State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2017

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STATE OF THE PHYSICAL, BIOLOGICAL AND SELECTED FISHERY RESOURCES OF PACIFIC CANADIAN MARINE ECOSYSTEMS IN 2017

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 ecosystem conditions in 2017 was held March 7-8, 2018 at the Vancouver Island Conference Centre in Nanaimo, B.C. This technical report includes submissions based on presentations given at the meeting.

The warm surface ocean temperatures along the B.C. coast observed over the past few years have returned to levels consistent with the average conditions recorded in the standard climatology period 1981 to 2010. The upwelling of cool, nutrient rich water along the west coast of Vancouver Island started later than usual in 2017, and was not as intense as previous years, but conditions were still favourable for productivity and fish growth. Non-toxic coccolithophorid algal blooms occurred again in 2017 but not to the same extent as in 2016. There was a high occurrence of gelatinous pyrosomes and salps along the entire B.C. coast in 2017. As predicted the warm ocean conditions in 2015-2016 were unfavourable for the survival of B.C.'s central to south coast salmon. There was a coast-wide synchronous decline of Sockeye Salmon indicator stock returns in 2017.

A special session focused on the work being undertaken on Marine Protected Areas (MPAs). Several experts from a variety of government groups in Canada provided overviews of ongoing research in MPAs. An expert from DFO's Maritimes Region provided an overview of the State of the Atlantic Ocean report and how habitat and MPA information were incorporated into that National Ecosystem Reporting process.

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 coupleé aux événements et conditions dans tout le Pacifique, des tropiques aux régions sous Arctic. 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 2017 a eu lieu les 7-8 mars 2018 à Centre de Conférence de l'île de Vancouver, Nanaimo, C.B. Ce document technique inclut des rapports basées sur des présentations donnés lors de la rencontre.

Les températures de l'eau de surface de la Colombie-Britannique sont revenues à la moyenne de la période climatologique standard de 1981 à 2010.Les remontées d'eau riches en nutriments le long de la côte ouest de l'île de Vancouver a débuté plus tard que d'habitude en 2017 et n'était pas aussi intense que les années précédentes. Malgré cela, les conditions étaient favorables à la productivité et à la croissance du poisson. Il y avait des proliférations d'algues coccolithophoridiques non toxiques encore en 2017, mais dans une moindre mesure qu'en 2016. Il y avait une forte présence de pyrosomes gélatineux et de salpes tout le long de la côte. Comme prévu, les conditions marines chaudes en 2015-2016 étaient défavorables à la survie du saumon de la côte centrale à la côte sud de la C.B. Il y a eu un déclin synchrone des stocks de saumons rouges en 2017.

Une session spéciale a porté sur les travaux en cours sur les aires marines protégées (AMP). Plusieurs experts de divers groupes gouvernementaux au Canada ont fourni des aperçus de la recherche dans les AMP. Un expert de la région des Maritimes du MPO a donné un aperçu du rapport sur l'état de l'océan Atlantique et de la manière dont l'information sur l'habitat et l' AMP a été intégrée au processus national de rapport sur l'écosystème.

1. HIGHLIGHTS

- Ocean temperatures observed in 2017 show that the warm conditions associated with the marine heat wave of 2015-2016, known as the “Blob”, have diminished to near normal levels. La Niña conditions in the equatorial Pacific contributed to these cooler temperatures. Forecasts by the U.S. National Oceanic and Atmospheric Administration (NOAA) predict the La Niña to persist through the Northern Hemisphere winter 2017/18.
- Physical oceanographic processes associated with the marine heat wave, including increased stratification and reduced upwelling intensity of nutrients to surface waters, have reverted to more normal conditions that may favour primary production and fish growth. The phytoplankton community composition also showed a return to a more normal distribution.
- The zooplankton surveys off the southwest coast of Vancouver Island observed remarkable numbers of pyrosomes and salps along the entire B.C. coast. The pyrosomes had both negative (clogged fishing gear) and positive (integrated into the food web) impacts and are expected to last into 2018.
- Multi-species small-mesh bottom trawl surveys conducted annually in May off the west coast of Vancouver Island indicate pink shrimp biomass in 2017 continued to decline from the peak in 2014, with anomalies now below the climatological mean.
- In 2017, the spring spawning biomass of Pacific Herring showed near historic high levels in the Strait of Georgia, but low levels off Haida Gwaii. The biomass increased on the Central Coast, decreased on the west coast of Vancouver Island, and remained similar to 2016 in the Prince Rupert District.
- Record wet spring conditions in southern British Columbia with abundant snow early in the season followed by heavy rains and rapid snowmelt in late spring contributed to a higher than average Fraser River discharge in June that was observed as negative surface salinity anomalies in the Strait of Georgia.
- Based on satellite imagery and in situ measurements, the 2017 Strait of Georgia spring bloom had close to average start timing, was short in duration and moderate in magnitude relative to historical records. It started in mid-March in the central Strait, and mid-April in the northern Strait.
- There was a coast-wide synchronous decline of Sockeye Salmon indicator stock returns in 2017. As discussed at previous DFO State of the Pacific Ocean meetings the warm ocean conditions in 2015-2016 were unfavourable for the survival of B.C.’s central and south coast salmon.
- With the exception of 2015 the Fraser River Eulachon spawning stock biomass index has been at low levels since 2004.
- A special session focused on the work being undertaken on Marine Protected Areas (MPAs). Several experts from a variety of government groups in Canada provided overviews of ongoing research in MPAs.
- An overview of the State of the Atlantic Ocean report and how habitat and MPA information were incorporated into that National Ecosystem Reporting process was presented.

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 2017 (for conditions in 2016) is available at

http://waves-vagues.dfo-mpo.gc.ca/Library/40617944.pdf

In 2018, the meeting on conditions observed on the west coast of Canada (Figure 2-1) in 2017 took place on March 7 and 8 at the Vancouver Island Conference Centre, Nanaimo, 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.

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

DFO Pacific's Regional Science Director, Carmel Lowe, gave opening remarks, then Snuneymuxw First Nations' Elder Lolly provided a ceremony and prayer to welcome participants to the Snuneymuxw territory. The main session included 39 presentations covering a range of observations from 2017. The special session included 8 presentations by invited speakers and focused on the work being planned or undertaken on Marine Protected Areas (MPAs). Several experts from a variety of government groups in Canada provided overviews of ongoing research in MPAs and a representative from DFO's Maritimes Regions provided an overview of the State of the Atlantic Ocean report and how habitat and MPA information were incorporated into that

National Ecosystem Reporting process. Information from the special session could form the basis of a case study, as undertaken by the Maritimes Region as part of DFO's Ecosystem Reporting Initiative.

At the end of the first day a poster session and mixer was held with support from Ocean Networks Canada. Fifteen posters were presented in conference centre while participants enjoyed snacks and refreshments. A poster on unusual marine events in 2017 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

Since 2014 the waters off the B.C. coast have been characterised by surface and subsurface temperatures well above normal which are unfavourable for the productivity and growth of species that typically inhabit these waters. Sea surface conditions observed in 2017 show a return to cooler temperatures, more consistent with the 30 year (1981-2010) climatology (Ross and Robert, section 7). The multivariate El Niño/Southern Oscillation (ENSO) Index (Figure 3-1) shows the cooling effects of a negative index, associated with La Niña, at the start and end of the year.

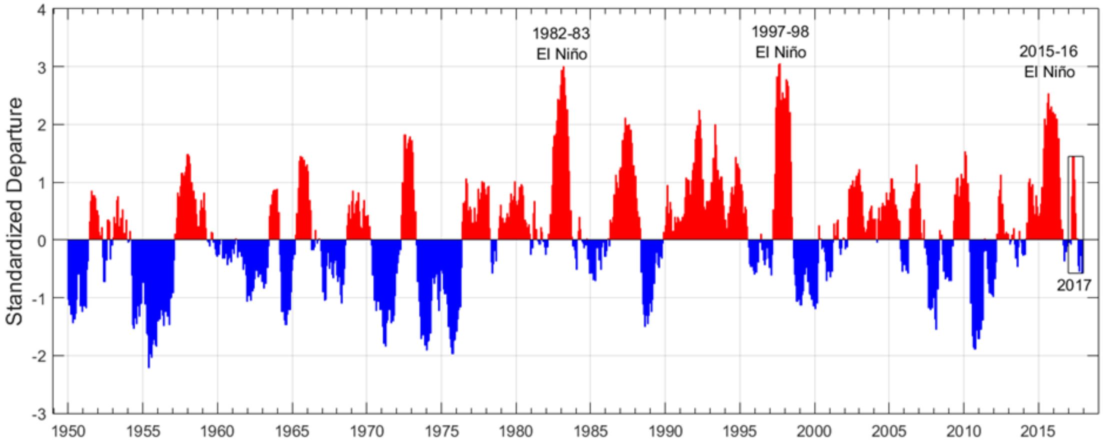

Figure 3-1. The multivariate ENSO Index. Data source: NOAA/ESRL/Physical Sciences Division – University of Colorado at Boulder/CIRES.

The marine heat wave ("the Blob") that was first observed in the Northeast Pacific in late 2013 was associated with reduced vertical mixing causing increased winter stratification during 2013/14, 2014/15 and 2015/16. Winter stratification in 2016/17 returned to levels similar to the winters of 2010/11 and 2011/12 (Figure 3-2; Ross and Robert, section 7). This suggests that there will be increased upwelling and nutrient supply from deep waters resulting in conditions that better support primary production and fish growth.

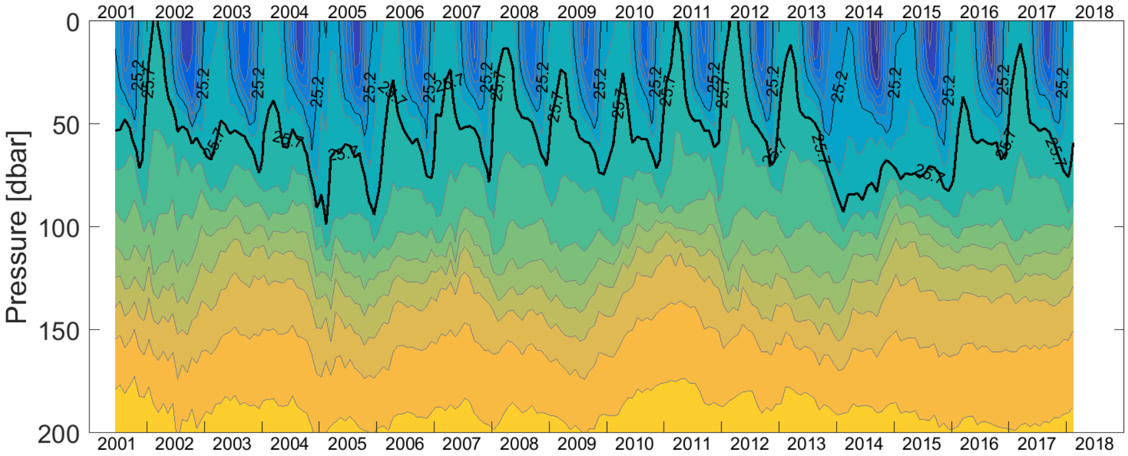

Figure 3-2. Coloured contour plot of density as observed by Argo floats near Ocean Station Papa (Figure 2-1). The colours indicate density (yellow is denser and blue lighter). The black lines highlight the r=1025.2 kg/m^3 (thin) and 1025.7 kg/m^3 (thick) isopycnals. Source: Ross and Robert, section 7.

While surface temperatures in 2017 were near normal the subsurface temperatures (based on the interpolation of Argo float data onto the location of Station Papa) show a strong warm anomaly between 100 and 200 m until about November 2017 (Figure 3-3).

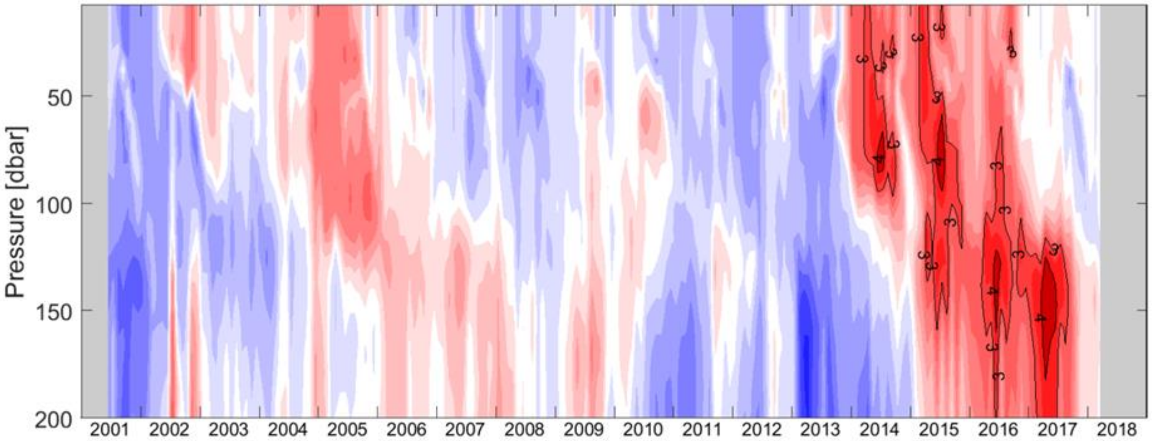

Figure 3-3. False colour plot of temperature anomalies relative to the 1956-2012 seasonally-corrected mean and standard deviation (from the Line P time series), as observed by Argo floats near Station Papa (P26: 50° N, 145° W); red – above average, blue – below average with darker colours corresponding to larger anomalies. The black lines highlight regions with anomalies that are 3 and 4 standard deviations above the mean. Source: Ross and Robert, section 7.

Despite the cooling conditions observed in 2017 the long term record of surface temperatures collected at lighthouses along the B.C. coast shows that overlying the multi-year oscillations in the annual sea surface temperature there remains a long-term trend towards rising ocean temperatures (Figure 3-4; Chandler, section 10).

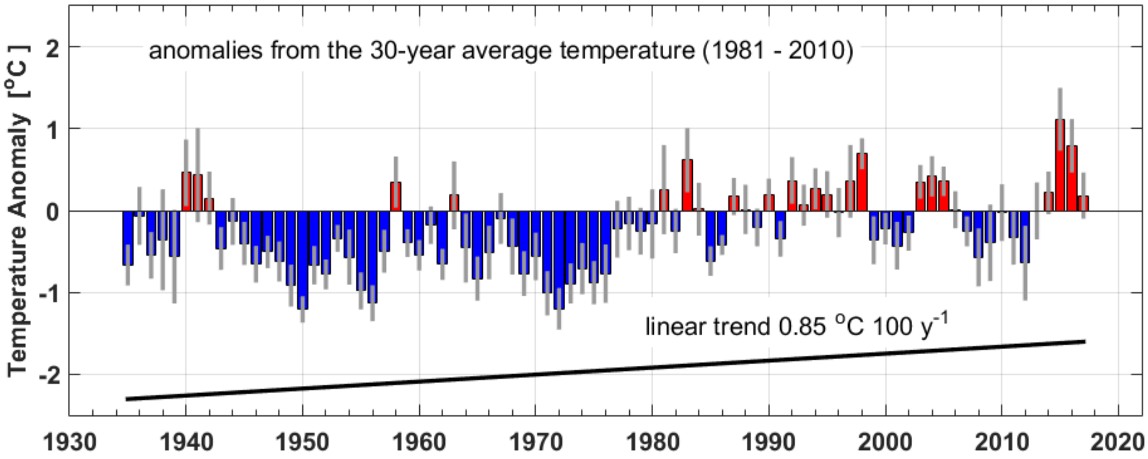

Figure 3-4. The trend in the annual temperature based on daily observations at B.C. lighthouses. The data shown are the anomalies from the average temperature (1981-2010). The bars represent the anomalies averaged over all stations (a coast wide indicator), (red – above average, blue – below average), the vertical grey lines show the variability in the lighthouse data for each year. Source: Chandler, section 10.

The upwelling of nutrient rich water off the west coast of Vancouver Island is an indicator of marine coastal productivity across trophic levels from plankton to fish to birds. Variability in the upwelling index corresponds to the strength and east-west position of the Aleutian low-pressure system in the Gulf of Alaska. Above average productivity is associated with an early and strong upwelling. The intensity of the upwelling in 2017 was average to late (Hourston and Thompson, section 6). There was also an average to late start to the season resulting in a negative index of upwelling productivity (Figure 3-5).

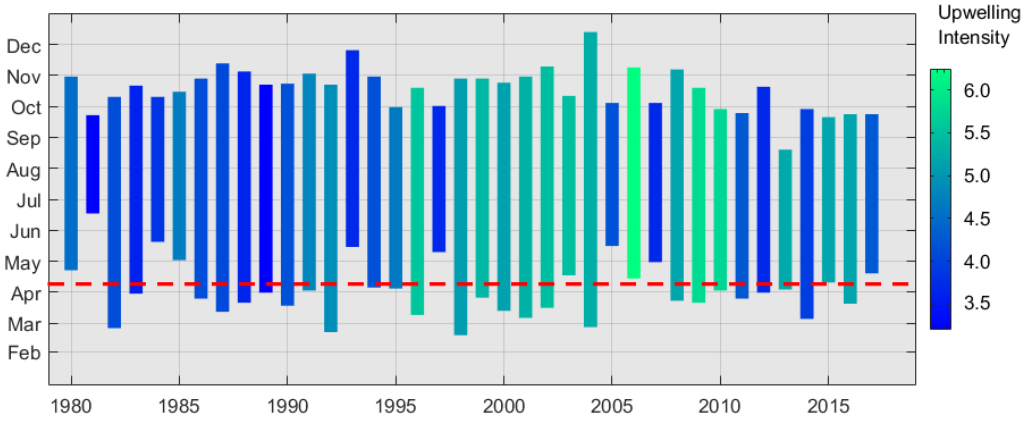

Figure 3-5. The upwelling index for the west coast of British Columbia. The length of the bar corresponds to the duration of the upwelling season, coloured by the intensity of the upwelling. The dashed red line indicates the average start to the upwelling season. Data source: NOAA/OAR/ESRL/Physical Sciences Division – University of Colorado at Boulder; https://www.esrl.noaa.gov/psd/data/.

On the west coast of B.C., the phytoplankton biomass and community composition returned to conditions observed prior to the marine heat wave, except for the most offshore stations of Line P, where a high abundance of diatoms was observed (Peña and Nina Nemcek, section 13; Batten, section 15).

The zooplankton surveys off Vancouver Island revealed fewer subarctic and boreal copepods that are favourable for fish growth, as well as higher abundances of southern copepods, consistent with warmer ocean temperatures (Galbraith and Young, section 16). By June 2017 the continental margin of B.C. was inundated with large masses of gelatinous animals: mainly pyrosomes on the shelf to shelf break, doliolids along the shelf break, and hydromedusae and ctenophores across all shelf areas (Figure 3-6).

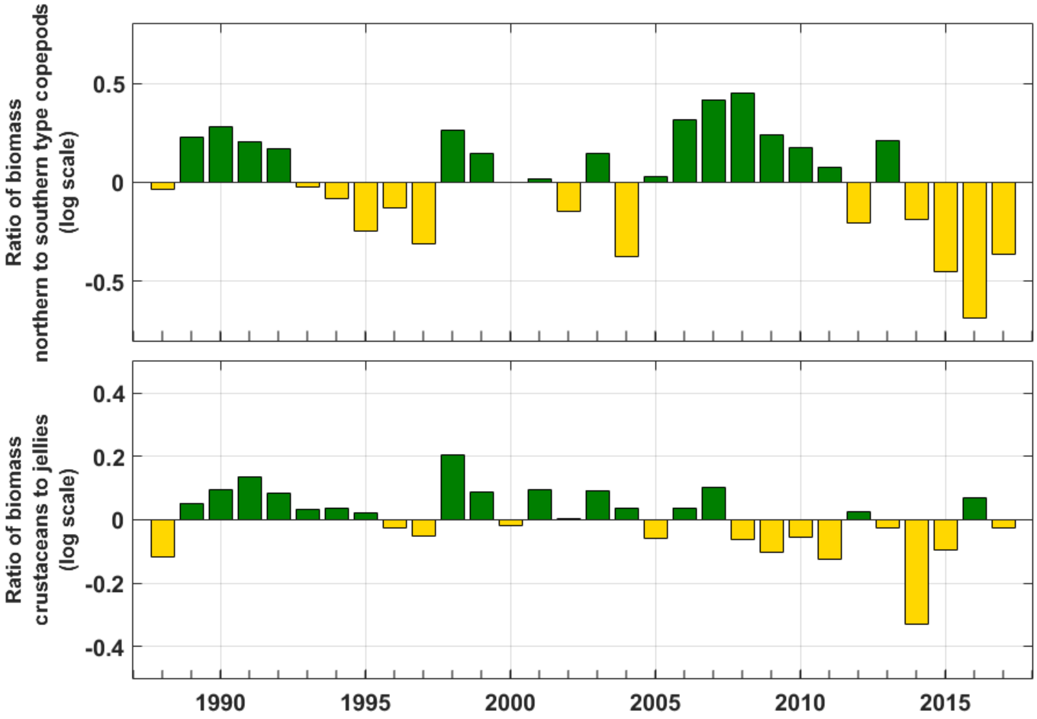

Figure 3-6. The 1988-2017 time series of yearly averaged anomalies of zooplankton biomass off southern Vancouver Island. (Top) the ratio of northern to southern species of copepods; (Bottom) the ratio of crustaceans to jellies. Green – fish food favourable, amber - less favourable fish food conditions. Source: Moira Galbraith.

Off the west coast of Vancouver Island Pink Shrimp biomass in 2017 continued to decline from the peak in 2014, with anomalies below the climatological mean (Perry et al., section 21). The population density of Northern Abalone on the East Coast of Haida Gwaii is increasing and abalone are more widely dispersed; however the size structure is highly skewed towards smaller, immature abalone (Curtis, section 17). Trends observed in multiple groundfish surveys include a decline in North Pacific Spiny Dogfish abundance and increase in Sablefish abundance over the last two to three years (Workman, section 22).

The warmer water temperatures observed in the Strait of Georgia over the past few years cooled in 2017 to levels consistent with average conditions since the water properties surveys began in 1999 (Chandler, section 33). Depth profiles of temperature made in the central Strait (near Nanoose) showed a return to winter cooling that had been absent since 2014 (Figure 3-7). The depth averaged temperatures continue to be higher than the long-term average. Salinities in the upper 200 m were fresher than normal during the spring and summer. The influence of the Fraser River discharge is particularly evident in the salinity of the surface waters of the central and southern Strait of Georgia. While the 2017 annual discharge of the Fraser River (as measured at Hope, B.C., Figure 3-8) was near the 100 year average there was a higher than average discharge in June due to snowmelt and late in the year due to rainfall events, that was observed as low surface salinity (Chandler, section 33).

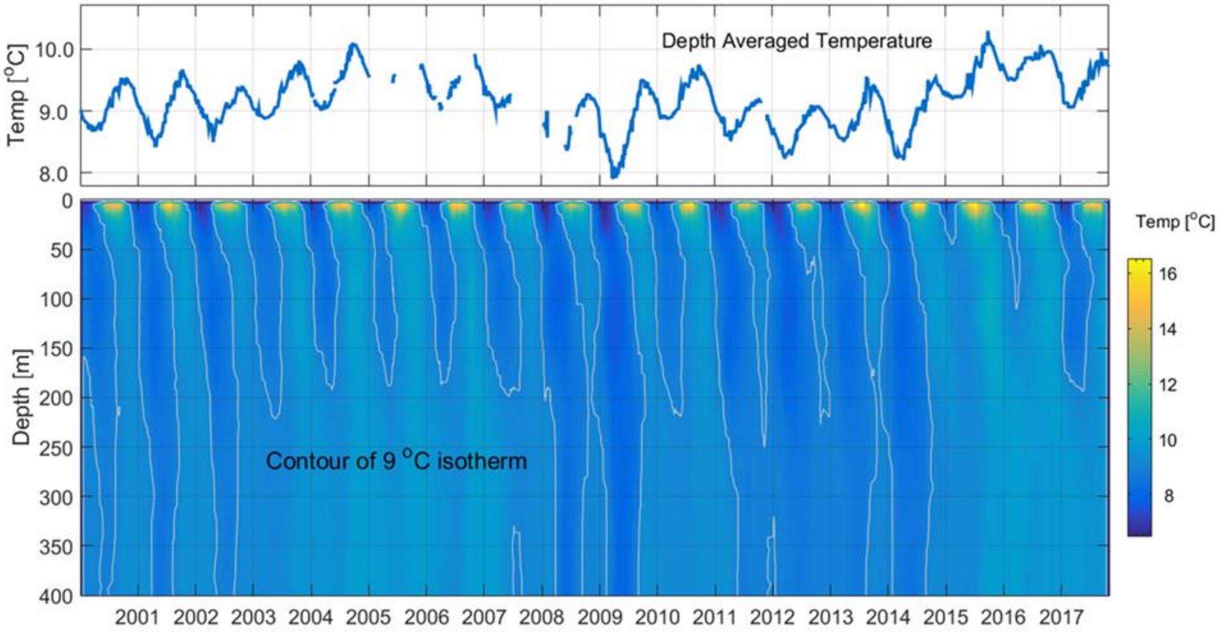

Figure 3-7. The time series of depth averaged temperature collected near Nanoose in the central Strait of Georgia (upper); the vertical distribution of these data (lower). Source: Canadian Forces Maritime Experimental and Test Ranges (CFMETR).

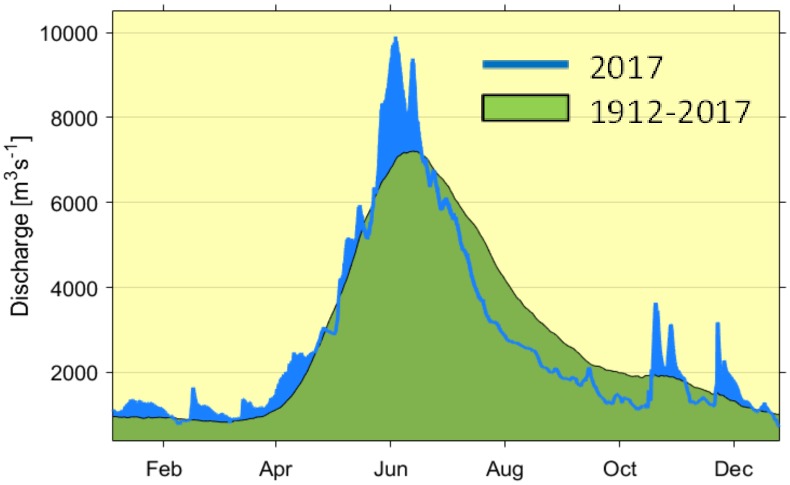

Figure 3-8. Fraser River discharge at Hope B.C.; 2017 (blue), 105 year average (green). Data source: The Water Survey of Canada).

In the Strait of Georgia (SoG) moderate levels of harmful algal species (*Dictyocha* spp.) that are toxic to salmon were observed in 2016 and 2017; however, there were no significant *Heterosigma akashiwo* blooms (Esenkulova et al., section 39). The biomass of most zooplankton taxa was above-average in 2017. The abundance of large copepods (*Neocalanus plumchrus*) was near average in 2017 but the timing of peak biomass has shifted to earlier in the year, potentially creating a mismatch with its predators (Young et al., section 40). The timing of the spring phytoplankton and subsequent zooplankton blooms in the Strait of Georgia are linked to the survival of herring larvae. Although there are regional differences, in general, the

2017 spring phytoplankton bloom had average start and peak times, was short in duration, and was moderate in magnitude relative to historical records (Gower and King, section 12; Costa et al., section 38). Species composition of the 2017 spring bloom was typical with a mix of three diatom species (Esenkulova et al., section 39).

In 2017, the spring spawning biomass of Pacific Herring showed near historic high levels in the Strait of Georgia, but low levels off Haida Gwaii (Cleary et al., section 18). The biomass increased in the Central Coast, decreased on the west coast of Vancouver Island, and remained similar to 2016 in the Prince Rupert District (Figure 3-9). During 2013-2017, the relative biomass of age-0 herring in the SoG was low and stable compared to the peaks within the time series; however, individuals were in good condition (Boldt et al., section 41). Anchovy were observed in more survey catches in the SoG than in previous years (Neville, section 43). Eulachon returns varied by river; for example returns to the Fraser River continued to decline but large returns were observed in Kingcome River during 2015-2017 (Flostrand et al., section 19).

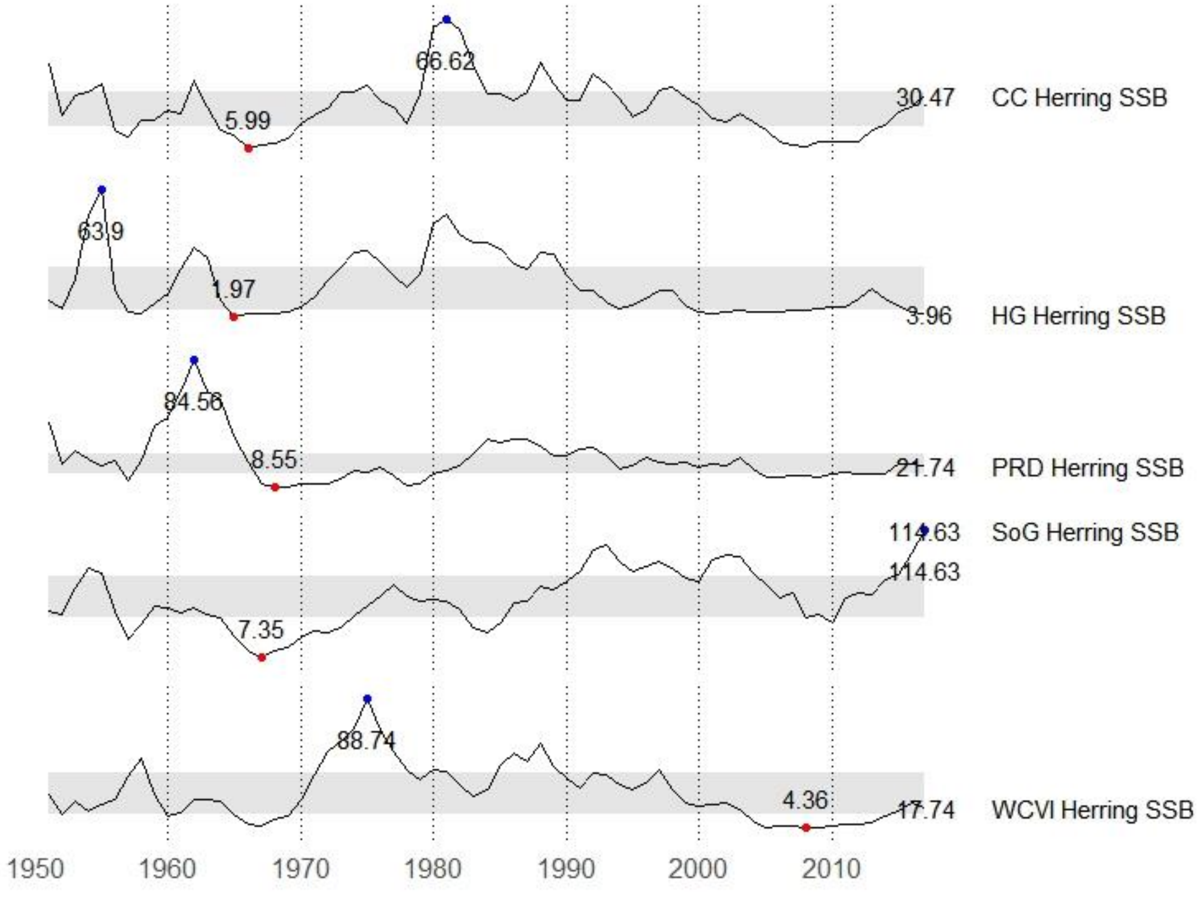

Figure 3-9. Herring spawning biomass in five major stock areas of B.C: Central Coast (CC), Haida Gwaii (HG), Prince Rupert District (PRD), Strait of Georgia (SoG), and West Coast of Vancouver Island (WCVI), 1951-2017. Minimum (red), maximum (blue) values are shown with circles and values, values for 2017 are shown, and the shaded ribbons encompass the 25% to 75% quartiles.

There was a coast-wide synchronous decline of Sockeye Salmon indicator stock returns in 2017 (Figure 3-10; Hyatt et al., section 26). As discussed at previous DFO State of the Pacific Ocean meetings the warm ocean conditions in 2015-2016 were unfavourable for the survival of B.C.'s central to south coast salmon returning in 2017 and 2018. Also, freshwater conditions (high temperatures, early freshets, and summer drought) likely negatively impacted smolt production in 2015, affecting adult returns two years later.

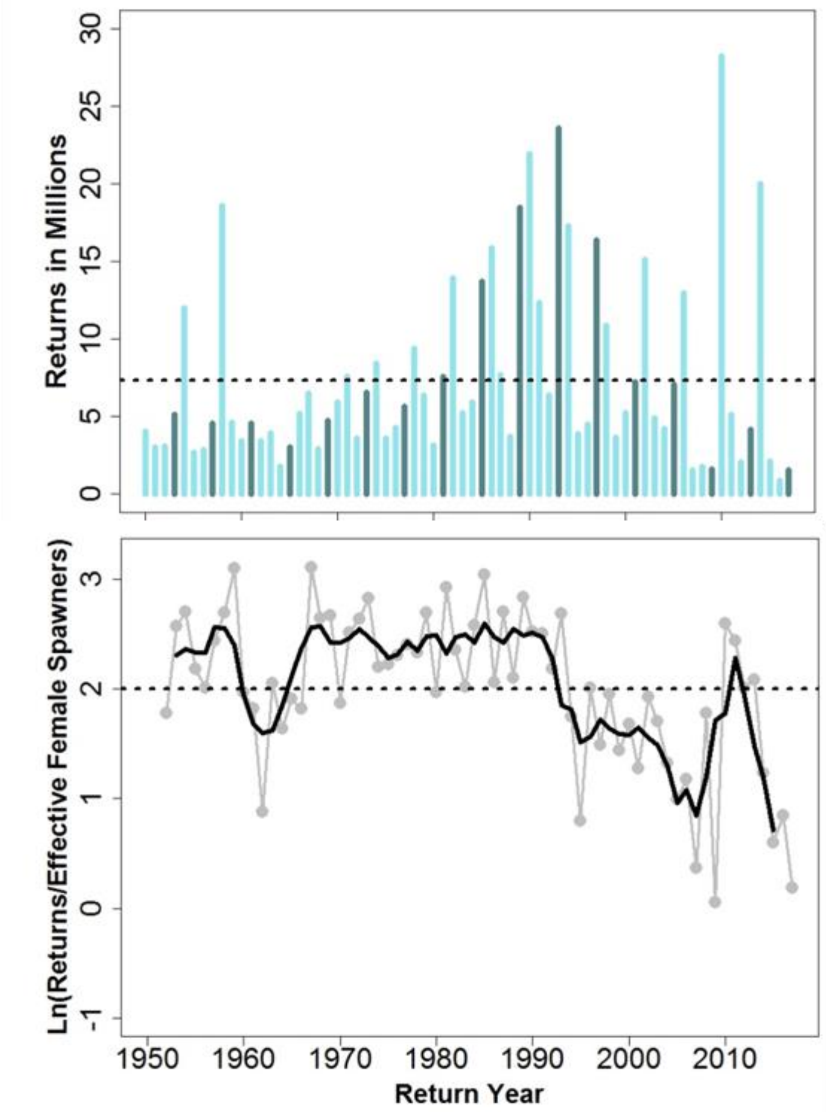

Figure 3-10. Top panel: Total Fraser Sockeye annual returns (dark blue vertical bars for the 2017 cycle and light blue vertical bars for the three other cycles). Recent returns from 2012 to 2017 are preliminary, and 2017 (the last data point) is an in-season estimate only. Bottom panel: Total Fraser Sockeye productivity (log$_e$ (returns/total spawner)) is presented up to the 2017 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. (Source: Grant et al., section 45).

4. ACKNOWLEDGMENTS

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

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

5. LAND TEMPERATURE AND HYDROLOGICAL CONDITIONS IN 2017

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5.1. Highlights

- Winter was cool and snowy in southern British Columbia while relatively warm and dry in the north.
- There were record wet spring conditions in southern British Columbia with abundant snow early in the season then heavy rains and rapid snowmelt in late spring.
- Record hot and dry conditions were observed in many areas of the province during the summer.
- Recent temperature and precipitation trends are consistent with climate change projections and recent warm El Niño events.

5.2. Description of the time series

Observations of near surface temperature and precipitation in British Columbia are collected by Environment and Climate Change Canada (ECCC), B.C. Ministry of Transportation, B.C. Ministry of Forests Lands Resource Operations and Rural Development, B.C. Ministry of Environment, B.C. Ministry of Agriculture and the provincial electrical utility, B.C. Hydro. These observations are compiled into a single database at the Pacific Climate Impacts Consortium (PCIC) on an ongoing basis for analysis and public redistribution as part of an agreement between the ministries, B.C. Hydro and PCIC with ECCC playing a supporting role. These observations are quality controlled by the individual agencies to their internal standard and no further quality control was applied.

Temperature and precipitation data were averaged and summed to monthly values respectively. Minimum and maximum daily temperatures (Tmin and Tmax, respectively) were analyzed independently. Precipitation was analyzed as monthly totals of liquid water or liquid water equivalent for locations with observed snow. A data coverage requirement of 85% is imposed for a monthly value to be computed which translates to 27 or more days of observations for months with 31 days. No consecutive missing value criteria were applied. The monthly values were converted to anomalies using 1981 – 2010 climate normal values computed from the combined ECCC and B.C. provincial dataset. Temperature anomalies were a simple difference between the observed monthly average and the climatology. Precipitation anomalies were calculated in percent using:

$$P' = 100 * \left(\frac{(P - \bar{P})}{\bar{P}} - 1 \right)$$

Where P' is the precipitation anomaly, P is the observed monthly total precipitation and $\bar{P}$ is the climatological average precipitation.

For analysis of trends and anomaly rankings, the monthly anomalies were interpolated onto a 0.5 degree geographical grid and regional averages for seasons and the annual period were calculated. Trends were computed from these regional averages as well as for B.C.-wide averages. The gridded climate anomaly product spans 1900 until the present, but the first 50 years of record for precipitation are less reliable due to the greater spatial variability of precipitation than temperature and the less dense observational network in the early 20th century. For this report the B.C. Ministry of Environment River Forecast Centre's snow index basins were used to define regions. These align with other analyses in the province and strike a balance between granular representation of spatial variability while retaining large enough regions to ensure statistical robustness.

5.3. Status and trends

5.3.1. Temperature anomalies

From the annual perspective, temperatures were warmer than the long-term average in British Columbia ranking 14th and 32nd warmest for Tmin and Tmax respectively within the 118 year 1900 – 2017 record (Table 5-1). As has been true in previous years, anomalies of daily minimum temperature have been greater than those for daily maximum temperature. Daily minimum was above normal everywhere excepting the northeast where it was much above normal. Daily maximum temperature was near normal in the central and southwest of the province and above normal in the north and southeast. The winter of 2016/17 was overall cool in the south and warm in the north with average temperatures in central B.C. Winter and spring temperature in British Columbia is strongly influenced by tropical El Niño–Southern Oscillation (ENSO) conditions and this past winter was a moderate La Niña event. The observed cold temperatures are typical of such an event in B.C. (Rodenhuis et al. 2009) as is a tendency for lower than normal precipitation amounts in northern B.C. In spring, patterns of anomalies began La Niña like, but tended toward growing preponderance of warm anomalies with May above or much above normal in the south and north respectively resulting in an overall seasonal average near normal (Figure 5-1a). The anomalous warmth of late spring increased into summer where the seasonal average maximum daily temperature was record breaking in eastern regions of the province (Figure 5-1c). Temperatures were never record hot on the monthly average, but daily temperature records were broken in late June and early July. These conditions corresponded with wildfire ignition events and ultimately the worst wildfire season ever recorded in British Columbia (British Columbia Government 2018). For B.C. as a whole, summer ranked as the 4th hottest on record for Tmax and 14th warmest for Tmin (Table 5-1). Fall conditions brought cool anomalies leading toward a second consecutive La Niña event beginning in the winter of 2017/2018. Still, September was much above normal for averages of daily minimum temperature across the entire province.

Table 5-1. The hierarchical ranking of the 2017 average for each variable for each season is also given with low ranks indicating hottest/wettest conditions and high ranks indicating coldest/driest. Records would be ranks of 1 or 118 in this 118 year record.

