State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2016

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Les numéros 1 à 456 de cette série ont été publiés à titre de Rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de Rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de Rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

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by

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ABSTRACT

Fisheries and Oceans Canada is responsible for the management and protection of marine resources on the Pacific coast of Canada. Oceanographically this area is a transition zone between coastal upwelling (California Current) and downwelling (Alaskan Coastal Current) regions. There is strong seasonality and considerable freshwater influence, and an added variability from coupling with events and conditions in the tropical and North Pacific Ocean. The region supports ecologically and economically important resident and migratory populations of invertebrates, groundfish, pelagic fishes, marine mammals and seabirds.

Since 1999 an annual State of the Pacific Ocean meeting has been held by DFO scientists in the Pacific region to present the results of the most recent year's monitoring in the context of previous observations and expected future conditions. The workshop to review conditions in 2016 was held March 22 and 23, 2017 at the Mary Winspear Centre near the Institute of Ocean Sciences, Sidney, B.C. This technical report includes submissions based on the ten-minute presentations given at the meeting.

Ocean temperatures along the B.C. coast were above the 1981-2010 average, but this warm water anomaly did not set records as in 2015. As the year progressed the temperature anomaly decreased and the upwelling of cool nutrient rich waters along the west coast of Vancouver Island marked a return to conditions more favourable for productivity and fish growth. The returns of most B.C. Sockeye Salmon stocks in 2016 were higher than expected and higher than the long term averages. The returns of Fraser sockeye in 2016, expected to be low, set an historic low record.

A special session focused on ecosystem reporting processes. Several experts from a variety of government and non-government groups in both Canada and the U.S. provided overviews of the processes they use for ecosystem reporting.

RÉSUMÉ

Pêches et Océans Canada est responsable de la gestion et de la protection des ressources marines sur la côte ouest du Canada. L'océanographie de cette région est une zone de transition entre les remontées d'eaux profondes côtières (courant de la Californie) et les régions de plongée d'eaux (courant côtier de l'Alaska). Il existe une saisonnalité importante, une forte influence des eaux douces, et une variabilité accrue sont reliées aux événements et conditions dans tout le Pacifique, des tropiques aux régions plus au nord. La région nourrit des populations résidentes et migratoires importantes d'invertébrés, de poissons de fond et pélagiques, et de mammifères et d'oiseaux marins.

Depuis 1999, les scientifiques du MPO ont organisé une rencontre annuelle de l'état de l'océan Pacifique pour présenter les résultats de la surveillance de la dernière année dans le contexte des observations précédentes et des conditions futures. L'atelier pour réviser les conditions de 2016 a eu lieu les 22 et 23 mars 2017 au Centre Mary Winspear près de l'Institute des sciences de la mer, Sidney, C.-B. Ce rapport technique inclut des présentations basées sur les présentations de dix minutes présentées lors de la rencontre.

Les températures de l'océan de la Colombie-Britannique étaient supérieures à la moyenne de 1981-2010, mais cette anomalie était moins de 2015. À la fin de 2016, l'anomalie chaude de l'eau de surface dans l'océan Pacifique Nord a diminué et les remontées d'eaux riches en nutriments a permis de revenir à des conditions plus favorables à la productivité et à la croissance du poisson. Les remontes de la plupart des stocks de saumons rouge de Colombie-Britannique en 2016 étaient plus élevés que prévu et plus élevés que les moyennes à long terme.

Une session spéciale a été convoquée sur les processus de déclaration des écosystèmes. Plusieurs experts d'une variété de groupes gouvernementaux et non gouvernementaux au Canada et aux États-Unis ont fourni des aperçus des processus qu'ils utilisent pour les rapports sur l'écosystème

1. HIGHLIGHTS

- The large mass of water observed in the Northeast Pacific Ocean in 2014 and 2015 (the ”Blob”), characterised by surface and subsurface temperatures well above normal (defined as the 30 year average between 1981 and 2010) dissipated in 2016 (except for a brief interval in mid-summer).
- In early 2016 the strong El Niño conditions first observed in late 2015 gradually weakened and transitioned to La Niña conditions by the end of the year.
- The offshore phytoplankton community composition, influenced by the warm waters of the past few years, showed a return to a more normal distribution in 2016. The higher trophic zooplankton community continued to exhibit characteristics consistent with warmer ocean temperatures.
- The spawning biomass of herring was near historic high levels in the Strait of Georgia. Although the abundance of juvenile herring was low in 2016, they were observed to be in good condition. Herring biomass levels in other regions of BC varied.
- The 2016 aggregate return of Fraser River Sockeye Salmon was the lowest on record. However, not all B.C. stocks exhibited a decline; returns of Sockeye Salmon stocks on the west coast of Vancouver Island (WCVI), the Central Coast and the Columbia-Okanagan system exceeded the pre-season forecast and were above the average return levels based on all years of data.
- The number of humpback whales observed in B.C. waters continues to increase and there has been a trend of increasing humpback presence over the last ten years within the inside waters of Vancouver Island, including the Strait of Georgia and Queen Charlotte Strait. [1]
- The melting of B.C. glaciers may release pollutants that had been trapped over the past several decades. This may become an increasing source of freshwater contamination and negatively impact the growth rates and survival of juvenile salmon in fresh water.
- Useful tools for ecosystem reporting include having a narrative or story line with an associated conceptual model of how the ecosystem works, as well as graphics, maps, and standardized reporting formats. Challenges include identifying an audience as varying levels of details are needed for different audiences.
- Unusual events reported in 2016 included abundances of plankton washing along beaches of the west coast of Vancouver Island (often gelatinous plankton), coccolithophorid blooms in the Strait of Georgia, and off of the WCVI, high abundances of juvenile rockfish along the west coast of Vancouver Island and Northern Anchovy in the Strait of Georgia, and sighting of unusual shark species.

[1] ERRATUM: October 2017, changed “The number of humpback whales observed in B.C. waters continues to increase and 2016 observations show a trend of these mammals overwintering along the Central Coast.” to “The number of humpback whales observed in B.C. waters continues to increase and there has been a trend of increasing humpback presence over the last ten years within the inside waters of Vancouver Island, including the Strait of Georgia and Queen Charlotte Strait.”

2. INTRODUCTION

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

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 2016 (for conditions in 2015) is available at

http://waves-vagues.dfo-mpo.gc.ca/Library/365564.pdf

In 2017, the meeting on conditions observed on the west coast of Canada (Figure 3-1) in 2016 took place on March 22 and 23 at the Mary Winspear Centre near the Institute of Ocean Sciences, Sidney, B.C. Over 200 people participated in person or by web-conference. The majority of participants were scientists from federal and provincial government, academia, non-profits, industry and private companies. A trend over the past few years has been the increased participation and presentations by non-DFO scientists. This has provided a broader perspective of the science being done on Canada's Pacific coast, and the audiences who are interested in this science.

The main session included 35 presentations covering a range of observations from 2016. The special session included 8 presentations by invited speakers and was used to examine how other organizations report on ecosystem status and trends, and what tools and resources are required for DFO to ensure more effective uptake by target audiences. The discussion is expected to help shape the development of ecosystem status reporting that will be undertaken for the first time for Canada's Atlantic Ocean in 2018 and Arctic Ocean in 2019.

At the end of the first day a poster session and mixer was held with support from Ocean Networks Canada. Eighteen posters were displayed in the meeting room. A poster on unusual marine events in 2016 provided space for participants to add their own observations.

The agenda for the meeting is presented in Appendix 1, and the participants are listed in Appendix 2. The meeting was co-chaired by Peter Chandler and Jennifer Boldt, and organized by Stephanie King.

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

3. OVERVIEW AND SUMMARY

Strong El Niño conditions at the beginning of 2016 significantly influenced the annual global temperature. With eight months of consecutive high monthly surface temperature records set from January to August, and the remainder of the year ranking among the five warmest, 2016 became the warmest year in the U.S. National Oceanic and Atmospheric Administration's (NOAA) 137-year time series. Daily average and daily minimum air temperature observations for British Columbia were at record-high levels in 2016. There was more precipitation than normal for most regions of B.C., and greater cloud cover that resulted in warmer night time temperatures. El Niño Southern Oscillation (ENSO) conditions became neutral in July and August and negative (La Niña) for the last five months of 2016.

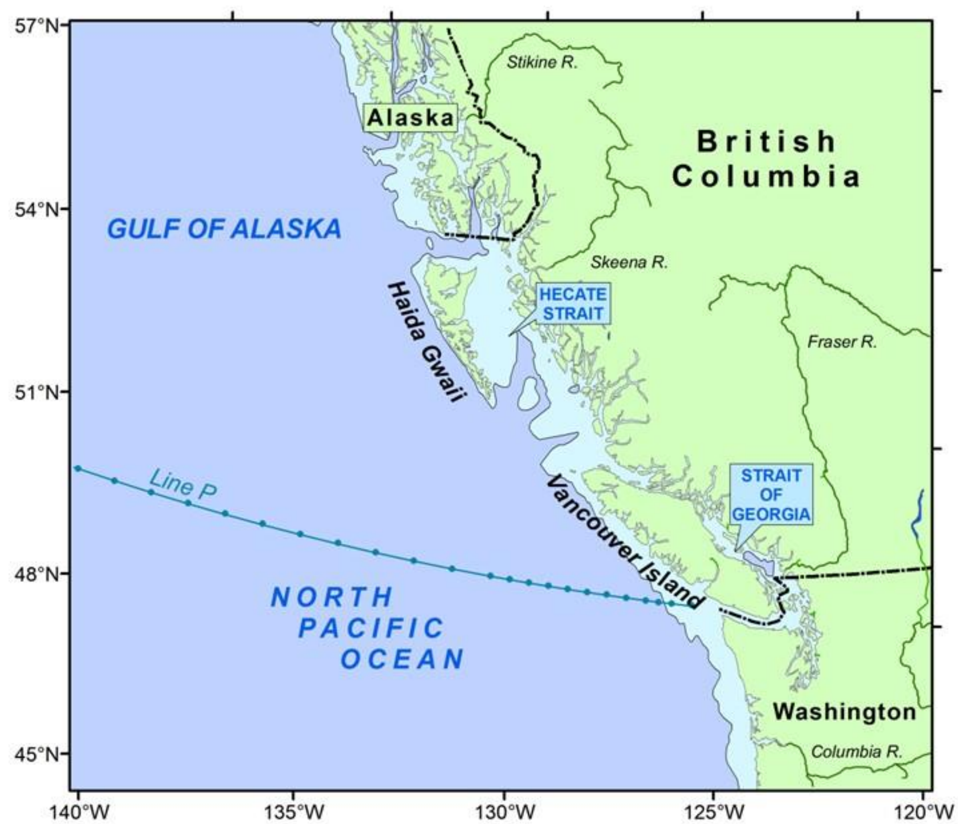

Figure 3-1. Map of regions described in this report.

The warm water observed in the Northeast Pacific ocean in 2014 and 2015 (the "Blob"), characterized by surface and subsurface temperatures well above normal (defined as the 30 year average between 1981 and 2010), dissipated in 2016. While the above average sea surface temperatures associated with this feature decreased during the year, relatively warm subsurface temperatures at depths of 100-200 m persisted (Figure 3-2). Physical processes associated with this anomaly, including increased stratification and reduced upwelling of nutrients to surface waters, have started to revert to more typical conditions that better support primary production and fish growth.

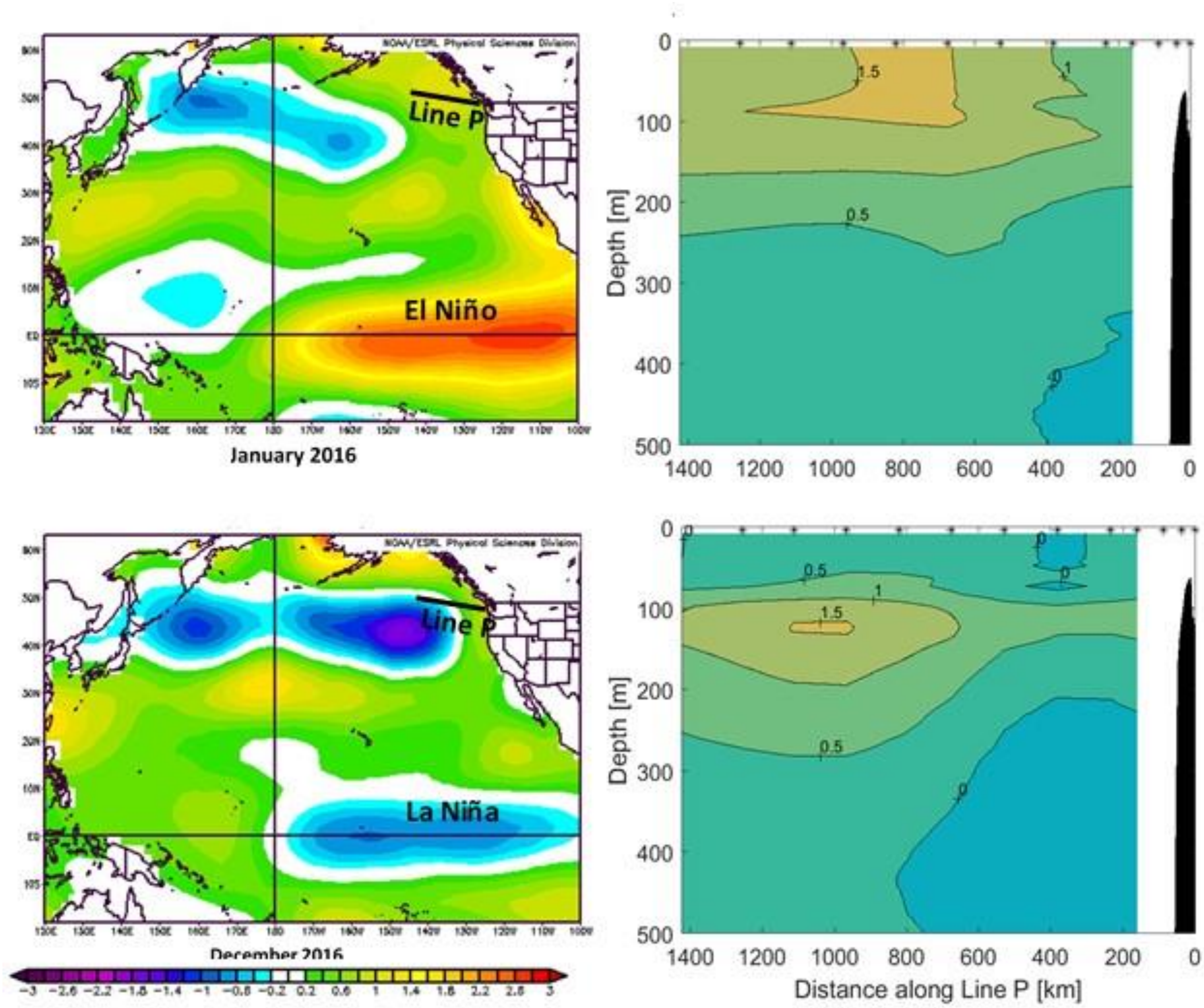

Figure 3-2. The upper panels show ocean temperatures in January 2016, the bottom panels show conditions in December 2016. The panels on the left show contours of sea surface temperature anomaly data from the National Oceanic and Atmospheric Administration Extended Reconstructed Sea Surface Temperature (NOAA_ERSST_V3) data which includes information from satellites, ships, moored and drifting buoys (Image provided by the NOAA/ESRL Physical Sciences Division, Boulder Colorado from their Web site at http://www.esrl.noaa.gov/psd/). The Line P monitoring transect is shown extending from the coast to Station Papa (145° W, 50° N). The panels on the right are derived by interpolating observations from Argo floats along Line P (courtesy Tetiana Ross).

While the phytoplankton community composition showed a return to a more normal distribution in 2016, the higher trophic zooplankton community continued to exhibit characteristics consistent with warmer ocean temperatures with fewer subarctic and boreal copepods and a greater abundance of southern copepods. As ocean conditions continue to cool it is expected there will be a greater abundance of the lipid-rich northern species that are favourable for fish growth.

A large bloom of coccolithophorids occurred in June 2016 along the shelf break of Vancouver Island and in August in the southern Strait of Georgia, which turned the water turquoise. The reason for this unexpected but harmless event is still under investigation.

The spawning biomass of herring varied along the coast but showed near historic high levels in the Strait of Georgia. While juvenile herring abundance was low in 2016 they were observed to be in good condition. There was an increase in the 2016 anchovy catch. Eulachon stocks continue to show a long-term decline with no single cause identified as responsible.

The timing of the spring bloom in the Strait of Georgia is linked to the survival of herring larvae and is identified using indicators of primary production such as chlorophyll concentration and phytoplankton community composition. 2016 was a typical year with the spring bloom occurring near the end of March.

Conditions in the Strait of Georgia reflected the delayed influence of the warm water conditions in the NE Pacific during 2015, and the 2016 discharge of the Fraser River. Warmer than normal temperatures were observed throughout the entire water column, with the anomaly strongest in the spring and summer, and weaker in the fall. A rapid and early snowmelt introduced large volumes of fresh water during the late spring resulting in negative surface salinity anomalies. Winter precipitation, and higher than normal discharge from the Fraser River, provided good conditions for spawning salmon.

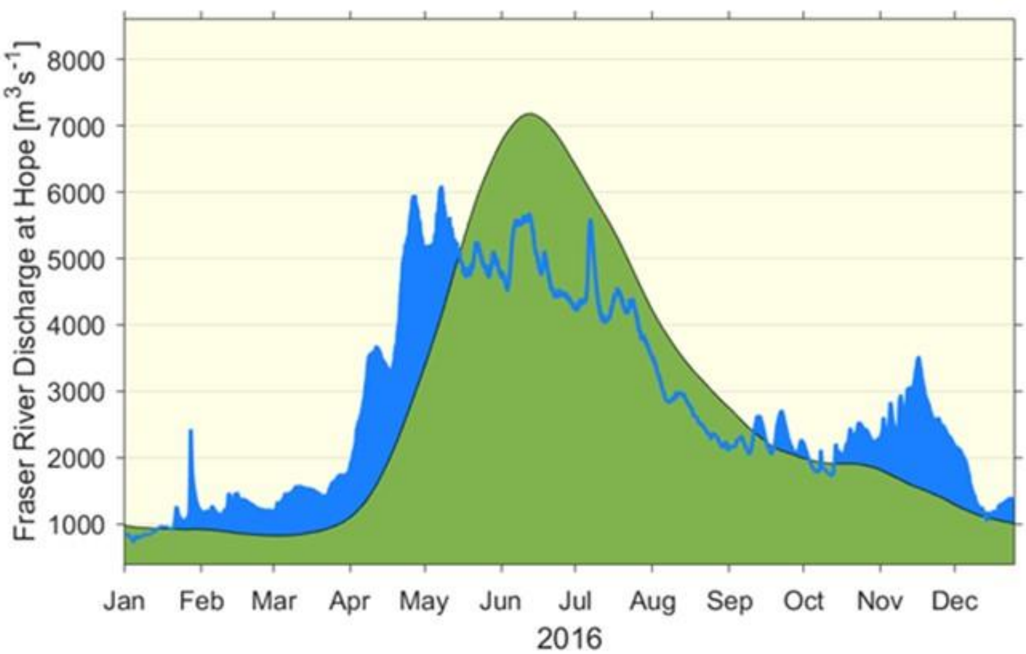

Figure 3-3. Fraser River discharge at Hope B.C.; 2016 (blue), 104 year average (green). Data source: The Water Survey of Canada).

The 2016 aggregate return of Fraser River Sockeye Salmon was the lowest on record, however, not all B.C. stocks exhibited a decline. Notably, returns of Sockeye Salmon stocks on the west coast of Vancouver Island, the Central Coast and the Columbia-Okanagan system exceeded the pre-season forecast and were above the average return levels based on all years of data. The returns in 2016 support the inverse north-south pattern of production.

The warm ocean water over the past several years suggest unfavourable survival conditions for south coast salmon returning in 2017, and summer drought in southern B.C. watersheds in 2015 may reduce salmon fry and smolt production causing lower than normal returns in 2018.

The populations of marine mammals, including humpback whales and sea lions, increased. The number of humpback whales observed in B.C. waters continues to increase and 2016 observations show a trend of these mammals overwintering along the Central Coast. The year-round presence of Humpbacks can be expected to impact their prey species (including Pacific Herring) and nearshore ecosystems.

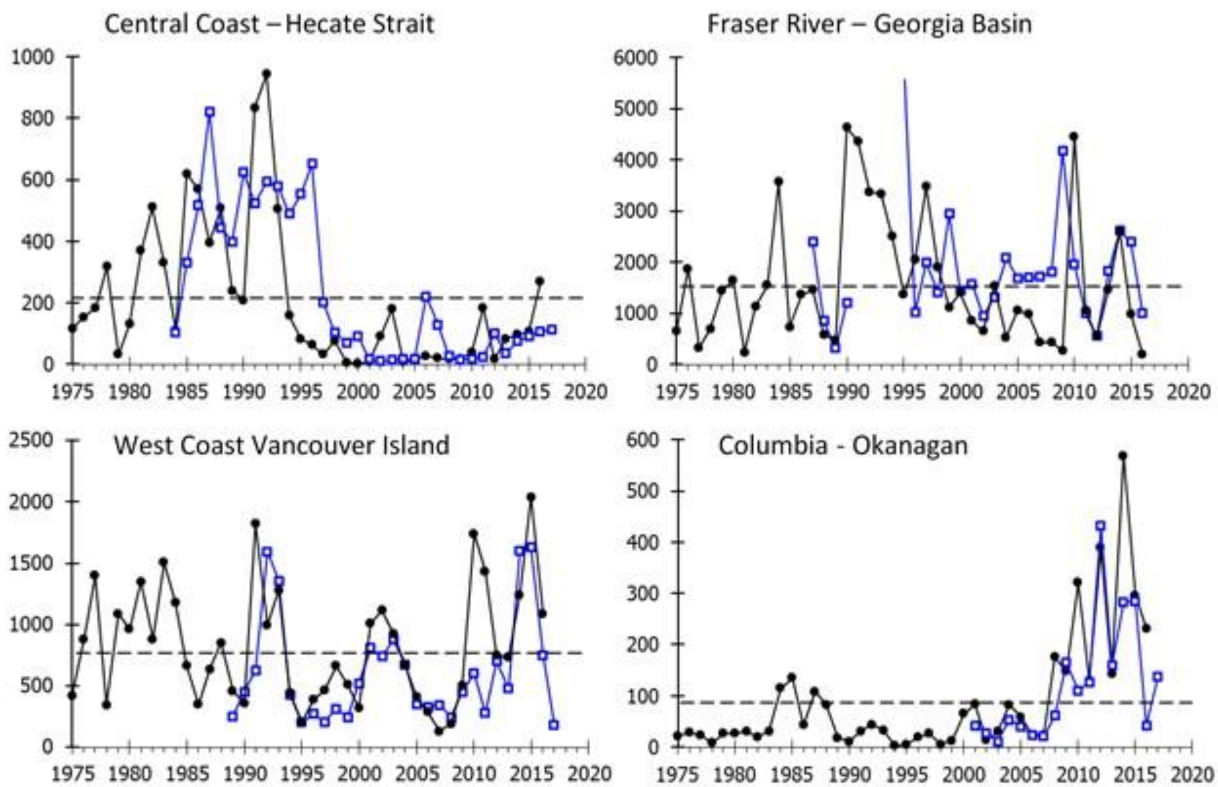

Figure 3-4. The total number of returns (in 1000's) of four indicator stocks for Sockeye Salmon (black line), and the corresponding forecast return (blue line); note varying scale on y-axis. The dashed line represents the all-years average return (Hyatt et al. 2017).

4. ACKNOWLEDMENTS

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

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

5. BRITISH COLUMBIA HYDROCLIMATOLOGICAL CONDITIONS, 2016

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5.1. Highlights

- 2016 marked new daily average and daily minimum high air temperature records for British Columbia.
- Precipitation was above normal almost everywhere but predominantly over the southern half of the province.
- Warm temperatures likely were a consequence of the concluding 2015/2016 El Niño but unusual for the growing La Niña in fall and winter, 2016.

5.2. Introduction

Surface air temperature and precipitation are two essential quantities that determine on-land hydrological conditions including the timing and magnitude of peak stream flows, the timing and severity of low flows and stream temperatures. These in turn impact ocean ecosystems near estuaries and other river discharge points as well as anadromous fish species that spend portions of their life-cycle in freshwater systems. Thus, understanding on-land weather events is critical for understanding conditions in the ocean during a given year and years subsequent to it. This report presents the on-going analysis of air temperature and precipitation data that are then used to investigate how the seasonal temperature and precipitation amounts compare with a long-term record dating back to 1900. Additionally, snow observations are compared with the historical record through the winter and spring months of 2016. These analyses help in understanding how 2016 compares with historical norms.

5.3. Data

Seasonal temperature and precipitation anomalies were calculated from data gathered through a data sharing agreement among several B.C. Ministries, B.C. Hydro and Environment Canada. These data are assembled into a centralized database housed at the Pacific Climate Impacts Consortium (PCIC) at the University of Victoria and made available via the web. Data are gathered from both hourly and daily sources. The database is updated with near real-time data feeds from the Ministry of Transportation and Infrastructure, the Ministry of Forests Lands and Natural Resource Operations Wildfire Management Branch, the Ministry of Environment`s Air Quality Network and Environment and Climate Change Canada. Basic quality control is done by the network operators before the data is made available to PCIC and no further quality control was done for this analysis.

Data processing involves assembling daily observational data, computing monthly and seasonal means and totals, computing anomalies between those values and climate normals and then interpolating the anomalies onto a uniform grid over the province. Anomalies are computed on a seasonal basis using monthly climatologies calculated based on the 1971 – 2000 climate normal period. For temperature, the calculation is a simple difference between the climate normal and the observed seasonal average. For precipitation, anomalies are computed on a relative basis as [*(P-Pnorm)/Pnorm] * 100. P* is the observed total precipitation for the season and *Pnorm* is the long-term average amount. Thus a season in which no precipitation was recorded will receive an anomaly of -100%. A normal precipitation season will have an anomaly of 0% etc.

To compute regional anomalies from station data anomalies at individual stations first are interpolated to a regular 0.5 degree grid using thin-plate splines. This grouping yields an area weighting of the stations within arbitrary regions and also provides support for regions that contain few observational stations by relying on the decorrelation length scales for precipitation and temperature monthly anomalies. For temperature, this length scale often far exceeds spatial gaps in stations. For precipitation, greater uncertainty arises from relatively short decorrelation length scales. Next, the gridded anomalies are sampled within a given region and an average of those anomalies is taken. We use a regional delineation developed by the B.C. Ministry of Environment's River Forecast Centre called the Snow Index Basins. These are divided both climatically and hydrologically to allow analysis of regions with coherent hydrometeorological characteristics. The samples from each region are then ranked among the averages from that region over the period of record spanning from 1900 through 2016. These percentile rankings are displayed in this analysis both as colourized percentiles and numerical rank in the figures.

For seasons, we combine three complete months such as December, January and February for winter and March, April and May for spring etc. Because of this, the annual anomalies computed over the months of 2016 are slightly different than what would be computed combining the individual seasons because, seasonally, December 2015 is included in the analysis of 2016.

Snow survey and automated snow pillow data are gathered by the Ministry of Environment and cooperatively through partner agencies. The data are analyzed by the Ministry of Forest Lands and Natural Resource Operations' River Forecast Centre as part of its tracking of potential flood risks due to spring snowmelt. Measurements of snow water equivalent are made as near to the start of each month as field conditions allow. Anomalies are calculated in a similar manner as those for precipitation except the anomaly is expressed as a ratio relative to the long-term average snow water equivalent. Station anomalies are averaged within regions to arrive at regional values. The data are compiled and summarised as part of the River Forecast Centre's Water Supply and Snow Survey Bulletins, which are issued at regular intervals from January until the threat of snow-melt related flooding has passed, typically June. These reports are available at http://bcrfc.env.gov.bc.ca/bulletins/watersupply/current.htm.

5.4. Seasonal Temperature and Precipitation

5.4.1. Winter

The winter of 2015/16 marked the arrival of a very strong El Niño. Although the relationship between precipitation and El Niño is weak in B.C. tending toward dryer conditions (Trenberth et al. 1998; Dai and Wigley 2000; Diaz et al. 2001; Rodenhuis et al. 2009), the relationship with temperature is strong with El Niño episodes correlated with warm wintertime temperature (Trenberth et al. 1998; Diaz et al. 2001; Rodenhuis et al. 2009; Yang and DelSole 2012). The winter season typified that relationship. Temperature was very warm in the months of January and February with minimum temperatures (Figure 5-1b) being more anomalously warm than daily maximums (Figure 5-1a). The disparity between daily minimum and daily maximum temperature anomalies is a feature that has been recognized globally as increases in minimum temperature have outpaced those for daily maximums although this effect has been less consistently observed globally in recent decades (Easterling et al. 1997; Vose et al. 2005;

Rohde et al. 2013). Moreover, monthly temperature anomalies exceeding five degrees for daily maximum temperatures were observed in February and even warmer anomalies recorded for the daily minima. Compared to the long-term record, these temperature anomalies ranked in the top 20 warmest for daily maximum and top 10 warmest for daily minimum. Correspondingly, precipitation was higher than normal across the southern half of the province (Figure 5-1c) trending toward drier in the northeast.

The temperature and precipitation conditions conspired to yield lower than normal snow amounts in the northern half of the province (Figure 5-1d; courtesy of the Ministry of Environment River Forecast Centre) as well as the west-central portion of the province. In the northeast, the dryness was more extreme with snow accumulation only slightly more than half of normal by the end of February. In the south and especially the south central and southeast, snow accumulation was normal to above normal reflecting the large precipitation totals and, in spite of warm temperatures, conditions were cold enough for snow accumulation.

5.4.2. Spring

Very warm temperatures continued through spring (Figure 5-2 a and b) especially March and April resulting in record monthly and seasonally averaged temperatures peaking for maximum daily temperature in April where anomalies above 5 °C were common province-wide. The warmth lead to a new record for warm average daily minimum temperatures everywhere in B.C. (Figure 5-2 b). There were also record high average daily maximum temperatures across the most of southern and central B.C. (Figure 5-2 a). This was a repeat of the previous year's spring and once again led to early snow melt and higher than normal streamflow accompanied by an early freshet. High streamflows were supported by high precipitation amounts with wetter than normal conditions in the southern half of B.C. and much wetter than normal amounts in the north (Figure 5-2 c). However, individual months reveal dry conditions in April and May in southern and southwestern B.C. respectively.

As was true in 2015, the warm spring of 2016 lead to very low snowpacks by the end of May (Figure 5-2 d; courtesy of the Ministry of Environment River Forecast Centre). The B.C. Ministry of Environment only mapped the snow anomalies into mid-May owing to low snow conditions by June 1st when snow anomaly maps are typically still being issued. Snow melting conditions were observed to be six weeks ahead of typical spring melt seasons. Only the central interior mountains retained a near-normal snowpack by mid-May owing to high accumulation amounts from the preceding winter.

5.4.3. Summer

Conditions in summer continued to be very warm and the mean of daily minimum temperatures dominated the anomalies (Figure 5-3 b). Records were set for warm daily minimums for the season in the northern 2/3^{rds} of the province. Elsewhere, temperatures were much above to above normal trending cooler toward the southeast. Averages of daily maximum temperatures were much less extreme (Figure 5-3 a). The northern 1/3rd of the province was much above normal and temperatures trended toward normal in the southern and southeastern part of the province.

Conditions continued to be very wet. Much above normal precipitation was recorded throughout the interior of B.C. (Figure 5-3 c) with only the far northwest showing below normal precipitation amounts. The overall wet conditions contributed to a moderate fire season in B.C. with the burned area about 2/3^{rds} of the 10 year average and costs at 70 percent of average. This is a stark comparison to the previous two years which were cooler, but much more severe suggesting that the conditions leading to abundant precipitation helped to suppress fire.

5.4.4. Fall

Warm temperatures continued into fall but the foci of the patterns shifted. During the latter months of the year, the southern and southeastern parts of the province were warm. As before, daily minimum temperatures were dramatically warmer than normal with records set throughout the southeast (Figure 5-4 b). Daily maximum temperature was close to normal (Figure 5-4 c). The season was punctuated with a record warm November. Finally, in December, temperatures cooled dramatically (not shown) with the onset of a series of arctic outbreaks which would continue into the 2017. Temperatures over much of the province were below normal although not record breaking.

Precipitation during fall continued to be above normal to record breaking with the wettest conditions in the southern half of the province where records were broken in several regions. This transitioned to a dry December in keeping with the typical dryness of arctic outbreak conditions.

5.5. Data Compared with Historical Trends

The conditions of 2016 were compared with the long term record in the box and whisker plots shown in Figure 5-5. The mean temperature (Figure 5-5 a) showed that for 10 out of 12 months, temperature was above the long term median and for nine of those months, the temperature was above the upper quartile suggesting that temperature was consistently warm through the year. Three of those months exhibited record temperatures for the mean (here the mean was the average of the daily minimum and daily maximum temperatures). For precipitation in the province as a whole, conditions were less extreme in terms of records broken, but consistently wet with 10 of 12 months above the median (Figure 5-5 b). Nine of those months were outside of the upper quartile. The transition to cold and dry conditions was reflected in the December temperature and precipitation box plots with temperature approaching the coldest quartile and precipitation within the driest quartile.

Cast as time series and trends across the entire province, both temperature and precipitation showed significant increases trends through the period of record from 1900 through 2016 (Figure 5-5 a and b). The long-term time series of temperature shows a statistically significant warming of 1.5 °C per century on average ($p<0.05$), which was dominated by increases in average daily minimum temperatures (increased 2.3 °C per century). An increasing precipitation trend was detected but over this time span, is not considered reliable due to low station density in the north in the early part of the 20th century and the short decorrelation length scales for precipitation which make interpolation of sparse data highly uncertain. The trend on the annual averages are statistically significant ($p<0.05$) and may be proceeding at a rate of 18 % per century. This is comparable to the trends found by Zhang et al. (2000) for a period ending in 1998. A more recent study (Mekis and Vincent 2011) revealed larger magnitude precipitation trends at individual stations in southern B.C. and smaller trends in the north which are compatible with the province-wide value reported here. Still, we stress that this number is highly uncertain.

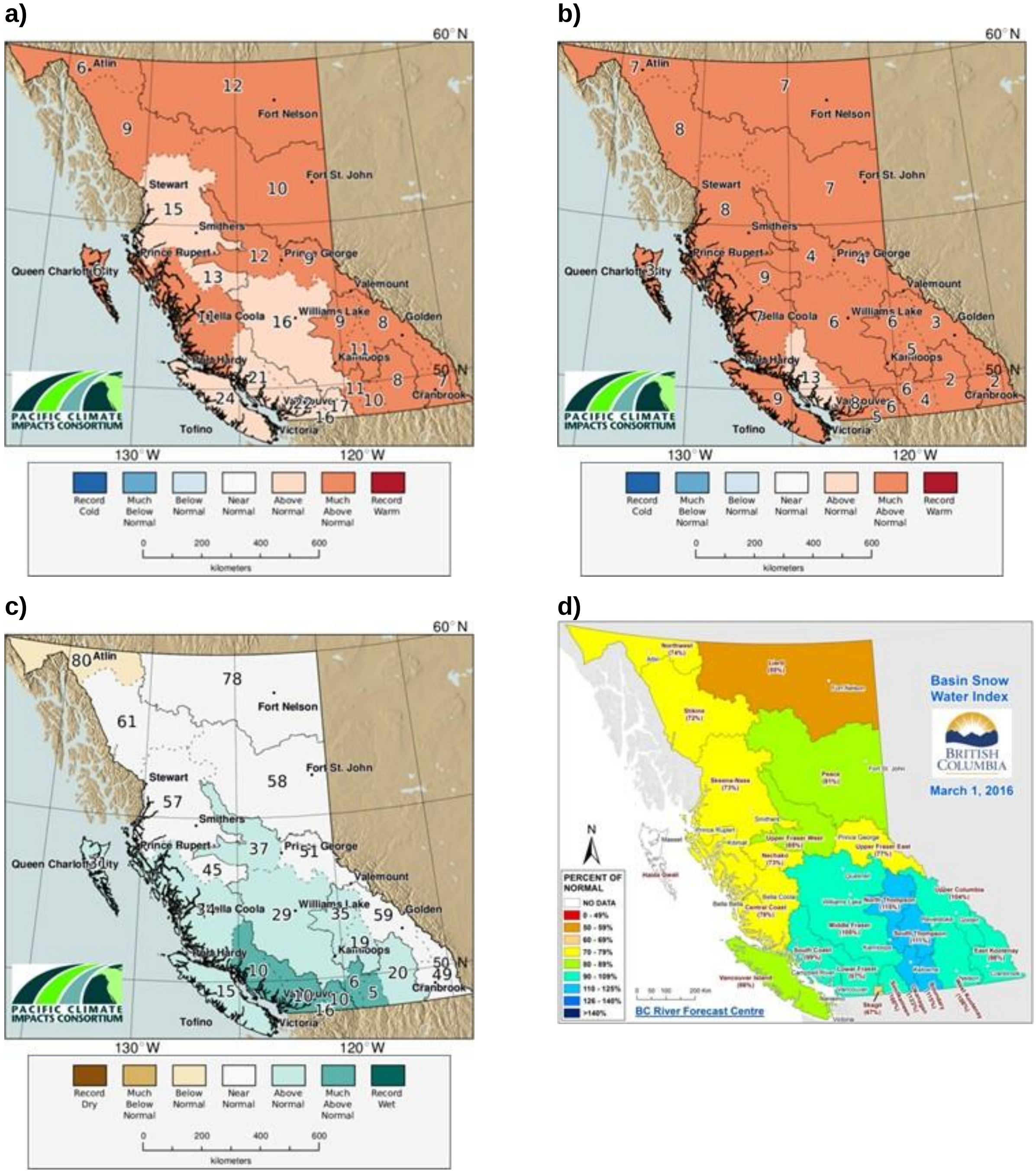


Figure 5-1. Panels (a), (b), and (c) depict winter (December 2015, January 2016 and February 2016) temperature and precipitation anomalies colour coded by ranking among the 117 years of data from 1900 through 2016. Minimum temperature is shown in panel (a), maximum temperature in panel (b), and precipitation in panel (c). Colour classification is such that Near Normal corresponds to the 33rd to 66th percentiles, Above Normal to the 66th through 90th percentiles, Much Above Normal to 90th to all but the record year. The final category is for record which is the 99.2 percentile. Analogous categories for the below normal values are 33rd to 10th, 10th to 0.8 and record for Below Normal, Much Below Normal and Record respectively. Numbers indicate ranking relative to warmest or wettest. Regional divisions are the snow index basins used by the B.C. Ministry of Environment's River Forecast Centre. Panel (d) depicts snow water equivalent as a percentage of normal and was provided by the B.C. MoE River Forecast Centre.

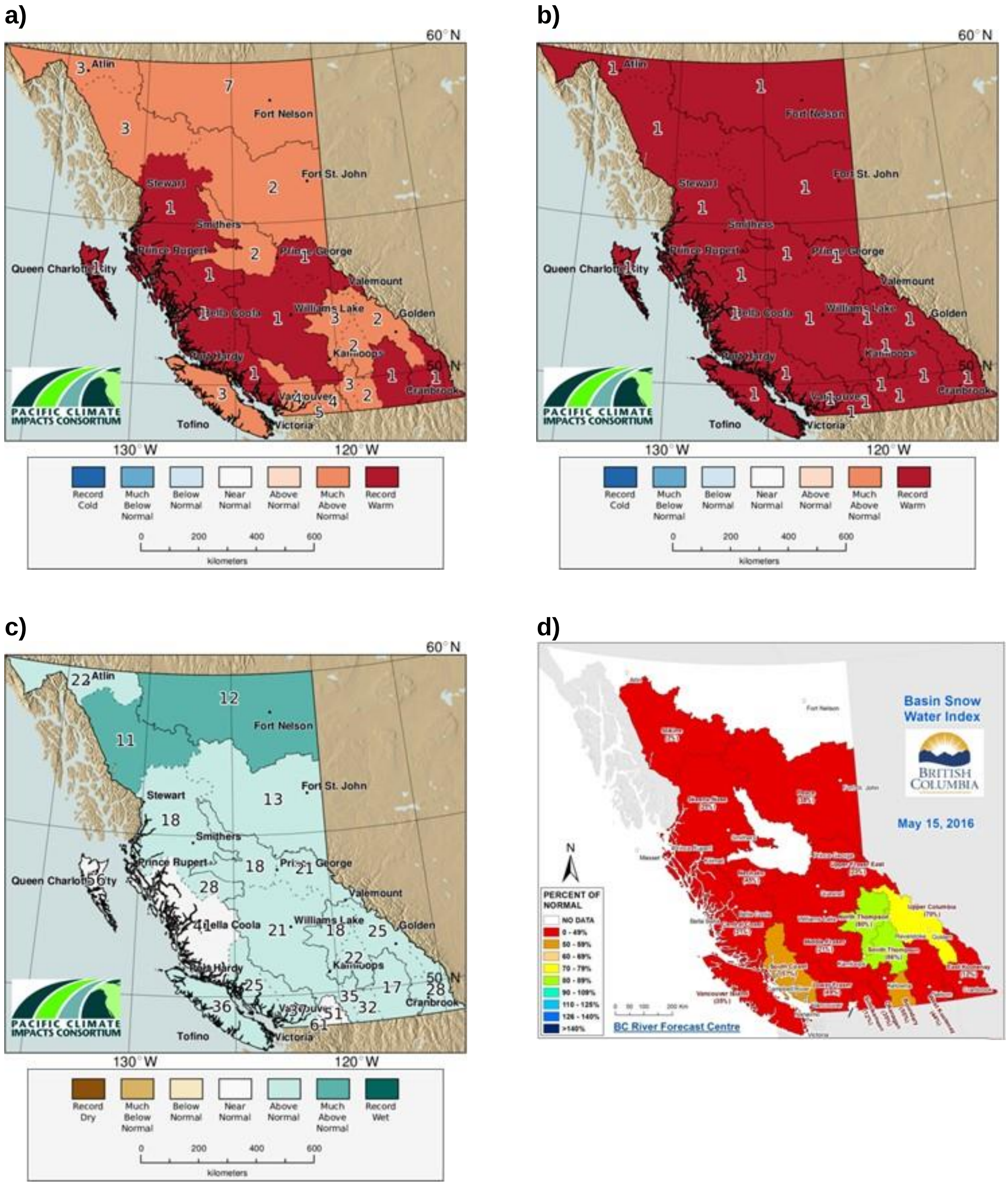
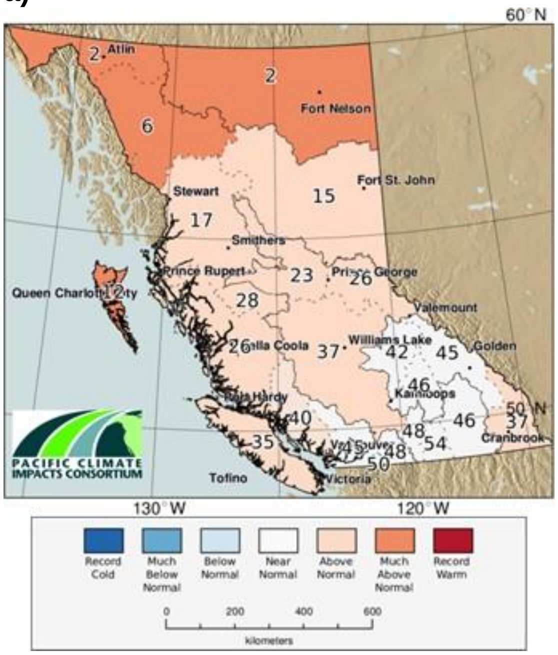
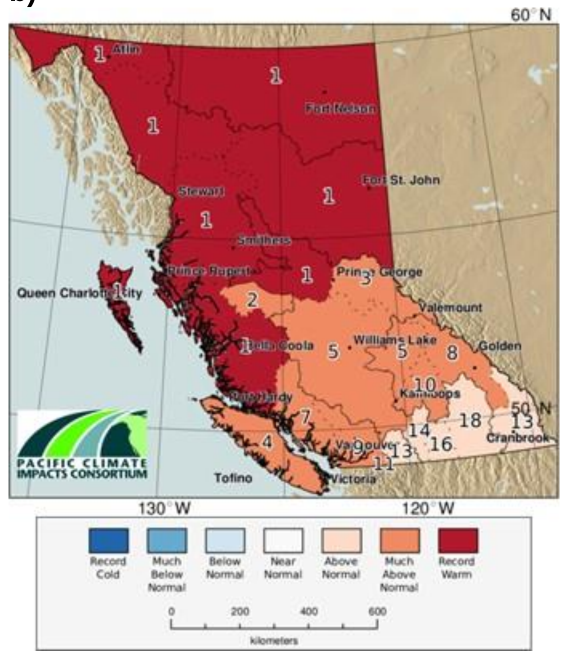


Figure 5-2. Panels (a), (b), and (c) as in Figure 5-1 but depicting spring (March, April and May 2016) temperature and precipitation anomalies colorized by ranking among the 117 years of data from 1900 through 2016. Panel (d) as in Figure 5-1 but for 15 May, 2016.

a)



b)



c)

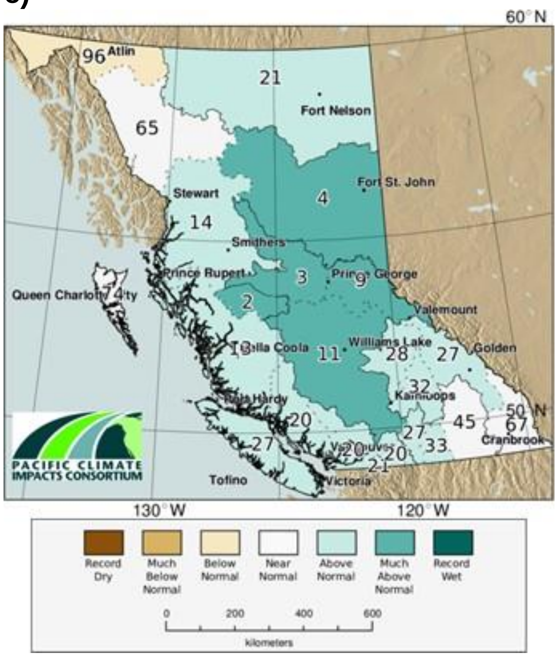
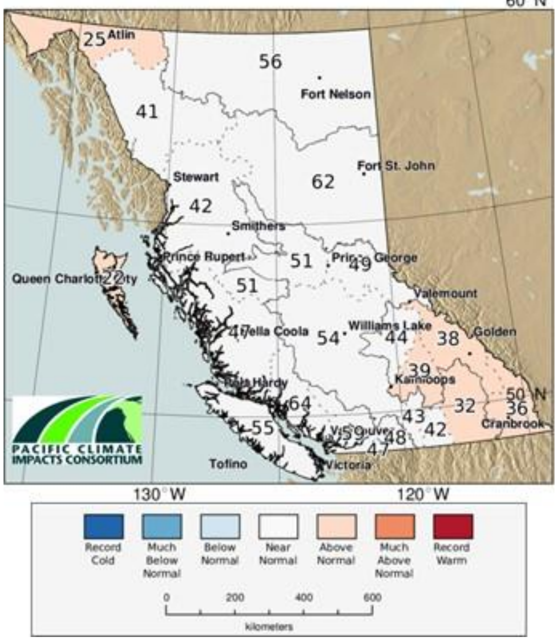
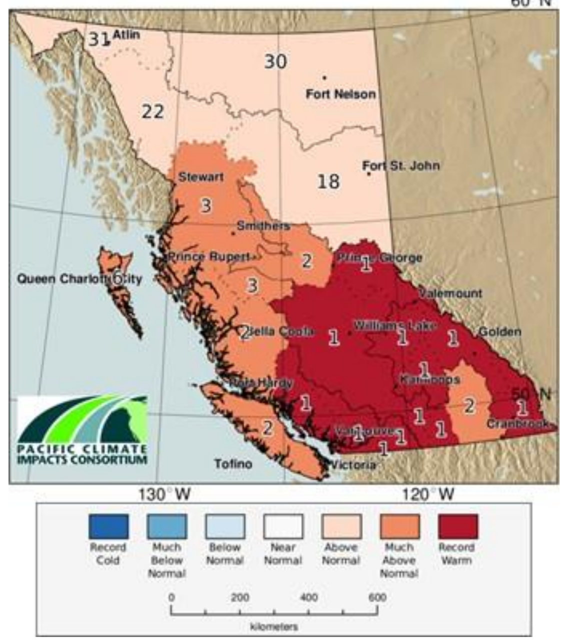


Figure 5-3. Panels (a), (b), and (c) as in Figure 5-1 but depicting summer (June, July and August 2016) temperature and precipitation anomalies colorized by ranking among the 117 years of data from 1900 through 2016.

a)



c)



c)

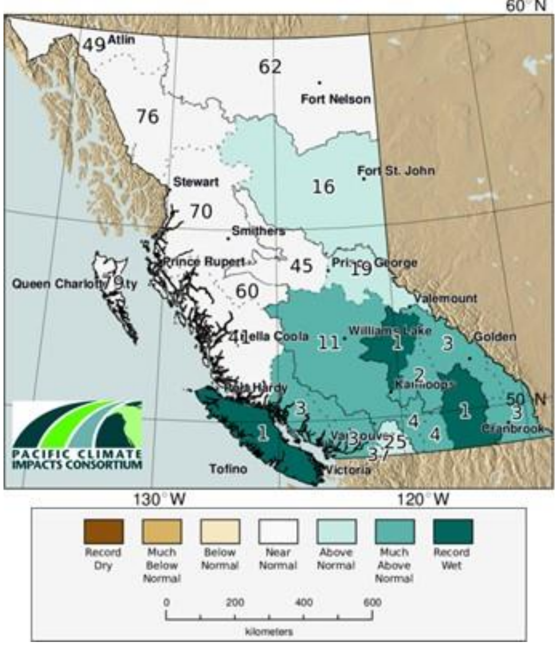


Figure 5-4. Panels (a), (b), and (c) as in Figure 5-1 but depicting fall (September, October and November 2016) temperature and precipitation anomalies colorized by ranking among the 117 years of data from 1900 through 2016.

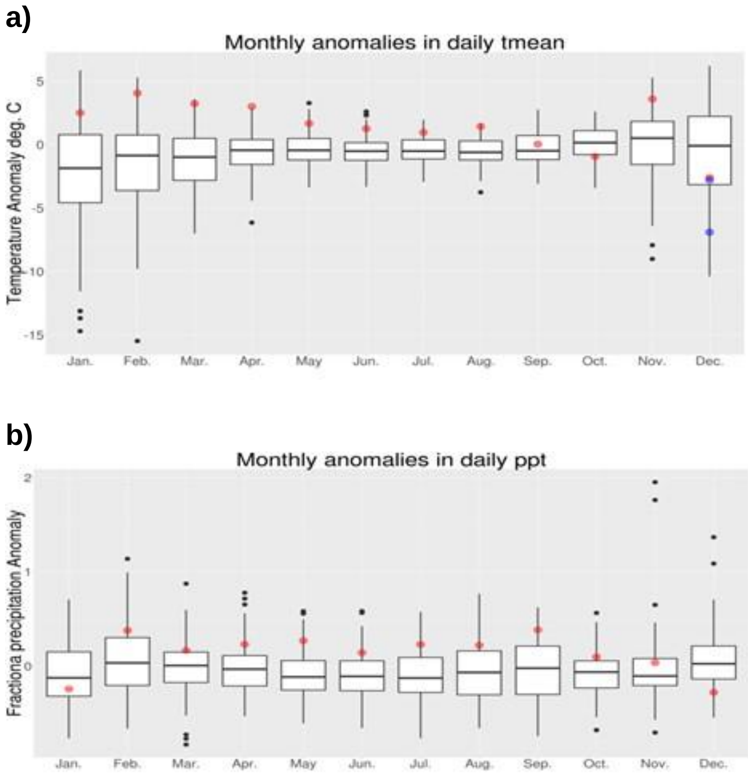


Figure 5-5. Box-and-whisker plots showing the historical distribution of monthly temperature a) and precipitation b). The heavy black line represents the median of the years from 1900 through 2016 for a given month. The white box indicates the upper and lower quartiles of the sample. The whiskers indicate the sample range with outliers shown as black points. Red points indicate where 2016 fell in that distribution. The blue points in figure a) indicate the December temperatures that would have been needed to prevent the year from breaking an annual temperature record (warmest blue point) or from taking the second place spot (coldest blue point). The plotted red point shows that it was just warm enough for the year to set a new mean temperature record for B.C. as a whole.

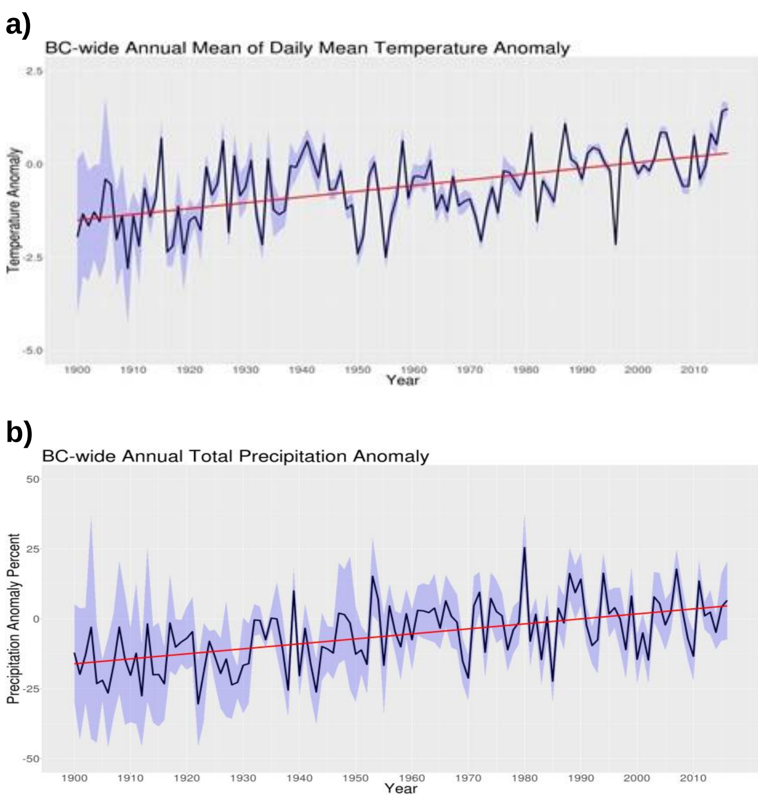


Figure 5-6. Timeseries of the mean annual temperature anomaly for British Columbia a) and the mean annual precipitation anomaly b). Trends in the data calculated using the Sen's slope method are shown in red. Blue shading indicates the uncertainty range (two times standard error) in the individual annual means/totals.

5.6. Conclusion

Temperature, precipitation and winter-spring 2015/2016 snow conditions have been analyzed for the province of B.C. on a seasonal basis throughout 2016. Results showed record breaking warmth in terms of annual average of mean daily temperature and of minimum daily temperature. Precipitation was above normal for most parts of the province. An early onset to spring resulted in rapid diminishment of the winter's snowpack and consequent high spring streamflow. Temperature and precipitation have increased over the last century. Warm temperatures early in the year were likely a consequence of the on-going El Niño while continued warmth into the fall was atypical for the La Niña conditions that developed during summer. However, the cold December was likely a return to typical La Niña conditions.

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

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6.1. Highlights

- Based on the timing of upwelling-favourable winds, the 2016 Spring Transition was average to earlier than average relative to the historical (1980 – 2016) average. The magnitude of the upwelling-favourable winds during the summer of 2016 was average to above-average.
- The timing and magnitude of the upwelling-favourable winds suggest average to above-average upwelling-based productivity along the southwest coast of Canada in 2016.
- The winters of 2015/16 and 2016/17 were characterized by stronger than average downwelling-favourable winds along the west coast of North America as a result of a stronger Aleutian Low caused by more intense/frequent winter storms in the Gulf of Alaska.

6.2. Upwelling Timing: The Spring Transition Index

6.2.1. The time series

The shift in spring from predominantly downwelling-favourable poleward winds in winter to predominantly upwelling-favourable equatorward winds in summer is referred to as the Spring Transition. The reverse process in fall is called the Fall Transition. The alongshore winds drive a seasonal cycle in the alongshore surface currents over the continental slope, from poleward in winter to equatorward in summer. The Spring and Fall Transitions for the Pacific coast are derived using along-shore wind stress time series from NCEP/NCAR Reanalysis-1 (Kistler et al. 2001), along-shore wind velocity from the Environment Canada meteorological buoy 46206, and the along-shore current velocity at 35 and 100 m depth at mooring A1 and at 30 m depth as modelled by the Princeton Ocean Model (POM (Figure 6-1; Folkes et al. 2017, Thomson et al. 2013).

The onset of seasonal upwelling that accompanies the spring transition varies from year to year (Thomson et al. 2014). In years such as 2005 and 2010, when the spring transition was relatively late, marine coastal productivity across trophic levels 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 (e.g. see Chandler et al. 2015, reports on outer British Columbia).

6.2.2. Status, implications, and recent trends

In 2016, the Spring Transition timing was average to early (Figure 6-1, see also Hunt et al. 2017), suggesting that upwelling-based spring productivity during the 2016 summer should have been average to above-average. Since 2008, the Spring Transition timing has been average to early, which has favoured average to above-average summer productivity.

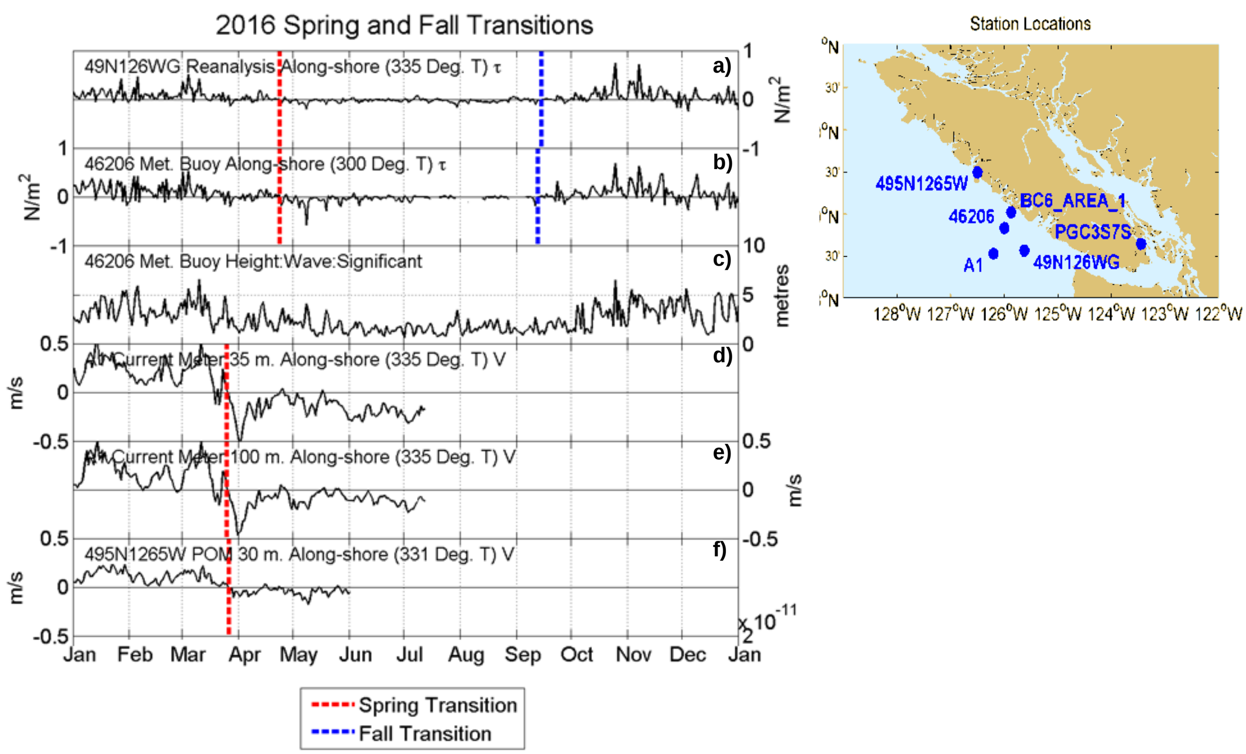

Figure 6-1. Left: Time series depicting the Spring and Fall Transitions off the west coast of Vancouver Island in 2016: along-shore wind stress at (a) Reanalysis-1 grid point 49N126W and (b) meteorological buoy 46206, (c) significant wave height at 46206, along-shore current velocity at (d) 35 m and 100 m at mooring A1 and as modelled using the (f) Princeton Ocean Model (POM) at 30 m (Folkes et al. 2017; Thomson et al. 2013). Positive flow is poleward (downwelling-favourable) and negative flow is equatorward (upwelling-favourable). Vertical dashed lines show derived transition times using a cumulative sum approach (e.g. Foreman et al. 2011). Right: Locations of the measurements.

6.3. Upwelling Magnitude: The Upwelling Index

6.3.1. The time series

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. To gauge low-frequency variability in coastal productivity, we have summed upwelling-favourable-only wind stresses by month along the west coast of North America from 45°-60° N latitude (Figure 6-2) using the NCEP/NCAR Reanalysis-1 analyses (Kistler et al. 2001).

6.3.2. Status, implications, and recent trends

An examination of the upwelling index time series over recent years (Figure 6-2) indicates that upwelling-favourable wind stress was above average in 2016, with positive anomalies occurring through most of the summer. As a consequence, conditions were favourable for large-scale upwelling-based productivity to have been above average over the summer of 2016. Figure 6-2 also reveals that over the last seven years, stronger-than-average upwelling-favourable winds occurred at some time in each year between 2010 and 2016, except 2014, which was generally below average. Above-average upwelling-based summer productivity has been favoured over most years since 2010.

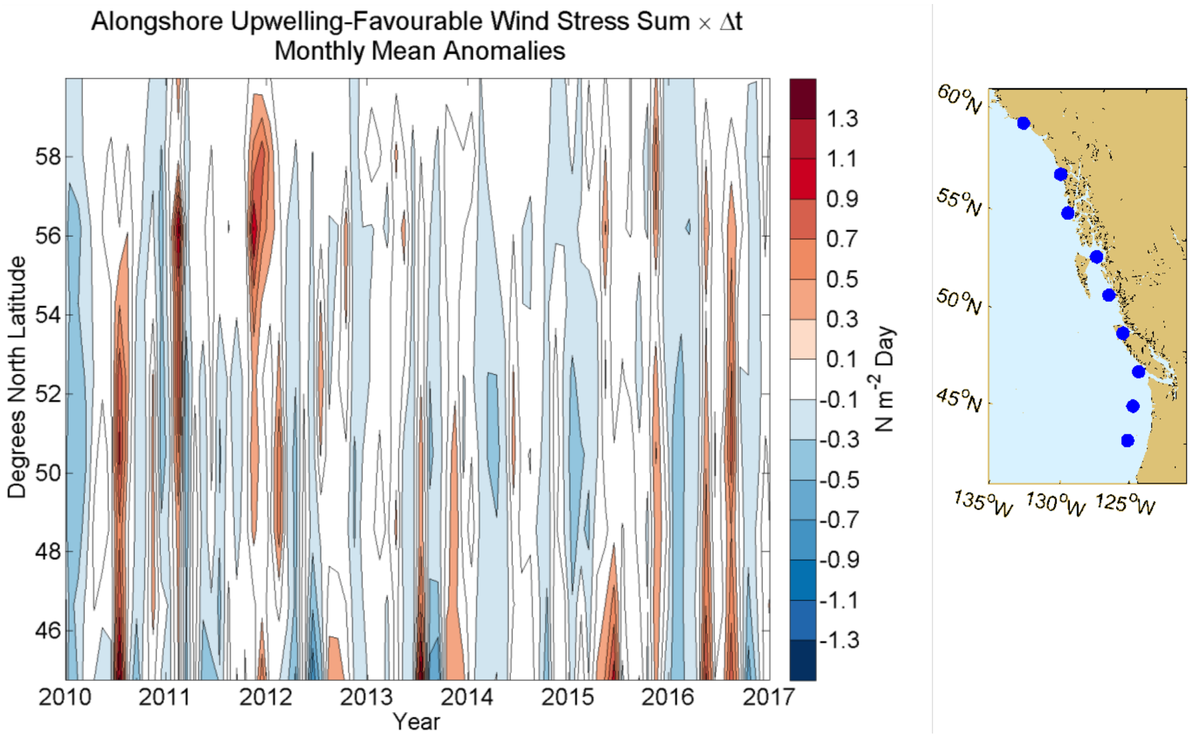

Figure 6-2. Recent (2010 to 2016) monthly mean anomalies of monthly sums of alongshore upwelling-favourable (equatorward) wind stress from the NCEP/NCAR Reanalysis-1 coastal surface wind stress grid locations, 45-60° N (grid locations on map).

6.4. The Spring Transition and Upwelling Indices Together

Upwelling conditions are summarized by combining the Spring Transition Timing and Upwelling Indices into a simple “stoplight” graphical format (Figure 6-3). Favourable coastal upwelling conditions are in green and unfavourable conditions in red. Annual upwelling timing and magnitude values appear in three equal terciles: early timing/high magnitude years are green; late timing/low magnitude years are red; and the middle third of values for both are yellow. The 2016 upwelling timing was in the early one third of annual values and summer upwelling magnitude was in the middle third of annual values. Consequently, coastal upwelling-favourable conditions for productivity were average to above-average in 2016. This supports Gower and King’s (2017) observation that the timing of the 2016 spring bloom off the west coast of

Vancouver Island was about average. Figure 6-3 also shows that in 2005, a year noted for poor productivity (DFO 2006), upwelling timing and magnitude were both in the red category (late and small, respectively).

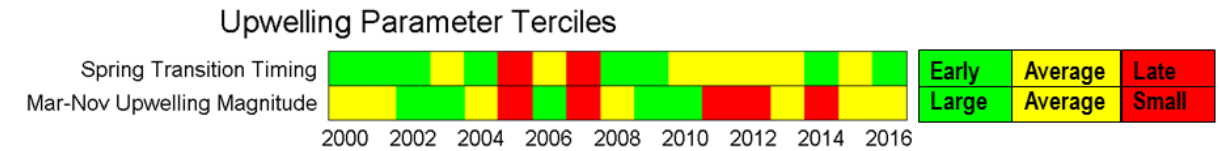

Figure 6-3. Stoplight diagram depicting equal terciles of both the Spring Transition Timing Index and the Upwelling Magnitude Index for 49° N, 126° W.

6.5. Downwelling Magnitude: The Downwelling Index

6.5.1. The time series

The effect of downwelling-favourable winds is obtained by considering only the poleward component of the alongshore wind stress.

As indicated by Figure 6-4, the downwelling index is highest during winter when storms are strongest and most frequent. Variations in the downwelling index are due to variability in the Aleutian Low arising from a combination of east-west shifts of the centre of the Low and variations in atmospheric pressure intensity. An eastward shift and/or intensification of the Aleutian Low leads to stronger than average downwelling (typical during El Niño), while a westward shift and/or weaker Aleutian Low leads to weaker than average downwelling.

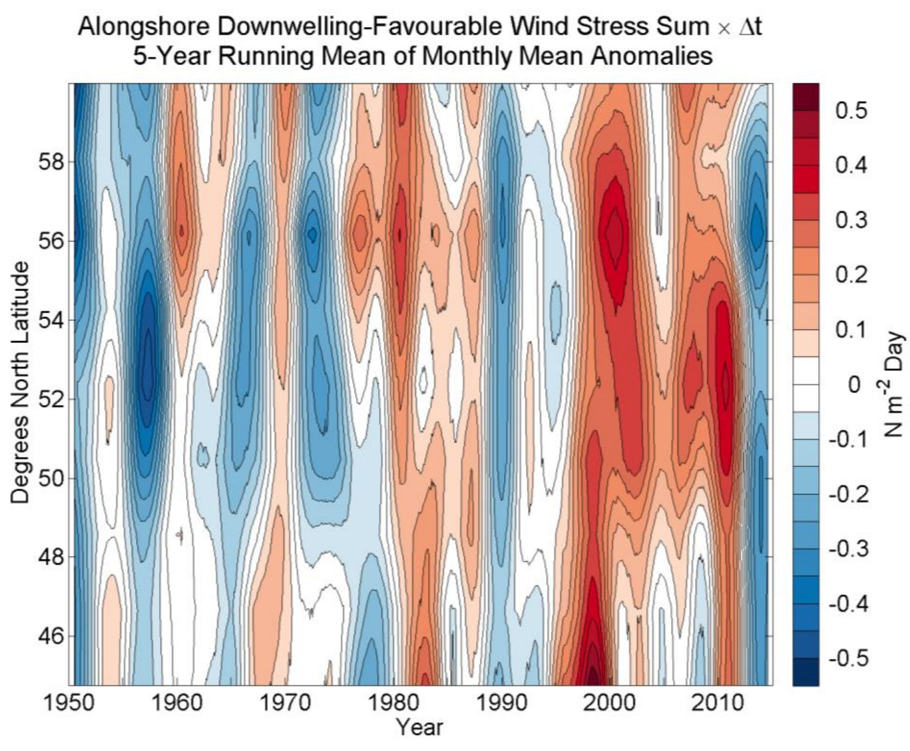

Figure 6-4. Five-year running means of monthly mean anomalies of monthly sums of alongshore downwelling-favourable (poleward) wind stress at coastal grid points from 45-60° N (grid locations on map in Figure 6-2.

6.5.2. Status, implications, and recent trends

An examination of the last seven years of the unfiltered downwelling index time series (Figure 6-5) shows wintertime downwelling-favourable wind stress anomalies were positive in the winters of early and late 2016. (See also Newton 2017.) This indicates enhanced downward displacement of near-surface ocean properties along the coast over these periods as a result of a stronger than average Aleutian Low, due to more intense and/or more frequent storms rather than a shift in storm trajectories.

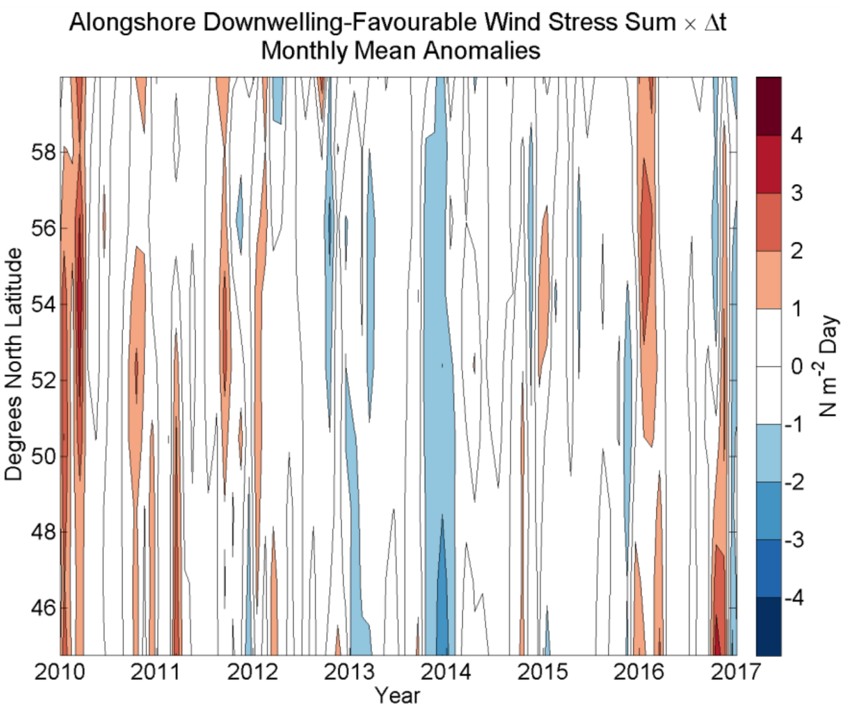

Figure 6-5. Recent (2010 to 2016) non-filtered monthly mean anomalies of monthly sums of alongshore downwelling-favourable (poleward) wind stress at coastal grid points from 45-60° N.

Figure 6-5 also shows that over recent years, wintertime downwelling-favourable wind stress anomalies were stronger than average through the winters of 2009/10 through 2011/12. In 2009/10, this was due to both an eastward shift of the Aleutian Low and associated storm tracks, as well as a more intense Aleutian Low. The winters of 2012/13 and 2013/14 experienced much weaker than average downwelling-favourable winds due to a much weaker Aleutian Low. The latter conditions were coupled with weaker surface wind mixing and led to the development and persistence of the large warm anomaly in the Northeast Pacific (Ross, 2016; Bond et al. 2015), and influenced coastal upwelling-based productivity (Chandler et al. 2015). Downwelling conditions were average to stronger-than-average over the 2014/15 winter (see also Dewey 2015).

6.6. Acknowledgements

Princeton Ocean Model (POM) current velocities were provided by Scott Tinis. NCEP/NCAR Reanalysis-1 wind stress and sea-level pressure, as well as NOAA Optimum Interpolation (OI) Sea Surface Temperature (SST) V2 provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/.

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7. SEA LEVEL IN BRITISH COLUMBIA, 1910 TO 2016

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7.1. Highlights

- For the 3rd year in a row the annual mean water levels at Victoria, Tofino and Prince Rupert were above the trend line.
- Removal of the land uplift from Tofino annual mean water levels brings that trend in line with the other two locations.
- Particularly stormy weather in March and November 2016 resulted in record monthly means for both months.

7.2. Summary

The Canadian Hydrographic Service monitors sea levels along the B.C. coast. The records show annual deviations from a long-term average at three ports (Figure 7-1). Both Tofino and Victoria have records that began in 1910, while the record at Prince Rupert began in 1912.

The average sea level in 2016 was above the century-long trend for all three locations for the third year in a row. The higher levels were the result of El Nino and record high monthly means in March, October and November.

The linear trend at each port is (in cm/century):

Prince Rupert	+11
Victoria	+7
Tofino	-13

Tectonic motion is lifting the land at Tofino faster than sea level is rising, so that local sea level is dropping at an average rate of 13 cm per 100 years. Removing the tectonic motion from the sea level values using a 2.34 mm annual uplift (James et al. 2014; Thomas James and Lisa Nykolaishen, Natural Resources Canada, pers. comm.) using measurements at Ucluelet as a proxy for Tofino) results in a linear trend at Tofino of 13.5 cm per 100 years (Figure 7-2).

The next Cascadia Subduction Zone earthquake could drop the land at Tofino and land along the nearby west side of Vancouver Island by as much

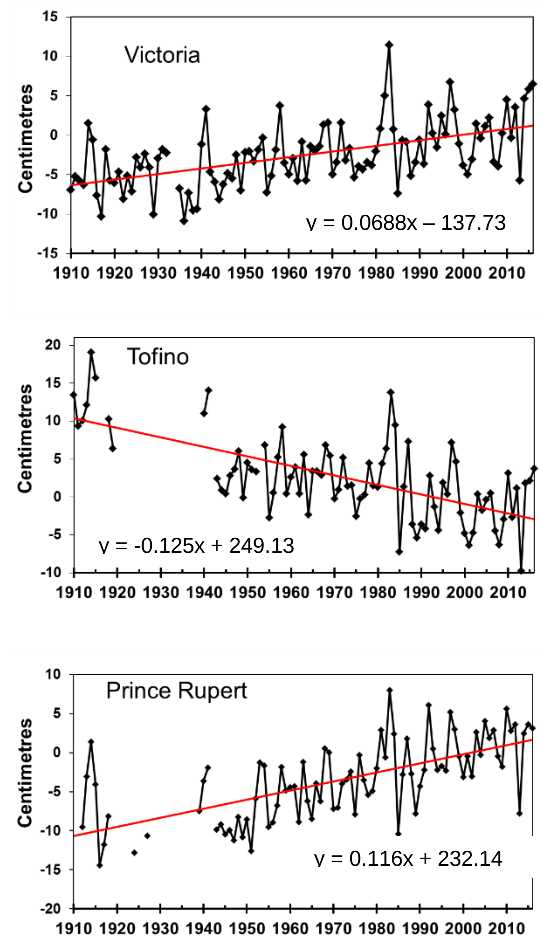

Figure 7-1. Annual-average sea level anomalies at three British Columbia ports. Reference years are 1981 to 2010. Average linear trends are plotted as red lines.

as one-half to two metres, and also send a major tsunami to the B.C. coast (Claque and Bobrowshy 1999).

Global sea levels rose by 17± 5 cm in the 20th century (Church et al. 2011). The Intergovernmental Panel on Climate Change (IPCC 2014) predicts sea level to rise from 26 to 55 cm to 45 to 82 cm toward the end of the 21st century, depending on levels of mitigation of CO_2 emissions, but recent observations of ice melt in Greenland and Antarctica suggest these projections might be too low. Therefore, we can expect to observe greater rates of sea level rise in British Columbia in the future than we saw in the 20th century.

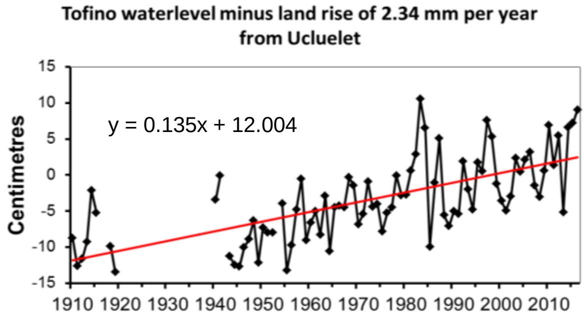

Figure 7-2. Annual-average sea level anomalies at Tofino after a tectonic uplift of 2.34 mm per year is removed. Reference years are 1981 to 2010. Average linear trend is plotted as a red line.

7.3. References

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8. LA NIÑA, THE BLOB AND ANOTHER WARMEST YEAR

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8.1. Highlights

- 2016 was the warmest year on record globally and sea surface temperatures were 1-2°C warmer than average throughout the Northeast Pacific.
- Temperature anomalies – perhaps related to the recent marine heatwave (also known as the Blob) – are still present in the Northeast Pacific:
  - Strong (2-3 °C) sea surface temperature anomalies in Aug-Oct in the NEP
  - Deep temperature anomalies (over 3 standard deviations above the mean) at Station Papa below 100 m
- The relatively weak 2016/17 La Niña has ended and warm conditions are suggested by ALPI, PDO, NPGO indices, thus, although we had a cool winter, we should expect another warm (but not record breaking) year in 2017.

8.2. Summary

Based on NOAA land and sea surface data dating back to the 1880's, 2016 was the warmest year on record both globally and sea surface temperatures were much warmer than average in the Northeast Pacific (Figure 8-1a). Globally, this is consistent with the recent trend, wherein the ten warmest years are nearly all in the last decade. In ranked order, the warmest years are 2016, 2015, 2014, 2010, 2013, 2005, 2009, 1998, 2012, 2003/2006/2007 (tie). In the Northeast Pacific, temperatures were 1-2 °C above normal (Figure 8-1b).

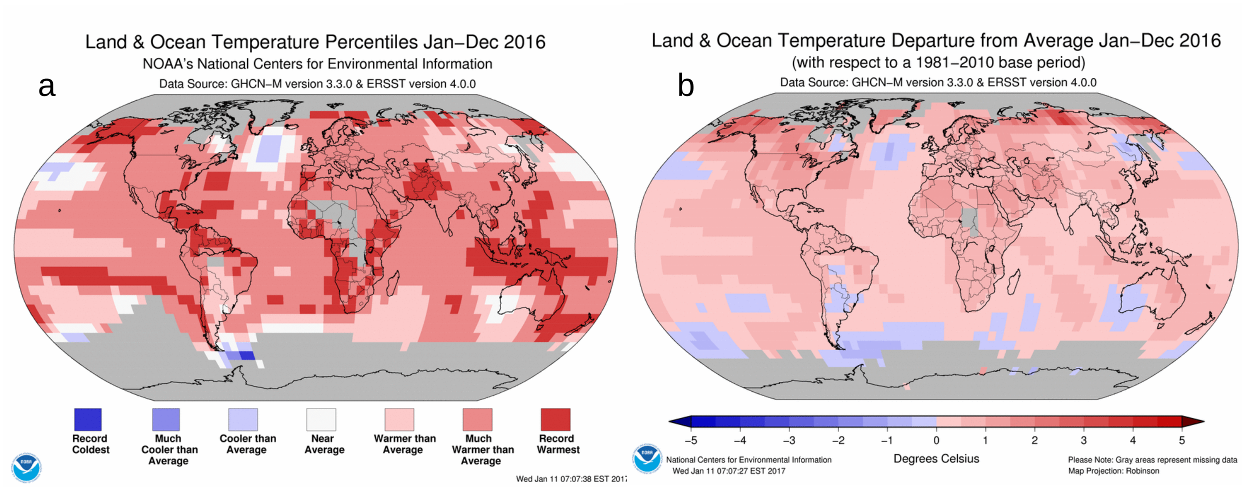

Figure 8-1. Map of the globe showing surface temperature percentiles (panel a) and anomalies (panel b) in the year 2016. ***Panel a:*** *Colours indicate percentiles, with "much warmer/cooler than average" indicating the top and bottom 10%. Source: https://www.ncdc.noaa.gov/sotc/service/global/map-percentile-mntp/201601-201612.gif.* ***Panel b:*** *Colour bar shows the magnitude of the temperature anomaly scale, with warm colours for relatively warm regions and cool colours for relatively cool regions. Source: https://www.ncdc.noaa.gov/sotc/service/global/map-blended-mntp/201601-201612.gif.* ***Both panels****: Grey areas represent missing data.*

The sea surface temperatures in the Northern Pacific throughout 2016 (Figure 8-2) show the transition from a strong El Niño to a moderate La Niña along the equator. In winter (Jan-Feb-Mar) and, particularly, spring (Apr-May-Jun) the distribution of surface temperatures resembled the positive phase of the Pacific Decadal Oscillation (PDO; see Section 8.3). However, in the late summer, early autumn (strongest in September, so appears best in the July-Aug-Sep panel), there was a strong temperature anomaly in the Northeast Pacific, similar in location and extent to the marine heat wave (also known as the Blob) observed in 2013-15 (Crawford 2015, Freeland 2015).

Whether this late summer sea surface temperature anomaly is related to the heat wave of recent years is uncertain. The record of temperature anomalies at Station Papa (based on the interpolation of Argo float data onto the location of Station Papa; Figure 8-3), shows that a strong warm anomaly is still apparent at depth. Over the course of 2015, the depth of the maximum temperature anomaly increased. During 2016, it has persisted and is still quite strong at about 150 m below the surface. It's possible that end of summer mixing connected this deep temperature anomaly to the surface, but also that the September 2016 sea surface temperature anomaly was a result of delayed late summer mixing. Note that while the deeper anomaly is further away from the mean (over 4 standard deviations, rather than the earlier/shallower 3; Figure 8-3), this is because the variability is smaller in the 100-200 m depth range, not because the deep temperature anomaly is larger in absolute value.

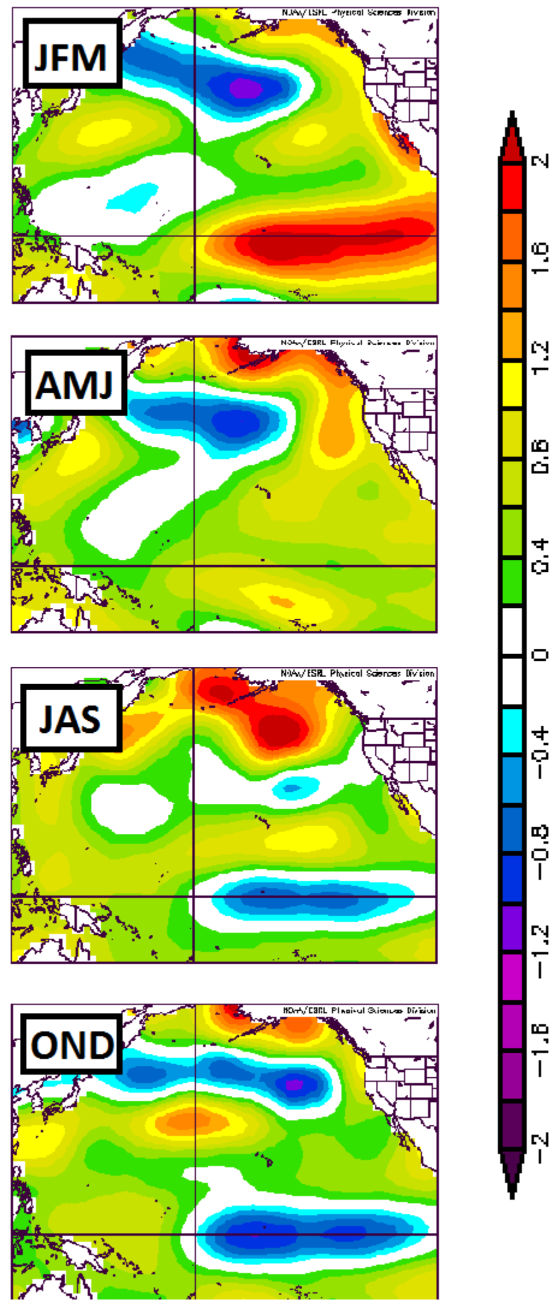

Figure 8-2. Seasonal maps of temperature anomalies in the Pacific Ocean for 2016. The colour bar on the right, showing the temperature anomaly in ºC, applies to all panels. Source: NOAA Extended SST v4 http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl.

After a period of stronger than usual winter stratification in the winters of 2013/14, 2014/15 (Freeland 2015), and 2015/16 (caused by reduced mixing due to warmer surface waters), the winter stratification returned to normal in the winter of 2016/17. The history of the 1025.7 kg/m^3 isopycnal (highlighted with a thick black line in Figure 8-4) illustrates this nicely. It remained very deep throughout the 2013-2015 marine heat wave, deeper even than during the 2003-2005 warm period, and shoaled in the winter of 2015/16 to levels last experienced during 2003-2005. In the 2016/17 winter, it appears to be reaching the depths it typically reached in 2007-2010, suggesting that winter mixing has returned to normal. Return to normal winter mixing suggests that nutrient supply from deep waters should return to normal after the lower nutrient conditions of 2015, due to the sea surface temperature anomaly (Freeland 2015).

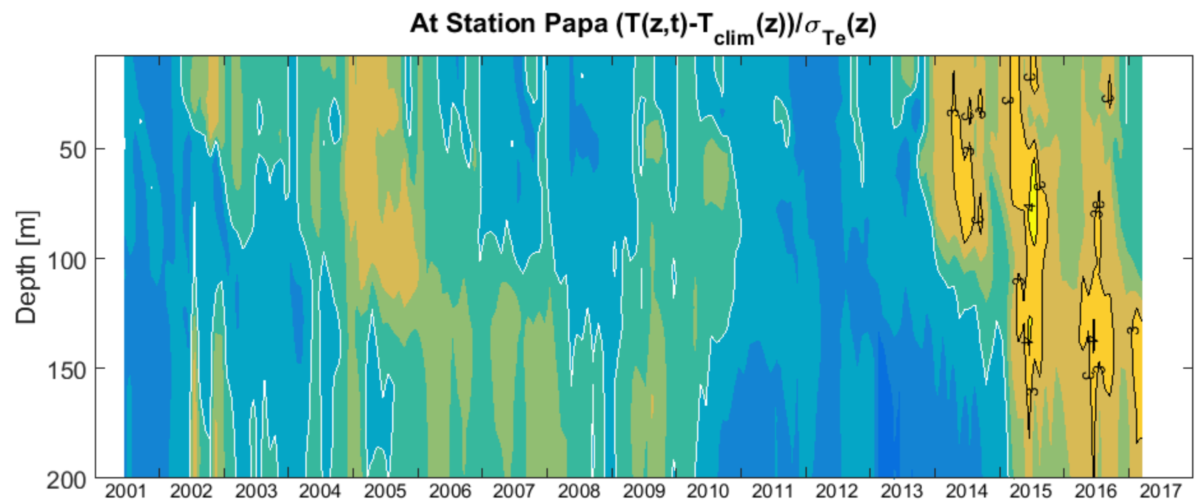

Figure 8-3. False colour plot of temperature anomalies relative to the 2001-2012 seasonally-corrected mean and standard deviation, as observed by Argo floats near Station Papa (P26: 50º N, 145 º W).The cool colours indicate cooler than average temperatures and warm colours indicate warmer that average temperatures. Dark colours indicate anomalies large compared with the 2001-2012 standard deviations. The black lines highlight regions with anomalies that are 3 and 4 standard deviations above the mean.

