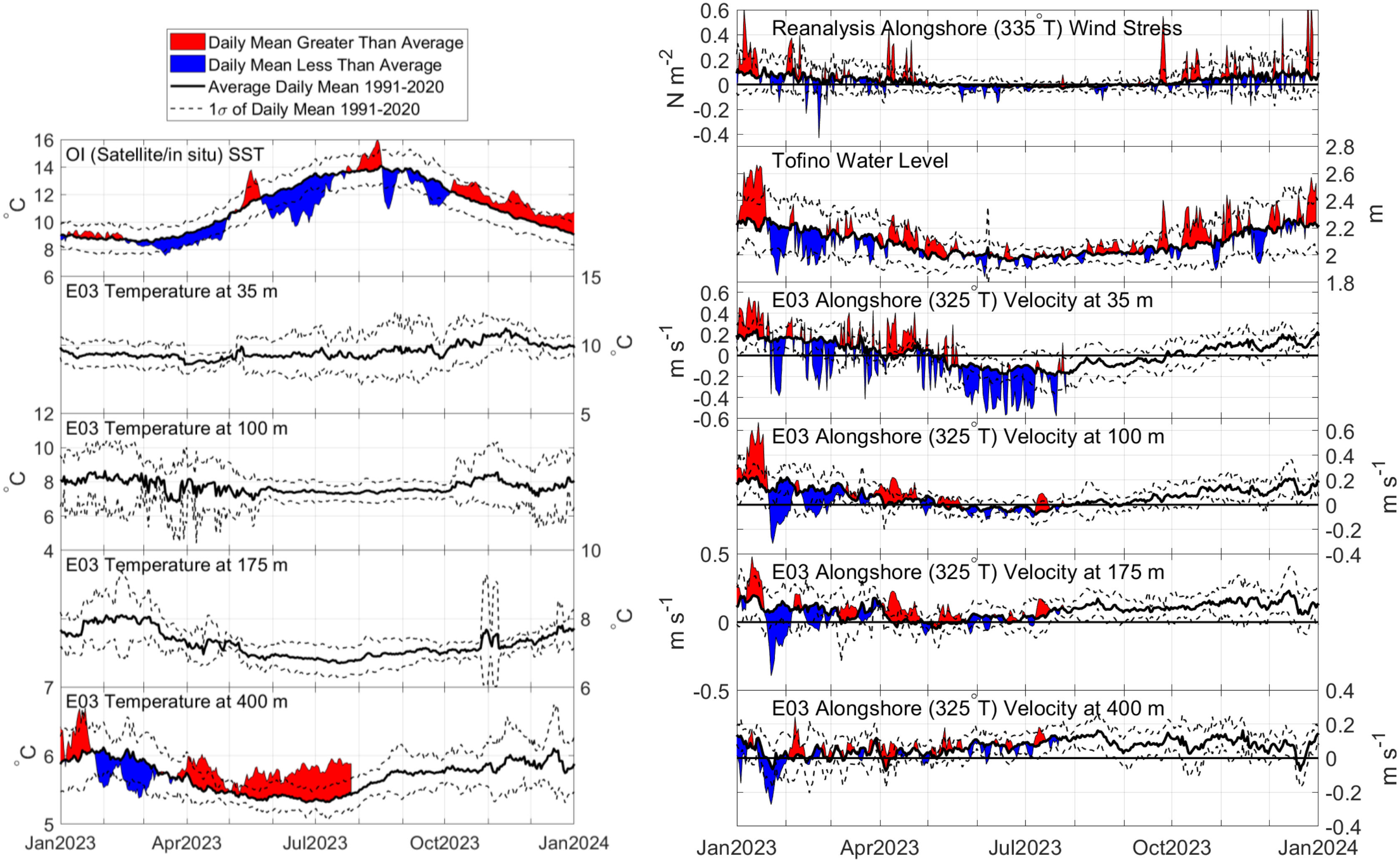

Figure 10-2. Daily mean values of temperature (left panels) and alongshore wind stress, water level, and alongshore ocean current (right panels) at the surface, 35 m, 100 m, 175 m, and 400 m depth from, respectively, the NOAA Optimum Interpolation (OI) SST V2 (1x1 latitude longitude degree), mooring E03, NCEP-NCAR Reanalysis 1, and Canadian Hydrographic Service Tofino station. Angle in brackets (°T) is the principal direction of the wind or current vector in degrees true compass bearing.

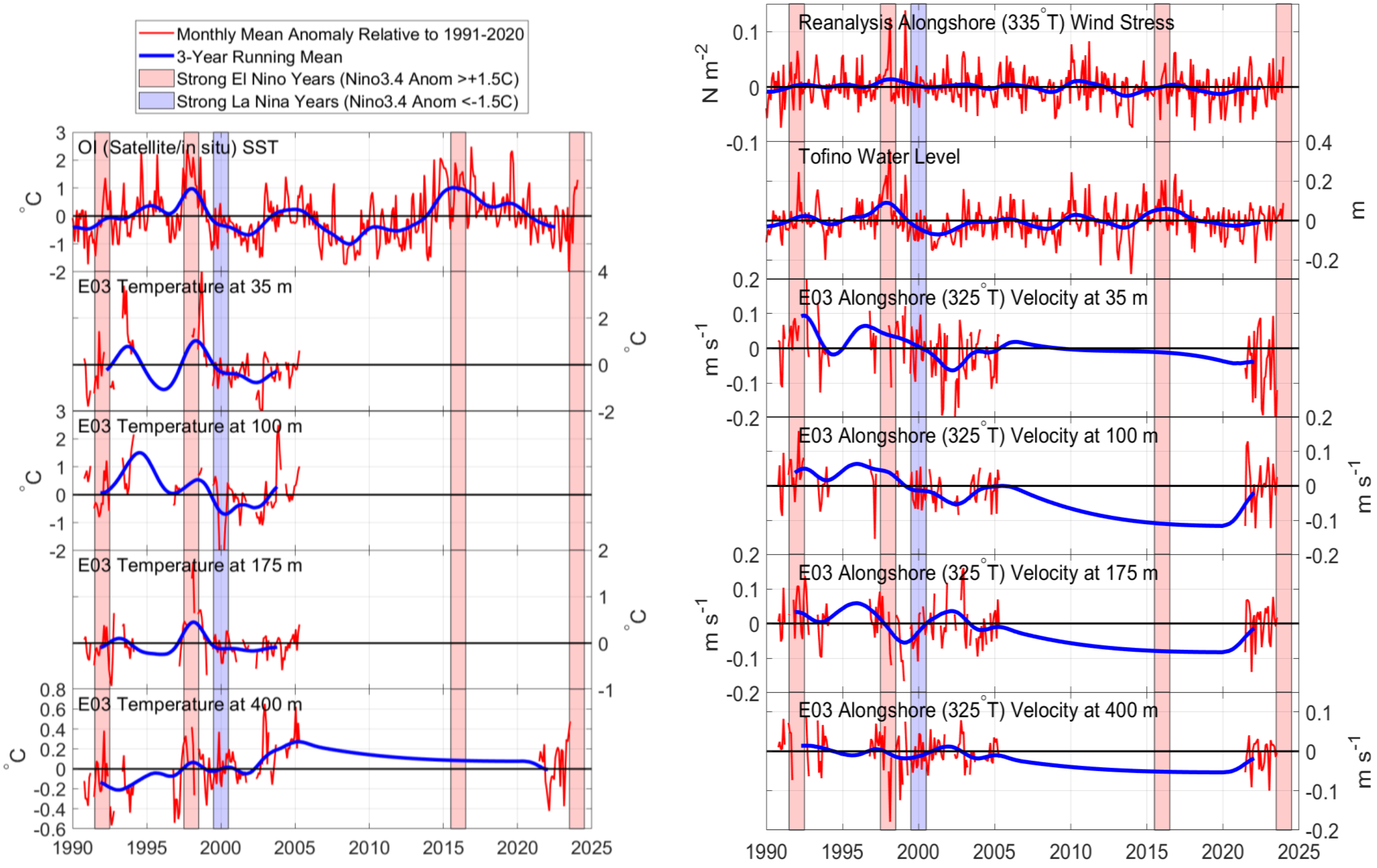

Figure 10-3. Monthly anomalies of temperature (left panels) and alongshore wind stress, water level, and alongshore ocean current (right panels) at the surface, 35 m, 100 m, 175 m, and 400 m depth from, respectively, the NOAA Optimum Interpolation (OI) SST V2 (1x1 latitude longitude degree), mooring E03, NCEP-NCAR Reanalysis 1, and Canadian Hydrographic Service Tofino station. Angle in brackets (°T) is the principal direction of the wind or current vector in degrees true compass bearing. Strong El Niño or La Niña years are those with at least three consecutive months of OISST.v2.1 SST anomalies ≥+1.5 °C or ≤-1.5 °C over the Niño 3.4 region (5ºN-5ºS, 120º-170ºW).

10.4. 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), and will likely be the case over the 2023-2024 winter due to another El Niño event.

10.5. 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 above average, but that no long-term trend is occurring. If these types of events increase in frequency in the future, they could impact long-term trends.

10.6. Acknowledgements

Mooring ocean velocity and temperature data provided by the Institute of Ocean Sciences Data Archive, Ocean Sciences Division, Department of Fisheries and Oceans Canada. http://www.pac.dfo-mpo.gc.ca/science/oceans/data-donnees/index-eng.html.

Water level data provided by Canadian Hydrographic Service from their website at https://tides.gc.ca/en/tides-and-water-levels-data-archive and D. Riedel at the Institute of Ocean Sciences https://www.pac.dfo-mpo.gc.ca/science/facilities-installations/index-eng.html#ios.

NCEP-NCAR Reanalysis 1 wind stress data provided by the NOAA Physical Sciences Laboratory, Boulder, Colorado, USA, from their website https://psl.noaa.gov.

NOAA OI SST V2 High Resolution Dataset data provided by the NOAA Physical Sciences Laboratory, Boulder, Colorado, USA, from their website https://psl.noaa.gov.

Niño 3.4 Region OISST V2 anomaly data provided by the NOAA Climate Prediction Center College Park, Maryland, USA, from their website https://origin.cpc.ncep.noaa.gov/data/indices/.

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11. SEA SURFACE TEMPERATURE AND SALINITY OBSERVED AT SHORE STATIONS ALONG THE B.C. COAST IN 2023

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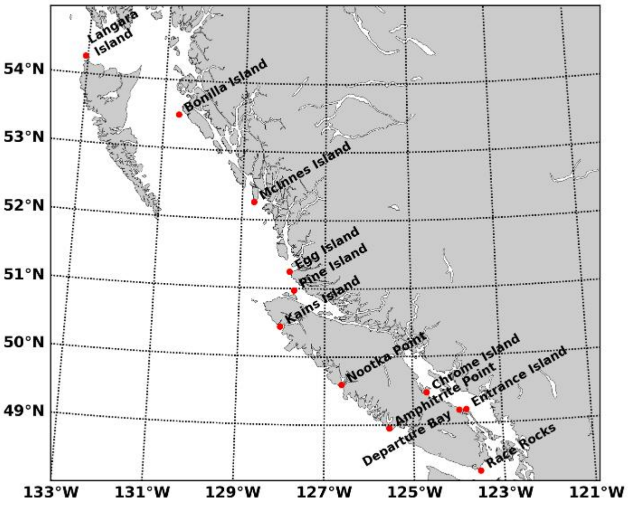
11.1. Highlights

- The annual average sea surface temperature (SST) from the 12 contributing shore stations in 2023 (10.7ºC) was generally warmer than in 2022 with a coast-wide average annual increase of 0.4ºC.
- 2023 was a continuation of a warm period that started in 2013. This 11-year span of above-normal annual SST is the longest warm period on record (1935-2023).
- The long-term data (1935-2023) from the shore stations showed a linear trend to warmer coastal SSTs at a rate of 0.85ºC per 100 years, up from 0.63ºC per 100 years a decade ago.
- Annual sea surface salinity (SSS) observations indicate an average coast-wide increase from 2022 to 2023 of 0.2, but the long-term data (1935-2023) do not have a significant trend.
- Longer and more frequent marine heatwaves (MHWs) were observed at the shore stations in 2023 than in 2022.
- All shore stations recorded an unusually warm end of year (Nov.-Dec.) in 2023.

11.2. Description of the time series



Station	Years of data	% good all time	% good 2023
Departure Bay	109	87	89
Race Rocks	102	97	93
Nootka	89	59	68
Amphitrite Point	89	96	93
Kains Island	88	95	92
Langara Island	87	91	93
Entrance Island	87	96	76
Pine Island	86	95	67
McInnes Island	69	93	56
Bonilla Island	63	98	100
Chrome Island	62	96	27
Egg Island	53	89	67

Figure 11-1. Left panel. Red dots show the locations of the 12 shore stations. Right panel. The number of years of data and percent good data for all sampling time and for 2023 are given.

As part of the British Columbia Shore Station Oceanographic Program (BCSOP), SST and SSS are measured daily at 12 shore stations, at the first daylight high tide. Most stations are lighthouses (Figure 11-1), with observations taken by lighthouse keepers using a handheld electronic instrument (YSI Pro 30).

11.3. Status and trends

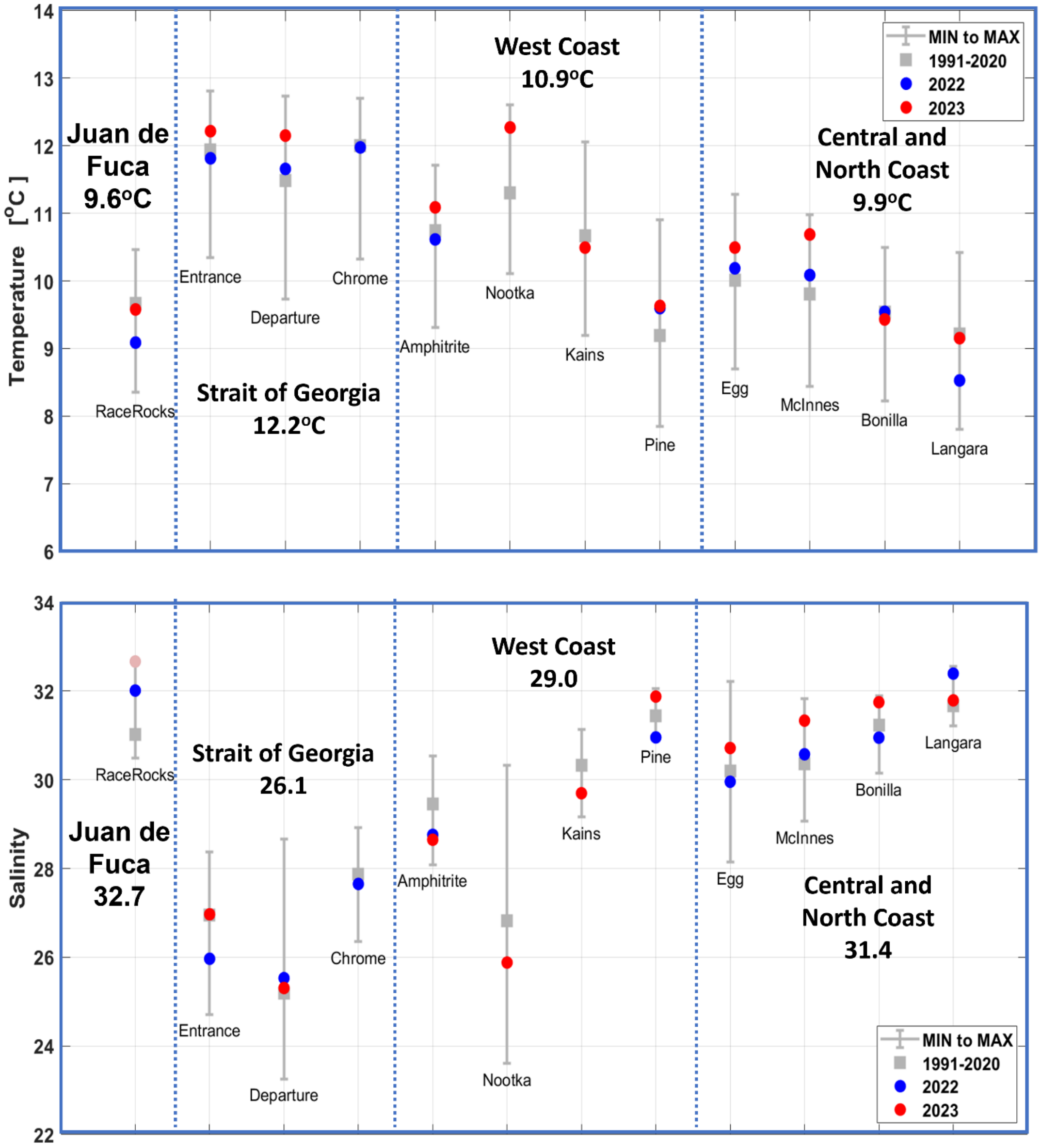


Figure 11-2. Upper panel. The annual-average SST in 2022 (blue dots) and 2023 (red dots) from daily observations at shore stations along the west coast of B.C. The grey squares represent the 1991-2020 average and the grey bars represent the historical range for each station. Lower panel. The same as the upper panel but for annual-average SSS.

The shore station observations show that the annual average SST (Figure 11-2) at all stations was generally warmer in 2023 than in 2022, with a coast-wide mean increase of 0.4ºC (over all stations with sufficient data). SSTs were above the climatological mean in the Strait of Georgia, along the West Coast of Vancouver Island and on the Central Coast. Conditions in 2023 were slightly more saline than in 2022 with a coast-wide mean increase of 0.2 (over all stations with sufficient data). SSSs were above average on the Central and North Coasts and below average in the Strait of Georgia. The climatological mean annual SST and SSS are calculated as the mean temperature and salinity at each station using values between 1991 and 2020.

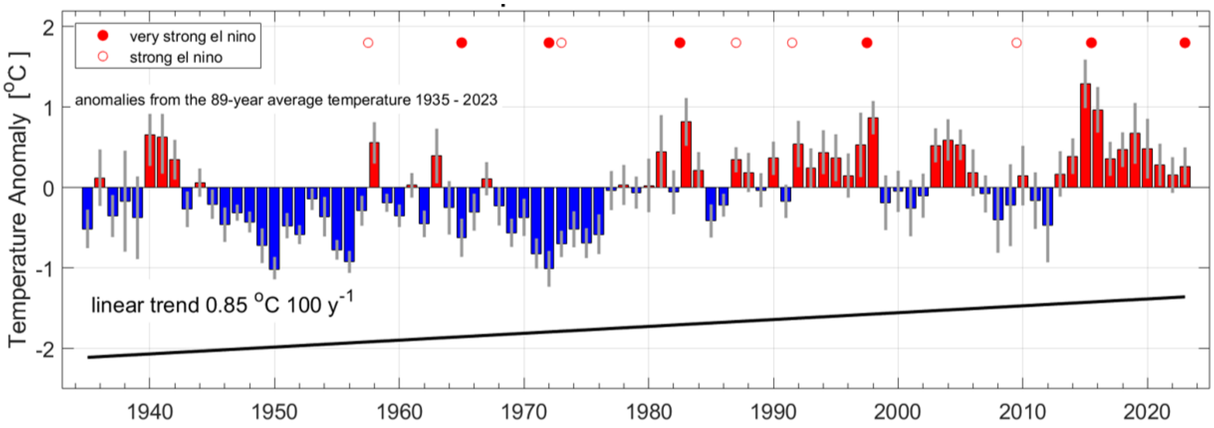


Figure 11-3. The trend in the annual-average sea surface temperature based on the observations from all shore stations for 1935-2023 (black line). The bars represent the anomalies over all the stations (a coast-wide indicator), (red – above average, blue – below average), the vertical grey lines show the variability in the shore station data for each year. Strong and very strong El Niño years using the NOAA ONI index are indicated by the red open and solid dots along the top of the plot.

The time series of temperature at all of the shore stations shows a warming trend at the 95% confidence level of 0.85ºC per 100 years, up from 0.63ºC per 100 years estimated a decade ago (Figure 11-3). No significant trend in salinity was found over the data record.

Table 11-1. MHW statistics by region for representative shore stations. MHWs are defined relative to each station's climatological average for the 30-year period 1983-2012. A heatwave day is defined as a day for which temperatures exceed the 90th percentile of the seasonal climatology.

		MHWs lasting >= 5 days		Number of heatwave days	
Station	Region	2022	2023	2022	2023
Bonilla Island	North Coast	1	4	30	75
McInnes Island	Central Coast	2	2	58	66
Amphitrite Point	West Coast	1	6	31	85
Departure Bay	Strait of Georgia	3	4	43	56

MHWs are defined as events during which temperatures exceed the 90th percentile of a 30-year historical baseline period for at least five consecutive days (Hobday et al. 2016). In 2023, all regions saw an equal or greater number of heatwaves than in 2022 using the seasonal climatology for 1983-2012 (Table 11-1). All regions saw more heatwave days in 2023 than in 2022, with many of these days occurring at the end of the year and contributing to an unusually and persistently warm November and December.

11.4. 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 marine species. The marine heatwave activity observed at the shore stations later in 2023 was not evident in the Northeast Pacific Ocean (Ross, Section 8), but may have been associated with El Niño and the arrival of anomalously warm water from the south.

Although SSTs were warmer during the MHW of 2014-16, the conditions in 2023 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 11 years, the longest span of above-normal temperature in the time series. While the record shows multi-year oscillations in the annual SST, there remains a long-term trend towards rising ocean temperatures.

Variability in the salinity signal along the coast of B.C. is governed by a combination of the integrated effects of atmospheric forcing and coastal precipitation; the Strait of Georgia is strongly influenced by the discharge from the Fraser River (Cummins and Masson 2014).

11.5. Implications of those trends.

There is growing interest in determining the predictability of the physical processes of the Northeast Pacific Ocean, including associated biological responses, on time scales of months to decades. The shore station time series provides daily data spanning more than a century, allowing for the quantification of both seasonal variability and long-term climate changes. It remains an open question the extent to which ecosystem responses to the observed slow warming will resemble those associated with MHWs, which are projected to become more frequent and extreme in B.C. coastal waters (Holdsworth et al. 2021). These responses will depend on the temporal and spatial scales relevant to species of interest and are described for various trophic levels in B.C. waters in Peña (Section 17), Galbraith (Section 22), and Neville (Section 46).

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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

- There were sustained hypoxia events in southern Queen Charlotte Sound (Goose Island Trough, a deep trough north of Cape Scott) in summer 2022 and 2023. The ocean glider data shows that both events extended across the shelf to the coastal zone.
- Wintertime upwelling drove a hypoxia event at Scott2 mooring (north of Cape Scott) in February 2023. Less intense winter upwelling events have been occurring for the last 7 years. We should expect winter upwelling events to continue to occur.
- The annual temperature minimums at 40 m continued to cool through early 2023 all along the B.C. shelf. This is an extended recovery from the Blob event and the 2015-16 El Niño. Warmer water was expected during winter of 2023/24 (El Niño).
- Subsurface warming events on the inner Vancouver Island shelf (E01 mooring in 100 m deep water) are generally unrelated to the surface warming events and can have larger amplitude. Many of the subsurface warming events at E01 are likely related to the timing of fall storms relative to the cooling of the SST in the fall.

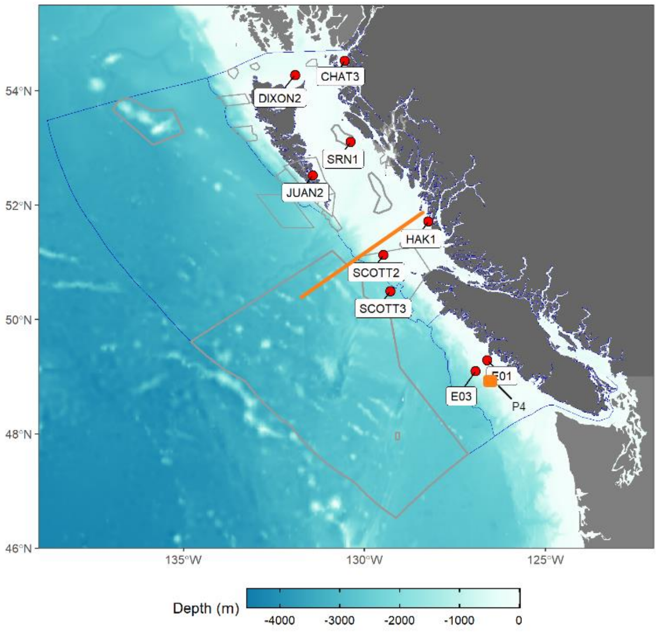

Figure 12-1. The location of the moored instrumentation for the period July 2022 to July 2023 (red circles). Station P4 and glider section are shown in orange. The Canadian Exclusive Economic Zone is shown in blue, along with the various existing and proposed Marine Protected Areas in grey.

12.2. Description of the time series

The B.C. Shelf Mooring Program has maintained 8-12 instrumented moorings on the B.C. shelf since 2016 (Figure 12-1). Measurements at all locations include temperature, salinity, dissolved oxygen at multiple depths, and water velocity through the water column. Moorings are recovered and redeployed on an annual basis. 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 goal is to maintain an array of moorings from southern Vancouver Island 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), SRN1 (Sponge Reef North), Juan2 (Juan Perez Sound), and Chat3 (Chatham Sound). The program inherited the long time series (30+ years) at E01, on the inner Vancouver Island shelf, and at A1, at the edge of the shelf. E01 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.

12.3. Status and trends

A declining trend in the annual minimum temperature at 40 m is evident broadly across the shelf (Figure 12-2) since 2017. We expect that the 2023/24 El Niño will lead to increased subsurface temperatures.

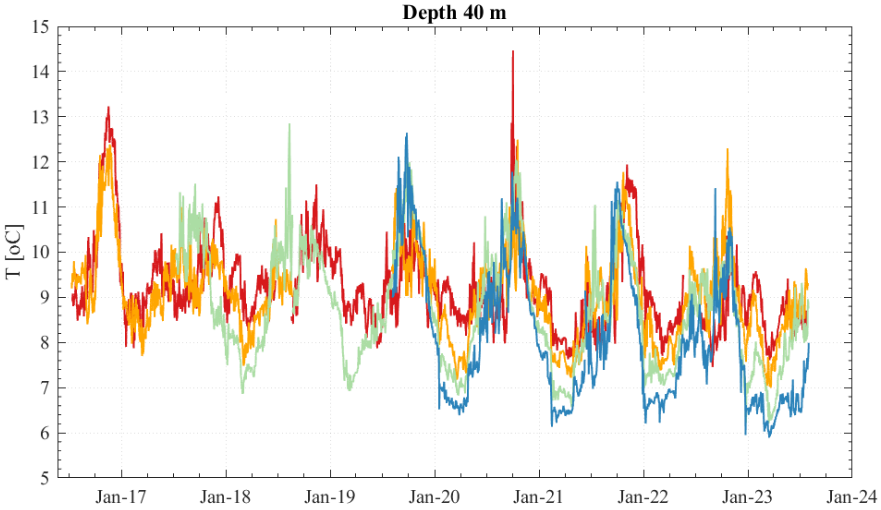

Figure 12-2. Subsurface water temperatures measured from moored instruments for E01 (red; 35 m), Scott2 (gold) and SRN1 (light green; both 40 m except 50 m for 2019-19), and Chat3 (blue; 40 m). A 25 h running mean average was applied to the measurements, which are typically collected at 10 to 30 min intervals. Line colors represent the moorings' latitude from south (red) to north (blue). The notable feature is the decline in annual minimum temperatures (winter) from 2017 to 2023.

The mooring record at E01 (Estevan Point) on the inner Vancouver Island shelf goes back to 1990. The temperature time series were reported in 2022 and there was nothing interesting to report in 2023's data. We show the subsurface and surface (satellite SST) daily anomalies to illustrate some points about the subsurface daily temperature anomalies. The anomalies are relative to the mean for the time period shown. The primary features of the anomalies (Figure 12-3) are: 1) the subsurface temperature anomalies tend to be larger than the SST anomalies; 2) there is no obvious relationship between the surface and subsurface anomalies; and 3) there is no obvious relationship between the subsurface anomalies and El Niño (the Nino3.4 index).

The longest dissolved oxygen time series are at the Scott2 mooring. Figure 12-4 shows the time series at 280 m depth. 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 can drop below the hypoxia limit of 1.4 ml/l. In the spring and summer of 2022 and 2023 there were sustained hypoxia events. Ocean glider data from July 2022 and July 2023 (Figure 12-4) show that the hypoxic water extended up Goose Island Trough to the entrance of Hakai Pass at the northern end of Calvert Island. In 2022 we were concerned that the low oxygen water could be evidence of instrument failure. We were wrong. The glider data provides independent confirmation of the very low oxygen values in the summer of 2022 and 2023.

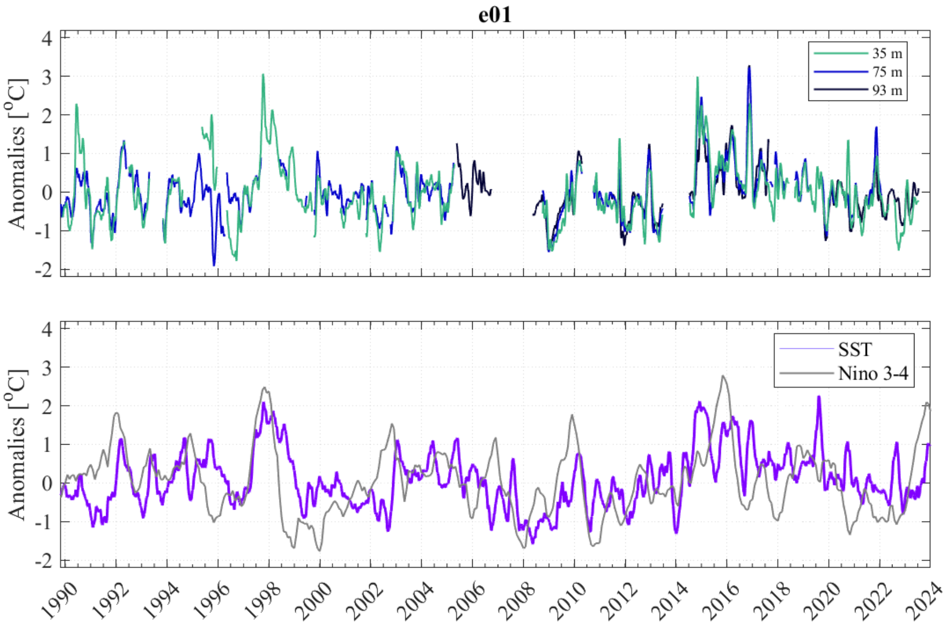

Figure 12-3. Upper panel is temperature anomalies at the E01 mooring at 3 depths (35 m, 75, and 95 m). The lower panel is the satellite SST anomalies and the Nino3.4 index anomalies. Notable features are the subsurface temperature anomalies are generally larger than the SST ones and that there is no clear relationship between the subsurface anomalies and the Nino3.4 index.

For the last 7 years, Hourston and Thomson (e.g., 2023 and Section 9) have been reporting wintertime upwelling. There was a particularly intense upwelling event in February 2023 which resulted in hypoxic water at the bottom of the Scott2 mooring (Figure 12-4). Previous wintertime upwelling events can be identified in the oxygen and density time series, however the 2023 event was particularly intense. Winter upwelling events seem to have become a regular feature.

Oxygen concentration on constant density surfaces at station P4 (Line P) are shown in Figure 12-5; which is an update on Crawford and Peña (2016 and 2021). The 26.7 isopyncal represents the typical density at the bottom of the Scott2 mooring. After several years above the trend line, the oxygen concentration on the 1026.5, 1026.7 and 1026.9 kg/m^3 isopycnals have returned to the trend line over the last few years. The oxygen units are different from those shown for Scott2 mooring in Figure 12-4. The hypoxia limit, taken as 1.4 ml/l here, is close 60 µmol/kg.

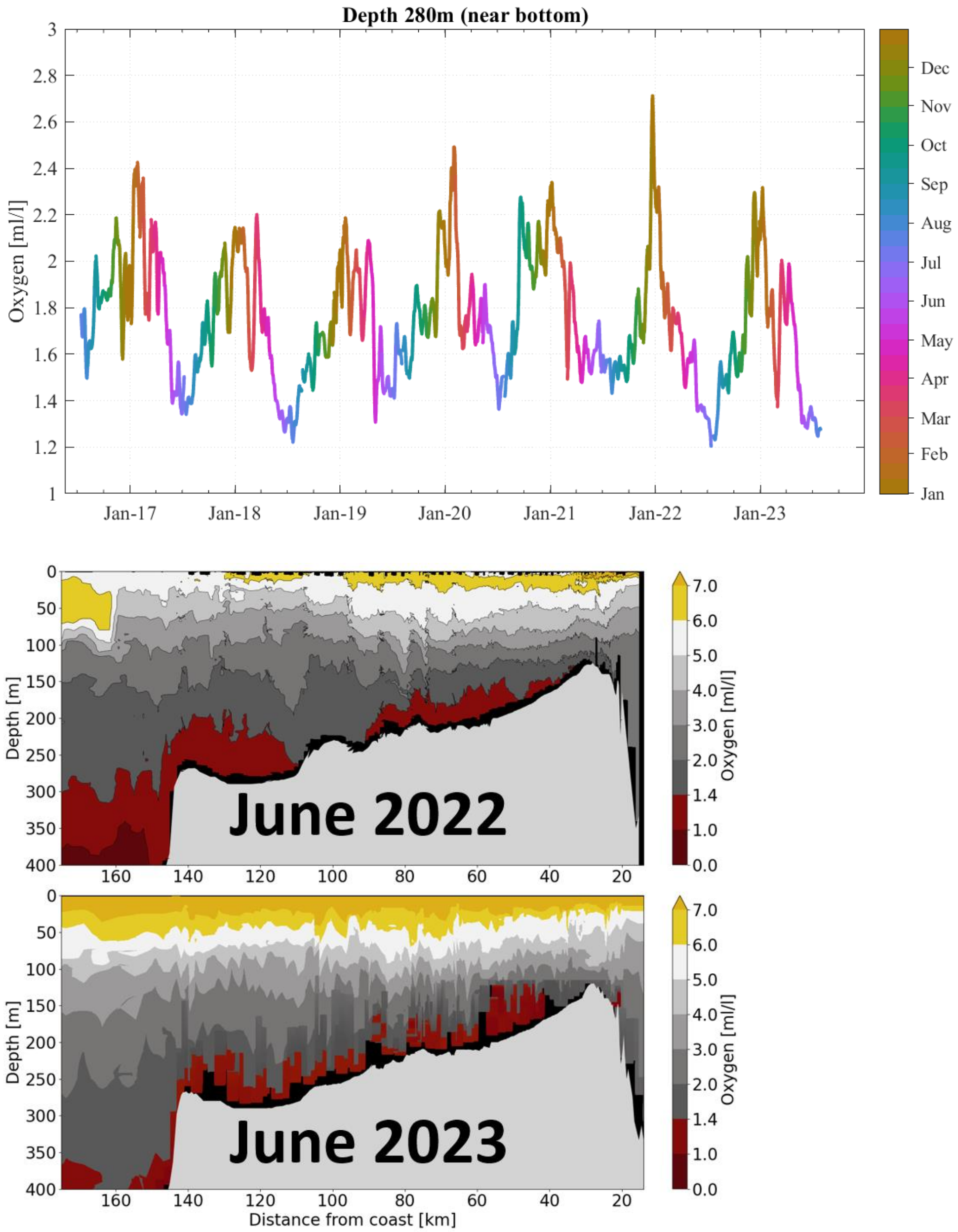

Figure 12-4. Oxygen concentration in southern Queen Charlotte Sound. Upper panel: oxygen concentration at 280 m at the Scott 2 mooring. The colouring is the month of the year with colour boundaries on the first of each month. Mid and lower panels: preliminary oxygen section from glider transect in southern Queen Charlotte Sound from June 2022 and June 2023. The section extends from the open North Pacific on the left to Hakai Pass (north of Calvert Island) on the right. The hypoxia limit is defined here as 1.4 ml/l.

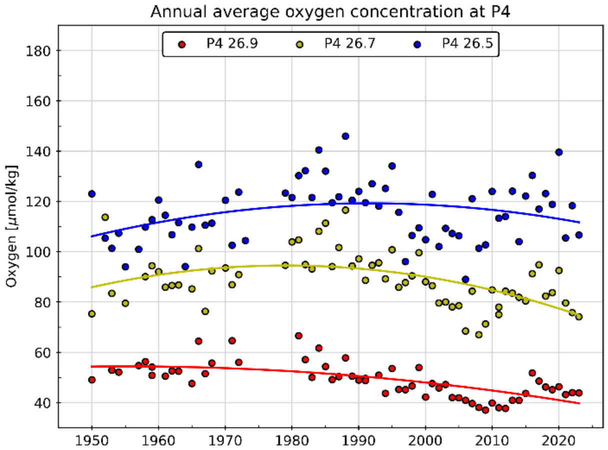

Figure 12-5. Oxygen concentration on constant density surfaces at station P4 (Line P). This is an update on Crawford and Pena (2016 and 2021). After several years above the trend line, the oxygen on all three isopycnals has returned to the trend line the last few years. The hypoxia limit, taken as 1.4 ml/l, is close 60 µmol/kg. Figure courtesy of Hana Hourston.

12.4. Factors influencing trends

We expect that the 2023/24 El Niño will lead to increased subsurface temperatures over most of the B.C. continental shelf starting in the late fall (or early winter). This should reverse the trend of declining annual minimum temperatures at 40 m.

We don't know why there were persistent hypoxia events in southern Queen Charlotte Sound in the summers of 2022 and 2023. A common contributing factor to hypoxia events on the shelf is a larger than normal bloom that leads to increased oxygen consumption at depth (e.g., Franco et al. 2023). This could have been a contributing factor for the summer of 2023 when a coccolithophore bloom was observed over much of the B.C. shelf in July. But that would not explain the summer of 2022.

The generally accepted view of B.C. shelf oceanography is that the winds blow poleward in the winter. The idea of persistent upwelling winds (equatorward winds) has not been part of the picture. However, winter upwelling events seem to have become a regular feature and should be expected to continue. The likely cause of the winter upwelling is that the weakening Aleutian low (Wills et al, 2022) and variable jet stream allow the North Pacific high to push north and provide upwelling winds along the B.C. coast for parts of the winter (Hourston and Thomson, Section 9).

12.5. Implications of those trends.

Hypoxia on the B.C. shelf north of Cape Scott has been a rare event. For example, Crawford and Pena (2013) stated, 'Concentrations below 1.4 ml L−1 on the continental shelf are rarely observed in samples north of 49.5°N.' This is clearly no longer true; hypoxia events have become part of the ecosystem north of 49.5 N.

The declining oxygen trends on the constant density surfaces at Station P4 mean that declining trends can be expected to influence oxygen concentrations in the bottom waters off B.C. For example, Hannah et al. (2024) provided evidence that the deep oxygen concentrations in Douglas Channel follow the decadal trends in oxygen at P4.

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13. OXYGEN IN 2023 FROM LINE P, LA PEROUSE, AND QUEEN CHARLOTTE SOUND

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13.1. Highlights

- Anomalously low dissolved oxygen was observed between density layers σt = 25.5 and 26.5 from Station P4 to P16 along Line P for August to November 2023, while the intermediate water at Ocean Station Papa was anomalously high in oxygen in early October.
- Hypoxic waters (< 1.4 ml/l) came within 50 m of the surface on the La Perouse LB Line in the Fall, though the spatial extent of the hypoxia was reduced compared to previous years.
- Hypoxic waters were upwelled onto and extended across the continental shelf in Queen Charlotte Sound in June, with low oxygen water (< 2.0 ml/l) entering Fitz Hugh Sound.

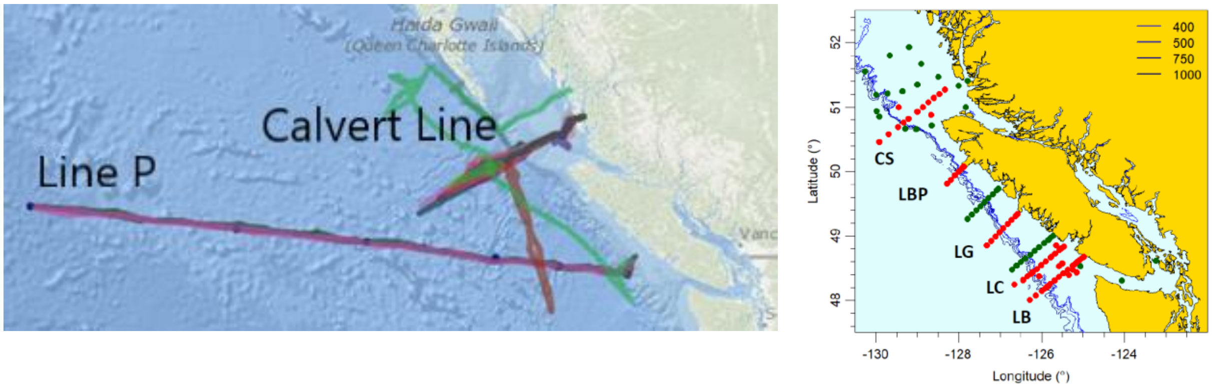

Figure 13-1. (Left panel) Ocean glider tracks for all glider surveys conducted in 2023. From cproof.uvic.ca. (Right panel) Map of the La Perouse standard survey stations with the names of survey lines labelled.

13.2. Description of the time series

DFO, in collaboration with the University of Victoria, the Hakai Institute, and the University of British Columbia as part of the Canadian-Pacific Robotic Ocean Observing Facility (C-PROOF), operates a fleet of autonomous ocean gliders equipped with sensors for high-resolution measurements of temperature, salinity, dissolved oxygen concentration, chlorophyll-a concentration, coloured dissolved organic matter (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, crossing southern Queen Charlotte Sound, and Line P, crossing the shelf near Tofino to station P4, then transiting to Ocean Station Papa (OSP).

Measurements of dissolved oxygen concentration are collected using optical sensors and corrected based on comparison with discrete seawater samples. The Line P climatology was developed by Tetjana Ross using ship-based hydrographic station data collected by the Line P cruise program for the 1991-2020 period. The climatology is heavily interpolated in some months due to the typical triannual cruise frequency.

The La Perouse/WCVI survey generally takes place in May and September each year and provides synoptic snapshots of physical and biogeochemical properties at shelf, slope, and offshore stations. The spring survey typically occurs within 30 days of the onset of upwelling and the fall survey generally precedes the transition to downwelling along the southern section of the west coast of Vancouver Island (WCVI). In 2023, the spring survey occurred from May 16-26th and the fall survey from August 24th to September 5th. Oxygen data was collected using an SBE 43 sensor with discrete seawater samples collected at key stations such as LB08.

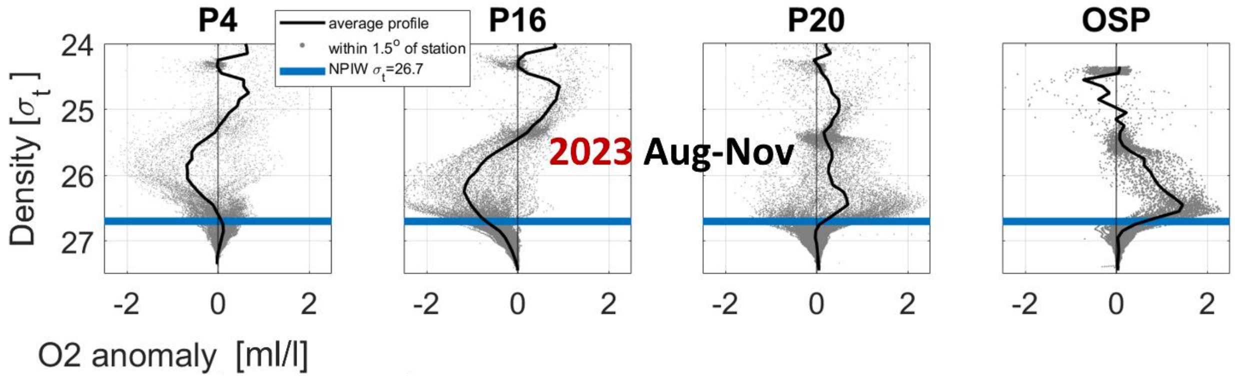

Figure 13-2. Oxygen anomaly (glider data minus climatology) as a function of potential water density at select Line P stations. Gray dots show all ocean glider data from profiles collected within 1.5° longitude of the station, while the black line gives the average of these data. The blue line indicates the σt = 26.7 density surface, associated with the NPIW.

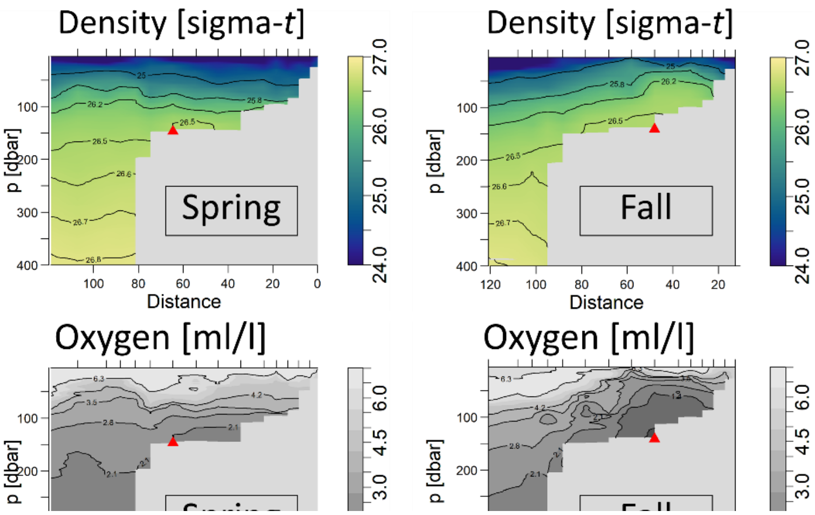

Figure 13-3. Section plots of density (top) and dissolved oxygen (bottom) along the LB Line in spring (left) and fall (right). The red triangle shows the location of Station LB08.

13.3. Status and trends

Glider data collected between August and November along Line P showed a positive oxygen anomaly at OSP for densities greater than about σt = 25.5, including those associated with the North Pacific Intermediate Water (NPIW; Figure 13-2). This anomaly (+27 μmol/kg) marked a major change from 2022, when a negative anomaly was seen at OSP (-29 μmol/kg). Low oxygen anomalies were seen at Stations P4 and P16 between the σt = 25.5 and 26.5 density layers in 2023, suggesting that lower than average oxygen concentrations for that density range extended from near the shelf to at least P16, though not as far as P20.

The California Undercurrent flows poleward along the WCVI slope. Its core (200-300 m depth) is characterized by low oxygen (1.4-2.1 ml/l) in May and September (Figure 13-3). Seasonal upwelling brings the σt = 26.5 density surface with this low oxygen water onto the WCVI southern shelf. In 2023, on the La Perouse LB Line, the lowest bottom oxygen concentration at Station LB08 was 1.78 ml/l in spring and 0.90 ml/l in fall, with hypoxic waters (< 1.4 ml/l) observed within ~50 m of the surface. Compared to 2021 and 2022, the spatial extent of the hypoxia on the WCVI shelf in September was reduced, with no hypoxia observed north of Barkley Sound (Figure 13-4).

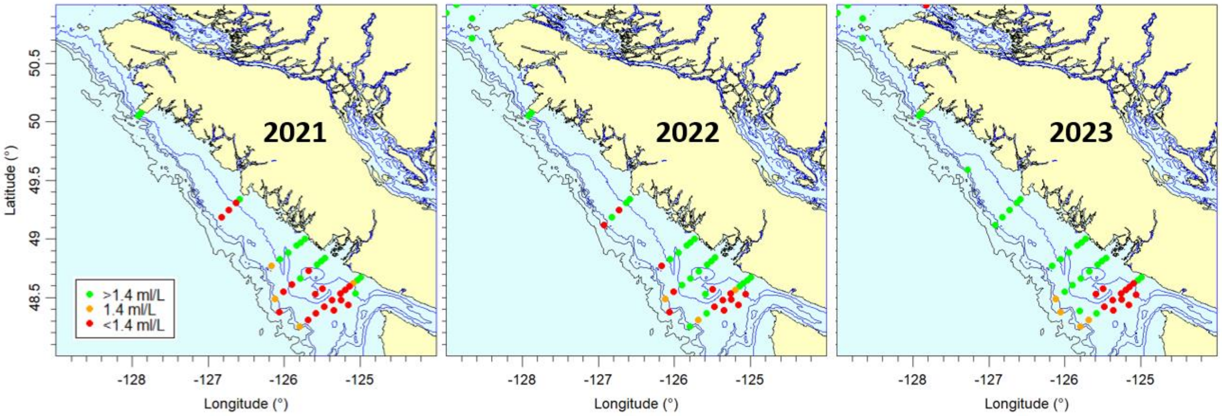

Figure 13-4. Bottom oxygen concentration at the La Perouse survey stations (dots) in September. Green symbols indicate oxygen concentrations above 1.4 ml/l, orange symbols indicate oxygen concentrations equal to 1.4 ml/l, and red symbols indicate hypoxic conditions with oxygen concentrations below 1.4 ml/l.

On the continental shelf in southern Queen Charlotte Sound, the gliders identified hypoxic conditions (< 1.4 ml/l) in June 2023. These conditions extended from the shelf break across most of the shelf to the near-shore region close to Calvert Island. Hypoxic conditions were more widespread than during June 2022, which had itself been identified as a significant low oxygen event for the region. Low oxygen water (< 2.0 ml/l) was seen in Fitz Hugh Sound in June 2023, which was not the case in 2022.

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 σt = 26.5, 26.7, and 26.9 density surfaces, based on the Line P historical data record which began in the late 1950s (Crawford and Peña 2016; Cummins and Ross 2020; Whitney et al. 2007). Intra-decadal variability at OSP is also high, sometimes exceeding 50 µmol/kg (Crawford and Peña 2016). These observed declines were explained in small part by changes in solubility and in larger part by warming and freshening in the Sea of Okhotsk driving reduced dense water formation (Cummins and Ross 2020).

Low oxygen values are common on the southern WCVI continental shelf in the summer, caused by upwelling of low oxygen water and increased remineralization of shelf blooms (Crawford and Peña 2013). Upwelling favourable winds in 2023 were similar to 2022 in terms of timing and magnitude (Hourston, Section 9), and drove weak but persistent upwelling that brought California Undercurrent source waters onto the shelf and supplied dense, nutrient-rich water to the near-surface. Deep oxygen-poor waters extended over the shelf eastward along the LB Line. Seasonal oxygen to nitrate ratios at LB08 were similar to 2022 and higher than 2021, suggesting reduced influence of respiration of organic material versus upwelling. The hypoxic event in Queen Charlotte Sound was associated with a temporary shift to stronger upwelling-favourable winds, and is described in more detail in Hannah, Section 9.

13.5. Implications of those trends

The shift in oxygen concentrations at OSP between 2022 and 2023, and the intra-decadal variability at OSP in general, may partially result from spatial variability along Line P. Ocean glider data provides a high-resolution observational record that can be used to quantify spatiotemporal variability and improve the existing climatology, while ship-based hydrographic surveys provide time series spanning decades and the high-quality discrete water samples necessary to correct data collected by other means. These and other dissolved oxygen data 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). Lower-than-average and hypoxic subsurface oxygen concentrations pose particular risks 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 up to Queen Charlotte Sound.

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14. WATER CURRENTS ALONG THE SHELF EDGE OFF THE B.C. COAST

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14.1. Highlights

- In fall 2023, the poleward shelf-edge surface current was stronger than normal at both the West Vancouver Island transect and the Queen Charlotte Sound transect.
- The shelf-edge current was weaker than normal at the West Vancouver Island transect in summer and at the Queen Charlotte transect in winter.

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 2023, 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. The mean currents averaged over 1993-2020 (the reference period) were removed to produce altimetric current anomalies.

Next, near-surface (averaged within the top 30 m) currents normal to the transects were derived based on the model output from a 1/36° Northeast Pacific Ocean Model (NEPOM). The model currents averaged over 1993-2020 were added to altimetric current anomalies to produce the total seasonal mean currents.

Further, the seasonal current climatology was calculated by averaging the total seasonal mean currents over 1993-2020 for each season. The seasonal current anomalies were produced by subtracting the seasonal climatology from the total seasonal mean currents. Finally, the standardized current index was calculated by dividing the seasonal current anomalies by its standard deviation over 1993-2020.

At the WCVI transect (Figure 14-2) the climatological seasonal surface current was poleward in winter and equatorward in summer, with the long-term mean surface current close to zero. At the Queen Charlotte Sound transect (Figure 14-3), the climatological seasonal surface current was poleward in winter and fall but weakly equatorward in summer.

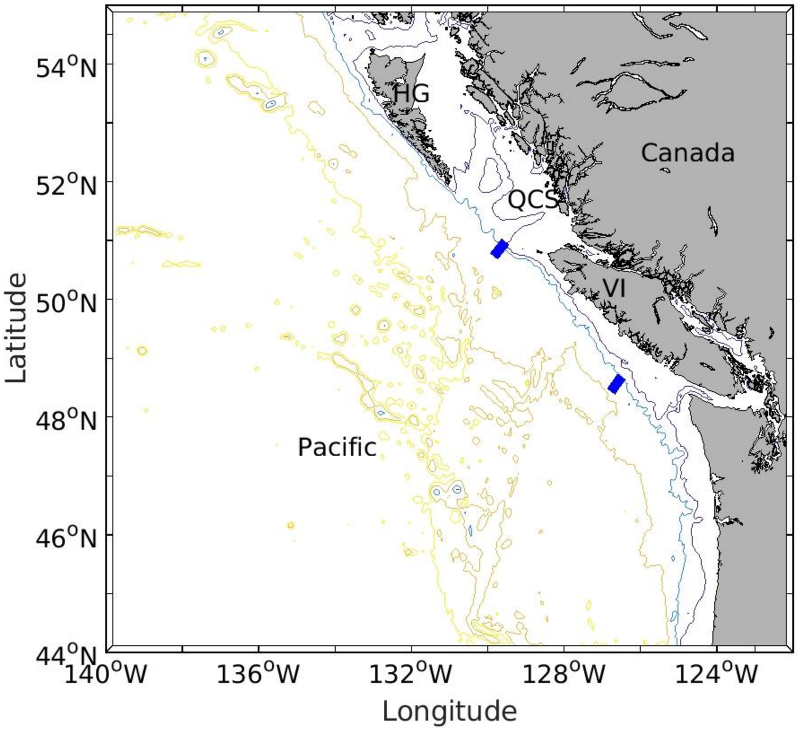

Figure 14-1. The study area showing the location of two altimetry transects (blue) and bathymetry (200- (black), 1000- (blue), 2000- (green) and 3000-m (yellow) isobaths). HG: Haida Gwaii. QCS: Queen Charlotte Sound. VI: Vancouver Island.

14.3. Status and trends

There was no long-term trend in the altimetric surface current at the WCVI transect over 1992-2023. In 2023, the surface current at the WCVI transect was weaker than normal in summer and much stronger than normal in fall, about two standard deviations different from the seasonal climatology (Figure 14-2). At the QCS transect, the poleward surface current was weaker than normal in winter and stronger than normal in spring and fall, over one standard deviation different from the seasonal climatology in winter and spring (Figure 14-3).

14.4. Factors influencing trends

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

In 2023 there was a transition from a weak La Niña in winter to a strong El Niño in fall. The Pacific Decadal Oscillation remained in a cool phase (Ross and Robert, Section 8). The El Niño led to a stronger-than-normal poleward shelf-edge current in fall.

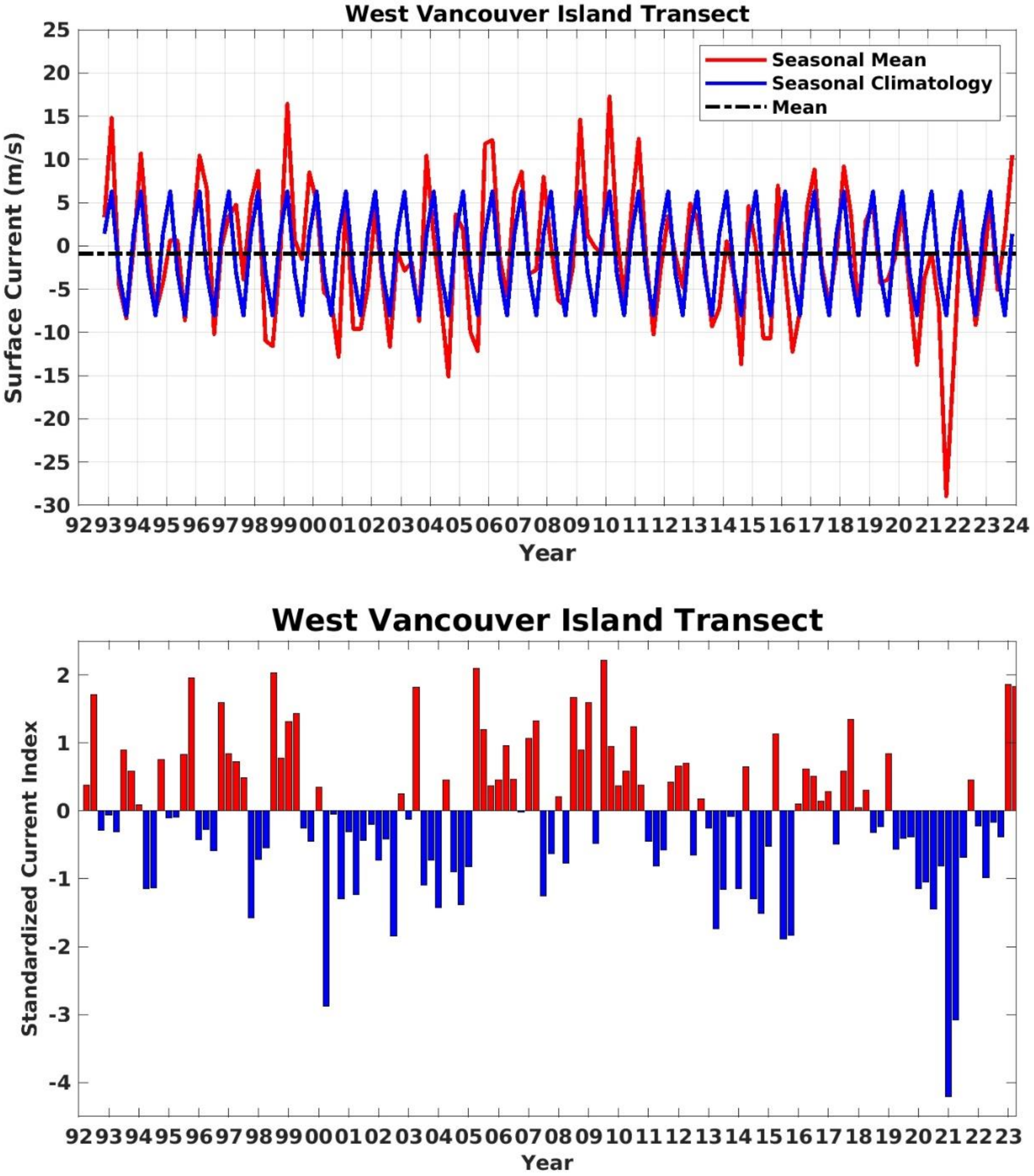

Figure 14-2. Seasonal-mean geostrophic surface currents (positive poleward) at the west coast of Vancouver Island (WCVI) (upper panel). Note that the current is the average over the transect of about 40 km wide. The standardized current index (lower panel) is calculated by dividing the seasonal current anomaly by its standard deviation over 1993-2020.

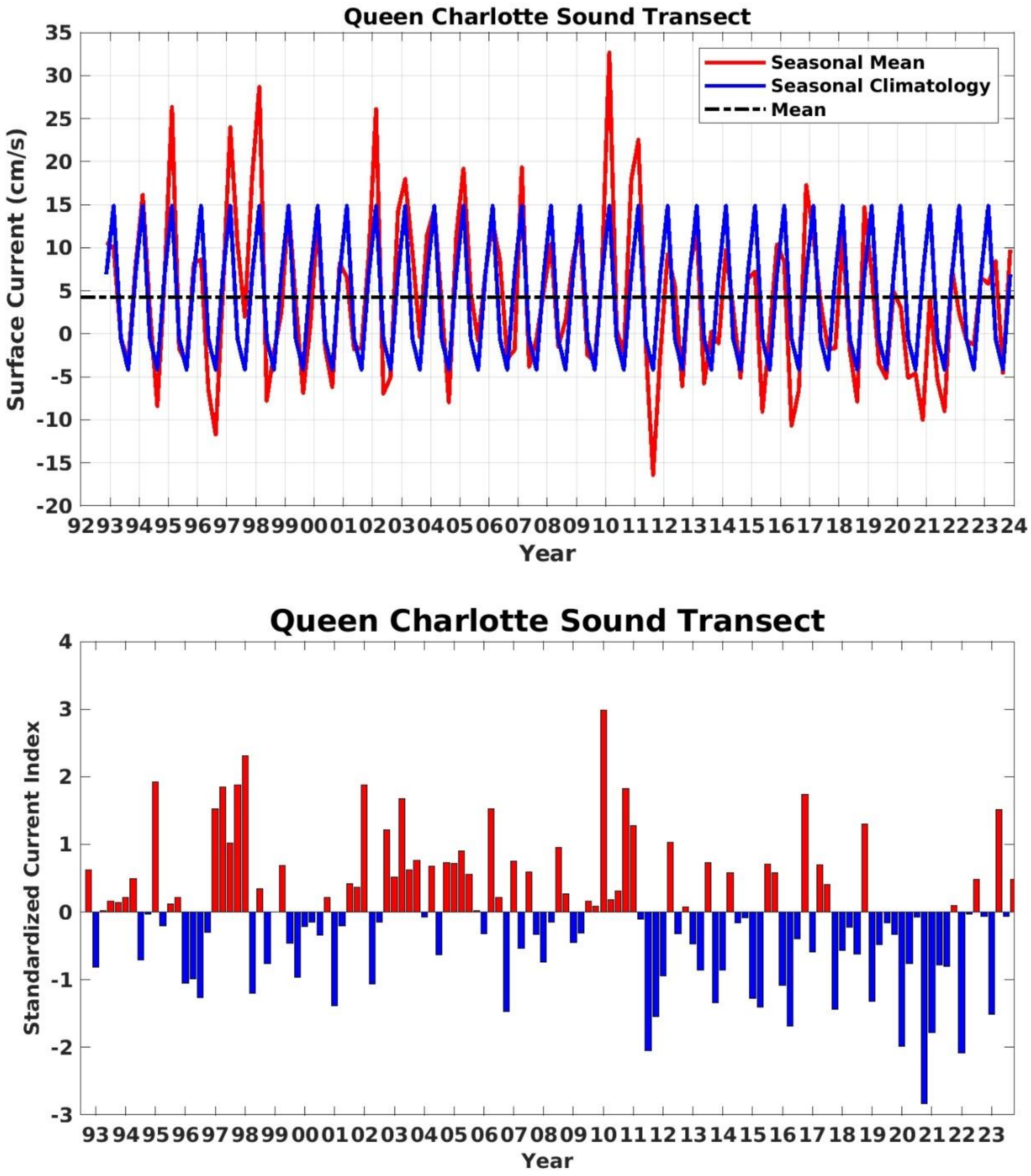

Figure 14-3. Seasonal-mean geostrophic surface currents (positive poleward) at the mouth of Queen Charlotte Sound transect (upper panel). Note that the current is the average over the transect of about 40 km wide. The seasonal current anomaly index (lower panel) is calculated by dividing the seasonal current anomaly by its standard deviation over 1993-2020.

14.5. Implications of those trends

These currents can affect water properties such as temperature, salinity, nutrients, and 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.

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15. OCEAN CURRENTS INFLUENCING THE SCOTT ISLANDS MARINE NATIONAL WILDLIFE AREA

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15.1. Highlights

- Surface drifters deployed in summer 2022 and 2023 showed new drift patterns not seen from 2014 to 2021:
- Drifters exiting Hecate Strait went south and west of the shelf break.
- Drifters crossing eastern Queen Charlotte Sound went southward into the Scott Islands marine National Wildlife Area.
- Drifters went westward off the shelf before turning into the Scott Islands marine National Wildlife Area.
- Drifters moved northward into Hecate Strait from areas south of Haida Gwaii.

15.2. Description of the time series

The Scott Islands marine National Wildlife Area (NWA) was established by the Government of Canada in 2018 to conserve marine habitat important to globally and nationally significant seabird populations. In 2015, the Canadian Wildlife Service of Environment and Climate Change Canada, and Ocean Sciences Division (OSD) of Department of Fisheries and Oceans Canada developed a Collaborative Agreement, 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, 2023).

GPS drifters reveal the 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 contribute to knowledge essential to understand relations between ocean currents and marine species populations and habitats. Information on ocean currents has contributed to spatial planning processes, including the NWA, and to understanding of the movements of anthropogenic and natural substances.

There is wide variation in the life span of the drifters used by OSD. Prior to 2022 most drifters transmitted to satellite at 5- or 10-minute intervals, providing data for about 9 days before the drifters stopped transmitting, with some lasting over 2 weeks. (Hourston et al. 2021). In 2022 and 2023 some drifters were set to provide locations at 30-minute intervals, facilitating longer periods of transmitting (R.A.S. Hourston, DFO, pers. Comm.). Most of those set at 30-minute intervals each year lasted 30 – 60 days, with some over 60 days.

The areas shown in the figures in this report are chosen to depict how currents related to the NWA in a specified time period. Consequently, the drifters shown in the figures are a subset of those deployed in that period coast-wide. Sample sizes for a particular theme may be small, and may reflect a portion of the entire sample period.

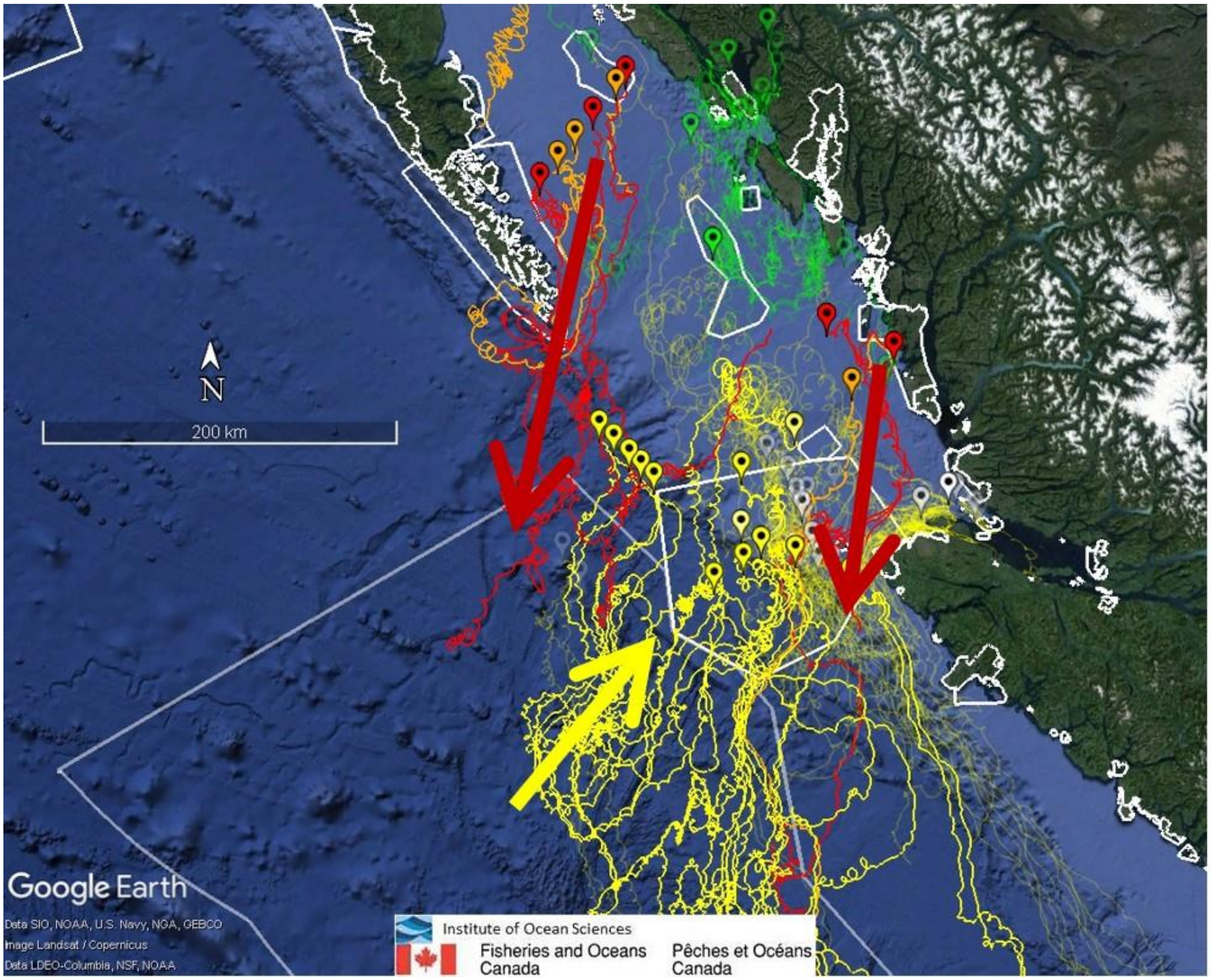

Figure 15-1. New drift patterns in July 2022. Red: Drifters released in July 2022 in Hecate Strait or northern Queen Charlotte Sound which travelled southward for first time observed; n=6. Orange: Drifters released in Hecate Strait or northern Queen Charlotte Sound in July 2022 that did not go southward; n=12. Bright Yellow: Drifters released in or near the NWA in July 2022; n=21. Faded Green: Drifters released in Hecate Strait or northern Queen Charlotte Sound (QCS), May through July 2014-2022; n=45. Faded Yellow with faded white icons: Drifters released in or near the NWA May through July 2015-2021; n=72. Coloured arrows show new drifts observed in July 2022.

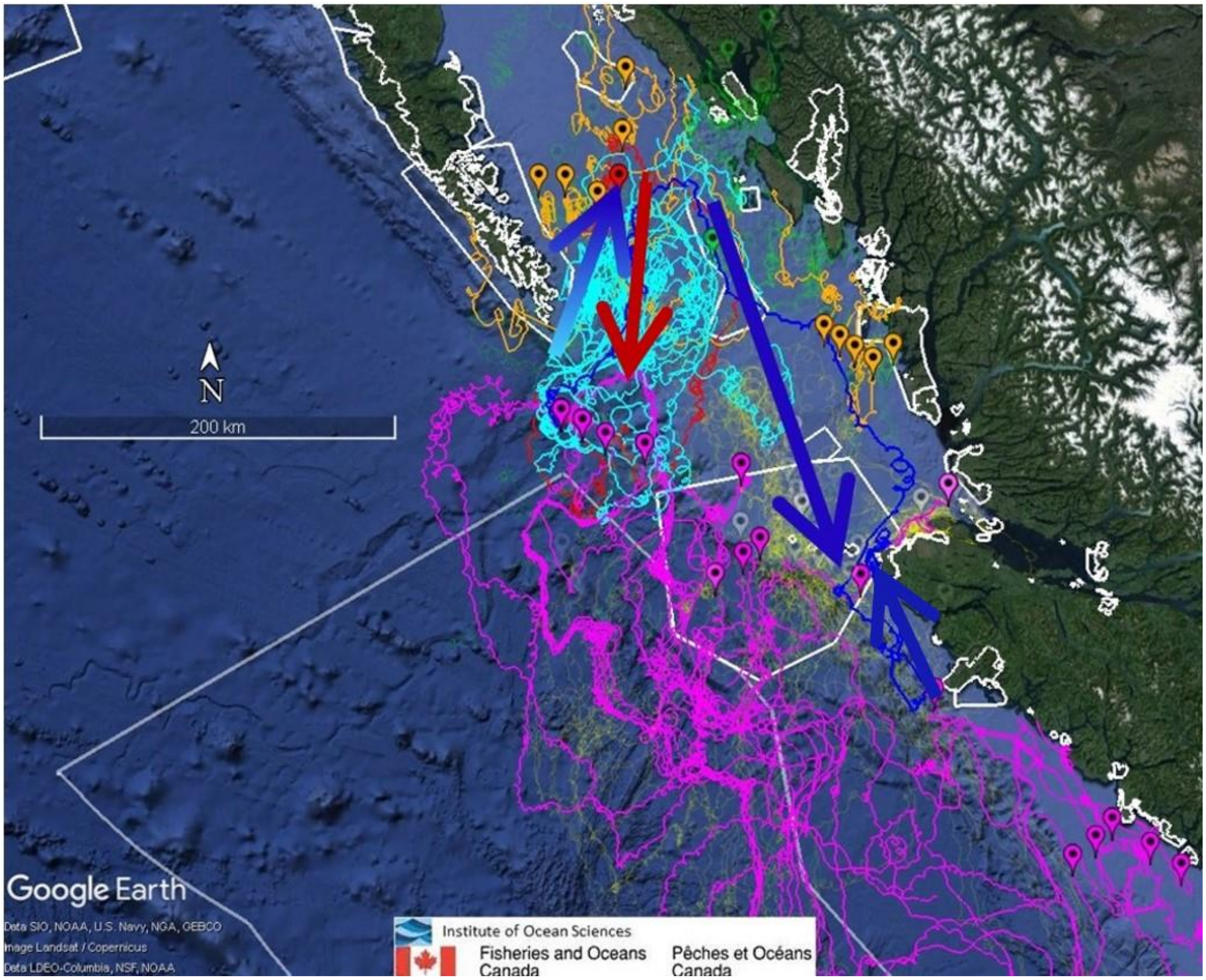

Figure 15-2. New drift pattern May through July 2023. Bright Blue: Drifters released June 2023 entered Hecate Strait northward from the shelf break; n=8. Dark Blue: Drifter released June 2023; went northward into Hecate Strait, then curved eastward and southward into the NWA, then exited to Brooks Peninsula before returning northward back into the NWA; n=1. Red: Drifter released July 2023; n=1. Orange: Drifters released in Hecate Strait or northern Queen Charlotte Sound in July 2023 that did not go southward; n=10. Magenta: Drifters released May to July 2023; n=27. Faded Green: Drifters released in Hecate Strait or northern Queen Charlotte Sound May through July 2014-2022; n=63. Faded Yellow with faded white icons: Drifters released south of QCS May through July 2015-2022; n=94. Blue arrows show new drift directions observed in 2023. Red arrow shows direction first observed in July 2022, and repeated July 2023.