2017 Anomaly Ranking	Tmax	Tmin	Precip
Annual	32	14	57
Winter	96	54	96
Spring	55	21	2
Summer	4	14	111
Fall	57	48	14

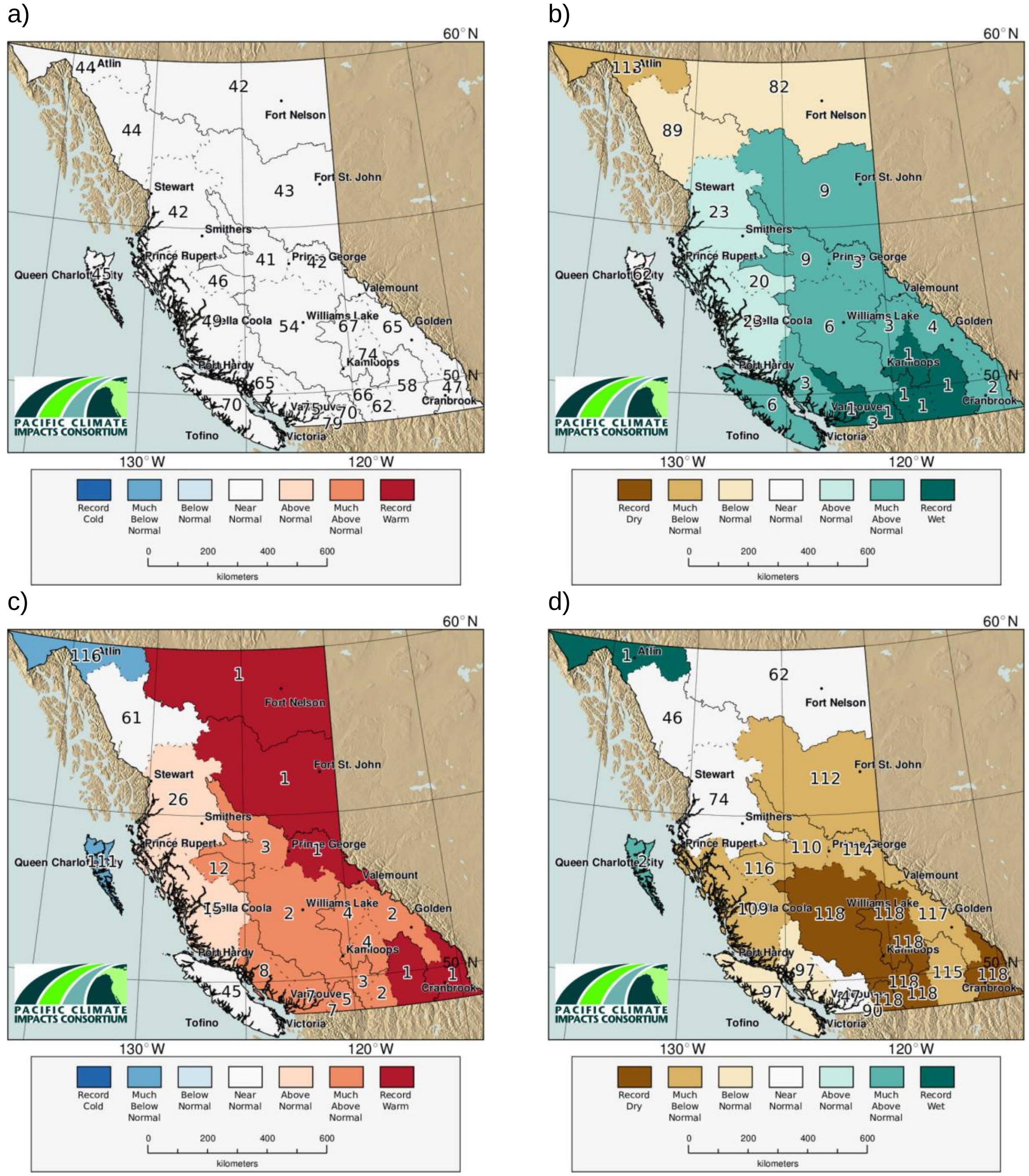

*Figure 5-1. 2017 percentile anomaly maps for **a)** spring average daily maximum temperature, **b)** spring total precipitation, **c)** summer average of daily maximum temperature, and **d)** summer total precipitation. Regional divisions are based on B.C. Ministry of Environment River Forecasting Centre Snow Index Basins. Numbers indicate ranking of the anomaly with low values indicating warm/wet and high values indicating cold/dry for temperature and precipitation respectively.*

5.3.2. Precipitation anomalies

In the annual average sense, precipitation was near normal across B.C. ranking 57th wettest on record (median is 59th) as shown in Table 5-1. Above normal amounts were received in the Okanagan and northern Rockies and below normal amounts in the far northwestern parts of the province. The individual seasons displayed more variability. Winter was dry across almost all of B.C. with below normal amounts recorded along the coast and northward of approximately 53 °N. Southern B.C. was near normal with the exception being the far southeast corner where above normal precipitation was recorded. Spring was dramatically wet everywhere in the province except north of approximately 57 °N where near normal or drier than normal conditions prevailed. The precipitation amounts were extreme with seasonal records set in the south that were accompanied by flooding and evacuations. Except the Central Coast, all regions that were wetter than normal were among the top ten wettest spring seasons in the 118 year record analyzed here (Figure 5-1b). The provincial average spring precipitation anomaly ranked as second wettest in the 1900 to 2017 record (Table 5-1). The transition to summer was very abrupt. June, July and August were drier than normal everywhere except northwestern and northern BC. On the seasonal average, the dryness was record setting throughout the southern interior and southeastern BC (Figure 5-1d) and over BC as a whole, the season ranked 111th wettest (8th driest) within the long-term record (Table 5-1). This lack of precipitation combined with record setting daily maximum temperatures caused rapid drying of fuels helping to promote the extreme fire season that B.C. experienced. Fall marked a return to wetter than normal conditions with much of B.C. recording above normal or much above normal precipitation amounts although December was extremely dry in northern B.C. and drier than normal almost everywhere in the province.

5.3.3. Evolution of winter and spring snowpack

The B.C. Ministry of Environment River Forecast Centre issues a monthly analysis of snow accumulation and depletion throughout the winter and spring seasons. The data are used to indicate potential flood risk and water supplies in the province. During winter, snow was at near normal amounts to slightly below normal in southern B.C. and as much as 50% below normal in northern B.C. with the transition occurring in the upper Fraser and Skeena-Nass watersheds. These patterns are in agreement with the precipitation patterns observed in winter indicating that precipitation rather than temperature was the driving factor. The pattern of more snow in southern B.C. and less in northern B.C. was continued into spring with some southern watersheds showing rapid gain and reaching almost 150% of normal snowpack by 1 May, 2017 (e.g. the Similkameen and Okanagan). Meanwhile, northern watershed snowpacks recovered but the furthest north basins remained below normal at ~60% of normal amounts. Changes in accumulated snow in spring again matched the precipitation patterns over the province. Snowpacks depleted rapidly in May and June in the north leading to amounts below 50% of normal by June 1 while snowpacks persisted into June in southern B.C. helping to supply snowmelt during the warm and wet flooding during spring, 2017.

5.3.4. Trend analysis

Using the gridded climate data described in section 5.2, trends in seasonal and annual averages were analyzed across the province. Three periods were chosen for analysis: 1900 – 2017, 1950 – 2017 and 1980 – 2017 shown in Table 5-2. These reflect the capabilities of the dataset as well as periods relevant for analyzing long-term to decadal climate change and variability. The 1900 to present period is indicative of long-term climate change due to both natural and anthropogenic forcing. Trends were calculated for both temperature and precipitation over this period, but the data for precipitation must be taken with caution given the sparse observational network in the first half of the 1900s that greatly increase the uncertainty in estimating province-wide precipitation anomalies. The period 1950 – 2017 is indicative of climate change under more dominant anthropogenic forcing although natural forcing and natural variability also play a role over the shorter time span. The temperature and precipitation data are suitable for analysis at this and more recent, shorter periods of record. Finally, the period from 1980 to present was analyzed to indicate what recent trends in the variables have been. One needs to take great care when considering trends in climate variables over these relatively short timescales. First, trend detection is much less certain over shorter records because temperature and precipitation display large interannual variability especially when calculating trends over seasonal or shorter averages. Second, decadal variability that accompanies fluctuations in the strength and frequency of ENSO events can play a very strong role. The short-term trends are displayed only to indicate recent fluctuations in observed values and should not be used to make an interpretation of large-scale anthropogenically forced climate change.

Table 5-2. Annual and seasonal trends in averages of daily minimum and maximum temperature and totals of precipitation for the 1900 - 2017, 1950 - 2017, 1980 - 2017 long-term record from BC-wide averages. Statistical significance at the 5% level is indicate by bold numbers. Precipitation trends for the 1900 to 2017 period were statistically significant but are deemphasized owing to uncertainties associated with the insufficient observational coverage for precipitation during the early 20th century in BC.

	1900-2017			1950-2017			1980-2017		
	Tmax °C yr^{-1}	Tmin °C yr^{-1}	Precip % yr^{-1}	Tmax °C yr^{-1}	Tmin °C yr^{-1}	Precip % yr^{-1}	Tmax °C yr^{-1}	Tmin °C yr^{-1}	Precip % yr^{-1}
Annual	**0.008**	**0.023**	0.17	**0.022**	**0.031**	0.06	0.019	**0.025**	0.02
Winter	**0.02**	**0.032**	0.18	**0.042**	**0.059**	-0.2	0.028	0.048	0.01
Spring	0.009	**0.021**	0.19	0.023	**0.031**	**0.29**	-0.007	0	**0.57**
Summer	0.004	**0.025**	0.2	**0.015**	**0.022**	0.14	**0.035**	**0.029**	-0.26
Fall	0	**0.015**	0.18	0.008	0.016	**0.24**	0.008	0.019	0.15

Beginning with trends in annual averages/totals, we see significant increasing trends for all variables at the 118 year timescale (Table 5-2). Among the temperature variables, Tmin shows a strong increasing trend that is in agreement with the predominance of warm (or less cool) anomalies in that variable over recent years and is an effect that has been documented globally although to a varying degree in more recent years (Hartmann et al. 2013). The trend for precipitation is positive and statistically significant for this long period only, but we have low confidence in this result given the issues of station coverage described above. Over the 1950 – 2017 period, temperature shows stronger warming rates. This does not necessarily indicate acceleration in climate change because decadal influence on the trends at this timescale cannot be ruled out. Finally, over the shortest period, only Tmin shows a significant trend for annual averages while other trends are positive but not statistically significant. This lack of statistically significant trend is indicative of the influence of decadal scale climate variability and the difficulty of quantifying trend in short observational records.

On a seasonal basis over the 1900 – 2017 period, Tmin and precipitation show statistically significant increasing trends for all seasons. Tmin is increasing in winter and summer the most quickly and winter overall shows the strongest trends over the longest time scale. Over the 1950 – 2017 period (Table 5-2), Tmin shows significant increases over all seasons except fall, the season for which temperature trends are the weakest at all time intervals. Precipitation shows significant increasing trends for spring and fall and an insignificant decreasing trend for winter. The only statistically significant short-term trends (Table 5-2) are for precipitation in spring which shows an increase of 0.57 % yr^{-1} and temperature in summer which shows a strong increasing Tmax trend of 0.035 °C yr^{-1} and Tmin trend of 0.029 °C yr^{-1}. These short-term trends are strongly influenced by natural variability and subject to spurious statistical significance due to the short period of analysis in light of that variability. This result awaits confirmation in subsequent years.

5.4. Factors influencing trends

The recent temperature and precipitation anomalies in winter 2016/17, spring 2017, and again in early winter 2017/18 have been influenced by the predominance of the La Niña pattern in the tropical Pacific Ocean. This is associated with colder than normal temperatures in southern B.C. and a tendency toward wetter than normal conditions although with a weaker link for that variable. The causes of the strong hot and dry temperature and precipitation anomalies in summer have not yet been identified nor distinguished from natural variability in B.C.'s climate.

The longest-term trends, over the period 1900 – 2017 are less affected by decadal scale natural climate variability and are more indicative of longer-term forcing associated with warming from the late 19th century global cool period and the increased forcing from anthropogenic emissions as the century progressed. We stress that the long-term precipitation trends are less reliable due to deficiencies in the observing network early in the 20th century. The intermediate length 1950 – 2017 period span the period when anthropogenic emissions began to supersede natural variability on the global and regional scales (Bindoff et al. 2013, Jones et al. 2013). However, decadal variability will also play a role in these trends. Discerning the factors that influence precipitation is challenging because of the large spatial and temporal variability of precipitation. Both anthropogenic and natural forcing linkages with precipitation trends are weak at all time scales when looking at regions the size of B.C. (Hartmann et al. 2013). The 1980 – 2017 period is likely strongly influenced by decadal variability in addition to ongoing global climate processes. We note that from 1998 through 2012, cold, La Niña conditions were more frequent than El Niño conditions and likely helped suppress temperature change in B.C. over that time. Only the most recent five years have seen a return to strong warming culminating in record setting 2015 and 2016 annual and seasonal average temperature in B.C. and globally.

5.5. Implications of those trends

Probably the most striking feature of British Columbia's weather in 2017 was the juxtaposition of extreme wet and moderately cool conditions in spring with extreme hot and dry conditions in summer. Some indication of this is apparent in the 1980 – 2017 trends. They show significant increases in spring precipitation with no temperature trend and strong, statistically significant, increases in summer temperature and non-significant decreases in summer precipitation. Taken together, this suggests that intensification of seasonality between spring and summer both in 2017 and in the recent trend data has been occurring, but more years of observation are needed to discern if this is a feature of climate change in B.C.

Both the wet spring in 2017 and the hot and dry summer required abundant provincial resources first for flood evacuation and repairs then for fire evacuations and fire suppression over a short overall span of time. If the trends observed over the 1980 – 2017 period continue, a similar pattern of events could occur in the future and place increased demands on agencies that support flood relief or those that manage wildfire.

The longer term trends are indicative of the climate response in B.C. to global changes in greenhouse gasses. Temperatures are rising overall with strongest trends in winter. Precipitation has shown non-significant increases during the 1950 – 2017 period with reliable records. Spring and fall show statistically significant increases while a statistically non-significant decline in winter precipitation is indicated.

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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 and alongshore currents, the 2017 Spring Transition timing was average to later-than-average relative to the historical (1981 – 2010) mean. The magnitude of the upwelling-favourable winds during the summer of 2017 was average to below-average.
- Considered together, the timing and magnitude of the upwelling-favourable winds and currents would have supported average to below-average upwelling-based productivity along the southwest coast of Canada in 2017.
- The winters of 2016/17 and 2017/18 were characterized by periods of both stronger and weaker than average downwelling winds along the west coast of North America. This variability was due to variations in the strength of the Aleutian Low and east-west shifts in its position.
- Surface and subsurface anomalies of temperatures and poleward winds/currents at the shelf break were positive at the beginning of 2017, reflecting recent El Niño conditions in the Pacific Ocean. Conditions returned to near average at the surface during the rest of the year (with no data available subsurface after May).

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 and Climate Change 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).

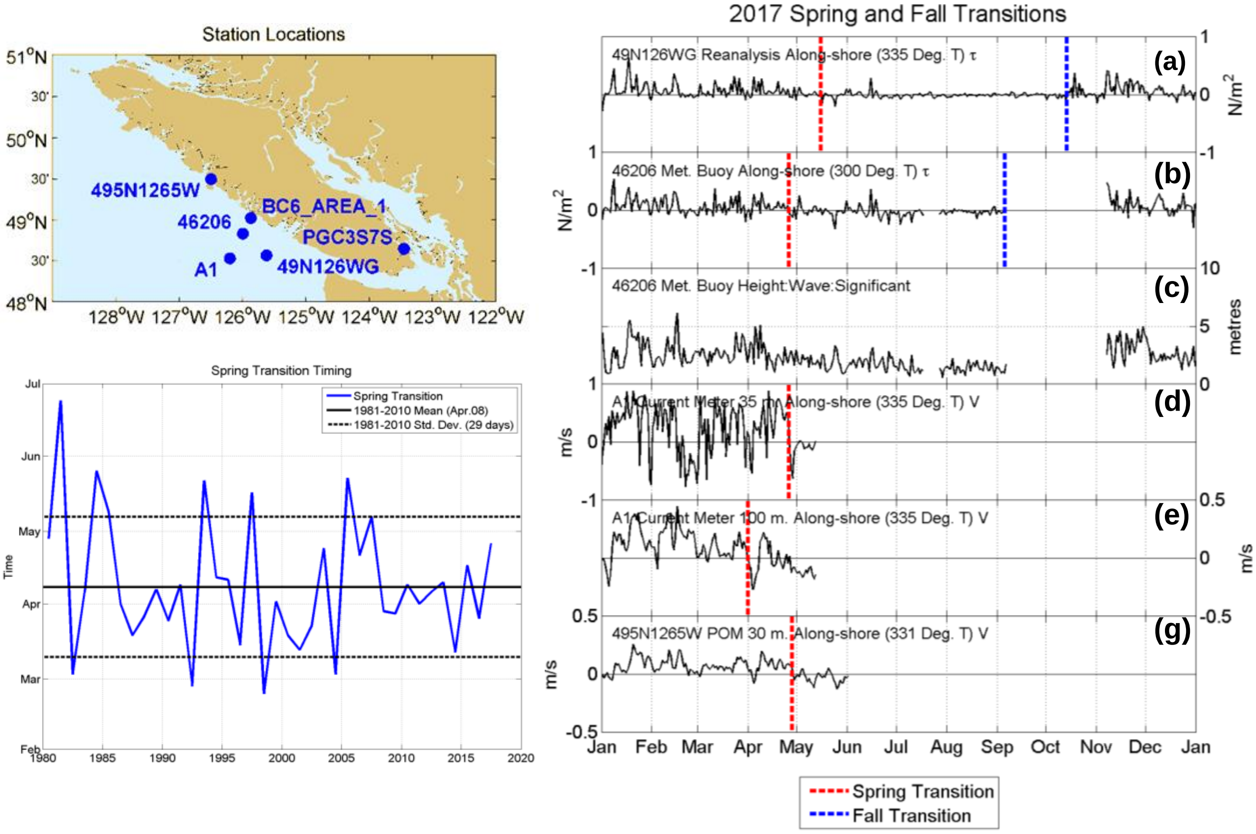

Figure 6-1. Top-left: Locations of observations delineating historical Spring and Fall Transitions. Right: Time series depicting the Spring and Fall Transitions off the west coast of Vancouver Island in 2017. Wind stress at (a) Reanalysis-1 grid point 49N126W and (b) meteorological buoy 46206; (c) significant wave height at 46206; (d) along-shore current velocity at 35 m depth at mooring A1; (e) same as (d) but for 100 m depth; and (f) along-shore current as modelled using the 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). Bottom-left: The annual Spring Transition derived from time series in the right panel.

6.2.2. Status, trends, and implications

In 2017, the Spring Transition timing was average to late compared to the 1981-2010 mean (Figure 6-1), suggesting that upwelling-based spring productivity near the west coast of Vancouver Island during the 2017 summer should have been average to below-average. From 2008 to 2016, the Spring Transition timing had generally been average to early, which favoured average to above-average summer productivity. The Spring Transition has exhibited marked variability since 1980 but there is no apparent linear trend over this period. Interannual variability in the winds, currents and other indices is sufficiently high to continue to mask any possible long-term trend due to the changing climate.

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) and subtracted the long-term mean to derive the Upwelling Index.

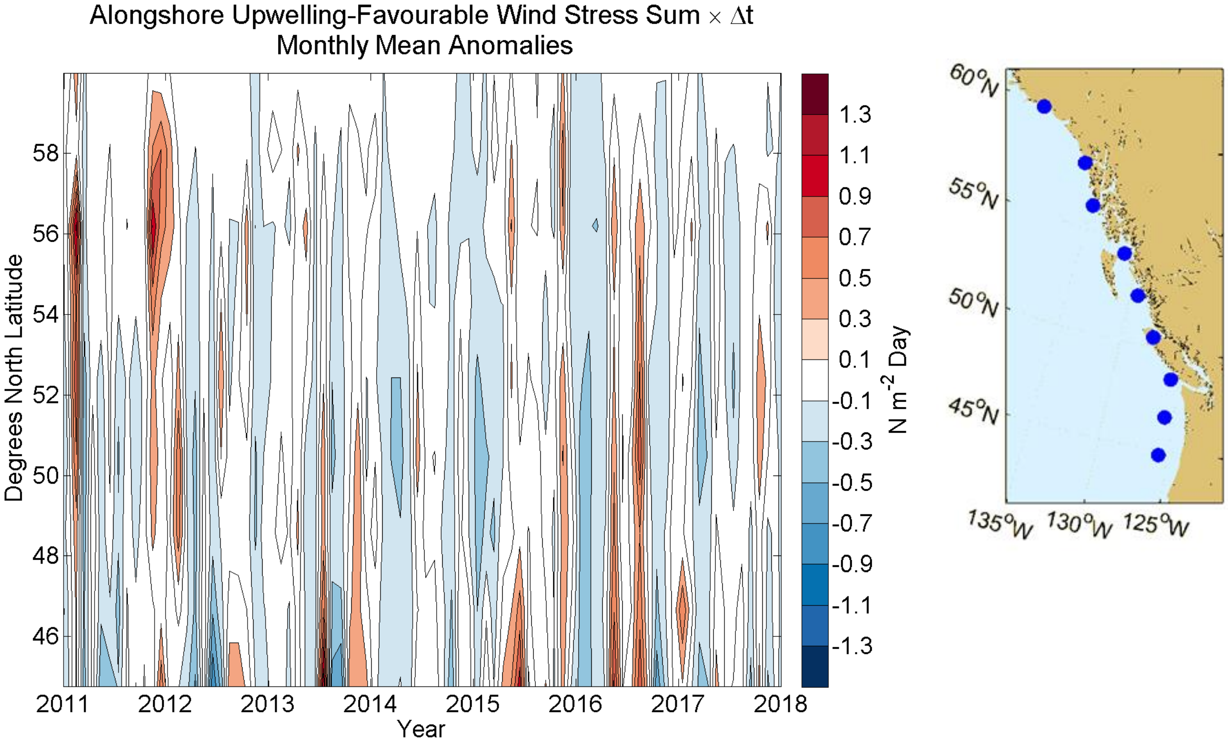

Figure 6-2. Recent (2011 to 2017) monthly mean anomalies of monthly sums of alongshore upwelling-favourable (equatorward) wind stress (left) from the NCEP/NCAR Reanalysis-1 coastal surface wind stress grid locations, 45-60° N (right).

6.3.2. Status, trends, and implications

Over recent years, the Upwelling Index time series (Figure 6-2) indicates that upwelling-favourable wind stress was average to below average in 2017 through the warm season. As a consequence, conditions for large-scale upwelling-based productivity were average to below average over the summer of 2017. No recent trends in upwelling-favourable winds are evident in Figure 6-2. Like 2017, average to below average warm- season upwelling favourable winds also occurred in 2014, 2012, and 2011.

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 2017 upwelling timing was in the middle one third of annual values and summer upwelling magnitude was in the lower third of annual values. Consequently, coastal upwelling-favourable conditions for productivity were average to below-average in 2017. 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).

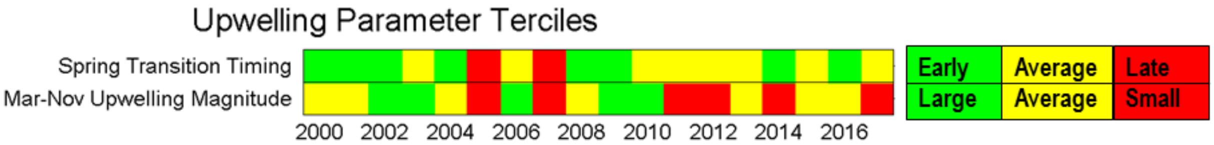

Figure 6-3. Stoplight diagram depicting equal terciles of both the Spring Transition Timing Index and the Upwelling Magnitude Index for 49° N, 126° W.

6.5. West Coast shelf break temperatures and currents

6.5.1. The time series

Subsurface temperature and current velocities at the shelf break have been observed at mooring A1, water depth ~500 m (Figure 6-1) since 1985. Nearby meteorological buoy 46206 has provided sea surface temperature and wind velocity time series since 1988. We have combined these series to obtain the vertical structure of temperature and flow through the water column.

6.5.2. Status, trends, and implications

At the beginning of 2017, temperatures at the surface, 35, 100, and 175 m depth continued to reflect the warm water signature of El Niño conditions that persisted over 2014-2016 (Figure 6-4, left). Near the end of the year temperatures were near average at the surface. Subsurface data are not available after May 2017 until the mooring is serviced in summer, 2018.

Also, at the beginning of 2017, the alongshore surface winds and subsurface currents at 35, 100, and 175 m depth continued to reflect stronger than average poleward (downwelling-favourable) flow (Figure 6-4, right). This may have hindered the coastal upwelling of nutrient richer waters in the spring. This figure also shows enhanced poleward flow during 2015-16, as well as stronger equatorward flow in the summers of 2015 and 2016. These features are likely due to stronger large-scale surface atmospheric circulation features (Aleutian Low and North Pacific High) associated with the El Niño at the time.

Both the positive temperature and poleward flow anomalies at the beginning of 2017 may have been due to an eastward shift of storm tracks to closer to the coast.

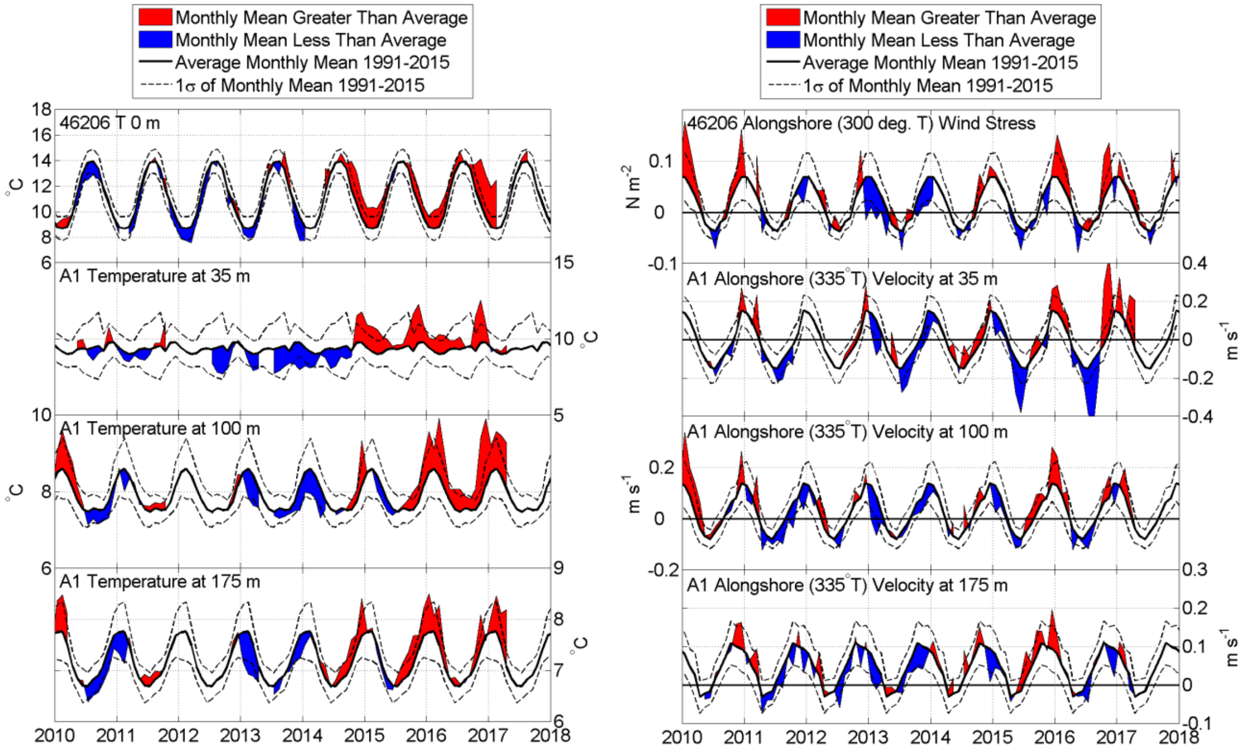

Figure 6-4. Monthly anomalies of temperature (left) and alongshore wind stress/ocean current (right) at the surface, 35 m, 100 m, and 175 m from meteorological buoy 46206 and mooring A1. Angle in brackets (°T) is the principal direction of the wind or current vector in degrees true compass bearing.

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. LA NIÑA AND ANOTHER WARM YEAR

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7.1. Highlights

- 2017 saw a return to near-average temperatures in the Northeast Pacific (NEP).
- Near-average conditions were only experienced because the cooling effect of La Niña balanced the persistent global temperature rise:
    - La Niña conditions were present throughout most of 2017, which would have normally led to cooler than average temperatures in the NEP.
    - Globally, 2017 was the third warmest year on record.
- Temperature anomalies – perhaps related to the recent marine heatwave (also known as the “Blob”) – are still present in the NEP:
    - Strong (2-3 ^{o}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.
- La Niña conditions are present again and climate indices are mixed, so 2018 may be another near-average year for temperatures in the NEP.

7.2. Summary

Based on NOAA land and sea surface data dating back to 1880 (Figure 7-1), 2017 was the third warmest year on record globally. This was consistent with the recent trend, wherein 8 of the ten warmest years were in the last decade. In ranked order, the ten warmest years were 2016,

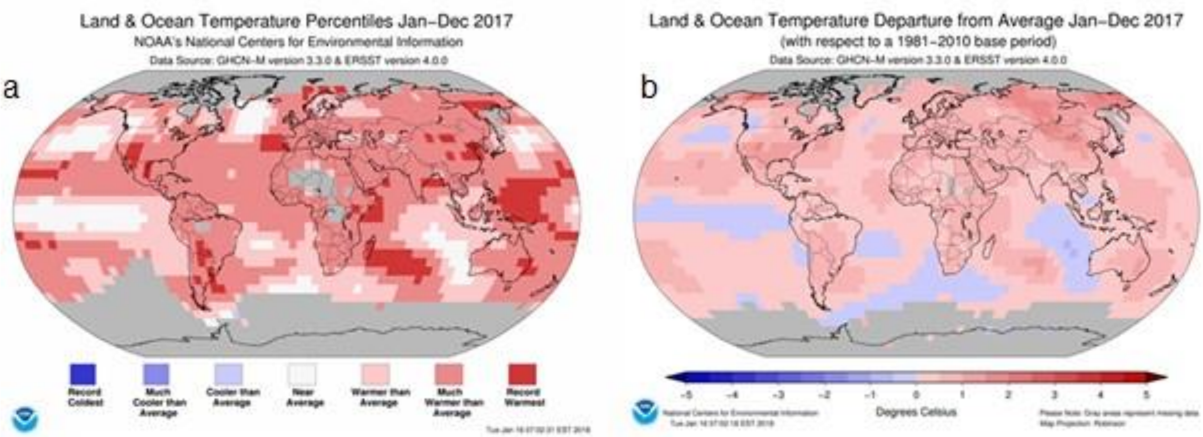

Figure 7-1. Maps of the globe show surface temperature percentiles (panel a) and anomalies (panel b) in the year 2017. ***Panel a:*** *Colours indicate percentiles, with “warmer than average”, “near average” and “cooler than average” indicating, respectively, the top, middle and bottom terciles of the 138 year record. Source: https://www.ncdc.noaa.gov/sotc/service/global/map-percentile-mntp/201701-201712.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/201701-201712.gif.* ***Both panels****: Grey areas represent missing data.*

2015, 2017, 2014, 2010, 2013, 2005, 2009, 1998, and 2012. Despite the fact that La Niña conditions were present for more than half of the year (Figure 7-2), sea surface temperatures in the Northeast Pacific (NEP) were near average or warmer than average (Figure 7-1a). Temperatures were slightly (i.e. about 0.5 °C) above the average for the 1981-2010 base period (Figure 7-1b).

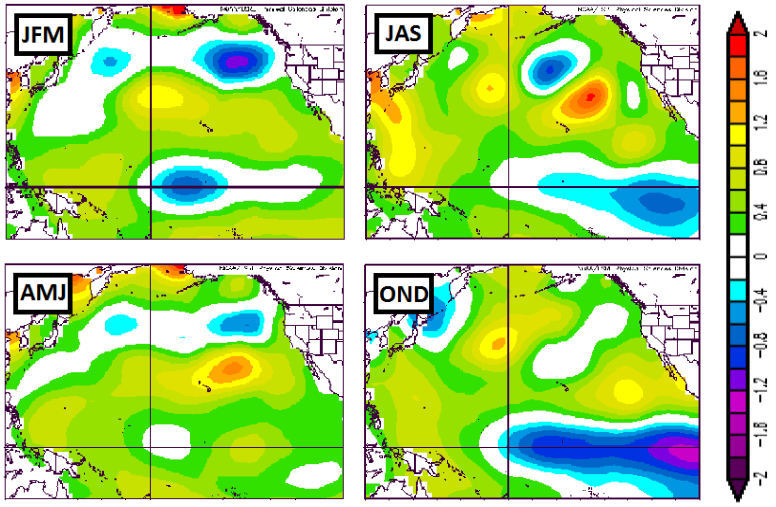

Figure 7-2. Seasonal maps of temperature anomalies in the Pacific Ocean for 2017. The colour bar on the right, showing the temperature anomaly in °C, applies to all panels. Source: NOAA Extended SST v4 http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl.

The sea surface temperatures in the NEP throughout 2017 (Figure 7-2) showed some seasonal variability, but were largely near the 1981-2010 average. Early in the year (Jan-Feb-Mar), a weak La Niña was fading along the equator. This La Niña was likely responsible for the lower than average temperatures in the NEP in the winter. La Niña conditions reappeared in the summer (Jul-Aug-Sep) and grew to be stronger than the 2016/17 La Niña by autumn (Oct-Nov-Dec).

While the surface temperatures were near both the 1981-2010 (Figure 7-1b and Figure 7-2) and 1956-2012 (Figure 7-3) averages, subsurface temperatures remained anomalously warm beneath 100 m at Station Papa throughout most of 2017. The record of temperature anomalies at Station Papa (based on the interpolation of Argo float data onto the location of Station Papa; Figure 7-3), shows that a strong warm anomaly was still apparent between 100-200 m until about November 2017. Note that while the deeper anomaly is further away from the mean (over 4 standard deviations, rather than the earlier/shallower 3 standard deviations seen in surface waters during the winters of 2014 and 2015; Figure 7-3), this is because the variability is smaller in the 100-200 m

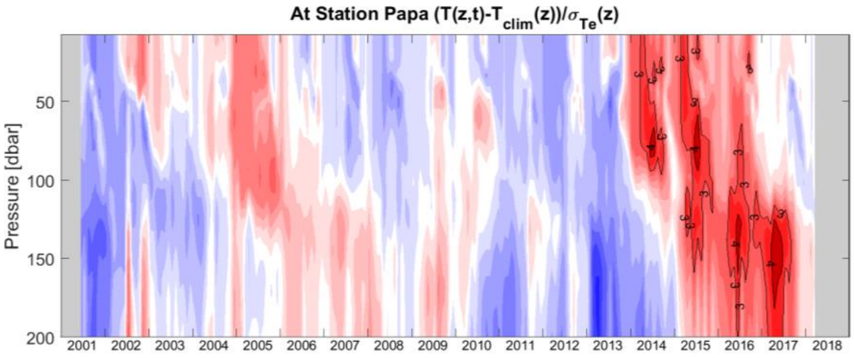

Figure 7-3. False colour plot of temperature anomalies relative to the 1956-2012 seasonally-corrected mean and standard deviation (from the Line P time series), as observed by Argo floats near Station Papa (P26: 50° N, 145° W). The cool colours indicate cooler than average temperatures and warm colours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

depth range, not because the deep temperature anomaly is larger in absolute value. This can be observed in the Line P shipboard observations (Figure 7-4), which show temperature anomalies of about 1 °C below 100 m in each of the February, June and August cruises. Note that these deep temperature anomalies were present along all of Line P, suggesting that the phenomenon was large spatially, but the anomalies were highest in the offshore waters.

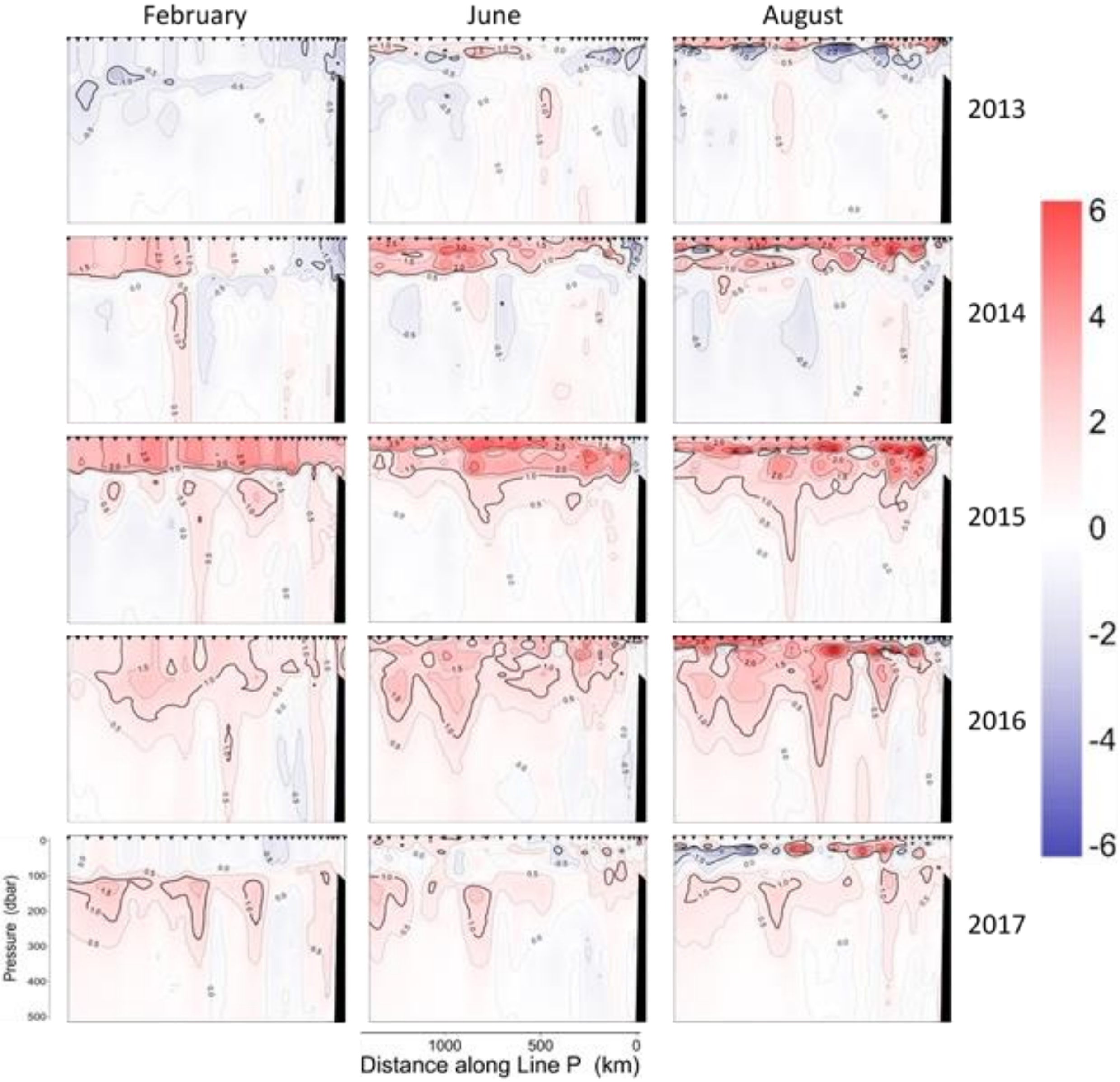

Figure 7-4. Temperature anomalies (°C) along Line P from 2013 to 2017 with respect to the 1981-2010 average.

After several years of stronger than usual winter stratification caused by reduced mixing due to warmer surface waters, i.e. the winters of 2013/14, 2014/15 (Freeland 2015), and even 2015/16, the winter stratification in 2017 returned to a level similar to the winters of 2010/11 and 2011/12. The history of the 1025.7 kg/m^3 isopycnal (highlighted with a thick black line in Figure 7-5) 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. Return to normal winter mixing suggests that nutrient supply from deep waters should be even better than in 2016, when offshore nutrients were near-normal (Peña and Nemcek 2017).

As mentioned above, La Niña generally leads to cooler than average winters in western North America. The combination of this negative anomaly with global temperature rise led to normal surface temperature conditions in the NEP in 2017. La Niña is represented by the Oceanic Niño Index (ONI; Figure 7-6). Unlike at the beginning of 2017, now the ONI is not the only index suggesting that the Northeast Pacific Ocean is currently in a cool period; both a negative Aleutian Low Pressure Index (ALPI) and a positive Southern Oscillation Index (SOI) suggest a cooler period. However, some climate indices also indicate a warm period: a positive Pacific Decadal Oscillation (PDO) and a negative North Pacific Gyre Oscillation (NPGO). This mixed group of indices suggest neutral climate conditions for 2018.