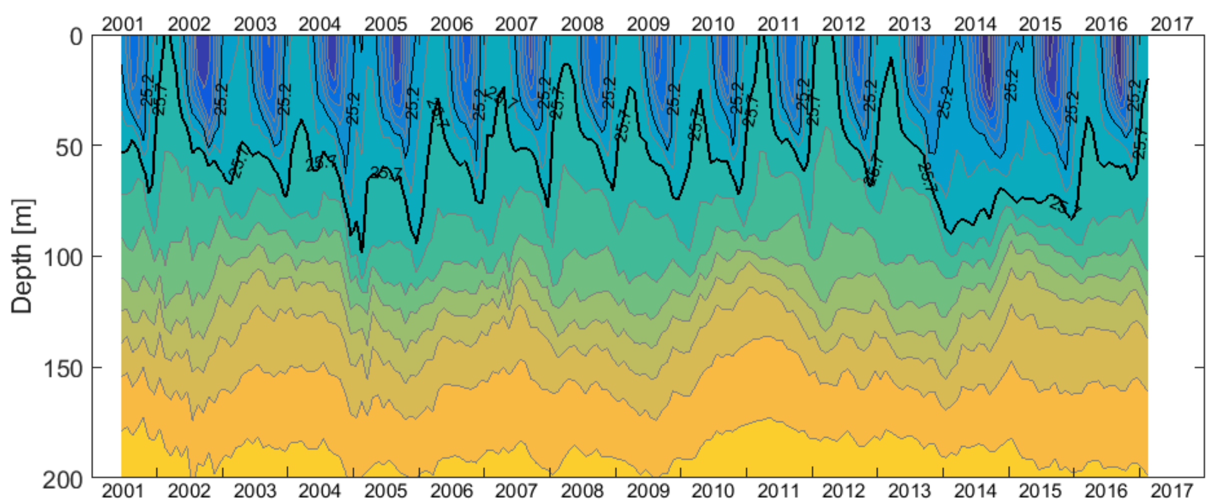

Figure 8-4. Coloured contour plot of density as observed by Argo floats near Station Papa (P26: 50º N, 145 º W).The colours indicate density (yellow is denser and blue lighter). The black lines highlight the r=1025.2 kg/m³ (thin) and 1025.7 kg/ m³ (thick) isopycnals.

Looking back to the sea surface temperature plots the most striking change that occurred throughout 2016 was the switch from positive (Figure 8-2, JFM) to negative (Figure 8-2, OND) sea surface temperature anomalies along the equator, indicating a switch from a strong El Niño (present Nov 2014-Apr 2016) to a moderate La Niña. La Niña generally leads to cooler than average winters in western North America. It is represented by the Oceanic Niño Index (ONI; Figure 8-5). However, the ONI is the only index that suggests the Northeast Pacific Ocean is currently in a cool period. Most of the other climate indices indicate a warm period: positive ALPI and PDO and negative NPGO. SOI is neutral (negative would indicate a warm period). As noted previously (Crawford 2015), the recent warm period follows a relatively long cool period (2007 to 2013, seen best in the PDO, NPGO and SOI indices).

8.3. Climate Indices

Aleutian Low Pressure Index (ALPI) measures the relative intensity of the Aleutian Low pressure system of the north Pacific (December through March). It is calculated as the mean area (in km²) that has sea level pressure less than or equal to 100.5 kPa and is expressed as an anomaly from the 1950-1997 mean (Surry and King 2015). A positive index value reflects a relatively strong, or intense, Aleutian Low. There is no value for 2016 yet. ALPI is provided by DFO Pacific (PBS) and is available from: http://www.pac.dfo-mpo.gc.ca/science/species-especes/climatology-ie/cori-irco/alpi/index-eng.html.

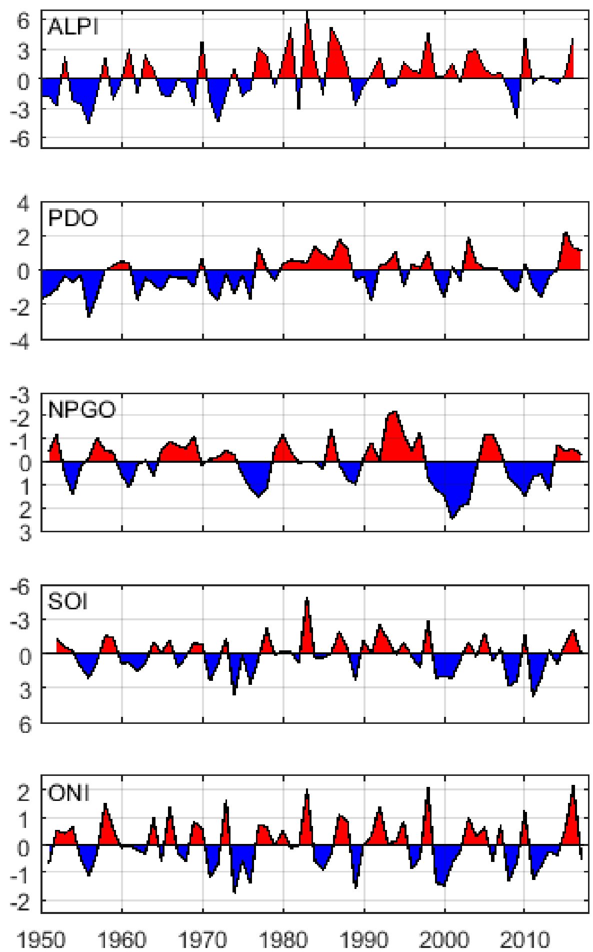

Figure 8-5. Time series of Pacific Ocean climate indices. Aside from ALPI, which is already an average, each of the monthly indices were averaged over the months of Nov, Dec, Jan and Feb and plotted for the year in Feb. Some series are inverted (negative values are above the axes) so that all series are red when coastal B.C. temperatures are anomalously warm. See text for a description and the source of each index.

The **Pacific Decadal Oscillation (PDO) Index** is defined as the leading mode of monthly sea surface temperature variability (1st PC of SST) in the North Pacific (Mantua et al. 1997, Zhang 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. PDO is provided by the Joint Institute for Studies of Atmosphere and Ocean of NOAA and is available from: http://research.jisao.washington.edu/pdo/.

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

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

The **Oceanic Niño Index (ONI)** is a monthly index which is a 3 month running mean of sea surface temperature (SST) anomalies in the Niño 3.4 region (5º N-5º S, 120º-170º W) plotted on the center month. The SST anomalies are calculated based on 30-year base periods that are updated every 5 years, which accounts for global warming and some of the decadal-scale SST variability (as seen in the PDO index). 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.

8.4. References

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9. PATTERNS OF SST VARIABILITY ALONG THE WEST COAST OF NORTH AMERICA

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9.1. Highlights

- The dominant mode of sea surface temperature (SST) variability from California to Alaska is a (largely) uniform fluctuation which explains 57% of the variance.
- This mode is associated with the Pacific Decadal Oscillation and El Nino both of which are driven by equatorial processes.
- The next two modes are a north-south variation (14%) and a California Current mode (8%) and SST off British Columbia is largely uncorrelated with these two modes.
- About 50% of the variance in coastal SST in British Columbia is associated with the large scale SST variability and 50% is very local.

9.2. Introduction

The analysis of ocean temperature variability tends to focus either on the links with large scale climate indices (e.g. El Nino, Pacific Decadal Oscillation, North Pacific Gyre Oscillation) or on the variability at a particular location such as a lighthouse. The purpose of this contribution is to investigate whether a regional scale analysis can provide insights that are useful for understanding ocean temperature variability along the British Columbia coast. The approach taken is to conduct an empirical orthogonal Function (EOF) analysis of the satellite SST data along the 1000 m isobath from California to Alaska and then assess whether the EOF modes have anything useful to contribute to the interpretation of the ocean temperature data from the British Columbia Shore Station Oceanographic Program (BCSOP) and other coastal temperature data sets.

9.3. Description of the time series

9.3.1. Satellite Sea Surface Temperature

The primary sea surface temperature (SST) dataset is derived from the gap free analysis of GRHSST (Group for High Resolution Sea Surface Temperature; http://www.ghrsst.org) for the period 1981 to 2016. The spatial resolution is 0.25 degrees. The SST was processed into 8 day time averages in order to be consistent with a similar data set for chlorophyll *a* data (Hannah and McKinnell 2016). The SST was sampled at 28 locations along the 1000 m isobaths (upper continental slope) from California to Alaska Figure 9-1. For each location, we averaged three SST data points, the centre point that is approximately at the 1000 m contour, and a point on either side (along the same latitude). For the northern part of the area, we did the same thing except the three points are at the same longitude. Along Haida Gwaii only two points were used because the 1000 m isobath is very close to the coast.

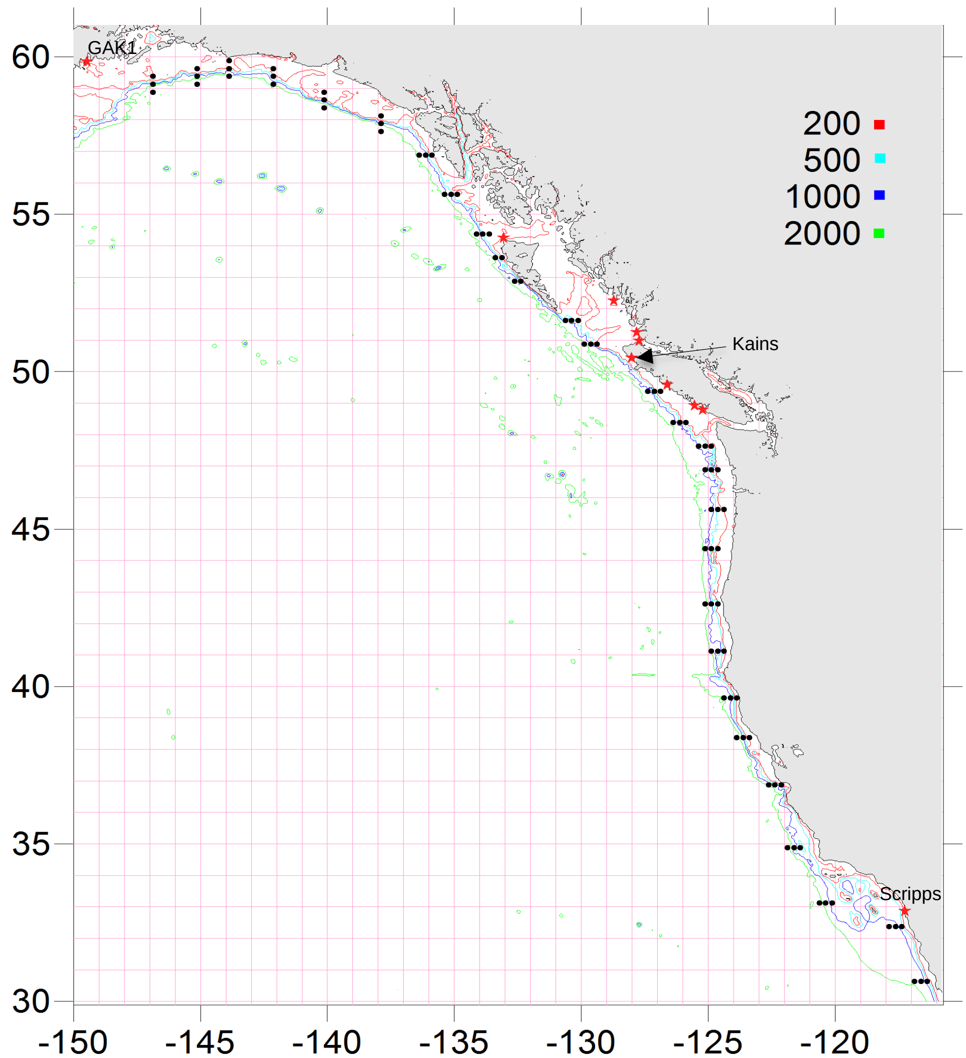

Figure 9-1. Map of the northwest coast of North America from California to Alaska showing the bathymetry of the upper continental slope (200, 500, 1000, 2000 m isobaths). The black dots are the locations where the satellite sea surface temperature data was sampled. The red stars are the locations of the coastal temperature data.

9.3.2. British Columbia Shore Station Oceanographic Program

Sea surface temperature data was compiled from the online data set at

http://www.pac.dfo-mpo.gc.ca/science/oceans/data-donnees/lighthouses-phares/index-eng.html

for the following lighthouses: Langara Island, McInnes Island, Egg Island, Pine Island, Kains Island, Nootka Point, Amphitrite Point, and Cape Beale (See Figure 10-1 in Chandler 2017 for lighthouse locations). The data was averaged onto the same 8 day temporal grid as the satellite SST and the seasonal cycle at each lighthouse was computed using the 30 period 1981 to 2010 except for Beale Light and Nootka Point where the time series did not cover the entire range. In those cases all the available data was used.

9.3.3. Other data

The ocean temperature at Scripps Pier in California was compiled from the website https://scripps.ucsd.edu/programs/shorestations/shore-stations-data/data-sio/. The data was averaged onto the same 8 day grid as the satellite SST and processed using the same procedure as the lighthouse data. Some adjustments were necessary from 2015 and 2016 when the sampling methods changed.

For Alaska, the coastal temperature time series for Station 1 in the Gulf of Alaska Section (GAK1; Figure 9-1) was compiled from the website http://www.ims.uaf.edu/gak1/. This time series is created from the combination of regular cruises and other occupations from ships of opportunity. As such the time series is very irregular. We have done our best to create an 8 day time series but it is better thought of as linear interpolation of a monthly time series.

9.4. Status and trends

An Empirical Orthogonal Function (EOF) analysis was performed on the 28 SST anomaly time series. Each mode produces a spatial pattern and an associated time series.

The first mode of the EOF (57% of the variance; Figure 9-2) is a coherent 'breathing' mode where the temperature anomalies increase and decrease together from California to Alaska This first mode includes, but is not dominated by, the major El Niño events (1983, 1997, 2015/6). The modal time series is weakly correlated with the PDO (r=.64) and ENSO indices (ONI r=.47; MEI r=.51). This makes sense as the major El Ninos and the PDO are associated with an approximately uniform temperature anomaly structure along the west coast.

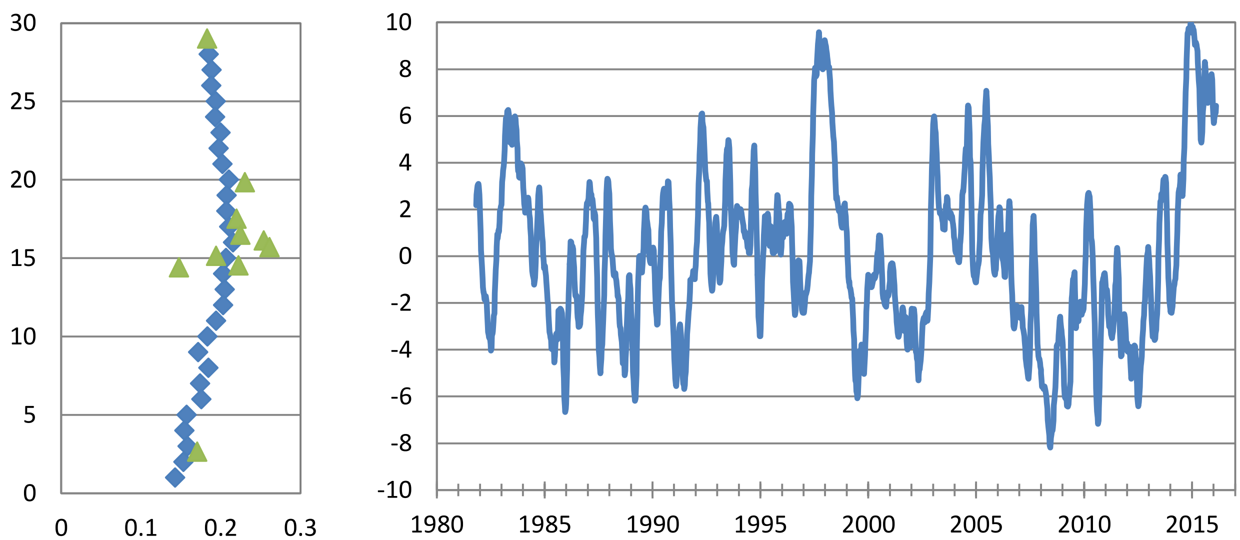

Figure 9-2. EOF Mode 1 (57.4% of the variance). The left panel is the spatial structure of the mode where the vertical axis is space with California at the bottom and Alaska at the top (blue diamonds). On the vertical axis British Columbia lies been values 14 and 20, GAK lies at value 29 and Scripps at value 3. The values of the linear correlations (r) between Mode 1 and the coastal data are shown with the values of r/3 (silver triangles). The scaling shows that the spatial structure of the correlations is consistent with the spatial structure of Mode 1. The right panel is the time series for Mode 1. The time series is dimensionless.

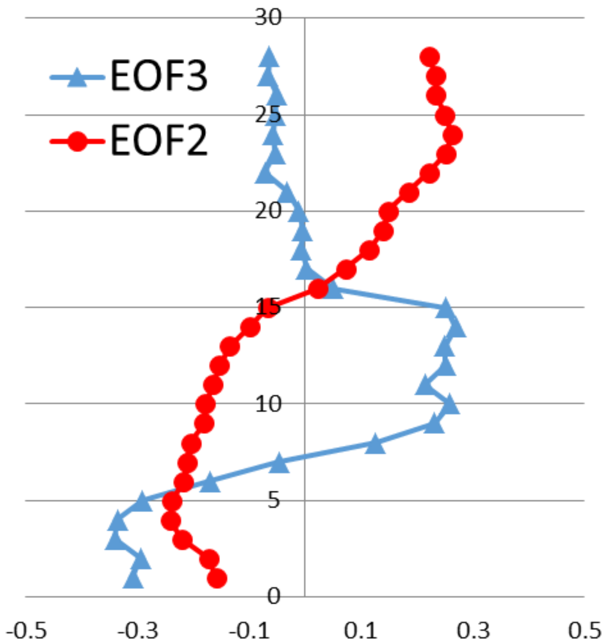

Figure 9-3. The spatial structures for Mode 2 (13.8% of the variance; red) and Mode 3 (7.7% of the variance; blue). The vertical axis is the same as in Figure 9-2.

The second mode (14%; Figure 9-3) is a north-south temperature tilt (warmer in north and cooler in the south and vice versa). The nodal point (zero variation) is at the latitude of Vancouver Island. The third mode (8%; Figure 9-3) looks like a California Current mode describing north south variations in the surface temperature associated with the California Current. Mode 3 has no expression north of Vancouver Island.

A correlation analysis was done to establish whether the EOF mode 1 is a useful for interpreting the coastal time series (lighthouses, Scripps, GAK1). This was done by computing the correlations between each coastal station and the time series associated with EOF Mode 1. The linear correlations ranged from a maximum value of 0.78 at Kains Island lighthouse to a minimum value of 0.5 at Scripps Pier in southern California. The spatial pattern of the correlations is broadly consistent with idea that the 'breathing' mode explains 50-60% of the temperature variability (Figure 9-2).

9.5. Factors influencing trends

The SST time series (not shown) don't show the signature of propagation of signals from south the north - this would manifest itself as time shift in the SST peaks. There are two obvious ways to accomplish this:

1. Weather gets warmer or colder along the entire coast;
2. The winds advect the mean surface temperature field north or south – recall that there is a substantial north-south gradient in the surface temperature field.

It seems clear that atmospheric teleconnections dominate over the propagation of oceanic signals such as a coastal trapped wave northward from the equator. As such we interpret Mode 1 as being weather (atmospheric forcing) driven. This would include direct effects of heating, cooling and mixing and the oceanic response to such changes (e.g. upwelling, advection of the large scale SST field). Therefore studies such as Di Lorenzo et al. (2013) and Ding et al. (2014) which link SST variability in the equatorial Pacific to the Northeast Pacific through various mechanisms are relevant to B.C. SST.

The second and third modes have simple interpretation but we have not established that they are more than statistical objects. Nevertheless it is interesting that both modes have a very small response over most of coastal B.C. To test the relevance of these modes we need additional coastal SST data from the locations to the south and the north. We will explore the correlations between the coastal time series and mode 2 and 3 at a later date.

The fact that B.C. is located in the null zone for modes 2 and 3 means that even if these modes prove useful for describing the variability along the west coast, they won't have much utility for describing variability in British Columbia. As such we propose that approximately half of the coastal SST variability in B.C. is due to the uniform pumping associated with large scale atmospheric processes and the other half must be due to more local processes such as coastal upwelling, wind driven circulation, changes in rainfall and river flows, local weather (e.g. Cummins and Masson 2014).

9.6. Implications of those trends

- The root mean square temperature variability at the B.C. Lighthouses ranges from 0.7 to 1 °C. About 50% of this variability is associated with the large scale SST variability and 50% is very local.
- EOF Mode is associated with the weather (atmospheric forcing). As such, analysis which considers the effect of anomalous winds due to atmospheric pressure anomalies is likely to be successful in capturing the SST variability represented by EOF mode 1. This approach has been used in previous State of the Pacific Ocean Reports.

9.7. Acknowledgements

Scripps Pier data are collected by Birch Aquarium staff and volunteers. Data provided by the Shore Stations Program sponsored at the Scripps Institution of Oceanography by California State Parks, Division of Boating and Waterways. Contact: shorestation@ucsd.edu

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10. SEA SURFACE TEMPERATURE AND SALINITY TRENDS OBSERVED AT LIGHTHOUSES AND WEATHER BUOYS IN BRITISH COLUMBIA, 2016

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10.1. Highlights

- Sea surface temperatures in 2016 were not as warm as 2015 but still warmer than the 30 year (1981-2010) normal.
- Despite the decrease in SST in 2016 there continued to be a long-term trend to warmer coastal sea surface temperatures.
- Annual salinity observations were near normal; salinity trends continued to be positive for the north and west coast, and negative in the Strait of Georgia.

10.2. Description of the time series

Two sources of data are used to describe changes in sea surface conditions in the coastal waters of B.C. in 2016. As part of the DFO Shore Station Oceanographic Program sea surface temperature (SST) and salinity are measured daily at 12 shore stations, at the first daylight high tide. Most stations are at lighthouses (Figure 10-1), with observations taken by lighthouse keepers using a handheld electronic instrument (YSI Pro 30). The buoy data are provided by Environment Canada from a network of ODAS (Offshore Data Acquisition Systems) buoys that collect weather data hourly.

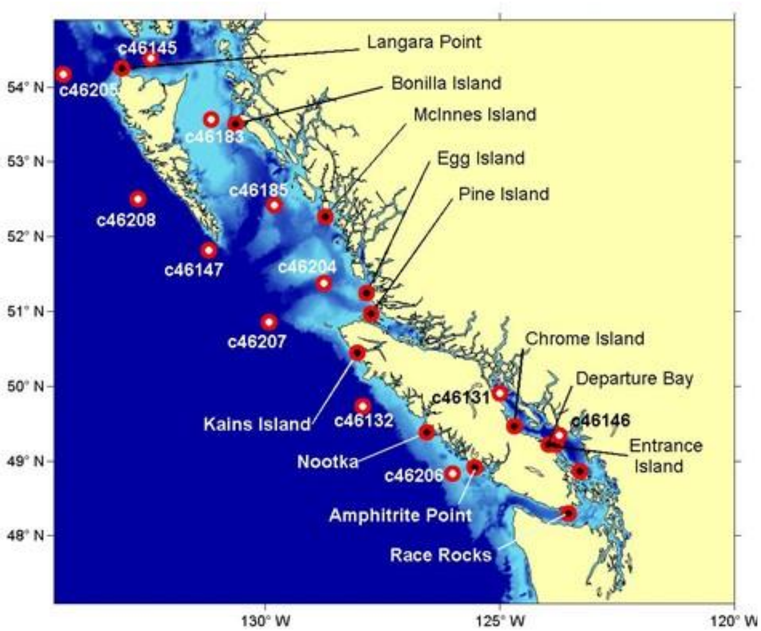

Figure 10-1. Red dots with black centres show the locations of 12 stations in the present shore station network. Red dots with white centers show the locations of 12 weather buoys in the Canadian weather buoy network. See table below for details.

Station	Years of data	Buoy ID	Buoy Location	Years of data
Departure Bay	102	c46146	Halibut Bank	24
Race Rocks	95	c46131	Sentry Shoal	24
Nootka	82	c46206	La Perouse	28
Amphitrite	82	c46132	South Brooks	22
Kains I	79	c46207	East Dellwood	27
Langara	80	c46147	South Moresby	23
Entrance I	80	c46208	West Moresby	26
Pine Island	79	c46205	West Dixon	26
McInnes	62	c46145	Central Dixon	25
Bonilla	56	c46204	West Sea Otter	27
Chrome I	55	c46185	South Hecate	25
Egg Island	46	c46183	North Hecate	25

10.3. Status and trends

The observations at the shore stations show the average daily SST (Figure 10-2, upper panel) at all stations, with the exception of Race Rocks, was cooler in 2016 than in 2015 (mean decrease of 0.34 °C, standard deviation of 0.26 °C), but still warmer in 2016 than the 30 year average,1981-2010).

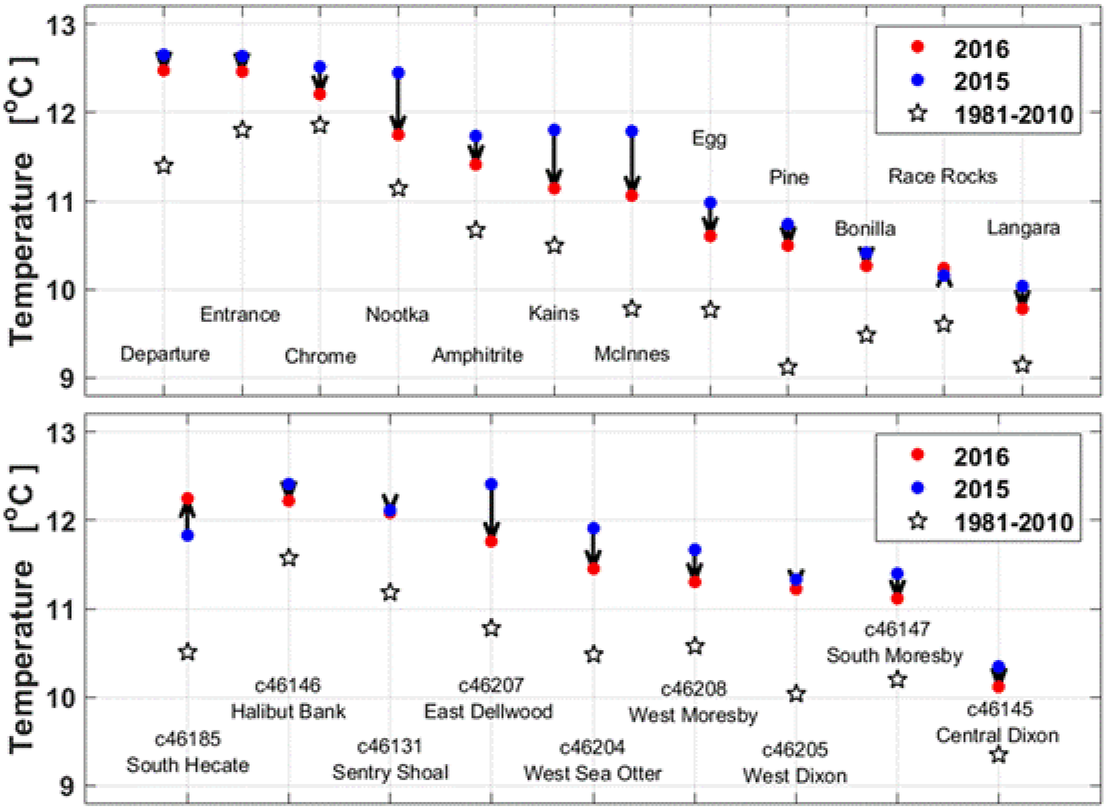

Figure 10-2. Upper panel. The average sea surface temperature in 2015 (blue dots) and 2016 (red dots) from daily observations at shore stations along the West Coast of Canada. The stars represent the mean annual temperature based on 30 years of data (1981-2010). Lower panel. The average sea surface temperature in 2015 (blue dots) and 2016 (red dots) from hourly observations at weather buoys along the West Coast of Canada. The stars represent the mean annual temperature based on all years of data.

The observations from the weather buoys show the average daily SST (Figure 10-2, lower panel) at all stations, with the exception of South Hecate, was cooler in 2016 than in 2015 (mean decrease of 0.21 °C, standard deviation of 0.31 °C), and warmer in 2016 than the 22 year average, 1989-2010 (mean increase of 0.98 °C, standard deviation of 0.33 °C). It can be seen that the change in SST between 2015 and 2016 at the buoys located in the Strait of Georgia (Halibut Bank and Sentry Shoal) was less than those on the west and central coasts of B.C.

Figure 10-3 shows the time series of sea surface temperatures observed at locations off the west coast of B.C., the north coast, and in the Strait of Georgia. All demonstrate above normal temperatures for the first part of the year, with cooler conditions during the second part of the year.

Assuming a linear change over the entire data record, the time series of temperature at all of the B.C. shore stations show a warming trend at a 95% confidence level. Figure 10-4 shows this warming at representative stations for each of three regions (North Coast, the West Coast Vancouver Island, and the Strait of Georgia). A similar trend analysis applied to the salinity data (Figure 10-5) shows a continuing long-term trend toward less saline conditions except in the Strait of Georgia where above normal salinity has been observed since the 1980s.

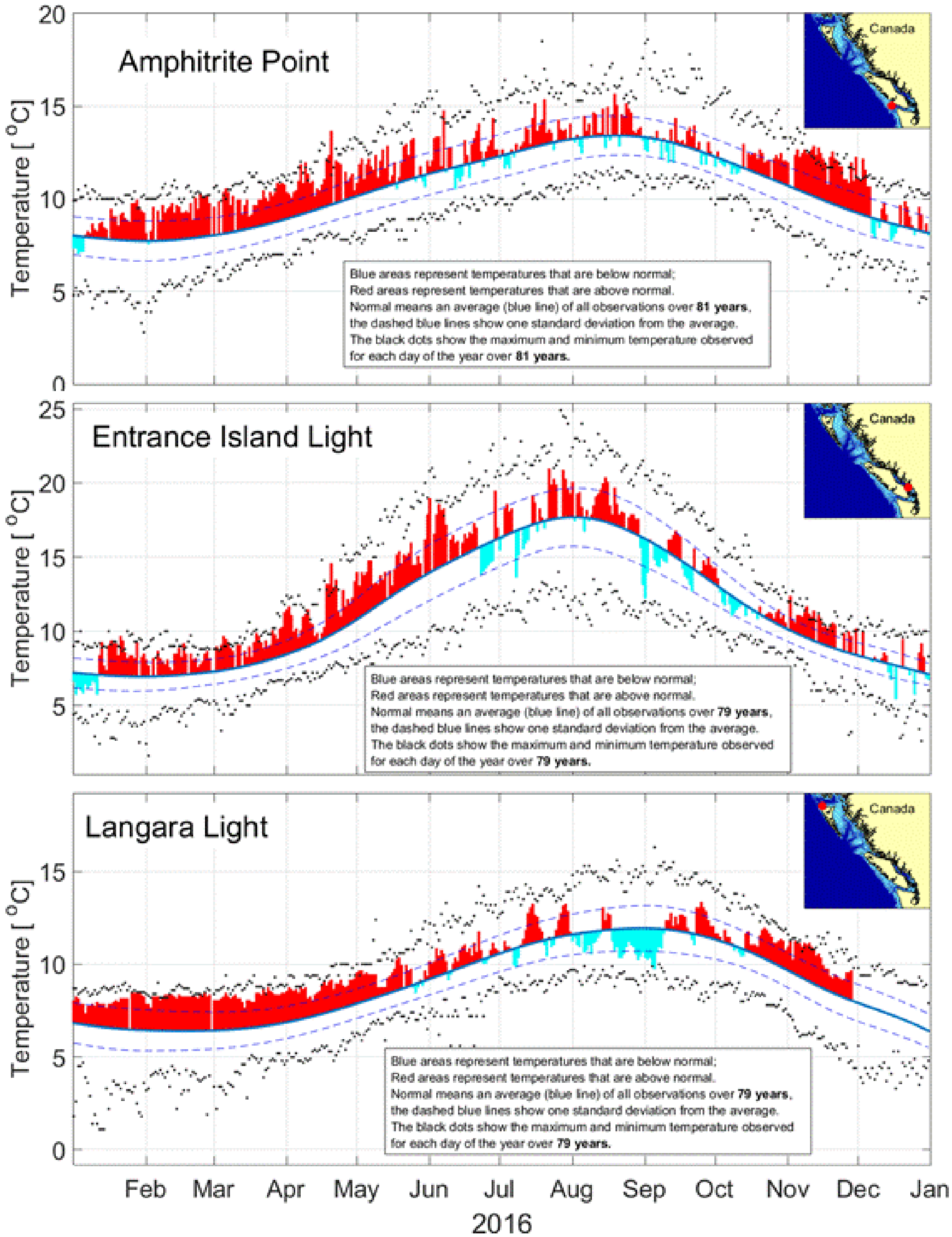

Figure 10-3. Time series of daily SST, blue areas represent temperatures that are below normal, red areas represent temperatures that are above normal. Normal means an average (blue line) of all observations and the dashed blue lines show one standard deviation from the average. The black dots show the maximum and minimum temperature observed for each day of the year.

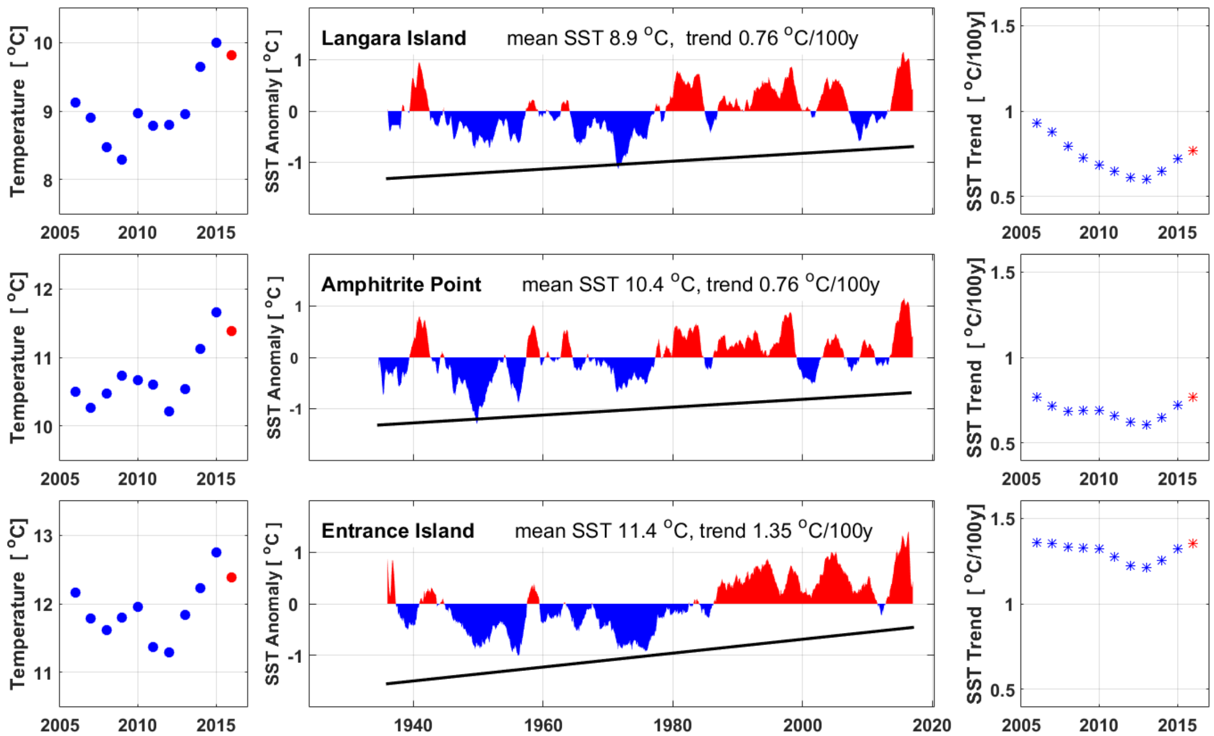

Figure 10-4. Time series of daily temperature observations, averaged over 12 months, at stations representing the North Coast, West Coast Vancouver Island and Strait of Georgia. Positive anomalies from the average temperature of the entire record are shown in red, negative in blue. The panel to the left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

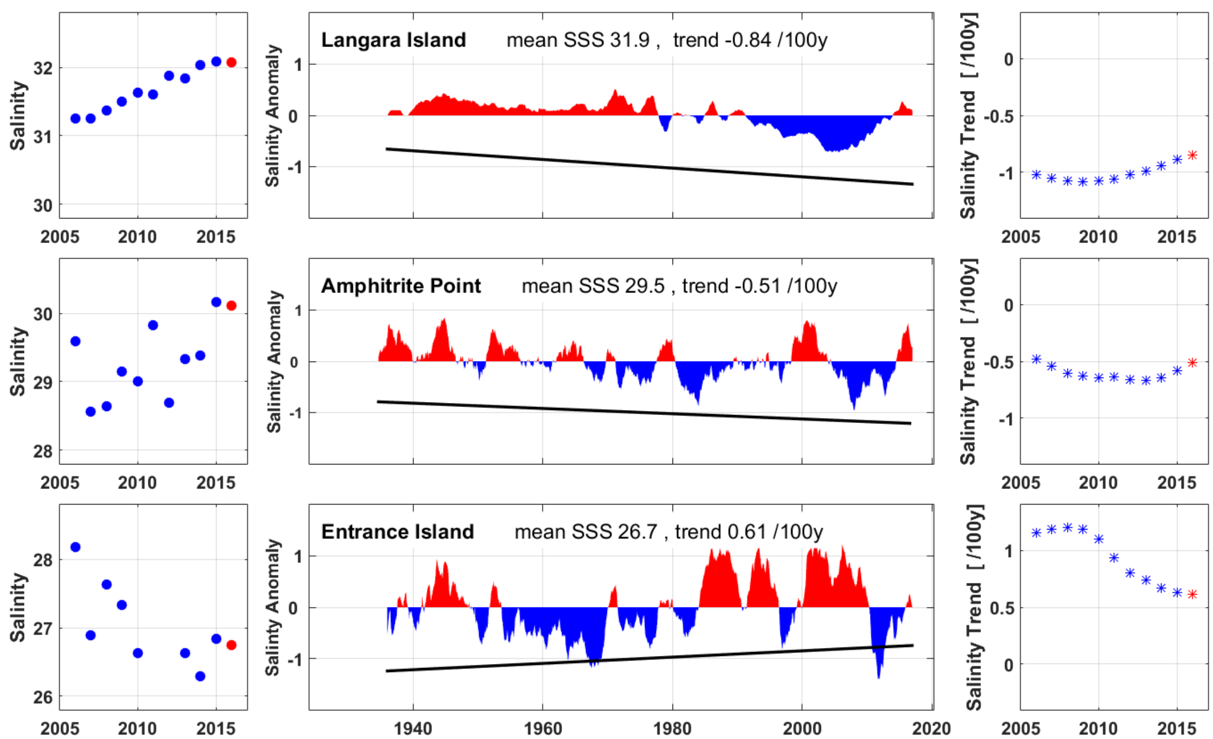

Figure 10-5. As in Figure 10-4 for long-term time series of daily salinity observations.

10.4. Factors influencing trends

Warmer than normal sea surface temperatures in the first part of 2016 coincided with both the positive phase of the Pacific Decadal Oscillation and strong El Niño conditions at the end of 2015. There was a transition to ENSO-neutral conditions in early summer and later in the year to La Niña conditions. The breakdown in the PDO pattern during the summer, and the re-emergence of the Blob in the central Gulf of Alaska in late summer contributed to cooler sea surface temperatures along the coast near the end of 2016.

While the average annual SST along the B.C. coast was lower in 2016 than in 2015, the ocean was warmer than the climatological average (1981-2010) and the all-data average. As a result there continues to be a trend to increasing SST, and it is more pronounced in the semi-enclosed Strait of Georgia than along the outer coasts.

The long-term salinity observations show a trend to less saline conditions along the outer coasts. The Strait of Georgia data, which is strongly influenced by the discharge from the Fraser River, shows a trend to more saline conditions than observed.

10.5. Implications of those trends

Both the temperature and salinity trends have been based on an assumed linear relationship between conditions over time. The variability evident in the time series as shown in Figure 10-4 and Figure 10-5 introduces a caveat to this assumption.

The sea surface temperature and salinity are fundamental water properties defining the habitat of organisms that live in the upper waters of the ocean. The impacts of these changes to the water properties will depend on the time and space scales relevant to organisms of interest and are described for various trophic levels in B.C. waters in Peña and Nemchek (2017), Galbraith and Young (2017), and Hyatt et al. (2017).

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11. OXYGEN CONCENTRATION IN SUBSURFACE WATERS

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11.1. Highlights

- Oxygen concentration (O_2) declined near the ocean bottom on the continental shelf of southwest Vancouver Island from 70 µmol/kg to 30 µmol/kg from 1980 to 2009, but increased since then to levels between 50 and 70 µmol/kg. Similar trends are observed on the continental slope at 200 and 250 m depth.
- On the continental margin to about 700 km offshore, O_2 on constant density surfaces in the thermocline increased between the decades of 1950s and 1980s, declined to the 2000s, and has increased since about 2010. Farther offshore there is a linear decrease since the 1950s, accompanied by an oscillation similar in period to the lunar nodal cycle of 18.6 years.

11.2. O_2 on the continental shelf and slope

An image of historical near-bottom O_2 in summer is presented in Figure 11-1. Symbols reveal locations where hypoxia was observed. (Hypoxia is defined as O_2 less than 1.4 ml/L or 60 µmol/kg.) Many of these symbols are in inlets where deep seawater is naturally hypoxic due to low rates of inflow from outside waters. On the continental shelf and slope, lowest O_2 is in deeper waters because O_2 decreases with depth. Lowest O_2 on the shelf is off southwest Vancouver Island, the region of the B.C. coast where summer upwelling is strongest. Sampling programs at station LB08 in 145 metres of water have monitored oxygen concentration off southwest Vancouver Island since 1979. Decreasing O_2 in subsurface waters in summer is normally accompanied by increasing acidity. Both trends are of great concern to marine life.

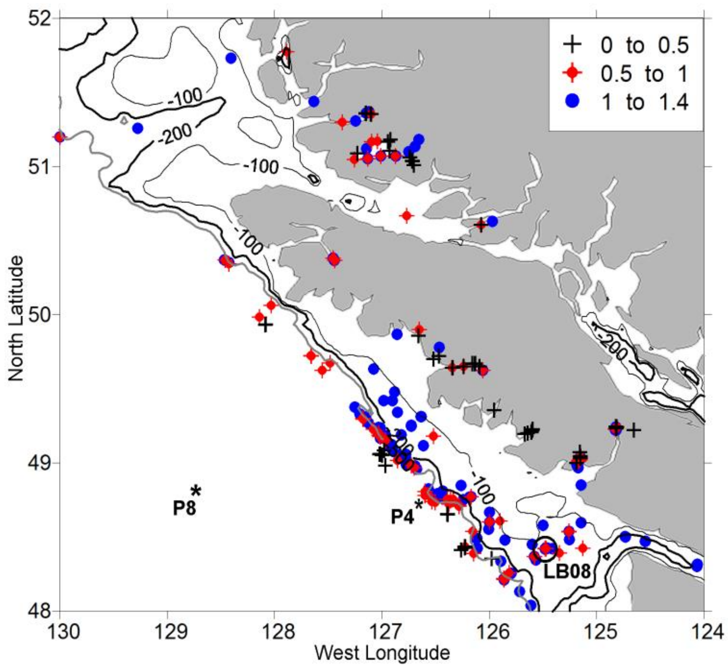

*Figure 11-1. Oxygen concentration (O_2, ml/L) in summer within 20 metres of the ocean bottom for regions of the continental shelf and slope where bottom depth is less than 1000 metres. (1 ml/L = 43 µmol/kg) Each symbol represents a measurement by DFO research programs. Only observations with O_2 less than 1.4 ml/L (60 µmol/kg) are plotted. A black O denotes the location of Station LB08, where O_2 has been monitored by DFO for almost 40 years. Stations P4 and P8 along Line P are indicated by *.*

The annual cycle of O_2 in near-bottom waters off southwest Vancouver Island at Station LB08 is presented in Figure 11-2, based on observations from 1979 to 2016 by Fisheries and Oceans Canada (DFO). This graph shows that O_2 decreases from winter to late summer, with lowest O_2 in late August to early October (days 240 to 290). For these months, lowest O_2 was in 2006 to 2009. Observations in the years 2010 to 2013 reveal somewhat higher O_2 than for the period 2006 to 2009. Even higher values of O_2 were observed in 2014 to 2016, with the highest ever late summer O_2 of 2.14 ml/L (92 µmol/kg) measured in early September 2015. This very high O_2 is attributed to a deep mixed layer of warm, well-oxygenated seawater.

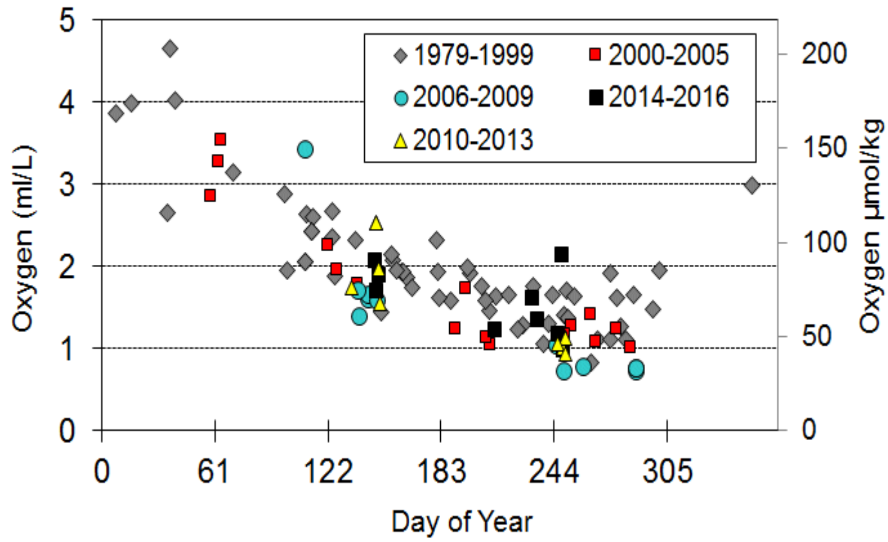

Figure 11-2. Oxygen concentration (O_2, ml/L and µmol/kg) at Station LB08 at 20 m above the ocean bottom and 125 m below the surface. Symbols represent individual observations, plotted on the day of the year the sample was collected. Figure is based on Crawford and Peña (2013).

Three times a year scientists of Fisheries and Oceans Canada sample ocean waters along Line P, which extends from the west end of Juan de Fuca Strait to Ocean Station Papa (OSP, also named P26) about 1450 km away. We present a time series of O_2 at Line P station P4 on the continental slope in 1200 m of water. Regular sampling at P4 began in 1981, and two surveys in the early 1960s also sampled at this location. The time series of O_2 at P4 is shown in Figure 11-3, where O_2 is plotted at two depth intervals. There is an annual cycle in O_2 due to upwelling winds in summer and downwelling winds in winter. Therefore, only measurements in late summer are included.

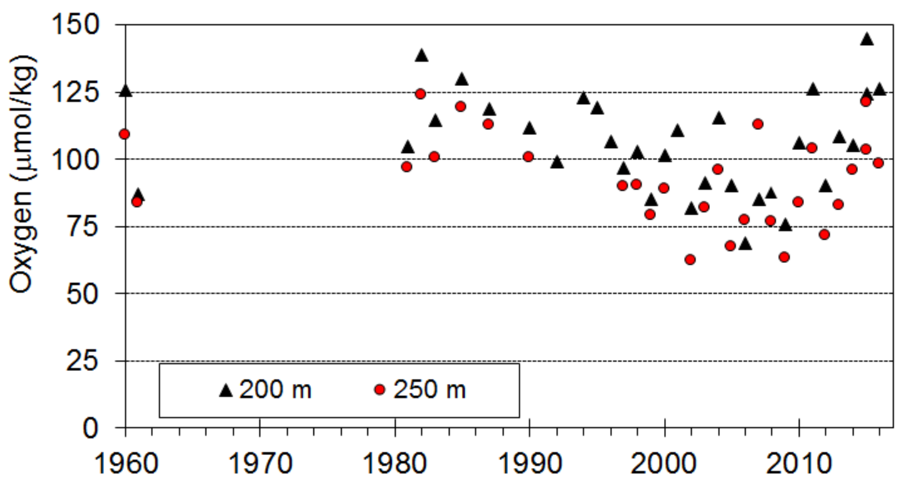

Figure 11-3. Oxygen concentration (O_2, µmol/kg) at depths of 200 and 250 metres below ocean surface at station P4 on the continental slope. Only measurements in August or September are included. Figure is based on Crawford and Peña (2013).

Data in Figure 11-3 reveal minimum O_2 in the summers of 2002 and 2009, together with a general decreasing trend from 1980s to 2000s, and an increasing trend after 2009. The few observations in the early 1960s suggest lower O_2 than observed in the 1980s; however, there are too few observations at 200 and 250 m at P4 to determine if the increase from 1960s to 2000s is significant. Observations on constant density surfaces, described below, provide more insight into the gap from 1961 to 1981.

11.3. Oxygen concentration in offshore waters

There are no stations in either coastal or offshore waters with regular sampling prior to 1980. To evaluate trends prior to 1980, we composited observations in areas around each of the intensive sampling stations along Line P, and included all observations in the archives of the Institute of Ocean Sciences (IOS) of Fisheries and Oceans Canada, and the U.S. National Oceanic Data Center (NODC). O_2 was calculated on constant density surfaces rather than at constant depths below surface to allow inclusion of observations in all months of the year, because O_2 on constant density surfaces changes very little as these surfaces move up and down through the year. Details of this process and results to 2011 are described by Crawford and Peña (2016).

Observations in an area surrounding station P4 reveal that O_2 increased from the 1950s to the 1980s, suggesting that the increase between these decades shown in Figure 11-3 for constant depths is significant.

Of the Line P stations that are intensively sampled, we present results below for Station P8 and Ocean Station P in Figure 11-4 below. Each symbol is an annual average of O_2 at and surrounding these stations.

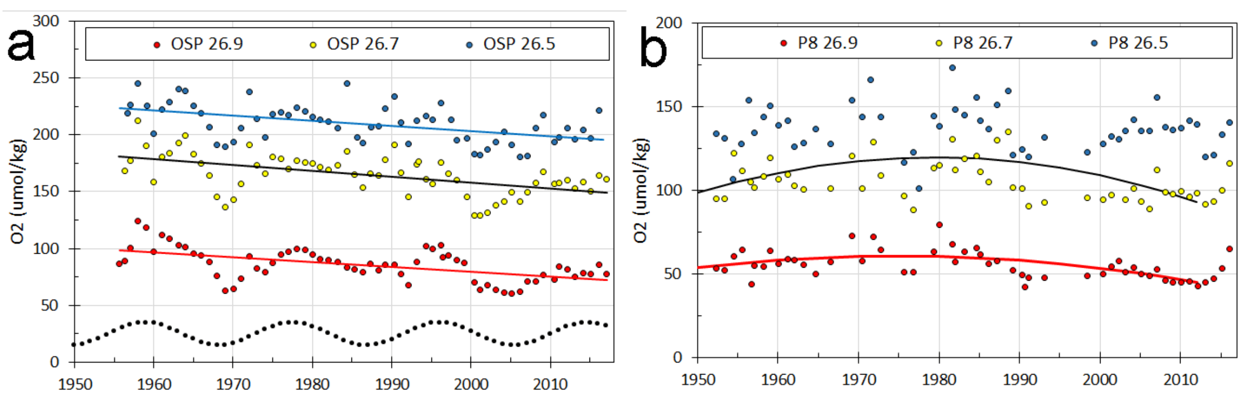

Figure 11-4. Annual average oxygen concentration (O_2, μmol/kg) at (a) Ocean Station P (OSP) and (b) station P8, interpolated onto the constant density surfaces 26.5, 26.7, and 26.9. The constant density surface of 26.5 has a water density of 1026.5 kg m^{-3}. Figure is based on Crawford and Peña (2016).

Linear trends in Figure 11-4a are -0.46, -0.52, and -0.43 μmol kg^{-1} y^{-1} for surfaces 26.5, 26.7, and 26.9, respectively. The black sinusoidal curve in Figure 11-4a is an 18.6-year signal that aligns in phase with the O_2 on the 26.9 surface. Analysis of OSP O_2 to 2006 by Whitney et al. (2007) also noted the linear decrease and 18.6-year oscillation. Curves in Figure 11-4b are quadratic polynomials fitted to O_2 on the 26.7 and 26.9 surfaces for the period 1950 to 2011. No statistically significant quadratic curve was observed to fit the oxygen observations on the 26.5 surface in Figure 11-4b. Note that the increase in O_2 after 2011 at P8 is not observed at OSP.

The temporal doming at P8 (Figure 11-4b) is also present at P4 and P12, while the linear trend and oscillation at OSP as also present at station P20. Station P16 marks the transition between the far-offshore variation at OSP and P20 and the near-offshore variation at P8. Most Haida eddies that cross Line P do so near Station P16, so the temporal variations there are more complex than at other Line P stations.

11.4. Factors influencing trends

Both the decrease and the oscillation in O_2 in far offshore regions near P20 and OSP are likely due to advection of subsurface waters from the northwest Pacific Ocean, where both signals have been observed. In contrast, the changes in O_2 on the continental shelf and slope and at P4, P8 and P12 are likely due to changes in winds along the west coast. The temporal doming pattern observed in Figure 11-4b is found along the entire continental slope from southern California to northern British Columbia, so we suspect changes in winds along the west coast over this entire domain could be the cause.

11.5. Implications of these trends.

Low oxygen is a serious threat to marine life. Subsurface waters along the west coast below the surface mixed layer are naturally low in O_2, and any additional decrease in O_2 will negatively impact marine life. The increase in O_2 after 2009 at Stations P4 and LB08 is welcome news. The continuing decrease in O_2 in far-offshore waters is a discouraging event. Low oxygen in these subsurface waters is almost always accompanied by increasing acidity, which is an additional threat to marine life.

11.6. References

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11.7. Acknowledgements

Scientists and technicians of the Line P and La Perouse Programs of Fisheries and Oceans Canada, as well as data quality and archiving by Germaine Gatien, Joe Linguanti and Roy Hourston of DFO.

12. 2016 OCEANOGRAPHIC CONDITIONS ALONG LINE P AND THE COAST OF VANCOUVER ISLAND

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12.1. Highlights

- The positive temperature anomaly (the “Blob”) was still present in the NE Pacific Ocean all through 2016. The warm waters were no longer confined to the near surface as in previous years. The ocean was less stratified, allowing the warm waters to be seen down to 300 dbar.
- Along the west coast of Vancouver Island the water in the spring of 2016 was warmer than that of 2015, but by fall the waters were colder than the previous year.

12.2. Programs

The La Perouse program is a series of sampling lines on the west and north coasts of Vancouver Island (WCVI), ranging from the mouth of the Juan de Fuca Strait in the south to Queen Charlotte Sound in the north (Figure 12-1). The program started in the late 1970s and is now sampled twice per year, in late May and early September.

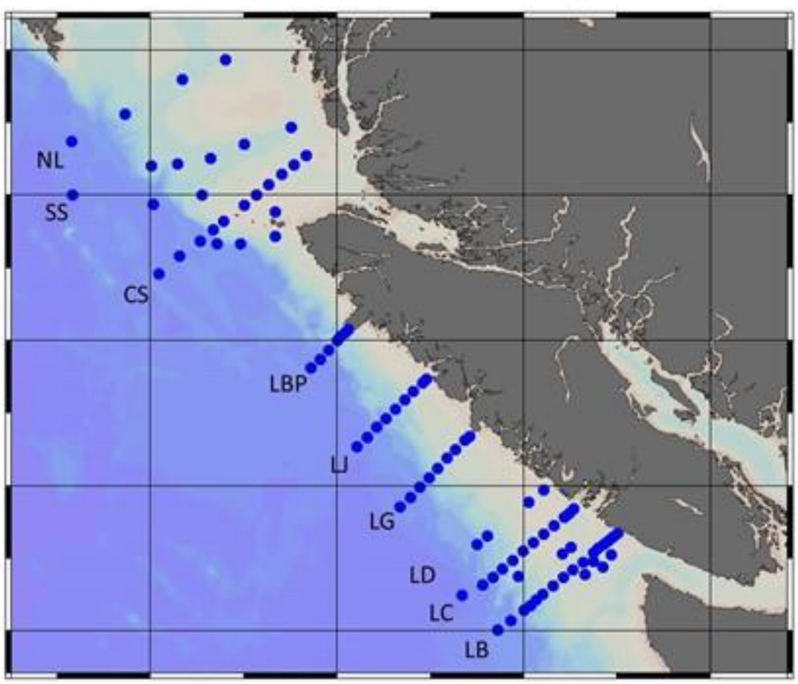

Figure 12-1. La Perouse stations along the west coast of Vancouver Island

Line P is a series of oceanographic stations extending from the mouth of the Juan de Fuca Strait, south of Vancouver Island, to Ocean Station Papa (OSP) at 50° N 145° W, in the Pacific Ocean (Figure 12-2). The Line P time series is one of the longest oceanographic time series in the world, with data going back to 1956. Fisheries and Oceans Canada surveys Line P three times per year, usually in February, June, and August.

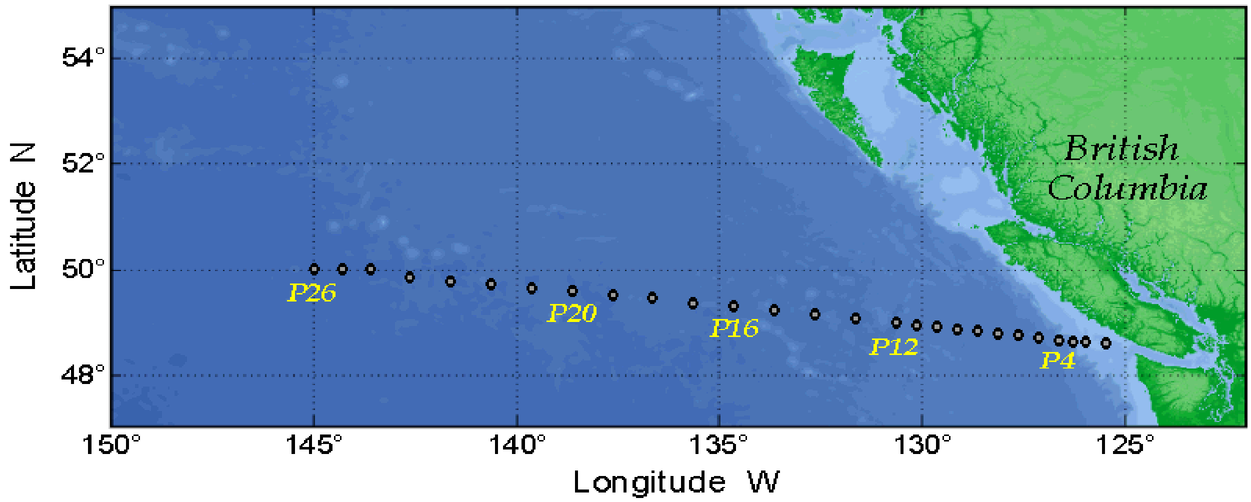

Figure 12-2. Line P and Station Papa (P26).

12.3. Status and Trends

Along the WCVI the year 2015 was the warmest year of the "Blob" era, with the temperature anomalies reaching their peak in September. By the spring of 2016 the warm waters were more diffuse, tending to be deeper and nearer the coast. In September 2016 the conditions were almost as cold as in the fall of 2014, particularly in the near-surface and further offshore, with the exception of the offshore end of the LG line where some warm anomalies still remained below the surface (Figure 12-3). A positive salinity anomaly persisted along the north end of Vancouver Island, higher in September than in May (Figure 12-4).

Offshore along Line P the warm Blob waters were still present, but they were much more diffuse than in the previous two years (Figure 12-5). The waters were less stratified, allowing the vertical mixing of warmer waters with the cold waters at depth. The coastal section of the August 2016 panel (Figure 12-5) demonstrates the same colder conditions as evident in the fall 2016 (Figure 12-3.)

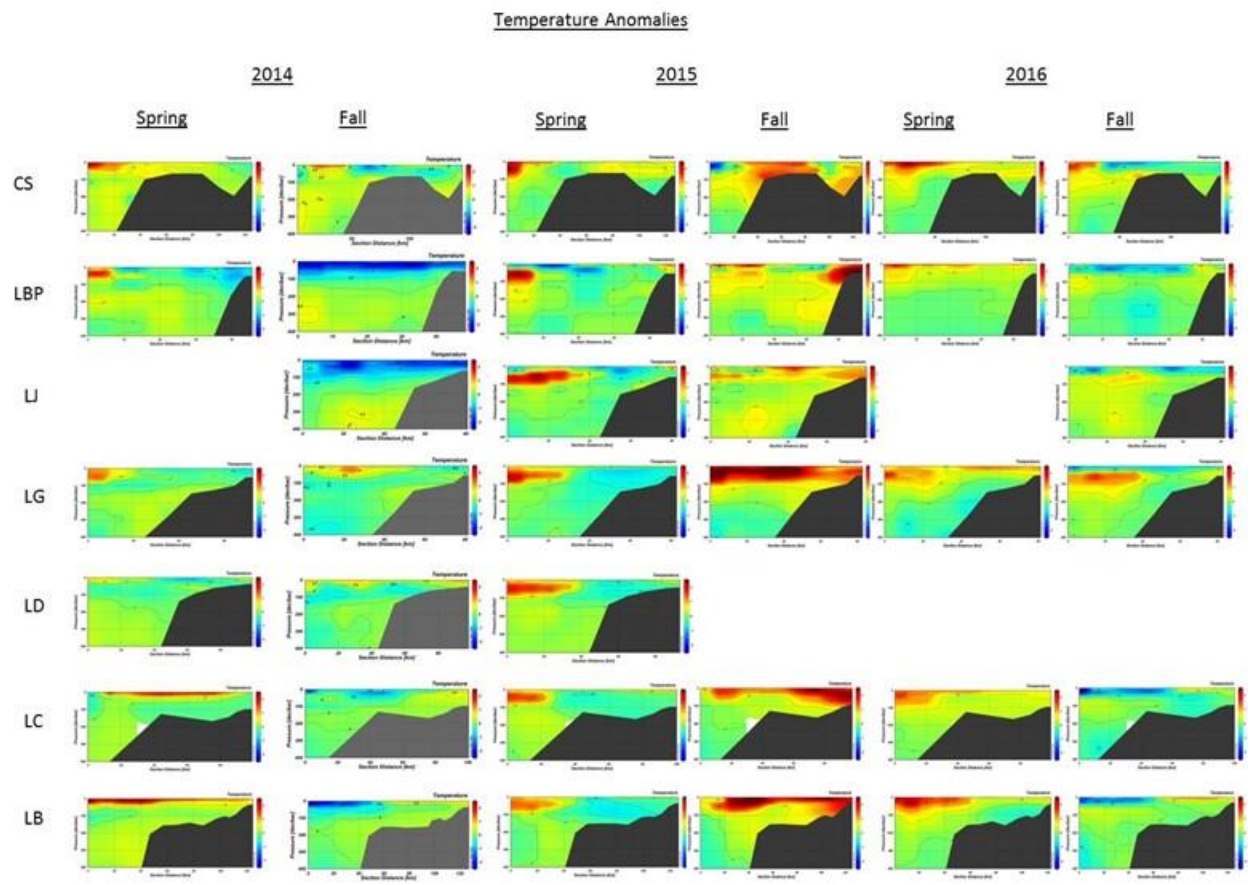

Figure 12-3. Temperature anomaly (°C) along the seven survey lines of the La Perouse program (see Figure 12-1) for spring and fall of 2014, 2015, and 2016, with respect to the 1980-2011 averages.

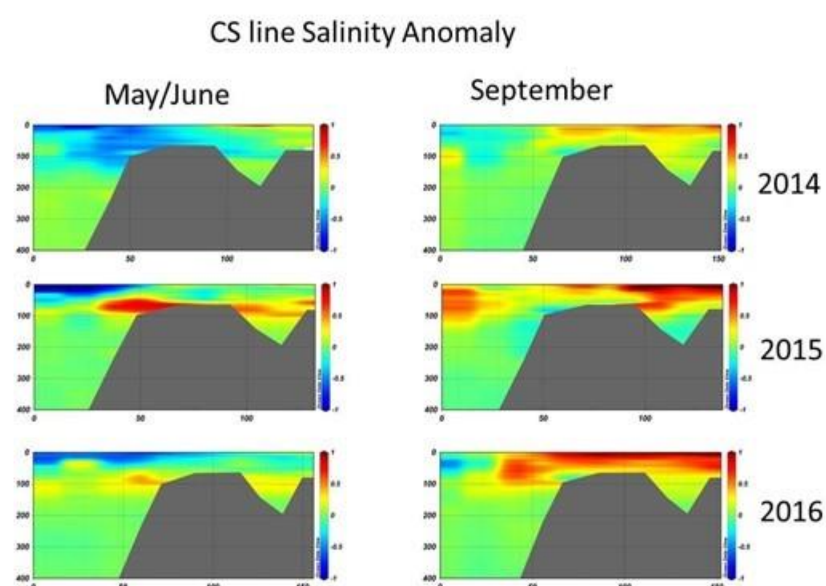

Figure 12-4. Salinity anomaly (°C) along CS line for 2014 – 2016 (wrt 1980-2011 averages).

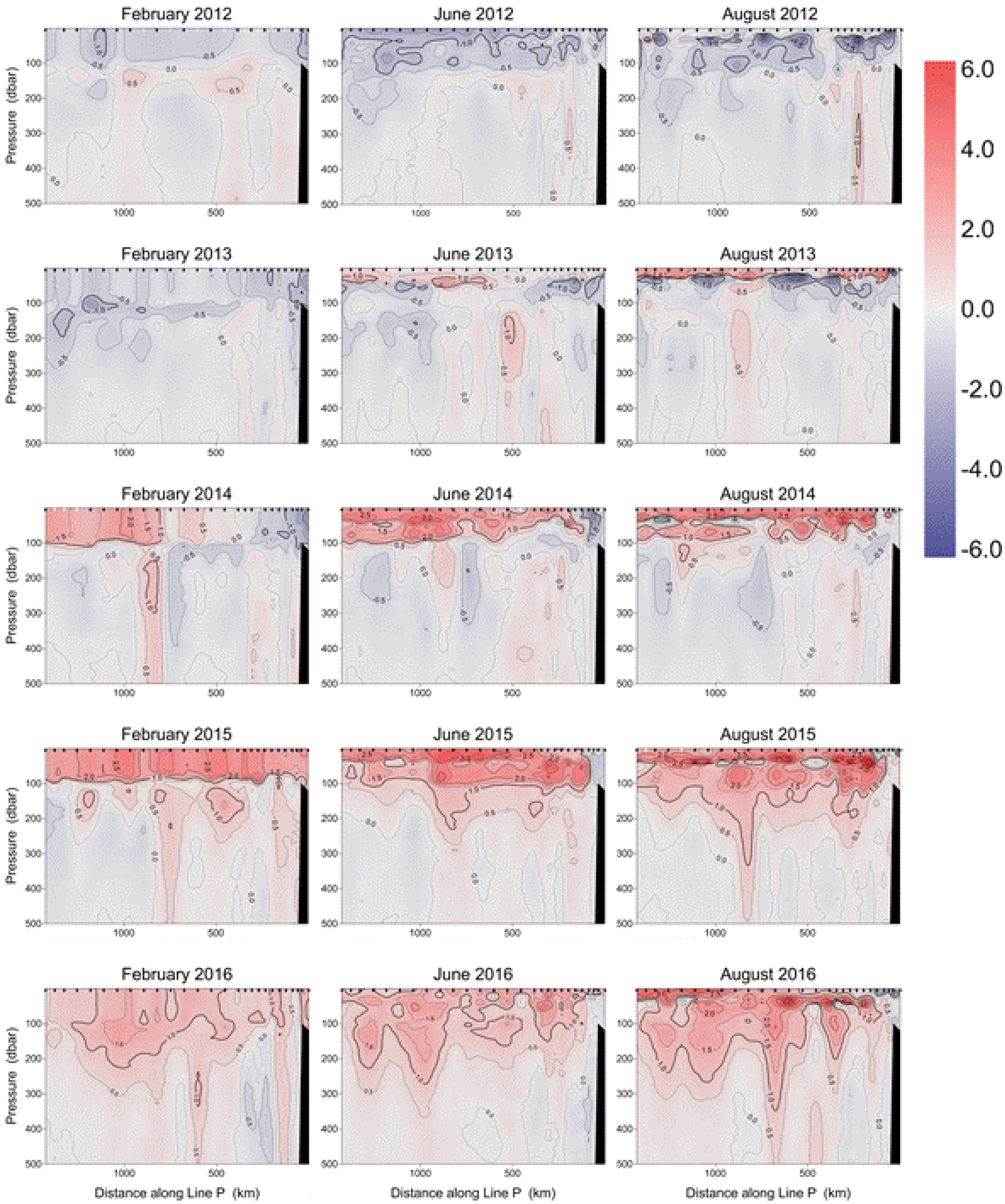

Figure 12-5. Temperature anomaly (°C) along Line P from 2012 to 2016 with respect to the 1981-2010 averages.

13. COASTAL MONITORING BY BUOYS AND SATELLITES

Jim Gower[1] and Stephanie King[2]

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13.1. Highlights

- The warm SST anomaly (+1 °C) continued along coast in 2016.
- Coccolithophores caused bright blooms in the Strait of Georgia and other coastal inlets. Such blooms have not been observed before.
- The spring bloom started on the west coast of Vancouver Island on March 24. The start dates in the Strait of Georgia were March 21 and 28 in the central and northern Strait respectively, but the bloom had relatively low biomass.

13.2. Time series and trends

13.2.1. Weather buoy SST time series

The sea surface temperature (SST) anomaly from Canadian west coast Environment Canada meteorological buoys shows that the warm anomaly of 2015 continued (Figure 13-1). Similar to the observations at coastal lighthouses (Chandler 2017), the magnitude of the warm SST anomaly was slightly lower (0.7 °C year average) in 2016 compared to 2015 (1 °C), but continued the change to a warm anomaly, from a roughly 0.8 °C cold anomaly through 2008 to 2013. Weather buoy time series since about 1990 still show no significant long-term warming along the B.C. coast.

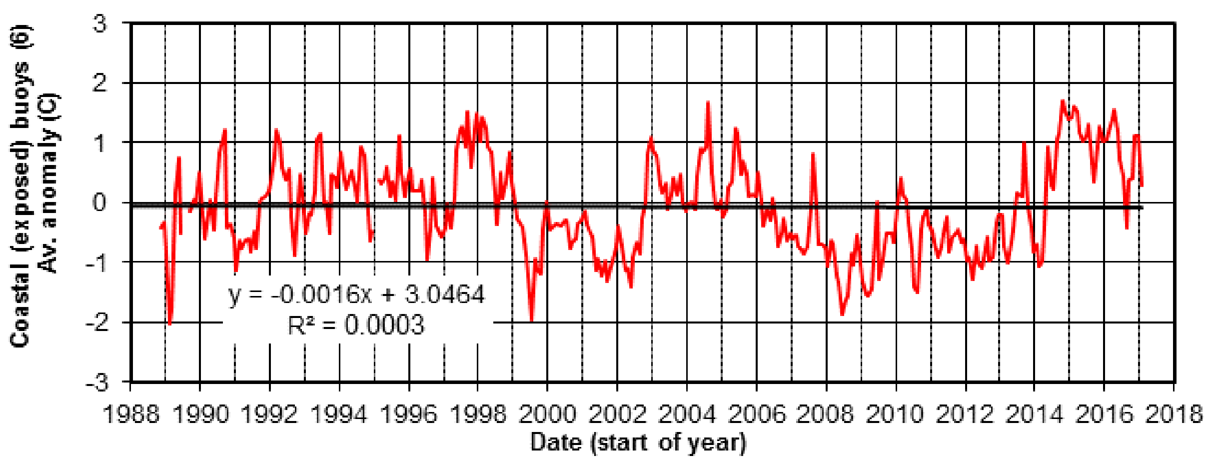

Figure 13-1. The SST anomaly from the 6 exposed meteorological buoys on the B.C. coast (46205, 46208, 46174, 207, 46132 and 46206). Temporary warming in 1997/98 and 2015/16 is connected to the El-Nino phenomenon.

13.2.2. Phytoplankton bloom timing and magnitude

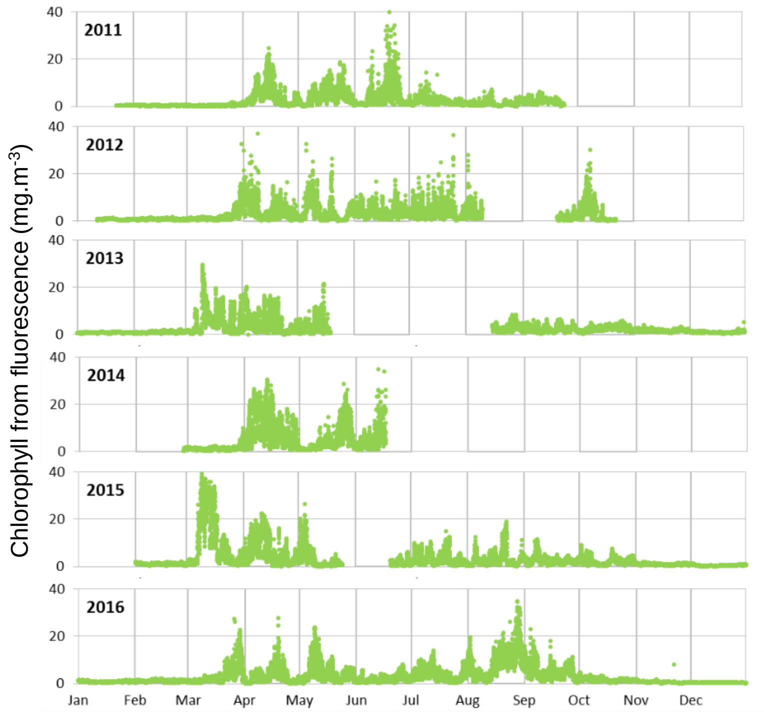

Figure 13-2. Chlorophyll from fluorescence measured at Halibut Bank in the central Strait from 2011 (top panel) to 2016 (bottom panel). Data are available online at the Strait of Georgia Data Center (www.sogdatacentre.ca). Gaps in the time series are periods of no data when the fluorometers weren't deployed or when there was fouling. X-axis labels mark the start of each month.

Fluorometers have been deployed at the surface on the Environment Canada buoys at Halibut Bank (c46146) in the central SoG since 2011 and at Sentry Shoal (c46131) in the northern Strait since 2015 (see Chandler 2017 for locations). The fluorometers measure chlorophyll fluorescence and give an estimate of phytoplankton biomass. The Sentry Shoal buoy has additional surface sensors measuring temperature, salinity and nitrate.

In the central Strait (Halibut Bank), the 2016 chlorophyll concentrations were average to low compared to previous years (Figure 13-2), with the exception of a large bloom in mid to late August. The first increase in chlorophyll was observed March 21 to March 29, when peak concentrations reached just over 20mg.m^{-3}. The Halibut Bank bloom timing observations roughly agree with the estimates from satellite chlorophyll fluorescence (Figure 13-3), satellite chlorophyll (the week of March 15±4 days; Hilborn et al. 2017), and the UBC models (March 25-27; Allen et al. 2017). The March 21 bloom start date was two weeks later than the bloom start in 2015.

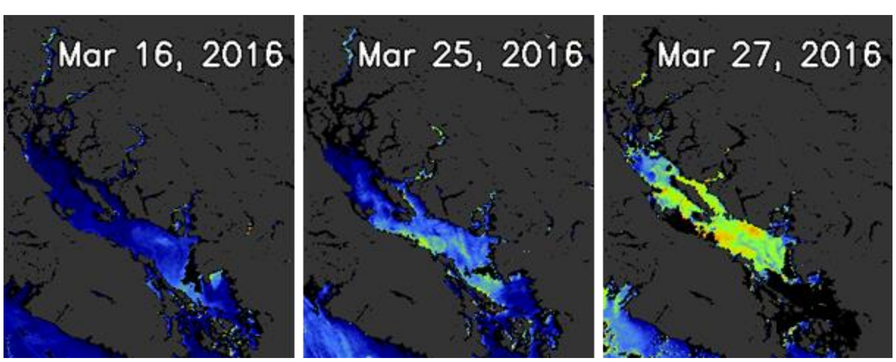

Figure 13-3. NASA MODIS Aqua fluorescence line height images leading up to and during the spring bloom in the Strait of Georgia. Blue, yellow and red indicate low, medium and high chlorophyll concentrations, respectively.

In the northern Strait, the start of the spring bloom was observed at Sentry Shoal on March 28, about 7 days later than in the central Strait, and about five weeks later than in 2015 (Figure 13-4). The bloom developed quickly with concentrations reaching over 20 mg.m^{-3} by March 30. The in situ observations agree with the northern Strait start date estimated from satellite chlorophyll (March 25±4 days; Hilborn et al. 2017). The surface nitrate measured at Sentry Shoal showed a strong inverse correlation with chlorophyll with no time delay, suggesting that the bloom was advected into the area (Figure 13-5), likely from the central Strait. Another mechanism for bloom initiation, observed later in the summer, was an increase in surface nitrate resulting from upwelling driven by strong NNW winds persisting for several days. Hare et al. (2017) observed a decrease in pH and aragonite saturation state during these events.

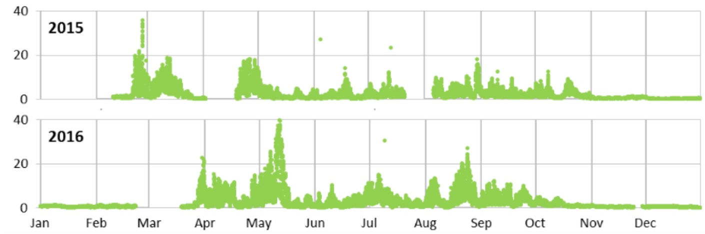

Figure 13-4. Chlorophyll from fluorescence as in Figure 13-2, but as measured at Sentry Shoal in the northern Strait in 2015 (top panel) and 2016 (bottom panel).

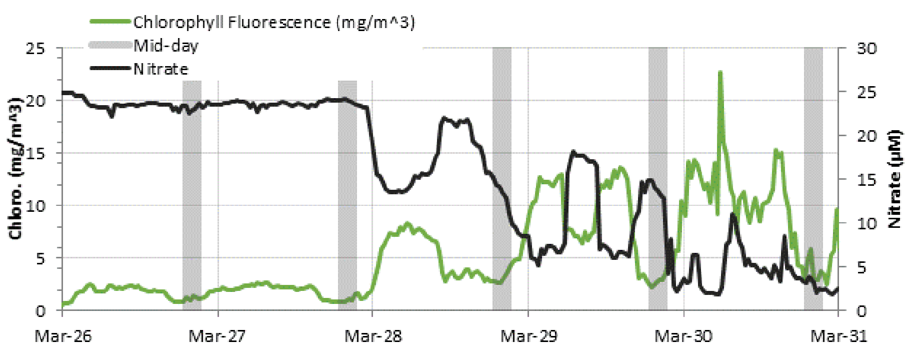

Figure 13-5. Chlorophyll from fluorescence (green, mg.m^{-3}) and nitrate (black, µM) at Sentry Shoal during the 2016 spring bloom in late March. Dates are UTC. Chlorophyll fluorescence decreases each day at local noon (grey vertical bars) due to non-photochemical quenching. This SUNA nitrate time series is the first record of continuous nitrate measurements in the Strait of Georgia

On the west coast of Vancouver Island, the timing of the 2016 spring bloom was average to late compared to previous years. The bloom start date was on about March 24 (Figure 13-6).

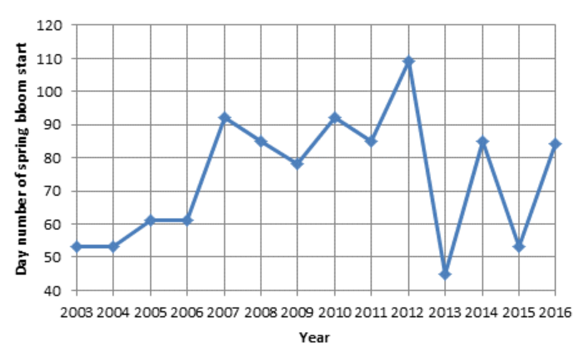

Figure 13-6. Spring bloom start dates for WCVI from MODIS FLH (NASA Giovanni, 8-day average FLH in 48-49N, 125-126W).

13.2.3. Bright coccolithophore blooms

Unusually bright coccolithophore blooms occurred in the Strait of Georgia and in many coastal inlets (Herbert Inlet, Sechelt Inlet, Broughton Island, Malaspina Inlet, Nitinat Lake) in 2016 (Figure 13-7; reported on elsewhere in this volume). Blooms occurred in May to September and were preceded by a bright bloom offshore in April and May. A time series of water brightness observed by MODIS Aqua for the central Strait of Georgia (not shown) confirms that the average brightness was about 4 times higher in August 2016 than in any month previously observed since 2002.

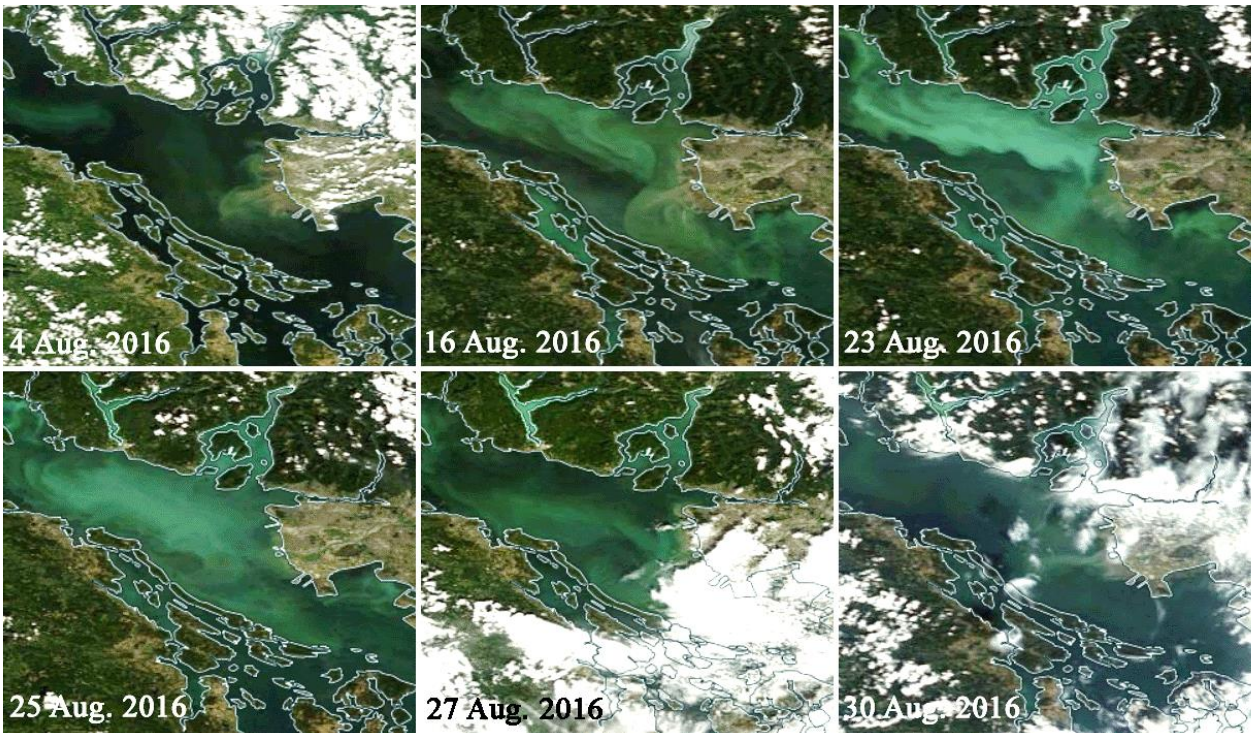

Figure 13-7. MODIS Terra (NASA Worldview) sequence of "true color" images at 250 m spatial resolution imaged the bright bloom in the Strait of Georgia on selected, relatively cloud-free days in August 2016. Similar bright blooms were observed in Herbert Inlet, Sooke Harbour, Nitinat Lake, round Broughton Island, in Malaspina Inlet and Sechelt Inlet (see 27 August panel above).

13.3. Factors influencing trends

A warming trend along the west coast is expected with on-going global warming, and is observed in long term lighthouse time series. The shorter buoy time series since 1990 show no appreciable warming. The coccolithophore blooms could be a response to long-term warming, coupled with possible seeding from offshore. Such blooms have not been previously observed in satellite or ship data. Local residents, for example in Sooke Harbour, call the bloom "unprecedented," suggesting uniqueness on a longer term.

13.4. Implications of those trends.

Any change in phytoplankton bloom patterns is a cause for concern. The coccolithophore blooms are not harmful in themselves, but may point to on-going changes in water properties.

13.5. Acknowledgements

The authors are grateful to Fisheries and Oceans Canada for access to government facilities under the Scientist Emeritus program, to the Pacific Salmon Foundation for funding in-situ monitoring, to NASA for satellite imagery and to Environment Canada for the buoy data and allowing use of the buoys for sensor deployments.

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14. PHYTOPLANKTON IN SURFACE WATERS ALONG LINE P AND OFF THE WEST COAST OF VANCOUVER ISLAND

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14.1. Highlights

- In 2016, phytoplankton biomass and community composition along Line P returned to normal, after low biomass and anomalous dominance of cyanobacteria in previous years associated with the pool of warm water known as "the Blob".
- On the continental shelf of the west coast of Vancouver Island, nitrate concentrations, phytoplankton biomass and community composition in May and September 2016 were within the range of values from previous years.
- Large blooms of coccolithophorids occurred in the summer of 2016 along the west coast of Vancouver Island, southern Strait of Georgia and nearby inlets. These harmless blooms turned the water a turquoise colour.

14.2. Description of the time series

Monitoring changes in phytoplankton biomass and community composition is important for the evaluation of ecosystem function and status, as well as for the study of biogeochemical cycles. Phytoplankton community composition, chlorophyll-a ("chl-a", an indicator of phytoplankton biomass) and nutrients are measured on DFO cruises three time a year in February, June, and August/September along Line P in the northeast subarctic Pacific and twice a year in May/June and early September off the west coast of Vancouver Island. Sampling for phytoplankton composition has been carried out at most of the stations along Line P (Figure 14-1a) since June 2010. Phytoplankton sampling along a series of transects on the west coast of Vancouver Island (Figure 14-1b) has been carried out since 2011.

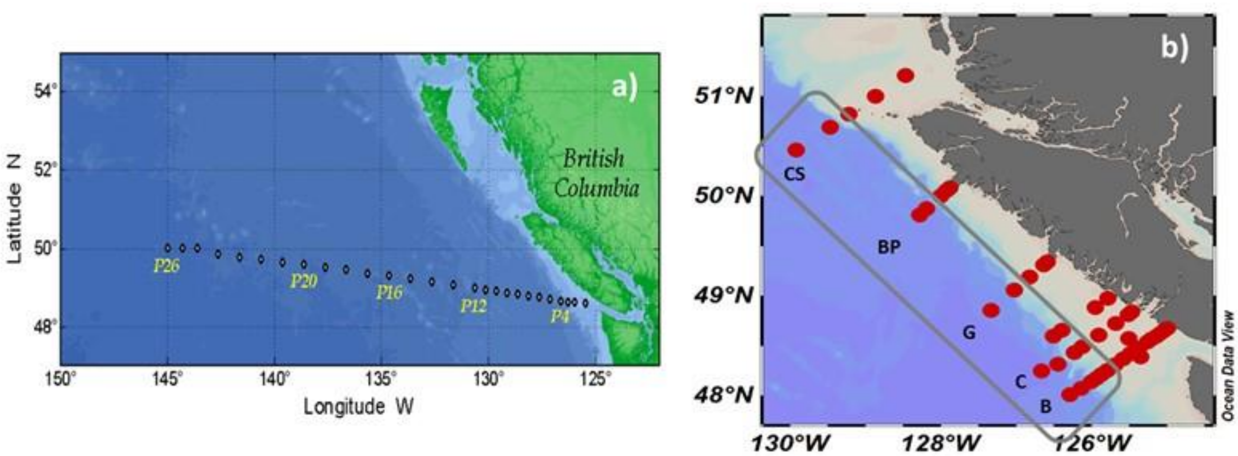

Figure 14-1. Location of sampling stations: a) along Line P, and b) on the west coast of Vancouver Island showing the outer coast region (grey rectangle) and continental shelf stations.

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

14.3. Status and trends

Nutrient concentrations in surface waters are usually high (>5 mmol m^{-3}) and chlorophyll concentrations low (<0.5 mg m^{-3}) year around in the Fe-poor haptophyte-dominated offshore waters, whereas high seasonal variability in phytoplankton biomass occurs in the nutrient-rich diatom-dominated inshore waters on the continental shelf. In 2016, surface nutrient values along Line P were slightly higher than those in 2015 (Figure 14-2), which were among the lowest on record since nutrient renewal was restricted in the winter of 2014/15 due to increased stratification. Nitrate was depleted at several stations along Line P in spring and summer of 2016 but the region of nitrate depletion was less extensive than in the previous year. Chl-a concentrations along Line P were within the range of values from previous years, except at the most offshore stations where high spring values were observed (Figure 14-2).