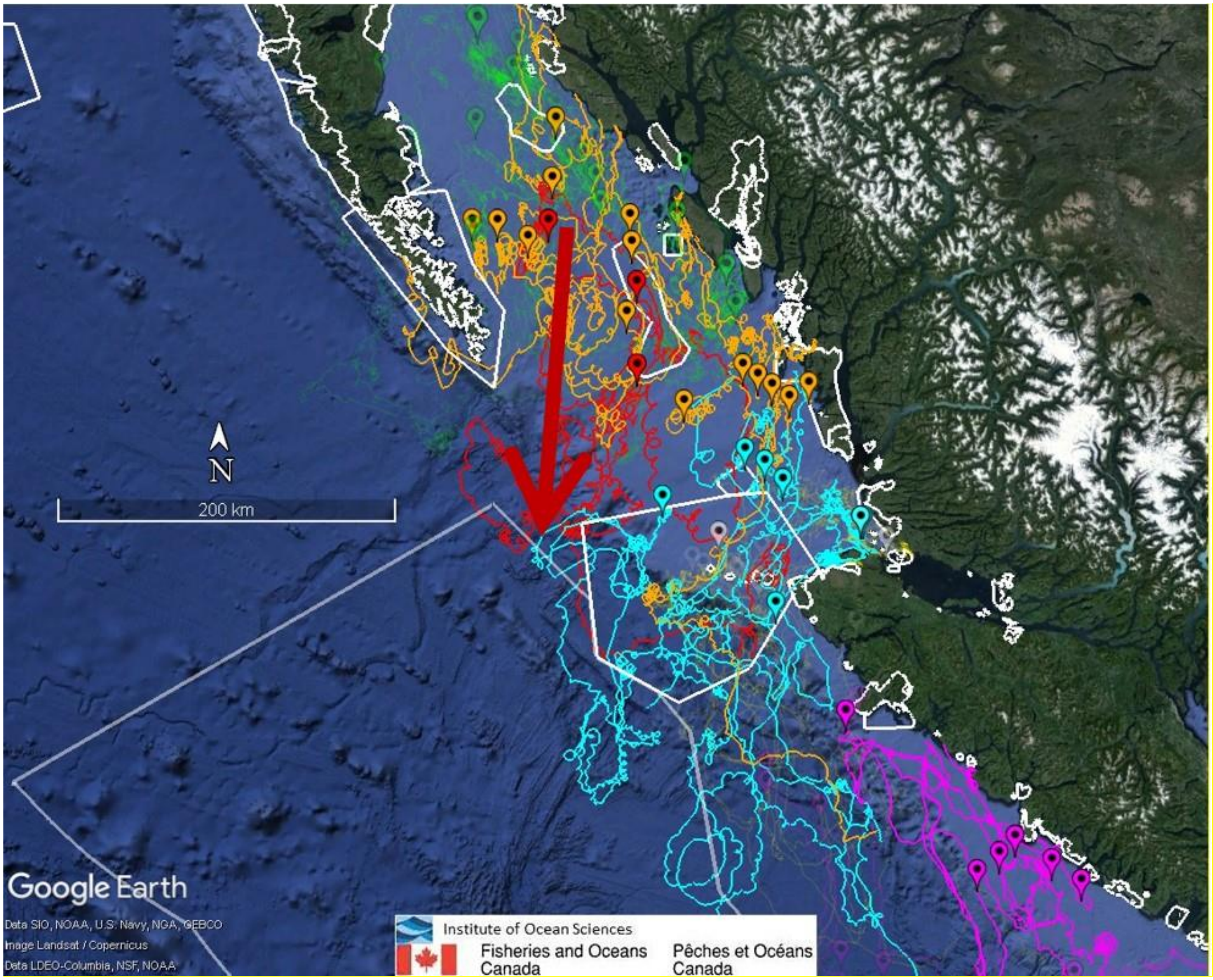

Figure 15-3. New observed directions in August. 2023 was the first time drifters crossed the gap southward from Hecate Strait in August. Red: August 2023; n=3. Orange: August 2023 released in Hecate Strait or northern Queen Charlotte Sound; n=18. Blue: Released August 2023; n=9. Magenta: Released August 2023; n=7. Faded Yellow: August 2015-2022; n=37. Faded Green: August 2015-2019; n=59. Faded Magenta: August 2017-2018; n=14. Red arrow shows new August direction first observed in 2023.

15.3. Status and trends

Several drifters released in Hecate Strait in July 2022 showed the first documented significant movement southward, with those exiting near Haida Gwaii going west past the shelf break and continuing southward (Figure 15-1). Another first observation was drifters crossing eastern Queen Charlotte Sound southward into the NWA (Figure 15-1). 2022 was also the first year that drifters travelled southward past the shelf break, then turned eastward into the NWA (Figure 15-1).

Drifters were released south of Haida Gwaii, off the shelf break, in June 2023. Many showed the first demonstrated movement northward into Hecate Strait (Figure 15-2). These then circulated around southern Hecate Strait and Queen Charlotte Sound, many going south of the release point (Figure 15-2). One went south through the NWA then turned northward re-entering the NWA (Figure 15-2). Most of those released south of Haida Gwaii on the same day in the same area moved generally southward, not northward (Figure 15-2). This result demonstrates the potential for high variability of surface currents in this area. One drifter released in Hecate Strait in July 2023 exited southward, repeating the southward exit first observed in July 2022.

Several drifters released in Hecate Strait in August 2023 were the first to move southward out of the Strait in that month (Figure 15-3).

15.4. Factors influencing trends

The new southward movements out of Hecate Strait, and eastward towards the NWA, identified in 2022 and 2023 may be caused by changing currents, or the pattern may have been missed by the drifters that were previously deployed. To show changes in patterns of currents requires several more years of data. In addition, future efforts should assess the factors causing currents in order to determine if the changes in patterns are real.

15.5. Implications of those trends.

The OSD drifter program covers the entire coast, supporting wide assessments of currents. For this project the resulting information is used to help show the relationship of currents to the Scott Islands NWA. The accumulated drifter data show that the summer-time circulation leads to the potential of entering the NWA from the east, west, north or south. Generally, drifters leave the NWA northward or southward. Many leaving the NWA turn to re-enter it.

There is substantial variability of summer-time currents as shown by drifters. A quantitative analysis is required to establish the probabilities of surface drifters entering the NWA from different directions.

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16. 2023 OCEAN CONDITIONS IN GWAII HAANAS & HAIDA GWAII Chaan sḵ’ada gud ahl hlɢ̱unggulaa | Tang.ɢ̱wan ɢ̱an gud ad hlɢ̱ang.gulx̱a *WORKING TOGETHER OCEAN SCIENCE EXPEDITION*

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16.1. Highlights

- In July 2023, sampling in Juan Perez Sound showed colder water deeper than 100 m, similar to 2020 and 2022, and colder than 2017; and lowest oxygen at depths deeper than 100 m, compared to 2017, 2020 and 2022.
- For all three Gwaii Haanas subregions (West, South and East), Sea Surface Temperature (SST) from satellite in 2023 was colder than average in March and April compared to the 1991-2020 climatology, and warmer than average in July and August.
- For Gwaii Haanas East, surface chlorophyll-a from satellite showed a later than average spring bloom and lower than average fall concentrations in 2023. Surface chlorophyll-a from satellite is higher in Gwaii Haanas East compared to the other two areas for all years since 2003.
- In September 2023, waters below ~100 m were observed to be hypoxic (i.e., < 2 mL/L) for the first time in Juan Perez Sound since annual sampling began in summer 2017.
- In September 2023, the Council of the Haida Nation, Parks Canada, and Fisheries and Oceans Canada conducted the collaborative Chaan sḵ’ada gud ahl hlɢ̱unggulaa | Tang.ɢ̱wan ɢ̱an gud ad hlɢ̱ang.gulx̱a Working Together Ocean Science Expedition on board the CCGS John P. Tully around Haida Gwaii.

16.2. Description of the time series

For the annual mooring cruise work, we examined data that were collected in and around 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). Temperature, salinity, and oxygen data were collected from both shipboard sampling and by moored instruments. Satellite-measured chlorophyll-a (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 1991-2022. GH was divided into east, west and south subregions (referred to as GHE, GHW and GHS, respectively; Figure 16-3), and monthly time series and climatological statistics were retrieved for each area (Hilborn et al. Section 19).

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 2023) and with both GH and Council of the Haida Nation (CHN; Jun-Jul 2019, Sep 2022 and 2023). Data were generally collected in summer (Jun, Jul, Aug) or fall (Sep, Oct) months.

Moorings in Juan Perez Sound (Juan1 and Juan2) 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 2019–2023. The moorings were equipped with two (2018–2019), three (2020–2021; 2021–2023) or four (2017–2018; 2019–2020) Seabird CTD sensors at various depths along the mooring line. The two deepest CTD instruments during each mooring deployment also collected dissolved oxygen (DO) data. Unfortunately, the deep oxygen sensor failed to record data in 2022-2023.

16.3. Status and trends

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

Waters in JPS were coldest in June 2020 and warmest in August 2018. In July 2023, waters were at a similar temperature to those collected in 2020 and 2022 while oxygen concentrations were lower in 2023 than 2017, 2020, or 2022. The highest oxygen concentrations were observed in July 2017 and the lowest were observed in September 2023. Indeed, oxygen was observed to be hypoxic (i.e., less than 2 mL L-1) in JPS in September 2023 for the first time since this sampling began, and this is similar to the low oxygen concentrations reported by Evans et al. (Section 18) in Fitz Hugh Sound and Hannah et al. (Section 12) in Queen Charlotte Sound.

Monthly chl-a patterns from satellite differed between the three GH subregions. 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 2023, the spring bloom started a month later (May) compared to the climatological data from 2003-2022. Further, the fall bloom was smaller compared to the same climatology.

Peak SSTs are typically reached in August in all three subregions. However, in 2023 SST reached a peak in July and cooled earlier than normal. SST were cooler than normal in spring (March to May 2023), which could be linked to the later than normal spring bloom.

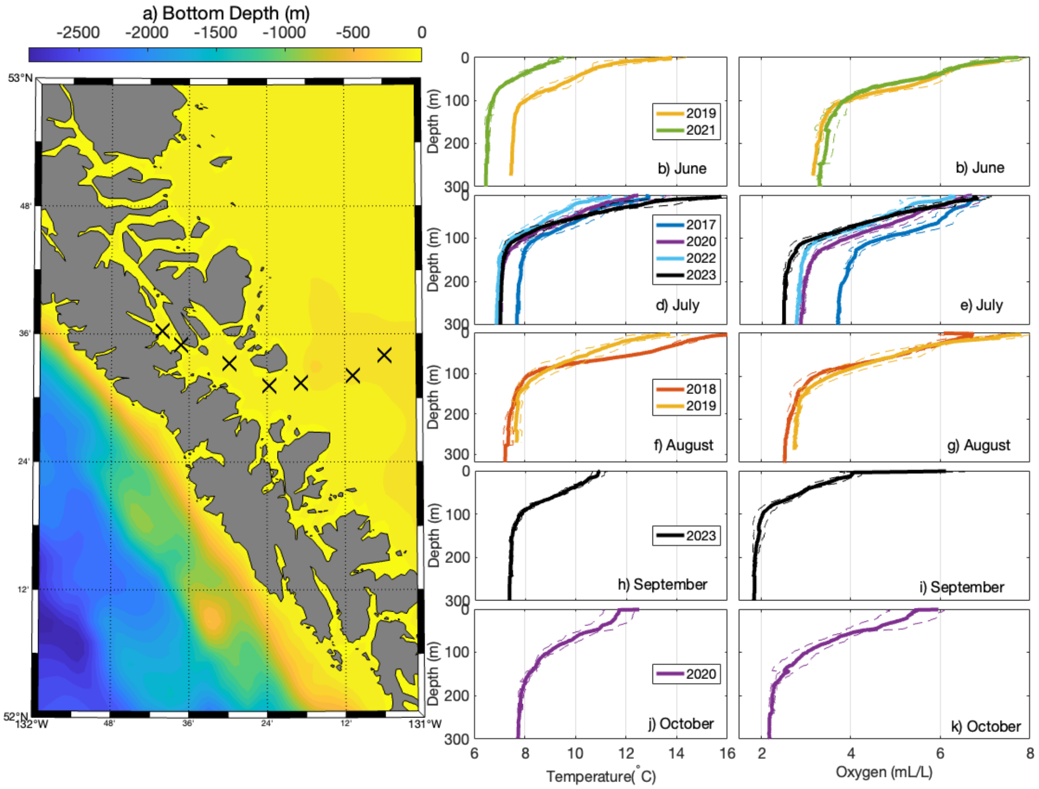

Figure 16-1. Average profiles of temperature (left column) and oxygen (right column) for data collected in Juan Perez Sound from 2017 to 2023. Station locations are indicated on the map (left). To minimize seasonal variation, data were plotted by month: Jun, Jul, Aug, Sep, and Oct. The solid line represents the average of all stations while the dashed line is the standard deviation of the mean.

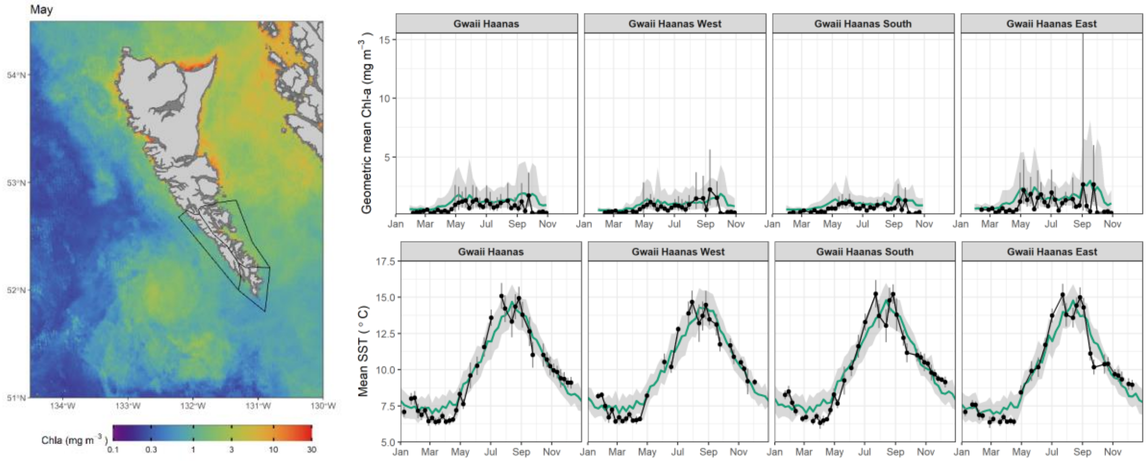

Figure 16-2. All of Gwaii Haanas and the three Gwaii Haanas subregions (west, south, east) identified on a chl-a monthly composite of May 2023 (left). The chl-a and SST climatological means from (1991-2020 for SST, and 2003-2022 for chl-a as this dataset spans a shorter length of time) are indicated (top and bottom respectively) with green line, and standard deviation shaded in grey. The 2023 monthly values are indicated in black dots and line, with standard deviation bars.

16.4. Factors influencing trends

The 2014-2016 marine heat wave (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 data from these moorings and annual sampling did not start until 2017, after the MHW event. While the deep water remained cool in JPS, oxygen was the lowest recorded in September 2023. Hypoxic deep water was observed throughout the north and central B.C. coast (Evans et al. Section 18; Hannah et al. Section12) in the summer and fall of 2023, suggesting a coast-wide hypoxic event.

SST could be one factor influencing chl-a trends. It is likely that the cool spring SST led to a delayed spring bloom. In addition, the early September cooling could be linked to a decreased fall bloom.

16.5. Implications of 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 hypoxic deep water observed in 2023 will impact the benthic and pelagic ecosystems.

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

16.6. CHN-PCA-DFO Collaborative Science Expeditions

In September 2023, the Council of the Haida Nation (CHN), Parks Canada Agency (PCA) and Fisheries and Oceans Canada (DFO) conducted the collaborative Chaan sk̲’ada gud ahl hlG̲unggulaa | Tang.G̲wan G̲an gud ad hlG̲ang.gulx̲a Working Together Ocean Science Expedition on board the CCGS John P. Tully, sampling from southern Haida Gwaii up the east coast, across Dixon Entrance, out to the Oshawa Seamount, through a Haida Eddy (dubbed Li’l Eddy), over to Gowgaia Shelf and Skidegate Channel, then south along the west coast (Figure 16-3). This trip was the third such collaborative expedition around Haida Gwaii waters, following the first on board the RV David Thompson in June/July 2019 and the second on board the CCGS Sir John Franklin in September 2022. A cruise report is expected to be completed following data compilation.

16.7. Acknowledgements

We thank the captain and crew of the CCGS John P. Tully and the science crew from DFO and Parks Canada listed in Figure 16-3 for their support of the expedition including all the logistical preparations; implementation of scientific work, knowledge sharing and daily planning during the expedition; post-field gear-down; and support for data compilation and analyses.

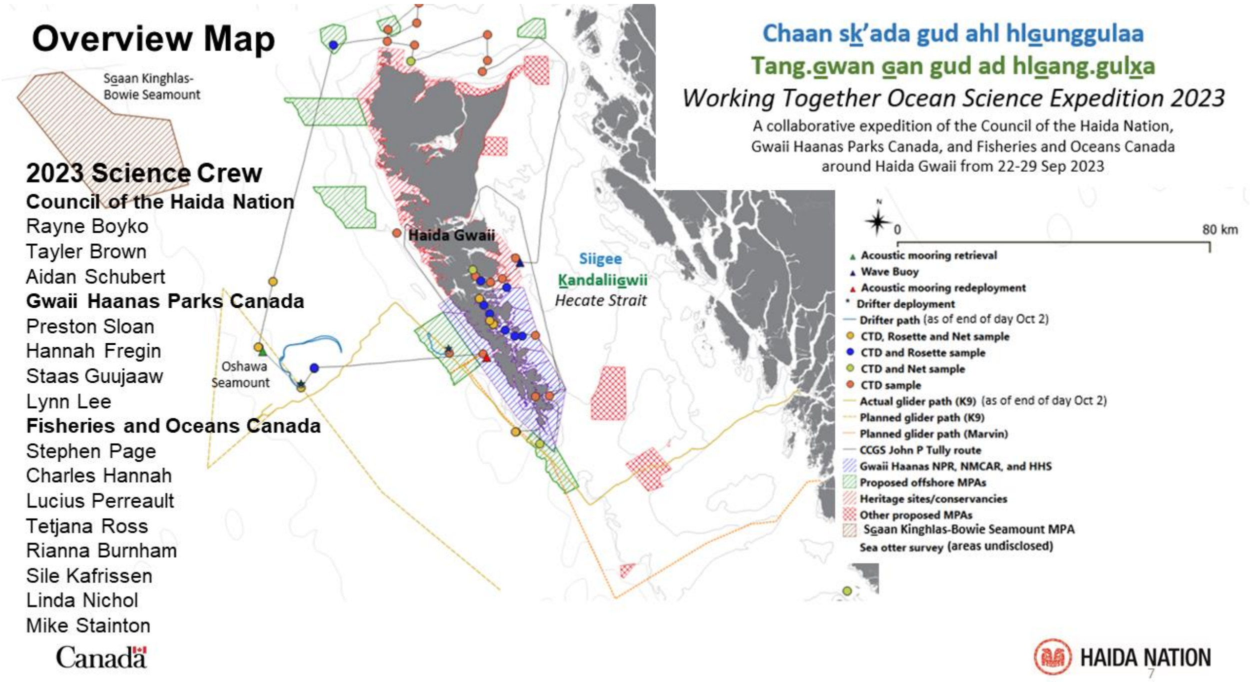

Figure 16-3. Overview map showing cruise travel route, locations of different types of oceanographic sampling in relation to boundaries of different marine protected area designations and proposed protected area designations around Haida Gwaii, including location of the Oshawa Seamount, and 2023 science crew.

16.8. References

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17. NUTRIENTS AND PHYTOPLANKTON BIOMASS IN THE NORTHEAST PACIFIC

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17.1. Highlights

- Spring nutrient concentrations in surface waters at nearshore stations of Line P in 2023 were higher than the average concentrations compared to previous years (2010-2022).
- Negative surface water nitrate anomalies at the offshore end of Line P persisted in 2023 but were less anomalous than during the Marine Heat Waves (MHWs) of 2014-2015 and 2019-2020 which restricted winter nutrient renewal from vertical transport due to increased stratification.
- Phytoplankton biomass in 2023 was similar to that of previous years along Line P, except for an increase in biomass between stations P8 and P11 in spring.
- Chlorophyll fluorescence measured by gliders along Line P showed a subsurface chlorophyll maximum in summer at most stations that would be hard to observe by ship-based measurements.

17.2. Description of the time series

Monitoring changes in nutrients, phytoplankton biomass, and community composition are 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 17-1) 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 2023, sampling occurred in early May and August but not in winter due to cancellation of the February cruise. Phytoplankton composition samples were collected in 2023 but are not presented in this report.

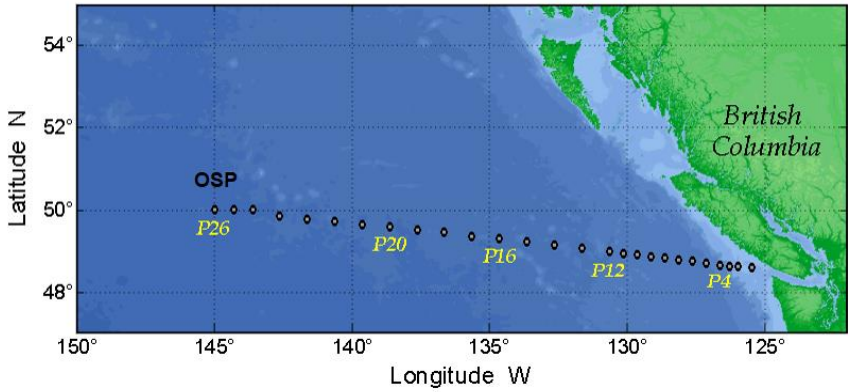

Figure 17-1. Location of sampling stations along Line P (P26 is Ocean Station Papa (OSP)).

To supplement ship-based phytoplankton biomass observations along Line P, chlorophyll fluorescence from autonomous ocean gliders equipped with optical sensors and operated by C-PROOF, the Canadian-Pacific Robotic Ocean Observing Facility, are presented. These high-resolution spatial and temporal measurements capture variability that is typically missed by ship-based sampling. Glider sampling of upper layer chlorophyll along Line P has been carried out sporadically since 2019 during both outbound and return trips. Sampling in 2023 occurred from August 11 to December 31 and at a similar time period in 2019 and 2021.

17.3. Status and trends

Line P extends from the southwest corner of Vancouver Island to Ocean Station Papa (OSP, Figure 17-1) in the high-nutrient low-chlorophyll (HNLC) region of the ocean 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 iron (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 May 2023, spring surface nutrient concentrations (Figure 17-2) at most stations along Line P were higher than the average from previous years (2010-2022). These higher nutrient values are likely due to the early timing of the spring cruise, but nutrient values from P4 to P10 were lower in 2012 and 2021, when sampling also occurred in May. Moreover, Chl-a concentrations between P8 and P11 were higher in the spring of 2023 than in 2012 and 2021 (Figure 17-2) suggesting the onset of the spring bloom was later in 2023 at these stations than in other years. Otherwise, nutrient and Chl-a concentrations in 2023 were similar to those of previous years.

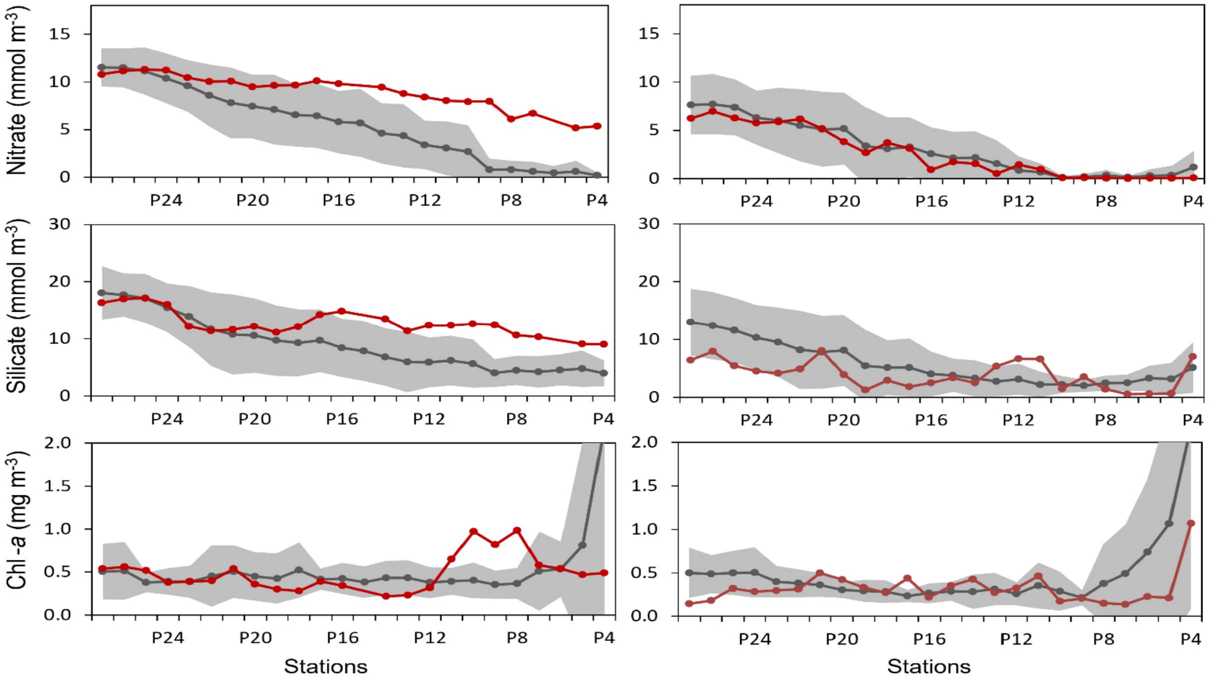

Figure 17-2. Concentrations of nitrate (top panels, mmol m^{-3}), silicate (middle panels, mmol m^{-3}), and chlorophyll-a (bottom panels, mgl m^{-3}) in surface waters along Line P from P4 to OSP in spring (left panels) and summer (right panels). All panels show the average (grey line) and standard deviation (shaded area) of concentrations in 2010-2022 as well as concentrations in 2023 (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). Stronger negative anomalies (Figure 17-3) were observed during the Marine Heat Waves (MHWs) in 2014-2015 and 2019-2020 which restricted winter nutrient renewal from vertical transport due to increased stratification. In 2023, negative surface water nitrate anomalies persisted at the offshore end of Line P, suggesting lower than normal winter mixing, but were less anomalous than during the MHWs.

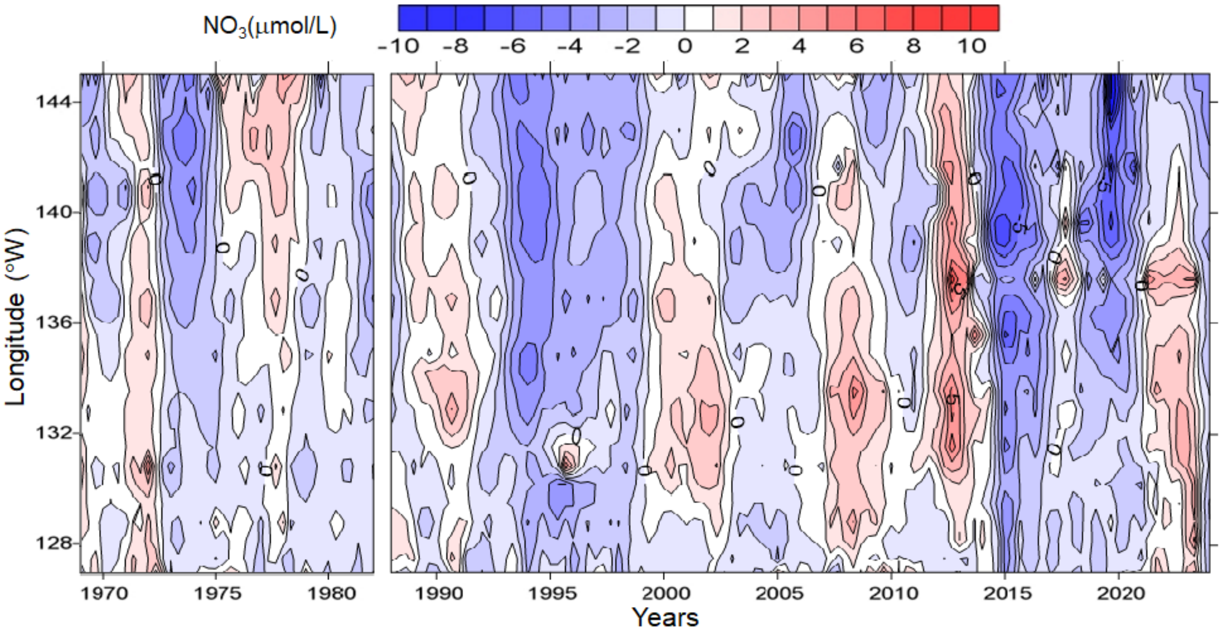

Figure 17-3. Hövemoller plot of surface mixed-layer nitrate concentration anomalies (µmol/L) along Line P from 1964 to 1981 and from 1988 to 2023.

Chlorophyll fluorescence concentrations measured by ocean gliders (Figure 17-4) show high-resolution spatial variations along Line P not captured by cruise sampling, including a subsurface chlorophyll maximum at ~ 25 to 35 m depth between P4 to P20 in summer. However, glider measured concentrations were higher than those measured by ship-based observations stressing the need to develop locally-validated algorithms to convert glider optical data to phytoplankton concentrations and other phytoplankton data products (Thomalla et al. 2017).

17.4. Factors influencing trends

Several environmental factors including temperature, solar 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 stratification, and changes in micronutrient (iron) 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 2023, nutrient concentrations and phytoplankton biomass have largely returned to pre-MHW conditions, but long time series of nitrate concentrations show persistent negative anomalies at the offshore end of Line P consistent with the observed decrease in winter mixing.

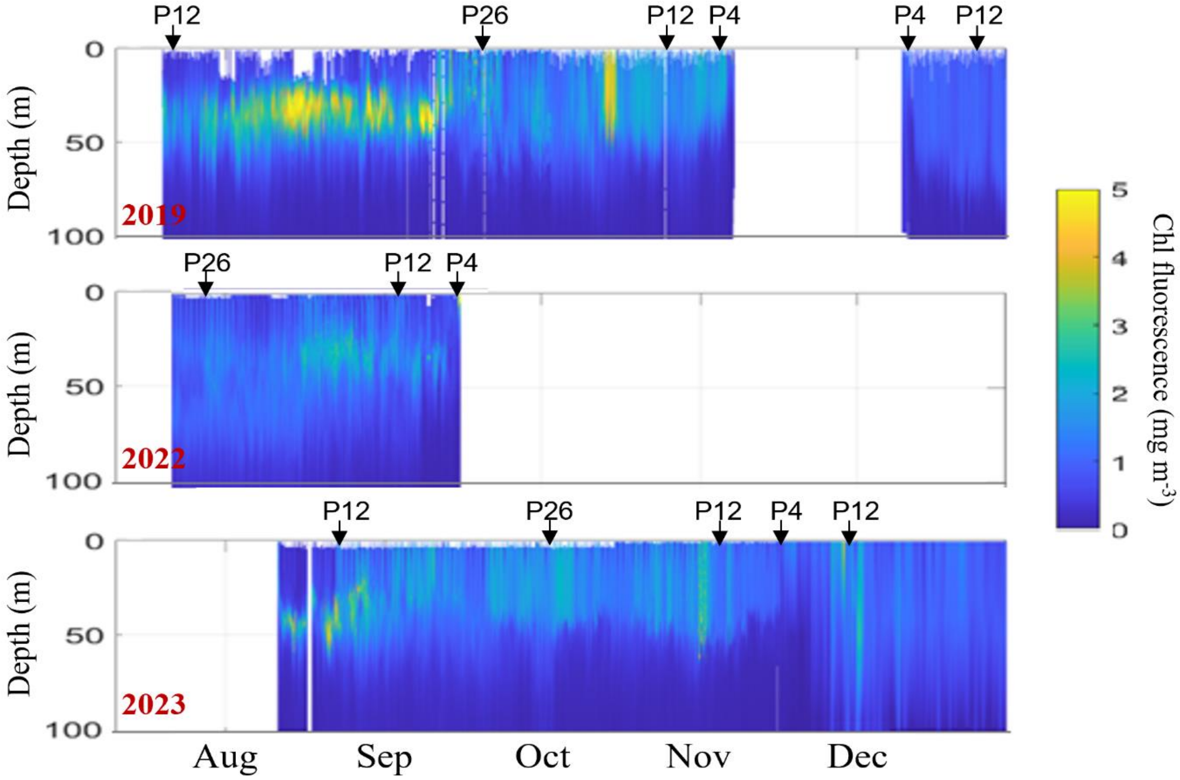

Figure 17-4. Chlorophyll fluorescence in the upper 100 m measured by ocean gliders at stations along Line P (see Figure 17-1) in July to December of 2019, 2022 and 2023.

17.5. 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, timing, 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 Marine Heat Waves could have ecosystem-wide implications.

17.6. References

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18. BIOGEOCHEMICAL OBSERVATIONS ON THE B.C. MARGIN DURING 2023

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18.1. Highlights

- On the central B.C. Coast, upwelling was stronger than observed since 2018 based on the 51°N Bakun Upwelling Index; oxygen was below 1.8 ml/l measured at depth to 100 m beginning in July and lasting throughout the year; lowest oxygen levels appeared confined to the continental shelf.
- In the northern Strait of Georgia winter storm conditions were stronger than observed since 2017; there was a continued trend toward less corrosive calcite saturation states during summer despite anthropogenic carbon addition.

18.2. Description of the time series

Biogeochemical time series are presented from two regions: Fitz Hugh Sound on the central B.C. coast and the northern Strait of Georgia. Data from Fitz Hugh Sound were collected from our oceanographic station KC10 (51.65°N, 127.95°W) on a near monthly frequency. Oxygen measurements are presented from this site and were collected using calibrated optodes on CTD profilers. The Bakun Upwelling Index for 51ºN is referenced, as well as inorganic carbon measurements from KC10 and oxygen measurements collected over the continental shelf and from within Burke and Dean Channels by Canadian Profiling Robotic Ocean Observing Facility (CPROOF) ocean gliders and Hakai Institute surveys, respectively. Data from the northern Strait of Georgia were collected at our oceanographic station QU39 (50.03°N, 125.11°W). Data presented from this site are oxygen measurements from calibrated optodes on CTD profilers and calcite saturation states (Ωcal) computed from inorganic carbon measurements collected every 2 weeks from 12 depths spanning the water column. Also presented are wind measurements from the Environment and Climate Change Canada (ECCC) Sentry Shoal weather buoy (46131). The calculation of Ωcal, along with the estimated uncertainty, is described in Evans et al. (2019) and Evans et al. (2022).

18.3. Biogeochemical observations

18.3.1. Central coast

While El Niño conditions occurred over much of 2023, and warm anomalies near +1°C were seen in the upper water column in Fitz Hugh Sound late in the year, the observed pattern in oxygen below 100 m was a significant biogeochemical signal likely forced by a regional increase in upwelling conditions. The 51°N upwelling indices during 2023 reflected an increase in persistent summer upwelling that had not been seen since 2018 (Figure 18-1). These persistent upwelling conditions were indicated by a greater uptick in the cumulative upwelling index curve over the summer months. Oxygen concentrations below 1.8 ml/l were observed at depth to 100 m beginning in July and persisted until the end of the year (Figure 18-1). Oxygen below this level had not largely been observed since 2018. Oxygen levels below 1.6 ml/l were measured, with a minimum near 1.4 ml/l in November. These conditions drove a negative oxygen anomaly from our 10-year mean annual cycle (2014-2024) near -0.5 ml/l. Total inorganic carbon content increased by ~25 µmol/kg within the low oxygen water, however there was no appreciable change in the extent or magnitude of corrosive conditions for aragonite.

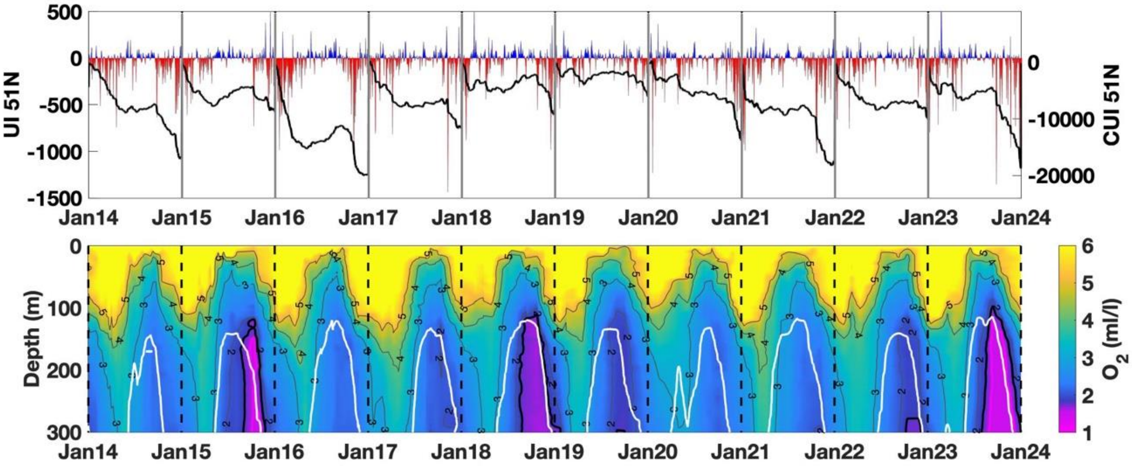

Figure 18-1. The Bakun Upwelling Index for 51°N (top; data from NOAA SWFSC) and oxygen (ml/l) over the upper 300 m at oceanographic station KC10 in Fitz Hugh Sound from 2014 to 2024. Six-hour upwelling indices were averaged to daily values and the black traces represent annual cumulative sums of these values. Highlighted oxygen contours are 1.8 ml/l (black) and 1.6 ml/l (magenta). White contours represent the 1026 kg/m^3 isopycnal that indicates the arrival of dense upwelled water.

CPROOF glider observations revealed that the low oxygen levels were present from the open Northeast Pacific over the continental shelf and into Hakai Pass. Within Hakai Pass, oxygen levels below 100 m increased likely due to mixing. An increasing pattern in deep water oxygen content was observed extending up Dean Channel (to station DE6) and to the inner portion of Burke Channel (station BUR8). Monthly surveys in both channels captured no measurements of oxygen as low as was seen on the continental shelf during 2023.

18.3.2. Northern Strait of Georgia

The northern Strait of Georgia does not exhibit the low oxygen levels seen on the central B.C. coast due to the influence of mixing in Haro Strait (Johannessen et al. 2014) However, because of the weakly-buffered seawater within the Strait (Evans et al. 2019), this region has the tendency to manifest extremely corrosive conditions for calcium carbonate biominerals. Calcite is less soluble than aragonite, which are the two major forms of calcium carbonate used by shell-forming marine organisms. The saturation state for calcite, Ωcal, reflects how corrosive seawater is for this form of calcium carbonate, with values below 1 favoring dissolution.

Observations from our oceanographic station QU39 have revealed extended periods of extremely corrosive conditions for calcite in intermediate water (i.e., 50-200 m) between 2018 and 2020, along with pH levels severe enough to potentially impact larval decapods (Bednaršek et al. 2021). Since 2021, the extent and magnitude of corrosive conditions for calcite have been decreasing in the northern Strait of Georgia (Figure 18-2). Coincident with this change is an increase in winter storm intensity. The trend toward improving conditions for calcite is counter to the expected changes due to increasing anthropogenic CO_2 content (Evans et al. 2022; Evans et al. 2019).

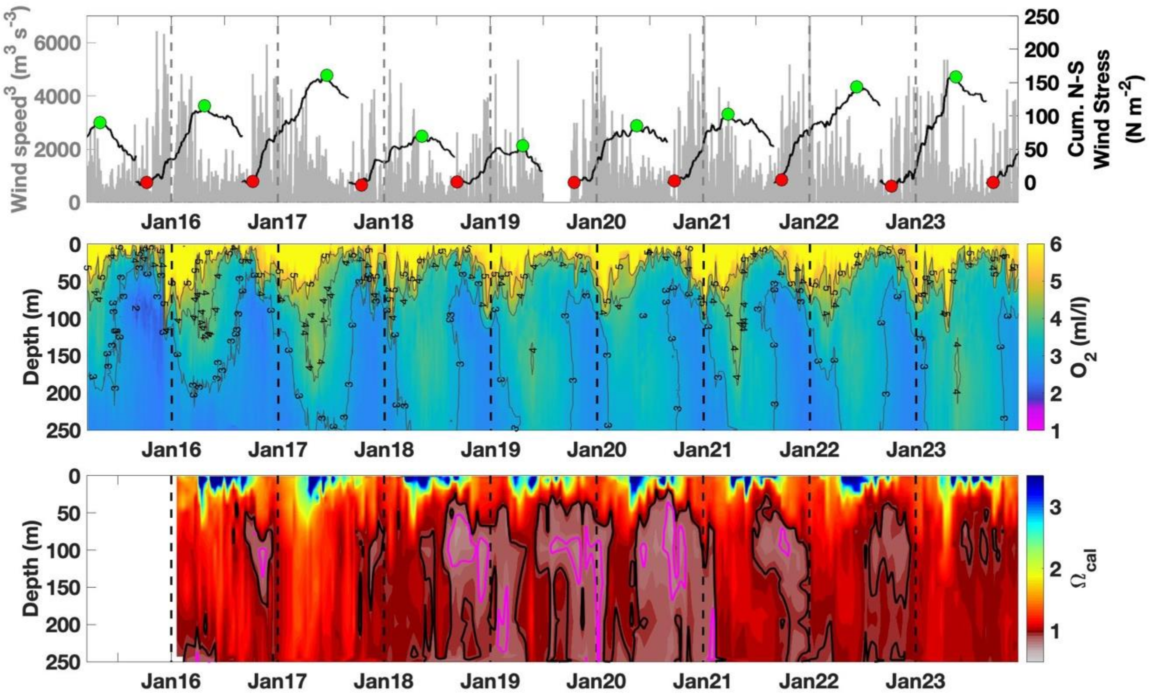

Figure 18-2. Wind speed cubed (m^3 s^{-3}) and cumulative north-south wind stress (N m^{-2}) computed using measurements from the ECCC Sentry Shoal weather buoy (46131; top) along with oxygen (ml/l; middle) and calcite saturation state (Ωcal; bottom) over the upper 250 m of the water column at oceanographic station QU39 beginning March 18, 2015 and ending December 19, 2023. Note the Ωcal record began January 19, 2016. Red dots in the top panel mark the first day of September that experienced gale force winds, whereas green dots mark the inflection in the cumulative wind stress curve as wind direction shifts during spring to blow predominantly from the north. The red and green dots denote the start and end of the winter storm season, respectively, and the magnitude of the green dot indicates the intensity of the winter storm season. The black line in the bottom panel marks Ωcal equal to 0.95 (thermodynamic threshold of 1 – 0.05% uncertainty) and the magenta line marks seawater pH equal to 7.52, representing extreme pH conditions that impact decapod larval survival (Bednaršek et al. 2021).

18.4. Factors influencing trends

Persistent summer upwelling is the most likely mechanism to deliver low oxygen water into Fitz Hugh Sound. 2023 was unique in that oxygen levels were the lowest observed in our 10-year record. However, these low oxygen values did not appear to extend landward from Fitz Hugh Sound into Burke and Dean Channels since observations below 100 m in the channels were significantly higher than those over the continental shelf for the same depth range.

Atmospheric forcing also likely played a major role in the northern Strait of Georgia, albeit there it was winter storm conditions shaping intermediate waters in the following spring and summer. There is a strong relationship between the intensity of the winter storm season (maximum cumulative wind stress; Figure 18-2) and the annual mean percent of the water column that is corrosive to calcite ($r^2 = 0.74$, $p = 0.006$). Two key pieces of information needed to explain this relationship are: (1) ~60% of intermediate water entering the Strait of Georgia is refluxed surface water (Pawlowicz et al. 2007) and (2) the transport time for intermediate water from Haro Strait to QU39 is ~3 months (Stevens et al. 2021). Years with stronger winter storm intensity may experience greater changes in inorganic carbon content in the surface layer (< 50 m). These modified surface waters would be circulated into Haro Strait, vertically mixed, and then recirculated as an intermediate water mass back to QU39 with a reduced inorganic carbon content; thereby leading to improved saturation state conditions even as the productivity season evolves.

18.5. Implications of those trends

The observed pattern of low oxygen conditions seemingly confined to the Queen Charlotte Sound continental shelf and Fitz Hugh Sound, with higher deep water oxygen content observed in Burke and Dean Channels, suggests the potential for refugia within some mainland inlets from shelf-derived low oxygen source waters. A hypothesis to explain this pattern is that deep water oxygen content is modified by mixing over geographical features along the flow path into these mainland inlets, and this likely isolates the inlets from low oxygen conditions occurring over the continental shelf.

The relationship between winter storm intensity and corrosive conditions for calcite in intermediate waters in the northern Strait of Georgia has potential to be a powerful forecasting tool over the near-term while anthropogenic carbon additions remain modest (Evans et al. 2019; Jarníková et al. 2022). 2023 saw improved conditions due to a strong winter storm season, and this has been the trend since 2021. However, weak winter storm seasons would lead to extremely corrosive periods, like those seen in 2018 through 2020, reflecting the fact that natural variability (e.g., storm season intensity) coupled with anthropogenic carbon addition can lead to intense manifestations of ocean acidification conditions of entire seasons. This logic implies that winter storm season intensity may presently be a good predictor of corrosive conditions in the following spring and summer.

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19. SATELLITE OBSERVATIONS OF SURFACE CHLOROPHYLL-A, TEMPERATURE AND MARINE HEATWAVES IN 2023

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19.1. Highlights

- Satellite sea surface temperature (SST) showed large surface marine heatwaves in the Northeast Pacific and B.C. Exclusive Economic Zone in 2023, with the largest extent in late July and early August.
- Satellite SST also showed much colder waters compared to climatological SSTs surrounding Vancouver Island during spring, and for a short period in August.
- Satellite chlorophyll-a was generally lower than usual in B.C. waters during spring. In northern Hecate Strait the spring bloom was on-time and higher magnitude compared to its climatology, while central and southern Hecate Strait was lower magnitude and later.

19.2. Description of the time series

Moderate-resolution satellite data is used for ongoing monitoring of surface waters in the Pacific Ocean. Numerous sources of satellite data were used to analyze time series of sea-surface temperature (SST) and chlorophyll-a (Chl-a), a proxy for phytoplankton biomass. SST and Chl-a were retrieved for the period 2003 through 2023 from the MODerate Resolution Imaging Spectroradiometer (MODIS-Aqua) at 1 km pixel resolution. The NASA Ocean Biology Processing Group (OBPG; https://oceancolor.gsfc.nasa.gov) standard products were used. The SST climatology was supplemented with night-time data from the NOAA Advanced Very High Resolution Radiometer (AVHRR) Pathfinder series, which extends back to late 1981 at 4 km spatial resolution (v5.3; https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.nodc:AVHRR_Pathfinder-NCEI-L3C-v5.3). Additionally, the interpolated Optimum Interpolation SST (OISST) dataset, which spans the same time period at 25 km spatial resolution, was used to calculate Marine Heatwave (MHW) statistics (https://doi.org/10.25921/RE9P-PT57). Seawater temperature (~2 m depth) measured by buoys maintained by Environment and Climate Change Canada (ECCC) were also acquired from the Canadian Integrated Ocean Observing System Pacific (https://data.cioospacific.ca/erddap).

Temporal statistics were extracted for the British Columbia Exclusive Economic Zone (B.C. EEZ) as well as regions of interest, and are summarized in Figure 19-1 a. These regions include Oceans Act marine protected areas (MPAs): Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs (north, central and southern sections: SRN, SRC and SRS), SGaan Kinghlas-Bowie Seamount (SK-B), and Tang.ɢ̱wan – ḥačxʷiqak – Tsig̱is (TḥT). Other areas included Scott Islands marine National Wildlife Area (SI), the Gwaii Haanas Offshore area (GHO), as well as Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve and Haida Heritage Site (Jackson et al. 2024).

For all areas, time series and climatologies for each week and month were extracted. For SST, the mean and standard deviation (SD) were calculated, using the 1991-2020 climate normals period for climatology. For Chl-a, the geometric mean and geometric SD were calculated to more accurately represent the average, using the shorter period 2003-2022 for the climatology. November, December and January images were excluded from the Chl-a due to the low sun angle causing higher uncertainty in the measurements and limiting the spatial data coverage. Further, forest fire smoke caused data loss particularly in September. Chl-a anomaly maps were also produced at the monthly scale by subtracting the monthly climatology from the monthly composite images from 2023.

MHWs were defined in the interpolated satellite data as events during which temperatures exceeded the 90th percentile of the 30-year climatology (or 1.29 SDs; Hobday et al. 2016). Similarly, this definition was applied to the buoy time series, indicating MHWs which lasted longer than 5 consecutive days.

19.3. Status and trends

In 2023, satellite Chl-a suggested variations in both timing and magnitude of phytoplankton biomass throughout the growing season among selected MPAs. Chl-a was much lower throughout the year in regions off the continental shelf (SK-B and TḥT), compared to coastally-influenced waters. SRS and SI had later, lower-magnitude spring blooms, while further north SRC and SRN had higher magnitude spring blooms compared to their climatologies, though with similar timing (Figure 19-1b). These patterns were emphasized when examining monthly anomaly images; spatially, May Chl-a anomalies were higher in regions with stronger blooms in the weekly time series. The western Juan de Fuca Strait, the Strait of Georgia, and northern Hecate Strait also experienced large Chl-a anomalies in May, including the coastal waters north of the Skeena River (Figure 19-1c). Eddies west and southwest of Haida Gwaii were evident in the Chl-a imagery, containing high phytoplankton biomass in their surface waters compared to their surroundings; many such eddies intersected the GHO region.

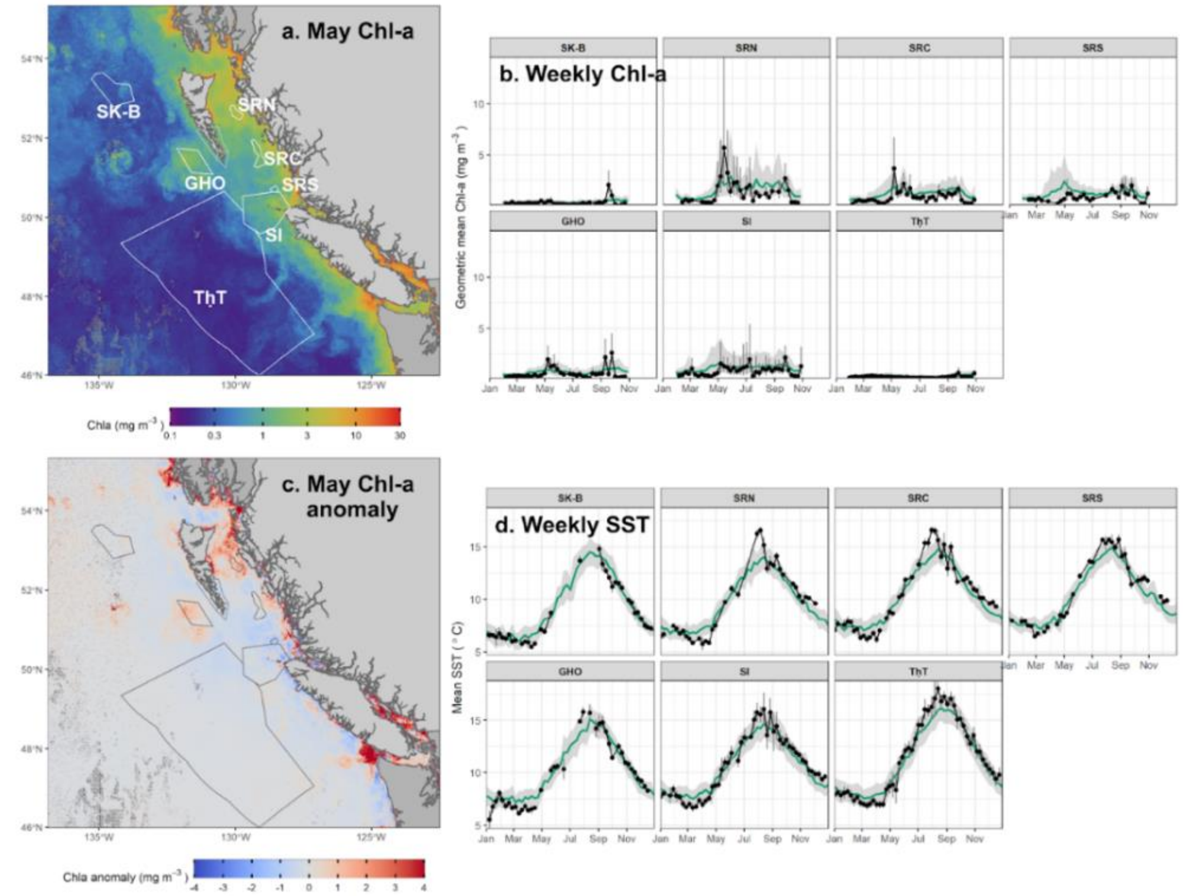

Figure 19-1. a. May geometric mean Chl-a showing the regions used for statistics (white lines). B. Weekly geometric mean Chl-a (black) and climatology (green, 2003-2022), with bars indicating geometric SD. C. May Chl-a anomaly. D. Weekly mean SST (black) and 1991-2020 climatology (green), with bars indicating SD. Night-time SST from MODIS-Aqua was lost particularly in May, June and July.

SST was low during winter (e.g., January, February and March) of 2023 throughout the B.C. EEZ. Notably cold conditions were observed at the Nanakwa Shoal buoy in February, and buoys in the area of Hecate Strait (North and South Hecate Strait, West Sea Otter and South Moresby buoys) in late March to mid-April. The satellite data similarly showed cooler temperatures in 2023 compared to the 1991-2020 climatology in all regions, with the greatest magnitude of cold anomalies in SRN and SRC (Figure 19-1d). Most regions also reached their maximum SST earlier than usual at the end of July, rather than during mid- or late-August. Toward the end of the year, SRC and SI in particular were warmer compared to their climatological temperatures in December.

MHW conditions, as observed in the OISST data, were persistent in the B.C. EEZ in 2023 after April (Figure 19-2c). The proportion of the B.C. EEZ in MHW status increased through the spring, to a maximum of >90% at the beginning of August (Figure 19-2a). However, while MHW conditions were present throughout the year, a number of cool events occurred, particularly in the Southern Shelf Bioregion and surrounding Vancouver Island. For example, a cold event occurred in late August, a few weeks after the large MHW that was present throughout the B.C. EEZ, with temperatures > 2.5°C cooler than the climatology (Figure 19-2b), that was similarly captured in the buoys at Sentry Shoal and South Brooks. By the end of 2023, waters in MHW conditions were located along the continental shelf and coastal waters, with approximately ⅓ of the B.C. EEZ in MHW status.

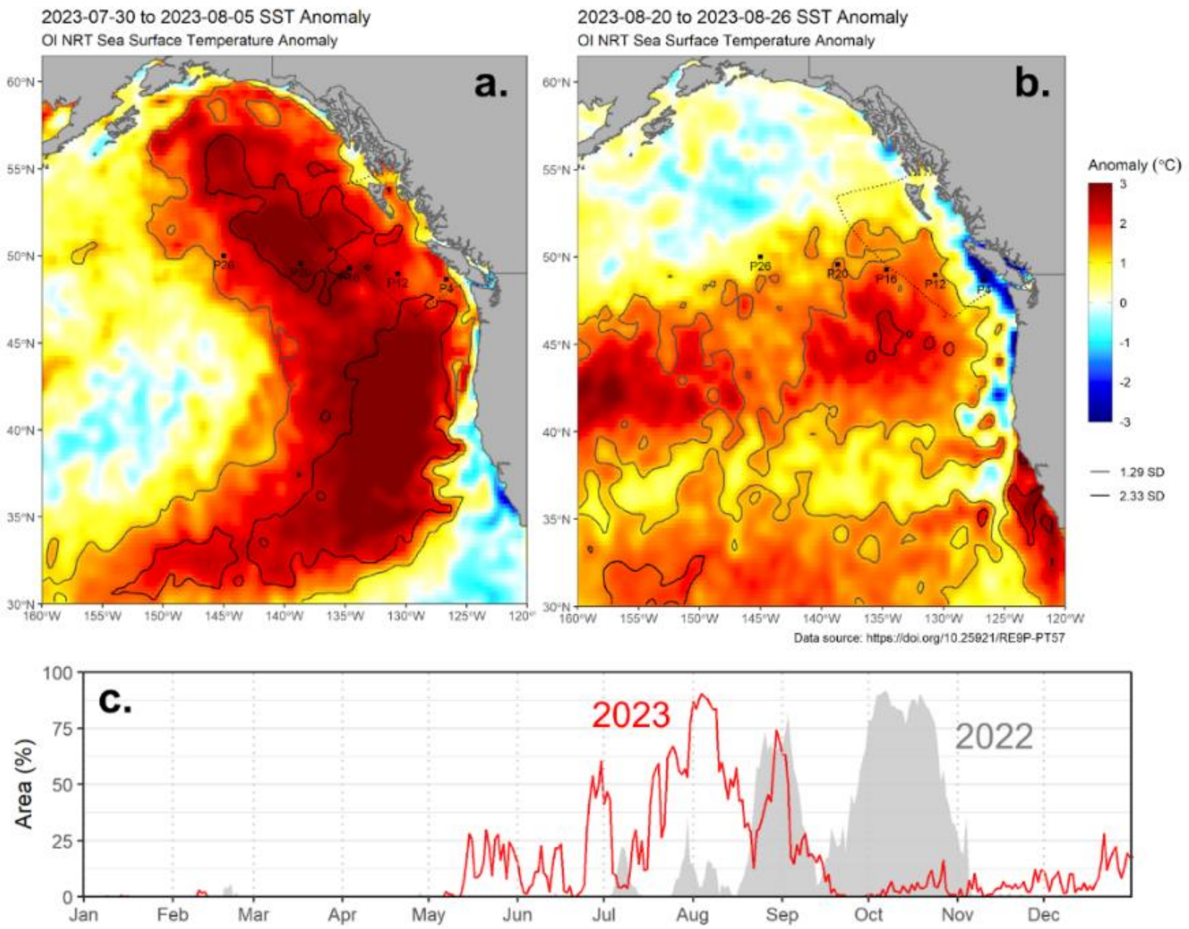

Figure 19-2. a. SST anomaly from the week of July 30th showing a large area of the NEP exceeding 2°C. The thin black line indicates 1.29 SD (~90th percentile) and the thick black line indicates 2.33 SD (~99th percentile). Selected stations along Line P are indicated as points, with the B.C. EEZ shown as a dashed line. B. SST anomaly from the week of August 20th, with strong cold anomalies surrounding Vancouver Island. C. The percent coverage of the B.C. EEZ in MHW status over 2023 (red), shown compared to 2022 (grey).

19.4. Factors influencing trends

Cool temperatures in winter and spring of 2023 may have impacted the timing and magnitude of phytoplankton blooms in some areas, causing them to be later compared to their typical annual timing. Similarly, the anomalously warm temperatures and MHW conditions that arrived in B.C. coastal waters in July and August may have made conditions more favourable for coccolithophore species that were observed blooming along the B.C. central coast, and west coast of Vancouver Island from July through late August.

Globally, SSTs in 2023 were much higher than previously observed, even during the months prior to the declaration of El Niño (see https://climatereanalyzer.org/clim/sst_daily). Upwelling along coastal Vancouver Island was associated with periods of anomalously cool water temperatures, while wide-spread warm conditions and some MHWs were associated with weather events. For example, a large heatwave weather event from mid-May was observed in buoy temperatures (particularly at the South Brooks and Sentry Shoal buoys) as well as the satellite SST sources, and corresponded to temperatures at MHW levels. The California Current Marine Heatwave Tracker (https://oceanview.pfeg.noaa.gov/projects/mhw/latest) provides a more detailed description of the large MHW that formed in May 2023, and was observed in the B.C. EEZ throughout 2023 (Figure 19-2). This large MHW was observed to decline rapidly in the B.C. EEZ as well as the Northeast Pacific (NEP), which was attributed to upwelling winds and effects from a strong storm system.

19.5. Implications of those trends

Anomalously warm SSTs can have negative ecosystem impacts. MHWs, for example, can contribute to Harmful Algae Bloom events (Crozier 2015). Blooms of coccolithophore species, with calcium carbonate plates that effectively scatter light and were observed extensively in B.C. coastal waters in summer 2023, can reduce the penetration of photosynthetically available radiation (PAR) to deeper waters below, causing darkening and slower heating from the surface (Tyrrell et al. 1999). Later or lower-magnitude phytoplankton blooms, as were noted in numerous areas of B.C. coastal waters, may have negative impacts on the ecosystem by reducing food available to higher trophic levels or altered timing of availability (e.g., match/mismatch), though later blooms may be less detrimental compared to early blooms in B.C. waters (Suchy et al. 2022).

SSTs in the NEP were anomalously warm prior to the declaration of El Niño in the summer. When considering SST anomalies and MHWs from the previous El Niño, the alarm was sounded for 2023 (e.g., Hobday et al. 2023). However, while MHW conditions persisted throughout the year in the NEP and the B.C. EEZ, temperature anomalies through the end of 2023 were lower than expected, and were overall cooler compared to many other areas of the larger North Pacific. With ENSO conditions predicted to transition to neutral and La Niña in summer of 2024, there may be fewer negative impacts than were anticipated earlier in 2023. However, B.C. SSTs have been increasing in the long-term (Cummins and Masson 2014; Hourston et al. Section 11), and the frequency, duration and intensity of MHWs are increasing globally due to anthropogenic climate change (Laufkötter et al. 2020). These trends are expected to continue.

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20. 2023 TRENDS IN PHYTOPLANKTON BIOMASS AND COMMUNITY COMPOSITION FROM TIME SERIES STATIONS IN THE NORTHERN SALISH SEA AND CENTRAL COAST, B.C.

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20.1. Highlights

- Large spring blooms with near time series median initiation dates were observed at the Hakai Institute northern Salish Sea (QU39) and central coast (KC10) monitoring sites (monitored since 2015).
- Station QU39 showed the second highest annual integrated 5m depth phytoplankton biomass of the time series as a result of high spring season diatom contributions and a large autumn diatom bloom. Similar to other years, the high diatom biomass coincided with negative freshwater content anomalies.
- Station KC10 showed high diatom biomass in April through June followed by moderate biomass phytoflagellate-dominated summer conditions and a small autumn dinoflagellate bloom. Spearman's rank correlations indicated links between phytoplankton biomass, wind, and incoming photosynthetically active radiation (PAR) while cryptophytes and dinoflagellates were correlated with stratification and river discharge.

20.2. Description of the time series

Figure 20-1. Study area map showing the location of the central coast (KC10) and northern Salish Sea (QU39) sampling locations.

Phytoplankton pigment time series were analyzed from two stations (QU39 and KC10) that are maintained by the Hakai Institute (Figure 20-1). In the northern Salish Sea, QU39 is sampled weekly whereas on the central coast, KC10 is sampled monthly. 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). At QU39, annual integrated TChla was calculated by subtracting the time series median TChla concentration from each weekly concentration and then for each year performing a cumulative sum on the difference. In each year, the beginning of the productive season was defined as when this integrated value became positive and the end at the annual maximum value. Furthermore, at QU39, monthly anomalies for CHEMTAX diatom outputs were calculated by subtracting the monthly time series climatology from averaged monthly outputs for these groups.

Physicochemical data were used to investigate trends in phytoplankton biomass and community composition. Salinity, temperature, density (used to derive stratification via Δρ30-3m) and freshwater content (FWC) were derived from Hakai CTD data. Nutrients were analyzed at the University of British Columbia (Del Bel Belluz et al. 2021). For QU39, monthly anomalies of these parameters were calculated in the same way as the CHEMTAX data described above.

20.3. Status and Trends

20.3.1. Phytoplankton time series

In 2023, the spring diatom bloom was observed on March 21st (TChla = 10.01 mg m^{-3}) near the time series median initiation date (March 19th) and following the cessation of strong wind conditions (Figure 20-2). Bloom termination was observed on April 4th coinciding with a resurgence of strong winds and surface nutrient replenishment suggestive of high mixing that likely diluted phytoplankton biomass. In late April, diatom biomass resurged following decreased winds and persisted until June 20th. Similar to prior years of the time series, FWC increased in late June coinciding with surface nutrient depletion and the succession to moderate biomass phytoflagellate-dominated conditions. Interestingly, a decrease in FWC and surface nutrient replenishment was observed on July 4th (FWC = 0.14), but despite subsequent nutrient drawdown, no increase in TChla or diatom biomass was observed. This trend is common in summer over the time series. Diatom contributions increased in August roughly coinciding with decreased FWC and increased nutrient concentrations and peaked during an early September diatom bloom (September 5th, TChla = 7.22 mg m^{-3}).

When compared to prior years, the high observed spring and September diatom biomass resulted in positive monthly diatom anomalies for these periods and the second highest annual integrated TChla (60.39 mg m^{-2}, black line on Figure 20-3) of the time series. Interestingly, these conditions coincided with strong negative monthly FWC and positive DSi anomalies. Of note, FWC was noticeably low during spring when diatom biomass persisted following the spring bloom. Over the time series, Pearson correlation analysis between monthly FWC and diatom anomalies showed negative correlations for March (R = -0.76, p = 0.018) and August and September combined (R = -0.60, p = 0.009, with 2021 removed R = -0.72, p = 0.002); however, no correlation was observed when all months were included.

Similar to the northern Salish Sea (NSS), KC10 showed a large spring bloom that occurred on April 2nd (TChla = 10.55 mg m^{-3}) near the time series median initiation date for this station (April 9th) (Figure 20-4). This bloom occurred during a brief window of calm winds and was captured by a moored fluorometer at the KC10 buoy (star on Figure 20-4). These transient blooms have occurred in the prior two years of the time series as shown by their development before seasonal reductions in monthly mean wind speeds. Diatom biomass remained elevated until June, with composition switching to phytoflagellate dominated, largely cryptophytes, in July. Similar to the prior three years of the time series, an increase in dinoflagellate biomass was observed in September. Across the time series, Spearman's rank correlations showed that stratification (+ correlation), wind speed (-) and direction (+), as well as photosynthetically active radiation (PAR, +) were correlated to TChla and the prominent phytoplankton groups (diatoms, cryptophytes and dinoflagellates). In turn, only TChla, cryptophytes and dinoflagellates showed positive correlations with temperature and 10-day backwards mean discharge from the head of the Owikeno River's Inlet, while dinoflagellates showed a negative correlation with salinity.

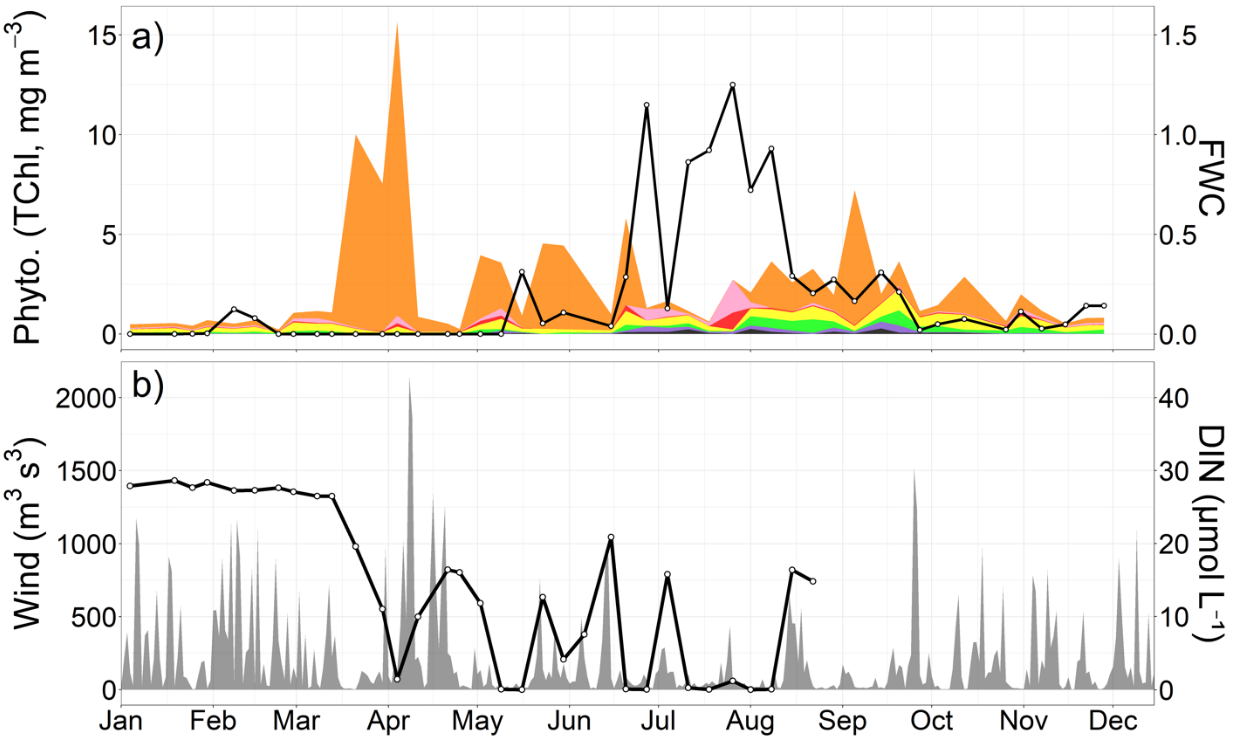


Figure 20-2. Station QU39 (northern Salish Sea) 2023 time series of a) 5m depth CHEMTAX phytoplankton functional group contributions (TChla mg m^{-3}, left y-axis) and FWC (black line, right y-axis) and b) wind speed cubed (m^{3} s^{3}) from the environment Canada Sentry Shoal Buoy (left y-axis) and dissolved inorganic nitrogen (DIN, µmol L^{-1}, right y-axis).

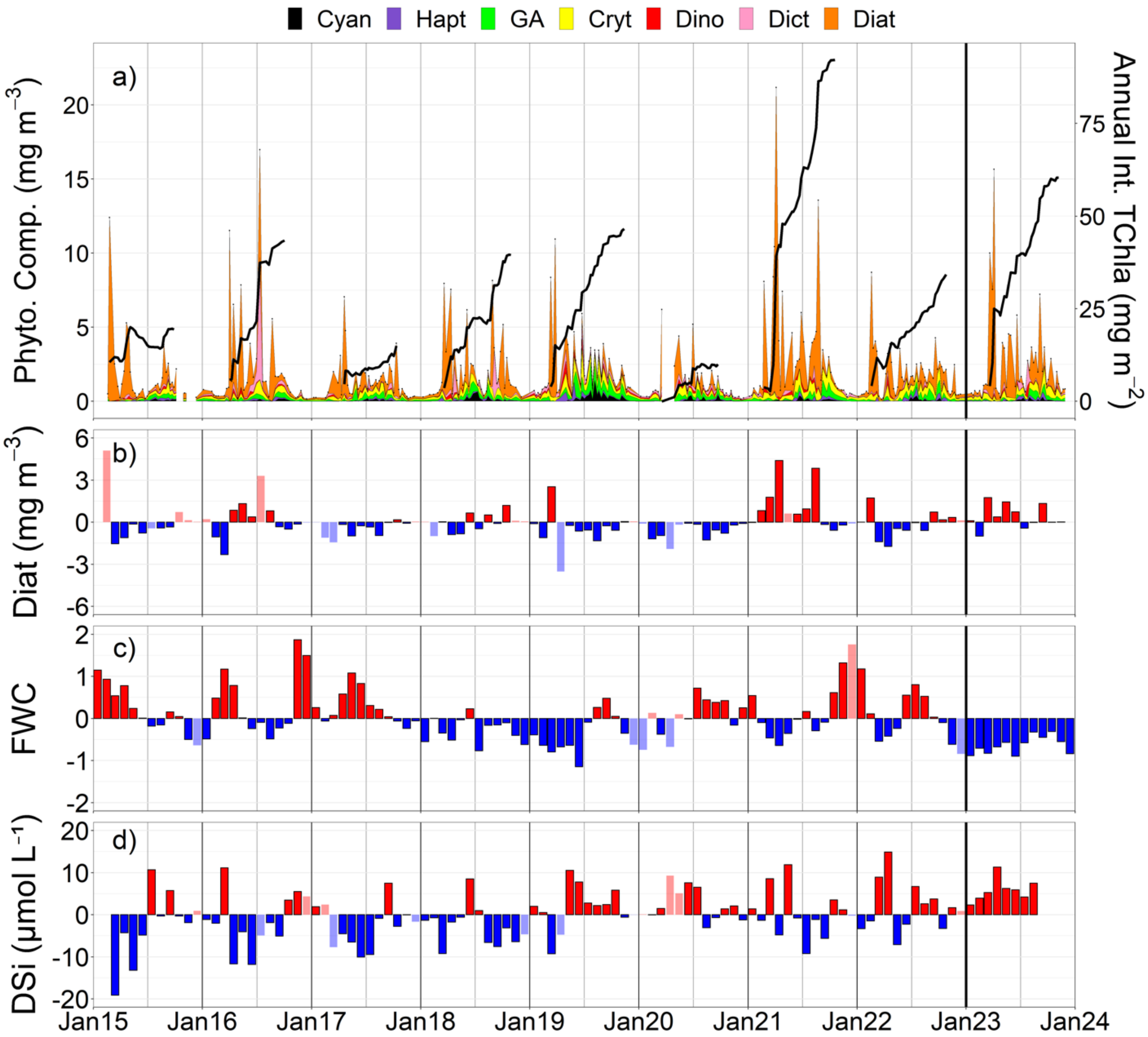
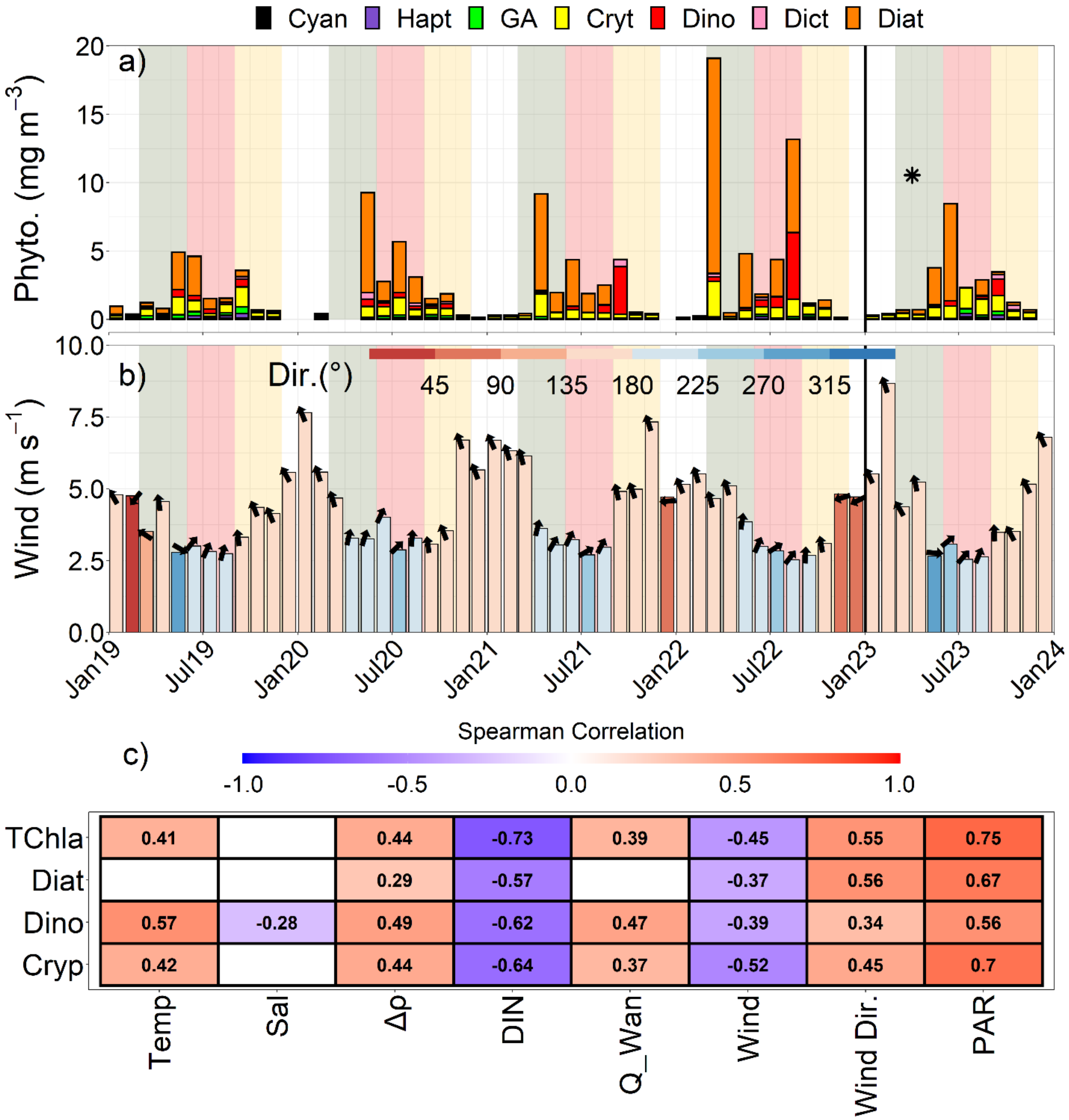


Figure 20-3. Station QU39 (northern Salish Sea) 5m depth 2015 - 2023 time series of a) CHEMTAX phytoplankton functional group contributions (TChla mg m^{-3}) and monthly anomalies for b) Diatoms (Diat), c) Freshwater content (FWC) and d) silicate (DSi). The groups shown in the CHEMTAX plot represent cyanobacteria (Cyan, black), haptophytes (Hapt, purple), green algae (GA, green), cryptophytes (Cryp, yellow), dinoflagellates (Dino, red), dictyochophytes (Dict, pink) and diatoms (Diat, orange). The black line on the CHEMTAX plot represents the annual integrated TChla over the productive season as described in section 20.2. The shaded bars on the anomaly plots represent months where < 3 samples were collected and may not represent robust monthly means. The solid vertical line on all plots delineates the start of 2023.