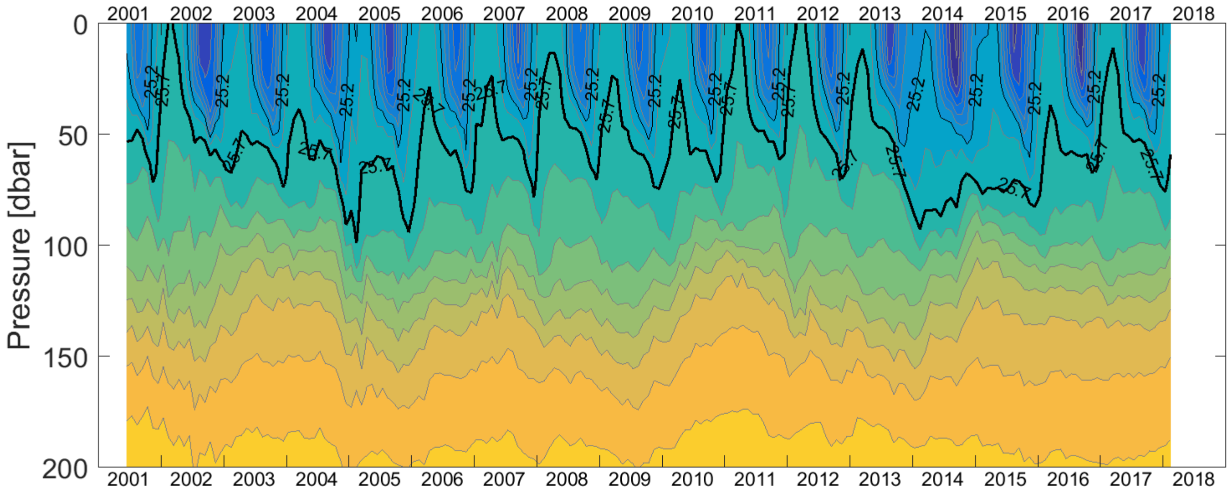

Figure 7-5. Coloured contour plot of density as observed by Argo floats near Station Papa (P26: 50^o N, 145^o W).The colours indicate density (yellow is denser and blue lighter). The black lines highlight the r=1025.2 kg/m^3 (thin) and 1025.7 kg/m^3 (thick) isopycnals.

7.3. 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 km^2) that has sea level pressure less than or equal to 100.5 kPa and is expressed as an anomaly from the 1950-1997 mean (Surry and King 2015). A positive index value reflects a relatively strong, or intense, Aleutian Low. ALPI is provided by DFO Pacific (PBS) and is available from: http://www.dfo-mpo.gc.ca/science/data-donnees/climatology-climatologie/index-eng.html.

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

Service National Centers for Environmental Prediction CPC and is available from: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml.

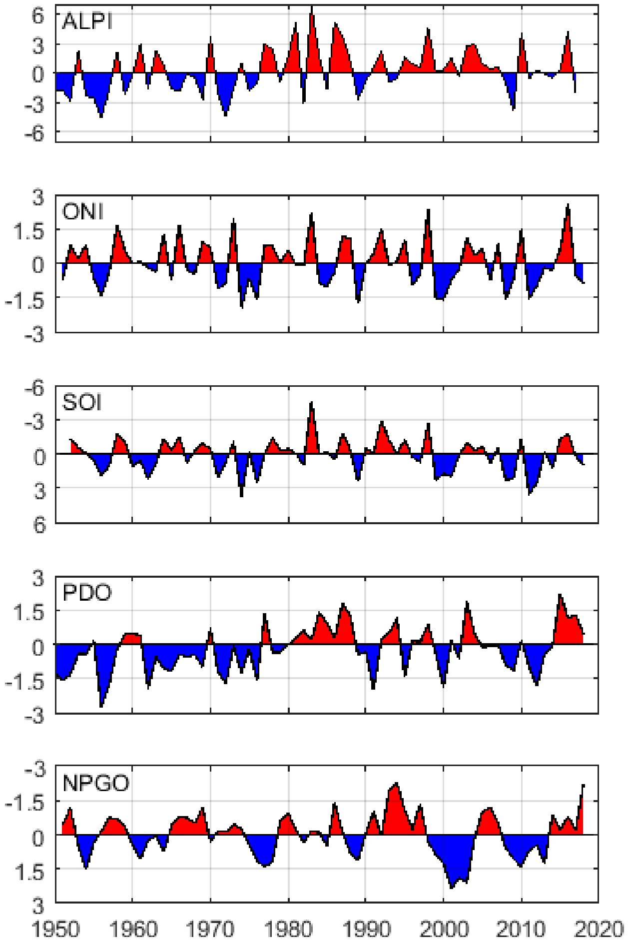

Figure 7-6. Time series of Pacific Ocean climate indices. Aside from ALPI, which is already an average, each of the monthly indices were averaged over the months of Nov, Dec, and Jan and plotted for the year in Jan. Some series are inverted (negative values are above the axes) so that all series are red when coastal B.C. temperatures are anomalously warm. See text for a description and the source of each index.

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

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

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.

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8. HAKAI OCEANOGRAPHY PROGRAM: BRITISH COLUMBIA CENTRAL COAST TIME SERIES (2012-2017)

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8.1. Highlights

- At 5 m depth in 2017, winter and spring were colder and saltier; summer warmer and fresher; and fall and early winter colder and saltier than average.
- Near bottom temperatures were average to above average. Near bottom salinity was below average in spring at all stations and higher than average in summer at all stations except one.
- Upwelled water was first observed on May 27 and reached the inner coast at Rivers Inlet by July 22.
- The spring phytoplankton bloom occurred between March 27 and April 8, 2017. Phytoplankton biomass was near average in 2017 and zooplankton biomass was above average.

8.2. 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 initiation), the seasonal cycles and interannual variability of processes that underpin B.C.'s coastal ecosystems, and;
- Detecting and understanding 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 measurements, are located in Queen Charlotte Sound (QCS01), Kwakshua Channel (Pruth), Fitz Hugh Sound (FZH01, KC10), and Rivers Inlet (DFO2) (Figure 8-1). In addition, CTD profiles are routinely collected in Hakai Pass (HKP01). 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.

8.3. Status and trends

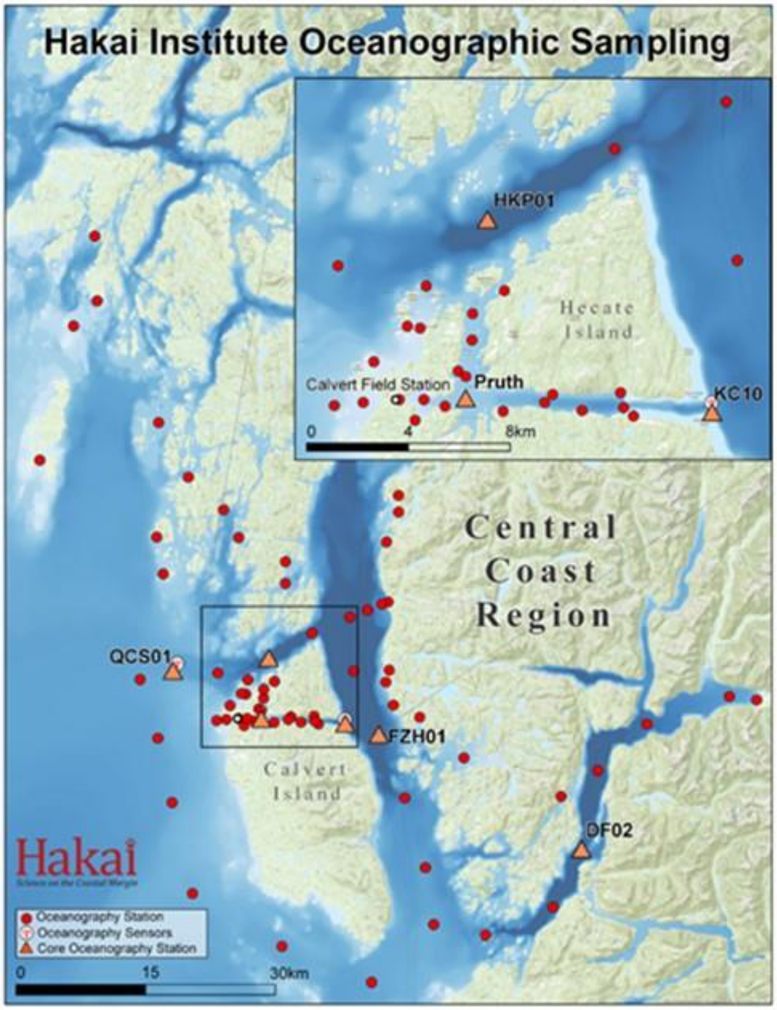

Figure 8-1. Map of oceanographic stations sampled by the HOP. Sampling regimes at core stations are: Pruth - daily between spring and fall, every six weeks in winter; All other stations - every two to three weeks during spring to fall, opportunistic in winter.

Here we present time series of temperature, salinity, and chlorophyll-a at 5 m, water column zooplankton biomass (Figure 8-2), and near bottom temperature and salinity (Figure 8-3).

In 2017, temperature and salinity at 5 m were colder and saltier than average in winter and spring (January to May), warmer and fresher than average in summer (June to September), and colder and saltier in fall and early winter (October to December).

Near bottom temperature was average at QCS01 and Pruth, and warmer than average at HKP01, KC10, and DFO2 (Figure 8-3). Higher near bottom temperatures at DFO2 are compared with results from the 1951 to 2018 time series by Jackson et al. (2018) elsewhere in this report.

Near bottom salinity was fresher in spring at all stations and saltier than average in summer at all stations except DFO2.

Upwelled water, based on when salinity of the deep water first began its seasonal increase, was first observed on May 27 at QCS01 and HKP01, June 2 at Pruth, June 8 at KC10, and July 22 at DFO2. The timing of these events followed the passage of upwelled water from the outer coast to the inner coast.

The spring bloom date at Pruth station was approximately April 8, 2017. This was later than 2016 (March 21, 2016). Phytoplankton biomass (measured as chlorophyll-a mg.m^{-3}) was close to average through the summer months at most stations. The spring bloom peak biomass was higher than average on the outer coast (QCS01) and substantially lower than average in Rivers Inlet (DFO2). Daily fluorescence data from Pruth showed no obvious fall bloom in 2017, which is different to previous years. Zooplankton biomass was higher than average at all stations in 2017, but particularly at the outer coast stations of QCS01 and Pruth.

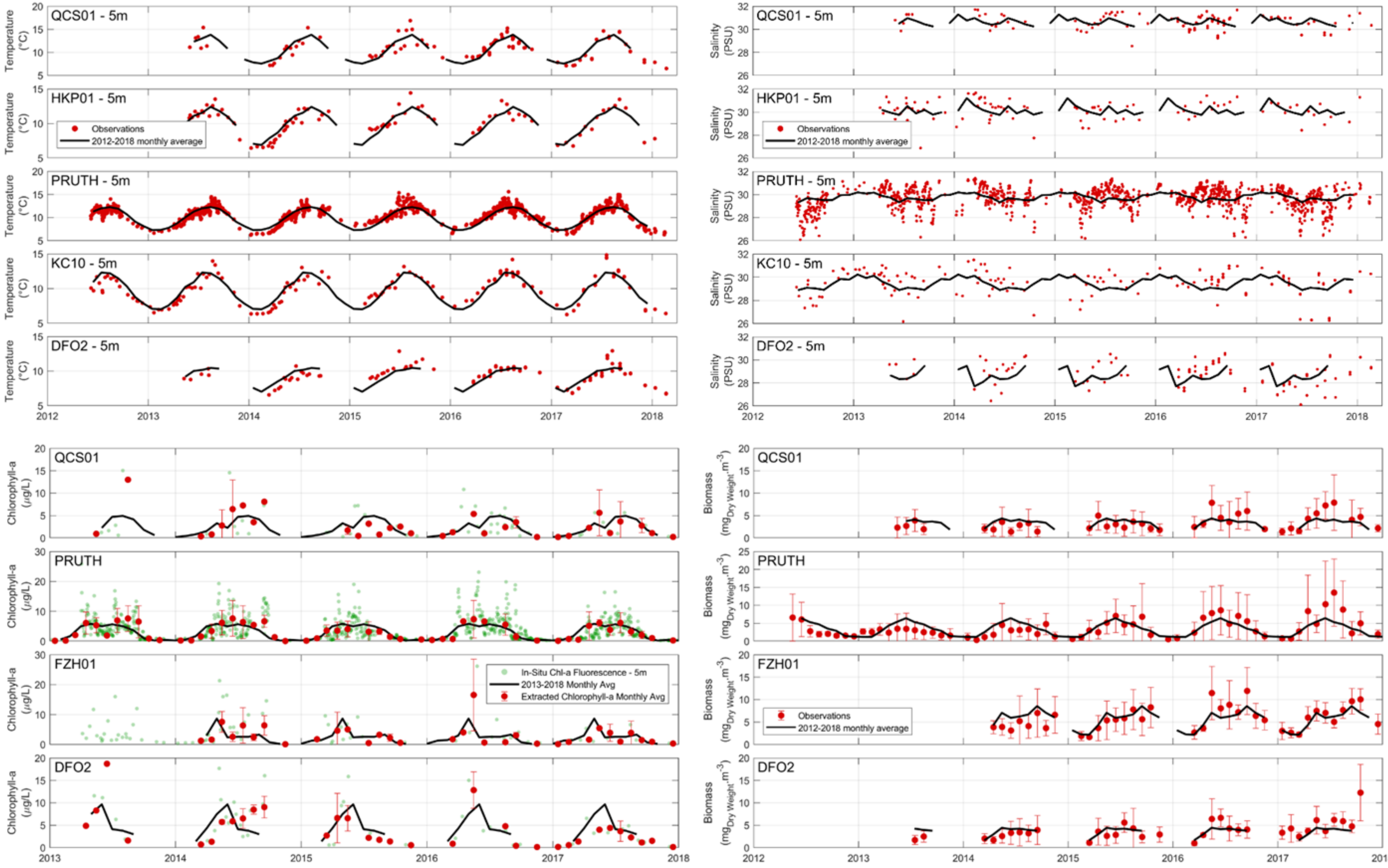

Figure 8-2. Time series of temperature, salinity, chlorophyll-a at 5m, and zooplankton biomass for the entire water column, for core stations in the Hakai Central Coast observation program. The black line is the monthly mean from June 2012 to December 2017.

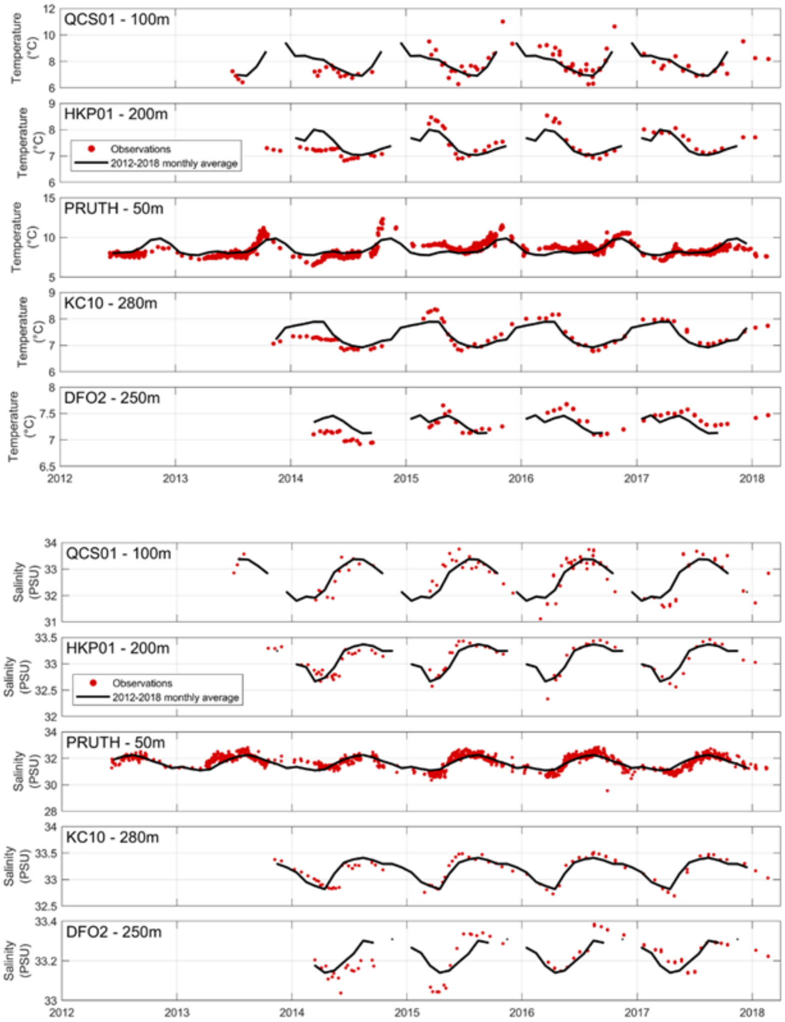

Figure 8-3. Time series of near bottom temperature and salinity for core stations in the Hakai Central Coast observation program. The black line is the monthly mean from June 2012 to December 2017.

8.4. Factors influencing trends

La Niña conditions in the winter of 2016/17 were responsible for the cooler surface temperatures observed in winter and spring of 2017. Warmer than average temperatures near bottom in the spring likely represented the persistent signal of the 2014-2016 marine heatwave.

The 2017 spring transition date (date of shift from predominantly downwelling favorable southwesterly winds to upwelling favorable northerly winds) at 45° N was April 26, one month later than 2016 and approximately 2 weeks later than average (https://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/b-latest-updates.cfm). This indicated a late start to the upwelling season and likely accounted for the delayed spring bloom in 2017.

8.5. Implications of those trends

Although the spring phytoplankton bloom was delayed at all stations in 2017, possibly due to the late spring transition, the peak bloom biomass was high on the outer coast and this was accompanied by higher than average zooplankton biomass in 2017. Previous research in Rivers Inlet has shown that a delayed spring bloom can negatively impact the recruitment of herbivorous calanoid copepods (Tommasi et al. 2013). The Hakai time series indicates that the response of outer coast zooplankton to bloom timing may differ to zooplankton in the mainland fjords.

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 Hakai Institute priority objectives.

8.6. References

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9. SEA LEVEL IN BRITISH COLUMBIA, 1910 TO 2017

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9.1. Highlights

- The annual mean water levels at Victoria and Tofino were above the long term trend line while the annual mean was below the trend line for Prince Rupert.
- A stormy April resulted in higher than normal monthly mean at all three locations.
- High pressure systems in October and December lead to lower than normal monthly means.

9.2. Summary

The Canadian Hydrographic Service monitors sea levels along the B.C. coast. At three of these locations (Victoria, Tofino and Prince Rupert) the annual deviations from the long-term average are shown in (Figure 9-1). Both Tofino and Victoria have records that began in 1910, while the record at Prince Rupert began in 1912.

A linear trend line was fitted to the data and the average sea level in 2017 was above the trend at Victoria and Tofino (for the fourth year in a row), while the 2017 average at Prince Rupert was below the trend line.

The linear sea level rise trend at each port (in cm/century):

Prince Rupert	+11.5
Victoria	+6.9
Tofino	-12.0

Tectonic motion is lifting the land at Tofino faster than sea level is rising, so that local sea level (measured relative to the land) is dropping at an average rate of 12 cm per 100 years. Removing the tectonic motion from the sea level values using a 2.34 mm annual uplift (James et al. 2014 at Ucluelet as a proxy for Tofino; Thomas James and Lisa Nykolaishen, pers. comm.) results in a linear trend at Tofino of 13.8 cm per 107 years (Figure 9-2).

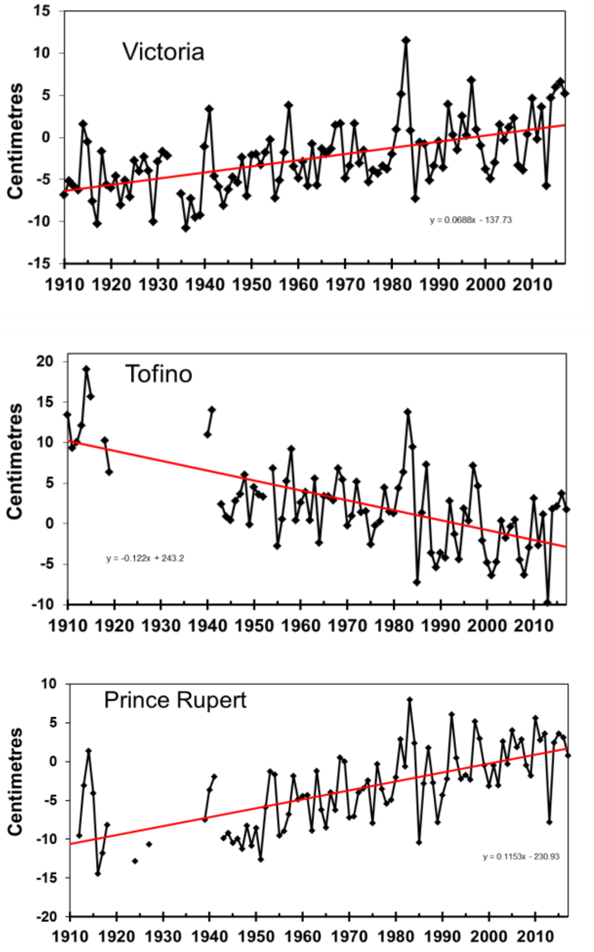

Figure 9-1. Annual-average sea level anomalies at three British Columbia ports. Reference years are 1981 to 2010. Average linear trends are plotted as red lines.

The monthly mean sea level for April 2017 was higher than normal at all three stations while the October and December means were lower than usual.

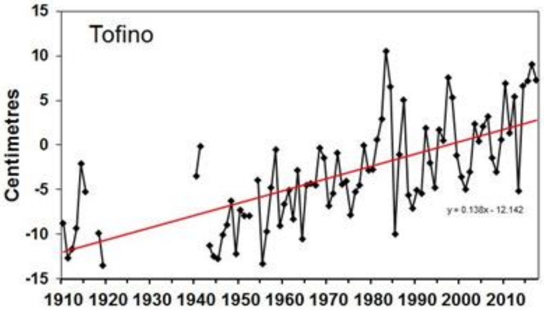

Figure 9-2. Annual-average sea level anomaly at Tofino with land uplift removed.

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.

9.3. References

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10. SEA SURFACE TEMPERATURE AND SALINITY OBSERVED AT LIGHTHOUSES AND WEATHER BUOYS IN BRITISH COLUMBIA, 2017

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10.1. Highlights

- The average annual sea surface temperature (SST) in 2017 (10.54 °C) was cooler than in 2016. Coast-wide the average annual decrease in SST was 0.62°C (standard deviation of 0.17 °C).
- Anomalies from the 30 year (1981-2010) sea surface temperature record show periodic warm and cold periods with durations of several years; the warmer SSTs evident since 2013 have diminished but for most stations remain above normal.
- Despite the decrease in SST in 2017 there continues to be a long-term trend to warmer coastal sea surface temperatures (linear trend of 0.81ºC over 100 years).
- 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 2017. 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.

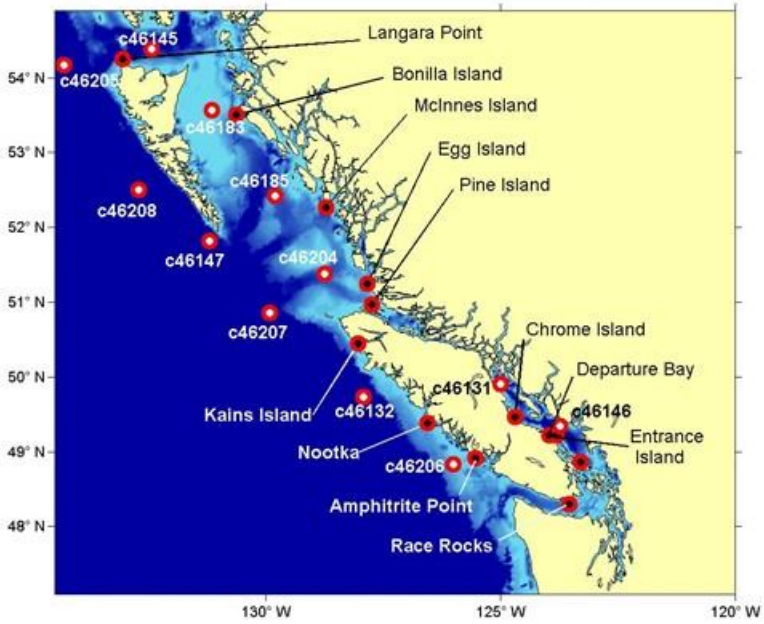

Figure 10-1. Red dots with black centers show the locations of 12 stations in the present shore station network. Red dots with white centers show the locations of 12 weather buoys in the Canadian weather buoy network. See table below for details.

Station	Years of data	Buoy ID	Buoy Location	Years of data
Departure Bay	103	c46146	Halibut Bank	25
Race Rocks	96	c46131	Sentry Shoal	25
Nootka	83	c46206	La Perouse	29
Amphitrite	83	c46132	South Brooks	23
Kains I	80	c46207	East Dellwood	28
Langara	81	c46147	South Moresby	24
Entrance I	81	c46208	West Moresby	27
Pine Island	80	c46205	West Dixon	27
McInnes	63	c46145	Central Dixon	26
Bonilla	57	c46204	West Sea Otter	28
Chrome I	56	c46185	South Hecate	26
Egg Island	47	c46183	North Hecate	26

10.3. Status and trends

The lighthouse observations show the annual average daily SST (Figure 10-2, upper panel) at all stations was cooler in 2017 than in 2016 (mean decrease of 0.62 °C, standard deviation of 0.17 °C). For the first time in several years some stations (Entrance, Chrome, Race Rocks and Langara) had annual average SSTs similar to the 30 year average (1981-2010).

The observations from the weather buoys show the average daily SST (Figure 10-2, lower panel) at all stations, with the exception of South Brooks, was cooler in 2017 than in 2016 (mean decrease of 0.63 °C, standard deviation of 0.46 °C). SSTs at two stations (Halibut Bank and North Hecate) were cooler than the 22 year average 1989-2010.

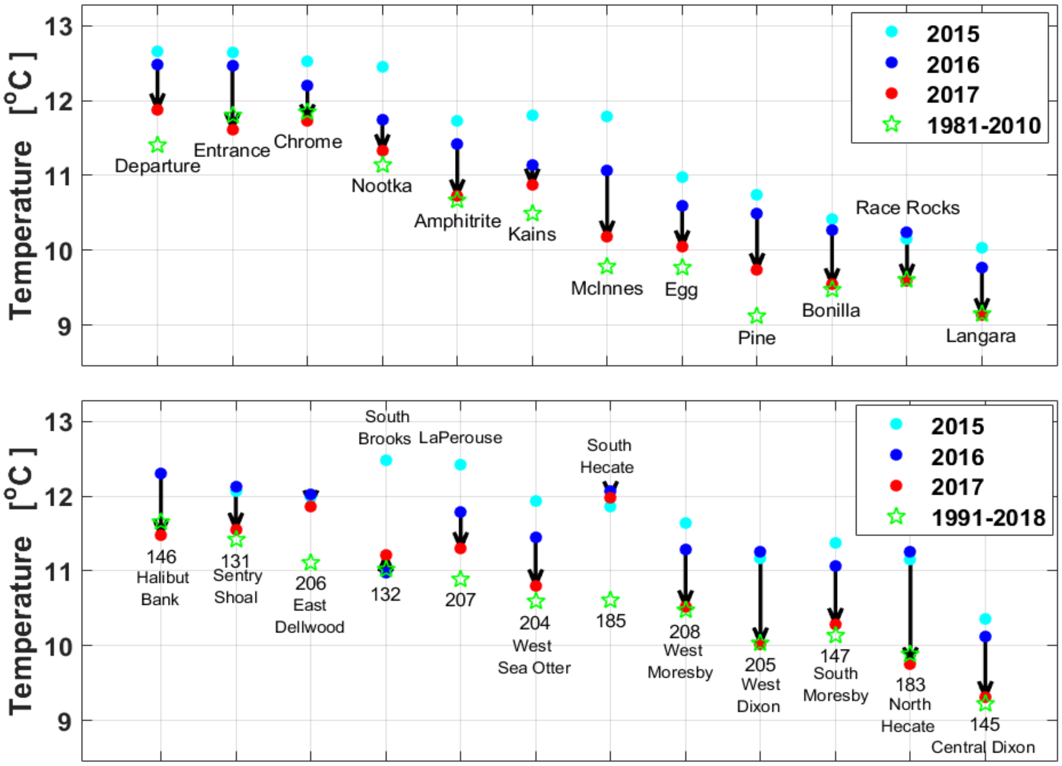

Figure 10-2. Upper panel. The average sea surface temperature in 2015 (light blue dots), 2016 (dark blue dots) and 2017 (red dots) from daily observations at shore stations along the west coast of Canada. The stars represent the mean annual temperature based on 30 years of data (1981-2010). Lower panel. The average sea surface temperature 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.

Assuming a linear change over the entire data record, the time series of temperature at all of the shore stations show a warming trend at a 95% confidence level. Figure 10-3 shows a coast wide warming trend (using data from all stations) as 0.81 °C over 100 years. Figure 10-4 shows this warming at representative stations for each of three regions (North Coast, 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.

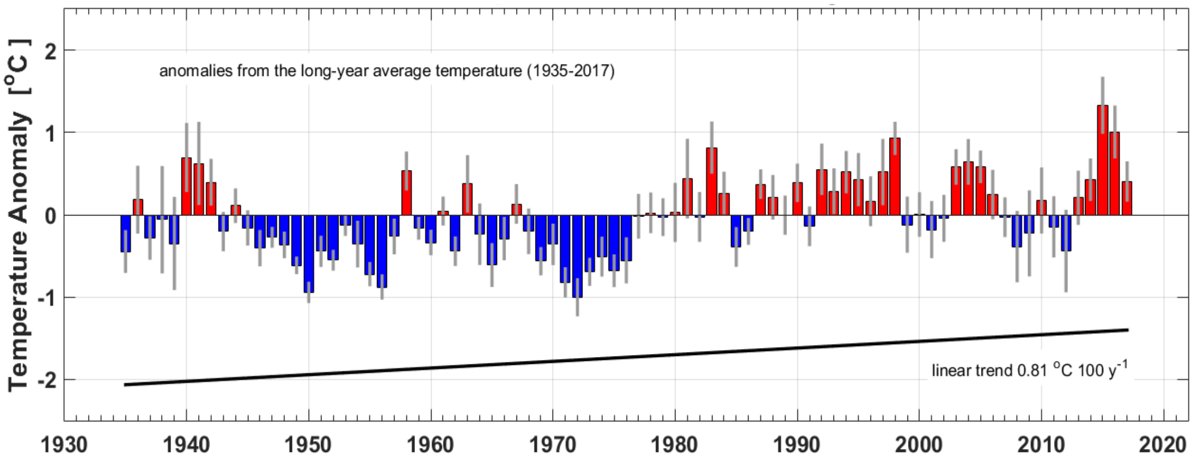

Figure 10-3. The trend in the annual temperature based on the observations of all lighthouses. The data shown are the anomalies from the long-term average temperature (1935-2017). The bars represent the anomalies averaged over all stations (a coast wide indicator), (red – above average, blue – below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

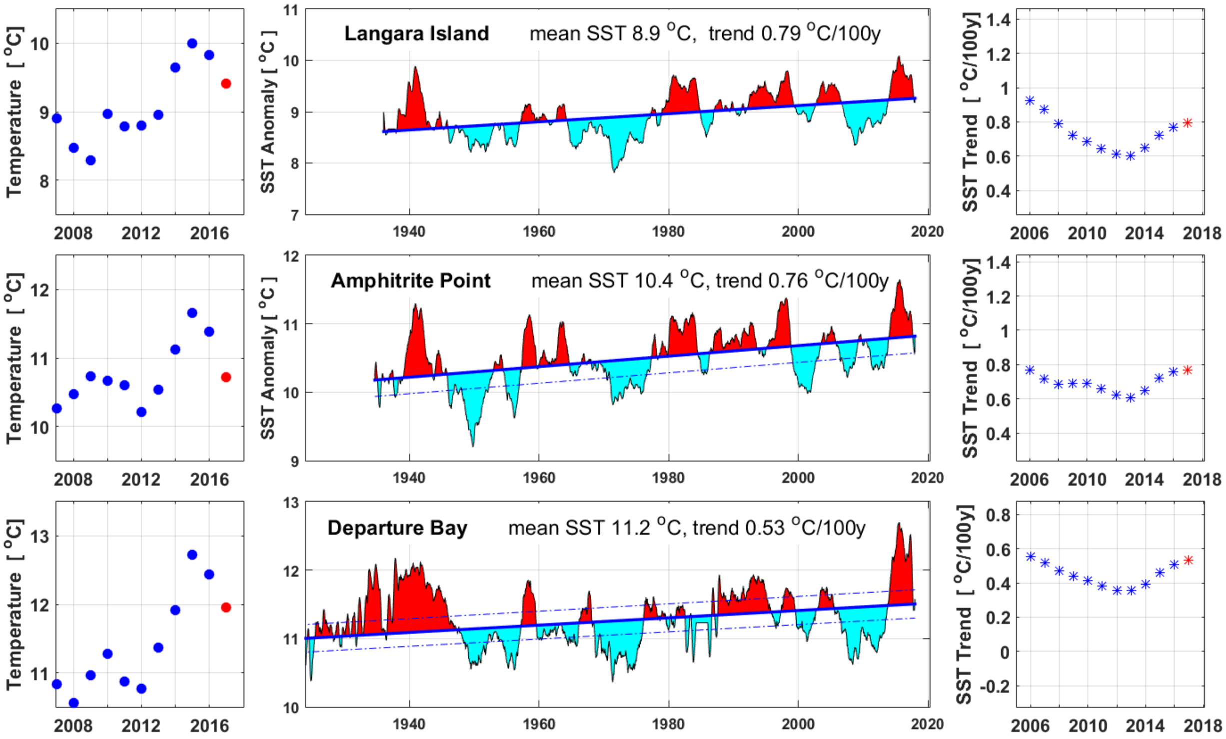

Figure 10-4. Time series of daily temperature observations, averaged over 12 months, at stations representing the North Coast, West Coast Vancouver Island and Strait of Georgia. Positive anomalies from the average temperature of the entire record are shown in red, negative in blue. The panel to the left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

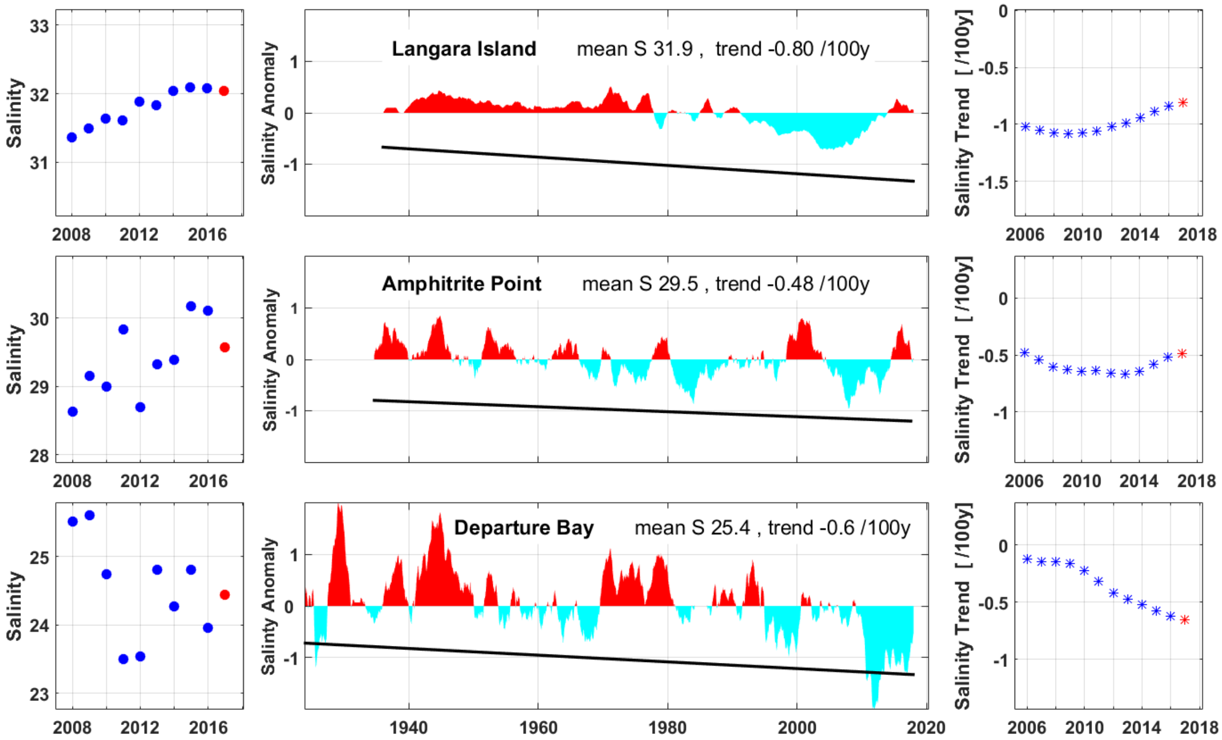

Figure 10-5. As in Figure 10-4 for long-term time series of daily salinity observations.

10.4. Factors influencing trends

The sea surface temperatures in 2017 indicate a change from the past several years where significantly warmer than normal conditions prevailed. Both the buoy and the lighthouse data show the ocean is cooling but that temperatures are close to or above the climatological mean (1981-2010). The transition to La Niña conditions in late 2016 and the ENSO-neutral conditions through most of 2017 moderated any significant features in the SST signal. This is consistent with the larger scale observations made in 2017 in the NE Pacific (Ross and Robert 2018, Hourston and Thomson 2018).

Despite the cooling conditions observed in 2017 the long-term temperature record shows that overlying the multi-year oscillations in the annual SST, there remains a long-term trend towards rising ocean temperatures 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 at most stations along the B.C. Coast. Variability in the salinity signal along the Pacific coast is governed by a combination of the integrated effects of atmospheric forcing and coastal precipitations; the Strait of Georgia data is strongly influenced by the discharge from the Fraser River (Cummins and Masson 2014).

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 Galbraith and Young (2018), and Hyatt et al. (2018).

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11. OXYGEN CONCENTRATION IN SUBSURFACE WATERS OF THE B.C. COAST

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11.1. Highlights

- Low concentrations of subsurface oxygen are usually observed on the continental shelf of southwest Vancouver Island in late summer. O_2 has been monitored regularly at Station LB08 in this region since 1979.
- O_2 decreased from typical values of 65 μmol kg^{-1} in 1979 to very low values of 35 to 50 μmol kg^{-1} in 2006 to 2014. Higher concentrations were observed in 2015 and 2016, attributed to warm, buoyant waters. However, with the intrusion of saltier, denser water in 2017, O_2 decreased to a very low concentration of about 40 μmol kg^{-1}.
- On the continental margin to about 700 km offshore, O_2 on constant density surfaces in the thermocline increased between the 1950s and 1980s, then declined until the 2000s, and has increased since about 2010. Farther offshore there has been 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

11.2.1. Continental Shelf

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^{-1} or 60 μmol kg^{-1}.) Many of these symbols are in inlets where deep seawater is naturally hypoxic due to low rates of inflow from outside waters.

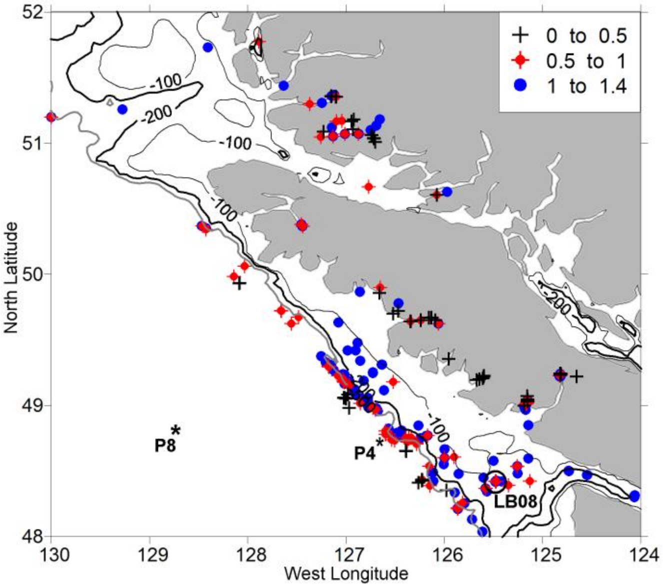

*Figure 11-1. Oxygen concentration (O_2, ml L^{-1}) in summer within 20 metres of the ocean bottom for regions of the continental shelf and slope where bottom depth is less than 1000 metres. (1 ml L^{-1} = 43 μmol kg^{-1}) Each symbol represents a measurement by DFO research programs. Only observations with O_2 less than 1.4 ml L^{-1} (60 μmol kg^{-1}) are plotted. A black O denotes the location of Station LB08, where O2 has been monitored for almost 40 years. Stations P4 and P8 along Line P are indicated by *.*

On the continental shelf and slope, the lowest O_2 is found in deeper waters because O_2 decreases with increasing depth and increasing water density. The lowest O_2 on the shelf is off southwest Vancouver Island, the region of the BC coast where summer upwelling is strongest. Sampling of oxygen concentration at station LB08 off southwest Vancouver Island in a water depth of 145 metres has been carried out since 1979. Decreasing O_2 in subsurface waters is normally accompanied by increasing acidity. Both trends are of great concern to marine life.

The annual cycle of O_2 in near bottom waters off southwest Vancouver Island at Station LB08 is presented in Figure 11-2. This graph shows that O_2 is usually lowest between late August to early October (days 230 to 280). Although there is considerable year-to-year variability in O_2 for this season, one can see in this season a decrease from higher O_2 in 1979 - 1999 to a minimum in 2006 – 2014, followed by an increase in 2015 and 2016. The highest ever late summer O_2 was 2.14 ml L^{-1} (92 µmol kg^{-1}) measured in early September 2015.