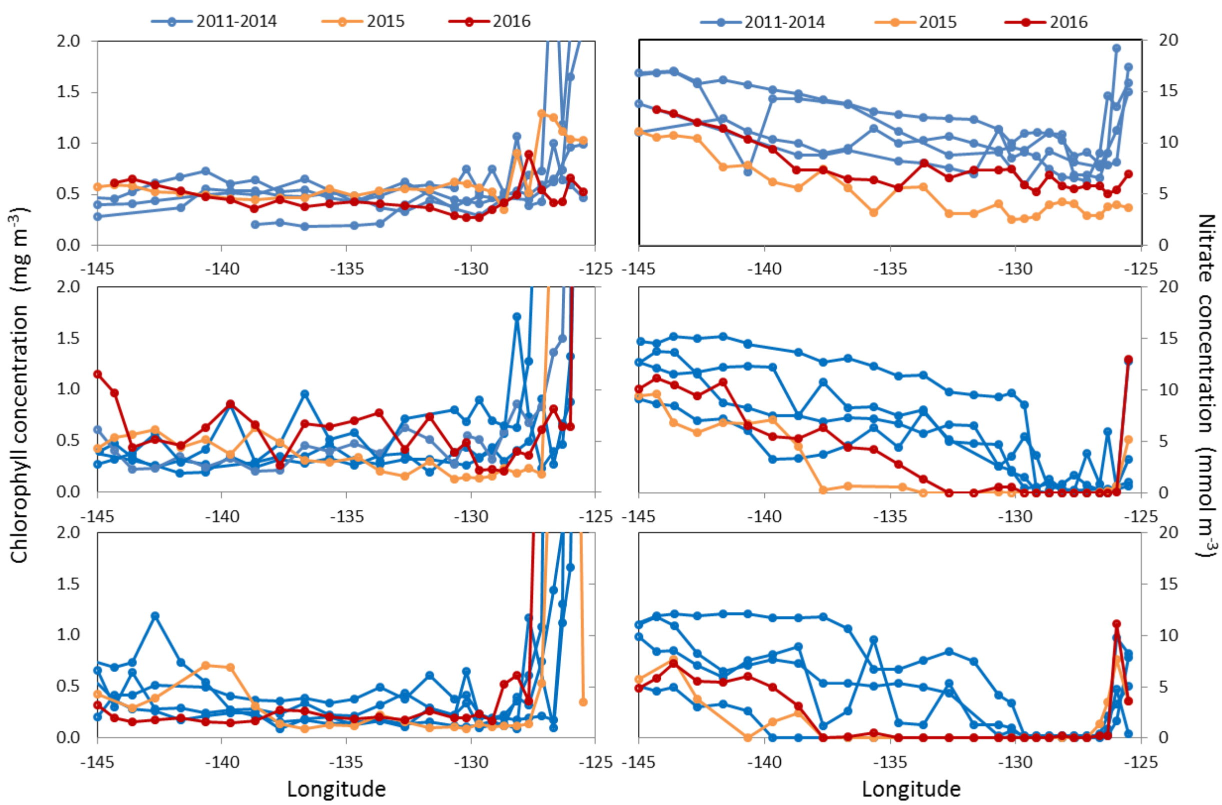

Figure 14-2. Chlorophyll-a (left panels, mg m^{-3}) and nitrate (right panels, mmol m^{-3}) in surface waters along Line P in winter (top panels), spring (middle panels) and summer (bottom panels) of 2016 (red symbols), 2015 (orange symbols) and 2011-2014 (blue symbols).

Phytoplankton assemblage composition returned to normal in August 2016 with haptophytes dominating phytoplankton biomass at the offshore stations and diatoms dominating closer to shore (Figure 14-3). At the farthest offshore stations, high chl-a values in June of 2016 were mostly due to an increase in diatom abundance.

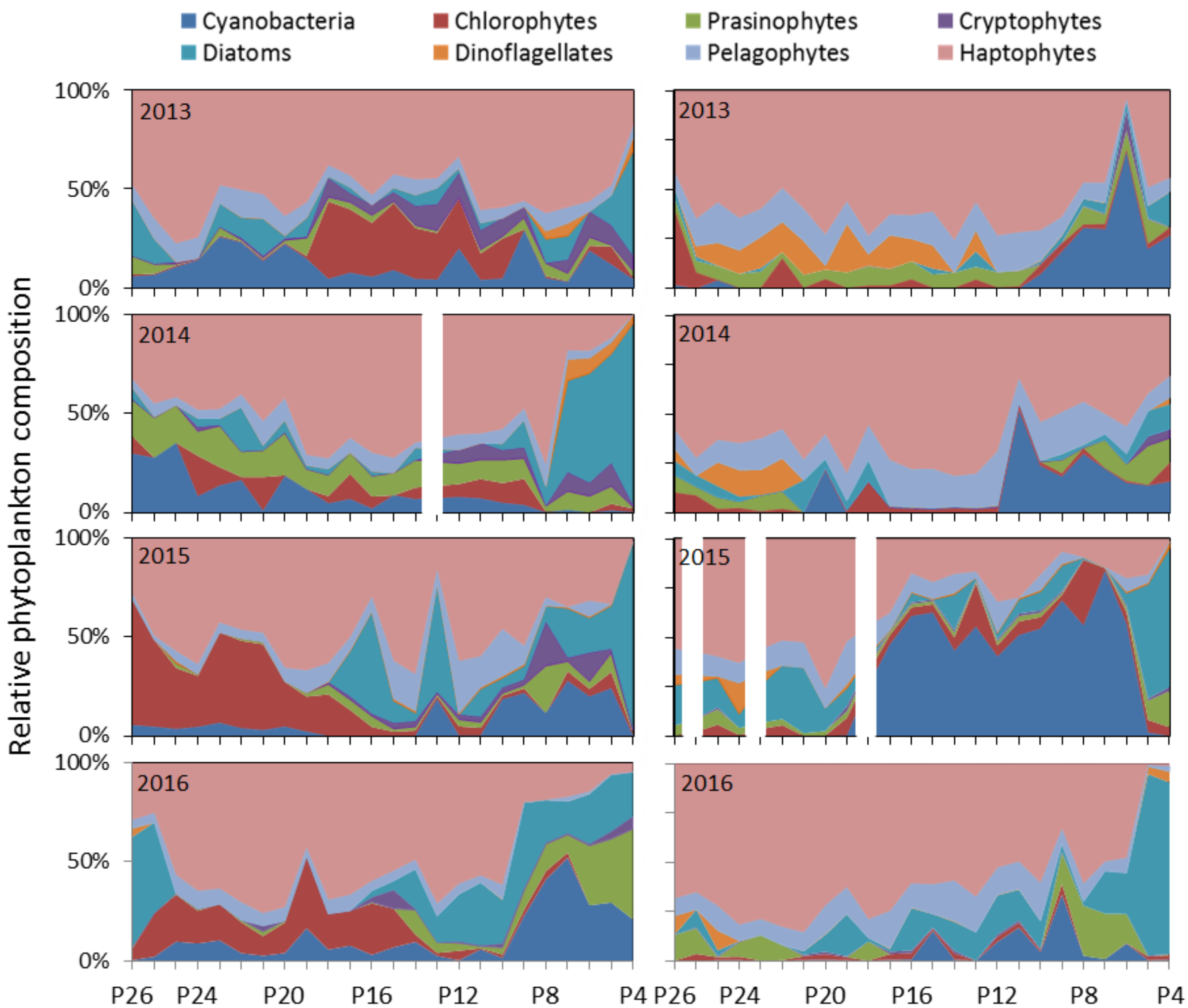

Figure 14-3. Relative phytoplankton composition in the upper layer at stations along Line P (see Figure 14-1) in June (left panels) and Aug./Sept. (right panels) of 2013 to 2016.

Nutrient and chl-a concentrations are highly variable in surface waters off the west coast of Vancouver Island. On the continental shelf, surface nutrient concentrations are usually lower in May compared to Sept. Chl-a is usually high (>5 mg m^{-3}) on the continental shelf off southern Vancouver Island where blooms of phytoplankton (>20 mg m^{-3} chl-a) are often observed in May and/or September. At stations beyond the continental shelf, chl-a and nutrient concentrations are usually lower than on the continental shelf. In 2016, nitrate concentrations in May were within the range of values observed in previous years, but in September they were often higher than in previous years (Figure 14-4). Chl concentrations in May 2016 were within the range of values observed in previous years. Very high chlorophyll concentrations (>25 mg m^{-3}) were observed in September off Estevan Point (Figure 14-4).

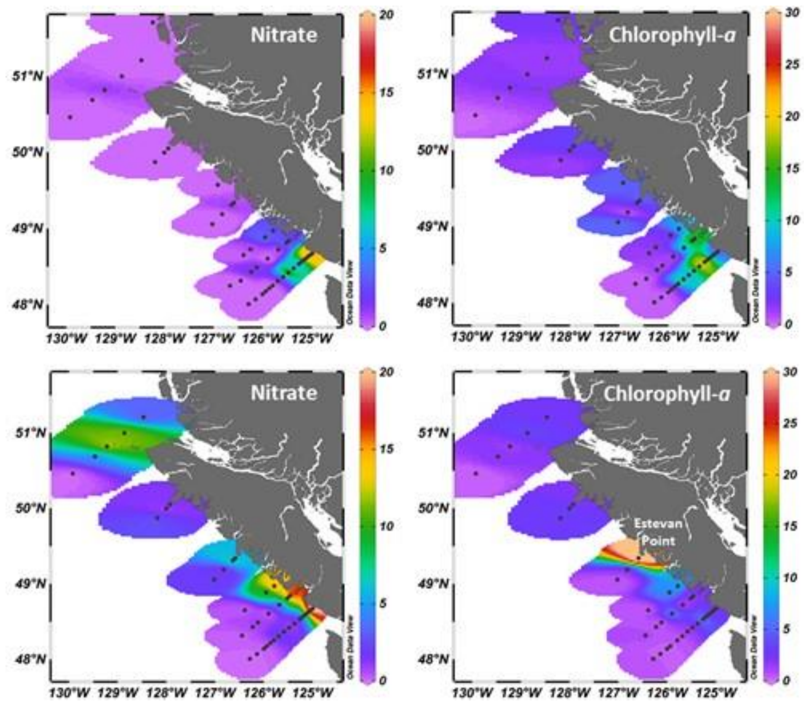

Figure 14-4. Nitrate (left panels, mmol m^{-3}) and chlorophyll-a (right panels, mg m^{-3}) at 5 m depth over the study area in May (top row) and Sept. (bottom row) of 2016.

Usually diatoms dominate phytoplankton biomass at the ocean surface along the continental shelf although dinoflagellates are found to occasionally dominate in September (Figure 14-5). At outer coast stations beyond the continental shelf phytoplankton community composition is more diverse and variable than on the continental shelf, with dinoflagellates, diatoms, haptophytes and cryptophytes dominating at times and far fewer diatoms than seen on the coast.

In May 2016, and similar to previous years, diatoms dominated the phytoplankton biomass on the continental shelf. At most locations in the outer coast, a mixed population was observed similar to previous years except for 2015. In September 2016, phytoplankton biomass and community composition in the continental shelf and outer coast were similar to previous years.

Between June and August 2016, large phytoplankton blooms of coccolithophores were observed along the west coast of Vancouver Island, southern Strait of Georgia and nearby inlets. These blooms were very news-worthy since they turned the water a turquoise colour and were clearly seen in by satellite (Gower and King 2017). Similar intense coccolithophore blooms occasionally occur off the west coast of Vancouver Island (e.g. June 2006) but a bloom like this in the Strait of Georgia is unusual. The main species found in most coccolithophore blooms, Emiliania huxleyi, is not harmful to fish or humans.

14.4. Factors influencing trends

Several environmental factors including temperature, irradiance and nutrient availability, as well as grazing pressure determine phytoplankton abundance and community composition. The observed changes in phytoplankton abundance and composition along Line P during the “Blob” years were likely in response to the increase in temperature and changes in nutrient availability. In coastal regions, such as the west coast of Vancouver Island where environmental conditions fluctuate rapidly, our sampling frequency (twice a year) is not adequate to study year-to-year variability in phytoplankton since the observed differences in chl-a concentrations and phytoplankton composition could be as much due to intra-seasonal as to inter-annual variability. To be able to compare among years, frequent (daily to bi-weekly) observations would be necessary depending on the time of the year.

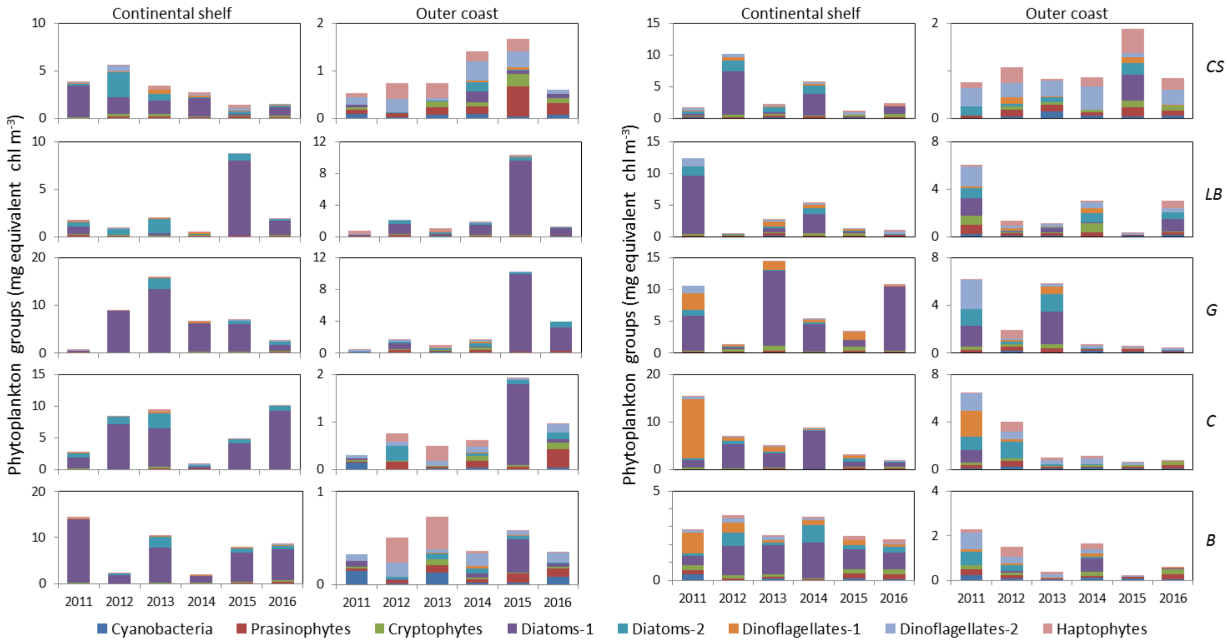

Figure 14-5. Time-series of mean phytoplankton composition at the surface at stations on the continental shelf and outer coast for Line B, C, G, BP and CS (see Figure 14-1) in May (left panels) and September (right panels).

14.5. Implications of trends.

Phytoplankton abundance and community composition are key factors influencing trophic processes and biogeochemical cycles in the ocean. Organic matter produced by phytoplankton is continuously transferred from lower to higher trophic levels, so the abundance, composition and distribution patterns of phytoplankton ultimately affect the sustainability of all marine life. The observed changes at the base of the food web could have ecosystem-wide implications. It is unclear, however, how fast can phytoplankton adapt to environmental conditions and how reversible are these responses.

14.6. References

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Mackey, M.D., Mackey, D.J., Higgins, H.W., and Wright, S.W. 1996. CHEMTAX-a program for estimating class abundance from chemical markers: application to HPLC measurements of phytoplankton. Mar. Ecol. Prog. Ser. 144: 265-283.

Nemcek, N., and Peña, M.A. 2014. Institute of Ocean Sciences Protocols for Phytoplankton Pigment Analysis by HPLC. Can. Tech. Rep. Fish. Aquat. Sci. 3117: x + 80 p.

15. LOWER TROPHIC LEVELS IN THE NORTHEAST PACIFIC

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15.1. Highlights

- Diatom abundance was high in May and August 2016, causing a positive anomaly for the year as a whole.
- Spring 2016 had high numbers of narrow diatoms, suggestive of lower nutrient conditions, although the bias towards these cell types was stronger in spring 2015.
- Zooplankton abundance was very high in summer 2016, biomass was above average, but the community was dominated by smaller taxa.

15.2. Sampling

Sampling from commercial ships towing a Continuous Plankton Recorder (CPR) occurs approximately monthly 6-9 times per year between March and October in the off-shore NE Pacific (Figure 15-1). Each CPR sample contains the near-surface (about 7 m depth) plankton from an 18.5 km length of transect, filtered using 270 µm mesh, and afterwards analysed microscopically to give taxonomically resolved abundance data. Data to June 2016 have been finalised at the time of writing, while data for July to Oct 2016 are still only partially complete. Several indices are now routinely updated and are summarized here.

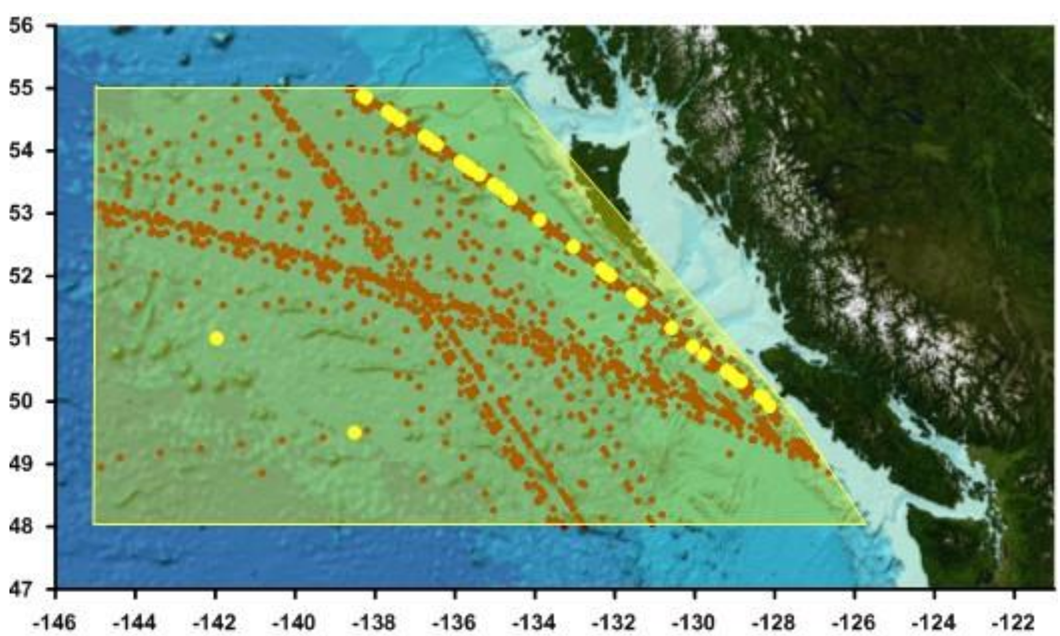

Figure 15-1. Map showing the location of the historical samples (dark red dots, 2000-2015) and those collected in 2016 (yellow) that are used in this report (additional 2016 samples are being processed). Data are averaged for the region outlined in yellow.

15.3. Plankton indices, Status and Trends

15.3.1. Diatoms

The CPR retains larger, especially chain forming, diatoms and an annual index of abundance is calculated (Figure 15-2). The 2016 abundance anomaly is likely to be positive when all data are finalised, with May and August concentrations being particularly high and other months close to average. 2015 was the first year to show a positive anomaly for almost a decade, and this was due to a very high late summer/fall abundance while spring 2015 was below average. It was also noted in 2015 that the spring community was biased towards species with long, narrow cell morphologies, and the data for spring 2016 (Figure 15-3) showed that their relatively high contribution continued, although not as dramatically as in 2015.

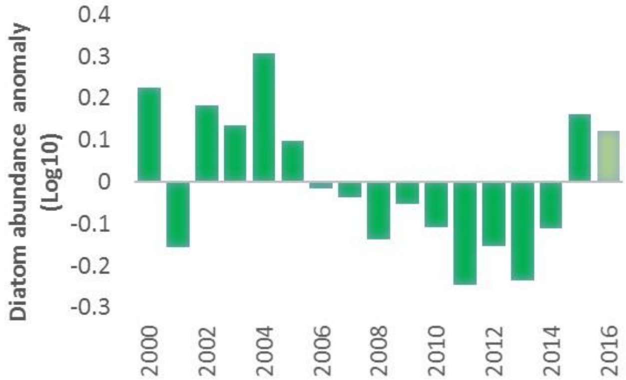

Figure 15-2. Annual abundance anomalies of large diatoms for the region shown in Figure 15-1. Value for 2016 is provisional.

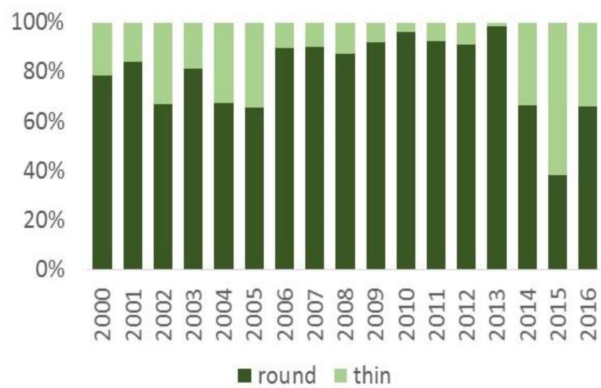

Figure 15-3. The proportion of the spring (Mar-June) diatom community comprised of either long, thin diatoms or round, chain forming cells.

15.3.2. Zooplankton

The mean annual abundance of mesozooplankton is projected to be very high for 2016, although at present this value is driven by high values in July and August which are not yet finalised (Figure 15-4) and spring values were closer to average. The estimated biomass was above average but not exceptional as most of the summer organisms were small copepods, with low individual biomass. In fact, the copepod community in summer 2016 consisted of much smaller than average species (Figure 15-5). Warm water species (typically smaller in size) were abundant in 2016, but not as abundant as in 2015 (Figure 15-6) so there were typical temperate/subarctic species prevalent in 2016.

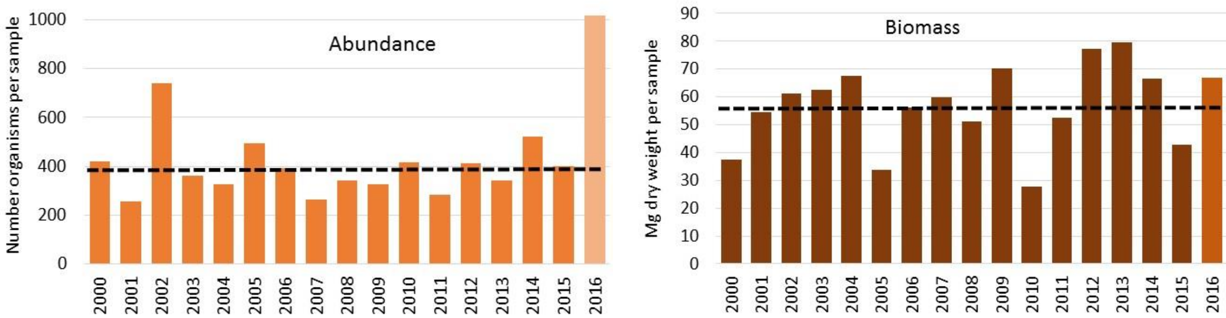

Figure 15-4. The mean annual abundance of zooplankton per sample (right) and biomass, estimated using taxon-specific values (left), for the region shown in Figure 15-1. 2016 values are provisional. Dashed lines indicate the long-term mean in each case.

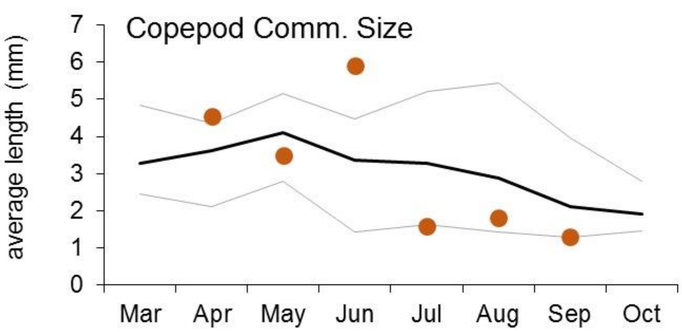

Figure 15-5. Seasonal cycle of mean size (length) of copepods. Black line is the long term monthly mean, grey lines are the long term monthly min/max and points are the monthly 2016 values (provisional after June).

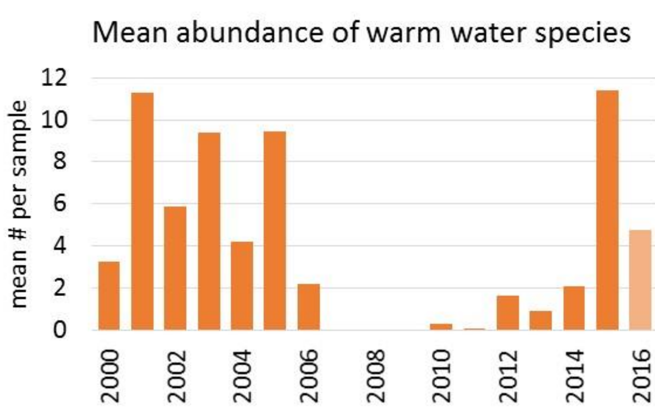

Figure 15-6. Mean annual abundance of a suite of warm water copepod species (Clausocalanus spp., Mesocalanus tenuicornis, Acartia danae and Corycaeus spp.).

15.4. Causes and Implications

The unusually warm conditions that began late in 2013 and persisted through 2016, termed a marine “Heat Wave” (DiLorenzo and Mantua 2016), had noticeable impacts on the plankton of the offshore NE Pacific. The abundance of large diatoms had been low in the cool years of 2008-2012 (Figure 15-2). During the last warm phase (2003-2005) diatoms were quite abundant, however, numbers did not increase with the arrival of increasing temperatures in 2013 and remained low until late in 2015. The cool years had also seen a dominance in spring by centric, chain forming taxa while warm years had an increase in the importance of cells with a narrow cell morphology. This was particularly true in spring 2015 (Figure 15-3) but 2016 was consistent with 2014 and warm years earlier in the time series. Low nutrient conditions (which might occur with increased thermal stratification, and/or reduced winter mixing and a shallower mixed layer) would favour narrower, smaller cells because of their higher surface area relative to their volume, consequently a more efficient uptake of nutrients.

The Heat Wave also reduced the numbers of large subarctic copepods present in surface waters after June (Figure 15-5) as they typically have a shortened life cycle in warmer conditions (Batten and Mackas 2009) and enter diapause by late spring. Warm water species (Figure 15-6) were favoured by the warm conditions, and other smaller but typically sub-arctic taxa were particularly abundant in summer 2016. While zooplankton biomass was relatively high in 2016, (Figure 15-4) it was packaged into smaller than normal organisms, especially in the summer/fall. This will likely have consequences for plankton predators, with more effort required to catch the same amount of food. Lower trophic level productivity in the offshore appears to be quite good in 2016 with positive anomalies in diatoms and zooplankton, however, given the prevalence of smaller diatoms and smaller copepods, the food web may have functioned differently.

15.5. References

Batten, S.D., and Mackas, D.L. 2009. Shortened duration of the annual *Neocalanus plumchrus* biomass peak in the Northeast Pacific. Marine Ecology Progress Series, 393: 189-198.

DiLorenzo, E., and Mantua, N. 2016. Multi-year persistence of the 2014/15 North Pacific marine heatwave. Nature Climate Change, published online:11 July 2016 DOI:10.1038/ nclimate3082

See http://pices.int/projects/tcprsotnp/default.aspx for CPR data, updates and more information.

16. ZOOPLANKTON ALONG THE B.C. CONTINENTAL MARGIN 2016

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16.1. Highlights

- Consecutive years of warm water intrusions from a southerly direction are effectively making the west coast of Vancouver Island like the nearshore California Current: high in gelatinous taxa and low in crustaceans.
- *Dolioletta gegenbauri* was observed for the first time in inside waters of B.C., in the waters off Port Hardy and Port McNeill.
- Sub-Arctic and boreal copepods and chaetognaths continue to decline as southern copepod and chaetognath species increase.
- There was no winter cooling of the waters off Vancouver Island.

16.2. Description of the time series

16.2.1. Shelf and exposed coastal waters

Zooplankton time-series are available for southern Vancouver Island (SVI; 1979 to present), northern Vancouver Island (1990 to present) and for Hecate Strait (1998 to present), although with lower density and/or taxonomic resolution for NVI and Hecate Strait earlier in the time series. For this report, we present data from 1990. The 'standard' sampling locations are averaged for the SVI, NVI and Hecate regions shown in Figure 16-1. Additional locations are included in averages when they are available. Samples were collected during DFO research surveys using vertical net hauls from near-bottom to sea surface on the continental shelf and upper slope, and from 250 m to surface at deeper locations. Abundance and biomass is estimated for more than 50 zooplankton species in these areas.

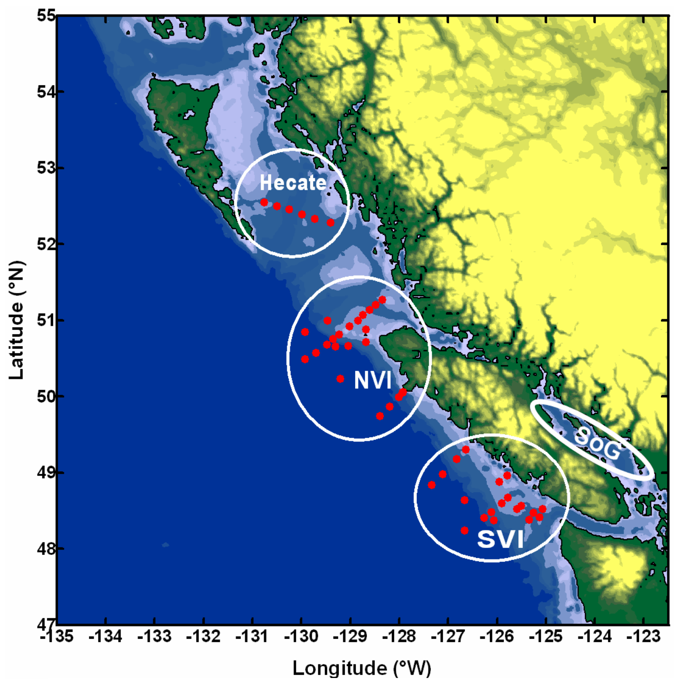

Figure 16-1. Zooplankton time series sampling locations (red dots) in B.C. marine waters. Data are averaged for samples within each area; the SVI and NVI regions are further classified into shelf and offshore subregions.

To avoid confounding seasonal and interannual variability, a climatology was estimated for each region, using the data from the start of each time series through 2008, and compared to monthly conditions during any single year. To describe interannual variability, our approach has been to calculate within each year a regional, logarithmic scale biomass anomaly for each species and for each month that was sampled in a given year. We then average the monthly anomalies in each year to give an annual anomaly (see Mackas 1992 & Mackas et al. 2001 for mathematical details; for SoG see Mackas et al. 2013).

Zooplankton species on the west coast with similar zoogeographic ranges and ecological niches usually have very similar anomaly time series (Mackas et al. 2006). Therefore multiple species are averaged within species groups to show interannual variability (Table 16-1).

Table 16-1. Zooplankton groups described in the time series in Figure 16-2

Zooplankton group	**Species**	**Comments**
Southern copepods	*Acartia, Clausocalanus, Calocalanus, Ctenocalanus, Mesocalanus*, *Paracalanus*	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 mimus, Acartia longiremis*	Southern Oregon to the Bering Sea
Subarctic oceanic copepods	*Neocalanus plumchrus*, *N. cristatus*, *N. flemingeri*, *Eucalanus bungii*	Inhabit deeper areas of the subarctic Pacific and Bering Sea from North America to Asia
Euphausiids	*Euphausia pacifica*	Euphausiids corrected for day/night tows.
Southern chaetognaths	*Mesosagitta minima, Serratosagitta bierii, Parasagitta euneritica*	Centered off California/Mexico
Northern chaetognaths	*Parasagitta elegans*	
Cnidarians		Siphonophores and hydromedusae

Several high-order zooplankton taxa (with widely differing ecological niches) are classified as “gelatinous zooplankton”. However, all have high to very high peak reproductive rates compared to the crustaceans and chaetognaths and all tend to have “boom and bust” population time series. The most important gelatinous zooplankton groups in the SVI and NVI regions are:

- Salps and doliolids. These are planktonic tunicates, and are primarily herbivorous (broad spectrum filter feeders)
- Thecosomatous pteropods (e.g. *Limacina helicina*). These are planktonic snails. Unlike the previous two groups, their bodies are not gelatinous, but they use a large external gelatinous feeding web to capture their food.
- Hydromedusae and siphonophores (“jellyfish”) and ctenophores (“comb jellies”). These are predatory on other zooplankton, sometimes on larval fishes but mainly competitors with larval fish.

16.2.2. The Strait of Georgia

We have also recently compiled historic data from various shorter term sampling programs in the Strait of Georgia (SoG). The majority of the SoG sampling prior to 2014 did not follow a standard grid or sampling protocols making it difficult to generate a time series. The analysis merged samples into broader categories (size classes within major taxa) as described in Mackas et al. 2013 and Irvine and Crawford (2013).

16.3. Status and trends

16.3.1. Shelf and exposed coastal waters

Figure 16-2 and Figure 16-3 illustrate the biomass anomaly time series for copepod species groups and representative chaetognaths and euphausiids in the WCVI and Hecate statistical areas. The range of interannual biomass variability within a species or species group is about one log unit (i.e. factor of 10). This is 2-3 times greater than the interannual variability of total biomass in our regions. Other features to note are that anomalies often persist for several years and that, in addition to the covariation within species groups mentioned above, there is strong covariation between some species groups. The clearest covariation has been in the three copepod groups and in the chaetognaths.

2016 started off as a warm year, very much like 2015 with no winter cooling (Yelland and Robert 2017). In both the near shore and offshore regions there were strongly positive anomalies for southern zooplankton. This increased throughout the year as warm nearshore water with higher abundances of southern oceanic zooplankton species moved poleward. By October the whole continental margin of B.C. was inundated with large masses of gelatinous animals: mainly salps, pyrosomes and gymnosomes.

There was no moderation of the monthly anomaly signal in all taxa groups for 2016 that is normally seen as seasons move from cold winter into warm fall. Thus, what was positive at the beginning of the year stayed a positive signal (same as 2015). This is a similar situation to 2005, with no winter cooling (Yelland and Robert 2017). In 2016, southern fauna were found in all areas (north and south Vancouver Island offshore and shelf), with the doliolids along the shelf break. In May, *Dolioletta gegenbauri* was observed in the waters off Port Hardy and Port McNeill, the first time recorded in inside waters of our coast, but was not found in Hecate Strait (Figure 16-3)

Both SVI and NVI nearshore and shelf regions had similar seasonal trends toward more southern copepods, stronger than in 2014 and 2015 (Figure 16-2). The southern copepod signal was stronger in Hecate as these copepods are rarely transported this far north. The overall trend was negative for boreal and sub-Arctic copepod species for the whole west coast. As more September/October samples are analyzed, it is expected this will enhance the warm water signal within the anomalies. One of the main reason for less boreal copepods is the near absence of *Pseudocalanus* species on the shelf in the south and the replacement of *Calanus marshallae* with *Calanus pacificus* in the north. And much like 2015 the influx of southern species brought in some rarer animals not usually seen off WCVI except in large El Niño events: *Mecynocera clausi, Acartia tonsa, Acartia danae, Centropages bradyi, Clausocalanus mastigophorus, Aetideus giesbrechti, Pleuromamma gracilis, Pleuromamma indica, Paracalanus quasimodo, Parvocalanus crassirostris, Oithona tenuis*, *Rhincalanus nasutus* and *Sapphirina spp.*

Boreal copepods were reduced along the shelf, more so in the south coast and in Hecate Strait. Southern copepods were positive in all regions for the second year in a row (Figure 16-2 and Figure 16-3). Subarctic oceanic copepods are typically found along the shelf break in the spring so the expectation was that they should do better in the offshore environment than on the shelf. For all regions, both on the shelf and offshore areas, the annual anomalies of the subarctic oceanic copepods were negative in 2016 (Figure 16-2 and Figure 16-3).

Euphausiids continue to trend fairly positive over the last five years off the west coast of Vancouver Island (WCVI). In Hecate Strait the euphausiid biomass has flip-flopped the last few years. Off California, both *Euphausia pacifica* and *Thysanoessa spinifera* are the dominant species suggesting that warmer waters may enhance their reproductive success along Vancouver Island, though in the past warming events tended to favour *E. pacifica* over *T. spinifera*. It may be possible that the currents of the El Niño may have carried more euphausiids from the south to mix with the resident population, doubling the biomass anomaly. *Thysanoessa gregaria, Nematocelis difficilis* and *Nyctiphanes simplex*, euphausiid species whose distribution centres off Oregon/California and south, were found in small numbers along the Vancouver Island shelf throughout the year.

Both the siphonophores and hydromedusae continue to be positive for 2016, especially on the shelf and shelf break areas of Vancouver Island. The gelatinous zooplankton community in Hecate Strait followed the same trend as off WCVI (Figure 16-3 and Figure 16-2).

Doliolids were absent or rare in nearly all years before 2003, but since then have been present in years of warm water incursions in the SVI region (and nearly as abundant in the NVI region). Years with positive doliolid anomalies have occurred throughout the time series, with 2015 being the highest recorded for doliolids (Figure 16-2). Doliolids were also abundant in Hecate Strait, from late August to October, but in much lower numbers than off WCVI (Figure 16-3). This year a large number of pyrosome colonies were found washing up on western exposed beaches along Vancouver Island and Haida Gwaii. Plankton nets do not adequately sample the larger ones but net samples did show numerous small colonies around 5-20 mm in length on the shelf and along shelf break of SVI.

For the last four years, a warm water pteropod, *Corolla spectabilis,* was found on the shelf and offshore areas of all regions. The last known occurrences were in 2005/6 and 1997/98. As with the long term trend in the copepod species groups, in 2015 and 2016 the gelatinous zooplankton community off B.C. was more similar to the community found in nearshore parts of the California Current System to the south of B.C., less like the historical SVI and NVI climatology, and less like the present-day zooplankton community off northern British Columbia and Alaska.

For the past five years ctenophores have seen a positive trend in both NVI and SVI which has been consistent over the shelf and offshore areas. In Hecate this increase has been seen over the last 2 years. The main ctenophore collected is *Pleurobrachia bachei* but there has been some *Horminophora*, a southern species, in the offshore areas.

With the increased interest in ocean acidification we have included anomaly trends for *Limacina helicina*, a pelagic thecosomate (shelled) pteropod with a calcareous shell susceptible to dissolution damage if water in the top 100 m is under-saturated for aragonite. For WCVI, the overall trend for *L. helicina* is negative; the small positive anomaly in 2013 in NVI was a result of sampling in cool spring conditions along the shelf and shelf break, not seen in recent years. Both the shelf and offshore areas of NVI and SVI have been trending negative in the early 2000's but recently have been just below average. *Limacina* in Hecate Strait showed a slight positive anomaly in 2015 but without the previous years it is difficult to determine if this is a positive trend or maintaining average abundance (Figure 16-3; note that there was a very low number of samples from many of the previous years, missing data from 2012-14 and 1996-97 when the area was not being sampled); 2016 was negative for the area. In SoG, there has been a positive trend in *Limacina* anomalies from 2010 onwards with just a slight downward trend in 2016 (not shown). However, their average size is smaller (<2 mm) for the past couple of years.

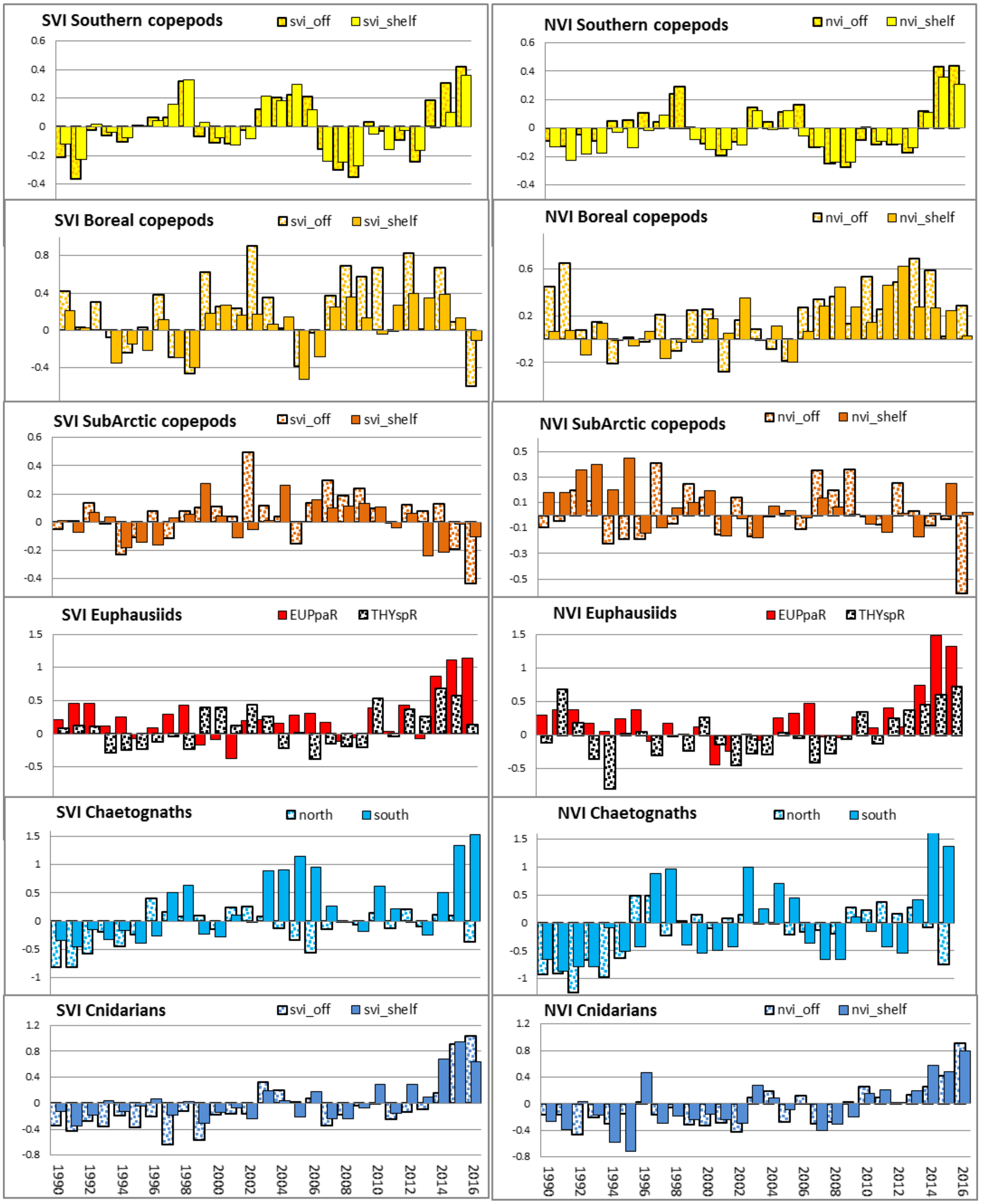

Figure 16-2. Zooplankton species-group anomaly time series for the SVI (left) and NVI (right) regions shown in Figure 16-1. Bar graphs are annual log scale anomalies. Cool years favor endemic 'northern' taxa; warm years favor colonization by 'southern' taxa. See earlier State of the Ocean reports for pre-1990 anomalies. Note the y-axis changes with each taxonomic group. It is important to note that the anomalies are log scale and therefore multiplicative on a linear scale: an anomaly of +1 for a given taxon means that taxon had 10X higher biomass than in the climatology; an anomaly of -1 means the biomass was 1/10th the climatology.

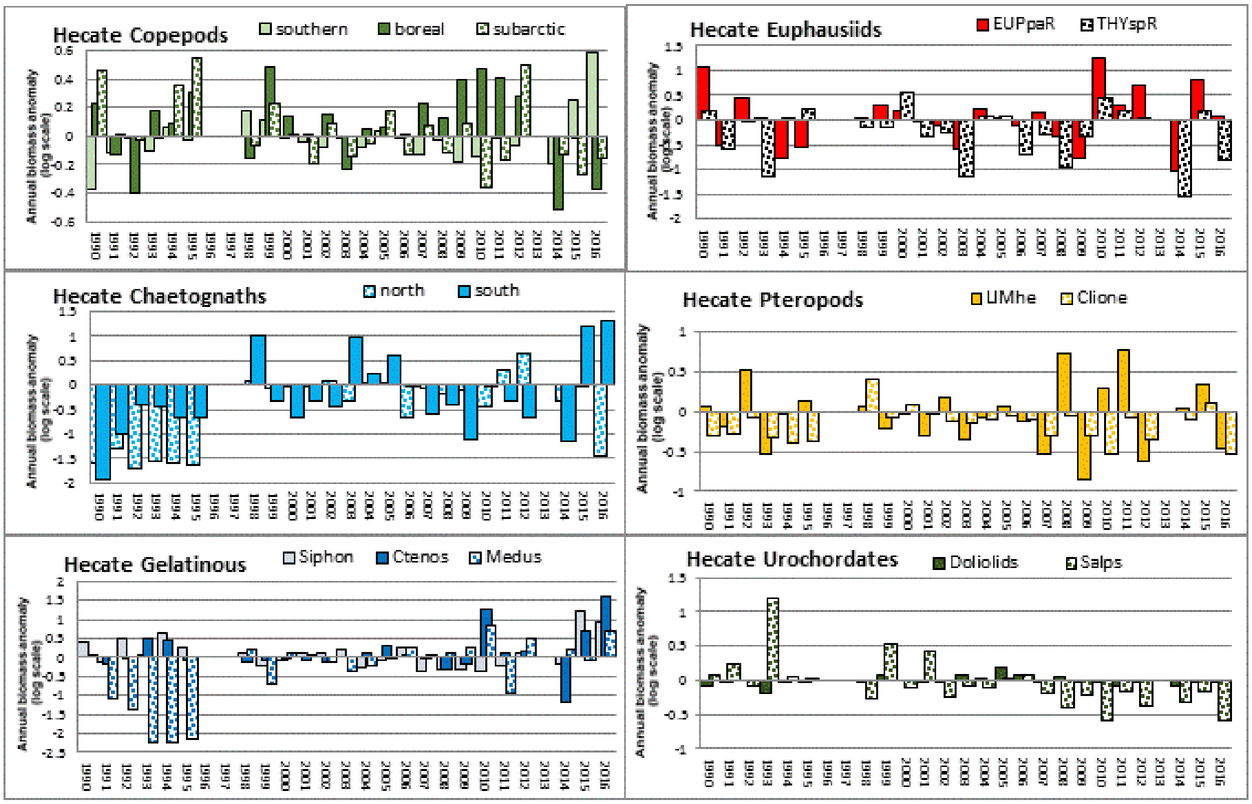

Figure 16-3. Zooplankton species-group anomaly time series (vs climatological baseline) for the Hecate Strait region shown in Figure 16-1. EUPpa: Euphausia pacifica; THYsp: Thysanoessa spinifera; Chaetognaths divided into north/south species groups; LIMhe: Limacina helicina; Clione one of the naked pteropods. Blank years mean no samples: 1996-97; 2013-14.

In an attempt to summarize and simplify, all the material presented here has been condensed into a CSIndex, or “Crunchie:Squishy” Index:

- Crunchies: all zooplankton having a hard, chitinous exoskeleton; mainly crustaceans with high protein and lipid material – copepods, euphausiids, amphipods, decapods, etc.
- Squishies: all zooplankton with a hydrostatic skeleton; mainly gelatinous animals with high water content and low nutritional value – hydromedusae, salps, doliolids, ctenophores, etc.

Low and/or sporadic sampling effort in Hecate Strait makes it difficult to summarize those data but the pattern is similar for the most part as that of NVI. Figure 16-4 illustrates that the SVI shelf and offshore area, in times of warming events (1997/98, 2003/04, 2015/16; Ross 2017), are inundated with low nutrient gelatinous animals and the more nutritious, lipid rich zooplankton are found along the NVI shelf break and offshore areas. For the animals that rely on the spring and summer bonanza of crustaceans in the nearshore areas, this makes foraging for food a more arduous (calorie consuming travel) and risky (more exposure to predators) undertaking. Expectations are that the years when gelatinous zooplankton are more abundant, such as 2015 and now 2016, equate to poor survival prospects for juvenile fish and seabirds.

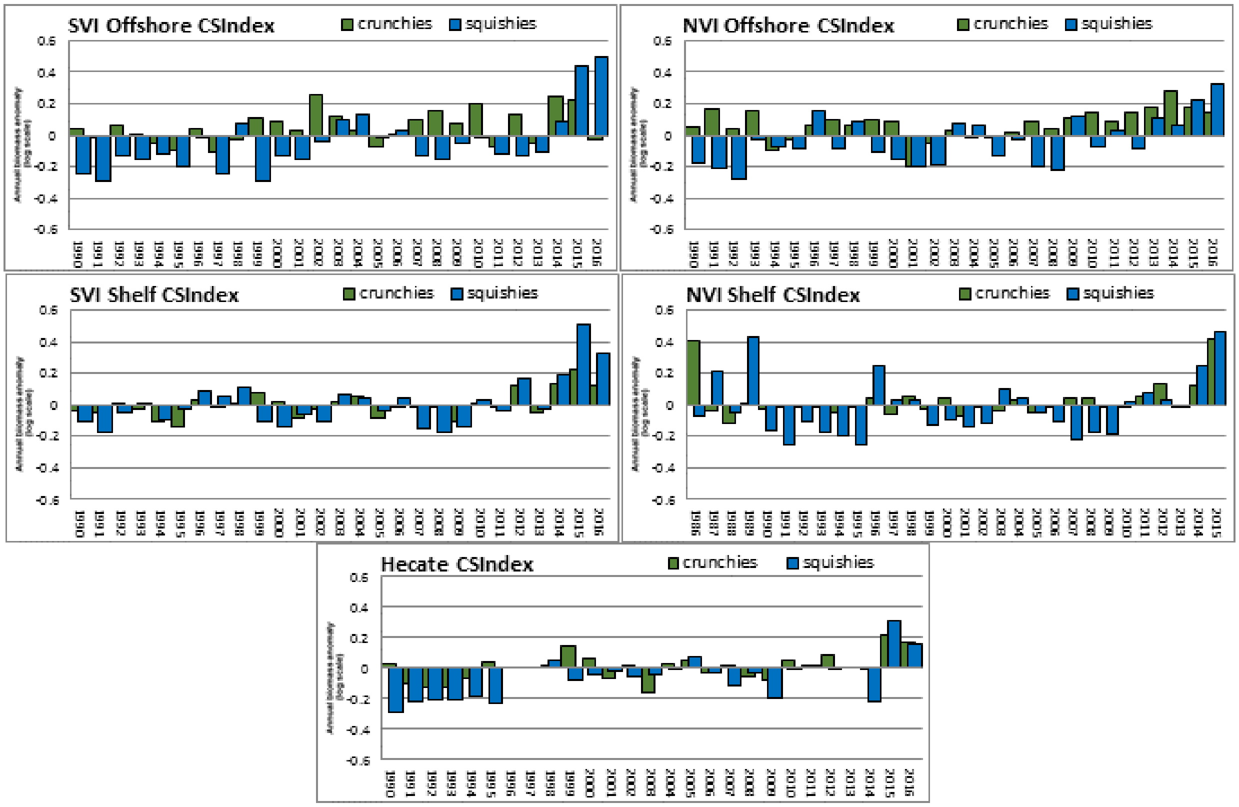

Figure 16-4. CSIndex: gelatinous zooplankton i.e. squishies; versus arthropod taxa: i.e. crunchies; (ignoring mero- and ichthyoplankton) off southern and northern Vancouver Island and Hecate Strait.

16.3.2. The Strait of Georgia

In the Strait of Georgia, the warming event of 2015 is having a noticeable effect (Figure 16-5). For *Neocalanus plumchrus*, the warming of the bottom of strait could be precluding the overwintering diapause for these large copepods and this may be leading another population collapse. For southern copepods and chaetognaths (upper water column dwellers) the wind and currents movements are allowing them to be carried in through the Juan de Fuca and/or Johnstone Strait. For zooplankton that are residents of the SoG year round (*N. plumchrus* and *E. pacifica*), something happened between 2010 and 2011 to increase their biomass (perhaps an influx of cold water), and then things settled into near average conditions after 2011, and a negative trend to 2016. There are several mechanisms for zooplankton from the shelf and open ocean to get into the strait but there is a time lag of one year to two years for those events to occur (Mackas et al. 2013).The full effects of the El Niño event of 2016 on the zooplankton community is not expected to be seen until sometime in 2017 or 2018.

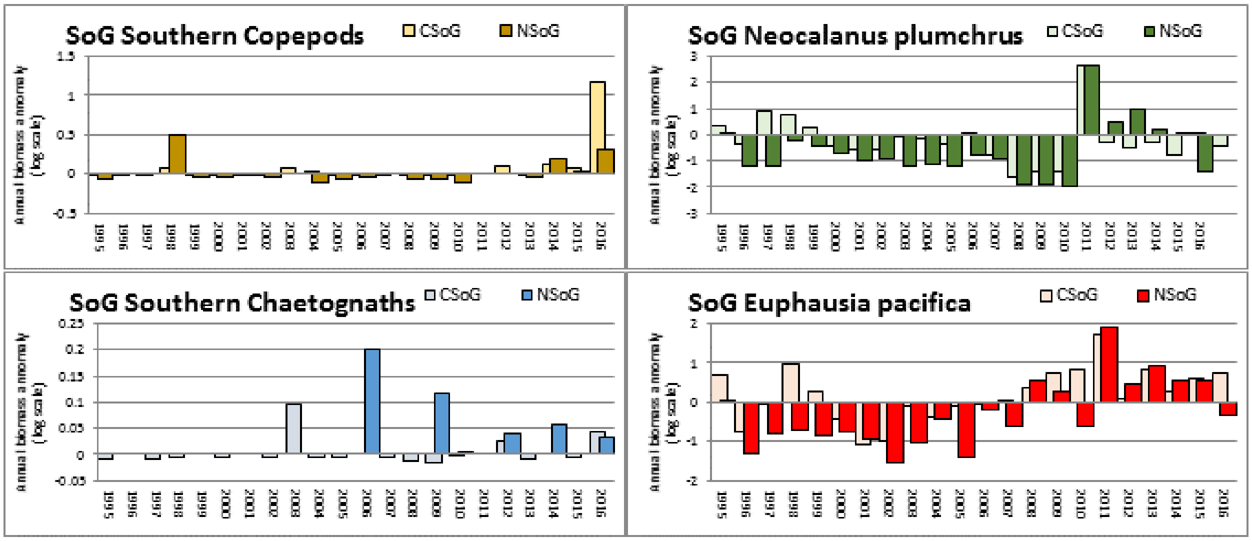

Figure 16-5. Biomass trends of selected species and groups from the Central Strait of Georgia (CSoG) and Northern Strait of Georgia (NSog)

16.4. Factors influencing and implications of the trends

Cool years such as the early 1980s, 1999-2002, and 2007-2009 had positive anomalies of boreal shelf and subarctic copepods, and northern chaetognaths. Warm intervals such as 1983, 1993-1998, 2004-2005 and 2010 tended to have negative anomalies of these taxa, but positive anomalies of southern copepods and southern chaetognaths.

Early in 2016, warm water was moving from south to north and the zooplankton reflected this with more southern coastal species along the shelf mixing with southern oceanic species. 2015 had more sub-tropical oceanic species, from water moving from offshore to nearshore rather than south to north.

Aglantha digitale is one of the most abundant hydromedusae in the North Pacific, but in further analyses it was discovered that it was not what was driving the positive signal in the hydromedusae off the WCVI (Figure 16-4). The majority of the biomass of hydromedusae can be attributed to an increase in numbers of *Mitrocoma, Clytia* and *Halitholus*. By late summer and into the fall, *A. digitale* was replaced by its southern counterpart *Aglaura hemistoma,* along the shelf and shelf break, whose normal distribution in the Pacific from 40° N to 40° S. Immature *Velella velella* were in collected in the fall samples from SVI, NVI and Hecate shelf areas. It is possible they may start washing up on beaches as they mature. Hydromedusae have always been abundant in the Strait of Georgia but there has been a definite increase in the numbers of *Pleurobrachia bachei,* especially in the near shore areas (not shown).

Bongo samples are notoriously impractical for the capture of Scyphozoans so it is difficult to ascertain their relative abundance. These would be the true jellyfish and a concern to the public due to their size and stinging properties. Efforts have been made to observe their numbers from deck sightings and 2015 and 2016 had an increase in the fall of each year, especially in the SoG and VI nearshore shelf areas.

From previous work, we know that positive anomalies of the cool water zooplankton community off Vancouver Island are also associated with good local survival and growth of juvenile salmon, sablefish, and planktivorous seabirds (Mackas et al. 2007; M. Trudel, DFO, pers. comm.).

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17. NORTHERN ABALONE (*HALIOTIS KAMTSCHATKANA*) ABUNDANCE IN BRITISH COLUMBIA

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17.1. Highlights

- Between 1978 and 1990, abundance of Northern Abalone (*Haliotis kamtschatkana)* at surveyed index sites in the Central Coast and East Coast Haida Gwaii declined 75-80%.
- The commercial fishery was closed in 1990, and short-term recovery was not subsequently observed, resulting in an assessment by COSEWIC as 'threatened' in 1999 and a re-assessment as 'endangered' in 2009.
- Recent observations from index sites in regions without sea otters (*Enhydra lutris*; East and West Coast Haida Gwaii and Central Coast) indicate that the population density may be increasing, however the age structure is highly skewed towards smaller individuals.
- Recent observations suggest that population densities in regions with sea otters (west Coast Vancouver Island and Queen Charlotte Strait) remain low.

17.2. Description of the time series

Northern Abalone populations are monitored at index sites in each of 5 regions throughout the British Columbia coast on a 5-year rotation. Index sites were originally established in 1978 on the East Coast of Haida Gwaii and the Central Coast for stock assessment purposes. Following the closure of the fishery and listing of the species, index sites were also established on the west coast of Vancouver Island (2003), Queen Charlotte Strait (2004), and the west coast of Haida Gwaii (2008) to monitor stock status on a coast-wide basis (Figure 17-1). These regions are further subdivided into smaller areas, each consisting of multiple index sites.

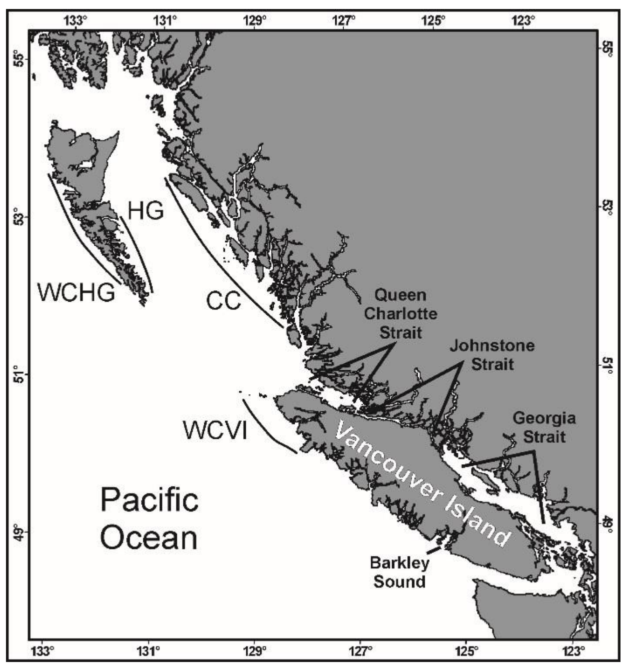

Figure 17-1. Map showing the five Abalone index site regions: West Coast Haida Gwaii (WCHG) East Coast Haida Gwaii (HG), Central Coast (CC), West Coast Vancouver Island (WCVI), and Queen Charlotte Strait.

Abalone are surveyed at each site using a standardized 'Breen' methodology (Breen and Adkins 1979, DFO 2016). Habitat attributes such as algae and substrate are also recorded. The results of these surveys are used to determine stock status relative to recovery objectives outlined in the "Action plan for the Northern Abalone (*Haliotis kamtschatkana*) in Canada" (DFO 2012) and are also used by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) to assess the status of the species and by the DFO Species at Risk program to guide management actions.

17.3. Status and trends

Between 1978 and 1990, the abundance of abalone showed a 75-80% decline at index sites on the east coast of Haida Gwaii and the Central Coast (Figure 17-2). This decline resulted in a closure of commercial, recreational, and First Nations fisheries. Despite the moratorium on harvest, densities remained depressed throughout the coast until about 2006, resulting in Northern Abalone being assessed as ‘threatened’ in 1999 and re-assessed as ‘endangered’ in 2009 by COSEWIC. Unlike many other endangered species, habitat is not a limiting factor for Northern Abalone. Possible causes for the lack of recovery, despite a ban on harvest, include low recruitment, illegal harvesting, and sea otter predation (DFO 2012).

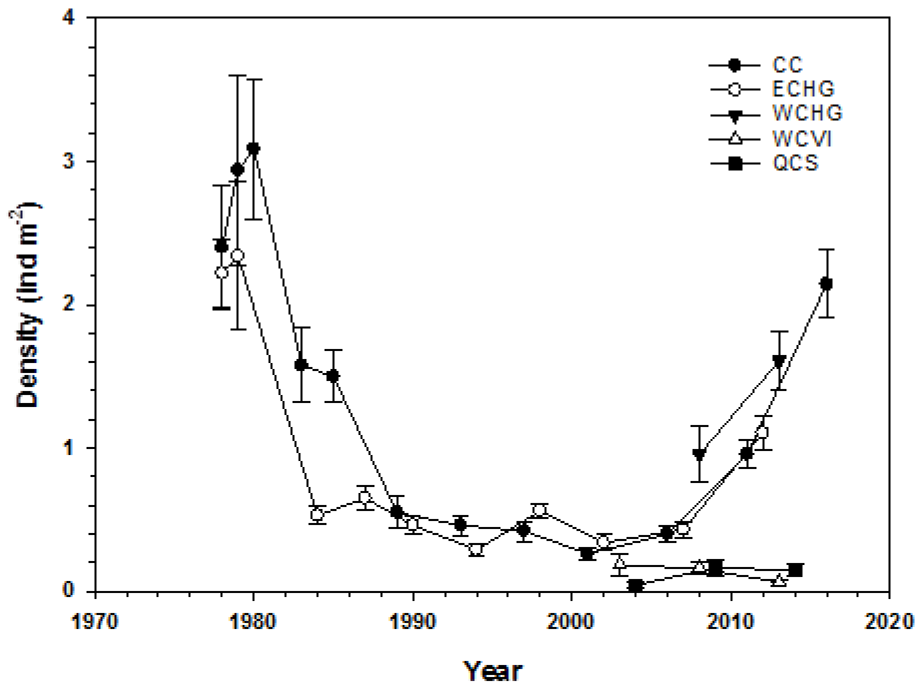

Figure 17-2. Total density of abalone (all sizes combined) for each index site region 1978-2016: Central Coast (CC), East Coast Haida Gwaii (ECHG), West Coast Haida Gwaii (WCHG), West Coast Vancouver Island (WCVI), and Queen Charlotte Strait (QCS). Values are mean ± SE.

Since about 2006, in regions without sea otters (East and West Coast Haida Gwaii, and Central Coast) the total density of abalone (individuals m^{-2}, for all size classes combined) at index sites has shown a steady increase. However, in regions with sea otters (West Coast Vancouver Island and Queen Charlotte Strait), total population density at index sites remains low (Figure 17-2).

Prior to the declines that led to the listing of Northern Abalone under the Species at Risk Act (SARA), the population was dominated by large individuals. Since that time, the population has begun to show a trend towards both proportionally and absolute higher densities of smaller individuals (Table 17-1).

Table 17-1. Representative shell length data from the Central Coast Index Sites (1978-2016).

	Shell Length (mm)					
Year	**Mean**	**SE**	**Median**	**Min**	**Max**	**Total Count**
1978	94.9	1.0	97	30	149	454
1979	81.6	0.7	83	17	139	804
1980	68.2	0.7	70	14	129	959
1983	80.9	0.6	82	8	131	1076
1985	82.5	0.8	85	6	129	702
1989	81.3	1.4	82	20	140	227
1993	78.4	1.1	80	16	126	421
1997	80.7	1.4	84	20	142	317
2001	77.6	1.4	81	29	122	230
2006	69.4	1.1	74	2	122	433
2011	63.8	0.8	66	3	124	1137
2016	52.9	0.5	50	2	132	2771

17.4. Factors influencing trends

While the exact reasons for the observed increases in density of Northern Abalone at index sites are unknown, there are a number of potential contributing factors. The closure of the commercial, recreational, and First Nations fisheries for abalone in 1990 likely reduced mortality however, despite these closures, populations continued to decline and densities in areas without sea otters did not begin to increase until about 2006. The factor which has primarily been implicated is that, despite increased enforcement efforts and public awareness campaigns, poaching convictions continue (DFO 2015). Another possible contributing factor to the delay in observed density increases is the ‘Allee Effect’, whereby the population may have been depressed below a critical density and only increased very slowly until the critical density was met and rates of fertilization and subsequently recruitment could increase. Lastly, although increases in density were observed prior to its occurrence, the coast wide spread of sea star wasting disease in 2013 resulted in a near eradication of the Sunflower Seastar (*Pycnopodia helianthoides)* (Hewson et al. 2014). Since *Pycnopodia* are a major predator of Northern Abalone (Sloan and Breen 1988), their absence likely resulted in a large decrease in predation pressure, and in turn, may have increased recruitment and survival. It is important to note that Northern Abalone populations have only been observed to be increasing in areas where sea otters are absent or their densities are low (East and West Coast Haida Gwaii, and the Central Coast). In areas where sea otters are well established (Queen Charlotte Strait and West Coast Vancouver Island), population densities remain low.

The exact causes for the observed change in the size structure of the population are also unknown. One possible reason may be the continued exploitation of large individuals, either through illegal harvest or other predation. Conversely, asymptotic growth at sizes larger than 100 mm may have historically led to many year classes accumulating in that size range.

Therefore, there may be a lag, whereby it may take many years before historic densities of large individuals are observed, despite increases in total population density.

17.5. Implications of those trends

As some regions of the B.C. coast continue to show increases in density, it may be necessary to re-evaluate the status of Northern Abalone. However it is important to note that not all regions are showing similar recovery, particularly regions with sea otters. The impact that the potential eventual recovery of *Pycnopodia* may have on Abalone populations is also unknown. Lastly, it is also important to note that the overall fecundity for regions that are showing recovery may not be the same as it was historically for a given density due to a shift in size distribution towards smaller individuals that produce fewer eggs (Campbell et al. 2003).

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18. EULACHON STATUS AND TRENDS IN B.C.

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18.1. Highlights

- In 2011 COSEWIC assessed Eulachon in B.C. as three designatable units:
  - Central Pacific Coast and Fraser River were assessed as endangered, and
  - Nass/Skeena was assessed as Special Concern.
- From 2004 to 2016 the index of Eulachon spawning stock biomass in the Fraser River was below a 150 tonne action level except for 2015 when it was estimated at 317 tonnes.
- Eulachon catch per unit effort observations from an annual spring west coast of Vancouver Island multispecies trawl survey were relatively high in 2013 to 2015 but dropped down in 2016 to levels seen in previous years.
- In the 2016 multispecies trawl survey, fish lengths were bi-modal in distribution but relatively few fish of the smaller size class were observed.
- It is unknown what factors are affecting trends in Eulachon abundance.

18.2. Description of indices

Three indices of Eulachon (*Thaleichthys pacificus)* population trends are: 1) Eulachon catches occurring in annual spring offshore multispecies trawl surveys off the west coast of Vancouver Island (WCVI, 1973-2016) and in Queen Charlotte Sound (QCS, 1998-2012, 2016); 2) commercial Eulachon catches in the Fraser (1900-2004) and Columbia (1888-2010 and 2014-2015) River systems; and 3) a spawning stock biomass index based on annual Fraser River Eulachon egg and larval surveys (1995-2016). In the past, information from these indices was used to assess population trends and provide science advice regarding Eulachon catch recommendations. Offshore indices of juvenile Eulachon abundance, however, do not always reflect the abundance of adult Eulachon that return to rivers (Schweigert et al. 2012) and Fraser River and Columbia River commercial fisheries have been closed in recent years (except for a re-start of the Columbia commercial and recreational fishery in 2014).

18.3. Status and trends

Eulachon have experienced long-term declines in many rivers throughout their distribution from California to Alaska. COSEWIC assessed Eulachon in B.C. as three designatable units (DUs): the Central Pacific Coast and Fraser River DUs were assessed as endangered, and the Nass/Skeena DU was assessed as a species of special concern (COSEWIC 2011, 2013). Information in support of a recovery potential assessment (Levesque and Therriault 2011) and a recovery potential assessment (Schweigert et al. 2012) are available online. Catches in the Columbia River system decreased dramatically in the early-1990s. Columbia River Eulachon were federally-listed in the U.S.A. as threatened under the Endangered Species Act (ESA) effective May 17, 2010 and all Eulachon-directed fisheries were closed in 2011 (NOAA 2010). In 2014 and 2015 commercial and recreational fisheries in the Columbia River were re-opened on an experimental basis. The Eulachon spawning stock biomass index in the Fraser River shows an overall decrease from 1995 to 2010, followed by some variable increases. Index levels were below the 150 tonne action level for 2004 to 2016 (Hay et al. 2003) except in 2015 (Figure 18-1).

In 2016, Eulachon catch per unit effort observations from the spring WCVI multispecies trawl survey declined from relatively high levels observed in 2013-2015 to a level similar to those observed before 2013 (Figure 18-2).

The distribution of Eulachon standard lengths measured from samples taken during the 2016 WCVI multispecies trawl survey show a prominent peak at lengths at or near 125 mm, a possible peak at or near 137 mm and a much smaller mode and peak below 90 mm (Figure 18-3). In contrast to length distributions from several previous survey years, the 2016 observations do no show a modal peak at or above 150 mm (Figure 18-4).

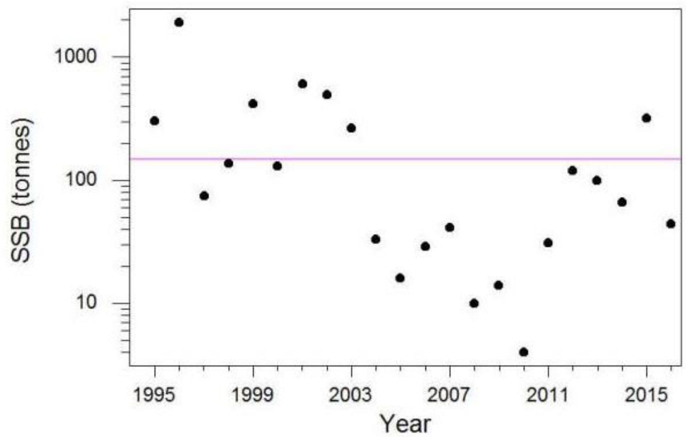

Figure 18-1. Estimated spawning stock biomass (SSB in tonnes) of Eulachon in the Fraser River, 1995-2015. Y-axis is on a log-scale. Horizontal pink line shows the 150 tonne action level.

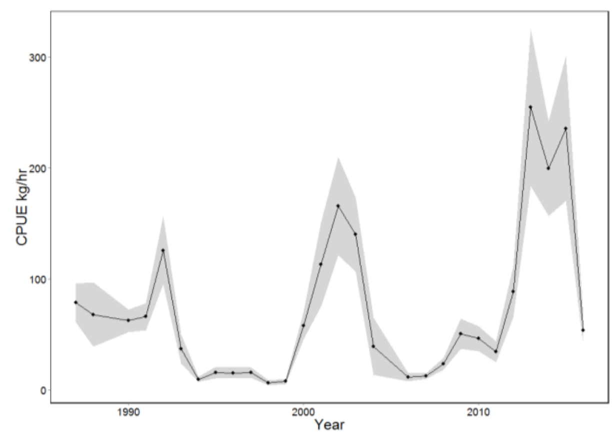

Figure 18-2. Eulachon mean catch per unit effort observations from spring WCVI multispecies trawl surveys (1987-2016). Mean 95% confidence intervals are enveloped in grey.

18.4. Factors causing those trends

It is unknown what caused the declining trends in Eulachon abundance in recent years. Schweigert et al. (2012) state that “No single threat could be identified as most probable for the observed decline in abundances among DUs [designatable units] or in limiting recovery. However, mortality associated with 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.” DFO (2015) also states that “Some existing threats are unlikely to have been responsible for recent declines (e.g. food, social and ceremonial (FSC) fisheries, marine mammal predation, and degradation of freshwater habitat) but may now be preventing recovery from low population abundance.”

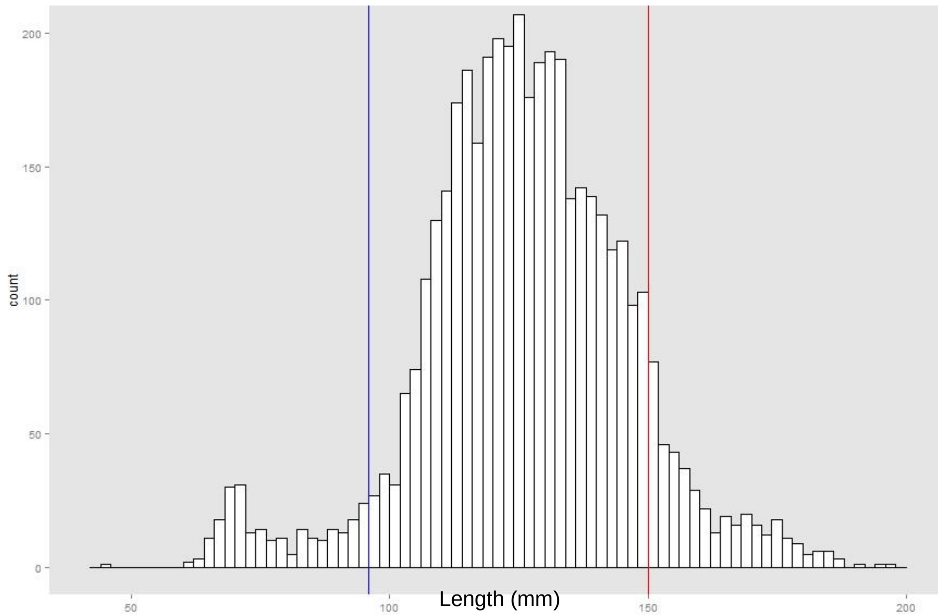

Figure 18-3. Length frequency histogram (in mm) from pooling sample data from Eulachon measured off the west coast of Vancouver Island from the May 2016 multispecies trawl survey. Blue and red vertical lines are estimated bi-modal means from pooling Eulachon length sample data across survey years (1995-2016).

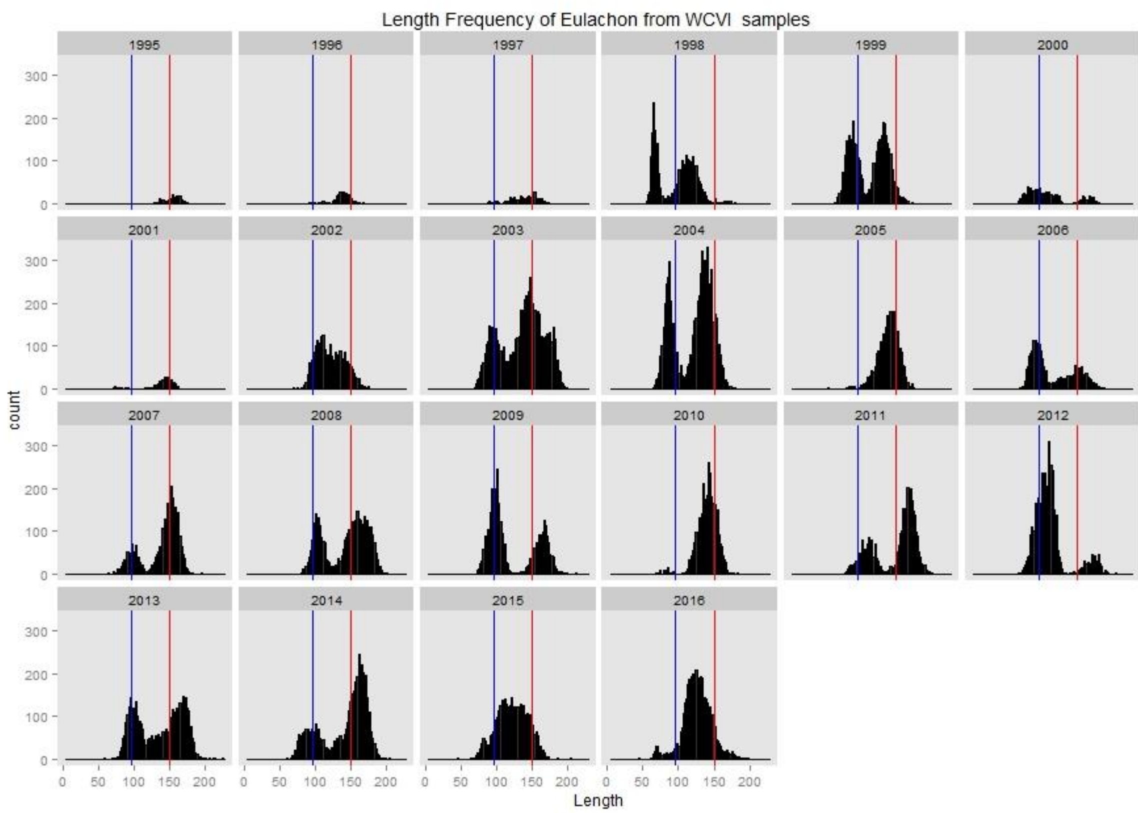

Figure 18-4. Length frequency histograms (in mm) of Eulachon from pooling sample data by year from WCVI survey samples. Blue and red vertical lines are estimated bi-modal means from pooling Eulachon length sample data across survey years (1995-2016).

18.5. Implications of those trends

Reduced biomass of Eulachon has negative implications for First Nations and commercial fishers. Eulachon are socially and culturally significant to First Nations and are harvested by First Nations at low levels. Recreational and commercial fisheries are currently closed.

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

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19. PACIFIC HERRING IN BRITISH COLUMBIA, 2016

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19.1. Highlights

- Biomass estimates increased in the last 2 to 6 years in 3 of the 5 main fished stocks of herring.
- Factors contributing to changes in biomass and stock status include:
    - consecutive years of below or above average recruitment;
    - increases or decreases in model estimates of natural mortality;
    - increases or decreases in mean weight-at-age; and
    - changes in the spawn index or model fits to the spawn index.
- There have been recent increases or levelling off in weight-at-age in all stocks, following a declining trend during approximately 1980 to 2010.

19.2. Summary

In B.C., herring are managed as five major stocks (Strait of Georgia, SOG; West Coast of Vancouver Island, WCVI; Prince Rupert District, PRD; Haida Gwaii, HG; and Central Coast, CC), and two minor stocks (Area 2W and Area 27) (DFO 2016; Figure 19-1). For each stock, model estimates of Pacific Herring biomass reflect herring population trends. Statistical catch-at-age models are fit to time series data: commercial and test fishery biological samples (age, length, weight-at-age), herring spawn survey data (spawn index), and commercial harvest data. In 2016, the model was used to provide (in part) estimates of Pacific Herring spawning biomass and age-2 recruit abundances under both AM1 and AM2 model parameterizations (DFO 2016). Herring biomass, recruit abundance, and weight-at-age are important indicators of stock status; however, there are additional considerations such as distribution of spawn. Readers are referred to DFO (2016) for important additional information regarding the status of B.C. herring stocks, as well as description of the assessment model.

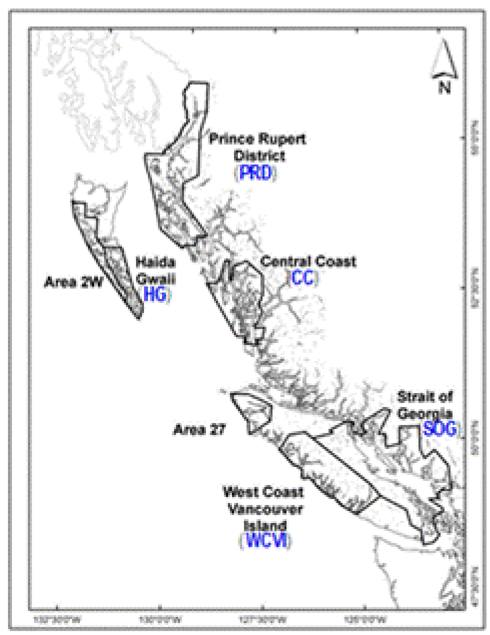

Figure 19-1. Location of the five major (Strait of Georgia, West Coast of Vancouver Island, Prince Rupert, Haida Gwaii, and Central Coast) as well as two minor (Area 2W, and Area 27) Pacific Herring stocks in B.C.

19.3. Status and trends

In all five major herring stocks, there was a declining trend in weight-at-age beginning in the 1980s through 2010, with an increase or levelling off in recent years (Figure 19-2). While there were some small increases in the median spawning stock estimates from 2015 to 2016 for WCVI, the absolute magnitude of the increases was small and the uncertainty in the estimates was large (Figure 19-3). Median spawning biomass for SOG herring increased from 2015 to 2016 due in part to above average recruitment and apparent decreases in model estimates of natural mortality. Median biomass estimates for PRD herring has remained about the same from 2014 to 2016. Median biomass estimates for HG herring decreased from 2013 to 2016, and recruitment in 2013 and 2015 was estimated to be below average, with an increase in 2016. Median biomass estimates of CC herring increased from 2013 to 2016 due to increased trends in the spawn index and decreased estimates of natural mortality.

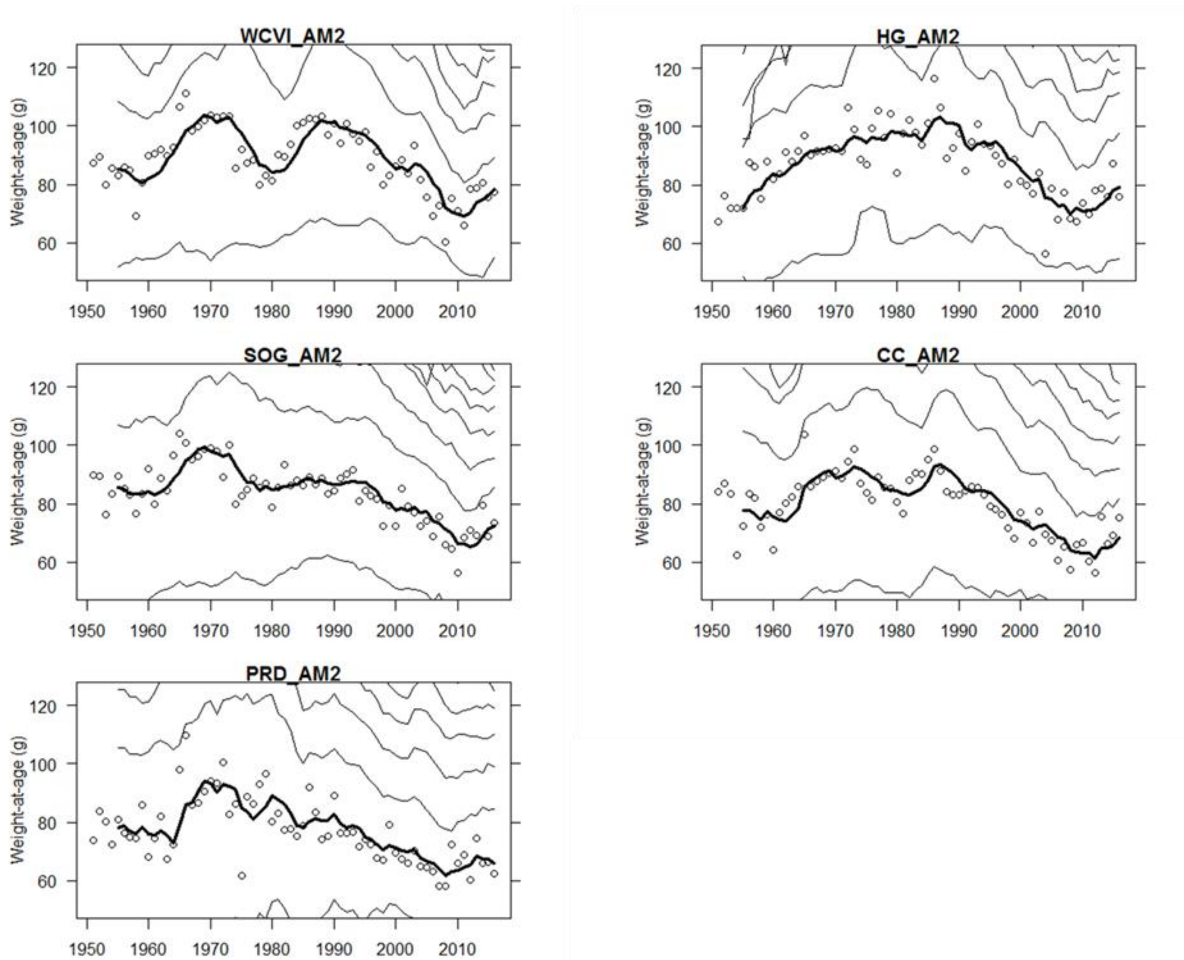

Figure 19-2. Time series of observed weight-at-age 3 (circles) and five-year running mean weight-at-age 3 (dark line) for major Pacific Herring stocks, 1951 to 2016. Thinner black lines represent five-year running mean weight-at-age 2 (lowest) and ages 4-7 (incrementing higher from age 3). Figure adapted from DFO (2016). AM2 refers to the model type (see DFO 2016).

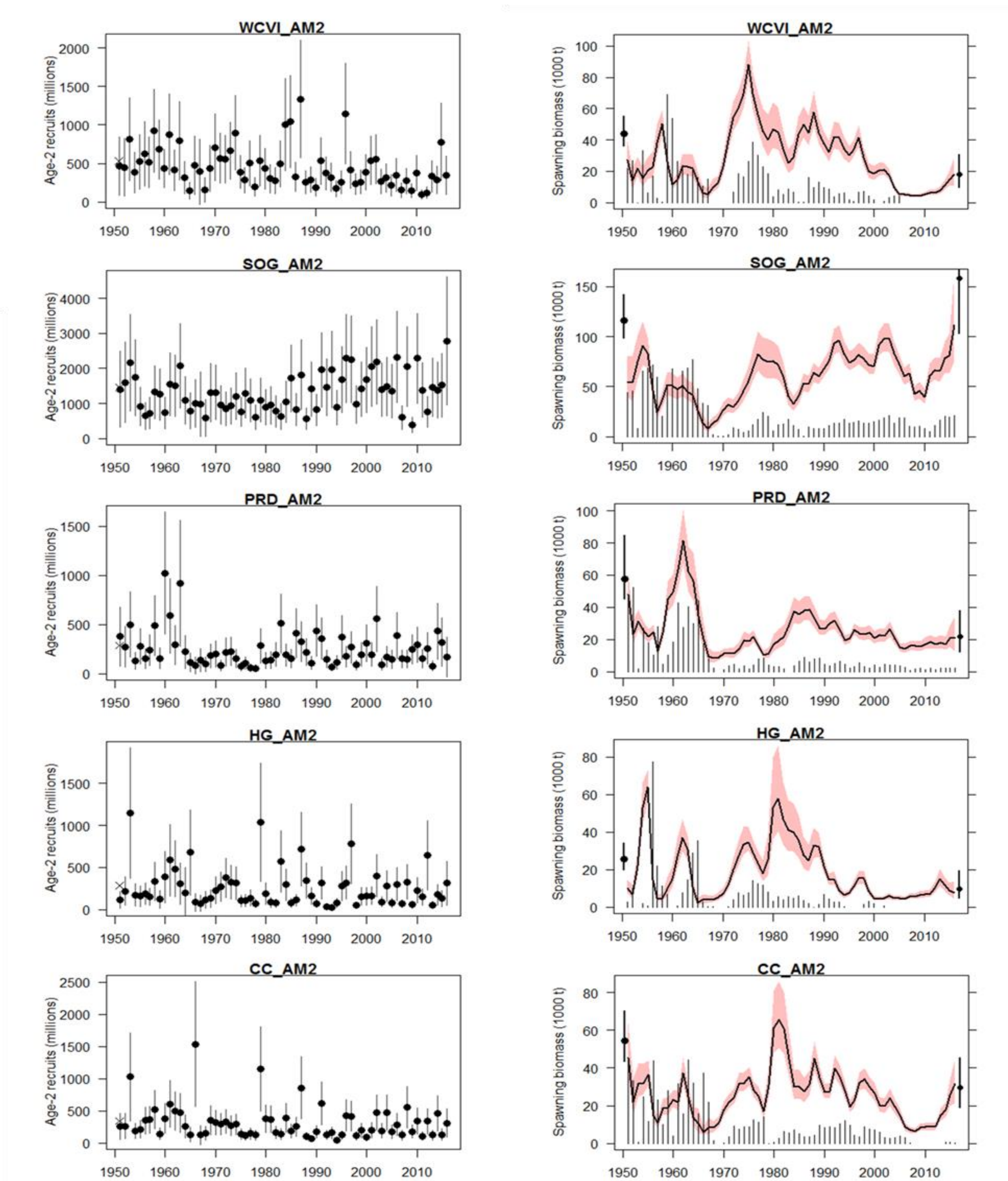

Figure 19-3. Summary of the dynamics of the five Pacific Herring stocks from 1951 to 2016, where solid circles with vertical lines, and solid lines with surrounding pink envelopes, represent medians and 5-95% credible intervals. Left panels show the reconstruction of number of age-2 recruits (millions); right panels show the reconstruction of spawning biomass (SBt) for each year t, with unfished values shown at far left (solid circle and vertical lines) and the projected spawning biomass given zero catch (SB2017) shown at the far right (solid circle and vertical lines). Time series of thin vertical lines denote commercial catch (excluding commercial spawn-on-kelp). Figure adapted from DFO (2016). AM2 refers to the model type (see DFO 2016).