	Temp	Sal	Δρ	DIN	Q_Wan	Wind	Wind Dir.	PAR
TChla	0.41		0.44	-0.73	0.39	-0.45	0.55	0.75
Diat			0.29	-0.57		-0.37	0.56	0.67
Dino	0.57	-0.28	0.49	-0.62	0.47	-0.39	0.34	0.56
Cryp	0.42		0.44	-0.64	0.37	-0.52	0.45	0.7

Figure 20-4. Station KC10 (central coast) 2019 - 2023 time series of a) monthly 5m depth CHEMTAX phytoplankton functional group contributions (TChla mg m^{-3}); b) monthly median wind speed (m s^{-1}) from the "Lookout" Hakai weather station and; c) Spearman's rank correlations for TChla and the dominant phytoplankton groups (Diat – Diatoms, Dino = Dinoflagellates, Cryp = Cryptophytes) versus physiochemical and environmental variables (Temp = 5m Temperature, Sal = 5m Salinity, Δρ = stratification, DIN = dissolved inorganic nitrogen, Q_Wan = 10-day backwards mean Wannock River discharge, Wind = 3-day backwards median wind speed from the Lookout station, Wind Dir. = 3-day backwards median wind direction from the Lookout station and PAR = 3-day backwards median photosynthetically active radiation from the Lookout station). The shaded backgrounds in a) and b) represent seasons with green = spring, red = summer and yellow = autumn. In b) the colours of the bars and arrows represent the median wind direction for that month. In c) white boxes represent insignificant correlations (p > 0.05).

20.4. Factors influencing those trends

The initiation of the March spring bloom in the NSS (QU39) followed expected trends developing after a strong storm season (Evans, Section 18) during a period of reduced wind and increased incoming PAR. Reductions in wind, lowering surface mixing, and increased light are important drivers of regional bloom timing as their combined influence lift light limitation to surface phytoplankton (Collins et al. 2009; Allen and Wolfe 2013). Similar trends were observed on the central coast (KC10) where the bloom developed during a short window of reduced winds. Over the time series at this station, correlations between TChla and wind speed, direction, and PAR suggest that spring bloom initiation mechanisms may be similar to those in the NSS.

Trends at QU39 suggest that surface freshwater is linked to annual phytoplankton dynamics potentially through its influence on stratification and nutrient renewal. In 2023, the Fraser River showed record low spring and summer discharge (Curry and Lang, Section 7) coinciding with our observed negative FWC anomalies. In addition, both positive diatom and silicate anomalies were observed, which was unexpected as diatoms are generally associated with low silicate concentrations as this nutrient is required to form their silica shells. For example, over the time series, years with positive silicate anomalies tended to show low diatom contributions (e.g., 2019). These trends suggest that low FWC may have allowed for easier mixing of the water column and increased surface nutrient renewal promoting diatom biomass. Specifically, the significant negative correlations between monthly FWC and diatom anomalies in March and August-September highlight that spring and autumn diatom bloom formation and strength may be tied to freshwater conditions.

Freshwater and stratification were also important drivers of phytoplankton community composition on the Central Coast. For instance, increased August and September dinoflagellate biomass at KC10 are typically constituted by *Ceratium fusus*, which is a species that favors stratification following freshwater events (Baek et al. 2007). This link is supported by the observed correlations between CHEMTAX based dinoflagellate biomass and stratification, river discharge, and salinity.

20.5. Implications of those trends

Spring bloom timing and magnitude are important ecological metrics with mismatches between peak spring phytoplankton and zooplankton biomass associated with poorer feeding conditions for higher trophic levels such as Pacific Salmon and sea birds (Borstadt et al. 2011; Tommasi et al. 2013; Suchy et al. 2022). At QU39, the 2023 spring bloom timing (near the time series median) and continued spring season diatom contributions occurred near the seasonal increase in zooplankton abundance, likely promoting favorable feeding conditions for higher trophic levels (Mahara et al. 2019; Suchy et al. 2022).

Comparatively, the drivers of autumn blooms and their ecological and biogeochemical implications are poorly understood. In the NSS, autumn blooms are typically diatom dominated; whereas, those on the central coast are flagellate dominated. These contrasting community compositions potentially highlight differences in zooplankton grazing as both locations show non-limiting diatom favorable nutrient conditions during autumn. Furthermore, these differences are notable as diatoms are associated with shorter food chains and increased vertical carbon export when compared to smaller flagellates such as cryptophytes (Tréguer et al. 2018; Lerner et al. 2022).

Overall, the Hakai time series presented here suggest strong links between freshwater and phytoplankton community composition on both the central coast and in the northern Salish Sea; however, other factors such as grazing also appear to be important in modulating phytoplankton structure and require further research. Freshwater delivery to the coastal zone is expected to drastically change with a warming climate (Bidlack et al. 2021) and will likely have profound impacts on phytoplankton community structure. The Hakai Institute's time series provide valuable information on phytoplankton dynamics and their drivers at temporal scales and resolutions necessary for resolving how changing ocean conditions influence ocean biology.

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21. WHAT TO DO WITH MILLIONS AND MILLIONS OF PHYTOPLANKTON IMAGES FROM CANADA'S WEST COAST

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21.1. Highlights

- During the May 2023 La Perouse plankton survey, we successfully completed the first at-sea deployment of a newly-acquired instrument for quantitative plankton imaging, the Imaging FlowCytobot.
- Approximately 1,000,000 phytoplankton images (as single cells or chain forming colonies) were captured. From these images, surface ocean biovolume estimates were calculated.
- Cross shelf variability of surface phytoplankton abundance was clearly resolved with this new sampling method, as well as cross shelf and along shelf differences in phytoplankton community composition.

21.2. Description of the time series

The La Perouse plankton time series is a long running program to monitor and describe phytoplankton and zooplankton along the west coast of Vancouver Island, including in the highly productive Juan de Fuca eddy. Satellite images of regional surface chlorophyll concentrations illustrate the highly variable nature of surface phytoplankton abundance, yet this variability is challenging to capture with discrete sampling approaches. Automated phytoplankton imaging techniques have elsewhere been demonstrated to be an efficient means of resolving high frequency variability in phytoplankton community composition and abundance along survey transects (Oliver et al. 2021; Oliver et al. 2022). Researchers at DFO's Institute of Ocean Sciences have recently acquired an Imaging FlowCytobot (IFCB) (Olson and Sosik 2007), which provides this capability. The May 2023 La Perouse plankton survey marked the first at-sea deployment and testing of this instrument.

The IFCB was plumbed to draw samples every 20–25 minutes from the surface underway seawater line aboard the CCGS J. P. Tully. The underway seawater was supplied from ~4.5 m depth by a Moyno® single-screw rotary pump. It has been identified that single-screw rotary pumps minimally alter particle morphology, which is critical for high quality plankton imaging applications. The sampling frequency translated to a horizontal spacing of approximately 8 km at normal transit speeds. At this sampling frequency, approximately 10 samples were collected across the shelf-break where the shelf is narrow, along the LBP transect, and close to 30 samples across the shelf to the south, where the shelf is much wider (Figure 21-1a). This sampling frequency was two to three times greater than the CTD station spacing where discrete samples were collected for phytoplankton analysis.

From the most simple presentation of the data, number of phytoplankton images recorded per mL seawater (Figure 21-1b; blue line), the IFCB's ability to capture rapid shifts in abundance is clear. From a comparison with biovolume estimates (Moberg and Sosik 2012) (Figure 21-1b;

orange line), it was inferred that the type of phytoplankton seen in Juan de Fuca Strait differed from those in Johnstone Strait and Strait of Georgia. Collage images from a subsample of the largest cells (or chains) in a sample from Juan de Fuca Strait (Figure 21-2a) and Johnstone Strait (Figure 21-2b) confirm this inference. Larger volume *Thalassiosira* sp. Chains dominate in Juan de Fuca, while smaller volume *Chaetoceros* sp. and *Skeletonema* sp. Chains dominate in Johnstone.

The survey included six cross shelf transects (LB, LC, LD, LG, LBP, and CS lines; Figure 21-1a). Across all lines, imagery showed a dominance of chain forming diatoms nearshore, with relatively few, single cells offshore of the shelf break. A progression of diatom species was also observed alongshore, with *Thalassiosira* sp. and *Asterionellopsis* sp. Dominating in the south and *Chaetoceros* sp. and *Skeletonema* sp. dominating in the north.

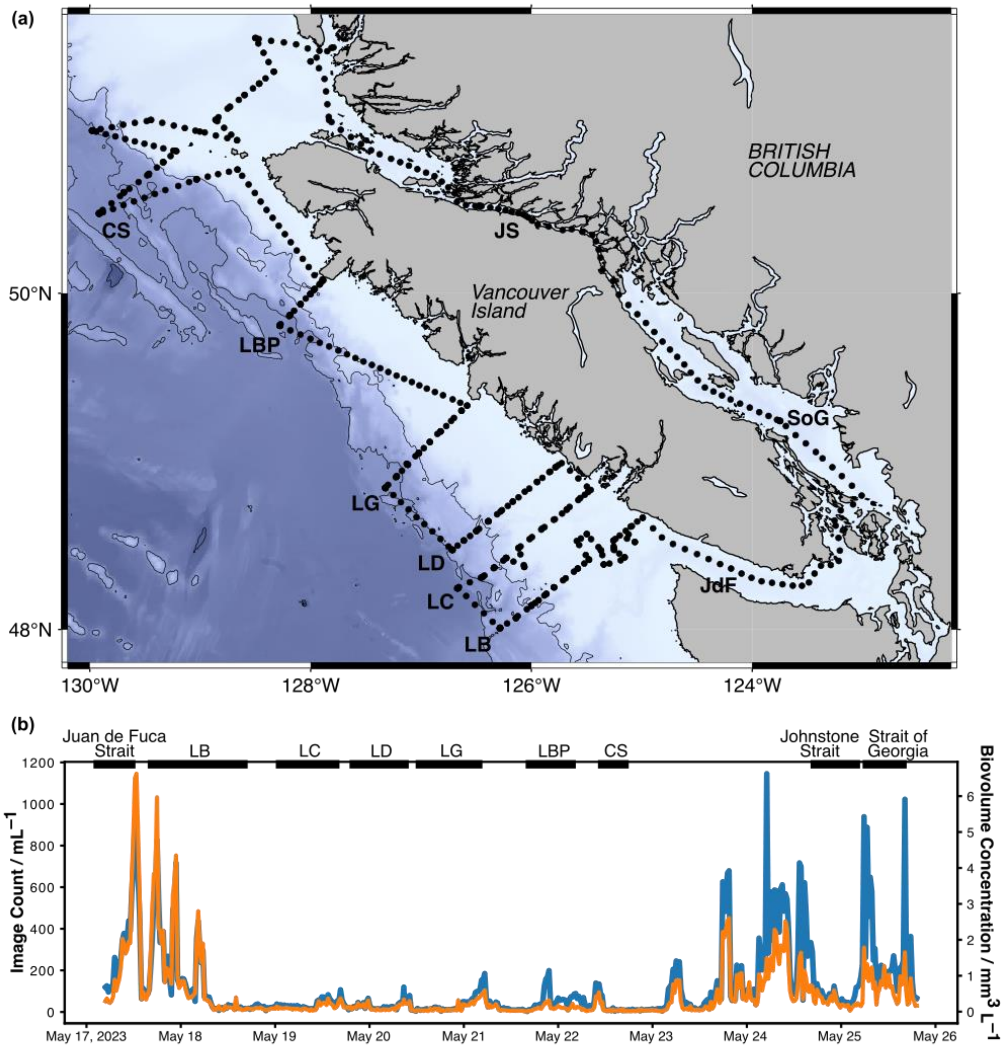

Figure 21-1. (a) Map of the cruise track. Individual dots identify the locations of each ifcb sample. (B) Phytoplankton image (individual cells or chains) count (blue) and bio volume concentration (orange) along the cruise track. Historically sampled cross-shelf lines LB, LC, LD, LG, LBP, AND CS are indicated by the bold line segment along the upper x-axis, as well as Juan de Fuca Strait, Johnstone Strait, and Strait of Georgia.

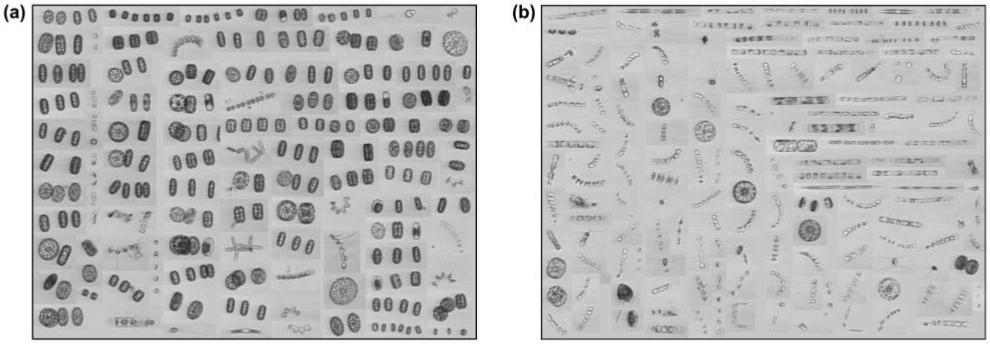

Figure 21- 2. Collages assembled from images of the larger size phytoplankton observed at two locations on the La Perouse plankton time-series survey. The plankton community at the entrance to Juan de Fuca Strait (a) is dominated by Thalassiosira sp., while the community in Johnstone Strait (b) is dominated by Chaetoceros sp. and Skeletonema sp.

21.3. Image classification model development

The results presented so far have relied on bio volume estimates, which are not species specific, and a taxonomic description of the dataset that was based on a cursory visual inspection of the image collection. A more comprehensive taxonomic description of the dataset can be achieved through the application of deep learning neural network classification models. These models require a sizeable training dataset; using the images from this survey, we have begun to develop that training dataset. As of Spring 2024, >250,000 images had been hand annotated. The first iteration of a classification model has been built and applied to the full dataset. We are currently in the process of validating the machine classifications. The next step will be to use the validated images to expand the training dataset and retrain the model. Ultimately, we seek to train a model that can rapidly and reliably classify the majority of the images recorded from NE Pacific waters.

21.4. Looking forward

We have demonstrated the ability to describe surface phytoplankton community composition at high spatial resolution using quantitative plankton imaging technologies deployed in a continuously sampling mode during oceanographic surveys. Continued deployment on the La Perouse plankton surveys will build a dataset that will provide additional perspective on phytoplankton dynamics, productivity, and the links to physics and biogeochemistry. In addition, high quality, high frequency, taxonomically resolved descriptions of phytoplankton communities will aid in refinement of satellite phytoplankton composition algorithms (Cetinić et al. 2024).

21.5. References

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22. WEST COAST BRITISH COLUMBIA ZOOPLANKTON BIOMASS ANOMALIES 2023

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22.1. Highlights

- Sub-arctic and boreal copepods dominated the zooplankton communities from late spring into early summer in 2023, replaced by southern copepods in the late summer/fall.
- There was an increase in gelatinous zooplankton biomass across shelf areas, mainly due to an increase in salps and doliolids through late summer and into fall.
- Southern chaetognaths and copepods were declining from a peak since 2015-2016, but 2023 saw a strong increase in abundance throughout the area, especially on the shelf.

22.2. Description of the time series

Zooplankton biomass anomaly time-series are calculated 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 early in NVI and Hecate Strait surveys.

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 22-1). Additional locations are included in averages when they are available. See Mackas et al. 2001 for methodology of zooplankton monitoring surveys along the West Coast.

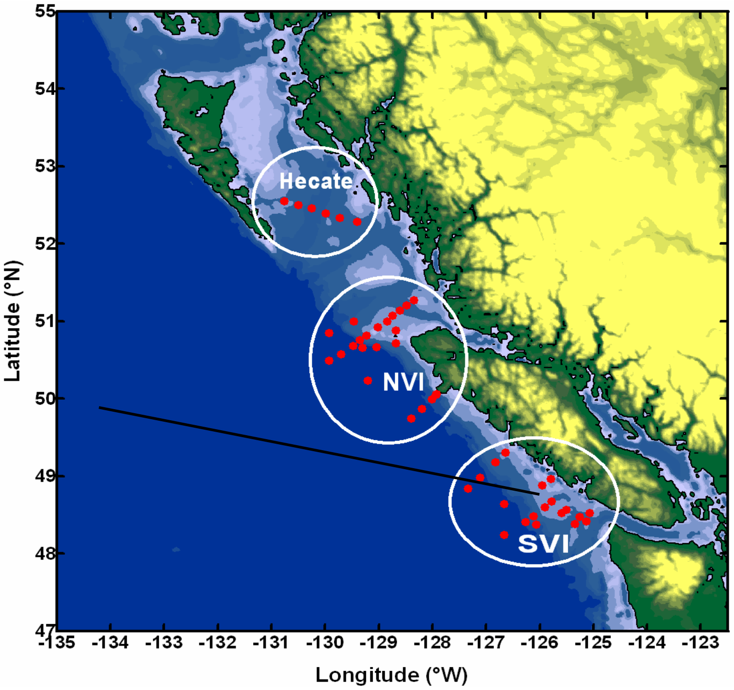

Figure 22-1. Zooplankton time series sampling locations (red dots; Line P – black line) in B.C. marine waters. Data are averaged for samples within each area. There are more samples included in the analysis than shown in figure.

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; introduced last year. For a more detailed description of the previous biomass anomaly series, see published articles Mackas 1992; Mackas et al. 2001 and Mackas et al.

2013a and 2013b. The new method follows ICES protocol (O'Brian 2022: see https://wgze.net/) for log10 transformed biomass anomaly calculations. 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 the pattern of positive/negative values: with range above and below average; but extremes are attenuated overall.

Zooplankton species (see Table 22-1 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.

22.3. Status and trends

The biomass anomaly time series for zooplankton community groups: 'southern', 'subarctic', 'boreal shelf', etc.; are described below and confined to SVI and NVI shelf/offshore (Figure 22-1) for this report. There were not enough samples collected for Line P or Hecate, due to loss of survey time, to produce a reliable climatology for these areas. 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 22-1. Zooplankton groups described in the time series in Figures 22-2, 22-3 and 22-5.

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 chaetognaths	*Parasagitta elegans, Eukrohnia hamata*	Boreal Pacific into the Arctic

In 2023, southern copepod species were more abundant in the SVI shelf and NVI offshore compared to SVI offshore and NVI shelf. There had been a steady decline in abundance of southern copepods in all areas since 2015, but that has now, in 2023, switched to positive, especially in the SVI shelf region (Figure 22-2). The boreal shelf and subarctic copepods decreased or neared average biomass across all areas. The dip in biomass, from 2022 to 2023, in the subarctic copepods for the west coast Vancouver Island may be a result of high numbers in the early summer (cooler waters) to the almost complete absence in the summer/early fall (much warmer waters). The boreal shelf copepods had a modest increase in the SVI shelf and NVI offshore areas, a pattern similar to the southern copepods, potentially showing along the shelf northerly transport of water being advected offshore.

Following is a partial list of some of the exotic copepods identified this year from the La Perouse Zooplankton Monitoring Program zooplankton samples: *Pareucalanus parki*, North Pacific transition zone species; *Cephalophanes tectus*, oceanic species; *Clytemnestra* and *Sapphirina* species, oceanic but associated with salps, oikopleurans and doliolids; *Euchaeta media*, subtropical southwest Pacific; *Calocalanus pavoninus*, equatorial Pacific.

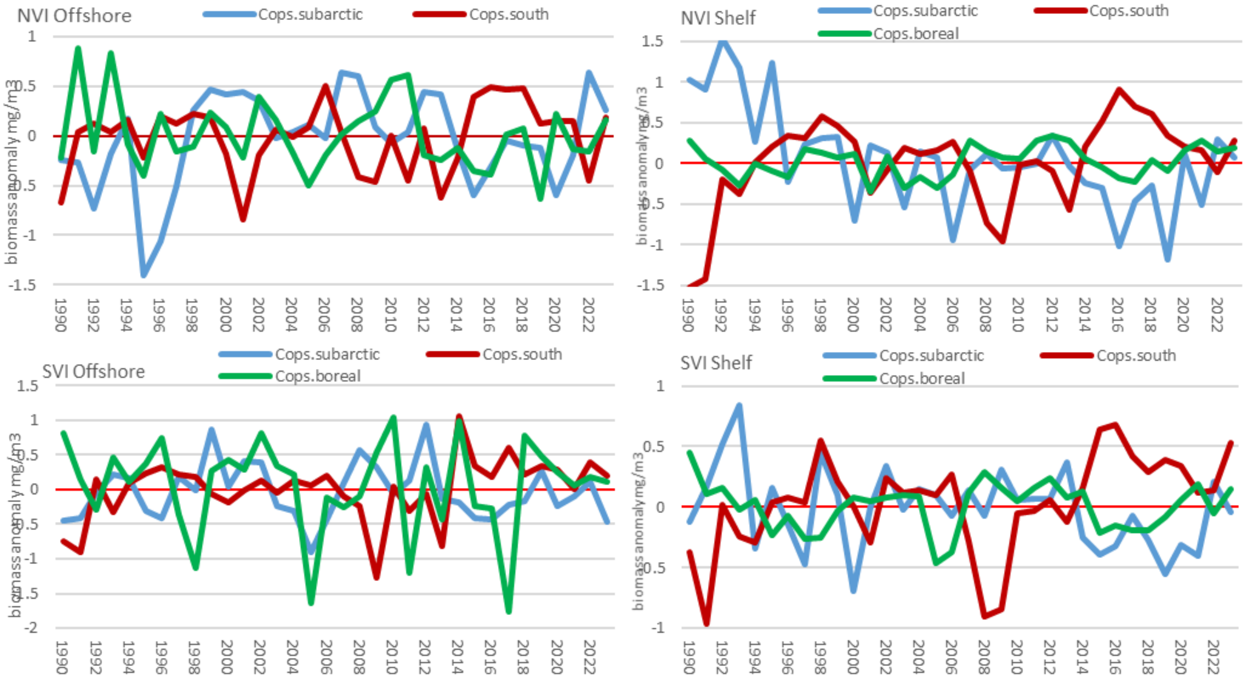

Figure 22-2. Zooplankton species-group anomaly time series for the regions shown in Figure 22-1. Southern Vancouver Island (SVI) bottom, Northern Vancouver Island (NVI) top, shelf areas on right and offshore areas on left panels. Subarctic copepods blue, southern copepods red, boreal copepods green lines.

Euphausiid biomass peaks in the NVI (Figure 22-3) were mainly caused by large increases in Euphausia pacifica biomass on the shelf with near average biomass for *Thysanoessa spinifera*. SVI had a strong decrease in *T. spinifera* in the offshore area with a modest increase on the shelf but little change in *E. pacifica* from average. Along Vancouver Island, in the offshore area, it is the large copepods, *Neocalanus* and *Eucalanus*; that dominate the yearly crustacean biomass but, on the shelf, the euphausiids represent the greater portion.

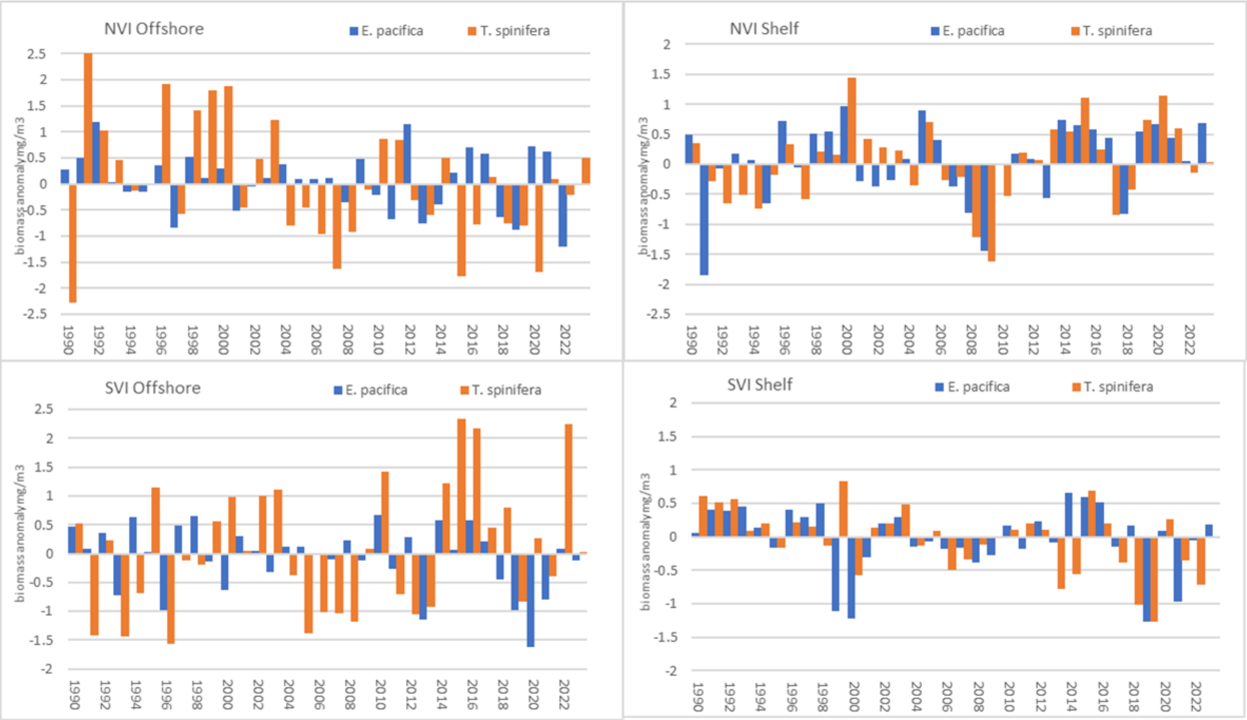

Figure 22-3. Euphausiid species anomalies time series comparison: Euphausia pacifica, blue and Thysanoessa spinifera, orange bars. Southern Vancouver Island (SVI) bottom, Northern Vancouver Island (NVI) top, shelf areas on right and offshore areas on left panels.

The ratio of crustaceans, higher in lipids and proteins, to the gelatinous community is an important aspect to keep in mind when assessing the zooplankton community structure, especially from point of view of food availability for forage fish, sea birds and marine mammals.

The CSIndex or “Crunchies (crustacean): Squishies (gelatinous)” Index (see Galbraith and Young 2019 for detailed explanation) in 2023 saw a strong increase for gelatinous zooplankton with little to no increase for crustaceans (close to average across all regions). Larvaceans, siphonophores, and ctenophore biomass anomalies were positive mainly on the shelf but overall salps and doliolids were the main contributors to the gelatinous group positive results (Figure 22-4).

Some southern gelatinous species not identified from WCVI zooplankton samples since the last El Niño event were *Aglaura hemistoma*, a southern oceanic hydromedusae, *Oikopleura longicauda*, a southern larvacean species and *Horminophora*, a large California/Mexico ctenophore. There were reports of *Praya*, *Velella* and *Thetys* species being sighted in the near shore and shelf areas along the coast by the general public: either washing up on shore or being spotted from canoe and kayak.

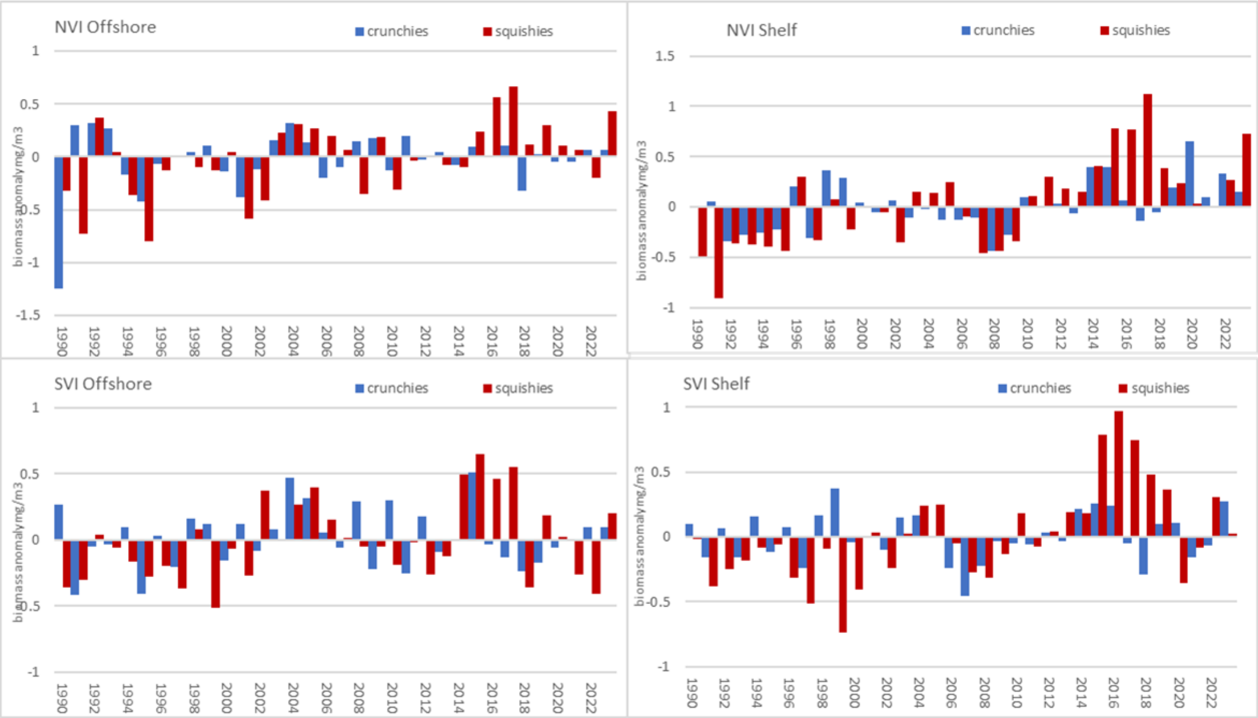

Figure 22-4. Biomass anomalies time series for selected crustaceans (blue: Crunchies) and gelatinous (red: Squishies). Southern Vancouver Island (SVI) bottom, Northern Vancouver Island (NVI) top, shelf areas on right and offshore areas on left panels.

Along with the northern versus southern copepod groupings, the chaetognaths show a strong correspondence to warm water intrusions, northern chaetognath species give way readily to the southern community (Figure 22-5). 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 WCVI. The last couple of years have seen a steady drop in southern chaetognath biomass, but in 2023 there was a strong increase especially in the SVI shelf and offshore.

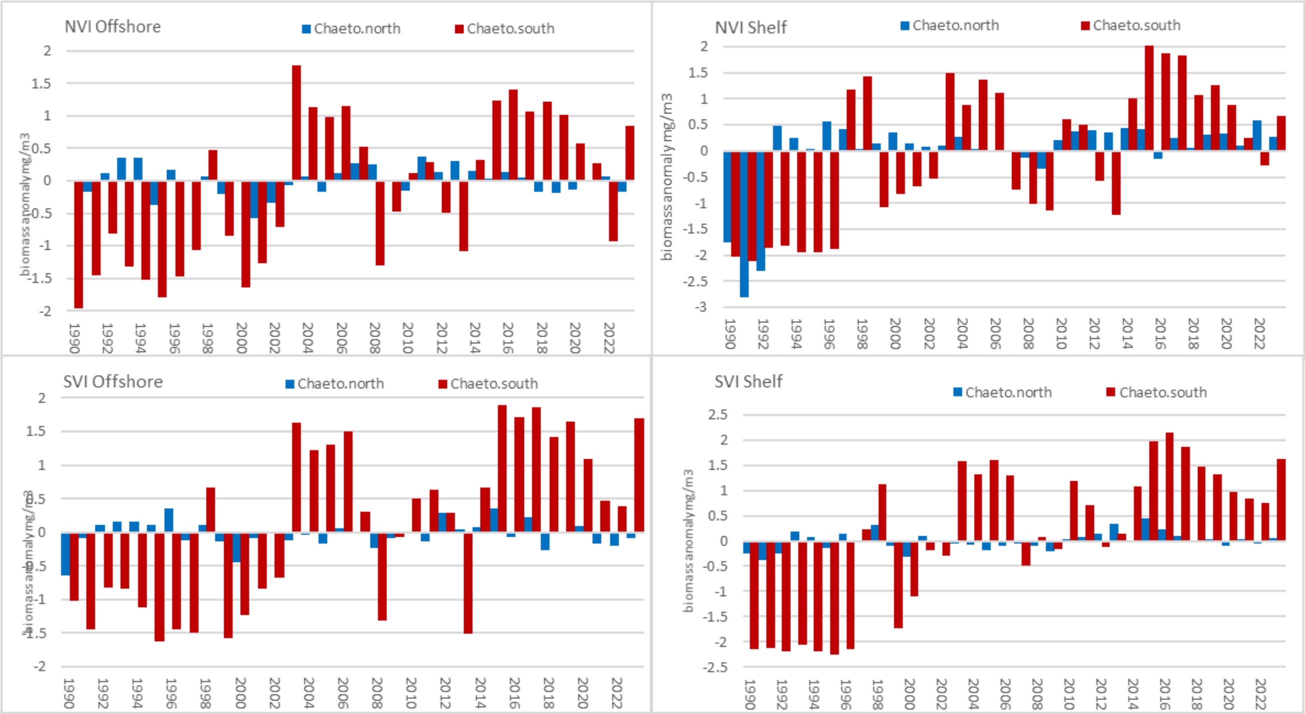

Figure 22-5. Northern chaetognaths (chaets.north) blue and Southern chaetognaths chaets.south) red, biomass anomalies time series for selected areas. Southern Vancouver Island (SVI) bottom, Northern Vancouver Island (NVI) top, shelf areas on right and offshore areas on left panels.

22.4. Implications of those trends

Overall, in 2023 there was an increase in biomass for the southern crustaceans, chaetognaths and gelatinous community across all 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 smolts), and planktivorous sea birds feeding in the early spring, but by summer the gelatinous community (low lipid content) dominated these regions.

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23. SEABIRD OBSERVATIONS ON THE B.C. COAST IN 2023

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23.1. Highlights

- For the third year in a row, diets fed to nestling Cassin's Auklets on Triangle Island in 2023 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 Protection Island in the Salish Sea and Lucy Island in Chatham Sound included normal amounts of Pacific Sand lance and Pacific Herring in 2023, but diets were very low in sand lance at Pine Island in southern Queen Charlotte Sound.

23.2. 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 2023 were quantified at Pine, Lucy, and Triangle islands, and our U.S. collaborators quantified diets on Protection Island WA.

23.3. Status and Trends

Diets fed to Cassin's Auklet nestlings

In 2023, 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 1996-2022 (Figure 23-1), https://www.ncei.noaa.gov/access/monitoring/pdo/. This was the third year in a row that this prey item occurred at lower than expected levels.

Diets fed to Rhinoceros Auklet nestlings

In 2023, diets fed to nestling Rhinoceros Auklets on Protection Island in the Salish Sea and Lucy Island in Chatham Sound included normal amounts of Pacific Sand Lance (*Ammodytes personatus*) and Pacific Herring (*Clupea pallasii*), but diets were very low in sand lance at Pine Island in southern Queen Charlotte Sound compared to an existing (2006-2022) time series (Figure 23-2). Salmon smolts were present in near-normal amounts.

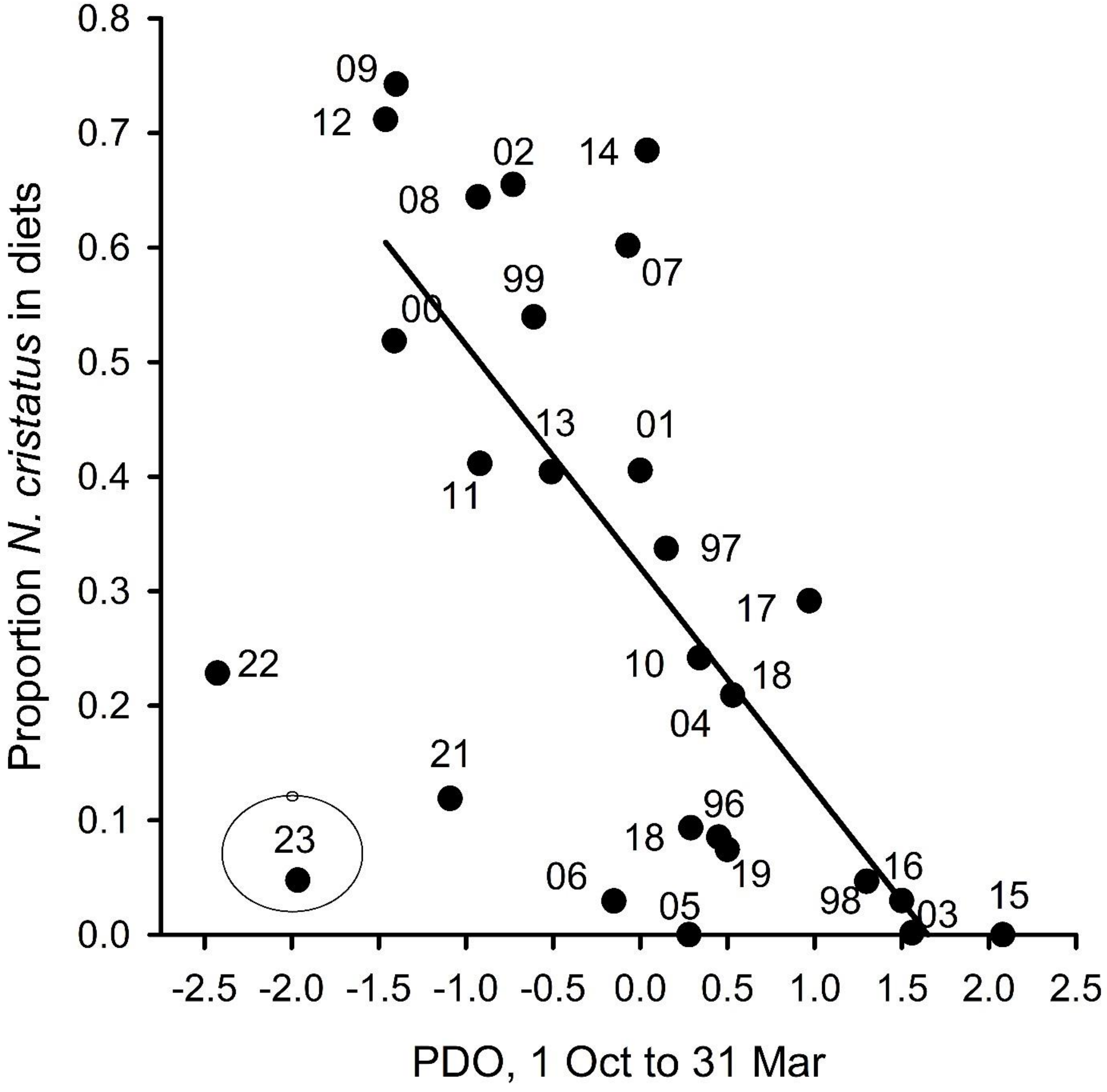

Figure 23-1. Proportion of Neocalanus cristatus in diets fed to nestling Cassin's Auklets in late June as a function of the PDO,1996 to 2023.

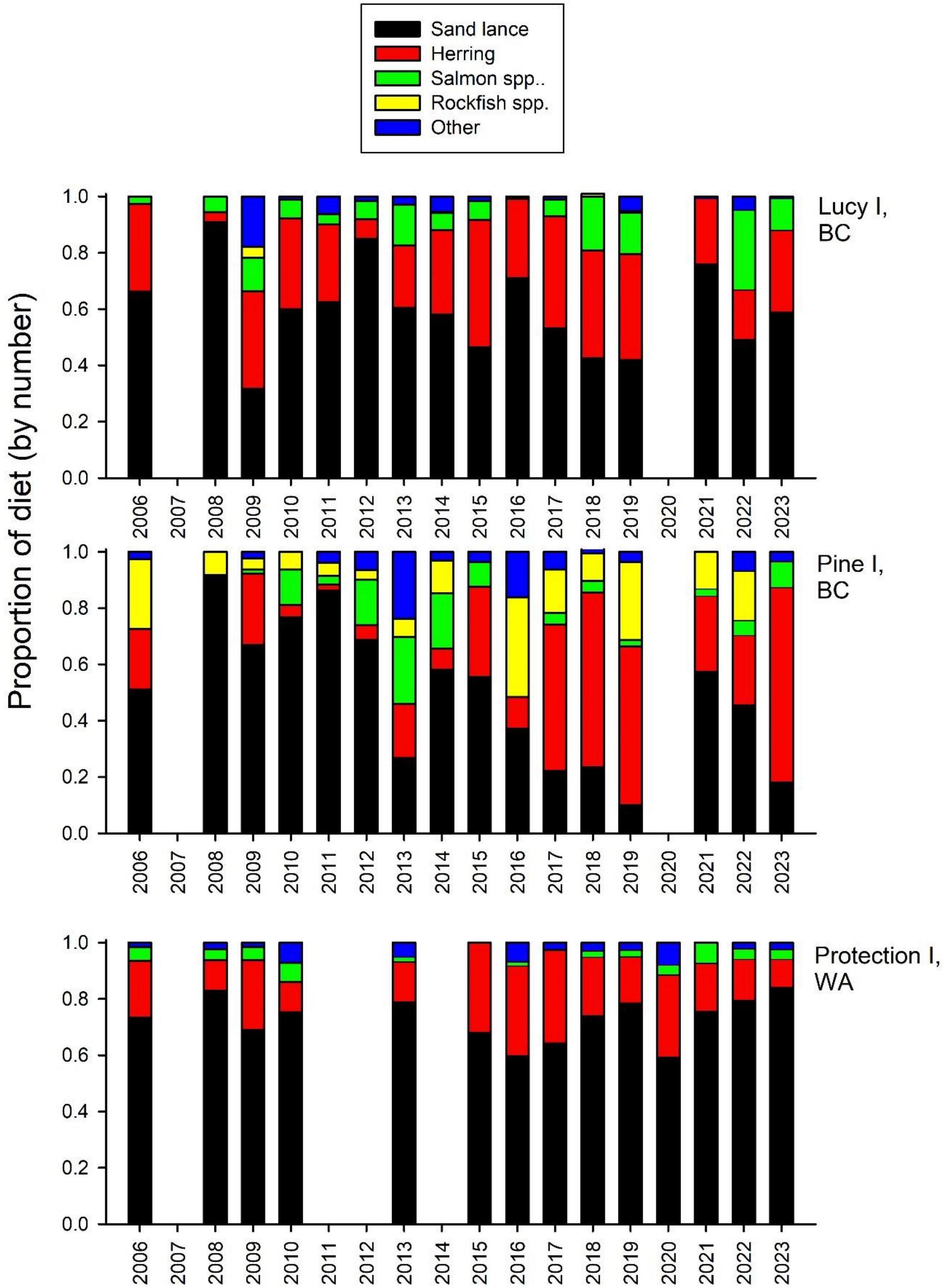

Figure 23-1. Species composition (by number) of the diets delivered to nestling Rhinoceros Auklets on 2 colonies in B.C. and 1 in WA in 2006-2023.

23.4. 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).

23.5. 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.

Diets fed to nestling Rhinoceros Auklets have shown little variation over the period of study on Protection Island, WA, in the Salish Sea; in combination, sand lance and herring make up ~90% of diet items in all years on that colony. Diets have also been relatively consistent on Lucy Island, in Chatham Sound off the North Coast, with sand lance and herring comprising ~70% or more of diet items there. By contrast, there has been very marked interannual variation in diets on Pine Island, in southern Queen Charlotte Sound off the Central Coast. Of particular note, was the marked reduction in Pacific Sand Lance content of diets in years following the Blob, and again in 2023. Although proportions are low, 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) underlying complex food web interactions.

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24. SURVEYS FOR OLYMPIA OYSTERS (*OSTREA LURIDA* CARPENTER, 1864) AT SIX INDEX SITES IN BRITISH COLUMBIA, 2010-2023

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24.1. Highlights

- Relative abundance of Olympia Oysters has remained stable at index sites between 2010 and 2023.
- On the west coast of Vancouver Island, density of Olympia Oysters was higher at Port Eliza in 2023 compared to 2022 while both Hillier Island and Harris Point were lower in 2023 compared to 2021, 2022. Density at east coast Vancouver Island sites remained stable.

24.2. 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 surveyed annually. Annual surveys more rapidly identify abundance trends and provide a better understanding of population dynamics. The six sites surveyed include: 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 (Herder et al. 2022). In agreement with Parks Canada in 2023, Joes Bay, Barkley Sound is now surveyed every other year to minimize impact to a local clam garden. Surveys were conducted during the lowest tides of the month (typically < 0.1 m tides) and took 1-2 days to complete. 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.

24.3. 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 survey time series in 2010, the large size class (> 15 mm) of Olympia Oysters at index sites have shown varying long-term trends (Figure 24-1).

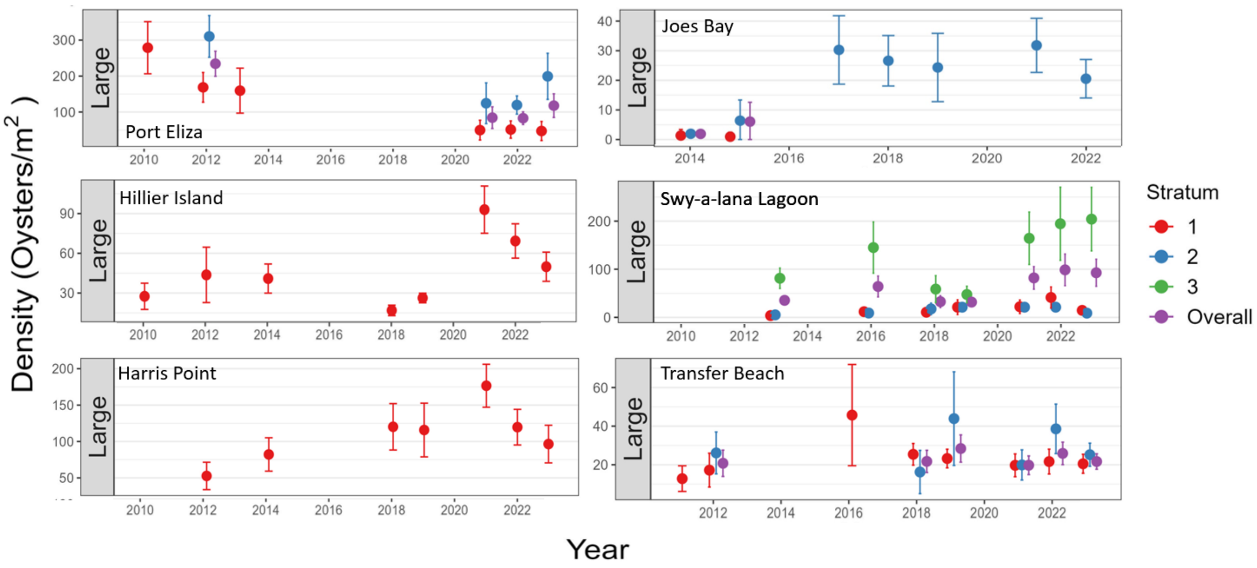

Figure 24-2. Density and 95% Confidence Intervals of large (>15mm shell length) Olympia Oyster, between 2010 and 2023, at index sites located around Vancouver Island.

Port Eliza, Nootka Sound: A high density site, Olympia Oysters in the large size class declined from 278.9 ± 73.5 (95% CI) oysters m^{-2} in 2010 to 82.9 ± 17.2 (95% CI) oysters m^{-2} in 2022. In 2023, density increased to 117.9 ± 32.2 (95% CI) oysters m^{-2}.

Hillier Island, Barkley Sound: Density of Olympia Oysters generally increased over the time series up until 2021. In 2010, density of large Olympia Oysters was 27.5 ± 9.7 (95% CI) oysters m^{-2} and in 2021 density was 93.0 ± 17.6 (95% CI) oysters m^{-2}, the highest in the time series. Density declined to 69.3 ± 12.7 (95% CI) oysters m^{-2} in 2022 and further declined to 49.9 ± 10.8 (95% CI) oysters m^{-2} in 2023.

Harris Point, Barkley Sound: Density of Olympia Oysters (large size class) increased steadily from 52.7 ± 18.4 (95% CI) oysters m^{-2} in 2012 to 176.6 ± 28.9 (95% CI) oysters m^{-2} in 2021 (highest value of the time series). Density declined to 119.7 ± 24.0 (95% CI) m^{-2} in 2022 and declined further to 96.5 ± 25.3 (95% CI) oysters m^{-2} in 2023.

Joes Bay, Barkley Sound: Only results from Stratum 2 are discussed (Stratum 1 has not been surveyed since 2015). Density of large Olympia Oysters in increased from 1.9 ± 1.2 (95% CI) oysters m^{-2} in 2014 to 30.3 ± 11.3 (95% CI) oysters m^{-2} in 2017. Density was highest in the time series in 2021 (31.8 ± 9.0 (95% CI) oysters m^{-2}) and declined slightly in 2022 to 20.5 ± 6.4 (95% CI) oysters m^{-2}. This index site was not surveyed in 2023.

Swy-a-lana Lagoon, Nanaimo: Small and large Olympia Oysters were not distinguished in 2010. Density of large Olympia oysters has fluctuated between 2013 and 2023. In 2013, density was 35.3 ± 8.4 (95% CI) oysters m^{-2} and in 2022 density was 98.7 ± 32.1 (95% CI) oysters m^{-2}; the highest value in the time series. In 2023, density slightly declined 92.7 ± 27.5 (95% CI) oysters m^{-2}.

Transfer Beach, Ladysmith: Density of large Olympia Oysters remained fairly constant at this site over the time series. Density was lowest in 2021 with 19.8 ± 4.7 95% CI) oysters m^{-2} and highest in 2019 with 28.4 ± 6.9 (95% CI) oysters m^{-2}. Density decreased between 2022 and

2023 but was within the density range for this site with 21.7 ± 3.9 (95% CI) 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).

24.4. Factors influencing trends

Found in the low intertidal zone, Olympia Oyster survival and reproduction is affected by extreme fluctuations in temperature (DFO 2009). The heat dome of 2021 does not appear to have affected 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 and these sites remained stable in 2023. On the west coast of Vancouver Island, it is less certain whether the heat dome affected oyster densities as varying trends were observed among sites: At Port Eliza, density was higher in 2023 compared to the 2021 and 2022 survey years and mean length of Olympia Oysters decreased from 25.1 mm in 2022 to 17.9 mm in 2023. The decrease in mean length of Olympia Oysters may have resulted from a recruitment event in 2023 or may be due to mortality of large oysters between the 2022 and 2023 surveys, as a large proportion of small oysters (≤ 15 mm) were observed in the length frequency data in 2023 and a smaller proportion of > 15 mm oysters were observed in 2023 compared to 2022. Comparatively, in Barkley Sound, density at Hillier Island and Harris Point declined in 2022 and again in 2023. In 2023, mean length of oysters increased at Hillier Island while mean length of oysters decreased at Harris Point; there was no indication of a recruitment event at either of these sites.

24.5. Implications of those trends

Olympia Oyster density continues to vary among Vancouver Island index sites suggesting that local-scale factors influence populations dynamics. Port Eliza experienced a slight increase in density and a recruitment event in 2023 and remains a relatively high-density site. Density at Barkley Sound sites declined in 2022 and 2023 after showing their highest respective densities in 2021, but density remains higher than the early survey years at both sites. 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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25. THE STATUS OF THE GULF OF ALASKA 2023

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25.1. Highlights

- The Gulf of Alaska shelf marine ecosystem had an average year of productivity in 2023, continuing a multi-year trend that is expected to change in 2024.
- Zooplankton were less available in 2023 (prey for adult Walleye Pollock, Pacific Ocean Perch, Dusky Rockfish, Northern Rockfish and juvenile groundfish) but nutritious large copepods were more abundant across the GOA.
- Forage fish (prey for Pacific Cod, Sablefish, Arrowtooth Flounder, Yelloweye Rockfish) varied across the GOA, and included increased Capelin abundance.
- The predominant GOA groundfish biomass continues to be characterized by increased Sablefish and Pacific Ocean Perch populations and reduced populations of Pacific Cod, Pacific Halibut, and Arrowtooth Flounder.
- Given our current El Niño status and the associated warming surface waters predicted in winter/spring of 2024, the reduction in zooplankton availability and quality may persist into the coming year.
- Vulnerable groundfish in 2024 (due to warm surface waters and reduced zooplankton quality) potentially include larval and age-0 Pacific Cod, Walleye Pollock, and Northern Rock Sole. Warm surface waters can be favorable for larval rockfish and Sablefish. Zooplankton-eating adult groundfish (Walleye Pollock, Pacific Ocean Perch, Dusky and Northern Rockfish) may have reduced prey availability but the deeper adult habitat is not predicted to warm unless El Niño-related warming continues long enough to be mixed to depth.

25.2. Description of time series

The NOAA Fisheries' 2023 Status of the Gulf of Alaska (GOA) Ecosystem Status Report (ESR) (Ferriss 2023) 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).

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

Summary

The Gulf of Alaska shelf marine ecosystem (Figure 25-1) had an average year of productivity in 2023, with some declining trends from the highly productive, previous year. Some highlights for 2023 include an increase in Pacific Cod and Capelin populations (both had not shown signs of recovery since declines related to the 2014-2016 marine heatwave), and a transition from three consecutive years of La Niña to El Niño conditions. Numerous groundfish populations increased in 2023, although some populations remain at relatively low levels. Of the assessed stocks this year, Pacific Ocean Perch, Sablefish and Walleye Pollock populations continue to increase to relatively high levels of abundance. Pacific Cod populations increased, but remain relatively low since 2017. Other populations continue a longer declining trajectory (Rougheye/Blackspotted and Shortraker Rockfish and Dover Sole).

Despite the generally productive year, some concerns persist around a decline in the zooplankton prey base. Zooplankton biomass in 2023 was variable, but declined to below average, as indicated by multiple zooplankton surveys and low biomass of age-0 Walleye Pollock and Pacific Cod (WGOA), and low energy density of juvenile Pink and Sockeye Salmon (EGOA). Given the current El Niño status and the associated warming surface waters predicted in winter/spring of 2024, the reduction in zooplankton availability and quality may persist into the coming year. The last El Niño event occurred in 2016, with warming effects augmented by the ongoing 2014-2016 marine heatwave. If we do not experience another separate marine heatwave event, the upcoming El Niño is predicted to be of a strength similar to that in 1997/1998 (Bond GOA ESR 2023). Vulnerable groundfish in 2024 (due to warm surface waters and reduced zooplankton quality) potentially include the larval and age-0 juveniles of Pacific Cod, Walleye Pollock, and Northern Rock Sole. Warm surface waters can be favorable for larval rockfish and Sablefish. Adult zooplanktivorous groundfish may have reduced prey availability (Walleye Pollock, Pacific Ocean Perch, Dusky and Northern Rockfish) but the deeper adult habitat is not predicted to warm unless El Niño-related warming persists long enough to be mixed to depth.

Western and Eastern Gulf of Alaska – Shelf

Ocean temperatures were approximately average to cooler than average in the winter and spring (surface and depth) and above average in the summer, ranging from 5.8°C (WGOA Bottom Trawl Survey, O'Leary et al. GOA ESR 2023) to 10.5°C (Icy Strait, SEAK, Fergusson et al. GOA ESR 2023). The cool early spring surface temperatures were favorable for Walleye Pollock, Pacific Cod, Northern Rock Sole egg and larval survival. The warm late spring/early summer surface temperatures may have been favorable for rockfish larval feeding and survival. Winter across- and along-shelf transport was reduced but variable, characterized by anomalous winter winds from the west that resulted in relaxed downwelling conditions, variable eddy kinetic energy (strength of eddies on the shelf edge), and strong spring gap winds around Kodiak that may have moderated the ability for groundfish larvae to be retained in favorable Shelikof Strait habitat. Reduced cross-shelf transport is less favorable to the movement of larval Arrowtooth Flounder, Pacific Halibut, and Rex Sole (slope spawners) to more favorable shelf habitat.

The spring chlorophyll-a concentration (an indicator of primary production) continued a multiyear below average trend, and peak bloom timing was considerably late (WGOA) to average (EGOA) across the regions (Gann et al. GOA ESR 2023). While late peak spring blooms can be driven by colder springs, this event may also be explained by a deeper mixed layer in the winter/spring. Weaker stratification of the water column and a deeper mixed layer depth can reduce the opportunity for wind mixing to bring plankton and nutrients to the surface to promote spring blooms. Stratification strengthened in early May, one of the factors contributing to the spring bloom along the Seward Line (Danielson et al. GOA ESR 2023).

Prey availability for zooplankton-eating adult groundfish (e.g., Walleye Pollock, Pacific Ocean Perch, Dusky and Northern Rockfish), and larval/juvenile groundfish, was below average to average across the GOA shelf. Total zooplankton biomass progressed from below average in the spring to improved conditions in the summer, with variable copepod biomass but relatively high euphausiid biomass across the GOA (Shelikof Straight, Kimmel et al. GOA ESR 2023; Seward Line, Hopcroft et al. GOA ESR 2023; Icy Strait, Fergusson et al. GOA ESR 2023). Planktivorous seabird reproductive success, an indicator of zooplankton availability and nutritional quality, was approximately average in the western (Chowiet Island) and the central GOA (Middleton Island) (Drummond et al. GOA ESR 2023.; Whelan et al. GOA ESR 2023). Catches of larval pollock and Pacific Cod in spring and summer surveys were low (Shelikof Straight, Rogers et al. GOA ESR 2023), suggesting less productive feeding conditions in the nearshore.

The reduced total zooplankton biomass could be explained by lower production, potentially connected to the late and reduced spring phytoplankton bloom, or by increased top down grazing pressure. Predators of zooplankton increased in 2023, relative to 2022, driven by large returns of Pink Salmon (Whitehouse et al. GOA ESR 2023; Vulstek et al. GOA ESR 2023), relatively large and increasing populations of Pacific Ocean Perch (Hulson et al. 2023) and Walleye Pollock (Monnahan et al. 2023), and continued production of large year classes of juvenile Sablefish in recent years (Goethell et al. 2023). Regardless of the mechanism, there appears to have been adequate, but less than optimal, zooplankton available to support predators in 2023. Signs of a restricted prey base include a decline from above average to average zooplanktivorous seabird reproductive success, lower body condition (weight at length) of adult Walleye Pollock, below average energy density of juvenile salmon, and juvenile Pink Salmon diet dominated by gelatinous prey (less nutritious alternative to zooplankton) (Icy Strait, SE Alaska, Fergusson et al. GOA ESR 2023). Predictions for 2024 returns of Pink Salmon seem less favorable based on juvenile CPUE, length, and energy density in 2023, highlighting the reduced zooplankton base in 2023 (Yasumiishi et al. GOA ESR 2023).

Prey availability for fish-eating groundfish (e.g., Pacific Cod, Sablefish, Arrowtooth Flounder, Yelloweye Rockfish) was approximately average with signs of reduced abundance. Capelin populations are rebounding for the first year since their decline during the 2014-2016 marine heatwave (McGowan et al. GOA ESR 2023; Whelan et al. GOA ESR 2023). Herring population biomass remains elevated, but is decreasing due to a declining 2016 strong year class (as assessed in EGOA but assumed GOA-wide trends; Hebert et al. GOA ESR 2023; Pegau et al. GOA ESR 2023). Age-0 Walleye Pollock, a common prey in western GOA, had very low abundance (Rogers et al. GOA ESR 2023). The reproductive success of piscivorous, diving seabirds (Common Murres and Tufted Puffins), decreased from 2022 to below average/average across the GOA (Drummond et al. GOA ESR 2023; Whelan et al. GOA ESR 2023), indicating less than sufficient/adequate prey to meet reproductive needs. In particular, Black Legged Kittiwakes experience reproductive failure on Chowiet Island (Alaska Peninsula), potentially due to lack of age-0 Walleye Pollock and Pacific Sandlance in that area.

The predominant GOA groundfish species, by biomass, continue to be characterized by reduced populations of Pacific Cod, Pacific Halibut, and Arrowtooth Flounder, and increased Sablefish and Pacific Ocean Perch populations. While the implications of the Pacific Ocean Perch population expansion (numerically and spatially) are not well understood, the biomass has grown large enough for the signal of this longer-lived, zooplankton-eating species to influence trends in various GOA groundfish community metrics (e.g., groundfish community stability and average groundfish lifespan (Whitehouse et al. GOA ESR 2023)).

GOA Shelf Edge/Upper Slope

The GOA shelf edge and upper slope demersal/benthic habitat is habitat for numerous managed groundfish species, including Sablefish, rockfish (Thornyhead Rockfish, Rougheye/Blackspotted Rockfish, Shortraker Rockfish, and the slope subgroup of the other rockfish complex), and the deepwater flatfish complex (e.g., Dover Sole). A number of these species migrate onto the shelf to spawn, and others are capable of changing depths in response to environmental conditions (Yang 2019), increasing their ability to mitigate unfavorable habitat and forage conditions.

This deeper habitat is often buffered from variable environmental conditions occurring in the upper water column (e.g., the predicted surface warming of El Niño in 2024). However, this habitat can be exposed to warmer temperatures mixed from shallower depths over time, as well as decreased dissolved oxygen, pH, and aragonite saturation from deep water intrusions from the central GOA gyre (Hauri et al. 2024). Bottom temperatures in 2023 along the shelf edge (250 m) cooled to the long-term average after being consistently above average since 2016 (Temperature Synthesis, GOA ESR 2023). In fall 2022 and winter 2023, the Gulf of Alaska experienced weaker downwelling conditions on the shelf, favoring intrusion of deeper, saltier, and more acidic water from the central GOA gyre onto the upper slope and shelf (Bond GOA ESR 2023; Pages et al. GOA ESR 2023). Modeled and observed time series along the Seward Line show statistically significant long-term decreasing trends of bottom water pH, aragonite saturation, and dissolved oxygen, an indication of steady degradation of the habitat. Observed bottom pH at GAK 9 (an outer shelf station of the Seward Line) was particularly low in spring of 2023, reaching values potentially detrimental to Tanner Crab (pH = 7.56; Pages et al. GOA ESR 2023). These environmental characteristics are not currently within the range of detrimental effects of groundfish species in the shelf edge/slope region.

Structural epifauna (primarily sponges), as measured poorly and indirectly from various surveys, continue to show signs of a multi-year decline in the WGOA (bottom trawl survey CPUE Laman et al. GOA ESR 2023; non-target catch, Whitehouse et al. GOA ESR 2023). These slow growing structures are important habitat for rockfish, but any mechanistic link to rockfish population survival and productivity is unknown.

Looking ahead to 2024 (El Niño)

Surface temperatures are predicted to warm in late winter/early spring of 2024, in alignment with the current El Niño (Bond 2023, NMME). The most recent El Niño events occurred in 2015/2016, 2002/2003, and 1997/1998. The warming impacts of the 2016 event was compounded by the ongoing multi-year marine heatwave. The mass of warm water (termed ‘the Blob’) that moved from the central north Pacific onto the Alaskan shelf to initiate the 2014-2016 marine heatwave has persisted offshore since then. To-date it does not show signs of moving back onto the shelf (as of Oct 2023). The trajectory of that warm mass would determine if Alaska experiences strong, but more typical, El Niño warming conditions (perhaps similar to 1997/1998) or a more persistent and intense separate marine heatwave/El Niño combination (similar to 2016). Past El Niño’s have been associated with a stronger Aleutian Low, driving stronger southerly winds, and an increase in eddy strength (Crawford et al. 2002; Whitney and

Robert 2002), potentially resulting in increased cross-shelf transport of slope-spawned larvae Arrowtooth Flounder, Pacific Halibut, Rex Sole (Bailey 1997; Bailey and Picquelle 2002). These climate-ecosystem relationships can be tenuous and remain to be seen for 2024 (Litzow et al. 2018).

Warm winter/spring surface temperatures in the GOA coincide with an early spring phytoplankton bloom (Gann et al. GOA ESR 2023), early hatch times of cod eggs (up to 19 days earlier) and potentially larger age-0 cod (Laurel et al. 2023). There is potential for the surface temperatures to exceed the optimal temperatures for larvae survival and feeding of the early spring shelf spawners (Pacific Cod, Walleye Pollock, Northern Rock Sole), negatively impacting the 2024 year classes of these species. Conversely, warm surface waters in spring and summer can be favorable for rockfish larval survival. As it takes time for warm surface waters to mix to depth, the extent of warming that might occur in the deeper habitat of adult groundfish is dependent on the intensity and persistence of the surface warming, but would be a delayed effect of the winter El Niño warming event.

Most groundfish populations have one or more recent strong year classes that could help the population persist through a challenging year. The warm period driven by 2014-2016 and 2019 marine heatwaves followed by a multi-year cooling during the 3 consecutive La Niña events (2020/2021-2022/2023) have jointly produced some strong year classes for numerous groundfish species across the spectrum of temperature affiliations. The cooler and productive winter/springs favored larval Walleye Pollock (2017, 2018, 2020) and Pacific Cod (2020, 2022). The warmer late spring/summers favored rockfish larvae (*Sebastes* spp., including Pacific Ocean Perch). Sablefish have had multiple strong year classes since 2016. Some important forage species have also benefitted from strong year classes, including Pacific Herring (2016, 2020), Capelin (2023) and Tanner Crab (2019).

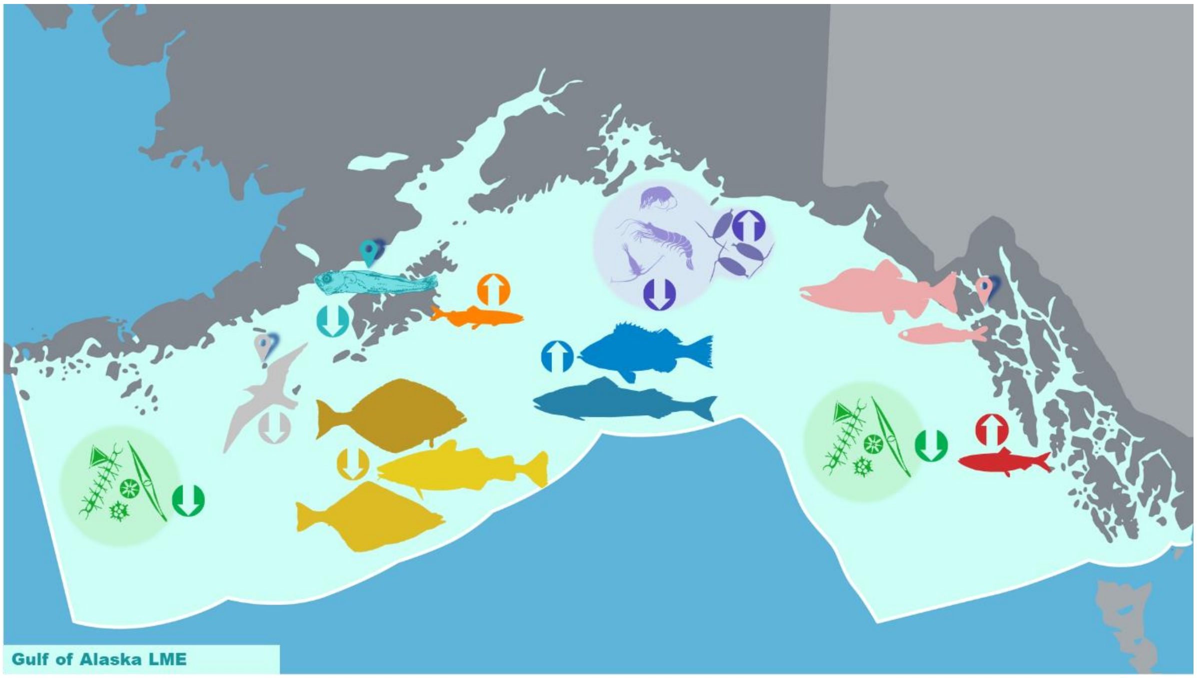

Figure 25-1. A visual summary of ecosystem trends in the Gulf of Alaska in 2023. Figure and additional details can be found in the Gulf of Alaska In Brief (2023) (https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands). The symbols include: chlorophyll-a, zooplankton biomass Biomass of larval Walleye Pollock and Pacific Cod, juvenile Pink Salmon diet, Pink Salmon returns, Capelin abundance, Pacific Herring biomass, age-0 Walleye Pollock abundance, Black-Legged Kittiwakes reproductive success, Pacific Cod biomass, Pacific Halibut biomass, Arrowtooth Flounder biomass, Sablefish biomass, and Pacific Ocean Perch biomass.

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26. NORTH PACIFIC ECOSYSTEM EFFECTS OF PINK SALMON: FROM DIATOMS TO KILLER WHALES

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26.1. Highlights (from Ruggerone et al. 2023)

- Salmon abundance and biomass increased in the North Pacific beginning in the mid-1970's in response to the 1977 regime shift and the development of hatcheries.
- There are now more salmon in the North Pacific than ever, and these abundances are dominated by Pink Salmon, especially during odd-numbered years, when these 2-year-old fish are most abundant.
- Biennial patterns (i.e., differences between even and odd numbered years) have been observed for many species ranging from phytoplankton to Killer Whales.
- Characteristics expressed by many of these species were inversely correlated with Pink Salmon abundance.
- Since physical factors are not known to vary biennially, the most parsimonious explanation for the majority of the biennial patterns is competition with Pink Salmon for a common pool of prey resources.
- It appears that predation by Pink Salmon in odd years can initiate pelagic trophic cascades by reducing herbivorous zooplankton sufficiently that phytoplankton increase.

26.2. Status and trends

Adult Pink Salmon (pre-fishery) returning to Asia and North America numbered ~300 million from 1925-1940, declined to ~150 million in the early 1970's after which they increased to as high as 800 million. Numbers returning in odd years consistently outnumbered those returning in even years.

26.3. Factors influencing trends

Pink Salmon numbers increased in response to a climate regime shift in 1977 and general heating in the North Pacific as well as increased hatchery production.

26.4. Description of other time series

Evidence for interactions between Pink Salmon and plankton, forage fishes, squid, Pacific salmon, seabirds and whales was provided by data from separate time series in 88 publications. These statistical relationships were described in the manuscript's supplemental online database.

26.5. Implications of these trends

Widespread interspecific competition for common-pool prey resources can be dominated by Pink Salmon, as indicated by numerous and consistent biennial patterns in the diet, growth, survival, abundance, age-at-maturation, distribution, and/or phenology of forage fishes, squid, Pacific Salmon and steelhead trout, seabirds, Humpback Whales, and endangered southern resident Killer Whales.

In aggregate, the evidence indicated that open-ocean marine carrying capacity in the northern North Pacific Ocean and Bering Sea can be mediated by top-down forcing by Pink Salmon and by ocean heating, and that large-scale hatchery production of all Pacific Salmon (~40% of the total adult and immature salmon biomass [primarily Chum but also Pink Salmon]) likely has unintended consequences for natural-origin salmon and many other marine species.

Further investigation of the effects of Pink Salmon on other species will increase our knowledge of ecosystem function and the key role top down forcing plays in the open ocean.

Researchers are encouraged to look for biennial time series patterns in their data and if found, consider explanatory mechanisms including Pink Salmon.

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27. PACIFIC HERRING IN BRITISH COLUMBIA, 2023

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27.1. 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 remained unchanged.
- Total B.C. coastwide spawning biomass summed across the 5 major stocks increased during 2010-2020 and leveled off in 2021-2023. The estimated Pacific Herring spawning biomass varied among the assessed stocks with the majority of the total biomass of herring in B.C. occurring in the Strait of Georgia (SOG).

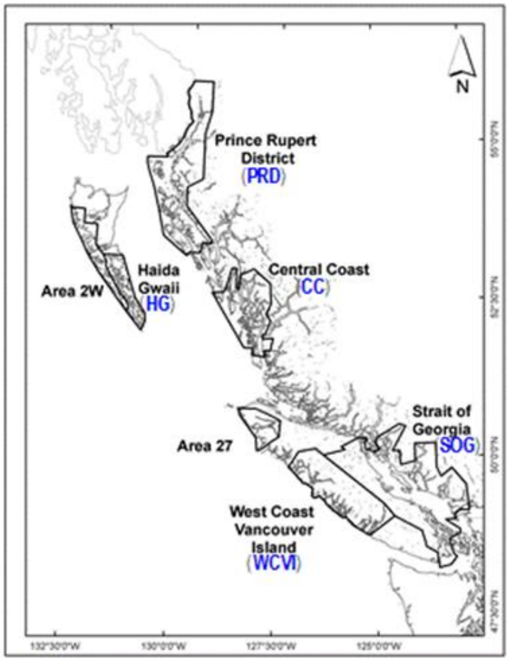

Figure 27-1. Location of the five major (Strait of Georgia, West Coast of Vancouver Island, Prince Rupert District, Haida Gwaii, and Central Coast) as well as two minor (Area 2W, and Area 27) Pacific Herring stocks in B.C.

27.2. 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 2024; Figure 27-1). For each stock, Pacific 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.), Pacific Herring spawn survey data (spawn index), and commercial harvest data (DFO 2024).