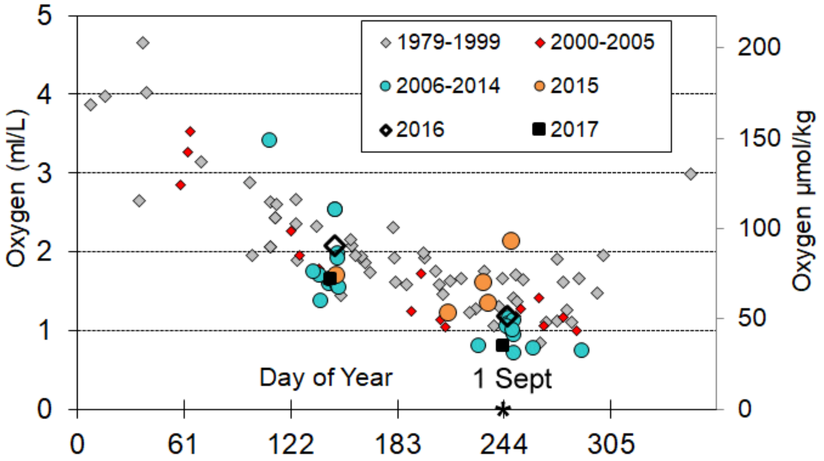

Figure 11-2. Oxygen concentration at 125 m below ocean surface at Station LB08. Symbols represent observation, plotted on the day of the year the sample was collected. Day 244 is September 1. Figure is based on Crawford and Peña (2013).

The observation on 1 September 2017 at LB08 revealed that O_2 had declined to a concentration of 35 µmol kg^{-1}, almost as low as the lowest observed in the entire time series. In addition, O_2 on 25 May 2017 (day 145) was also in the low range of concentrations observed for this month since 1979. The temperature and salinity of O_2 samples is noted in Figure 11-3.

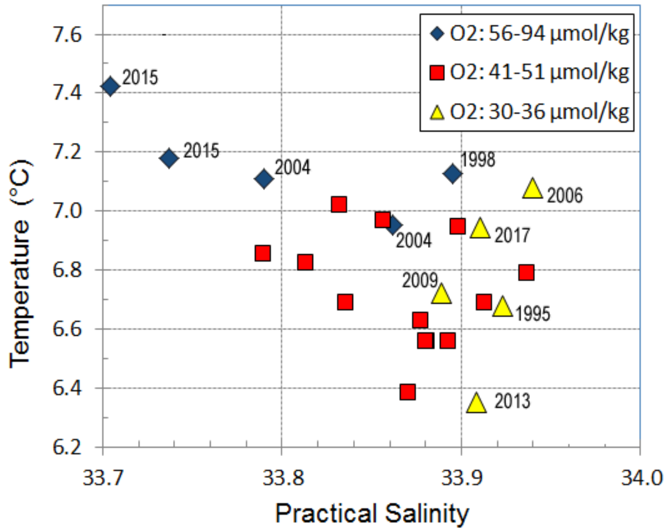

Figure 11-3. Observations of temperature and salinity at Station LB08 in late summer from 1991 to 2017. The colour of symbols denotes O_2. Blue symbols with highest O_2 represent waters that are usually warmer and more buoyant than average. Yellow symbols with lowest O_2 represent waters that are usually saltier and denser than average. Denser water is normally lower in O_2 on this continental shelf. Saltier water indicates a higher fraction of low- O_2 water advected from the south along the upper continental slope. Warmest waters in 2015 are attributed to the "Blob" and were also the richest in O_2.

11.2.2. Continental slope

We present a time series of O_2 at Line P station P4 on the continental slope where the bottom depth is 1200 m. Line P is sampled three times a year by scientists of Fisheries and Oceans Canada, usually from the Coast Guard ship *J.P. Tully*. Line P extends from the west end of Juan de Fuca Strait to Ocean Station Papa (OSP) about 1450 km away. Regular sampling at P4 began in 1981. Two surveys in the early 1960s also sampled at this location. The time series of O_2 at P4 is shown in Figure 11-4, 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 in Figure 11-4.

Data in Figure 11-4 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 until 2016. Observations in 2017 reveal a slight decrease from those of 2016 and 2015, in agreement with the changes found at LB08 on the continental shelf.

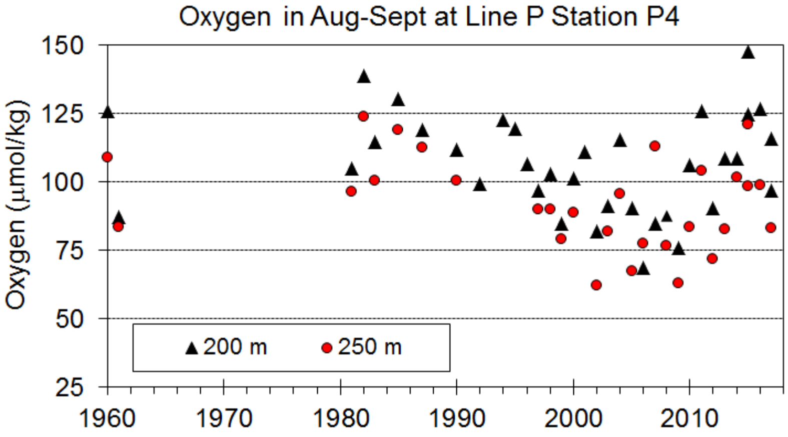

Figure 11-4. Oxygen concentration (O_2, µmol kg^{-1}) at depths of 200 and 250 metres at station P4 on the continental slope. Only measurements in August or September are included. Figure is based on Crawford and Peña (2013).

11.3. Oxygen concentration in offshore waters

There are no stations in offshore waters with regular O_2 sampling before 1980. To evaluate trends prior to 1980, we composited observations in areas around each of the intensive sampling stations along Line P, and included all observations in the archives of the Institute of Ocean Sciences (IOS) of Fisheries and Oceans Canada, Marine Environmental Data Service of DFO Ottawa, and the U.S. NOAA National Centers for Environmental Information (formerly NODC). Details of this process and results to 2011 are described by Crawford and Peña (2016). Of the six main Line P stations that are intensively sampled, we present updates for Ocean Station P (OSP, also named P26) and for a region surrounding Station P4 in Figure 11-5 below. The region surrounding P4 extends from 48° N to 49° N, and across the continental slope where the bottom depth is between 210 m and 1500 m.

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. Observations are included for regions surrounding each of these two locations. Additional details are provided by Crawford and Peña (2016). The time series at OSP (Figure 11-5a) are an update of results presented by Whitney, Freeland and Robert (2007). Time series at 48 to 49° N (Figure 11-5b) are an update of Crawford and Peña (2016).

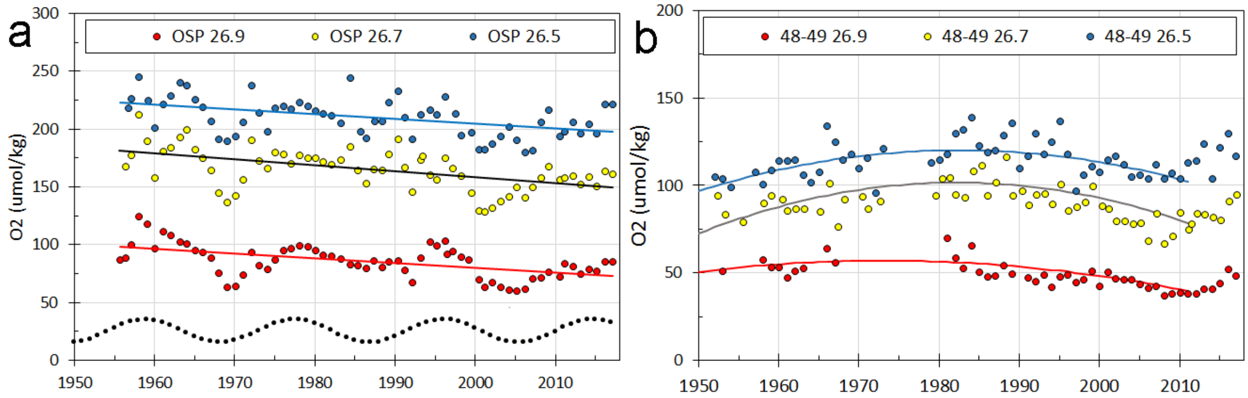

Figure 11-5. Annual average oxygen concentration (O_2) at (a) Ocean Station P (OSP) in offshore region, and (b) for the latitude range of 48° N to 49° N on the continental slope. O_2 has been interpolated onto the constant density surfaces 26.5, 26.7, and 26.9, representing potential densities of 1026.5 to 1026.9 kg m^{-3}.

Linear trends in Figure 11-5a are -0.42, -0.52, and -0.41 µmol kg^{-1} y^{-1} for surfaces 26.5, 26.7, and 26.9, respectively. The black sinusoidal curve in Figure 11-5a is an 18.6-year signal that aligns in phase with the O_2 on the 26.9 surface. Curves in Figure 11-5 b are quadratic polynomials fitted to O_2 on the 26.7 and 26.9 surfaces for the period 1950 to 2011. All plotted lines in Figure 11-5 are statistically significant at the 95% confidence level. Analysis of OSP O_2 to 2006 by Whitney, Freeland and Robert (2007) also noted the linear decrease and 18.6-year oscillation. The temporal doming in panel Figure 11-5b is also present at P4 and P12. The transition between the far-offshore variation at OSP and P20 and the near-offshore variation at 48-49° N is near P16. Note that the increase in O_2 after 2011 at 48-49° N is not observed at OSP.

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11.5. Acknowledgements:

Analysis of O_2 on constant density surfaces was undertaken by Nick Bolingbroke. We are also grateful for the Line P and La Perouse Programs of DFO, managed respectively by Marie Robert and Doug Yelland, as well as data quality and archiving by Germaine Gatien, Joe Linguanti and Roy Hourston of DFO. The Marine Environmental Data Service of DFO Ottawa, and NOAA National Centers for Environmental Information (formerly NODC) provided data for observations on constant density surfaces.

12. SATELLITE AND IN-SITU OBSERVATIONS

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12.1. Highlights

- As global carbon emissions continue to grow, long-term climate change continues with warming temperatures and rising sea levels.
- Buoy-measured SST shows significant decadal variability, with 2017 an average year after a warm period.
- Based on satellite imagery and in situ measurements, the Strait of Georgia spring bloom started on about 17 March in the central Strait, and April 16 in the northern Strait.
- Coccolith blooms again occurred in inlets, but fewer than in 2016.

12.2. Description of time series

12.2.1. Global and North Pacific climate datasets

We present several time series that reflect ocean and atmospheric conditions in the North Pacific and/or globally:

- The Keeling time series of monthly-average, season-adjusted carbon dioxide (CO_2) concentrations in the earth's atmosphere (Tans and Keeling 2018).
- The global monthly-average sea surface temperature (SST) measured by the UK Hadley Centre (Kennedy et al. 2011a and b).
- The global 10-day-average sea surface height as measured by satellite altimetry since 1993 (Figure 12-1).
- The Reynolds time series of monthly-average maps of global SST anomaly at 1-degree spatial resolution since 1981 (Reynolds et al. 2002).
- SST (1 m depth) measured hourly by 16 weather buoys on the B.C. coast (Figure 12-2).

12.2.2. Phytoplankton observations

The timing of the start of the spring bloom in the Strait of Georgia has been monitored since 2000 using satellite fluorescence line height (FLH) and buoy- and ferry-mounted fluorometers. We define the start as the date when high chlorophyll concentrations (i.e. >5-10 mg m^{-3}) are observed over a significant area (e.g. 40-60%) using satellite data and *in situ* measurements. In 2017 *in situ* measurements came from Ocean Networks Canada fluorometers on the B.C. Ferries (https://data.oceannetworks.ca/DataSearch) and fluorometers deployed on weather buoys in the northern (Sentry Shoal, 46131) and central Strait (Halibut Bank, 46146).

We also report on bright, surface blooms imaged by NASA's MODIS and VIIRS satellites. Data are from NASA Worldview at https://worldview.earthdata.nasa.gov (e.g. Figure 12-4).

12.3. Status and trends

12.3.1. Climate datasets

Concentration of CO_2 (in parts per million by volume) in the earth's atmosphere continued to rise in 2017, following the same "business as usual" relation, expressed by 301.4+.0123*(year-1925.7)^2, which has been a good fit to data collected over all years since the series started in 1958. In this sense, efforts to reduce anthropogenic carbon emissions have been offset by some combination of increased emissions from industrial and social development, and from natural sources.

Monthly global-average SST shows significant monthly and annual variation, but also a relatively steady long-term rising trend of 0.135 °C per decade. In 2017, the average value dipped about 0.4 °C from its maximum during the El-Nino in 2016, but this is consistent with previous El Niños and within the range of previous variations.

Global average sea surface height (Figure 12-1) shows a rising trend of about 3.3 mm/year, but with an increased rise rate since about 2008, suggesting acceleration. A plausible (but as yet uncertain) long-term model is of exponential increase, expressed by exp(0.0285*(year-1920)), implying 1.6 m rise by the year 2100.

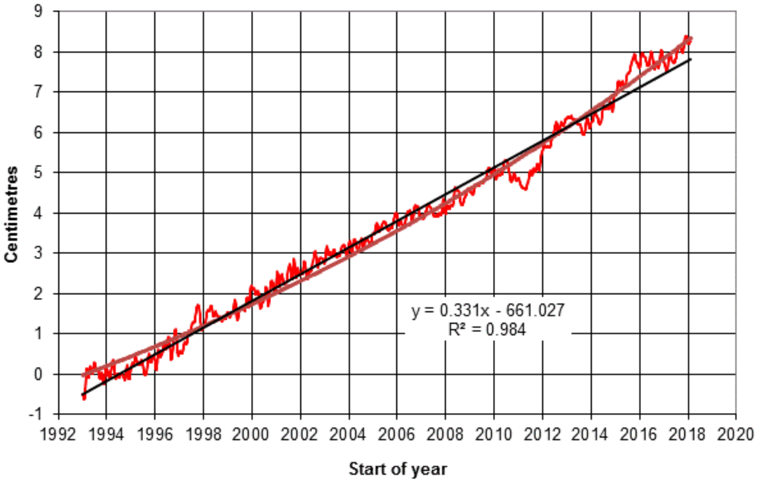

Figure 12-1. Global average sea level, 1993 through 2017, as measured by satellite altimetry on an orbit grid covering latitudes 66^o S to 66^o N, and providing a value every 10 days. The black line shows the linear rise rate of 3.3mm/year. The pink line shows a possible long-term, exponential rise, leading to 1.6 m in 2100. Data are available at: ftp://ftp.aviso.altimetry.fr/pub/oceano/AVISO/indicators/msl/MSL_Serie_MERGED_Global_AVISO_GIA_Adjust_Filter2m.txt

Global SST anomaly maps showed neutral El Niño conditions through 2017. In 2017, the B.C. coast and Gulf of Alaska was one of the few areas of the world showing zero or negative SST anomaly. Most areas now show warm temperature anomalies consistent with the 0.135 °C per decade rise rate. A new baseline "normal" may soon need to be defined, depending on what is understood by "anomalies."

Buoy SST data on the B.C. coast since about 1990 (Figure 12-2) show similar decadal variations from the average of buoys located offshore, near-shore and inshore. The top plot in Figure 12-2 shows the average temperature from the three buoys located about 400 km offshore. The centre plot shows the average of the six buoys located about 50 km offshore, and the bottom plot shows the average of the four buoys located in Dixon Entrance, Hecate Strait, and Queen Charlotte Strait. All three series are dominated by decadal variability, with the year 2017 at the end of the warm half of a 10-year cycle. In spite of the recent few warm years, the indicated long-term trends show less warming than the global average, especially for buoys close to the B.C. coast.

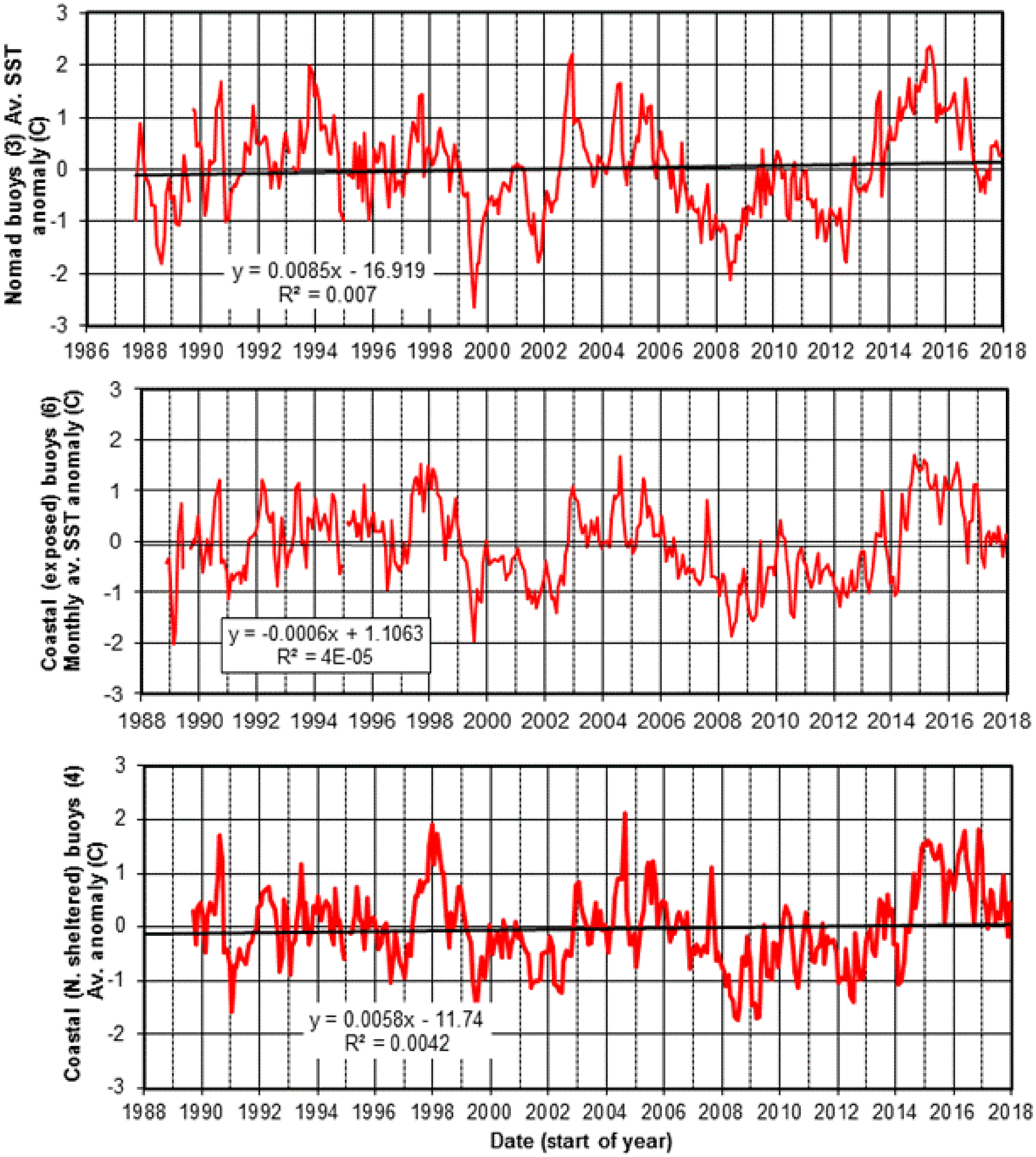

Figure 12-2. Surface temperatures (1 m depth) measured by weather buoys on the B.C. coast. The top plot shows the average temperature from the three buoys located about 400 km offshore. The centre plot shows the average of the six buoys located about 50 km offshore, and the bottom plot shows the average of the four buoys located in Dixon Entrance, Hecate Strait, and Queen Charlotte Strait. Data are available through http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/waves-vagues/data-donnees/index-eng.asp .

12.3.2. Phytoplankton

Strait of Georgia spring bloom start times have shown considerable variability, from mid-February to mid-April, which must have significant implications for survival of young salmon. Figure 12-3 shows the time series since 2000 for the central and northern Strait. The relatively short time series shows no long-term trends. In 2017 the spring bloom started on about 17 March (day 76) in the central Strait, and April 16 (day 106) in the northern Strait. The one-dimensional biophysical model failed due to inadequate solar radiation data (Allen et al. 2018), however our observations agree with the satellite observations of Costa et al. (2018), which suggest a bloom initiation date of mid-March for waters around the Fraser River plume.

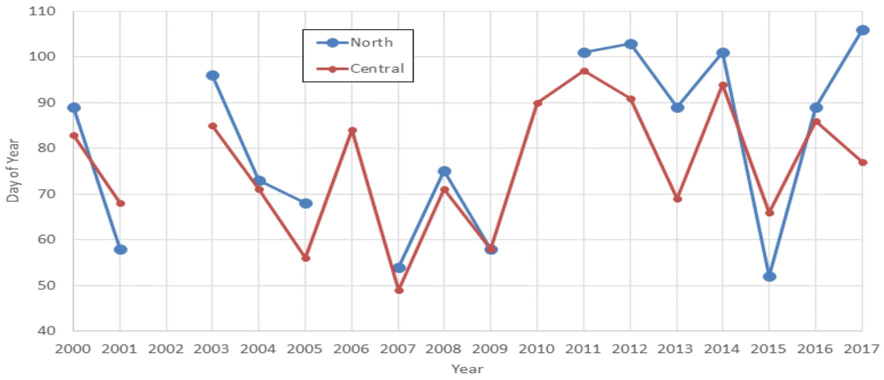

Figure 12-3. Time series of start dates for the spring bloom in the Strait of Georgia as observed by satellites and buoy- and ferry-mounted fluorometers in the central Strait and northern Strait (areas shown on the map in Costa et al. 2018).

Bright Coccolithophore blooms have been frequently observed in the summer in the Gulf of Alaska especially since the advent of satellites in the 1970s, but have not been observed in coastal inlets before 2016. In 2016, many inlets showed bright blooms, including Nitinat Lake, Sooke Basin and a major event in the Strait of Georgia (NASA 2016). In 2017 blooms again occurred, but in fewer areas. Figure 12-4 shows the MODIS Terra image of bright blooms on July 30, 2017 in Barkley Sound and in Nitinat Lake (faintly visible to the east of the Sound). Blooms occurred in Barkley Sound, July 28 to August 4, 2017 and in Nitinat Lake July 11 to August 10.

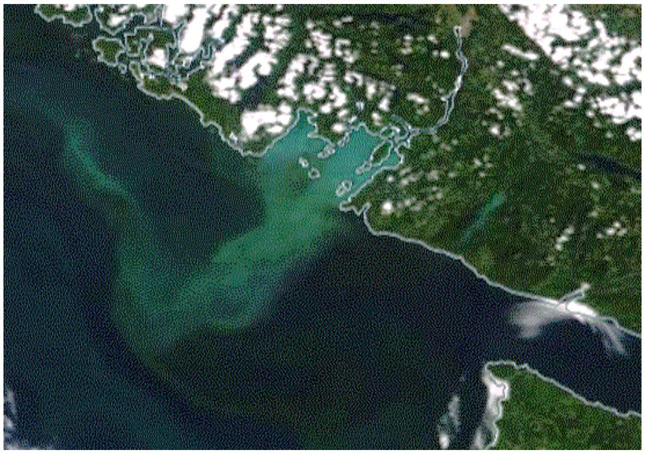

Figure 12-4. Image from NASA Worldview (https://worldview.earthdata.nasa.gov) on July 30 2017 and showing the MODIS Terra image of bright blooms in Barkley Sound and in Nitinat Lake (faintly visible to the east of the Sound).

12.4. Factors influencing trends

We live in a time of significant climate change, driven by increasing concentration of CO_2 in the earth's atmosphere. As a result of the present continuing rise in CO_2 concentration, globally-averaged sea surface temperature and height both show a continuing, long-term rise, obvious on a decadal time scale for SST, and on an annual scale for height. Recent globally-averaged sea surface height data suggest an accelerating rise, confirmed in 2017, which will lead to significant future coastal flood problems in many parts of the world.

Global SST anomaly maps and the weather buoy data from the B.C. coast both show less than the global average warming in the Gulf of Alaska and near shore. Cause of this anomaly is uncertain, but may be connected with freshening of surface waters in this area.

The cause of the Coccolithophore blooms into B.C. coastal waters in 2016 and to a lesser extent in 2017, is similarly uncertain, but may be an indirect effect of climate change, since this will lead to unusual conditions which may allow new species to gain a competitive advantage. In fact, this region is naturally acidic (Ianson et al. 2016) and would not be expected to favour carbonate-based species like Coccolithophores (Haigh et al. 2015).

The timing of the spring bloom in the Strait of Georgia (Figure 12-3) is thought to be an important factor for salmon survival in the Strait. A simple model has been used to predict start date for the bloom, based on wind, sunlight and other factors (Allen et al. 2018). Satellite observations suggest that seeding from inlets is also a factor (Gower et al. 2013). The time series of observed start times is relatively short (since 2000) and shows no long-term trend.

12.5. Implications of those trends

The global trend in CO_2 concentration is increasing ocean temperature, sea level and ocean acidification. Added to these must be changes in average wind speed, storm tracks, upwelling and river flow. The lower rate of warming in B.C. coastal and offshore waters, noted above, must be a transient phenomenon unless some mechanism can provide cooling that grows in step with increasing global warming. If the cooling mechanism remains constant from now on, then local waters will start to warm at the global rate. If the cooling mechanism stops altogether, then local waters will experience stronger warming. In either case, significant future warming must be expected.

The implications for sea level rise are less significant in B.C. than in many other parts of the world. Many parts of the B.C. coast are rising, due to post-glacial rebound, at about the present rate of global sea level rise (3 mm/year). Tidal ranges are relatively high (2 to 5 m), and communities have experience with storm surges and tsunamis, so that a change of up to 1 m can probably be accommodated. Also, many coasts are steep, making defence easier. There will still be problems in low-lying areas, such as the Fraser delta.

Arrival of any new phytoplankton species in B.C. inlets is a cause for concern to B.C.'s large and growing aquaculture industry. While Coccolithophores are not harmful to fish or humans, their sudden arrival suggests changes in coastal or offshore waters which may well have economic impacts.

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

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13.1. Highlights

- Phytoplankton biomass and community composition along Line P returned to values similar to those observed before the warm water pool the “Blob” occurred, except for at the most offshore stations.
- There was an unusual increase in phytoplankton biomass at the offshore end of Line P in the summer of 2017. This was mostly due to an increased abundance of diatoms.
- On the continental shelf of the west coast of Vancouver Island, nitrate concentrations, phytoplankton biomass and community composition in May and September 2017 were within the range of values from previous years.

13.2. 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 on the La Perouse cruise off the west coast of Vancouver Island. Sampling for phytoplankton composition has been carried out at most of the stations along Line P (Figure 13-1a) since June 2010. Phytoplankton sampling along a series of transects on the west coast of Vancouver Island (Figure 13-1b) has been carried out since 2011. Sampling along the west coast was extended farther north in 2017.

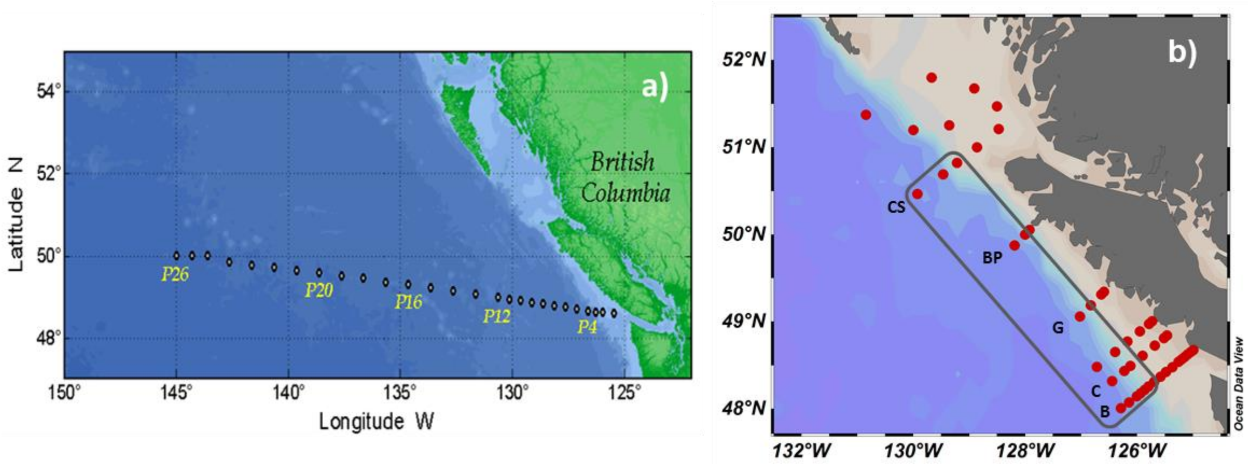

Figure 13-1. Location of sampling stations: a) along Line P, and b) on the west coast of Vancouver Island showing the outer coast region (grey rectangle) and continental shelf stations.

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).

13.3. 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 round 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 2017, surface winter nutrient values along Line P were higher than those in 2016 (Figure 13-2) and within the range of values observed before the presence of the Blob that restricted winter nutrient renewal in 2014/15 due to increased stratification. Nitrate was depleted at several stations along Line P in spring and summer of 2017 but the region of nitrate depletion was less extensive than in the previous years. At the offshore end of Line P, summer nitrate and silicate concentrations (values not shown) were similar to those of 2015 and 2016 but lower than the values in previous years. Chl-a concentrations along Line P were within the range of values from previous years, except at the most offshore stations where unusually high summer values were observed (Figure 13-2).

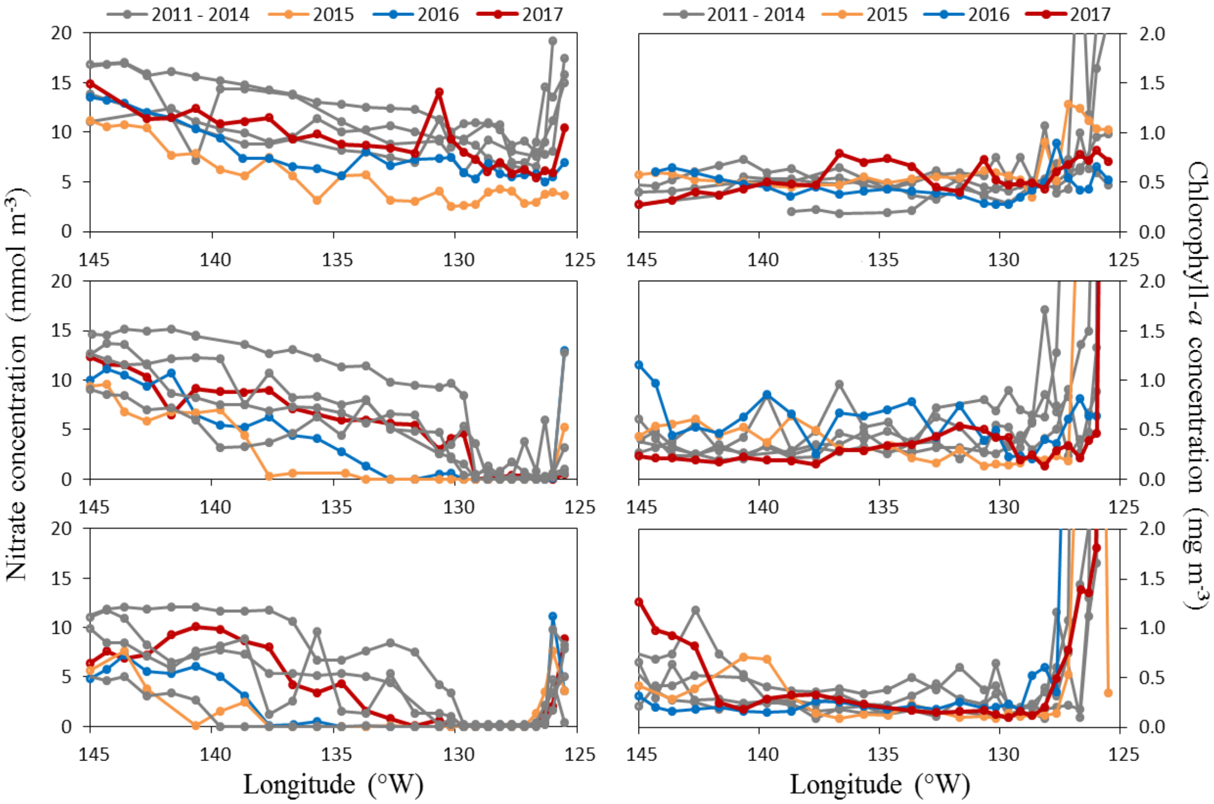

Figure 13-2. Nitrate (left panels, mmol m^{-3}) and chlorophyll-a (right panels, mg m^{-3}) in surface waters along Line P in winter (top panels), spring (middle panels) and summer (bottom panels) of 2017 (red symbols), 2016 (blue symbols), 2015 (orange symbols) and 2011-2014 (grey symbols).

Phytoplankton assemblage composition in 2017 was in general similar to those observed in 2016 and before the Blob with haptophytes dominating phytoplankton biomass at the offshore stations (Figure 13-3). However, there was an unusual increase in the relative abundance of diatoms at the farthest offshore stations in August 2017, similar to that observed in June 2016, but also a decrease in their abundance at other stations along the transect and in June 2017.

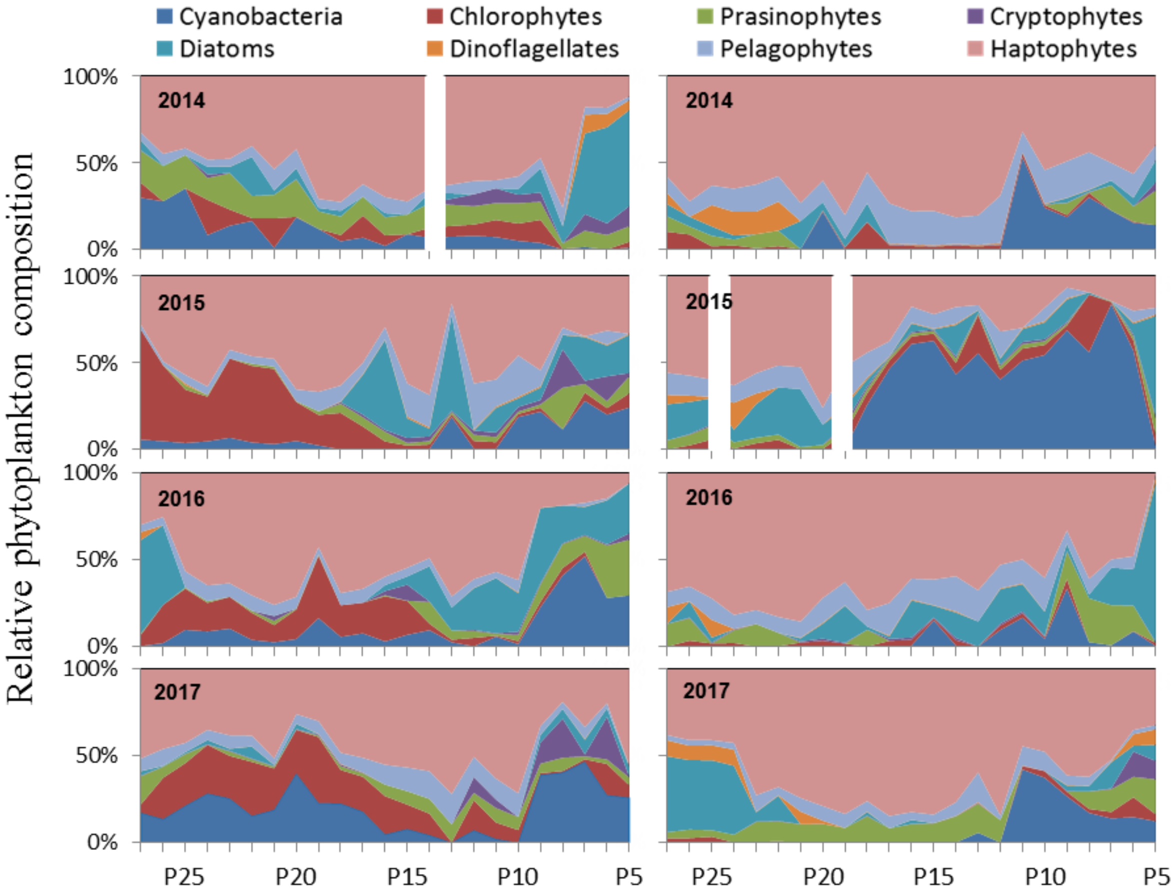

Figure 13-3. Relative phytoplankton composition in the upper layer at stations along Line P (see Figure 13-1) in June (left panels) and Aug./Sept. (right panels) of 2014 to 2017.

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 September. Chl-a is usually high (>5 mg m^{-3}) on the continental shelf off southern Vancouver Island where blooms of phytoplankton (>20 mg m^{-3} chl-a) are often observed in May and/or September. At stations beyond the continental shelf (outer coast), chl-a and nutrient concentrations are usually lower than on the continental shelf. In 2017, nitrate concentrations in May and September were within the range of values observed in previous years (Figure 13-4). Chl-a concentrations in May 2017 were within the range of values observed in previous years but in September 2017 they were somewhat lower than in previous years (Figure 13-4).

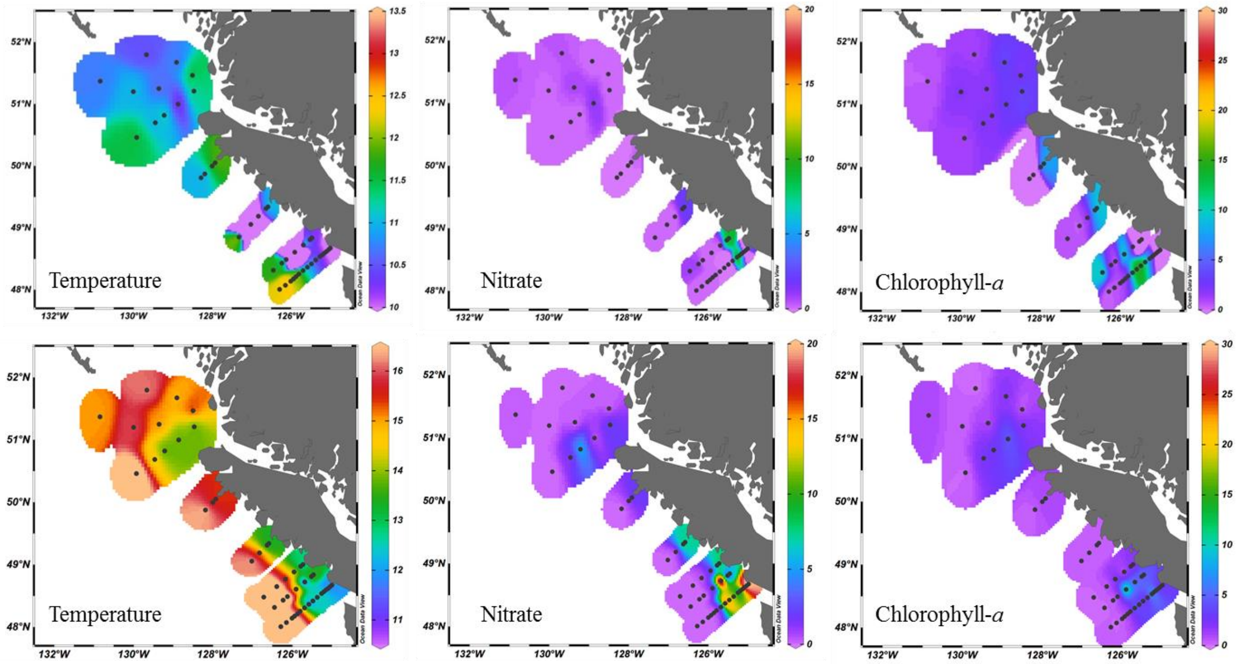

Figure 13-4. Temperature (°C), nitrate (mmol m^{-3}) and chlorophyll-a (mg m^{-3}) at 5 m depth over the study area in May (top row) and Sept. (bottom row) of 2017.

Usually diatoms dominate phytoplankton biomass at the ocean surface along the continental shelf although dinoflagellates are found to occasionally dominate in September (Figure 13-5). At the 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.

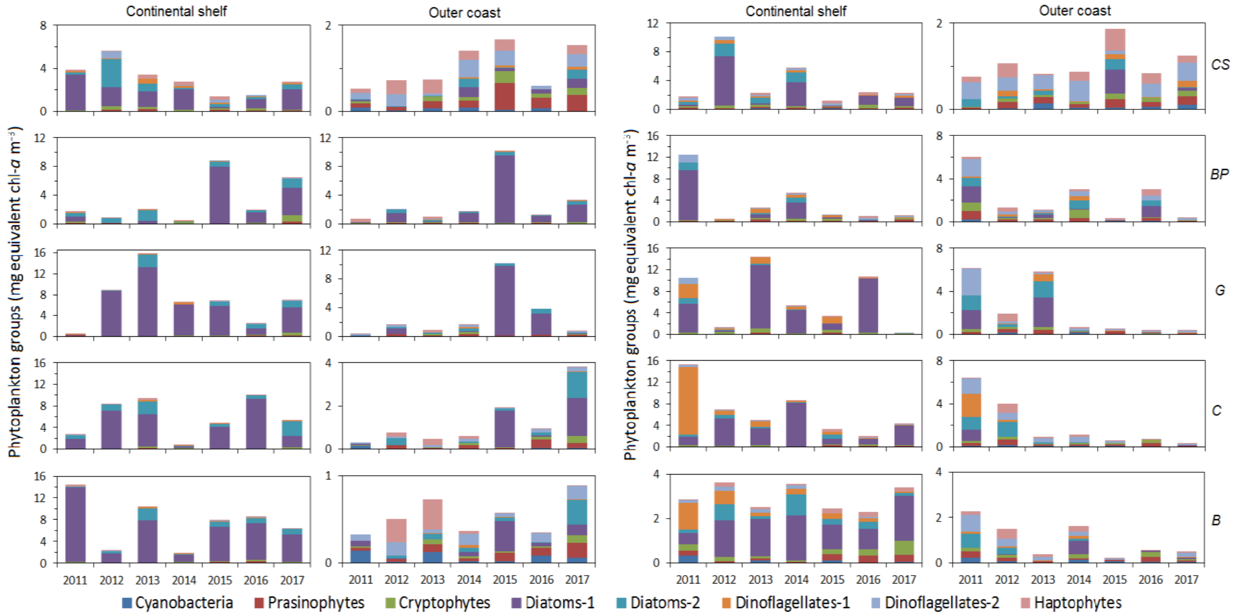

Figure 13-5. Time-series of mean phytoplankton composition at the surface at stations on the continental shelf and outer coast for Line B, C, G, BP and CS (see Figure 13-1) in May (left panels) and September (right panels).