19.4. Factors influencing trends in herring biomass

The biomass of Pacific Herring in three major stock areas (HG, CC and WCVI) have experienced prolonged periods of low biomass in the absence of fishing (DFO 2016). The two areas that are open to fishing (PRD and SOG) maintain stable or high biomass estimates. Consideration of these biomass trends in combination with the declining trend in herring weight-at-age (with an increase in recent years) observed for all stock areas suggests that factors other than (or in addition to) fishing may be influencing herring population trends. Changes in food supply and quality, predator abundance, and competition are factors that could affect trends in herring biomass and weight-at-age (Schweigert et al. 2010, Hay et al. 2012).

Pacific Herring are zooplanktivorous, consuming primarily euphausiids (krill) and some copepods (Wailes 1936). Changes in ocean conditions, such as temperature or currents, could affect the amount and types of prey available. For example, a northerly current direction could result in the presence of California current waters off the WCVI, bringing California Current zooplankton species that have a lower energetic value, creating poorer feeding conditions for herring (Schweigert et al. 2010, Mackas et al. 2004). In addition, Tanasichuk (2012) related WCVI herring recruitment to the biomass of euphausiids.

There are a wide variety of herring predators, including Pacific Hake, Lingcod, Spiny Dogfish, Pacific Cod, Sablefish, Arrowtooth Flounder, Pacific Halibut, Steller Sea Lions, Northern Fur Seals, Harbour Seals, California Sea Lions, and Humpback Whales (Schweigert et al. 2010). Off the WCVI, fish predator abundance has decreased in recent years, while the abundance of most marine mammal predators has increased (Olesiuk 2008, Olesiuk et al. 1990). This has resulted in a relatively stable or slightly decreasing trend in the amount of WCVI herring consumed by predators since 1973 (Schweigert et al. 2010). Although a significant proportion of the herring population could be consumed annually by predation, trends in model estimates of natural mortality of WCVI herring were not found to be directly attributable to trends in estimates of predation (Schweigert et al. 2010). Herring recruitment, however, has been correlated with piscivorous hake biomass (piscivorous hake are those hake that are large enough to consume herring), suggesting that predation may be an important factor influencing WCVI herring recruitment (Tanasichuk 2012).

19.5. Implications of trends

Trends in herring biomass have implications for both fisheries and predators. Pacific Herring comprise an important component of commercial fisheries in British Columbia. Fisheries management uses forecasts of herring biomass, in conjunction with decision tables, performance metrics, and harvest rates to set total allowable catches.

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

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20. 2016 PELAGIC ECOSYSTEM ACOUSTIC SURVEY IN THE STRAIT OF GEORGIA

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20.1. Highlights

- The 2016 Pacific Hake biomass estimate is approximately 49,290 mt, showing a small increase compared to the biomass estimate of 2014 (42,678 mt).
- In late March, Pacific Hake aggregations were mainly distributed in the central-northern Strait, while Walleye Pollock were mainly distributed in the central-southern Strait, displaying a north-south separation with overlap.
- Distinct narrow juvenile hake layers at 50-120 m were observed over the entire Strait with higher biomass in central-northern area during the March survey. Trawl catch data also suggested a strong year class of age-1 hake.
- No adult Pacific Hake aggregations and only small Walleye Pollock aggregations were observed in the July survey, suggesting possibility of out migration from the open Strait.

20.2. Summary

Bio-acoustic techniques offer a unique approach to assess the marine ecosystem. Acoustic-trawl surveys, in particular, can provide fishery-independent assessment of biomass, abundance and spatial distribution of target fish species for monitoring and management purposes. In the Strait of Georgia (SoG), acoustic-trawl surveys were originally applied to study biology of Pacific Hake in the mid-1970s and 1980s (1981 & 1988), and then were conducted intermittently in the 1990s (1993 & 1996-1998), 2000s (2000, 2002, 2004 & 2009) (Saunders and MacFarlane 2009) and recent years (2010-2011, 2014-2016) to serve more objectives including estimating biomass and assisting population modelling and stock assessment of dominant fish species. Over the past thirty years, the operating acoustic system has transitioned from BioSonics to dual-frequency EK500 in 1995, and then to multi-frequency EK60 in 2009, which allows better fish detection and separation between marine nekton and zooplankton.

The Strait of Georgia is an important spawning, nursery and rearing ground for many fish taxa, among which Pacific Hake and Walleye Pollock are the two most abundant demersal species. Stocks of these two species are recognized as distinct resident stocks within this semi-enclosed coastal basin, with a lack of exchange with migratory stocks from outer coast (Mason 1985, McFarlane and Beamish 1985, King and McFarlane 2006). In addition to several discrete hake stocks within the Strait, smaller local stocks have also been observed in major mainland inlets. Usually, hake adults migrate into the central-southern Strait in preparation for spawning in early winter, and then aggregate in the deep basins (> 200 m) to spawn around late February to May

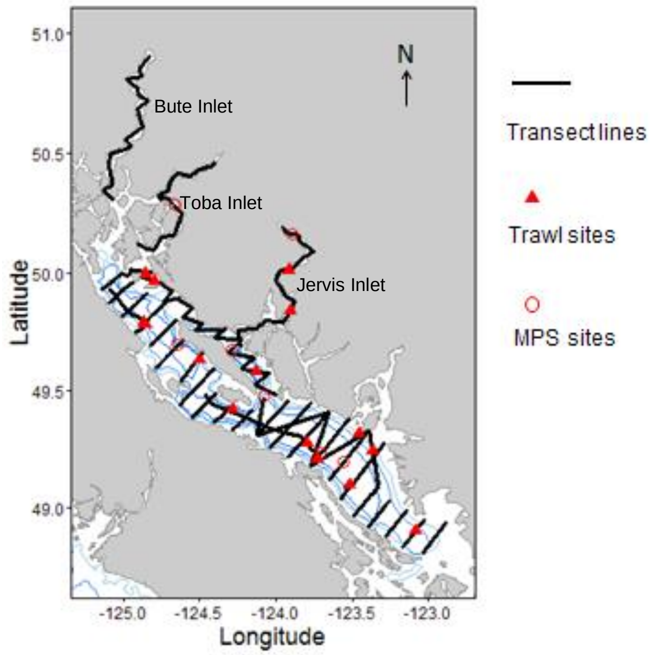

Figure 20-1. Map of the Strait of Georgia ecosystem acoustic survey coverage in March 2016. MPS stands for multinet zooplankton sampling.

with peak spawning in late March/April (McFarlane and Beamish 1985). After spawning, aggregations disperse towards shallower depths in the northern Strait.

2016 Acoustic-trawl surveys were conducted in March (14th-27th) and July (21st -29th) with major focus on nekton and zooplankton, respectively. The March survey coverage included 22 spaced parallel and 26 zigzag transects over the entire SoG and three mainland inlets (Bute, Toba, Jervis; Figure 20-1). Meanwhile, 15 midwater trawls, 7 multinet plankton sampler (MPS) casts and 15 SLYCAM drops were applied to ground-truth acoustic signatures and to collect biological information (e.g. species composition, length, weight, sex ratio, etc.). Based on catch data and camera images, acoustic backscatter recorded along survey transects were classified and partitioned into species aggregations, integrated to acoustic density estimates, and eventually converted to biomass estimates over survey area using established species-specific target strength (TS) to length models (Traynor 1996). The July survey mostly followed the March survey design, but used multinet and MOCNESS casts to specifically ground-truth acoustic signatures of zooplankton swarms and layers (midwater trawl hauls were not conducted).

In the March survey, distinct narrow juvenile hake layers (thickness ~ 5-20 m) distributed over depths of 50-120 m have been consistently observed. In addition, a consistent hake layer from 150 to 250 m depth existed in Jervis Inlet. The biomass estimate for Pacific Hake was approximately 49,290 mt in total with 11,359, 21,846 and 16,087 mt for adult males, adult females and juveniles, respectively. The biomass estimate for Walleye Pollock was approximately 29,897 mt in total with 18,051 and 11,391 mt for adult males and adult females, respectively. Three size classes of Pacific Hake were observed, the most abundant of which was between 10 and 20 cm fork length, suggesting a strong year class of age-1 (Figure 20-2). In contrast, length distribution of Walleye Pollock indicates

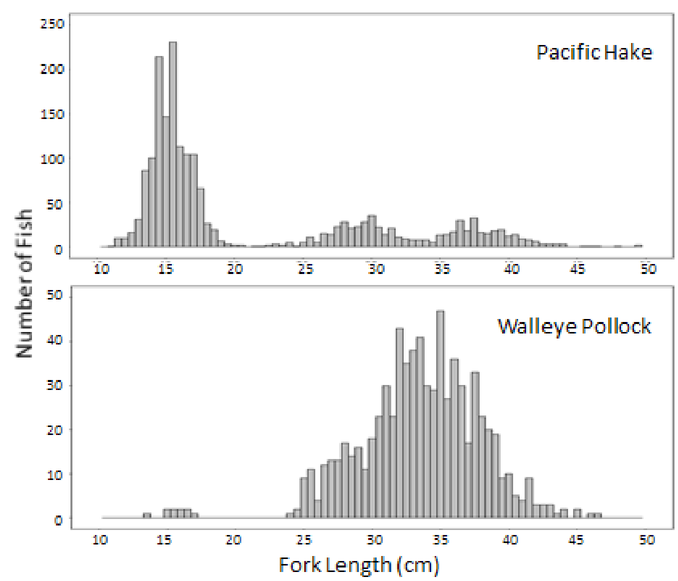

Figure 20-2. Length frequency of Pacific Hake and Walleye Pollock sampled in all trawls catches for the 2016 March survey.

only one major size class of 24-46 cm (Figure 20-2). In July, there were no observed aggregations of adult Pacific Hake and only small aggregations of walleye pollock, suggesting the possibility of post-spawning migration out of the open Strait for these two species.

Distinct north-south separation in spatial distribution of Pacific Hake and Walleye Pollock appeared in the March survey (Figure 20-3). More specifically, the biomass of adult and juvenile hake displayed largely consistent spatial distributions over the central-northern Strait, with relatively higher biomass near the north tip of Texada Island for adults but along Malaspina strait for juveniles. Walleye Pollock distribution was mainly constricted in central-southern Strait with the highest biomass close to Gabriola Island. In addition, Pacific Herring were spread over the entire Strait with higher biomass along shallower nearshore areas (Figure 20-3).

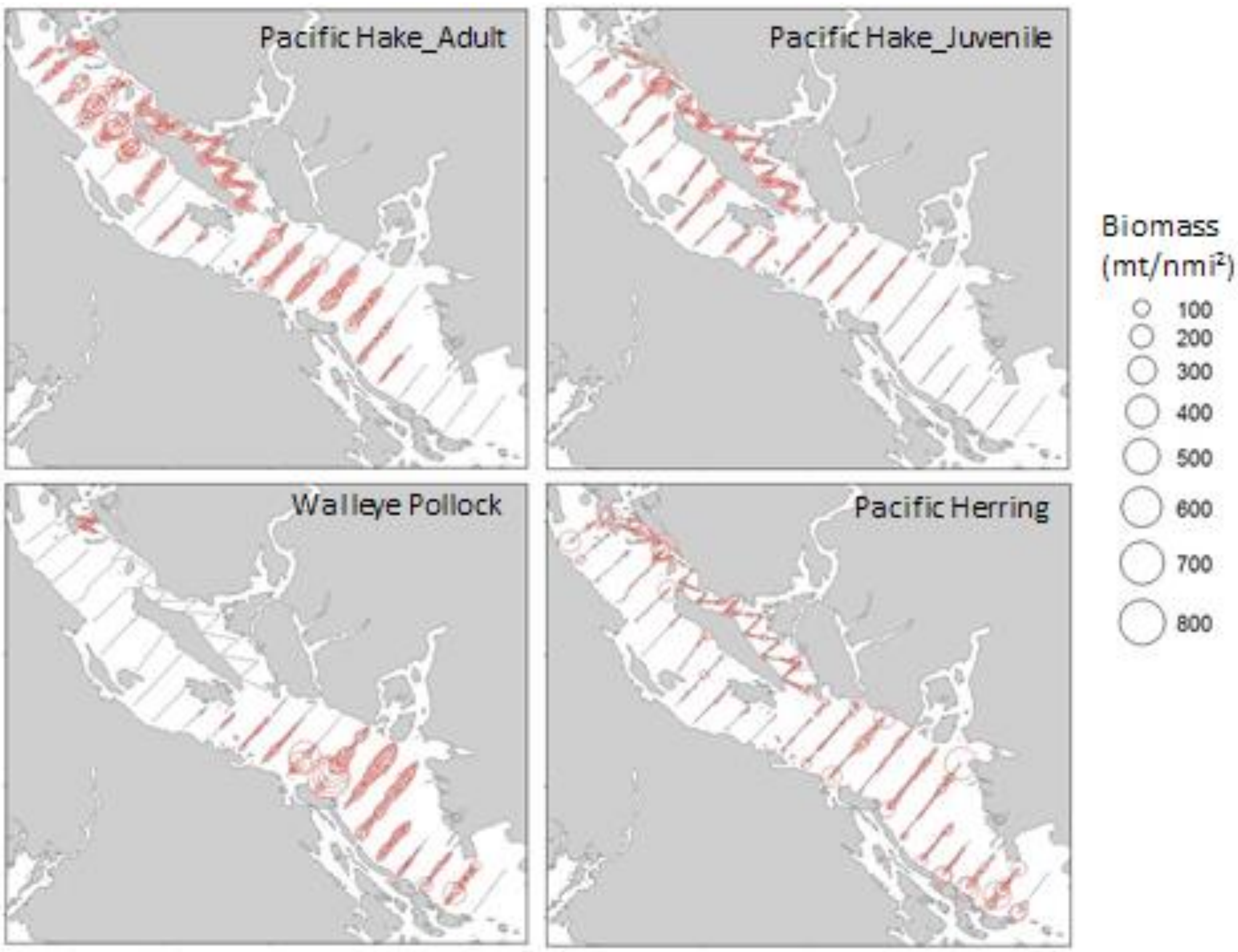

Figure 20-3. Spatial distribution of Pacific Hake adults, Pacific Hake juveniles, Walleye Pollock and Pacific Herring in the Strait of Georgia in March, 2016.

The time series of hake biomass estimates in the Strait of Georgia was first developed based on six previous acoustic surveys from 1981 to 1998 to assist population modelling and stock assessment (Keiser et al. 1999, Figure 20-4). The hake biomass estimates in the Strait were at similar level (> 65,000 mt) between 1981 and 1988, while the biomass dropped from ~ 60,000 mt in 1996 by half (~30,000 mt) in 1998. The anomalously high biomass estimate in 1993 was probably an overestimate due to inclusion of plankton backscattering (Keiser et al. 1999). In the 2010s, hake biomass was at historical low level of approximately 12,325 mt in 2011 (C. Grandin, DFO, personal communication), but rose up to over ~40,000 mt in 2014 and 2016 (Figure 20-4). The relatively low estimates in 1998 and 2011 were associated with warm ocean conditions in the Strait of Georgia. Updates of hake biomass time series based on acoustic surveys completed in recent years (2009-2016) will be necessary to study the local stock dynamics and to explore their links to local oceanographic conditions in the Strait of Georgia.

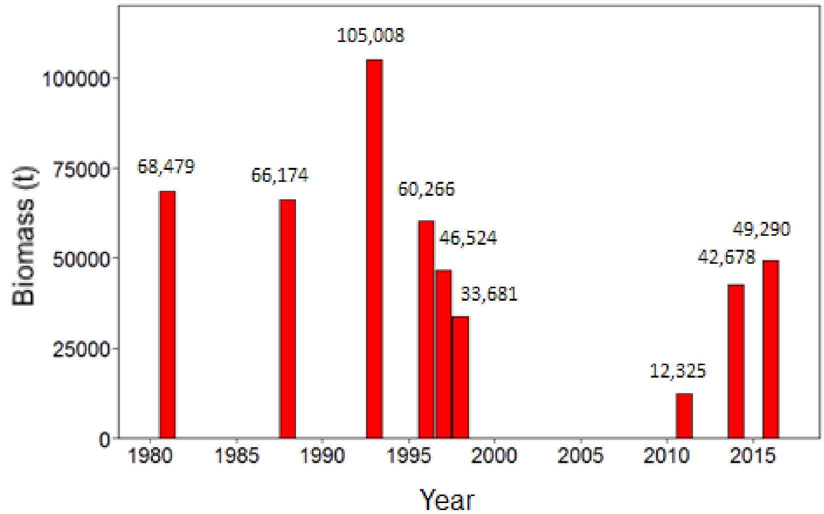

Figure 20-4. Biomass estimates of Pacific Hake from 1981 – present in the Strait of Georgia.

20.3. References

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21. WCVI MULTI-SPECIES SMALL-MESH BOTTOM TRAWL SURVEYS (TARGET SPECIES SMOOTH PINK SHRIMP): 2016 UPDATE

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21.1. Highlights

- Smooth Pink Shrimp biomass off the west coast of Vancouver Island in Areas 124-125 declined in 2016 from the peak in 2014, with $\log_{10}$ anomalies now below the climatological (1981-2010) mean.
- Among fish taxa considered to be “well-sampled” by this program, both Arrowtooth Flounder and Walleye Pollock declined over the past 3 years, but remained above their climatological means.
- The surveyed biomass of “well-sampled” taxa has generally increased since 2009 compared with 2006-2008; the peak anomaly years were around 2002.

21.2. Description of the time series

Fishery-independent bottom trawl surveys using a small-mesh net (targeting the Smooth Pink Shrimp *Pandalus jordani*) have been conducted during May since 1973 in two regions, and since 1996 in three regions, off the west coast of Vancouver Island (Figure 21-1). The survey masks for these regions, over which the total biomass of each species has been estimated, generally occur between the 100 m and 200 m isobaths for Areas 124 and 125.

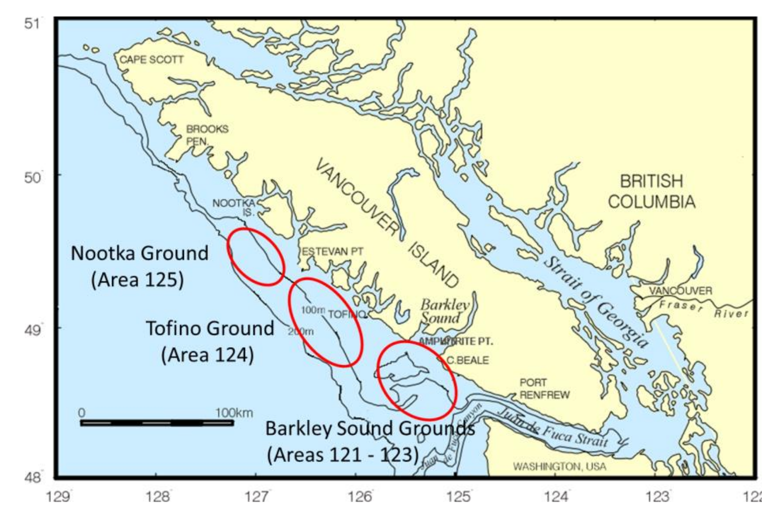

Figure 21-1. Map showing the three main shrimp (Pandalus jordani) fishing grounds and survey areas off Vancouver Island (red ovals).The Nootka (Area 125) and Tofino (Area 124) Grounds are the northern and middle ovals, respectively, and have been surveyed since 1973. The southern oval represents the shrimp fishing grounds off Barkley Sound, surveyed since 1996.

This small-mesh bottom trawl survey was designed to target Smooth Pink Shrimp on the shrimp fishing grounds in a relatively small area off the west coast of Vancouver Island. The interannual variability of biomass estimates of other taxa caught along with Smooth Pink Shrimp depends on whether these other taxa are highly mobile in and out of the survey area or are highly patchy in their distribution. An autocorrelation analysis indicates that of the 36 taxa regularly sampled and identified to species on this survey, 16 of them appear to be "well-sampled" (i.e. have positive autocorrelations of at least a one year lag; Table 21-1). Data are calculated as the total biomass over the survey area and are presented as standardised (by the standard deviation) log_{10}-scaled species anomalies from the climatological period 1981-2010.

Table 21-1. List of 'core' species which have been sampled and identified routinely during these small mesh surveys since 1973 and for which annual biomass estimates are calculated. Taxa in blue are those with significant (p<0.05) autocorrelations and which are therefore considered to be "well-sampled" by this survey.

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

21.3. Status and Trends

Surveys in May 2016 found the biomass of *Pandalus jordani* shrimp off central Vancouver Island had declined from the record high level observed in 2014, and was now presenting as a negative anomaly (Figure 21-2). Since 2008, biomass anomalies have generally been positive. The biomass anomalies of Arrowtooth Flounder have remained mostly positive since 2000. The biomass anomalies of Walleye Pollock turned positive in 2009 after 14 years (1995-2008) of neutral or negative anomalies (Figure 21-2). A cumulative anomaly index (calculated by stacking the anomalies for each species in each year and then adding them) illustrates that anomalies for most species were mostly negative from 1973 to 1999, and have been mostly positive since 2000 with a slight negative period from 2006-2008 (Figure 21-3).

Based on the "well-sampled" taxa, the standardised anomalies from 1973 to 2016 were clustered to identify years with similar taxonomic compositions, using a chronological clustering method. Results indicate five significant clusters, with three outlier years early in the time series (1973, 1975, 1976; no survey was undertaken in 1974). The largest composition change separated 1993 and prior years from 1994 and subsequent years (Figure 21-4). The years 2014, 2015 and 2016 clustered together, but only weakly with 2009-2013, which may indicate changing species composition in 2014-16 from the rest of that cluster.

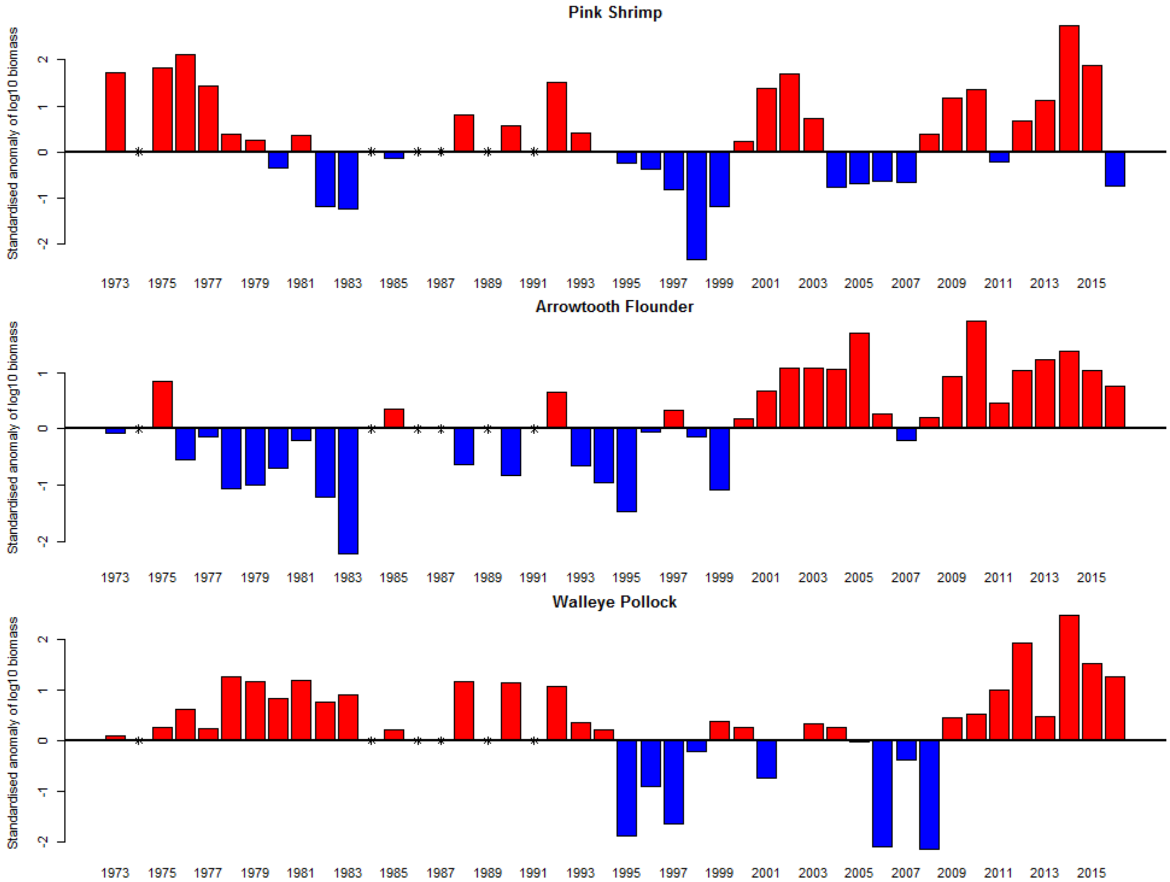

Figure 21-2. Standardised (by the standard deviation) anomalies of log_{10} species biomass for three of the "well-sampled" taxa. Climatology period is 1981-2010.

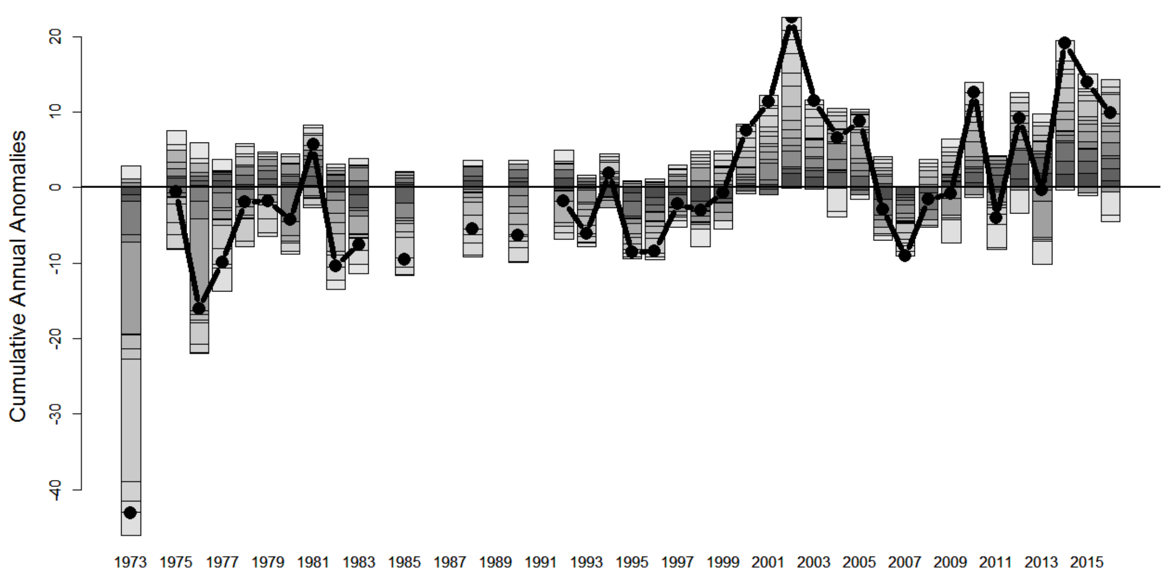

Figure 21-3. Cumulative anomaly index for the 16 "well-sampled" taxa. The climatology period is 1981-2010. Individual shaded boxes represent the anomalies (positive or negative) for each of the 16 taxa.

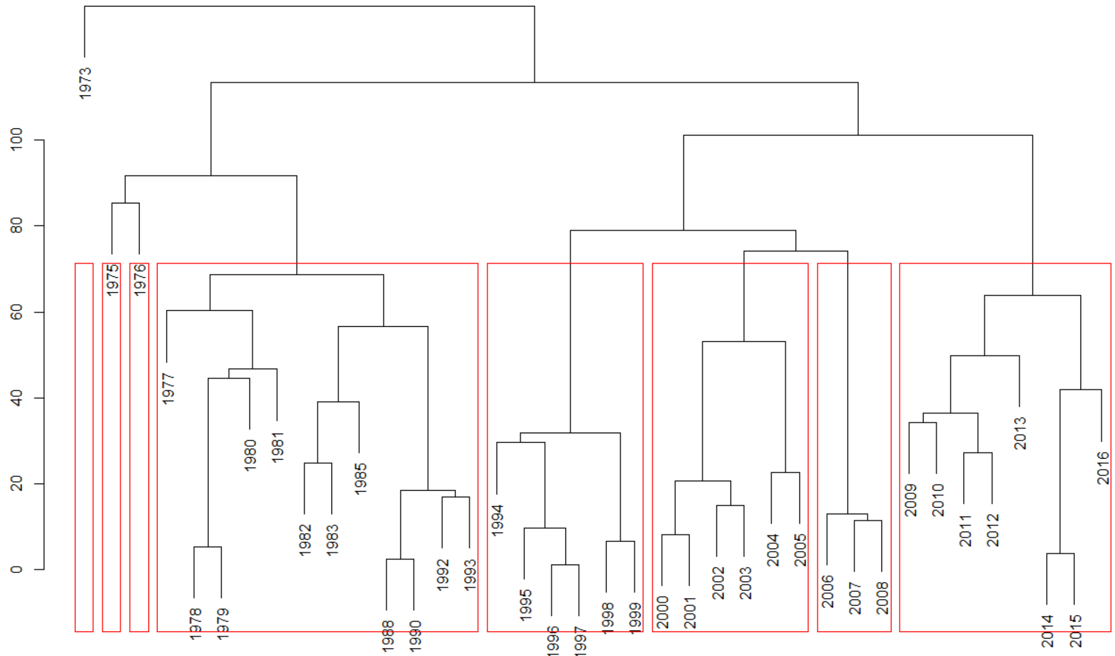

Figure 21-4. Dendrogram of years and clusters based on biomass anomalies of "well-sampled" taxa (blue font taxa in Table 21-1) using a chronological clustering method. The largest break separated clusters in 1993 and prior years from 1994 and subsequent years. Sampling was conducted in May of each year. Significant clusters (red boxes) are identified by a randomisation procedure.

21.4. Factors influencing trends

Potential causes for the observed trends are under investigation. Climate and environmental factors are expected to be the main drivers of trends over this length of time. The time trends of Smooth Pink Shrimp (the target species for this survey) are consistent with inverse relationships with sea surface temperature two years previously (e.g. Perry et al. 2014).

21.5. Implications of those trends

Many of the species considered to be "well-sampled" by this survey are of commercial interest. Considered collectively (Figure 21-3), biomass anomalies of many of these taxa have been largely positive since 2000. This suggests that groundfish biomass off the west coast of Vancouver Island may also have increased compared with the 1980s and 1990s, at least for these selected species in these small areas surveyed with sandy bottom types that are the preferred habitat for Smooth Pink Shrimp. This is under investigation.

21.6. References

Perry, R.I., Fong, K., Waddell, B., and Rutherford, D. 2014. Small-mesh bottom-trawl surveys west of Vancouver Island: update for 2013, p. 59-62. *In:* Perry, R.I. (Ed.). 2014. State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2013. Can. Tech. Rep. Fish. Aquat. Sci. 3012.

22. A REVIEW OF GROUNDFISH SURVEYS IN 2016

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22.1. Highlights

- Arrowtooth Flounder, Splitnose Rockfish, Pacific Ocean Perch, Redstripe Rockfish, and Sablefish were the most abundant species caught on the WCVI bottom trawl survey.
- Pacific Ocean Perch, Rougheye/ Blackspotted Rockfish, Sharpchin Rockfish, Silvergray Rockfish, and Redstripe Rockfish were the most abundant species caught on the west coast of Haida Gwaii bottom trawl surveys.
- Yelloweye Rockfish, followed by Pacific Halibut, Quillback Rockfish, and Pacific Cod were the most abundant species caught on the Pacific Halibut Management Association (PHMA) longline survey.
- North Pacific Spiny Dogfish, followed by Quillback Rockfish, Yelloweye Rockfish, and Spotted Ratfish were the most abundant species caught on the DFO hard bottom longline survey in the northern half of the inside waters.
- Sablefish, followed by Pacific Halibut, North Pacific Spiny Dogfish, and Lingcod were the most abundant caught on the Sablefish Research and Assessment Survey.
- Survey catch suggests a decline of North Pacific Spiny Dogfish and Longnose Skates on the B.C. coast, but these trends need more investigation.

22.2. Description of the time series

The Fisheries and Oceans, Canada (DFO) Offshore Assessment and Monitoring Section of the Aquatic Resources Research and Assessment Division includes a surveys program. The cornerstone of the surveys program is a suite of surveys using bottom trawl, longline hook, and longline trap gear covering most of the B.C. coast on a biennial rotation (Figure 22-1). All surveys use random depth stratified designs and in aggregate provide good coverage for both the inshore and all offshore waters of Canada's Pacific Coast. They also have in common full enumeration of the catches (all catch sorted to the lowest taxon possible), size composition sampling for most species, and more detailed biological sampling of selected species. Several of these surveys are

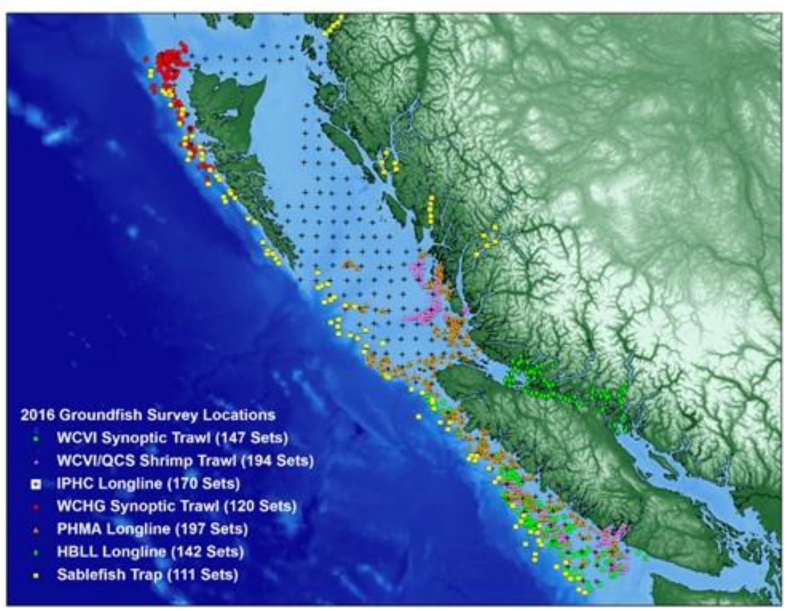


Figure 22-1. Locations of Groundfish survey fishing activities during 2016.

conducted in collaboration with the commercial fishing industry under the authorities of various Joint Project Agreements.

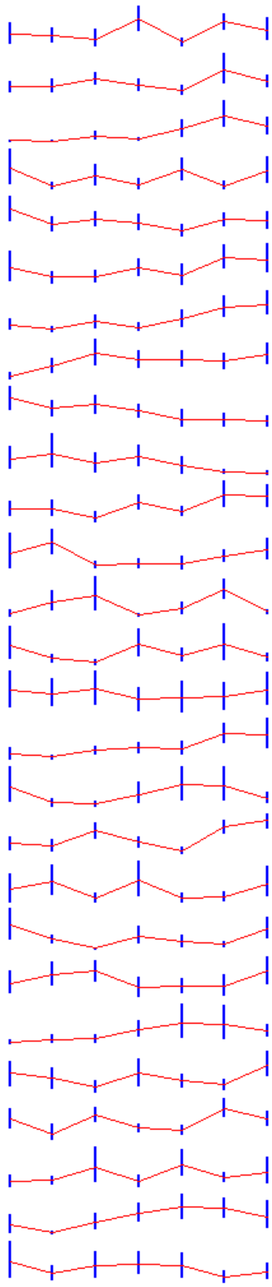
In this summary we present the results from the following 2016 surveys:

- Bottom trawl surveys off the west coast of Vancouver Island (WCVI Synoptic Trawl) in late spring and off the west coast of Haida Gwaii (WCHG Synoptic Trawl) in late summer.
- Longline hook surveys in the southern half of outside waters along the B.C. coast (Pacific Halibut Management Association longline) and along with the northern half of the inside waters (DFO hard bottom longline hook longline) in August.
- Longline trap survey targeting Sablefish for the entire outer B.C. coast as well as a number of central coast inlets (Sablefish Trap) in October and November.
- A fixed-station survey of commercially important shrimp grounds.
- An annual coast-wide (California to the Bearing Sea) longline hook survey to index the abundance of, and collect biological data from, Pacific Halibut.

22.3. Status and trends

On the WCVI synoptic bottom trawl survey, the total catch weight of all species was 125,192 kg. The mean catch per tow was 857 kg, averaging 27 different species of fish and invertebrates in each. The most abundant fish species encountered were Arrowtooth Flounder (*Atheresthes stomias*), Splitnose Rockfish (*Sebastes diploproa*), Pacific Ocean Perch (*Sebastes alutus*), Redstripe Rockfish (*Sebastes proriger*), and Sablefish (*Anoplopoma fimbria*). Biological data were collected from a total of 33,948 individual fish of 51 different species. Figure 22-2 presents the survey biomass indices for the 27 most precisely indexed species (lowest CV) for the duration of the survey time series. Notable trends include a prolonged decline in the abundance index for North Pacific Spiny Dogfish and Longnose Skate as well as prolonged increasing trends for Petrale Sole, Flathead Sole and Greenstripe Rockfish.

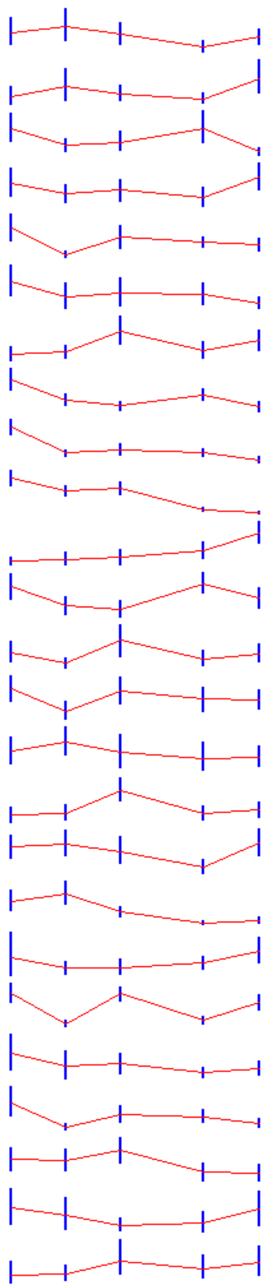
The total catch weight of all species on the WCHG synoptic bottom trawl survey was 160,511 kg. The mean catch per tow was 1337 kg, averaging 22 different species of fish and invertebrates in each. The most abundant fish species encountered were Pacific Ocean Perch (*Sebastes alutus*), Rougheye/ Blackspotted Rockfish (*Sebastes aleutianus/ Sebastes melanostictus*), Sharpchin Rockfish (*Sebastes zacentrus*), Silvergray Rockfish (*Sebastes brevispinis*), and Redstripe Rockfish (*Sebastes proriger*). Biological data were collected from a total of 28,686 individual fish of 46 different species. Notable trends include a prolonged decline in the abundance index for Shortspine Thornyhead (*Sebastolobus alascanus*) and Shortraker Rockfish (*Sebastes borealis*) as well as Sablefish and prolonged increasing trends for Sharpchin and Redstripe Rockfish (data not shown).



Species	2004	2006	2008	2010	2012	2014	2016
Arrowtooth flounder	8,581.3	8,077.6	6,604.1	14,829.0	5,541.9	13,942.1	10,282.4
Bigfin eelpout	6.9	7.6	13.4	8.4	4.0	20.6	11.3
Blackbelly eelpout	7.9	4.5	35.5	18.4	80.4	160.0	91.6
Curlfin sole	47.2	9.9	32.4	12.1	45.1	9.6	41.8
Dover sole	2,701.4	1,790.5	2,110.2	1,901.8	1,426.0	2,095.9	2,001.1
English sole	1,617.8	1,071.1	1,091.3	1,620.0	1,151.7	2,162.4	2,005.6
Flathead sole	400.2	188.3	583.4	302.5	731.1	1,345.1	1,476.0
Greenstriped rockfish	206.9	558.3	1,016.7	799.8	808.7	727.6	995.3
Longnose skate	698.6	524.3	591.6	478.0	334.8	325.2	308.3
rth pacific spiny dogfish	17,071.6	22,141.1	12,885.4	20,740.9	10,702.6	4,692.4	3,473.7
Pacific cod	1,144.9	1,166.9	518.5	1,596.0	931.8	2,172.2	2,047.4
Pacific halibut	909.9	1,339.2	518.0	545.4	563.3	841.0	1,094.0
Pacific herring	7.3	23.8	35.2	3.9	14.3	43.6	10.1
Pacific ocean perch	4,921.0	2,142.0	1,420.5	5,183.0	2,810.1	5,354.4	2,398.6
Pacific sanddab	1,042.4	928.7	1,079.2	765.2	796.8	845.3	1,055.6
Petrale sole	385.5	288.7	545.9	667.1	635.2	1,247.3	1,206.4
Redbanded rockfish	243.8	96.3	82.6	175.7	264.7	261.5	138.7
Rex sole	1,991.4	1,840.6	2,925.8	2,127.0	1,450.3	3,174.0	3,625.1
Rougheye rockfish	332.2	487.2	137.3	533.3	134.7	165.1	439.0
Sablefish	4,000.5	1,807.0	416.4	2,381.4	1,408.7	1,095.1	3,536.3
Sandpaper skate	7.8	12.1	13.5	5.4	6.2	6.3	13.8
Sharpchin rockfish	418.3	842.2	898.9	2,198.6	2,988.8	2,880.0	2,015.8
Shortspine thornyhead	294.7	245.2	173.4	292.0	226.1	191.8	365.9
Slender sole	212.5	90.9	248.3	142.7	120.8	304.0	214.0
Spotted ratfish	1,225.8	1,304.8	2,920.8	1,180.0	3,194.5	1,699.3	2,193.6
Threadfin sculpin	19.7	4.3	23.9	41.5	51.5	48.9	34.6
Yelloweye rockfish	175.0	89.1	148.4	157.1	143.9	62.5	101.5

Figure 22-2. Plot of annual biomass indices (red lines) and estimated CVs for those index points (blue bars) over time along with a table of the biomass index estimates for the 27 most precisely indexed species (lowest average CVs across the time series) encountered on the WCVI synoptic bottom trawl survey.

The most common species captured during the 2016 Pacific Halibut Management Association (PHMA) longline survey was Yelloweye Rockfish (*Sebastes ruberrimus*), followed by Pacific Halibut (*Hippoglossus stenolepis*), Quillback Rockfish (*Sebastes maliger*), and Pacific Cod (*Gadus macrocephalus*). During the survey, detailed biological samples including ageing structures were collected from 50 rockfish in each set with a focus on Yelloweye Rockfish. A total of 4506 individual fish were sampled for biological data in 2016. Notable trends include a prolonged decline in the abundance index for Lingcod, Longnose Skate, and North Pacific Spiny Dogfish as well as prolonged increasing trends for Pacific Cod and Yellowtail Rockfish (Figure 22-3).



Species	2007	2009	2011	2014	2016
Arrowtooth flounder	4,235.1	5,002.1	4,062.3	2,327.4	3,583.6
Big skate	617.1	933.0	703.9	548.5	1,199.4
Cabezon	307.4	114.9	153.3	306.4	45.0
Canary rockfish	4,252.8	3,182.4	3,508.7	2,781.0	4,805.6
China rockfish	3,244.1	591.5	2,351.6	1,836.4	1,557.6
Copper rockfish	1,763.0	1,031.3	1,233.3	1,173.5	716.2
Greenstriped rockfish	592.9	669.4	1,314.8	700.6	1,020.1
Lingcod	6,898.8	3,828.1	2,909.8	4,547.2	2,726.9
Longnose skate	7,579.5	3,525.7	4,085.7	3,585.3	2,470.6
rth pacific spiny dogfish	47,217.7	31,288.2	34,748.8	8,473.3	4,483.8
Pacific cod	2,492.0	2,781.1	3,170.6	4,214.9	7,299.6
Pacific halibut	16,244.6	11,465.1	10,571.5	17,019.3	13,368.1
Petrale sole	173.7	85.2	275.9	118.5	164.8
Quillback rockfish	10,717.5	6,584.4	10,164.1	8,696.9	8,525.7
Redbanded rockfish	3,828.0	5,130.3	3,674.8	2,827.6	3,035.9
Rosethorn rockfish	599.3	667.4	1,517.6	651.5	804.5
Sablefish	5,978.9	6,458.8	5,278.4	3,013.2	6,521.0
Silvergray rockfish	2,950.2	3,858.4	1,719.2	555.9	793.5
Southern rock sole	163.7	68.7	71.2	118.3	221.7
Spotted ratfish	6,960.8	1,754.6	6,874.4	2,366.7	5,418.6
Tiger rockfish	272.3	157.3	180.1	100.8	134.4
Vermilion rockfish	665.7	86.8	388.8	328.8	180.7
Yelloweye rockfish	20,045.5	19,814.4	24,105.7	14,649.5	14,208.7
Yellowmouth rockfish	491.3	361.9	158.9	209.1	485.0
Yellowtail rockfish	158.7	177.8	359.6	251.8	338.6

Figure 22-3. As in Figure 22-2 but for the PHMA longline survey.

On the DFO hard bottom longline (HBLL) hook survey the total catch of the survey was 6281 kg. The average catch per set was 88 kg, averaging five different species of fish and invertebrates in each. The most abundant fish species encountered were North Pacific Spiny Dogfish (*Squalus suckleyi*), followed by Quillback Rockfish (*Sebastes maliger*), Yelloweye Rockfish (*Sebastes ruberrimus*), and Spotted Ratfish (*Hydrolagus colliei*). Biological data were collected from a total of 3719 individual fish of 20 different species. Notable trends include a prolonged decline in the abundance index for Longnose Skate, North Pacific Spiny Dogfish as well as a prolonged increasing trend for Lingcod (Figure 22-4).

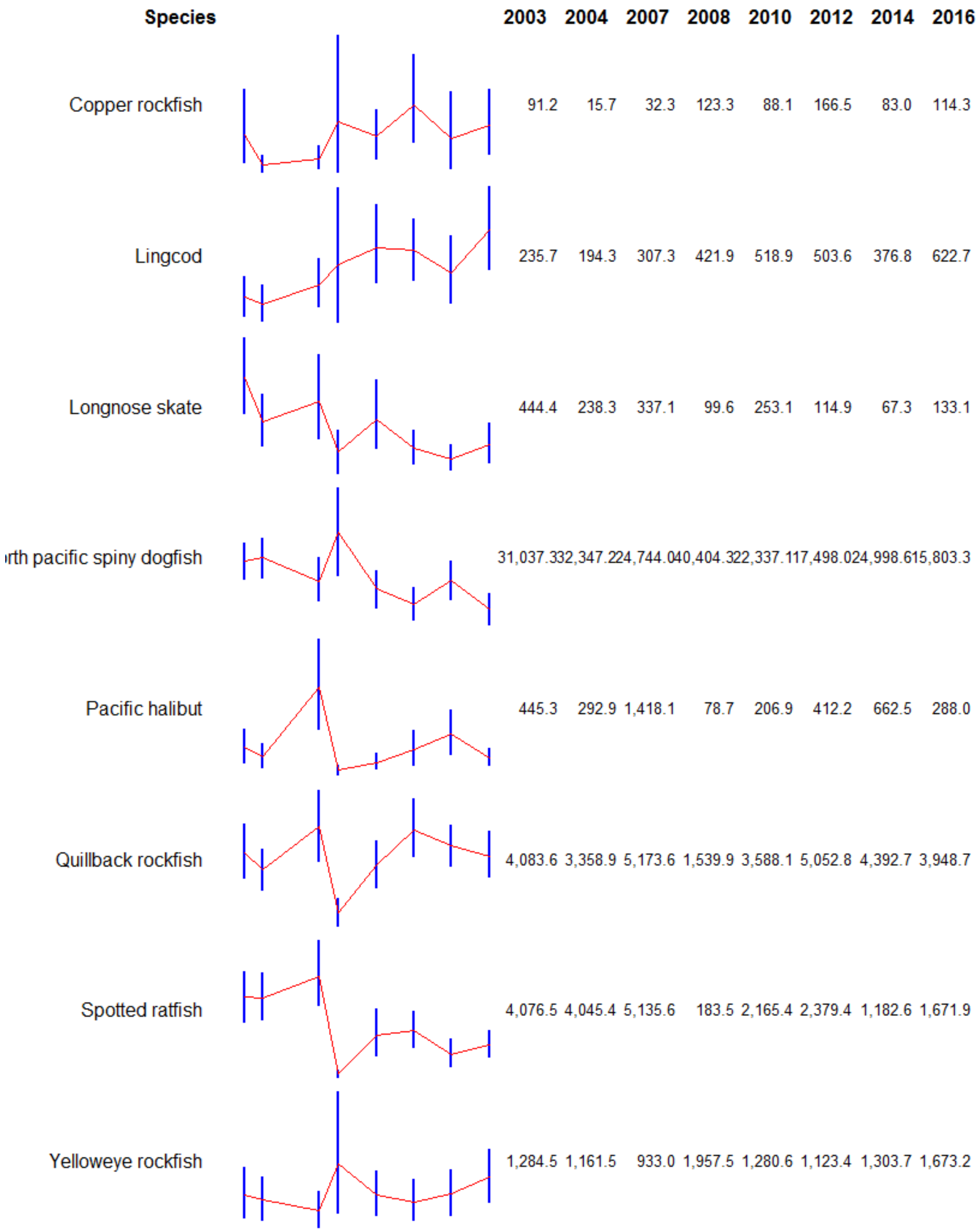


Figure 22-4. As in Figure 22-2 but for the Hard Bottom Longline Hook Survey.

The total catch on the 2016 Sablefish Research and Assessment Survey was 67,166 kg and the average catch per set was 605 kg. The most abundant fish species encountered by weight were Sablefish (*Anoplopoma fimbria*), followed by Pacific Halibut (*Hippoglossus stenolepis*), North Pacific Spiny Dogfish (*Squalus suckleyi*), and Lingcod (*Ophiodon elongatus*). Biological data were collected from a total of 13,583 individual fish of 7 different species. Notable trends include a prolonged decline in the abundance index for Sablefish as well as a prolonged increasing trend for Shortraker Rockfish (Figure 22-5).

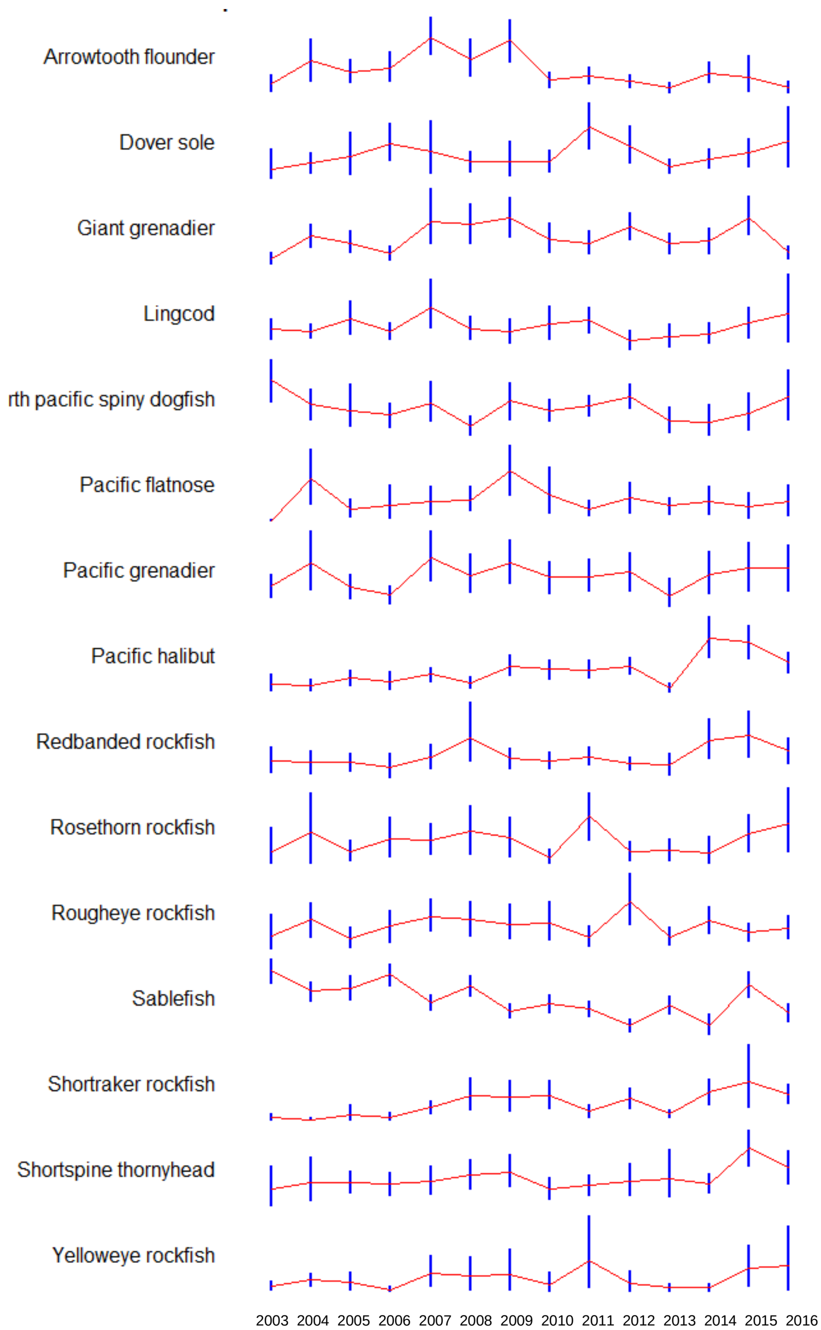


Figure 22-5. As in Figure 22-2 but for the Sablefish Research and Assessment Survey, 2003 to 2016.

While there do appear to be persistent trends for some species in several of these survey time series, they cannot be considered as definitive of stock status in and of themselves. These indices must be incorporated as tuning data into a comprehensive stock assessment analysis before conclusions can be drawn about stock status. That said, at least a couple of trends do bear further consideration, in particular the apparent persistent decline in North Pacific Spiny Dogfish and Longnose Skate. Recently (the last two decades) dogfish have been one of the most common and abundant species on the B.C. coast, their apparent decline in our surveys strongly suggests further investigation is warranted (Figure 22-6). At this point it is impossible to say if abundance has declined or availability to the gears used has changed. Further, we do not know if there has been a change in spatial or depth distribution due to changing climatic conditions.

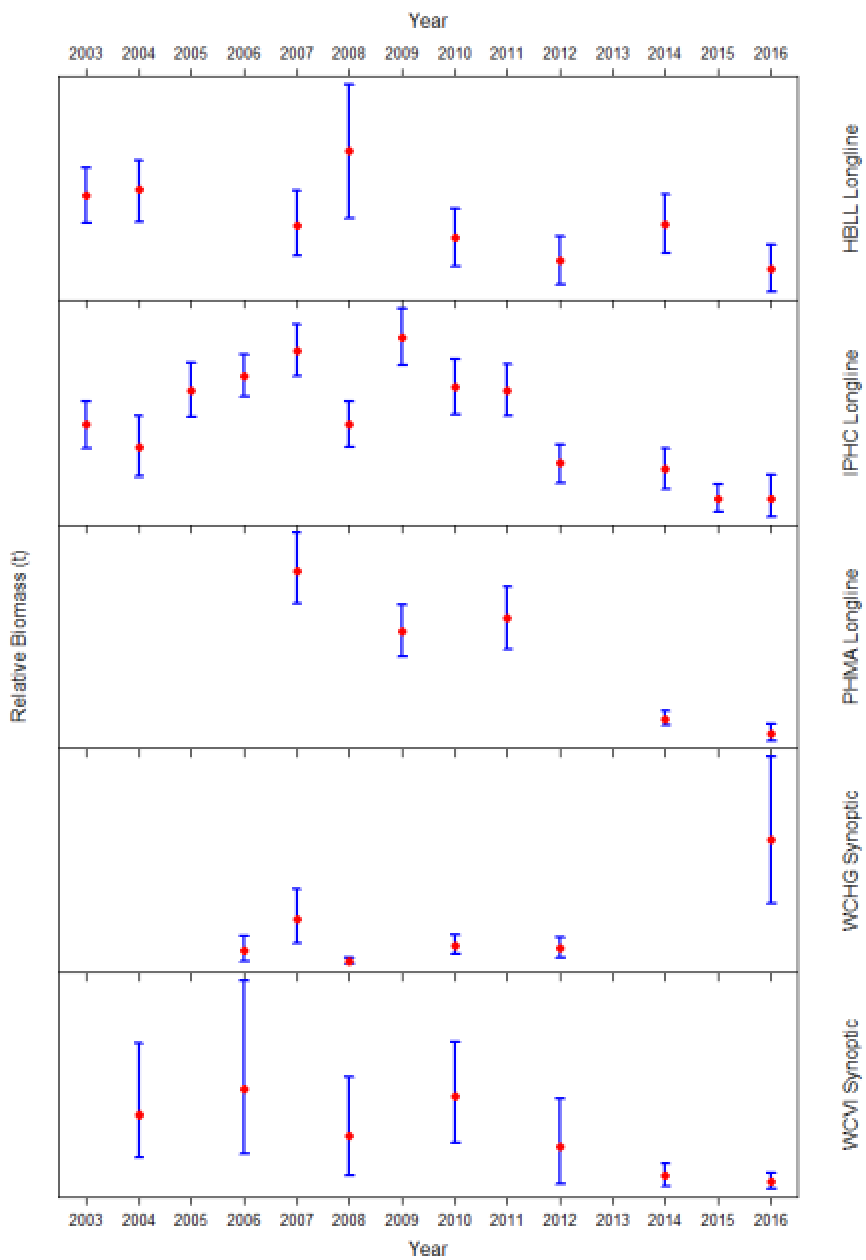


Figure 22-6. Survey indices for North Pacific Spiny Dogfish.

22.4. Factors influencing trends

Potential causes for observed trends range from large scale influences such as the direct impacts from fishery removals, climate change, and increasing benthic anoxia (oxygen dead zones), to small scale influences such as the effect of different fishing masters during surveys, subtle changes to survey gear or gear rigging and the potential impacts of re-randomizing each year. A more fulsome analysis than is presented here is required to tease apart the various influences on survey trends.

22.5. Implications of those trends

Persistent trends, either up or down, can help identify potential issues of concern and focus resources on specific question. Downward trends can be concerning when CV intervals do not overlap, i.e. index points have a high probability of being different from each other if these intervals do not overlap.

The apparent persistent declining trend for North Pacific Spiny Dogfish (Figure 22-6) is consistent across a number of surveys with the notable exception of the West Coast of Haida Gwaii where there appears to be an increasing trend in recent years. Possible explanations include local declines in southern waters, a possible change in distribution driven by either climate change or a temporary phenomenon like the warm “Blob” or a shift in the distribution of prey. It is impossible to draw conclusions from a simple visual inspection of survey trends but these observations coupled with fisher reported declines in the abundance of North Pacific Spiny Dogfish highlight this as an issue deserving further investigation.

23. 2016 SUMMER GROWTH INDEX OF JUVENILE COHO SALMON CAPTURED OFF WCVI IN THE FALL WAS BELOW AVERAGE

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23.1. Highlights

- The estimate of summer growth of juvenile Coho Salmon captured off the west coast of Vancouver Island in the fall of 2016 was below the long-term average. It is important to note that less than 20% of the juvenile Coho Salmon captured off the west coast of Vancouver Island in the fall are from WCVI stocks. Therefore caution should be used in interpreting this index for WCVI Coho Salmon stocks.
- The physical indices that have previously been used to forecast marine survival of Robertson Creek Hatchery Coho Salmon indicate poor conditions for marine survival in 2016, suggesting below average returns of adults in the fall of 2017.
- In 2014, the above average Coho Salmon summer growth index failed to forecast the observed below average marine survival of WCVI stocks, while climate-ocean indices successfully forecasted marine survival.
- In 2015, the above average coho salmon summer growth index did forecast the above average marine survival of WCVI stocks, while climate-ocean indices did not.

23.2. Summary

This contribution updates the juvenile Coho Salmon summer growth index presented in previous SOPO reports (see Trudel et al. 2016). Trudel et al. (2007) observed regional differences in the summer growth of juvenile Coho Salmon as estimated by their relative size and time of capture in the fall compared to assumed size and date of ocean entry. Assuming that smolt survival will be higher in years when salmon are growing rapidly, Trudel et al. (2008) surmised that smolt survival would be positively correlated to this summer growth index. Prior to 2014, this juvenile Coho Salmon summer growth index had been used to forecast the marine survival for Coho Salmon from the Robertson Creek Hatchery on the WCVI. However, the summer growth index values for 2014 and 2015 overestimated and underestimated respectively the marine survival for those years (Figure 23-1).

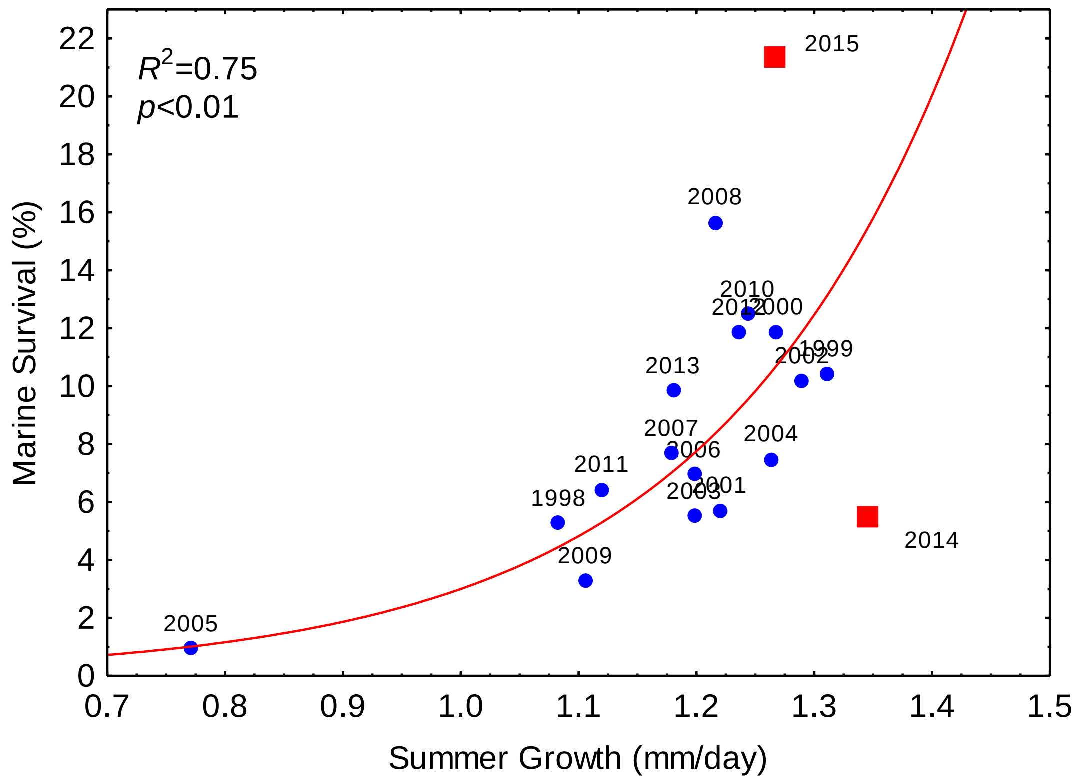

Figure 23-1. Correlation between survival of Robertson Creek Coho Salmon smolts with juvenile Coho Salmon summer growth (May-September) off the west coast of Vancouver Island as reported in Trudel et al. (2016). The ocean entry years, and summer growth seasons of 2014 and 2015 overestimated and underestimated respectively the marine survival. Since marine survival is calculated using the resulting number of returning adults, the 2016 value will not be available until adults return in the fall of 2017.

23.3. Description of the time series

Since 1998, juvenile salmon surveys have been conducted off the west coast of Vancouver Island (WCVI) during the fall, typically October-November. Tows are made at the surface, 15 m or 30 m using mid-water trawl gear along standard transects (weather permitting). In 2016, the survey was conducted from October 27-November 2 on the *M.V. Frosti*. An index of summer growth (mm·day^{-1}) was calculated as per Trudel et al. (2007), based on the fork length (mm) at capture and day of year at capture relative to size and date of ocean entry. WCVI Coho Salmon smolts are assumed to enter the ocean at a mean fork length of 105 mm on May 19th (Trudel et al. 2007). Marine survival estimates are based on the numbers of released smolts from the Robertson Creek Hatchery at the Stamp Falls fishway (WCVI) and the resulting number of returning adults the following year.

Previously, Trudel et al. (2016) applied the ecosystem indicator reporting approach of Peterson et al. (2015) for salmon marine survival in the Northern California Current system to WCVI Coho Salmon. Trudel et al. (2016) selected a small subset of the Peterson et al. (2015) environmental variables, specifically the summer (May-September) mean Pacific Decadal Oscillation index (PDO; http://jisao.washington.edu/pdo/PDO.latest), North Pacific Gyre

Oscillation index (NPGO, http://www.o3d.org/npgo/npgo.php) and Multivariate El Niño Southern Oscillation index (ENSO, https://www.esrl.noaa.gov/psd/enso/mei) supplemented with March-June mean sea surface temperature at Amphitrite Point (SST, http://www.pac.dfo-mpo.gc.ca/science/oceans/data-donnees/lighthouses-phares/data/amphitriday.txt) as physical indicators relating to marine survival of WCVI Coho Salmon. These indicators, along with the summer growth index, were summarized as mean ranks within each time series and sum mean ranks for all series, and color-coded to denote assumed poor conditions (red), average conditions (yellow) and good conditions (green) for marine survival.

23.4. Status and trends

The median and mean estimates of juvenile Coho Salmon summer growth in 2016 were below the long-term average (Figure 23-2). This suggests that Coho Salmon marine survival in 2016 will be below average; however the marine survival estimate will not be available until adult Coho Salmon return to Robertson Creek Hatchery in fall 2017. In 2016, the PDO was in a positive phase, the NPGO was in a negative phase and the ENSO index was positive (i.e. El Niño event). When presented as mean ranks, the physical and summer growth indices in 2016 all suggest poor conditions for marine survival of Robertson Creek Hatchery Coho Salmon (Table 23-1).

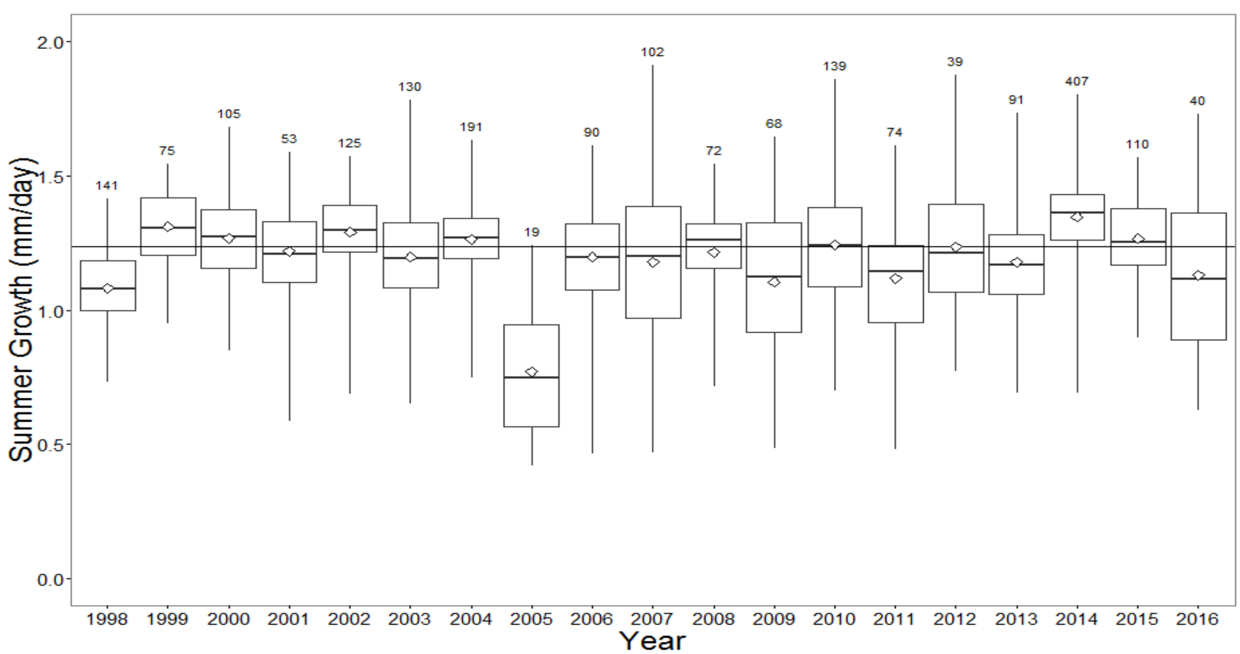

Figure 23-2. Annual summer growth (mm/day) estimates of juvenile Coho Salmon (<400 mm) captured in fall research surveys off the west coast of Vancouver Island [updated from Trudel et al. (2016)]. Boxes are inter-quartile range, whiskers are minimum and maximums, bars are medians, diamonds are means. Horizontal line is long-term mean summer growth. Numbers denote sample size.

Table 23-1. Physical and biological indicators of marine survival for Robertson Creek Hatchery Coho Salmon on WCVI (updated from Trudel et al. 2016). PDO: Pacific Decadal Oscillation (mean May-September); NPGO: North Pacific Gyre Oscillation Index (mean May-September); ENSO: Multivariate El Niño Southern Oscillation Index (mean May-September); SST: Sea Surface Temperature at Amphitrite point (mean March-June); Growth: Summer Growth Index of juvenile coho salmon based on fish captured in fall off WCVI (October-November). As noted in the text, the summer growth index is not based solely on Coho Salmon from WCVI stocks and should be interpreted with caution. Variables are ranked from good conditions (rank 1; green) to poor conditions (rank 19; red) for marine survival. Marine survival for 2016 will not be available until fall of 2017 when adults return to Robertson Creek Hatchery.

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
PDO	10	4	6	5	11	15	14	16	12	13	2	9	7	3	1	8	17	19	18
NPGO	14	5	3	1	8	10	13	18	15	9	2	11	6	7	4	12	16	19	17
ENSO	13	2	7	8	17	9	10	11	12	4	5	16	1	3	15	6	18	19	14
SST	16	1	8	3	4	12	15	17	11	5	6	9	13	10	2	7	14	18	19
GROWTH	18	2	4	9	3	11	6	19	12	14	10	17	7	16	8	13	1	5	15
Mean Rank	14.20	2.80	5.60	5.20	8.60	11.40	11.60	16.20	12.40	9.00	5.00	12.40	6.80	7.80	6.00	9.20	13.20	16.00	16.60
Rank of Mean Ranks	16	1	4	3	8	11	12	18	14	9	2	13	6	7	5	10	15	17	19
Observed marine survival	16	6	4	13	7	14	10	18	11	9	2	17	3	12	5	8	15	1	

23.5. Factors influencing trends

Recent analyses indicate that less than 20% of the juvenile Coho Salmon captured annually off the WCVI in the fall are from WCVI stocks (Beacham et al. 2016), suggesting that this summer growth index may not adequately represent summer growth of Coho Salmon from the WCVI. It is therefore not surprising that the correlation between the summer growth index and marine survival for Robertson Creek Hatchery Coho Salmon has broken down in recent years (Figure 23-1). This also purports that the index of summer growth integrates factors across several ecosystems, not just the WCVI. As such interpretation of the factors influencing the 2016 below average growth is difficult.

23.6. Implications of those trends.

Given that Coho Salmon captured off the WCVI in the fall are from multiple stocks, the below average growth index suggest synchronous poor Coho Salmon growth conditions across a suite of ecosystems such as the Strait of Georgia, Puget Sound and the Northern California Current system. What remains to be determined are the coastal productivity mechanisms that contribute, in conjunction with overwinter conditions in the Gulf of Alaska, to the marine survival of WCVI Coho Salmon stocks. The physical indices that have previously been used to forecast marine survival of Robertson Creek Hatchery Coho Salmon indicate poor conditions for marine survival in 2016, suggesting below average returns of adults in the fall of 2017.

23.7. References

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24. SOCKEYE SALMON INDICATOR STOCKS – REGIONAL OVERVIEW OF TRENDS, 2016 RETURNS, AND 2017-2018 OUTLOOK

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24.1. Highlights

- The 2014-15 anomalously warm "Blob" and continued warm conditions in 2016 in the North Pacific Ocean did not induce widespread salmon recruitment failures in 2016 due to common ocean effects as some feared (Hyatt et al. 2014). However, returns of Fraser Sockeye exhibited historic low levels but were not representative of any coast-wide pattern shared in common among several broadly distributed Sockeye indicator stocks.
- Central Coast Sockeye returns to Smith and Rivers Inlet rose above the all-year average for the first time in more than 20 years.
- Consideration of return patterns for Sockeye Salmon populations throughout their range from the Columbia River in the south to Bristol Bay, Alaska in the north suggests that 2016 returns were generally consistent with the inverse production regime hypothesis in which below average returns on the southern end of Sockeye range in British Columbia is accompanied by above average returns on the northern end of Sockeye range from northwest B.C. to Alaska.
- Impacts of a warmer than average ocean in 2015 followed by an El Niño in spring 2016 suggest survival unfavourable conditions for juvenile salmon making sea entry from the B.C. central to south coast in those years so significant reductions in returns to many populations of salmon (Okanagan-Columbia River salmon; Barkley and west coast Vancouver Island salmon) may be expected in 2017-2018.

24.2. Summary

Studies by Mueter et al. (2002a, 2002b) and Pyper et al. (2005) suggest associations between Pacific salmon survival and coastal environmental variables (upwelling index, sea surface temperature [SST], and sea surface salinity [SSS]) are strongest at local spatial scales (<500 km intervals) for adjacent stocks and exhibit little to no co-variation at scales larger than 1000 km. Correlation scales for SST in summer most closely matched the correlation scales for salmon survival. Regional averages of SST appeared to be better predictors of survival than large-scale measures of SST variability (e.g. the Pacific Decadal Oscillation, Mueter et al. 2002b). Regional-scale variations in coastal SST's may reflect processes causing co-variation in survival rates of neighbouring stocks. Thus, the latter may be expected to exhibit stronger similarities in survival and production variations than widely separated stocks. In addition, geographical overlap of salmon species during freshwater and early marine life stages appear more important in determining shared environmental effects on survival rates than life history differences between species (Pyper et al. 2005).

Comparisons of forecasts and observed returns of Sockeye Salmon for major rivers and fisheries in B.C. have been completed annually by DFO for decades (Figure 24-1). Given the observations above, production trends for major Sockeye populations or stock aggregates (i.e. "indicator stocks") may reflect environmental changes and production trends for other salmon

species originating from coastal-areas constituting separate production domains. Trend comparisons (1970-2016) among Sockeye indicator stocks permit the following generalizations:

- Return variations are large with maximum annual returns at 10-90 times minimum returns.
- Maximum returns for all Sockeye indicator stocks from the North Coast to the Fraser occurred in the early 1990s in association with a powerful 1989 La Niña event 2-3 years earlier. Similarly, a major La Niña in 2008 was followed in 2010/11 by record to near-record returns of Sockeye to Vancouver Is. (Barkley), Fraser R. (Chilko), and Columbia R. (Okanagan), reversing a trend for several years of sub-average returns (Figure 24-1).
- As anticipated earlier (Hyatt et al. 2015), due to a combination of reduced freshwater production and reduced marine survival, southern Sockeye stocks, with sea-entry into the northern California Current upwelling domain (Okanagan, Barkley Sockeye) declined relative to record returns in 2014 (Okanagan) and 2015 (Barkley). However, in both cases these declines were not as severe as initially expected.
- In the central (Smith Inlet Sockeye), north (Nass Sockeye) and transboundary (Tatsamenie Sockeye) coastal regions, returns were near average (Nass) to above average (Tatsamenie) with central coast Sockeye exceeding pre-season expectations to rise above the all-year average return (Smith Inlet) for the first time in two decades.
- Although there are several examples in each Sockeye indicator series for which observed returns diverged greatly from pre-season forecasts (Figure 24-1), the latter commonly anticipate decadal-scale trends within each of their six coastal production domains of origin.
- SST and/or ENSO indices in the Pacific shifted to strongly positive in 2014-2016 so Columbia River (principally Okanagan) and West Coast Vancouver Island Sockeye (principally Barkley Sound) salmon marine survivals appear to have declined significantly for these sea-entry years (i.e. 2016-2018 adult return years). Returns of Barkley and Okanagan Sockeye are anticipated to decline well below their recent decadal averages in 2017 (panels 5 and 6 in Figure 24-1).
- The weight of evidence indicates that salmon survival is determined primarily during the first several weeks after sea entry. Thus, for Sockeye and Chinook Salmon from B.C.'s south coast, conditions for sea entry in spring 2015 and 2016 were highly unfavourable for adult returns beginning in 2017-2018.
- Marine survivals exhibited by Sockeye indicator stocks originating from production domains in the Central, North Coast, and Transboundary areas and returning in 2016 were mixed with no clear indications of strong trends.

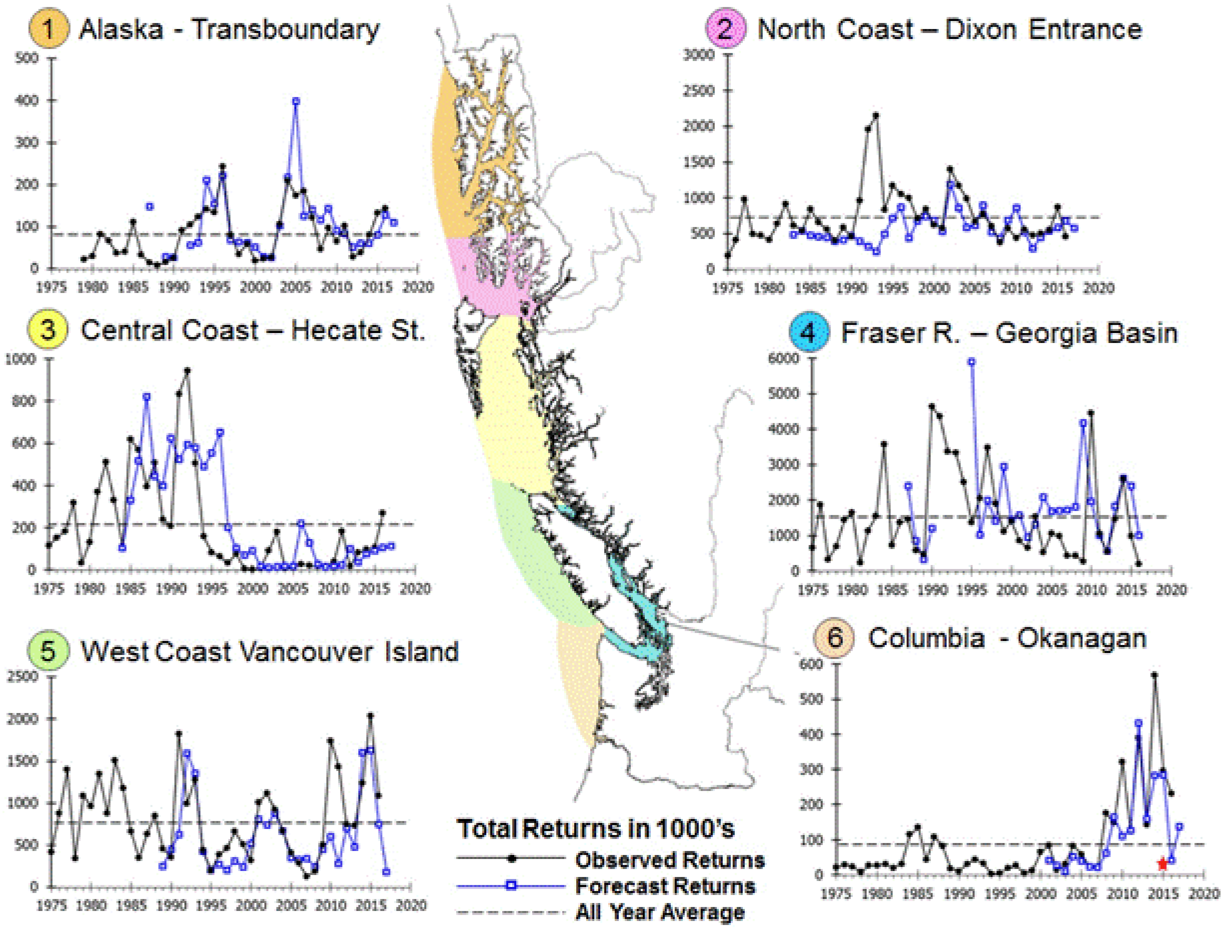

Figure 24-1. Trends in the total returns and forecasts for British Columbia sockeye index stocks including: 1. Tahltan, 2. Nass, 3. Smith's Inlet, 4. Chilko, 5. Barkley Sound, and 6.Okanagan Sockeye Salmon. Y-axis represents returns in thousands of fish. Okanagan 2015 (red point) represents <12000 adults that survived migration to reach the terminal spawning area in the Okanagan River.

Consideration of broader scale return patterns for Sockeye salmon populations throughout their range (Figure 24-2) from the Columbia River in the south to Bristol Bay, Alaska in the north suggests that 2016 returns were generally consistent with the inverse production regime hypothesis (Mantua et al. 1997) in which below “average” returns on the southern end of Sockeye range in British Columbia are accompanied by above average returns on the northern end of Sockeye range from northwest B.C. to Alaska (Figure 24-2).

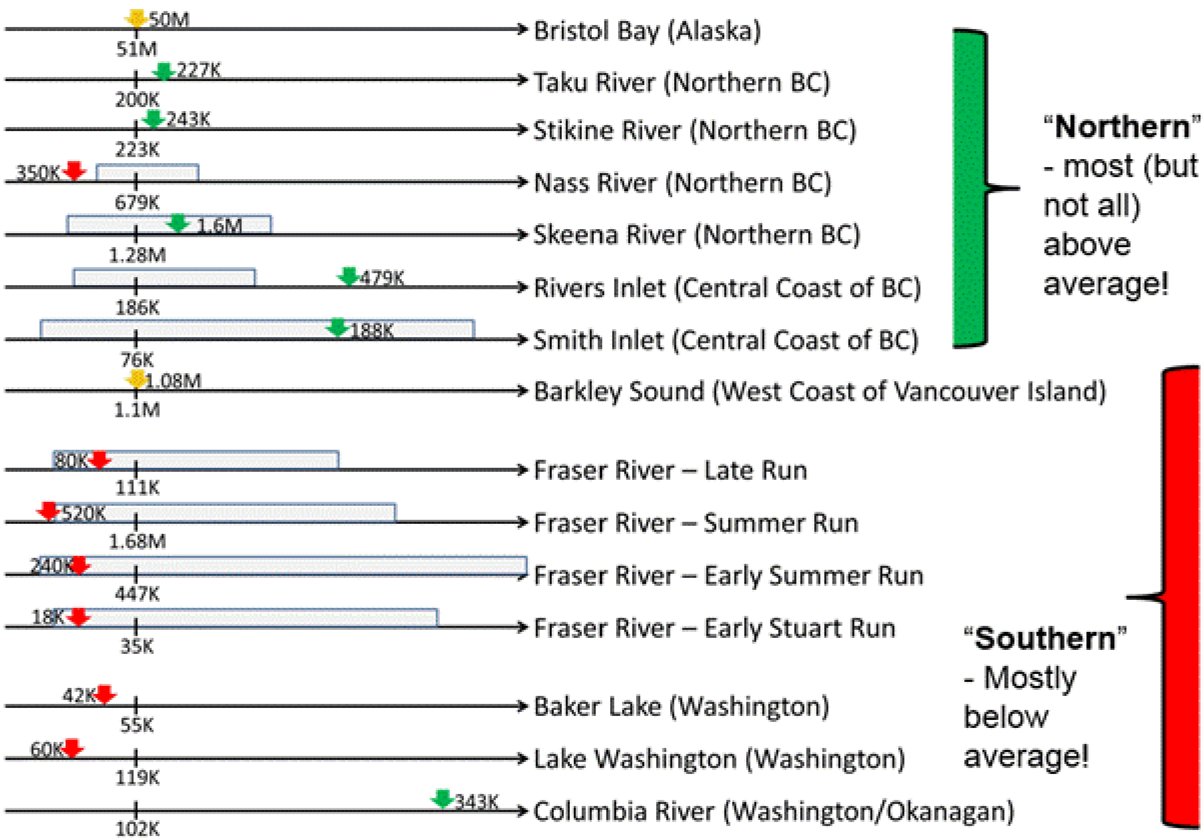

Figure 24-2. A summary of observed versus predicted returns in 2016 for Sockeye Salmon populations located between the southern (Columbia River) and the northern ends of their range (Bristol Bay Alaska) along the eastern margin of the North Pacific Ocean. Green arrows indicate returns were above the median pre-season forecast, red arrows signify returns that were below the median, pre-season forecast.

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25. HUMPBACK WHALES, HARBOUR SEALS AND STELLER SEA LIONS IN BRITISH COLUMBIA: POPULATION TRENDS OF FORMERLY HARVESTED MARINE MAMMALS

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25.1. Highlights

- The humpback whale population in B.C. has increased substantially following depletion by commercial whaling and was last assessed in 2006 at 2,145 individuals (95% CI: 1,970-2,331) (Ford et al. 2009).
- Humpback whales are present year-round on the B.C. coast and use the area as a foraging habitat, with the greatest seasonal abundance occurring from spring to late fall.
- Harbour seals in the Strait of Georgia remain at carrying capacity; 2014 aerial survey results estimated a population of approximately 40,000 individuals in this region (Majewski & Ellis In press).
- Steller sea lions continue to exhibit population growth, with an estimated B.C. summer breeding season population of 39,200 individuals in 2013 (Olesiuk In press).

25.2. Summary

We present updated statuses and population trends for three marine mammal species that were severely depleted by commercial harvesting and predator control programs in British Columbia during the late 19th to mid-20th centuries. These species now exhibit population trajectories that are either recovered/stable (Pacific harbour seal *Phoca vitulina*) or increasing (humpback whale *Megaptera novaeangliae* & Steller sea lion *Eumetopias jubatus*).

25.3. Description of the time series

The most recent population estimate for humpback whales from 2006 was calculated using mark-recapture methodology. Individuals were distinguished by photo-identification of unique natural markings and scars on the ventral side of the tail flukes, as well as by the shape of the trailing edge of the flukes (Ford et al. 2009). Standardized photographs for mark-recapture have been collected in B.C. since the 1980s (6,401 photo-identifications were collected during 1984-2007) and photographs taken from 1992-2006 were used in the 2006 analysis (Ford et al. 2009).

Harbour seal populations in the Strait of Georgia (SoG) have been assessed by DFO since 1973 using standardized aerial survey protocols, with the most recent survey conducted in 2014. During the pupping season, seals hauled out on land at low tide were photographed and counted, and a correction factor was applied to account for seals in the water that were missed during the survey period (Majewski & Ellis *In press*).

Steller sea lions in B.C. have been assessed since the early 1970s using province-wide aerial surveys, with the most recent assessment taking place in 2013 (Olesiuk *In press*). Surveys were typically conducted at the end of the breeding season, which allowed for an estimate of pup production from aerial photographs, in addition to determining counts of non-pups. Correction factors were applied to these counts to adjust for animals at sea that were missed during the surveys. Non-breeding season aerial surveys were also conducted in autumn (2012) and winter (2009-2010).

25.4. Status and trends

Humpback whales were severely depleted by commercial whaling in B.C., which operated from the late 19th century until 1967 (Nichol et al. 2002). Between 1908 and 1965 (when humpback whales became internationally protected), at least 5,638 humpbacks were killed in B.C. (Gregr et al. 2000). Most of these humpbacks were processed by the Kyuquot and Sechart whaling stations on Vancouver Island in the early years of whaling operations (1905-1913; Nichol et al. 2002). By 1915, humpback catches had declined precipitously due to over-exploitation (Gregr et al. 2000; Figure 25-1). Historic abundance of this species prior to the advent of commercial whaling is uncertain; however, a minimum of 4,000 individuals has been estimated for 1905, the year that large-scale, shore-based whaling began in B.C. (DFO 2009).