27.3. Status and trends

In all five major Pacific Herring stocks there was a declining trend in weight-at-age from the 1980s through to 2010, with a leveling off in recent years (Figure 27-2). Since 2000, the HG stock continues to exist in a low biomass low productivity state, fluctuating above and below the limit reference point (LRP). Compared to 2022, the biomass in 2023 decreased (DFO 2024). The estimated stock biomass for PRD is above the LRP and increased in 2019, and 2021-2023. The CC survey biomass is above the LRP; however, it has declined since 2020. 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 2023 but remains above both the LRP and the upper stock reference (USR), and is still relatively high compared to historic estimates (Figure 27-3). WCVI stock biomass has slowly increased since 2012 and is currently above the LRP (DFO 2024; Figure 27-3).

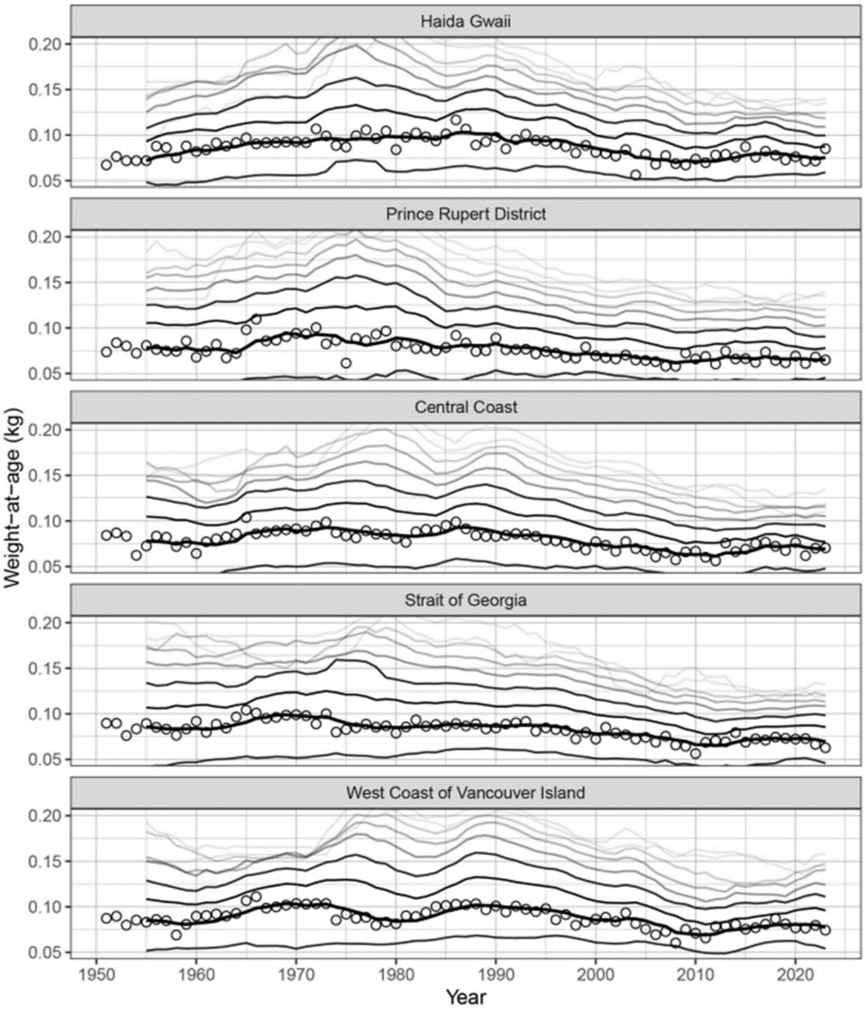

Figure 27-2. Observed weight-at-age 3 (circles) and five-year running mean weight-at-age 3 (dark line) for major Pacific Herring stocks, 1951 to 2022. Thinner black lines represent five-year running mean weight-at-age 2 (lowest) and ages 4-10+ (incrementing higher from age 3). Figure from DFO (2024).

27.4. Factors influencing trends in herring biomass

Common trends in Pacific Herring weight-at-age observed for all B.C. stocks suggests that large-scale factors may be influencing Pacific Herring growth. Changes in environment, food supply and quality, predator abundance, and competition are factors that could affect trends in Pacific 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 Pacific Herring (Schweigert et al. 2010; Mackas et al. 2004).

There are a wide variety of Pacific 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). Pacific 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 Pacific Sardines (Godefroid et al. 2019).

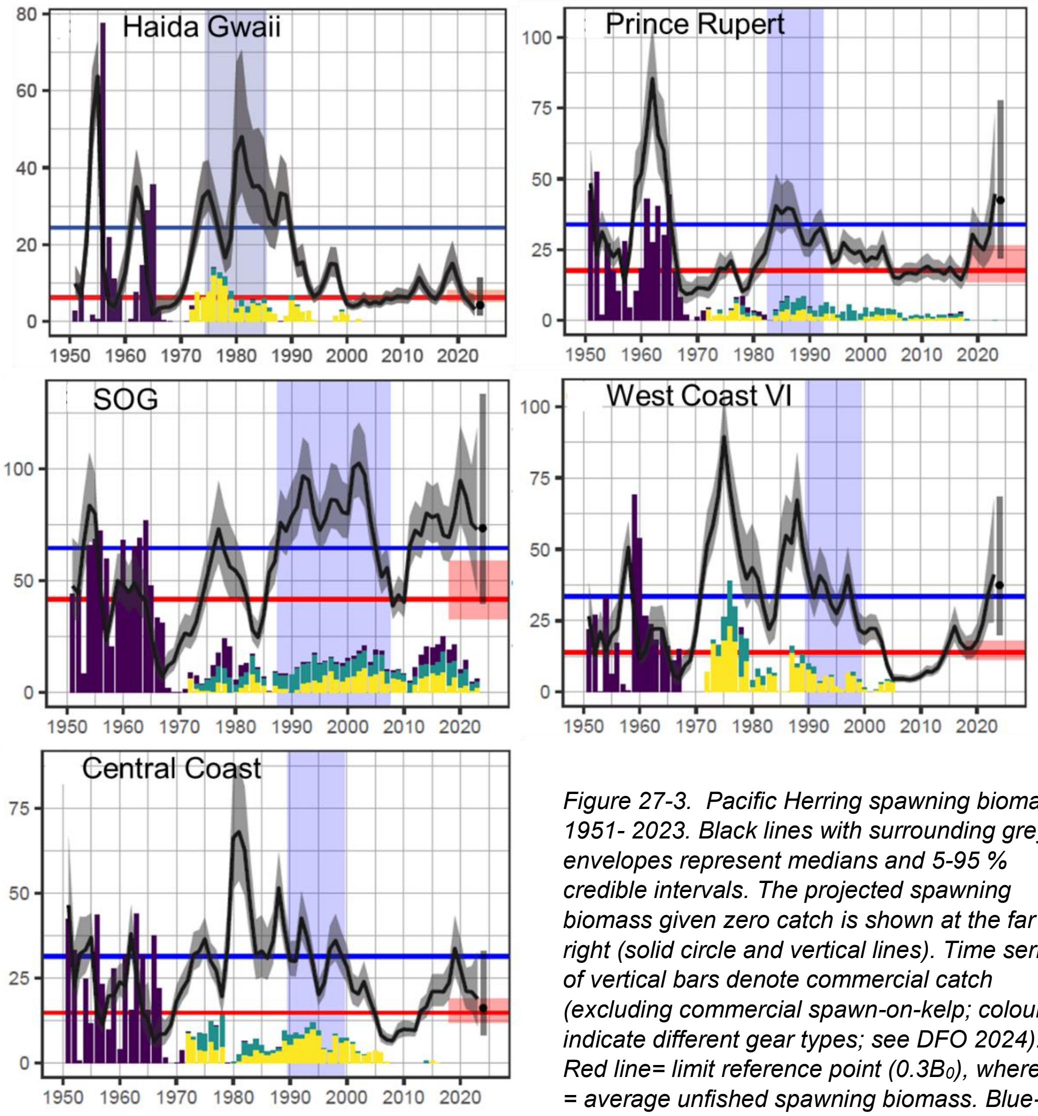

Figure 27-3. Pacific Herring spawning biomass, 1951- 2023. Black lines with surrounding grey envelopes represent medians and 5-95 % credible intervals. The projected spawning biomass given zero catch is shown at the far right (solid circle and vertical lines). Time series of vertical bars denote commercial catch (excluding commercial spawn-on-kelp; colours indicate different gear types; see DFO 2024). Red line= limit reference point ($0.3B_0$), where B_0 = average unfished spawning biomass. Blue-shading denotes productive years used to calculate the USR (blue line-correct?). Figure from DFO (2024).

27.5. Implications of trends

Trends in Pacific 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 biomass. All TAC options reflect MPs that meet the conservation objective of avoiding the LRP with a minimum 75% probability.

Trends in Pacific Herring biomass have implications for their predators, such as fish, marine mammals and seabirds. The relative importance of Pacific Herring in each predator's diet varies; however, Pacific 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, Pacific 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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28. PACIFIC HERRING SUMMER DISTRIBUTION AND ABUNDANCE OFF THE VANCOUVER ISLAND CONTINENTAL SHELF

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28.1. Highlights

- In July 2023 off the west coast of Vancouver Island, Pacific Herring biomass was the 2nd highest in the time series, 2006-2023.
- In July 2023, Pacific Herring were particularly high off of the southwest coast of Vancouver Island.

28.2. Description of the time series

Since 2017, the Integrated Pelagic Ecosystem Science (IPES) survey has been conducted to study the structure and function of the pelagic ecosystem on the Vancouver Island continental shelf (< 200 m bottom depth), during the summer (see King et al. 2019; Boldt et al. 2020; Boldt et al. 2024). 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 that has 8 strata, defined by depth and biological communities. Each survey year, a subset of blocks is randomly selected (allocated by strata sizes) and a midwater trawl net is 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) is estimated as species' catch weights divided by swept volume (product of net mouth opening height, width, and distance towed). Two products of this survey are Pacific Herring biomass and distribution, which are the focus of this summary. To extend the time series, Pacific Herring biomass was estimated using a spatio-temporal model (Anderson et al. 2022) that combined IPES data with historic night-pelagics survey data (2006-2014; see Flostrand et al. 2014), while accounting for important variables, such as daytime or nighttime trawl sets and gear depth. In 2023, the survey was conducted from July 5 to 31, 2023.

28.3. Status and trends

As seen in previous years Pacific Herring dominated the catches and represented 62% of the total survey catch weight (Boldt et al. 2024). Pacific Herring are typically broadly distributed on the Vancouver Island continental shelf in the upper ~45 m of the water column during night time hours. In 2023, Pacific Herring biomass was the 2nd highest in the time series (with a high variance estimate) at 124,812 t (Figure 28-1). Areas of highest CPUE were located off the southwest coast of Vancouver Island.

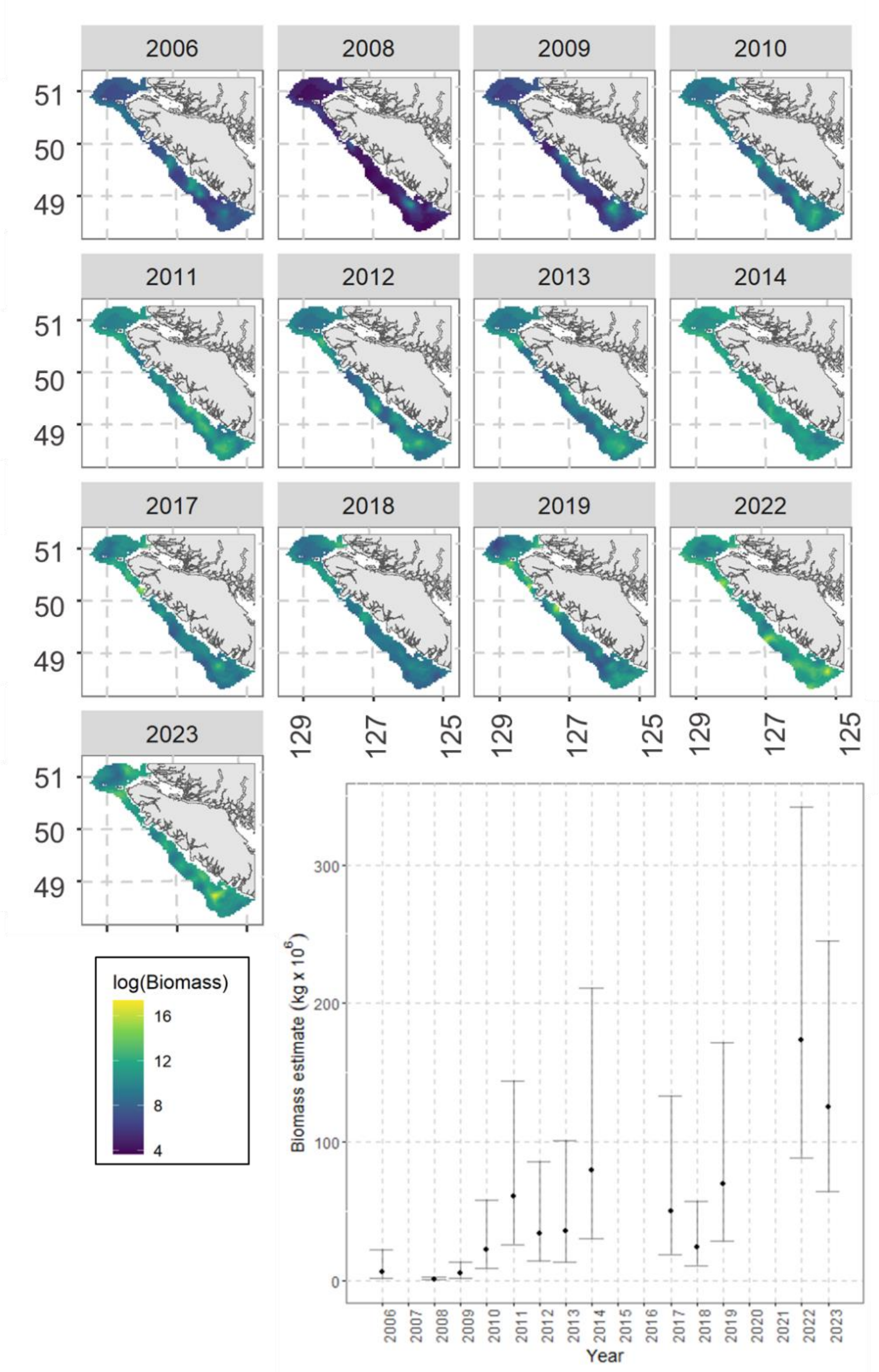

Figure 28-1. Pacific Herring biomass, as estimated with a spatio-temporal model, in the night pelagics (2006-2014) and Integrated Pelagic Ecosystem Science surveys (2017-2023) (top panel) and total biomass estimates, 2006-2023 (bottom panel).

28.4. 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 on the west coast of Vancouver Island, 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) and 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).

28.5. 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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29. 2023 JUVENILE SALMON SURVEYS ON THE CONTINTENTAL SHELF OF VANCOUVER ISLAND

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29.1. Highlights

- Chum Salmon relative abundance estimates were above average. Juvenile Chum Salmon are usually dominated by west coast Vancouver Island stocks (summer) and by Strait of Georgia stocks (summer and fall) returning in 2026.
- Chinook Salmon relative condition in summer was above average, and these fish are usually dominated by Columbia River stocks stream-type cycles that will return predominately in 2025.
- Coho Salmon were in above average condition in summer; these fish originate from west coast watersheds (Vancouver Island, Washington State, Columbia River) and Puget Sound. Coho Salmon abundance was above average in fall; these fish are usually dominated by stocks originating from west coast Vancouver Island, Strait of Georgia and Puget Sound. Juvenile Coho Salmon will return in 2024.
- Pink Salmon were in above average condition in summer, and will return in 2024.
- Sockeye Salmon relative abundance in summer has increased significantly from 2021 and 2022 and these salmon were in above average condition in summer. These juvenile salmon are typically dominated by west coast Vancouver Island stocks returning in 2025.

29.2. Description of the time series

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

Since 1998, 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 beyond the shelf-break and into coastal inlets. In 2017, the survey design was switched to a stratified, random design (King et al. 2019). 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) since 2018. Since 2017, 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). In 2023, 123 tows were completed on the continental shelf from Queen Charlotte Sound to the mouth of Juan de Fuca (Boldt et al. 2024).

Fall Juvenile Salmon Survey on the continental shelf and inlets of Vancouver Island

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 2023, vessel breakdown resulted in only 22 tows completed on the northern portion of the continental shelf in Queen Charlotte Sound, north of Brooks Peninsula.

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 effort, and include impacts from headrope depth, diurnal vs. nocturnal sampling, and changes in summer survey design (Freshwater et al. 2024). The model can provide estimates for years where no surveys were completed, and can also accommodate incomplete surveys (e.g., fall 2023); however, these estimates should be interpreted with caution. Length and weight data were used to estimate species-specific length-weight regressions across years with annual weight residuals presented to represent condition for the summer survey only since the fall survey was not completed in its entirety.

29.3. Status and trends

Relative abundance

The Abundance Indices (log) derived from seasonal and species-specific geostatistical models (Figure 29-1) indicate that Chum Salmon were the most abundant species encountered in both summer and fall. The 95% confidence intervals associated with the 2023 Abundance Index for summer and fall caught Chum Salmon marginally included the average values, but the index value was the highest in both time series (Figure 29-1). Fall caught Coho Salmon were also above average (Figure 29-1). All other Abundance Indices were close to the time series average (Figure 29-1). Of note is the 2023 summer Sockeye Salmon index which, while only average, increased substantially from the historic low summer index values estimated in 2021 and 2022 (Figure 29-1).

Condition

The 2023 summer median and quartile ranges of weight residuals Chinook Salmon, Coho Salmon, Pink Salmon and Sockeye Salmon were above average (Figure 29-2) indicating these juvenile salmon were fatter than normal.

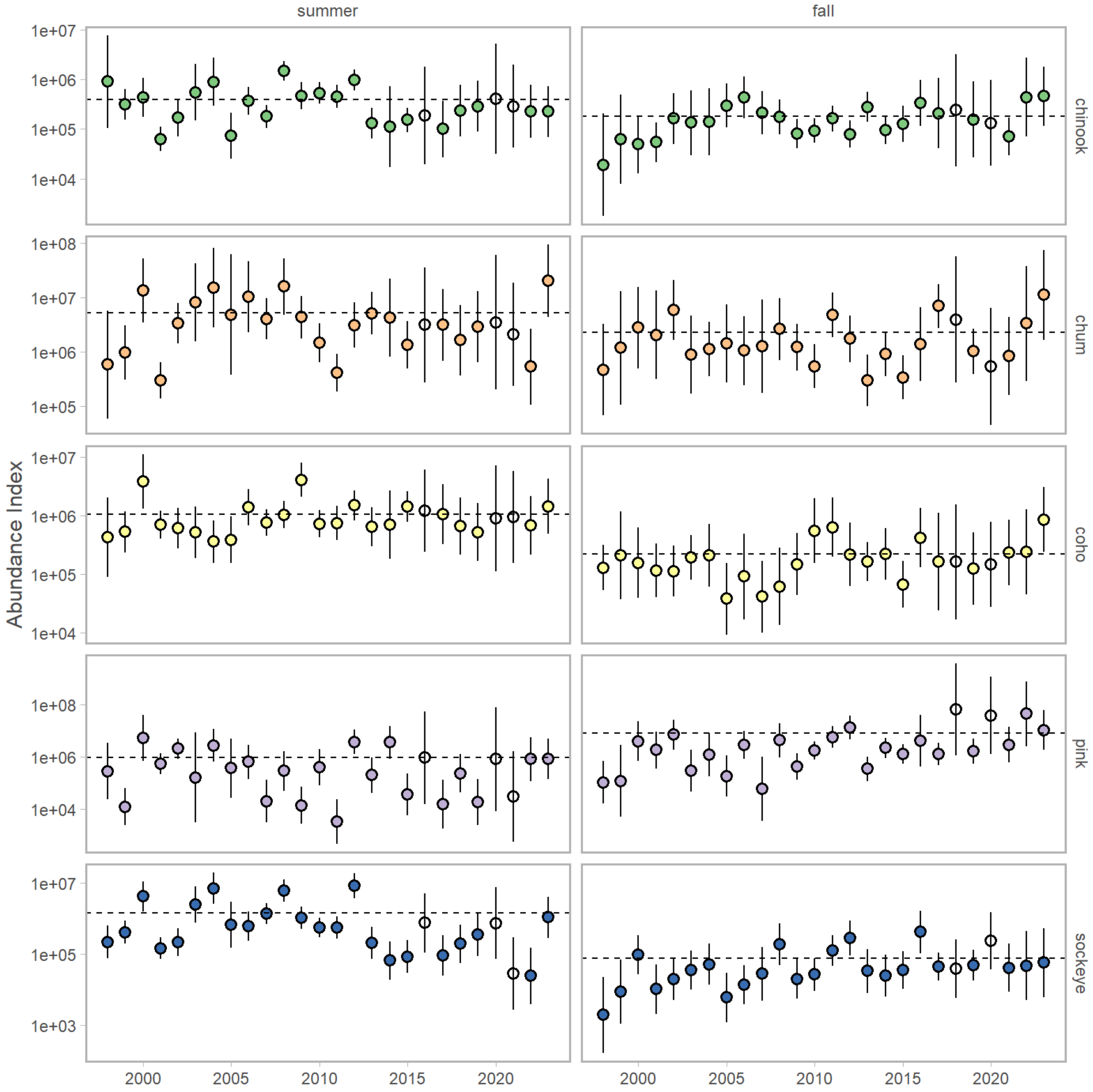

Figure 29-1. Annual (log) Abundance Index estimated from geostatistical models for juvenile Chinook, Chum, Coho, Pink and Sockeye Salmon caught in summer on the continental shelf of Vancouver Island and in fall on the continental shelf and inlets of Vancouver Island. Dashed lines indicate the long-term averages. 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. Fall estimation for 2023 based on reduced survey area. See Freshwater et al. (2024) for estimation methods.

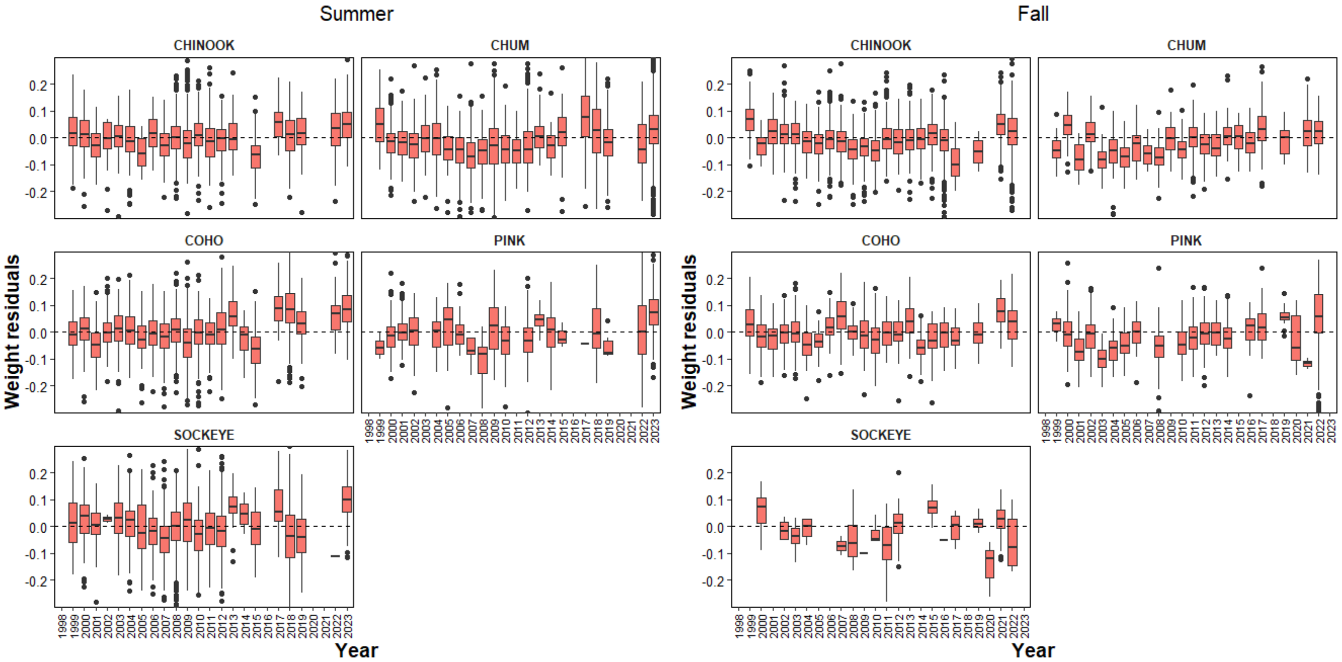

Figure 29-2. Box plots of weight residuals calculated from species-specific length-weight regressions (all years and seasons combined) for juvenile Chinook, Chum, Coho, Pink and Sockeye Salmon caught in summer on the continental shelf of Vancouver Island in fall on the continental shelf and inlets of Vancouver Island. Fall 2023 values are not provided since only a small portion of the survey area was completed.

29.4. 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 2023, summer Sockeye Salmon were fatter than normal and euphausiids were >90% of the prey consumed, which has not been observed in previous years with stomach enumeration (i.e., 2017-2022).

29.5. 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 2024; stream-type Chinook and Sockeye Salmon returning in 2025; and ocean-type Chinook and Chum Salmon returning in 2026. Genetic stock identification from previous surveys provide general indication of regional origins of the salmon encountered. The above average condition of Chinook Salmon in summer applies mainly to stream-type Columbia River stocks returning predominantly in 2025. The above average Abundance Index in summer and fall for Chum Salmon apply predominately to west coast Vancouver Island stocks (summer) and Strait of Georgia stocks (summer and fall) returning in 2026. The above average condition of Coho Salmon in summer applies to west coast stocks (Vancouver Island, Washington State, Columbia River) and Puget Sound stocks returning in 2024. The above average Abundance Index fall for Coho Salmon apply to stocks originating from west coast Vancouver Island, Strait of Georgia and Puget Sound returning 2024. The improved Abundance Index and above average condition for Sockeye Salmon in summer most likely apply to west coast Vancouver Island stocks 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.

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30. BROAD SCALE MARINE AND FRESHWATER SOCKEYE PRODUCTIVITY IN B.C.

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30.1. Highlights

- Freshwater Sockeye Salmon productivity was variable with several watersheds showing above average (Fraser, Stikine, Taku), Columbia showing average, and Somass showing below average productivity in recent years.
- Marine survival of Sockeye Salmon was generally below or near the long-term average for all watersheds.

30.2. Time series - annual productivity of Sockeye “indicator stocks”

Smoothed Sockeye Salmon productivity time series were generated from data produced by various stock assessment programs across B.C., Washington, and Alaska (Figure 30-1). Smolt and fry abundances were monitored using a combination of fish fences and hydroacoustic surveys. Methods for estimating recruit abundance (i.e., the number of fish that arrived in terminal locations) 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. Stock-level freshwater productivity was calculated as the annual deviation from predicted ln(recruits/spawner) based on a linearized Ricker model fit to each Sockeye Salmon stock. Stock-level marine survival was calculated as smolt year (based on ocean age) recruit abundance divided by smolt year juvenile abundance (smolts or fry).

We fit Bayesian Multivariate Auto-Regressive State Space (MARSS) models to stock-specific time series of freshwater productivity and marine survival. Briefly, MARSS models estimate one or more autocorrelated, shared trends among multiple time series (Holmes et al. 2020). Here, we structured our MARSS models to produce shared trends in freshwater productivity and marine survival by watershed origin (e.g., Fraser, Somass; Figures 30-2, 30-3). Note that shared trends are based on centered and scaled time series and therefore can be interpreted as anomalies in freshwater productivity and marine survival.

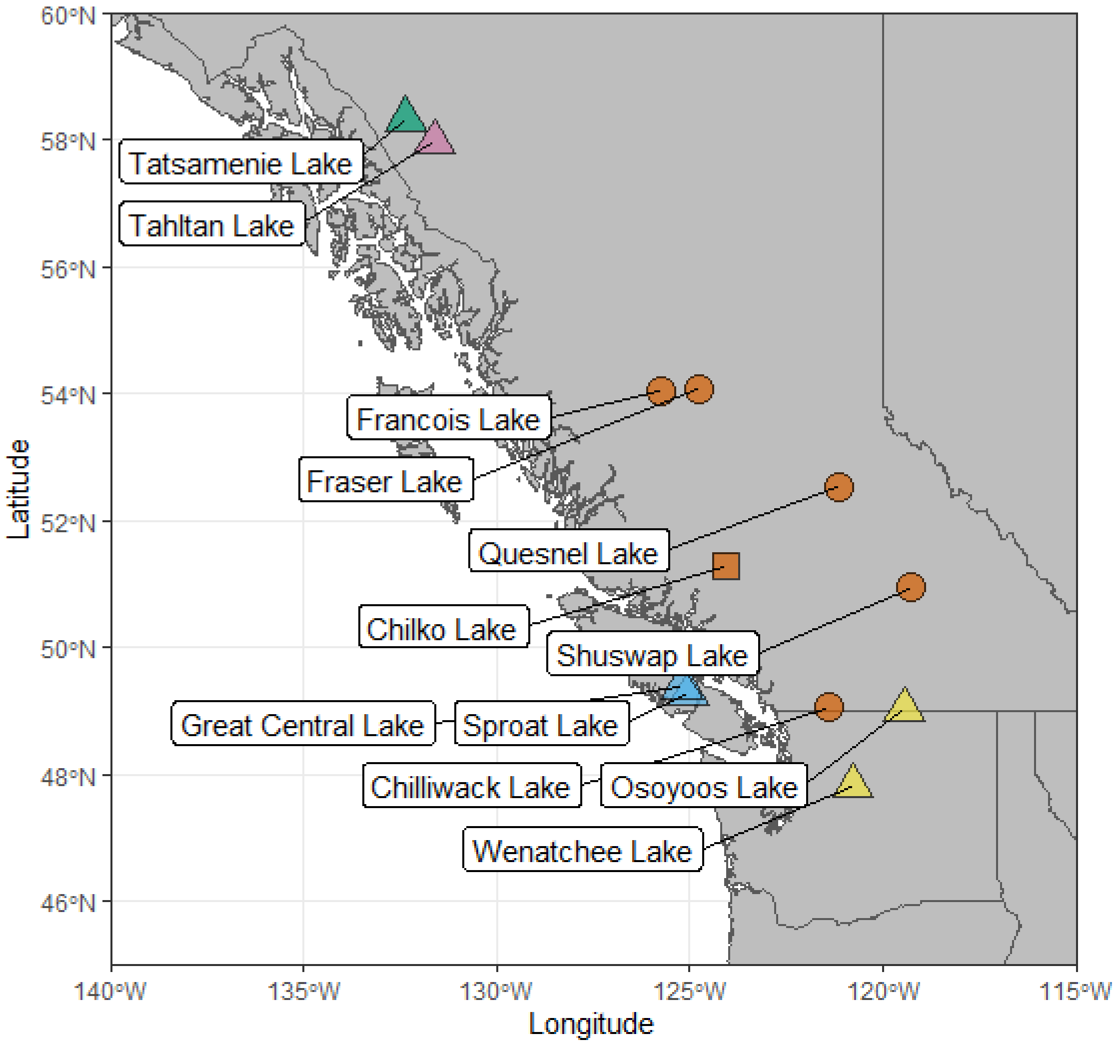

Figure 30-3. Locations and juvenile enumeration method of Sockeye Salmon "indicator stocks". Squares represent stocks with both fry and smolt estimates, circles for fry hydroacoustic surveys only, and triangles for smolt estimates only. Stocks are coloured by watershed, where orange represents the Fraser, light blue Somass, yellow Columbia, pink Stikine, and green Taku watersheds, respectively.

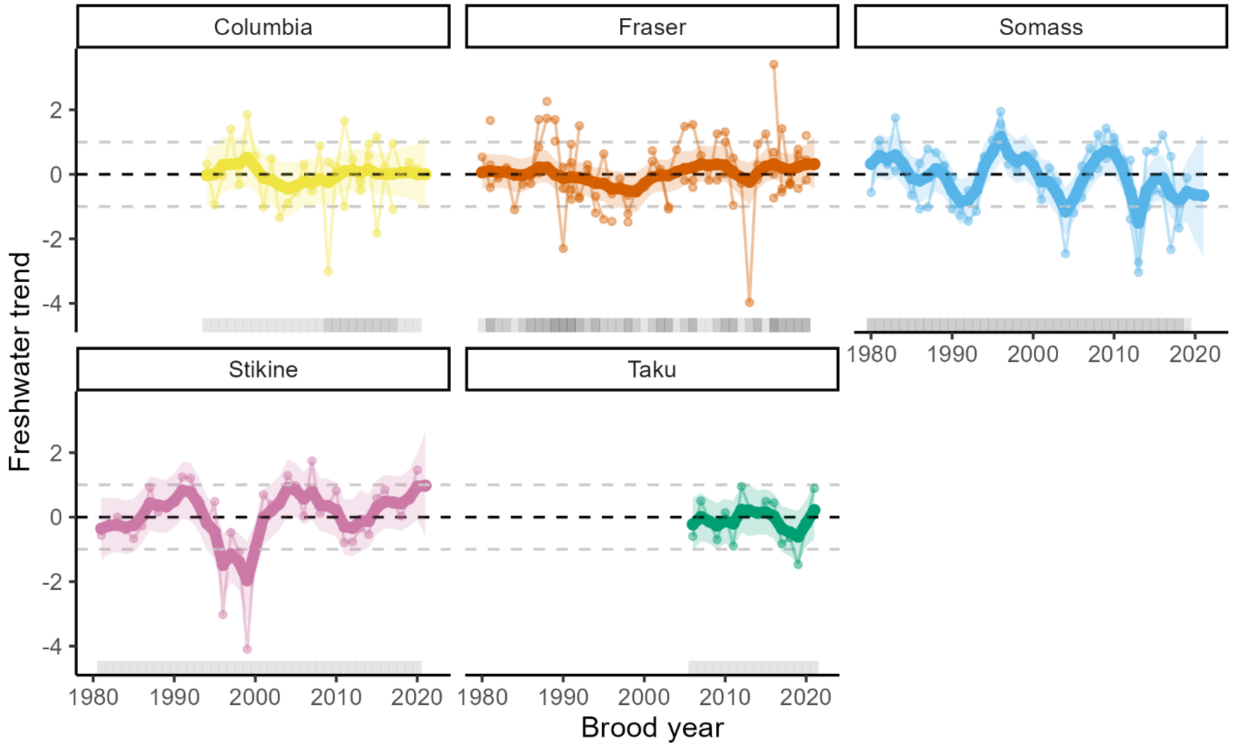

Figure 30-2. Watershed-level shared trends in freshwater productivity (Ricker model residuals) centered and scaled by 1 SD. Shared trends among stocks are coloured by watershed, where yellow represents the Columbia, orange for Fraser, light blue for Somass, pink for Stikine, and green for Taku watersheds, respectively. Individual points represent the underlying stock-specific data, the bold central line represents the mean shared trend, and the shaded areas represent the 95% credible interval around each trend. The dashed horizontal black and grey lines represent the mean and +/- 1SD of each timeseries. Finally, the vertical grey bars along the x-axis show the density of stock-specific data available for each year where darker bars represent more stocks informing a shared trend for a given year.

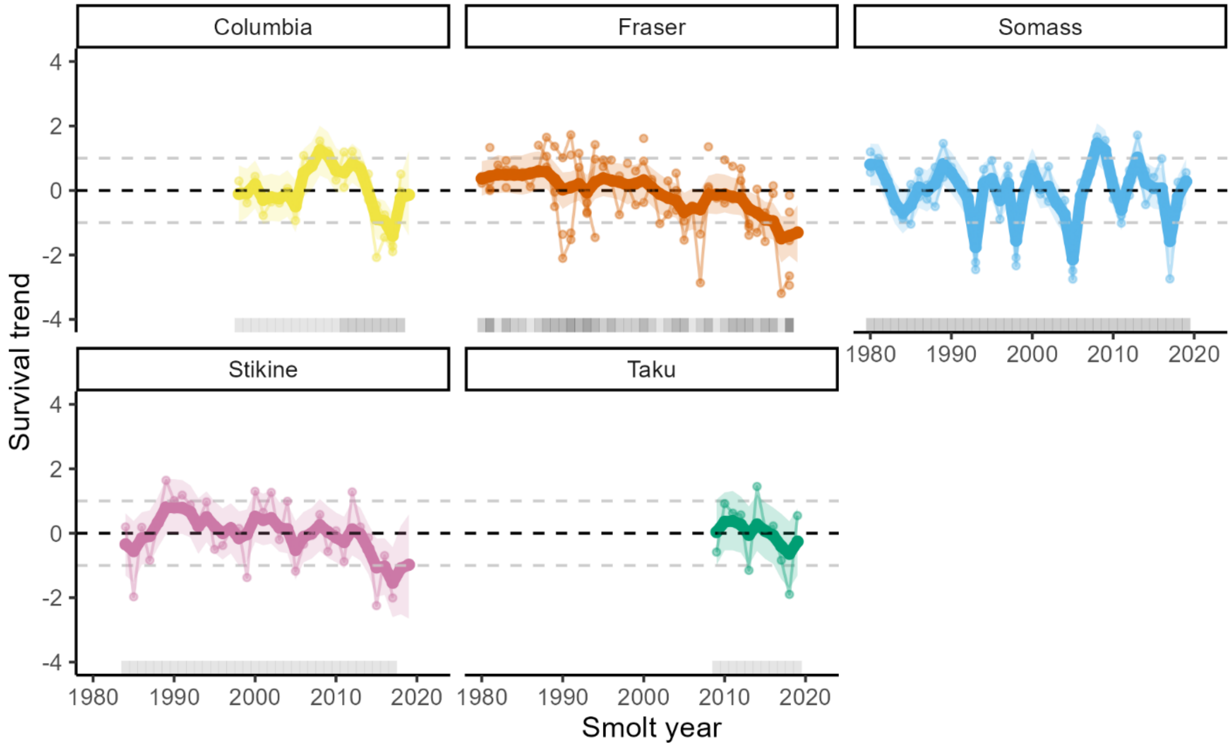

Figure 30-3. Watershed-level shared trends in logit-transformed marine survival centered and scaled by 1 SD. Shared trends among stocks are coloured by watershed, yellow represents the Columbia, orange for Fraser, light blue for Somass, pink for Stikine, and green for Taku watersheds,, respectively. Individual points represent the underlying stock-specific data, the bold central line represents the mean shared trend, and the shaded areas represent the 95% credible interval around each trend. The dashed horizontal black and grey lines represent the mean and +/- 1SD of each timeseries. Finally, the vertical grey bars along the x-axis show the density of stock-specific data available for each year where darker bars represent more stocks informing a shared trend for a given year.

30.3. Status and trends

Time series were characterized by variability. Fraser and Stikine Watersheds show above average freshwater productivity in recent years, with Columbia and Taku near their means, and the Somass displaying below average productivity (Figure 30-2).

The marine productivity time series showed below average to average marine survival in recent years for all watersheds (Figure 30-3). Fraser and Stikine were particularly poor with below average and declining marine survival.

Overall, individual stock marine survival tended to display a higher frequency of shifts in productivity, while individual stock freshwater productivity tended to show more infrequent but higher magnitude shifts in productivity (Figures 30-2, 30-3).

30.4. Factors influencing trends and implications

While there have been many attempts to uncover the environmental drivers of Sockeye Salmon abundance and marine survival, these remain poorly understood with many hypotheses still being explored (Irvine and Akenhead 2013; Walters et al. 2020; McKinnell and Irvine 2021). This may be in part due to marine survival estimates incorporating downstream migration mortality for smolt-based estimates, and at least one winter plus downstream migration mortality for fry-based estimates. It is generally accepted that marine heatwaves such as the “Blob” reduce Sockeye Salmon marine survival, and ultimately stock productivity, at the southern portion of the species’ range (Cheung and Frölicher 2020; Connors et al. 2020). Nevertheless patterns in Sockeye Salmon marine survival were not homogeneous, suggesting regional oceanographic processes may regulate variability along distinct migration corridors (e.g., Mckinnell et al. 2014).

Density-dependent spawner-to-juvenile production relationships are well-documented (Schindler et al. 2005). The Ricker model residuals we used to estimate freshwater productivity reflect environmental variation in productivity rather than changes in juvenile production driven by varying spawner densities. Above average freshwater productivity in the Fraser and Stikine Watersheds and below average productivity in the Somass Watershed may be the result of warming temperatures affecting nursery lake productivity. A meta-analysis by Gallagher et al. (2022) showed that salmonid stocks inhabiting waters far from their upper thermal limits are likely to increase productivity in reaction to warming, whereas stocks near their upper thermal limits are more likely to decline in response to warming. In the Skeena Watershed, Price et al. (2024), demonstrated that lakes greater than 50 m depth have produced more Sockeye Salmon smolts as air temperatures rise, but that higher temperatures had the opposite effect on lakes in highly glaciated watersheds. However, while warming may play a role in changes in lake productivity across Sockeye Salmon stocks, other factors such as spawning habitat stability/accessibility or carry-over effects of upstream migratory conditions may obscure the effects of warming on Sockeye Salmon freshwater productivity.

Ultimately understanding drivers of freshwater and marine productivity 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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31. TRENDS IN PACIFIC CANADIAN GROUNDFISH STOCK STATUS AND SURVEYS

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31.1. Highlights

- Average groundfish stock status declined from 1950 to around 2000, and following management changes, has remained relatively stable since then.
- In 2023, assessments were updated for five stocks (Pacific Ocean Perch 3CD, 5ABC, 5DE; outside Quillback Rockfish; Pacific Cod 3CD). The Pacific Ocean Perch and outside Quillback Rockfish stocks were estimated to be above their Limit Reference Point (LRP) and above their Upper Stock Reference (USR) with very high probability (>99%). Pacific Cod had a 23% probability of being below the LRP and a >99% probability of being below the USR.
- Over the last two decades, survey indices increased for ~66% of stocks, remained neutral for ~14%, and declined for ~20% 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 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.

31.2. 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 (QCS; Areas 5A and 5B) and Hecate Strait (HS; 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 2023, the HBLL outside north, HBLL inside north, synoptic HS, synoptic QCS, and 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 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 2023, and (2) we develop model-based indices from relevant surveys for all assessed stocks, as well as stocks with outstanding requests for Science Advice.

31.3. Description of the time series

We gathered Bayesian posterior distributions of estimated biomass from assessments for 26 stocks, including five updated assessments (Pacific Ocean Perch 3CD, 5ABC, 5DE; outside Quillback Rockfish; Pacific Cod 3CD). 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 26 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 (44 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 spatiotemporal 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 Gaussian Markov random field random walk. For each stock–survey type combination, we fit delta-gamma (Bernoulli for encounter probability and gamma for positive density) observation error models. 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.

31.4. Status and trends

Across all stocks, there was a decline in average stock status until approximately 2000 (Figure 31-1). 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 2023 to be 3.9 (95% CI: 3.2–4.7). The overall mean B/USR and B/BMSY (biomass divided by biomass at maximum sustainable yield) in 2023 was 1.9 (95% CI: 1.6–2.3) and 1.8 (95% CI: 1.5–2.2), respectively (Figure 31-1, 31-2). 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 31-3).

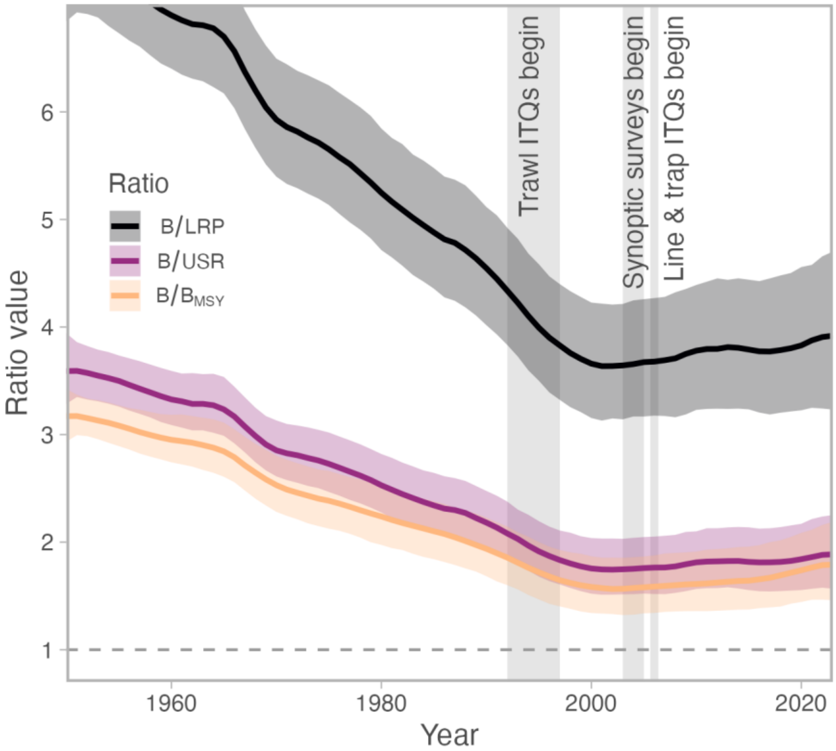

Figure 31-1: Overall mean biomass status across all stocks for B/LRP, B/USR, and B/BMSY (see text for definitions) from the hierarchical time-series model. Dark lines represent the posterior median and shaded ribbons represent 95% quantile credible intervals. ITQ = individual transferable quota.

Estimated biomass was above the LRP and USR for most stocks as of the most recent assessment (Figure 31-2). Of the stocks with full posterior distributions available, inside (4B) Lingcod, inside Quillback Rockfish, and Pacific Cod 3CD were the only stocks with 5% or greater posterior density below their LRP as of their most recent assessments (Figure 31-2). 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 had a 99% probability of being above the LRP and USR (DFO 2023c). Considering the USR instead of the LRP, 7/26 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 31-3). 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 31-3). Trends among the skates generally appeared stable or positive. Pacific

Spiny Dogfish (herein ‘dogfish’) stocks, however, experienced the steepest declines of all stocks (Figure 31-3), with a particularly steep decline in outside Vancouver Island waters.

Figure 31-2: Posterior distribution of the two measures of stock status for 26 assessed stocks (Edwards et al. 2011, 2013; Edwards et al. 2014; DFO 2015, 2019, 2020a, 2020b, 2020c, 2020d, 2021, 2022b, 2023a, 2023b, 2023c, 2024; Holt et al. 2016a, 2016b; Huynh et al. 2023; Starr et al. 2016; Starr and Haigh 2017, 2021a; Starr and Haigh 2021b; Grandin et al. 2023; Starr and Haigh 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. 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.

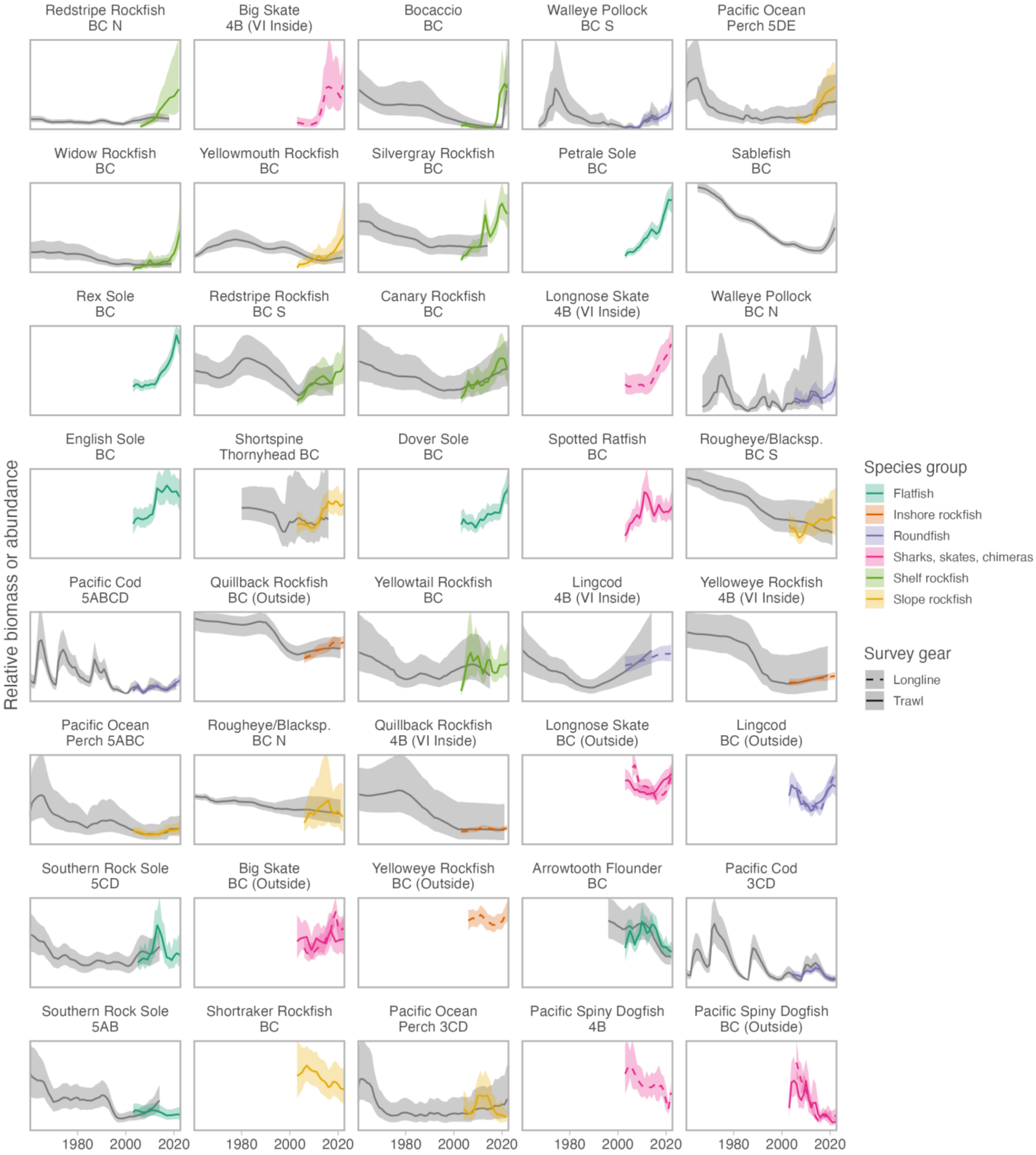

Figure 31-3: Trends for 44 B.C. groundfish stocks with assessments in the last ~15 years or outstanding requests for Science Advice. Dark grey lines and ribbons represent output from stock assessments: trajectories of median B/LRP 95% quantile credible intervals (see citations in Figure 29-2 caption). 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 2023. Stocks are ordered by the slope of the survey index trend from most increasing to most decreasing.

31.5. 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/or climatic effects. For example, Pacific Spiny Dogfish are not currently targeted commercially and used to be caught in higher numbers—the reason for their survey declines is not clear and is currently a subject of research. In the western North Pacific, seasonal distribution patterns for this species have changed (Kanamori et al. 2023). 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 rockfish species due to high recruitment around 2016—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).

31.6. Implications of those trends

The Sustainable Fisheries Framework and the Fish Stocks provisions of the Fisheries Act require that “major stocks” be maintained above their LRP with high probability (≥75% if subject to the Fish Stocks provisions). Three stocks had >5% probability of being below their LRP as of their last assessment and none are currently a major stock. Roughly one-third of assessed stocks had 25% probability or greater 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.

31.7. 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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32. DISTRIBUTION AND ABUNDANCE OF PACIFIC HAKE (*MERLUCCIUS PRODUCTUS*) FROM THE U.S.A.-CANADA JOINT ACOUSTIC-TRAWL SURVEY

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32.1. Highlights

- The 2023 total survey estimate of Pacific Hake of 0.907 million t was the third lowest for the time series, slightly higher than the estimates from 2001 and 2011.
- Under 3% of the total estimated survey biomass was encountered in Canadian waters, the lowest of the survey time series. For Canada, the distribution of hake was limited and confined to the west coast Vancouver Island.

32.2. Description of the time series

Pacific Hake ranges from southern California to northern B.C. (25-55° N). It is a migratory species that is thought to spawn mainly off of the southern to central California coast during January to March (Saunders and McFarlane 1997). Adult Pacific Hake then migrate north in the spring and, by the summer, can be detected in large aggregations from northern California to the northern end of B.C., with distributions sometimes exceeding these boundaries. Size and age generally increase with increasing latitude during the migratory season. The populations of Pacific Hake found in the Strait of Georgia and Puget Sound are genetically distinct and not included in this survey (Iwamoto et al. 2004; King et al. 2012; Longo et al. 2024).

The Pacific Hake fishery is one of the largest fisheries on the west coast of the U.S. and Canada. The joint U.S. and Canadian integrated acoustic-trawl survey is the primary fishery-independent source of data used to assess the distribution, abundance and biology of the Pacific Hake population (see Edwards et al. 2022). The survey was completed on a triennial basis during 1995-2003, when the decision to switch to a biennial basis was made; there was an additional survey in 2012.

The acoustic survey typically starts in southern California in mid-June and progresses northward in a continuous and uninterrupted sequence, ending in northern Canada in early September. The survey design consist of E-W transects from the 50 m to the 1500 m isobaths, or beyond if signals extend over this limit. The transects are 10-20 nmi apart. Acoustic marks are targeted with a midwater trawl to assess species composition and collect biological samples. Backscatter values assigned to Pacific Hake are interpolated between transects using kriging to obtain an overall estimate of abundance for the entire coast. Using the biological information gained from the midwater trawls, the backscatter is scaled to biomass using the fish length to target strength relationship (Traynor 1996).

32.3. Status and trends

The NOAA ship Bell M. Shimada surveyed between 27 June and 5 September, collecting acoustic data from 70 transects between Point Conception (CA) and Grays Harbor (WA) and from 15 transects between Tofino (B.C.) and the south end of Queen Charlotte Sound (B.C.) for a total linear distance of 3,027 nmi. The Franklin surveyed between 19 August and 10 September, collecting acoustic data from 11 transects between Copalis Beach (WA) and Barkley Sound (B.C.) and from 20 transects between southern Hecate Strait and Dixon Entrance, then south along the west coast of Haida Gwaii, for a total linear distance of 1,184 nmi. Transects were spaced 10 nmi apart through most of the coast (all the way to just north of Vancouver Island) with the exception of 6 skipped transects. North of Vancouver Island spacing increased to 20 nmi. Transects were traversed sequentially, usually in alternating directions.

Distribution of Pacific Hake has been variable over the history of the survey, with the widest distribution seen in 1998. In 2023, the distribution in Canadian waters was confined off the southern half of the west coast of Vancouver Island (Figure 32-1). The 2023 estimated total biomass of 0.907 million tons was the third lowest of the time series, slightly above the 2001 and lowest estimate of 2011 (Figure 32-2). Catch data from the survey indicated a dominance of the 2021 and 2020 year classes, suggesting strong recruitments in 2019-2020. The survey age-1 index in the stock assessment also supports this upward trend in recruitment for those two years. No age-1 (nor age-0) Pacific Hake were observed in Canadian waters in 2023. Less than 3% of the estimated biomass of adult Pacific Hake (age-2+) from the survey was observed in Canadian waters, the lowest proportion (and biomass) of the time series for two consecutive surveys (Figure 32-2).

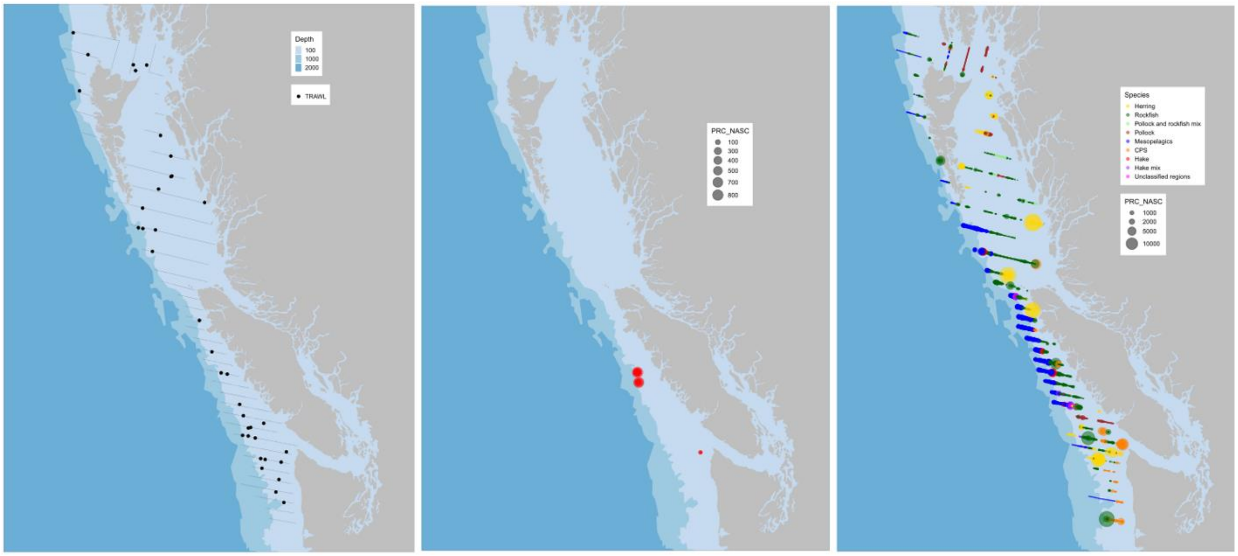

Figure 32-1. Map of acoustic transects and midwater trawl locations (black circles) for the Canadian portion of the survey (left panel), Nautical Area Scattering Coefficients (NASC, m^2nmi^{-2}) of detected Pacific Hake aggregations (central panel), and NASC of other pelagic species observed (right panel). Note that the legend for NASC differ between the central and right panels.

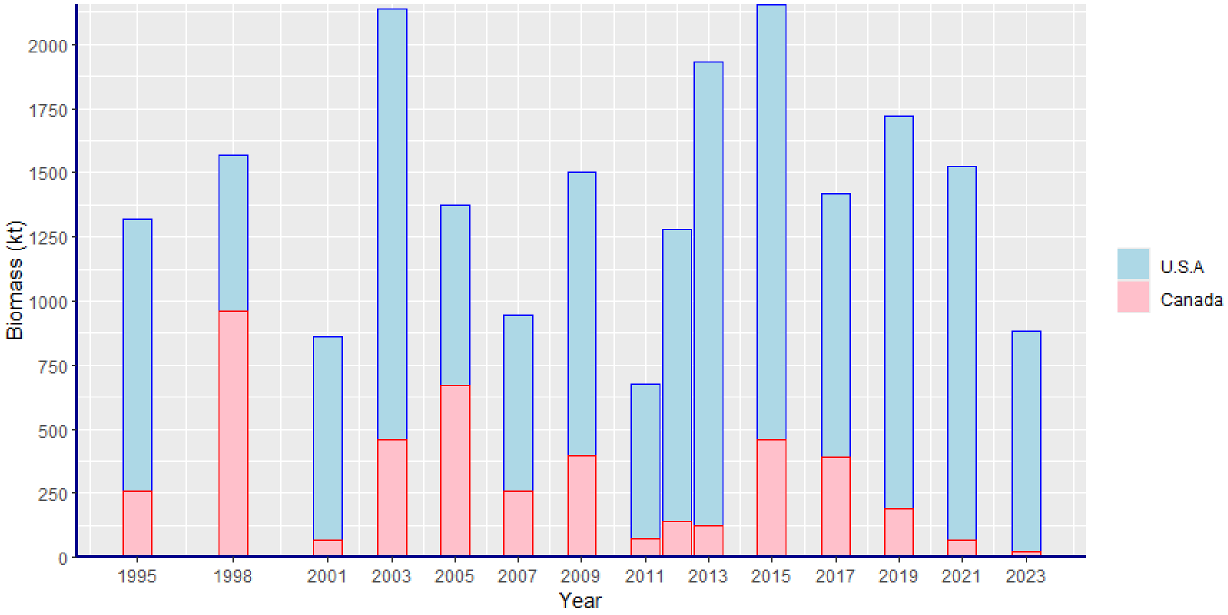

Figure 32-2. Survey estimated biomass (kt) of adult (age 2+) Pacific Hake (Merluccius productus) in Canadian and U.S.A. waters from 1995 to 2023.

32.4. Factors influencing trends

It has been observed that during warm ocean conditions (such as the 1998 El Niño event) a larger proportion of the stock migrates into Canadian waters, apparently due to intensified northward transport (Agostini et al. 2006). This was also observed in 2015 (with the so-called warm ”Blob”), although the distribution did not extend much beyond the northern tip of Vancouver Island. The proportion of Pacific Hake that migrated into Canadian waters in 2017 was over 27% and the largest observed since 2005, while in 2019 the proportion in Canadian waters was only 11%. In 2021 this proportion was less than 5%, and again in 2023 it was less than 3%, the two lowest of the time series. There were also no aggregations recorded off the north end of west coast Vancouver Island, and nothing recorded further north. These observations are partly in line with the somewhat return to more normal (or pre-Blob) conditions. Further down south (off USA), the Pacific Hake distribution was relatively constricted, and there was a noticeable break in distribution associated with an area of midwater hypoxia off central Washington.

For other pelagic species, high acoustic backscatter for Pacific Herring (*Clupea pallasii*) were recorded off both the southern and northern end of the west coast of Vancouver Island, as well as in southern Hecate Strait. Pelagic rockfish species (*Sebastes* spp.) were recorded in high numbers off northern Washington and southern/central west coast of Vancouver Island. A small population of Walleye Pollock (*Theragra chalcogramma*) was recorded in Dixon Entrance (Figure 32-1). New time series of abundance and distribution for these species are being developed from the Pacific Hake historical surveys. These trends and observations emphasize the need for more research into the links between environmental variables and the distribution and migration of Pacific Hake and associated fauna.

32.5. Implications of those trends

During the strong El Niño of 1998, Pacific Hake extended well into Alaska, but during recent warming events the distribution was retracted and confined mostly to the west coast of Vancouver Island. With a recent return to cooler (or somewhat normal) ocean temperatures the past two surveys have recorded the lowest biomass and proportion of the population in Canadian waters. These trends suggest that temperature alone may not be a good predictor of Pacific Hake northward migration extent, but that other mechanisms (such as the source and onset of warming conditions) have differential effects on poleward currents, distribution and availability of prey, or other factors influencing the distribution of these fish. Hypoxia events encountered along the coast, which appear to be increasing, may also affect the distribution or the migration dynamics of this species.

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33. YEAR-ROUND SURVEY EFFORTS TO INFORM CETACEAN DISTRIBUTION AND ABUNDANCE IN THE SOUTHERN SALISH SEA AND SWIFTSURE BANK

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33.1. Highlights

- Systematic cetacean survey efforts conducted from 2020 - 2023 have provided the first season-specific abundance estimates for Humpback Whales, Harbour Porpoises, and Dall's Porpoises for Canadian portions of the southern Salish Sea and Swiftsure Bank.
- All three species are present in the area year-round, though distribution and abundance vary seasonally. Quantifying the return of Humpback Whales and Harbour Porpoises to the southern Salish Sea provides evidence of this ecosystem's capability to support recovering populations of marine mammals.

33.2. Description of the time series

Systematic boat-based line-transect surveys in the southern Salish Sea were initiated in summer 2020 to address data gaps in the seasonal abundance and distribution of whales, dolphins, and porpoises in this area. The study area was designed to encompass the marine shipping route between Vancouver and Swiftsure Bank, including a 6 km buffer on either side of the shipping lanes (Figure 33-1). Annual surveys were conducted monthly or bi-monthly using an equal-spaced zig-zag design with a distance of 18 km between transect lines.

Effort-corrected abundance in the study area was estimated for each season using a distance sampling approach (i.e., the sighting data are used to assess how detectability of each species decreases with distance, depending on weather conditions). Seasons were defined as: winter (January – March), spring (April to June), summer (July – September), and fall (October to December). See McMillan et al. (2022) for further detail on survey design and methods.

Results from these surveys have led to the first season-specific abundance estimates for three species of cetaceans in Canadian portions of the southern Salish Sea, and will inform spatially-explicit seasonal density estimates required for effective mitigation of threats to these species.

33.3. Status and trends

A total of 28 systematic cetacean surveys were conducted from 2020 - 2023, comprising almost 7,000 km of survey effort. Sufficient data have been collected to estimate season-specific abundance of Humpback Whales, Harbour Porpoises, and Dall's Porpoises.

Humpback Whales

Humpback Whales in Canadian Pacific waters were severely depleted by commercial whaling until 1967, and sightings of these whales in the Salish Sea remained very infrequent for several subsequent decades. As recently as 2004, no Humpback Whales were detected during marine mammal surveys conducted in this area (Williams and Thomas 2007). However, the results of more recent systematic and opportunistic data collection demonstrate that Humpbacks have now reoccupied this historical habitat (Calambokidis et al. 2017; Wright et al. 2021).

The current time series indicated the year-round presence of Humpback Whales in the waters of the southern Salish Sea and Swiftsure Bank (Figure 33-2). Abundance of Humpback Whales was estimated to be lowest in winter at 17 (95% CI: 11-26); increasing through spring and summer to 60 (41-89) and 155 (93-259) respectively, and reaching a peak in fall of 416 (261-663).

Distribution of Humpback Whale sightings varied by season. Winter sightings were primarily located in Juan de Fuca Strait, while most spring sightings were concentrated in the western part of the study area, on and around Swiftsure Bank (Figure 33-2). Large aggregations of Humpback Whales were sighted in central and western Juan de Fuca Strait in summer. The broadest distribution and highest number of Humpback Whale sightings consistently occurred in fall.

Harbour Porpoise

Harbour Porpoises were reported to have been present in relatively large numbers year-round in parts of the southern Salish Sea at least through the 1940s, followed by a period of very few sightings in the 1970s to 1990s (Elliser and Hall 2021). Aerial surveys conducted in August 1996 and April 2015, and boat-based surveys in summer 2018, indicated that Harbour Porpoises had returned to the southern Salish Sea in higher numbers (Calambokidis et al. 1997; Jefferson et al. 2016; Wright et al. 2021).

The current time series confirmed that Harbour Porpoises are now present in the southern Salish Sea at relatively high abundances year-round. Harbour Porpoises were sighted during all 28 surveys, and were the most frequently detected cetacean in all seasons. Estimated abundance was highest in fall at 1,418 (95% CI: 977-2,059) and lowest in winter at 609 (367-1,009). Abundance in spring and summer was estimated at 838 (657-1,067) and 1,229 (937-1,613) respectively.

Harbour Porpoises were sighted in the southern Strait of Georgia, Haro Strait, Boundary Pass, and eastern Juan de Fuca Strait during all seasons (Figure 33-2). Sightings were less frequent in the western portion of the study area, though preliminary data from acoustic recorders deployed on Swiftsure Bank indicate that the paucity of sightings in this area may be attributed more to the difficulty of visually detecting Harbour Porpoises in exposed portions of the study area and in imperfect weather conditions, rather than to low numbers of Harbour Porpoises in the area (DFO-CRP unpublished data).

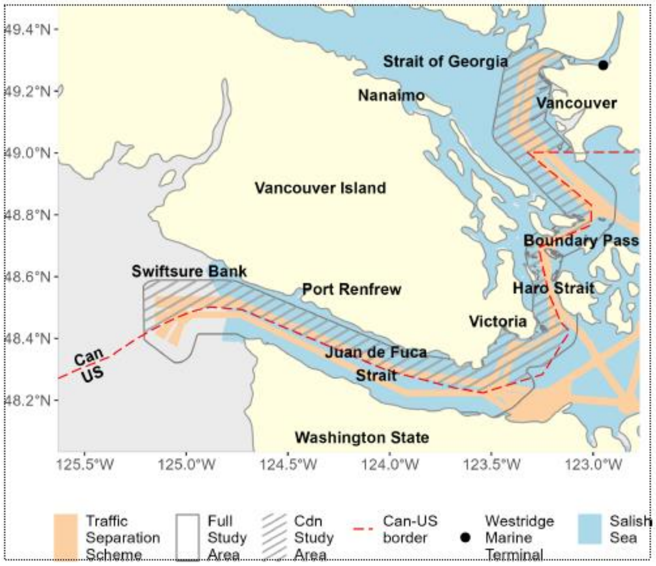

Figure 33-1. Study area, highlighting the inbound and outbound shipping lanes (traffic separation scheme). Survey efforts to the end of 2022 were limited to the Canadian portions of the study area, indicated by grey hatched lines. Surveys were expanded in 2023 to include U.S. waters within the study area boundary.

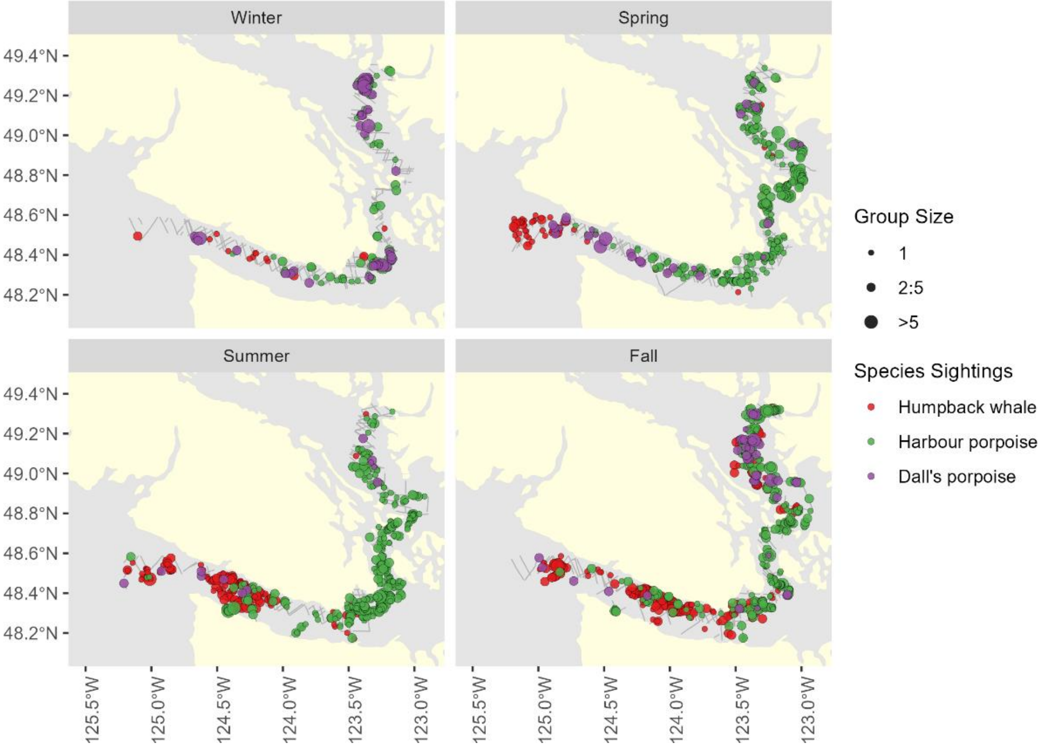

Figure 33-2. Sightings of the three most frequently detected species (Humpback Whales, Harbour Porpoises, and Dall's Porpoises) in the southern Salish Sea and Swiftsure Bank by season. Completed transect lines surveyed are included in grey.

Dall's Porpoise

Very little data exist regarding the historical abundance and distribution of Dall's Porpoise in the study area prior to the 1990s. Aerial surveys conducted in 1996 and boat-based surveys in 2018 indicated that Dall's Porpoises were present in lower numbers than Harbour Porpoises in the southern Salish Sea, and were found in deeper waters than Harbour Porpoise (Calambokidis et al. 1997; Wright et al. 2021).

Dall's Porpoises were sighted in all seasons during the 2020-2023 surveys, though less frequently than Harbour Porpoises. Estimated abundance of Dall's Porpoises peaked during winter (333; 95% CI: 224-494). Abundance of Dall's Porpoise in spring, summer, and fall was estimated at 182 (74-445); 65 (38-112); and 161 (77-336), respectively. Dall's Porpoises were sighted in the southern Strait of Georgia in all seasons (Figure 33-2).

33.4. Factors influencing trends

Though North Pacific Humpback Whales have shown significant recovery throughout most of their range following cessation of commercial whaling, their return to the Salish Sea has been more recent than for many other parts of the B.C. coast. The reasons for this are not well-understood, though humpback whales are known to show strong maternally-driven site fidelity to specific areas which may limit their rate of re-establishing historical habitat.

Factors influencing historical and current trends in porpoise abundance and distribution are largely unknown, though it has been proposed that fisheries bycatch may have contributed to previous Harbour Porpoise declines (Elliser and Hall 2021). Hall (2011) identified hotspots in areas of high tidal currents for Harbour and Dall's Porpoise in a portion of the southern Salish Sea and suggested that these areas serve as important foraging and breeding areas for these species. Interspecies dynamics may also be a factor. Harbour and Dall's Porpoises in the area share many of the same prey species (Nichol et al. 2013) thus their respective seasonal trends in abundance may indicate some temporal partitioning of habitat between these two species.

Modeling efforts are underway to provide spatially-explicit seasonal density estimates for each of these species based on data from the 2020 – 2023 survey efforts and physical and environmental variables such as depth, slope, sea surface temperature, and current speed. The results of this work will help to inform the factors that contribute to the abundance and distribution of each of these species in the southern Salish Sea.

33.5. Implications of those trends

The return of Humpback Whales and Harbour Porpoises to the southern Salish Sea in greater numbers, and the year-round presence of these and Dall's Porpoise in this area, provide evidence of this ecosystem's capability to support recovering populations of marine mammals. However, the waters of the southern Salish Sea are also the site of intensive human activity that has the potential to impact each of these cetacean species. For example, large vessel transits in this area account for more than 50% of the total Canadian shipping traffic and are expected to increase significantly in upcoming years due to recently approved pipeline and port expansion projects. Humpback Whales are the cetacean species most frequently reported to be struck by vessels in Canadian Pacific waters (COSEWIC 2022), while Harbour Porpoises are considered particularly sensitive to disturbance (DFO 2009). Ongoing cetacean survey efforts will continue to provide quantitative information regarding the seasonal abundance and distribution of cetacean species at risk in this area, which are required to inform effective management of anthropogenic threats including vessel strikes, entanglement in fishing gear, and acoustic disturbance in the southern Salish Sea.

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34. EMERGING SOUNDSCAPE PATTERNS IN THE SALISH SEA (2018-2023)

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34.1. Highlights

- Up to five years of passive acoustic and auxiliary oceanographic data were considered.
- Recordings showed strong spatial (east-west) and temporal (seasonal, diurnal) patterns in the soundscape as result of various vessel and/or meteorological sources.

34.2. Description of the time series

Acoustic moorings, instrumented with Autonomous Multichannel Acoustic recorders (AMAR, G4, JASCO Applied Sciences), GeoSpectrum Technologies M36-100 hydrophones, RBR CTDs, and JFE current meters were deployed to describe spatiotemporal patterns in sound levels and sound speed in the Salish Sea. Deployments were first made in early 2018, and recordings have been constant ever since (Table 34-1). Mooring locations were chosen to represent different exposures, topographies, and water properties, as well as areas used by the endangered southern resident Killer Whales (SRKW, *Orcinus orca*). To understand the inputs to the soundscape, comparison to meteorological data and vessel tracking records were made. Data from wave buoys, weather stations, and the SalishSeaCast model (Sootiens et al. 2016; Sootiens and Allen 2017) for environmental conditions, and vessel presence data from Automatic Identification System (AIS) was used.

Table 34-1. Deployment location, date, and water depth of each of the Salish Sea moorings.