In May 2017, 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 2017, phytoplankton biomass and community composition in the continental shelf were similar to previous years. At the outer coast, phytoplankton biomass was in the lowest range but community composition was similar to previous years.

13.4. 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 surface temperature and changes in nutrient availability. The observed sporadic increases in phytoplankton biomass and diatoms at the most offshore stations of Line P in the last two years is likely related to changes in subsurface nutrient remineralization and vertical transport due to the Blob. 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.

13.5. 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.

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14. NSERC STRATEGIC SPEAR PROJECT: NET PRIMARY PRODUCTION, NET COMMUNITY PRODUCTION, AND PHYTOPLANKTON COMMUNITY COMPOSITION IN THE NORTHEAST PACIFIC

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14.1. Highlights

- The NSERC-funded Strategic Grant Program aiming to quantify key ecosystem services in the Subarctic Pacific Ocean and characterize their responses to climate variability and anthropogenic disturbances.
- Estimates of primary productivity and phytoplankton biomass, derived from high spatial-resolution observational field data collected on Line P and La Perouse cruises (2015 onwards), will be coupled with hydrographic survey data to calibrate regional satellite algorithms and refine climate-fisheries models.
- A >20 year-times series of phytoplankton community composition in the NE Pacific was derived from satellite observations of chl-a, using algorithms regionally-validated by *in-situ* measurements.
- Data products and a data website will be available shortly.

14.2. Overview

The NSERC Strategic Grant Program (nick-named SPEAR: Subarctic Pacific Ecosystem Analysis Research Project) was funded to quantify key ecosystem services (fisheries production and carbon export) in the Subarctic Pacific Ocean, and to characterize their responses to climatic and anthropogenic forcings. The project is divided into five modules: Phytoplankton, Carbon Export Flux, Trophic Transfer and Fisheries Yield, Environmental Statistics, and Climate-Fisheries Models (for details on objectives see Izett et al. 2016). Here, we present progress towards the development of time-series data sets of phytoplankton productivity, biomass and community taxonomic composition.

Significant progress has been made towards developing and applying a variety of robust observational tools for long-term, high-resolution, and broad-coverage estimates of primary production, and phytoplankton biomass and community composition. Data have been collected via ship-based observations on Line P and La Perouse cruises using autonomous instruments and discrete sampling. These data have been, and will be, used to calibrate regional satellite algorithms for metrics of the phytoplankton community, and will be used to investigate the links between the planktonic trophic levels, climate variability, and fisheries yields.

A main objective of this project is to provide advanced monitoring tools for evaluating large-scale environmental impacts on ecosystem services of the Subarctic Pacific Ocean. By combining new observational data, remote sensing, advanced statistical analyses and numerical models, we seek to better understand climate-driven variability and improve fisheries stock assessments and ecosystem-based management. Strategic partnerships between University-based scientists (U. British Columbia, U. Victoria, Dalhousie), and DFO Researchers and Applied Scientists, will ensure continued progress towards the project's main objectives. Further, our data products, both *in-situ* field measurements and satellite output, will be made available shortly for other project stake-holders and end-users. We invite all levels of collaboration and encourage others to get in contact with the authors about data needs and interests.

14.3. Description of the observational tools and time-series preliminary results

The data collected to-date consist of two broad categories: high-resolution ship-based measurements, and satellite products. Through the development and application of a variety of autonomous instrument platforms we have obtained high-resolution data sets of primary productivity (net primary production (NPP) and net community production (NCP)) and phytoplankton biomass (chl-a and phytoplankton carbon (C_{phyto})) on Line P and La Perouse cruises since 2015. These data have been paired with discrete sampling, and observations of various hydrographic properties to calibrate our underway measurements and refine regional satellite products. Subsequently, validated algorithms for basin-wide phytoplankton community composition have now been used to re-construct a >20-year time-series (1997-present) in the NE Pacific from satellite observations of chl-a.

Continuous estimates of chl-a and C_{phyto} are obtained empirically from underway optical measurements of seawater absorbance and back-scatter. By measuring the optical properties from the ship's seawater supply system, it is possible to resolve changes in chl-*a* and C_{phyto} that cannot otherwise be captured by conventional discrete sampling. High-resolution data, based on measurements from 2016 cruises in the NE Pacific (Figure 14-1), demonstrated that there is significant spatial and temporal variability in chl-a and C_{phyto} that was linked to variability in micro- and macronutrient concentrations and the presence of submesoscale hydrographic fronts (Burt et al. 2018). Moreover, the coupling of these measurements enables derivation of an underway C_{phyto}:Chl-a ratio, which reflects changes in phytoplankton physiology and turn-over rates, and has been related to ambient light and nutrient availability. Finally, NPP can be

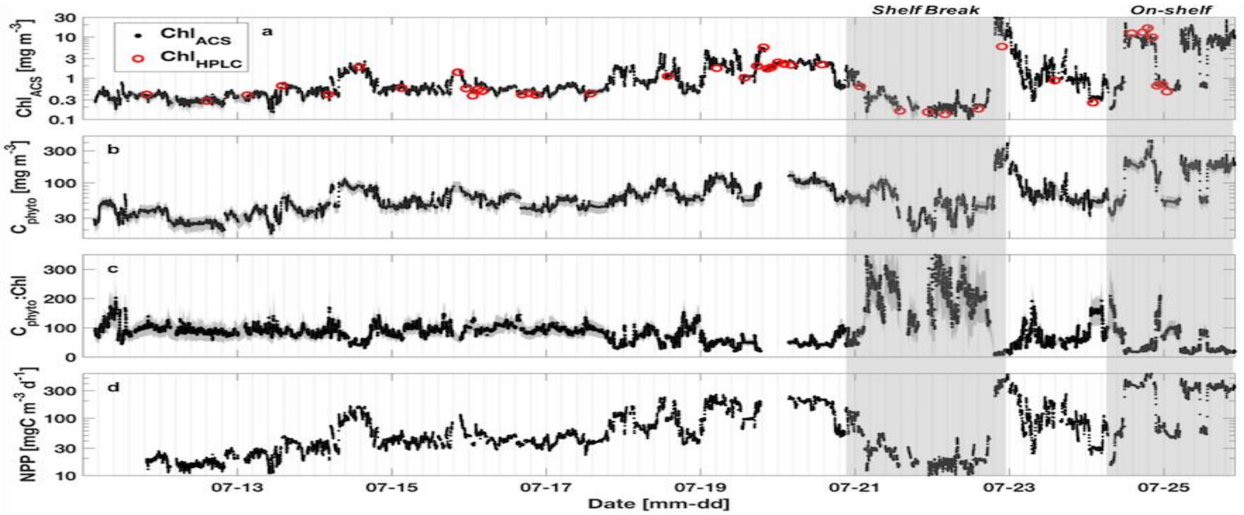

Figure 14-1. Example of chl-a (a), C_{phyto} (b), C_{phyto}:Chl (c) and NPP (d) derived from optical measurements obtained during a summer 2016 cruise in the NE Pacific (see Burt et al. 2018). Differences between different hydrographic regions (e.g. shelf break, and on-shelf regions; shaded) and fine-scale variability can be easily resolved.

derived from Chl-a and C_{phyto}, and has been validated using independent estimates derived through ^{14}C-uptake studies (Burt et al. 2018).

Net community production is estimated by evaluating the mixed layer O_2 budget. Using underway instrumentation, measurements of O_2 and the biologically inert analogs Ar or N_2 (i.e. O_2/Ar or O_2/N_2) can be used to quantify the fraction of biologically-produced O_2 (Craig and Hayward 1987). However, most previous estimates of NCP derived from ship-based O_2/Ar or O_2/N_2 measurements are biased by the vertical mixing of low-O_2 water from below the mixed layer. Our estimates of NCP, from 2015-2017 Line P and La Perouse cruises (Figure 14-2), have been corrected for the vertical mixing flux, and therefore represent more accurate and robust estimates of true NCP, particularly in dynamic and highly-productive coastal regions (Izett et al. 2018). Additionally, our NCP record has far-improved spatial resolution over any previous efforts in the NE Pacific, and reveals strong relationships with chl-a, sea surface temperature (SST) and mixed layer depth (mld; a proxy for light availability) (Izett et al., 2018).

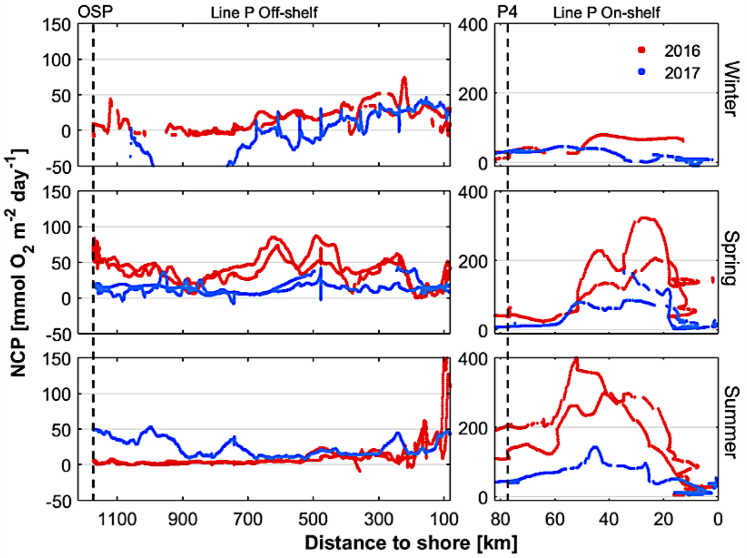

Figure 14-2. A two-year record of NCP estimates from winter (top), spring (middle) and summer (bottom) Line P cruises. A similar record has been obtained on La Perouse cruises since 2015. Values less than zero represent regions where community-wide respiration and heterotrophic consumption exceeds gross primary production. Note the difference in scales between off- and on-shelf regions. The resolution of measurements obtained via underway instrumentation enables the identification of fine-scale features and spatial patterns that cannot be captured using conventional discrete sampling methods.

Based on data obtained during several cruises in the NE Pacific (including Line P and La Perouse) from 2007-2011, and 2016-2017, a suite of algorithms relating seawater chl-a concentrations to the relative abundance of different phytoplankton functional groups (e.g. diatom) and size classes (micro-, pico-, and nanoplankton) were validated and refined for the NE Pacific (Zeng et al. 2018). Strong relationships were observed between the relative abundance of phytoplankton groups, deduced from high-performance liquid chromatography (HPLC) pigment measurements provided by A. Peña at IOS and following pigment analyses by Hirata et al. (2011), and corresponding chl-a concentrations (Figure 14-3a). Fractionated chl-a measurements that represent the micro-, pico-, and nanoplankton size classes fit polynomial NE Pacific-specific relationships between the relative abundance of each phytoplankton size class and total chl-a, as well (Zeng et al. 2018). These algorithms were applied to underway and remote sensing observations of chl-a, producing high-resolution data sets of phytoplankton community composition on basin-wide scales.

By applying these algorithms to satellite observations of chl-a, we have resolved phytoplankton taxonomy in the NE Pacific from weekly to monthly grids with a 4-9 km x 4-9 km resolution

(Figure 14-3b). This has yielded a >20-year taxonomy time-series from 1997-present (Figure 14-3c), enabling us to examine the climatic controls on phytoplankton community composition.

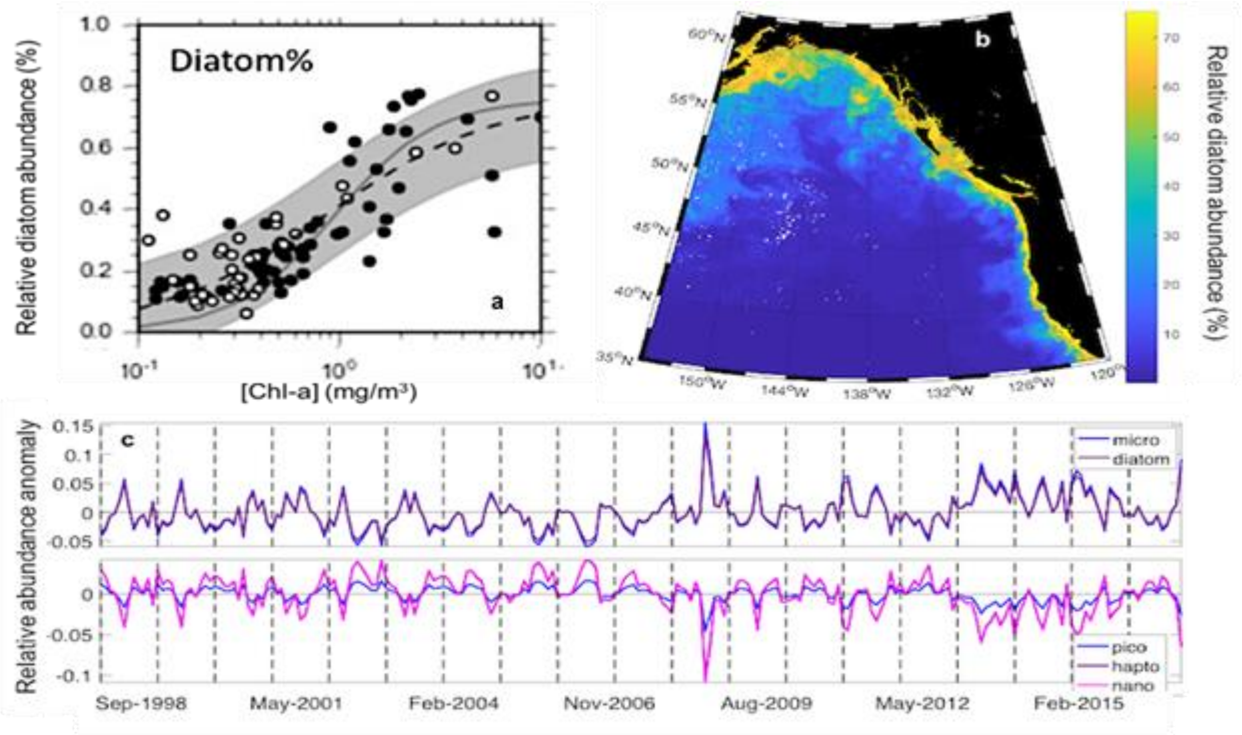

Figure 14-3. (a) Example of a regional algorithm relating chl-a concentration to the percent diatom abundance (dashed line), validated by discrete HPLC measurements from several NE Pacific cruises (circles) (Zeng et al. 2018). (b) Diatom relative abundances in the NE Pacific in September 2016, derived by applying the empirical relationship in (a) to satellite-based monthly mean [chl-a]. (c) Monthly time-series of phytoplankton relative abundance anomalies integrated over a sub-region in (b) bounded by the Pacific Subarctic Gyre East Province (Longhurst et al. 1995; Longhurst 1998), obtained from three generations of NASA satellite coverage (1997 to present). The large spikes in August 2008 (c) likely correspond to a large phytoplankton bloom triggered by the deposition of large amounts of Fe from a volcanic eruption in the Aleutian Island chain (Hamme et al. 2010).

14.4. Continuing progress

Moving forward, our underway measurements will continue to be a routine component of future Line P and La Perouse survey cruises. Significant progress has been made on developing instrumentation capable of high-throughput autonomous measurements, and these platforms can be deployed on various other research vessels to further expand data coverage in the region. We aim to obtain large *in-situ* data sets that will be used to develop and calibrate additional regional remote sensing products. The strong coherence between *in-situ* and satellite-derived estimates of chl-a (Burt et al. 2018) is promising for the future calibration of a regional satellite algorithm predicting chl-a and NPP in the NE Pacific. Similarly, the observed relationships between NCP, chl-a, SST and mld demonstrate the potential to develop an empirical remote sensing product for the estimation of NCP in the region.

Ultimately, both *in-situ* and satellite-derived data will be used to investigate climatic controls on phytoplankton productivity, physiology and community composition, and to understand the links between these variables and higher trophic level processes, such as secondary production, carbon export and fish production. Specifically, time-series data sets of phytoplankton productivity and community composition will be used to improve forecast models for regionally-significant fisheries, including Sockeye Salmon. This work is in progress, and future efforts will prioritize: (1) validation and refinement of the remote sensing taxonomy products by matching satellite-derived and *in-situ* data, (2) correlation analysis between phytoplankton taxonomy and climatology time-series, (3) integration of phytoplankton time-series over different time and space scales to match Sockeye Salmon productivity time-series collected by DFO, and (4) use of phytoplankton time-series data to improve the predictive capacity of fisheries stock assessment models. Throughout this process, we aim to collaborate with other university and DFO-based scientists and applied scientists to share our data products.

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15. LOWER TROPHIC LEVELS IN THE NORTHEAST PACIFIC

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15.1. Highlights

- The diatom abundance anomaly was positive and diatom composition was near normal.
- The zooplankton biomass anomaly was slightly negative and the seasonal cycle was early. There was still a bias towards smaller species and warm water taxa were still relatively abundant indicating a continued, though diminished, influence of the marine heat wave.

15.2. Sampling

Sampling from commercial ships towing a Continuous Plankton Recorder (CPR) occurred approximately monthly 6 to 9 times per year between March and October in the off-shore Northeast Pacific (Figure 15-1). Each CPR sample contained the near-surface (about 7 m depth) plankton from an 18.5 km length of transect, filtered using 270 µm mesh, and afterwards analysed microscopically to give taxonomically resolved abundance data. Data to June 2017 have been finalised at the time of writing, while data for July to Oct 2017 are still only partially complete. Several indices are now routinely updated and are summarized here.

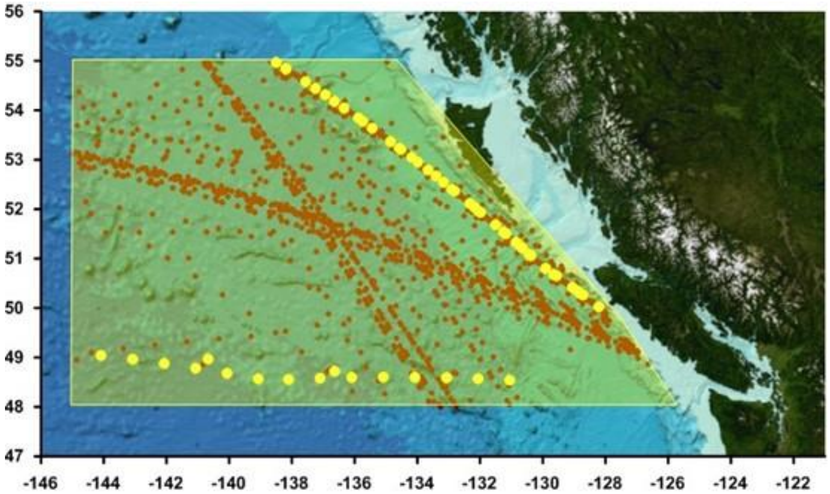

Figure 15-1. Map showing the location of the historical samples (dark red dots, 2000-2016) and those collected in 2017 (yellow) that are used in this report (additional 2017 samples are being processed). Data are averaged for the region outlined in yellow.

15.3. Description of the Plankton Time Series.

15.3.1. Diatoms

The CPR effectively retains larger, especially chain forming, diatoms and an annual index of abundance is calculated from individual taxon abundances. Annual anomalies are calculated based on the whole time-series. An index of broad community composition is calculated for spring diatoms as the proportion of the community comprising long, narrow cells versus round, centric-type cells.

15.3.2. Zooplankton

Biomass of mesozooplankton is estimated from taxon-specific dry weights that are multiplied by the abundance of each taxon. Annual anomalies are then calculated. The mid-point of the seasonal cycle is determined by integrating over the annual cycle of sampling dates each year and finding the day at which 50% of the cumulative biomass was reached.

The CPR is particularly effective at sampling the copepod community and two copepod indices give information on community composition. Taxon specific lengths and abundances are used to calculate the mean copepod length each month. Since most copepods are identified to species, and all to genus, the abundance of a suite of taxa indicative of warm water is also counted.

15.4. Status and Trends

15.4.1. Diatoms

The 2017 diatom abundance anomaly is likely to be positive when all data are finalised (Figure 15-2). Seasonality was typical, slightly higher in spring and fall than in summer. During the marine heat wave years of 2014-15 it was noted that the proportion of the long thin celled diatoms was much higher (Figure 15-3) but in 2017 the diatom composition had reverted to a more typical ratio.

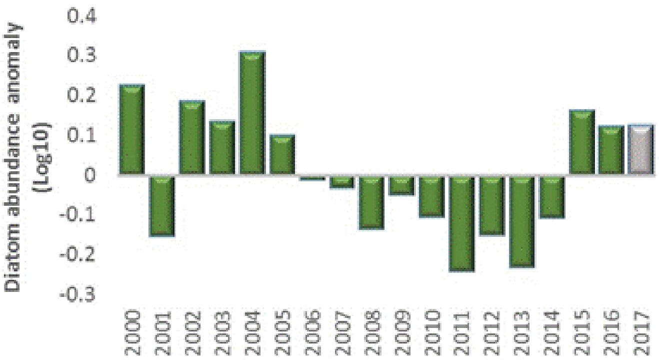

Figure 15-2. Annual abundance anomalies of large diatoms for the region shown in Figure 15-1. Value for 2017 is provisional.

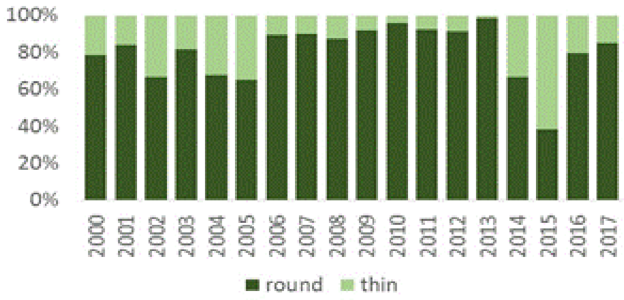

Figure 15-3. The proportion of the spring (March to June) diatom community comprised of either long, thin diatoms or round, chain forming cells.

1.4.2. Zooplankton

The annual mesozooplankton biomass anomaly for 2017 is projected to be a little below average (Figure 15-4). The midpoint of the seasonal cycle was early, second only to 2014. There is a significant, negative correlation between this date and the Pacific Decadal Oscillation (PDO) index so that in warm, PDO positive years the seasonal cycle is shifted earlier.

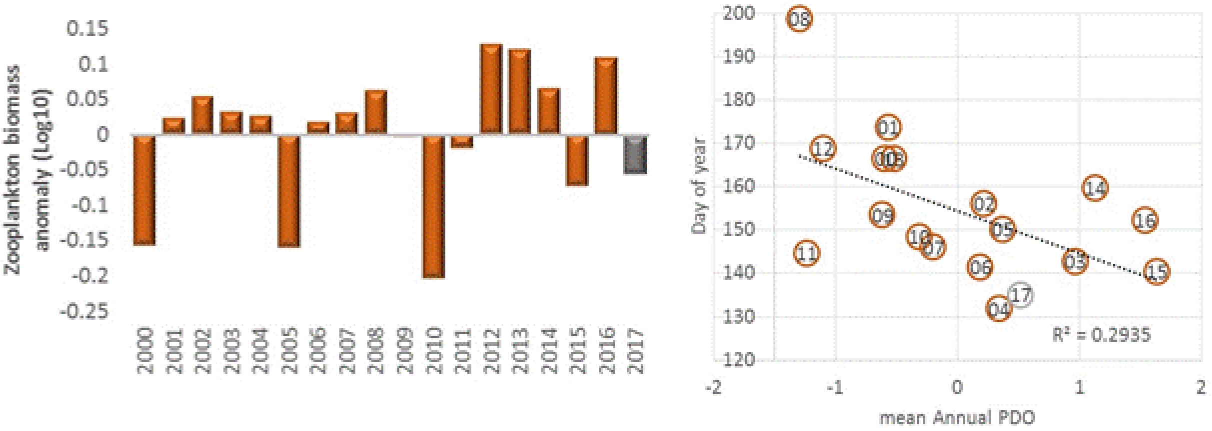

Figure 15-4. The mean annual zooplankton biomass anomaly (left), estimated using taxon-specific values for the region shown in Figure 15-1 and the relationship between the midpoint of the biomass seasonal cycle and the PDO index (right, year shown in the centre of each point). Biomass peaks earlier in warm, PDO positive years (p=0.01). 2017 values are provisional.

The mean size of the copepod community through the year is shown in Figure 15-5. Values for each month of 2017 were either close to or below the long-term mean, indicating that the community was biased towards smaller species, particularly in the autumn.

Warm water taxa were still quite abundant in 2017 (Figure 15-6) with numbers likely close to those of 2016.

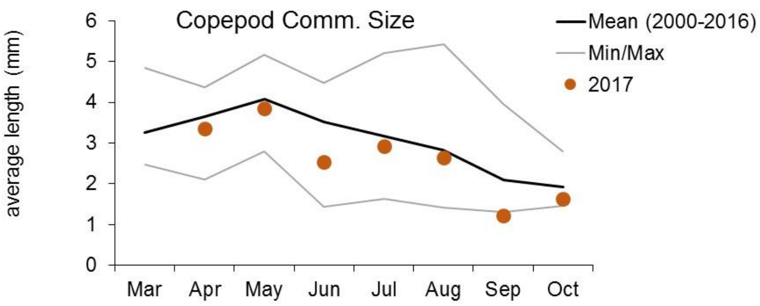

Figure 15-5. Seasonal cycle of mean size (length) of copepods. Black line is the long term monthly mean, grey lines are the long term monthly min/max and points are the monthly 2017 values (provisional after June).

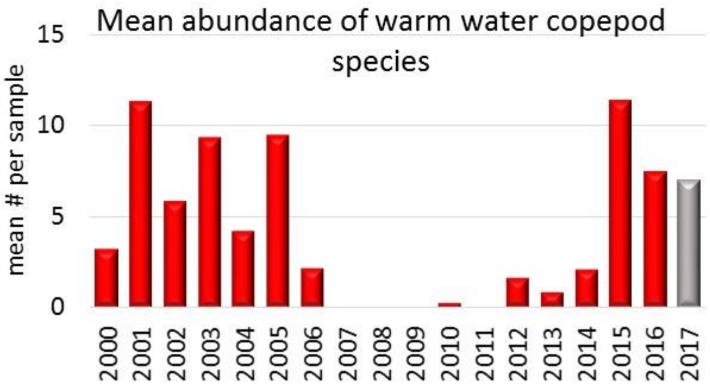

Figure 15-6. Mean annual abundance of a suite of warm water copepod species (Clausocalanus spp., Mesocalanus tenuicornis, Acartia danae and Corycaeus spp.).

15.5. Factors Influencing the trends and implications

The unusually warm conditions that began late in 2013 and persisted through 2016, termed a marine “Heat Wave” (DiLorenzo and Mantua 2016), were still having some influence on the plankton in 2017 although indices reflected a more average community. Diatom abundances and the ratio of cell-types in 2017 were not unusual. The PDO was still positive through 2017 and so an early zooplankton seasonal cycle would be expected. The timing was indeed early (Figure 15-4), and in fact about two weeks earlier than predicted from the relationship between timing and the PDO alone. This may have implications for predators whose seasonal timing may therefore miss the peak of prey biomass.

There was a slight bias towards smaller copepod species (Figure 15-5) through 2017. While not extreme, it may have some influence on predator diets since with smaller individuals contributing to the biomass more energy needs to be expended to catch the same amount of food. Warm water specific taxa, while much less abundant than sub-arctic species, were still relatively abundant in 2017 (Figure 15-6). Implications are likely to be minor at this time although if they become more dominant members of the community there may be implications for ecosystem functioning and nutritional effects on predators.

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

16. WEST COAST BRITISH COLUMBIA ZOOPLANKTON BIOMASS ANOMALIES 2017

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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.
- *Pyrosoma atlanticum* was observed in large numbers along the coast, from Oregon to SE Alaska.
- Sub-Arctic and boreal chaetognaths continue to decline as southern copepod and chaetognath species increase.

16.2. Description of the time series

Zooplankton time-series are available for southern Vancouver Island (SVI; 1979 to present), northern Vancouver Island (NVI; 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 onwards. The 'standard' sampling locations are averaged within 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 (methods see Mackas 1992 and Mackas et al. 2001). Abundance and biomass is estimated for all zooplankton species in these areas (>50 species).

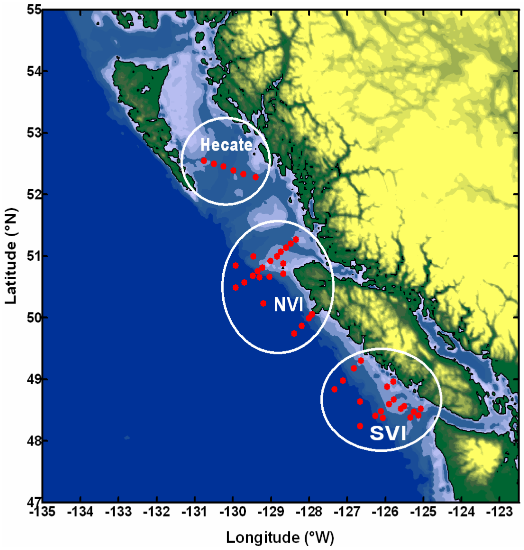

Figure 16-1. Zooplankton time series sampling locations (red dots) in B.C. marine waters. Data are averaged for samples within each area; the SVI and NVI regions are further classified into shelf and offshore subregions.

To avoid confounding seasonal and interannual variability, 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 the 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 and Mackas et al. 2001 for mathematical details). 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). The analysis merged samples into broader categories (size classes within major taxa) as described in Mackas et al. (2013) and Irvine and Crawford (2013). All data presented here is preliminary, analysis is on-going and numbers will change.

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

Zooplankton group	**Species**	**Comments**
Southern copepods	*Acartia danae, A. tonsa, Clausocalanus spp., Calocalanus spp., Ctenocalanus vanus, Mesocalanus tenuicornis*, *Paracalanus spp.*	Centered about 1000 kilometers south of our study areas (either in the California Current and/or further offshore in the North Pacific Central Gyre)
Boreal shelf copepods	*Calanus marshallae, Pseudocalanus 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, Thysanoessa spinifera*	Centered off west coast of N. America; euphausiid biomass corrected for day/night tows.
Southern chaetognaths	*Mesosagitta minima, Serratosagitta bierii, Parasagitta euneritica*	Centered off California/Mexico
Northern chaetognath	*Parasagitta elegans*	Boreal Pacific into the Arctic
Cnidarians	*Aglantha digitale, Pleurobrachia bachei, Nanomia bijuga*	Hydromedusae, ctenophores, siphonophores ; boreal Pacific to Arctic

16.3. Status and trends

The biomass anomaly time series for copepod species groups and representative chaetognaths and euphausiids in the west coast of Vancouver Island (WCVI) and Hecate statistical areas are shown in Figure 16-2 and Figure 16-3. 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. 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.

In both the near shore and offshore regions of Vancouver Island, there were strongly positive anomalies for southern zooplankton in 2017. This increased throughout the year as warm nearshore water with higher abundances of southern oceanic zooplankton species moved poleward but was not as strong as in 2016. By June 2017 the whole continental margin of B.C. was inundated with large masses of gelatinous animals: mainly pyrosomes on the shelf to shelf break; doliolids along the shelf break and hydromedusae and ctenophores across all shelf areas. Subarctic and boreal copepods exhibited an upward trend for the first time in a while, except for in the Hecate region.

Boreal copepods increased along the shelf, more so along the north coast but not in Hecate Strait. Southern copepod anomalies were positive in all regions but not as strong as in 2016 (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 Vancouver Island, both on the shelf and the offshore areas, the annual anomalies of the subarctic oceanic copepods were positive in 2017 (Figure 16-2 and Figure 16-3). The Hecate region had a negative anomaly for subarctic copepods, which, coupled with the decline in boreal copepods and the inundation of southern species is of somewhat of a concern for seabirds and larval and juvenile fish which feed on copepods.

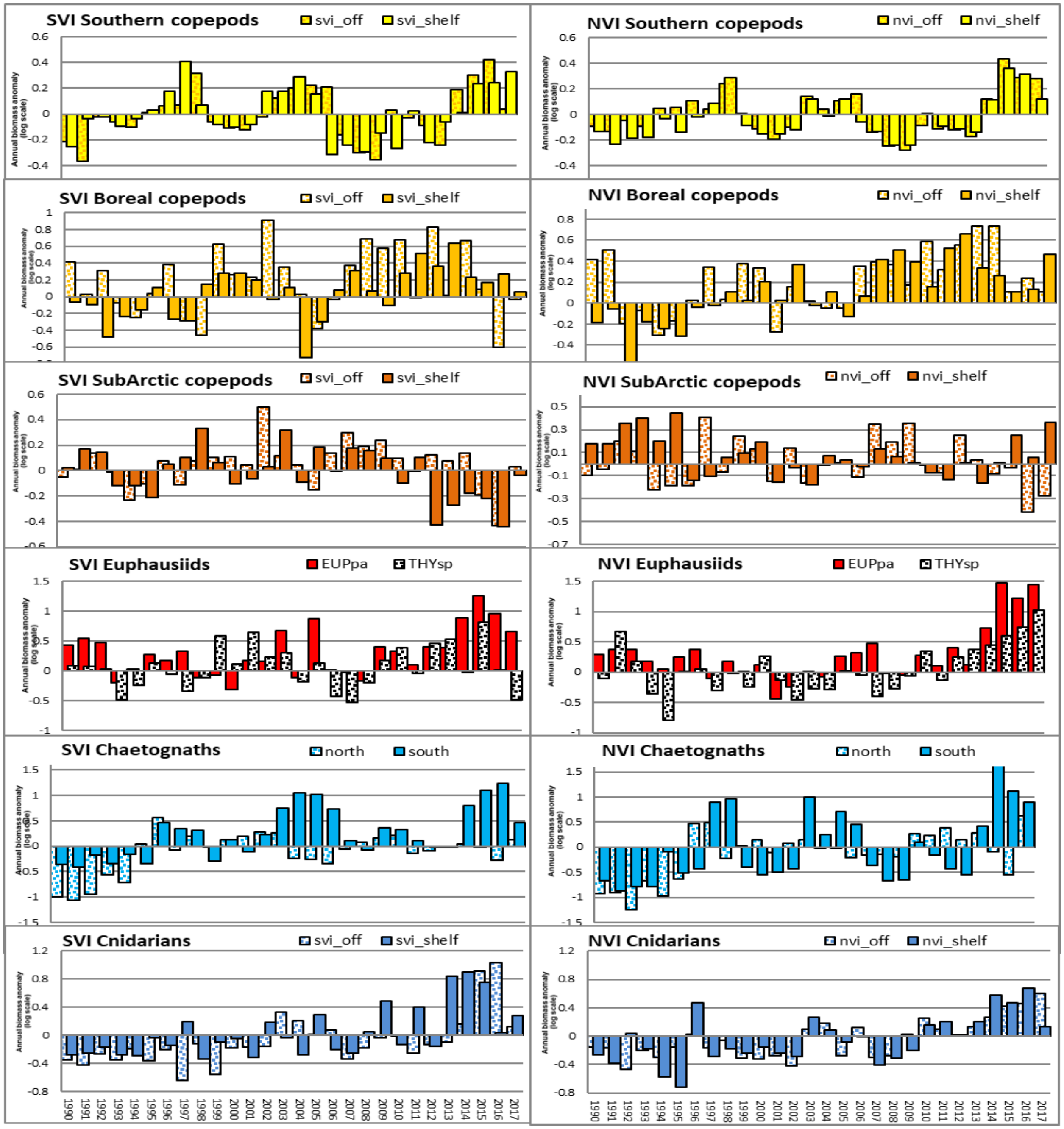

Figure 16-2. Zooplankton species-group anomaly time series for the SVI (left) and NVI (right) regions shown in Figure 16-1. Bar graphs are annual log scale anomalies for 1990 to 2017. Cool years favor endemic 'northern' taxa; warm years favor colonization by 'southern' taxa. See earlier State of the 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.

Euphausiids have trended positively over the last five years off the WCVI. Off California, both *Euphausia pacifica* and *Thysanoessa spinifera* were the dominant species suggesting that warmer waters may enhance their reproductive success along Vancouver Island. However, in the past, warming events tended to favour *E. pacifica* over *T. spinifera* off the B.C. coast. It may be possible that the currents of the El Niño carried more euphausiids from the south to mix with the resident population, increasing the biomass anomaly. In 2017, in Hecate Strait and SVI shelf, there was a decrease in *T. spinifera* biomass. Euphausiid species whose distribution centres off Oregon/California and south (*Thysanoessa gregaria, Nematocelis difficilis* and *Nyctiphanes simplex*) continue to be found along the Vancouver Island shelf throughout the year (data not shown).

Ctenophores, siphonophores and hydromedusae anomalies were positive for 2017; more occurred in the SVI shelf area and along the shelf break of NVI (not shown) which is a reverse from 2016 (Figure 16-2). The cnidarian community in Hecate Strait has continued to show positive anomalies since 2014 (Figure 16-3). On the NVI shelf area and into Hecate there was an unusually high number of *Bolinopsis* encountered in the sampling gear. These are very fragile creature that fall apart through the sampling procedure and are therefore underrepresented in sample counts. Basically the calculated gelatinous biomass anomaly may be lower than what was in the water column for all areas.

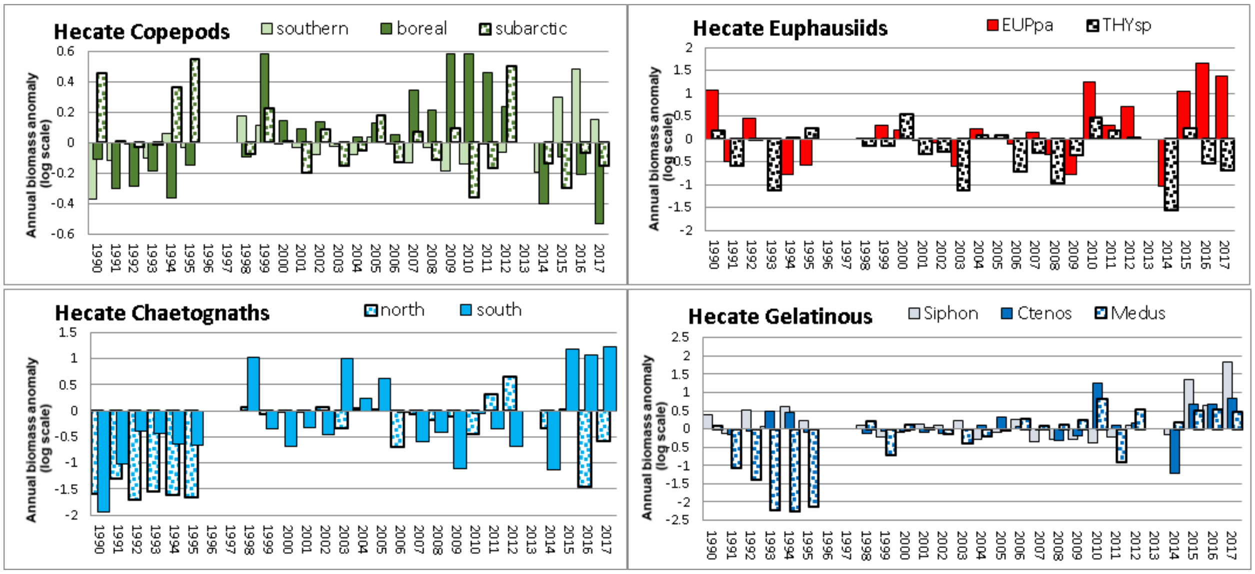

Figure 16-3. Zooplankton species-group anomaly time series (vs climatological baseline) for the Hecate Strait region shown in Figure 16-1. EUPpa: Euphausia pacifica; THYsp: Thysanoessa spinifera; Chaetognaths divided into north/south species groups; Siphon: Siphonophora; Ctenos: Ctenophora; Medus: Hydromedusae. Blank years mean no samples: 1996-97; 2013.

Doliolids were absent or rare in nearly all years before 2003, but since then have been present in years of warm water incursions into 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 16-4). This year, doliolids were more abundant in Hecate Strait, from late August to October, with lower numbers off WCVI (Figure 16-4), being found mainly along the shelf break.

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 collect numerous small colonies around 5-20 mm in length on the shelf and along shelf break of SVI in the early part of the year. Data not shown but trawl sampling would be a better source of information on these peculiar creatures (Brodeur et al 2017).