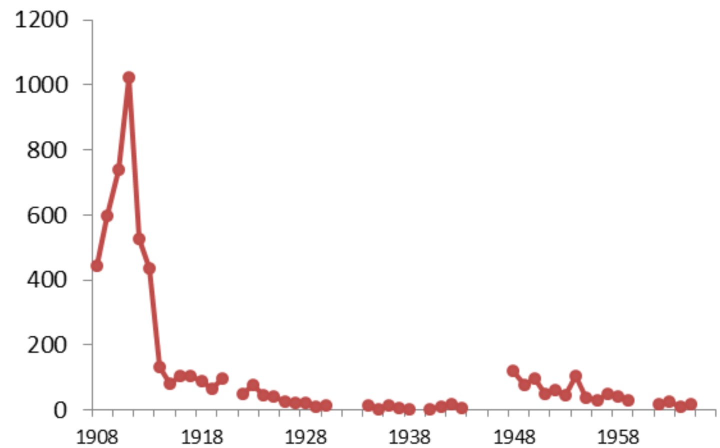

Figure 25-1. Annual catches of humpback whales by shore-based whaling stations in British Columbia, 1908-1965.

The most recent estimate of population size for humpback whales off the coast of B.C. is 2,145 individuals (95% CI 1,970-2,331) in 2006 (Ford et al. 2009). Annual estimated growth rate of this population averaged 4.1% per year during the period of 1992-2006 (Ford et al. 2009). The humpback population in the Northeast Pacific has continued to grow since 2006, and the photo-identification catalogue for B.C. maintained by Fisheries & Oceans Canada contained 2,154 unique individuals as of 2010 (R. Abernethy, DFO, pers. comm.). Humpbacks were also the most commonly sighted cetacean (59%, *N*=1,700) during ship surveys conducted by DFO from 2002-2008 (Ford 2014). The status of the Pacific population of humpback whales was first evaluated by COSEWIC in 1982, at which time it was designated as Threatened. It has since been re-evaluated as Threatened in 1985 and 2003, and as Special Concern in 2011, an evaluation that was upheld in 2013 (DFO 2009, Species at Risk Public Registry 2017). The north Pacific humpback population was legally listed as Threatened under Canada's federal Species-at-Risk Act (SARA) in 2005, and is currently under consideration for down-listing as Special Concern under SARA (Species at Risk Public Registry 2017).

Sightings of humpback whales within Queen Charlotte Strait (northeastern Vancouver Island) were comparatively rare until the mid-2000s, but have increased significantly from seven individuals photographed in 2003 to 90 in 2016 (Figure 25-2). The number of humpbacks photo-identified off Victoria in Juan de Fuca Strait has also increased greatly over a similar time frame, with <10 individuals documented in 2003 to >90 seen in 2016 (M. Malleson, Prince of Whales Whale Watching, pers. comm.,). These data provide substantial evidence that humpbacks are re-populating the inside passage off eastern Vancouver Island, an area from which they were extirpated by commercial whaling.

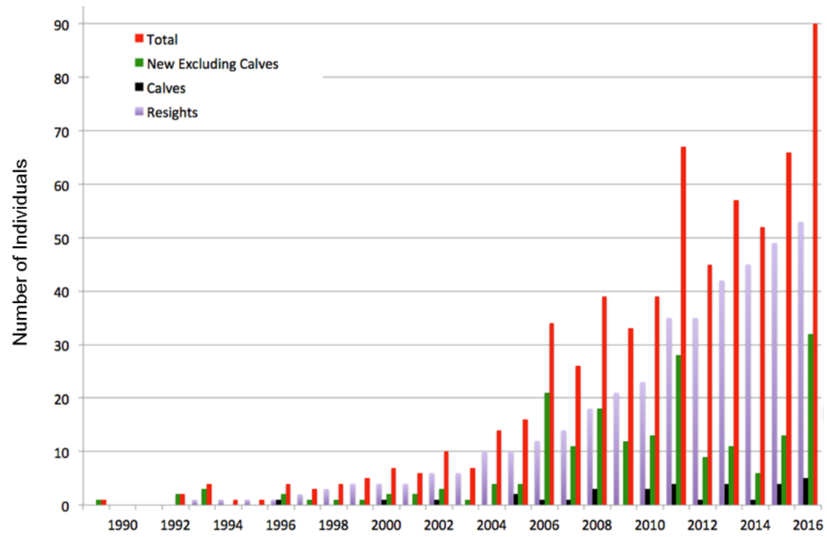

Figure 25-2. Trend in the number of photo-identified humpback whales sighted off northeastern Vancouver Island between 1989 and 2016, including new individuals, previously-identified individuals (resights), and calves. Figure provided courtesy of the Marine Education and Research Society (MERS).

The Pacific harbour seal population in B.C. suffered significant declines as a result of commercial fur harvests (1879-1914, 1962-1968) and predator control programs (1914-1964). By the time the species was first protected in B.C. in 1970, the coast-wide population had been reduced to an estimated 10,000 seals, but it has since increased dramatically (Majewski & Ellis *In press*). Current coast-wide abundance (approximately 105,000 seals) is considered to represent a successful recovery to pre-exploitation levels (Majewski & Ellis *In press*). In the Strait of Georgia, harbour seal numbers grew at a rate of 11.5% annually (95% CI 10.9-12.6%) from 3,600 individuals in 1973 to 39,000 in the mid-1990s, when numbers stabilized (Majewski & Ellis *In press*; Figure 25-3). The most recent SoG survey in 2014 produced an estimate of 39,600 seals (95% CI 33,200-45,000), indicating no significant change from the levels observed since 1994 (Majewski & Ellis *In press*; Figure 25-3).

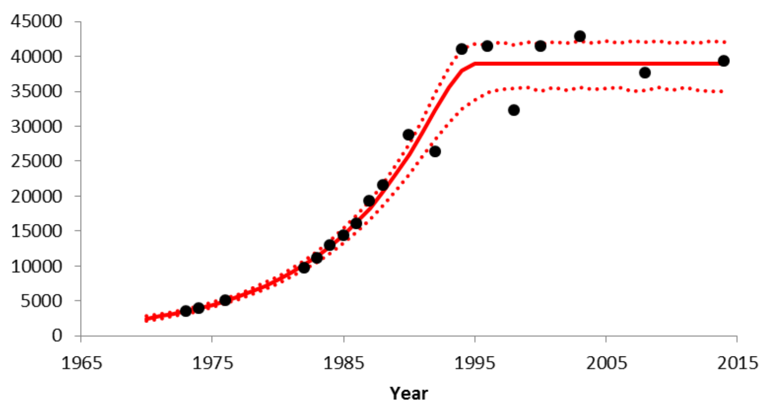

Figure 25-3. Recent trends in harbour seal abundance in the Strait of Georgia. The solid trend line represents generalized logistic curves fitted using maximum likelihood methods and the dotted lines show 95% confidence intervals. Figure reproduced from Majewski & Ellis (In press).

Steller sea lions were depleted by commercial harvesting and predator control programs that removed 55,000 animals between 1912 and 1968. By the 1970s, the B.C. breeding population had been reduced to 25-33% of peak historic levels (Olesiuk *In press*). The population began rebounding in the early 1970s, with non-pup numbers shifting from stable to 4.9% growth annually in the early 1980s (Figure 25-4). Pup abundance also exhibited an increase in annual growth rate in the mid-1980s, up from about 1.7 to 7.0% per year (Olesiuk *In press*). The summer 2013 breeding season survey estimated 39,200 (95% CI 33,600-44,800) Steller sea lions coast-wide, slightly lower than the winter 2009-2010 population estimate of 48,000 (95% CI 38,100-58,900) (Olesiuk *In press*). The Steller sea lion was designated as Special Concern by COSEWIC in both 2003 and 2013, and has also been legally listed under SARA at the same level (Ford 2014, Species At Risk Public Registry 2017).

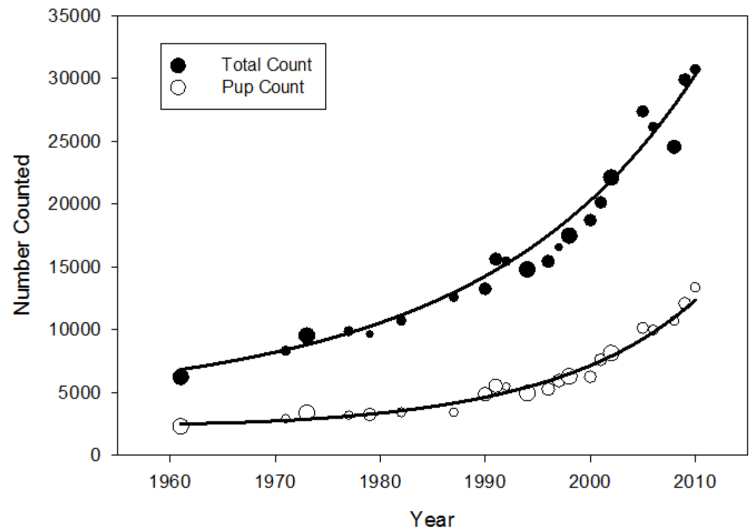

Figure 25-4. Increase in the number of Steller sea lion pups (open circles) and total individuals (closed circles) on rookeries during summer surveys in B.C. and southeast Alaska from 1961-2013. Trend lines represent second-order polynomial regressions fitted to log-transformed counts and symbol size indicates the relative weighting given to counts based on the proportion of the animals surveyed each year. Figure reproduced from Olesiuk (In press).

25.5. Factors influencing trends

Humpback whales are highly migratory and predominately occur in B.C. from April to November, when they feed in the productive colder waters of the North Pacific (Ford 2014). Humpbacks mostly feed on krill, but also consume other zooplankton and small forage fish such as Pacific Herring (*Clupea pallasii*) and Pacific Sardine (*Sardinops sagax*) (Ford et al. 2009, Ford 2014). Their distribution in B.C. likely reflects the availability and spatial occurrence of these prey. For example, sightings of humpbacks in eastern Queen Charlotte Strait (Figure 25-2) in late summer through fall have been linked to the occurrence of dense schools of Pacific herring (McMillan 2014). The continued upward trend of humpback whale population growth in B.C. is largely due to the cessation of commercial harvesting and subsequent high survivorship (97.6% from 1992-2006; Ford et al. 2009) experienced by this population in recent years.

Humpbacks also demonstrate high site fidelity in B.C., with many individuals returning to feed within 100 km of where they were sighted in previous years (Rambeau 2008). Although most individuals undergo a breeding season migration to Hawaii or Mexico in late fall, some humpback whales have recently been documented in B.C. during the winter (December-February; Figure 25-5). It is possible that some of these individuals could be ‘resting’ females that are either choosing to forgo or delaying an energetically costly migration in years when they do not reproduce. Evidence from the central B.C. coast (Figure 25-5) and Prince Rupert (C. Birdsall, Vancouver Aquarium, pers. comm.) regions suggest that humpbacks present in winter may be exploiting herring that congregate at inlet entrances while waiting to spawn. These fish may represent a predictable, energy-rich prey source available to humpbacks in the wintertime.

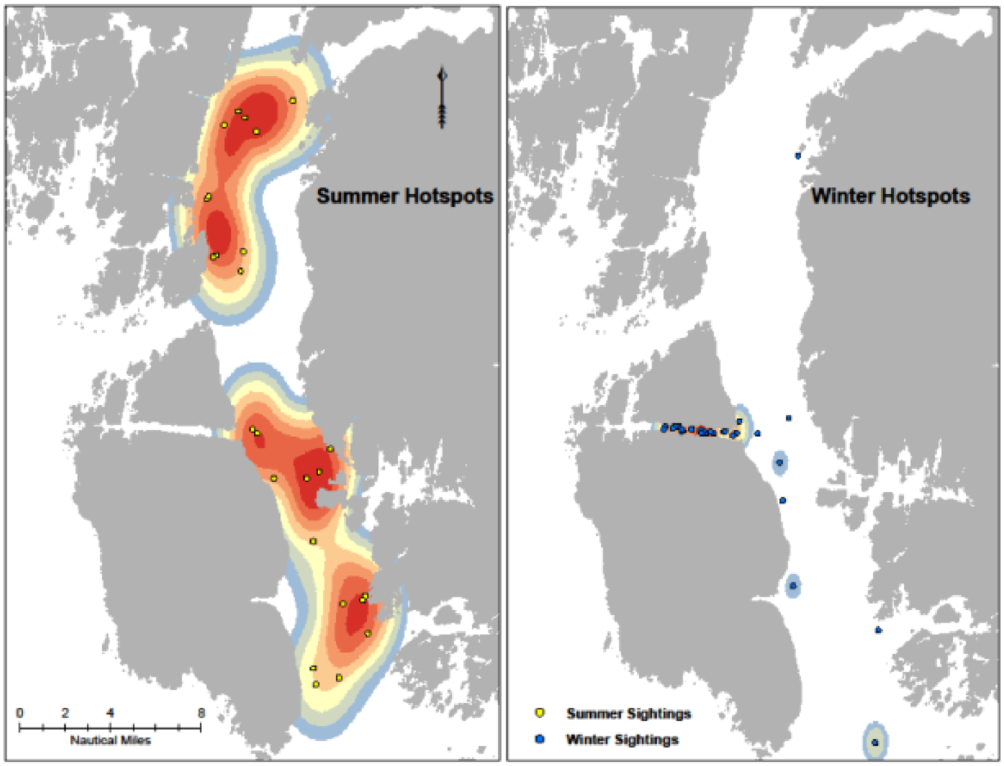

Figure 25-5. Humpback whale sightings and hotspots during summer (left) and winter (right) surveys in Kwakshua Channel and Fitz Hugh Sound, British Columbia. Figure courtesy of the Hakai Institute.

Harbour seals are considered to be non-migratory and individuals exhibit a high degree of site fidelity to specific haulout locations (Majewski & Ellis *In press*). Seals forage locally within 10-20 km of these haulouts and primarily feed on small to medium-sized schooling fish. Diet in the SoG was predominately comprised of herring and hake (*Merluccius productus*) (75% combined; Olesiuk et al. 1990). The increase in harbour seal abundance from the 1970s to 1990s was due to the cessation of harvesting and predator control, and the stability of the population since the mid-1990s implies that harbour seals have now reached carrying capacity in the SoG (Figure 25-3).

Patterns of distribution for Steller sea lions in B.C. are seasonally driven, with summer occupation of large rookery sites followed by redistribution of individuals onto smaller, more spatially diffuse haulouts in the winter. The larger winter population observed during the 2009-2010 survey is likely the result of a net immigration of animals from U.S. waters during the non-breeding season (Olesiuk *In press*). Steller sea lions have shown positive population trajectories for both pups and non-pups since the end of hunting and predator control programs (Figure 25-4). Mortality rates for pups are estimated to be fairly high (only 48% of females survive to age 3 y), but become significantly lower for adults (7-15% and 12-25% per year for females and males, respectively) (Olesiuk *In press*).

25.6. Implications of observed trends

Year-round presence and growing abundance of humpback whales in B.C. will likely have significant impacts on nearshore and continental shelf ecosystems due to top-down effects on low trophic level prey (e.g. euphausiids, forage fish). The recovery of humpback whales in B.C. also has implications for increased marine nutrient subsidies. These can arise from both whale feces, which cycle nutrients from deeper water to the surface, and from whale carcasses, which sequester carbon on the ocean floor and provide a source of food and habitat for deep sea invertebrates (Roman et al. 2014). An updated population estimate for humpback whales is needed to assess the current and future effects that this species may have on coastal ecosystems, as well as to mitigate the impacts of human-caused threats on humpback whale survival. These threats include vessel strikes, underwater noise, oil spills, reduced prey availability and entanglements (DFO 2009, Ford et al. 2009), all of which are expected to increase in frequency/severity due to both the expansion of industrial activities and the continued recovery of humpback whales in B.C.

The stable, recovered population of harbour seals and the growing population of Steller sea lions on the B.C. coast have ecosystem-level implications, since these pinniped species are important predators of many commercially harvested fish species (e.g. Olesiuk et al. 1990, Thomas et al. 2016). Harbour seals and Steller sea lions are also key prey species supporting the recovery of Threatened West Coast Transient (WCT) killer whales. Harbour seals represent 53% of observed kills and harassments by WCT killer whales, with Steller sea lions being the next most common prey species at 13% (Ford et al. 1998).The increasing occurrence of WCTs in the Strait of Georgia over the last 40 years, as well as the growing population size of this killer whale ecotype, are thought to be linked to the rebound of the B.C. harbour seal population to pre-exploitation levels (Majewski & Ellis *In press*).

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26. NEARSHORE FISH AND SEABIRD POPULATION TRENDS IN PACIFIC RIM NATIONAL PARK RESERVE OF CANADA

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26.1. Highlights

- 2016 had the highest count of black-yellowtail rockfish complex in kelp and eelgrass monitoring sites in Barkley and Clayoquot Sound since 2004 and was likely due to favourable winter oceanographic conditions during the species' pelagic larval stage.
- In 2016, Clayoquot Sound had higher counts of copper-quillback rockfish than Barkley Sound and eelgrass habitats in both regions, also had high seaperch counts. These observations likely reflect a response to favourable local habitat conditions, such as temperature and good foraging conditions.
- In 2016 pelagic fish feeders (marbled murrelet, rhinoceros auklet, and common murre) were lower than average and this was likely due to poor inshore foraging conditions driven by warm waters observed in 2016. Whereas, demersal (mixed-diet) fish feeders (Pacific loon, pigeon guillemot, and pelagic cormorant) were above average and this was likely due to a growing local population/high winter survival and good foraging conditions.
- Overall, pelagic fish feeders displayed stable or declining long-term trends and demersal (mixed-diet) fish feeders displayed increasing long-term trends.

26.2. Description of the time series

The Parks Canada ecological integrity monitoring program annually assesses the status and trend of ecological communities in national parks. In Pacific Rim National Park Reserve (PRNPR) we survey marine communities including nearshore fish and seabirds, as part of the annual monitoring program. Nearshore fish species are measured through annual counts of species that are common and abundant in both kelp and eelgrass habitats. Successful young of the year fish species' recruitment into these nearshore habitats rely on favourable oceanographic and within habitat conditions, such as temperature and food availability. We present annual abundance trends of nearshore fish species in six kelp forest beds in Barkley Sound (BS) surveyed from 2008 to 2016, and 22 eelgrass meadows surveyed from 2004 to 2016 in Barkley and Clayoquot Sound (CS) (Figure 26-1). Kelp forest fish surveys were conducted using scuba transects that involved four 25-metre transects placed at similar depths (approximately 10 m) with all fish identified, counted and total length measurements recorded to the nearest centimetre. Eelgrass meadows were sampled using triplicate beach seine sets made at low tide, where all fish captured within a $90m^2$ area were counted, identified, subsampled for length and weight, and returned to the ocean (see Robinson et al. 2011 for details).

Seabird abundance in a given year reflects both local foraging conditions and breeding success. We reviewed the annually averaged May-to-August marine abundance trends of the more common seabirds in Barkley Sound along an adjacent coastal stretch in PRNPR. PRNPR staff conducted biweekly at sea surveys in 1995 - 1996 and 1999 – 2016 along three transects – two in the Broken Group Islands and one further south along the West Coast Trail (BGI-Inner, BGI-Outer, and WCT; Figure 26-2).

The nearshore fish and seabird data (annual abundance estimates) were analysed for overall slope (trend) as well as any break points across the entire time series using generalised estimating equations implemented in the TRIM software (http://www.ebcc.info/trim.html). Kelp fish abundance was expressed as average total count per transect with all six sites combined, eelgrass fish abundance as total individuals (or species) of combined three sets of seines for all sites per year in each region separately and seabird abundance was expressed as average total count per transect.

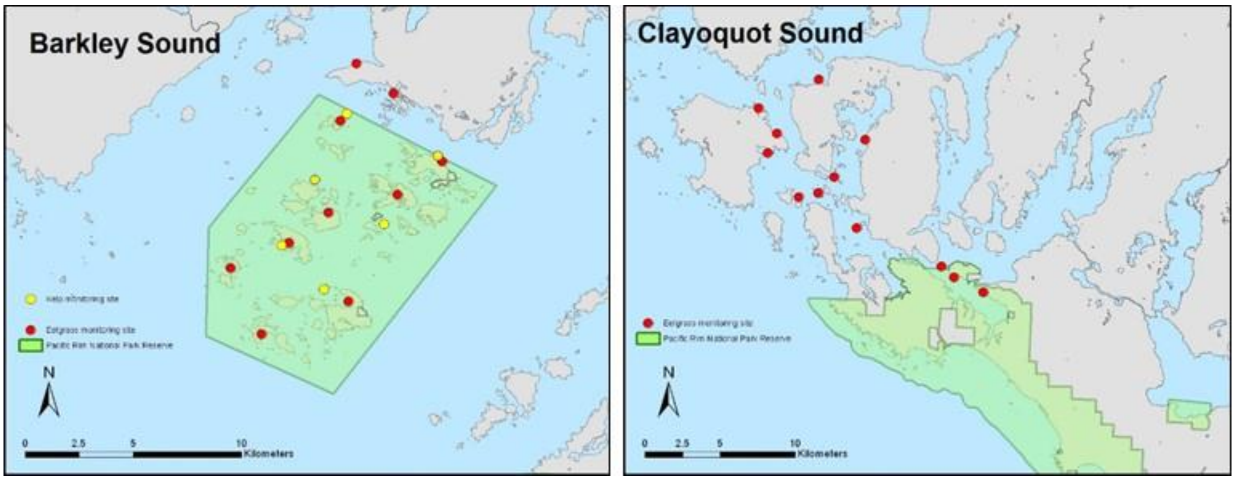

Figure 26-1. Kelp and eelgrass monitoring sites in Pacific Rim National Park Reserve. The green areas indicate the national park boundaries, yellow circles are kelp monitoring site locations and red circles are eelgrass monitoring site locations.

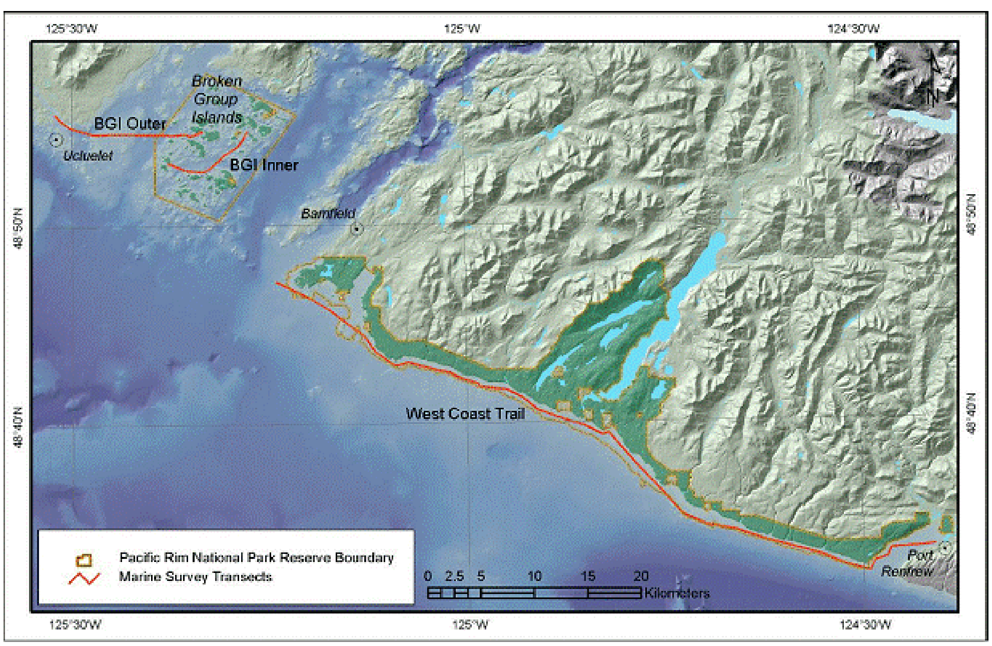

Figure 26-2. At-sea seabird transects in the waters of Pacific Rim National Park Reserve. The Broken Group Islands unit of the Park Reserve is in the top left corner.

26.3. Status and trends

26.3.1. Nearshore fish species

Three species groups that were common and abundant in both kelp and eelgrass fish surveys were evaluated: black-yellowtail rockfish complex (*Sebastes melanops/flavidus*), copper-quillback rockfish complex (*Sebastes caurinus/maliger*), and seaperch (*Brachyistius frenatus, Embiotoca lateralis, Rhacochilus vacca*) (Figure 26-3). Overall, black-yellowtail rockfish had the highest count in 2016 for all regions and habitats, since 2008 in kelp and 2004 in eelgrass. In comparison, copper-quillback rockfish and seaperch counts were lower in Barkley Sound (BS) in 2016, but higher in Clayoquot Sound (CS). Rockfish trends were stable in BS kelp and eelgrass, but in CS eelgrass there was a declining overall trend in black-yellowtail rockfish from 2004 to 2016 (-0.9 +/- 0.05% per year). In comparison, copper-quillback rockfish had an increasing trend in CS from 2004 to 2016 (1.2 +/- 0.03% per year). Lastly, seaperch trends were stable in BS kelp, but showed an increasing overall trend in BS and CS eelgrass from 2004 to 2016 (BS: 1.1 +/- 0.04% per year, CS: 1.1 +/- 0.02% per year).

26.3.2. Seabirds

Six seabird species were evaluated in this report and include the marbled murrelet (*Brachyramphus marmoratus*), the rhinoceros auklet (*Cerorhinca monocerata*), the common murre (*Uria aalge*), the Pacific loon (*Gavia pacifica*), the pigeon guillemot (*Cepphus columba*), and the pelagic cormorant (*Phalacrocorax pelagicus*) (Figure 26-4). In the 2016 summer season, the pelagic cormorant, pigeon guillemot and Pacific loon had considerably higher than long-term average inshore abundances, the common murre was about average, and the rhinoceros auklet and marbled murrelet had below average abundances. Overall trends for the marbled murrelet, rhinoceros auklet and Pacific loon were stable, the common murre showed a decreasing trend from 1995 to 2016 (-2.7 +/- 1.0% per year), and both the pigeon guillemot and pelagic cormorant had increasing trends from 1995 to 2016 (7.0 +/- 0.8% per year and 4.2 +/- 0.6% per year, respectively).

26.4. Factors influencing trends

26.4.1. Nearshore fish species

The observed high black-yellow rockfish complex counts in 2016, were likely a response of pelagic juveniles to regional oceanographic conditions. The reproductive strategy of black-yellowtail rockfish is to release larvae into the water column in late winter-early spring, remain as pelagic juveniles for 4 to 6 months and then emigrate to nearshore areas. The warmer than average sea surface temperatures measured at Amphitrite point lighthouse station in 2016 from January to April likely provided ideal conditions for larval survivorship for this species (Figure 26-5). In comparison, copper-quillback rockfish release larvae in late spring-early summer and lack an extensive pelagic stage, quickly recruiting into nearshore habitats. Consequently, counts of this species may reflect local habitat conditions, such as food and temperature, rather than regional oceanographic regions and may explain differences observed between Barkley and Clayoquot Sound.

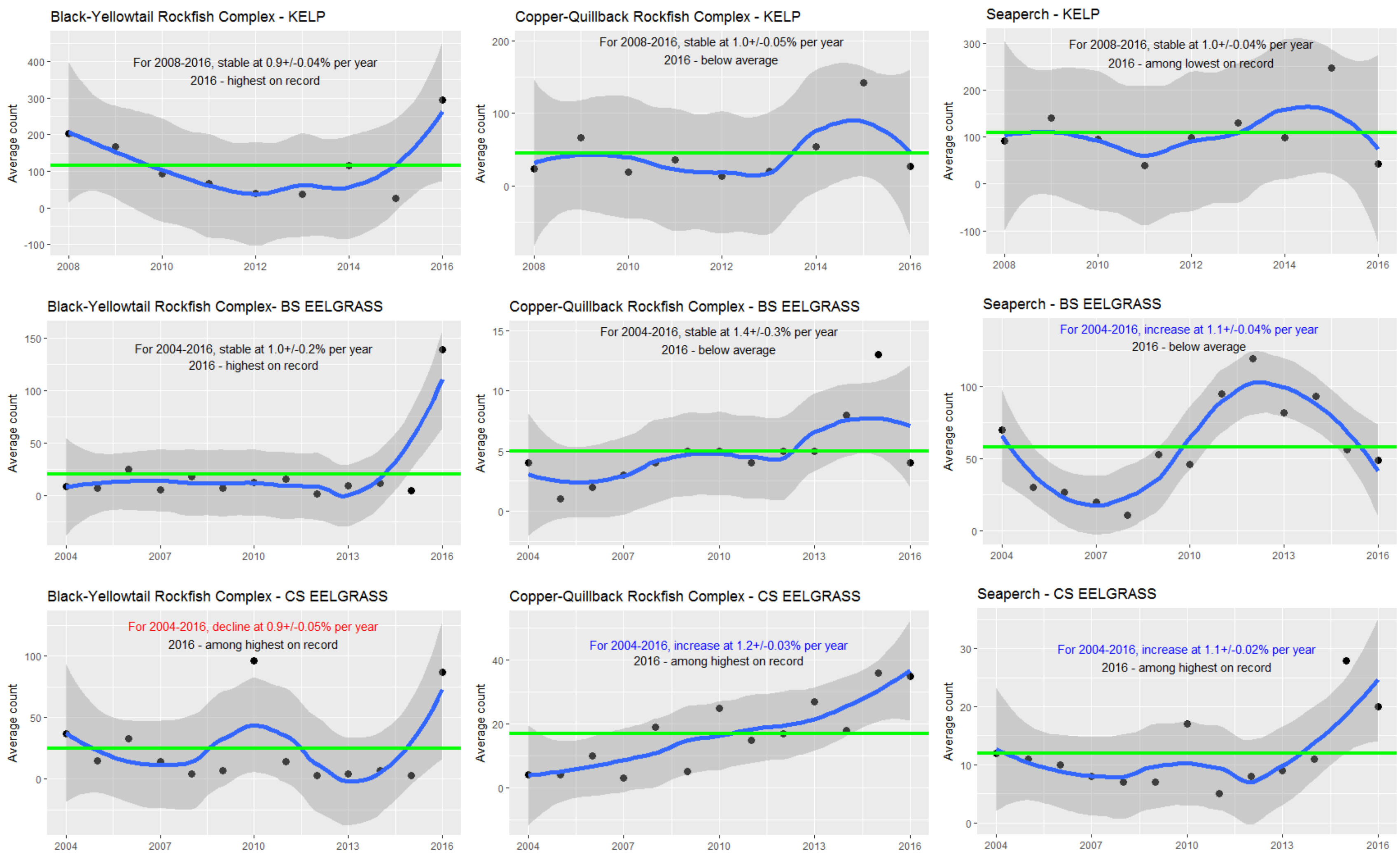

Figure 26-3. Temporal trends in fish species abundance (average count per survey – all transects/sets combined) in Barkley Sound kelp forest and eelgrass sites and Clayoquot Sound eelgrass sites (LOESS trend in blue with the 95% confidence interval bands in grey, green line indicates the overall average abundance for the time series). All slopes are reported. Significant (p<0.05) slopes are coded in red for decreasing populations and blue for increasing populations.

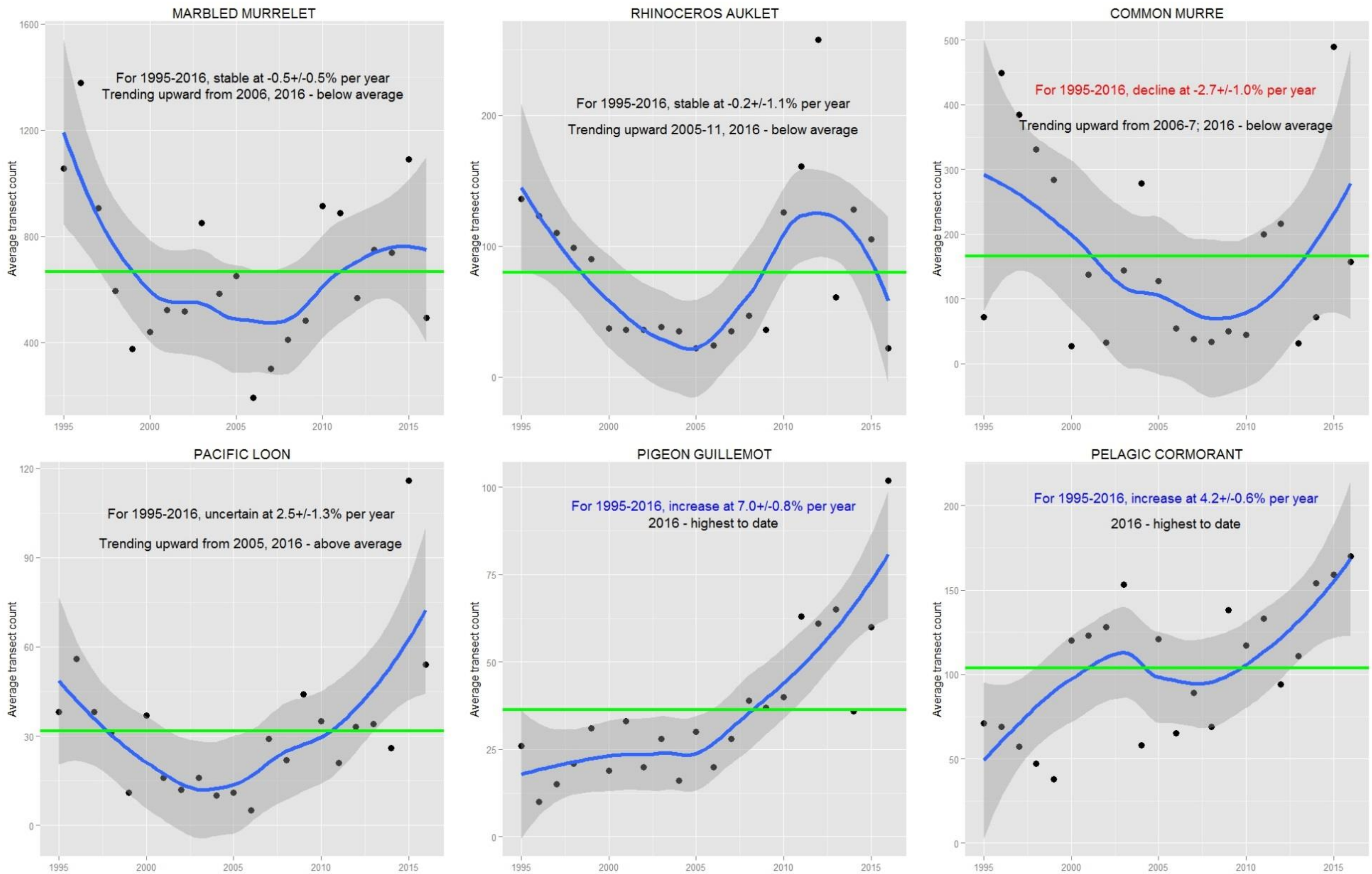

Figure 26-4. Temporal trends in seabird abundance (average count per survey – all three transects combined) in Pacific Rim National Park Reserve (LOESS trend in blue with 95% confidence interval bands in grey, green line indicates the overall average abundance for the time series). All slopes are reported. Significant (p<0.05) slopes are coded in red for decreasing populations and blue for increasing populations.

Lastly, seaperch migrate into nearshore habitats in early spring and give birth to well-developed young in late spring. Within eelgrass habitat conditions in 2016 were likely favourable for seaperch species. In both Barkley and Clayoquot Sound within eelgrass meadow temperatures were warmer in 2016 than in previous years and may provide better reproductive and foraging conditions for seaperch species (Figure 26-6).

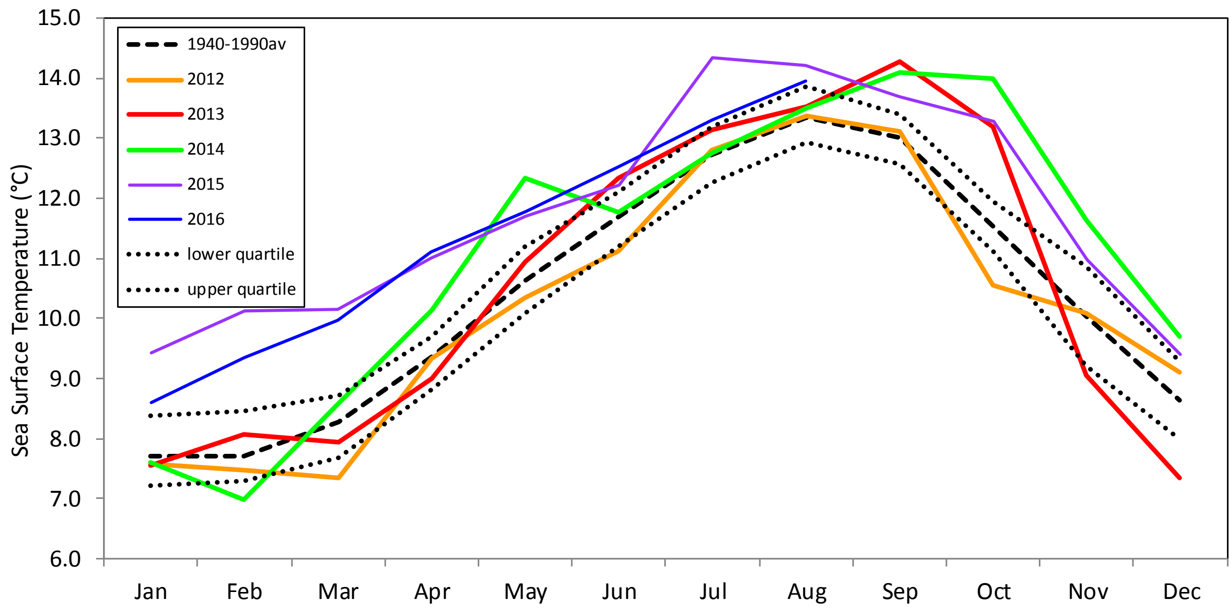

Figure 26-5. Average monthly sea surface temperature at Amphitrite Point Lighthouse (data source: http://www.pac.dfo-mpo.gc.ca/science/oceans/data-donnees/lighthouses-phares/index-eng.html).

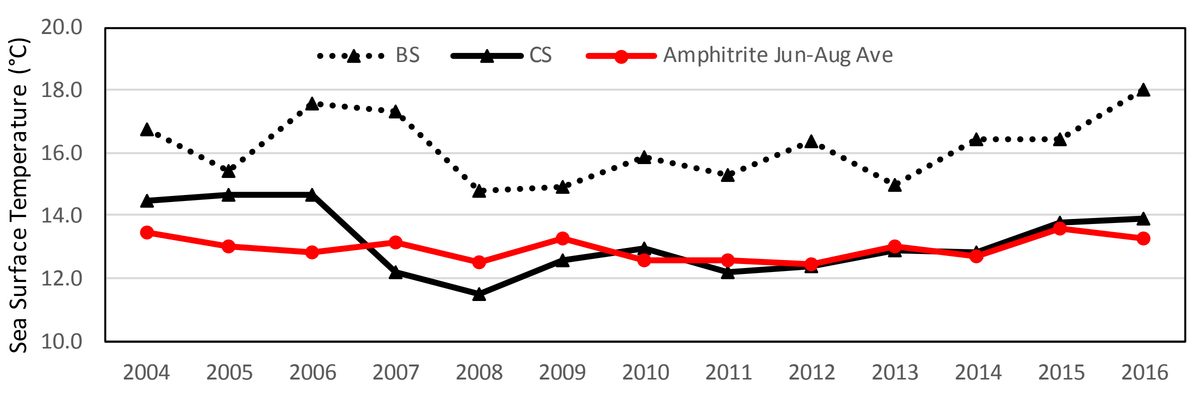

Figure 26-6. Average within-eelgrass-meadow temperature taken during fish sampling event from 2004 to 2016 and average monthly June through August sea surface temperature at Amphitrite Point Lighthouse.

26.4.2. Seabirds

The 2016 observations likely represent local (re) distribution of birds in response to foraging conditions. With warmer coastal waters through most of 2016 pelagic feeders (murre, auklet and murrelet) may have not bred locally, or had a breeding failure and thus were either not present in the area or dispersed earlier than usual. Interestingly, the two storm-petrels (*Oceanodroma* leucorhoa and *Oceanodroma furcata*) nesting on an island within PRNPR, and which also are pelagic feeders, in July 2016 were at about 50% breeding abundance relative to a "normal" year. July is a peak chick-rearing time for these species in PRNPR, which suggests that many adult pairs failed to breed in 2016. This observation also points towards locally unfavourable foraging conditions for pelagic feeders and thus lower breeding effort or success in 2016 across a number of taxa. Demersal or mixed-diet feeders on the other hand (cormorant, guillemot and to some extent loon) did not appear to be impacted by the broader oceanic conditions as their numbers were both high and increasing in the long-term. The high number of young of the year black-yellowtail rockfish observed in 2016 not only in PRNPR, but along their entire coastal range, likely also contributed to favourable foraging conditions for demersal or mixed-diet feeders. Interestingly enough all species covered in the report had a more or less pronounced dip in local abundance around 2005 - 2006 when the oceanic conditions were also warm, followed by an upward trends during a series of colder-water years (2007 - 2012). Considering often large year-to-year fluctuations in the local seabird abundances, the observed trends are likely mostly driven by the local foraging conditions and thus represent an aggregative response by these mostly long-lived birds.

26.5. Implications of those trends

In general, nearshore fish species trends, in kelp and eelgrass habitats in PRNPR, are stable or increasing overtime. A shift towards decreasing trends in these fish species would warrant further examination of habitat condition and an assessment of other factors may also contribute to a decreasing population trend. Identification of these factors could trigger management actions, such as habitat restoration, and prevent further population declines and habitat loss.

Seabirds populations provide a snap shot of the status of local conditions (i.e. foraging conditions), as well as local or distant breeding success. Understanding the long term trends in seabird populations can aid in identifying if population declines can be locally mitigated through breeding site restoration or protection, or if the factors are acting on a broader scale.

26.6. References

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27. OBSERVATIONS ON SEABIRDS ALONG THE OUTER B.C. COAST

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27.1. Highlights

- Cassin's Auklets had a mediocre breeding season in 2016 on the world's largest colony at Triangle Island, with nestling growth rates in that year close to average compared to the years from 1996 to 2015.
- There was little juvenile salmon in diets fed to nestling Rhinoceros Auklets on Lucy Island in 2016, and none on Pine Island.

27.2. Growth rates of Cassin's Auklet nestlings

Like other breeding parameters, growth rates of Cassin's Auklet (*Ptychoramphus aleuticus*) nestlings are very strongly affected by oceanographic conditions, which have a profound influence on seasonal patterns of prey availability. In general, nestling auklets grow more quickly on Triangle Island (northwest of Vancouver Island), the world's largest breeding colony, in cold-water years when the subarctic copepod *Neocalanus cristatus* persists in their diets through the bulk of the provisioning period from May to July (Hipfner 2008). Since 2007, growth rates (gauged by 25 day masses) have tended to be near or above average on Triangle Island, with the notable exception of 2010. Growth rates in the 2016 season were only slightly below long-term averages, which as in 2015, was far better than had been expected based on the continued warm ocean conditions (Figure 27-1).

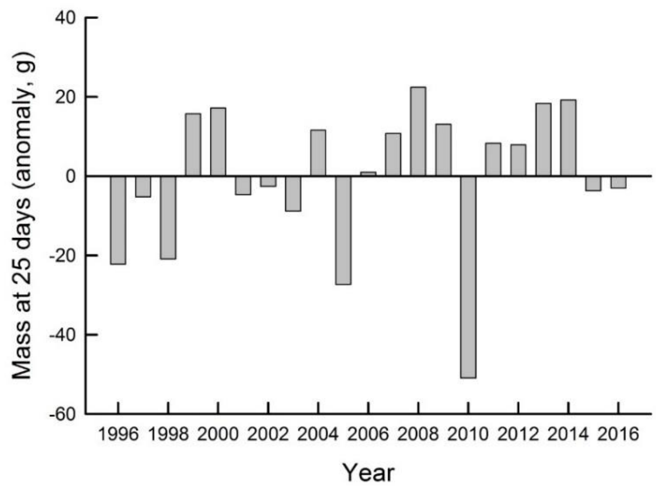

Figure 27-1. Yearly anomalies of mean 25 day mass (a proxy for growth rate) of nestling Cassin's Auklets on Triangle Island, B.C., in 1996-2016.

27.3. Salmon in Rhinoceros Auklet diets

Pacific Salmon (*Oncorhynchus* spp.) have an anadromous life-cycle, spending a few months to 2 years in freshwater, followed by 1-4 years at sea where they fall prey to a variety of fish, mammals and birds. Mortality rates during the marine phase of the life cycle of Pacific Salmon generally exceed 90%, and it is widely believed that most mortality is due to predation in the first few weeks to months following ocean entry (Beamish & Mankhen 2001). On their northerly seaward migration, the vast majority of Pink Salmon (*O. gorbuscha*), Chum Salmon (*O. keta*) and Sockeye Salmon (*O. nerka*) smolts from stocks in southern and central British Columbia funnel past aggregations of hundreds of thousands of Rhinoceros Auklets (*Cerorhinca monocerata*) breeding on colonies scattered along the province's central and north coasts. The auklets are wing-propelled, pursuit-diving seabirds that forage mainly in the top 5-10 m of the water column and within about 90 km of their breeding colonies. The smolts' migration occurs in June and July, coinciding with the period when the auklets are delivering whole and intact fish, including salmon smolts, to their nestlings.

Scientists with Environment Canada and the Fisheries and Oceans Canada have been quantifying predation by Rhinoceros Auklets on salmon smolts since 2006, and some clear patterns have emerged. First, there is marked temporal and spatial variation in the importance, and species and stock composition, of salmon in nestling diets. In general, salmon is most important at Pine Island (Queen Charlotte Strait); in 2016, however, salmon was completely absent in meals at that site – a stark contrast with the years from 2012 to 2014 (Figure 27-2). Salmon has been less important, and less variable, in diets at Lucy Island (Chatham Sound), and the amount present in 2016 was well below average. Salmon was an important component of auklet nestling diets at Triangle Island only in 2012 (almost entirely Fraser River sockeye); no sampling was done at that site in 2016.

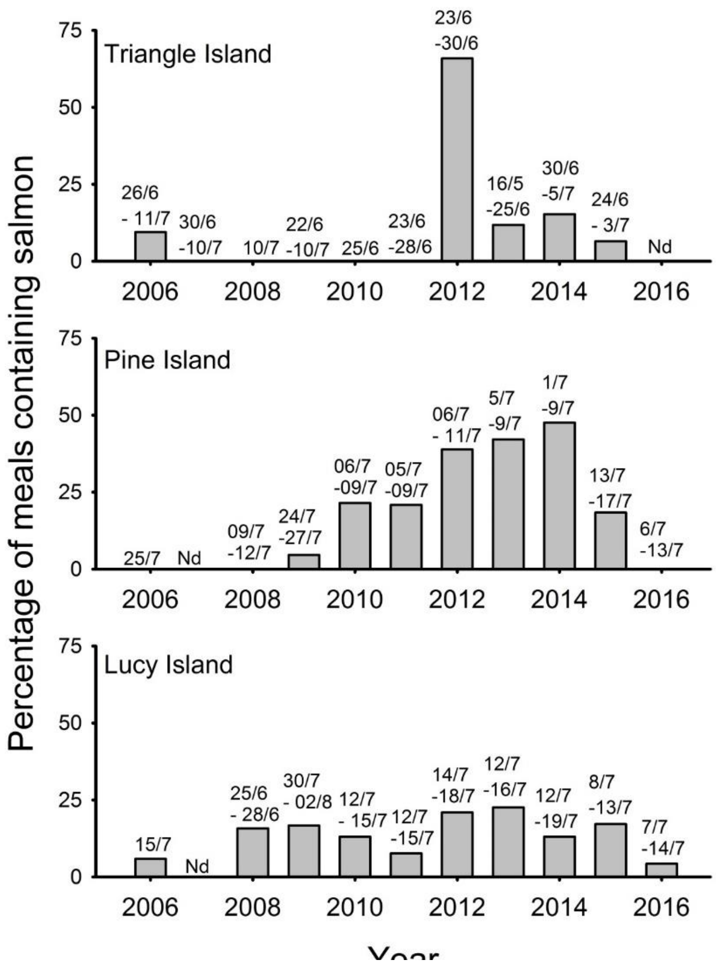

Figure 27-2. Percentage of meals delivered to nestling Rhinoceros Auklets that included one or more salmon (pink, chum, or sockeye) on 3 colonies in BC, Triangle, Pine and Lucy islands, in 2006-2015. Dates of sampling (day/month) are indicated above the bars.

27.4. References

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28. SEABIRDS EXPOSURE TO PLASTIC AND OIL POLLUTION

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28.1. Highlights

- Oil pollution continues to be a major marine stressor; marine plastic pollution is considered a major emerging issue.
- Most of the documented oil pollution incidences likely come from smaller fishing and recreational vessels and marinas in the Pacific Region of Canada; however ship-source oil pollution appears to be increasing, especially in offshore areas.
- Oil exposure models indicate coastal seabirds are most at risk; however, pelagic foraging species such as Cassin's Auklets are increasingly at risk.
- Marine plastic pollution (including microplastics) drift with ocean currents and concentrate in areas where plankton and nutrients are also concentrated (convergent fronts for example); areas that attract many species of seabird when foraging.
- Cassin's Auklet forage in areas of upwelling during the breeding season and are less exposed to risk of ingesting plastic – exposure risk increases during winter months when upwelling decreases or stops.
- It is unclear what the implications are for most (if not all) species of seabirds from ingesting plastic.

28.2. Introduction – Exposure Models, Seabirds, Plastic and Oil

The classic risk matrix framework assigns risk as a composite of equally weighted probabilities of likelihood of exposure, and the potential consequences once exposed (Figure 28-1). Here we develop exposure models, which are essentially spatially explicit risk models, where each spatially defined area is assigned a risk value based on likelihood of exposure to plastic or oil, and the density of potentially sensitive organisms in that same area. In this case, the Pacific Exclusive Economic Zone is partitioned into a grid of hexagonal cells (Figure 28-1), and risk is determined by likelihood of exposure to plastic pollution and chronic operational discharges of oil for several species of seabirds in each grid cell.

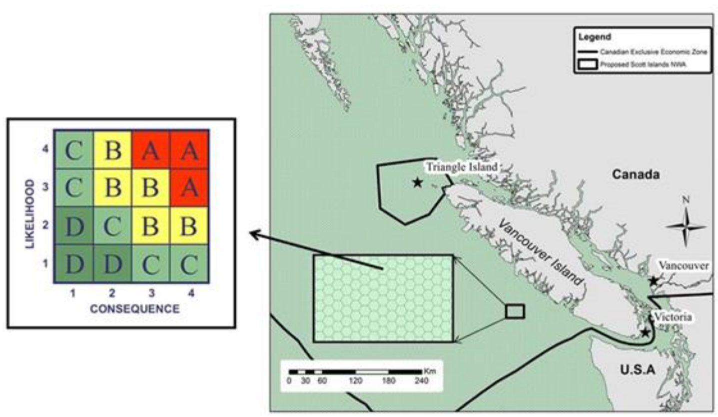

Figure 28-1. Schematic diagram for spatially explicit risk matrix. Risk is assigned for each hexagonal grid square (centroids separated by 4 km), and risk determined by likelihood of exposure (likelihood) and sensitive species in the grid cell.

Both plastic and oil pollution are ubiquitous marine stressors. Since the early 1950s, world plastic production has increased to approximately 269 million tonnes per year (PlasticsEurope 2015). Plastics were developed to withstand degradation, and can persist for long periods in the marine environment. Plastic pollution was initially identified in 2011 as one of three emerging environmental challenges by the United Nations Environment Programme (UNEP 2011), and continues to be identified as a major emerging issue (UNEP 2016). It has been reported that over 260 marine species (including invertebrates, turtles, fish, seabirds, and mammals) have ingested or been entangled by plastics (Boerger et al. 2010, Laist 1997), and new species affected are being reported with increasing frequency.

It is well known that marine birds are highly sensitive to oil exposure (O'Hara and Morandin 2010, Morandin and O'Hara 2016), and even small scale spills associated with chronic discharges of oil can have devastating effects (Wiese and Ryan 2003). Marine vessel discharges that occur as a result of normal operational activities are responsible for a significant quantity of oil pollution in the marine environment; a quantity greater than that resulting from the typically larger scale accidental spills (GESAMP 2007, NRC 2003).

In this report, we describe how we determined spatially explicit risk for seabirds to exposure to oil spills and microplastics by combining, in a risk matrix framework per grid cell, oil spill or plastic likelihood with predicted densities of seabirds.

28.3. Description of the time series

Oil spill likelihood was assigned for each grid cell from model output based on Transport Canada's National Aerial Surveillance Program (NASP) oil spill observation data (Bertazzon et al. 2014, Fox et al. 2016). Microplastic concentrations were assigned for each cell based on the interpolated results published by Desforges et al. (2014). Seabird densities (consequence component of risk) were assigned to each cell from predictive modeling output (Fox et al. 2016). Oil spill likelihood, plastic concentration, and seabird densities per grid cell were all standardized to three ordinal categories using natural breaks or Jenks (oil spill likelihood, plastic concentrations), or terciles (predicted seabird densities). Risk per cell was determined using ordinal categories for likelihood (oil or plastic) and consequence (predicted seabird density). Oil spill likelihood and risk of exposure was constrained spatially to where NASP was effort was most concentrated (see Figure 28-2).

As well, spatially explicit oil exposure risk was determined for each seabird species by calculating the proportion of the total predicted abundance for a species (correcting for spatial variability in effort) in grid cells assigned to each of the three oil spill likelihood categories (for details see Fox et al. 2016).

The oil exposure analyses were based on seabird data collected during the spring (April and May 2007; June 2008), summer (August 2005, 2006, 2008), and fall (October and November 2007), and oil spill data collected all year during the years 2008 to 2010 inclusive. For microplastics, exposure was estimated for Cassin's Auklet (CAAU) breeding season only as the exposure model was based on microplastic water samples taken August and September 2012 and a density prediction model output for CAAU with average conditions for the months of May – August, 2006 -2010. Breeding densities for CAAU were predicted using the machine learning algorithm Random Forest (implemented in R: R Core DevelopmentTeam 2017) and the following predictor variables: depth, latitude, longitude, distance from shore, Julian day, year, distance from centroid of mesoscale eddies (identified using sea surface height), sea-surface temperature, chlorophyll a, and ocean basin scale indices (MEI, PDO, NPGO). Data were insufficient to model CAAU during winter, and for this reason, winter exposure to microplastic was inferred by means of necropsy of CAAU carcasses that were recovered during the massive die-off that began at the end October 2014. Stomach contents were analyzed using microscopes, and plastics were identified, categorized (user versus industrial), and measured for number, size, and total mass.

A bibliometric analysis was conducted on research literature that focused on marine plastic pollution, using search terms "marine bird", "seabird", "plastic", and/or "microplastic" using the document search engine "Scopus" (available through Environment and Climate Change Canada library).

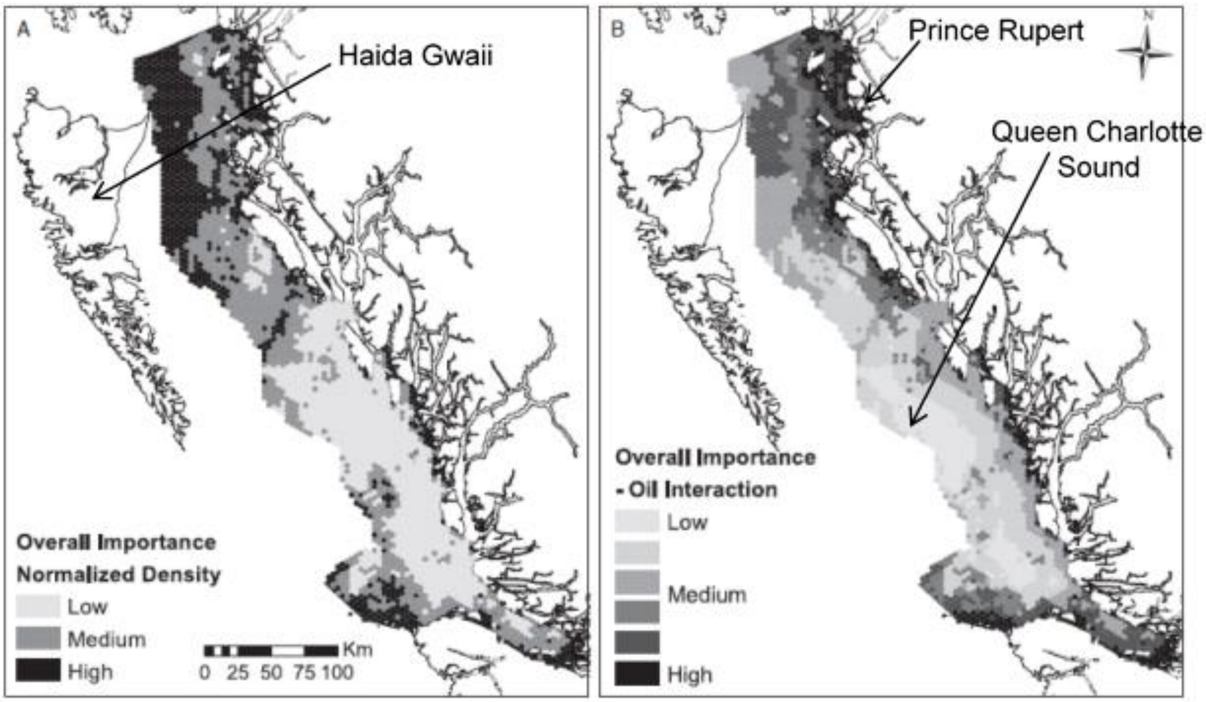

Figure 28-2. Seabirds concentrations (left panel), and risk of exposure to oil spills (right panel). Figure from Fox et al. (2016).

28.4. Status and trends

28.4.1. Oil spills

In terms of oils spills, marina density, and presumably recreational and fishery vessel traffic density, was the major determinant for oil spills. Data for recreational and fishery vessel traffic is lacking, but most of the oil spills occurred close to shore where this maritime activity is most likely to concentrate. In some areas, where there were sufficient oil spill data, commercial vessel traffic density was also a determinant for oil spill concentrations (Bertazzon et al. 2014).

Categorized bird densities were concentrated in small patches along the coast throughout the study area, and in particular in the north. Large concentrations occurred in northern Hecate Strait East and Northeast of Haida Gwaii (Figure 28-2, left panel). Seabird exposure risk from oil is highest in the northern part of the study area where seabirds and oil spills are concentrated. Oil spills in this region are associated mostly with marinas in and around the Prince Rupert area, and lowest in the Queen Charlotte Sound. There were patches of elevated exposure risk along the coast.

Spatially explicit oil exposure risk was determined for each of the species based on proportion of the total predicted abundance in spatially assigned to each of the three categories of oil spill likelihood (Table 28-1).

Of note, Cassin's Auklet (CAAU) is ranked low risk, in this exposure model, which is heavily influenced by coastal maritime activity and associated oil spills documented by NASP. As well, the highest concentrations of foraging CAAU occur outside the Fox et al. (2016) study area (see Figure 28-3, right panel). These concentrations are located in the Central Coast, West Coast Vancouver Island, and offshore patrol regions for NASP (Figure 28-3, left panel), and oil spill detections in these regions have increased in frequency since the publication of the Bertazzon et al. (2014) model. As well, detection rates in these areas are typically less than 1% (O'Hara et al. 2013)

Table 28-1. Percent of marine bird total abundance in study area (quantile rank value 1–3) predicted to occur in oil spill areas (quantile rank low, medium, high), and rank exposure risk in coastal British Columbia. Adapted from Fox et al. (2016).

Common Name	Predicted Population in oil risk areas (%)			Exposure Risk Rank
	Low	Medium	High	
Large Gull (California, Glaucous-winged, Herring, and Thayer's)*	20.2	30.0	49.8	1
Cormorant (Brandt, Double-crested, and Pelagic)	21.6	28.9	49.6	2
Pigeon Guillemot	23.1	29.6	47.4	3
Grebe (Eared, Horned, Red-necked, and Western)	24.1	28.2	47.7	4
Small Gull (Bonaparte's, Mew, Sabine's, and Black-legged Kittiwake)*	23.6	29.6	46.7	5
Rhinoceros Auklet	23.6	31.3	45.1	6
Common Murre	24.4	30.9	44.8	7
Scoter (White-winged, Surf, and Black)	25.7	28.6	45.7	8
Loon (Common, Pacific, Red-throated, and Yellow-billed)	25.6	30.4	44.0	9
Marbled Murrelet	26.4	29.1	44.5	10
Red-necked Phalarope*	27.3	31.2	41.5	11
Leach's Storm-petrel*	30.9	34.0	35.1	12
Black-footed Albatross*	35.5	31.6	32.9	13
Cassin's Auklet	35.2	32.4	32.4	14
Fork-tailed Storm-petrel*	36.9	31.7	31.4	15
Ancient Murrelet	39.8	31.7	28.4	16
Pink-footed Shearwater*	39.1	34.3	26.6	17
Dark Shearwater (Flesh-footed, Short-tailed, Sooty Shearwater)*	40.0	34.0	26.1	18
Tufted Puffin	42.9	34.3	22.8	19

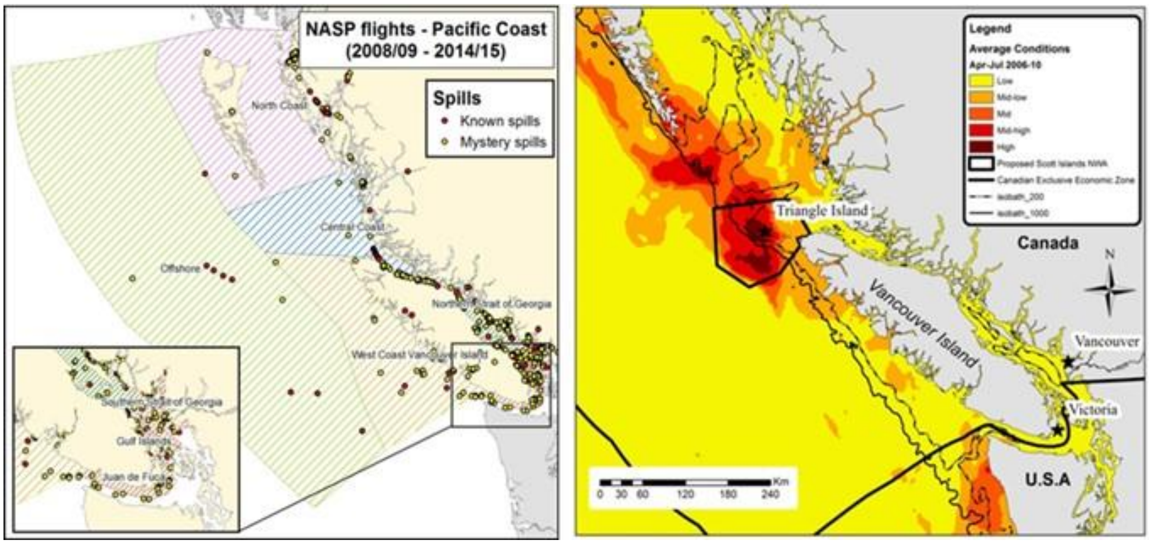

Figure 28-3. Left panel: Oil spills detected by the National Aerial Surveillance Program (NASP) from fiscal years (April 2008/March 2009 to April 2014/March 2005), with known source spills indicated as red dots and mystery spills as yellow. Adapted from unpublished report to NASP by Norma Serra-Sogas. Right panel: Random forest machine learning algorithm prediction for Cassin's Auklet based on average conditions for the months of April-July and years 2006-2010. Density categorized into 5 categories using Jenks or Natural Breaks.

28.4.2. Microplastics

CAAU are exposed to relatively low microplastic concentrations (Figure 28-4), at least while foraging during the breeding season (May – July) and during the years 2006 to 2010. This makes sense as this seabird species is known to exploit upwelling features, where deeper and presumably less contaminated waters shoal.

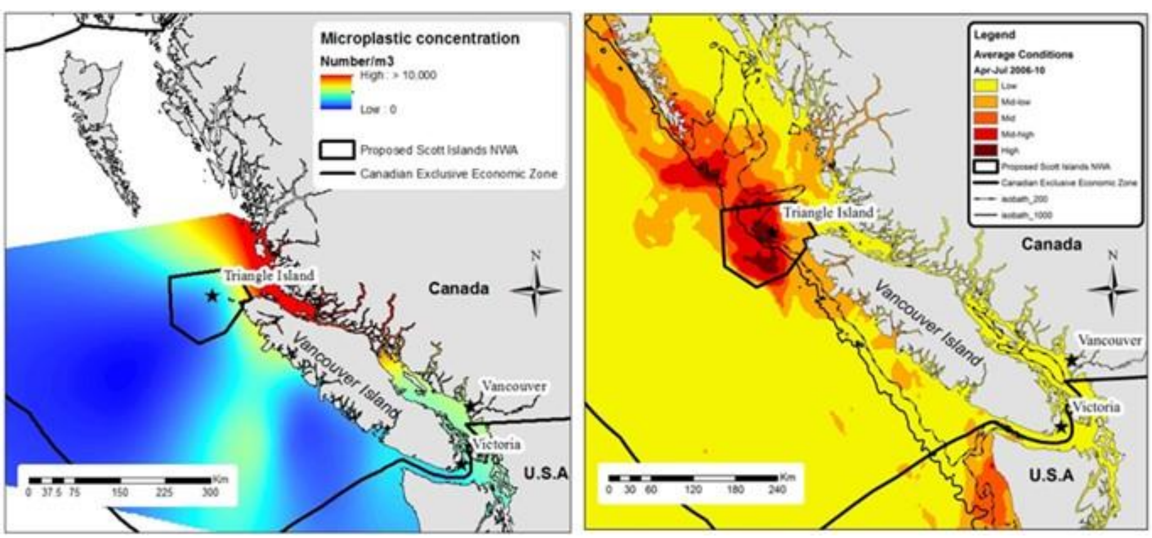

Figure 28-4. Left panel: Microplastic concentration (#/m³) provided by Desforges et al. (2014). Right panel: Random forest machine learning algorithm prediction for Cassin's Auklets based on average conditions for the months of April-July and years 2006-2010. Density categorized into 5 categories using Jenks or Natural Breaks.

However results from necropsies of CAAU carcasses recovered during the massive dieoff that occurred during the winter of 2014 indicate that CAAU are exposed to higher levels of microplastic concentrations. Over 40% of CAAU necropsied (total of 85 birds) had plastic in their stomachs (40% of adults, 44% of juveniles), and most of the plastic found was user (83%) or plastic that has been used to create an end product (i.e. not industrial pre-user nurdles used to make plastic products). Although incidence was relatively high, average load was relatively low with a mean total load of around 0.022 g, which represents less than 0.12% of the average body mass of CAAU (200 g).

Although incidence of plastics in seabirds has increased since it was first reported in 1960 (Provencher et al. 2009, 2010), and it is estimated that nearly half the global marine species of birds ingest plastic (Provencher et al. 2010), the rate of scientific publication on plastic seabirds (number of publications per year) has not increased until recently (Figure 28-5). Publication of studies on plastics and seabirds has increased over the last ten years by a factor of 6 to10 times the rate prior to 2008, where the rate of publication was consistently between 2 to 4 publications per year. Although publication rate has increased, most report incidence (number of pieces, toxic indicators), characterize plastic ingested, and suggest possible implications on individual fitnesses and population level rates. To date there are no clear implications of plastic loads in birds, although in some cases (e.g. birds with heavy loads) it is hard to imagine that there are no implications at the individual fitness level at least.

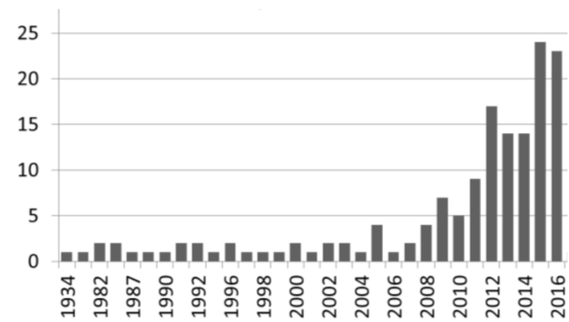

Figure 28-5. Annual rate of publications (#/year) focusing on marine plastic pollution and seabirds (for search terms see section 28.3 Description of Time Series).

28.5. Factors influencing trends and implications

Factors affecting distributions and abundances of seabirds will affect the exposure models for both oil spills and microplastics. The main factors affecting seabirds include climate change, fishery bycatch, oil (and other contaminants to an unknown extent), and loss of critical habitat (for both foraging area and breeding sites) that is attributable to climate change and other causes related to human activities.

Oil spills decreased dramatically with the onset of NASP and the Integrated Satellite Tracking of Oil Polluters (ISTOP), presumably as a result of deterrence. However, preliminary analyses based on more recent data indicate that rates of oily discharges from larger vessels are on the rise again in the Canadian Pacific Exclusive Economic Zone (EEZ). This could have major implications on seabirds, particularly during the breeding season when birds concentrate along the coast of B.C. in areas where maritime traffic is intense. It takes a tiny amount of oil to kill a bird, so even small discharges of oil can impact large numbers of seabirds if the discharge occurred in an area where marine birds are concentrated.

Most of the plastic pollution floating in the Canadian Pacific EEZ come from terrestrial based sources in Alaska, B.C., and Washington, and also from Asia via the North Pacific Current as plastic persists for a very long time in marine environments. Plastics move with the currents, and tend to collect in areas where plankton and nutrients are also concentrated (a convergent front for example). Marine birds that exploit these areas, because they tend to be areas with elevated productivity, are also exposed to higher levels of plastic concentrations. Conversely, birds that exploit features associated with upwelling of deeper water are less exposed to plastic pollution. Regardless of exposure, it remains unclear if there are any serious implications of plastic ingestion in birds. On the other hand, entanglement in plastic larger than microplastics (macroplastics) does have clear implications, but this exposure model did not address macroplastics.

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

29. WEATHER DRIVEN DYNAMICS OF PLUVIAL WATERSHEDS ON THE CENTRAL COAST OF BRITISH COLUMBIA (CALVERT ISLAND) FROM 2013 TO 2016

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29.1. Highlights

- We characterize watershed conditions in the 2015-2016 water year (October through September) in comparison to the previous two years and long term climate normals, using data from a small (780 ha) pluvial watershed on the B.C. Central Coast.
- Peak freshwater runoff spans the period from October to April of each year, as expected for a rain-dominated system.
- All three years were warmer and drier than spatially interpolated 30-yr normals. Our latest data underscore the degree to which summer 2015 was unusual in terms of both runoff and stream conditions. In summer 2016, stream flow was not as low – nor was stream temperature as high – as in summer 2015. This suggests more favourable freshwater conditions for fish in summer 2016 than 2015.
- In this system, weather anomalies – at annual, monthly and storm scales – exert strong controls on soil water, stream conditions, and watershed discharge. In turn, variable freshwater runoff contributes to dynamic ocean conditions.

29.2. Introduction

A long-term coastal margin observatory was established by the Hakai Institute on the B.C. Central Coast in 2013. The goal of the research program (the Kwakshua Watersheds Program) is to understand watershed interactions with the coastal ocean, with a focus on the generation and flux of terrestrial organic matter from land to sea. The core measurements are also broadly relevant to monitoring freshwater conditions for anadromous fish in the many small rain dominated streams of the B.C. Central Coast and freshwater influences on the nearshore Pacific Ocean. Here we briefly characterize watershed conditions in the 2015-2016 water year (October through September) in comparison to 2013-2014 and 2014-2015, with emphasis on watershed 708 (Figure 29-1) where we have the longest record of observations.

29.3. Methods

29.3.1. Study Area

The observatory is located on Calvert and Hecate Islands on the outer-coast of central British Columbia (Figure 29-1). Mean annual precipitation from 1981 to 2010 is estimated at >3000 mm, primarily as rain (ClimateWNA, Wang et al. 2012). Our focal watersheds vary in size from 317 ha to 1279 ha. Elevations range from 0 to 1012 m above sea level. Wetlands are extensive, including blanket bogs and forested wetlands. Tree sizes and growth rates are small compared to more mountainous areas of the mainland coast. These watersheds yield more dissolved organic carbon to the coastal ocean, per unit area, than most places on earth (Oliver et al. 2017). These watersheds are broadly representative of the many small outer-coast watersheds that drain directly into the Pacific Ocean from Vancouver Island to Southeast Alaska.

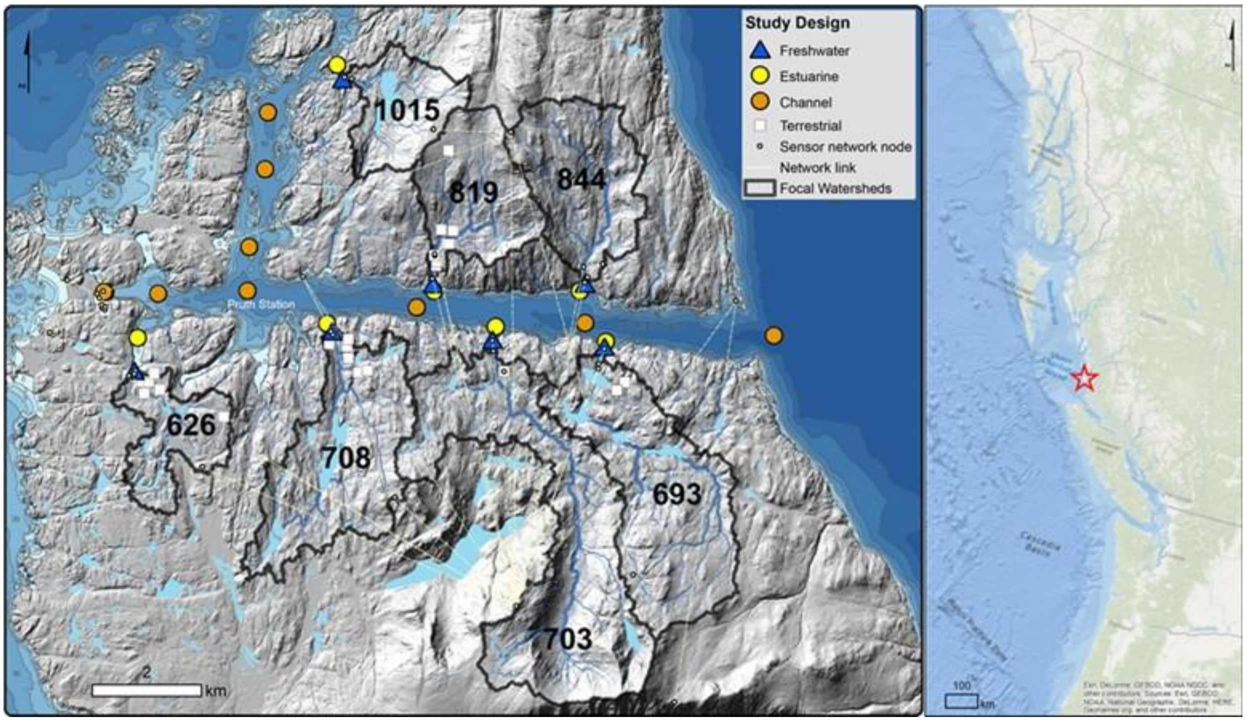

Figure 29-1. Location and design of the Hakai Institute's coastal watersheds observatory on Calvert Island, on the Central Coast of British Columbia. The seven focal watersheds (boundaries and ID numbers shown) drain into Kwakshua Channel. A network of weather, terrestrial, stream and ocean monitoring sites was established in 2013. The bare-earth hillshade was produced from a LiDAR derived digital elevation model.

29.3.2. Data Collection

We used a network of in-situ sensors to monitor weather, soil, and stream conditions (Figure 29-1). Water chemistry samples were collected approximately once per month on average through the focal time period. Salt-dilution stream gauging and stream stage sensors were used to build rating curves and to estimate freshwater discharge on 5 min intervals. Weather and stream data are presented for watershed 708, a 780 ha watershed draining directly into Kwakshua channel. Water table data are presented from a terrestrial sensor node at the west end of Kwakshua channel.

29.4. Results

December, March, and September of the 2015-2016 water year were very wet compared to our 3-yr record and the interpolated 30-yr normal (Wang et al. 2012) (Figure 29-2). However, total rainfall for the water year remained well below the 30-yr normal. Summer 2016 was drier than the estimated normal but not nearly as dry as 2015. Mean air temperature in 2015-2016 was above normal for the year, particularly in winter and spring.

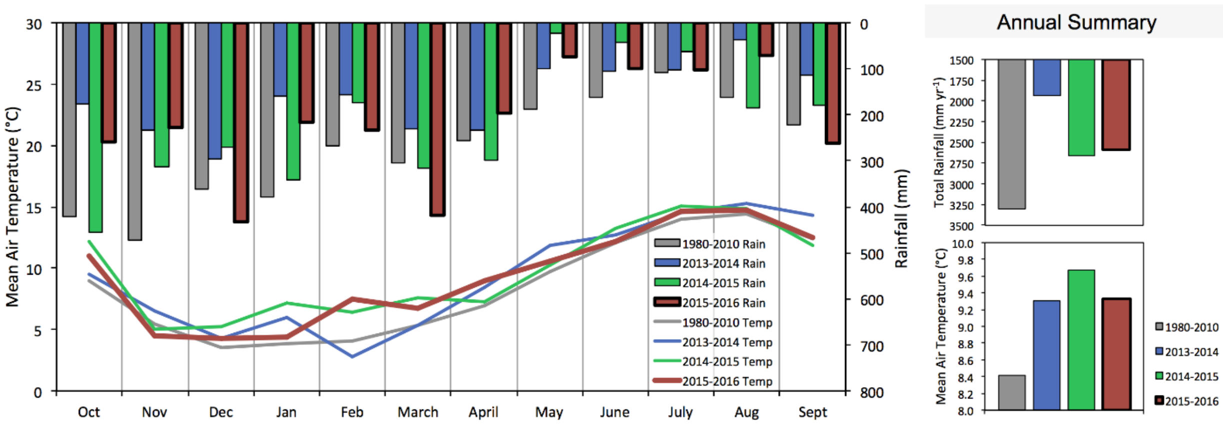

Figure 29-2. Rainfall and air temperature at the outlet of watershed 708 showing local data for three years in comparison to 30-year averages estimated using ClimateWNA spatially interpolated data (Wang et al. 2012).

In the soil of a wetland at the western end of Kwakshua Channel , the monthly median water table was high – within 20 cm of the surface – from October to April each year (Figure 29-3), as expected for this rainforest climate. However, each year we observed a distinct drawdown of the water table in mid to late summer – when monthly median water table depth fell below 30 cm (Figure 29-3) – corresponding with a period of reduced rainfall and higher evapotranspiration. This pronounced summer drawdown occurred two months earlier in 2015 than in 2014 or 2016. In 2016, drawdown below 30 cm occurred in only one month, compared to two months in each of the previous two years.

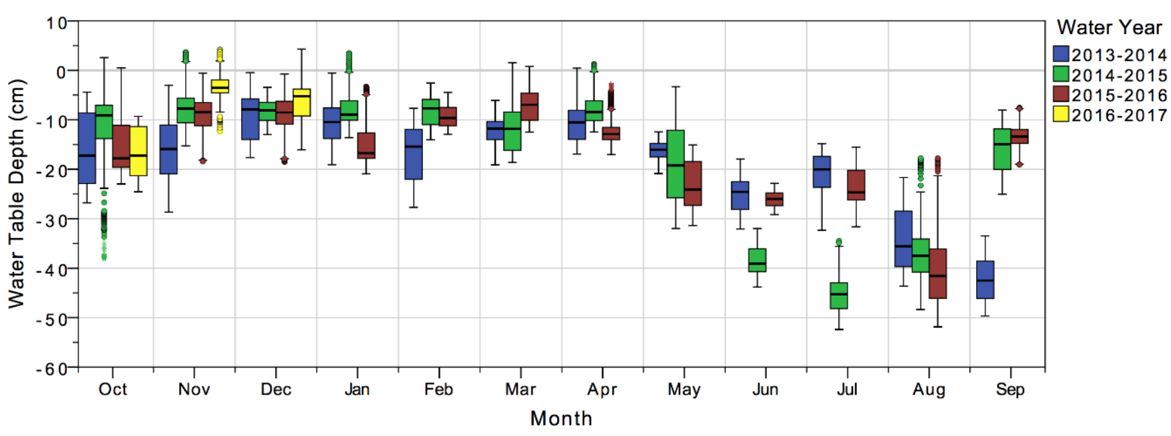

Figure 29-3. Water table depth measured in a freshwater wetland at the western end of Kwakshua Channel.

Monthly freshwater discharge (Figure 29-4) closely tracked changing rainfall inputs and water table seasonality and interannual variability (Figure 29-2 and Figure 29-3). Each year we measured >1,000,000 m^3/month freshwater runoff from October through April and less than 600,000 m^3/month from May through August. In the 2015-2016 water year, we observed a particularly large freshwater flux in March 2016 (2,822,447 m^3; 35% more than the 3-yr average for March) due to record rainfall that month (Figure 29-2). We saw 18 times more discharge in June-July 2016 than in June-July 2015, highlighting how dry summer 2015 was in the context of our 3-yr dataset. In 2016, the summer low flow period ended with heavy rains in September.

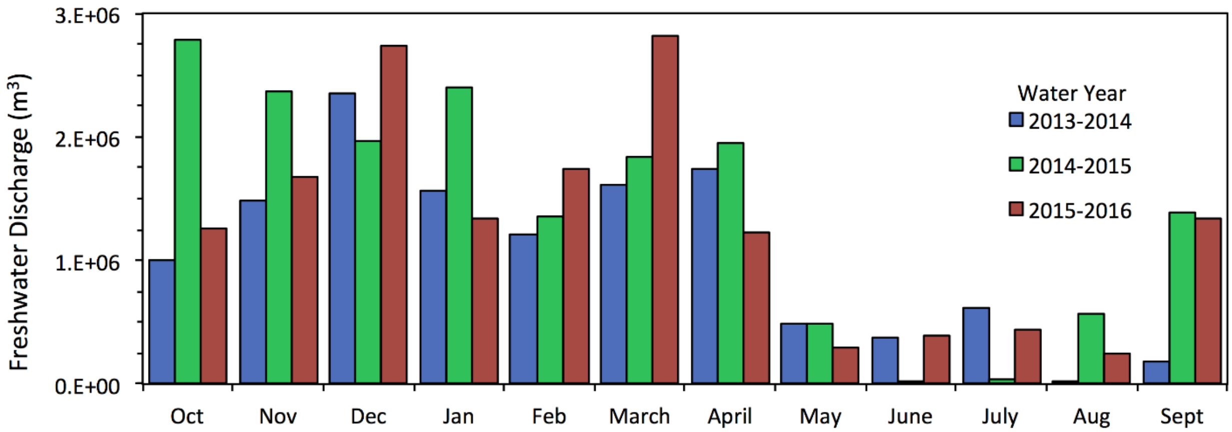

Figure 29-4. Freshwater discharge (flux) from watershed 708 on Calvert Island, by month and year.

Hourly observations of stream stage and temperature revealed dynamics of stream conditions for fish at multiple time scales. Hourly stream stage measurements were highly storm-driven over the full period of observation, yet we can see two clear seasonal modes in median stage: high flows in fall-winter and low flows in summer. Median stage was high from October through April, and most of the extreme stage events were observed in this period (Figure 1-5). Each year we observed a distinct low flow period in June, July, or August, with the timing, duration, and severity varying from year to year. In 2015, the lowest flow period arrived two months earlier (June) than in 2014 or 2016 (August). In 2016, the lowest flow period occurred in August, which had the lowest median stage in three years. Atypically high stream stages were observed in November 2016.

Stream temperature showed a more steady seasonal cycle corresponding with air temperature, both peaking in July/Aug (Figure 29-5). Peak stream temperatures in 2016 were not as high or sustained as in 2015. However, in all three years we recorded periods with stream temperatures well above 18 °C.

The seasonal and storm-driven cycles of rainfall and runoff can be traced through to changing ocean conditions in Kwakshua Channel, as shown by salinity profile monitoring at Pruth Station. Heavy March rainstorms delivered enough freshwater to reduce the salinity of Kwakshua Channel through the entire 70 m of the measured profile. Similarly, late 2016 saw low salinity corresponding with large rainfall and runoff events.

Results from watershed 708 on Calvert Island suggest that freshwater runoff and stream habitat conditions of small outer-coast watersheds are sensitive to changes in water inputs from year to year, month to month, and even storm to storm. We observed weather driven changes in the seasonality and extremes of water table depth, stream flow, and stream temperature. Analyses are underway to explore the implications of this dynamic freshwater runoff regime on coastal circulation, freshwater content, marine foodwebs, and the coastal carbon cycle.

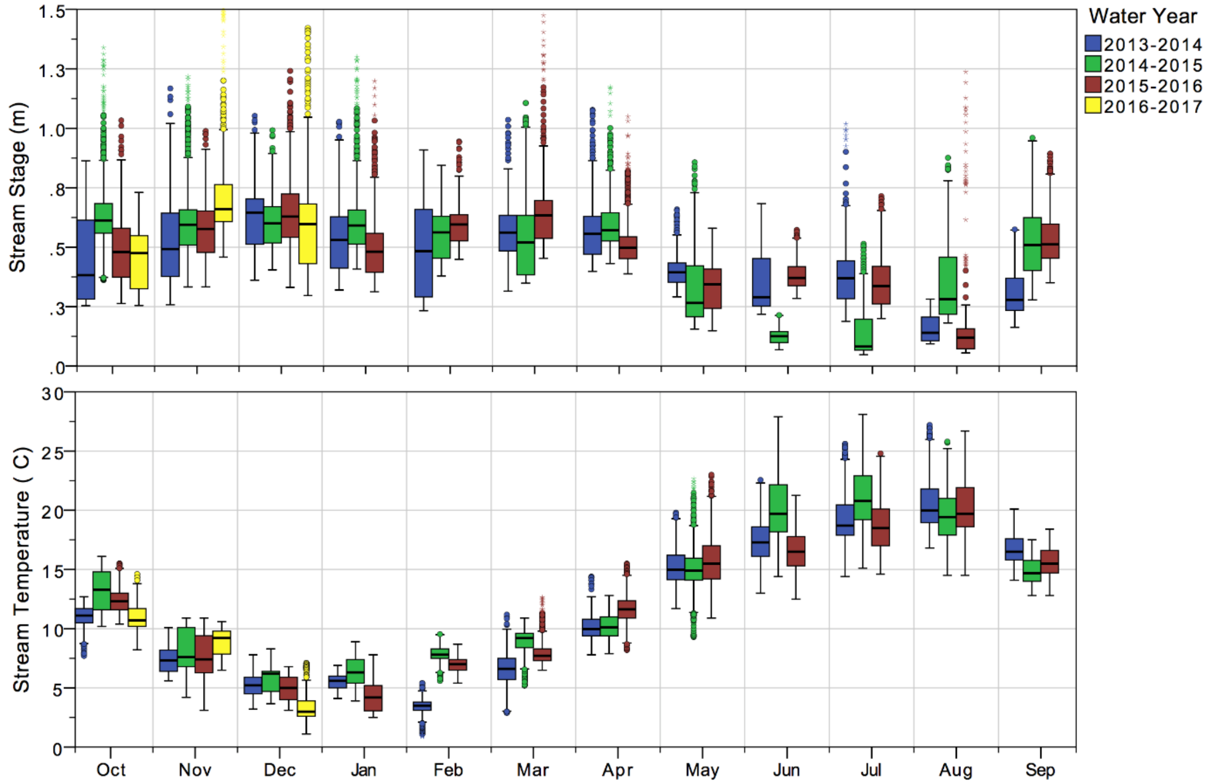

Figure 29-5. Box plots of stream stage (top panel) and stream temperature (bottom panel) at watershed 708, Calvert Island.

29.5. References

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30. HAKAI OCEANOGRAPHY PROGRAM: BRITISH COLUMBIA CENTRAL COAST TIME SERIES (2012-2016)

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30.1. Highlights

- Ocean temperatures observed at 5 m on the Central Coast were above average from January to July 2016, but fell below average for the remainder of the year.
- In 2016, the coldest, saltiest bottom water, indicative of upwelling, was observed on July 31 at station QCS01, which was the earliest occurrence in the 2013 - 2017 time series.
- The spring phytoplankton bloom date at Pruth Station was approximately 15 April, one month later than 2015 and the latest of the five year time series.
- Phytoplankton biomass was largely below average in 2016.
- Zooplankton biomass was below average in Queen Charlotte Sound, and average to above average at inner coast stations, including Rivers Inlet.

30.2. Description of the time series

The Hakai Oceanography Program (HOP) is an integrated multidisciplinary program founded on the principals of Long Term Ecological Research (www.hakai.org). The HOP maintains year-round, long-term measurement of key physical, chemical (macronutrients, carbon chemistry) and biological parameters (bacteria, phyto- and zooplankton) on the B.C. coast. The high temporal resolution of the sampling program is aimed at meeting the program objectives of:

- Advancing understanding of the timing and amplitude of key events (e.g. spring bloom, upwelling/ downwelling initiation), the seasonal cycles, and interannual variability of processes that underpin B.C.'s coastal ecosystems, and;
- Detecting and informing ecosystem response to changing climate and anthropogenic impacts.