Location	Latitude-longitude	Depth (m)	Deployment Date
La Perouse Bank	48° 23.085'N, 125° 48.326'W	150	May 2019-
Swiftsure Bank	48° 30.924'N, 124° 56.156'W	75	Jul. 2017-
Swiftsure Bank ISZ	48° 33.120'N, 125° 00.432'W	40	Feb. 2020-Jun. 2023
Port Renfrew	48° 30.274'N, 124° 31.016'W	170	Feb. 2018-
Jordan River	48° 23.793'N, 124° 07.976'W	120	Feb. 2018-
Sooke	48° 17.365'N, 123° 39.137'W	165	Feb. 2018-
Haro Strait	48° 29.750'N, 123° 11.567'W	235	Jan. 2018-
Turn Point	48° 42.099'N, 123° 16.654'W	195	Jun. 2018-Aug. 2018
Boundary Pass	48° 44.014'N, 123° 08.741'W	180	Feb. 2018-
Swanson Channel	48° 44.340'N, 123° 15.340'W	75	Aug. 2019
East Point	48° 46.566'N, 123° 04.156'W	85	May 2020-Jul. 2023
Strait of Georgia N	49° 11.568'N, 123° 20.788'W	190	Aug. 2020-
Strait of Georgia S	48° 58.862'N, 123° 24.303'W	240	Aug. 2020-
Strait of Georgia SE	48° 53.400'N, 123° 10.200'W	132	Jul. 2023-

34.3. Status and trends

Year to year variations in sound levels were limited, but there were strong seasonal patterns (Figure 34-1). Elevated higher-frequency noise during daylight hours, and over weekends in Juan de Fuca Strait and the Gulf Islands indicated increased recreation vessel presence (see Burnham et al. 2021). This contrasted to the consistency of median sound levels of commercial vessel traffic (113-141 Hz; column 1 in Figure 34-1). Increases in background, Q1 levels, during the winter, especially at Swiftsure Bank represents increased shipping demand for Christmas (A-1 in Figure 34-1). Recovery from the supply chain issues reported through the COVID-19 pandemic were seen, with 2021 showing the highest levels of shipping noise (Figure 34-1). In the Strait of Georgia, elevated vessel noise resulted from increased ferry transits during the summer (D-4 Figure 34-1). The regularity of the noise emissions, and change to reflect daylight saving time was an indicator to the source. Wind noise (7,500-8,500 Hz) was generally reduced during the summer (column 2 in Figure 34-1), except for localised increases around Sooke in June-July (Figure 34-2). Storm events characterized the winter soundscape at Swiftsure Bank, with the influence of this extending eastward to Port Renfrew and Jordan River (Figures 34-1; 34-2). This also meant a reduction in SRKW communication call frequencies (500-15,000 Hz; column 3 Figure 34-1). Spatially, there is an east-west/ inshore-offshore divide with vessel presence by type, and wind/storm events the dominant additions to the soundscape (Figures 34-1 and 34-2).

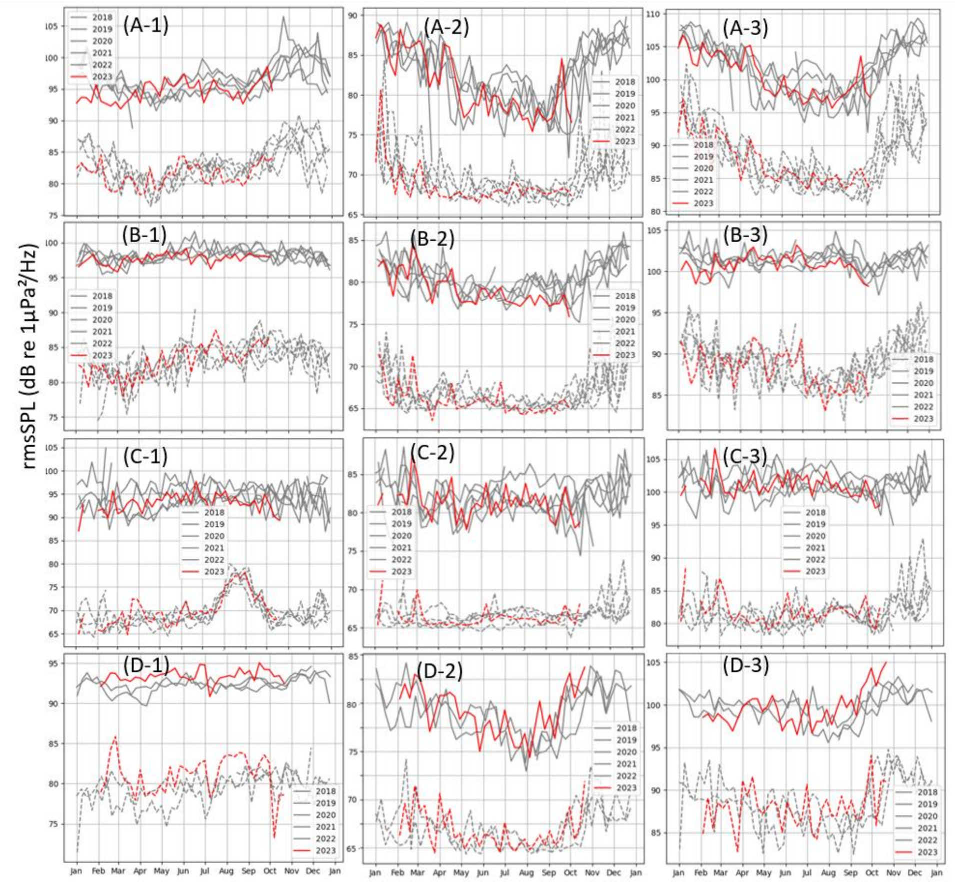

Figure 34-1. Sound pressure levels (SPL) for sites in the Salish Sea. (A): Swiftsure Bank, (B): Port Renfrew, (C): Boundary Pass, (D): Strait of Georgia South for frequency ranges (1): 113-141 Hz representing commercial vessel noise, (2): 7,500-8,500 Hz representing wind noise, and (3): 500-15,000 Hz for the range of SRKW communication calls. Median (solid lines) and background, Q1 (dashed line), SPL are indicated.

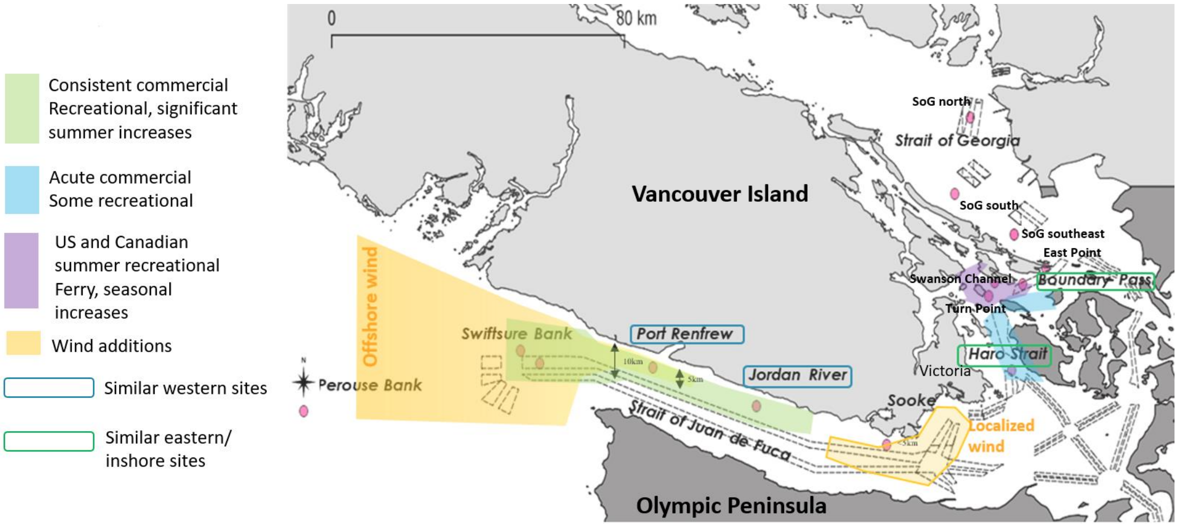

Figure 34-2. Map of mooring locations (pink circles), with dominant soundscape additions indicated through shading (consistent commercial vessel noise: green; acute vessel noise: blue; recreational vessels: purple; wind: yellow). Sites with similar soundscapes and shipping lanes (dashed lines) are indicated.

34.3. Factors influencing trends

For all mooring locations the proximity to the commercial shipping lanes shaped the spatiotemporal patterns seen in the soundscape (Figures 34-1; 34-2). The presence of smaller, recreational vessels also influenced sound levels in the higher frequencies in the summer. Wind and wave noise resulting from winter storm events was most influential at Swiftsure Bank and sites in western Juan de Fuca (A, B in Figure 34-1, Burnham et al. 2021).

34.4. Implications of the observed trends

This acoustic time series sets a baseline for changes in traffic through the Salish Sea. It helps validate predictions made by a vessel noise model for increased vessel density scenarios, and describes the effectiveness of mitigation measures introduced to lessen vessel noise. Much of the Salish Sea is designated as critical habitat for SRKW and increased noise in communication and echolocation ranges indicated acoustic disturbance and potential for masking, which could reduce their success and survival. The recordings also allow us to consider weather patterns, with it suggested that stronger and more frequent storm events will be seen in the coming years. This may be confirmed by the acoustic and the oceanographic data from instrumentation on the moorings.

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

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35.1. Highlights

- Marine Aquatic Invasive Species (AIS) continue to spread in B.C.
- European Green Crab (EGC; *Carcinus maenas*) continue to spread throughout B.C., including new detections near Prince Rupert and the Skeena River estuary.
- A standardized, quantitative approach for assessing EGC population abundance is needed, given the variability in trapping methodologies across programs.
- Early detection of AIS is critical for effective management and requires participation by DFO, First Nations, NGOs, and members of the public.

35.2. Monitoring Aquatic Invasive Species in Pacific Region

Two long-term marine AIS monitoring programs led by DFO 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*). The work of the AIS National Core Program (NCP) in detecting and responding to AIS in the Pacific region is also reviewed.

35.2.1. 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. It is an effective method for understanding the risk of spread of fouling AIS by small vessels (Clarke Murray et al. 2011) and marine infrastructure (Iacarella et al. 2019). Plates are primarily deployed in the summer (May-Sept/Oct) and the program is currently restricted to sites in and around the ports of Prince Rupert, Vancouver, and Nanaimo (Figure a).

35.2.2. European Green Crab Trapping Programs

The DFO AIS Science Program has been monitoring EGC in B.C. since 2006 (Gillespie et al. 2007). These standardized annual surveys are essential for understanding how EGC abundance has changed over time. This long term dataset will also be crucial to the development of methods for estimating absolute EGC abundance (e.g., population estimates) from catch-per-unit-effort (CPUE). In 2023, DFO Science trapped 10 sites in Barkley Sound and 13 sites in Quatsino Sound, two of which had not been trapped previously (Figure 35-1a).

The AIS National Core Program (NCP) is responsible for the early detection and management of AIS in the Pacific Region. This is done through direct trapping efforts and engagement with First Nations and NGOs. In addition to new detections (Figure 35-1b), EGC removal efforts led by NCP continue in the Kokish, Quatse, and Cluxewe River estuaries, Ladysmith Harbour, and Boundary Bay.

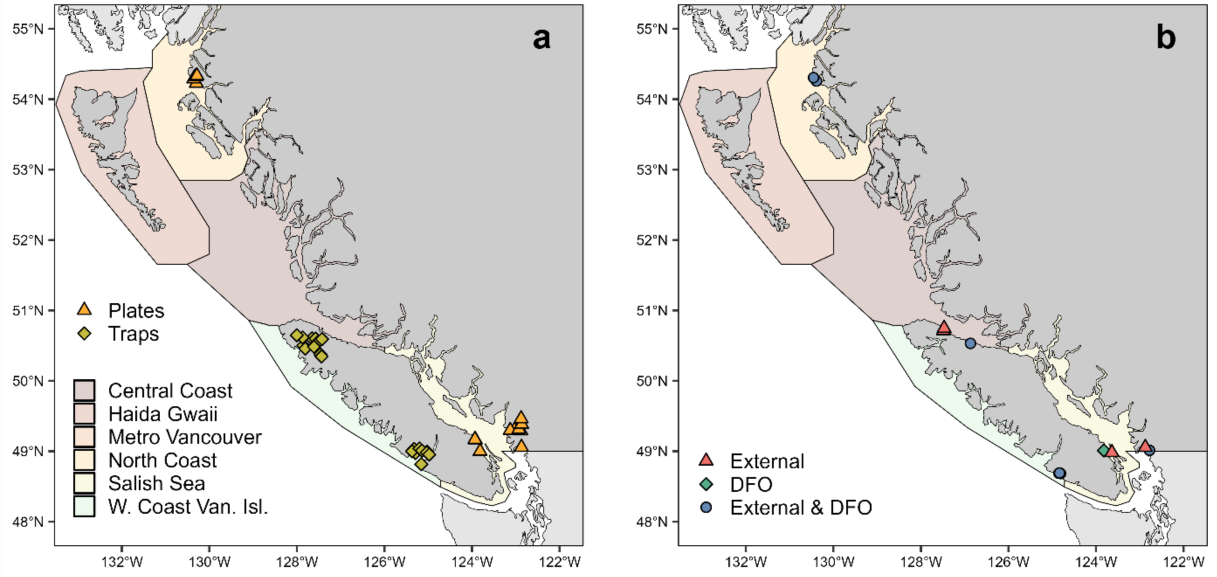

Figure 35-1. a) DFO AIS Science settlement plate deployments and European Green Crab (EGC) trapping locations for 2023; b) New detections of EGC made by DFO (NCP and/or DFO Science) and external partners in 2023.

35.3. Status and Trends

35.3.1. Settlement Plate Program

No new fouling AIS were detected in B.C. in 2023 and both the invasive botryllid tunicate species (*Botrylloides violaceus* and *Botryllus schlosseri*) were absent in Prince Rupert (North Coast, Figure 35-2) for the first time since their initial detection. Although the invasive bryozoan *Bugula neritina* has been found in the Salish Sea previously, this year was the first time it was detected by the Settlement Plate Program in Nanaimo (Figure 35-2).

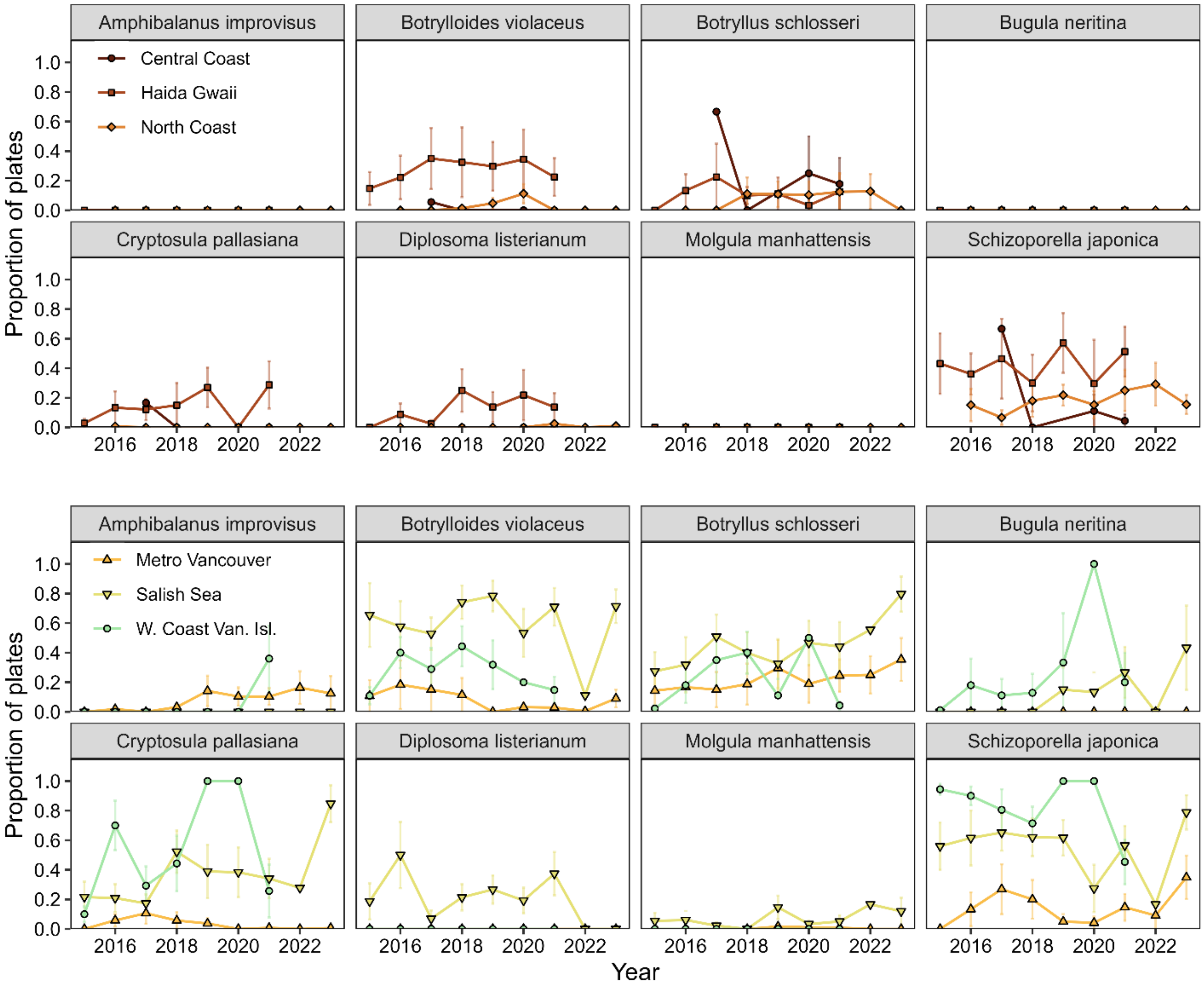

Figure 35-4. Change in prevalence of some AIS found on settlement plates in three areas in northern B.C. (top two rows) and southern B.C. (bottom two rows), presented as the proportion of plates at each site on which each species was found, averaged within regions. Only data from summer deployments (May–Sep/Oct) are shown. Note that in 2023, data were only collected in the North Coast (5 sites), Metro Vancouver (8 sites), and Salish Sea (3 sites).

35.3.2. European Green Crab Trapping Programs

Catches of EGC in Barkley Sound have continued to increase gradually since an unexplained localized collapse in 2021 (Gale et al. 2022). In Quatsino Sound, EGC were detected both at sites where they had been trapped previously and at the new sites added to the DFO Science survey in 2023. DFO Science trapping support also led to the first confirmed detections of EGC around Prince Rupert and the Skeena River estuary in 2023 (Figure 35-1b).

Trapping efforts by DFO NCP and external partners contribute significantly to the spatial coverage of EGC catch data throughout B.C. (Figure 35-3). In 2023, NCP and their partners made new detections of EGC in Little Campbell River estuary and Penelakut Island in the Salish Sea, and Nitinaht Lake on the WCVI (Figure 35-1b). However, the large variation in CPUE values that result from differences in methodology across programs (Figure 35-3) highlights the need for more accurate and standardized methods of estimating abundance (i.e., population estimates).

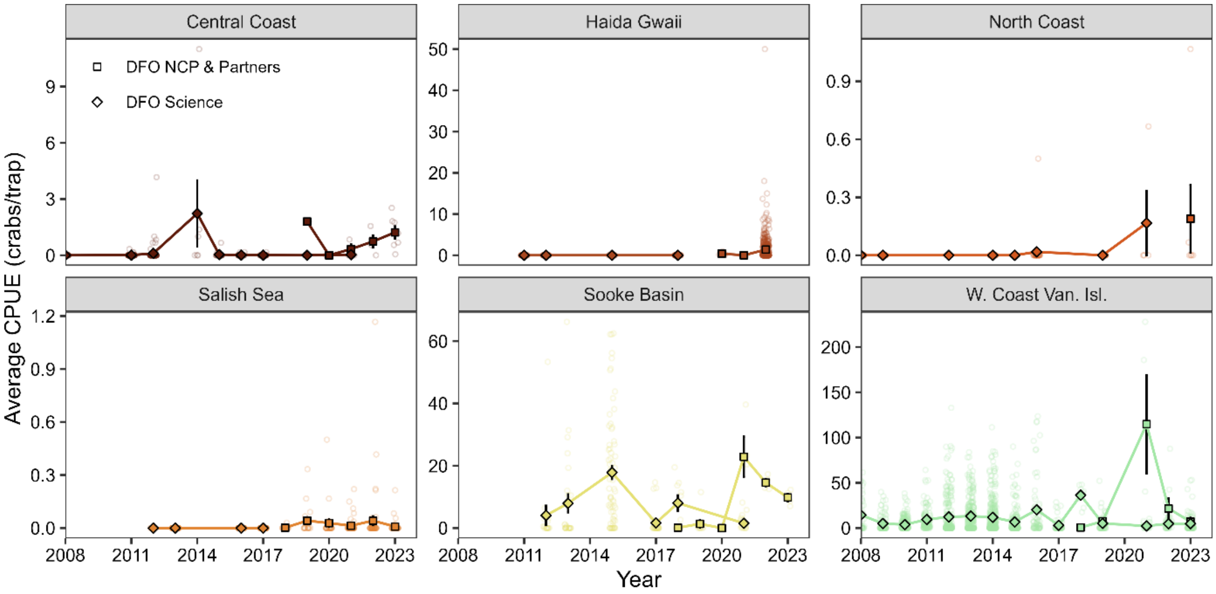

Figure 35-5. Annual CPUE of European Green Crabs (mean ± SE of all trapping events within a region) from the DFO Science trapping program (diamond points) and DFO NCP and their external partners (square points) for major regions in B.C. Note the large differences in scale. Empty points represent individual trapping events. For the WCVI, note that the 2021 data shows both the anomalously low catches in Barkley Sound (DFO Science data, diamond) and a massive eradication trapping effort initiated by the Coastal Restoration Society in Clayoquot Sound (CRS data provided to NCP).

35.3.3. Reports of Chinese Mitten Crab

In 2023/2024, NCP, Conservation & Protection (C&P), and DFO Science responded jointly to a detection of Chinese Mitten Crab (CMC; *Eriocheir sinensis*), a high-risk potential AIS. On two occasions members of the public reported finding carcasses of CMC washed up at John Lawson Park, West Vancouver. After confirming the reports, NCP and C&P followed up with targeted eDNA sampling at the detection site and surrounding water bodies. No CMC genetic signal was detected and no live CMC have been observed at this time.

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

AIS in B.C. continue to spread through both anthropogenic and natural means, as demonstrated by EGC in the Salish Sea and the North Coast. The spread of EGC in particular is being exacerbated by climate change (Yamada et al. 2021) and will likely result in more severe impacts for native species and ecosystems (Howard et al. 2019; 2021). Addressing these issues requires multiagency management partnerships, such the Salish Sea Transboundary Action Plan for Invasive EGC, between DFO and Washington state (Drinkwin et al. 2019), and the reduction trapping program in Haida Gwaii, led by the Council of the Haida Nation (Gale et al. 2023). Similar partnerships will be necessary to address newly invaded areas, such as Prince Rupert and the Skeena River estuary.

In addition to the ongoing spread of existing (known) AIS, the risk of novel AIS being introduced in B.C. is also increasing. Addressing this requires a wide range of detection and monitoring tools, including public engagement. The benefits of increased public awareness of AIS was demonstrated by the recent reports of CMC carcasses made by members of the public. This created an opportunity for management action, including increased enforcement attention on key vectors for this species. Expanded AIS Regulations in the Fisheries Act and management plans for high-risk AIS are being developed with the goal of reducing spread of both established AIS and newly introduced or undetected ones whose impacts are not yet known.

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36. MARINE ENVIRONMENTAL RESPONSE IN B.C. 2023

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36.1. Highlights

- In 2023, 1,137 marine spills were reported to Canadian Coast Guard; DFO was activated for 53 spills.
- The significant spills were the MV Maipo River spill in Nanaimo, the Fraser River Fuel Barge and the overboard Fuel Truck in Chancellor Channel. The wreck of the USAT Zalinski in Grenville is an ongoing incident since November 2022.

36.2. Summary

In 2023, a similar number of overall spills occurred as in every year since DFOs spill response program was established in 2017. However, DFO was activated by CCG in a record number of incidents last year, with 53 activations. In the years between 2017 and 2022 DFO was activated between 19 and 35 times. The number of activations is likely not indicative of more significant spills, but rather a greater public awareness and expectation around what level of pollution makes a response necessary.

There were two significant incidents involving heavy fuel oil (Bunker C) in B.C., the MV Maipo River which lost an undetermined amount of Bunker C into Nanaimo Harbour during fueling in Nanaimo Harbor on 26-July 2023.

In the Fraser River an old fuel barge was observed to be leaking heavy fuel on 3-August 2023. After the initial assumption that the tanks were empty, the final amount of oil and oily water removed was 367,400 L.

A barge lost a diesel tanker truck overboard in inclement weather in Chancellor Channel on 20-April 2023. The recovery operation took place in close collaboration with Tlowitsis and Wei Wai Kum Nation and the truck was removed from the water with some Diesel escaping from one damaged tank section.

Two longer term response have been ongoing throughout 2023. The USAT Zalinksi in Grenville Channel started releasing Bunker C in November 2022 again. This has triggered a number of research and development projects including a static camera for oil monitoring and a process for converting annotations into automatically generated emails to share with response partners. Additionally, Marine Spatial Ecology and Analysis Section (MSEAS) and Ocean Sciences Division are collaborating to develop a small oceanographic buoy to be deployed at the site during a planned oil removal that will transmit real time weather and current data.

The Zim Kingston container loss was the focus of a Tully Expedition in 2023, that lead to the discovery of 29 lost containers and the associated debris field.

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

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37.1. Highlights

- Algal biotoxins including those responsible for amnesic (ASP), paralytic (PSP) and diarrhetic shellfish poisoning (DSP) are present in B.C. coastal waters.
- Biotoxin concentrations are positively correlated with water temperature and the presence of harmful algae, falling in winter but increasing in spring or summer.
- ASP toxin (domoic acid) peaks in April in the Strait of Georgia but later along the west coast of Vancouver Island (WCVI) where it can reach high concentrations on the shelf.
- PSP toxins tend to peak in summer but were much less abundant in 2023 than in 2022 except on the WCVI shelf, in Malaspina Strait, and during fall in the Strait of Georgia.
- DSP toxin concentrations were generally lower in 2023 than in 2022 except in Cowichan Bay whereas yessotoxin was much lower in the Strait of Georgia and absent from WCVI.
- Azaspiracid AZA2 was detected in Malaspina Strait during fall 2023.

37.2. 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 amnesic shellfish poisoning (ASP) in humans and has been associated with illness and mortality in marine mammals (Moriarty et al. 2021). In 2019, DFO funding was provided to study DA and other algal biotoxins 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 (https://www.marinescience.ca/citizen-science-programs/) 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) and La Perouse cruises off the west coast of Vancouver Island (WCVI). This report provides a summary of results obtained between 2020 and 2023 as part of DFO's collaborative Marine Biotoxin Monitoring Program.

Surface seawater samples were collected monthly at long-term monitoring sites by B.C. salmon farmers and PSF citizen scientists (Figure 37-1) as well as two or three times a year from multiple locations during DFO surveys (Figure 37-1) along with taxonomic samples and environmental data. Samples for biotoxin analysis were obtained using a filter holder and vacuum pump to draw up to 1 L of seawater through a 0.45-μm 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, and for DSP and other lipophilic toxins using reversed phase liquid chromatography, combined with tandem mass spectrometry. 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.

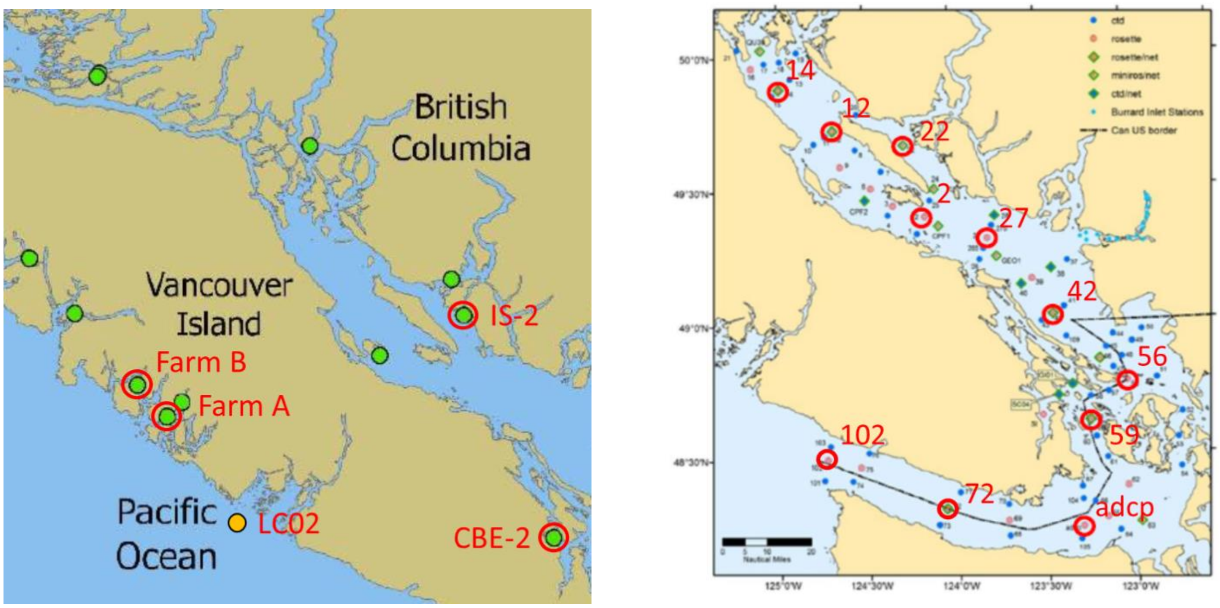

Figure 37-1. Long-term biotoxin monitoring locations near B.C. salmon farms and at PSF citizen science sites (red circles) with La Perouse station LC02 shown in orange (left panel). Seasonal biotoxin sampling locations during DFO Salish Sea Biophysical Surveys (right panel).

37.3. Status and trends

Data collected at the WCVI farm sites between November 2020 and August 2023 show that the total concentration of DA initially peaks in June or July at Farm A and tends to be much higher than at Farm B, approaching 100 ng/L in June 2021. DA concentrations at Farms A and B were more similar in 2023 than in previous years, showing similar trends between November 2022 and August 2023 when they reached 49 ng/L at Farm A (Figure 37-2). In contrast, total DA in samples collected off the WCVI during the August 2023 La Perouse cruise reached a maximum of 223.2 ng/L at station LC02 off Barkley Sound (Figure 37-1) of which 92.5 ng/L was in particulate form, suggesting that DA-producing *Pseudo-nitzschia* cells were present. Time series for the PSF citizen science sites (Figure 37-3) suggest that total DA tends to peak in April in the SoG, reaching concentrations of around 50 to 70 ng/L. However, total DA at CBE-2 was lower than usual in 2023, reaching 10 ng/L in April, well below concentrations (i.e., >100 ng/L) associated with the accumulation of DA in shellfish (Perry et al. 2021; 2023).

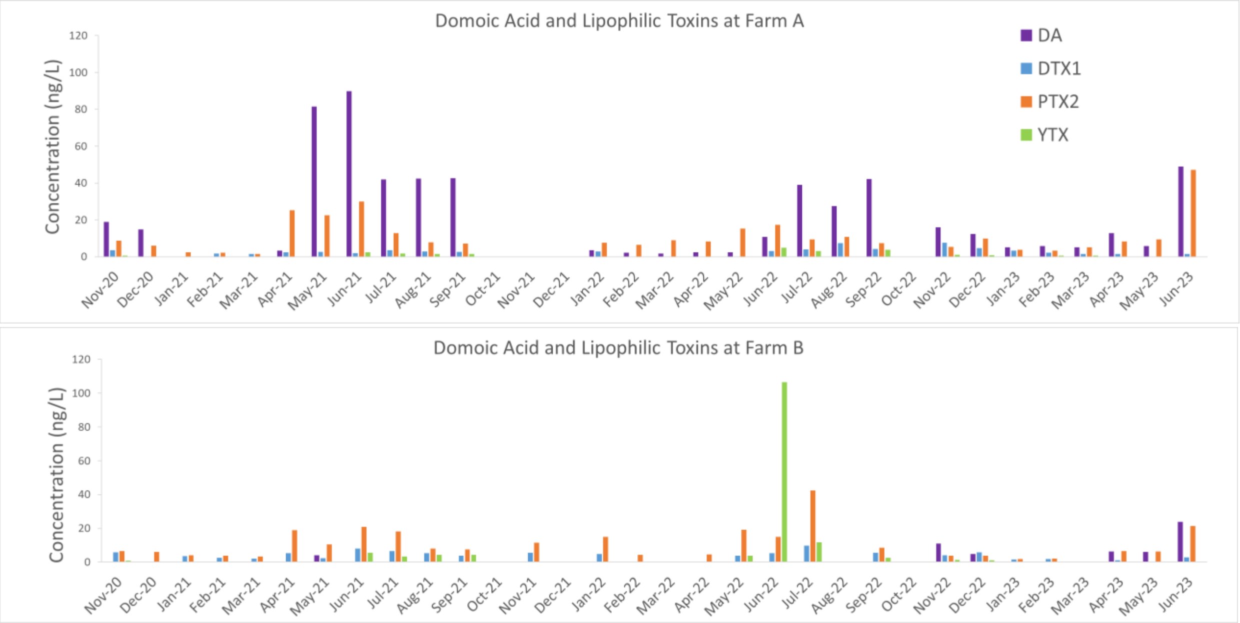

Figure 37-2. Time series of DA and Lipophilic Toxins at Farms A and B in Clayoquot Sound (Nov. 2020 to Jun. 2023).

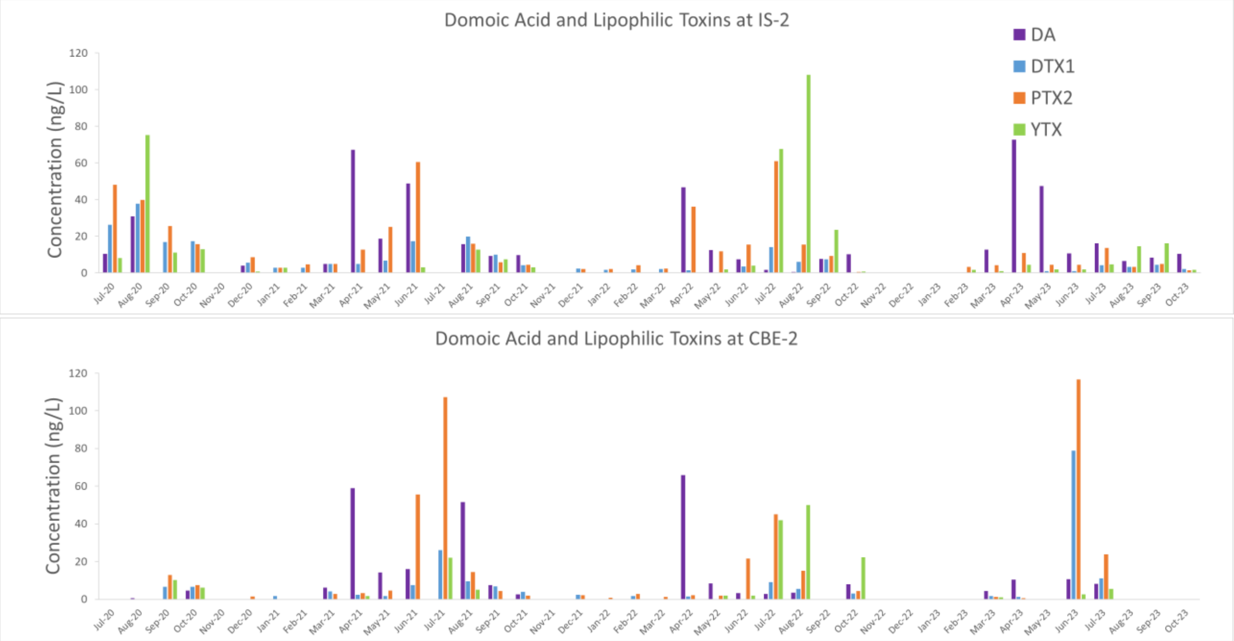

Figure 37-3. Time series of DA and Lipophilic Toxins in Malaspina Strait and Cowichan Bay (Jul. 2020 to Oct. 2023).

Dinophysistoxin-1 (DTX1) and pectenotoxin-2 (PTX2), which are produced by dinoflagellate species of the genus *Dinophysis*, peaked earlier and at higher than usual concentrations at CBE-2 in 2023 but were much lower than normal at IS-2 (Figure 37-3). Concentrations of these lipophilic toxins at Farms A and B were more similar in 2023 than in previous years and showed similar trends between November 2022 and August 2023 (Figure 37-2). Yessotoxin (YTX) which may be produced by dinoflagellate species of the genus *Protoceratium*, *Lingulodinium* or

Gonyaulax was detected at IS-2 and CBE-2 in 2023 but at much lower concentrations than in 2022 and was not found at the WCVI farm sites.

The most abundant PSP toxins observed in B.C. coastal waters were C1, C2, and saxitoxin. Long-term time series for these toxins (Figure 37-4) show that they tend to reach much higher concentrations than other biotoxins (Figure 37-2) at WCVI farm sites (C2 reached a concentration of 4,569 ng/L in June 2022). In 2023, however, PSP toxin concentrations were much lower than usual at Farms A and B where (like DA, DTX1 and PTX2) they showed similar trends over time.

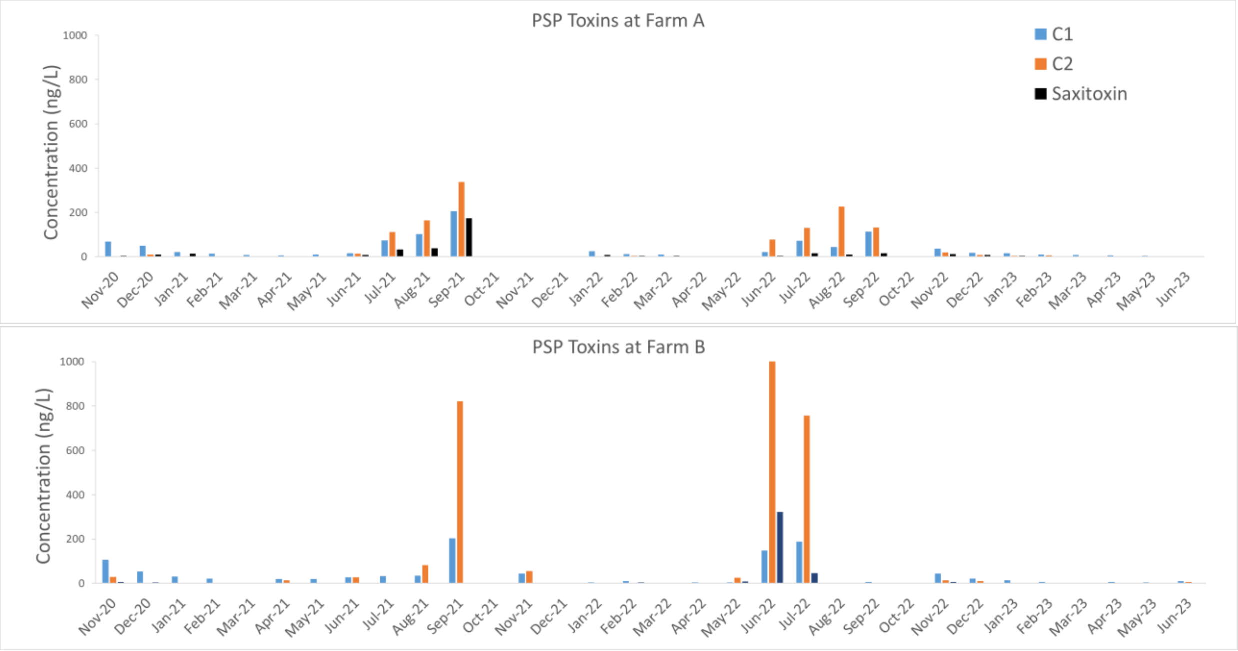

Figure 37-4. Time series of PSP Toxins at Farms A and B in Clayoquot Sound (Nov. 2020 to Jun. 2023).

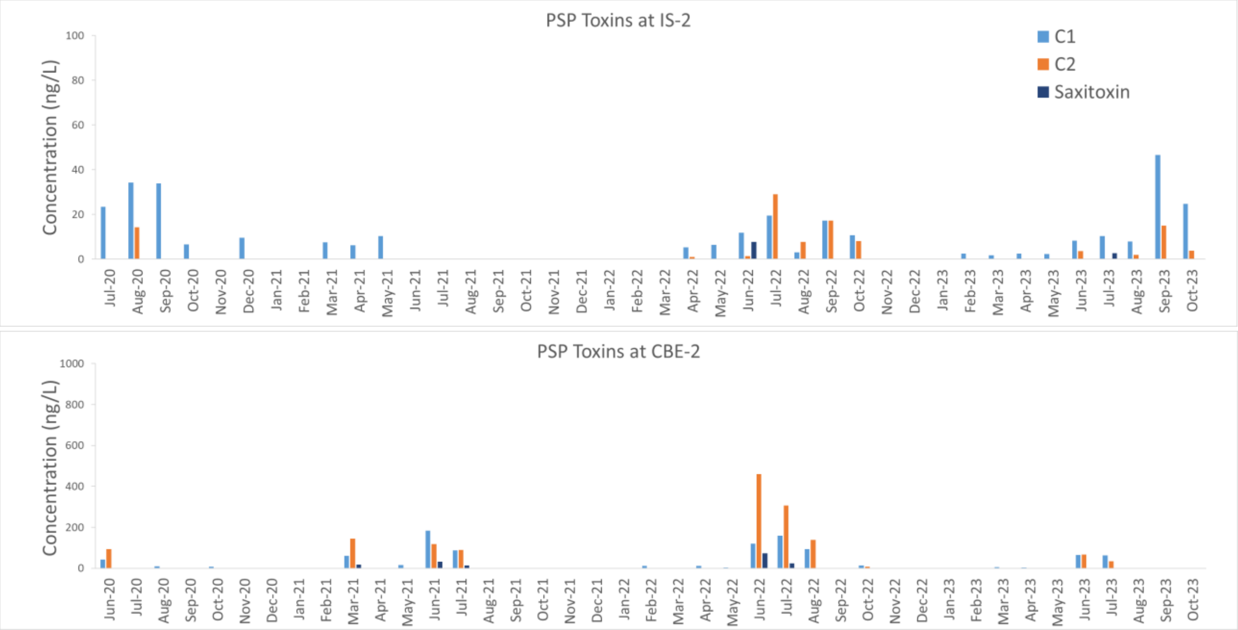

Figure 37-5. Time series of PSP Toxins in Malaspina Strait and Cowichan Bay (Jul. 2020 to Oct. 2023).

In contrast, total PSP toxins measured during the August 2023 La Perouse cruise reached a maximum concentration of 1,027.7 ng/L at station LC02 (Figure 37-1) of which 575.5 ng/L was in particulate form, suggesting that PSP toxin-producing cells were also present at this location. PSP toxin concentrations were lower than usual at CBE-2 in 2023, although they remain an order of magnitude higher than at IS-2 (Figure 37-5). However, azaspiracid AZA2 (Twiner et al., 2008) was detected at IS-2 in September and October 2023 having first been reported in B.C. coastal waters, at the same location, in September 2020 (Ross et al. 2021).

Analysis of samples collected in spring, summer and fall 2023 during Salish Sea Biophysical Surveys show spatial and seasonal variations in biotoxin concentrations between the northern and southern SoG (Figure 37-6). Total DA in spring 2023 was higher and more evenly distributed than in spring 2022. In the southern SoG, total DA in 2023 was lower in the summer (especially at station adcp) but higher in the fall than in 2022, reaching 54 ng/L at station adcp and 38 ng/L at station 59 and station 72 in the Juan de Fuca Strait (Figure 37-1). When compared with 2022, total PSP concentrations in 2023 were lower in spring and in summer but significantly higher in the fall, reaching 130 ng/L at station adcp (Figure 37-6) and 420 ng/L at station 102 in the Juan de Fuca Strait (Figure 37-1). Some PSP toxins (dcGTX-2, GTX-6) were higher in spring than in summer while others (C1, C2, GTX-5) were higher in summer than in spring, although all were most abundant in the fall.

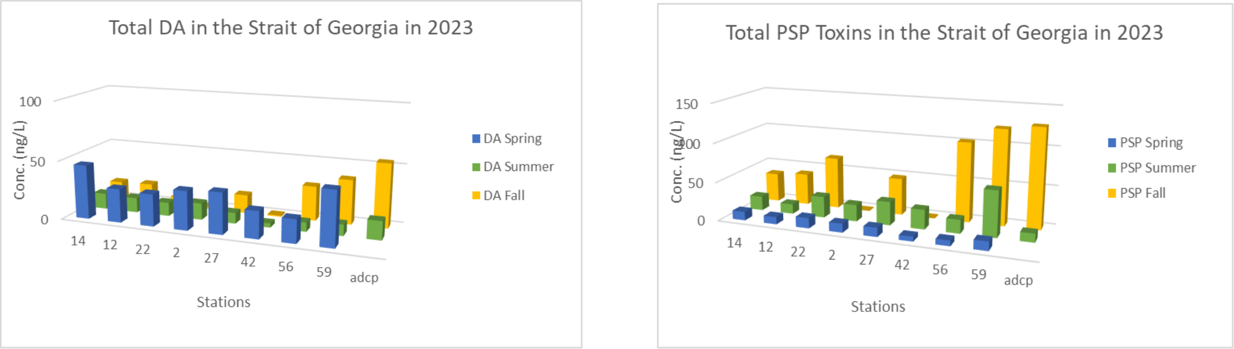

Figure 37-6. Seasonality in total DA and PSP toxins from the northern to southern SoG (Stns. 14 to adcp) in 2023.

DSP toxins PTX2 (Figure 37-7) and DTX1 were most abundant in the summer but were much lower in 2023 than in 2022 (DTX1 was comparable at station 72) and more evenly distributed throughout the SoG. YTX in 2023 was most abundant in the fall but an order of magnitude lower in concentration than in 2022, and was essentially absent from the SoG in spring and summer.

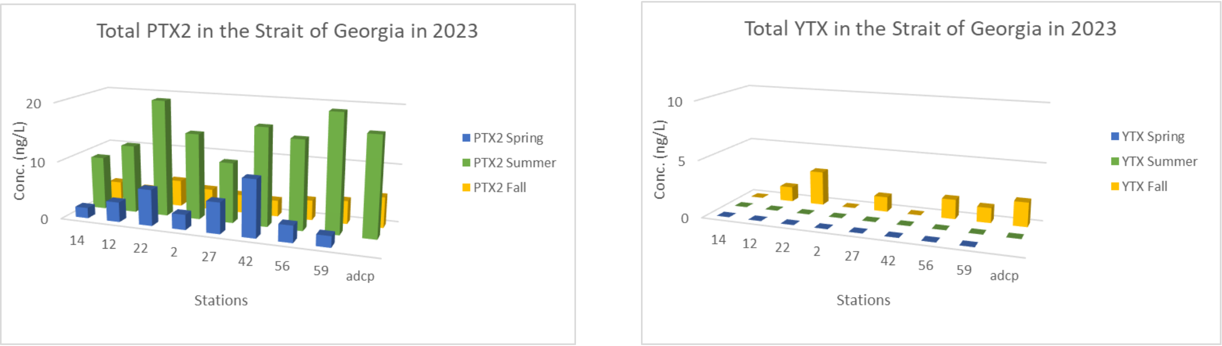

Figure 37-7. Seasonality in total PTX2 and YTX from the northern to southern SoG (Stns. 14 to adcp) in 2023.

37.4. Factors influencing trends

The occurrence and abundance of biotoxins in B.C. coastal waters appear to correlate with water temperature and the presence of associated harmful algae (Ross et al. 2023). This is illustrated by the seasonal trends in DA and DSP toxin concentrations at WCVI Farms A and B between November 2022 and August 2023 (Figure 37-2), the regular appearance of DA in April at SoG monitoring sites IS-2 and CBE-2 (Figure 37-3), and the presence of particulate DA and PSP toxins at La Perouse station LC02 in August 2023. In addition, taxonomic data from the PSF Citizen Science Oceanography Program indicates that *Protoceratium* and *Alexandrium* spp. were few in number during 2023, which is consistent with lower levels of yessotoxin and PSP toxins, while at CBE-2 *Dinophysis*, *Alexandrium*, DSP and PSP toxins all peaked in June 2023.

37.5. Implications of those trends

Algal biotoxins are known to harm marine mammals (Moriarty et al. 2021) and to be associated with illness and mortality in wild and farmed fish (Starr et al. 2017; Berge 2018). 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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Individual reports on inside waters (including the Strait of Georgia)

38. OCEAN OBSERVATORY CONTRIBUTIONS TO ASSESSING 2023 SOUTHERN B.C. COAST CONDITIONS

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38.1. Highlights

- Very strong downwelling happened at the beginning of 2023.
- Spring transition to upwelling was fairly on time (24 April 2023).
- The sustained upwelling (after spring transition) lasted until 14 Sep 2023 and then shifted to strong downwelling.
- Both upwelling and downwelling were stronger compared to 2022.
- Early Fraser River freshet happened at the beginning of May.
- Freshwater discharge was relatively small compared to 2022.
- CODAR data drops off during the freshet, so there was poor data in the beginning of May.

38.2. Description of the time series

Here we report on four types of data time series recorded from permanent installations, including upwelling winds in the west of Cape Flattery, CTD data recorded in the cabled platforms in the Strait of Georgia, Fraser River Discharge (the 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 – downwelling) per 100m of coastline. The daily upwelling indices are summed cumulatively for each year, revealing the winter/fall down-welling strength, 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 2023 has been obtained and used for analysis in the following report.
3. CODAR (HF Radar) data from the southern Strait of Georgia provided wide regional coverage of ocean surface currents throughout 2023 from four shore-based antennae at Pt Atkinson, Iona, West Port, and Georgia Pt.
4. 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 & O2 data record extending back to

2008, as well as temperature records from the Folger Deep that were used to assess the temperature trend in 2023.

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-favorable. 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 downwelling-favorable. 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 downwelling (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 downwelling (negative index) conditions and upward trending segments indicate upwelling (positive index) conditions.

In 2023, the oceanic dynamics exhibited a noteworthy pattern characterized by significant upwelling and downwelling events. At the outset of the year, a robust upwelling event was observed, indicating the ascent of nutrient-rich waters from the deep ocean layers. Subsequently, from April to September, prevailing winds favored strong downwelling conditions, deviating notably from historical norms. Particularly striking was the strength of southerly downwelling winter winds at the start of the year, surpassing both previous year's measurements and the 57-year average index. Despite the expected transition from the downwelling season to the upwelling season in late April, downwelling persisted intensely until mid-late September, extending beyond typical seasonal boundaries. This prolonged downwelling phase during the transition period is significant, potentially influencing marine ecosystems and nutrient cycles.

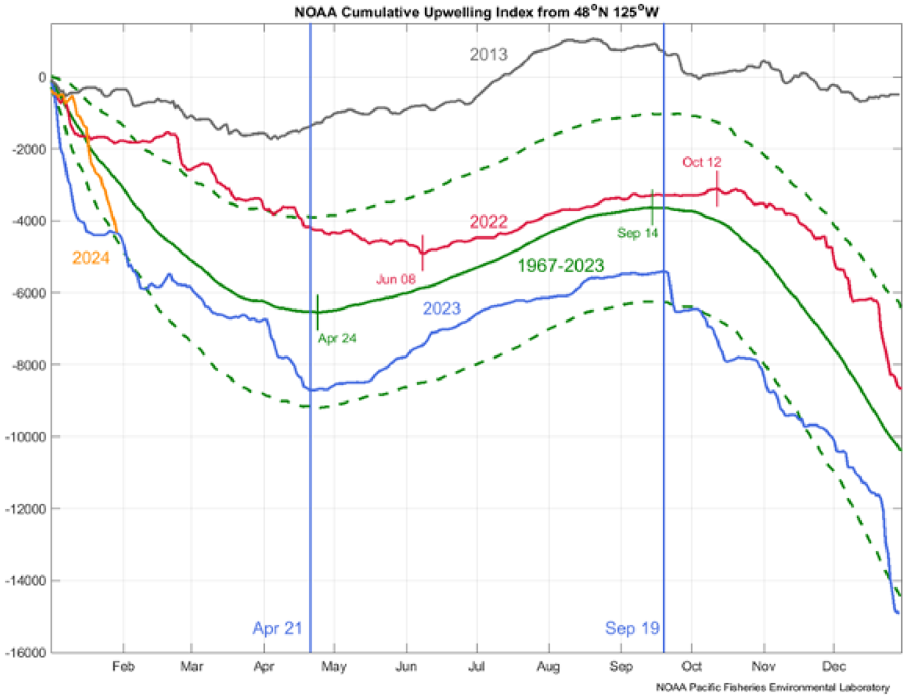


Figure 38-2. The cumulative daily upwelling index from reanalysis wind stress at 48°N 125°W, west of Washington State. Downward (downwelling, negative indices) trends occur during northward winds (winds from the south) and upward (upwelling, positive indices) trends occur during southward winds (winds from the north). 2023 is shown in a solid blue line. The green curve is the long-term (57 year) average, with plus and minus one standard deviations (green dashed curves). 2013 is shown as the weakest downwelling year on record, contributing to the development of the warm blob in the Northeast Pacific. The vertical lines indicate the late beginning (April 21) and delayed end (Sep 19) of the 2023 upwelling season.

38.3.2. Fraser River Discharge

Dictated by large-scale atmospheric conditions, the early warm spring in 2023 and earlier summer caused an earlier than usual freshet from the Fraser River. Figure 38-3 shows the historical Fraser River discharge in m^3/s at Hope, averaged into three-decade climate periods, and the discharge for 2023 (in red). The early discharge compared with the historically averaged freshet records had an impact on the availability of high frequency (HF) Radar data (Figure 38-4).

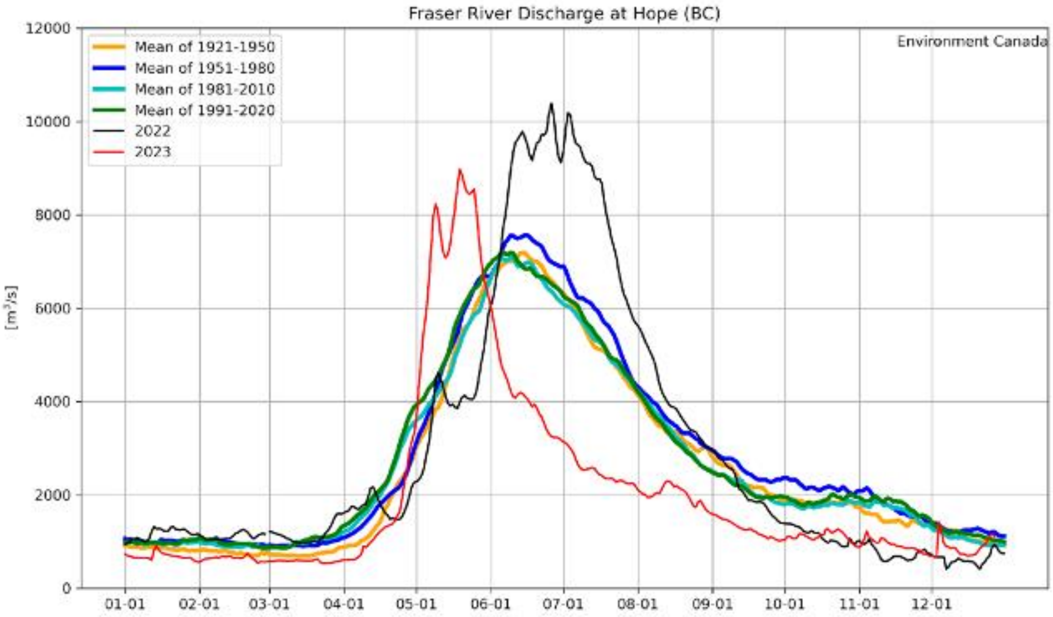
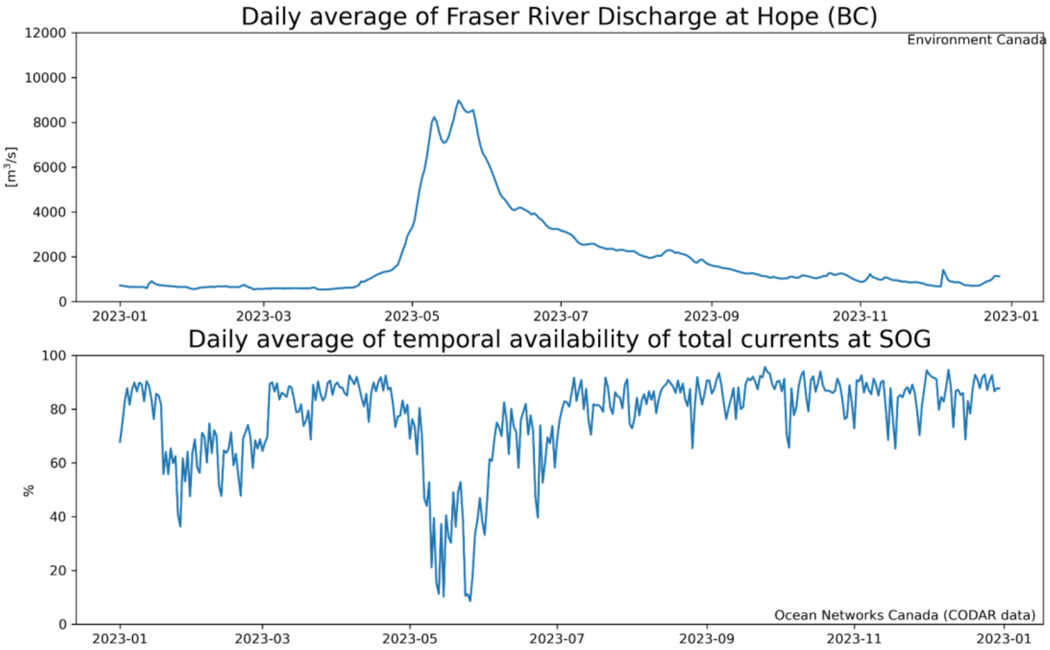


Figure 38-3. Fraser River discharge (m^3/s) at Hope as reported by Environment Canada. Shown are three 30 year climate averages and the discharge curve for 2023 (red).

38.3.3. Surface currents

ONC's Strait of Georgia CODAR (HF Radar) surface currents measurements 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. Figure 38-4 shows 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 early discharge, poor CODAR data was evident from early May through to mid-July 2023.


Daily average of Fraser River Discharge at Hope (BC)

Environment Canada

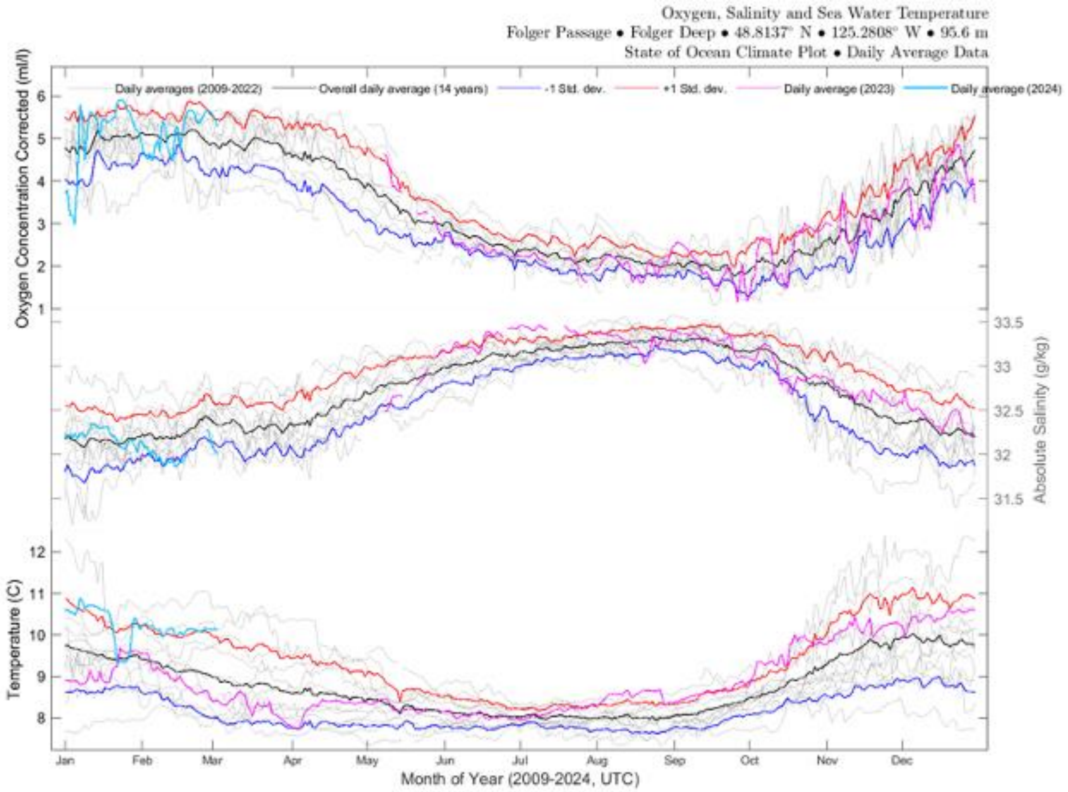
Daily average of temporal availability of total currents at SOG

Ocean Networks Canada (CODAR data)

Figure 38-4. 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 early freshet, resulted in a drop in CODAR data coverage from late May through June.

38.3.4. Folger Deep (~100 m)

Environmental data obtained from the ONC's central cabled observatory at Folger Deep, at a depth of approximately 100 meters, indicates a prolonged period of low temperatures during the first half of the year. However, in August, a sharp increase in temperature was recorded, which persisted at elevated levels throughout the remainder of the year (Figure 38-5).



Sample period: 34.4 seconds (average). Comments: Clean Data (major quality failures (QAQC 3,4,6) excluded): all data plotted pass QAQC. QAQC testing complete. See documentation for details. Standard deviations calculated from daily averages. Leap days excluded.

Figure 38-5. Time series of dissolved oxygen concentration (ml/l), absolute salinity (g/kg), and temperature (C°) from Folger Deep station.

38.4. Factors influencing trends

In 2023, the southwest coast of Vancouver Island experienced notable environmental patterns. Strong downwelling, induced by powerful winds, characterized the region, influencing oceanic dynamics. Both the spring transition from downwelling to upwelling and the fall transition from upwelling to downwelling occurred punctually. However, the early onset of warm weather led to an earlier freshening of the Fraser River discharge, resulting in reduced CODAR surface current data coverage in early May. Additionally, elevated temperatures were recorded in Folger Deep from April onward, persisting throughout the year.

38.5. References

NOAA Pacific Fisheries Environmental Laboratories Upwelling Indices:
https://www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/upwelling.html

Ocean Networks Canada Oceans 3.0 Data Portal: https://data.oceannetworks.ca/home

39. SALISH SEA TEMPERATURE, SALINITY AND OXYGEN OBSERVATIONS IN 2023

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39.1. Highlights

- Conditions in the summer of 2023 were cooler, more saline, and more oxygenated than average in the subsurface waters of the Strait of Georgia, with warm, more saline, less-oxygenated waters in Juan de Fuca Strait.
- The fall survey revealed warm, saline, and less oxygenated water throughout much of the system, with a layer of less oxygenated water in Juan de Fuca Strait at depths of around 100 m.
- The 25-year time series show trends of increasing temperature and decreasing oxygen throughout the system at all depths, with the exception of depths below about 75 m in the northern Strait of Georgia. Salinity is generally trending towards fresher conditions at the surface and more saline conditions at depth, increasing the stratification.
- The annual Fraser River discharge was the 2nd lowest in the 101-year record, with historically low discharge in June and July. SalishSeaCast model results suggest this reduced discharge may have weakened stratification and resulted in above average mixing rates in the southern Strait of Georgia and Haro Strait.

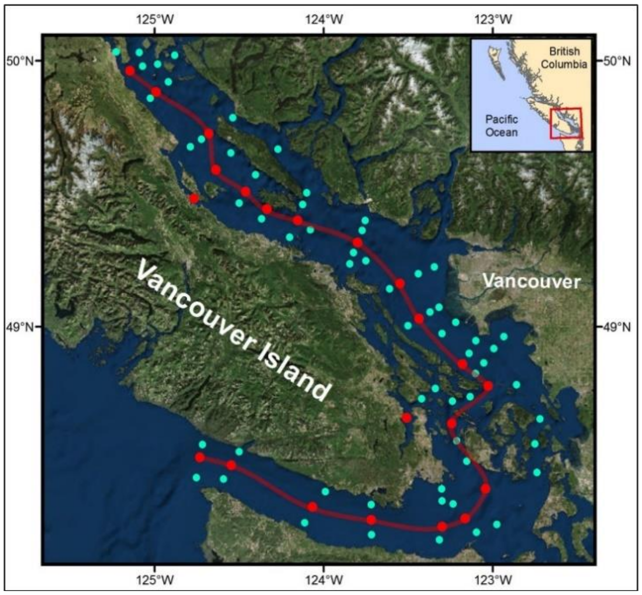

Figure 39-1. Dots show the locations of stations sampled during the water properties surveys. The thalweg is the red line joining the deepest stations along the centerline of the Straits.

39.2. Description of the time series

Changes in the water properties of the Strait of Georgia and Juan de Fuca Strait are described using profile data collected with a SeaBird 911 CTD equipped with a SeaBird 43 oxygen sensor during the Salish Sea Biophysical Surveys (Figure 39-1). In 2023, surveys were carried out during June 24-29 and October 8-14. The Salish Sea Spring Survey was cancelled due to the Canadian federal worker strike. Data collected since 1999 are used to calculate long-term averages and identify the 2023 anomalies from these average conditions for temperature and salinity. Data collected since 2004 are used for oxygen.

To provide context for conditions in 2023, survey results are compared to SalishSeaCast model output (Allen, Section 41). SalishSeaCast is a three-dimensional coupled bio-physical model of the Salish Sea. Fields were extracted for a fifteen-day period from July 9-23, 2023 and compared to a 2007-2022 climatology.

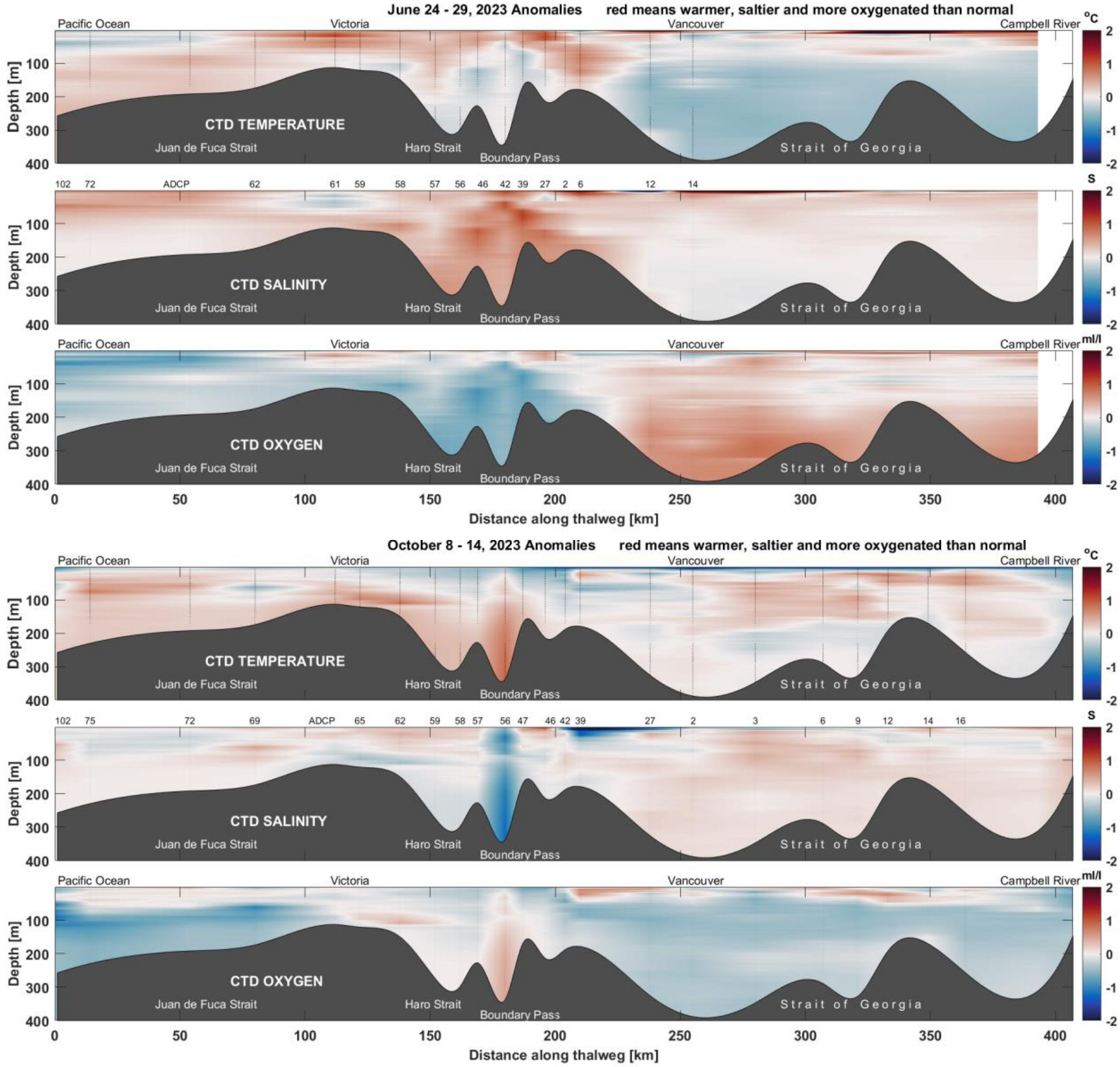

Figure 39-2. Temperature, salinity and oxygen anomalies along the thalweg observed in the summer (top three panels) and fall (bottom three panels) of 2023.

39.3. Status and trends

Observations of temperature, salinity and oxygen in 2023 are compared to the 1999-2022 averages (2004-2022 for oxygen) and shown as anomalies in Figure 39-2. The Salish Sea was generally more saline than average in 2023, especially in the spring. The Strait of Georgia was predominantly cooler than average with above average oxygen concentrations in the spring and warmer than average with below average oxygen concentrations in the fall, with a fresh, high-oxygen near-surface layer likely associated with the Fraser River plume (Wang et al. 2019). Juan de Fuca Strait was warmer than average during both spring and fall, with lower-than-average oxygen concentrations.

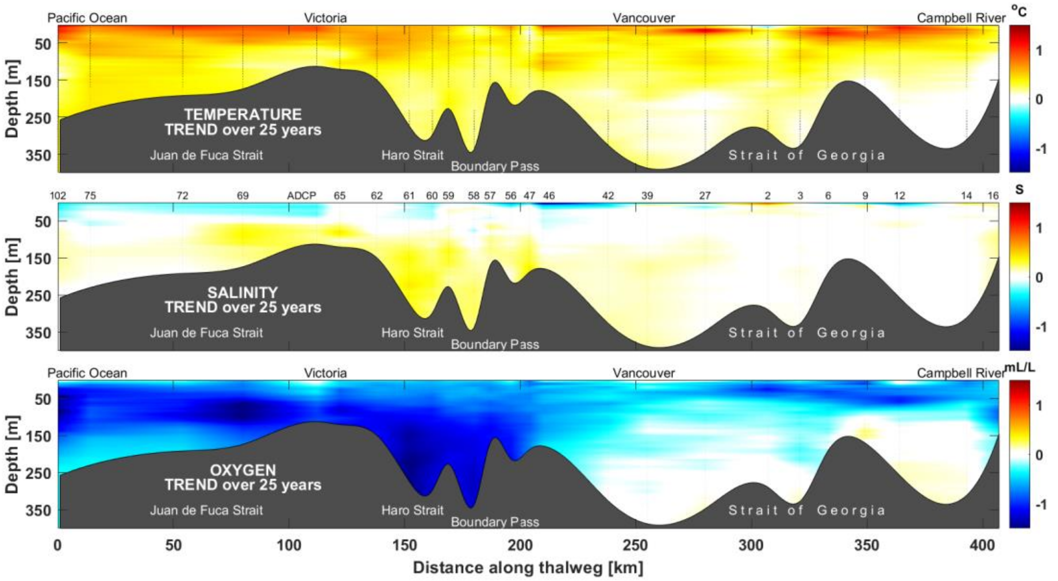

Figure 39-3. Trends in temperature, salinity and oxygen at each depth and station along the thalweg over the 25-year time series.

Long-term trends (Figure 39-3) in temperature over the 25-year record show warming throughout the system, with increases on the order of 1°C in the near-surface. The upper water column has become fresher while mid-to-deep waters have become more saline, increasing stratification. Oxygen has declined everywhere except in the deep northern Strait of Georgia, with a particularly large decrease in Juan de Fuca Strait associated with declining oxygen in the seasonally upwelled water from the north Pacific (Crawford and Peña 2013).

The Fraser River influences the salinity of surface waters in the central and southern Strait of Georgia and is a driving force for the exchange of water masses through Haro Strait. The 2023 annual discharge of the Fraser River measured at Hope, B.C. (Figure 39-4) was the 2nd lowest in the 101-year record. The annual discharge of the Fraser River is increasing at a rate of 3.2 x 109 m^3 per 100 years. The spring freshet in 2023 peaked early and was higher than average, followed by historically low discharge in June and July and lower than average fall runoff.

The SalishSeaCast model indicates that as a result of the low Fraser River discharge, exceptionally high sea surface salinities in the southern Strait of Georgia reduced the stratification there, in Haro Strait and Boundary Pass, strengthening vertical mixing in July. Similar evidence of high surface salinities and mixing can be seen in the June survey data. As a result, nitrate was fluxed towards the surface and drove a major diatom bloom in the model in the southern Strait of Georgia. These high surface salinities may have also delayed or weakened deep water renewal in the early summer.

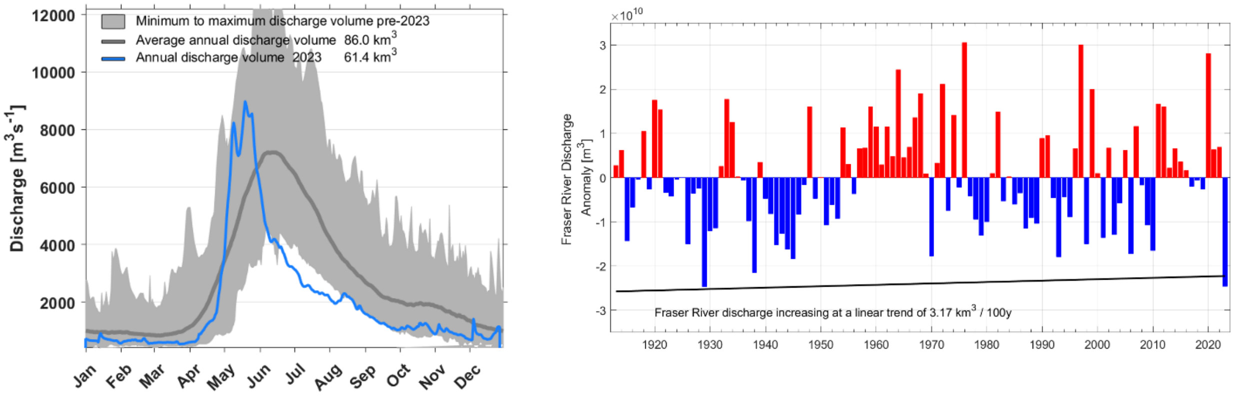

Figure 39-4. (Left panel) Fraser River discharge at Hope B.C.; 2023 (blue), 101-year average (dark gray), and minimum to maximum historical discharge pre-2023 (gray envelope). (Right panel) Time series of the annual Fraser River discharge anomaly and linear trend. Data extracted from the Environment and Climate Change Canada Real-time Hydrometric Data web site (https://wateroffice.ec.gc.ca/mainmenu/real_time_data_index_e.html) on 28 Feb 2023.