Limacina helicina along the shelf had being trending negatively for quite a few years since 1998 but this year there has been increase in biomass for Vancouver Island and a tenfold increase for Hecate Strait. It is difficult to determine a trend for Hecate Strait pteropods due to the low number of samples for the area but it does appear to be highly variable year to year and episodic in nature.

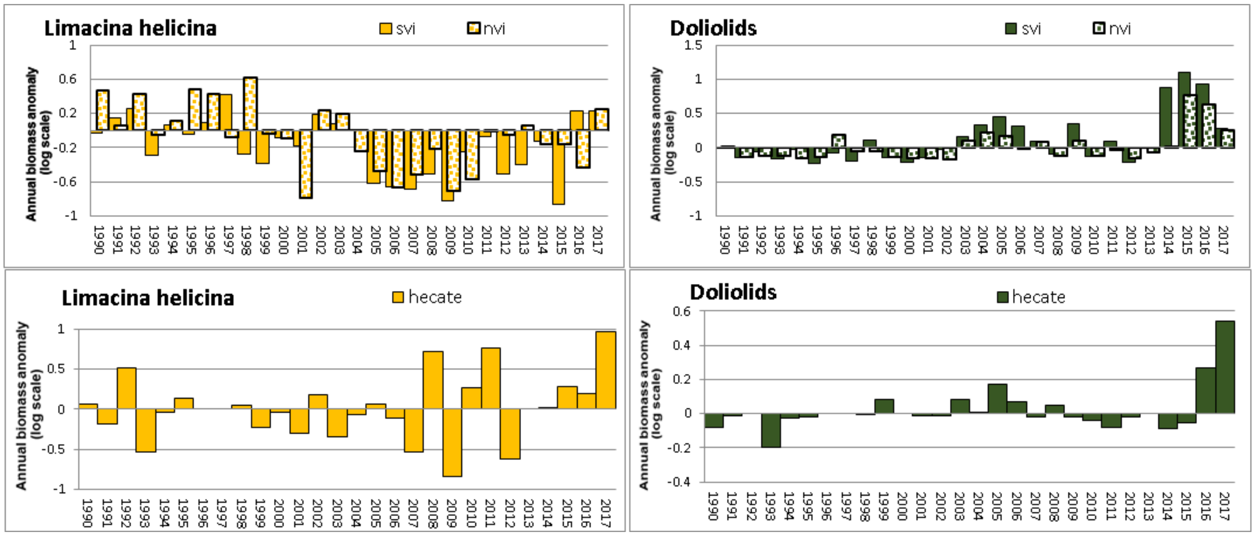

Figure 16-4. Limacina and doliolid biomass anomaly time series (vs. climatological baseline) for Vancouver Island and Hecate Strait region shown in Figure 16-1. Blank years mean no samples: 1996-97; 2013.

16.4. Implications of those trends

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.

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, doliolids and this year, pyrosomes. 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.

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 shelf. The 2017 pattern shows that something unusual was going in Hecate Strait; the amount of gelatinous biomass far exceeded the crustacean contribution. Temperature was elevated in 2016 for the whole west coast of British Columbia (Yelland and Robert 2017) and this continued into 2017 but perhaps not as high. Figure 16-5 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, equate to poor survival prospects for juvenile fish and seabirds.

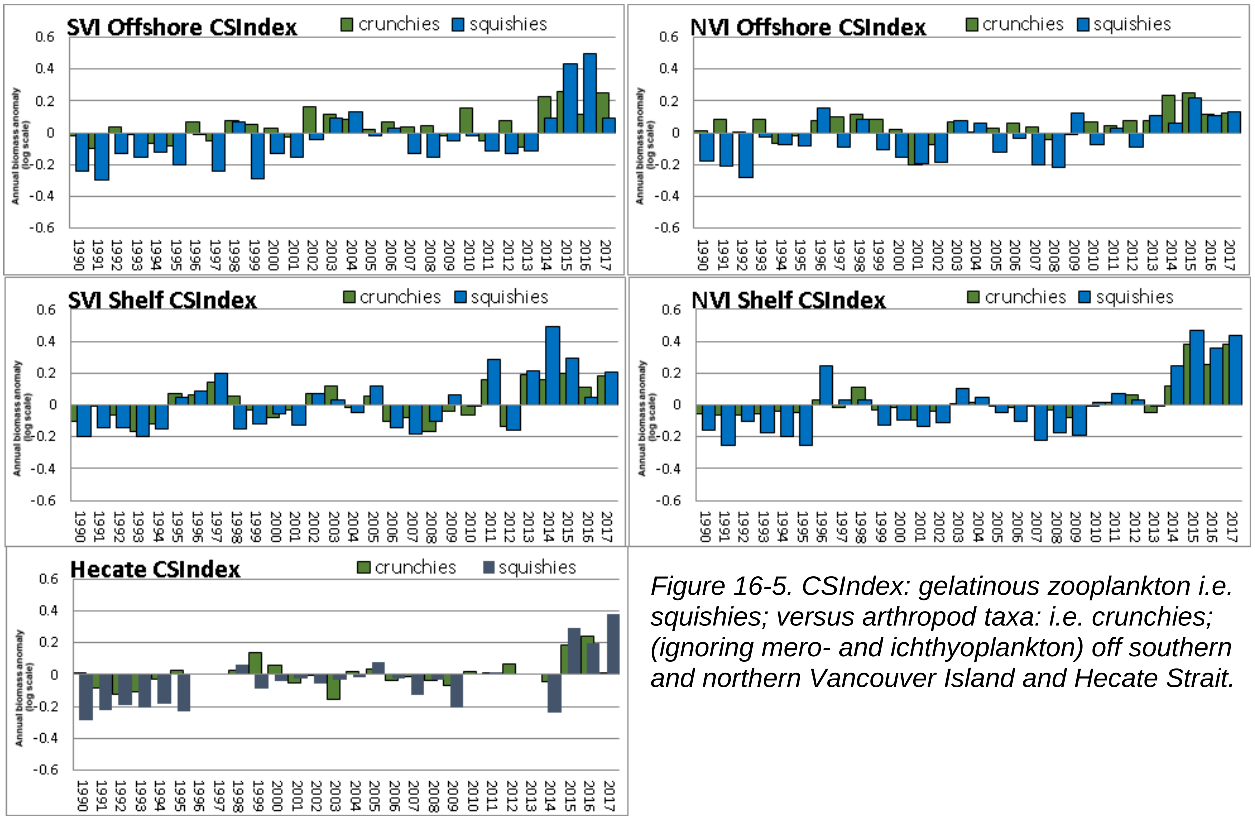

Figure 16-5. CSIndex: gelatinous zooplankton i.e. squishies; versus arthropod taxa: i.e. crunchies; (ignoring mero- and ichthyoplankton) off southern and northern Vancouver Island and Hecate Strait.

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17. PRELIMINARY RESULTS OF THE 2017 EAST COAST HAIDA GWAII NORTHERN ABALONE INDEX SITE SURVEY

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17.1. Highlights

- Between 1978 and 1990, abundance of Northern Abalone (*Haliotis kamtschatkana*) at surveyed index sites on the East Coast of Haida Gwaii declined by about 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.
- Preliminary results indicate that the population density on the East Coast of Haida Gwaii is increasing and abalone are more widely dispersed; however, the size structure is highly skewed towards smaller, immature individuals.

17.2. Description of the time series

Northern Abalone populations are monitored at index sites in each of five regions throughout the British Columbia (B.C.) Coast on a five-year rotation. Index sites were originally established in 1978 on the East Coast of Haida Gwaii (ECHG; Figure 17-1) 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), in Queen Charlotte Strait (2004), and the West Coast of Haida Gwaii (2008) to monitor stock status on a more coast-wide basis. Index site regions are further subdivided into smaller areas, each consisting of multiple index sites.

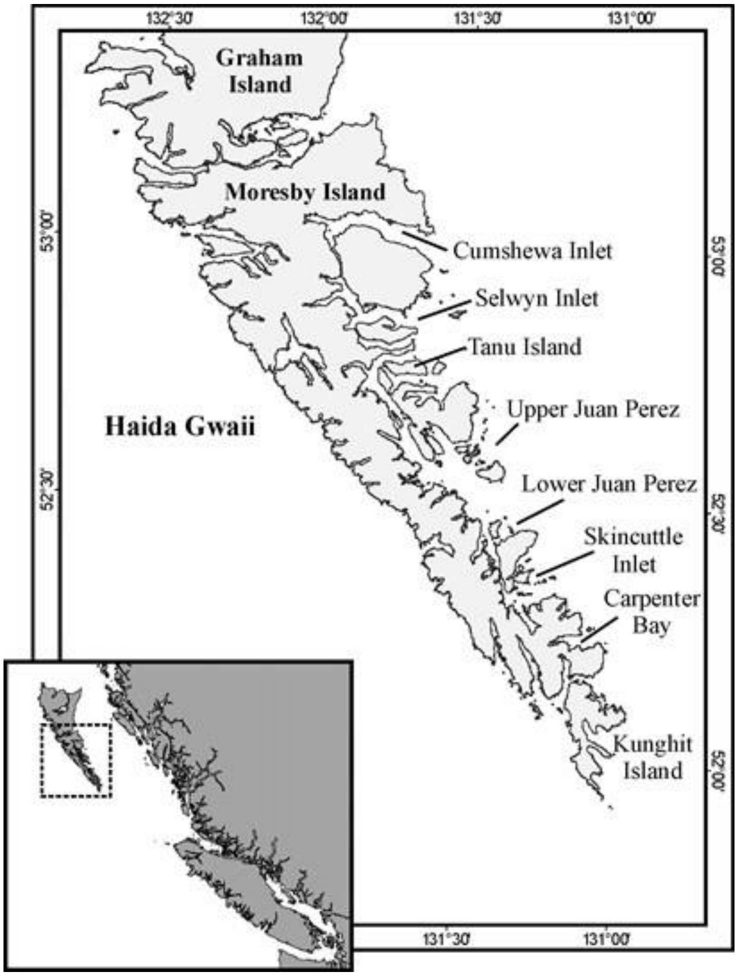

Figure 17-1. Map showing the 8 Abalone index site areas for the East Coast Haida Gwaii (ECHG) Region: Cumshewa Inlet (9 sites), Selwyn Inlet (8 sites), Tanu Island (8 sites), Upper Juan Perez Sound (15 sites), Lower Juan Perez Sound (9 sites), Skincuttle Inlet (14 sites), Carpenter Bay (11 Sites), and Kunghit Island (9 sites).

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 the population and distribution 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 declined approximately 80% at index sites in the ECHG Region (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. Suggested causes for the lack of recovery, despite a ban on harvest, include low recruitment, illegal harvesting, and Sea Otter predation (DFO 2012).

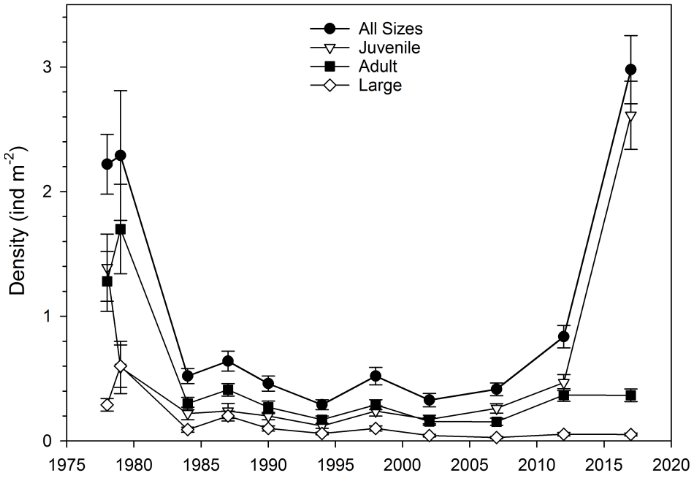

Figure 17-2. Observed density of abalone measured at index sites in the East Coast Haida Gwaii (ECHG) Region, 1978 – 2016. Densities are shown for: ‘All Sizes’ (≥ 20 mm Shell Length (SL), ‘Juvenile’ (≥ 20 and < 70 mm SL),’Adult’ (≥ 70 mm SL), and ‘Large’ (≥ 100 mm SL) abalone. Values are mean ± SE.

Since about 2007, the total density of abalone (individuals m^{-2}, for all size classes combined) at index sites on the ECHG has been increasing, with preliminary results showing a pronounced increase between 2012 and 2017 (Figure 17-2). However, the relative contribution to this increase has not been the same across all size classes and has primarily resulted from high densities of juveniles. In turn, abalone have become more widely dispersed and the percentage of quadrats containing abalone continues to increase at both the regional (Figure 17-3) and the site level.

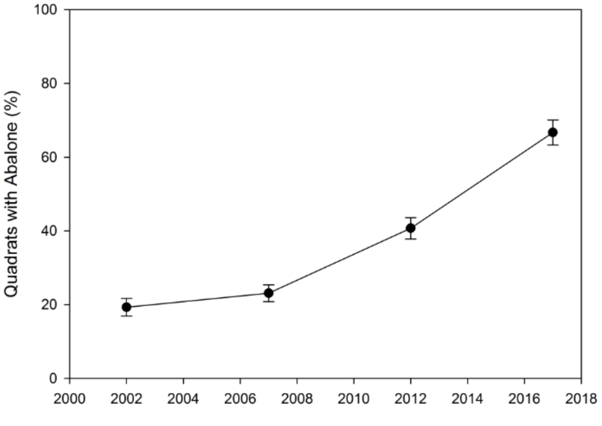

Figure 17-3. Percentage of quadrats surveyed at index sites for the East Coast Haida Gwaii (ECHG) Region that contained at least one Northern Abalone, 2002-2017. Values are mean ± SE.

Prior to the declines that led to the listing of Northern Abalone under the Species at Risk Act (SARA), the population at index sites on the ECHG was dominated by large individuals. Until about 2007 there was a decline in the median shell length, primarily as a result of a decline in the density of adults. Despite the density of juvenile and adult abalone increasing since 2007 (Figure 17-2), the median shell length has continued to decline as a result of a proportionally greater increase in juvenile density. In 2017, there was a pronounced shift in the size frequency distribution of abalone measured at index sites in the ECHG Region towards smaller sizes (Figure 17-4), resulting in a reduction in median shell length from 65 mm in 2007, to about 44 mm.

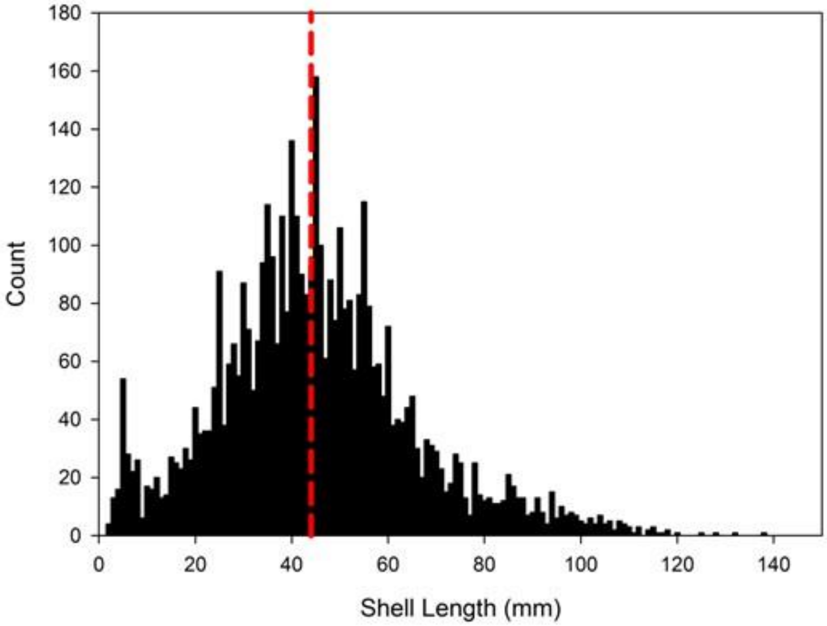

Figure 17-4. Size frequency histogram of all Northern Abalone (n = 4355) measured during the 2017 index site survey on the East Coast of Haida Gwaii. Bars are 1-mm increments. Vertical line is at 44 mm, the median shell length.

17.4. Factors influencing trends

While the exact reasons for the observed increases in density of Northern Abalone at index sites on the ECHG 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 density did not begin to increase until about 2007. The factor which has primarily been implicated for this lack of recovery 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 juvenile 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.

The 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, such as the ECHG, 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 those with Sea Otters. The impact that the potential eventual recovery of *Pycnopodia* may have on Abalone populations is also unknown. Lastly, while the ECHG Region is showing signs of recovery, it is important to note that the overall fecundity of the region may not be the same as it was historically for a given density due to a shift in the size distribution towards smaller individuals that produce fewer eggs (Campbell et al. 2003).

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18. PACIFIC HERRING IN BRITISH COLUMBIA, 2017

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18.1. Highlights

- Biomass estimates increased in the last 5 to 7 years in 2 of the 5 main fished stocks of herring.
- Factors contributing to changes in biomass and stock status include changes in recruitment, natural mortality, mean weight-at-age, spawn index or model fits to the spawn index.
- There has been a recent increase of weight-at-age in all stocks, following a declining trend during approximately 1980 to 2010.

18.2. 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 18-1). 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, sex, etc.), herring spawn survey data (spawn index), and commercial harvest data. In 2017, the model was used to provide (in part) estimates of Pacific Herring spawning biomass and age-2 recruit abundances (DFO 2018). 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 (2018) for important additional information regarding the status of B.C. herring stocks.

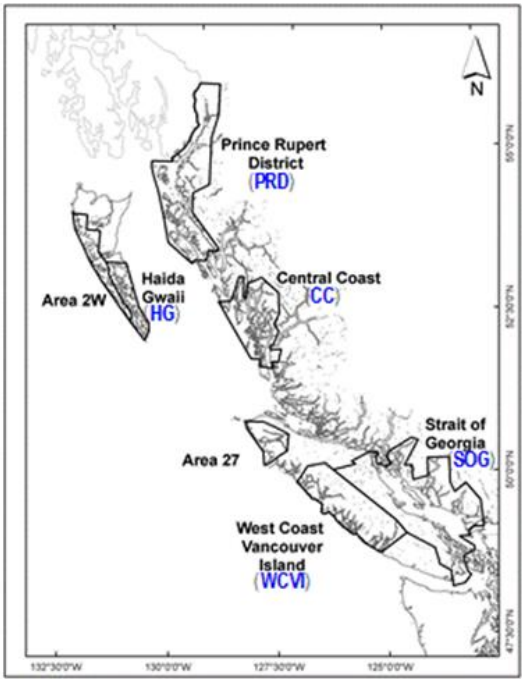

Figure 18-1. Location of the five major (Strait of Georgia, West Coast of Vancouver Island, Prince Rupert, Haida Gwaii, and Central Coast) as well as two minor (Area 2W, and Area 27) Pacific Herring stocks in BC.

18.3. 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 in recent years (Figure 18-2). While there were some small increases in the median spawning stock estimates from 2015 to 2016 for WCVI, the absolute magnitude of the increase was small and the uncertainty in the estimates was large; there was a decrease in 2017 (Figure 18-3). Median spawning biomass for SOG herring increased from 2010 to 2017 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 2012 to 2017. Median biomass estimates for HG herring decreased from 2013 to 2017. Median biomass estimates of CC herring increased from 2012 to 2017 due to increased trends in the spawn index or fits to the index along with decreased estimates of natural mortality.

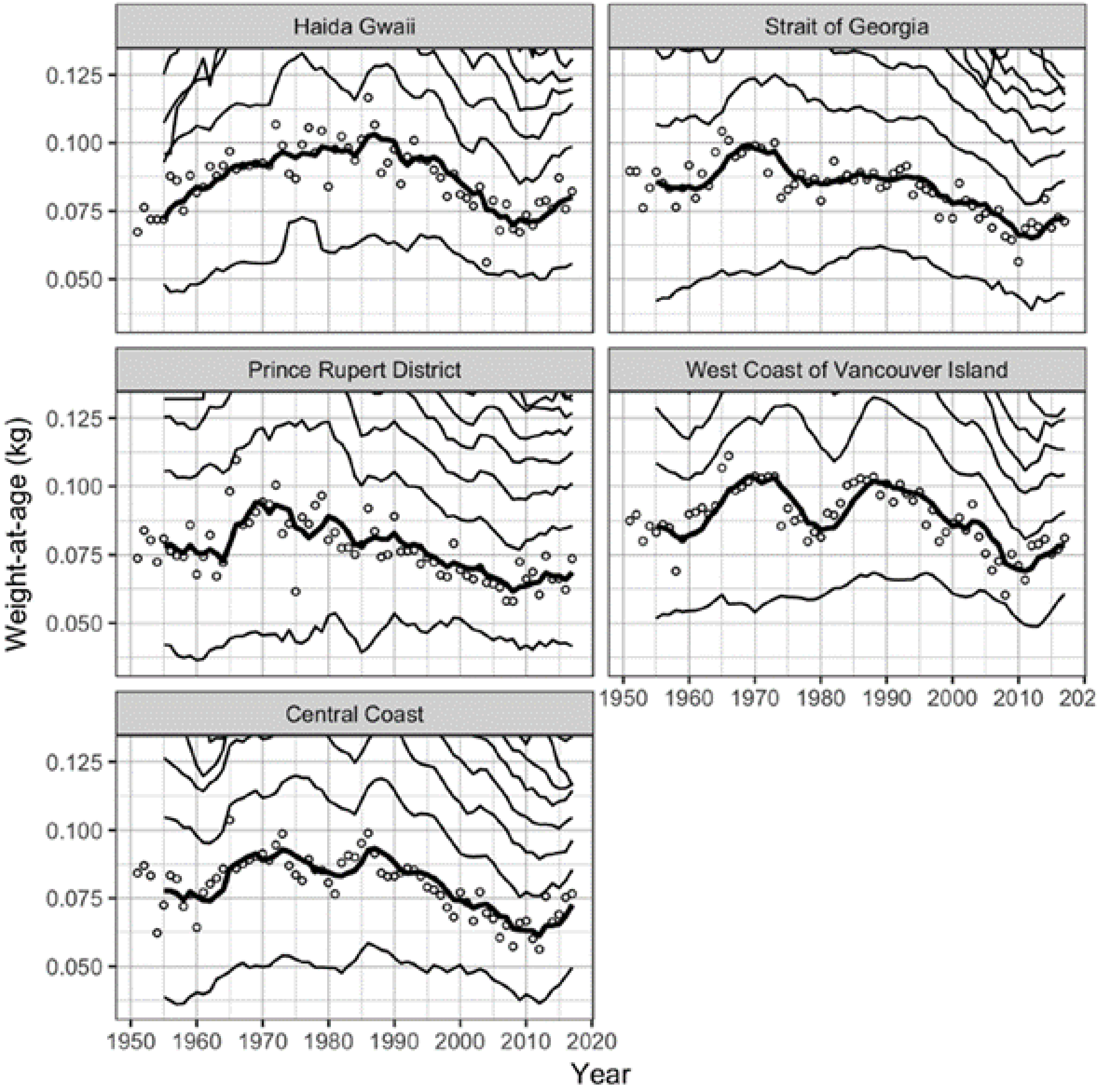

Figure 18-2. Time series of observed weight-at-age 3 (circles) and five-year running mean weight-at-age 3 (dark line) for major Pacific herring stocks, 1951 to 2017. Thinner black lines represent five-year running mean weight-at-age 2 (lowest) and ages 4-7 (incrementing higher from age 3). Figure adapted from DFO (2017).

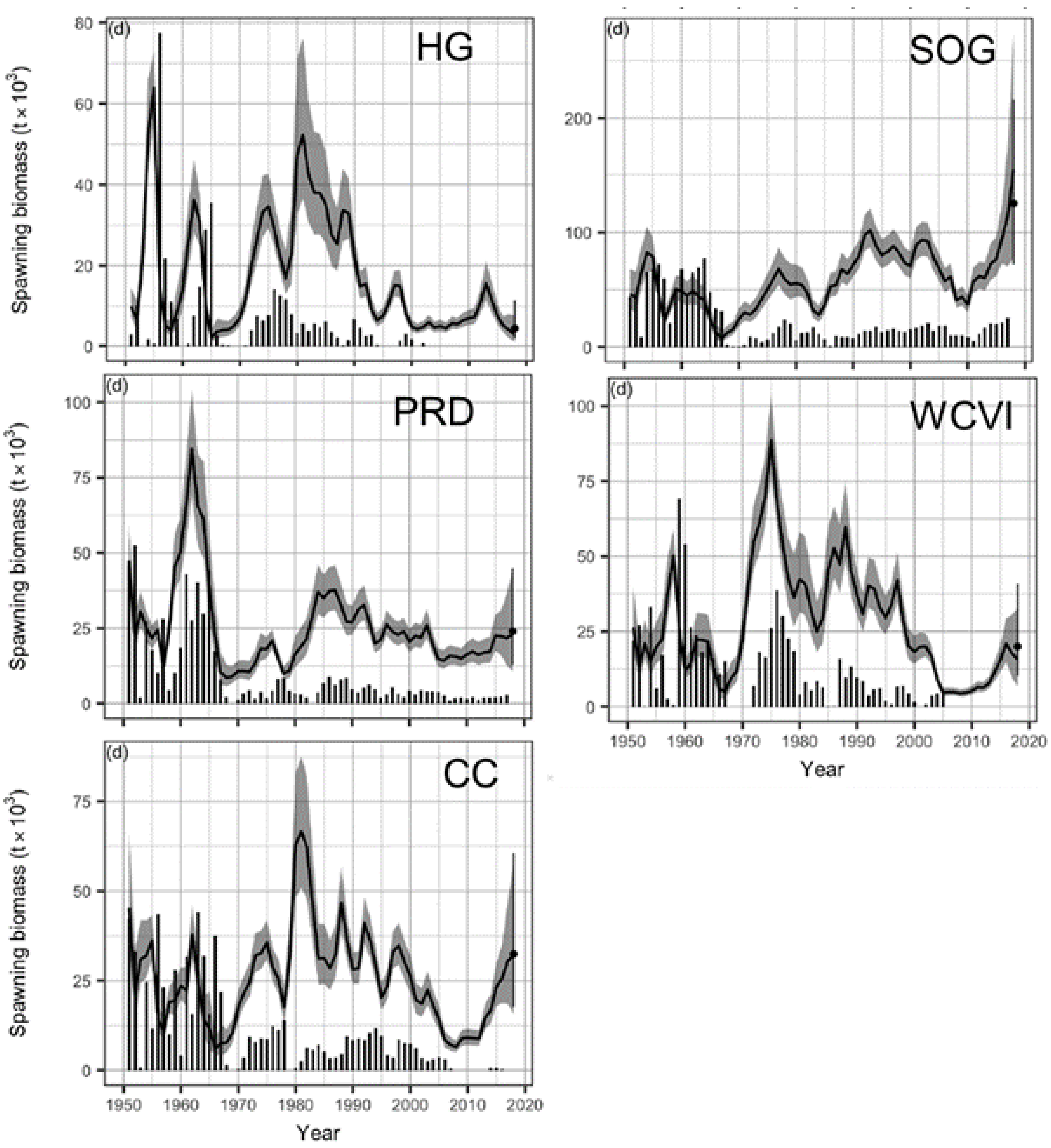

Figure 18-3. Summary of the dynamics of the five Pacific Herring stocks from 1951 to 2017, where solid lines with surrounding grey envelopes, represent medians and 5-95% credible intervals. Also shown is the reconstruction of spawning biomass (SBt) for each year t, with unfished values shown at far left (solid circle and vertical lines) and the projected spawning biomass given zero catch (SB2018) 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 (2018).

18.4. 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 2018). 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).

18.5. Implications of trends

Trends in herring biomass have implications for both fisheries and predators. Pacific Herring comprise an important component of commercial fisheries in British Columbia. Fisheries Management uses forecasts of herring biomass, in conjunction with 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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19. EULACHON STATUS AND TRENDS IN B.C.

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19.1. Highlights

- In 2011 COSEWIC assessed Eulachon in British Columbia as three designatable units:
    - Central Pacific Coast and Fraser River were assessed as endangered, and
    - Nass/Skeena was assessed as special concern.
- Commercial fishing for Eulachon in Canada has been closed since 2004.
- From 2004 to 2017 the index of Eulachon spawning stock biomass in the Fraser River has been relatively low (4-120 tonnes) except for 2015 when it was estimated at 317 tonnes.
- Eulachon catch per unit effort estimates from an annual spring west coast of Vancouver Island multispecies trawl survey were relatively high in 2013 to 2015 but dropped to relatively low levels in 2016 to 2017.
- In the 2017 spring multispecies trawl survey, fish lengths appeared to have a bi-modal distribution although, similar to in 2016, relatively few smaller fish were observed.
- There is considerable uncertainty associated with the factors that affect trends in Eulachon abundance.

19.2. Description of indices

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

1) commercial Eulachon catches from the Fraser River (1900-2004) and Columbia River (1888-2010 and 2014-2015) systems;
2) annual Fraser River Eulachon egg and larval surveys (1995 to 2017) used to estimate spawner abundance. For information on methods associated with the egg and larval survey index, see Hay et al., (2002) and McCarter and Hay (2003).
3) Eulachon catches and catch samples from spring small-mesh multispecies trawl surveys off the west coast of Vancouver Island (WCVI, 1973-2017) and in the Queen Charlotte Sound (QCS, 1998-2012, 2016).

In the past, information from these indices was used to assess population trends and provide science advice regarding Eulachon catch recommendations.

19.3. Status and trends

Eulachon have experienced long-term declines in many rivers throughout their distribution from California to Alaska. The *Committee on the Status of Endangered Wildlife in Canada* (COSEWIC) assessed Eulachon in British Columbia as three designatable units (DUs): the 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 Eulachon recovery potential assessments in Canada are reported in Levesque and Therriault (2011) and Schweigert et al. (2012). There was an active commercial fishery for Eulachon in the Fraser River for over 96 years until a closure in 1997, followed by temporary openings in 2002 and 2004. Commercial fishing for Eulachon in the Fraser River has been closed since 2004.

Columbia River Eulachon were federally-listed in the U.S.A. as threatened under the Endangered Species Act (ESA) in 2010 (NOAA, 2010). In the Columbia River system, Eulachon catches decreased dramatically in the early-1990s and since then, there has been limited commercial and/or recreational fisheries up until 2017, with no or very low catches in 2010-2013 (NMFS, 2017).

The Fraser River Eulachon spawning stock biomass index has been at low levels since 2004, with the exception of 2015. The 2017 abundance estimate from the egg and larval survey was approximately equal to the 2016 level (Figure 19-1).

In 2017, the mean Eulachon catch per unit effort (CPUE) from the spring WCVI multispecies trawl survey was lower than the 2016 CPUE estimate, both of which were relatively low compared to levels observed in 2013-2015 (Figure 19-2).

The distribution of Eulachon standard lengths measured from samples taken during the 2017 WCVI multispecies trawl survey shows a large proportion of fish across the range of 13-17 cm (Figure 19-3). This length distribution also shows a lower frequency mode for smaller fish with a peak around 7-8 cm, similar to 2016 observations.

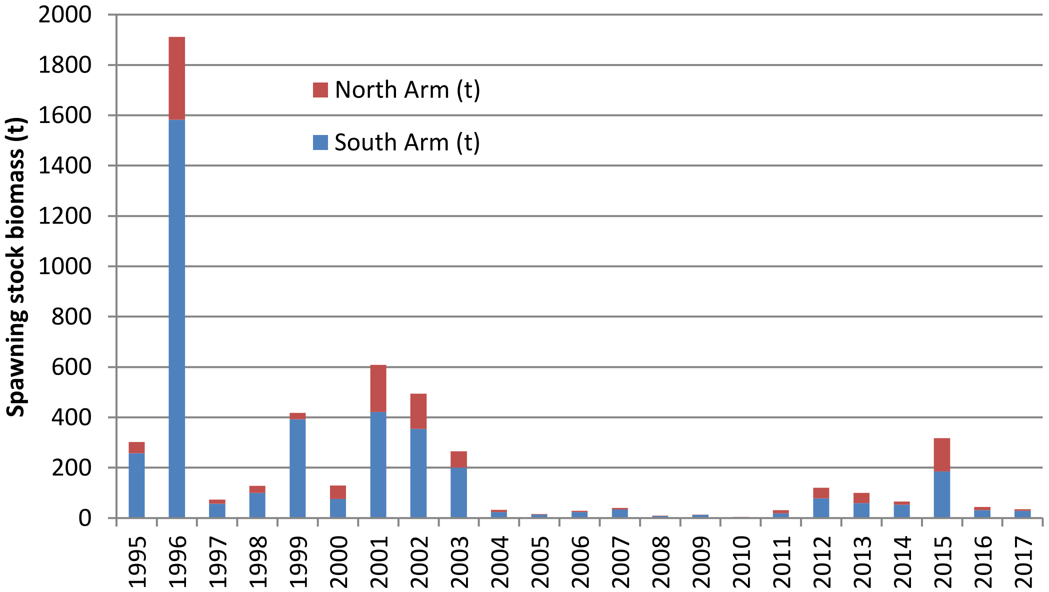

Figure 19-1. Estimated spawning stock biomass (SSB in tonnes) of Eulachon in the Fraser River, 1995-2017, comprised of sampling observations from the South and North Arms combined.

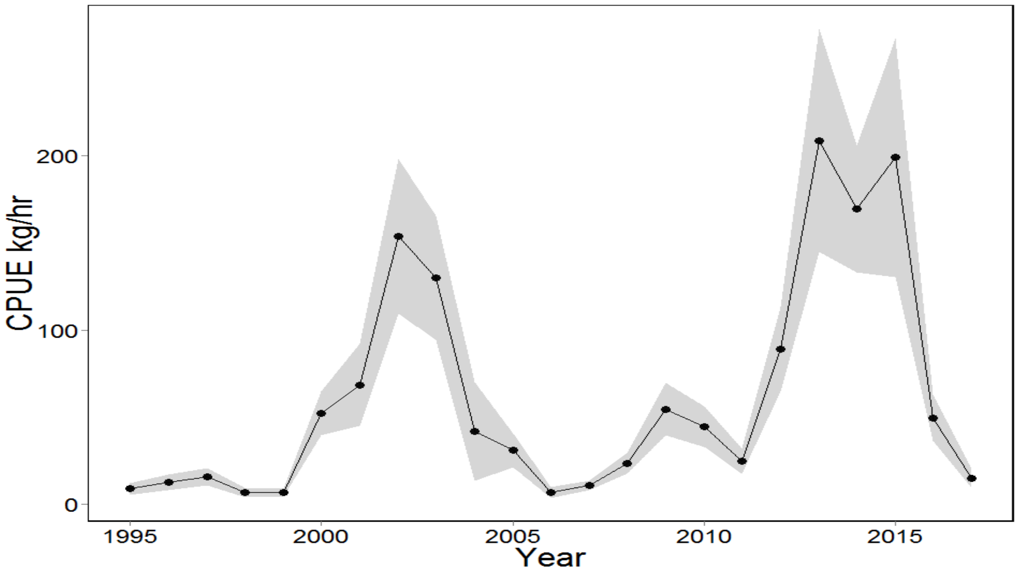

Figure 19-2. Eulachon mean catch per unit effort observations from spring WCVI multispecies trawl surveys (1987-2017). Mean 95% confidence intervals are enveloped in grey.

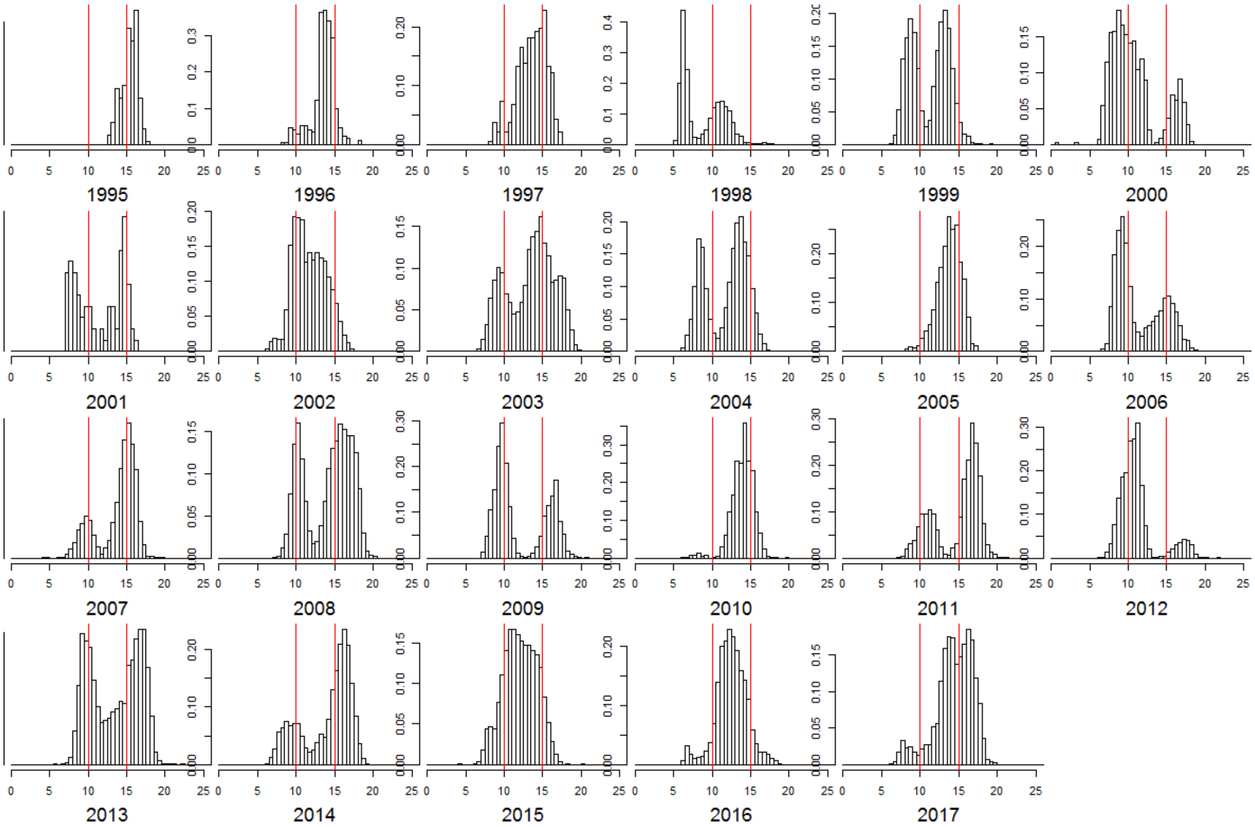

Figure 19-3. Density histograms of Eulachon standard lengths (in cm) from pooling sample data by year from WCVI survey samples 1995-2017. Red vertical lines are visual markers at 10 cm and 15 cm to assist comparisons between positions and shapes of annual length distributions.

19.4. Factors causing those trends

There is uncertainty with factors that have caused the declining trends in Eulachon abundance. 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.”

19.5. Implications of those trends

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

Reduced Eulachon abundance also likely has negative impacts on their predators. Important predators of Eulachon include: marine mammals (particularly seals and sea lions in the estuaries, 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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20. 2017 DISTRIBUTION AND ABUNDANCE OF PACIFIC HAKE (*MERLUCCIUS PRODUCTUS*)

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20.1. Highlights

- The 2017 Pacific Hake biomass survey estimate of 1.418 million mt was lower than in 2015 and 2013,but approached the average value for the whole time-series.
- Pacific Hake were distributed mostly along the northern portion of the west coast Vancouver Island, with some aggregations further into Hecate Strait.
- Significant aggregations of age-0 and age-1 hake were observed in the southern end of Vancouver Island.

20.2. Description of the time series

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

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

The 2017 survey effort included parallel transects that were run from southern California to southern Alaska (Figure 20-1). Transects were 10-20 nmi apart and spanned from the 50 m isobath to the 1500 m isobath along each transect. Transects would extend beyond the 1500 m isobath if there was still obvious hake signal to ensure the offshore extent of the population was properly covered. Acoustic marks were targeted with a midwater trawl to assess species composition, length distribution, and other biological parameters. Backscatter assigned to Pacific Hake was interpolated between transects to obtain an overall estimate of abundance for the entire coast. Using the biological information gained from the midwater trawls, the backscatter was scaled to biomass using the fish length to target strength (TS) relationship (Traynor 1996).

20.3. Status and trends

The distribution of hake has been variable over the history of the survey, with the widest distribution seen in 1998 (Figure 20-1). In comparison to 2015 the 2017 hake distribution was constricted but broader with more biomass off the northern tip of Vancouver Island to Hecate Strait (Figure 20-1 and Figure 20-2). The estimated total biomass of 1.418 mt was lower than the previous two surveys (2013, 2015, Figure 20-3), but higher than in the 2011 and 2012 surveys. Catch data from the survey indicated a dominance of the 2014 and 2010 year classes. Age-1 Hake (as well as age-0) were observed off the southern end of Vancouver Island. While age-1 Hake is not used in the biomass estimate, it is used in the stock assessment model as an indicator of recruitment.