The HOP Central Coast observatory has been in operation since June 2012. Core stations, defined by full parameter measurement, are located in Queen Charlotte Sound (QCS01), Kwakshua Channel (Pruth), Fitz Hugh Sound (FZH01, KC10), and Rivers Inlet (DFO2) (Figure 30-1). This spatial distribution of sampling effort is specifically designed to characterise the three principal regions of the B.C. coast along the ocean to land gradient – shelf, inner coast, and fjord ecosystems - and the connectivity between them.

30.3. Status and trends

Figure 30-2 and Figure 30-3 show anomaly plots of temperature (5 m and near-bottom), phytoplankton biomass (chla mg m^{-3}) and zooplankton biomass (mg m^{-2}). Anomalies are calculated relative to the monthly means for each variable from June 2012 for Pruth and KC10 and January 2013 for remaining stations, until December 2016.

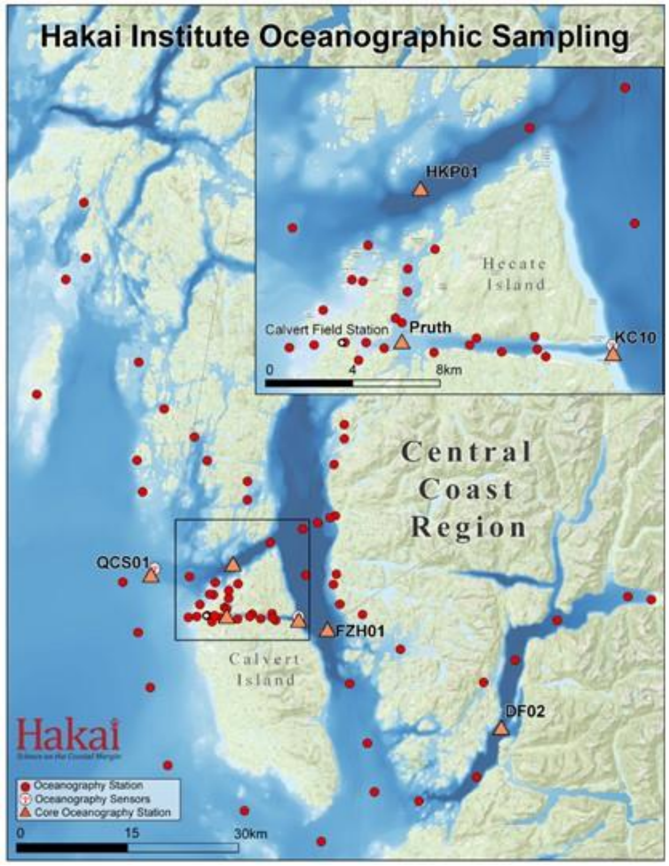

Figure 30-1. Map of oceanographic stations sampled by the HOP. Sampling regimes at core stations are: Pruth - daily between spring and fall, every 6 weeks in winter; All other stations - every 2-3 weeks during spring to fall, opportunistic in winter. Map produced by Will McInnes and Keith Holmes.

At 5 m, above average temperatures were observed from October 2014 to July 2016 at all stations. In 2016, the highest temperature (15.2 °C) at QCS01 was observed on July 25, which was slightly warmer than the maximum temperature of 15.0 °C that was observed at QCS01 on August 15, 2015. The coldest temperature at 5 m in 2016 was 6.6 °C, which was observed on January 6 at Pruth, while the coldest temperature at 5 m in 2015 was 7.7 °C, which was observed on February 25 at KC10.

The coldest near-bottom water, which indicates the peak of wind-driven upwelling, was 6.3 °C, observed at 100 m at QCS01 on July 31, 2016. The near-bottom water gradually warmed as it was advected towards the coast, with minimum temperatures of 6.8 °C at HKP01 on July 31, 7.9 °C at Pruth on August 3, 6.7 °C on August 15 at KC10, 6.8 °C at FZH01 on September 1, and 7.1 °C at DFO2 on September 8.

The spring phytoplankton bloom occurred on approximately April 15, one month later than in 2015, and the latest observed in the five year time series. Phytoplankton biomass in 2016 was below average, as in 2015, with the exception of the spring bloom which was close to average at QCS01 and Pruth, above average at FZH01, but below average at DFO2 in Rivers Inlet. Zooplankton biomass data are available up until mid-2016. Zooplankton biomass was below average on the outer coast (QCS01), but average to above average at inner coast stations.

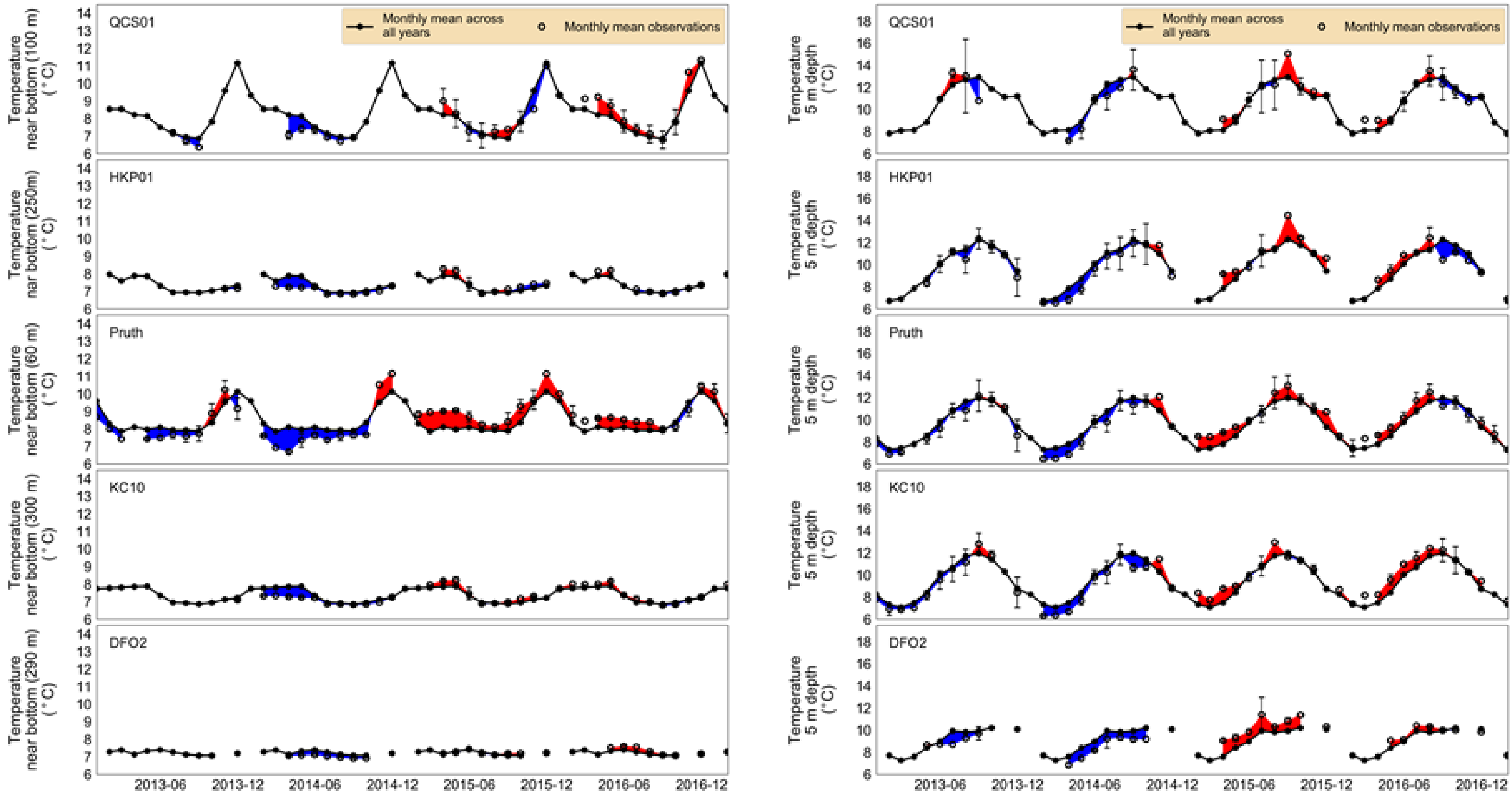

Figure 30-2. Average and anomaly plots of temperature (at near-bottom and 5 m depth) for core stations in the Hakai Central Coast observation program. The black line with solid circles is the monthly mean from June 2012 to December 2016 (minimum two data points were needed to calculate the mean). The black line with open circles is the monthly mean for each year (error bars are standard deviations). Blue indicates a negative and red a positive anomaly compared to the 2012 to 2016 monthly mean.

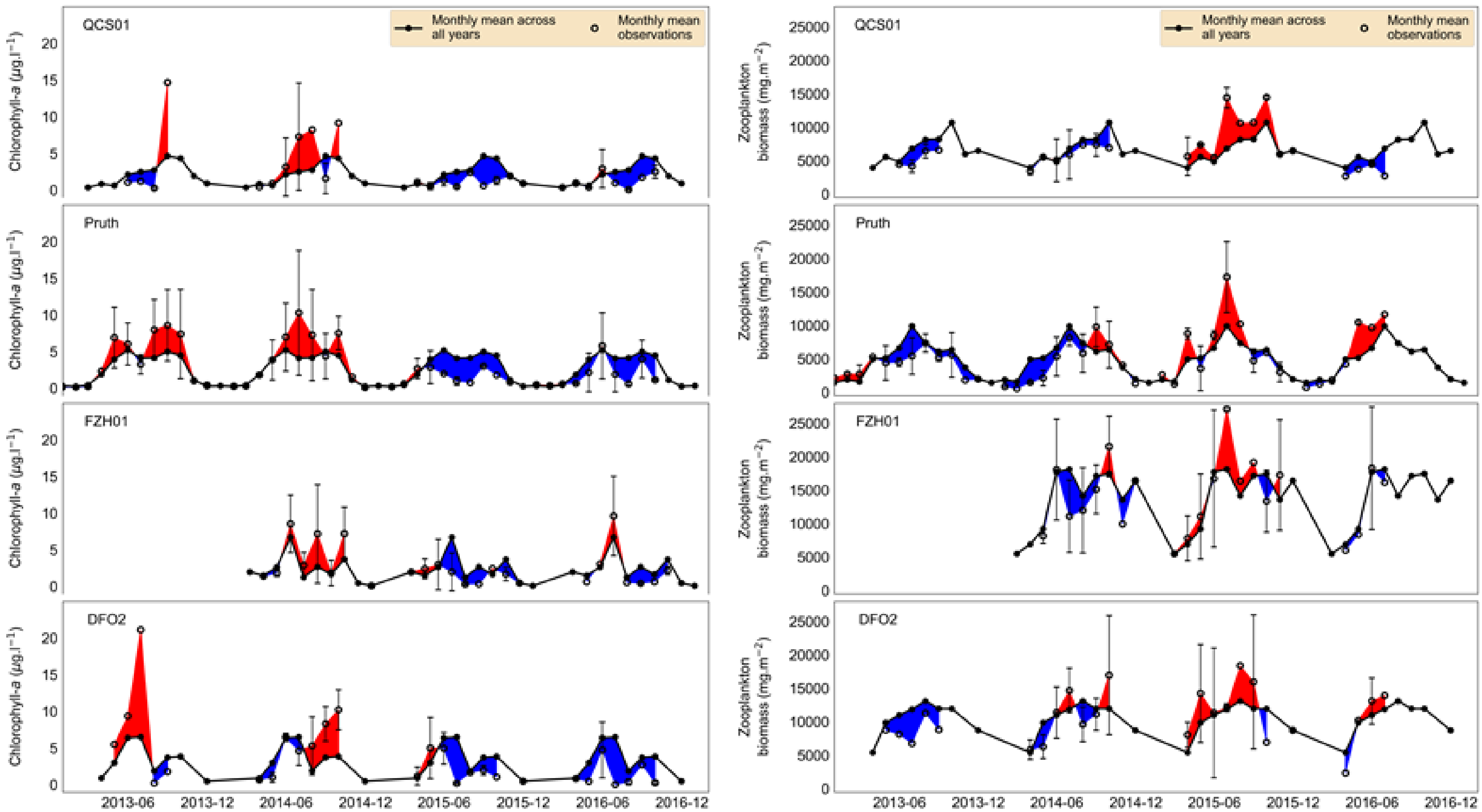

Figure 30-3. As in Figure 30-2 but for chlorophyll-a, and zooplankton biomass.

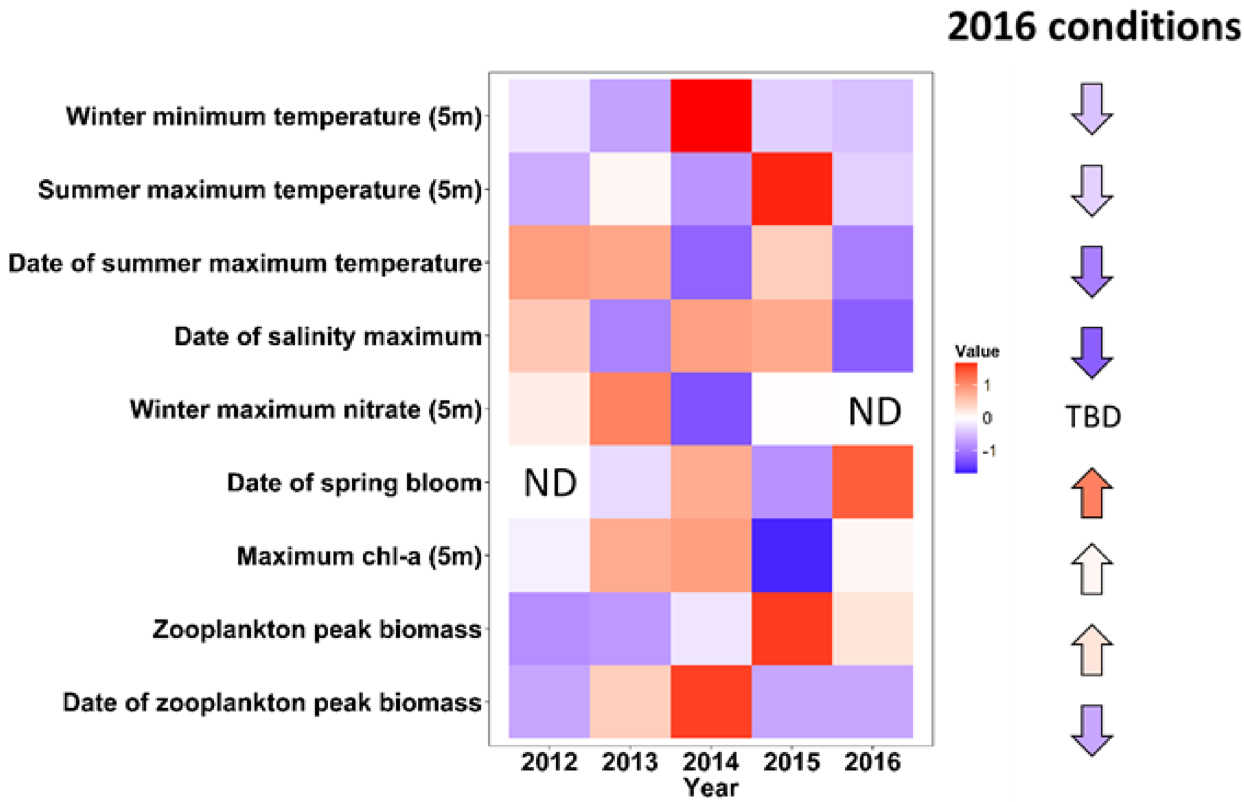

Figure 30-4. Indices of key ecosystem processes and variables, produced using data from the high temporal resolution Pruth Station (Figure 30-1; daily CTD from March 15 to October 15, 2012 to 2016). Date of the salinity maximum is for the average salinity in water with S > 31, indicative of upwelling. The spring bloom was determined as the date of first occurrence of chl-a biomass values of > 2 mg m^{-3}). All data are standardized to zero mean and unit variance [(value – mean)/stDev]; positive values are > mean; negative values are < mean; Winter values are for the period Nov-Feb; Summer values are for the period May-Sep; ND = no data.

Figure 30-4 introduces an indicator suite aimed at capturing the trends of key ecosystem processes and variables on the B.C. Central Coast, as measured at Pruth station (Figure 30-1). Winter temperature in the surface ocean in 2016 was similar to 2015 (6.5 °C), 2 °C cooler than the winter of 2014-2015. Summer maximum surface temperature was 13.2 °C in 2016, approximately 1 °C cooler than 2015 which was the warmest in the time series. Although cooler than 2015, the date of the summer maximum surface temperature was earlier in 2016 than 2015 (July 13 vs August 19). The date of the salinity maximum in 2016, indicative of summer upwelling, was August 23, the earliest in the time series. As observed above, the 2016 spring bloom date was the latest in the time series and maximum chl-a values during the year were below those observed in 2013 and 2014. The complete zooplankton time series for 2016 is not yet available. However, considering data up to June 2016, peak biomass was higher than 2012-2014. As in 2015, in 2016 the date of peak zooplankton biomass was earlier than in 2013 and 2014.

30.4. Factors influencing trends

Warm surface ocean conditions in the first part of 2016 are expected to have been influenced by the positive phase of both the Pacific Decadal Oscillation and the Ocean Niño Index. The 2015-2016 El Niño conditions weakened at the end of May 2016, corresponding with surface ocean cooling, were neutral through the summer and early fall, and were replaced with La Niña conditions in November 2016.

The 2016 spring transition date at 45° N was March 23, indicating an early start to the upwelling season (https://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/b-latest-updates.cfm). This together with higher than average upwelling winds for May through June (http://www.pfel.noaa.gov/products/PFEL/modeled/indices/upwelling/NA/daily_upwell_graphs.html#p05daily.gif) support early and strong upwelling observed on the Central Coast in 2016.

Spring transition date has been correlated with spring bloom timing (Wolfe et al. 2015). The delayed spring bloom observed in 2016 was therefore somewhat surprising. The delay was potentially associated with local atmospheric conditions (e.g. local winds, cloudiness) and will be analysed further using Central Coast weather data.

30.5. Implications of those trends.

The role of upwelling timing and intensity, and seasonal mixing dynamics, in nutrient cycling on the Central Coast remains a fundamental question, the answering of which will inform the implications of short to long-term climate change for coastal productivity. This is one of the priority objectives of the Hakai Institute.

A delayed spring bloom, such as that observed in 2016, has been shown to negatively impact the recruitment of herbivorous calanoid copepods (Tommasi et al. 2013). This zooplankton group is of major importance as prey for zooplanktivorous fish, including herring and juvenile salmon, and their predators. However, we note that zooplankton biomass remained high on the inner coast in 2016, and thus the role of these areas as nurseries may not have been diminished despite the late spring bloom. Emerging data on zooplankton composition will further inform this question.

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31. CARBONATE SYSTEM TIME SERIES OF THE NORTHERN SALISH SEA

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31.1. Highlights

- The carbonate system in surface waters of the northern Salish Sea shows strong seasonal characteristics of higher pCO_2 (around 600 µatm) and lower pH (around 7.8, pH_T) during winter seasons, and opposite characteristics during summer seasons (around 250 µatm pCO_2, around 8.2 pH_T).
- These seasonal dynamics are associated with wind-driven mixing upwards of high pCO_2 deep waters in winter and presumed lower rates of primary productivity, and, during summer, more stratified conditions coupled with intense biological draw-down of surface mixed layer pCO_2.
- Large (up to 300 %), rapid (1-2 days) and short term (about 1 day) changes in surface water pCO_2 occur in summer following strong NW wind events, with associated decreases in pH and aragonite saturation state.
- Both seasonal and short term changes in surface water carbonate chemistry appear largely coherent from Hyacinthe Bay (Quadra Island) to Sentry Shoal (south of Mitlenatch Island).

31.2. Description of the time series

This carbonate time series is produced from a continuous flow-through system containing a LICOR-based nondispersive infrared (NDIR) gas analyzer and supplementary Seabird Electronics sensors that collectively measure pCO_2, TCO_2, temperature and salinity in surface seawater from Hyacinthe Bay, Quadra Island (Figure 31-1, 50.116° N, 125.222° W). This system is managed and operated by staff from the Hakai Institute and has been in continuous operation since December 2014, with the exception of several servicing periods per year that are generally on the order of days in length. A data product from the beginning of measurements to April 2016 has been produced that contains a detailed description of all methods including data quality assurance procedures and measurement uncertainties. This data product and related information is available at http://dx.doi.org/10.21966/1.437736 and https://hecate.hakai.org/geonetwork.

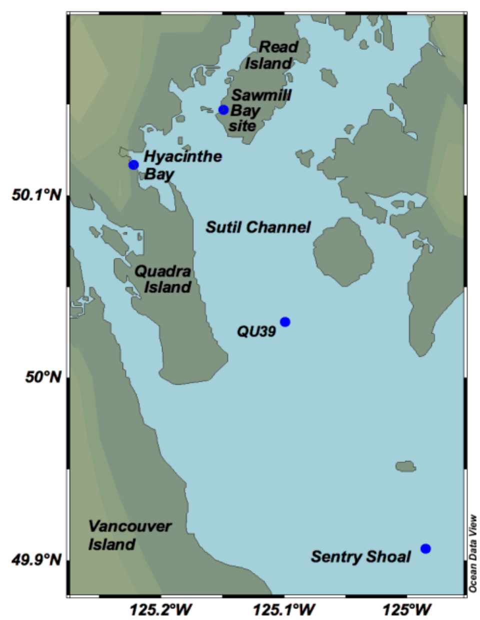

Figure 31-1. Locations of carbonate system time series data collected by the Hakai Institute in the northern Salish Sea during 2016.

Supplementary carbonate system data in the northern Salish Sea is produced from TCO_2/pCO_2 measurements made from discrete bottle samples collected approximate bi-weekly, year-round from station QU39 located at the south end of Sutil Channel (50.0307 º N, 125.099 º W), and a near-surface SeaFET pH sensor located on Environment Canada weather buoy #46131 located at Sentry Shoal (49.92 º N, 125.0 º W). Mineral saturation states, ion concentrations, and pH are derived from directly measured TCO_2/pCO_2 pairs or through pCO_2/TA pairing derived from TA/S relationships produced by the flow through system in Hyacinthe Bay, Quadra Island (Evans and Gurney-Smith 2015).

Ocean CO_2 content is increasing as oceans absorb increasing amounts of atmospheric CO_2 from anthropogenic activities. This process also lowers oceanic pH and is commonly referred to as ocean acidification. Surface seawater pCO_2 concentrations track atmospheric CO_2 concentrations in the offshore ocean, however, the strength of this relationship in coastal waters is less clear due to added complexities such as greater direct anthropogenic impacts and land-ocean interactions, and shorter available time series in coastal regions. The saturation states of aragonite (Ω_A) and calcite (Ω_C) are measurements of the suitability of seawater for the survival, growth, or reproduction of aragonite and calcite-producing organisms. These parameters are derived from carbonate system and salinity measurements and naturally fluctuate widely in coastal settings. Trends towards longer periods of unfavourable Ω_A and Ω_C conditions are major biological impacts expected from climate change.

31.3. Status and trends

The current status (2015-2016) of this carbonate time series demonstrates that surface seawater (upper 30 m) has highest pCO_2 levels (roughly 600 µatm) and lowest average pH levels (7.8, pH_T) during winter, and opposite characteristics during summer (250 µatm pCO_2, 8.2 pH_T) (Figure 31-2). Ω_A levels followed the seasonal pH trend, with lowest values (< 1) during winter and highest values (< 2) during summer. Historical direct measurements of pCO_2 and TCO_2 in the northern Strait of Georgia are limited to 2003, and 2010-2012, which prevents determining robust historical trends from direct measurements with which to compare recent observations. However, direct measurements from these years and a model covering this period both demonstrate a seasonal Ω_A cycle with similar values of < 1 during winter and > 2 during summer (Ianson et al. 2016, Moore-Maley et al. 2016).

Observations of the carbonate system time series from this report also reveal large episodic departures from summer seasonal characteristics. Summertime spikes in pCO_2 concentrations up to nearly 900 µatm and associated drops in pH < 7.7 and Ω_A < 1 typically lasted for 1 to 2 days and demonstrated sea-air CO_2 fluxes equal or greater in magnitude (2-3.5 mmol m^{-2} h^{-1}) to those observed during winter. The lower historical frequency of carbonate system measurements in the northern Strait of Georgia does not permit a comparison with these episodic departures from seasonal characteristics. However, similar behaviour in terms of the timing, frequency and magnitude has been observed in pCO_2 measurements from Netarts Bay, OR on the NW pacific coast (Barton et al. 2015).

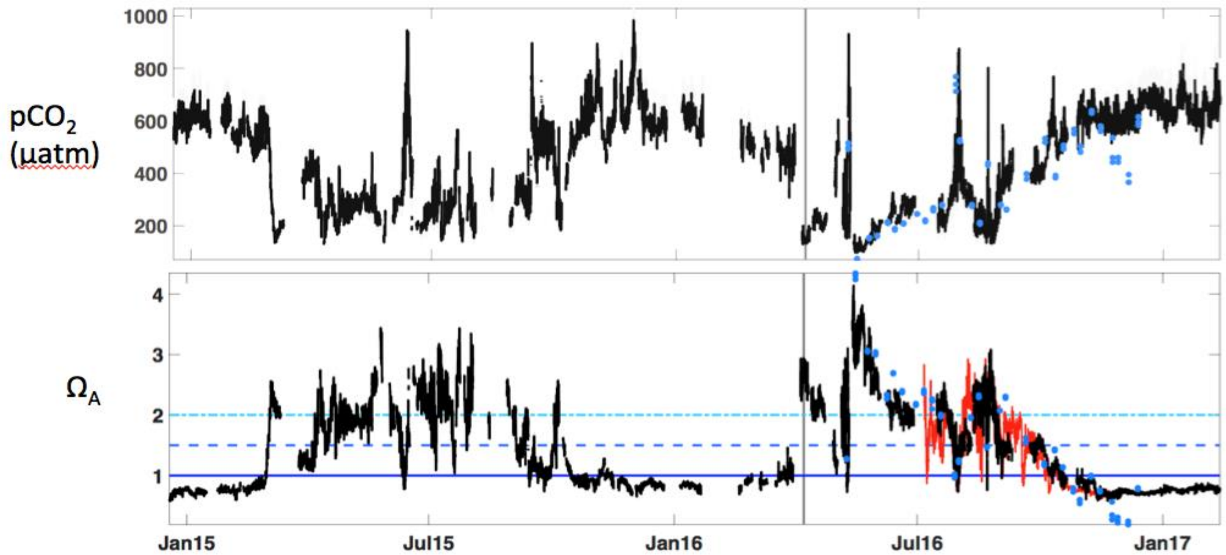

Figure 31-2. pCO_2 and Ω_A time series in the northern Strait of Georgia. pCO_2 and Ω_A from measurements at Hyacinthe Bay, Quadra Island (black lines), Sawmill Bay, Reed Island (blue dots), and Sentry Shoal (red lines). See text for method details. Horizontal blue lines represent Ω_A thresholds of thermodynamic or biological significance as described in Waldbusser et al. (2014). The vertical grey line indicates the start date of continuous TCO_2 measurement capacity at Hakai Institute's Quadra Island Field Station.

31.4. Factors influencing trends

The seasonal carbonate system characteristics in the northern Strait of Georgia appear driven by wind and temperature-controlled mixing of the water column and by biological activity. Low temperatures reduce density differences between surface and deep waters that high winds act upon, driving water column mixing and upwards transport of high pCO_2 deep waters. This process is strongest during fall, winter and spring seasons due to high winds and reduced air temperatures, and weakest during summer, due to low winds and higher air temperatures. This process also appears to briefly break down the summer surface mixed layer and drive the high pCO_2/low Ω_A episodes observed during summer. Such episodes were associated with strong NW wind events with high daytime wind stress ($\tau_{Meridional}$ N $m^{-2} > -0.1$) sustained for 12 hours for 2-4 days. Departures from seasonal carbonate system characteristics lasted for 1-2 days post-wind event before returning to seasonal levels.

Biological activity acts upon the seasonal pCO_2 signal by driving down the CO_2 content during periods of 'bloom' activity, when phytoplankton growth is rapid and substantial. Such events occur multiple times each year, with the largest 'bloom' responses in pCO_2 observed during spring (February to April) and smaller secondary responses observed in late summer (late July/August).

31.5. Implications of trends

The implications of the observed seasonal carbonate system characteristics in the northern Strait of Georgia apply to local biological activities and to climate change/ocean acidification tracking and modelling efforts that include the NE Pacific region of the global ocean.

The seasonal nature of Ω_A demonstrates that seawater conditions are poor ($\Omega_A < 1$) for growth of aragonitic-shell forming organisms throughout fall, winter and early spring, and that brief periods of surface seawater corrosive to aragonite also occur during summer. A projection of Ω_A using the latest 5-year trend (2011 – 2016) in atmospheric CO_2 concentrations and based on coastal seawater tracking atmospheric CO_2 concentrations indicates that summer Ω_A conditions will be < 2 by 2070. Thus wind-driven departures from seasonal characteristics will diminish in relative magnitude over the next several decades under this scenario.

This information can be used to plan for implementing efforts to mitigate the impact of reduced Ω_A on some populations of aragonitic-shell forming organisms. For instance, in the states of Washington and Alaska, shellfish industry stakeholders have installed carbonate system monitoring and water chemistry modifying instrumentation that limits the effect of natural Ω_A variability on farmed shellfish populations grown in natural seawater (Barton et al. 2015).

The implication of episodic departures from seasonal carbonate system characteristics during summer is that seasonal level monitoring of the carbonate system may be insufficient to accurately parameterize the net sea-air exchange of CO_2 in mass balances and regional models. Summer time sea-air CO_2 fluxes in both 2015 and 2016 matched or exceeded maximum winter flux rates, and accounted for a substantial portion of the net seasonal balance of sea-air CO_2 exchange. This information implies that seasonal level measurements of the coastal ocean carbonate system may produce large uncertainties in regional models, and that efforts to track and understand ocean acidification should prioritize high frequency measurement strategies that can resolve sub-seasonal features of the coastal carbonate system.

31.6. References

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32. TEMPERATURE AND SALINITY OBSERVATIONS IN THE STRAIT OF GEORGIA AND JUAN DE FUCA STRAIT IN 2016

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32.1. Highlights

- Observations from three surveys in the Strait of Georgia showed warmer than normal temperatures through the entire water column, with the anomaly strongest in the spring and summer, and less so in the fall.
- A rapid and early snowmelt introduced large volumes of fresh water resulting in negative salinity anomalies in the first part of the year, and positive anomalies after the summer.

32.2. Summary

Two sources of data are used to describe changes in the temperature and salinity conditions in the Strait of Georgia (east of Vancouver Island) and Juan de Fuca Strait (south of Vancouver Island) in 2016. The first is profile data collected with a SeaBird 911 CTD during the Strait of Georgia water properties survey (Figure 32-1). In 2016 surveys were carried out in late April, mid-June, and late September. The second dataset is provided by the Department of National Defence from the 66 temperature and salinity profiles collected in 2016 with a SeaBird 19 CTD at its Maritime Experimental and Test Range (CFMETR) near Nanoose. Both sources have information available since 2000 that are compared to the 2016 conditions to identify anomalies from these 16 year average conditions.

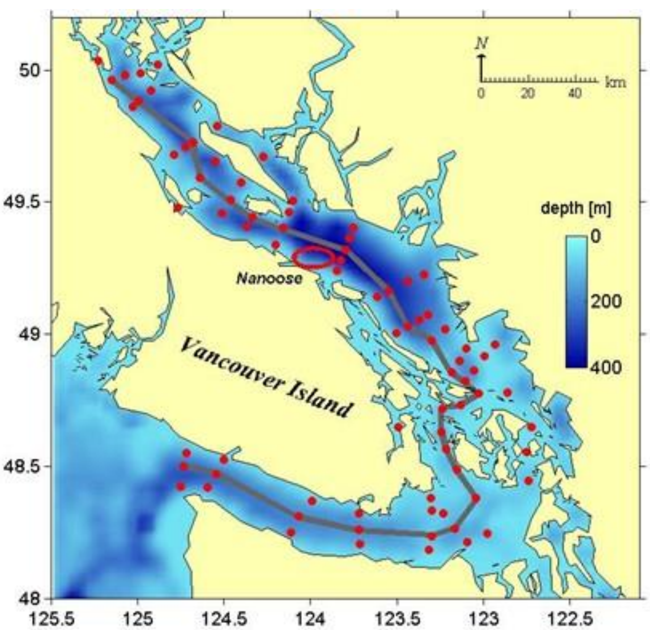

Figure 32-1. Red dots show the locations of 79 stations sampled during the water properties survey in April, June and October. The thalweg is shown as the grey line joining the deepest stations along the centerline of the survey. The red ellipse marks the area where depth profiles of temperature and salinity are collected at the Canadian Forces Maritime Experimental and Test Range (CFMETR).

The analysis of the temperature data for all three surveys showed warmer than normal conditions during the spring; the only exceptions being the deeper sections of Juan de Fuca where near normal conditions were observed. Later in the year a positive anomaly was still evident but to a lesser extent than in the spring (Figure 32-2).

The Nanoose temperature and salinity profiles show the annual variability in the central Strait of Georgia. The 2016 temperature and salinity are shown in Figure 32-3.

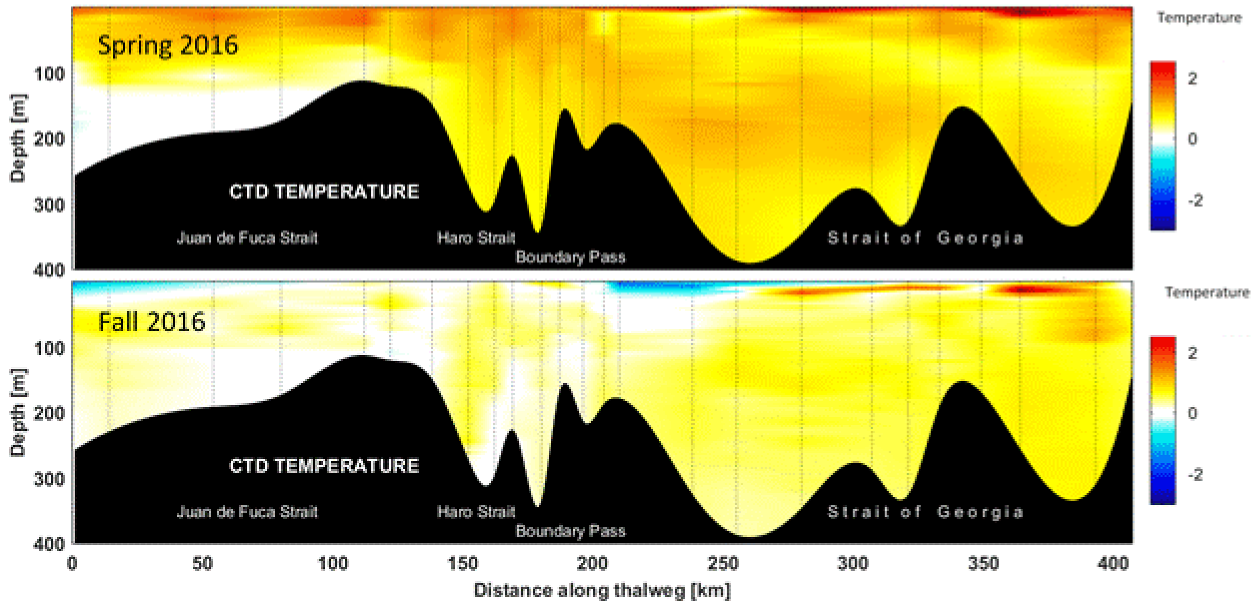

Figure 32-2. The vertical distribution of temperature anomalies along the thalweg observed in the April (upper) and September (lower) 2016 water properties survey.

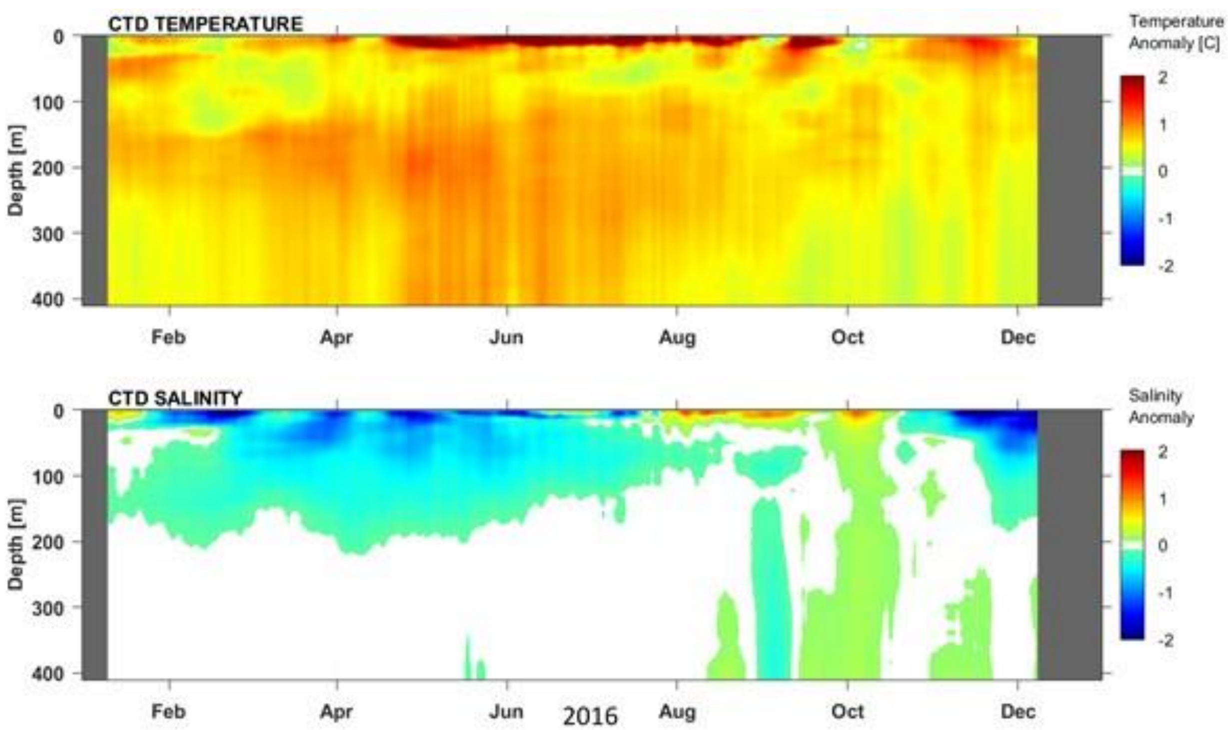

Figure 32-3. The time series of the vertical distribution of anomalies (temperature (upper) and salinity (lower)) collected in 2016 in the central Strait of Georgia near Nanoose; red indicates warmer and saltier than normal. Data source: The Canadian Forces Maritime Experimental and Test Range (CFMETR).

In 2016 an earlier than typical snowmelt introduced significant volumes of fresh water via the Fraser River into the central Strait (see Figure 32-4). The negative surface salinity anomalies were evident in the upper 150 m until June, after which the surface waters (upper 30 m) were saltier than normal due to the lower than normal Fraser River outflow. Increased precipitation during the last three months of the year contributed to positive salinity anomalies.

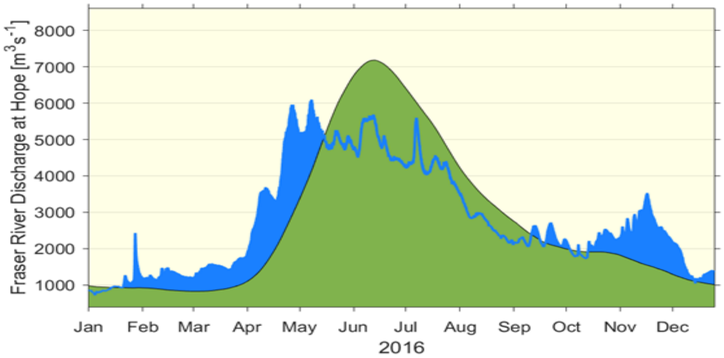

Figure 32-4. Fraser River discharge at Hope B.C.; 2016 (blue), 104 year average (green). Data source: The Water Survey of Canada).

The interannual variations in the Nanoose temperature are shown in Figure 32-5 and show depth averaged temperatures at the start of the year, normally the cool period, as exceeding those at any part of the years between 2011 and 2015. This reservoir of warmer water in the central Strait is likely a remnant of the warm water anomaly seen in the Pacific Ocean in 2014 and 2015. The 9 °C isotherm, which did not extend deeper than 50 m in 2015, was observed in 2016 to have deepened to more normal levels.

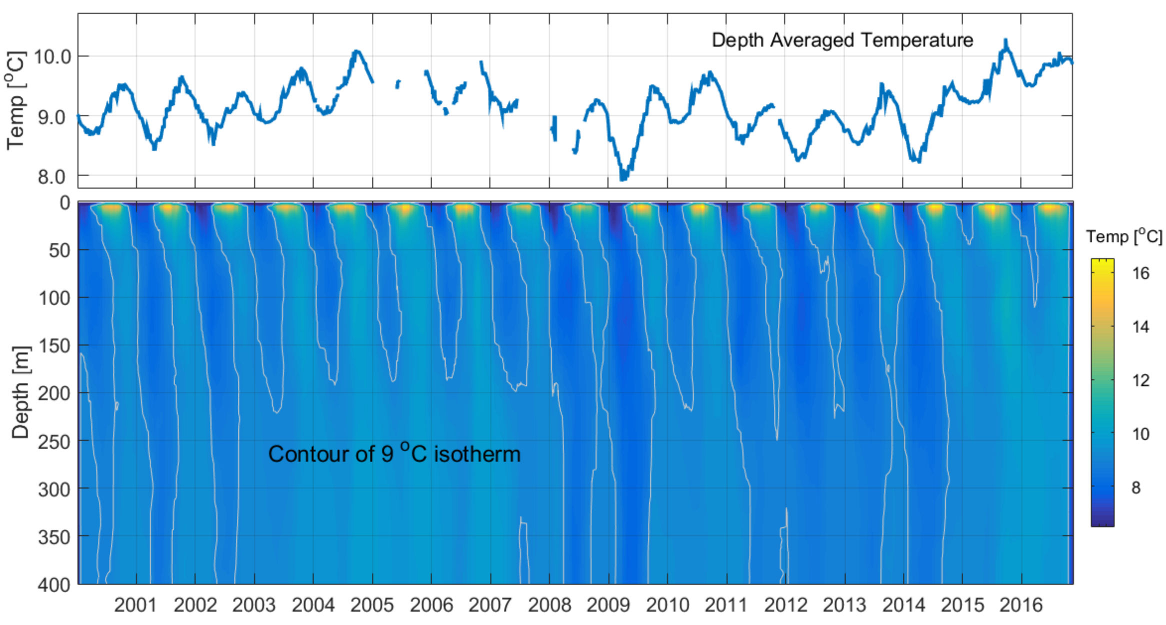

Figure 32-5. The time series of depth averaged temperature collected in the central Strait of Georgia near Nanoose (upper); the vertical distribution of these data (lower).

33. DEEP WATER AND SEA SURFACE PROPERTIES IN THE STRAIT OF GEORGIA DURING 2016: CABLED INSTRUMENTS AND FERRIES

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33.1. Highlights

- Downwelling water at Folger Passage (97 m) (starting in late summer 2016) was the warmest for the 7-year time series until a shift to cooler conditions started on December 14, 2016.
- Virtually no winter (2015/16) cooling was observed at either 170 m (East Node) or 300 m (Central Node) in the Strait of Georgia. The 2016 'winter-spring-summer' temperatures for both time series were the warmest for each record. Fall/winter conditions were still very warm but cooler than 2015.
- The spring phytoplankton bloom was recorded by all three instrumented ferry routes in the central and southern Strait of Georgia. The bloom started March 17-18, 2016 and peak biomass was recorded on March 21.
- The magnitude of the 2016 spring bloom was low relative to the last 13 years of ferry-based measurements.

33.2. Description of the time series

Here we report on temporal patterns of core seawater properties (temperature, salinity, density, and dissolved oxygen; 1 Hz) for three fixed-point cabled bottom moorings and surface monitoring of core seawater properties and chlorophyll fluorescence (0.1 Hz) by instrumented ferries in the Strait of Georgia (detailed methods for each deployment and real-time data are available at oceannetworks.ca):

i. *ONC Folger Deep*: 98 m cabled, fixed-point mooring (48° 48.8278' N, 125° 16.8573' W). The instrument platform is located on the west coast of Vancouver Island shelf and the time series reported here started on September 2, 2009. The time series is particularly useful for monitoring interannual variability of: i) the timing of upwelling and downwelling in the southern WCVI shelf; and ii) of water mass properties associated with upwelling and downwelling.
ii. *Strait of Georgia East Instrument Platform*: 170 m cabled fixed-point mooring (48° 48.8278' N, 123° 18.9986' W). The instrument platform is located in the southern Strait of Georgia at a 'mid-basin' depth on the seafloor and the time series reported here started on February 29, 2008. Inshore deep- and intermediate water properties in the Strait of Georgia (SoG) reflect seasonal patterns of increasing salinity and heating during the summer; due to the arrival of salty upwelled water on the shelf transiting through Juan de Fuca Strait and mixing with warm surface waters in Haro Strait (Mason 2002, Pawlowicz et al. 2007). Winter water

properties are characterized by cooling and freshening associated with deep mixing of local surface waters in Haro Strait/Gulf Islands.

iii. *Strait of Georgia Central Instrument Platform*: 300 m cabled fixed-point mooring (49° 02.3850' N, 123° 25.5800' W). The instrument platform is located in the southern Strait of Georgia at a 'deep-basin' depth on the seafloor and the time series reported here started on September 24, 2008. See description above for the Strait of Georgia East instrument platform.

iv. *ONC-BC Ferries instrumented vessels*: Surface monitoring of water mass (temperature, salinity, density, dissolved oxygen) and biogeochemical (chlorophyll fluorescence, turbidity, coloured dissolved organic matter fluorescence, and *p*CO2) properties in the central and southern Strait of Georgia. This surface monitoring program is useful for it broad spatio-temporal resolution for monitoring: i) water properties in the Strait of Georgia; ii) Fraser River plume dynamics; and iii) monitoring interannual patterns of the timing and magnitude of phytoplankton production. Instrumented ferries transit between:
   a) *M/V Queen of Oak Bay:* Horseshoe Bay – Departure Bay. Started: July 2015 (single year of operations in 2003 as well).
   b) *M/V Queen of Alberni*: Tsawwassen – Duke Point. Started: May 2012.
   c) *M/V Spirit of Vancouver Island*: Tsawwassen – Swartz Bay. Started: December, 2001.

33.3. Status and trends

ONC Folger Deep: The transition from upwelling (southward winds) to downwelling (northward winds) along the southern west coast of Vancouver Island starts during the late summer/early fall; whereas the transition from downwelling to upwelling starts during the spring. At ONC Folger Deep, the onset of downwelling on the shelf is signaled by the arrival of fresher, warmer and more oxygenated water characteristic of summer surface waters in the Gulf of Alaska (Figure 33-1). Dominant northward winds associated with the strengthening of the Aleutian Low pressure system drive this process.

The warm and fresh conditions of late 2015 continued into early 2016. The timing of events in 2016 was consistent with previous years and with the onset of upwelling beginning mid-April (year-day 100) and downwelling beginning in late-September (year-day 270). A rapid freshening and elevation of temperature occurred on year-day 289 (mid-October) as a result of a large downwelling favourable wind event. Temperature and salinity remained extremely warm and fresh (time series extremes for this time of year) until late December when temperatures cooled to near-'normal' (Figure 33-1).

Strait of Georgia East Instrument Platform: Properties at the SoG East instrument platform (Figure 33-2) reflect, in part, mid-water renewal to the SoG: During the 2015/16 winter, this water was cool and fresh (as expected for the season); however, similar to the 2014/15 winter, this low-density water, relative to the entire time series (extending back to 2008), was atypically warm. Winter (2015/16) temperatures were the warmest for the time series and these extreme temperatures continued through mid-July. Extremely warm conditions persisted into the fall and winter and represent the second warmest for this time series for this period. Dissolved oxygen concentrations [DO] followed a seasonal (and time series) expectation of high winter values and lower summer values. Of note are the very low (2nd lowest) [DO] registered starting in the late fall and into the winter of 2016 (Figure 33-1).

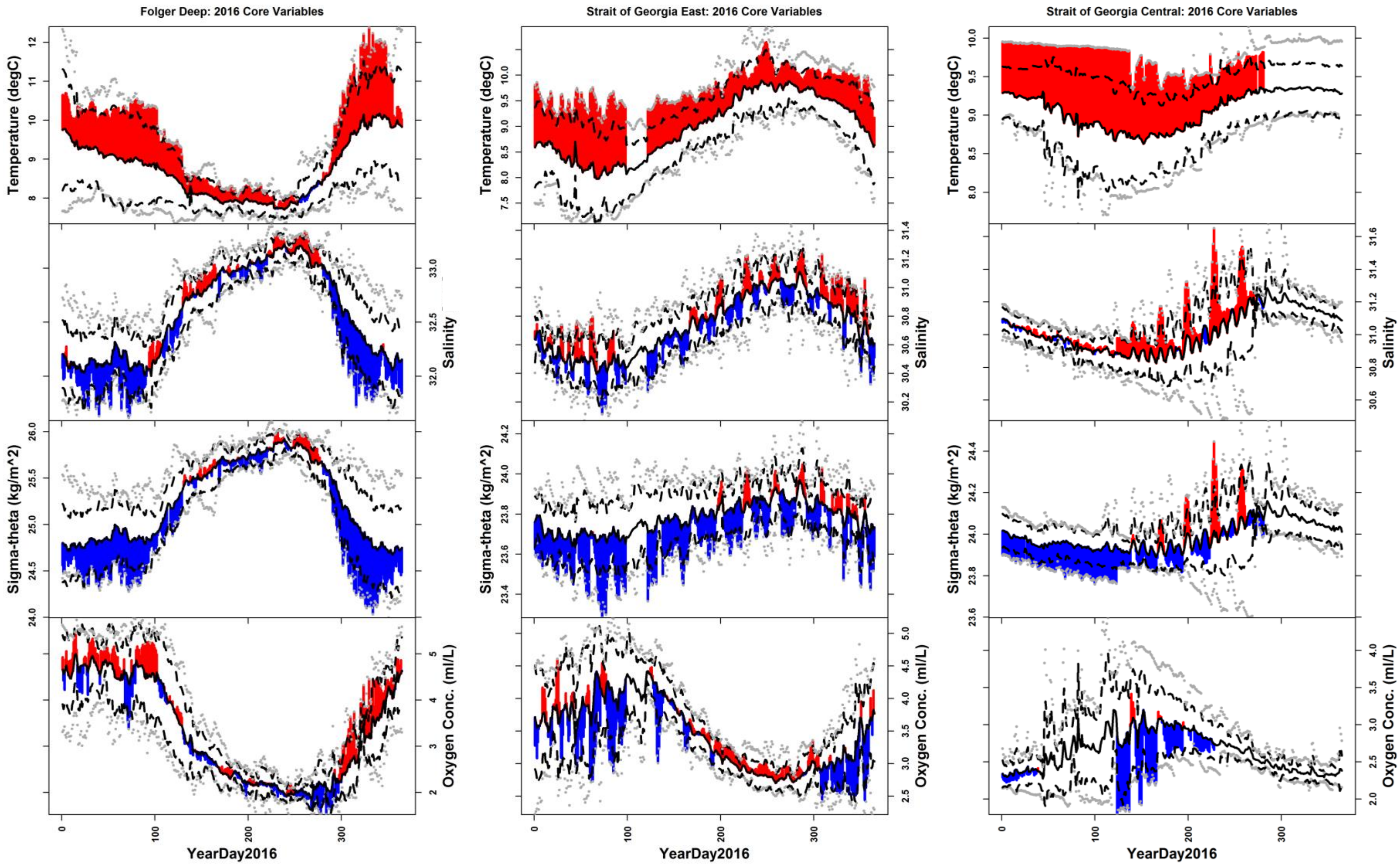

Figure 33-1. From top to bottom, mean daily temperature (°C), salinity, density (kg m^{-2}), and dissolved oxygen concentration (ml L^{-1}) for Folger Deep (left), SoG East (middle), and SoG Central (right). Red/blue bars represent values greater/less than the time series mean (solid black line). The dashed black lines represent +/- 1 standard deviation about the mean, and grey symbols are the maximum and minimum daily values for each time series.

Strait of Georgia Central Instrument Platform: Seasonal patterns of cooling/freshening (top-down flux) and warming/increasing salinity (renewal events) are similar to SoG East, but more closely tied to deep-water renewal events (Masson 2002). Observations from this platform are only presented through to October 8, 2016, when the cabled platform was disconnected. An autonomous mooring was deployed in its stead and cable reconnection is expected by June 2017.

Measurements of [DO] throughout the year were also sporadic. However, the lowest values for this time series were recorded during the May-July period when [DO] is expected to start declining (Figure 33-1). Winter cooling in 2016 was negligible; and as at 170 m, the 2015/16 winter was the warmest for this time series (remaining at approximately 10 °C). These time series extremes for temperature continued into the late summer, followed by a fall period characterized by the second warmest for this record.

2016 Spring Bloom in the Strait of Georgia: The start and development of the spring phytoplankton bloom in 2016 was captured by all three instrumented ferries: the Queen of Oak Bay (northern route); the Queen of Alberni (central route); and the Spirit of Vancouver Island (southern route) (Figure 33-2a). The timing of the start of the bloom was similar for all three ferries (March 17-18, 2016) and peak biomass was measured on March 21 (Figure 33-2b). Relative to both the instrumented ferry time-series and the long-term mean of March 25 (Allen and Wolfe 2013), the 2016 bloom timing was ‘average’. The bloom started outside of the Fraser River plume and was among the lowest for the 2003-2016 time series in terms of production (Figure 33-3).

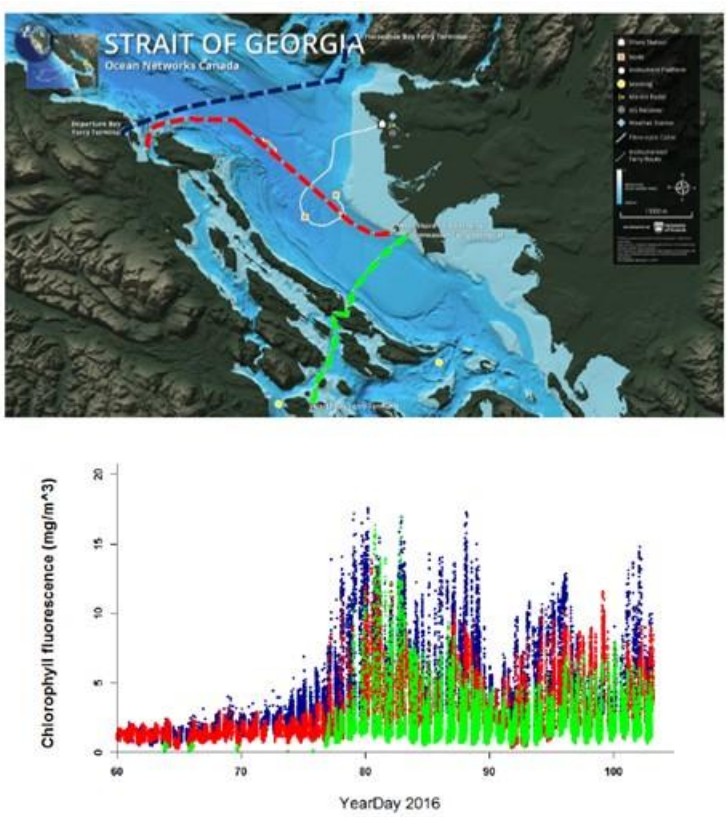

Figure 33-2. a) Map of the central and southern Strait of Georgia indicating each of the instrumented ferry routes(coloured dashed lines; white line represents the deep-water cable connecting nodes and instrument platforms); and b) in situ chlorophyll fluorescence (mg m^{-3}) measured at about 3m along each route; with colour corresponding to routes identified on the map. Each of the three ferries captured the start of the spring phytoplankton bloom during the March 17-18th, 2016 period.

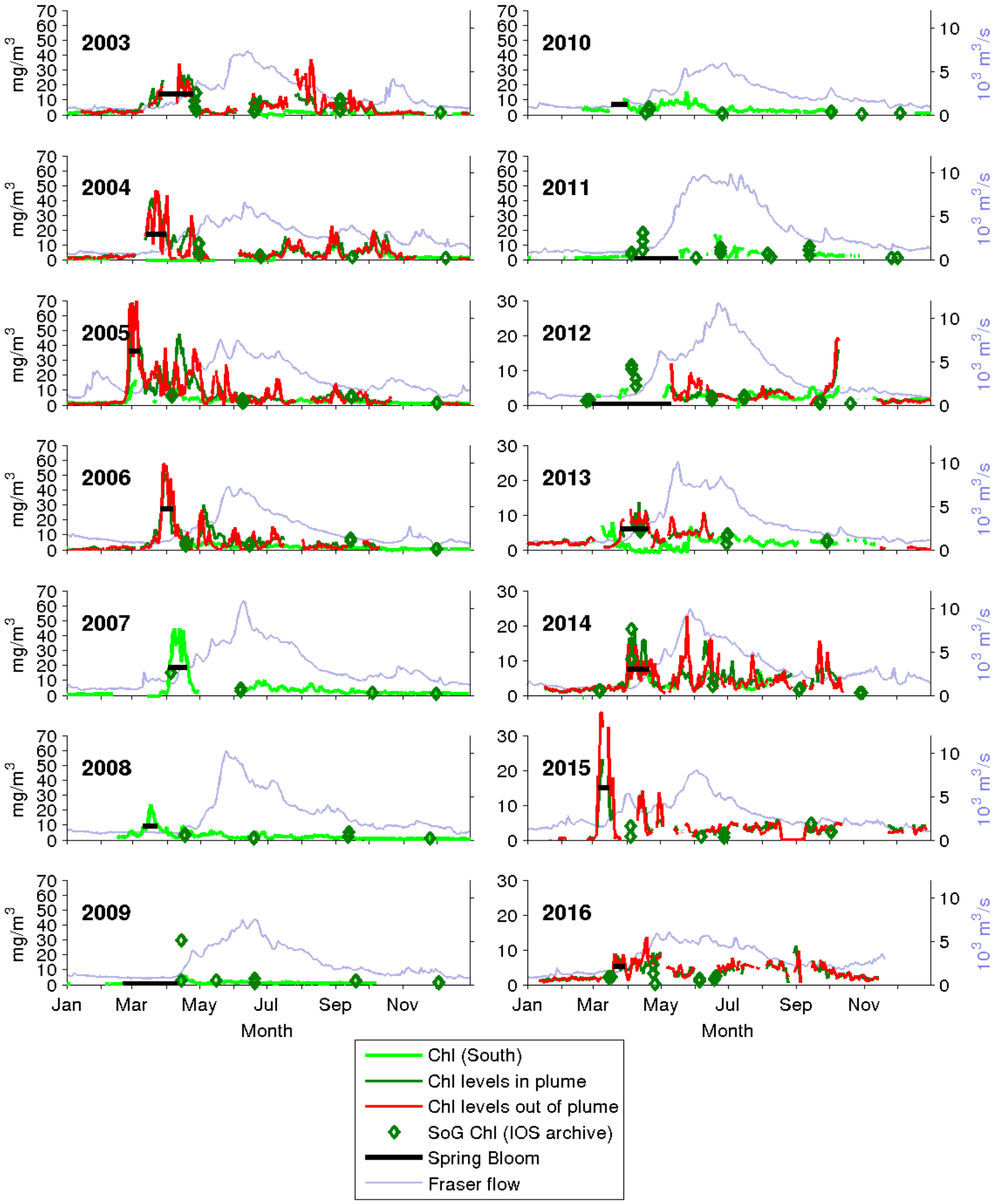

Figure 33-3. Time series of phytoplankton biomass (chlorophyll fluorescence) inside and outside of the Fraser River plume as measured from instrumented ferries transiting between Duke Point and Tsawwassen (dark green and red) and Swartz Bay and Tsawwassen (light green). Fraser River discharge (right-hand axis) is superimposed over the annual phytoplankton biomass time-series. Black lines show bloom timing (presumed in 2009, 2011 and 2012).

33.4. Factors influencing trends

Warmer than average temperatures were first observed at Folger Passage Deep in October of 2014 when the warm water anomaly (the “Blob”) arrived on the shelf with the onset of downwelling. The anomalously warm water is thought to have transited through Juan de Fuca and mixed in Haro Strait with warm surface waters before entering the Strait of Georgia basin. The warm inshore conditions of 2015 (Anslow et al. 2016) have continued throughout 2016 resulting in warming of deep- and intermediate-depth waters entering the SoG and little to no seasonal cooling during the winter of 2015/16. The persistently warm conditions from late 2015 and into 2016 are more likely a result of local heating than significant remnants of the Northeast Pacific anomaly (the Blob).

The timing of the 2016 spring bloom was intermediate to the relatively late bloom of 2014 (Dewey et al. 2015) and the very early bloom of 2015 (Allen et al. 2016, Sastri et al. 2016). Warm and calm conditions led to the exceptionally early bloom of 2015. While 2016 was similarly warm, it was not as calm and several wind events disrupted another relatively early bloom start (Allen et al. 2016).

33.5. Implications of those trends.

The very warm conditions over the last two winters at mid- and bottom depths in the Strait of Georgia basin has potential biological implications for deep water species as well as pelagic groups which spend a portion of their life history overwintering at depth. The large, lipid-rich copepod, *Neocalanus plumchrus* overwinters in the deep Strait of Georgia and may experience periodic population collapse associated with deep water winter warming; as has been observed between 1969 and 1977 (Gardner 1977) and in 2005 (Dower et al. 2006). Early indications are that *N. plumchrus* biomass is now well below the climatological mean (Galbraith and Young 2017). This species is considered an important food resource for young of the year fish in the Strait. Similarly, variability in the timing of the spring phytoplankton bloom and/or variable production can yield poor production of higher trophic levels.

33.6. References

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34. BUOY DATA FROM THE WASHINGTON COAST AND PUGET SOUND

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34.1. Highlights from 2016

- Northeast Pacific surface waters were warmer than average.
- Shelf surface waters were generally warmer than average with upwelling modulated temperature.
- Shelf deep waters were warmer, fresher, and higher in oxygen in early summer, then transitioned to cooler, saltier and lower oxygen in late summer, which was followed by a rapid transition to much warmer, fresher, higher oxygen in October.
- Strait of Juan de Fuca and Puget Sound waters were consistently warmer, with salinity trending with precipitation/runoff in a “wet:dry:wet” cycle, and oxygen deficits in Hood Canal and Carr Inlet.

34.2. Description of the time series

Data were collected from multiple moorings deployed throughout the Puget Sound and Washington Coast shelf (Figure 34-1), with location, individual station information, and data available online at nvs.nanoos.org. These time series contain multiple variables, most notably: temperature, salinity, density, and dissolved oxygen concentration. A time series of these parameters is essential to not only establishing a climatological baseline, but also to identify and monitor seasonal and annual anomalies with respect to this baseline, a critical first step to understanding climate change and its impacts.

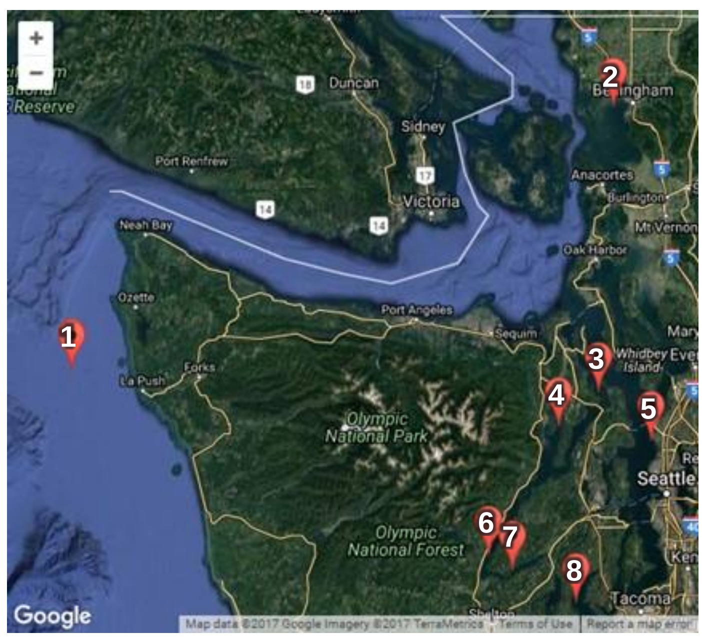

Figure 34-1. Map of the mooring locations deployed throughout the Puget Sound and Washington Coast shelf. Red balloons are 1) Cha’Ba, 2) Bellingham Bay, 3) Hansville, 4) Dabob Bay, 5) Point Wells, 6) Hoodsport, 7) Twanoh and 8) Carr Inlet.

34.3. Status and trends

Coastal buoy data from the Northeast Pacific and coastal shelf show that surface waters were warmer than average, with upwelling modulating temperature on the shelf (Figure 34-2). Subsurface waters on the shelf showed a seasonal progression, with warmer, fresher, higher oxygen conditions in early summer, a slow transition over summer and early fall to cooler, saltier, lower oxygen conditions in late summer, and a rapid transition in late October to much warmer, fresher, higher oxygen (Figure 34-3). This rapid transition was consistent with that observed in 2014 (Mickett and Newton 2016), when winds and currents fueled the onshore advection of anomalously warm water. Conditions in the Strait of Juan de Fuca were consistently warmer than average, with few periods near normal. Puget Sound waters were also consistently warmer, with rain/drought precipitation patterns and similar low/high streamflow conditions dominating salinity trends basin-wide.

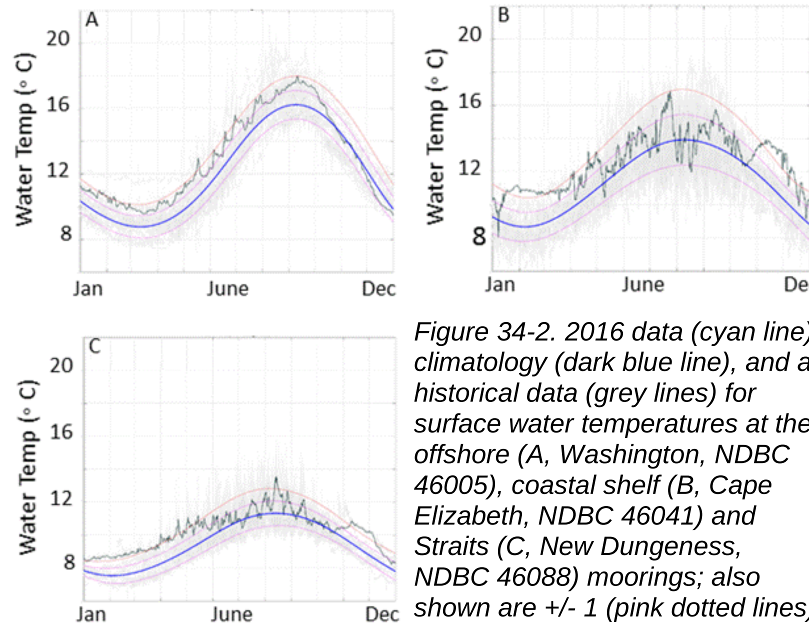

Figure 34-2. 2016 data (cyan line), climatology (dark blue line), and all historical data (grey lines) for surface water temperatures at the offshore (A, Washington, NDBC 46005), coastal shelf (B, Cape Elizabeth, NDBC 46041) and Straits (C, New Dungeness, NDBC 46088) moorings; also shown are +/- 1 (pink dotted lines) and 2 (red dotted lines) standard deviations from the climatology.

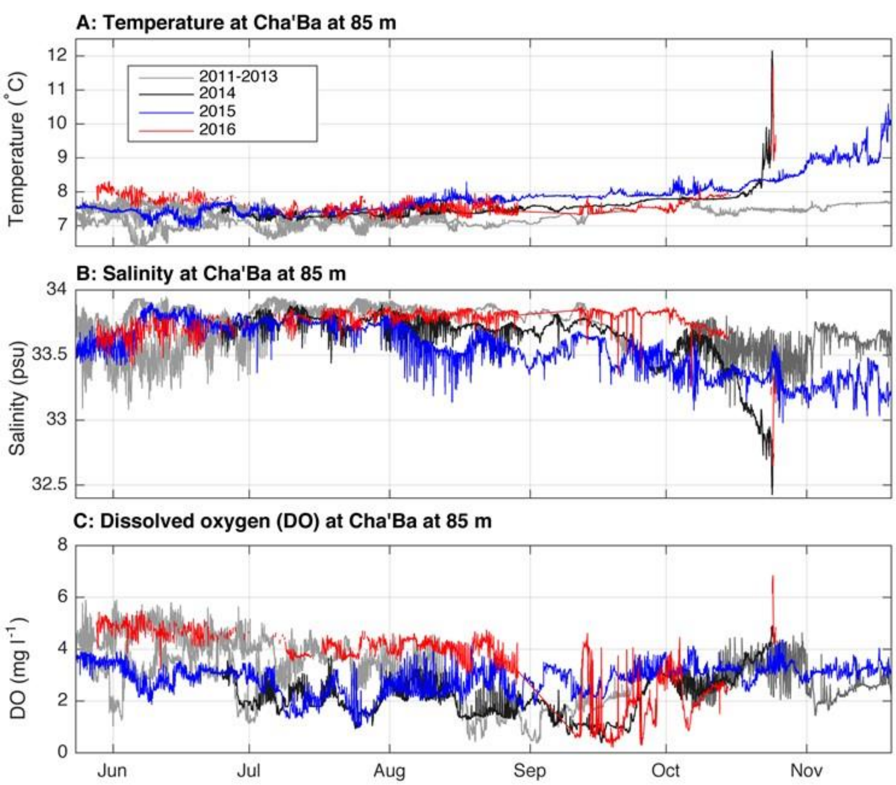

Figure 34-3. 2016 deep (85 m) data for water temperature (A), salinity (B), and dissolved oxygen (C) at the Cha'Ba (coastal shelf; Figure 34-1) mooring (red line), 2015 data (blue line), 2014 data (black line) and historical (2011-2013) data (grey lines).

In Puget Sound waters, significant, full-depth warm water anomalies were observed throughout 2016 (Figure 34-4), though overall they were slightly less intense than those observed in 2015. At depth, temperature anomalies were at least + 1 standard deviation above the 6- and 10-year observation means (2005-2015) in South Sound and the Main Basin, with even more pronounced anomalies in southern Hood Canal where temperatures at depth were consistently greater than +2 standard deviations for most of the year (Figure 34-4, E-G). Excepting temperature values, overall seasonal cycles were consistent with the historical averages throughout the basin, with winter cooling through the end of winter (Jan – Mar) followed by warming through late summer and cooling in early winter.

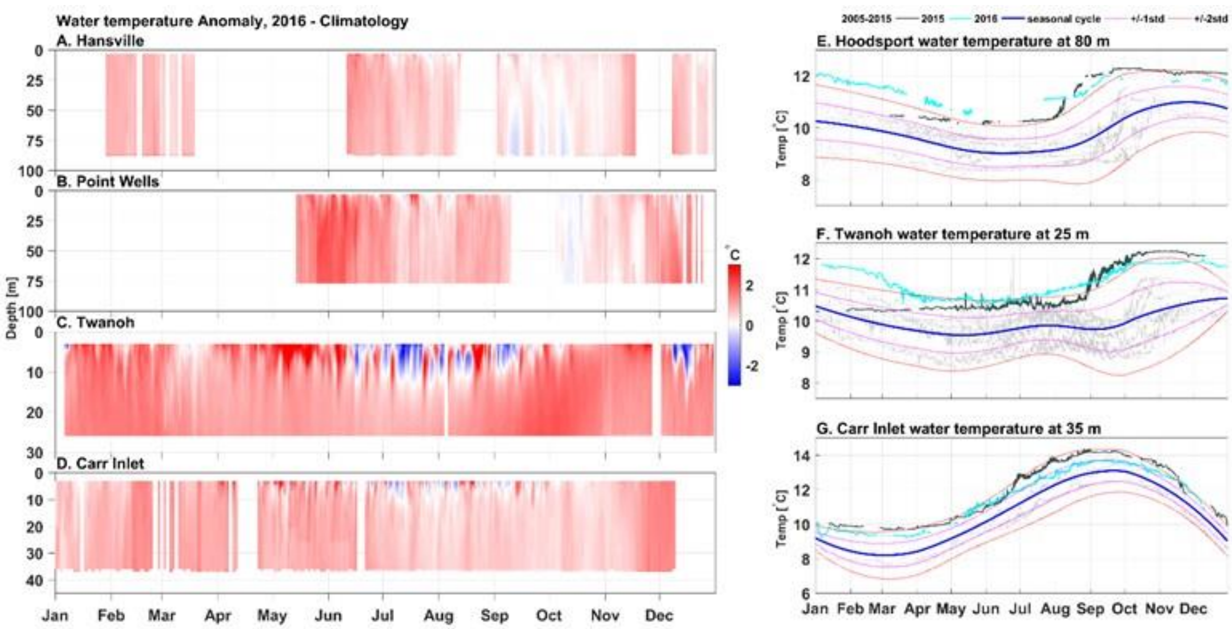

Figure 34-4. Left-side: 2016 water temperature anomalies (compared to 2005-2014 average) for Hansville (A), Point Wells (B), Twanoh (C), and Carr Inlet (D) moorings. Data are colored by a white threshold at 0, with red indicating warmer- and blue colder-than historical-average conditions. Right-side: 2016 data (cyan line), climatology (dark blue line), and all historical data (grey lines) for near-bottom water temperatures at the Hoodsport (E), Twanoh (F), and Carr Inlet (G) moorings; also shown are +/- 1 (pink dotted lines) and 2 (red dotted lines) standard deviations from the climatology.

Salinity variations during 2016 were remarkably similar to 2015 (Ruef et al. 2016) and varied in three distinct periods: 1) in early 2016 a wetter than normal spring contributed to full-water column salinities that were fresher than long-term averages; 2) throughout summer more saline conditions developed as drought conditions persisted until early fall; 3) toward the end of 2016, rainfall associated with one of the wettest winters on record contributed to a fresher than average water column (Figure 34-5). Though the succession of a wet spring, summer drought, and wet fall produced an extreme salinity reversal (Figure 34-5, E, F) similar to that observed in 2015, there were a few distinct differences in 2016. The spring freshening, a result of rain influences rather than “blob”-originated waters as seen in 2015, resulted in salinities in both south Sound and southern Hood Canal that were more than 2 standard deviations below average and lower than any observed in the historical record. This was followed by a steep summer-drought fueled increase in salinity, ending in early fall at more than 1 standard deviation above historical averages, less than the high salinities seen in early fall of 2015. Salinities quickly decreased as one of the wettest falls on record began, and continued to fall through early winter. As with temperature, seasonal patterns were consistent with historical averages despite extreme high and low values, with local variations due to differing river inputs and stratification similar to those in previous years.

In southern Hood Canal, similar to 2015, the warmer than average waters coupled with anomalously low salinities to result in some of the least dense waters observed in the southern Hood Canal record. These waters were easily displaced with comparatively more dense oceanic waters, and the Hood Canal experienced the annual fall flushing event more than 4 weeks earlier than in previous years, excluding 2015.

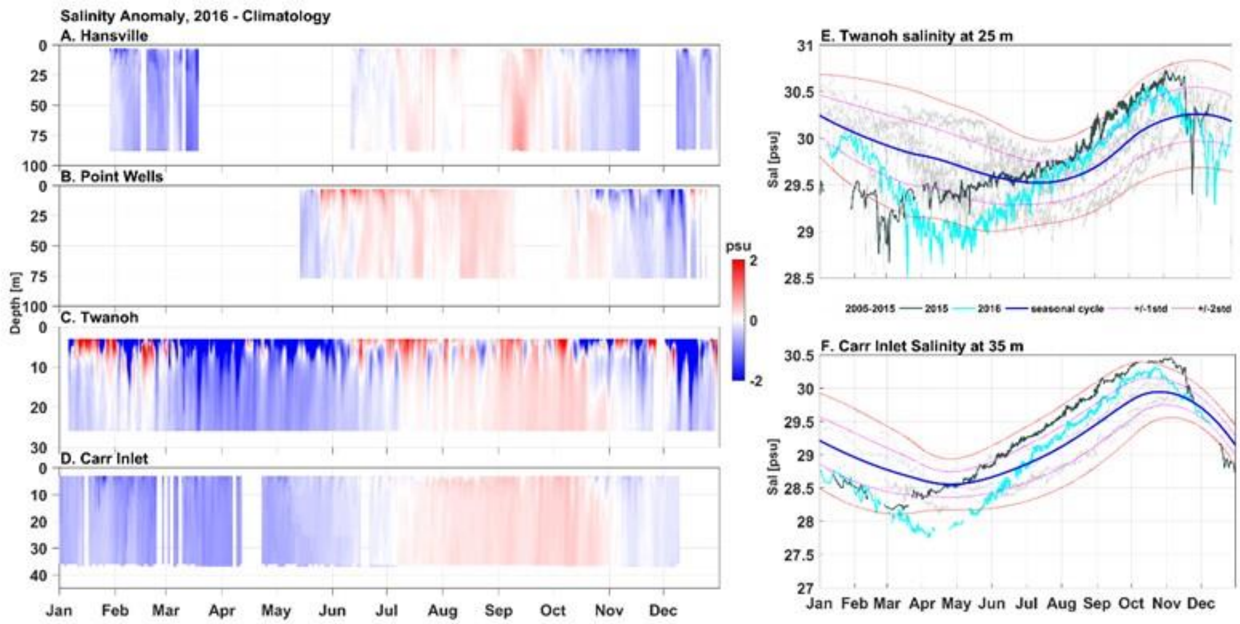

Figure 34-5. Left side: 2016 salinity anomalies (compared to 2005-2014 average) for Hansville (A), Point Wells (B), Twanoh (C), and Carr Inlet (D) moorings. Data are colored by a white threshold at 0, with red indicating saltier- and blue fresher-than historical-average conditions. Right side: 2016 data (cyan line), climatology (dark blue line), and all historical data (grey lines) for near-bottom salinity at the Twanoh (E) and Carr Inlet (F) moorings; also shown are +/- 1 (pink dotted lines) and 2 (red dotted lines) standard deviations from the climatology.

Dissolved oxygen (DO) anomalies during 2016 were moderately negative in south Sound and the Main Basin of Puget Sound, within +/- 1 standard deviation of the station long term average, while intense hypoxia and negative oxygen anomalies were observed in southern Hood Canal, ranging between +/- 2 standard deviations of the climatology. Figure 34-6 illustrates how 2016 compared to 4 previous years, including 2015. Overall seasonal cycles were similar to those observed in previous years, with seasonal hypoxia developing at depth through the summer and abating with the fall flushing. Concentrations at depth ranged from some of the lowest observed, followed by a steep increase during the fall flushing to some of the highest observed. Though oxygen concentrations at Twanoh is 2016 were most similar to 2015 and 2010, both years with an observed fish kill, no such wide spread event occurred in 2016.

Another unusual observation of 2016 was a coccolithophore bloom that occurred in the mainstem of Hood Canal Canal and Dabob Bay mid-summer, visible from space due to the reflectance of the coccoliths on these plankton.

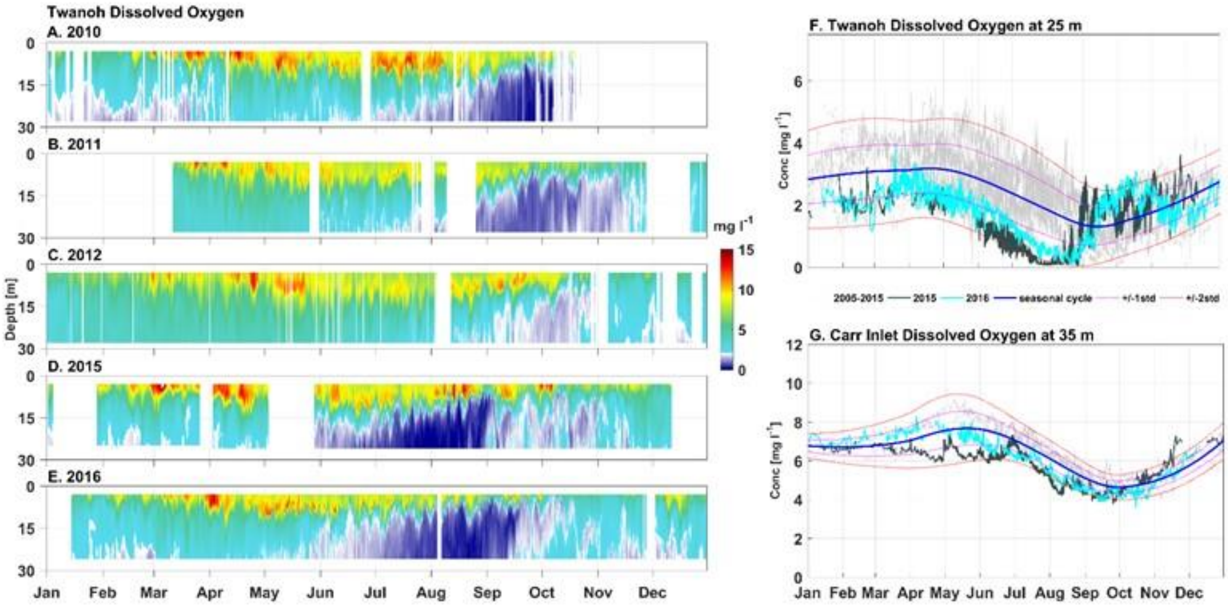

Figure 34-6. Left side: Time series of water column dissolved oxygen concentrations at the Twanoh ORCA mooring from multiple years between 2010 and 2016. Right side: 2016 data (cyan line), climatology (dark blue line), and all historical data (grey lines) for near bottom oxygen concentration at the Twanoh (F) and Carr Inlet (G) moorings; also shown are +/- 1 and 2 SDs from the climatology.

34.4. Factors influencing trends

Conditions appear to be strongly influenced by the continuing marine heat wave, with all locations showing above average temperatures for most of the year. Seasonal upwelling was also an influencing factor to temperature trends on the coastal shelf, but the effects of driving temperatures down did not carry over to the inland waters, implying local heating could also be a factor. Shelf salinity and oxygen appear to follow seasonal upwelling progression, however within Puget Sound also closely matched the rain/drought precipitation pattern as well as the co-occurring "high/low/high" stream flow and precipitation conditions observed in 2016.

34.5. Implications of those trends.

The persistence of warm temperatures could have metabolic demands on higher organisms such as fish. The hypoxia, while not resulting in a wide spread fish kill event in 2016, is an additional stressor that could affect biota if it becomes an annual recurrence. The unusual salinity excursions observed in 2016 and 2015 should be investigated for their effect on density-driven circulation in Puget Sound.

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35. TIMING OF THE SPRING PHYTOPLANKTON BLOOM IN THE STRAIT OF GEORGIA, 2016

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35.1. Highlights

- Timing of the spring phytoplankton bloom in the Strait of Georgia is estimated for 2016 using ferry data, and both one-dimensional and three-dimensional computer simulation models.
- Model results for 2016 predicted the bloom would occur in late-March, which was observed.
- Timing is close to the previous year and close to the mean.

35.2. Description of the time series

The timing of the spring phytoplankton bloom in the southern Strait of Georgia is highly variable, ranging from late February to mid-April. We describe two time-series, one from data, one from a model, and the beginning of a third time-series from a new model.

35.2.1. Data-based estimates from ferry observations

A recent compendium of data from all ferry systems in the Strait of Georgia has been compiled. This includes 1) STRATOGEM data, 2) Institute of Ocean Sciences Data from Jim Gower, and 3) recent Ocean Networks Canada data. The first and third of these are from the Tsawwassen/Duke Point route; the second is from the Tsawwassen/Swartz Bay route. For the latter, data were averaged over the Strait of Georgia section of the route.

Ferry observations of bloom timing are defined by the period during which Chlorophyll fluorescence values are more than 50% of the peak value except during 2009, 2011, and 2012 where the gaps in the ferry time series make such a determination impossible. In those years, bounds on the bloom time are specified as narrowly as the data allow. Data are available from 2003-2016.

35.2.2. Model-based estimates from one-dimensional model

The model is a vertical-mixing layer model forced by observed winds at Sand Heads, observed air temperature and humidity at Vancouver International Airport (YVR), Fraser River flow at Hope and Englishman River flow at Parksville (Environment Canada 2015a,b). The latter is multiplied by 55 to represent all river flows into the Strait other than the Fraser River (Collins et al. 2009). Cloud fraction is interpreted based on the weather description and the historical average cloud fraction, done by month for the most common weather descriptions. The physical model is based on the Large et al. (1994) KPP-model with an estuarine circulation model added (Collins et al. 2009).

To model a spring bloom, only a simple nitrate-diatom biological model is used. The diatom growth parameters are taken from the literature based on the first phytoplankton to bloom in the Strait (*Thalassiosira* spp.). The model zooplankton concentration was taken from observations (Sastri and Dower 2009), and the model was tuned by adjusting the phytoplankton growth rate

(Allen and Wolfe 2013) within the range measured in the laboratory. The model was tuned, within 4 days, for the spring blooms of 2002-2005 for which detailed observations were made as part of the STRATOGEM project (Allen and Wolfe 2013).

The spring bloom in the model is defined as the time of the peak phytoplankton concentration (averaged from the surface to 3 m depth) within four days of the average 0-3 m nitrate concentration falling below 0.5 μm for two consecutive days. Results are available from 1968-2016.

35.2.3. Model-based estimate from three-dimensional model

The three-dimensional circulation model based on NEMO (Madec 2012) is configured for the Salish Sea (Soontiens et al. 2016, Soontiens and Allen 2017). It is forced by Environment Canada High Resolution Deterministic Prediction System (HRDPS) winds and solar radiation, gauged Fraser River flow at Hope, and all other rivers, including the Fraser downstream of Hope, based on climatology (Morrison et al 2011). Eight tidal constituents are modelled. The biological model, SMELT, has three phytoplankton groups, two zooplankton groups and three nutrients (Figure 35-1; Moore-Maley et al. 2015). The mesozooplankton is closed as in the one-dimensional model.

The spring bloom is defined from the results at the same station as the one-dimensional model in the same way. Results are only available for 2016.

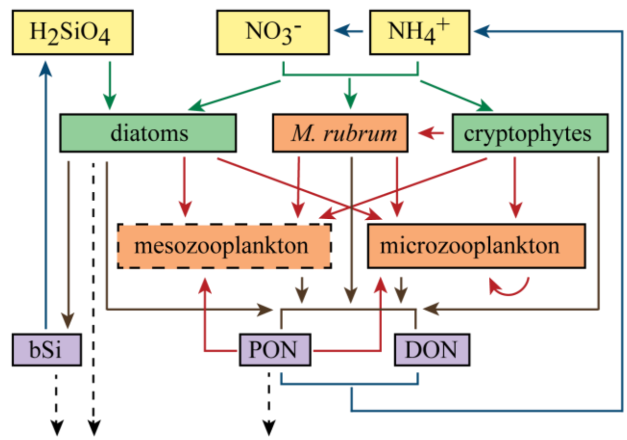

Figure 35-1. The three-dimensional biological model, SMELT. Three nutrients, three photosynthesizers, three grazers (Mesodinium rubrum is both), and three detrital classes are modelled.

1.1. Status and trends

The 2016 spring bloom (Figure 35-2) began in late February but was set back by storms on February 23, March 10 and March 22. According to the one-dimensional model, the mean timing of the spring bloom from 1968-2016 is March 21 (Figure 35-3), so the March 27 date in 2016 is one week later. Observations (Figure 35-3) for 2016 give a range between March 18-29 and the three-dimensional model (Figure 35-2) gives March 25.

On March 19, 2016, during the spring bloom in the southern Strait, the three-dimensional model showed high phytoplankton biomass from Boundary Pass in the south to the north end of Texada Island in the north, with the western Strait having higher biomass than the eastern (Figure 35-4).