39.4. Factors influencing trends

Water properties in the Salish Sea are considerably influenced by ocean conditions at the western entrance of the Strait of Juan de Fuca, and the freshwater discharge of rivers, primarily the Fraser River. In addition to summer warming and winter cooling, seasonal changes occur as salty, oxygen-poor ocean water is upwelled during the summer months, and Fraser River runoff peaks during the early summer. The global trends of ocean warming are reflected directly in the Salish Sea water properties, and the trend of increased discharge of the Fraser River is reflected in the freshening trend of the surface layer. The intense tidal mixing that occurs in Haro Strait effectively controls the exchange of water masses between Juan de Fuca Strait and the Strait of Georgia (Masson 2002; Pawlowicz et al. 2007; Masoud and Pawlowicz 2022).

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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 2023 was typical. The spring bloom timing was very similar when compared to 2022.
- The timing of the 2024 spring bloom was also typical according to the model and preliminary observations.

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 timing back to 1967 (Allen and Wolfe 2013).

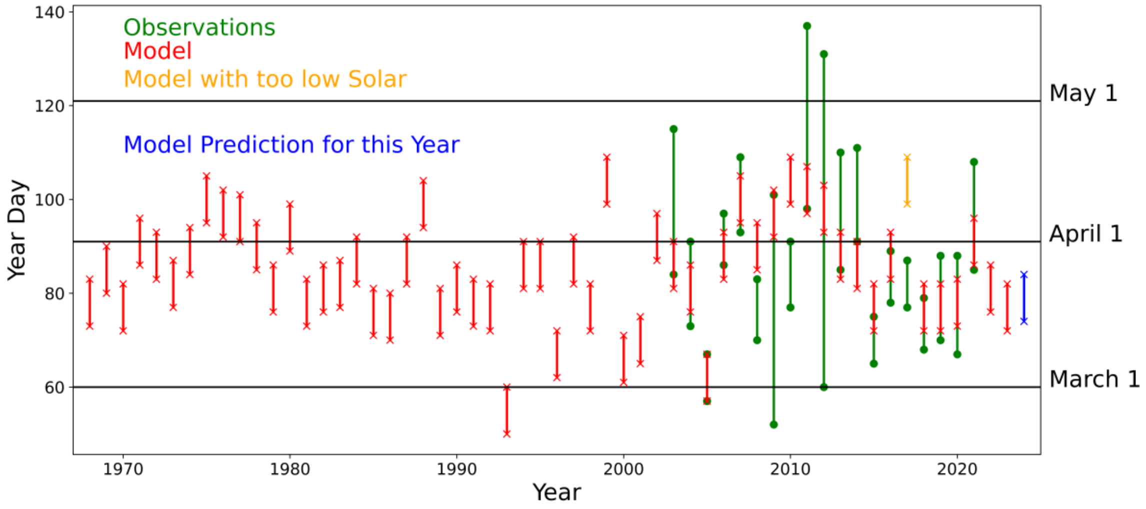

Figure 40-1. Time series of the timing of the peak of the spring phytoplankton bloom. Green- observations from various systems (see Sastri et al. 2019) Red – SOG model. Orange – SOG model with too little solar radiation (see Allen et al. 2018). Blue –SOG result for 2024.

40.3. Status and trends

The 2023 spring bloom happened between March 13 – March 23, 2023 according to the SOG model (Figure 40-1). Ferry data is unfortunately not available for 2023. The 2024 spring bloom peaked between March 14 – March 24, 2024 according to the SOG model and in agreement with preliminary ferry observations (R. Pawlowicz, UBC, personal communication).

According to the model, the 2023 and the 2024 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. All but one of the spring blooms since 2018 has been near median timing. The only exception was 2021 which was late. Importantly, the last three years, 2022, 2023 and 2024 have had very similar timing.

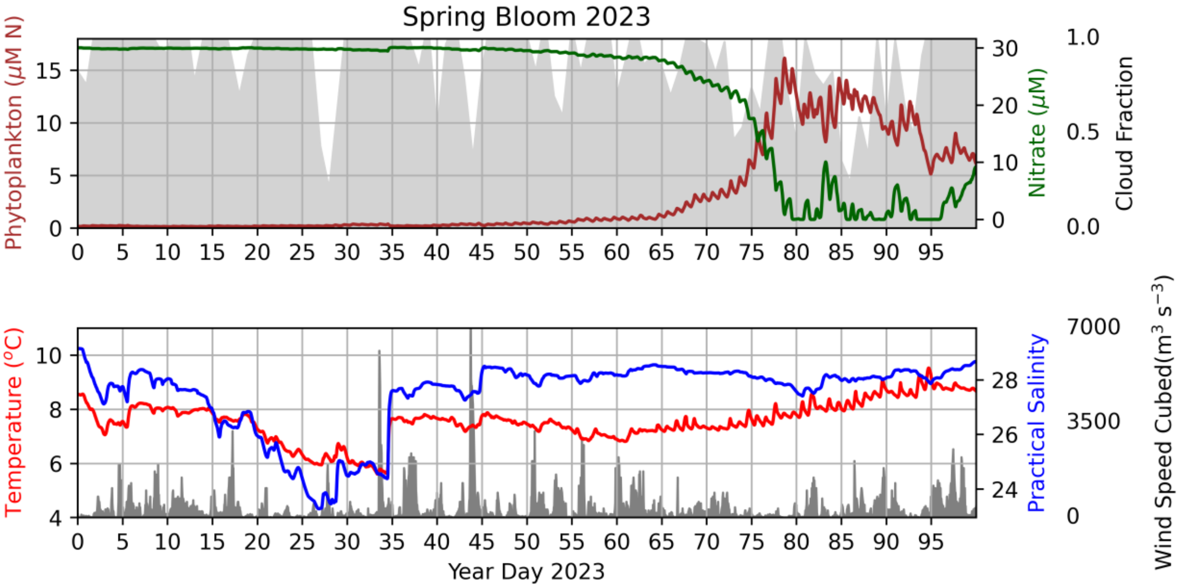

Figure 40-2. Hindcast of the 2023 spring bloom and related conditions in the Strait of Georgia. The lower panel shows temperature (in red) and salinity (in blue) averaged over the upper 3 m of the water column; in grey is the wind-speed cubed which is directly related to the strength of the mixing. The top panel shows phytoplankton biomass (in dark red) and nitrate (in green); in grey is the cloud fraction averaged over the day. The 2023 spring bloom was March 18 plus or minus 5 days. Plots span the period January 1, 2023 to April 10, 2023.

40.4. Factors influencing trends

According to the SOG model, in 2023 cloudy skies and strong storms throughout February did not allow the spring bloom to start until early March (Figure 40-2). A period of lighter winds in the first week of March, followed by quiet and sunny weather in the second week allowed the bloom to initiate. The spring bloom peaked on March 18 and high phytoplankton biomass continued into early April.

40.5. Implications of those trends

The timing of the spring phytoplankton bloom can impact age-0 Pacific 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 2023 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 Pacific Herring abundance. Observations support this expectation (Galbraith et al. Section 22; 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 2023 was low compared to the long term average.
- Zooplankton summer diet was more nanoflagellate-based than the long term mean.
- Sea surface temperature was high and winds were low in 2023 compared to the long term mean, 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 biomass in the Strait of Georgia (SoG). As described in previous reports, 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 an empirical fit to local, gauged rivers. The biological model, SMELT, is a 3 nutrient, 2 phytoplankton, 2 zooplankton, and 3 detritus class model (Olson et al. 2020; Suchy et al. 2023). The two phytoplankton boxes are diatoms: representing both pennate and centric diatoms, and nanoflagellates: representing primarily haptophytes, cryptophytes and prasinophytes. Here we present summer phytoplankton dynamics in the Central SoG (Figure 41-1) based on version v202111 of the model, for which we have a 17-year time series (2007-2023).

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. Recent research using SalishSeaCast has shown the mechanisms for these correlations (Suchy et al. 2024). The warmer sea surface temperatures (SST) favour the nanoflagellates, as do weaker winds as they reduce nitrate flux. Warm/weak wind years 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) (Figure 41-2).

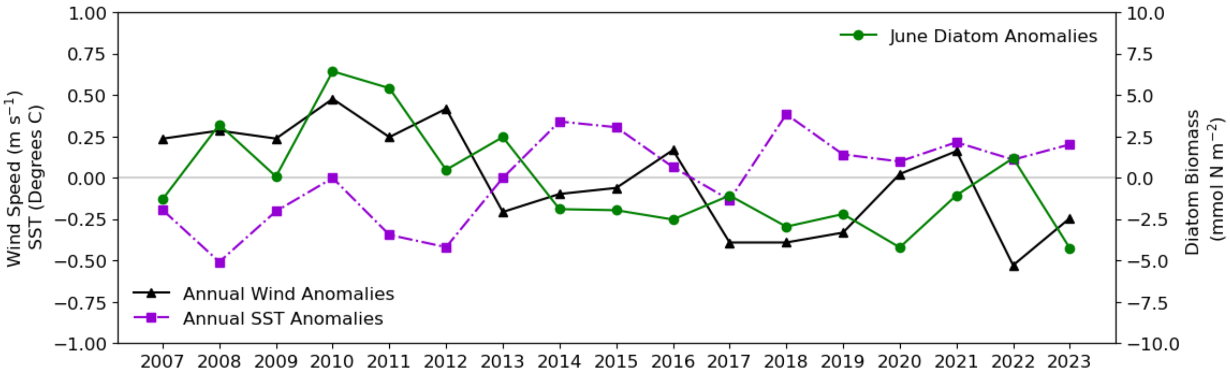

Figure 41-2. Annual wind anomalies (black triangles), and annual sea surface temperature anomalies (purple boxes) versus June diatom biomass anomalies (green circles) in the Central SoG. Note the positive correlation with winds and the negative correlation with temperature.

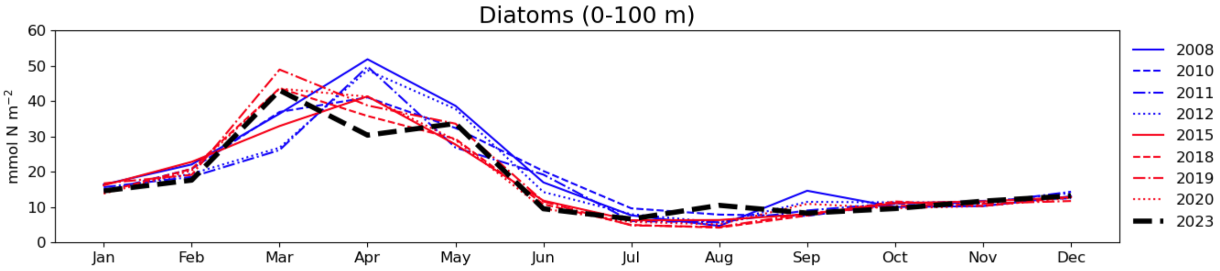

Figure 41-3. The diatom biomass in 2023 in the Central SoG (black dashed line) compared to four positive NPGO years (blue) and four negative NPGO years (red). Note the very low biomass in June and September but higher biomass in July and August 2023.

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 cooler SST and stronger winds than those with warm SST and weaker winds. Like the decade before, 2023 was a warm SST, low winds year and a low diatom biomass year.

41.4. Factors influencing trends

Weak summer winds and warm SST are correlated in the Salish Sea with the negative phase of the NPGO (Suchy et al. 2024). Since 2017, the NPGO has been consistently in its negative phase. The NPGO affects the Salish Sea in multiple ways, 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). In 2023, diatoms were low, particularly in June and September (Figure 41-3). Some revival was seen in July and August which might be due to the very low Fraser River flow (Dosser et al., Section 39).

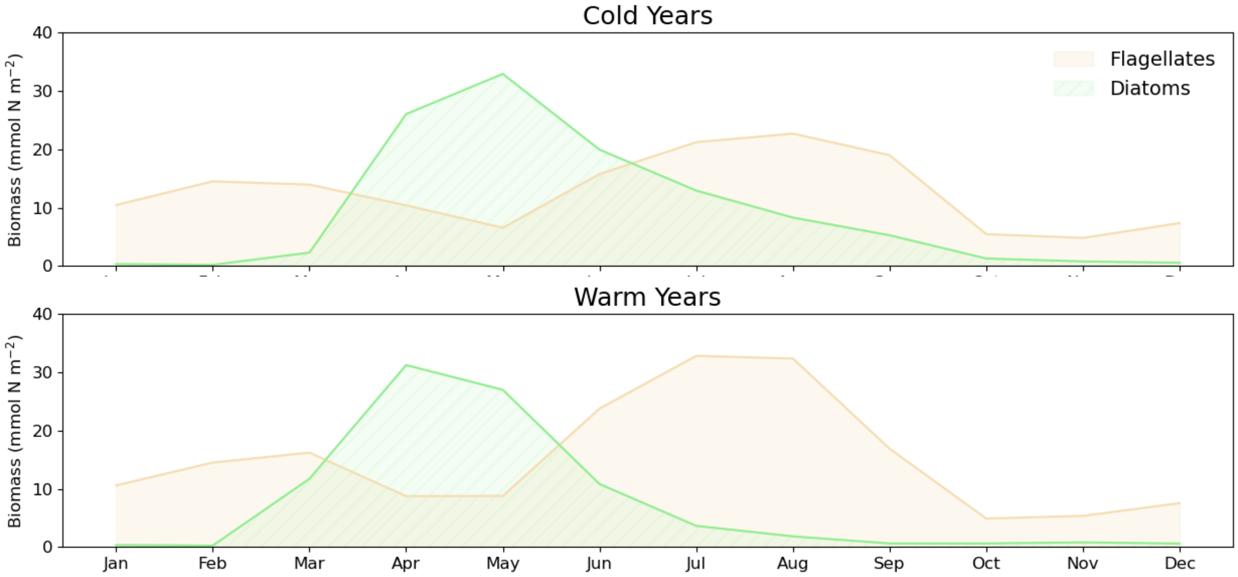

Figure 41-4. For the four highest NPGO years in the time series (Cold Years) and the four lowest NPGO years in the time series (Warm Years) the mean monthly nanoflagellate and diatom biomass.

41.5. Implications of those trends

The phase of the NPGO is strongly linked with ratio of the two types of phytoplankton in SalishSeaCast and their seasonal progression (Figure 41-4). In years with warm-phase conditions (negative NPGO), the summer phytoplankton consisted of fewer diatoms and more nanoflagellates. 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 2023

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42.1. Highlights

- Strait of Georgia temperatures appear to reflect a link with El Niño/Southern Oscillation, while salinities appear to be linked with the North Pacific Gyre Oscillation in recent years.
- 2023 had a relatively weak spring bloom and summer chlorophyll levels, and more nutrients than in 2016-2019.
- In summer, there were widespread, very dense blooms of *Noctiluca scintillans* and dense but localized blooms of *Heterosigma akashiwo* and *Dictyocha*; a few local blooms of *Rhizosolenia setigera*, and *Pseudo-nitzschia* were seen in late summer and spring respectively; *Alexandrium* (PSP causing taxa) occurrence was noticeably lower than usual while *Dinophysis* (DSP causing taxa) was close to average.
- Long-term patterns of some HAB taxa occurrence and their association with large-scale climate patterns have started to emerge.

42.2. Citizen Science Program

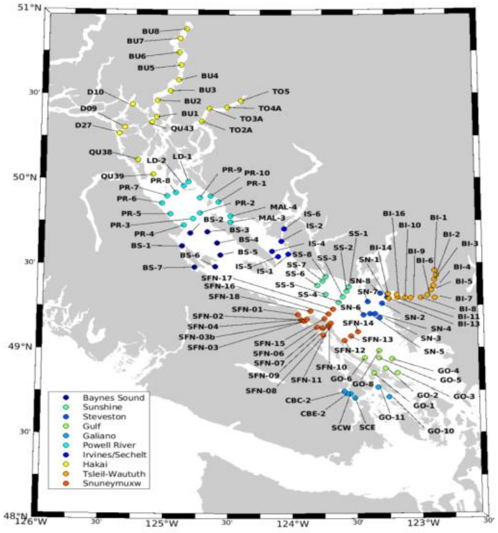

Figure 42-1. Map of the Strait of Georgia with CitSci (and other) program sampling locations in 2023. Different colours represent different patrols.

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 (UVic and 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).

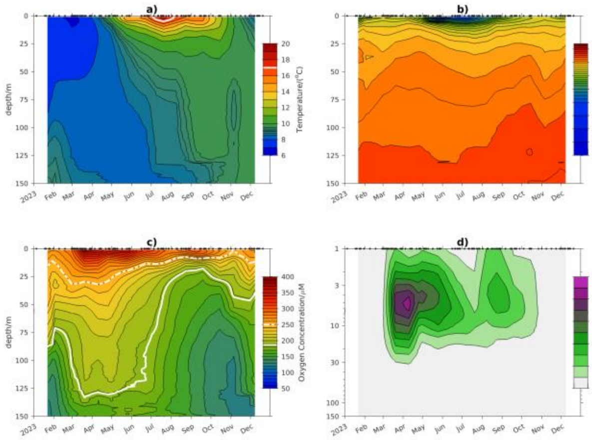

Figure 42-2. Annual cycle for water properties in the Strait of Georgia in 2023. White lines mark conservative physiological boundaries for salmonids (warmest temperature 17℃, lowest O_2 6ppm or 187 uM (solid) and 8 ppm or 250 uM (dashed) for instantaneous and 30-day mean limits in approved B.C. Water Quality guidelines for fish at all life stages).

42.3. Description of the time series

In 2023, 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, chlorophyll fluorescence (CTD/O2/Fl) profiles to 150 m depth were collected at all stations for a total of 811 profiles. These were combined with additional stations obtained by the Hakai Institute (214 profiles), the Tsleil-Waututh Nation (58 profiles), and the Snuneymuxw Nation (148 profiles) for averaging purposes. Raw data for all except Hakai profiles were archived and processed by ONC (community fishers web app). Nutrient samples were collected at two depths (0 and 20 m) at ~30 stations (722 samples in total), phytoplankton samples at the surface at all stations and additional 5, 10, and 20 m at ~30 stations (~1100 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 2023, 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). Oxygen levels were greater than 6 ppm or 187 uM only in waters shallower than about 25 m depth in late summer, and greater than 8 ppm in waters shallower than about 10m at the same time (Figure 42-2). This seasonal cycle was similar to conditions in most years. However, added to this annual cycle, temperatures below 100 m warmed slightly in the last half of the year compared to 2022, and became more saline in 2023 compared to 2022 (Figure 42-3).

Based on in-situ chlorophyll fluorescence observations, there was a distinct spring bloom in mid-April, whose magnitude was relatively weak compared with those of the past few years, with a weaker fall bloom in September. Based on surface water samples, algae cell concentrations reached only hundreds cells per mL during spring bloom, as opposed to thousands of cells in many previous years. The bloom also did not end with nutrient exhaustion, although surface nitrate levels finally reached very low values in June. Although the summer had reasonably low nitrate conditions, exhaustion was not as pronounced as in 2016-2019, and silicate levels remained relatively high (Figure 42-4).

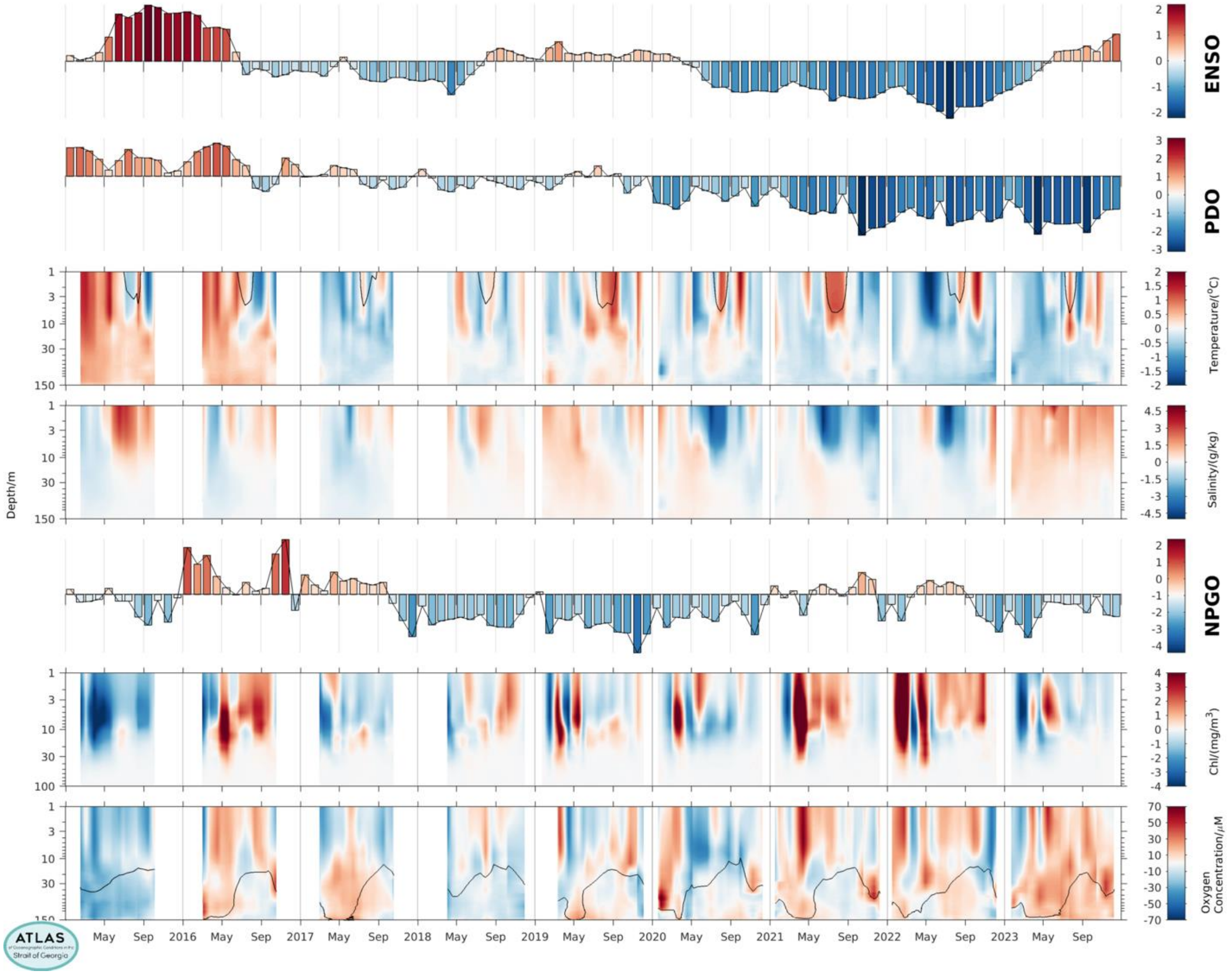

Figure 42-3. Strait of Georgia-wide trends in water property anomalies from 2015-2023. Red values are higher than a 2015-2023 seasonal average, and blue values are lower. Interspersed are values of ENSO, PDO, and NPGO climate indices relevant to the NE Pacific.

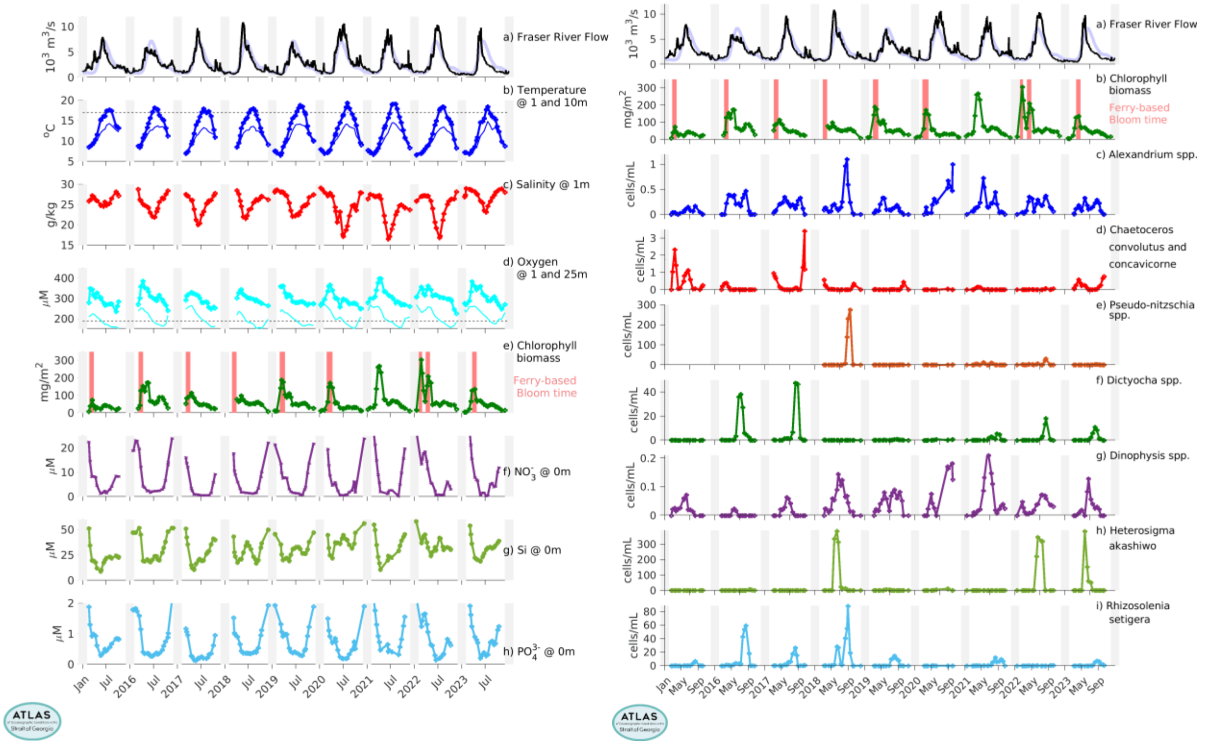

Figure 42-4. Strait of Georgia-wide trends in average surface properties (left) and average harmful algae (right) during 2015-2023; note that Fraser River flow and Chlorophyll are duplicated in both sides to facilitate vertical comparisons.

There were many harmful algal blooms (HABs) in 2023; 2023 and 2022 were the only two years in 2015-2023 time series when all five HAB taxa formed dense (>100 cells per mL) blooms (Table 42-1). Diatom *Pseudo-nitzschia* spp. was blooming in April in Cowichan Bay. There were widespread, vivid orange blooms of *Noctiluca scintillans* (up to 2000 cells per mL) in May, June, and July (e.g., Pender, Saltspring, Indian Arm, Cowichan Bay, Brentwood Bay, Maple Bay, etc.) (Figure 42-5). These blooms garnered public attention and received news coverage (e.g., Time Columnist, 2023). *Ichthyotoxic raphidophyte*, *Heterosigma akashiwo*, was seen from April to August in many areas and formed very dense (>1000 cells per mL) localized blooms in late May in Steveston area and Malaspina Strait and dense (>100 cells per mL) blooms in May-July in Steveston, Irvine's Sechelt, and Sunshine coast areas. These blooms were followed by blooms of silicoflagellate *Dictyocha* in July-August in Nanaimo, Cowichan Bay, and Irvine's Sechelt areas. New partnership with Snuneymuxw First Nation provided non-routine samples from coastal embayments near Nanaimo, one of these samples (SFN7 station sampled on July 18) had the highest concentrations of *Dictyocha* ever observed in the Citizen Science history – 2000 cells per mL. In late August and September there were a few blooms of diatoms *Rhizosolenia setigera* near Powel River and Irvine's Sechelt.

*Table 42-1. Maximum concentrations (cell per mL) observed in routine 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 (max cells per mL)	2015	2016	2017	2018	2019	2020	2021	2022	2023
*Noctiluca scintillans**	1	2	2	3000	800	1	3200	1000	2000
Heterosigma akashiwo	6	150	20	11000	25000	7000	10	15000	11000
Dictyocha spp.	5	700	400	10	10	50	150	140	800
Rhizosolenia setigera	250	800	1800	4000	500	5	500	400	180
Pseudo-nitzschia spp.**	N/A	N/A	N/A	4500	30	70	1800	2000	350

Figure 42-5. Noctiluca bloom in Maple Bay, May 24, 2023. Photo by K. Shehan, PSF (left panel). Noctiluca bloom in Brentwood Bay, May 28, 2023. Photo by S. Hocker, DFO (central panel). Noctiluca cell under the microscope (right panel). Photo by S. Esenkulova, PSF.

Several algae cause harmful effects at non-bloom densities. Some of them, like *Chaetoceros convolutus* and *C. concavicorne*, are nontoxic but have very large cells with spikes that are mechanically harmful to fish gills (Haigh et al. 2004). These species were found in ~8% of samples collected during spring (April-May) and fall (September, October). This occurrence rate marked the second highest percentage recorded, following the peak observed in 2015 when they were present in ~15% of samples within the same time frame. Some algae 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). Overall, *Alexandrium* abundance was noticeably (~1/4) lower than average and similar to that of the years 2015 and 2019. *Dinophysis* was present in ~5% of May-September samples, which is comparable to the nine year average.

Powell River crew observed a substantial krill (aff. female *Thysanoessa spinifera*; M. Galbraith, DFO) die off event near Beach Gardens on March 16, 2023. Both CTD and algae data looked normal. Observations, krill samples and water for biotoxins analysis were collected by the PSF Citizen Science crews and delivered to IOS, DFO. Krill die offs may be a common occurrence in the Strait in the springtime; possible causes may be related to suboptimal aquatic conditions or breeding swarms (Akash Sastri and Kelly Young, DFO pers. comm.). This demonstrates, yet again, how community involvement contributes valuable information that can complement government studies and enhance our understanding of ecosystem health and natural events.

42.5. Factors influencing trends

A clear correlation can be seen in deep water temperature anomalies, obtained after subtracting a 2015-2023 seasonal average (and to a lesser degree in near-surface temperature anomalies) with an El Niño/Southern Oscillation (ENSO) index (Figure 42-3). Both shallow and deep salinity anomalies, however, are most strongly (and negatively) correlated with the North Pacific Gyre Oscillation (NPGO). This is a little surprising, as shallow salinities in the Strait are directly related to the magnitude of freshwater inflow from the Fraser (and other) rivers (Figure 42-4), itself a reflection of winter snowpack, whereas precipitation is often correlated with ENSO in climate discussions. Dissolved oxygen anomalies, especially in deep water, and summer chlorophyll levels are also correlated with the NPGO. Correlations between salinity and chlorophyll levels with the NPGO are also seen elsewhere in the coastal NE Pacific but the mechanisms involved in outer shelf and inner-basin (Strait of Georgia) variations are not necessarily the same. However, we have not yet discovered an obvious link between the depth of oxygen and temperature thresholds with a climate index.

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 2023, although this is not different than in most years, however there are interannual changes in water conditions that are linked to changing climate. 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 the 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, 2023

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43.1. Highlights

- 2023 zooplankton biomass peaked in June, estimated at 144.3 mg m^{-3} (sd 41.3 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. Euphausiid biomass was low in summer 2023.
- 2023 zooplankton biomass trended up from 2022 and was 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 2023 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 (SoG; 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.

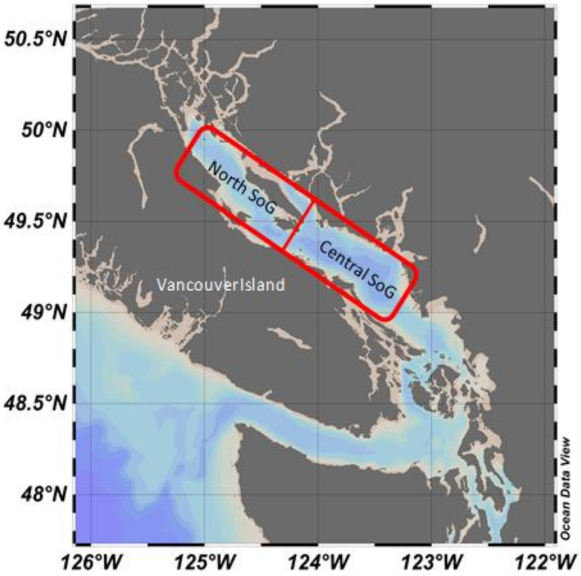

Figure 43-1. The central and northern Strait of Georgia (SoG) shown by the red boxes.

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). The anomaly data by major zooplankton groups for 1996-2023 can be accessed in the ‘pacea’ R package (Edwards et al. 2023).

43.3. Status and trends

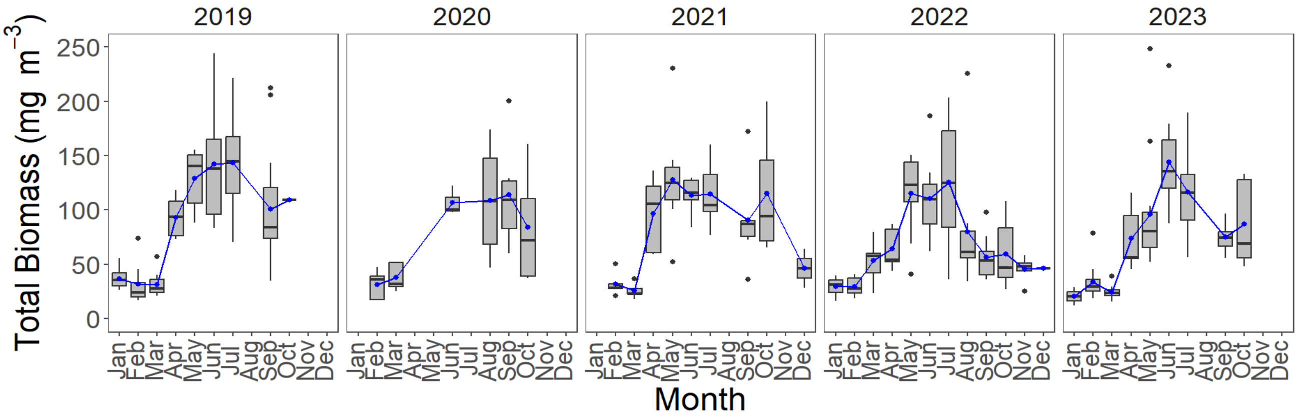

Figure 43-2. Average total biomass (mg m^{-3}) of zooplankton by month in the north and central (averaged together) Strait of Georgia for 2019-2023. Boxplots show median and spread of data, blue dot and line follows the mean biomass.

The total zooplankton biomass in 2023 ranged from 11.8 - 248.3 mg m^{-3}, with the lowest biomass occurring in the winter (Jan-Mar) and peaking in June (mean 144.3 mg m^{-3} sd 41.3 mg m^{-3}; Figure 43-2).

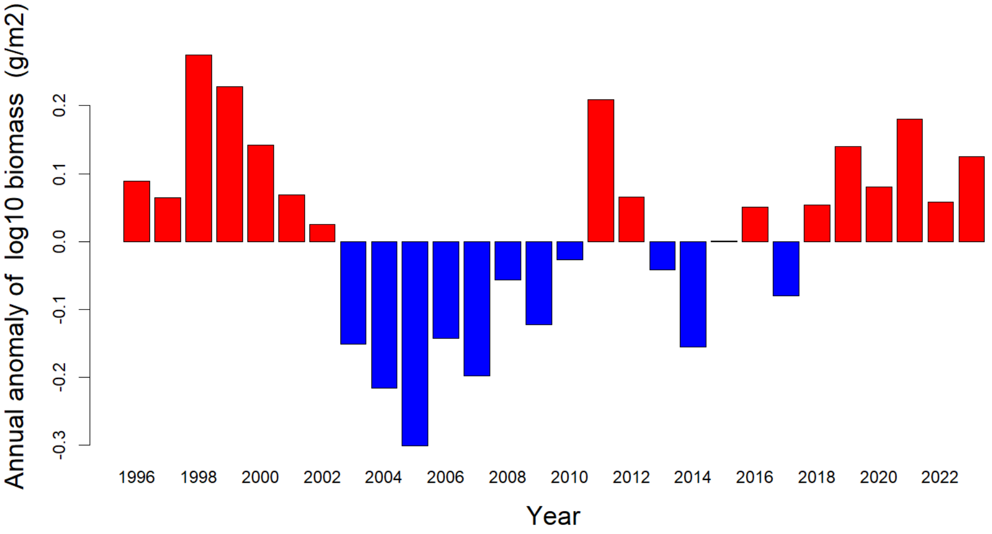

Figure 43-3. Annual biomass anomalies of total zooplankton biomass in the deep waters of the central and northern Strait of Georgia, 1996-2023.

Overall, total biomass was above average in 2023 and was higher than in 2022 (Figure 43-3).

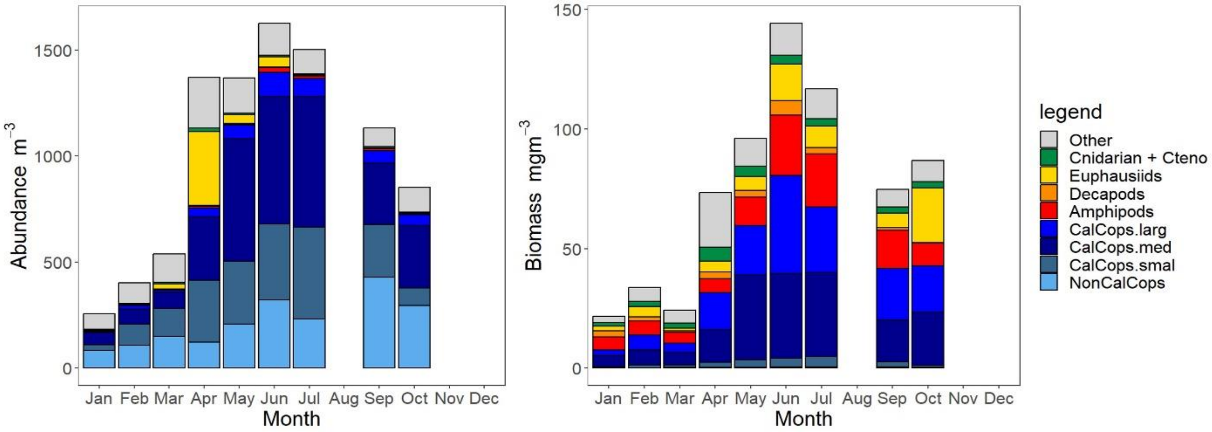

Figure 43-4. Taxonomic composition of zooplankton from northern and central Strait of Georgia in 2023, averaged by month. Left: abundance (m^{-3}); Right: biomass (mg m^{-3}). Legend: CalCops.larg – calanoid copepods, prosome length (PL)>3mm; CalCops.med – calanoid copepods PL 1-3mm; CalCops.smal – calanoid 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. 2021; 2022). 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-sized copepods was similar to previous years with Calanus sp. (*C. pacificus* and *C. marshallae*) and *Metridia pacifica* making up the majority of the biomass (Figure 43-5). There was an increase in the proportion of *Neocalanus plumchrus* and less *Eucalanus bungii* for large-sized copepods in 2023 than in the previous years.

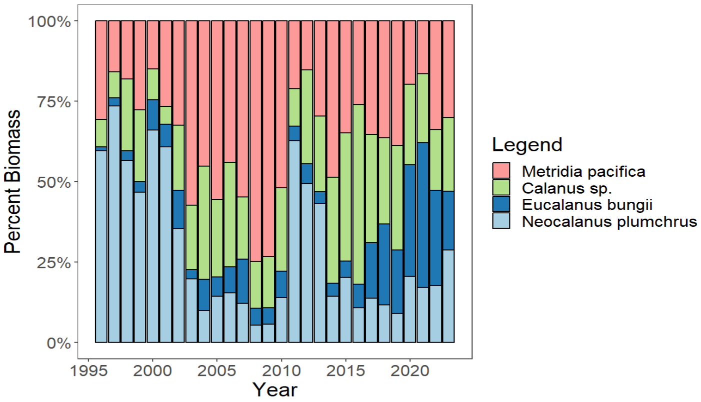

Figure 43-5. Yearly averaged percent biomass of the medium (M. pacifica and Calanus sp.) and large (E. bungii and N. plumchrus) calanoid copepods from 1996-2023.

Euphausiid biomass in 2023 was lower than average in summer, and average in the winter and fall, with an overall average biomass for the year (Figure 43-6).

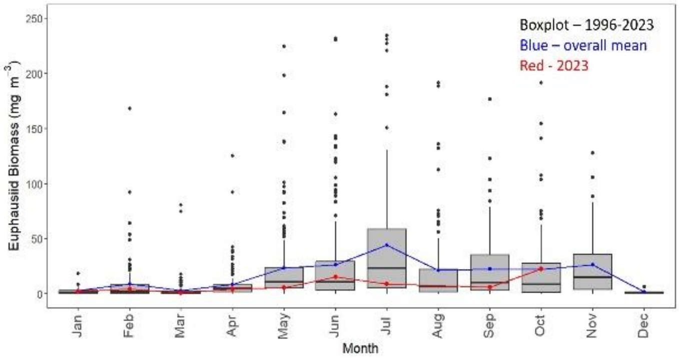

Figure 43-6. Average biomass (mg m^{-3}) per month of euphausiids (all stages) for 1996-2023. Boxplots show median and spread of data, blue dot and line follows the mean biomass. Red dot and line represent 2023 data.

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 SoG, 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 SoG 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 2023, the index of the relative biomass of age-0 herring was the highest it has been since 2010 and above the time series mean.
- Age-0 herring were smaller than average, but their condition was above average.
- In 2023, Northern Anchovy were present in 24% of the fishing sets; this is the seventh 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 Pacific Herring as a potential predictor of the abundance of age-3 Pacific 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), 2022 (2), and 2023 (1; 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 Pacific 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, Pacific Herring condition was calculated as residuals from a double-log-transformed length-weight regression (Boldt et al. 2019). In 2021-2023, 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 2023, 8 of 10 standard transects plus one additional transect were sampled. Weather prevented sampling of some stations. Age-0 Pacific Herring were caught in 37 of the 41 stations sampled, and 33 of the 37 standard stations sampled. Estimates of mean catch weights (g), abundance, and CPUE (weight and abundance) of age-0 Pacific Herring varied interannually with no significant linear trend during 1992-2023 (Figure 44-2). The age-0 Pacific 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, but the index appears to have peaked again in 2023 (Figure 44-1). In 2023, indices (using standard transects) were the highest observed since 2010 and above the time series average. High estimates of variability are associated with peak index values; the survey coefficient of variation (CV) was 0.48 (Figure 44-2).

Age-0 Pacific Herring length-weight residuals increased during 1997-2012, and were positive in 2005 and 2007-2023 (Figure 44-2). In 2023, Pacific Herring condition was above average; however, the average length, weight, and energy density of age-0 Pacific Herring was low compared to time series average (Figure 44-2). In 2023, Northern Anchovy were caught in 9 of 37 standard stations sampled (Figure 44-3); this is the 7th highest proportion in the time series (Figure 44-3). Northern Anchovy were caught at 1 of 4 non-standard stations sampled in 2023.

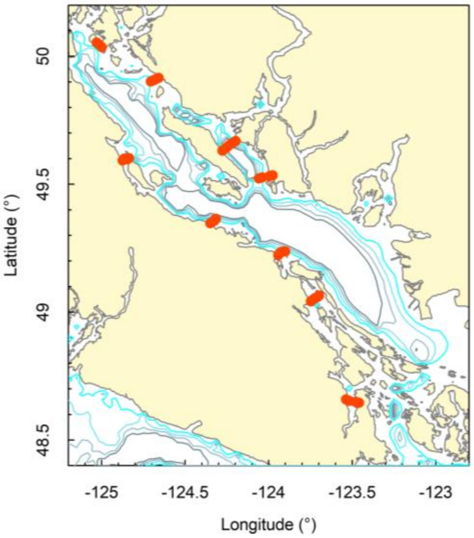

Figure 44-1. Stations sampled during the 2023 Strait of Georgia age-0 Pacific Herring survey. Southern most transect was added in 2023.

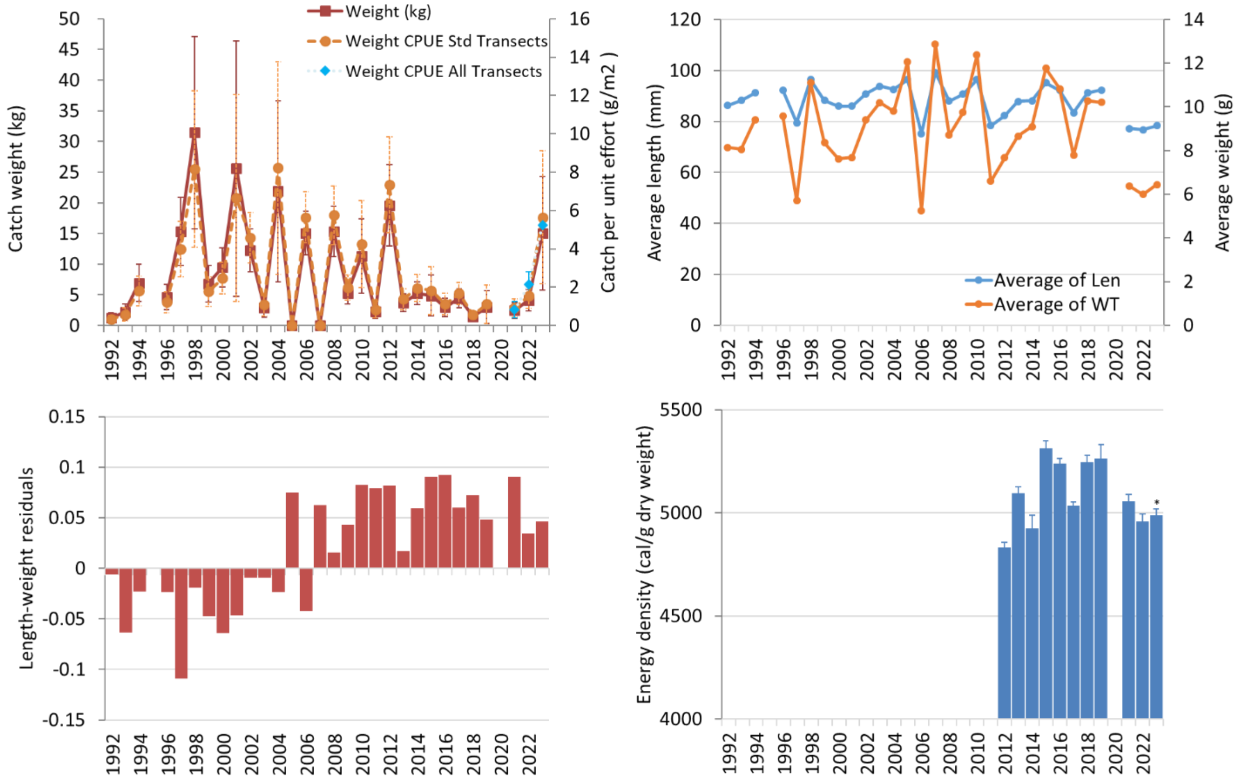

*Figure 44-2. Mean catch weight (kg) and catch weight-per-unit-effort (weight CPUE; g/m2; for standard stations and all stations sampled) (top, left panel); mean standard length (mm) and weight (g) (top, right panel); mean condition (residuals from a double log-transformed length-weight regression; bottom, left panel); and energy density (bottom, right panel) of age-0 Pacific Herring in the Strait of Georgia. Standard error bars are shown. * indicates partial data*

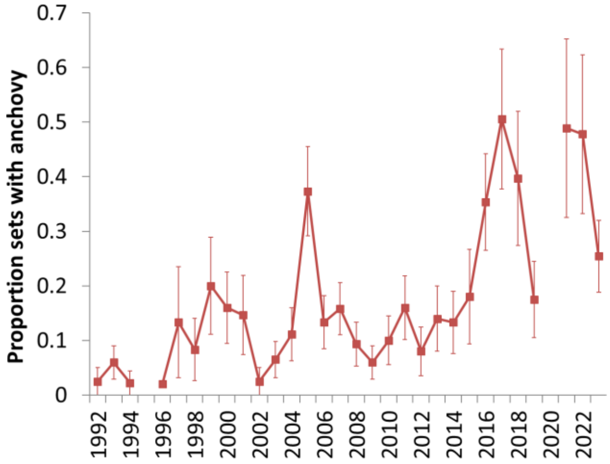

Figure 44-3. Proportion of purse seine sets at standard transects that contained Northern Anchovy, 1992-2023 (no survey in 1995 or 2020). Time series updated from Duguid et al. 2019. Standard error bars are shown.

44.4. Factors causing trends

Bottom-up processes (prey-driven) are the main factors affecting the interannual variability in age-0 Pacific Herring abundance and condition (Boldt et al. 2018). Bottom-up factors include zooplankton prey availability, Pacific Herring spawn biomass, temperature, and the date when most Pacific Herring spawn relative to the spring bloom date. The timing or match-mismatch between spawning Pacific Herring and the subsequent availability of prey to juveniles appears to be important in determining abundance of age-0 Pacific 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 Pacific Herring abundance (Boldt et al. 2018), implying that when conditions are good for age-0 Pacific 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 Pacific 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 Pacific Herring abundance may affect availability to commercial fisheries as well as the survival of predators, such as Coho and Chinook Salmon. Age-0 Pacific 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 2023 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 2019-2023.

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45. PACIFIC HERRING SEASONAL USE OF NEARSHORE HABITAT ASSESSED BY MOORED ACOUSTICS AND STEREO-OPTICS

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45.1. Highlights

- Year-long acoustics and stereo camera deployments in 2022-2023 indicate that juvenile and age 0+ Pacific Herring can be found in the nearshore throughout the entire year, but have seasonal declines in winter months (November-January and peaks in summer July-September).
- Species distribution modeling of survey data from 1992-2022 indicates juvenile and age 0+ Pacific Herring are distributed throughout the nearshore Strait of Georgia in the late spring and summer and have persistent areas of high and low density.

45.2. Description of the time series

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. Pacific Herring spawn in the spring, 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 Pacific Herring in September-October (Boldt et al 2015); additional seine surveys were conducted in June in the 1990s. Data were also available from a juvenile salmon survey from 2014-2020 in both June and September (Neville 2023). In 2021, we began using advanced sampling technologies (acoustics, optics and spatial modeling) to estimate Pacific Herring abundance and to improve our understanding of juvenile Pacific Herring residency nearshore. The main tools used in this work were stationary underwater stereo camera systems and moored acoustic arrays deployed at two Salish Sea transects that are sampled by the juvenile Pacific Herring seine survey: French Creek and Clarke Rock. Vessel mounted acoustics were also added to the September seine surveys.

45.3. Status and trends

Juvenile Pacific Herring were found to be abundant in the nearshore acoustic arrays throughout most of the year (Figure 45-1). The abundance peaked in summer (July – September) and was low in the winter (November – January). Abundance was generally higher at Clarke Rock compared to French Creek. Stereo camera data indicated that a mix of age classes was present in the summertime, but most of the fish measured were age 0+. The two main forage fish species observed in the stationary cameras were Pacific Herring and juvenile Walleye Pollock. In addition a number of predatory fish were observed (Dogfish, Lingcod, Copper Rockfish, Pacific Cod) and marine mammals (sea lions and Harbor Seals).

Species distribution modeling (sdmTMB; Anderson et al. 2024) was used to combine the various trawl and seine net surveys into estimates of the distribution of both age 0+ and older fishes. The results showed that all age classes of Pacific Herring were present in the nearshore of the Strait of Georgia throughout the summer (June and September surveys). There were hotspots of abundance in the southern Strait of Georgia for age 0+ Pacific Herring and low abundance in some areas of the central Strait of Georgia. Older age classes were a bit more patchy, but were also distributed throughout the Strait. Time series of their center of gravity showed that in recent years (since ~2010) there has been a tendency for the distribution of age 0+ Pacific Herring to be further south in the fall than in early years (Figure 45-2). There appears to be no recognizable trend for older fish or the June time period for center of gravity.

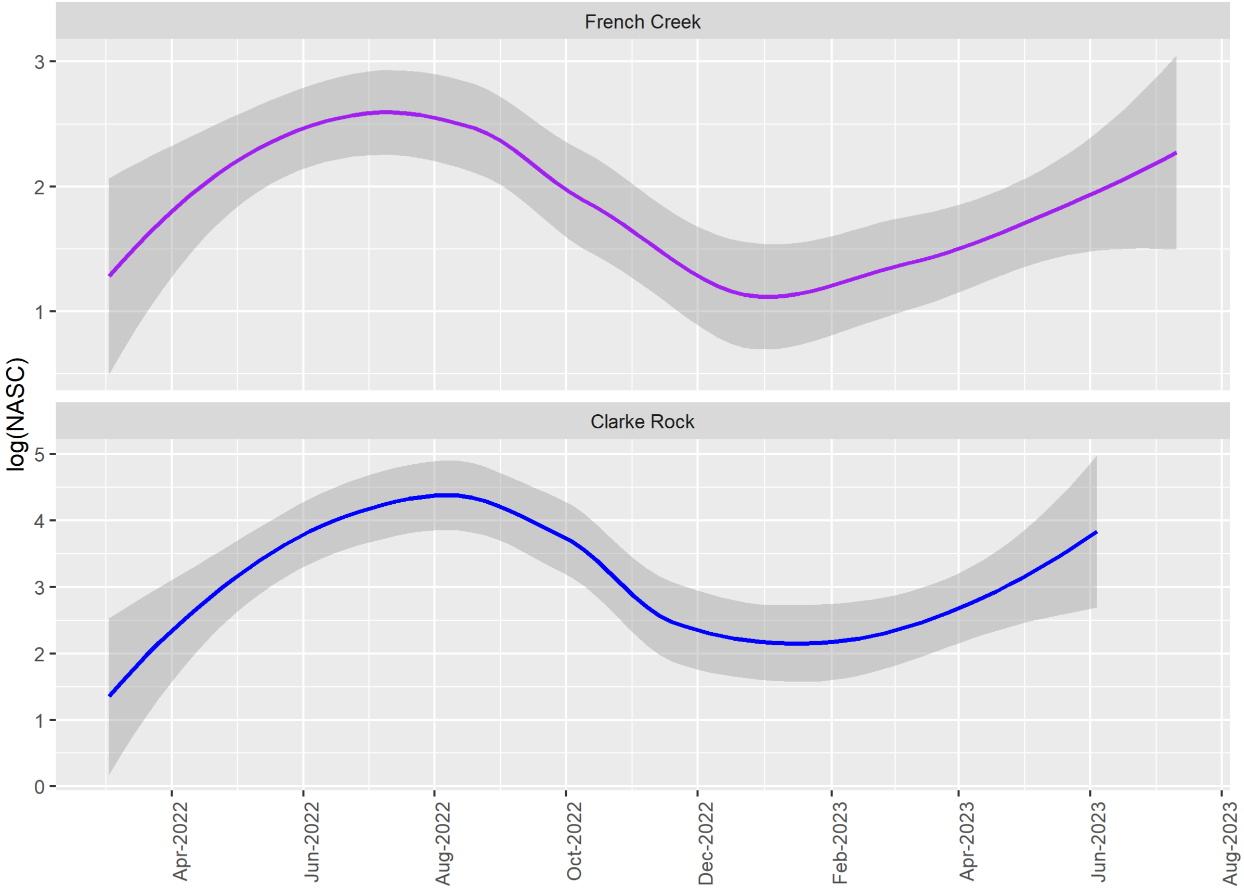

Figure 45-1. The abundance of Pacific Herring echosign at two moored acoustic arrays in the Strait of Georgia over a period of 17 months from March 2022 to August 2023 at French Creek and Clarke Rock. Lines represent generalized additive model fits to the nautical area scattering coefficient for echosign identified as Pacific Herring schools.

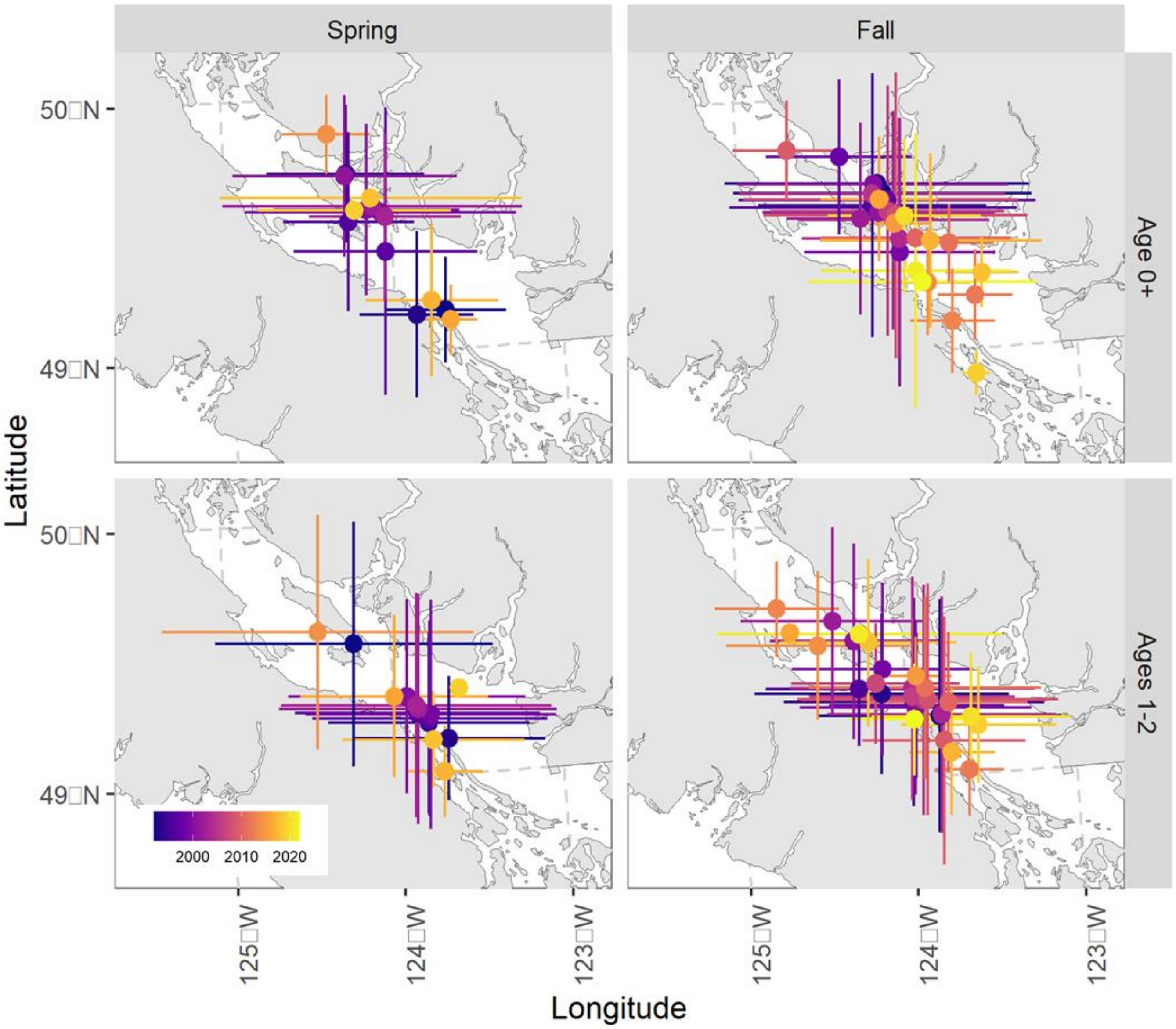

Figure 45-2. Center of gravity of distribution of Pacific Herring age classes in spring (June) and fall (September) juvenile Pacific Herring and juvenile salmon surveys of the Strait of Georgia (1992-2022) estimated from a species distribution model.

45.4. Factors influencing trends

The trend in nearshore abundance measured by the acoustics is likely due to seasonal changes in prey abundance, Pacific Herring growth and overwintering behaviour. It is known that overwintering herring tend to aggregate in deeper water prior to spawning, so perhaps this is the reason for their lower abundance in the nearshore during November-January.

The population of Strait of Georgia Pacific Herring has been higher in the last decade than prior to 2010. This may be causing some of the changes in distribution for age 0+ Pacific Herring in the fall. As their population has increased in recent years, juvenile Pacific Herring may have distributed to the south.

45.5. Implications of those trends

The trends observed in this study imply that Pacific Herring are found in the nearshore throughout the year as both age 0+ and older juveniles (ages 1-2). Summertime abundances can be high. This has consequences for the food chain, as Pacific Herring are known to be important forage for salmon, marine mammals and birds. It is important to continue to monitor the nearshore abundance of this species and link it to the success and abundance of upper trophic levels (piscivorous predators). Advanced technologies have provided an opportunity to monitor the nearshore abundance of Pacific Herring on fine temporal and spatial scales with reduced cost and effort compared to conducting net-based surveys.

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

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46.1. Highlights

- In 2023, the Fraser River Eulachon egg and larval survey index of spawning stock biomass was low (~10 tonnes), at a level comparable to 2022 and to the lowest estimates in the time series since 1995.
- In 2023, mean Eulachon catch per unit effort estimates from an annual spring west coast of Vancouver Island multispecies bottom trawl survey were at moderate levels, with a slight reduction in average catch weight from 2022 but an increase in the total number of eulachon caught (mostly smaller fish).

46.2. 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 2023) characterizing relative 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, 2021-2023) and in 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; 2017-2023; not reported here).

46.3. 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 Indigenous food, social and ceremonial (FSC) resource and in-river FSC fisheries targeting Eulachon have occurred in years up until and including 2023 (DFO 2023). 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 2023).

In 2023, the index of Eulachon spawning stock biomass in the Fraser River was estimated to be low (~10 tonnes), comparable to 2022 and 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 46-1).

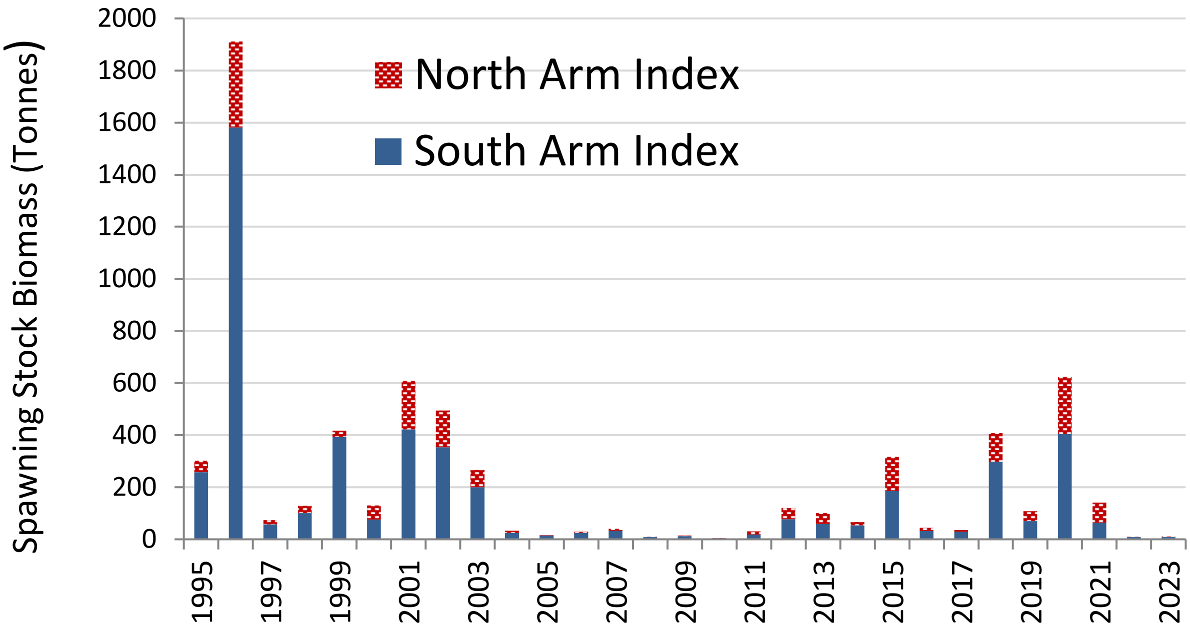

Figure 46-1. Estimated spawning stock biomass indices (SSB in tonnes) of Eulachon from the South and North Arms of the Fraser River, 1995-2023.

In 2023, mean Eulachon catch per unit effort (CPUE) observations from the spring WCVI multispecies trawl survey were at moderate levels, with a slight reduction in mean catch weight from 2022 but an increase in the total number of eulachon caught, mostly comprising smaller fish (up to and including 12.5 cm standard length; Figure 46-2).

Annual Eulachon standard length frequency distributions are represented in two ways; unweighted standard length frequency histograms (Figure 46-3, left panel) from pooling length observations across all fishing events and standard length frequency histograms where length observations were weighted by catch per unit of effort (CPUE in kg per hour) of each fishing event (Figure 46-3, right panel). In 2023, the weighting method increased the representation of fish less than 10 cm.

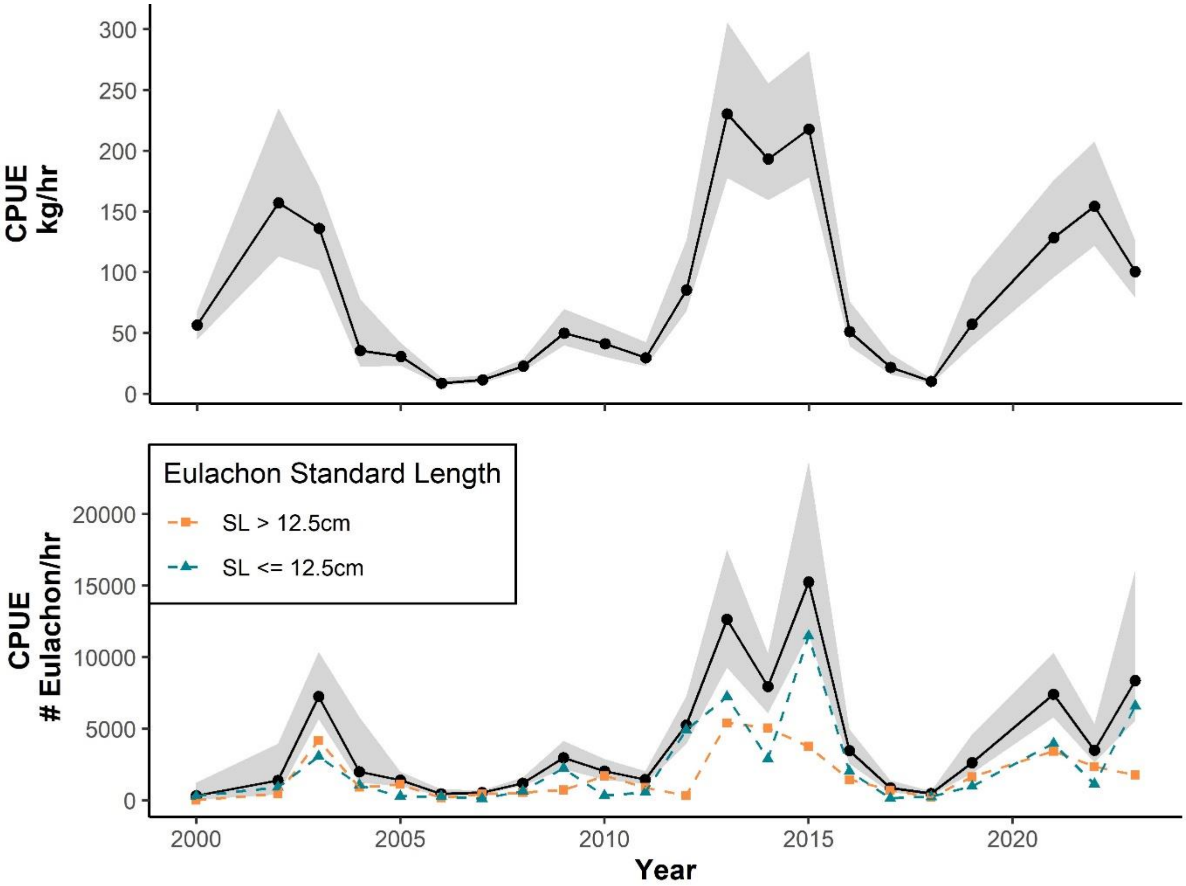

Figure 46-2. Eulachon mean CPUE from spring WCVI multispecies trawl surveys (2000-2023, no survey in 2020) and 95% studentized bootstrap confidence intervals (gray envelopes), as catch weight per trawl tow duration (kg/hour, top panel) and number of fish per tow duration (bottom panel). Dashed lines 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).

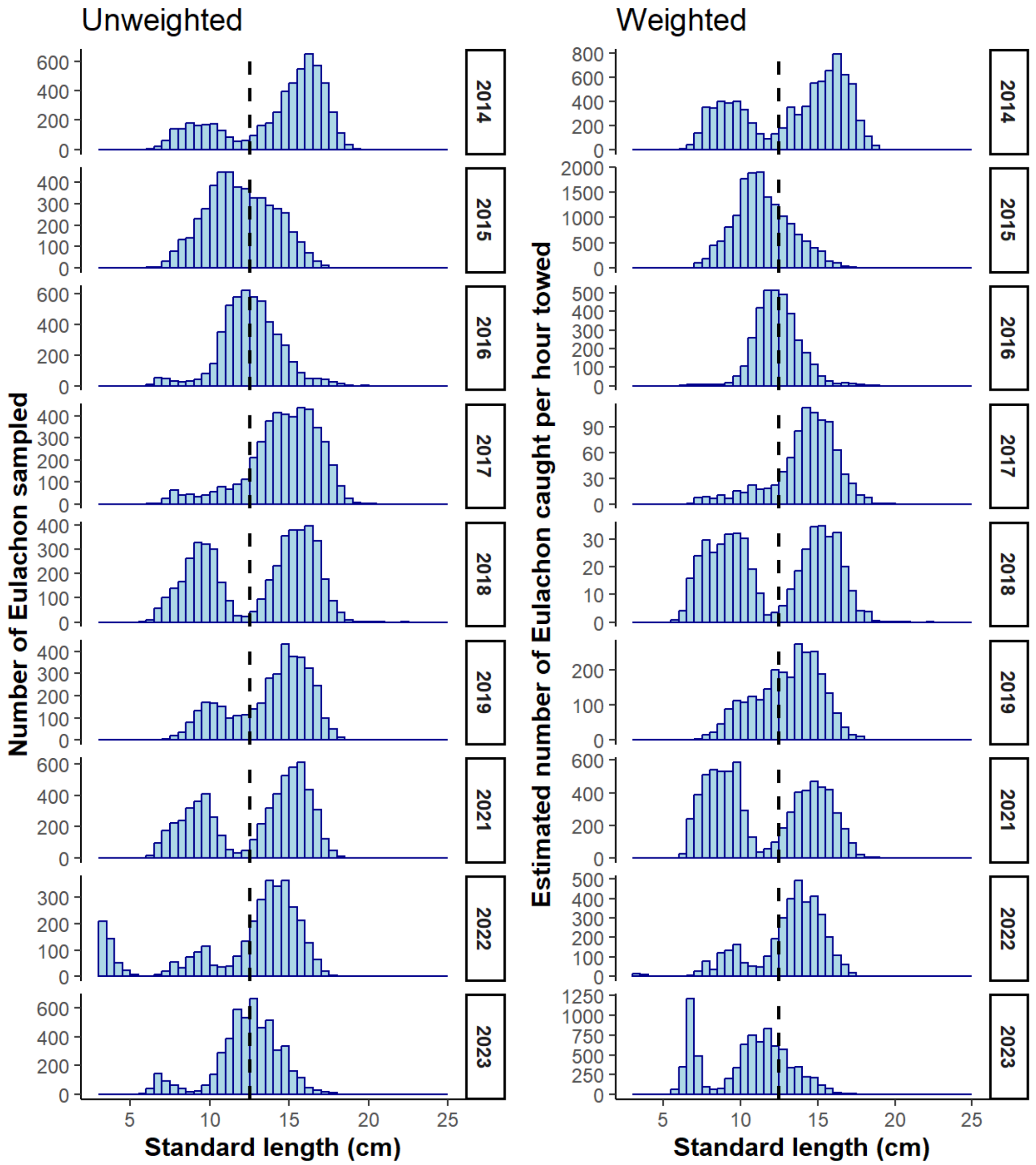

Figure 46-3. Eulachon standard length frequency histograms (in cm) from 2014-2023 WCVI survey samples, from pooling length data by year (left panel) and by statistically weighting data by the estimated total number of Eulachon caught in each fishing event and standardizing by the fishing duration (right panel). Dashed vertical lines are visual markers at 12.5 cm to assist comparisons between positions and shapes of length distributions.

46.4. 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 are not well understood. The low 2022 and 2023 indices were not anticipated, especially given the moderately high marine WCVI CPUE trends in 2021-2023 and that Eulachon abundance trends for the Columbia River in 2022 and 2023 had two of the highest levels over the last 20 years.

It is uncertain to what degree spawning stocks of different rivers and cohorts may mix in the marine environment and what may be inter-annual drivers influencing metapopulation dynamics. There is also uncertainty with the age ranges and compositions comprising the Fraser Eulachon spawning stock each year, due to difficulties ageing Eulachon and limited collection and dissemination of biological sampling information of spawning Eulachon. Furthermore, although it is generally believed that most Eulachon die after spawning, 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."

46.5. Implications of those trends

Reduced biomass of Eulachon has negative implications for First Nations, commercial and recreational fishers. Commercial and recreational fisheries targeting Eulachon have been closed for over a decade (DFO 2023). Eulachon are socially and culturally significant to many First Nations people who have been harvesting Eulachon for centuries. In recent years, Eulachon fishing limits for Indigenous FSC purposes have been set at conservative levels. 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). A better understanding of the diets of Eulachon and of their predators, such as to develop a time series of observations, would improve our ability to examine temporal trends in predator-prey interactions and the implications of those trends.

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47. JUVENILE SALMON IN THE STRAIT OF GEORGIA 2023

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47.1. Highlights

- The 25th year of trawl surveys in the Strait of Georgia (SoG) was completed using standard fishing and sampling protocols.
- CPUE of Coho Salmon in September was the highest on record. Their condition and presence in the SoG in January/February 2024 suggests that 2024 will be another year of good sport fishing for this species.
- Declines and changes in the stock composition of juvenile Chinook Salmon in September may be an early indication of a shift in productivity or of increased competition for this species in the SoG.
- CPUE of Chum Salmon in the summer was average and in the fall was below average. The stock structure of the juveniles utilizing the SoG needs to be understood as a critical step in identifying why marine survival has declined.