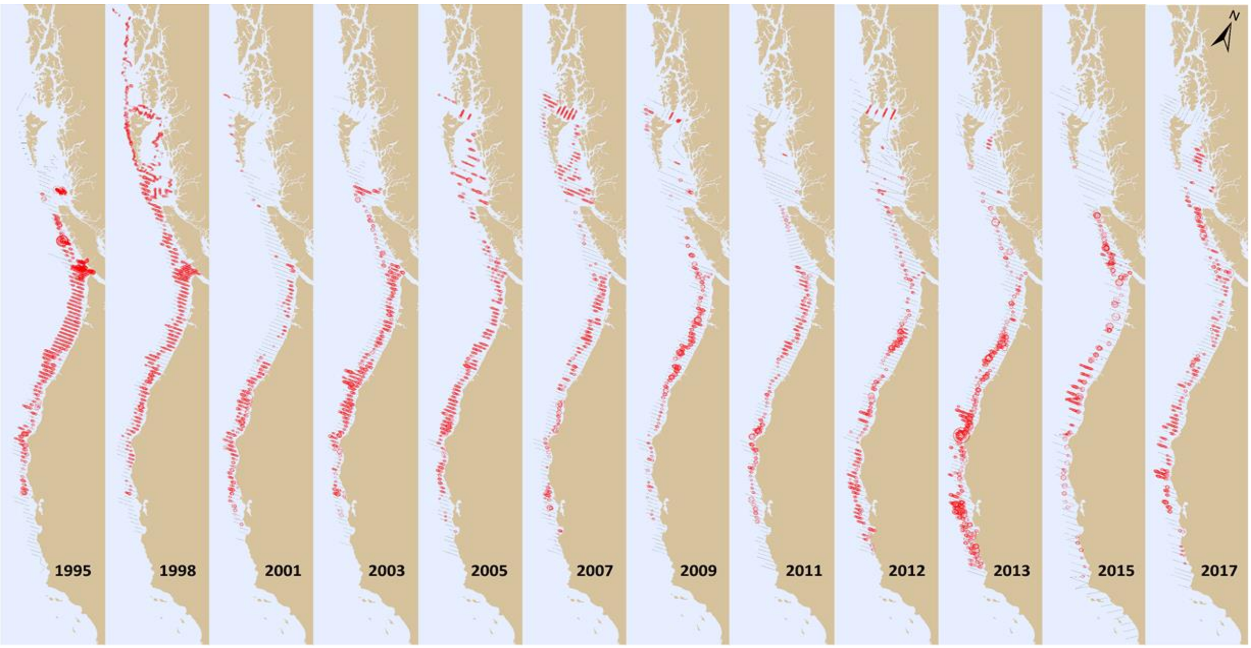

Figure 20-1. Northeast Pacific distribution of Pacific Hake from 1998-present.

20.4. Factors influencing trends

It has been observed that during warm ocean conditions (such as the 1998 El Niño event) a larger proportion of the stock migrates into Canadian waters, apparently due to intensified northward transport (Agostini et al. 2006). This was also observed in 2015 (with the so-called warm ”Blob”). The proportion of Pacific Hake into Canadian waters in 2017 was over 27 % and the largest observed since 2005, but their distribution did not extend too much beyond the northern tip of Vancouver Island. These trends and observations emphasize the need for more research into the links between environmental variables and the migration of Pacific Hake.

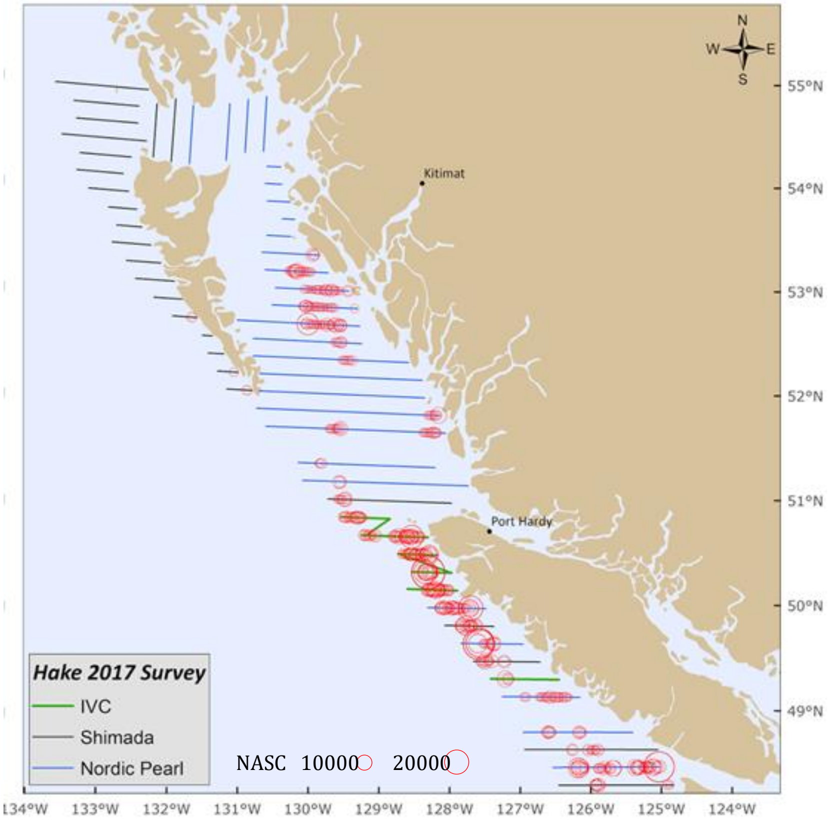

Figure 20-2. Distribution of adult Pacific Hake in Canadian waters in 2017. Red circles represent Nautical Area Scattering Coefficients (NASC, m^2nmi^{-2}). Transects run by the R/V Shimada and F/V Nordic Pearl are shown (blue and brown lines) and transects completed by both vessels are shown in green (Inter-Vessel Comparison (IVC)).

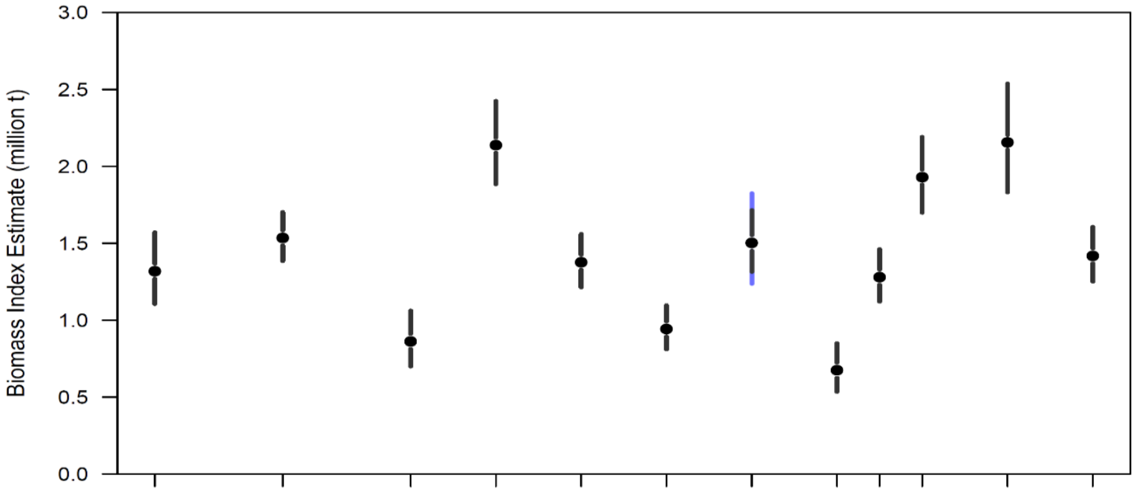

Figure 20-3. Time-series of coast-wide Pacific Hake biomass estimates from the joint DFO-NOAA surveys. Approximate 95% confidence intervals are based on only sampling variability (1995-2007, 2011-2017) in addition to squid/hake apportionment uncertainty (2009, in blue).

20.5. Implications of those trends

2017 seemed to be an average year for Pacific Hake, with the biomass and extent of the migration falling around the average value for the time series from 1995 to 2017. Research into the effect of oceanographic conditions on the extent of the migration and amount of Pacific Hake into Canadian waters are currently underway, along with research on some of their key forage species, such as euphausiids.

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21. WCVI SMALL-MESH MULTI-SPECIES BOTTOM TRAWL SURVEYS (TARGET SPECIES: SMOOTH PINK SHRIMP): 2017 UPDATE

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21.1. Highlights

- Smooth Pink Shrimp biomass off the west coast of Vancouver Island in Areas 124-125 in 2017 continued to decline from the peak in 2014, with $\log_{10}$ anomalies now below their climatological (1981-2010) mean.
- Among the “well-sampled” fish taxa, all but three (Lingcod, Smooth Pink Shrimp, sea cucumber), remained above their climatological means.
- The long term trend (since the 1970’s) has been increasing positive biomass anomalies.
- The surveyed biomass of “well-sampled” taxa has generally increased since 2009 compared with 2006-2008.
- The peak anomaly years (of the composite anomaly index for all taxa examined) were 2002, and 2014.
- The “fire salp” *Pyrosoma atlanticum* was extraordinarily abundant (higher biomass than Smooth Pink Shrimp), and 2017 was the first time it had been observed in any abundance during this survey.

21.2. Description of the time series

Fishery-independent bottom trawl surveys using a small-mesh net 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. A different vessel was used for the survey in 2017.

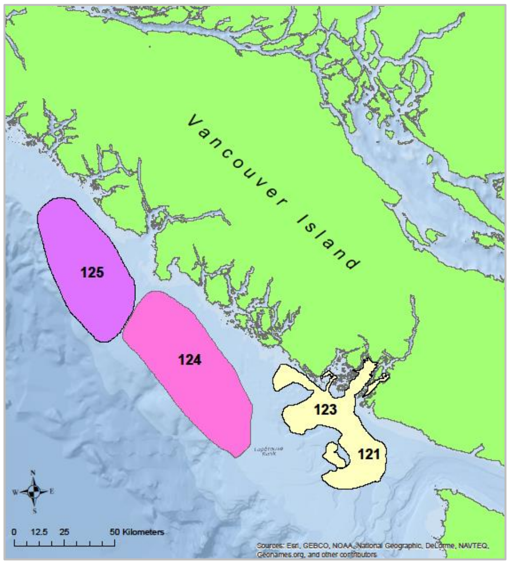

Figure 21-1. Map showing the three main shrimp (Pandalus jordani) fishing grounds and survey areas off Vancouver Island. The Nootka (Area 125) and Tofino (Area 124) grounds have been surveyed since 1973. The area off Barkley Sound (Areas 23, 121 and 123) has been surveyed since 1996.

This small-mesh multi-species bottom trawl survey was designed to target Smooth Pink Shrimp *Pandalus jordani* 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 2017 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 substantial negative anomaly (Figure 21-2). The biomass anomalies of Arrowtooth Flounder declined in 2017 but have remained mostly positive since 2000. The biomass anomalies of Walleye Pollock in 2017 remained among the highest of its time series (Figure 21-2). A cumulative anomaly index (calculated by stacking the anomalies for each species in each year) 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). The year 2017 had the third highest cumulative biomass anomaly of the time series. Negative biomass anomalies occurred for Lingcod, sea cucumber, and Smooth Pink Shrimp (Figure 21-4).

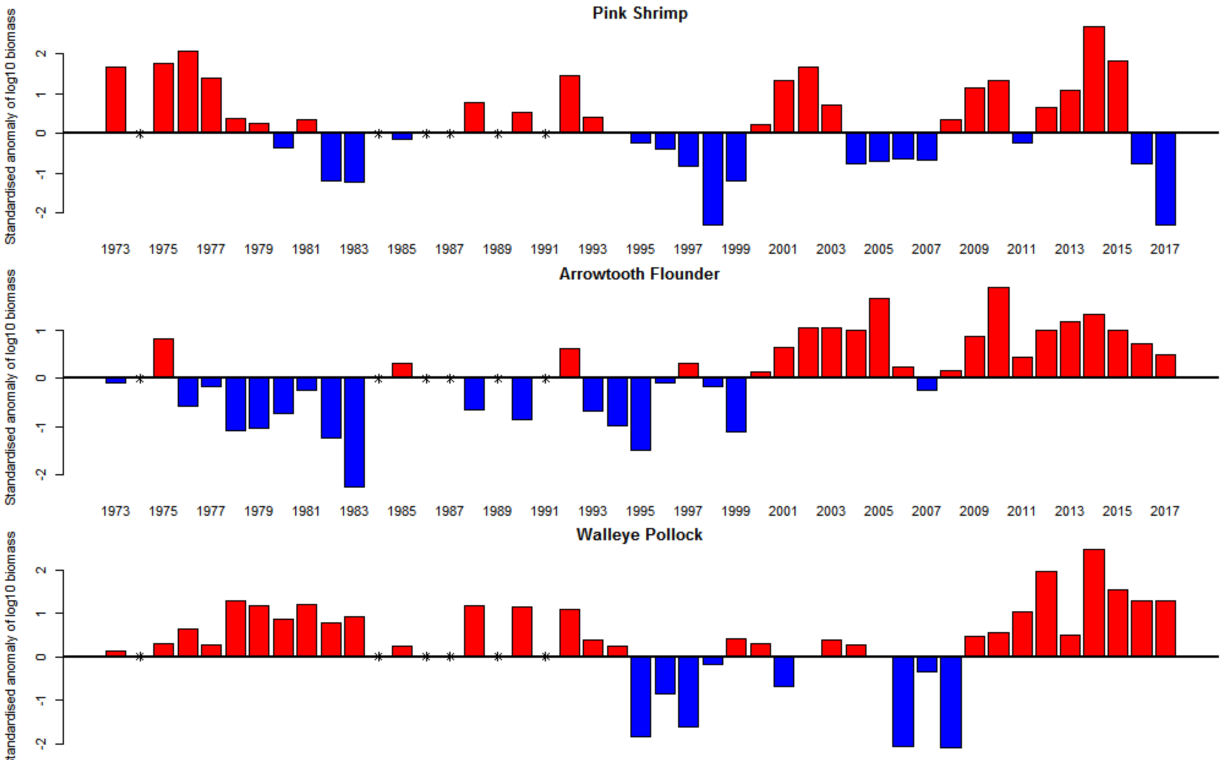

Figure 21-2. Standardised (by the standard deviation) anomalies of $\log_{10}$ species biomass for three of the "well-sampled" taxa. Climatology period is 1981-2010.

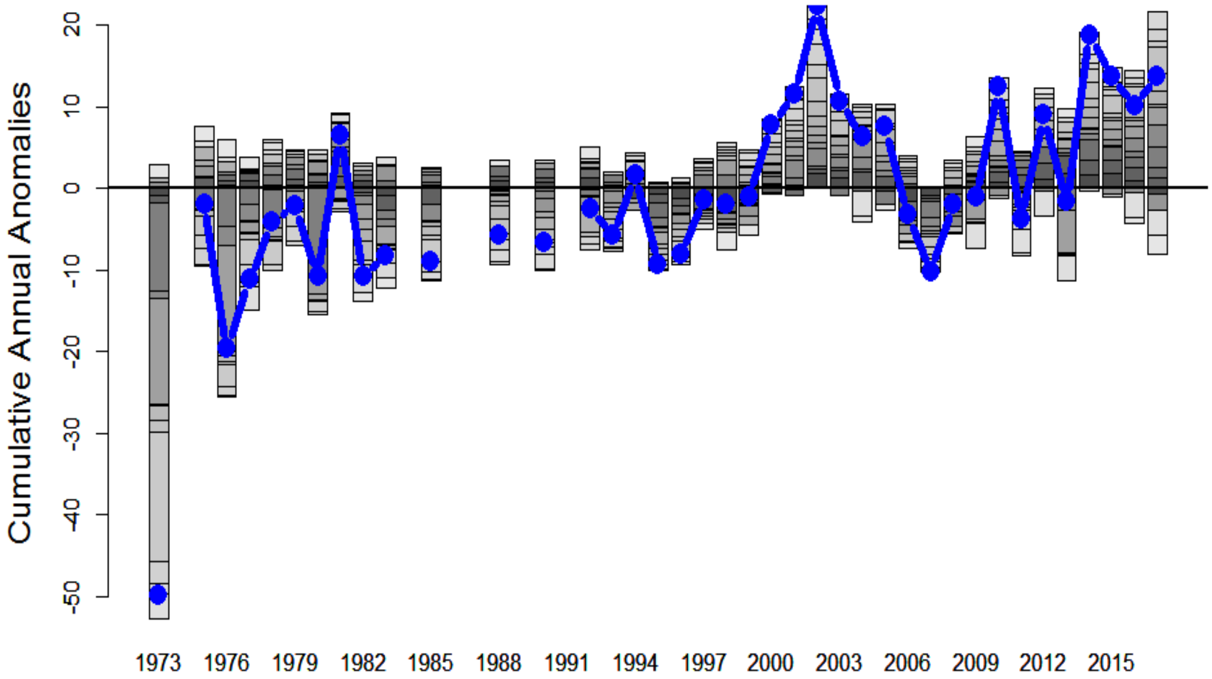

Figure 21-3. Cumulative biomass anomaly index for the 16 "well-sampled" taxa. The climatology period is 1981-2010. Individual shaded boxes represent the anomalies (positive or negative) for each of the 16 taxa (see Figure 21-4).

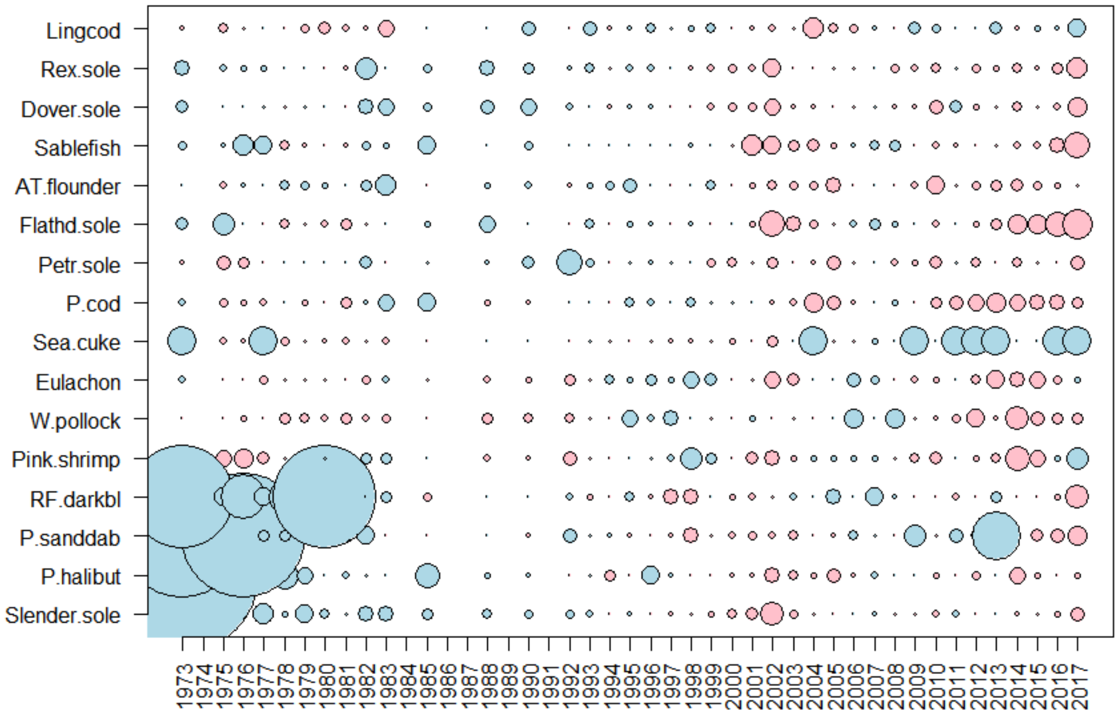

Figure 21-4. Bubble plot of biomass anomalies of the "well-sampled" taxa versus years. Size of bubble is proportional to the anomaly; the colour of bubble represents positive (red) or negative (blue) anomalies.

The pyrosome *Pyrosoma atlanticum* was an extraordinary species caught during this survey in 2017. A few specimens were caught on this survey in 2016, but in 2017 it occurred in 68% of the tows and sometimes at very high densities (Figure 21-5). Expanded to the total areas surveyed in Areas 124 and 125, the biomass of *P. atlanticum* exceeded that of the Smooth Pink Shrimp captured during this survey.

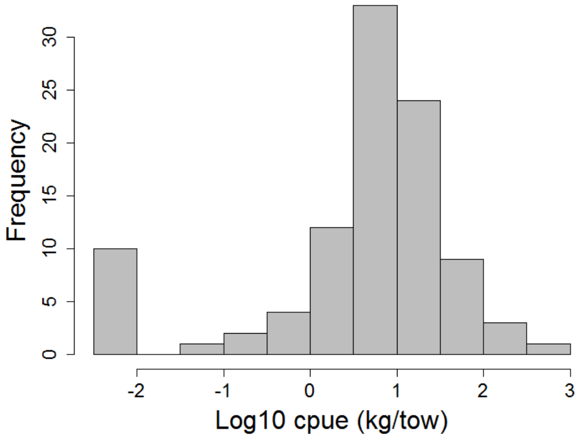

Figure 21-5. Frequency histogram of catch per tow of the pyrosome Pyrosoma atlanticum. The x-axis range is from tens of grams to 1 tonne. The frequency of zero catches was 32%.

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 previous (e.g. Perry et al. 2014). The extraordinary outburst of pyrosomes may also have been a result of recent warm ocean conditions, and is under investigation (e.g. Brodeur et al. 2018).

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. The implication is 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

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22. A REVIEW OF GROUNDFISH SURVEYS IN 2017

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22.1. Highlights

- On the Hecate Strait Synoptic Bottom Trawl Survey:
    - The most abundant fish species encountered were Arrowtooth Flounder, Spotted Ratfish, English Sole, Dover Sole and Sablefish.
    - Notable trends include an apparent persistent decline in North Pacific Spiny Dogfish and Silvergray Rockfish.
- On the Queen Charlotte Sound Synoptic Bottom Trawl Survey:
    - The most abundant fish species encountered were Pacific Ocean Perch, Arrowtooth Flounder, Yellowmouth Rockfish, Silvergray Rockfish and Sablefish.
    - Notable trends include a recent increase in Sablefish and an apparent persistent increase in Shortspine Thornyhead.
- On the Hard Bottom Longline Hook Outside Survey (North Coast):
    - The most common species captured during the 2017 was Pacific Halibut, followed by Quillback Rockfish, Yelloweye Rockfish and North Pacific Spiny Dogfish.
    - Notable trends include an apparent persistent increase in Quillback Rockfish and an apparent persistent decline in North Pacific Spiny Dogfish.
- On the Sablefish Research and Assessment Survey (Coast-wide, outside waters):
    - The most abundant fish species encountered by weight were Sablefish, followed by Pacific Halibut , Arrowtooth Flounder and Lingcod.
    - The total catch rate in 2017 was roughly 1.6 times the total catch in 2016.
    - Notable trends include a recent decrease in Pacific Halibut and an apparent persistent increase in Shortspine Thornyhead.

22.2. Description of the time series

The Fisheries and Oceans, Canada (DFO) Groundfish section conducts a suite of randomized surveys using bottom trawl, longline hook, and longline trap gear that, in aggregate, provide good coverage for all offshore waters of Canada's Pacific Coast (Figure 22-1). Two Multi-species Synoptic Bottom Trawl Surveys are conducted each year. Surveys in Queen Charlotte Sound (QCS) and Hecate Strait (HS) alternate with surveys on the West Coast of Vancouver Island (WCVI) and the West Coast of Haida Gwaii (WCHG). In addition to the bottom trawl surveys, two Hard Bottom Longline Hook (HBLL) surveys are conducted. One survey is conducted in "Inside" waters (east of Vancouver Island) while the second is conducted in "Outside" waters (everything else). Each year the surveys alternate between northern and southern areas. Lastly, a coast-wide longline trap survey targeting sablefish (Sablefish Research and Assessment Survey) is also conducted every year.

All the randomized surveys follow depth-stratified designs and have in common full enumeration of the catches (all catch sorted to the lowest taxon possible), size and sex composition sampling for most species, and more detailed biological sampling of selected species. Most of the surveys are conducted in collaboration with the commercial fishing industry under the authorities of various Collaborative Agreements.

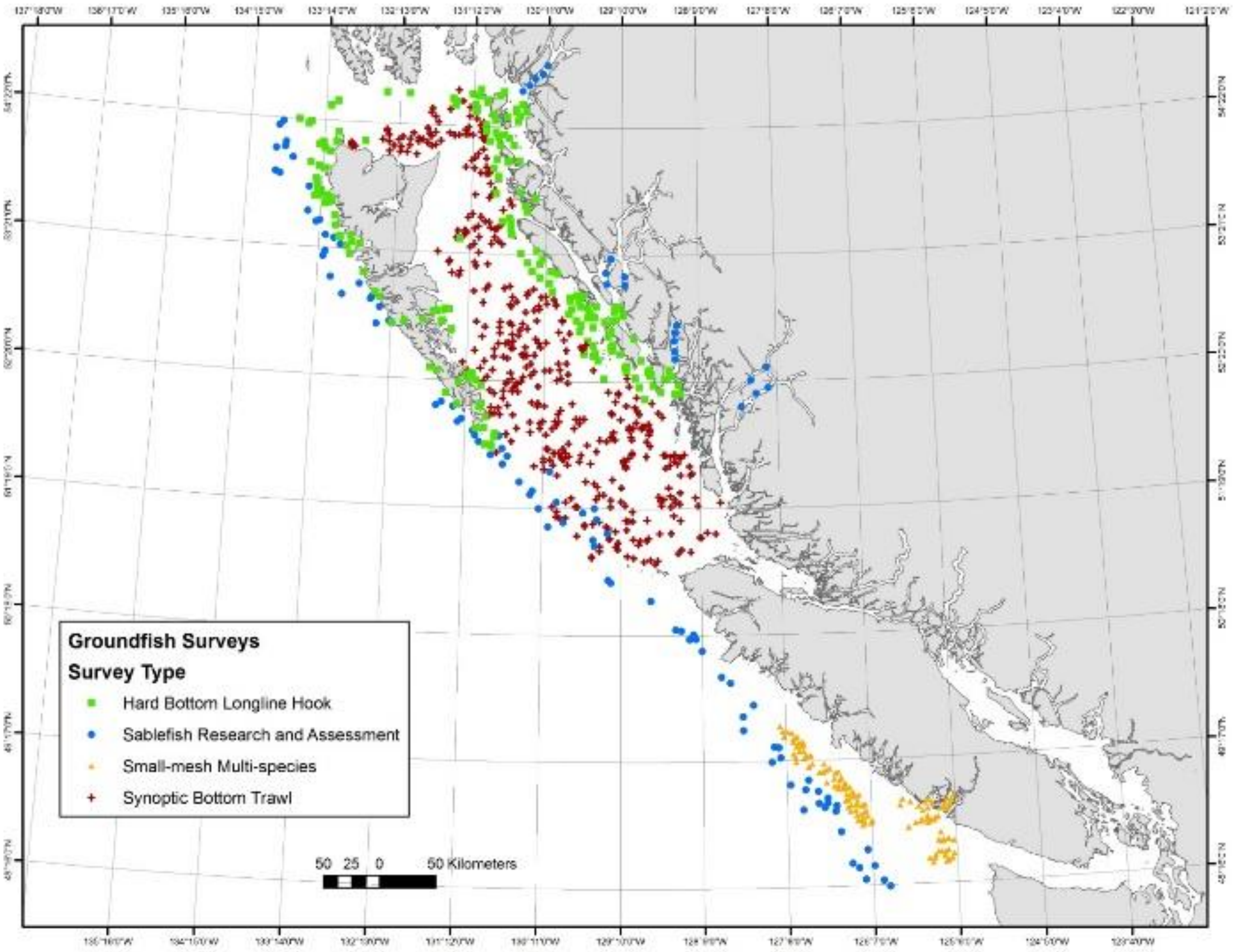

Figure 22-1. Fishing locations of the 2017 Groundfish surveys.

In this summary we present the results from the following 2017 surveys (Figure 22-1):

- Multi-species Synoptic Bottom Trawl: Hecate Strait in late spring and Queen Charlotte Sound in summer.
- Hard Bottom Longline Hook: northern half of the outside waters (the inside area was not surveyed in 2017 due to vessel crew limitations).
- Sablefish Research and Assessment Survey.

Data from the International Pacific Halibut Commission Setline Survey are not yet available.

Abundance indices have been calculated for each species captured during each survey. For the synoptic bottom trawl surveys, swept area biomass estimates were calculated following Stanley et al. (2004). The hook and line biomass indices are derived using similar methods, but use counts instead of weights (Lochead and Yamanaka, 2004). The sablefish survey abundance index is the catch weight per trap (Cox et al. 2011).

Bootstrapping was used to estimate the uncertainty of the biomass indices. One thousand bootstrap replicates with replacement were made for each survey to provide bias-corrected 95% confidence limits. We estimate the relative error (RE) of the index by calculating the coefficient of variation (CV) of the distribution of the 1000 bootstrapped estimates for each biomass index (Stanley et al. 2004). The CV is an estimate of sampling variance caused by variation within the catch rates from one survey year, and is used as a proxy for the overall relative error of the survey (Stanley et al. 2004). We use the RE as a measure of the capability of an abundance index to track changes in a population over time with the following standards:

- Excellent: < 0.2
- Good: 0.2 – 0.3
- Adequate: 0.3 – 0.4
- Poor: 0.4 – 0.6
- Very poor: > 0.6

22.3. Status and trends

Figure 22-2 and Figure 22-3 show biomass indices by species for the Hecate Strait Synoptic Bottom Trawl Survey, Queen Charlotte Sound Synoptic Bottom Trawl Survey, Hard Bottom Longline Hook Outside Survey, and Sablefish Research and Assessment Survey, respectively. Each figure shows only those species that have been captured in every year of the survey and where the relative error of each annual abundance index is below 0.5. The 2017 biomass estimate is also shown for the synoptic bottom trawl and longline hook surveys.

The total catch weight of all species during the Hecate Strait Synoptic Bottom Trawl Survey was 81,391 kg. The mean catch per tow was 550 kg, averaging 23 different species of fish and invertebrates in each. The most abundant fish species encountered were Arrowtooth Flounder (*Atheresthes stomias*), Spotted Ratfish (*Hydrolagus colliei*), English Sole (*Parophrys vetulus*), Dover Sole (*Microstomus pacificus*), and Sablefish (*Anoplopoma fimbria*). Biological data were collected from a total of 19,907 individual fish of 43 different species. Notable trends include an apparent persistent decline in North Pacific Spiny Dogfish and Silvergray Rockfish (Figure 22-2 left side).

The total catch weight of all species during the Queen Charlotte Sound Synoptic Bottom Trawl Survey was 119,374 kg. The mean catch per tow was 452 kg, averaging 24 different species of fish and invertebrates in each. The most abundant fish species encountered were Pacific Ocean Perch (*Sebastes alutus*), Arrowtooth Flounder (*Atheresthes stomias*), Yellowmouth Rockfish (*Sebastes reedi*), Silvergray Rockfish (*Sebastes brevispinis*), and Sablefish (*Anoplopoma fimbria*). Biological data were collected from a total of 33,198 individual fish of 48 different species. Notable trends include a recent increase in Sablefish and an apparent persistent increase in Shortspine Thornyhead (Figure 22-2 right side).

The most common species captured during the 2017 Hard Bottom Longline Hook Outside Survey was Pacific Halibut (Hippoglossus stenolepis), followed by Quillback Rockfish (Sebastes maliger), Yelloweye Rockfish (Sebastes ruberrimus), and North Pacific Spiny Dogfish (Squalus suckleyi). 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 4692 individual fish were sampled for biological data in 2017. Notable trends include an apparent persistent increase in Quillback Rockfish and an apparent persistent decline in North Pacific Spiny Dogfish (Figure 22-3 left side).

The total catch on the 2017 Sablefish Research and Assessment Survey was 100,415 kg and the average catch per set was 921 kg. The most abundant fish species encountered by weight were Sablefish (*Anoplopoma fimbria*), followed by Pacific Halibut (*Hippoglossus stenolepis*), Arrowtooth Flounder (*Atheresthes stomias*), and Lingcod (*Ophiodon elongatus*). Biological data were collected from a total of 21,042 individual fish of 6 different species. Of note is that the total catch rate in 2017 was roughly 1.6 times the total catch in 2016. Other notable trends include a recent decrease in Pacific Halibut and an apparent persistent increase in Shortspine Thornyhead (Figure 22-3 right side).

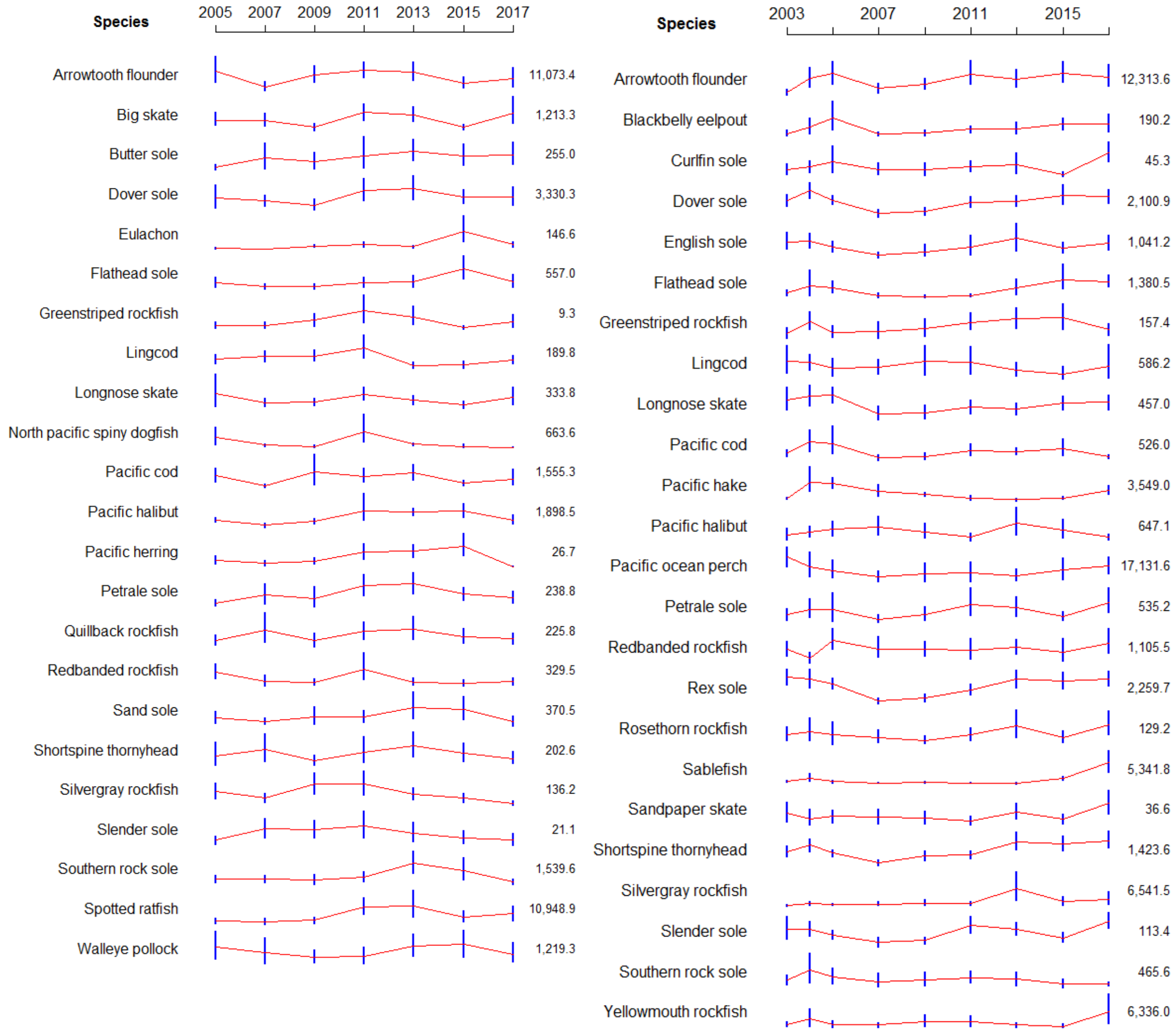

Figure 22-2. Selected annual biomass indices (red lines) estimated CVs (blue bars) from the Hecate Strait Synoptic Bottom Trawl Survey in late spring (left side) and the Queen Charlotte Sound Synoptic Bottom Trawl Survey in summer (right side). The 2017 biomass estimate (kg) is also shown to the right of each plot.

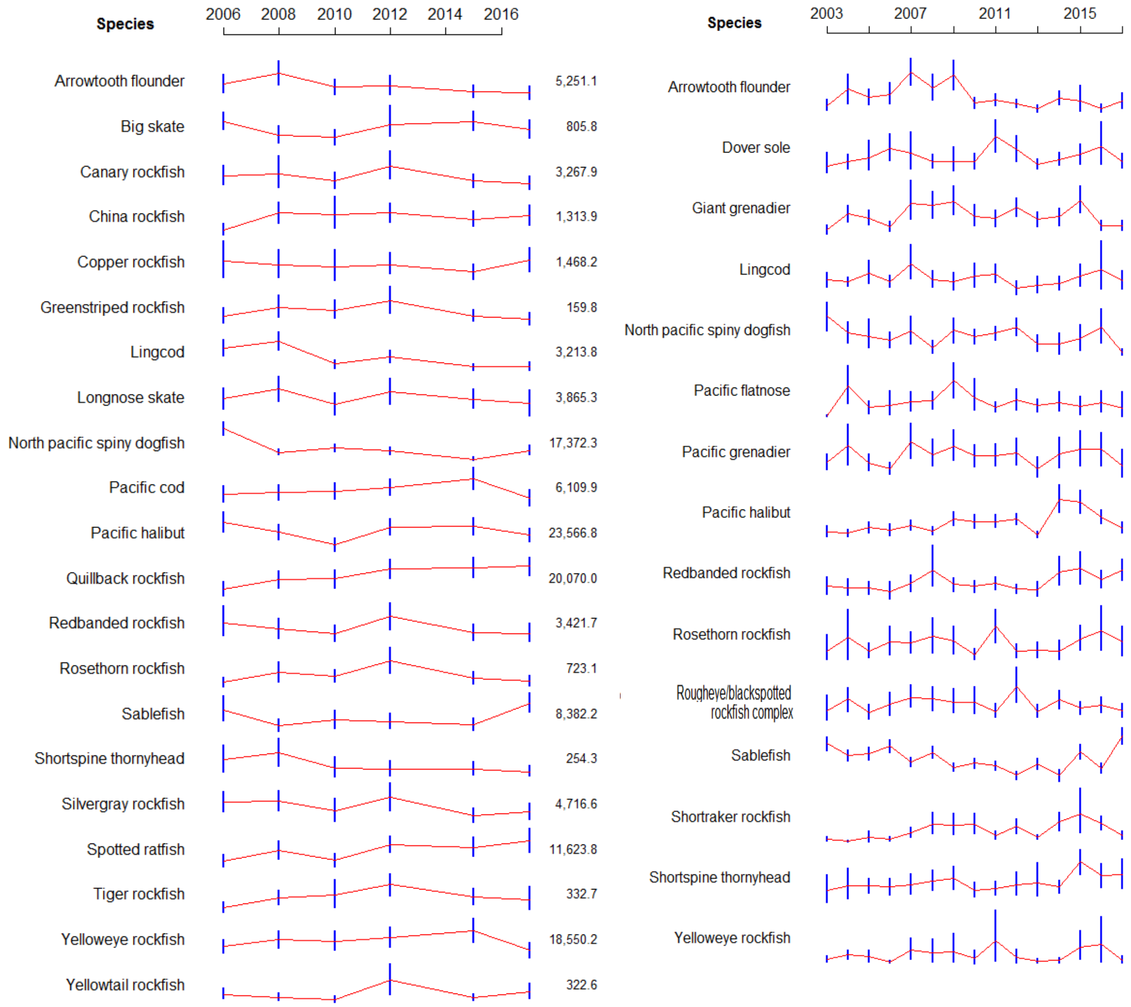

Figure 22-3. Selected annual biomass indices (red lines) and estimated CVs (blue bars) from the Hard Bottom Longline Hook Outside North Survey with the 2017 biomass estimate (kg) (left side) and the Sablefish Research and Assessment Survey (right side).

22.4. Factors influencing trends

There are many potential causes for observed trends including the direct impacts from fishery removals, climate change, and increasing benthic anoxia (oxygen dead zones). A more fulsome analysis than is presented here is required to tease apart the various influences on survey trends.

22.5. Implications of trends.

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 into comprehensive stock assessment analyses before conclusions can be drawn about stock status. That said, at least a couple of trends do bear further consideration as they have been observed in more than one survey. The persistent decline in North Pacific Spiny Dogfish that was noted following the 2016 surveys may be apparent in the 2017 survey areas as well (Figure 22-4 left side). Lastly, Sablefish abundance has increased dramatically over the past two to three years (Figure 22-4 right side).