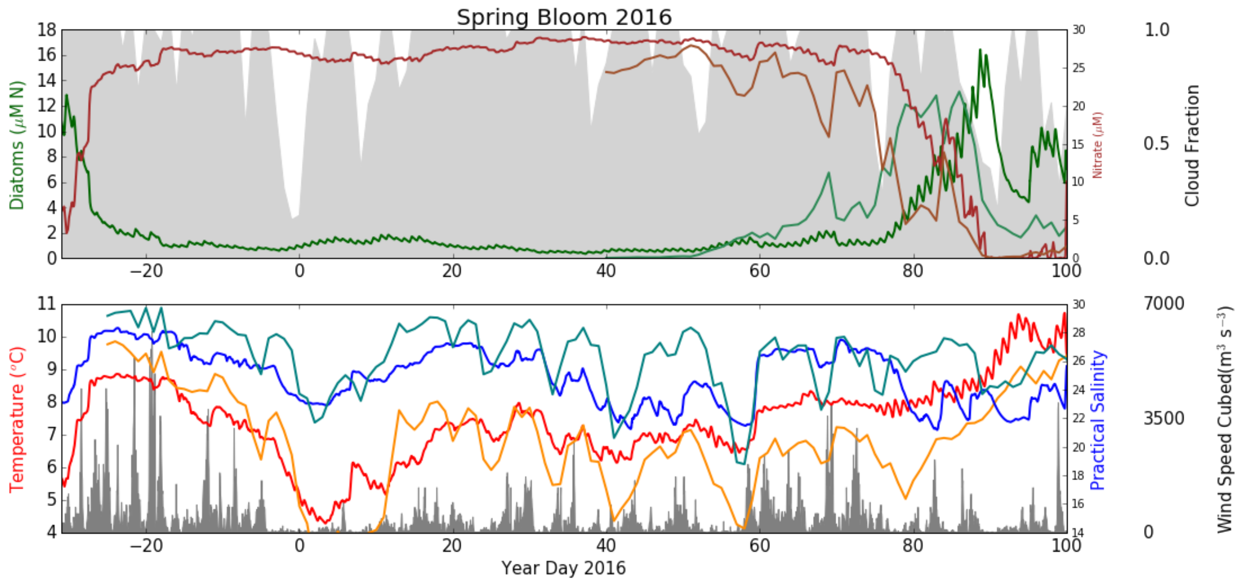

Figure 35-2. Hindcast of the 2016 spring bloom and related conditions in the Strait of Georgia. The lower panel shows temperature (in red for 1-D model, in orange for 3-D model) and salinity (in blue for 1-D, in teal for 3-D) averaged over the upper 3 m of the water column; in grey is the wind-speed cubed which is directly related to the strength of the mixing. One can clearly see the mixing associated with the storm about day 58 (February 27); salinities increase as deeper high salinity water is mixed into the surface waters. The top panel shows phytoplankton biomass (in dark green for 1-D in light green for 3-D) and nitrate (in dark red for 1-D, in brown for 3-D); in grey is the cloud fraction averaged over the day. One can see the influence of low wind, low cloud periods such as that after day 75 (March 15). Here phytoplankton biomass steadily increases and nitrate decreases with a stronger response in the three-dimensional model than the one-dimensional model. The 2016 spring bloom (March 27 hindcast, March 18-29 observed) was one week later than the time series mean. Plots span the period December 1, 2015 to April 10, 2016.

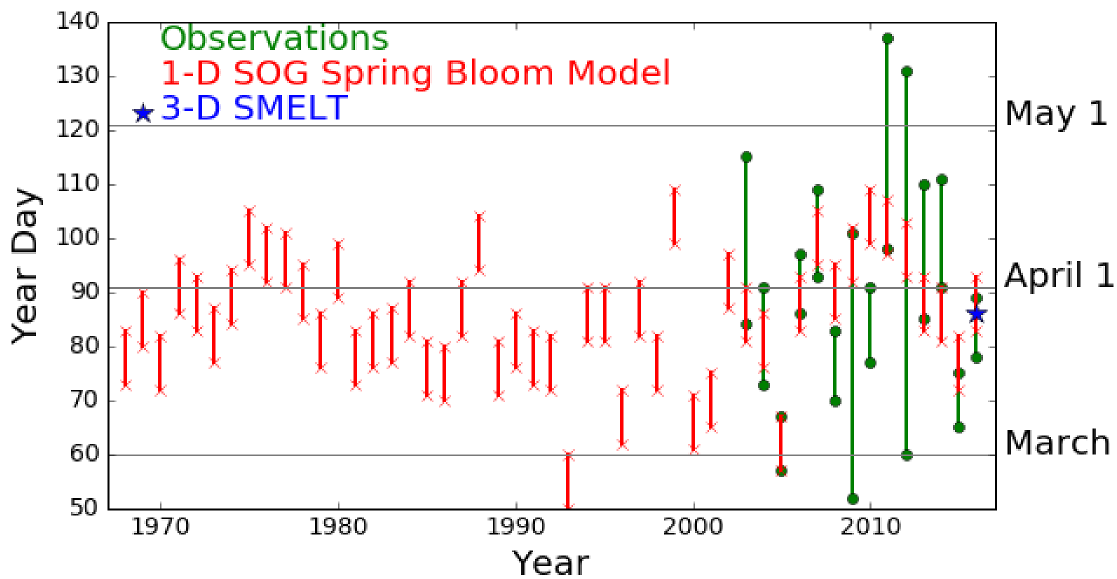

Figure 35-3. A 49 year time series of the timing of the spring phytoplankton bloom according to the one-dimensional model (red). Note the five very early blooms that all occurred between 1993 and 2005 and the persistently late blooms from 2006 to 2014. The model agrees with the ferry observations (green) in most years. The bloom in 2016 was the fourth latest March bloom in a row.

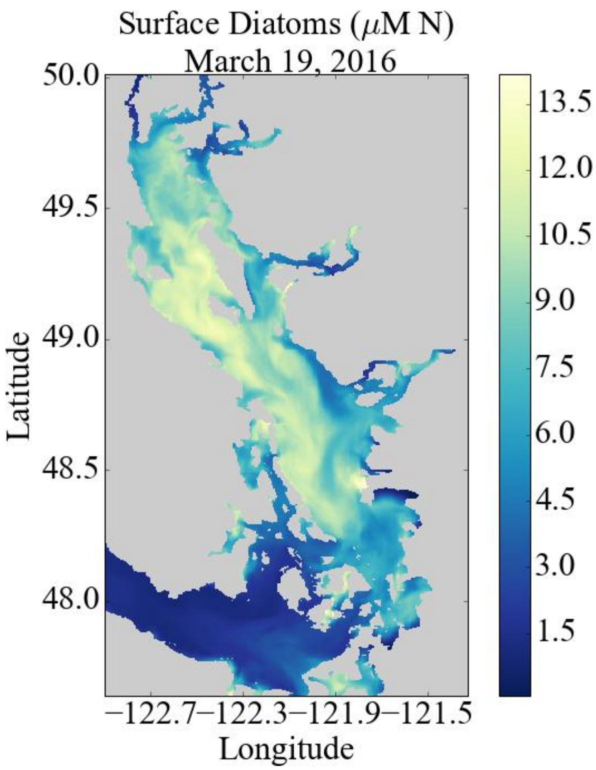

Figure 35-4. Preliminary results from the three-dimensional model showing the surface diatom con-centration on March 19, 2016 during the spring bloom.

1.2. Factors influencing trends

Very early spring blooms were seen occasionally in the years 1990-2005. A model study suggested these blooms were only possible due to warmer water temperatures (Allen and Wolfe, 2013). We have not seen a return to these blooms in model results because February-March has had strong wind storms as the jet stream moves north earlier than typical.

1.3. Implications of those trends.

Changes in the timing of the spring phytoplankton bloom have been linked to the success of herring recruitment in the Strait of Georgia (Schweigert et al. 2013) and to summer zooplankton community composition in Rivers Inlet, a nearby fjord (Tommasi et al. 2013). The timing of the spring phytoplankton bloom is not a good measure of all interannual variability in any setting, including the Strait of Georgia. However, it is a good measure of biological spring. Sharp interannual changes may lead to mis-match conditions with grazers.

The relatively steady, near mean, bloom timing that we have seen over the last four years should allow a good timing match for grazers to transfer biomass up the food chain and support herring recruitment.

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36. SPATIAL AND TEMPORAL SATELLITE-BASED CHLOROPHYLL PHENOLOGY IN THE SALISH SEA: 2002-2016

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36.1. Highlights

- Satellite chlorophyll (*chl-a)* climatology (2002-2016) indicates seasonality in the Salish Sea, where lower values (approximately 3.0 and 1.6 mg m^{-3}) are present at both the beginning and end of the year corresponding to winter conditions, and average higher *chl-a* values (>5.0 and > 3.0 mg m^{-3}) are present in the spring and summer periods in the central and north regions, respectively.
- The *chl-a* time series also shows that fall blooms are more prevalent in the central region where *chl-a* exceeding 5.0 mg m^{-3} occurs after September in almost every year.
- Based on the bloom criteria for the time of initiation in the central and north Salish Sea, the *chl-a* time series indicate that, on average, the spring bloom initiation is on the week of March 15 (±4 days) and on the week of March 25 (±4 days) for the central and northern regions, respectively.
- 2016 was characterized by bloom conditions representing the climatology of this region, i.e. week of bloom initiation in the middle of March (March 15), for both central and north regions.

36.2. Summary

The spatial and interannual variability of the surface chlorophyll conditions in the Strait of Georgia (SoG) can be used as an indicator of primary productivity, and therefore to assess the impact of bottom-up forcing on fish populations. Data derived from satellite remote sensing offer an unparalleled tool for synoptic biomass sampling associated with high sampling frequencies. This report provides the analysis of chlorophyll yearly dynamics and bloom initiation for the central and northern regions of the Strait of Georgia based on a time series (2002-2016) of MODIS-Aqua imagery.

36.3. Description of the time series

Image data (Level 1a) were accessed from NASA's OceanColor web portal, and processed in the SeaDAS (SeaWiFS Data Analysis System) environment. All available good quality MODIS-Aqua images from July 2002 through December 2016 at 1 km^2 spatial resolution were processed. As a first step, the images were atmospherically corrected using the Management Unit of North Seas Mathematical Model (MUMM) using shortwave infrared bands and evaluated based on regional Aerosol Robotic Network (AERONET) and in situ above-water reflectance data. The OC3M chlorophyll algorithm was applied to the atmospherically corrected imagery, excluding pixels with standard quality-control flags. The quality control flags include pixel contamination caused by stray light and high solar and zenith angles (above 60 and 75, respectively). Angular conditions result in time series restricted from mid-February to mid-November. The daily derived satellite chlorophyll concentrations (*chl-a*) products were validated with *in situ* data from the DFO Institute of Ocean Sciences database and our own high-performance liquid chromatography (HPLC) measurements.

Following validation, all *chl-a* images were spatially binned and mapped to a common grid, and transformed to base 10 logarithm. Missing pixels were spatially interpolated using the Data Interpolating Empirical Orthogonal Functions (DINEOF) methodology. Gaps in satellite datasets are iteratively filled by signal recombination, following iterative identification of the dominant spatial and temporal EOFs using random cross-validation points (~3% of dataset) and the global average as an initial missing pixel value (Beckers and Rixen 2006). Image interpolation criteria require at least 2% ocean coverage and 2% presence of individual pixels in the time series. The impact of study area size and input time series length were investigated, with interpolations restricted to the Salish Sea boundaries, run with daily *chl-a* time series on an annual basis producing optimal results (RMSE 1.7 mg m^{-3}). The resulting gap-filled time series was binned into weekly (8-day) composites, from which statistics for the northern and southern SoG were recalculated based on median *chl-a* for the region. As a quality-control measure, weeks in which less than 5% of pixels were available in the uninterpolated imagery were not included.

Timing of bloom initiation was defined as the yearday (+/- 4 days) where *chl-a* were greater than the annual median plus 5% in the last two consecutive measurements, or the yearday of the first *chl-a* estimate greater than a threshold value of 5.0 mg m^{-3} or 3.0 mg m^{-3}, for the central and north regions, respectively (similar to Schweigert et al. 2013 and Siegel et al. 2003). These thresholds were defined based on yearly regional statistics. We are presently investigating other approaches to define regional bloom initiation, for instance, taking into account progression of bloom conditions.

36.4. Status and trends

The chlorophyll climatology (2002-2016) indicates the seasonality in the central and north Salish Sea with a certain degree of synchronicity between the two regions, except in the fall (Figure 36-1). In the central region, the lowest median chlorophyll concentrations (3.3 mg m^{-3}) were observed in the winter period, followed by the highest concentrations defining the spring bloom (5.7 mg m^{-3}), mid-level concentrations in summer (4.8 mg m^{-3}), and mid-level concentrations in the fall that were often associated with a fall bloom (4.6 mg m^{-3}). In the north region, concentrations were generally lower with winter periods showing 1.6 mg m^{-3}, a spring bloom with concentrations of 3.0 mg m^{-3}, summer of 3.8 mg m^{-3}, and lower fall concentrations of 2.6 mg m^{-3}.

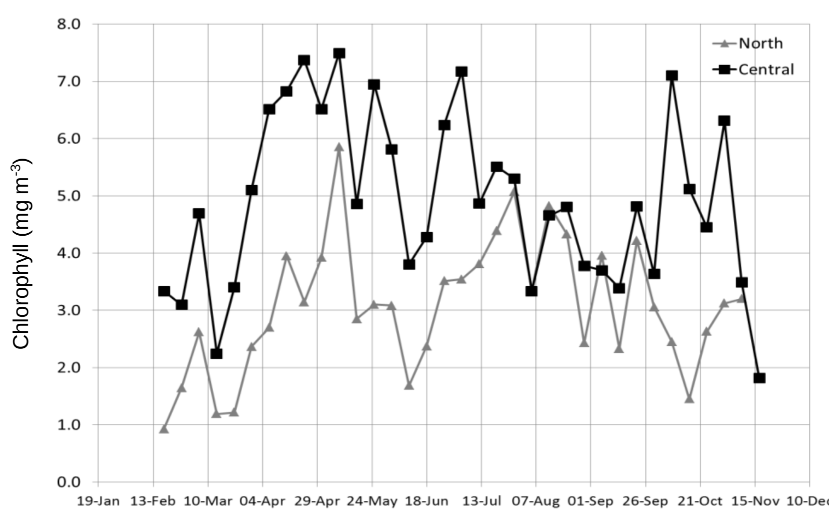

Figure 36-1. Weekly-median Chlorophyll climatology for the central and north Salish Sea (2002-2016).

The time series analysis of the MODIS Aqua imagery shows that on average, the spring bloom initiation week (YW_{init}) is on the week of March 15 (±4 days) and on the week of March 25 (±4 days) for the central and northern Salish Sea, respectively. In 2014, the spring bloom initiation happened on the week of April 3 (±4 days), similar to Ocean Networks Canada (ONC) ferry box data, in 2015 on the week of February 22 (±4 days), two weeks earlier that ONC ferry box data, and 2016 on the week of March 15 (±4 days), similar to ONC ferry box data (Sastri et al. 2016).

Figure 36-2 illustrates the spatial and temporal differences between 2014, when the bloom started in the first week of April, and 2015, when the bloom started in the third week of February, and 2016 when the bloom conditions represent the climatology for this region, i.e. week of bloom initiation in the middle of March.

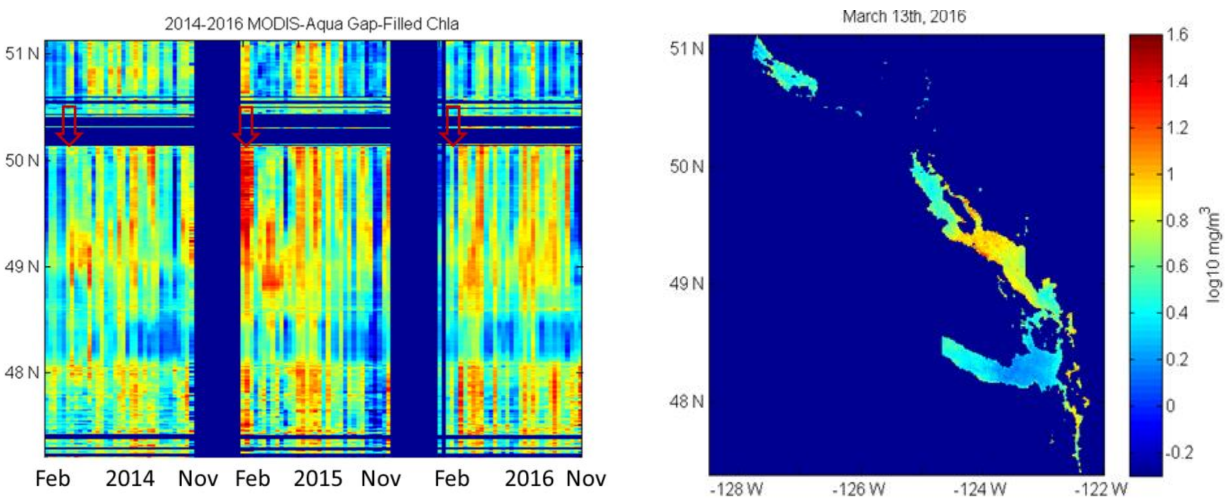

Figure 36-2. Left: Hovmoller plot of 2014-2016 chl-a averaged by latitude. Red arrows correspond to week of bloom initiation for the different years. A graphic of Vancouver Island is shown on the right with MODIS interpolated chl-a concentrations for March 13, 2016 when bloom conditions were present in both the central and north regions. Note that the dark blue areas correspond to land and ocean masks beyond the Salish Sea area.

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37. THE PHYTOPLANKTON COMMUNITY IN THE SALISH SEA

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37.1. Highlights

- Based on thousands of samples (collected bi-monthly from February to October at ~80 sites) in 2015 and 2016, PSF's Citizen Science Program has unprecedented, high-resolution data on in-situ phytoplankton dynamics in the Strait of Georgia.
- In 2016, the spring bloom was recorded several weeks later than in 2015; it was comprised of a mixture of species (*Thalassiosira* spp., *Skeletonema costatum*, *Chaetoceros* spp.), whereas the spring bloom of 2015 was comprised mostly by one species (*Skeletonema costatum)*. Dinoflagellate and silicoflagellate contributions to the phytoplankton biomass were strikingly higher in 2016 than in 2015.
- The year of 2016 was somewhat unfavorable in terms of harmful algal blooms: there was an early and persistent presence of *Alexandrium* spp. (cause of Paralytic Shellfish Poisoning), elevated levels of non-skeletal *Dictyocha* (toxic to salmon), moderate levels of *Rhizosolenia setigera* (mechanically harmful to salmon), low levels of *Heterosigma akashiwo* (toxic to salmon and zooplankton) observed in some areas. There also were several non-harmful blooms (*Ditylum brightwellii*, coccolithophores).

37.2. Citizen Science Program

The Citizen Science Program was initiated in 2015 by the Pacific Salmon Foundation (PSF), Ocean Networks Canada (ONC) and Department of Fisheries and Oceans Canada (DFO) as part of the Salish Sea Marine Survival Project www.marinesurvivalproject.com. Selected members of the public took on a role as citizen scientists, collecting information in the Strait of Georgia every 2 weeks between February and October. Phytoplankton samples and water properties were collected and measured at ~80 sites in the Strait (Figure 37-1). At selected sites nutrients, zooplankton and chlorophyll samples were also collected.
Sample/measurement processing and analysis was performed at the PSF, ONC, DFO and University of Victoria. The Citizen Science Program is more cost effective than conventional monitoring and provides unique data for the entire Strait at a resolution that has not been possible before.

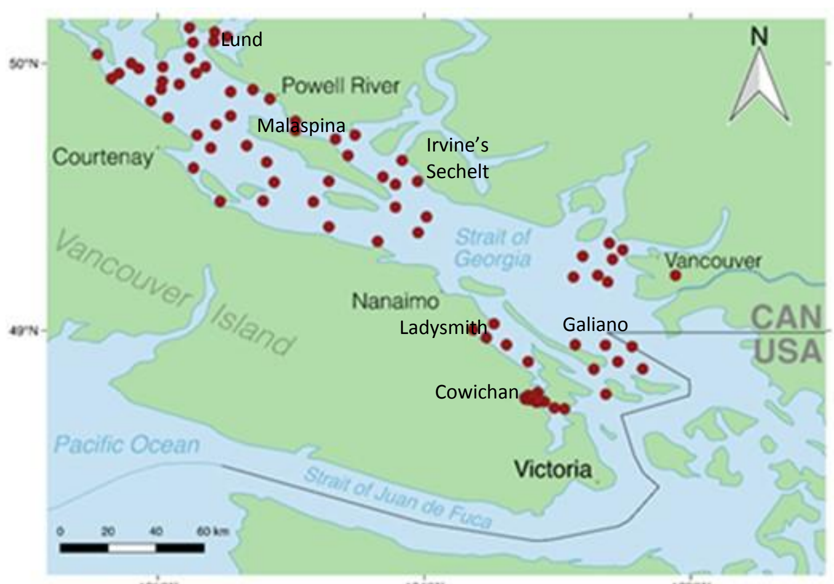

Figure 37-1. Citizen Science Program station locations 2016.

Outreach and updates on the phytoplankton component of the Program is posted on the social media - Facebook page

"Phytoplankton - Citizen Science" at https://www.facebook.com/CitizenSciencePhytoplankton; phytoplankton and environmental databases are accessible at http://sogdatacentre.ca and http://www.oceannetworks.ca respectively.

37.3. Description of the time series

Under its current mandate, the Citizen Science Program is scheduled to collect samples during three sampling periods (February to October) from 2015 to 2017. Phytoplankton samples are collected bi-monthly at the surface (0 m) at ~80 sites and depths (5, 10, and 20 m) at ~10 sites. Each year, thousands of phytoplankton samples are analyzed which provides unprecedented, high resolution data on *in situ* spatial and temporal fluctuations of phytoplankton, including harmful algae species.

Phytoplankton samples are analyzed on a Sedgewick-Rafter slide; the identification of specimens is done to the lowest taxonomic level possible; the enumeration (as cells mL^{-1}) is performed for the species or group that is dominant in the sample and species that are known or suspected to have a negative effect on salmonids in B.C. (Haigh et al. 2004). The biomass index used by the Citizen Science Program is a subjective visual estimation of a biomass level as it appears on the 1 mL Sedgewick-Rafter slide under compound microscope. Very low biomass usually corresponds to 1 – 2 cells mL^{-1}, while very high biomass corresponds to very thick bloom conditions (usually above tens of thousands cells mL^{-1})

37.4. Status and trends

In 2016, the spring bloom was recorded several weeks later than in 2015 and it lasted longer (Figure 37-2). Composition of the spring bloom was also different - in 2016 it was comprised by a mixture of species (*Thalassiosira* spp., *Skeletonema costatum*, *Chaetoceros* spp.), whereas the spring bloom of 2015 was comprised predominantly by one species (*Skeletonema costatum)*.

2015	02-18	03-12	03-20	03-27	04-04	04-11	04-18	05-11	05-18	05-25	06-09	06-16	07-01	07-15	08-06	08-14	09-14
Cowichan	1.5	3.3	2.2	2.0	2.2		1.5	2.1	2.1	2.0	1.8		2.5	2.9	2.7		2.4
Nanaimo	1.5	3.6	3.0				2.2	1.8	1.8	2.0	1.6	1.8	1.5	1.6		1.6	1.5
Lund	1.5	3.4	2.1	1.5	1.5	1.6	1.6	1.8	1.6	1.9	1.6		1.6	1.5	1.7	1.8	1.5
Powell River	1.5	3.6	2.6	1.8	1.5	2.7	1.8	1.5	1.5	1.9	1.5		1.6	1.7	1.8	1.6	1.7
Irvines Sechelt		3.8	2.6		2.4	4.0	1.9	1.9	2.4	2.2	2.0	2.3	1.8	1.9	2.2	1.8	

2016	02-18	03-18	03-29	04-10	04-19	04-26	05-10	05-17	05-22	06-05	06-15	07-05	07-12	08-02	08-22	09-07	09-21
Cowichan			1.7		2.8	[illegible]	2.0		2.3			2.4				1.5	2.0
Nanaimo	1.7	[illegible]	2.1	2.6	2.7	2.2	3.8	2.5	2.6	2.1		2.3	2.1	2.8	1.8	2.0	1.6
Lund	1.5	[illegible]	3.2	3.2	1.9	1.6	1.7	1.8	1.8	1.6	2.0	2.8	2.0	2.0	1.9	1.5	1.5
Powell River	1.5	1.6	2.9	2.5	2.3	[illegible]	1.8	1.8	1.7	1.8	2.0	2.5	1.8	2.4	2.7	1.7	1.5
Irvines Sechelt	1.7	1.7	2.8	2.6	2.8	3.0	3.7	3.5	2.9	2.6	2.0	2.8		3.5	3.4	2.2	2.1

Figure 37-2. Averaged biomass index (from 1=very low to 5=very high) per area at several Citizen Science sampling areas based on surface (0 m) samples; spring blooms are circled in red.

The overall phytoplankton biomass in 2016 had strikingly higher contributions of dinoflagellates, and silicoflagellates than in 2015. Raphidophytes were present in some areas in 2016 but mostly absent in 2015. Raphidophytes are often toxic to direct grazers (zooplankton) and consumers at higher trophic levels including salmon, so conditions in the Strait of Georgia (in regards to the presence of raphidophytes) were more favorable in 2015 than in 2016.

In contrast to 2015, which had few harmful algal blooms, the year of 2016 was somewhat unfavorable. Cells of *Alexandrium* spp. (cause of Paralytic Shellfish Poisoning) started to appear earlier and were more abundant in 2016 than in 2015 – e.g. some March 2016 samples from Cowichan Bay, Irvine's Sechelt, and Powell River areas had *Alexandrium* spp. up to ~4 cells mL^{-1}; for reference - a cell density of 0.5 cell mL^{-1} can result in closure of shellfish harvest (Andersen et al. 2004). The areas most affected by *Alexandrium* spp. throughout the whole sampling season were Cowichan Bay, Irvine's Sechelt, and Galiano. After periods of heavy rains in June and July there were elevated levels (up to ~450 cells mL^{-1}) of silicoflagellate *Dictyocha* spp. (toxic to salmon); the most affected areas were Lund, Powell River, and Malaspina. Moderate blooms of *Rhizosolenia setigera* (mechanically harmful to salmon) were observed in August with the highest cell density of ~800 cells mL^{-1} recorded in the Campbell River area; Galiano, Irvine's Sechelt and Ladysmith were also affected with cell densities of ~500 cells mL^{-1}. Low levels of *Heterosigma akashiwo* (toxic to salmon) appeared in a few areas in August/early September samples; the most affected area was Irvine's Sechelt with the maximum cell density of ~150 cells mL^{-1} observed on September 9, 2016. There also were several non-harmful blooms (*Ditylum brightwellii*, coccolithophores) observed in July and August.

37.5. Factors influencing trends

Phytoplankton dynamics are directly governed by primary environmental factors – light, temperature, nutrients, turbidity, etc. This direct connection enables mostly successful predictions of spring bloom timing based on models, however only *in situ* monitoring provides data on bloom composition and harmful algae presence. Knowledge of phytoplankton groups/species dynamics and its relation to environmental factors can be critical in assessing bottom-up and top-down control of zooplankton, herbivorous fish and higher trophic levels.

Timing and magnitude of spring blooms in both 2015 and 2016 appeared to be closely affected by the Fraser River discharge. Very low silicoflagellate contribution in 2015 was associated with low river discharge and lower than usual rainfall in summer. In contrast, elevated levels of the silicoflagellate *Dictyocha* spp. were observed in 2016 after periods of heavy rain. More data on environmental parameters and nutrients are available through the Citizen Science Program and statistical analysis could potentially establish statistically significant links between phytoplankton at the species level and environmental characteristics in the Strait of Georgia.

37.6. Implications of those trends

The Citizen Science Program's phytoplankton database offers information on *in situ* phytoplankton dynamics as well as spatial/temporal distributions of harmful algae. These data sets are integrated into the Salish Sea Marine Survival Project and are used to examine potential linkages between composition, abundance and distribution of phytoplankton and zooplankton and the distribution, growth and feeding of juvenile Chinook and Coho Salmon in the Strait of Georgia. A continuous phytoplankton monitoring program can provide information (both bottom-up and top-down) that could improve the accuracy of adult returns forecasting and could reduce uncertainty around the role of the marine environment in overall productivity.

Routine phytoplankton monitoring data can also be used to extract data on the harmful species of interest. For example, knowledge of the spatial-temporal distribution of *Alexandrium* spp. and its relation to environmental factors (*e.g.* Esenkulova et al. 2017) could be beneficial for shellfish farm management.

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38. EPIBENTHIC COMMUNITY STRUCTURE ALONG A DISSOLVED OXYGEN GRADIENT

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38.1. Highlights

- We continued a long-running hypoxia time series (2005-present) in Saanich Inlet, B.C. where we used ROVs to survey the epibenthic megafaunal community along a dissolved oxygen gradient (0-4.5 mL L^{-1}) from 180-40 m depth.
- Transects from spring, summer, and fall 2016 were compared with three similar transects from 2013 to determine changes in the epibenthic community.
- Severe habitat compression was evident in 2016 as bottom anoxia and hypoxia (O_2 < 1.4 mL L^{-1}) boundaries shoaled into shallower depths compared to 2013 transects done at the same time of year.
- Distribution and abundance of three main mobile species (slender sole, squat lobster, spot prawn) show that hypoxia-tolerant species (slender sole and squat lobsters) were generally unaffected, while hypoxia-sensitive spot prawn were notably absent in fall 2016.
- We note the occurrence of two species, a nudibranch and a sea cucumber, that were previously rare or absent from the site but increased in abundance in 2016.
- The long-term decrease in dissolved O_2 from the 96 m VENUS cabled node in Saanich Inlet has accelerated due to several weak deep-water renewals after 2010.

38.2. Description of indices

Since 2005, benthic surveys with remotely operated vehicles (ROVs) outfitted with a dissolved oxygen sensor and high-definition video cameras have repeated the same transect (n=13) in Patricia Bay, Saanich Inlet, B.C. This transect transitions through near-bottom zones of low to high oxygen along a shallow depth gradient (180-40 m) and allows for direct comparisons of bottom oxygen and epibenthic animal abundances between years. The transect was flown three times in 2013 and illustrated the influence of seasonal hypoxia expansion on the epibenthic community (Chu and Tunnicliffe 2015). As a direct comparison, the transect was surveyed three times in 2016 at approximately the same times of year (i.e. spring, summer, and fall). *In situ* oxygen occurrence in 2013 versus 2016 was calculated for two hypoxia-tolerant and one hypoxia-sensitive mobile species: slender sole (Lyopsetta exilis), squat lobster (Munida quadrispina), and spot prawn (Pandalus platyceros). We also used the maximum depth of slender sole as an indicator of the extent of oxygenated habitat for the epibenthic community as they have high fidelity to the low oxygen waters and are the first megafaunal species to appear when transecting from deep to shallow along the transect (Chu and Tunnicliffe 2015). Ocean Network Canada's VENUS cabled node provides dissolved oxygen measurements in one-minute intervals at a fixed station of 96 m, which is approximately mid-way between the start and end of the benthic transect.

38.3. Status and trends

In situ oxygen occurrences of the three numerically dominant mobile macrobenthos along the transect show that the effects of the increased spatial extent of hypoxia varied by species. Slender sole and squat lobster, two species that generally occur at low oxygen (Chu and Tunnicliffe 2015), did not show a marked difference in either abundance or distribution with oxygen along the transect (Figure 38-1). A dense aggregation of squat lobsters in the shallow normoxic area of the transect was seen in spring 2016, but was likely a mating aggregation rather than a spatial re-assortment due to hypoxia (Doya et al. 2016). However, there were marked changes in the abundance and distribution of the hypoxia-sensitive and commercially important spot prawn in 2016. In spring 2016, spot prawn were observed within a low and narrow range (0.81-1.94 mL L^{-1}) of oxygen (Figure 38-1, bottom). In the Fall 2016 transect, spot prawn were completely absent for the first time in the 10 years of this time-series. No evidence of a large mortality event was observed.

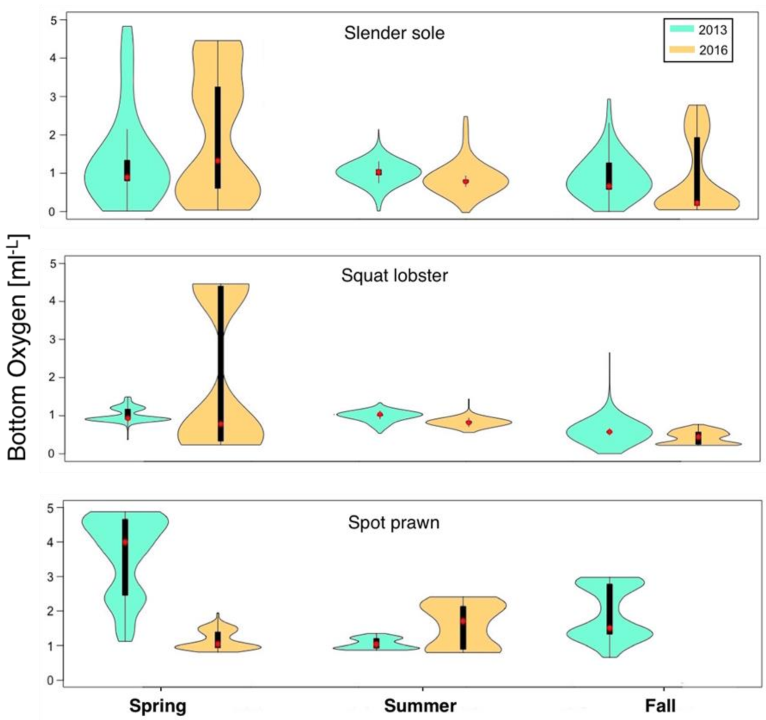

Figure 38-1. In situ oxygen occurrence violin plots for the three main mobile species in Saanich Inlet in 2013 versus 2016. Red dots represent median oxygen occurrence, while bold black lines are the second and third quartiles of the data and thin black lines are the first and fourth quartiles. Abundance is represented by the width of the violin. Slender sole (top), the most abundant and hypoxia-tolerant of the mobile macrobenthos, was largely unaffected by the increased extent of hypoxia. Squat lobster (middle) was, for the most part unaffected as well, although a dense mating aggregation was seen in spring 2016 normoxia. The hypoxia-sensitive spot prawn (bottom) was seen at much lower oxygen in spring 2016 than 2013, and was completely absent from the Fall 2016 transect.

In addition to the absence of the spot prawn, the striped nudibranch, *Armina californica*, was notably abundant in the shallow, oxygenated portions of the transect where spot prawn are usually found. This species has been rare in past transects (five observed in 10 transects from 2005-2013; Chu and Tunnicliffe 2015); they were abundant in summer (n=68) and fall 2016 (n=167). The white sea cucumber, *Pentamera calcigera*, was also abundant (n=63) in the fall 2016 transect, but had never been observed in past transects. This species was common in low-oxygen (0.12-0.2 mL/L) and was often near large burrows.

Along-bottom oxygen, measured from 2016 ROV transects, were also notably different between 2016 and 2013 (Figure 38-2); both bottom anoxia and hypoxia (O_2 < 1.4 mL L^{-1}) extended shallower in 2016 in all seasons compared to 2013. The shoaling anoxia was most evident between fall transects, where anoxia reached approximately 40 m shallower in 2016 than 2013. The 2016 profiles, particularly in spring and fall, had shallow and sharp boundaries between hypoxia and normoxia, while 2013 transects showed more gradual increases in oxygen with depth. The maximum depth of occurrence for slender sole (Figure 38-2, dashed lines) along the transects was also shallower in each season compared to 2013. Again, the change from 2013 to 2016 was most evident in the fall transects, where the first slender sole was not seen until 95 m in 2016 versus 155 m in 2013.

Mean dissolved oxygen at the VENUS node steadily decreased (Figure 38-3). Figure 38-3 also shows successive weak renewals in 2015 and 2016, where the maximum oxygen levels at the node failed to reach 3 mL L^{-1} for the first time since the time series began. Linear regressions show that the slope of the oxygen decrease has steepened since 2014, as Chu and Tunnicliffe (2015) report a -0.05 slope while we report a -0.07 slope after including oxygen data after March 2014.

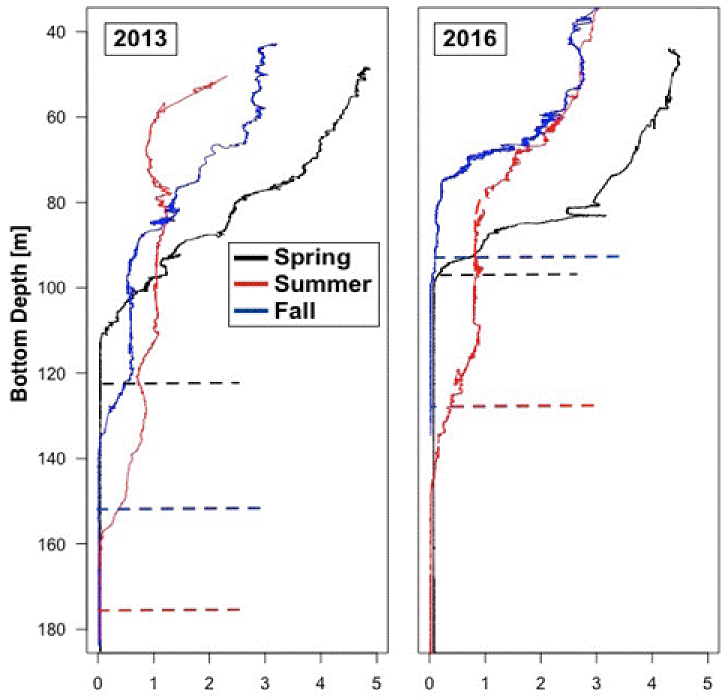

Figure 38-2. Seasonal along-bottom oxygen profiles show significant habitat compression between 2013 and 2016. Dashed horizontal lines show the maximum depth of slender sole (Lyopsetta exilis) occurrence along the transect which indicates the limit of oxygenated megafaunal habitat. Anoxia extended shallower in all seasons in 2016 versus 2013. The first slender sole occurrence was also shallower in every season in 2016, with a maximum difference between years of 60 m in fall transects.

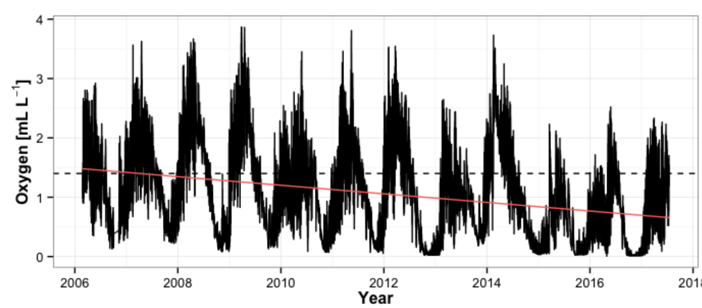

*Figure 38-3. One-hour interval VENUS dissolved oxygen data at 96 m in Saanich Inlet from April 2006 to April 2017. Oxygen is replenished annually by a fall deep-water influx over the sill, and spring mid-depth intrusions; it is depleted over the course of the year by respiration. Weak renewals in several years after 2010 led to an increase in the amount of time that oxygen levels are below the general hypoxia threshold (1.4 mL L^{-1}; dashed line). Oxygen is steadily decreasing in the long-term (linear regression, O_2=1.48-0.07*year, $p < 0.001$; solid red line).*

38.4. Factors influencing trends

The absence of spot prawn in fall 2016 was likely linked to the increased duration and spatial extent of the hypoxic waters in Saanich Inlet. The high abundance of striped nudibranch in normoxia suggests that they may have replaced the spot prawns. The sudden appearance of white sea cucumbers in fall 2016 is also a notable anomaly with no precedent in the last 10 years. Their distribution in severe hypoxia implies that the extended hypoxia due to the 2015-2016 weak oxygen renewal may have caused their occurrence, but little is known about this species and this claim requires further investigation. The maximum depth of occurrence of slender sole along the 2016 transects suggest that the shoaling hypoxia had influenced the deep-water extent of megafaunal habitat. The narrow range of oxygen occurrence values for spot prawn in spring 2016 also shows habitat compression occurring early in the year; similar compression in spot prawn oxygen occurrence was not seen until the summer of 2013 (Figure 38-1).

The difference in bottom oxygen profiles between 2016 and 2013 was due in large part to weak deep-water oxygen replenishments in 2015-2016. From 2006-2014, the declining oxygen trend at the VENUS node was driven by a 2010 El Niño event that caused the annual deep-water oxygen renewal over the Saanich Inlet sill to be particularly weak (Chu and Tunnicliffe 2015). The successive weak oxygen renewals in 2015-2016 (Figure 38-3) may have also been caused by the coincident El Niño event; this event may have also exacerbated the warm Pacific temperature anomaly (Chandler et al. 2016) with the confluence of the two causing the anomalous animal distributions.

38.5. Implications of those trends

The long-term trend of deoxygenation in Saanich Inlet follows the general trend of deoxygenation in the Northeast Pacific (Ito et al. 2017). As warming water leads to decreased oxygen solubility and increased stratification, ventilation decreases. This leads to expanding low-oxygen zones and shoaling hypoxia; habitat compression is a main consequence of this trend (Stramma et al. 2008). However, in a seasonally hypoxic system such as Saanich Inlet, the dynamism in dissolved oxygen also plays a large role in determining community persistence (Chu and Tunnicliffe 2015). Thus, the change in oxygen variability due to successive weak renewals in 2015-2016 may have acted in concert with deoxygenation to create the observed community change, as decreases in environmental variability are a known precursor to ecological change (Dakos et al. 2012).

While both slender sole and squat lobster only showed minor changes in occurrence along the oxygen gradient in 2016, it is unknown whether the increased temporal extent of hypoxia, coupled with the changes in community structure, will have some effect going forward. The disappearance of spot prawn in fall 2016 was a major anomaly notable not only because spot prawn are a commercially important species, but because it may, along with the increase in striped nudibranchs and white sea cucumbers, represent the first glimpse of a phase-shift in the Saanich Inlet macrobenthos due to changes in oxygen. These anomalies display the utility of long-term ecological time-series in understanding the unpredictable results of environmental changes on community structure and the importance of *in situ* measurements of animal oxygen occurrence for determining community responses to deoxygenation. Whether the Saanich Inlet macrofauna return to baseline levels in 2017 after the renewal event remains an intriguing question. Spot prawn have been seen in the inlet in 2017 (Frank Whitney, IOS/DFO, pers. comm.), so these first anomalies may be an insight into the future community structure should oxygen and temperature anomalies like those in 2016 become more frequent in the future.

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39. STRAIT OF GEORGIA JUVENILE HERRING SURVEY

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39.1. Highlights

- An index of the relative biomass of age-0 herring in the SoG was lower and stable during 2013-2016, compared to the peaks within the time series.
- Age-0 herring were heavier for a given length in 2016 than herring prior to 2007.
- The age-0 herring index may be a leading indicator of the number of recruits joining the population 2.5 years later and the amount of prey available to predators in the SoG.

39.2. Description of indices

The Strait of Georgia (SoG) juvenile herring and nearshore pelagic ecosystem survey, supported in part by the Pacific Salmon Foundation, is a long-term monitoring program that samples the nearshore pelagic fish community, the zooplankton community, as well as the physical water column properties (e.g. temperature, salinity, oxygen). One goal of the survey is to provide an index of the relative biomass (abundance) of age-0 herring and relate it to the abundance of age-3 herring in the stock assessment model. This index may also represent trends in potential prey availability to Coho and Chinook Salmon and other predators. The methods of calculating an index of age-0 herring from the survey data collected to date are described in Boldt et al. (2015). There are multiple indices calculated in the report, but since temporal trends are similar among indices, only one is presented here.

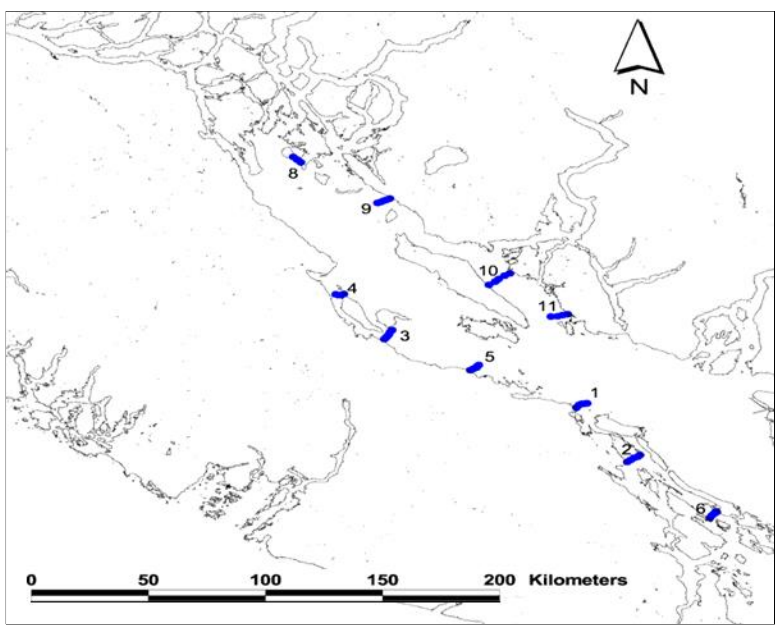

Figure 39-1. Purse seine set locations along the 10 core transects of the Strait of Georgia juvenile herring survey.

There are ten core transects, each with 3 to 5 core stations, distributed at approximately equal intervals around the perimeter of the SoG that have been consistently sampled during the autumn since 1992 (except 1995; Thompson et al. 2013; see Thompson et al. 2003 for detailed survey design and methods; Figure 39-1). Sampling was conducted after dusk when herring were near the surface and, generally, one transect was sampled per night over the course of a 4-7 hour period. The stations were sampled with "blind" (undirected) purse seine sets (sets were made at predetermined stations). Catch weights were estimated and all fish (or a subsample of fish) were retained for sampling in the laboratory, with the exception of large predator species (e.g. adult salmon and flatfish), which were individually measured in the field. In the laboratory, fish from each station were sorted to species and up to 100 individual age-0 herring were weighed and measured. Herring were measured to standard length (nearest millimeter) and were between 54 and 125 mm long in all years sampled. The age-0 herring index was calculated using Thompson's (1992) two-stage (transect, station) method and variance estimator to calculate the mean (and associated variance) of juvenile herring survey catch weight per unit effort (CPUE; for details see: Boldt et al. 2015). In addition, herring condition was calculated as residuals from a log-transformed length-weight regression.

39.3. Status and trends

Estimates of age-0 catch weight CPUE (the index) varied annually, with no overall trend during 1992-2016 (Figure 39-2). The age-0 herring index tended to peak every two or three years, with the peaks occurring in even years during 2004-2012. The index was relatively low and stable during 2013-2016, compared to the peaks within the time series. High estimates of variability are associated with peak estimates; the survey CV is 0.47. Age-0 herring condition increased since 1997, with positive residuals since ~2005 (Figure 39-3).

39.4. Factors causing trends

Factors that can potentially affect herring abundance or condition include zooplankton prey availability, predators (e.g. juvenile Coho and Chinook Salmon), competitors (juvenile Sockeye, Pink and Chum Salmon), herring spawn biomass, temperatures, and the date when most herring spawn relative to the spring bloom date. The timing or match-mismatch between herring and their prey appears to be important in determining abundance of age-0 herring in the fall (Schweigert et al. 2013). 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).

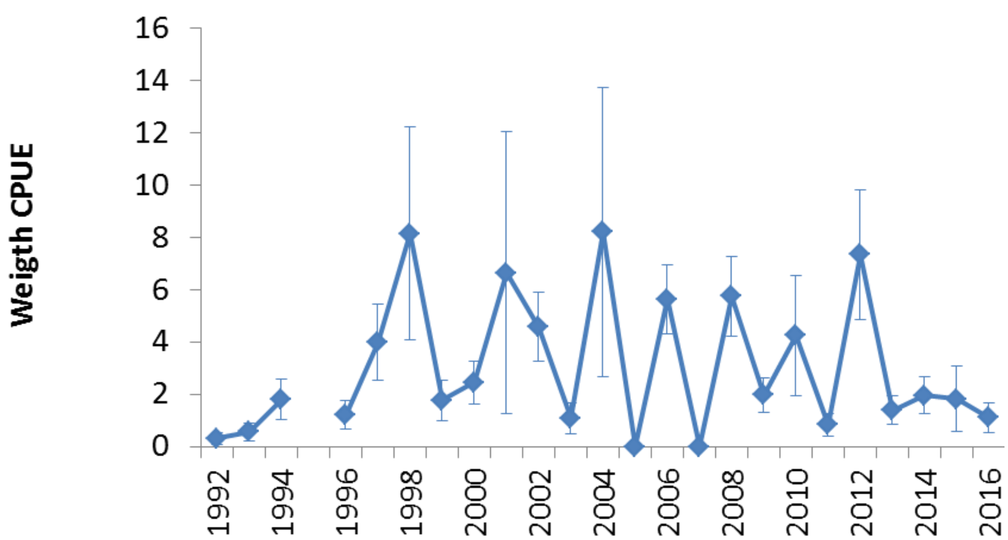

Figure 39-2. Mean catch weight per-unit-effort (CPUE) of age-0 herring caught in the Strait of Georgia juvenile herring survey at core transects and stations during 1992-2016 (no survey in 1995; Boldt et al. 2015). Standard error bars are shown.

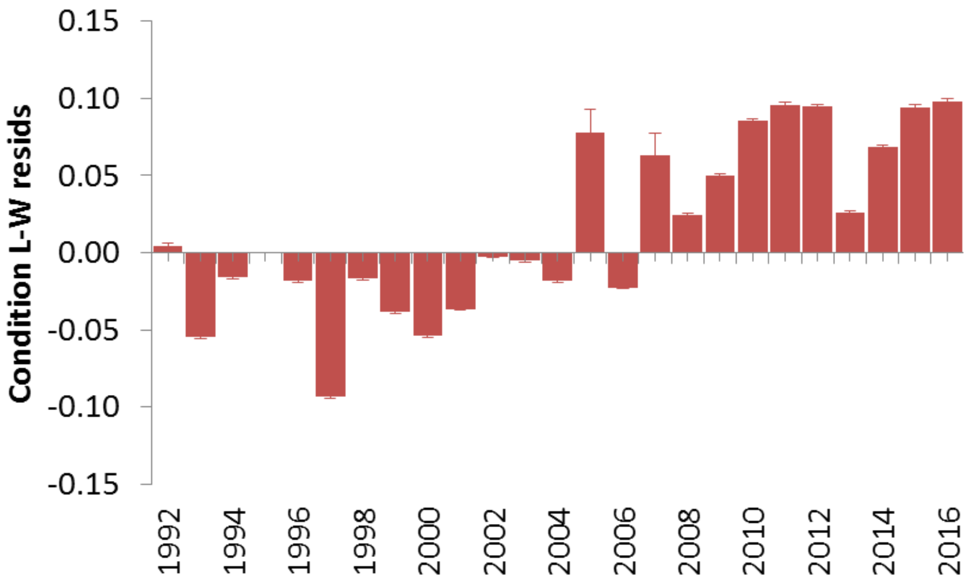

Figure 39-3. Mean age-0 herring condition (residuals from a log-transformed length-weight regression) from the Strait of Georgia juvenile herring survey, 1992-2016 (no survey in 1995; Boldt et al. 2015). Standard error bars are shown.

39.5. Implications of trends

Boldt et al. (2015) and previous analyses (Schweigert et al. 2009) showed that age-0 herring survey indices are correlated with the abundance of age-3 recruits (2.5 years later) as estimated by the age-structured stock assessment model (J. Cleary, DFO, personal communication). This supports the hypothesis that age-0 herring indices may be indicative of the relative amount of herring in the SoG and the number of recruits joining the population 2.5 years later. Pacific Herring are prey for piscivorous fish, marine mammals, and seabirds and are important commercial species in British Columbia's coastal waters. Changes in herring abundance may affect availability to commercial fisheries as well as the survival of predators, such as Coho and Chinook Salmon. Boldt et al. (2015) state that increased age-0 herring condition indicates that "fish are heavier for a given length and 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 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.

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40. STRAIT OF GEORGIA JUVENILE SALMON

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40.1. Highlights

- The survey timing in both summer and fall was late in 2016 due to the loss of *W.E. Ricker*. The shift in timing, especially fall, makes comparison of catch between years difficult.
- The catch of juvenile Coho Salmon in October 2016 was below average but would represent the minimum number of juveniles. In combination with high catch rates in July and large average size in both surveys, we expect that returns in 2017 will be better than the average over the past 15 years.
- There was a large increase in the catch of Northern Anchovy within the Strait of Georgia. Laval anchovy were observed in the diets of Coho and Chinook Salmon in the summer survey. In addition, large catches of multiple age classes were encountered in the southern Strait of Georgia in both summer and fall surveys. The occurrence of these fish in very large numbers in the SoG is unique in the 18 year history of the survey.

40.2. Introduction

Juvenile salmon generally enter the Strait of Georgia (SoG) from April to June and many may remain and rear in the strait until the fall. The juvenile trawl surveys are designed to sample juvenile salmon throughout the Strait of Georgia during this first ocean summer and fall. In 2016 juvenile salmon were sampled during two trawl surveys (July 5-14 and October 17-26). The Canadian Coast Guard research vessel *W.E. Ricker* that is generally used for these surveys was scheduled to do the work. However, due to mechanical issues this vessel was not available and charters had to be established with commercial trawl vessels. In July the vessel acquired for the survey was the 35 m FV *Nordic Pearl*. In October the vessel acquired for the survey was the 40 m FV *Frosti*. The requirement of charters resulted in the summer survey being delayed by two weeks and the fall survey delayed by about a month due to contracting processes. Both these surveys fished standard track lines that have been fished since 1998 following the protocol in Beamish et al. (2010). Additional sampling that typically occurs in mainland inlets and Gulf Islands was limited due to a reduction in the number of fishing days available due to charter operations.

Beamish et al. (2010) demonstrated that there was a good relationship between the catch rate of juvenile Coho Salmon in the September survey and returns of adults the following year. This work indicated that brood year strength for Coho Salmon from the Strait of Georgia was determined during their first summer in the ocean and within the Strait of Georgia region. In this report we make the assumption that early marine survival is a major component of determining overall marine survival for all salmon species in the Strait of Georgia. We examine the catch rates of juvenile salmon in 2016 in comparison to catch levels from 1998-2015 and the condition of the juveniles in the Strait of Georgia. Due to the delayed timing of the surveys, specifically the fall survey, caution must be taken in comparing catch rates with previous years. However, by combining catch rates and fish condition, we comment on the potential relative strength of

Coho Salmon in 2017, provide information on the condition of Chinook Salmon and provide information on the presence of species not typically observed in these inside waters.

40.3. Coho Salmon

Coho Salmon generally spend one winter in the ocean, therefore, most juveniles that entered the ocean in 2016 will return to spawn in 2017. Chittendon et al. (2009) demonstrated that Coho Salmon from the Strait of Georgia remain and rear in the strait until late fall. Beamish et al. (2010) used the abundance and survival of Coho Salmon up to the annual September surveys to demonstrate that brood year strength for Coho Salmon was determined in the Strait of Georgia during the first marine summer.

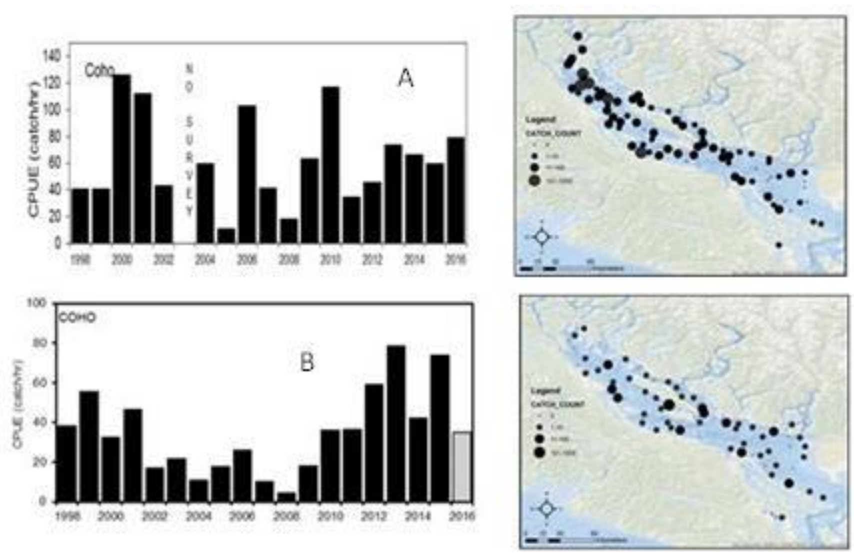

Figure 40-1. The CPUE (left) and distribution and relative catch (right) of Coho Salmon in (A) June/July and (B) September/October trawl surveys in the Strait of Georgia 1998-2016. The October 2016 is shaded grey due to the delayed timing of survey.

The catch-per-unit-effort (CPUE) of juvenile Coho salmon in July was above average, however, in the delayed fall survey the CPUE was average (Figure 40-1). In the fall survey very few “jacks” were observed. However, in the fall of 2016 hatcheries on the east coast of Vancouver Island observed 17-20% of returns represented by this younger age group. Therefore, it is probable that the survey occurred after the majority of the “jacks” returned to their natal streams. In addition, previous acoustic tagging work (Chittenden et al. 2009) indicated migration out of the SoG in October/November. We cannot determine if the decline in catch in October 2016 was due to the delayed survey timing or a change in distribution or survival of the juvenile Coho Salmon. However, based on the additional information from hatchery returns, previous tagging studies and previous late fall surveys that indicated decline in abundance between September and November, we expect that the observations in October would be a minimum number for the fall survey. In addition, the CPUE of Coho Salmon in July was above average (Figure 40-1) and the largest catch observed since 2010. The average size of the Coho in both surveys was above average and similar to observations in 2015. Therefore assuming average to above average catch levels and the large average size of the juveniles in both surveys in comparison to other years the conditions would suggest a good return of Coho Salmon in 2017.

40.4. Chinook Salmon

Chinook Salmon early life history is complex with variation in life history type (ocean and stream-type, hatchery and wild), age at ocean entry and timing of ocean entry. Beamish et al.

(2011) demonstrated that the catch of Chinook Salmon in the June-July surveys are a mixture of ocean and stream type fish. Neville et al. (2015) demonstrated that a large proportion of these juvenile fish present in the June-July survey do not survive to September. The CPUE of Chinook in the June-July survey was higher in 2016 than had been observed for the past few years (Figure 40-2A). The juveniles were captured throughout the SoG with the largest numbers observed in Malaspina Strait. The average size of the fish was similar to 2014 and 2015 and fish were on average some of the largest we have observed in the 18 year time series. The proportion of empty stomachs was average however there was an increased occurrence of larval fish (anchovy) in the diet. Larval anchovy was also observed in the diet of Chinook Salmon in 2015.

The stock composition of Chinook Salmon shifts in the fall with the majority of the Chinook Salmon from the South Thompson region of the Fraser River (Beamish et al. 2011). These fish generally enter the ocean in late July and August and, similar to Harrison River Sockeye Salmon, have had improved production over recent years. In October 2016 the CPUE of Chinook Salmon was below average and one of the lowest in the time series (Figure 40-2B). The average size of these fish was above average. South Thompson stocks represented 68% of the catch on the standard track line which was similar to other years. The number of empty stomachs in the samples examined to date has been low and the fish appeared to be in good condition. Due to the late timing of this survey we cannot determine if the decline in CPUE represents decreased production for these fish in the SoG or if it is due to migration or movement of these fish out of the SoG or into deeper water and demonstrates the importance of consistent timing in the surveys between years.

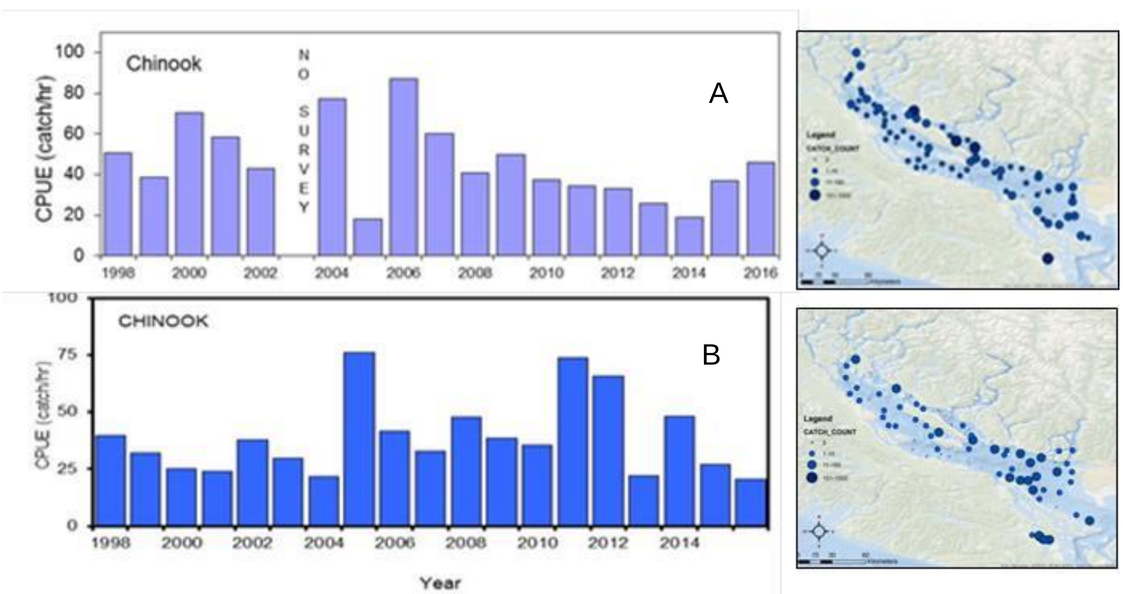

Figure 40-2. The CPUE of Chinook Salmon (left) and the distribution and relative catch (right) in the (A) June/July and (B) September/October survey of the Strait of Georgia 1998-2016.

40.5. Other species

In 2016 large numbers of Northern Anchovy were observed for a second year within the Strait of Georgia (Figure 40-3). This species has typically been observed in small numbers (total catch < 30) during both summer and fall surveys since 1998. However over the past two years, large catches (>20,000 pieces) have been captured. The length frequency of the catch suggests that at least two year classes were present within the SoG. In addition, during the summer survey, juvenile Coho and Chinook are observed feeding on larval anchovy. The occurrence of this species in large numbers in the SoG may be important to juvenile salmon as it appears to be providing a teleost food source during the critical summer feeding period at a size range different than juvenile or young of year herring.

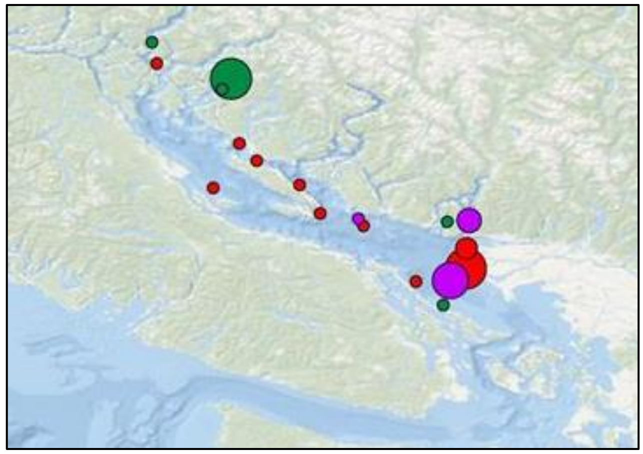

Figure 40-3. Catch of Northern Anchovy in October 2015 (green), July 2016 (red) and October 2016 (pink). The size of the mark indicates relative catch level in 4 categories (<100; 101-5000; 5001-20,000; 20,001-40,000)

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41. TELEMETRY-BASED ESTIMATES OF EARLY MARINE SURVIVAL AND RESIDENCE TIME OF JUVENILE SALMON IN THE STRAIT OF GEORGIA AND QUEEN CHARLOTTE STRAIT, 2016

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41.1. Highlights

- Wild, age-1 Chilko Lake Sockeye smolts were tagged for the first time in 2016 by the University of British Columbia using new smaller, internally-implanted acoustic tags and additional marine receivers.
- Survival of age-1 smolts during downstream migration in 2016 was the highest in the Chilko Sockeye time series (56% vs 22-48% for age-2 smolts from 2010-2014 & 2016).
- Daily survival rate (96%/day; 32% total survival in the Strait of Georgia (SoG)) of age-1 smolts in the SoG in 2016 was the lowest in the time series, and survival of age-2 fish was too low to estimate; therefore survival in the SoG was poor for both age classes relative to previous years.
- Survival of age-1 fish through the Discovery Islands was relatively high (78%), and therefore overall survival from the lake to central Johnstone Strait was 16%.
- Median travel time from Chilko Lake to central Johnstone Strait (~950 km) was 34 days. Smolts migrated through the Strait of Georgia in ~21 days at about 1.3 body lengths per second (BL/sec), and faster through the Discovery Islands region.

41.2. Summary

In 2016, we used a large-scale acoustic telemetry array to track age-1 and age-2 Chilko Lake Sockeye Salmon smolts during the initial 1000 km of their freshwater and marine migration as part of the MSc research of Christine Stevenson and postdoctoral research of Nathan Furey.

Smolts were collected at the DFO-managed enumeration weir at the outlet of Chilko Lake and were surgically implanted with uniquely coded acoustic transmitters ("tags"; Figure 41-1).

Figure 41-1. Age-1 (top picture) and age-2 (bottom picture) Chilko Lake Sockeye smolts. Age-1 smolts (n=200; 85-100 mm fork length [FL]) were tagged with new, smaller transmitters (model V4; 180 kHz). Age-2 smolts (n=99; 117-143 mm FL) were tagged with model V7 transmitters (69 kHz). Photos taken by Christine Stevenson.

Fish were tracked with a network of acoustic sensors positioned in the river and throughout the greater Salish Sea area, including two new dual-frequency sub-arrays in the Discovery Islands and in Johnstone Strait which were field tested in 2015 (Figure 41-2), thus allowing us to estimate survival and travel times for wild, age-1 Sockeye smolts in the ocean for the first time since the time series began (see Section 41.3).

By reconstructing the movements of each individual recorded by the array, it was possible to estimate survival from Chilko Lake to the lower Fraser River, through the Strait of Georgia (SoG), the Discovery Islands (DI) and Johnstone Strait (JS) using the Cormack-Jolly-Seber model (CJS; Cormack 1964, Jolly 1965, Seber 1965). We also determined residence time (travel time) and travel rate in these areas.

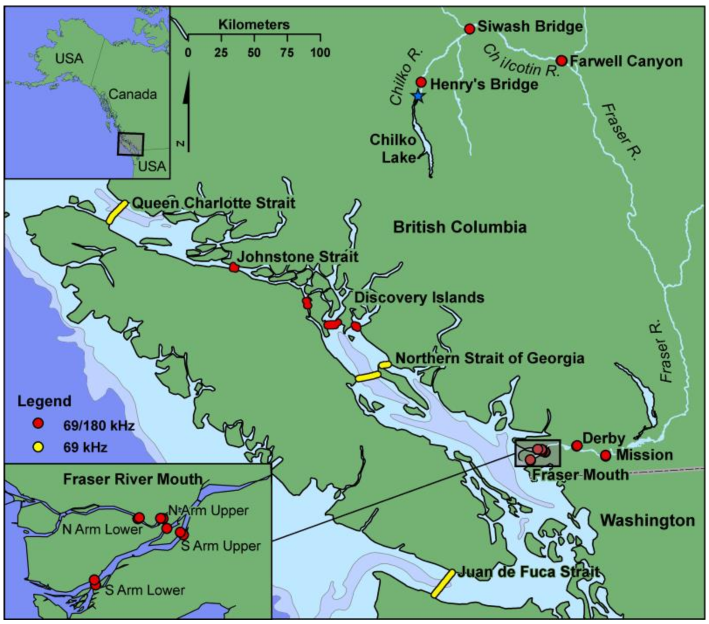

Figure 41-2. Map of the acoustic receiver array used to track juvenile salmon. Yellow lines and dots represent single frequency (69 kHz) receiver sub-arrays, while red dots and lines represent dual frequency (180 kHz) sub-arrays. Components of the array are variously managed by Kintama Research Services (Fraser River), the University of British Columbia (Chilko and Chilcotin rivers), the Pacific Salmon Foundation (Discovery Islands and Johnstone Strait), and the Ocean Tracking Network (OTN; Juan de Fuca, Northern Strait of Georgia, Queen Charlotte Strait). The blue star represents the release site of acoustic tagged smolts in 2016. Isobaths (200 and 500 meter) are coloured in pale blue.

41.3. Freshwater and Early Marine Survival

Survival of age-1 Sockeye smolts from Chilko Lake to the Fraser River mouth (654 km) in 2016 was 56% (Figure 41-3) Survival of the age-2 smolts was half that: 28%, largely due to high mortality in the tributaries (the Chilko and Chilcotin rivers).

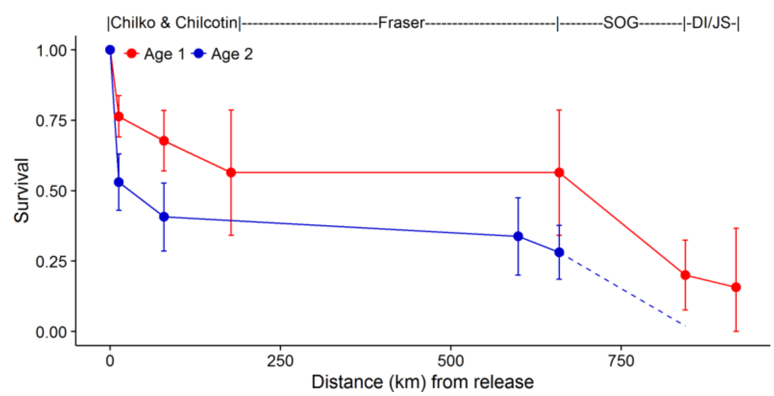

Figure 41-3. Cumulative survival of Chilko Lake Sockeye smolts in 2016. SOG=Strait of Georgia, DI/JS= Discovery Islands/Johnstone Strait.

Survival of age-1 smolts through the SoG (from the Fraser River mouth to the DI sub-array; about 200 km) was 32% (SE=13%), and subsequent survival to the JS sub-array (about 100 km) was 78.3% (SE=58%). Oddly, of the estimated 28 age-2 fish that survived to the Fraser River mouth (of 99 released), only two fish were subsequently detected on the northern SoG, JS, and Queen Charlotte Strait (QCS) sub-arrays and only one was detected at DI. Early marine survival of age-2 smolts was therefore not estimable because of the limited sample size.

41.4. Travel Times and Rates

Travel time from Chilko Lake to the Fraser River mouth was the same for both age classes, only 4.9 days (median), and travel rate was thus very rapid (133 km/day). The median travel time (or residence time) for age-1 smolts in the SoG was 20.5 days, and travel rate was 10.3 km/d at 1.25 BL/sec. Too few age-2 fish were detected on sequential sub-arrays to calculate travel times and rates beyond the Fraser mouth, except for the JS-QCS segment.

Table 41-1. Median travel time for Chilko Lake Sockeye (days). SoG= Strait of Georgia, QCS=Queen Charlotte Strait sub-array, NA=not applicable (because 180 kHz tags could not be detected at QCS), ID=insufficient data, [a]: n=2, [b]: Fraser to NSoG, [c]: NSoG to QCS.

	Release to Fraser River mouth	**Fraser to Discovery Islands (SoG)**	**Discovery Islands to Johnstone Str**	**Johnstone Str to QCS**
Age-1 (2016)	4.9	20.5	7.0	NA
Age-2 (2016)	4.9	ID	ID	4.1[a]
Age-2 (2010-2014)	5.2-8.4	11.9-18.6[b]	9.1-15.5[c]	

Table 41-2. Median travel rate for Chilko Lake Sockeye (body lengths/sec (km/day)). SoG= Strait of Georgia, QCS=Queen Charlotte Strait sub-array, NA=not applicable (because 180 kHz tags could not be detected at QCS), ID=insufficient data, [a]: n=2, [b]: Fraser to NSoG, [c]: NSoG to QCS.

	Release to Fraser River mouth	**Fraser to Discovery Islands (SoG)**	**Discovery Islands to Johnstone Str**	**Johnstone Str to QCS**
Age-1 (2016)	17.0 (133.2)	1.3 (10.3)	1.8 (15.0)	NA
Age-2 (2016)	12.3 (133.9)	ID	ID	2.4 (26.9)[a]
Age-2 (2010-2014)	7.1-11.8 (78.3-126.9)	0.7-1.1[b] (7.6-11.9)	1.4-2.3[c] (15.5-26.5)	

41.5. Description of the time series

We began estimating early marine survival of juvenile salmon upon deployment of the Pacific Ocean Shelf Tracking (POST) array in 2004. Large, hatchery-reared Cultus Lake Sockeye were tagged (with 69 kHz transmitters) and tracked from 2004-2007 (Welch et al. 2009). In 2010, we began tracking wild, age-2 Sockeye migrating from Chilko Lake (Clark et al. 2016). The Chilko project has been on-going since that time; however, in 2015 the DFO fence could not be deployed at Chilko Lake due to high water at the outlet of the lake. (The weir was critical for capturing sufficient age-2 smolts for tagging because age-2 smolts make up only ~5% of the millions of smolts migrating from the lake annually).

In 2015, two dual-frequency sub-arrays with a new sub-array design were deployed in the Discovery Islands and Johnstone Strait which are capable of detecting the new, smaller transmitters (Figure 41-1). In 2016, tagging resumed at Chilko Lake and we were able to successfully track wild, age-1 Sockeye into the ocean for the first time and compare their movements and survival with that of larger age-2 Sockeye smolts used in the past.

These data can be used to determine when and where mortality occurs for juvenile salmon during the early marine life history, and could potentially be incorporated into stock productivity and forecast models under changing climate scenarios to better understand how climate affects survival in the early life history period.

41.6. Status and trends

The Chilko Lake Sockeye survival time series began in 2010 with age-2 smolts (see details in Clark et al. 2016). Survival of age-2 smolts to the mouth of the Fraser River varied between 22-48% from 2010-2014 (Figure 41-4). In 2016, freshwater survival was 28% for age-2 fish, and 56% for age-1 fish- the highest in the time series, but the first data point for age-1 smolts.

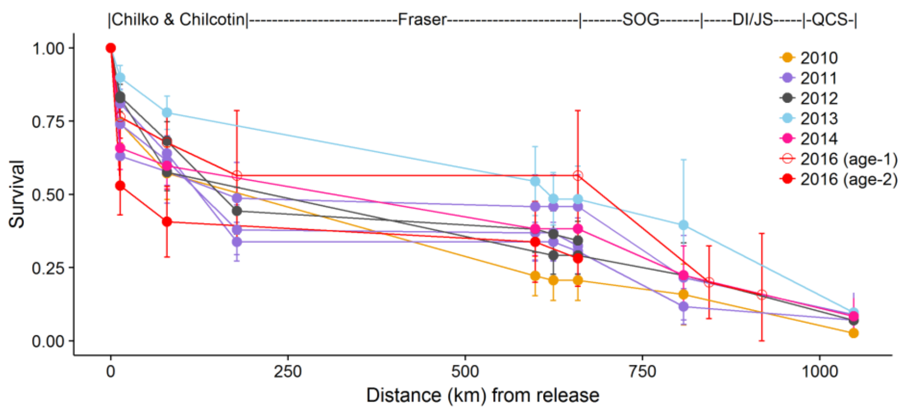

Figure 41-4. Cumulative survival of Chilko Lake Sockeye smolts 2010-2016 (excluding 2015). Only age-2 smolts were tagged from 2010-2014. SoG=Strait of Georgia, DI= Discovery Islands, JS=Johnstone Strait, QCS=Queen Charlotte Strait.

Although age-1 fish had relatively high fresh water survival, survival in the SoG was relatively low when compared age-2 smolts and hatchery-reared Cultus Lake smolts in previous years: survival of age-2 smolts from 2010-2014 ranged between 47-83% from the Fraser River to the NSoG sub-array, and hatchery-reared Cultus Lake Sockeye survival ranged between 38-92% (2004-2007). Survival of age-1 Chilko smolts from the Fraser River to the DI sub-array was 32% (50 km north of NSoG; recall that age-1 smolts could not be detected on the NSoG sub-array because their tags transmit on a frequency not monitored by the NSoG sub-array).

To directly compare survival when migration segments vary, we estimated daily survival rates. The mean daily survival rate in the SoG was 96.6% d^{-1} for Cultus Sockeye, and 97.5% d^{-1} for age-2 Chilko Sockeye, whereas survival rate of age-1 smolts in 2016 was 96.0% d^{-1} (Figure 1-5). Although the difference appears slight, after several weeks of marine migration the initial freshwater survival advantage was lost in 2016, and age-1 fish were on the same survival trajectory as the age-2 fish up to QCS (Figure 1-4).

Daily survival rates can also be used to compare survival in the southern and northern major migratory areas (i.e. SoG and the area between the Discovery Islands and up to northern Queen Charlotte Strait; see Figure 41-2). In our 11 year data set (including Seymour River steelhead in 2015), daily survival rate was higher in the SoG relative to the area to the north in all years except for 2006.

Migration rate for age-1 smolts was 1.3 BL/sec, and ranged between 0.7-1.1 BL/sec for age-2 smolts (Table 1-2), indicating that Chilko Sockeye smolts are rapidly migrating north upon ocean entry, similar to the earlier finding for Cultus Lake Sockeye.

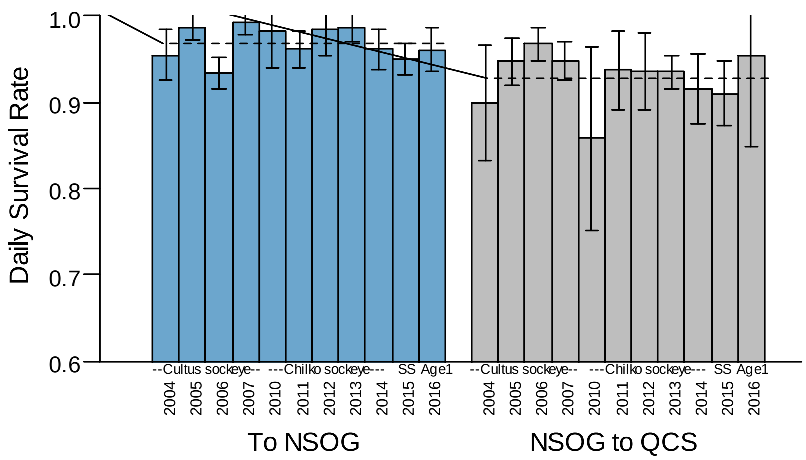

Figure 41-5. Daily survival rates for Cultus Lake Sockeye, Chilko Lake Sockeye, and Seymour River steelhead smolts (SS). The dashed line represents the mean daily survival rate for all years. Age1=Chilko Sockeye, NSOG=northern Strait of Georgia, QCS=Queen Charlotte Strait. Error bars are 95% confidence intervals. Note that Age-1 Sockeye survival in 2016 is from the Fraser River to DI and DI to JS.

41.7. Factors influencing trends

We observed three major trends: high mortality in the small freshwater tributaries to the Fraser (and low mortality in the Fraser River mainstem), higher mortality in the northern marine area relative to the SoG, and rapid migration rates (Clark et al. 2016). In the tributaries, mortality occurs very rapidly and is partially due to bull trout predation (Furey et al. 2015) and vulnerability related to downstream migration timing (Furey et al. 2016). In the marine environment, a number of top down and bottom up contributing factors are currently being investigated by the Salish Sea Marine Survival Project (marinesurvival.org) such as warming ocean temperatures, zooplankton distribution and abundance, increases in marine mammal populations, diseases from open net-pen salmon farms, and harmful algal blooms. Rapid fresh water migration rates were due to river flow, and tidal currents likely increased ocean migration rate north of the SoG.

41.8. Implications of those trends

Cumulative survival of Chilko Lake Sockeye from release to northern Vancouver Island ranged between 4-14% for age-2 smolts from 2010-2014 and was 16% (SE=10.6) for age-1 smolts (to mid-Johnstone Strait) in 2016; therefore preliminary results indicate that survival of the two age classes is similar. Smolt-to-adult return rates have been ~5% in recent years (see Grant et al. 2017), so although much of the mortality occurs in the freshwater and early marine phase only 1/2-2/3 of tagged fish migrating out of the array area will survive to return as adults. Median travel time through the SoG (~20 days for age-1 Sockeye) is consistent with earlier estimates (Healey 1980; Peterman et al. 1994) but is significantly shorter than the average residence time recently estimated from trawl data by Preikshot et al (2012, 43-54 days). Therefore Chilko Sockeye appear to actively migrate north through the SoG upon ocean entry

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42. FRASER RIVER SOCKEYE: ABUNDANCE AND PRODUCTIVITY TRENDS

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42.1. Highlights

- Fraser Sockeye Salmon (*Oncorhynchus nerka*) total returns have varied over the time series. In the past decade overall returns improved, particularly on the current large cycle year (2010 and 2014), compared to previous decades. However, in the most recent years returns again decreased, with 2016 returns (853,000) being the lowest on the 100+ year record.
- Chilko is the only Fraser Sockeye Salmon stock where total survival can consistently be partitioned into freshwater and marine survival. This stock also contributes significant proportions to the total returns in most years. In the past decade, this stock has generally exhibited average to above average freshwater survival; while in the previous decade (1990s) freshwater survival had been below average. Marine survival on the other hand did not improve to the same extent during this same period, and remained predominantly below (though close to) average in the last decade. However, in the 2015 and 2016 return years, marine survival was again poor for Chilko, which resulted in poor returns for this stock in these years.
- In recent years (2010-2016 returns years), productivity has been particularly variable across the 19 Fraser Sockeye stocks with stock-recruitment data. Both marine and freshwater factors contribute to the differences in productivity, and the impact of these factors on returns varies by stock and year.
- Given the inconsistent productivity responses across Fraser Sockeye stocks in recent years, productivity experienced by stocks returning in 2017 is uncertain. Chilko Sockeye Salmon, which are expected to contribute a large proportion to the total 2017 returns, have recently experienced poor marine survival that coincided with warmer marine water temperatures.
- Both freshwater and marine water temperatures have been generally warmer than average since 2013. As a result, Fraser Sockeye Salmon stocks returning in the upcoming year (2017) will have experienced warm water temperatures throughout their life-history from the egg and juvenile stages in freshwater, to post-smolt stages in the marine ecosystem.

42.2. Description of the time series

Fraser River Sockeye Salmon returns, productivity (recruits-per-spawner), and Chilko Sockeye Salmon freshwater and marine survival time series are presented in the current report. Methods associated with these data are described in Grant et al. (2011). Details on the annual recruitment data quality are presented in Ogden et al. (2015). Fraser Sockeye Salmon typically return to freshwater to spawn as four year old fish, after generally spending their first two winters in freshwater, and their last two winters in the ocean. Therefore, total Fraser Sockeye Salmon returns and survival are influenced by both the freshwater and marine ecosystem.

Within these broad freshwater and marine ecosystems, Fraser Sockeye Salmon use different habitats throughout their life. Specifically, after their second winter in freshwater, Fraser Sockeye smolts leave their rearing lakes and migrate down the Fraser River to the Strait of Georgia. Fraser Sockeye migrate north through the Strait of Georgia in approximately 40 days (Preikshot et al. 2012; Neville et al. 2016) and exit this system via the Johnstone Strait. Fraser Sockeye juveniles continue their northward migration along the continental shelf, and move into the Northeast Pacific Ocean in their first winter at sea (Tucker et al. 2009). They subsequently spend one more winter in the marine environment before they return to their natal freshwater spawning grounds as adults.

42.3. Status and trends

Total Fraser Sockeye adult returns have historically varied (Figure 42-1A) due to the four-year pattern of abundances (cyclic dominance) exhibited by some of the larger stocks, and variability in annual productivity (returns-per-spawner) (Figure 42-1B) and spawning escapement. After reaching a peak in the early 1990s, returns decreased to a record low in 2009 due to declines in stock productivities. Although from 2010 to 2014, total productivity, and consequently returns increased, 2015 and 2016 productivity and returns were again poor for the total aggregate. The total Fraser Sockeye return and productivity trends largely represent stocks that comprise the greatest proportion of total Fraser Sockeye abundance, namely Summer Run stocks (based on return timing of adults to their spawning grounds) such as Chilko and Shuswap stocks (on dominant cycle years).

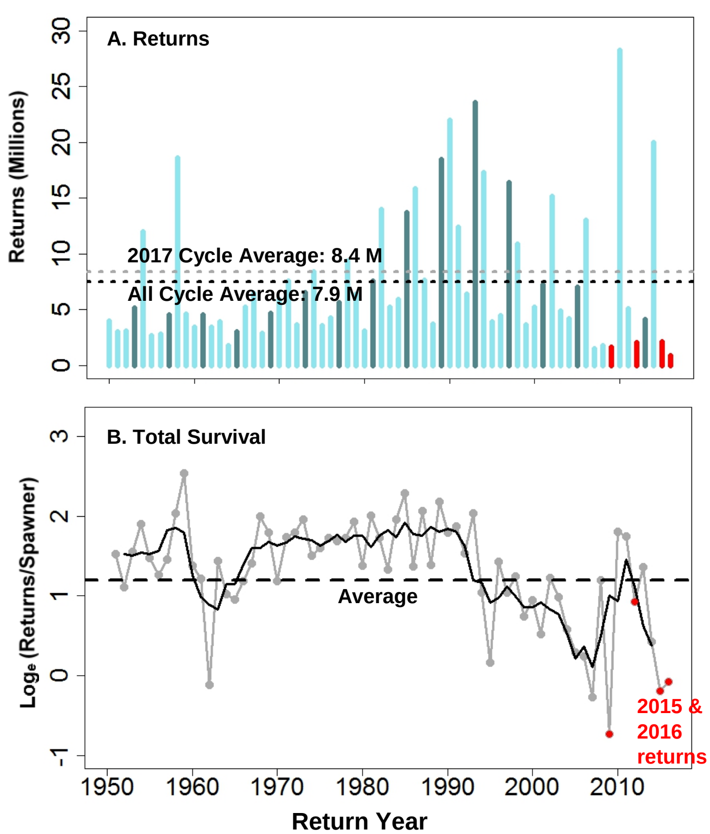

Figure 42-1. A) Total Fraser Sockeye annual returns (dark blue vertical bars for the 2017 cycle and light blue vertical bars for the three other cycles). Recent returns from 2012 to 2016 are preliminary, and 2016 is an in-season estimate only. B) Total Fraser Sockeye productivity (log_e (returns/total spawner)) is presented up to the 2016 return year. The grey dots and lines represent annual productivity estimates and the black line represents the smoothed four year running average. For both figures, the dashed line is the time series average. The first red vertical bar in A (or first red dot in B) represents the 2009 returns (low productivity across the majority of the stocks), and the following three red vertical bars in A (or red dots in B) represents the 2012, 2015 and 2016 returns (low productivity for the Fraser Sockeye aggregate).

42.4. Factors influencing trends

Chilko is the only Fraser Sockeye stock with a long and complete time series of smolt data (counted through an enumeration weir located at the outlet of Chilko Lake), which can be used with this stock's escapement and return data to partition total survival into freshwater and 'marine' components ('marine' survival includes their migration downstream from the counting weir to the Strait of Georgia, and their entire marine residence period) (Figure 42-2). Chilko is a key stock that contributes large proportions to the total Fraser Sockeye returns. Therefore, understanding which broad ecosystem influences total survival for this stock, explains a large proportion of the total returns. For Chilko Sockeye, freshwater survival has generally improved in recent years (Figure 42-2A). 'Marine' survival data for Chilko is similar to the aggregated Fraser Sockeye survival trend (Figure 42-2B and Figure 42-1B). Chilko exhibited 'marine' survival declines in the 1990's, which culminated in the lowest survival on record in the 2005 brood year (2009 return year). Although 'marine' survival has improved in recent years (with the exception of the last two year's 2011 and 2012 brood year, which were poor), it has remained generally below average.

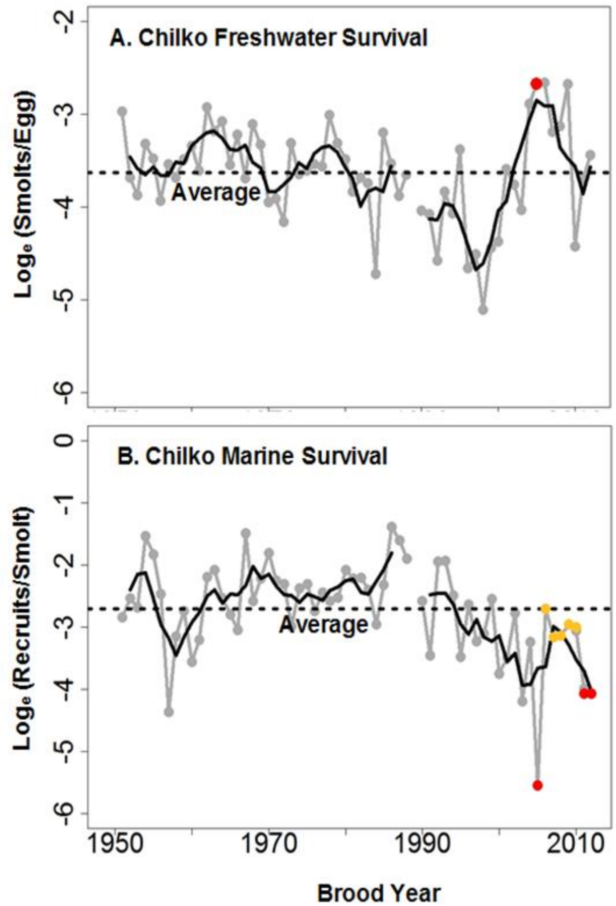

Figure 42-2. A) Chilko River Sockeye freshwater survival (log_e smolts-per-egg) and B) 'marine' (log_e recruits-per-smolt) annual survival. The filled grey circles and grey lines are annual values and the black line is the smoothed four-year running average survival. Freshwater survival has generally increased in the past decade, with the notable exception of 2010 (red filled circle in A), when poor survival was associated with density-dependent factors caused by the large escapements in this brood year. Marine survival has generally been below average for the past decade, and particularly low in the 2005 and last two brood years: 2011 and 2012 (two red filled circles in B). Note: Chilko 'marine' survival includes a freshwater period during their downstream migration as smolts from the outlet of Chilko Lake to the Strait of Georgia, and their entire marine residence period. The horizontal dashed line indicates average survival.