47.2. Description of the time series

Juvenile Pacific salmon generally enter the SoG from April to June and many may remain and rear in the SoG until the fall. The trawl surveys are designed to sample juvenile salmon across the SoG during this first ocean summer and fall. The surveys, which sample the surface 75 m of the SoG, also catch other year classes of salmon and other small pelagic species. In 2023, the surveys following standard survey protocol (Beamish et al. 2000; Sweeting et al. 2003) and used the LFS 7742 net that replaced the Cantrawl 350 net in 2019 (Anderson et al. 2019).

The survey in September 2023 completed sampling on the standard track line (Neville et al. 2023) as well as sets in Desolation Sound, Discovery Islands, Bute Inlet, Jervis Inlet, and Juan de Fuca Strait. Catch-per-unit-effort (CPUE) was calculated as catch per hour 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). The 25-year time series demonstrates that there are seasonal changes, interannual changes and longer-term trends in the abundance, distribution, and condition of juvenile salmon rearing in the SoG. It is important to note that overall, the surface waters in the entire SoG are important rearing areas for juvenile salmon from ocean entry through September/October when the fall survey is conducted.

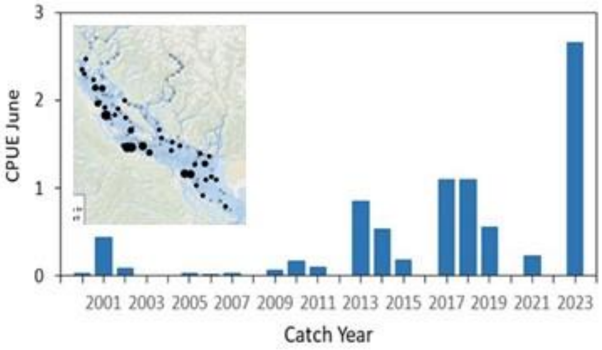

Figure 47-1. The CPUE of age 1+ Coho Salmon in June/July surveys 2000-2023. Inset is the catch distribution of these fish in 2023.

47.3. Status and trends

Although the surveys are designed for juvenile salmon, older age classes are also intercepted but typically in small numbers. Therefore, it was surprising in the June 2023 survey when large numbers of age 1+ Coho Salmon were caught across the survey area. The catch of this age class was the highest in the 25 year time series (Figure 47-1) and the stock mixture was consistent with observations of juveniles in the September 2022 survey. The trend in CPUE of this age class since about 2013 is consistent with the summer (to August) sport catch of Coho Salmon over this period (Neville and Beamish 2024). The high catch in in the June survey was followed by a strong sport fishery in the SoG through the summer months with anglers reporting the best fishing since the 1980s.

Juvenile Coho Salmon CPUE in September was the highest observed in the time series and continued a trend that started in about 2010 (Figure 47-2). The size of the Coho was also the largest in the time series and consistent with sizes observed since 2010 (Figure 47-3). The CPUE of Chinook Salmon in the summer survey was the above average and the highest observed since 2006. However, the CPUE in September was below average and continued a decline over the past four years (Figure 47-4). Possibly as important as the decline of the CPUE in September, was the shift in stock composition. Unlike juvenile Coho Salmon that have a similar stock mixture in both the summer and fall surveys, the stock structure of Chinook Salmon shifts between the surveys. The mixture of stocks observed in the June survey remained present but in smaller numbers. The South Thompson Chinook Salmon that enter the ocean in late June/early July typically represent over 60% of the juveniles in the September survey. However, in 2023 these stocks represented only about 35% of the juvenile Chinook Salmon. The length frequency of the Chinook in this 2023 survey

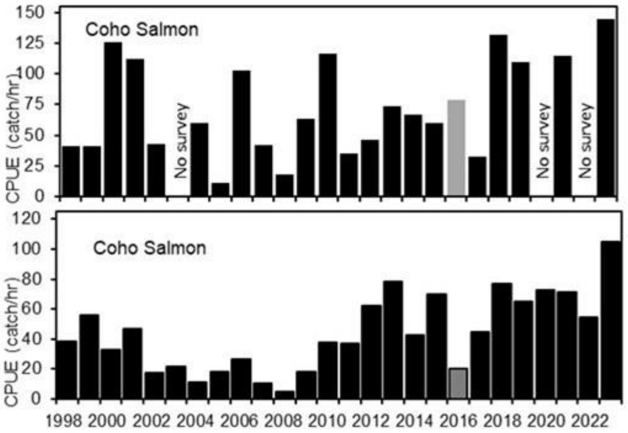

Figure 47-2. CPUE of ocean age 0 Coho Salmon in (top panel) June and (bottom panel) September 1998-2023. The survey in 2016 was late and is not considered in time series. Note y axis differ between surveys.

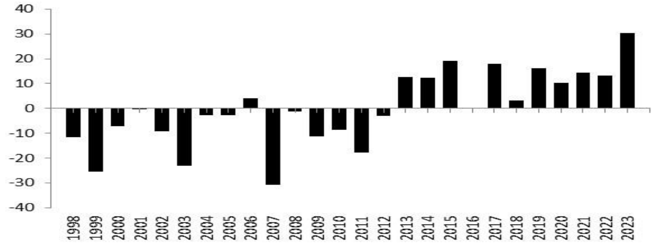

Figure 47-3. The length anomaly of Coho Salmon in the September surveys 2000-2023.

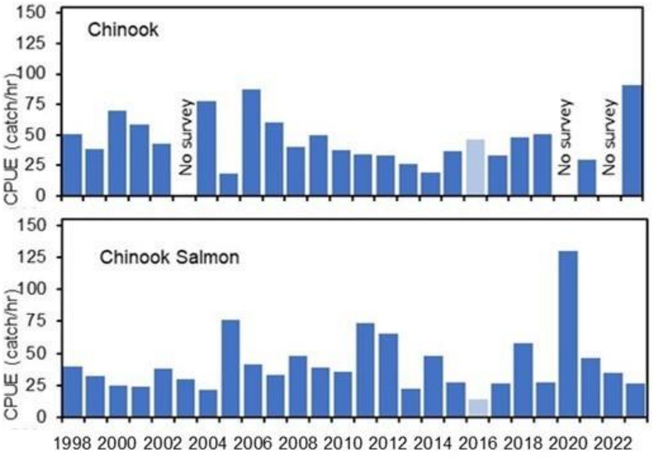

Figure 47-4. CPUE of ocean age 0 Chinook Salmon in (top panel) June and (bottom panel) September 1998-2023. The survey in 2016 was late and is not considered in time series. Note y axis differ between surveys. Also note, stock mixture changes between surveys.

was bimodal (Figure 47-5), similar to the past few years. Although the lower mode of this length frequency included the late entry South Thompson stocks, it also included some juveniles from the lower Fraser River and from Puget Sound, both regions that have increased hatchery releases in recent years. The CPUE of juvenile Sockeye Salmon in the summer survey was the highest observed since 2012 (Figure 47-6). If only compared to similar run cycle years (2023, 2019, 2015, 2011 ect), it was the highest observed since 1999. The CPUE of Sockeye Salmon in September, typically representing the ocean type Harrison River stock, was one of the lowest on record. The CPUE of Chum Salmon in June was average although the CPUE in September was below average for the time series. Catch of juvenile Pink Salmon is typically low in odd numbered years and 2023 was not an exception. The Pink Salmon that were caught in September were probably from ECVI systems including Quinsam River.

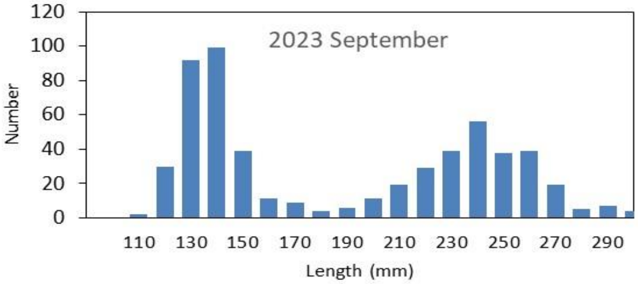

Figure 47-5. The length frequency of Chinook Salmon in the September survey in 2023.

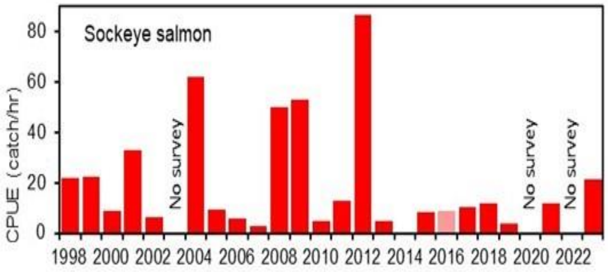

Figure 47-6. CPUE of ocean age 0 Sockeye Salmon in June 1998-2023. The survey in 2016 was late and is not considered in time series. Note cycle years consistent with 2023 are 2007, 2011, 2015, 2019.

47.4. Factors influencing trends

Beamish and Neville (2021) showed an increase in Coho Salmon productivity and size of the juveniles in September 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 juvenile Coho Salmon in the SoG and the abundance in September is related to this carrying capacity and not the number of juveniles that entered the ocean in June. In addition, Beamish and Neville (2021) suggested that the increased growth and condition of juvenile Coho Salmon may be related to changes in residency patterns with large numbers remaining in the SoG through the winter. The presence of large numbers of age 1+ Coho Salmon in the SoG in the summer of 2023, supports this hypothesis. The combination of shifts in the length frequency of Chinook Salmon (beginning in 2020) and the decline in the percentage of South Thompson fish in the September survey suggest that there may be a shift in productivity occurring for this species or for these specific stocks. The changes may be related to ocean conditions but could also be related to increased competition from increasing hatchery production from both Puget Sound and lower Fraser River hatcheries. The mechanisms that may be influencing this growth include changes in zooplankton production in August, increased competition between Chinook Salmon stocks or other species, and changes in freshwater production in the South Thompson region. The declining returns of Chum Salmon over the past decade remain a concern. The lack of a trend in the summer CPUE, good growth and condition of juveniles, and similar poor adult returns in other regions of the Pacific indicate that the declines are a result of a marine impacts occurring after their first marine summer. However, to determine if this is the case, the DNA collected over the past 15 years needs to be examined to determine if select stocks of Chum Salmon are utilizing the SoG over the summer months.

47.5. Implications of those trends

Several hypotheses suggest that growth and energy storage during the first marine summer are related to the ability of salmon to survive their first marine winter and affect their total marine survival. The size and condition of juvenile salmon, especially Coho Salmon, suggests good early marine growth for this species within the SoG. Beamish and Neville (2021) indicated that productivity periods change quickly and identifying these changes in productivity is essential as they can have large impacts on the marine survival of the juvenile salmon including the carrying capacity for juveniles in the SoG. South Thompson Chinook Salmon juveniles, that have dominated the catch in September between 2010 and 2020 and resulted in the record high return of Chinook Salmon to the Fraser River in 2023, have been declining both in CPUE and in size. The result of this decline may be lower returns to the South Thompson starting in 2024 or 2025. The cause of declining returns of Chum Salmon to many British Columbia rivers and to Japan has not been identified. As one of B.C.s most important salmon species by weight, it is essential we identify mechanism for the future success of this Chum Salmon. The variability in the trends of the salmon species indicates that the drivers regulating marine survival is not consistent across all species. The ability to understand the mechanisms that regulate changes in the marine survival of all salmon species may provide early forecasts of survival, but more importantly, may help ensure that fisheries are managed to retain resiliency in salmon species over large-scale changes in climate.

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48. BODY SIZE OF FRASER PINK AND SOCKEYE SALMON

Steve Latham[1], Kaitlyn Dionne[2], Dejan Brkic[1], Angela Phung[1], Jin Gao[2], Eric Taylor[1]

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48.1. Highlights

- Fraser River Pink Salmon body size in 2023 was the 2nd smallest since estimates began in 1927. Only 2015 was estimated to have smaller average weights than 2023.
- Fraser Sockeye Salmon lengths in 2023 were ranked 17th and 6th smallest, for ocean age-2 and ocean age-3 fish, respectively, out of 30 odd-numbered years since 1964. This is consistent with recent body size anomalies being more strongly negative for older fish.

48.2. Description of the time series

Body size trends of mature Pacific salmon simultaneously integrate effects of various bottom-up and top-down processes occurring during their marine residence. The 1Pacific Salmon Commission (PSC) makes data available on its website, including body size measurements of Fraser River Sockeye and Pink Salmon. These data are described briefly below; more detailed documentation and interactive visualizations can be accessed through Shiny applications here: https://www.psc.org/publications/data/.

The first time series reported here is the average weight of Fraser River Pink Salmon, for fish maturing during odd-numbered years only (returns to the Fraser River on even-numbered years are negligible). These weight estimates span 1927-2023 and are based primarily on landings of purse seine fisheries in Juan de Fuca Strait, focusing on time periods when stocks from the Fraser River should dominate the catch.

The second time series is average length of Sockeye Salmon carcasses on Fraser River spawning grounds from 1964-2023. 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 Salmon, respectively), age- and sex-specific annual anomalies are calculated as the difference between year-specific average lengths and the average length across all years. These anomalies were averaged across the sexes for this report.

The third time series reported here includes Sockeye Salmon body size measurements of individuals caught during their return to the Fraser River from 2003-2023. Samples are obtained from fisheries in the lower Fraser River and marine approach areas. Length and weight data are used to calculate condition factor on a stock-, age-, and sex-specific basis. 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 relatively low sample sizes of other age classes, only 2-ocean ages were included in analyses. Anomalies were averaged across the sexes.

48.3. Status and trends

Average weights of mature Fraser River Pink Salmon fluctuated around 2.5 kg during the first third of the century-long time series, then declined from the late 1970s to early 1990s and have remained under 2.0 kg since, with the exception of 2017 (Figure 48-1A). A record low average weight was observed in 2015, at less than 1.5 kg. In 2023, Fraser River Pink Salmon were again less than 1.5 kg and were the 2nd smallest on record.

Average lengths of mature Fraser Sockeye tend to be shorter in odd-numbered years than in even-numbered years (Figure 48-1B). A sharp decline in length occurred, across stocks and ages, from the 1970s to the 1990s, similar to Pink Salmon weights, but then recovered somewhat in the 2000s. Since then, declines in average length have been more severe for 3-ocean versus 2-ocean Sockeye Salmon, especially for fish returning on odd-numbered years. In 2023, the average length anomaly for 3-ocean fish ranked 6th lowest among 30 odd-numbered years, with a larger size than 1993 and each odd-numbered year from 2015-2021. In contrast, 2-ocean Sockeye Salmon recovered to nearly average lengths, with only the 17th lowest anomaly for an odd-numbered year and higher anomalies than multiple even-numbered years (Figure 48-1B).

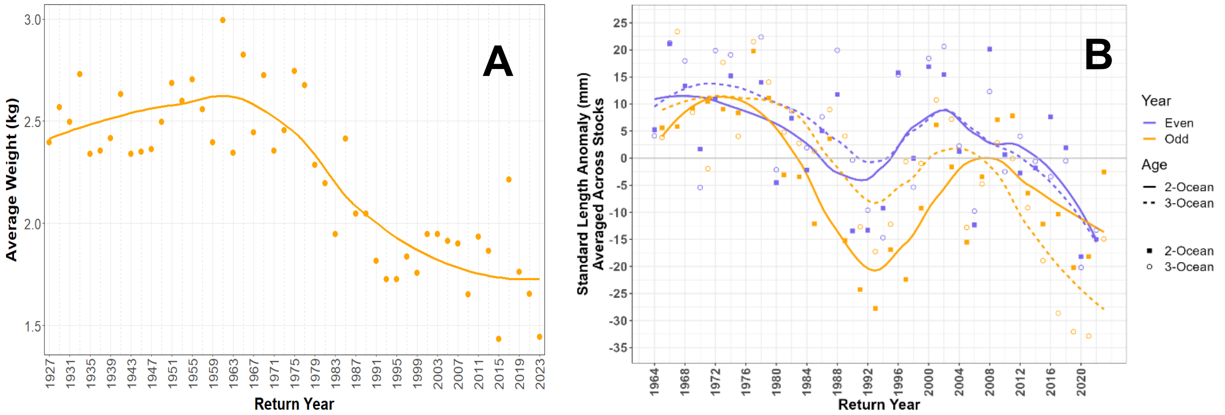

Figure 48-1. Trends in average body sizes of Fraser River salmon. Pink Salmon sizes are average weights in Juan de Fuca Strait fisheries that occurred when Fraser River stocks were numerically dominant in the area (A). Sockeye Salmon sizes are anomalies of average standard lengths on their spawning grounds (B), with annual anomalies calculated relative to long term averages and averaged across stocks. Curves were fit using LOESS.

Stock-specific length and weight anomalies of Sockeye Salmon caught in fisheries also showed some recovery in 2023, but lengths recovered more than weights, and no even-numbered year since 2004 had a lower condition factor anomaly. The 2023 condition factor anomaly was only higher than odd-numbered years from 2015-2021 (not shown).

48.4. Factors influencing trends

These time series show historical and recent declines in overall size-at-age of Fraser Pink and Sockeye Salmon and a biennial fluctuation in which Sockeye Salmon 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 Salmon 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, 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).

48.5. Implications of those trends

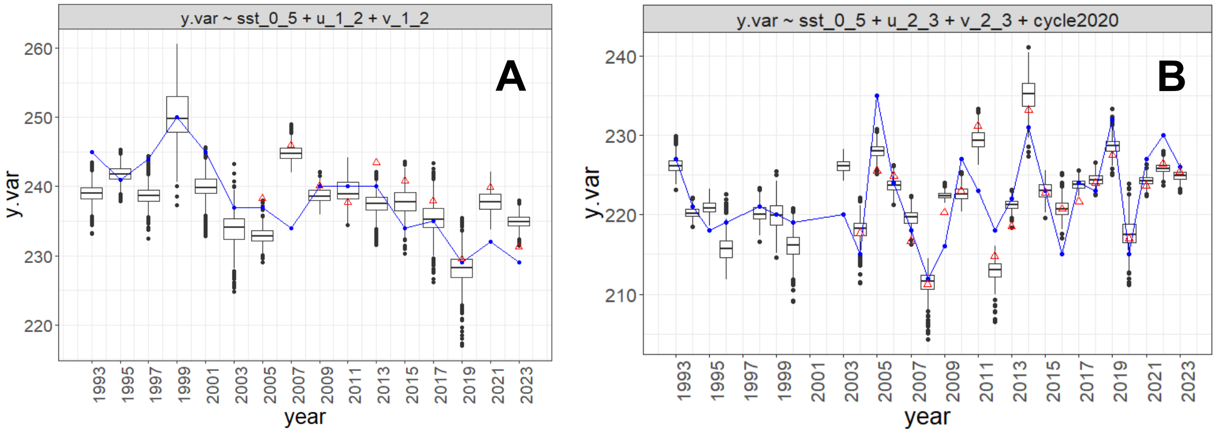

Figure 48-2. Forecasted and observed run timing (in day of year) for Fraser River Pink Salmon (A) and Sockeye Salmon from the Chilko River, a Fraser River tributary (B). Observed run timing is in blue, red triangles are the forecasted timings from the top model (selected via cross-validation in 2023), and the boxplots represent uncertainty in the timing forecasts for this model.

Body size of salmon is directly tied to their value in fisheries, their transport of nutrients to natal habitats, and their fecundity. It may also be related to their migration behaviour and timing. Poorer feeding conditions may lead to greater dispersal in foraging or reduced body size, which could delay or slow the return migration, such that smaller body size would correlate to later return timings. Estimates of return timings were reviewed for Fraser River Pink and Sockeye Salmon from 1993-2023 (Figure 48-2). Return timings for Fraser River Pink Salmon have not corresponded to their annual body size anomalies, at least under simple inspection of the time series. In 2005, Sockeye Salmon were small and late, whereas in 2008 they were large and early, congruent with expectations. Return timings of Fraser River Sockeye Salmon appear to be earlier on even-numbered years (especially every four years from 2004-2020), possibly indicating an effect of competition for food with other salmon. Current timing forecast methodology (Folkes et al. 2018) does not take body size or possible competitive effects into account, but this should be explored to better understand the ecology of these species and to better estimate return timing, which is a fundamental parameter in fisheries management.

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49. ADULT SALMON DIET MONITORING 2017-2023

Nathanael Tabert, Kristina Duchscher, Will Duguid, Wesley Greentree, Bridget Maher, and Francis Juanes, University of Victoria, Victoria, B.C., uvicsalmondiet@gmail.com

49.1. Highlights

- Chinook Salmon stomach fullness was highest in the Strait of Georgia in 2023 continuing the trend from previous years.
- Pacific Herring remained important prey for Chinook and Coho Salmon in the Strait of Georgia and south and west coasts of Vancouver Island in all seasons in 2023.
- There was an apparent decrease in the importance of squid in the diets of Chinook Salmon on the west coast of Vancouver Island in 2023 compared to previous years.
- Coho Salmon diets consist mainly of Pacific Herring and crustaceans with a diversity of other fish species.

49.2. Description of 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 operates out of the Juanes Lab at the University of Victoria and was supported primarily by the Pacific Salmon Foundation and Fisheries and Oceans Canada in 2023. The short-term objectives of the ASDP are to characterize spatial and seasonal trends in adult Chinook and Coho Salmon diets and to increase understanding of forage fish ecology. Long term objectives are to monitor ecosystem change and to foster dialogue between anglers and fisheries scientists through a citizen science framework.

Digestive tracts of Chinook and Coho Salmon were collected from anglers and fishing guides as well as from fishing derbies and through collaborators including creel surveyors, First Nations, and NGOs. In the lab, prey items were identified and weighed, subsamples were measured, and otoliths were extracted and archived for future analysis.

To investigate temporal variation in diet composition and prey-specific feeding intensity, mean "partial fullness scores" (Magnussen 2011) for all 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 salmon is more commonly available than weight.

Our timeseries was split into two seasons: Winter defined as October to March and Summer as April to September. To prevent splitting the winter season between years the months of October to December were shifted forward into the following calendar year. Starting in 2019, Chinook non-retention closures around the Salish Sea have limited sampling in some regions between April and July. To allow for comparison across years, samples collected in these regions and seasons before closures began were removed from this analysis. Five regions were used for this analysis: Gulf Islands/Haro Strait (Pacific Fishery Management Areas – PFMAs 18-19), Strait of Georgia (SOG; PFMAs 13-17 and 29), Howe Sound (PFMA 28), Strait of Juan de Fuca (JDF; PFMA 20), and West Coast Vancouver Island (WCVI; PFMAs 21-27 and 121-127) (Figures 49-1 and 49-2).

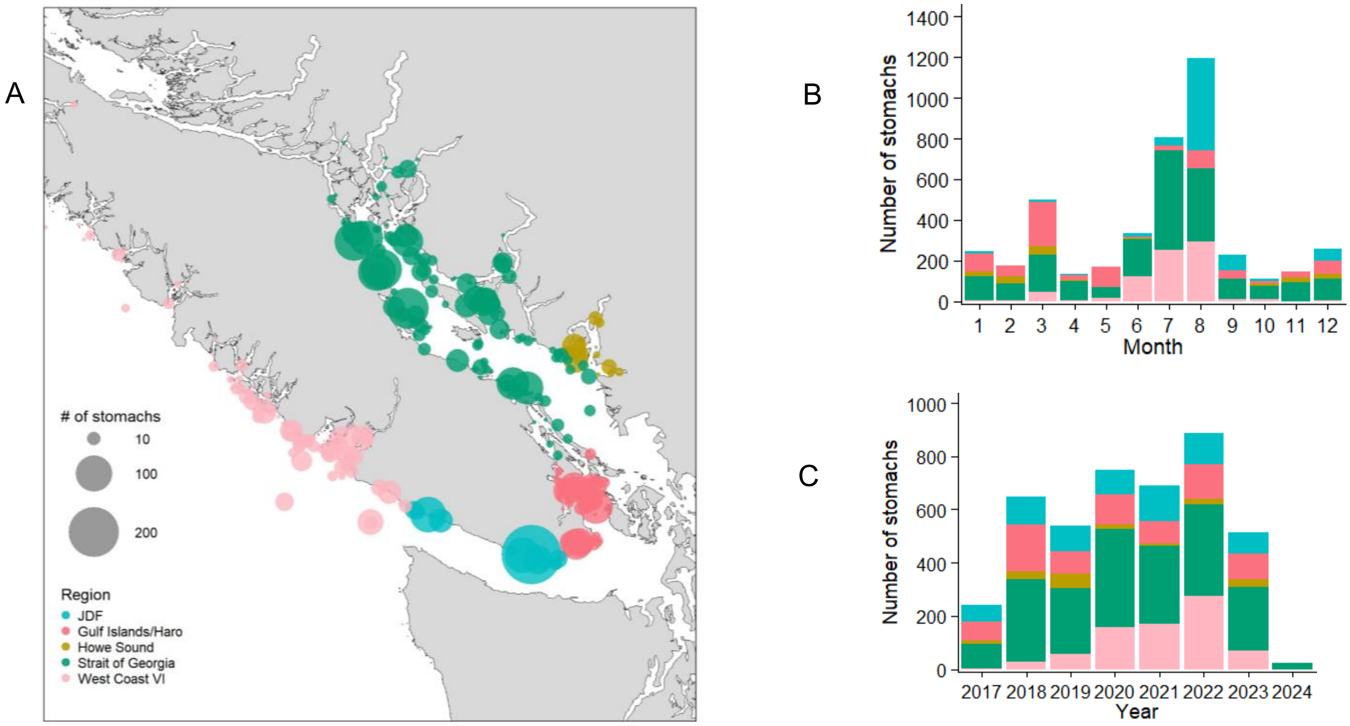

Figure 49-1. Sampling distribution of 4390 adult Chinook Salmon in space (A) and by month (B) and year (C). Colours indicate the five regions used to spatially aggregate samples for this talk. JDF = Juan de Fuca; VI = Vancouver Island. This figure shows all samples processed by the program, not only those included in the time series reported here (see text).

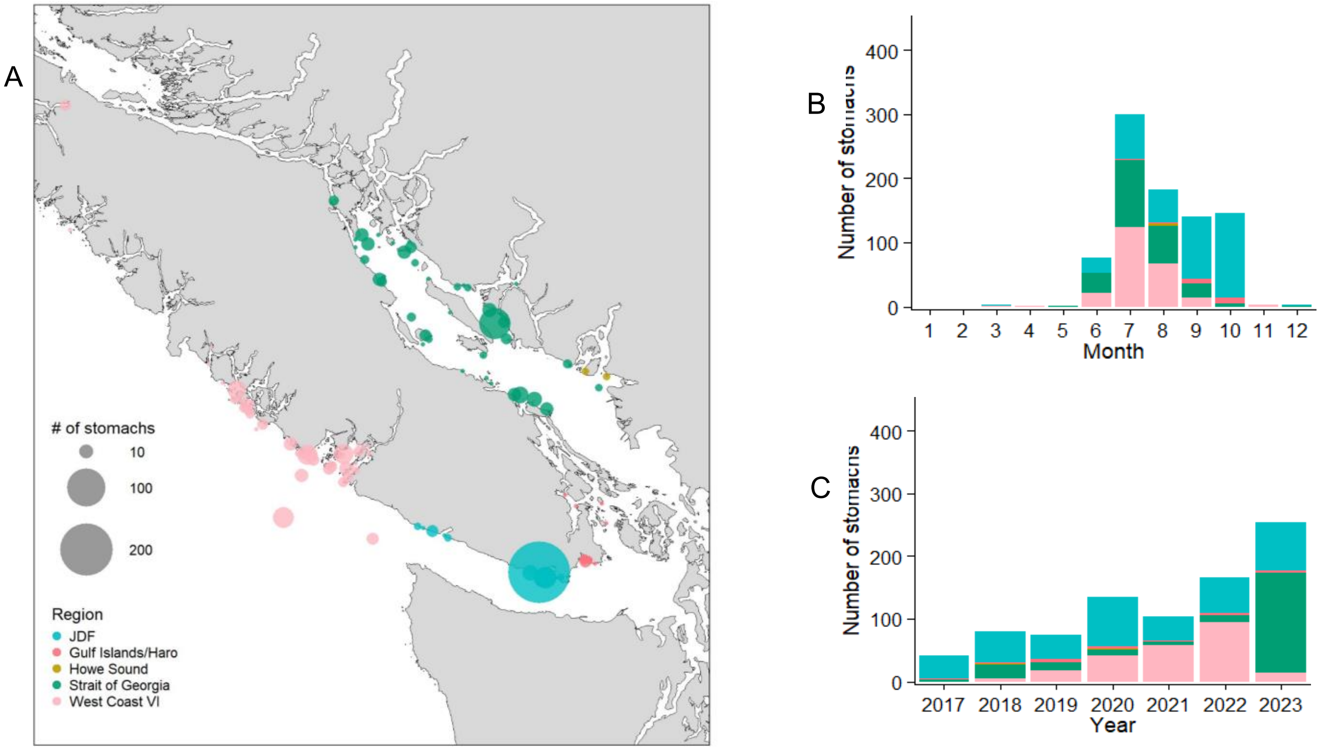

Figure 49-2. Sampling distribution of 901 adult Coho Salmon in space (A) and by month (B) and year (C). Colours indicate the five regions used to spatially aggregates samples for this talk. JDF = Juan de Fuca; VI = Vancouver Island.

49.3. Status and Trends

Trends in Chinook Salmon stomach fullness and diet composition in 2023 were similar to those observed in previous years (Figure 49-3). Chinook Salmon in the SOG had elevated fullness across seasons and fullness was heavily dominated by Pacific Herring. Age 2+ Pacific Herring (defined as ≥ 145mm standard length or estimated standard length from an otolith width to standard length regression) constituted the majority of the overall mass consumed by Chinook Salmon in the SOG in all seasons. Pacific Herring were also the most important prey item in the Strait of Juan de Fuca where fullness continued to be relatively low, particularly in the summer (winter samples in this region are limited). Patterns in the Gulf Islands and Haro Strait were comparable to previous years with low fullness in the summer and elevated fullness in the winter. Pacific Herring dominated the diet in both seasons. Prior to implementation of Chinook Salmon retention closures in 2019, Pacific Sand Lance were very important in diets from this region between April and July. Exclusion of these months from the data presented here likely lead to an underestimation of the importance of Pacific Sand Lance to summer diets in this region. In Howe Sound in the winter, fullness was relatively high, with an elevated importance of Northern Anchovy in the diet compared to other regions. The occurrence of Northern Anchovy in this region has been observed consistently across years and has also been reported by anglers in the area (Duguid et al. 2019). As in previous years, there was high fullness in WCVI in the summer and the importance of Pacific Herring has increased on WCVI from 2021 to 2023. In summer 2023 on WCVI, there was an apparent decrease in the importance of squid, which have historically been important in this region.

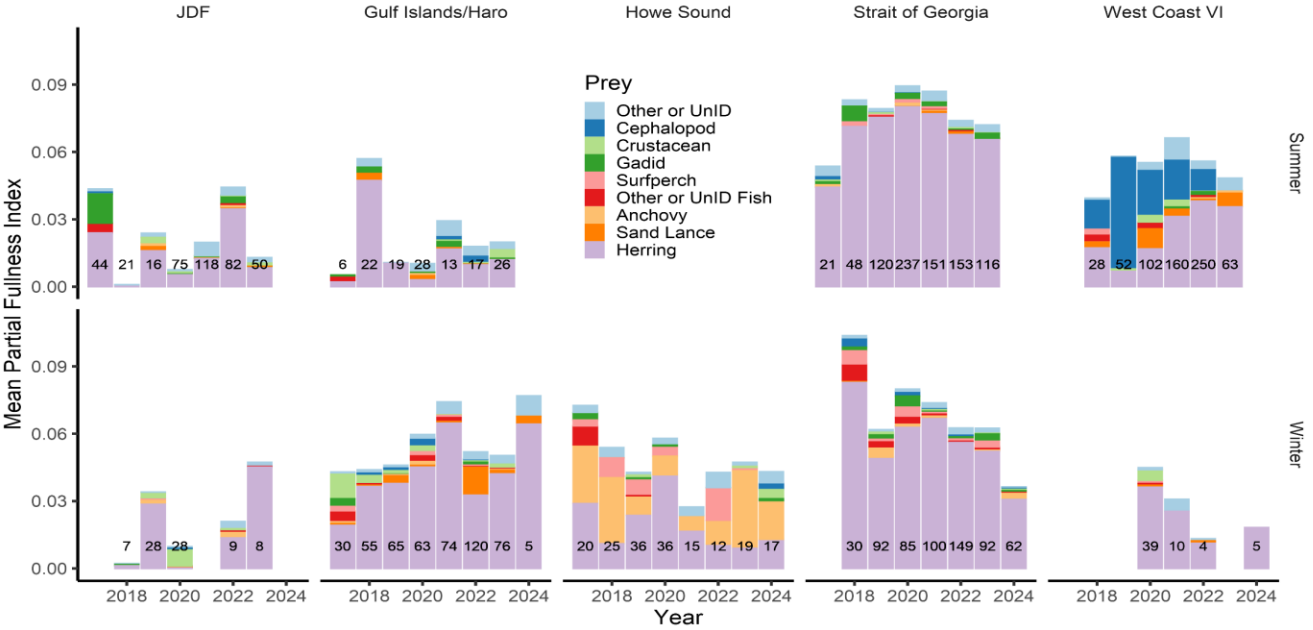

Figure 49-3. Mean Partial Fullness Index of adult Chinook Salmon diets in summer (April- September; top row) and Winter (October-March; bottom row) for five regions (Figure 49-1) of coastal B.C. from 2017 to 2024. Note that data for some periods and regions were removed for all years to account for regional 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.

Mean regional fullness and diet composition were more variable among years for Coho Salmon than Chinook Salmon. Pacific Herring are an important prey item for adult Coho Salmon in most regions and seasons (Figure 49-4), although not to the same extent as in Chinook Salmon. Crustaceans, primarily amphipods, euphausiids, and crab larvae (megalopae and zoeae), are an important prey group for Coho Salmon. Squid does not appear to be as important to Coho Salmon on the WCVI, even in years where squid were a common prey for Chinook Salmon. Coho Salmon also consume a larger diversity of fish species, represented by the “Other or UnID Fish”.

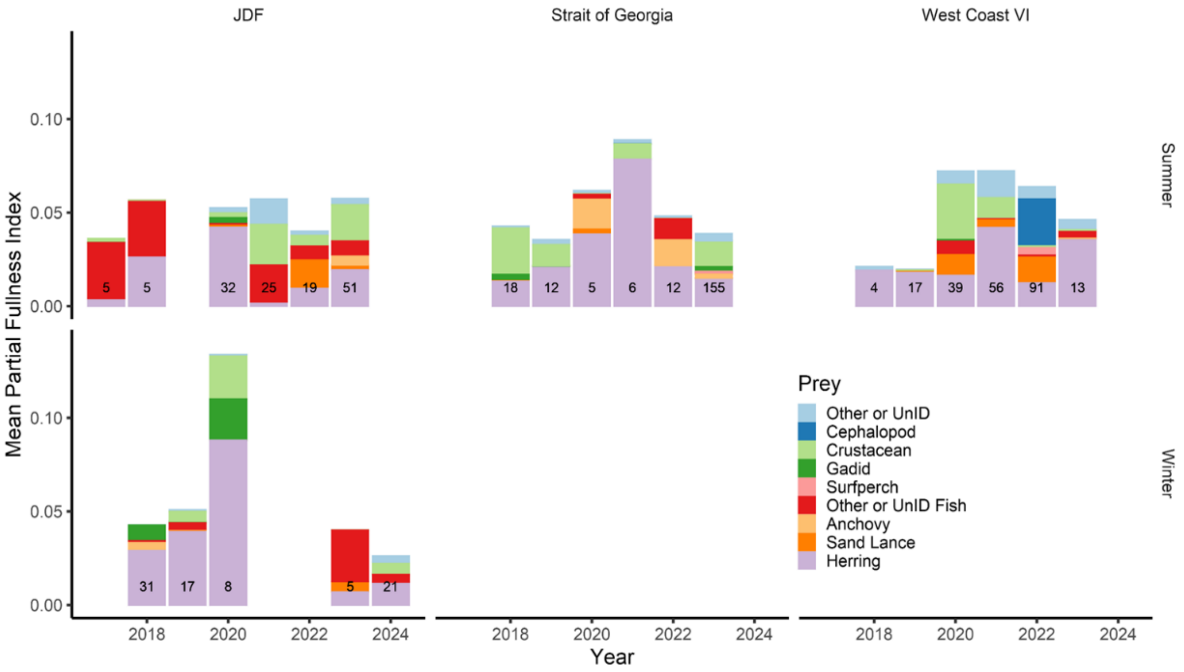

Figure 49-4. Mean Partial Fullness Index of adult Coho Salmon diets in summer (April- September; top row) and winter (October-March; bottom row) for three regions of coastal B.C. from 2017 to 2024. October-December were moved forward to the following calendar year to prevent splitting of a season. Only 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.

49.4. Factors Influencing Trends

As Pacific salmon are opportunistic feeders (Brodeur 1990) our diet data likely reflect the availability of forage species in different regions, seasons, and years. Pacific Herring continue to be an important part of Chinook Salmon diets, especially in the SOG. This highlights the importance of this region not only as a Pacific Herring spawning and rearing area, but also as a foraging ground for age-2+ non-migratory Pacific Herring which contribute to Chinook Salmon fullness throughout the year. The occurrence of other forage species in salmon diets may be driven by suitable habitat types. Northern Anchovy tend to occur in areas of freshwater influence such as Howe Sound which is influenced by the discharge of the Squamish and Fraser Rivers. Historically, Northern Anchovy have also been associated with warmer waters, and rising sea temperatures may continue to alter their range within the Salish Sea and beyond (Duguid et al. 2019).

The reduction in the number of squid in Chinook Salmon diets on WCVI in 2023 was the greatest deviation from past trends. While we do not identify cephalopods to species, intact squid from salmon diets appear to be primarily *Doryteuthus opalescens* (opal or market squid). While this species is widely distributed in the coastal northeast Pacific, peak biomass occurs off California and spawning in Northern regions (Alaska) has been linked to warmer ocean conditions (Eiler 2021). The importance of squid in Chinook Salmon diets on WCVI has declined from a peak in 2019 (Figure 49-3), corresponding to decreasing ocean temperatures (Hourston et al. Section 11) over this period. Going forward, salmon diet sampling on the West Coast of Vancouver Island may provide insights into how squid abundance in this region is related to environmental conditions.

The large number of Coho Salmon samples collected in 2023 reflected the high abundance of Coho observed in the Strait of Georgia through the summer. Although small sample size limits inferences about interannual trends, some general trends are apparent. Coho Salmon consume more crustaceans and a greater diversity of fish species (“Other or UnID Fish”) than Chinook Salmon. This may be the result of the shallower habitat distribution of Coho Salmon resulting in greater overlap with larval crustaceans as well as juvenile and nearshore fishes (Smith et al. 2015).

49.5. Implications of Trends

From 2017-2023, our data on Chinook Salmon diets have suggested relatively consistent regional and seasonal patterns in fullness and diet composition. This consistency highlights the potential of our program as a tool for monitoring both Chinook Salmon and the forage species on which they rely. We will be well positioned to detect major shifts in salmon feeding ecology and forage fish distribution and abundance that may occur. The importance of Pacific Herring in Chinook Salmon diets highlights the essential role of Pacific Herring as a forage species in the marine food web and the need for ongoing conservation and monitoring. The reduction in the number of squid observed in Chinook Salmon diets on WCVI may be indicative of trends in squid abundance in this region; we will continue to monitor this closely.

The high abundance of Coho Salmon in the Strait of Georgia in 2023 provided a strong baseline for comparison if abundances and sampling remain high in the future. The tendency of Coho Salmon to feed on a greater variety of nearshore and juvenile fish species may have implications for the survival of these species in the Strait of Georgia in years such as 2023 when Coho Salmon abundance was high through summer.

49.6. References

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50. 2023 CHS PACIFIC HYDROGRAPHIC SURVEY UPDATE

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50.1. Highlights

- In 2023 58 multibeam surveys and 11 laser scanner surveys were completed. This represented 1,512 hrs of sounding time, 17,844 km of survey lines, and a coverage of 2,976 km2.

50.2. Description

The Canadian Hydrographic Service's 2023-24 survey priorities were defined following extensive client consultation regarding multibeam, laser scanner, and backscatter data requirements. COVID-19 was less of a challenge than in previous years, allowing CHS to continue regular operations while taking basic communicable disease precautionary measures to ensure the safety of its employees and the public. As most restrictions were lifted, CHS was able to return surveys to a full crew compliment on most survey platforms.

The priority areas on the north coast of B.C. (Figure 50-1) were identified as Kitasu Bay, Skidegate Inlet/Channel, Buck Channel, and Rennel Sound. These areas were selected in support of charting priorities (especially charts 3670, 3671), and in support of NRCAN-PNCMIA/flood modeling, Haida Nation, Transport Canada, CCG, RPSS, and Parks Canada priorities. These survey operations were carried out by the CCGS Vector, the CCGS Otter Bay, and the CSL Kalman L. Czotter.

The priority areas on the south coast of B.C. (Figure 50-2) included Amphitrite Bank, Swiftsure Bank, Boundary, Sand Heads, Strait of Georgia, Port Mellon, Earls Cove, Harmony Islands, Saltery Bay, Blubber Bay, Oyster Bay, Bute Inlet, Carrie Bay, and Pulteney Point. The priority areas were selected based on continuing and completing efforts from the 2022 survey season, as well as in support of charting priorities, ECCC-DAS, ECCC-CWS and NRCAN-SASIMA priorities. These survey operations were carried out by the CCGS Vector, the CCGS Otter Bay, and the CSL Shoal Seeker.

The priority areas in the Western Arctic (Figure 50-3) included Kugmallit Valley, Beaufort Shelf, Baillie Knolls, Thesiger Bay, Cape Bathurst, Cape Perry, Cambridge Bay, as well as transit line surveys between varying program locations. The priority areas were selected based on low-impact shipping corridors (LISC) and areas of opportunity while in transit or transitioning between various other Arctic programs. LISC surveys are continuing and completing efforts from the 2022 survey season, as well as in support of charting priorities and NRCAN priorities. These survey operations were carried out by the CCGS Sir Wilfred Laurier.

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 1a, and adhering to appropriate reference, administration and safety manuals, relevant marine regulations, and departmental policies (Cloutier et al. 2023).

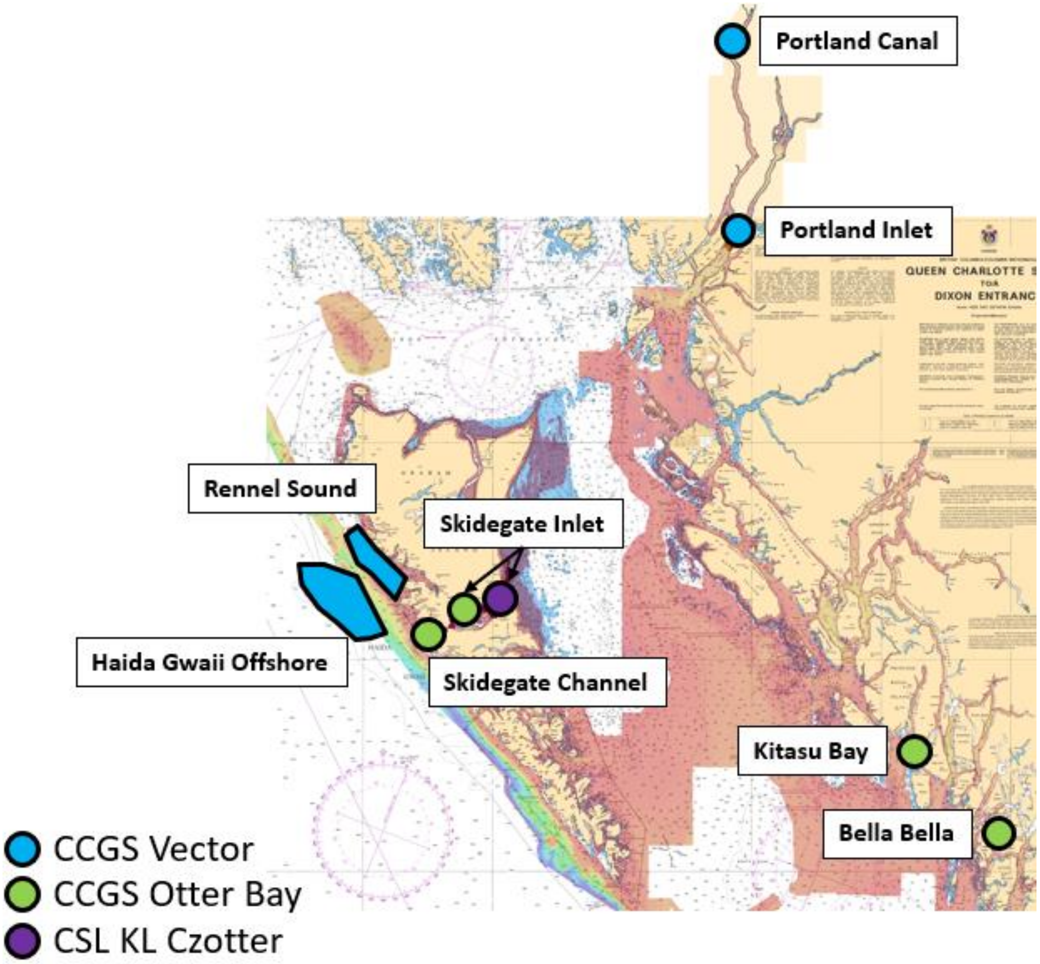

Figure 50-3. Overview of areas surveyed by CHS/CCG vessels on the Central and North Coast in 2023.

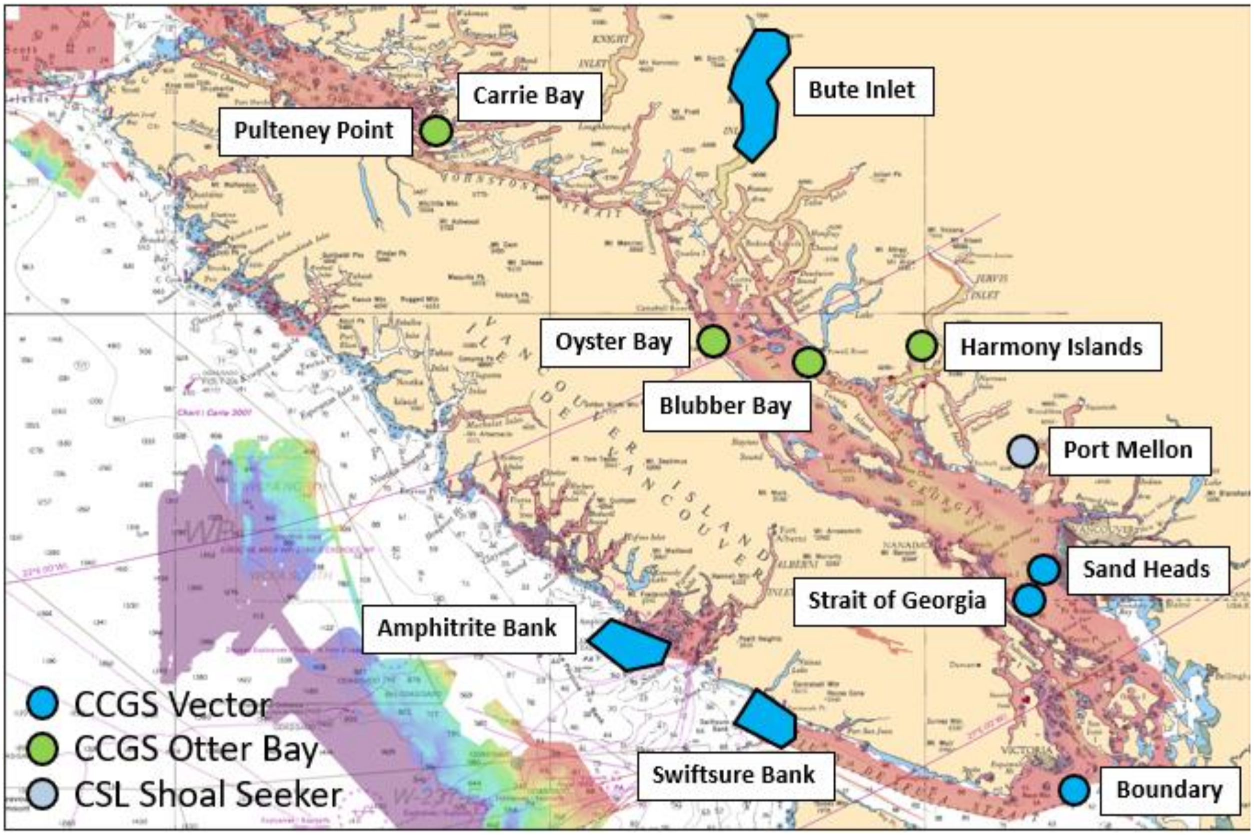

Figure 50-4. Overview of areas surveyed by CHS/CCG vessels on the South Coast in 2023.

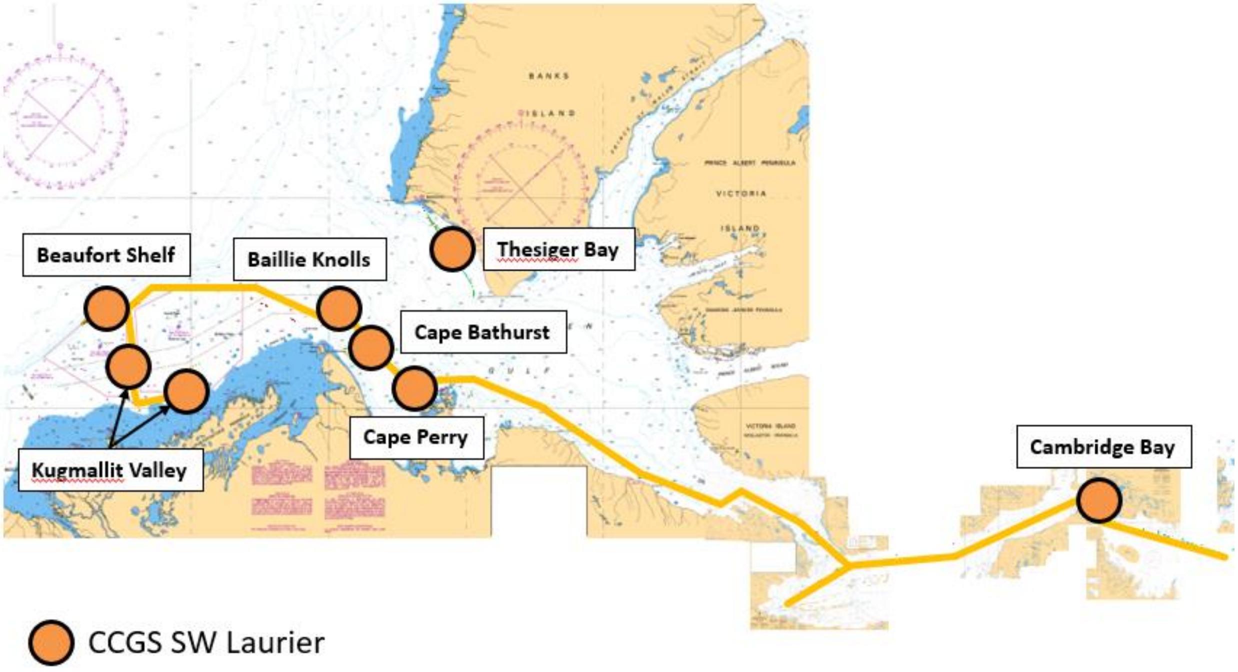

Figure 50-3. Overview of areas surveyed by CCG vessels in the Western Arctic in 2023.

50.3. References

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Appendix 1 - Poster Abstracts

51. LOWER TROPHIC LEVELS IN THE NORTHEAST PACIFIC

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

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51.1. Highlights

- In spring 2023, numbers of copepods typically associated with warm waters were low, with abundances appearing to be close to average, following the long-lasting impacts of marine heatwaves that started in 2014, in both the offshore and shelf regions around B.C.
- In spring 2023, phytoplankton community indicators appear to be returning to values of pre-heatwave (2014-2016) conditions in both regions, consistent with the report in 2022 that showed the impacts of the heat wave were no longer evident.

51.2. Sampling

The Continuous Plankton Recorder (CPR) is towed behind commercial ships, and in the NE Pacific samples approximately monthly, 6-9 times per year, between March and October (Figure 51-1), 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. 2023 CPR data presented within this report is provisional and only includes the spring months April-June, as the rest of the samples are still being analyzed.

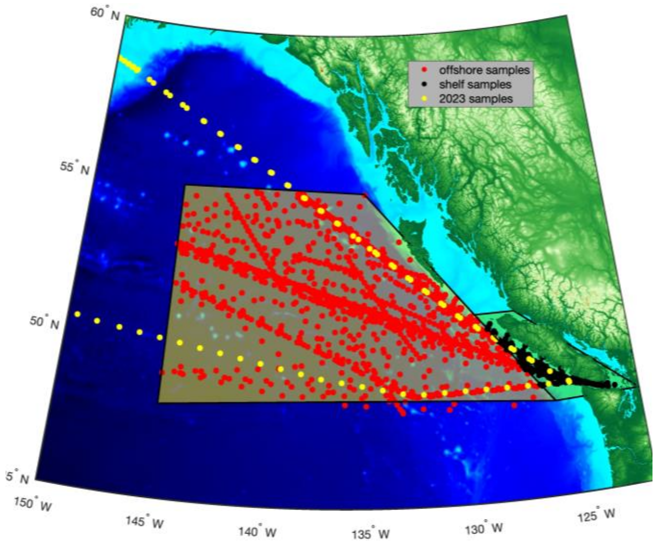

Figure 51-10. Map showing the location of historic CPR samples (2002-2022) red = offshore, black = shelf. Yellow circles are the location of the 2023 samples, note some 2023 samples are not yet analysed so are not shown.

All 2023 tows were completed as scheduled (Figure 51-1, see yellow circles). 2023 data have not yet been finalized (where shown) and are therefore provisional and likely to change.

Sea Surface Temperature (SST) data from 2000 to 2023 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.

51.3. Description of the Plankton Time Series

51.3.1. Phytoplankton

The CPR effectively retains larger phytoplankton cells, especially chain forming diatoms and hard-shelled dinoflagellates, and several time series were 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).

51.3.2. Zooplankton

Mesozooplankton, especially crustacea, are well sampled by the CPR and several zooplankton time series were generated: i) total zooplankton abundance, ii) taxon specific lengths and abundances were 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.

51.4. Status and Trends

51.4.1. Phytoplankton

In the offshore and shelf regions SST was similar to what it has been in recent warm 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 51-2).

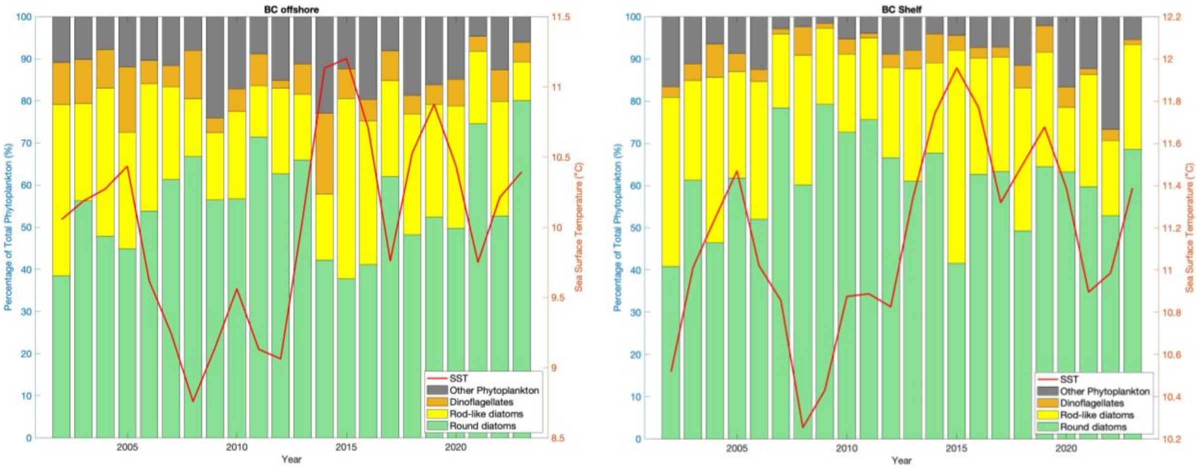

Figure 51-2. Contribution of each group to the mean annual phytoplankton community offshore (left) and on the shelf (right). SST is shown in red (right-hand axis, °C). Note: 2023 CPR data are provisional and only for spring months to date.

Both offshore and shelf regions showed similar trends in phytoplankton CTI which correlated with observed SST: warmer communities in the early-2000s, cooler communities during 2006 to 2013, a maximum in 2015, followed by a warm period (Figure 51-3). The phytoplankton CTI values for both the offshore and shelf region in 2023 were lower than they have been since 2012.

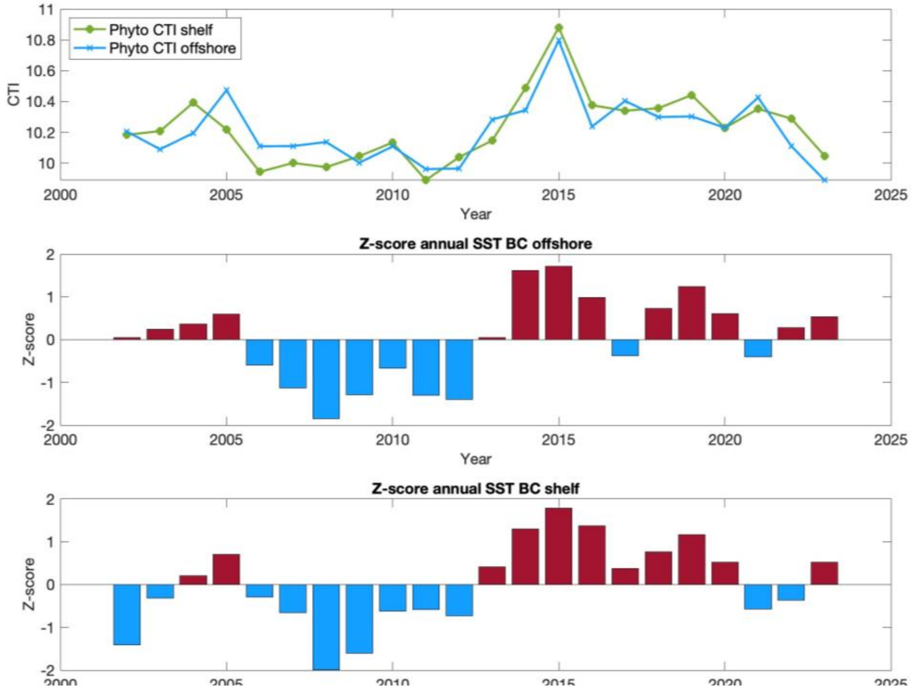

Figure 51-3. The mean annual phytoplankton Community Temperature Index for each region (top subplot) and the annual standardized z-score for Sea Surface Temperature in the offshore (middle subplot) and shelf (bottom subplot) region. Note: 2023 CPR data are provisional.

51.4.2. Zooplankton

The numbers of copepods typically associated with warm waters were low, however the mean copepod length decreased in 2023 compared to 2022 (Figure 51-4). Numbers of salps and doliolids (gelatinous plankton) were also low in both regions in 2023.

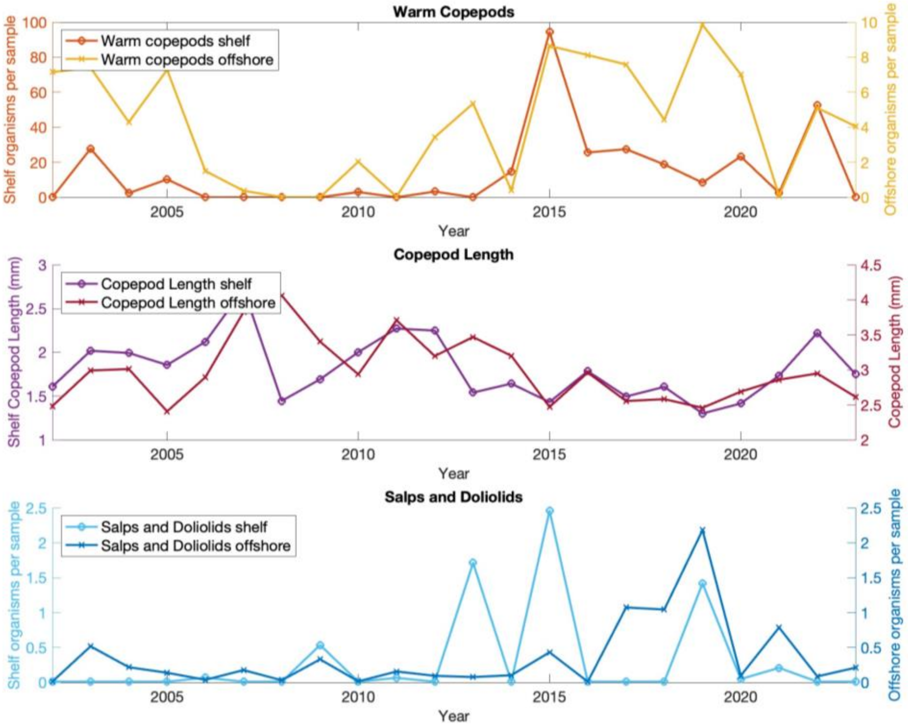

Figure 51-4. The mean annual abundance of warm water copepods (top), mean copepod length (middle), and salp and doliolid abundance (bottom) for both the shelf (left axis) and offshore (right axis) regions of B.C. Note: The CPR only captured small or fragments of salps and doliolids. Note: 2023 data are provisional and only for spring months to date.

51.5. Factors Influencing the trends

In 2023, ocean temperatures in both the shelf and offshore regions around B.C. were higher than the mean, 2002-2023 (Figure 51-3), 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 both regions, reducing the community temperature index (Figure 51-3), and the copepods associated with warmer waters were lower in numbers in both regions in 2023 (Figure 51-4). It is important to note however that as samples from the rest of the year are analyzed this may change. Anomalously warm surface waters can increase stratification thereby reducing nutrient availability. Lower nutrients can affect the phytoplankton composition and shape by promoting growth of smaller and narrower cells because of a relatively larger surface area over which to absorb nutrients (Karp-Boss and Boss 2016; Pahlow et al. 1997). 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.

51.6. 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. In 2022, however, plankton had returned to more typical sub-arctic/temperate communities and this appears to be persisting at least into spring 2023. 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.

51.7. References

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52. UNUSUAL EVENTS IN CANADA’S PACIFIC MARINE WATERS IN 2023

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52.1. Highlights

- Unusual events occur in Canada’s Pacific marine waters every year but are often not reported on or linked to the broader environmental context.
- Some unusual events in 2023 that were reported include: in southern B.C., numerous air temperature records were broken, record numbers of Bigg’s Killer Whales were observed in the Salish Sea, rare species were observed, such as Bluefin Tuna, and more.

52.2. 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 2023 that have been reported to or noted by the Pacific science community. 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.

52.3. Status and trends

Observations in 2023 that were reported to DFO by participants at the 2024 State of the Pacific Ocean workshop are presented in Table 52-1. For example, there were multiple record high air temperatures in B.C., record low Fraser River flow, Bluefin Tuna and Japanese Sardine spotted off of the U.S. west coast, and a record number of Bigg’s Killer Whale sightings in the Salish Sea, sightings of pelicans off the west coast of Vancouver Island and Sea Otters off of Victoria. More than 60 sick sea lions washed ashore in California, due to neurotoxin from algae bloom, a fish kill in the Cowichan River, and a diesel fuel spill off of Sayward. In February 2024, a loggerhead turtle was found in Pedder Bay. Other unusual occurrences are listed in Table 52-1.

Table 52-1. Observations of weird, wonderful and/or unusual marine events reported during 2023 or reported at the 2024 State of the Pacific Ocean meeting.

Event	**Where**	**When**	**Reported by**	**(Brief) Details**
Lowest Fraser River	Fraser River, Harrison Lake	Apr. and summer, 2023	CTV News Susan Allan, UBC	Lowest water levels in over a century in April; record low in summer
Diesel fuel spill	Johnstone Strait	Apr. 20, 2023	Chek News	Fuel truck carrying 17,000 liters of diesel fuel sunk off Sayward, after rolling off barge during windstorm
Record high air temperatures	B.C. Interior	Apr. 28-30, 2023	CTV News	e.g., Yoho National Park, Blue River, Vernon, Williams Lake
Record high air temperatures	B.C.	Apr. 13-15, 2023	CTV News	Three days across B.C., dozens of daily records broken, including 17 Apr. 13, 33 on Apr. 14, 37 Apr. 15
Record high air temperatures	Pitt Meadows	Jun. 7, 2023	CTV News	125-year-old temperature record fell
Hottest day	Planet Earth	Jul. 4, 2023	Chek News	Hottest day in at least 44 years
Sick sea lions	California beaches	Jun., 2023	Reuters	Sick sea lions washing ashore due to neurotoxin from algae bloom; 60+ animals
Fish die-off	Skutz Falls, Cowichan River	Jul. 14, 2023	CBC News	Hundreds of Coho Salmon and trout killed; due to some environmental stress
Juvenile Wolf Eels	North and west coasts Vancouver Island	Jul., 2023	Jackie King, DFO	Integrated Pelagic Ecosystem Survey caught juveniles; 6-fold increase in catch numbers
Bluefin Tuna	Orcas Island	Jul. 12, 2023	SeadocSociety	Bluefin Tuna found dead on Crescent Beach in Eastsound
Bluefin Tuna	Washington /Oregon; southern B.C.	Nov. /Jul.-Aug. 2023	Andy Edwards, DFO; Sarah Hawkshaw, DFO	US midwater trawl fishery caught 10 Pacific Bluefin Tuna in the previous 2 weeks; 4 caught in Canadian Albacore Tuna fishery

Event	Where	When	Reported by	(Brief) Details
Bigg's Killer Whale sightings	Salish Sea	2023	Times Colonist	Record annual high number of sightings
Sea Otters spotted	Victoria	2023, late Feb. **2024**	Skip McKinnell; Erin Herder, DFO	Sea Otters observed in waters of Victoria; west Race Rocks during DFO dive survey
Pelicans spotted	SWCVI	2023	Skip McKinnell	Brown and White Pelicans spotted in the last 3 years
Loggerhead Turtle	Pedder Bay	Feb. 4, **2024**	Kelly Young, DFO	Sean and Ed Hutchinson found the turtle. After contacting DFO, they took it to the Vancouver Aquarium. 2nd sighting in B.C.
Japanese Sardine	West coast U.S.	Summer 2022-2023	NOAA, Longo and Craig (in prep.)	Genetic sampling from NOAA's acoustic-trawl survey indicates the presence of Japanese Sardine

52.4. 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 and long-term temperature increases will continue to be factors affecting marine biology.

52.5. References

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Pecl, G., Barry, Y., Brown, R., Frusher, S., Gärtner, E., Pender, A., Robinson, L., Walsh, P., and Stuart-Smith, J. 2014. REDMAP: ecological monitoring and community engagement through citizen science. The Tasmanian Naturalist. 136: 158-164.

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

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

The Open Information publication process has been supported by Enterprise Data Hub (EDH) since July 2023. The EDH is a strategic initiative and collaboration between Chief Digital Officer Sector (CDOS) and Office of the Chief Data Steward (OCDS) that allows DFO digital assets to be discoverable, shareable, and usable.

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, journal articles, provides additional explanations to the dataset, and would help users to better understand, interpret and use the published data.

So far, DFO Pacific has published about 188 datasets to Open Maps and Open Government Portal. For the 2023-2024 fiscal year, twenty new datasets and thirty six published datasets have been published and updated, respectively. More specifically, the published new datasets are:

- Active Commercial Shipping Anchorages in Pacific Canada
- Coastwide distribution of Dungeness Crab
- Commercial whale watching in British Columbia
- Dive Survey Algae and Substrate Data
- Epifauna Diversity on Dockside Surface Perimeters in Burrard Inlet and Fraser River Delta, British Columbia
- Evaluation of Methods for Identification of Early Detection Monitoring Sites Based on Habitat Suitability for Invasive European Green Crab in the Salish Sea, British Columbia
- Extreme Sea Levels for Harbours in British Columbia
- Fieldnotes 2024-2025: Pacific Science Field Operations
- Groundfish biodiversity change in northeastern Pacific waters under projected warming and deoxygenation

- National Aquatic Invasive Species (AIS) Risk Assessment for Zebra (*Dreissena polymorpha*) and Quagga (*Dreissena rostriformis bugensis*) Mussels
- Northeast Pacific Monthly Mean Ocean Current Climatology (October - March)
- Northeast Pacific Monthly-Mean Ocean Current Climatology (April - September)
- Recreational Vessel Traffic Model for British Columbia
- Sablefish Offshore Stratified Random Trap Survey
- Sablefish Standardized Trap Survey -- Mainland Inlets
- Seasonal Salinity climatologies of the British Columbia Exclusive Economic Zone (2001-2020)
- Shrimp and Fish Abundance Observed by a Towed-Video Along Trawling and Trapping Transects in Simoom Sound, British Columbia
- Shrimp catch and bycatch estimates from trawling and trapping in Simoom Sound, British Columbia
- Summer Model Outputs and Observations in Discovery Islands, British Columbia (In Progress)
- Winter occurrence of Killer Whale populations off eastern Vancouver Island, British Columbia (2015-2018)

The updated datasets are:

- British Columbia Lightstation Sea-Surface Temperature and Salinity Data (Pacific), 1914-present
- British Columbia Spot Prawn (*Pandalus platyceros*) Spawner Index
- Characterization of sediment and faunal attributes of Simoom Sound, British Columbia
- Chinook Salmon (*Oncorhynchus tshawytscha*) Conservation Units, Sites & Status
- Chum Salmon (*Oncorhynchus keta*) Conservation Units, Sites & Status
- Coho Salmon (*Oncorhynchus kisutch*) Conservation Units, Sites & Status
- Demersal (groundfish) community diversity and biomass metrics in the Northern and Southern shelf bioregions
- Epifauna Diversity on Dockside Surface Perimeters in Burrard Inlet and Fraser River Delta, British Columbia
- Even Year Pink Salmon (*Oncorhynchus gorbuscha*) Conservation Units, Sites & Status
- Groundfish Synoptic Bottom Trawl Surveys
- Hecate Strait Multispecies Assemblage Bottom Trawl Survey
- Hecate Strait Synoptic Bottom Trawl Survey
- Herring Roe Fishery Catch Data
- Lake Type Sockeye Salmon (*Oncorhynchus nerka*) Conservation Units, Sites & Status
- Monthly Satellite Chlorophyll-a Climatology of the Canadian Pacific Exclusive Economic Zone (2003-2020) - 1 km Resolution
- Monthly Satellite Chlorophyll-a Climatology of the Canadian Pacific Exclusive Economic Zone (2003-2020) - 4 km Resolution
- Monthly Satellite Chlorophyll-a Climatology of the Canadian Pacific Exclusive Economic Zone (2003-2020)
- Monthly Satellite Sea Surface Temperature Climatology of the Canadian Pacific Exclusive Economic Zone (1981-2010) – 4 km Resolution

- Monthly Satellite Sea Surface Temperature Climatology of the Canadian Pacific Exclusive Economic Zone (1990-2020) – 4 km Resolution
- Monthly Satellite Sea Surface Temperature Climatology of the Canadian Pacific Exclusive Economic Zone (2003-2020) – 1 km Resolution
- Odd Year Pink Salmon (*Oncorhynchus gorbuscha*) Conservation Units, Sites & Status
- Pacific Herring spawn index data
- Pacific Marine Ecological Classification System and its Application to the Northern and Southern Shelf Bioregions
- Pacific Region Commercial Salmon Fishery In-season Catch Estimates
- Pacific Salmon Conservation Units, Sites & Status
- Predicted distributions of 65 groundfish species in Canadian Pacific waters
- Productivity (Recruits-per-Spawner) data for Sockeye, Pink, and Chum Salmon from British Columbia
- Queen Charlotte Sound Synoptic Bottom Trawl Survey
- River Type Sockeye Salmon (*Oncorhynchus nerka*) Conservation Units, Sites & Status
- Seasonal Climatologies of the Northeast Pacific Ocean (1980-2010)
- Seasonal sigma-t climatology of the Canadian Pacific Exclusive Economic Zone (1980-2010)
- Seasonal Temperature Climatology of the British Columbia Exclusive Economic Zone (2001-2020)
- Southern British Columbia Chinook Salmon (*Oncorhynchus tshawytscha*) Conservation Units, Sites & Status
- Strait of Georgia Synoptic Bottom Trawl Survey
- West Coast Haida Gwaii Synoptic Bottom Trawl Survey
- West Coast Vancouver Island Synoptic Bottom Trawl Survey

54. MONITORING SG̲ÁAN K̲ÍNGHLAS-BOWIE SEAMOUNT MARINE PROTECTED AREA

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54.1. Highlights

- Official name change: SG̲áan K̲ínghlas-Bowie (SK̲-B) from “Bowie” in the Geographical Names Board of Canada, and subsequently global databases.
- Published ecological monitoring framework Science Advisory Report with accompanying Research Document in press.
- Recently completed and on-going studies: flow and eddies around SK̲-B, zooplankton communities, new coral species, and analysis of long-term monitoring sites.
- New outreach and education activities, including: Live It Earth programming, developing Haida curricula, and the UN Ocean Decade Action NEPDEP.

54.2. Extended Abstract

SK-B and its two sister seamounts were designated by the Haida Nation as a X̲aads siigee tl'a damaan tl'a k̲ing giigangs Haida MPA in 1997 and by the Canadian Government as an Oceans Act MPA in 2008 (management plan: CHN and DFO 2019). Our DFO and CHN science team recently co-created a framework for ecological monitoring (DFO 2023; Du Preez et al. in press) and officially updated the name of the namesake seamount. Though there was no in situ monitoring in 2023, there was plenty of increased co-created knowledge of the area through science using previously collected data.

Research using coral growth, Argo float data, and oceanographic modeling is looking into multiscale flow dynamics (e.g., possible presence of a Taylor cone on SK̲-B Seamount) and revealed evidence of a north-to-south bottom flow and “captured” Haida Eddies (Ross et al. in prep.). Implications include a strong ecological connection between the SK̲-B MPA and the continental slope.

A Master’s thesis by Daniel Labbé used size-fractionated zooplankton samples to quantify the spatiotemporal variability in zooplankton biomass and nutritional quality around NW Pacific seamounts, including SK̲-B, and demonstrated that natural patchiness and mesoscale processes affect zooplankton over large regions (Labbé 2024).

A new species of cold-water coral was discovered within the SK̲-B MPA (from Davidson/Pierce Seamount). Preliminary examinations of gross morphology and scanning electron microscope images of sclerites (small supporting hard structures) suggest the specimens are bubblegum coral (Corallidae) from the Genus Sibogagorgia (first known record within the Canadian Pacific).

The 2022 SK-B MPA expedition enabled the first repeat surveys of 6 of the 12 long-term benthic monitoring sites in SK-B MPA (established in 2018 at depths identified as vulnerable to oxygen depletion: Ross et al. 2020; Gartner et al. 2022). Ecological analyses are in progress for animal abundance and condition, including cold-water corals and sponges, 3D photogrammetry models, and environmental data (CTD) for each 10 m x 10 m site. The research is part of Lindsay Clark's PhD, who is investigating environmental drivers of seamount biodiversity and changes over time. 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 (hypothesis: caused by oxygen depletion related to climate change).