Across the individual Fraser Sockeye stocks, however, there has been considerable variability in productivity (recruits-per-spawner) (Figure 42-3). Although most stocks, such as Chilko and Stellako have exhibited declining trends in the 1990's, some stocks, such as Late Shuswap, have not exhibited any systematic trends, and one stock in particular (Harrison Sockeye) has increased in productivity during this period (Figure 42-3). The common feature amongst all stocks is that productivity for the 2005 brood year was below average, and in many cases was the lowest on record, and productivity has been more variable across recent years and across stocks (Figure 42-3). Some stocks such as Birkenhead and Weaver have experienced exceptionally poor survival in recent years, which coincide with a major landslide adjacent to their Lillooet rearing lake. Quesnel also experienced a mine breach (Mount Polley), which dumped mine tailings into the west arm of Quesnel Lake; the effect of this mine breach on this stock's productivity is currently unclear. Other stocks that rear in the Shuswap Lake (Scotch, Seymour and Late Shuswap), also appear to have experienced lagged density-dependent effects in recent years from the contribution of the large 2010 brood year escapement on high juvenile densities in this lake.

42.5. Implications of the observed trends

Understanding factors that contribute Fraser Sockeye Salmon return trends can increase the certainty associated with the pre-season return forecasts (DFO 2016a). These return forecasts are used pre-season to provide a preview of potential fishing opportunities to stakeholders and are used early in-season to manage fisheries until sufficient in-season test-fishery data are available. To capture inter-annual random (stochastic) uncertainty in the pre-season return forecasts, which are largely attributed to Fraser Sockeye productivity, return forecasts are presented as standardized cumulative probabilities (10%, 25%, 50%, 75%, and 90%), using Bayesian statistics, rather than as single deterministic point estimates (Grant et al. 2010). At the 25% probability level, for example, there is a one in four chance the actual return will fall at or below the specified return prediction, given the historical data. Currently, these probability distributions are wide (Grant et al. 2010).

To improve our understanding of Fraser Sockeye Salmon population dynamics, a supplement Canadian Science Advisory Secretariat paper is being prepared as part of the 2017 forecast process (DFO 2016b). This supplement provides additional information on the condition and abundance of various stocks from the 2013 brood year escapement through to 2016 jack returns. It currently provides supplemental information on the survival conditions Fraser Sockeye stocks experienced throughout their life-history, from their brood year as eggs in the gravel, up to the return year.

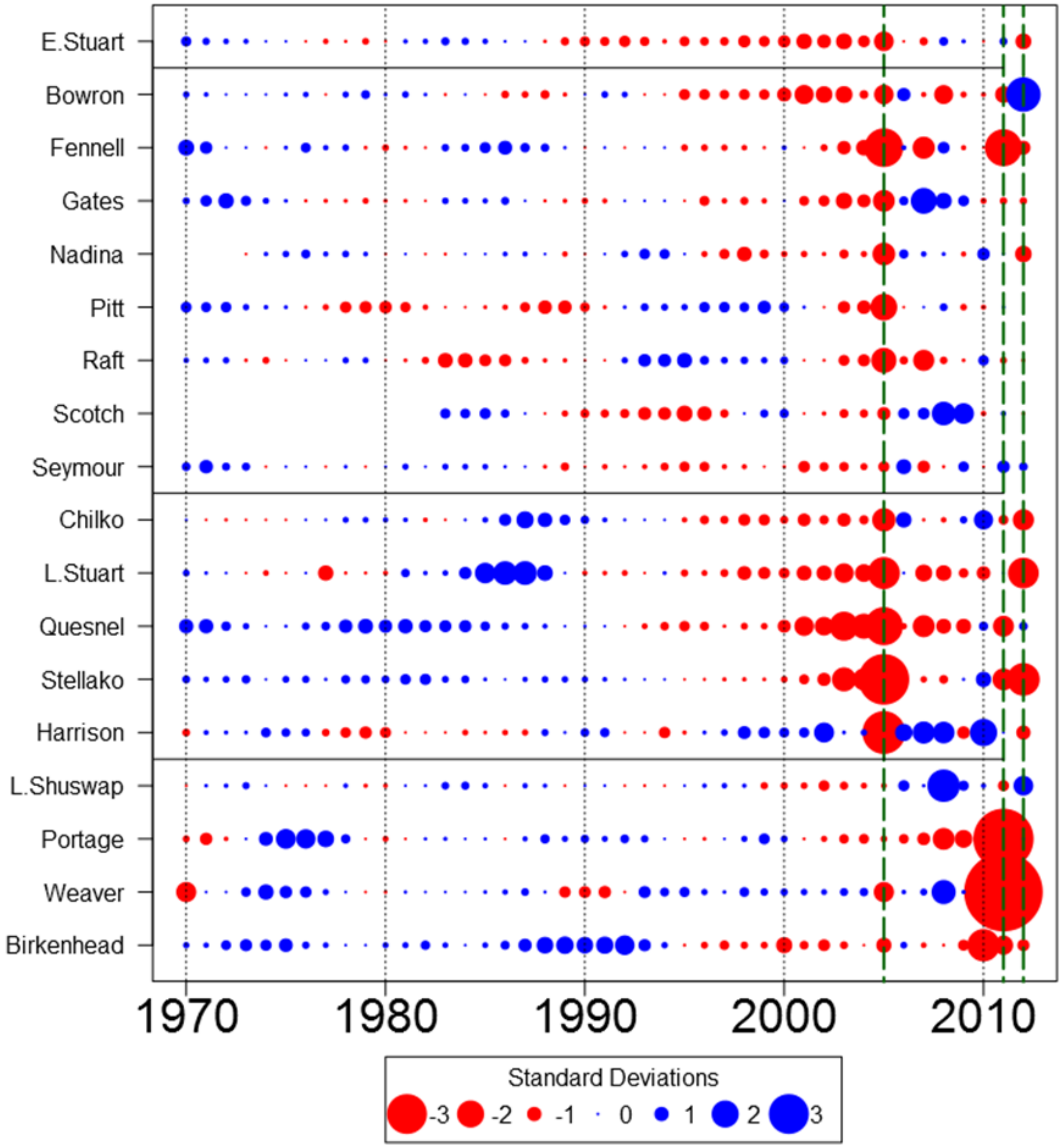

Figure 42-3. Fraser Sockeye productivity (standardized z-scores of Ricker model residuals for all stocks except Scotch, Seymour and Late Shuswap, which are Larkin residuals) up to the 2012 brood year (2016 return year). For the 2012 brood year (2016 return year), preliminary in-season estimates of returning four year old fish were not yet available and five year old returns will not be available until after the 2017 season. Both freshwater and marine factors contribute to the observed productivities. Red dots indicate below average productivity and blue dots indicate above average productivity. The smallest dots represent average annual productivity and the larger the diameter, the greater the deviation from average. The 2005, 2011 and 2012 brood years (2009, 2015 and 2016 return years) have been highlighted using a broken vertical green line.

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43. ARE CENTRAL COAST SOCKEYE AFFECTED BY GLACIAL RETREAT?

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43.1. Highlights

- Glacial ablation, dramatically evident in Landsat satellite images, has been extensive in coastal British Columbia over the past 4 decades.
- All mountain glaciers condense volatile organic pollutants such as DDT and PCBs. In the Alps, increased levels of these pollutants have been detected in biota in the past decade as a consequence of the melt of glacial ice accumulated during 1950-1980.
- The concern is that these organochlorines could accumulate in the foodweb, causing sub-lethal (or lethal) effects on the growth and survival of salmon fry. Description of the time series

43.2. Description of the time series

Rivers Inlet Sockeye Salmon production (catch plus escapement, Figure 43-1) data from DFO (2010) show the decline in adult returns to Owikeno Lake in the early 1990s. McKinnell et al. (2001) suggested poor marine survival explains the decline. In this brief report, I suggest that poor marine survival could be related to developmental problems caused by organochlorine assimilation by fry in Owikeno Lake.

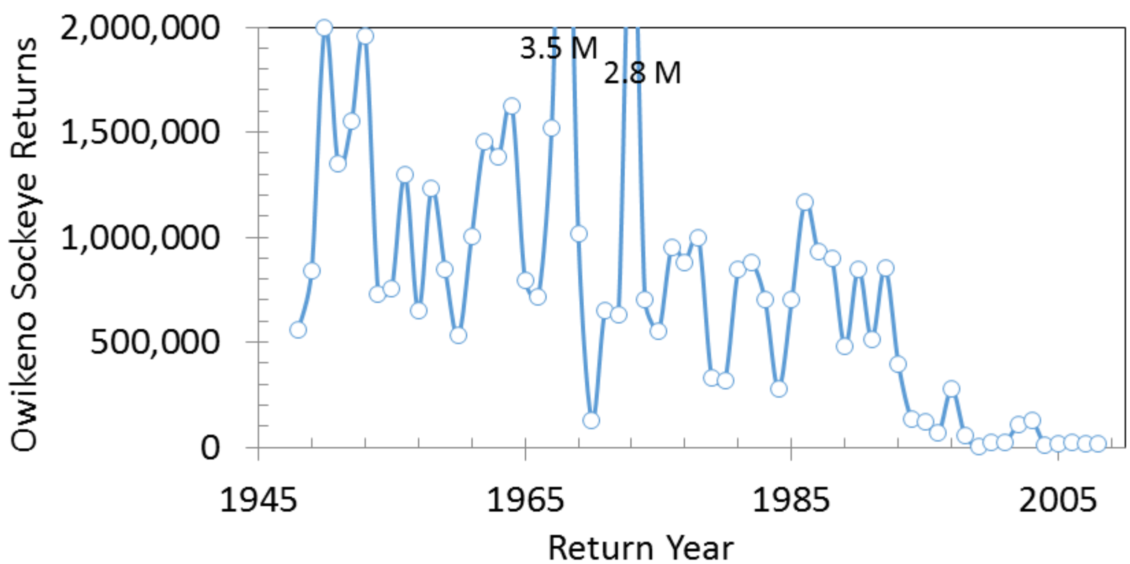

Figure 43-1. Total Sockeye Salmon adults returning to Owikeno Lake.

Data on glacial extent is catalogued by the National Snow and Ice Data Center (WGMS and NSIDC 1999). The data shows a persistent decline in glacial ice mass in western North America over the past several decades, following a brief period of glacial expansion in the 1970s (Figure 43-2). Glacial retreat paused during the 1990s then accelerated in 2003. Data are not available post 2003.

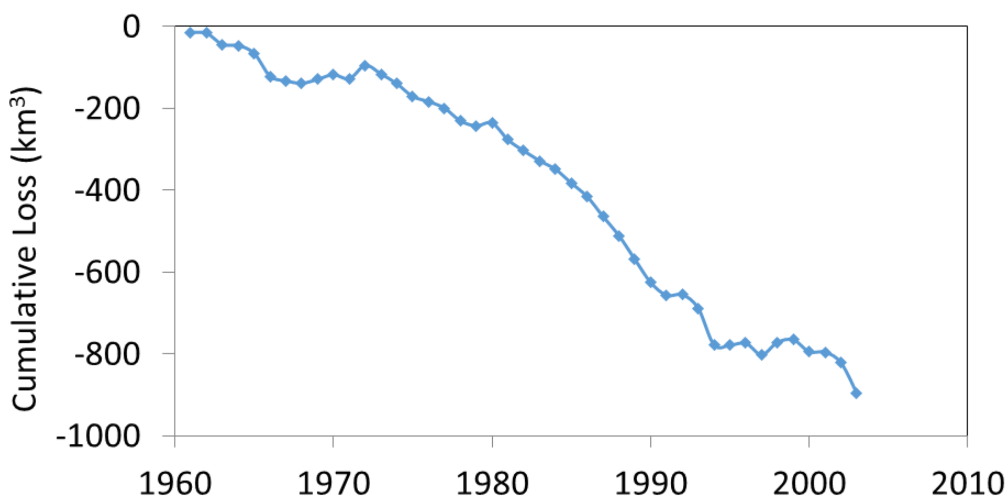

Figure 43-2. Cumulative loss of glacial mass (in km^3 of water) for western North America (35 to 60^o N, 105 to 130^o W).

Landsat satellite images (https://landsatlook.usgs.gov/) show an extensive retreat in summer snow and ice cover between 1977 and 2014 (Figure 43-3) in the area east of Owikeno Lake on the B.C. central coast. Images from a broader area are available, but shown is detail of an important feeder area for the fresh water habitat of Rivers Inlet Sockeye. Many high altitude ridges are devoid of ice cover in the recent image.

43.3. Status and trends

Glaciers worldwide are steadily losing mass. Ice losses from Alaskan and Northern B.C. glaciers has been approximately 75 km^3 y^{-1} between 1994-2013 (Larsen et al. 2015), dwarfing estimates of ice loss from B.C. central coast glaciers (approximately 1.3 km^3 y^{-1} between mid 1980s and 1999; VanLooy and Forster 2008). This loss of glacial mass helps explain a trend towards a fresher and more strongly stratified upper NE Pacific Ocean which may be weakening nutrient supply to the mixed layer and oxygen transport into the pycnocline (100-200 m depth; Whitney et al. 2013). The loss of glaciers is occurring at a time when the numbers of central coast Sockeye Salmon are declining. For more than a decade, Rivers Sockeye have been unable to recover from a precipitous drop in returning adults that occurred in the early 1990s. Ocean conditions have oscillated over this period, with strong El Niño (1997/98 and 2015/16) and La Niña events (1999 and 2008; https://www.ncdc.noaa.gov) creating the temperature fluctuations that should cause substantial variability in salmon survival. It is the lack of stock recovery that suggests pesticide release from glaciers is contributing to poor Sockeye survival in Owikeno Lake.

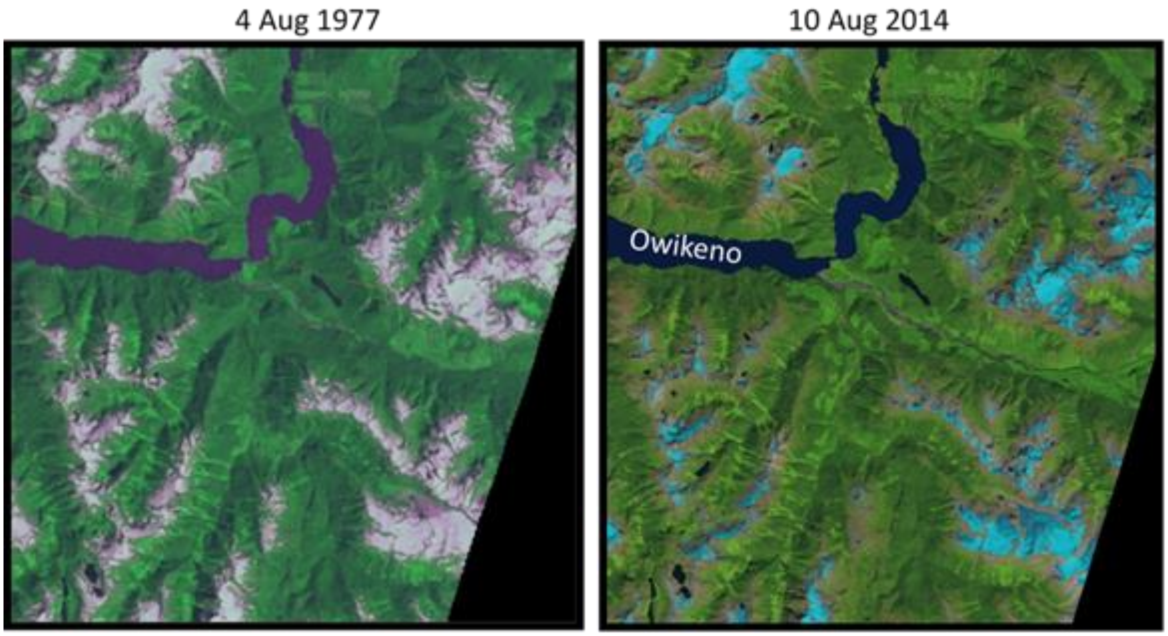

Figure 43-3. Landsat images from August 1977 and 2014, showing the extent of snow and ice cover (white in 1977, blue in 2014) in mid-summer in the mountains behind Owikeno Lake, Central Coast, B.C.

43.4. Factors influencing trends

Glacial melt is a product of global warming. In British Columbia, the loss of glaciers, evident in Landsat images (Figure 43-1), is apparently leading to a reduction in summer river flow in regions where glaciers contribute to river discharge (Stahl and Moore 2006). Less snow pack and warmer summers result in glacial melt being a larger portion of river flow.

43.5. Implications of those trends

Organochlorines such as DDT (dichlorodiphenyltrichloroethane) were in heavy use during the 1950s to 1970s. Bettinetti et al. (2008) observed a sharp increase in 2005 of DDT in mussels and fish from glacial fed lakes in the southern Alps, enough that these fish exceeded the Italian safety threshold for human consumption. They suggest that glacial expansion during the cool 1970s retained enough DDT to supply the observed enrichments during the recent period of melt.

Mountains behind Owikeno Lake are ideal for capturing volatile pesticides. They are a first contact for winds carrying pollutants across the North Pacific and are tall enough to trap more highly volatile hydrocarbons. Blais et al. (1998) noted a substantial increase in many organochlorines at elevations above 2000 m. Coastal mountains are commonly above this height, with Monarch Mt. reaching 3555 m within the drainage basin of Owikeno Lake.

Bogdal et al. (2009) state that global warming is creating "the potential for dire environmental impacts due to pollutants delivered into pristine mountainous areas." The B.C. central coast is just such a region. Modeling suggests the glacial reserves of the Coast Mountains will be steadily lost over the next century (Clarke et al. 2015). The ice collected between the 1950s and 1970s likely carries the greatest burden of pesticides, so as it melts it will govern inputs into coastal lakes in coming decades.

A program of measuring organochlorines in Sockeye Salmon fry from lakes strongly and weakly influenced by glacial melt could indicate whether "legacy" pesticides (stored in ice decades ago) are contributing to weak Sockeye Salmon returns seen in some B.C. lakes. The best sampling times would be when glacial melt most strongly contributes to freshwater supply to our lakes. In addition, glacial coring would help determine the amount of pesticides yet to be released.

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Individual reports State of the Ocean Reporting

44. SYNTHETIC INDICATORS FOR THE STRAIT OF GEORGIA MARINE ECOSYSTEM: 2016 UPDATE

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44.1. Highlights

- Three physical variables have significant explanatory power to identify shifts in ecosystem conditions in the Strait of Georgia (as defined over the period 1971-2007).
- Ecosystem conditions, as represented by these three proxy variables, differed in 2013-2016 from those in 2007-2012.
- 2016 clustered with 2013, 2014, and 2015, but grouped most closely with 2015, suggesting very similar conditions during these two recent years.

44.2. Description of the time series

This project involves the identification and development of synthetic ecosystem-scale indicators of changes in the Strait of Georgia. In a previous analysis, Perry and Masson (2013) used redundancy analysis to explore the relationships between 15 physical and human driver and pressure (explanatory) variables with 22 state and impact (response) variables for the Strait of Georgia from 1970-2010 (Table 44-1). They concluded that six variables had significant explanatory power to identify shifts in the broad suite of ecosystem response variables in the Strait. These six variables were sea surface temperature (SST), wind speed, North Pacific Gyre Oscillation (NPGO), human population, recreational fishing effort, and the number of Chinook Salmon released from hatcheries in the Strait. A previous analysis (Perry 2016) found that these three physical variables can be used to adequately describe changes in the overall conditions of the same broad suite of physical and human state and impact (response) variables for the Strait of Georgia. The present analysis provides an update using data for 2016 (for the physical variables: SST at Entrance Island, wind speed at Vancouver airport (YVR), and the annual mean NPGO index) to identify the potential for changes in ecosystem conditions in 2016 compared with recent years and the base period (1970-2010).

44.3. Status and trends

The full time series of annual values for these three physical variables, extending from 1970 and updated to 2016, is presented in Figure 44-1. These variables were standardized (0 mean, unit variance) and a chronological clustering technique was used to group adjacent years which had similar values (this method keeps years in their sequential order). A randomization test indicated that seven clusters were statistically significant (Figure 44-3), with 2016 grouping very closely with 2015, and in the same statistical cluster as 2013 and 2014. A box-and-whisker plot (Figure 44-2) shows that this most recent cluster (2013-2016) had the highest annual average SST, high annual average wind speeds at YVR, and a moderate to low annual NPGO index.

Table 44-1. The suite of physical and human driver, pressure, state and impact variables for the Strait of Georgia examined by Perry and Masson (2013) for the period 1970-2010, which were used to identify ecosystem indicators.

	Drivers & Pressures	**States & Impacts**
Natural	Northern Oscillation Index (NOI; annual) Oceanic Niño Index (ONI; annual) Pacific Decadal Oscillation (PDO; annual) North Pacific Gyre Oscillation (NPGO; annual) Wind speed (Vancouver airport; annual) Air temperature (Vancouver airport; annual mean) Precipitation (Vancouver airport; annual sum) Sea surface temperature (SST: Entrance Is., annual) Sea surface salinity (SSS; Entrance Is., annual) Fraser River flow (volume, annual) pH (annual modal values)	Spring phytoplankton bloom start date (modelled) Sockeye salmon marine survival (Chilko Lake) Herring (number at age 3) Herring (spawning biomass) Sockeye salmon (returns to Fraser River) Pink salmon (escapement, excluding Fraser River) Chum salmon (returns to Fraser River) Harbour seals (annual number) Killer whales (residents, annual number) Seabirds – demersal feeding (Christmas Bird Count) Seabirds – pelagic feeding (Christmas Bird Count)
Human	Chinook (number of hatchery releases) Coho (number of hatchery releases) Recreational fishing effort Human population (of Regional Districts around the Strait)	Herring (commercial catch) Flatfish (commercial catch) Pacific cod (commercial catch) Lingcod (commercial catch) Pacific hake (commercial catch) Dogfish (commercial catch) Total commercial fish catch Total pelagic fish catch Total demersal fish catch Chinook salmon recreational catch Coho salmon recreational catch

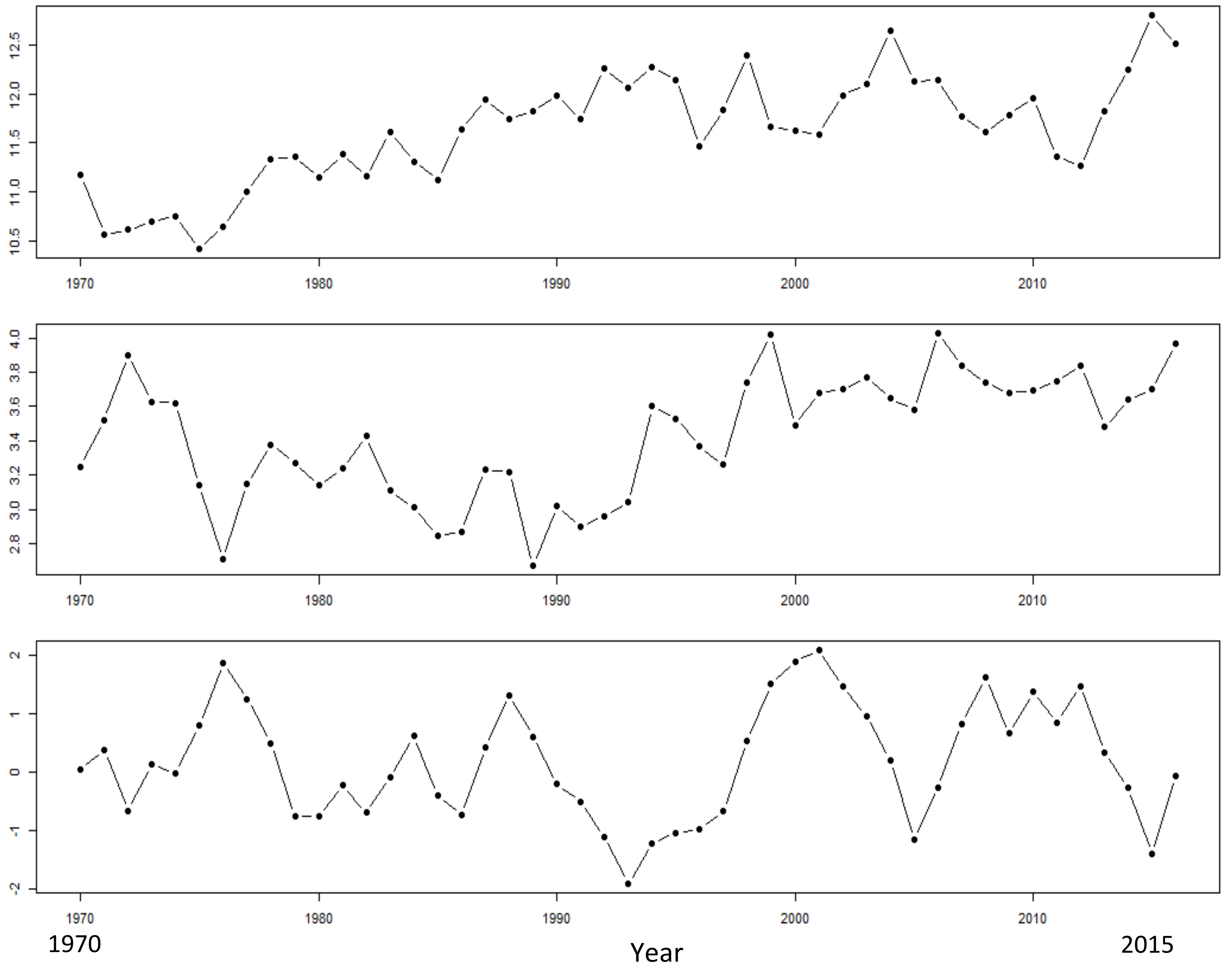

Figure 44-1. Time series of the three key explanatory physical variables, as annual means from 1970 to 2016. These key variables are sea surface temperature (°C) at Entrance Island (top), wind speed at Vancouver airport (YVR: m s^{-1}) (middle), and the North Pacific Gyre Oscillation Index (NPGO) (bottom).

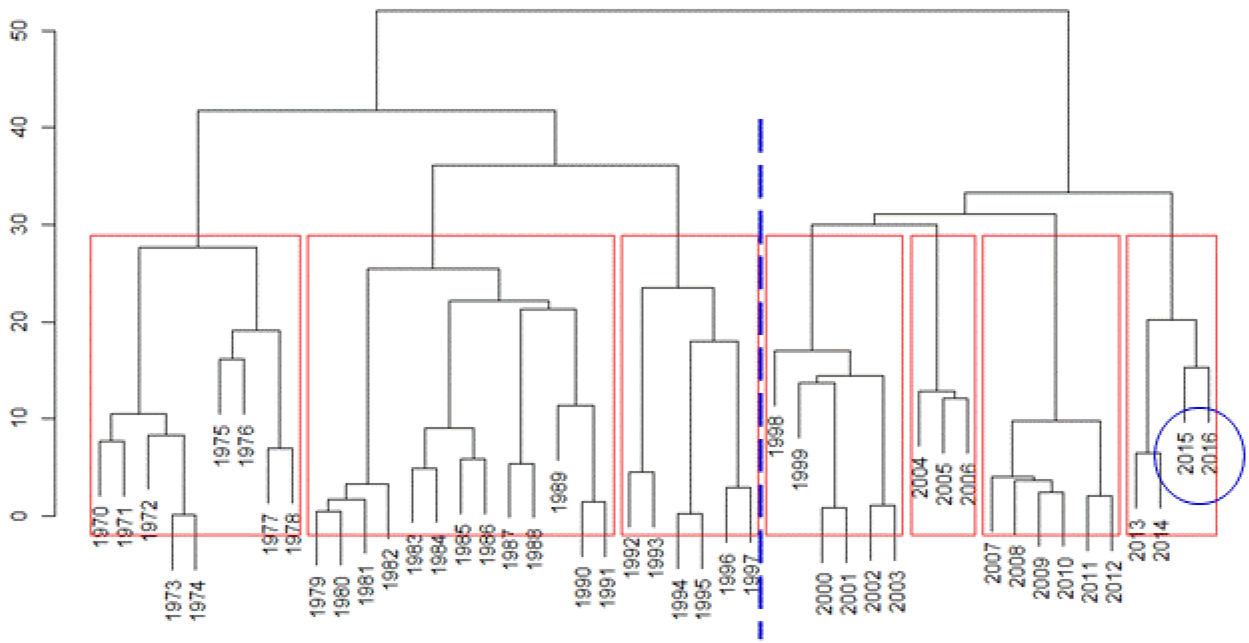

Figure 44-3. Chronological clustering of years (1970-2016), using the three key explanatory physical variables (NPGO, YVR wind, Entrance Island SST). Red boxes identify significant clusters based on a randomisation technique. Dashed blue line: separation between 1970-1997 and 1998-2016.

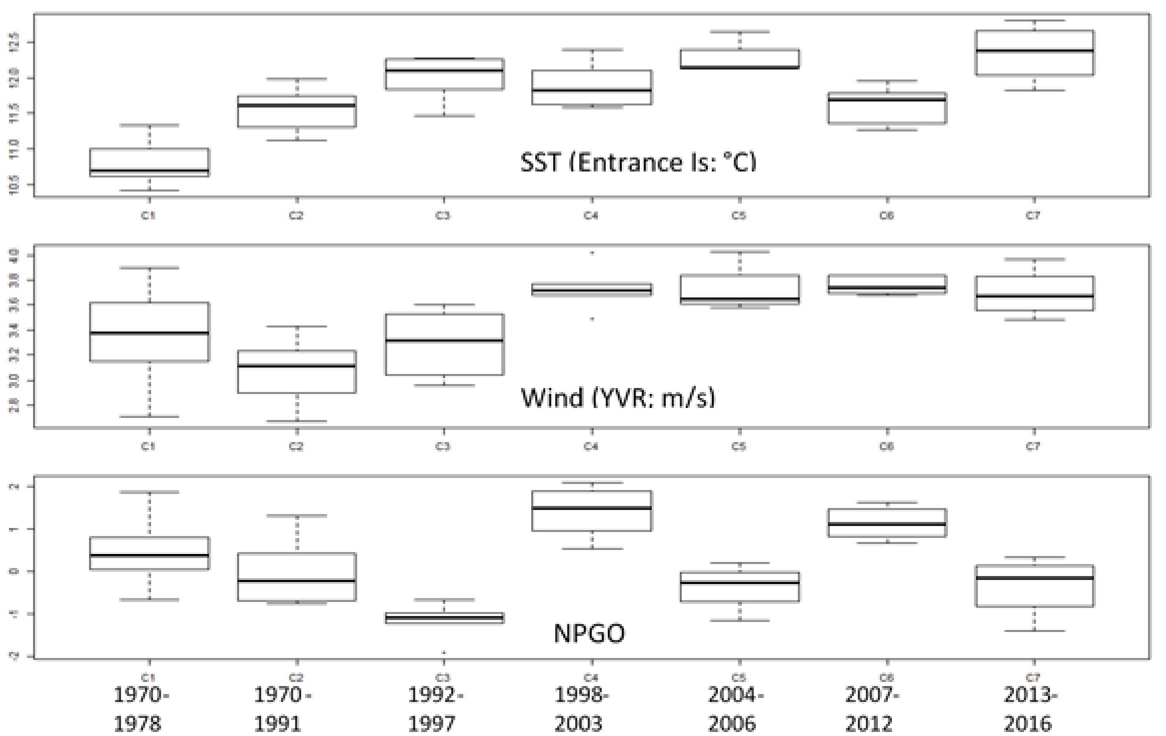

Figure 44-2. Box-and-whisker plots summarising conditions for each variable within the time periods defined by the significant clusters (red boxes in Figure 44-3).

44.4. Factors influencing trends

These three explanatory physical variables are able to capture the 'regime-shift like' behaviour of many natural and human social variables characterising the marine social-ecological system of the Strait of Georgia. The results indicate that this system in 2016 was very similar to that in 2015 (blue circle in Figure 44-3), and was broadly similar to conditions since 2013. The major separation of clusters occurred between 1970-1997 and 1998-2016 (blue dashed line in Figure 44-3).

44.5. Factors influencing trends

Potential causes for these results are under investigation. However, these three explanatory physical variables encompass both local environmental conditions, i.e. SST at Entrance Island and winds at Vancouver airport, and large-scale atmospheric forcing, as represented by the North Pacific Gyre Oscillation Index.

44.6. Implications of those trends

The purpose of the study by Perry and Masson (2013) was to identify a small set of variables which might 'explain' or capture the large-scale regime-like behaviour of the Strait of Georgia, at least as represented by the suite of the 22 state and impact (response) variables that were selected. The conclusion is that recent conditions (in 2016) were very similar to those in 2015, and broadly similar to those during 2013 and 2014, as all four years were grouped into the same cluster. However, the separation between 2013-2014 and 2015-2016 suggests that conditions may be diverging, which is consistent with the expectation that conditions in the Strait of Georgia generally lag those off the west coast of Vancouver Island by 12-18 months. Conditions off the west coast of Vancouver Island have been very different over the past couple of years, so these results for the Strait of Georgia may reflect those changes working their way into the Strait.

44.7. References

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Perry, R.I. and Masson, D. 2013. An integrated analysis of the marine social-ecological system of the Strait of Georgia, Canada, over the past four decades, and development of a regime shift index. Progress in Oceanography 115: 14-27.

45. OCEAN WATCH: HOWE SOUND EDITION

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45.1. Highlights

- The Coastal Ocean Research Institute launched its Ocean Watch report series in February 2017 with a pilot report focusing on many aspects of the health of Howe Sound.
- The main delivery mechanism is the Ocean Watch website, which is tailored for a general audience and uses a story-telling approach and communication tools ranging from illustrations of complex concepts, to simple charts and maps, to “Snapshot Assessments.”
- A list of key issues and an action plan document our synthesis of the collated information contained in 34 articles in seven reporting themes, which cover all realms of Ecosystem-Based Management.
- Ocean Watch will report on the whole B.C. coast in the next edition, scheduled for release in the spring of 2018.

45.2. Coastal Ocean Health Initiative

We introduced the Coastal Ocean Health Initiative at the DFO State of the Pacific Ocean meeting in March 2016. Through annual reporting on coastal ocean health, the initiative strives to:

- bring together the best available information on the state of B.C.’s coastal ecosystems;
- include status, trends, drivers, risks, and emerging issues;
- include different perspectives and ways of knowing;
- report to the public, stakeholders, and decision makers in a clear and engaging manner; and
- inspire and inform actions taken by the public, stakeholders, and decision makers.

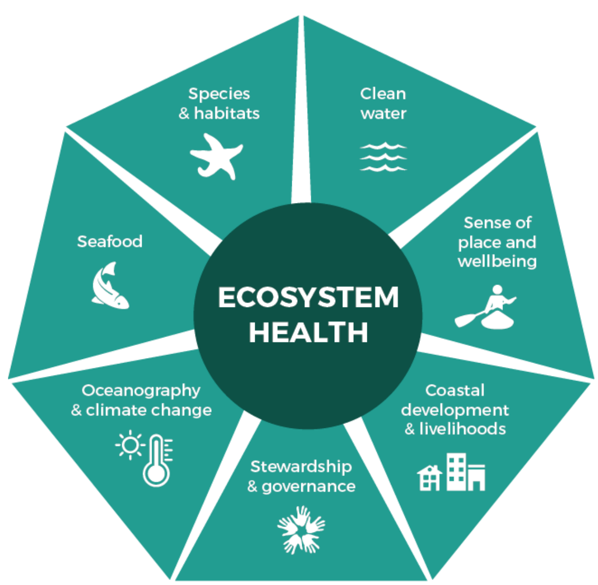

Figure 45-1. Ocean Watch Themes

Seven themes representing aspects of ecosystem health provide the framework for our reports (Figure 45-1). Topics discussed at the State of the Pacific Ocean meeting generally fall into the oceanography and climate change, seafood, species and habitats, and clean water themes. We also report on human aspects including sense of place and wellbeing, coastal development and livelihoods, and stewardship and governance.

These seven themes inform Ecosystem Based Management (EBM) as it has been defined in Marine Planning initiatives, including the recently endorsed Pacific North Coast Integrated Management Area (PNCIMA) plan and the Marine Plan Partnership for the North Coast (MaPP).

45.3. Ocean Watch pilot report format and approach

In February 2017, we released our pilot report focusing on the health of Howe Sound. The Ocean Watch website is the main delivery mechanism and is tailored for a general audience. The website includes links to PDF versions of the full report (365 pp.) and/or each of 34 articles individually. We also produced an executive summary, available in both print and PDF format, which is intended for decision makers, managers, and to draw people to the website. A limited edition printed report is available and is more popular than we anticipated.

The Howe Sound OCEANWATCH report contains 34 articles in total, spread among the seven themes. Thirty-one of these report on topics that sprung from community interest and emerging issues. Ocean Health Index (OHI) scientists contributed three additional articles that present and explain OHI scores, as calculated for the Howe Sound area.

For each article, we generally solicited experts to author the content and invited reviewers to undertake a non-blind technical review. All contributors, including reviewers, are acknowledged by name. The content template is consistent among articles and follows a series of questions:

1. What's happening?
2. Why is it important?
3. What's the current state?
4. What can you do?

The last section lists ideas for individual actions and government actions or policy. In addition, some articles include a First Nations perspective and/or include historical content.

Throughout the report, we used a variety of tools to help communicate the science to a general audience. We used 30 charts to illustrate data and were cognizant of keeping them clear and simple. Over a dozen diagrams summarize and illustrate points made in the narrative, and several communicate complex issues such as cumulative effects and coastal squeeze. We also used a variety of maps.

Each article webpage displays a rating and summary text, drafted for those with less time who might be looking for a status at a glance. We created the ratings section (Figure 45-2), called "Snapshot Assessment," as a way to communicate quickly and clearly. Ratings for each of the topics or issues were assigned by applying explicit criteria to the content of each article. Criteria considered current status and trends, presence or absence of data, and the kind of actions that are being taken. Authors reviewed the ratings and a few edited the summary text.

A few of the Ocean Watch articles reference information originally presented in DFO State of the Pacific Ocean report (DFO 2016), including:

- Forage fish: a critical link in the food web
- Temperatures rise in the ocean
- Sport Fishing: increased participation requires increased vigilance

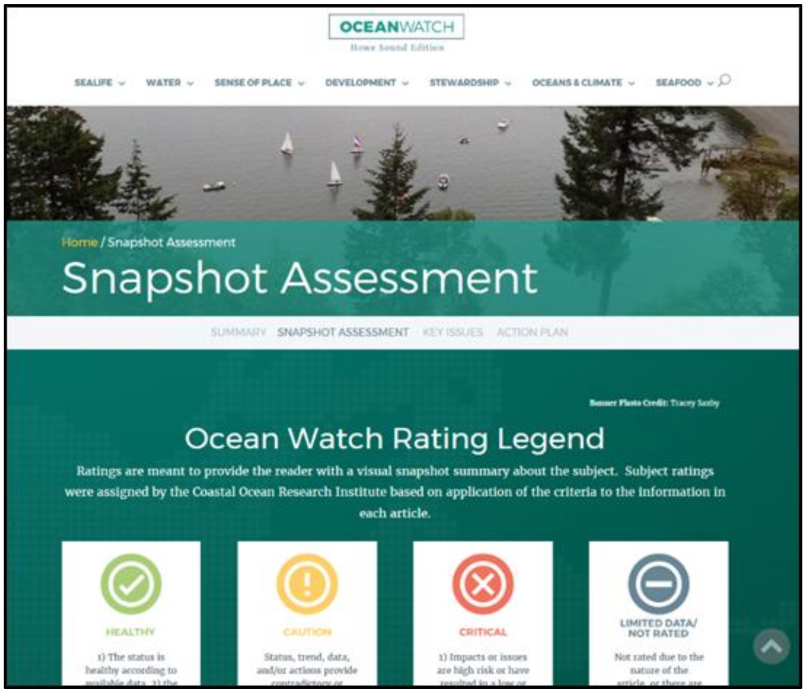

Figure 45-2. Snapshot Assessment webpage with rating legend.

Synthesis of the collated article content produced a list of 10 key issues, and we developed an action plan in response to those issues, consistent with our goal to inspire action. The key issues and action plan are presented through the website and the executive summary brochure.

45.4. Did we accomplish our goals with this report?

We compiled and presented a large volume of information on the state of Howe Sound and included as much data as we could obtain to discuss status, trends, drivers, and emerging issues. We included several different perspectives including traditional science, citizen science, First Nations and historical perspectives, and the quantitative ecosystem services perspective that Ocean Health Index scores bring.

To date, we have reached segments of all of our target audiences through the website, targeted communications, and events including a launch event on February 16, 2017. Almost 150 citizens, stakeholders, and decision makers from many levels of government, including federal, First Nations, provincial, and municipal governments, attended the report launch event. The policy makers each spoke about their government’s commitments to ocean conservation and the Howe Sound Action Plan.

We solicited feedback from many before, during, and after the website launch. All comments have been positive and some included constructive ideas for improvements to the website, which we made prior to the launch. For example, the OHI content confused some reviewers, so we took steps to clarify that content. A few additional minor tweaks improved website navigation. People are impressed with the look and feel of the report; they appreciate the diagrams, charts and photos. More than a few have said, “It’s surprisingly readable.”

The general audience and Howe Sound stakeholders appreciate the fact that each article includes ideas for action. People have said that they want to know how they can help, especially when they feel passionate about an issue. All in all, we have accomplished our goals and continue to engage our audiences and inspire them to take action.

45.5. Implications of the report

The Ocean Watch Howe Sound report continues to educate and engage readers in action. The Coastal Ocean Research Institute is developing recovery and long term monitoring programs, and following up on interest expressed by a variety of groups and individuals including NGOs, businesses, citizens and policy makers.

We are looking at the whole B.C. coast for our next edition of Ocean Watch, which will follow the same format, and we anticipate a release in the spring of 2018. We will continue to work with OHI, the Marine Plan Partnership (MaPP), DFO and others to advance the state of ecosystem reporting.

45.6. References

Chandler, P.C., King, S.A., and Perry, R.I. (Eds.). 2016. State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2015. Can. Tech. Rep. Fish. Aquat. Sci., 3179: viii + 230 p.

46. CHANGING HUMAN BEHAVIOR THROUGH STORY-TELLING

Christopher Krembs, Washington State Department of Ecology, Lacey WA., USA, Christopher.Krembs@ecy.wa.gov

46.1. Highlight

- To prepare the public and stakeholders for climate impacts, the story, the value, the risk of changing marine resources and opportunities need to be told on the human scale.

46.2. Summary

We live in a world of abundant information. To reach people, environmental information needs to be presented effectively. One way is to present this information in terms of a story. The human brain evolved around storytelling and images, sharing experiences, knowledge and emotions. Stories create a vantage point that enhances the personal experience in time and space. A succinct story requires quick data availability, integrative visual graphics, personal engagement, effective communication, a willingness to generalize, and time. The benefit is that a successful story is remembered, shared, and can change human behavior.

46.3. Stories need to reach the human scale to effectively engage people

Marine ecosystems and climate change reach beyond the human scale. To communicate stories outside our daily experience, the content as to include the human scale (Krembs and Sackmann 2015). The human time scale commonly spans a few weeks around the present. To relate to the present, scientifically-backed stories can reach back in time for context in order to connect to the present. The pathway from data collection to publication in a scientific journal is typically too long. A wide variety of alternative formats exist to report on marine ecosystems ranging from indices (Krembs 2012, PSEMP Marine Waters Workgroup 2016), report cards, annual reports (Krembs, 2013) to story maps. Most approaches, however, lack the human scale and cannot present the associated value of the changing ecosystem in an intuitive way.

Changes related to climate in the Salish Sea (Mauger et al 2015) require experts and stakeholders to expedite data turnaround and flexible communication strategies, while entire ecosystems are shifting under our feet. Traditional formats of tracking and communicating ecosystem performance against established baselines becomes complex because physical mechanisms structuring the timing and connectivity of interactive processes are shifting relative to one another. Consideration therefore should be given to developing stories focusing on the relative timing of processes to one another across different temporal and spatial scales.

For a story, the connection to the human scale using pictures can say more than a thousand words and speak to the human emotional value. People relate to the experience of other people, such as images of people working in or enjoying the marine ecosystem. Controversial images such as fish kills, large red tides, jellyfish, likewise can foster discussions, actions, and reactions.

46.4. Stories benefit from multiple minds and vantage points

Effective communication of ecosystem attributes hinges on the concerted effort of multiple marine monitoring programs. The challenge rests on making a faster connections across different scales of time, space, disciplines, and programs. Key to success is early data availability and shared visualizations that can foster collective thinking using guiding questions, hypothesis and conceptual models. Keeping everyone engaged in developing the story including engaging stakeholders and media early in the process. The benefit is a greater sense of importance, and connection of the human and scientific observation.

46.5. Stories need to be told differently as climate change unfolds

Climate has large impacts on our marine life, economy and human prosperity. This requires that climate impacts are quickly accessed, regional to global scales are connected, and a story is shared with stakeholders and the public. Social media offers an endless opportunity for the public to navigate to the information source. On the web images and compelling graphics telling a succinct story with little words are, however, more important than ever.

46.6. Stories that touch lives engage the community and influence decision making

Politicians and decision makers pay attention to public and stakeholders concerns. A concerted effort to collect powerful pictures, stories of stakeholders, and shared experience of scientists, stakeholders and the public (outreach) reflect a larger engaged community. People want to be part of larger groups and start sharing their experience on social media. Media responds to the same cues. Public visibility has the benefit to increase public support for a larger scientific community to explore climate impacts across marine ecosystem boundaries, human behavior and commercial interests.

46.7. An example of a story: A changing Puget Sound

While walking along Puget Sound shores I quickly make contact with people preparing shellfish on the barbeque, fisherman, boaters, artists, and beach goers. When talking to them I get the sense of a unique value they share. Puget Sound adds to their lives in many unique ways.

Puget Sound is nestled in the beautiful setting between high snow covered mountains and blue waters adorned with ships connecting our urban centers to the Pacific Ocean and distant ports. This region of the northwest is known for its excellent seafood. The abundant and diverse life of Puget Sound's marine food web and salmon rely on the timing of meltwater from the mountains and cold water upwelled along the Washington coastline. Water circulates in Puget Sound making it possible for nutrient-rich, cold water from the coast to reach our doorsteps and fuel a marine food web that can support salmon, orcas, and many iconic species for our enjoyment.

Climate change has, however, also reached this unique place. Have you noticed when the snow melts in spring and when the rivers crest as meltwater returns to the sea? Now, with warmer winters, snow melts earlier, leaving some streams to go dry in summer. This changes Puget Sound. Without the flowing rivers driving water exchange, cold, nutrient-rich water from the coastal ocean is no longer felt at our doorsteps. Puget Sound water is warmer and circulates more slowly.

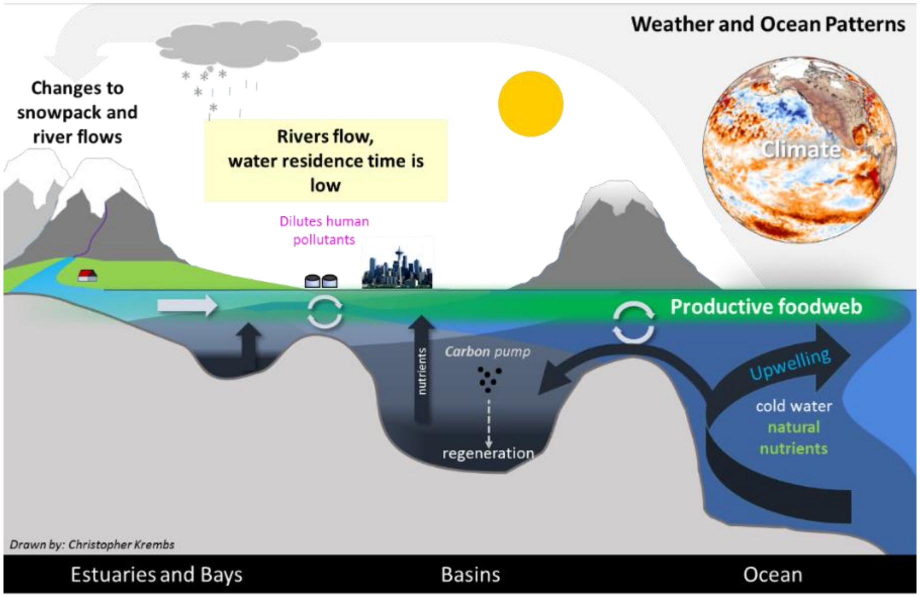

Figure 46-1. Snowmelt and upwelling historically occur at the same time. This renews water in Puget Sound through circulation diluting pollutants, and bringing the benefits of a productive upwelling system from the coast to our doorsteps.

While this seems like a good thing, certainly appealing for summertime swimmers, stagnant water in Puget Sound receives the same amount of wastewater as before. What does this mean? One theory is that the creatures at the base of the foodweb slurp up these nutrients and some nuisance species love the new nutrient cocktail. Most other species in Puget Sound don't like to eat the newcomers, and so these interlopers become numerous.

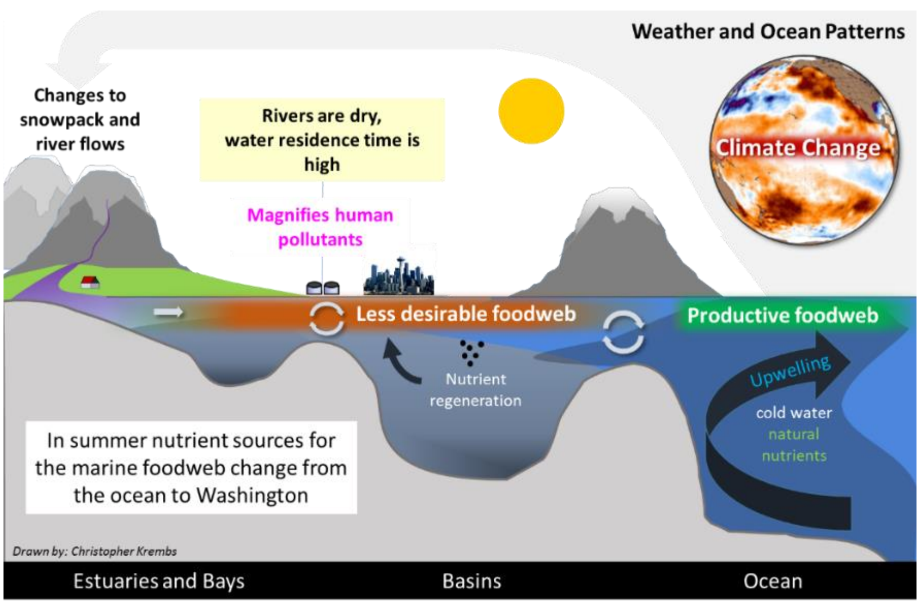

Figure 46-2. Low river flow driven by earlier snowmelt in the mountains, reduces the renewal of water in Puget Sound. Human nutrient inputs however, remain the same. As a consequence, the nutrient cocktail available to the foodweb changes

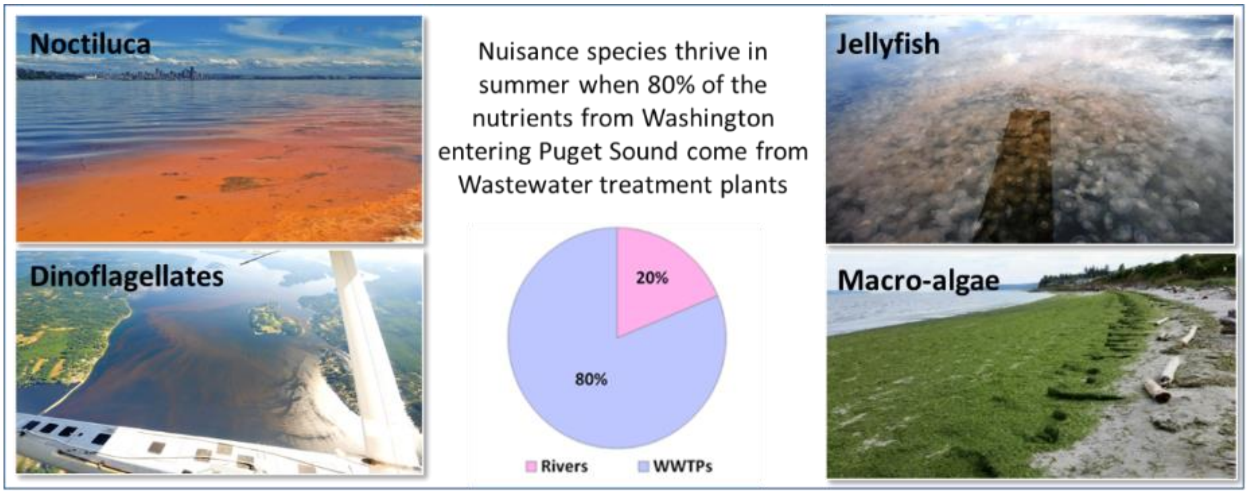

Figure 46-3. Nuisance species float in large quantities at the surface of Puget Sound in summer, a time when the nutrient contribution from wastewater treatment plants is the highest and water renewal in Puget Sound is weak.

Many nuisance species, like macro algae and jellyfish grow near the surface in the summer and wash up on our beaches. Just below the surface, hidden from the eyes, the microscopic food web is also changing. Red and orange-stained water can mean that a sea of microbes (such as Noctiluca and Dinoflagellates) is surfacing. These same waters can contribute to a breeding ground for harmful algae blooms and bacteria dangerous to humans and wildlife. But life adapts. Recently, we have seen species from southern reaches adding to some of our iconic species of herring and Orcas, such southern visitors as anchovies and common dolphins. While the future will tell us how climate effects will play out in different regions of Puget Sound, we should keep a watchful eye on our waters in the meantime, with the help of our experts and you.

46.8. References

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Krembs, C., and Sackmann B., 2015. Strategies to Increase the Impact and Effectiveness of Long-Term Marine Monitoring Programs. In: Coastal Ecosystems, Experiences and recommendations for environmental monitoring programs: Maria-Teresa Sebastia (Ed), 2015 Nova Science Publisher: 43-56.

Krembs, C., 2013. Eutrophication in Puget Sound. In: Irvine, J.R. and Crawford, W.R., 2013. State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems in 2012. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/032: 106-112.

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46.9. Links

We have Eyes Over Puget Sound which reaches 40 000 downloads per edition: http://www.ecy.wa.gov/programs/eap/mar_wat/surface.html

Examples of story maps:

- http://waecy.maps.arcgis.com/apps/MapSeries/index.html?appid=dc75a9754ed442c2a2c0ac0098124a27
- https://earth.nullschool.net/#current/ocean/surface/currents/orthographic=-71.25,35.48,1640
- http://www.arcgis.com/apps/MapJournal/index.html?appid=7530f28f065c486ba0420ca8e26a13f4
- http://esrioceans.maps.arcgis.com/apps/Cascade/index.html?appid=70f95ebd47754b1a905459a14387e198
- http://story.maps.arcgis.com/apps/MapTour/index.html?appid=de5576908cd0436cba94a7b768efecd8&webmap=cb530d04876a4ec0b6f8ab3b40e36204

47. TAILORING THE OCEAN HEALTH INDEX TO BRITISH COLUMBIA

Courtney Scarborough[1], Casey O'Hara[1], Ben Halpern[1], Karen Hunter[2], Ian Perry[2], Karin Bodtker[3] and Andrew Day[3]

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47.1. Highlights

- Our team is working to adapt the Ocean Health Index (OHI) to capture characteristics that make British Columbia's coastal ecosystems unique by incorporating locally meaningful information, priorities, and perspectives to characterize ocean health in British Columbia over each of the last 10 years.
- The Ocean Health Index defines a healthy ocean as one that sustainably delivers a range of benefits to people both now and in the future.
- We are using a newly developed OHI Toolbox, a suite of collaborative, open-source tools and instruction that provide structure for data organization and storage, data processing and goal modeling to make sure our assessment methods and computational code are transparent, reproducible, and repeatable for future use by scientists and managers in British Columbia.

47.2. Description of the Ocean Health Index

Determining ocean health requires an approach that integrates social, economic, and environmental information. The Ocean Health Index (OHI) is an assessment framework that measures progress towards a suite of key societal 'goals' representing the benefits and services people expect healthy oceans to provide. By analyzing these goals together and scoring them from 0-100, OHI assessments provide an integrated picture of the state of the ecosystem and can be communicated to a wide range of audiences.

Originally developed by an interdisciplinary team of scientists (Halpern et al. 2012), the OHI framework is standardized yet tailorable to different contexts and spatial scales. This is possible because the core framework used to develop goal scores does not change while the goal models themselves are developed with local information and local decisions specific to the unique social-ecological context.

The Ocean Health Index British Columbia team is working with local partners to adapt and tailor the OHI framework to the unique social-ecological systems of British Columbia in order to better inform policy and management practices. Using previously delineated planning regions as well as known biogeographic boundaries we have developed eight separate reporting regions shown in Figure 47-1. Working with our partners at Vancouver Aquarium's Coastal Ocean Research

Institute (CORI) we have also completed a smaller-scale partial assessment for the Howe Sound region (highlighted in green in Figure 47-1).

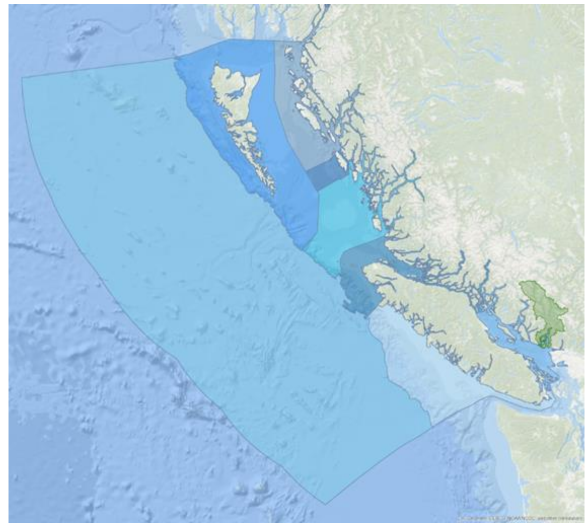

Figure 47-1. Reporting regions planned for the OHI British Columbia assessment. Each of the regions outlined below will be assessed based on eight goals people have for healthy oceans in the region and receive separate, comparable scores.

Based on feedback from our partners and local science, management, and policy groups as well as a comprehensive review of literature and ecosystem reporting from across the region our team has defined eight goals people have for healthy oceans that we are working to measure across British Columbia:

1. **Seafood Provision:** Sustainably harvested seafood from wild-caught fisheries and aquaculture
2. **First Nation's Resource Access Opportunities:** Opportunities for First Nations to access local natural resources
3. **Carbon Storage & Coastal Protection:** Mitigation of climate change impacts through healthy marine ecosystems that provide carbon storage and coastal protection
4. **Tourism and Recreation:** Opportunities for people to enjoy coastal areas through tourism and recreation
5. **Coastal Economies:** Economic well-being for coastal communities
6. **Sense of Place:** A deep sense of identity and belonging provided through connections with our marine communities, landscapes and cultural and heritage resources
7. **Biodiversity:** A diversity of healthy marine species, habitats, and landscapes
8. **Clean Waters:** Coastal waters which are free of pollution

47.3. Ocean Health Index Methods

Assessments using the OHI framework are facilitated by the OHI Toolbox, a suite of collaborative, open-source tools and instruction that provides structure for data organization and storage, data processing and goal modeling. The Toolbox enables assessments to be transparent, reproducible through access to detailed methods and computational code, and repeatable with the ability to modify methods and computational code. Once we tailor the toolbox to British Columbia and calculate scores for each of the last 10 years we hope to train local scientists on use and maintenance of the Toolbox so OHI scores can be more easily calculated and methods adapted based on advances of our understanding of the system in the years to come

For each goal determined to be important to the people of the region four dimensions are measured and scored. Present **Status** is a goal's current value compared to its reference point. **Trend** is the average percent change of a goal's status over the most recent five years. **Pressures** are the ecological and social factors that decrease status. **Resilience** includes the ecological factors and social initiatives (policies, laws, etc.) that increase status by reducing or eliminating pressures (Figure 47-2).

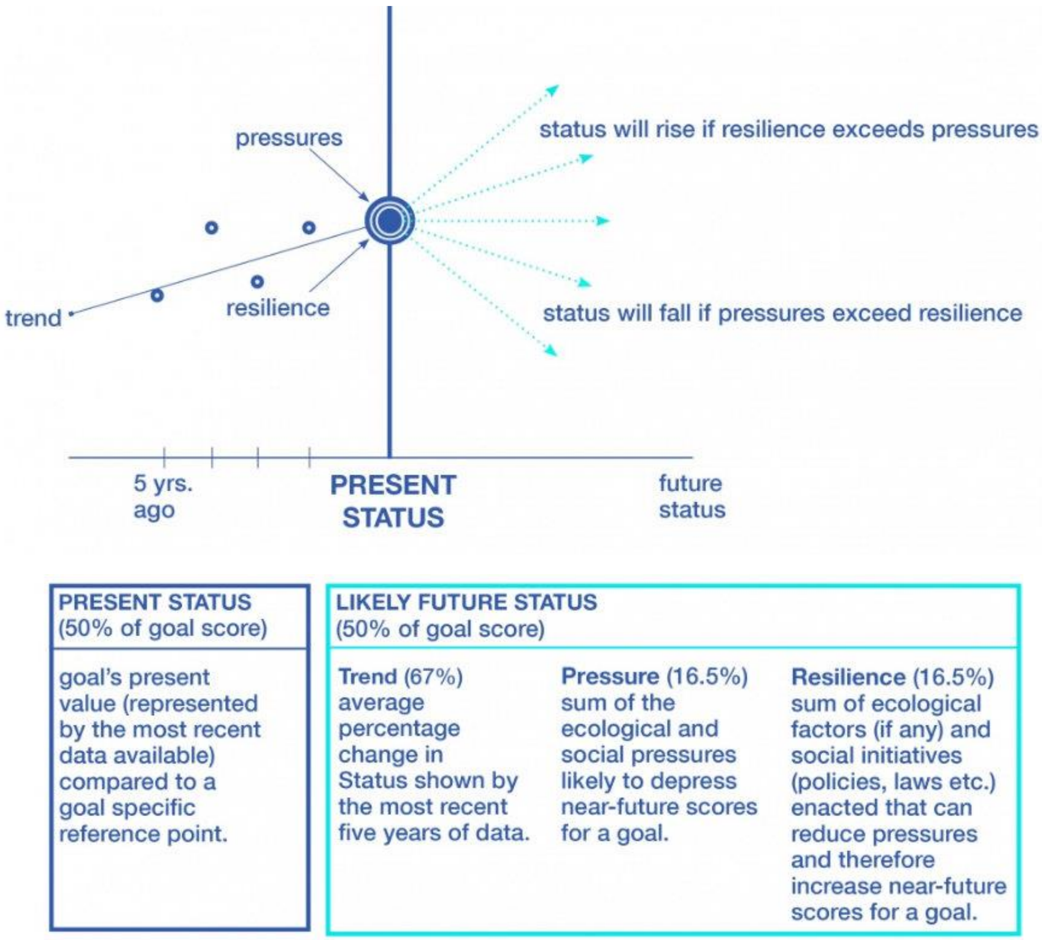

Figure 47-2. Influence of Trend, Pressures, and Resilience components on the overall calculation of the Present Status of ocean health using the Ocean Health Index methodology.

The results of each OHI assessment are visualized in a *Flower Plot* for easy communication with a wide audience - each petal represents one goal with the length of each petal showing the score of the goal, and the width of each petal representing how much each individual goal score contributes to the overall calculation of the Index score when aggregating all goals. Figure 47-3 is a flower plot representing the scores from the 2016 global assessment, where all of Canada's oceans were assessed together. By incorporating local information and redefining the goals used to assess ocean health in British Columbia, our work will evaluate ocean health at a finer resolution with goals tailored to the region, providing scores for several sub-provincial regions in B.C.

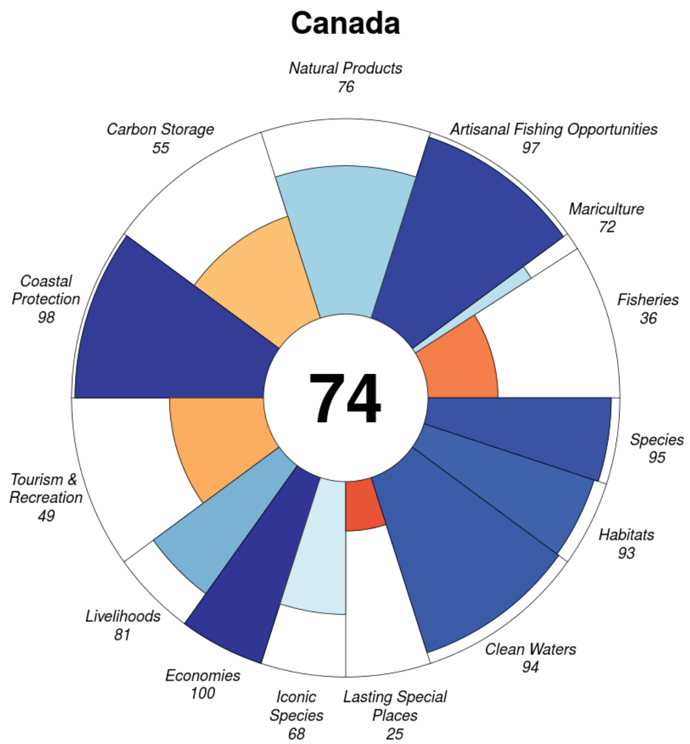

Figure 47-3. A flower plot representing the OHI scores for Canada f based on the 2016 global assessment, which assessed all of Canada's oceans together

47.4. Priorities for the Ocean Health Index British Columbia project

With this regional Ocean Health Index assessment for the social-ecological marine systems of British Columbia we aim to address three core questions that inform management needs:

1. Have past management actions affected overall ocean health, and if so, in what ways?
2. How do different communities view and value aspects of ocean health, and how does this influence people's understanding of how healthy the ocean is?
3. How can the Index be used to inform and support ongoing comprehensive ocean planning efforts?

Results are expected for this project in December 2017. For further reading regarding the methodology used to conduct Ocean Health Index assessments, please see the references listed below.

47.5. References

Halpern, B.S., Longo, C. Hardy, D., McLeod, K.L., Samhouri, J.F., Katona, S.K., Kleisner, K., Lester, S.E., O'Leary, J., Ranelletti, M., Rosenberg, A.A., Scarborough, C., Selig, E.R., Best, B.D., Brumbaugh, D.R., Chapin, F.S., Crowder, L.B., Daly, K.L., Doney, S.C., Elfes, C., Fogarty, M.J., Gaines, S.D., Jacobsen, K.I., Bunce Karrer, L., Leslie, H.M., Neeley, E., Pauly, D., Polasky, S., Ris, B., St Martin, K., Stone, G.S., Sumaila, U.R., and Zeller, D. 2012. An Index to assess the health and benefits of the global ocean. Nature 488: 615-620. doi:10.1038/nature11397. (original 2012 global assessment methods)

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48. UNUSUAL EVENTS IN CANADA'S PACIFIC MARINE WATERS IN 2016

R. Ian Perry[1], Stephanie King[2], Jennifer Boldt[3] and Peter Chandler[4]

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48.1. Highlights

- Weird, wonderful, and/or unusual events in B.C. marine environments occur every year, but are often not reported or not set into a broader context.
- Unusual events that were reported include abundances of plankton washing along beaches of the west coast of Vancouver Island (often gelatinous plankton), coccolithophorid blooms in the Strait of Georgia, high abundances of juvenile rockfish along the west coast of Vancouver Island and Northern Anchovy in the Strait of Georgia, and sighting of unusual shark species.
- Patterns that emerge from these observations include: the impacts of the recent marine heat wave continue to be felt by the biology all along the B.C. coast; "explosions" of marine organisms continue to astonish; and disease remains a potent factor causing mortality of marine animals, but which is often overlooked or difficult to assess.

48.2. 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 2016 that have been reported to DFO Science staff. Some of these events may be included in other short reports in this document, whereas other observations may not be presented in detail or at all. In addition, viewers of this poster during the State of the Ocean meeting were invited to provide their own observations of weird and wonderful unusual events, which are included in this report.

48.3. Status and trends

A sample of the observations reported to DFO Science staff is presented in Table 48-1. Additional observations contributed by participants at the 2017 State of the Pacific Ocean workshop are presented in Table 48-2.

Table 48-1. Observations of weird, wonderful and/or unusual marine events observed by or reported to DFO Science staff during 2016.

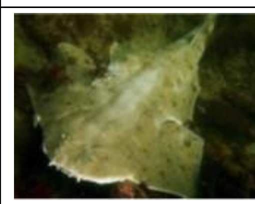
Event	Where	When	Reported by	Details
Widow rockfish juvenile recruitment explosion	Nootka Sound and in Browning Pass (Queen Charlotte Strait)	August and September 2016	Pauline Ridings and Bryan Rusch	  Photograph by Pauline Ridings
Large abundance of juvenile rockfish	Various reefs in Barkley Sound	June to September 2016	Peter Mieras (Subvisionproductions.com)	High yellowtail, black and blue rockfish recruitment was observed in Washington State as well as all along the west coast of Vancouver Island
Northern Anchovy very abundant in Salish Sea (and large die-off on Sunshine Coast in January 2017)	Salish Sea	All year	Multiple observations (DFO, US, VanAqua)	 Anchovy schools are back in session, with 'phenomenal numbers' spawning in Howe Sound Report from Vancouver Sun, August 20, 2016
Isolated die-offs of sea cucumbers and sea urchins; urchins in wild seem to be suffering from “bald sea urchin disease”			Chris Pearce; Janet Lochead; Dan Leus; reports from industry and DFO divers	
First ever record of a Pacific angel shark in B.C. waters	Off Clover Point, Victoria	April 2016	Report by underwater diver to Pacific Shark Sightings Network of Fisheries and Oceans Canada	 Photograph By Mark Cantwell
Coccolithophore blooms	Inside waters, Salish Sea	July – September 2016		

Table 48-1 continued. Observations of weird, wonderful and/or unusual marine events observed by or reported to DFO Science staff during 2016.

Event	**Where**	**When**	**Reported by**	**Details**
A huge influx of Giant fire salps (pyrosomes)	Barkley Sound	December 2016	Peter Mieras (Subvisionproductions.com)	Influx onto coastal WCVI after a few big storms.
Rhinoceros auklet unexplained mortality event	Juan de Fuca Strait	August 2016	Scientists, beach walkers	 Photograph By Kelly Young
Large ‘slicks’ of *Velella velella* at sea and washed on shore	Northwest Vancouver Island coast	March 2016	Transport Canada pollution tracking flights	

Table 48-2. Observations of weird, wonderful and/or unusual marine events provided by participants at the 2017 State of the Pacific Ocean meeting.

Event	**Where**	**When**	**Reported by**	**Details**
Large-scale wash up of *Velella velella* at Pacific Rim (Tofino)	Tofino – Pacific Rim and local beaches	March 2016	Commonly observed by everyone there	Discussions with surfers – event lasted a week or more
Doliolids at Pacific Rim	Pacific Rim park, Tofino	March-April 2016	Cindy Wright	Occurred just at the end of the *Velella velella* wash up
Extended “hypoxia”, 2015-2016; absence of commercial shrimp, abundance of typically ‘rare’ species of nudibranchs, sea cucumbers	Saanich Inlet, Pat Bay at about 100 m off bottom	October 2016	Jackson Chu	Event was unusual when compared to 11 years of annual ROV surveys at the same site
Pyrosomes (“fire salps”) washing up on Cox Beach	Tofino - only at Cox Beach	Observed in December 2016, and again in February 2017	Cindy Wright	
Plumose anemones detaching from rock faces and dying	Howe Sound	Fall 2016	Jessica Schultz/Karin Bodtker (CORI, Vancouver Aquarium)	Photos are available
Basking shark sightings.	Laredo Channel, central BC coast	May 2016	Tammy Norgaard (DFO)	Observed during a DFO science survey
Norovirus in B.C. oysters	Source not identified	Late 2016	CFIA, DFO; several news stories	Ongoing into 2017 and continues to impact oyster producers

48.4. References

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

Appendix 1. Review Meeting Agenda

March 22 and 23, 2017
Bodine Hall, Mary Winspear Centre, Sidney, B.C.

Wednesday, March 22nd (Conditions in the NE Pacific and outer B.C. coast)

Time	Name	Presentation
9:00-9:30	**Registration and settling-in**	**Refreshments provided**
9:30-9:40	Peter Chandler/Jennifer Boldt	Introduction and purpose
9:40-9:45	Carmel Lowe	Welcome from DFO
9:45-11:30	Faron Anslow	Overview of land temperature and hydrological conditions for 2016
	Tetjana Ross	An update on the ENSO/blob
	Charles Hannah	Patterns of SST variability along the west coast of North America
	Doug Yelland/Marie Robert	Line P/La Perouse
	Roy Hourston	Wind-driven upwelling along the Northwest coast of North America: timing and magnitude
	Jan Newton	Buoy data from Washington coast and Puget Sound
	Bill Crawford	Oxygen concentrations on the West coast of Vancouver Island
	Stephanie King	Satellite and buoy observations of BC waters
11:30-12:50	**Lunch**	**Not provided**
12:50-15:00	Angelica Pena	Phytoplankton in surface waters along Line P and off the west coast of Vancouver Island
	Brian Hunt	Hakai Oceanography (Central Coast)
	Peter Chandler	Sea surface temperature and salinity at BC lighthouses in 2016
	Anne Ballantyne	Water level observation from 2016
	Moira Galbraith	Zooplankton
	Ian Perry (for Sonia Batten)	Offshore plankton indices from the Continuous Plankton Recorder sampling
	Ian Perry	Update on the WCVI small-mesh trawl survey
	Jennifer Boldt	Herring and other pelagic fish in BC
	Greg Workman	Groundfish time series
	Kim Hyatt	Coast-wide sockeye indicator stock returns in 2016 and prospects for 2017 and beyond
15:00-15:30	**Break**	**Refreshments provided**
15:30-17:15	Frank Whitney	Are Central Coast sockeye affected by glacial retreat?
	Dan Curtis	Northern Abalone time series
	Linda Nichol	Update on marine mammals
	Svein Vagle	A changing Soundscape in the NE Pacific: Are we getting close to a tipping point?
	Jennifer Yakimishyn	Population trends in seabirds and nearshore fish communities in Pacific Rim National Park Reserve
	Mark Hipfner	Seabird observations on the BC Coast
	Patrick O'Hara	Oil spills and plastics in the seabird world
	Dave Jackson	CHS 2017 – status of bathymetry, products and other data available and plans for the future
17:15-17:30	Peter Chandler/Jennifer Boldt	Discussion
17:30-19:30	**Ocean Networks Canada Poster Session** Enjoy the posters and some light snacks. Cash bar for those who are interested.	

Thursday, March 23rd (Inside waters and special session on the future of SOPO reporting)

Time	Name		Presentation
8:45-9:00	**Registration and settling-in**		**Refreshments provided**
9:00-9:15	Peter Chandler/Jennifer Boldt		Reflections on day 1, key highlights and new ideas
9:15 - 11:30	Peter Chandler		SoG water properties in 2016
	Akash Sastri		Deep water and surface properties (ferries) in the Strait of Georgia for 2016 as measured via the VENUS infrastructure
	Mark Halverson		Surface circulation in the Fraser River plume and Salish Sea from satellite imagery and drifter studies
	Alex Hare		Environmental coherence of high CO2 signals revealed by multiple platforms in the Northern Salish Sea
	Elise Olson		The Strait of Georgia Phytoplankton Bloom: 2017 Prediction (1-D model) and 2016 Spatial Variation (3-D model)
	Maycira Costa		Satellite chlorophyll phenology in the Salish Sea
	Svetlana Esenkulova		The phytoplankton community in the Salish Sea
	Chelsea Stanley		Strait of Georgia pelagic ecosystem surveys
	Erin Rechisky		Telemetry-based estimates of early marine survival and residence time of juvenile salmon in the Strait of Georgia and Queen Charlotte Strait
	Chrys Neville		Update information on conditions for juvenile salmon in the Strait of Georgia in 2016
11:30-12:50	**Lunch**		**Not provided**
12:50 - 14:30	Sue Grant		Fraser River Sockeye: Abundance and Productivity Trends and Forecasts
	Special Session	Jennifer Boldt	SOPO reporting overview
		Ian Perry	SoG integrated ecosystem indicators
		Andrew Day	Ocean Watch Howe Sound report
		Andy Teucher	Environmental Reporting in the Digital Age: Lessons learned from B.C.'s State of Environment Reporting
		Courtney Scarborough	Applying the Ocean Health Index to BC waters
14:30 - 15:00		**Break**	**Refreshments provided**
15:00 - 16:40		Kimberle Stark	Summary of the 2016 Puget Sound Marine Waters Monitoring Components
		Christopher Krembs	Water quality monitoring in Puget Sound
		Chris Harvey	California Current Integrated Ecosystem Assessment
		Stephani Zador	Alaska Ecosystems Considerations report
		Peter Chandler/ Jennifer Boldt	Special session discussion
16:40 - 17:30	Peter Chandler/ Jennifer Boldt		Take away messages and wrap-up

Posters (Ocean Networks Canada Poster Session, March 22)

1. Erika Loc - The Scott Islands: A Marine National Wildlife Area
2. Ian Perry - Strange events in 2016
3. Charles Hannah - Patterns of SST variability along the west coast of North America.
4. Andrew Ross - International Group for Marine Ecological Time Series (IGMETS): assessing global oceanic changes through joint time series analysis
5. Brett Johnson - The Hakai Institute juvenile salmon program
6. Theresa Venello - Estimating secondary production and trophic transfer efficiency along Line P
7. Cheryl Greengrove – Hydrographic and Bathymetric Survey of Tofino Inlet, Clayoquot Sound – Summer 2016
8. Peter Chandler – PICES North Pacific Ecosystem Status Report (NPESR)
9. Maartje Korver (for Ian Giesbrecht)- Weather driven dynamics of pluvial watersheds on the Central Coast (Calvert Island) from 2013 to 2016
10. Kang Wang - Hakai Ocean Observatory time series
11. Jackie King – Juvenile Coho salmon growth off WCVI
12. Kimberle Stark - Puget Sound Central Basin 2016 Conditions
13. Ryan Gasbarro - A time-series of epibenthic community turnover along a dissolved oxygen gradient
14. Michael Dunphy- SalishSeaCast A 3-D coupled prediction system for the Salish Sea
15. Jim Gower - Coccolithophore blooms in 2016
16. Cathryn Clark Murray - Aerial surveillance for marine and tsunami debris in British Columbia, Canada
17. Tom Okey – The Local Environmental Observer (LEO) Network
18. Patrick Cummins - Interannual to decadal variability in the depth of the pycnocline at Ocean Weather Station P: an update analysis

Appendix 2. Review Meeting Participants (based on sign-in and WebEx)

Participant	Affiliation
Ahdia Hassan	DFO, Species at Risk Program
Scott Akenhead	Ladysmith Institute, Ladysmith
Faron Anslow	UVic, Victoria
Stephanie Archer	DFO, PBS, Nanaimo
Sandy Argue	Argus Bio-Resources, Victoria
Anne Ballantyne	DFO, IOS, Sidney
Stephen Ban	Canadian Parks and Wilderness Society
Douglas Bertram	Environment Canada, Institute of Ocean Science, Sidney
Michelle Bigg	DFO, Fisheries Protection Program
Karin Bodtker	Coastal Ocean Research Institute at the Vancouver Aquarium
Jennifer Boldt	DFO, PBS, Nanaimo
Alston Bonamis	DFO, Fisheries Protection Program
Virginie Bornarel	UBC, Vancouver
Julia Bradshaw	DFO, PBS, Nanaimo
Heather Brekke	DFO, Species at Risk Program
Leslie Brown	ASL Environmental Sciences, Sidney
Fred Burgess	Royal Roads
R. Burnham	UVic, Victoria
Syd Cannings	Environment Canada
Chantelle Caron	DFO, Resource Management, Vancouver
Barron Carswell	Province of British Columbia
Peter Chandler	DFO, IOS, Sidney
Lais Chaves	Haida Oceans Technical Team (HOTT)
Elly Chmelnitsky	DFO, RHQ
Sean Cheesman	Province of British Columbia
Jackson Chu	DFO, IOS, Sidney
Steven Colwell	DFO, IOS, Sidney
Maycira Costa	UVic, Victoria
Bill Crawford	DFO (retired), IOS, Sidney
Stuart Crawford	Haida Oceans Technical Team, EBM monitoring coordinator
Patrick Cummins	DFO, IOS, Sidney
Terry Curran	Pacific Salmon Foundation
Dan Curtis	DFO, PBS, Nanaimo
Audrey Dallimore	Royal Roads / Geologic Survey of Canada, Sidney
Shaun Davies	DFO, North Coast
Andrew Day	Coastal Ocean Research Institute at the Vancouver Aquarium
Scott Decker	DFO, Interior Fraser Office
Anya Dunham	DFO, PBS, Nanaimo
Michael Dunphy	UBC, Vancouver
Mairi Edgar	BC Salmon Farmers Association
Michael Engelsjord	DFO, Fisheries Protection Program
Svetlana Esenkulova	UVic, Victoria
Boris Espinasse	UBC/Hakai
Rick Ferguson	DFO
Jonathan Fershau	DFO, Species at Risk Program
Linnea Flostrand	DFO, PBS, Nanaimo
Michael Folkes	DFO, PBS, Nanaimo
Mike Foreman	DFO, IOS, Sidney
Ian Forster	DFO
Rowan Fox	DFO, IOS, Sidney

Tamara Fraser	DFO, IOS, Sidney
Howard Freeland	DFO (retired), IOS, Sidney
Caihong Fu	DFO, PBS, Nanaimo
Moira Galbraith	DFO, IOS, Sidney
Katie Gale	DFO, IOS, Sidney
Lindsay Gardner	
Ryan Gasbarro	UVic, Victoria
Germain Gatien	DFO, IOS, Sidney
Erin Gertzen	DFO, Species at Risk Program
Lyse Godbout	DFO, PBS, Nanaimo
Steve Gormican	Camosun Collage, Victoria
Rhona Govender	Canadian Parks and Wilderness Society
Sue Grant	DFO, Delta
Cheryl Greengrove	University of Washington
Matthew Grinnell	DFO
Ben Grupe	DFO, IOS, Sidney
Lu Guan	DFO, IOS, Sidney
Christina Gulbransen	DFO
Nicky Haigh	VIU, Nanaimo
Charlotte Haley	DFO, Nanaimo
Ben Halpern	University of California, Santa Barbara
Mark Halverson	UBC, Vancouver
Charles Hannah	DFO, IOS, Sidney
Lucie Hannah	DFO, IOS, Sidney
Alex Hare	Hakai Institute
Chris Harvey	NOAA, NWFSC
Sarah Hawkshaw	DFO
Carly Haycroft	Province of British Columbia
Melissa Hennekes	DFO, IOS, Sidney
Margot Hessing-Lewis	Hakai Institute
Joy Hillier	DFO, Prince Rupert
Mark Hipfner	Canadian Wildlife Service, Delta
Maia Hoeberechts	Ocean Networks Canada, Victoria
Amber Holdsworth	DFO, IOS, Sidney
Roy Hourston	DFO, IOS, Sidney
Kim Houston	DFO, IOS, Sidney
Ann-Marie Huang	DFO
Brian Hunt	Hakai Institute
Karen Hunter	DFO, PBS, Nanaimo
Kim Hyatt	DFO, PBS, Nanaimo
Josie Iacarella	DFO, IOS, Sidney
Hilary Ibey	DFO, Vancouver
Robert Izett	UBC, Vancouver
Dave Jackson	DFO, CHS, IOS, Sidney
Jennifer Jackson	Hakai Institute
Marlene Jeffries	Ocean Networks Canada, Victoria
Shelley Jepps	DFO
Brett Johnson	Hakai Institute
Kirsten Johnson	DFO
Stewart Johnson	DFO, PBS, Nanaimo
Greg Jones	Environment Canada, IOS, Sidney
Eddy Kennedy	DFO, PBS, Nanaimo
Stephanie King	Sea This Consulting, Nanaimo

Maartje Korver	Hakai Institute
Christopher Krembs	Washington State Department of Ecology
Jason Ladell	DFO
Aleria Ladwig	DFO, Resource Management, Vancouver
Doug Latornell	UBC, Vancouver
Lynn Lee	Parks Canada
Erika Loc	Environment Canada, Canadian Wildlife Service
Andrea Locke	DFO, IOS, Sidney
Eddie Loos	ASL Environmental Sciences, Sidney
Carmel Lowe	DFO, Regional Director, Science
Jason Mahoney	DFO, Salmon Enhancement (Burrard St.)
Romney McPhie	MaPP
Steve Mihaly	Ocean Networks Canada, Victoria
Andrea Moore	DFO
Mike Morley	UVic, Victoria
Ken Morgan	Canadian Wildlife Service, Institute of Ocean Sciences, Sidney
Cathryn Clarke Murray	PICES North Pacific Marine Science Organization
Brian Naito	DFO, Fisheries Protection Program
Nina Nemcek	DFO, IOS, Sidney
Jessica Nephin	DFO, IOS, Sidney
Jan Newton	University of Washington, Seattle
Tammy Norgard	DFO, PBS, Nanaimo
Krista Northcott	DFO
Byron Nutton	DFO, Fisheries Protection Program
Miriam O	DFO, IOS, Sidney
Athena Ogden	DFO, PBS, Nanaimo
Patrick O'Hara	Environment Canada, IOS, Sidney
Tom Okey	Ocean Integrity Research, Victoria
Elise Olson	UBC, Vancouver
Stephen Page	DFO, IOS, Sidney
Tim Parsons	IOS, Sidney (emeritus)
Isobel Pearsall	Pacific Salmon Foundation, Vancouver
Angelica Peña	DFO, IOS, Sidney
Ian Perry	DFO, PBS, Nanaimo
Eric Peterson	Hakai Institute
Corinne Pomerleau	DFO, Biodiversity and Ecosystem Science, Ottawa
Erin Rechisky	Kintama Research Services, Nanaimo
Tessa Richardson	DFO, Fisheries Protection Program
Brenda Ridgway	DFO, PBS, Nanaimo
Marie Robert	DFO, IOS, Sidney
Gwil Roberts	DFO, CHS, IOS, Sidney
Steve Romaine	DFO, IOS, Sidney
Andrew Ross	DFO, IOS, Sidney
Tetjana Ross	DFO, IOS, Sidney
Saurav Sahu	UBC, Vancouver
Akash Sastri	Ocean Networks Canada, Victoria
Courtney Scarborough	University of California, Santa Barbara
Sarah Schroeder	UVic, Victoria
Jessica Schultz	Vancouver Aquarium, Vancouver
Steven Schut	DFO, Science advisor
Alison Scoon	
Sharlene Shaikh	DFO, Species at Risk Program
Lara Sloan	DFO, Communications Advisor

Ben Snow	DFO
David Spear	DFO, IOS, Sidney
Chelsea Stanley	DFO, IOS, Sidney
Kimberle Stark	King County Dept. of Nat. Res. & Parks, Seattle
Nadja Steiner	DFO, IOS, Sidney
Kira Stevenson	Province of BC, Ministry of Environment
Howard Stiff	
Margot Stockwell	DFO, PBS, Nanaimo
Karyn Suchy	UVic, Victoria
Megan Sullivan	Province of BC, Ministry of Environment
Andy Teucher	Province of BC, Ministry of Environment, State of the Env. Reporting
Amanda Timmerman	UVic, Victoria
Arlene Tompkins	DFO, PBS, Nanaimo
Karen Topelko	Province of BC, Ministry of Forests, Lands and Natural Resource Operations
Strahan Tucker	DFO, PBS, Nanaimo
Michael Turner	Province of BC, Ministry of Agriculture
Svein Vagle	DFO, IOS, Sidney
Peter Van Buren	DFO
Theresa Venello	UVic, Victoria
Brenda Waddell	DFO, PBS, Nanaimo
Kang Wang	UBC, Vancouver
Rachel Wang	WWF, Canada
Bill Wareham	David Suzuki Foundation
Maryann Watson	West Coast Environmental Law
Lauren Weir	DFO
Caroline Wells	DFO
Christie Whelan	DFO, PBS, Nanaimo
Thomas White	Province of BC, Ministry of Environment, Climate Action Secretariat, Victoria
Charlotte Whitney	UVic, Victoria
Frank Whitney	DFO, IOS, Sidney (emeritus)
Daniel Williams	DFO
Jasmine Wietzke	DFO, IOS, Sidney
Andy Witt	Province of BC, Ministry of Forests, Lands and Natural Resource Operations
Cecilia Wong	Environment Canada
Greg Workman	DFO, PBS, Nanaimo
Kristin Worsley	Province of BC, Ministry of Forests, Lands and Natural Resource Operations
Cynthia Wright	DFO, IOS, Sidney
Brianna Wright	DFO, PBS, Nanaimo
Jennifer Yakimishyn	Parks Canada
Lynne Yamanaka	DFO
Doug Yelland	DFO, IOS, Sidney
Kelly Young	DFO, IOS, Sidney
Stephani Zador	NOAA, NMFS