A key goal of the MPA is to increase awareness and there are several science initiatives that continue to connect people to this remarkable place. CHN and DFO scientists developed content for Live It Earth, as well as participated in a live question and answer event with classrooms across Canada. The team co-created a new United Nations Ocean Decade Action, the NorthEast Pacific Deep-Sea Exploration Project (NEPDEP), which will ensure SK-B science contributes to our global understanding of the deep. CHN is developing curricula in the Haida language (X̲aad Kil- the Old Masset dialect and, X̲aayda Kil- the Skidegate dialect) and in English for schools on Haida Gwaii to teach students about the cultural and ecological significance of SK-B and deep-sea ecosystems. CHN and DFO scientists produced videos and educational materials.

54.3. References

CHN and DFO. 2019. SG̲aan K̲inghlas–Bowie Seamount Gin siigee tl'a damaan k̲inggangs gin k̲'aalaagangs Marine Protected Area Management Plan 2019. 45 p.

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Gartner, H., Norgard, T., Yakgujanaas, J., Rangeley, R., Leith, M., MacIntosh, H., Du Preez, C. 2022. Pacific Seamounts 2018 Expedition Report (Pac2018-103 & NA097). Can. Tech. Rep. Fish. Aquat. Sci. 3460: ix + 147 p.

Labbé, D. 2024. Quantifying spatiotemporal variability in mesozooplankton distribution and nutritional quality around seamounts within the Canadian Offshore Pacific Bioregion [Master's Thesis]. University of Victoria.

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Ross, T., Du Preez, C. and Ianson, D. *In progress*. Coral and float-derived observations of flow around a seamount in the Northeast Pacific: revisiting the Taylor cone.

55. PACEA: AN R PACKAGE OF PACIFIC ECOSYSTEM INFORMATION TO HELP FACILITATE AN ECOSYSTEM APPROACH TO FISHERIES MANAGEMENT

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55.1. Highlights

- Pacea is an open-source R package that contains various types of ecosystem data and model output. Pacea stands for PACific Ecosystem Approach.
- While its primary purpose is to help implement an Ecosystem Approach to Fisheries Management, it is likely of interest to a wider audience and is updated monthly.
- Variables are directly included in the package, which contains default plotting functions, extensive help files, and vignettes to assist users.

55.2. Extended abstract

Currently, pacea (Edwards et al, 2023; https://github.com/pbs-assess/pacea) contains:

- 204,373 calculations of daily sea surface temperature based on data from 19 buoys.
- Outputs from the spatial British Columbia continental margin model, the coupled physical-biogeochemical model by Peña et al. (2019). Variables are for 40,580 spatial cells across Canada's Pacific Exclusive Economic Zone, and are given as 27 years of monthly means (from 1993 to 2019). The variables are:
    - dissolved oxygen concentration
    - pH
    - salinity
    - temperature
    - depth-integrated phytoplankton
    - depth-integrated primary production.

  For applicable variables these are available at the sea surface, the sea floor, and three depth layers.

- NOAA’s spatial Optimum Interpolation Sea Surface Temperature record, that incorporates observations from different platforms (satellites, ships, buoys, and Argo floats), provided as weekly and monthly means from Sep 1981 onwards.
- 9 climatic and oceanographic indices, such as the Pacific Decadal Oscillation and those related to El Niño (e.g., Figure 55-1).
- estimates of abundances for Harbour Seals and Pacific Hake (with Pacific Herring coming soon).

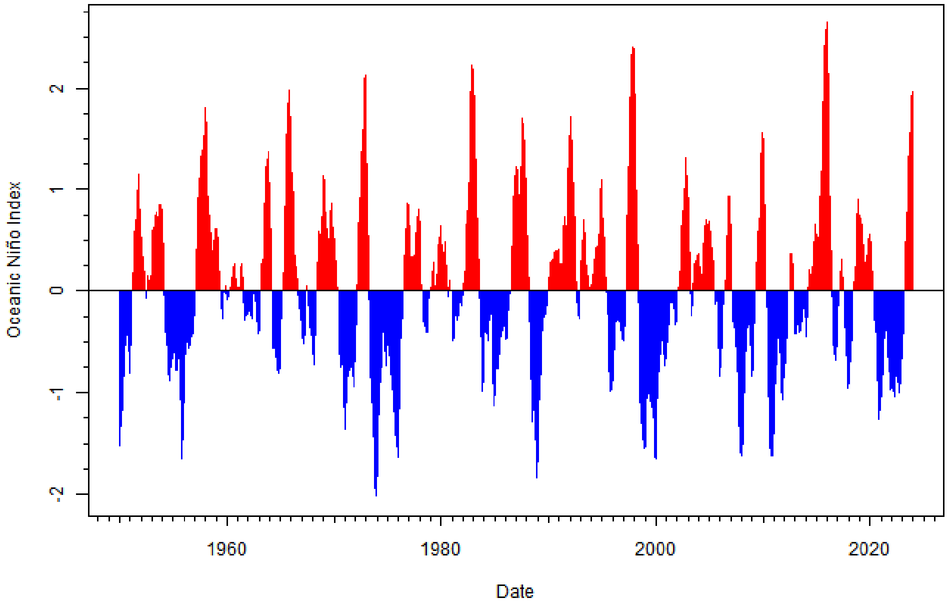

Figure 55-6: The monthly Oceanic Niño Index, as plotted in pacea using the simple R code ‘`plot(oni)`*‘.*

55.3. References

Edwards A.M., Tai T.C., Watson J., Peña M.A., Hilborn A., Hannah C.G., and Rooper C.N. 2023. pacea: An R package of Pacific ecosystem information to help facilitate an ecosystem approach to fisheries management. https://github.com/pbs-assess/pacea

Peña, M.A., Fine, I., and Callendar, W. 2019. Interannual variability in primary production and shelf-offshore transport of nutrients along the northeast Pacific Ocean margin. Deep-Sea Research II, doi:10.1016/j.dsr2.2019.104637. https://www.sciencedirect.com/science/article/pii/S0967064519300220

56. ILLUMINATING PATHWAYS: FLUORESCENCE AND ENZYMES AS TOOLS FOR ASSESSING PRODUCTIVITY AND TROPHIC TRANSFER IN THE STRAIT OF GEORGIA

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56.1. Highlights

- In 2023, sampling effort to measure phytoplankton to zooplankton production rates and trophic transfer efficiency (TTE) was increased (biweekly-monthly) in the Strait of Georgia (SoG) as part of the Pacific Salmon Strategy Initiative (PSSI).
- These measurements are essential for understanding how much production at the base of the SoG food web is available for fisheries production.
- Timing of the spring bloom was average in 2023, and both zooplankton and phytoplankton production were spatially variable and showed strong seasonality.

56.2. Extended abstract

The study was conducted at multiple sites (Figure 56-1) in the Strait of Georgia (SoG), ranging from north of Texada Island (Stn 12, 49° 43.6' N, 124° 40.8' W), to the southern Gulf Islands (Stn 59, (48° 36.852' N, 123° 14.862' W). Three of these stations, 12 (northern SoG), GEO1 (central SoG), and 42 (southern SoG), were the focus of paired phytoplankton and zooplankton production rate measurements (Figure 56-2, Figure 56-3).

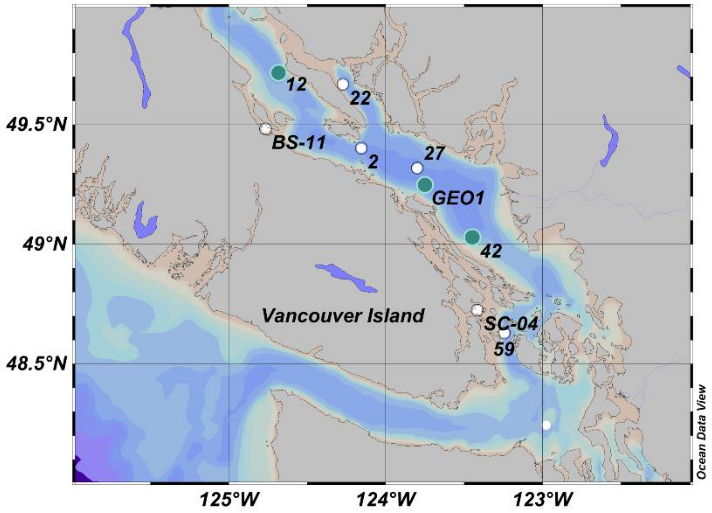

Figure 56-1. Stations sampled in the Strait of Georgia in 2023. Primary productivity was measured at all stations, secondary productivity was measured at stations marked with a teal circle.

Estimates of gross phytoplankton primary productivity (GPP) were taken using the Chelsea Technologies single turnover active fluorometer system (LabSTAF) (Oxborough, 2022). Key measurements for these estimates were fluorescent light curves (FLC), constructed for each sample and used to derive electron transport rate and the maximum gross oxygen production (GOPIIm) (Figure 56-2); (Boatman et al. 2019; Oxborough 2022).

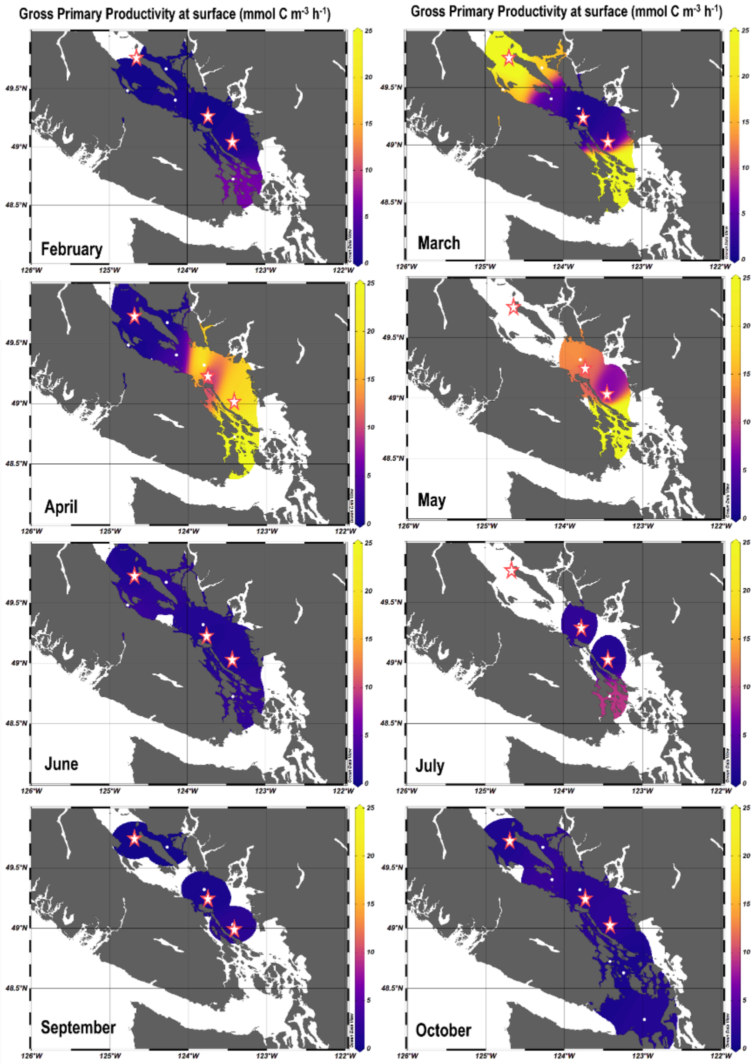

Figure 56-2. Gross primary productivity rate (mmol C m-3 hr-1) measured in the surface (0-2m) in 2023. Stations where secondary production was measured are marked with red bordered stars (12, GEO1, 42).

Zooplankton abundance and biomass measurements have been a regular part of sampling projects in the SoG extending back at least 40 years (Mackas et al. 2013; Perry et al. 2021; Young et al., Section 43). However, direct measurements of zooplankton production rates are much less common, but can provide crucial knowledge of the food web dynamics in the SoG. Starting in 2023, biweekly to monthly seawater incubation experiments were performed to measure in situ zooplankton biomass production rates using the chitobiase enzyme decay method (Sastri et al., 2006).

In the SoG in 2023, BPR and GPP were highly spatially heterogeneous, and both showed strong seasonal patterns consistent with previous rate and biomass estimates (Figure 56-3, Sastri et al. 2009; Perry et al. 2021).

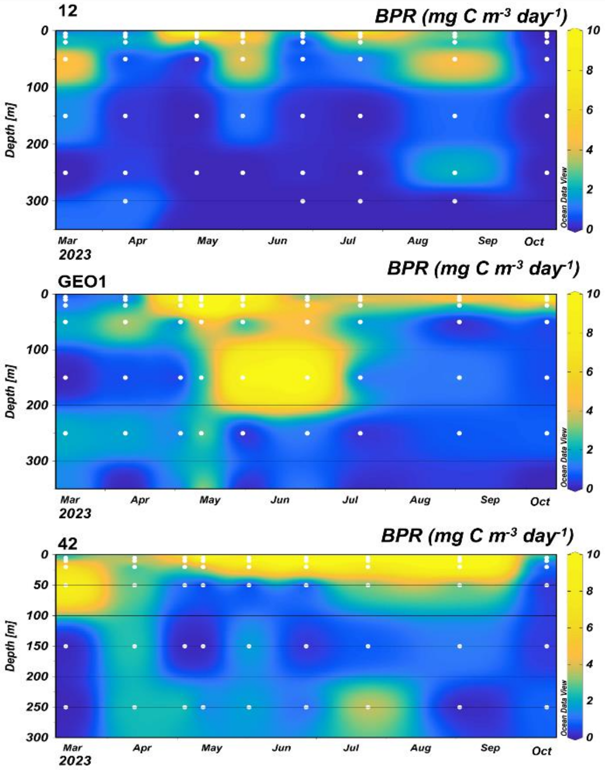

Figure 56-3. Chitobiase-based biomass production rates (BPR; mgC m-3 day-1) at stations 12 (top panel), GEO1 (center), and 42 (lower) over eight months in the Strait of Georgia in 2023.

Calculation of TTE rates is the next step in the project and it is our hope that these improved methods will allow TTE to become a regular part of time series initiatives in the SoG and wider Pacific region.

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57. INTERANNUAL VARIABILITY IN NORTHERN SALISH SEA MICROBES

Colleen Kellogg, Carolyn Prentice, Rosie Savage, Isabelle Desmarais, Drew Jordison, Kim Bedard, Jon Bergshoeff, Chris Mackenzie, Katie Campbell, Carrie Weekes, Bryn Fedje, Emma Myers, Jessy Barrette, Justin Del Bel Belluz, and Wiley Evans. Hakai Institute, Campbell River, B.C. colleen.kellogg@hakai.org

57.1. Highlights

- Salinities in the surface mixed layer were among the highest in our 9-year time series.
- Multiple diatom blooms occurred throughout the growing season, with Prymnesiophytes (*Phaeocystis* sp.) abundant both early and in between diatom blooms. Lower freshwater content and wind mixing of surface waters may have contributed to diatom success.
- Positive anomalies for canonically deeper, nitrifying prokaryotic taxa were observed in the surface waters throughout 2023, potentially indicative of increased mixing and enhanced nitrogen cycling.

57.2. Extended Abstract

Microbes (Bacteria, Archaea, and Protists) play important roles in marine food webs. They are primary producers and food for higher trophic levels. They are carbon and nutrient cyclers, driving global biogeochemical cycles. Despite their integral roles in ocean chemistry and biology, we lack a holistic understanding of microbial diversity and ecosystem function along the coast of B.C. As part of the Hakai Ocean Observing Program, we have been collecting weekly biomolecular samples from surface to near bottom to genetically characterize plankton communities in the Northern Salish Sea (Station QU39: 50.0307, -125.0992, Figure 57-1 A) since 2015, developing a climatology from which we can begin uncover the physical, chemical and biological drivers of community and functional change.

2023 surface waters at QU39 were notably saltier, with lower freshwater content, than any prior year of the time series (Figure 57-1 B). Additionally, surface mixed layer temperatures were cooler with lower dissolved oxygen than average for much of the year. For more details, see Wiley Evans (Section 18) and Justin Del Bel Belluz (Section 20).

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). Across the time series, Plastid DNA sequences from phytoplankton revealed interannual variation in seasonal succession of major groups of phytoplankton in the Salish Sea. Diatom and Prymnesiophyte blooms typically give way to cryptophytes and mamiellophytes, which dominate the community much of the year in the Northern Salish Sea. Notable Prymnesiophyte blooms occurred in 2015 and 2022. In 2023, notable positive anomalies of bolidophytes, pelagophytes (typically oceanic groups), and diatoms belonging to Mediophyceae were observed, the latter highlighting that 2023 was productive year (Figure 57-1 C). Lower freshwater content and wind mixing of surface waters in 2023 may have contributed to diatom success.

Like phytoplankton, marine prokaryotic community composition in the surface waters of the Salish Sea was highly dynamic, resetting annually. Steep changes in composition are likely driven by phytoplankton community succession, nutrient availability, temperature, and salinity.

Prokaryotic community composition is more stable in the intermediate waters, but gradual changes in Crenarchaeota, Chloroflexi, Bacteroidota, Nitrospinota (among other groups) are evident and drive variation below the photic zone. Striking negative anomalies were observed for Actinomarinales both in the surface and intermediate waters in 2023 (Figure 57-1 D, E); the implications of which are still being evaluated. Positive anomalies for canonically deeper, nitrifying prokaryotic taxa were observed in the surface waters throughout 2023, potentially indicative of increased mixing and enhanced nitrogen cycling (Figure 57-1 D). In the intermediate waters, positive anomalies were observed for heterotrophic taxa associated with higher organic matter concentrations while the orders SAR324 and Nitrosopumilales, that typify deeper waters, were depressed (Figure 57-1 E). This is suggestive of the potential for enhanced organic matter respiration, possibly in response the diatom blooms in the surface waters, and increased oxygen drawdown in Northern Salish Sea intermediate waters, as was observed by Evans et al. (Section 18).

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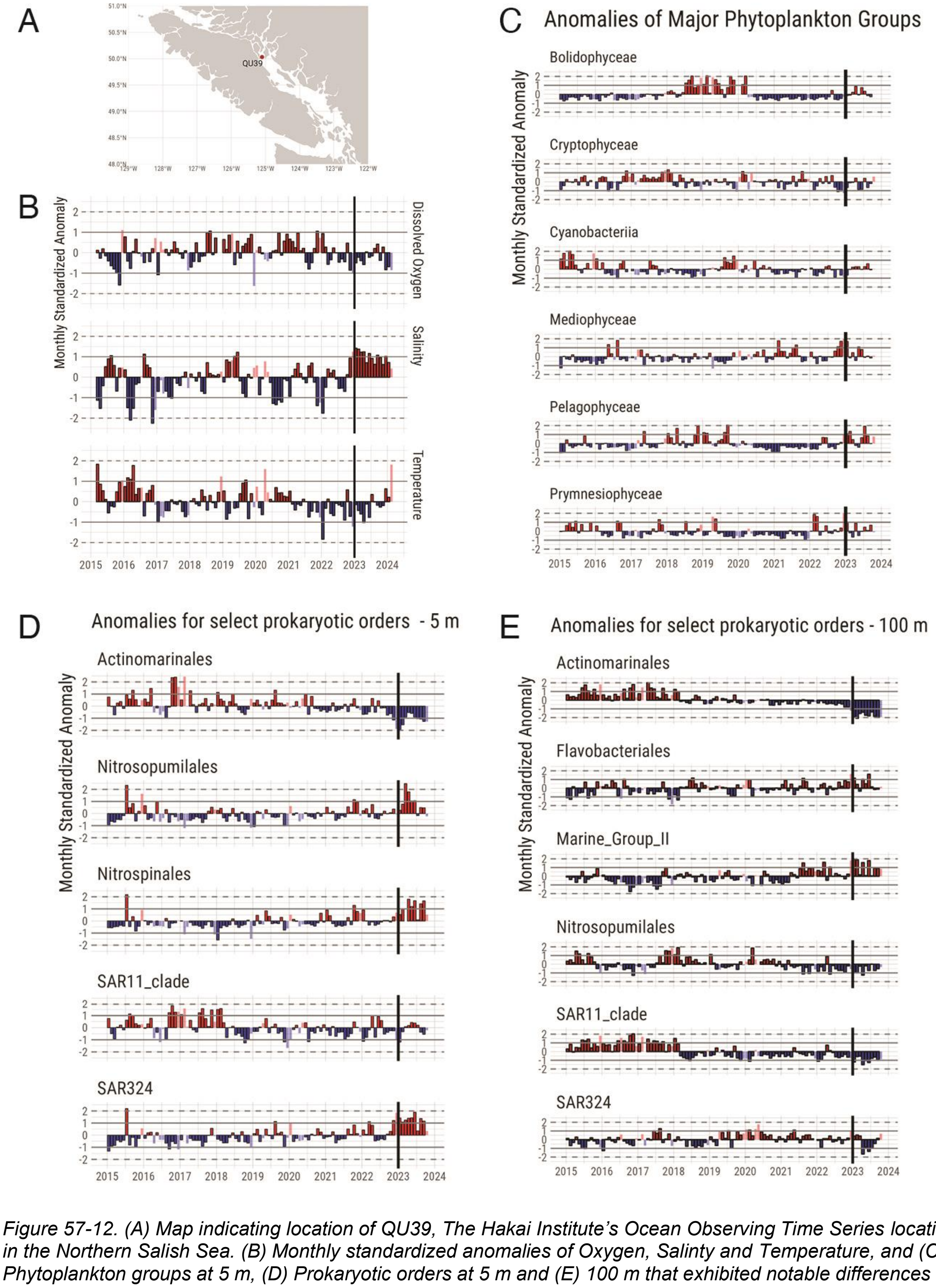

Figure 57-12. (A) Map indicating location of QU39, The Hakai Institute's Ocean Observing Time Series location in the Northern Salish Sea. (B) Monthly standardized anomalies of Oxygen, Salinty and Temperature, and (C) Phytoplankton groups at 5 m, (D) Prokaryotic orders at 5 m and (E) 100 m that exhibited notable differences relative DNA sequence abundances in 2023 from previous years.

58. STATE OF THE MESOSCALE AND SUBMESOSCALE IN THE NORTHEAST PACIFIC

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58.1. Highlights

- 2023 saw more Haida Eddies than usual in satellite altimetry, both in number and in area occupied by eddies;
- Smaller scale lateral statistics are relatively constant through the observation period;
- 2023 saw anomalously warm water in the California Undercurrent, and down to 1000 m in the 300 km closest to the continental slope.

58.2. Extended abstract

Mesoscale eddies, like Haida eddies spawned on the southern tip of Haida Gwaii, are believed to play a central role in transporting nutrients, including micronutrients to the open ocean, hence fueling primary productivity. Data from altimeters in 2023 showed 7 Haida eddies in the study region, which is higher than the average 5, though less than years when 10 have been seen. These eddies covered 1% of the study region for the year, again a relatively high proportion. For future years, we plan to improve detection of the eddies and their strength using Surface Water and Ocean Topography (SWOT) altimetry, and to test their fidelity in Northeast Pacific Ocean Model (NEPOM) simulations.

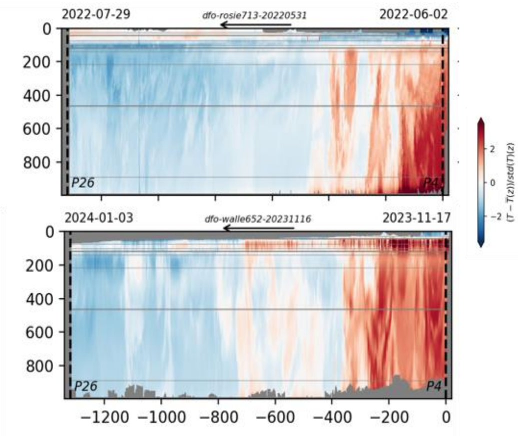

Figure 58-13. Temperature anomaly scaled by the standard deviation along Line P along isopycnals plotted at the mean depth of the isopycnals. The coordinate system is distance offshore (km).

Submesoscale processes cause mixing within mesoscale features, so we gather statistics on the strength of the submesoscale as well, using both 1.5-km lateral scale shipboard surveys and 3-km scale underwater glider surveys. Within 500 km of the coast, there appears to be some universality in the turbulent statistics, indicating active local mixing, probably due to instability of the California Undercurrent system. We have not seen evidence that this mixing changes with seasons, though we are still dealing with relatively few observations. We are also actively comparing these statistics to the statistics in NEPOM to improve the turbulence in those simulations.

Glider surveys along Line P make it clear that 2023 saw anomalously warm water down to 1000 m depth within 300 km of the continental slope (Figure 58-1). In terms of normalized temperature anomaly, this warmer water is surprisingly homogenous, and evident as early as August 2023. This warm water was not readily apparent in simulations of the region, though it can be seen in Argo data with moderate fidelity. We are working towards operating more consistent glider lines offshore of P4 to track features like this.

59. UNIQUE MATERNAL TRANSFER OF TRACE METALS AND PERFLUOROALKYL SUBSTANCES (PFAS) IN A BLUNTNOSE SIXGILL SHARK (*HEXANCHUS GRISEUS*) FROM THE SALISH SEA

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[2]Vancouver Island University, Nanaimo, B.C. Erik.Krogh@viu.ca

59.1. Highlights

- Toxic heavy metals (cadmium, lead) were detected in the liver of a Bluntnose Sixgill Shark found dead on Vancouver Island.
- Bluntnose Sixgill Sharks demonstrate hepatic maternal transfer of toxic contaminants such as PFAS to their unborn offspring.
- Maternal transfer of PFAS was greater than transfer of toxic metals in Sixgill Sharks, indicating differential maternal transfer mechanisms.

59.2. Extended Abstract

A 4 m long Bluntnose Sixgill Shark (*Hexanchus griseus*) was discovered washed ashore deceased in Coles Bay, Victoria, B.C. in February 2019. This specimen was pregnant with 72 offspring, one of which was discovered in the cloaca. Pregnant organisms can transfer contaminants to their offspring through a process termed maternal transfer. Sixgills exhibit lecithotrophic viviparity wherein maternal nutrition reaches embryos solely via a yolk sac. This specimen provided a unique opportunity to study the accumulation of chemical pollutants in the region, as well as the potential for hepatic maternal transfer (Figure 59-1). Contaminants in the Strait of Georgia include toxic metals (e.g., Pb, Cd) and persistent organic pollutants (POPs) such as the class of “forever chemicals”, perfluoroalkyl substances (PFAS). Here, the concentration of 18 targeted inorganic elements and 21 targeted PFAS were analyzed in liver samples from the mother and offspring, using inductively coupled plasma optical emission spectroscopy (ICP-OES) and liquid chromatography-electrospray ionization-high resolution mass spectrometry (LC-ESI-Orbitrap), respectively. The adult and offspring livers were 55% lipid by weight, requiring extensive sample preparation. Findings showed accumulation of toxic metals in the adult shark (7 ± 3 mg kg-1 dw Pb, 6 ± 2 mg kg-1 dw Cd), with low maternal transfer of most inorganic elements. Conversely, high maternal transfer efficiencies were observed for PFAS (ΣPFAS = 71 ± 9 ng g-1 ww in offspring compared to 13 ± 9 ng g-1 ww in the adult). This indicated that PFAS was accumulated by the adult shark and was subsequently transferred with very high efficiency to the unborn offspring. This work demonstrated the accumulation of toxic contaminants and unique contaminant-specific maternal transfer behaviour.

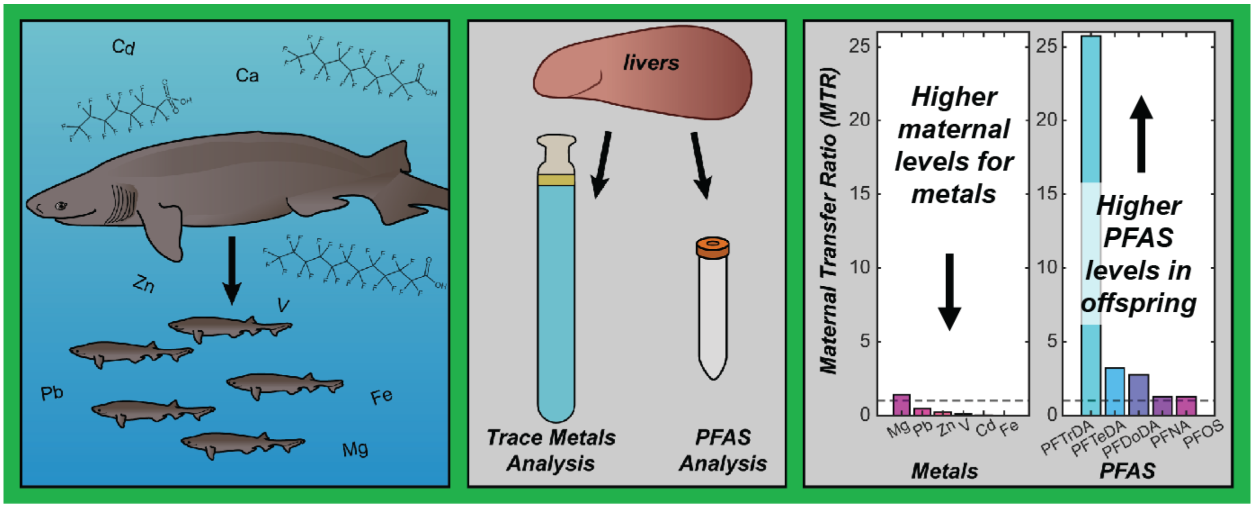

Figure 59-1. Illustrations of A) an adult Bluntnose Sixgill Shark bioaccumulating aquatic contaminants and potentially transferring the contaminant loads to offspring, and B) liver sample extraction and treatment for trace metals and perfluoroalkyl substances (PFAS) analysis. C) Graphical summary of findings, in which maternal transfer ratios were smaller than 1 for metals and greater than 1 for PFAS, generally.

60. ESTABLISHING BASELINES, RISKS, AND MECHANISMS OF THIAMINE DEFICIENCY IN BRITISH COLUMBIA CHINOOK SALMON

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60.1. Highlights

- Thiamine in salmon is derived from their prey in the marine environment and is transferred to offspring. The most acute effects of thiamine deficiency are manifested in pre-feeding fry, with high mortality.
- Thiamine (vitamin B1) deficiency has been identified in Chinook Salmon to our north (Alaska) and south (California), but has not been evaluated in B.C. Chinook.
- A new project funded by the BC Salmon Recovery Innovation Fund (BCSRIF) is evaluating the occurrence and drivers of thiamine deficiency in B.C. Chinook Salmon.

60.2. Extended abstract

Thiamine (vitamin B1) deficiency complex (TDC) is a rapidly emerging issue impacting Chinook Salmon in California (Mantua et al. 2021) and Alaska (Larson and Howard 2019) but has received limited evaluation in B.C. TDC can cause high mortality in emerging fry as well as other latent behavioral effects. TDC is expected to be a burgeoning issue under climate change and may already be a factor in B.C. Chinook declines. Chinook do not produce thiamine; they derive it from prey in the marine environment. Chinook thiamine levels may be affected by changing ocean conditions, diet, or even the amount of lipid used during migration. B.C.'s Chinook populations vary in their marine distribution, diets, and migration lengths, meaning TDC is likely to manifest differently across these populations.

To date, very few data on Chinook thiamine levels in B.C. exist (Welch et al. 2018). To address this data gap, a new BCSRIF funded project is establishing baselines and investigating mechanisms of TDC in B.C. Chinook Salmon. This project will measure egg thiamine levels in Chinook populations from the Fraser River and southern B.C. during the 2023-2024 spawning seasons. These levels can be compared thresholds for fry survival established in California. Thiamine samples will also be taken from female Chinook intercepted at the Albion test Fishery.

A second goal of the project is to build a thiamine nutrition database for prey species of Chinook. Prey vary in their thiamine content as well as thiaminase—a thiamine-degrading enzyme found in some forage fish, which has been linked to TDC in California Chinook. Notably, a diet dominated by northern anchovy, which are high in thiaminase, has been linked to the recent surge of TDC observed in California. Due to the increased presence and abundance of northern anchovy within the Strait of Georgia, this prey item is of particular interest.

Ultimately, we plan to link the thiamine status of Chinook to their different life histories, marine distributions, and prey preferences based on stable isotope and fatty acid markers. These results will inform the risk of TDC in B.C. Chinook and other salmonids.

60.3. References

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61. RESEARCHING THE RESEARCH STATIONS: NEW ANNUAL MONITORING AT PBS AND IOS

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61.1. Highlights

- A new monitoring project aims to create a time series of ecological and biophysical properties of areas surrounding the Pacific Biological Station (PBS) and the Institute of Ocean Sciences (IOS) over time.
- By taking a collaborative approach, keeping protocols simple, and selecting areas that can be accessed without travel, the project aims to maintain annual monitoring over time.

61.2. Extended abstract

If we walk out of our offices at IOS and PBS, what will we find? Are the ecosystems at our own research stations changing over time?

The Ecosystem Stressors Program, together with members from ROPES (Research in Ocean Properties and Ecosystem Stressors), MSEA (Marine Spatial Ecology and Analysis), AEMMS (Aquatic Ecosystem & Marine Mammals Section), Marine Invertebrates, Nearshore Ecosystems, and Integrated Marine Response Planning, is initiating a monitoring program at each research station to track ecological and biophysical properties over time. By using established, standard protocols and selecting areas that we can access without travel, we aim to repeat the survey each year with the goal of creating a long-term dataset.

Starting in the spring of 2024, we will document intertidal diversity and marine debris through transect surveys, fish diversity through baited remote underwater video, fouling species through settlement plates; we will also collect eDNA samples, and measure temperature, salinity, and turbidity. In future years, we hope to add a dive survey for subtidal biodiversity and begin deploying current meters. We are open to more ideas if you have suggestions or requests; the only limitation is the availability of staff willing to commit to repeating the survey annually and within our goal of a single-day event.

There are currently datasets at PBS for temperature and salinity through the lighthouse data, introduced fouling species through settlement plates by the Aquatic Invasive Species Program, Dungeness crab larvae from the Hakai Institute's Sentinels of Change light trap survey, and daily plankton samples at IOS by Coastal Environmental Baseline. We aim to summarise available datasets from each station into an annual report, so please reach out if you know of others.

If you are interested in participating in this collaborative field work, please contact us.

62. HOTSSEA V1: NEMO-BASED 3D PHYSICAL HINDCAST OF THE SALISH SEA SUPPORTING ECOSYSTEM MODEL DEVELOPMENT AND PACIFIC SALMON RESEARCH

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62.1. Highlights

- HOTSSea v1 is a 3D physical model hindcast for the Salish Sea extending back to 1980 developed using the NEMO 3.6 framework.
- Evaluation against observations indicates model skill is relatively high in the Strait of Georgia and long-term ocean temperature trends from HOTSSea v1 generally agree with measurements taken at Nanoose station.
- HOTSSea v1 was used to examine ocean temperature trends in areas of the Strait of Georgia with observation gaps to show spatial and temporal heterogeneity.
- The model shows promise for addressing gaps in observations and to understand drivers of ecosystem productivity via linking to ecosystem models.

62.2. Extended Abstract

The Hindcast of the Salish Sea (HOTSSea) v1 is a retrospective hindcast of physical ocean properties intended to fill gaps in sparse observations and to aid with examining dynamical linkages between physical ocean properties and the marine ecosystem. Various changes to physical ocean properties over the past four decades have been observed or hypothesised to have occurred in the Salish Sea such as warming ocean temperatures, increased seasonal stratification, increased intensity of Fraser River flow, more variable seasonal temperatures and winds (Johannessen and Macdonald 2009; Masson and Cummins 2007; Riche et al. 2014). These changes may have affected survival and productivity of wild Pacific salmon and other marine ecosystem components. The primary motivation for the development of HOTSSea v1 was to provide physical oceanographic fields to drive ecosystem models to investigate mechanisms behind long-term increases in early marine mortality of juvenile salmon.

HOTSSea v1 is a 3D model developed using the NEMO v3.6 framework (Madec 2016) with temporal coverage from 1980 to 2018. The spatial-temporal resolution compliments existing models and the omission of a biogeochemical module was necessary to reduce computational cost, enabling a long hindcast on high performance computing resources. The model has horizontal resolution of approximately 1.5 km (square grid; finite difference) with 40 vertical

depth levels of varying widths (< 1 m at surface, 27 m at 400+ m). The barotropic and baroclinic time steps are 30 seconds and two minutes, respectively.

An inter-model comparison and preliminary evaluation of model performance using several atmospheric and ocean reanalyses products for boundary forcing was completed. Biases inherited from forcings were identified. A simple temperature bias correction factor was applied to the boundary condition fields from the ORAS5 global reanalysis product used at the Juan de Fuca ocean boundary. The crude bias correction improved model performance substantially and therefore further exploration of more sophisticated methods are planned for subsequent iterations. Evaluation of model's performance with respect to salinity and temperature indicates skill is relatively high in the southern Strait of Georgia where temperature bias over all depths over the hindcast period in the southern Strait of Georgia was –0.08 ℃ with an overall correlation coefficient (R) of 0.94. Mean salinity bias over all depths was +0.38 PSU with R=0.96. Although the preliminary evaluation indicates that HOTSSea v1 performs well in many respects, further evaluation should be done to fully understand the limits of the model's performance. A high priority is extending the hindcast further to capture the 1970s which were relatively cold, including the 1976-1977 regime shift (Beamish et al. 1999; Di Lorenzo et al. 2008; Mantua and Hare, 2002).

Modelled versus observed ocean temperature anomalies and trends were analysed and compared at Nanoose station, the one location where consistent biweekly measurements were available for the duration of the hindcast. The model predicts temperature anomalies in good agreement with observations (Figure 62-1). Bolstered by the model's performance at Nanoose station, we analysed modelled ocean temperature trends throughout the northern and central part of the domain. Results indicate warming trends at Nanoose (previously reported by Masson and Cummins 2007) are generally representative of elsewhere in the Strait of Georgia, though patterns exhibit spatial-temporal heterogeneity (Figure 62-2).

Overall, HOTSSea v1 simulates observed decadal scale changes in water properties which are hypothesised to have impacted Pacific salmon in a core area of interest within the Salish Sea, the Strait of Georgia. Physical ocean models coupled or linked to biogeochemical and ecosystem models can be used to extrapolate from limited observations, and to explore and evaluate the pathways of effects from water properties to marine ecosystems, revealing dominant drivers of ecological productivity (Hermann et al. 2023; Macias et al. 2014; Piroddi et al. 2021). HOTSSea v1 will be used in an end-to-end spatial-temporal ecosystem model framework for the Strait of Georgia and has potential for other research and management applications related to decadal scale climate effects on marine ecosystems, fish, and fisheries.

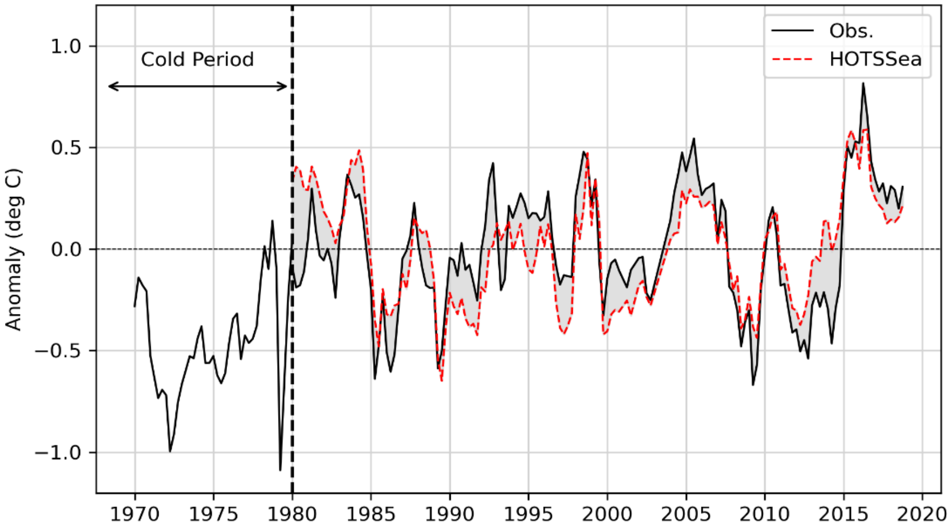

Figure 62-1. Temperature anomalies (seasonal) from observations (red, solid) at Nanoose station in the central Strait of Georgia versus those derived from HOTSSea v1.02 model outputs, depth integrated over 4.5 m – 400 m. The grey area represents the model bias. Observations from the 1970 – 1980 period at Nanoose are included to illustrate the cooler period, a multiyear swing in temperature anomalies (1977,1978), followed by a regime shift occurring circa 1977 (Beamish et al. 1999; Hare and Mantua 2000).

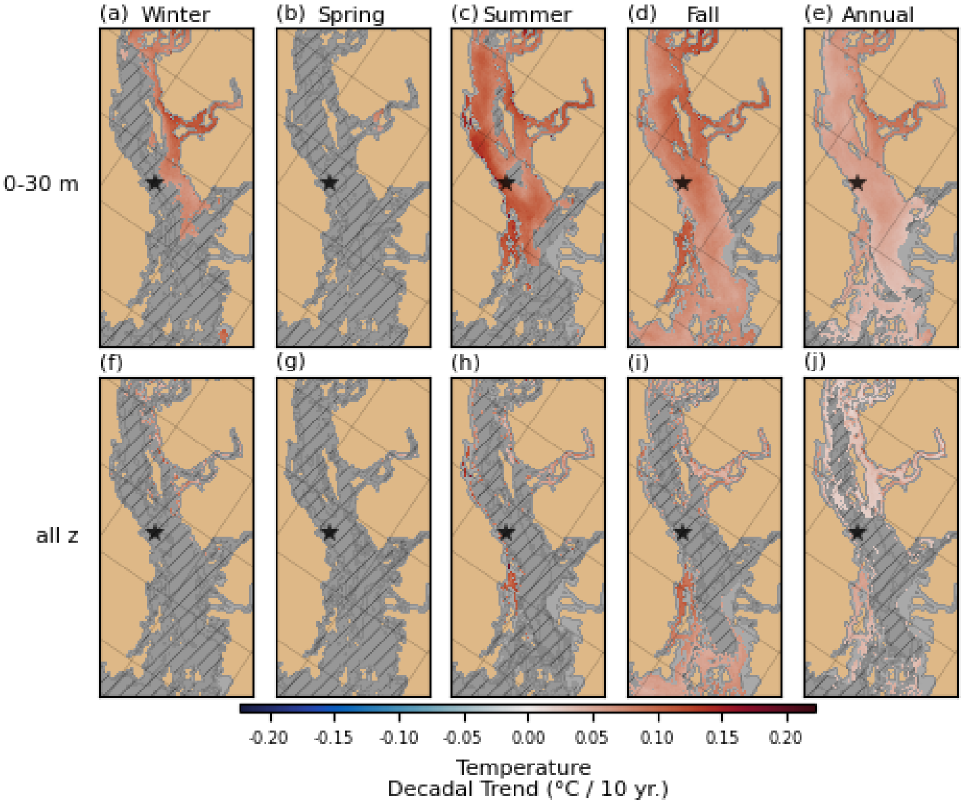

Figure 62.2. Seasonal water temperature trends for 0 – 30 m depth stratum and over all depths extracted from HOTSSea v1.02 model outputs. Mask (grey) has been applied to grid cells that are shallower than the depth stratum. Grey hatching has been applied to grid cells where trend was not statistically significant. Star symbol denotes approximate location of Nanoose station. Note the detection of a significant trend is hampered by the omission of the relatively cold 1970s.

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63. SEA LEVEL IN B.C., 1910 TO 2023

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63.1. Highlights

- Annual mean sea levels in 2023 at Victoria, Tofino, and Prince Rupert increased by 3.4 cm, 3.7 cm, and 3.7 cm respectively relative to the average of the previous five-years.
- Removing the vertical tectonic uplift changes the long-term trend at each location, particularly in Tofino, where it is reversed.
- Despite the notable rise in sea level from 2022 to 2023, the post-1993 rate of sea level rise in B.C. remains, at present, substantially less than that seen in the global mean sea level data.

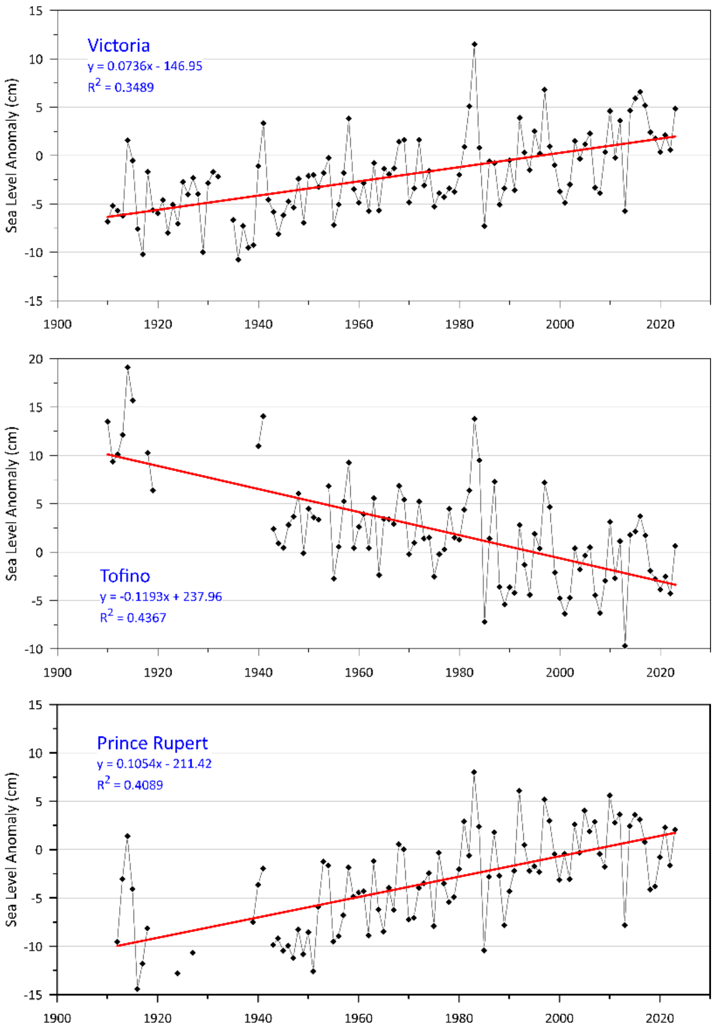

Figure 63-1. Annual-average sea level anomalies at three B.C. ports. Reference years for anomaly calculation are 1981 to 2010. Linear trends shown in red.

63.2. Summary

The Canadian Hydrographic Service performs long-term monitoring of sea levels along the B.C. coast. Particularly long time-series have been collected at Tofino and Victoria (1910-present) and at Prince Rupert (1912-present). The annual deviations from the long-term average (1981-2010) are shown for these stations in Figure 63-1.

A linear trend line was fitted to the full dataset for each location. In 2023, the deviation at Victoria and Tofino increased by over 4 cm to reach almost 3 cm above the trend line. At Prince Rupert, the deviation also increased by nearly 4 cm. This brought the value back to slightly above the trend line. This is in contrast to 2022 when all three were slightly below the trend line. Note that there is considerable variability in the record.

The linear sea level rise trend at each location (cm/century) is +7.36 cm for Victoria, +10.54

cm for Prince Rupert, and -11.93 cm for Tofino. The latter value is of interest in that the local sea level (measured relative to the land) is decreasing at an average of 11.9 cm/per 100 years. This is the result of a tectonic process. As the Juan de Fuca plate moves beneath the North American plate, coastal B.C. and in particular western Vancouver Island experience uplift at a rate of a few millimetres annually. The amount decreases as you move eastward nearing zero as you reach Vancouver (Thomson et. al. 2008). A consequence of this uplift is that the land at Tofino is rising faster than the sea level. Removing the tectonic motion of 1.9 mm annual uplift, derived as the average from 1994 to 2017 (Thomas James, Geological Survey of Canada, pers. comm. 2018), from the sea level values at Tofino from 1910 to 2023 results in a linear trend of +7.1 cm per century - an increase of 0.3 cm compared with 2022.

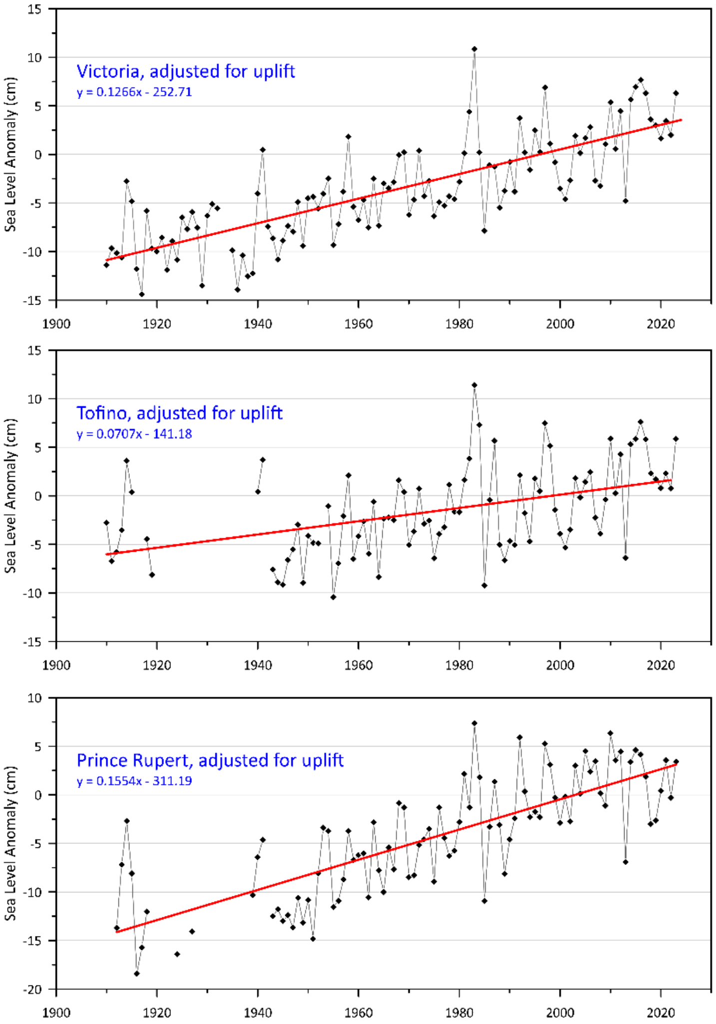

Figure 63-2. Annual-average sea level anomalies (relative to the average from 1981 to 2010) at three B.C. ports with vertical land movement removed.

More modest uplift is present at Victoria (+0.53 mm/year) and Prince Rupert (+0.5 mm/year). The linear sea level rise trend at these ports corrected for vertical land movement (cm/century) is +12.7 cm at Victoria - an increase of 0.2 cm since 2022, and +15.5 cm at Prince Rupert - no change from 2022. The three uplift-adjusted time-series are shown in Figure 63-2.

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

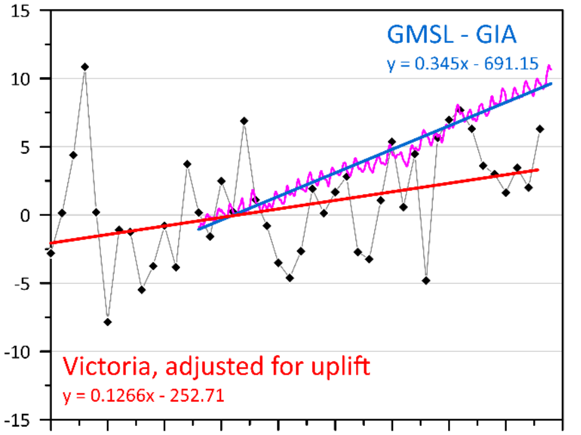

Figure 63-3. Annual-average sea level anomaly at Victoria (vertical land movement removed) in contrast to global mean sea level (GMSL) with global isostatic adjustment (GIA). Red and blues lines are linear fits to the Victoria and GMSL data respectively.

rise in B.C. in recent years compared with the past century. 2023 may be an indication of accelerated increase, however, we have not observed significant acceleration thus far. It will be interesting to see if the levels from 2023 continue into 2024.

Global mean sea level data have been collected by NASA's Goddard Space Flight Center (GSFC 2021) since 1993. These data (corrected for global isostatic adjustment, GIA) with respect to the 20-year TOPEX/Jason collinear mean reference show rates of sea level rise of +3.4 mm/year, or +34 cm/century (Figure 63-3). This is substantially higher than the observed rates of sea level rise in B.C. presented here.

63.3. References

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64. DETECTION OF HIGH-FREQUENCY BIOGEOCHEMICAL EVENTS AND THEIR PHYSICAL FORCINGS IN THE NORTHERN STRAIT OF GEORGIA

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64.1. Highlights

- During the analysis period a localized 16-day late fall chlorophyll-a (Chl-a) bloom event was detected in the northern Strait of Georgia. Over 16 days the bloom event went through a full cycle from baseline to growth to subduction to baseline.
- The bloom evolved at the surface over ~5 days, at which time a strong southeasterly storm moved in and subducted the bloom mass to ~30 m (half the water column depth). This downward transport took 4 days. Some bloom activity continued at surface through day 14 of the event, then the signal returned to baseline. The subduction mechanism for vertical transport is supported by the rate at which it occurred and dissipated, density changes in the water column, and local atmospheric and wave measurements.

64.2. Extended abstract

We analyzed a 22-day late fall period (2023-10-22 – 2023-11-13) in which the 60 m water column was profiled 3,626 times by a Del Mar Oceanographic Wirewalker. This wave-powered rapid vertical profiling system was equipped with an RBR Maestro3 CTD and Sea-Bird Scientific ECO Puck sampling at 8 Hz, and an RBR Coda3 T.ODO dissolved oxygen optode sampling at 1 Hz, providing high vertical resolution to complement the high-frequency profiles. 1,813 of these profiles were upcasts at 0.5 m/min. Downcasts were rejected due to the stop-and-go nature of the wave-powered profiler. The sample site was Hakai Institute's QU5 station (50.1202 N, 125.2115 W) in the northern Strait of Georgia.

The biogeochemical impacts of these high-frequency and fine-scale events in the northern Strait of Georgia (nSoG) is generally poorly understood. A high-resolution nSoG CO_2 dataset (Evans et al. 2019) and the SalishSeaCast model (Moore-Maley and Allen 2021) both show upwelling-favourable winds as an important source of high-frequency variability with large biogeochemical impacts to the region. Phytoplankton biomass increases have also been observed in the region following short-lived summer increases in surface nutrients with limited understanding of the underlying physical mechanism (Del Bel Belluz et al. 2021). Better understanding these events and their impacts through different seasons is key to better understanding the biogeochemical dynamics of the region.

We found the Wirewalker technology complemented the low-cost mooring developed at the Hakai Institute for measuring conductivity, temperature, depth, and dissolved oxygen at discrete depths with a high temporal resolution of 10 minutes. Coupling Wirewalkers with the low-cost mooring, the Quadra Island Field Station infrastructure (surface seawater flow through lab, meteorological station and bottom node observatory), and the Sentry Shoals buoy will allow us to resolve the impacts of short duration upwelling-favourable winds in the region, as well as other high-frequency, localized events like the one presented here (Figure 64-1).

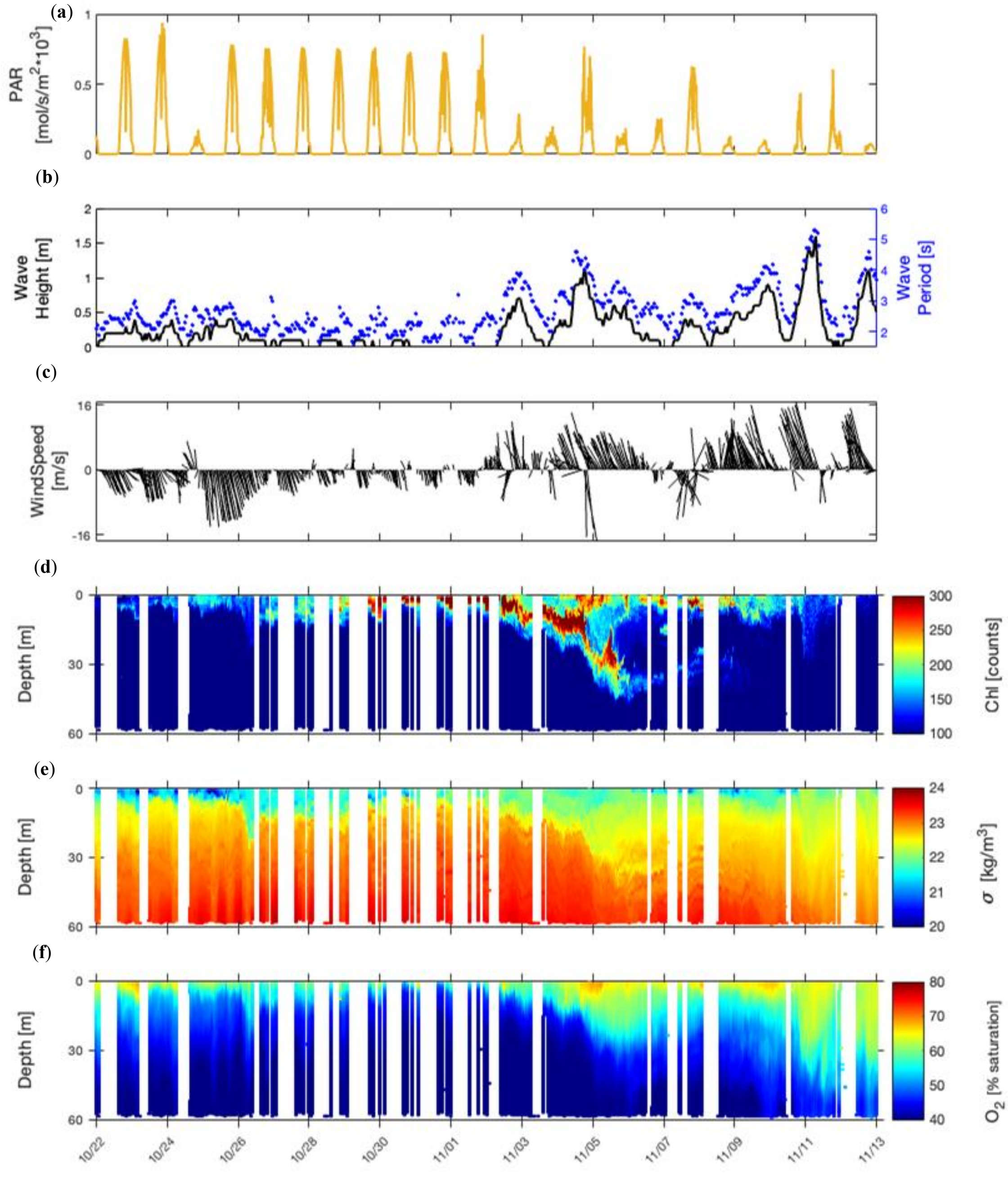

Figure 64-1. November 2023 chlorophyll bloom event at QU5 station. (a) PAR 5-minute averaged from Hakai Weather Station; (b) hourly 20-minute averaged wave height (black) and wave period (blue) from Sentry Shoals buoy #46131; (c) hourly 10-minute averaged wind speed and direction from Sentry Shoals buoy #46131; (d) raw chlorophyll counts from Wirewalker mounted ECO Puck sampling at 8 Hz; (e) water density from Wirewalker mounted RBR Maestro^3 sampling at 8hz; (f) oxygen saturation as measured from Wirewalker mounted RBR Coda^3 T.ODO with fast response foil and 1Hz sample rate. All profiles filtered for upcast.

64.3. References

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65. ROYAL CANADIAN NAVY OCEANOGRAPHY

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Stephan Brulot-Sawchyn, University of Victoria, Victoria, B.C., stephan.brulot@icloud.com

65.1. Highlights

- Over the last several years, a renewed urgency has been placed upon revamping the Royal Canadian Navy’s (RCN) oceanographic capability.
- The Directorate of Meteorology and Oceanography (DMETOC) is collaborating and engaging with governmental and non-governmental agencies to improve oceanographic capability and data sharing.
- Under the new Environmental Sustainability Manager (ESM; Melina Sorensen, MSc.), the Canadian Forces Maritime Experimental Test Ranges (CFMETR) Marine Ecosystem-Level Monitoring and Research Program is continuing and enhancing with planned surveys, monitoring, and community engagement.
- As stewards of vast maritime assets, the RCN and the Department of National Defence (DND) are committed to mitigating and reducing impacts to marine species that may result from naval operations.

65.2. Extended abstract

Throughout the early 2010’s, the oceanographic capability of the RCN was largely stripped resulting in overreliance on open and external sources in providing oceanography data to the Pacific and Atlantic fleets. Recognizing the strategic importance of oceanography data in naval operations, DND has intensified its efforts to revitalize oceanographic capabilities while concurrently emphasizing environmental stewardship.

In spring 2023, Mr. Martin Taillefer joined DMETOC as Chief Oceanographer with the aim of re-bolstering the RCN's oceanographic capabilities. Over the past year, DMETOC's oceanography working group has forged partnerships with various governmental and non-governmental entities enhancing the availability and synthesis of oceanographic data for the Canadian fleets. Additionally, investments have been made in user-friendly oceanography data visualization tools, such as DFO’s Ocean Navigator which facilitate efficient access to oceanographic data and improve real-time decision making.

In addition to initiatives to improve the oceanographic capability of the RCN, the RCN continues to work towards improving its commitment to environmental sustainability. At CFMETR in Nanoose Bay, Ms. Melina Sorensen, MSc, has assumed the role of Environmental Sustainability Manager (ESM), and is entrusted with overseeing environmental monitoring and research programs. Environmental research and monitoring efforts like the Marine Ecosystem-Level Monitoring and Research Program at CFMETR are integral for ensuring that the RCN upholds its environmental stewardship responsibilities.

Appendix 2 - Meeting Agenda

Oral presentations					**SOPO DAY 1 - Wednesday March 6, 2024**		
P#	**Length**	**Start time**		**End time**	**Name**	**Affiliation**	**Title**
1	0:10	9:00	-	9:10	Tucker/Gauthier/Boldt/Dosser	DFO	Introduction
2	0:15	9:10	-	9:25	Stephanie Thomas	Snuneymuxw First Nation	First Nation Opening
3	0:05	9:25	-	9:30	Andy Thomson	DFO	Welcome from DFO
4	0:10	9:30	-	9:40	Strahan Tucker	DFO	Summary of SOPO survey and intro of 25th anniversary
5	0:10	9:40	-	9:50	Jennifer Boldt	DFO	25 years of SOPO
6	0:15	9:50		10:05	Ian Perry	DFO	Major marine environmental events over the past 25 years of SOPO
	0:25	10:05	-	10:30	Break		
7	0:15	10:30	-	10:45	Kristyn Lang	Pacific Climate Impacts Consortium, UVic	Land Temperature and Hydrological Conditions over B.C. in 2023
8	0:15	10:45	-	11:00	Tetjana Ross	DFO	Review of temperature, salinity and density of the northeastern Pacific in 2023 using Argo, glider, satellite and Line P data
9	0:15	11:00	-	11:15	Andrea Hilborn	DFO	Satellite observations of surface chlorophyll-a, temperature, and marine heatwaves in 2023
10	0:15	11:15	-	11:30	Roy Hourston	DFO	Wind-driven upwelling/downwelling along the northwest coast of North America: timing and magnitude
11	0:15	11:30	-	11:45	Hana Hourston	DFO	Sea surface temperature and salinity observed at shore stations along the B.C. coast in 2023
12	0:15	11:45	-	12:00	Charles Hannah	DFO	Subsurface ocean conditions on the B.C. shelf: the B.C. shelf mooring program
	1:15	12:00	-	13:15	**Lunch**		
13	0:15	13:15	-	13:30	Hayley Dosser	DFO	Oxygen in 2023 from Line P, La Perouse, and Queen Charlotte Sound
14	0:15	13:30	-	13:45	Angelica Peña	DFO	Nutrients and chlorophyll in the northeastern Pacific in 2023 using Line P and glider data
15	0:15	13:45	-	14:00	Guoqi Han	DFO	Ocean current and transport from long-term satellite observation and ocean modelling
16	0:15	14:00	-	14:15	Wiley Evans	Hakai Institute	Coastal biogeochemical observations on the British Columbia margin during 2023
17	0:15	14:15	-	14:30	Justin Del Bel Belluz	Hakai Institute	2023 trends in phytoplankton biomass and community composition from timeseries stations in the northern Salish Sea and central coast, British Columbia
18	0:15	14:30	-	14:45	Paul Covert	DFO	What to do with millions and millions of phytoplankton images from Canada's west coast
	0:30	14:45	-	15:15	Break		
20	0:15	15:15	-	15:30	Moira Galbraith	DFO	West coast zooplankton: annual anomaly time series
21	0:15	15:30	-	15:45	Mark Hipfner	ECCC	Observations on seabirds along the B.C. coast
22	0:15	15:45	-	16:00	Duncan Havens	CHS	CHS hydrographic surveys for 2023
23	0:15	16:00	-	16:15	Greg Jones	DFO	Use of drifters to support spill response planning for a large MPA – Scott Islands Marine National Wildlife Area
24	0:15	16:15	-	16:30	Erin Herder	DFO	An update to Olympia Oyster index site monitoring around Vancouver Island
25	0:15	16:30	-	16:45	Bridget Ferriss	NOAA Fisheries	Ecosystem Status of the Gulf of Alaska in 2023
	2:00	17:00	-	19:00			POSTER SESSION

Oral presentations					**SOPO DAY 2 - Thursday March 7, 2024**		
P#	**Length**	**Start time**		**End time**	**Name**	**Affiliation**	**Title**
26	0:15	9:00	-	9:15	Tucker/Gauthier/Boldt/Dosser	DFO	Introduction
27	0:15	9:15	-	9:30	Jim Irvine	DFO	From diatoms to Killer Whales: impacts of Pink Salmon on North Pacific ecosystems
28	0:15	9:30	-	9:45	Jennifer Boldt	DFO	Pelagic fish: an update on status and trends
29	0:15	9:45	-	10:00	Jackie King	DFO	2023 juvenile salmon surveys on the Vancouver Island continental shelf
30	0:15	10:00	-	10:15	Colin Bailey	DFO	Sockeye Salmon indicator populations across B.C.: smolt abundance, marine survival and adult recruitment
	0:30	10:15		10:45	Break		
31	0:15	10:45	-	11:00	Chrys Neville	DFO	Twenty-five years of pelagic surveys in the Strait of Georgia and what was unique about 2023
32	0:15	11:00	-	11:15	Jillian Dunic	DFO	Trends in Pacific Canadian groundfish stock status and surveys
33	0:15	11:15	-	11:30	Stéphane Gauthier	DFO	Distribution and abundance of Pacific Hake (Merluccius productus) from the U.S.A.-Canada joint acoustic-trawl survey
34	0:15	11:30	-	11:45	Christie McMillan	DFO	Year-round survey efforts to inform cetacean distribution and abundance in the southern Salish Sea and Swiftsure Bank
35	0:15	11:45	-	12:00	Svein Vagle	DFO	Emerging soundscape patterns in the Salish Sea
	1:15	12:00	-	13:15	**Lunch**		
36	0:15	13:15	-	13:30	Brett Howard	DFO	Update on the distribution of aquatic invasive species in the Pacific Region
37	0:15	13:30	-	13:45	Matthias Herborg	DFO	A review of 5 years of marine oil spills in B.C. waters
38	0:15	13:45	-	14:00	Andrew Ross	DFO	Marine biotoxin monitoring in B.C. coastal waters
39	0:15	14:00	-	14:15	Lynn Lee & DFO, CHN & Hakai collaborators	DFO, Gwaii Haanas Parks Canada, Council of the Haida Nation, Hakai Institute	2023 Ocean conditions in Gwaii Haanas and Haida Gwaii **Chaan sk̲'ada gud ahl hlg̲unggulaa** | **Tang.g̲wan g̲an gud ad hlg̲ang.gulx̲a** *Working Together Ocean Sciences Expedition*
40	0:15	14:15	-	14:30	Manman Wang	ONC	Ocean observatory contributions to assessing the 2023 southern B.C. coastal conditions
41	0:15	14:30	-	14:45	Hayley Dosser	DFO	Salish Sea temperature, salinity and oxygen observations in 2023
	0:15	14:45	-	15:00	Break		
42	0:15	15:00	-	15:15	Susan Allen	UBC	Update to 2023 (and a look forward to 2024) for the timing of the spring phytoplankton bloom and the summer productivity in the Strait of Georgia
43	0:15	15:15	-	15:30	Svetlana Esenkulova/Rich Pawlowicz	PSF	Oceanographic conditions and harmful algal blooms in the Strait of Georgia 2023
44	0:15	15:30	-	15:45	Kelly Young	DFO	Zooplankton status and trends in the central and northern Strait of Georgia, 2023
45	0:15	15:45	-	16:00	Chris Rooper	DFO	Pacific Herring seasonal use of nearshore habitat assessed by moored acoustics and stereo-optics
46	0:15	16:00	-	16:15	Linnea Flostrand	DFO	Eulachon status and trends in southern B.C.
47	0:15	16:15	-	16:30	Steve Latham	PSC	Trends in body sizes of Fraser River Sockeye and Pink Salmon
48	0:15	16:30		16:45	Nathanael Tabert	UVic	Adult salmon diet monitoring 2017-2023
49	0:15	16:45		17:00	Tucker/Gauthier/Boldt/Dosser		Summary discussion

Appendix 3 - Meeting Participants

First Name	Last Name	Affiliation
Gillian	Adam	Fisheries and Oceans Canada
Selina	Agbayani	Fisheries and Oceans Canada
Chevy	Alexander	T'Sou-ke First Nation
Hussein	Alidina	WWF-Canada
Susan	Allen	University of British Columbia
Kurtis	Anstey	Fisheries and Oceans Canada
Chelsea	Ashbrook	Fisheries and Oceans Canada
Hannah	Avenant	Environment and Climate Change Canada
Emma	Badgery	Parks Canada
Colin	Bailey	Fisheries and Oceans Canada
Steve	Baillie	Fisheries and Oceans Canada
Shannon	Balfry	Fisheries and Oceans Canada
Katherine	Bannar-Martin	Fisheries and Oceans Canada
Sarah	Bartnik	Environment and Climate Change Canada
Cynthia	Barwell	Kitselas First Nation
Arthur	Bass	Fisheries and Oceans Canada
Sonia	Batten	North Pacific Marine Science Organization
Adam	Batty	B.C. Ministry of Water, Land, and Resource Stewardship
Kohen	Bauer	Ocean Networks Canada
Sydney	Baxter	Fisheries and Oceans Canada
Jesse	Beaubier-Brulotte	Fisheries and Oceans Canada
Kim	Bedard	Hakai Institute
Jeannette	Bedard	Fisheries and Oceans Canada
Travis	Bell	Fisheries and Oceans Canada
Douglas	Bertram	Environment and Climate Change Canada

First Name	Last Name	Affiliation
Laura	Bianucci	Fisheries and Oceans Canada
Michelle	Bigg	Fisheries and Oceans Canada
David	Blackbourn	Fisheries and Oceans Canada
Hauke	Blanken	Fisheries and Oceans Canada
Cynthia	Bluteau	Fisheries and Oceans Canada
Jennifer	Boldt	Fisheries and Oceans Canada
John	Bones	Mamalilikulla First Nation
Isabella	Borea	Fisheries and Oceans Canada
Julia	Bos	King County
Bert	Boucher	Mamalilikulla First Nation
Hal	Bradbury	University of British Columbia
Julia	Bradshaw	Fisheries and Oceans Canada
Stephanie	Braig	Ocean Wise
Hannah	Bregulla	Council of the Haida Nation
Stephan	Brulot-Sawchyn	Department of National Defence
Maya	Buckner	Fisheries and Oceans Canada
Alice	Bui	Ocean Networks Canada
Dominique	Bureau	Fisheries and Oceans Canada
Lily	Burke	Fisheries and Oceans Canada
Rianna	Burnham	Fisheries and Oceans Canada
Will	Burt	Planetary Technologies
Brianna	Cairns	Fisheries and Oceans Canada
Danielle	Caleb	Fisheries and Oceans Canada
Wendy	Callendar	Fisheries and Oceans Canada
Jill	Campbell	Fisheries and Oceans Canada
Katie	Campbell	Hakai Institute
Rowshyra	Castaneda	Fisheries and Oceans Canada

First Name	Last Name	Affiliation
Kristina	Castle	Fisheries and Oceans Canada
Spencer	Chaisson	Fisheries and Oceans Canada
Jon	Chamberlain	Fisheries and Oceans Canada
Don	Chamberlain	Fisheries and Oceans Canada
Katie	Chan	Fisheries and Oceans Canada
Justin	Chao	VIU Fisheries & Aquaculture
Michelle	Charbonneau	Fisheries and Oceans Canada
Kashanna	Charlie	Takla Nation
Lais	Chaves	Tsawout First Nation
Julek	Chawarski	ASL Environmental Sciences
Sean	Cheesman	Provincial Ag and Food
Christine	Chen	Tsawout First Nation
Nancy	Chen	Fisheries and Oceans Canada
Elly	Chmelnitsky	Fisheries and Oceans Canada
Nicole	Christiansen	Pacific Salmon Foundation
Lindsay	Clark	University of Victoria
Matt	Clarke	Fisheries and Oceans Canada
Jennifer	Claxton	Tsawout First Nation
Sarina	Clay-Smith	Pacific Salmon Foundation
Holly	Clermont	First Nations Health Authority
Rory	Cleveland	Fisheries and Oceans Canada
Nik	Clyde	Environment and Climate Change Canada
Georgia	Clyde	Fisheries and Oceans Canada
Brendan	Connors	Fisheries and Oceans Canada
Chelsea	Cooke	Fisheries and Oceans Canada
Amelia	Cooper	Tsawwassen First Nation
Rachel	Costall	Fisheries and Oceans Canada

First Name	Last Name	Affiliation
Paul	Covert	Fisheries and Oceans Canada
Bill	Crawford	Fisheries and Oceans Canada
Ken	Cripps	Kitasoo Xai'xais First Nation
Rodrigo	Cristi	MCW
John	Cristiani	Fisheries and Oceans Canada
Rebecca	Croke	Fisheries and Oceans Canada
Jonquil	Crosby	Ucluelet First Nation
Lindsay	Curle	Council of the Haida Nation
Terry	Curran	Pacific Salmon Foundation
Charles	Curry	PCIC
Fiona	Davidson	Fisheries and Oceans Canada
Lindsay	Davidson	Fisheries and Oceans Canada
Katie	Davidson	Fisheries and Oceans Canada
Sandra	Davies	Fisheries and Oceans Canada
Megan	Davies	University of Victoria
Lindsay	Dealy	Fisheries and Oceans Canada
Justin	Del Bel Belluz	Hakai Institute
Danielle	Denley	Province of B.C.
Hilari	Dennis-Bohm	Fisheries and Oceans Canada
Brad	deYuong	CIOOS Pacific
Ariane	Dilay	Fisheries and Oceans Canada
Sean	Dimoff	Fisheries and Oceans Canada
Jake	Dingwall	Pacific Salmon Foundation
Kaitlyn	Dionne	Fisheries and Oceans Canada
Phillip	Dionne	Washington Department of Fish and Wildlife
Cassidy	Donaldson	University of British Columbia
Claire	Dookwah	Fisheries and Oceans Canada

First Name	Last Name	Affiliation
Hayley	Dosser	Fisheries and Oceans Canada
Kelsey	Dougan	Fisheries and Oceans Canada
John	Dower	University of Victoria
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