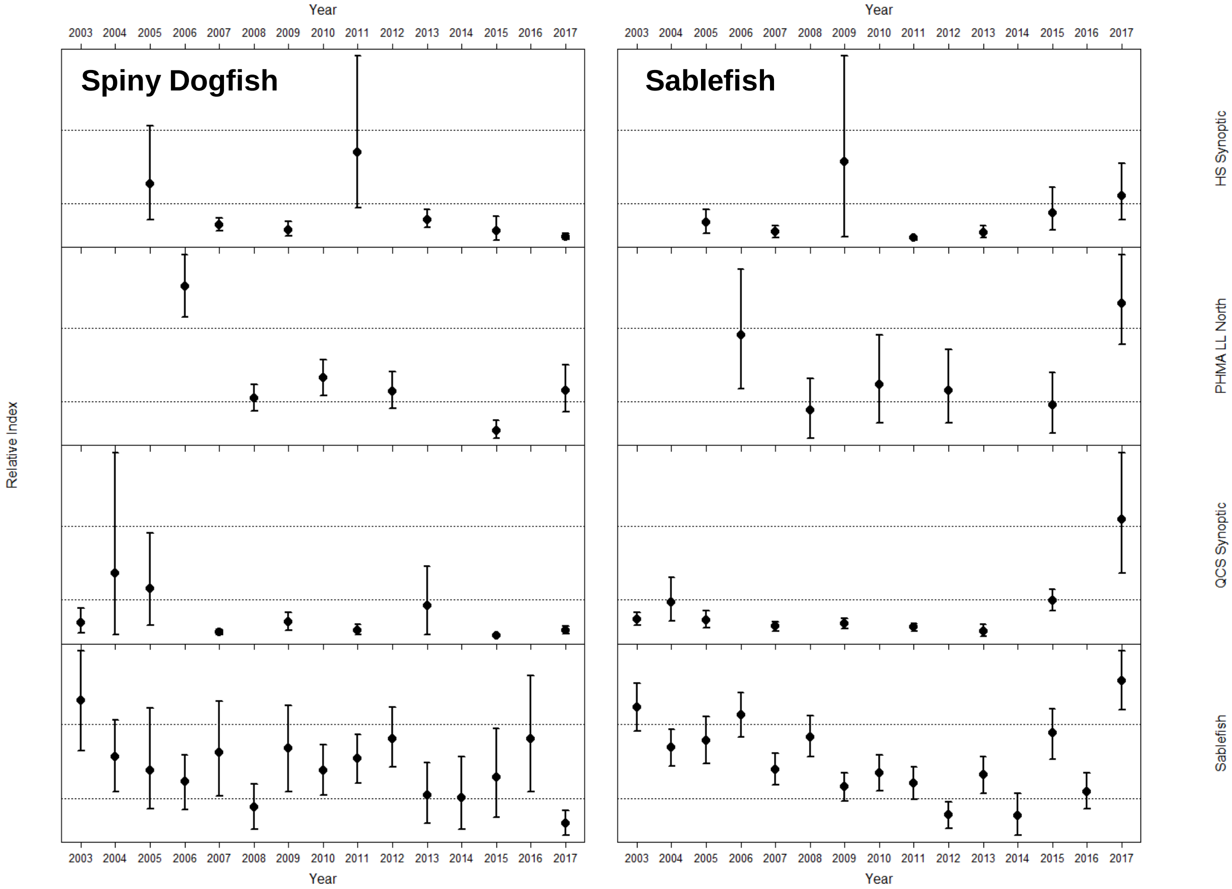

Figure 22-4. Survey indices for North Pacific Spiny Dogfish (left) and Sablefish (right). The HBLL Outside North survey is shown as PHMA LL North.

22.6. References

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23. RELATIONSHIP BETWEEN EARLY MARINE GROWTH AND ADULT FRASER SOCKEYE SALMON RECRUITMENT

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23.1. Highlights

- Early marine daily growth rates of juvenile Chilko Lake Sockeye Salmon differed between years of extreme marine survival. Juveniles that entered the ocean in 2008 grew at a significantly faster rate and had higher smolt-to-adult survival (6.7%) than those entering the ocean in 2007 that had record low smolt-to-adult survival (<0.25%). Somatic early marine growth rates (approximately the first 1.5 months) of the smolts that entered the ocean in 2008 were on average 20% faster than the smolts that entered the ocean in 2007, suggesting that the higher survival observed in 2008 may be related to ocean conditions that were favorable to growth.
- Using 10 ocean entry years (2004-2013), we found that
    - Recruitment of Chilko Lake Sockeye Salmon tended to increase with the number of smolts, early marine growth rate, biomass of boreal shelf copepods, and to decrease with warmer sea surface temperatures in Strait of Georgia (SoG).
    - In a stock-recruitment model that included these covariates, the best-performing model included early marine somatic growth rate. Recruitment tended to increase with the number of smolts and early marine somatic growth rate, except in 2005.
- Smolts that entered the ocean in 2005 had lower than expected recruitment given the number of smolts and high early somatic growth rate.
- Also in 2005, ocean conditions were poor coast-wide and the biomass of boreal shelf copepods was at a record low in Queen Charlotte Sound (as measured at northern Vancouver and Triangle Island) and in the SoG. One hypothesis is that only the fastest growing juveniles survived the early marine period.

24. 2017 JUVENILE SALMON CATCH RATES ON THE VANCOUVER ISLAND CONTINENTAL SHELF

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24.1. Highlights

- Summer juvenile salmon research survey on the continental shelf of Vancouver Island
    - Juvenile Sockeye Salmon catch rates were below average. Typically, the majority of these fish originate from West Coast Vancouver Island rivers or the Fraser River.
    - Juvenile Chinook and Coho Salmon catch rates were average. Typically, the majority of these fish originate from the Columbia River or Puget Sound watersheds.
    - Juvenile Pink Salmon (odd year) catch rates were also average, while those for juvenile Chum Salmon were above average.
    - Pacific Salmon captured in summer were in the best observed condition of the 20 year time series, except for Pink Salmon (odd year) which had an inadequate sample size.
- Fall juvenile salmon research survey in southern Queen Charlotte Sound, Queen Charlotte and Johnstone Straits
    - Sockeye and Chinook Salmon catch rates were above average, while those for Coho Salmon were average. Typically, the majority of these fish originate from Strait of Georgia, particularly Fraser River, or Puget Sound watersheds.
    - Pink Salmon catch rates were average, while those for Chum Salmon were above average
    - Pacific Salmon were in average condition compared to previous years.

24.2. Description of the time series

Since 1998, juvenile salmon surveys have been conducted off the west coast of Vancouver Island (WCVI) during summer, typically June-July, and in southern Queen Charlotte Sound (QCS) and surrounding areas, including Queen Charlotte and Johnstone Straits, in fall, typically October-November. For 1998-2016 summer surveys, tows on the continental shelf of Vancouver Island were conducted at headrope depths of surface, 15 m or 30 m using mid-water trawl gear (CanTrawl 250) along standard transects. In 2017, the survey design was switched to a stratified, random design. The survey area was portioned into 8 strata based on depth contours (50-100 m; 100-200 m) and known biological communities. Each strata was gridded into 4 x 4 km blocks, from which a random set of blocks are selected in proportion to the relative area of each region to the whole survey area. Fishing was conducted with the same historical trawl gear, but limited to headrope depths of surface and 15 m. In order to calculate comparable catch-per-unit effort (CPUE; numbers of fish per swept area) across the summer time series, we selected only trawls with headrope depths of surface and 15 m, and that were conducted within waters with depths 50–200 m, excluding any historic fishing events that occurred within inlets. For 1998-2017 fall surveys, tows were conducted at headrope depths of surface, 15 m or 30 m using mid-water trawl gear (CanTrawl 250) along standard transects. Fall CPUE (numbers of fish per swept area) were calculated only from trawls conducted on the north Vancouver Island continental shelf in southern Queen Charlotte Sound westward to Rivers Inlet, along with Queen Charlotte and Johnstone Straits. For both summer and fall surveys, length and weight data were used to estimate species-specific length-weight regressions across years with annual weight residuals presented to represent annual summer or fall condition.

24.3. Status and trends

The 2017 mean summer CPUE estimates of Sockeye Salmon were below the long-term average, while those for Chinook, Pink and Coho Salmon were near average and Chum Salmon CPUE were above average (Figure 24-1). The 2017 summer weight residuals from each species-specific length-weight regression were above average for Sockeye, Chinook, Coho and Chum Salmon indicating above average summer condition for these four species and in fact are some of the highest values observed in these four time series (Figure 24-2). Weight residuals for Pink Salmon were average, however sample size for this species was too low to provide sufficient estimation (Figure 24-2).

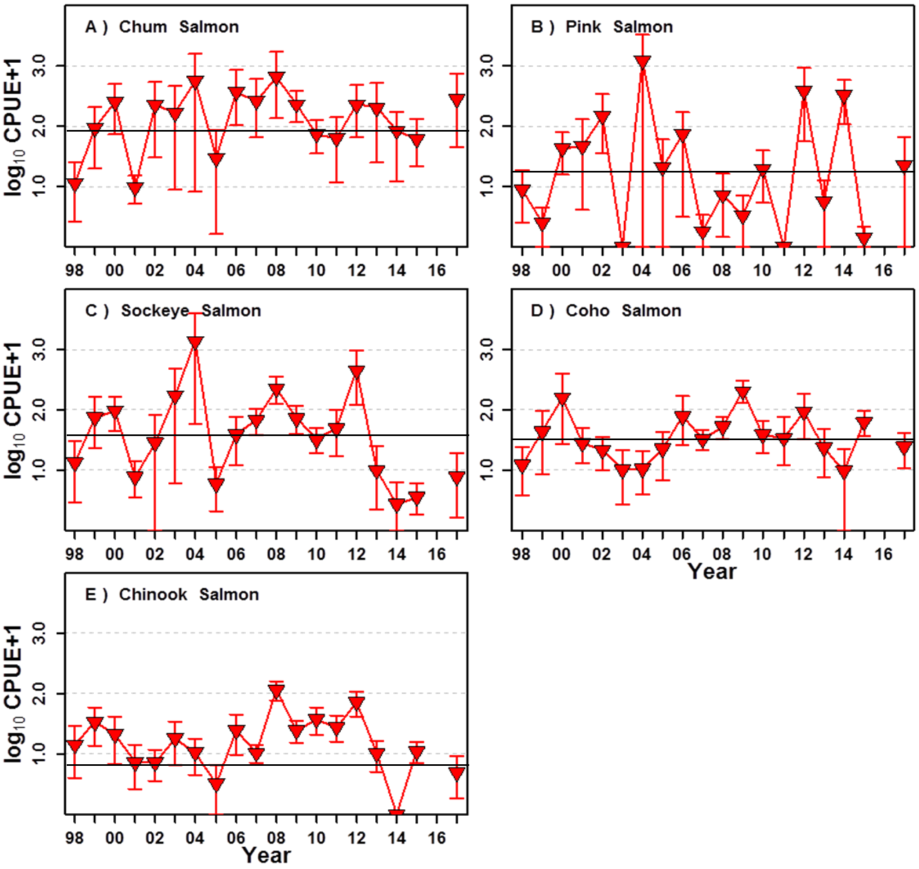

Figure 24-1. Catch-per-unit-effort (CPUE) of juvenile Chum, Pink, Sockeye, Coho and Chinook Salmon on the Vancouver Island continental shelf in June-July, 1998-2017. Mean CPUE (black line) and 95% confidence intervals were obtained by bootstrap approximations.

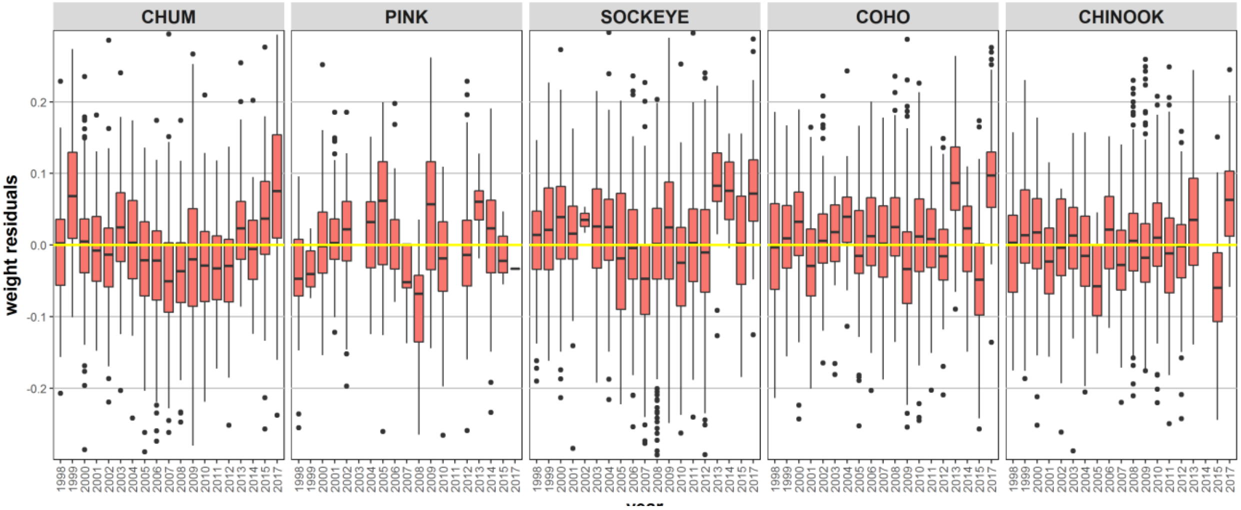

Figure 24-2. Annual weight residuals for salmon sampled in summer 1998-2017. Residuals were calculated from species-specific length-weight regressions (all years combined).

The 2017 mean fall CPUE estimates of Sockeye, Chinook and Chum Salmon were above the long-term average, while those for Coho and Pink Salmon were near average (Figure 24-3). The 2017 fall weight residuals from each species-specific length-weight regression were average for all salmon species, indicating only average condition (Figure 24-4).

24.4. Factors influencing trends

The Northwest Fisheries Science Center (National Marine Fisheries Service) has conducted similar surface trawl surveys for juvenile salmon off the coasts of Washington and Oregon since 1998. The survey catches salmon stocks from California, Oregon and Washington, including those originating from the Columbia River. Data from the summer 2017 survey indicates one of the lowest CPUE for Chinook and Coho Salmon in the last 20 years (Morgan et al. 2017). The Alaska Fisheries Science Center (National Marine Fisheries Service) has conducted similar surface trawl surveys for juvenile salmon in southeastern coastal waters of the Gulf of Alaska since 1997. The survey focuses in Icy Strait, the primary northern migratory pathway to the Gulf of Alaska for juvenile salmon originating from over 2000 southeast Alaska streams and rivers. The 2017 survey CPUE was the lowest on record for juvenile Sockeye, Chum and Pink Salmon while Chinook and Coho Salmon CPUE were near long-term averages (Watson et al. 2017). These large-scale coherencies in average and below average catch rates for Sockeye, Chinook, Pink and Coho Salmon suggest that large-scale regional drivers of productivity are contributing factors.

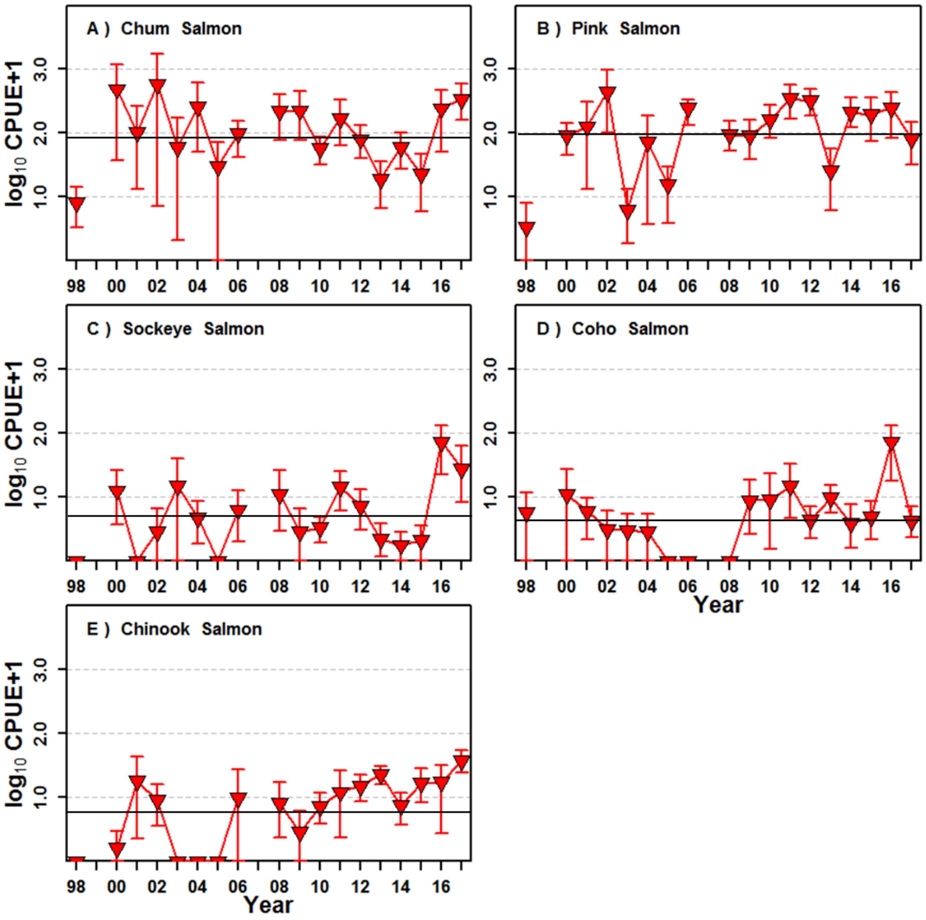

Figure 24-3. Catch-per-unit-effort (CPUE) of juvenile A) Chum, B) Pink, C) Sockeye, D) Coho and E) Chinook Salmon on the Vancouver Island continental shelf with Queen Charlotte and Johnstone Straits in fall (Oct-Nov) 1998-2017. Mean CPUE (black line) and 95% confidence intervals were obtained by bootstrap approximations.

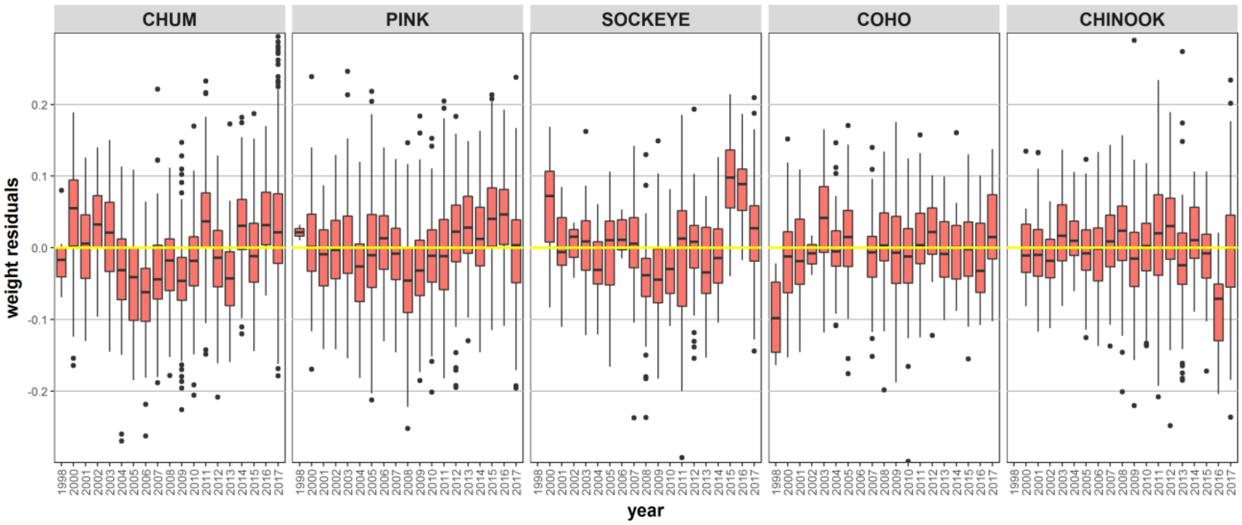

Figure 24-4. Annual weight residuals for salmon sampled in fall 1998-2017. Residuals were calculated from species-specific length-weight regressions (all years combined).

24.5. Implications of those trends

While tissue samples are collected on all surveys for genetic stock identification of Sockeye, Chinook and Coho Salmon, results from 2017 are not yet available. However, results from previous surveys indicate that in summer, the majority of Sockeye Salmon captured along the Vancouver Island continental shelf originate from the Fraser River or west coast of Vancouver Island watersheds, while the majority of Chinook and Coho Salmon originate from the Columbia River or Puget Sound watersheds. In fall, the majority of Chinook, Coho and Sockeye Salmon captured in our survey area were typically originating from Strait of Georgia rivers, particularly Fraser River, or from Puget Sound watersheds. Additionally, some of the Chinook and Sockeye Salmon were from central coast watersheds, particularly Rivers Inlet.

Empirical studies indicate that early marine growth is positively correlated to early marine survival of Pacific Salmon; additionally, condition (i.e. energy reserves) in fall are correlated to first marine winter survival (Beamish and Mahnken 2001, Duffy and Beauchamp 2011, Farley et al. 2007, Roggerone and Goetz 2004). Applying those hypotheses to above average summer condition and average fall condition, the early marine-stage and first winter survival of Pacific Salmon will likely be average to above-average. For Sockeye, Chinook and Coho Salmon from West Coast Vancouver Island rivers, Strait of Georgia rivers, particularly Fraser River and Puget Sound rivers, this may translate into average to above-average numbers of returning adults.

24.6. References

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25. CHATHAM POINT TO CAPE ST. JAMES; THE CRITICAL PLACE

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25.1. Highlights

- Sea surface temperatures in the Queen Charlotte Strait/Sound region have had no trend since 1977.
- Spring temperatures can be predicted with a modicum of skill from atmospheric and oceanic variability in winter at the Equator. The year 2017 was above the post-1977 average while the forecast suggests that 2018 will be nearer to the average.
- Survival of juvenile Fraser River Sockeye Salmon, and perhaps other salmon species, in 2017 (returns in 2019) will be no better than average but better outcomes are possible in 2018 (returns in 2020) because of the cooler spring.
- The timing of the spring phytoplankton bloom in Queen Charlotte Strait/Sound region in 2017 was about average. Later springs with cooler temperatures (expected in 2018) in Queen Charlotte Sound are generally associated with better survival of Cassin's Auklet at Triangle Is.

25.2. Background

The oceanic region extending from Discovery Passage to Queen Charlotte Sound is attracting greater scientific interest because of the Trophic Gauntlet Hypothesis (McKinnell et al. 2014) to explain why juvenile Sockeye Salmon from the Fraser River might be stressed there during their migration to the Gulf of Alaska. Intense tidal mixing in these narrow channels limits biological productivity and prey resources for migrating salmon, leading to slower growth (Journey et al. 2018). Recovery from the trophic deficit likely occurs after reaching the biologically productive waters of Queen Charlotte Strait (McKinnell et al. 2014). It is critical to growth and survival to reach a favourable environment after the salmon emerge from the gauntlet. Some of what the salmon will experience is determined by climatic events at the Equator (Deser et al. 2004).

25.3. Description of the time series

My Equatorial Oceanic Index (EOI; Figure 25-1) is a principal component analysis (PCA) of equatorial (5° S to 5° N, 130° E to South America) sea surface temperature (SST) anomalies (Reynolds et al. 2002). My Equatorial Atmospheric Index (EAI; Figure 25-1) is computed by PCA of the correlation of geopotential heights from surface to 100 hPa (Kalnay et al. 1996) over the same domain as the equatorial SST analysis.

Sea surface temperatures have been recorded daily at lighthouses along the length of the B.C. Coast since the 1930s (Chandler 2015). Monthly anomalies at four of them (Langara, Pine, Kains, Amphitrite) share 81% of their non-seasonal variation indicating that relatively large-scale climate features affect the B.C. Coast.

Chlorophyll data are from NASA's average 8-daily SeaWiFS (1998 to 2002) and MODIS-A (2003-present) on a 9 km^2 grid. A bloom timing index was computed at each pixel as the first 8-day period during a year when the chlorophyll concentration (ln transformed, standardized anomaly) exceeded +2 s.d. above the winter average values for that pixel. Only pixels with more than 85 observations in winter were selected which generally excluded pixels adjacent to land. Spring blooms are relatively large compared to winter values so their arrival is relatively easy to detect.

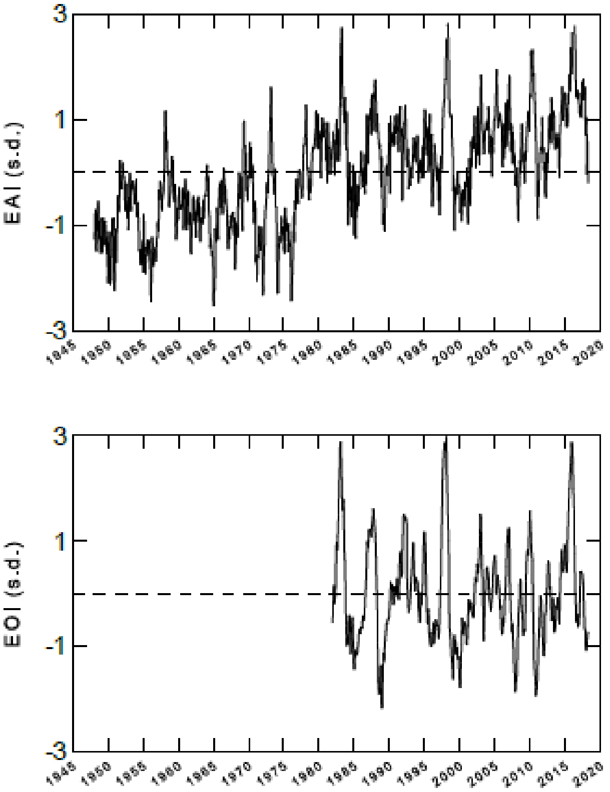

Figure 25-1. [Upper] Dominant principal component of geopotential heights from surface to 100 hPa (data source: Kalnay et al. 1996) over the equatorial Pacific Ocean (5° S to 5° N, 130° E to 75° W) from 1948 to 2018. [Lower] Dominant principal component of sea surface temperature (data source: Reynolds et al. 2002) in the same domain as above. Cross-correlation between them is maximum at 3-month lag, ocean leading with the strongest atmospheric response in January (r=0.92).

25.4. Status and trends

During the boreal summer/fall of 2017 the EOI changed from slightly positive (+0.5 s.d.) to negative (-1 s.d.) as a La Niña developed (Figure 25-1). A NOAA forecast (http://www.cpc.noaa.gov) gave a 55% chance of a transition from La Niña to El Niño–Southern Oscillation (ENSO)-neutral during the March-May season, with neutral conditions likely to continue into the second half of 2018. The persistence of a neutral state following a major El Niño has not occurred since this SST record began in 1981. The two previous major El Niños were followed by extended periods of a generally La Niña-like state (34 months in 1983 and 43 months in 1998). The 2015-16 El Niño differs because the negative EOI values that followed it did not persist. The first half of 2017 featured weakly positive values before declining into a La Niña.

Since 1948, the dominant principal component of correlations of atmospheric geopotential heights measured along the equatorial Pacific Ocean (surface to 100 hPa) indicates widespread coherence in its variability. When the index is positive (negative), geopotential heights are generally higher (lower). The dominant feature of the index is the 1976/77 climate regime shift (Figure 25-1). Atmospheric teleconnections with the Equator have a downstream effect on B.C. that begins with the state of the equatorial ocean in autumn. As the EOI leads the EAI by three months, the strongest atmospheric response at the Equator is during the boreal winter (Table 25-1).

Table 25-1. From 1982 to present, correlations between the EAI by calendar month with the EOI three months earlier.

1	2	3	4	5	6	7	8	9	10	11	12
0.92	0.83	0.89	0.85	0.75	0.67	0.56	0.61	0.62	0.52	0.73	0.79

Average SST on the B.C. coast is generally warmer (~ -0.5 °C) now than in the early 20th century (Figure 25-2). There are at least two views on the nature of this change. I argue that it is primarily due to a shift in the mean state that occurred between the fall of 1976 and the spring of 1977. Similar changes occurred in the EAI (Figure 25-1) and the PDO (Mantua et al. 1997, not shown) at the same time. Another view is that the rate of change in B.C. SST at coastal lighthouses is a constant (e.g. Chandler 2015) but an objective comparison of which model of change has a better fit to the data favours the former. Abrupt changes in mean state of Pacific climate are a characteristic feature of North Pacific decadal climate variability. As for Queen Charlotte Sound/Strait (Kains Is., Pine Is.), there has been considerable variability and some strong positive anomalies recently, but there is no (linear) trend since 1976/77.

The long-standing correlation between the western tropical Pacific (WTP) sea level pressure (SLP) and B.C. coastal SST (Figure 25-2) provides an opportunity to forecast spring SST from winter conditions in the WTP. Above average SLP in the WTP in the winter of 2016/17 was associated with above average SST on the B.C. coast in 2017. A forecast of 2018 SSTs from 2017/18 SLP suggests something closer to the long-term average SST in the spring of 2018. What is very clear from Figure 25-2 is that the spring of 2015 was not due to this teleconnection.

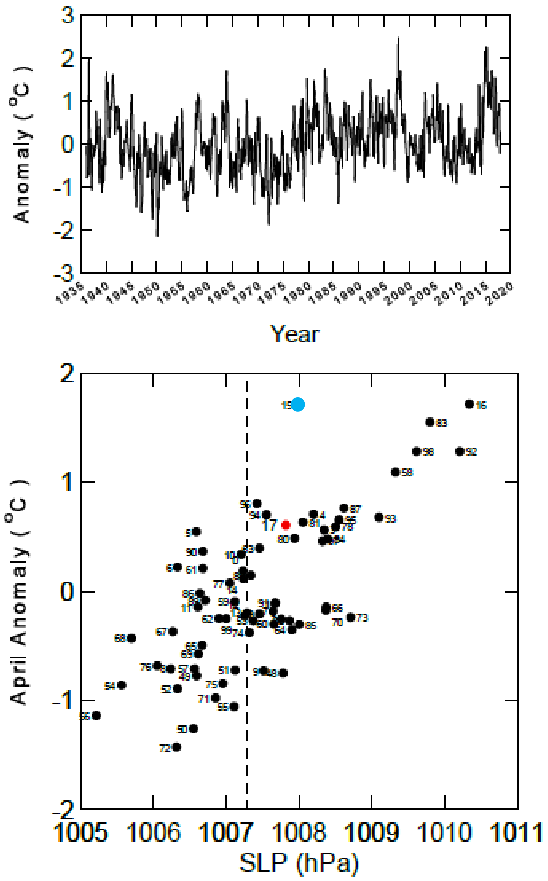

Figure 25-2. [Upper] Sea surface temperature (SST) anomalies determined from four lighthouses from 1936 to 2017. [Lower] April SST anomalies versus January sea level pressure (SLP) in the western tropical Pacific. The red dot is 2017 and the blue dot is 2015. The dashed vertical line indicates SLP for January 2018 which suggests a relatively neutral spring SST anomaly in 2018.

Biological productivity in the Queen Charlotte Sound/Strait region begins with the growth of plankton in the ocean. A bloom occurs when there is enough light from the sun, sufficient nutrients, and a stable water column. Bloom timing is earliest in the stratified open waters of Queen Charlotte Sound and latest, if at all, where there is strong tidal mixing. Timing has ecological consequences in the region (Bertram et al. 2001). Generalizing for the region, the timing of the spring bloom of 2017 was about average (Figure 25-3).

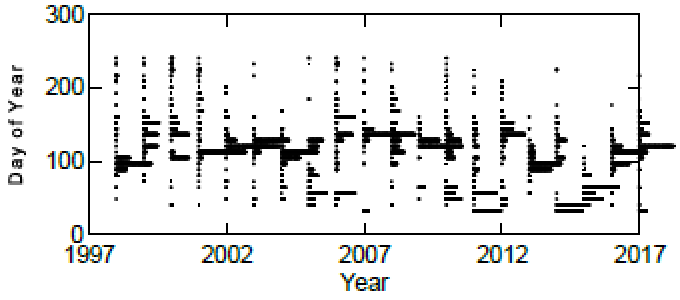

Figure 25-3. Annual histograms of the day of year, at each pixel in Queen Charlotte Sound/Strait, when the 8-daily average log-transformed chlorophyll concentrations exceeded 2 s.d. above the wintertime average at that pixel. 2017 is about the long-term median whereas 2013-2015 were early. SeaWiFS data are from 1998-2001, MODIS-A data from 2002-2017. Missing data were not interpolated which will add a late bias to spring bloom timing in cloudy springs.

25.5. Factors influencing trends

A large fraction of the variability of SST in the North Pacific is determined by ocean-atmosphere processes at the Equator, particularly in the region of the WTP warm pool where deep atmospheric convection has downstream effects throughout much of the North Pacific (Deser et al. 2004). The teleconnection that is primarily responsible for this large-scale climate effect is the Pacific-North American pattern (PNA, Barnston and Liversey 1987). Cross-correlation between the PNA index and the EAI is greatest at zero lag. Seasonal correlations of the EAI index with the PNA develop strongly in December and continue through early spring. The PNA pattern is associated with enhanced (or diminished) cyclonic circulation in the NE Pacific which in turn causes greater or lesser poleward advection of heat, primarily via the atmosphere but also via the coastal ocean. Because of the temporal lag that occurs between the equatorial oceanic forcing and the NE Pacific response it is possible to have advance warning of spring ocean-climate in the British Columbia coastal ocean.

25.6. Implications of those trends

25.6.1. Equatorial atmosphere-British Columbia ocean

Since 1948, the winter EAI accounts for about 40% of monthly SST variation at lighthouses along the B.C. Coast. Much of this is due to the climate shift of 1976/77. Focusing only on the WTP, SLP over the warm pool “explains” about 55% of spring SST anomalies in B.C. The lag-lead times involved suggest that a forecast of spring SST could be available at the New Year. December 2017 SLP was 1007.9 hPa, which translates to a March 2018 SST anomaly near neutral, or a 95% chance that the anomaly will lie in a range ±1 °C of average (Figure 25-2).

25.6.2. Northern Diversion Rate

Sockeye Salmon return to the Fraser River via Johnstone Strait (northern) or the Strait of Juan de Fuca (southern). One year after 1976/77, preference for the northern route increased abruptly and has persisted to the present. In the 1980s, David Blackbourn found that the choice was associated with spring coastal SST at Kains Island. The developing La Nina in 2018 suggests that a lesser fraction of the Sockeye will use the northern route than in the past few years, but as the post-1977 climate regime persists, the fraction using the southern route will remain relatively low.

25.6.3. Salmon marine survival 2018 forecast

Good survival of juvenile salmon in B.C. is rarely, if ever associated with warmer than average SST along the B.C. coast. Warm water often brings with it a more subtropical prey composition of poorer quality (Mackas et al. 2007). The springs of 2015 and 2016 were extremely warm while that of 2017 was simply warm. As Pine Is. in April of 2017 was as warm as during some major El Niños, the best possible survival for the 2017 ocean entry year will be average. As spring of 2018 will be nearer to the long-term average, something more than average is possible but perhaps not to be expected based on recent trends.

25.6.4. Seabird survival

Phenology in Queen Charlotte Sound/Strait affects the survival of seabirds (Bertram et al. 2001). Breeding failures of Cassin's auklet (*Ptychoramphus aleuticus*) have occurred when there are mismatches between the timing of hatching and the timing of prey availability (*Neocalanaus cristatus*). When spring is early and the region is warm, seabird survival is likely to be lower. The spring of 2017 was the 5th warmest in the record of SST at Pine Is. since the 1930s which suggests lower survival. The timing of the spring phytoplankton bloom was about average in 2017. Large-scale ocean climate suggests that the spring of 2018 will be cooler which suggests that survival may be better in 2018 than in 2017.

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26. SOCKEYE SALMON INDICATOR STOCKS REGIONAL OVERVIEW OF TRENDS, 2017 RETURNS AND 2018-2019 OUTLOOK

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26.1. Highlights

- Multi-year (2014-17) warm ocean phenomena (“Blob”, El Niño) induced survival-unfavourable conditions for B.C.’s Sockeye Salmon ‘index stocks’ returning in 2017. Freshwater conditions (high temperatures, early freshets, and summer drought) likely negatively impacted smolt production in 2015, affecting adult returns two years later.
- Returns of Transboundary, North Coast and Central Coast Sockeye index stocks in 2017 were well below their all-year average returns. Returns of Fraser Sockeye were near (Chilko Sockeye) or below historic lows (Fraser Sockeye aggregate) and far below pre-season forecasts. Returns of WCVI and Columbia (Okanagan) index stocks continued a multi-year decline from record returns in 2014-2015.
- The 2017 coast-wide pattern of synchronous decline among all Sockeye indicator stocks in Canada’s Pacific region is a rare event but was not unexpected, given the anomalous environmental conditions affecting juvenile salmon survival in freshwater and marine ecosystems in 2014-2016.
- A weak La Niña in 2017/18 signals a modest boost in marine survival for salmon with 2017-2018 sea entry into the California Current System (CCS) and subsequent adult returns in 2019-2020.

26.2. Time Series – B.C. Sockeye “Indicator Stock” Annual Returns

Comparisons of annual forecasts and observed returns of Sockeye Salmon for major rivers and fisheries in B.C. have been completed annually by DFO for decades. Total Sockeye returns are comprised of estimates of total annual harvest from all fishery sectors plus total ‘escapement’ to spawning grounds based on standard site-specific methods (e.g. counting weirs, electronic counters, mark-recapture, etc.). Historical returns and pre-season forecasts are generally available from DFO’s regional Integrated Fisheries Management Plans, infilled where necessary with unpublished summaries from DFO resource managers.

The weight of evidence suggests that juvenile salmon survival and subsequent abundance of adult returns are determined primarily during the first several weeks after ocean entry (Beamish et al. 2004, Ruggerone and Connors 2015). Production trends of six “data-rich” Sockeye populations or stock aggregates (i.e. “indicator stocks”) are assumed to represent other populations sharing the same marine domains that characterize the critical first weeks of early marine life (see Hyatt et al. (2016) for additional details of rationale behind “indicators”). Representative domains (with associated indicator stocks) are loosely defined by the coloured areas in Figure 26-1, spanning 1,400 km of the west coast from southeast Alaska in the north to the Oregon border in the south.

1. Marine domain #1 is represented by the Tahltan Sockeye stock. Smolts leave the Tahltan watershed and swim 250 km down the Stikine River to enter the ocean in southeast Alaska.

2. Marine domain #2 is represented by the Meziadin stock. Smolts swim 180 km down the Nass River to enter marine waters in Dixon Entrance, B.C.
3. Long Lake Sockeye (#3) enter the Central Coast marine domain of Queen Charlotte Sound via Docee River (< 1 km) and Smith Inlet.
4. Chilko Sockeye (#4) represent Fraser fish that spend their early marine life in the Salish Sea. Chilko smolts swim over 700 km to sea via the Chilcotin and Fraser rivers.
5. Somass Sockeye are a stock aggregate that swim 15-30 km down the Somass River to Alberni Inlet into Barkley Sound and the California Current System (CCS) on the west coast of Vancouver Island (#5).
6. The most southerly stock, Okanagan Sockeye, swim over 800 km via the Columbia River directly into the CCS (#6).

26.3. Status and Trends

Trend comparisons among Sockeye indicator stocks permit the following generalizations:

- Return variations are large, with maximum annual returns at 10 to 90 times the minimum returns.
- Despite wide variation in abundances between stocks, multi-year productivity correlations exist, especially for proximal stocks such as Tahltan and Meziadin, or Somass and Okanagan. Chilko Sockeye returns co-vary the least with other stocks.
- In 2017, all stock returns were lower than the all-year average, and most were well below the median level forecast, ranging from 25% (Chilko) to 60% (Tahltan) of expected returns[1,2]. WCVI[3] and Columbia (Okanagan) index stocks continued a multi-year decline from record returns in 2014-2015.

The emerging pattern from 2017 is a synchronous decline among all Sockeye indicator stocks (i.e. Transboundary to Columbia). This is a rare event, but not totally unexpected, given the anomalous environmental conditions affecting juvenile salmon survival in both freshwater and marine ecosystems in 2014 through 2016.

26.4. Factors Influencing Trends

Freshwater and coastal marine conditions along the continental shelf during winter 2014 and spring 2015 likely drove the 2017 decline in adult salmon returns. In the freshwater environment, above-average air temperatures in the winter to early spring of 2014/15 resulted in early snowmelt and rapid run-off, reducing snowpack to <50% of normal levels across much of B.C. (Anslow et al. 2016). High winter to early spring flows may have scoured spawning grounds, potentially reducing fry survival from brood year 2014. Low snow-pack and below-average spring precipitation resulted in late spring drought conditions in many locations, and likely reduced seaward migration rates of smolts in 2015 (as was observed for Okanagan Sockeye). Reduced migration rates and associated delays can negatively impact smolt-to-adult survival via increased predation during in-river migration and predator-prey mismatch events at ocean entry (Scheuerell et al. 2009).

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[1] Total Long Lake returns were unavailable, as the escapement counting weir was not operated in 2017.

[2] With the exception of Somass stocks, commercial fisheries were closed or restricted and some First Nation fisheries were also limited.

[3] Somass returns were below average but still 250% of forecast levels, due to an unexpectedly large contribution of age 5 fish (pers. comm., D. Dobson, Stock Assessment Biologist, DFO).

For any successful seaward migrants, biophysical conditions were not favourable for survival in the marine environment. During ocean entry in 2015, the anomalous multi-year marine heatwave (the "Blob") was still in effect. The strongest temperature anomaly was along the west coast of North America, consistent with the Blob having moved onto the continental shelf (Ross 2016), as juvenile Sockeye Salmon were migrating north along the shelf. In addition, the most powerful El Niño event[4] since 1998 was developing in the tropical Pacific (ibid). The Oceanic Niño Index (ONI) is a useful predictor of sea surface temperature (SST) in south- and central coast B.C., accounting for ~50% of regional water temperature variability (Hannah et al. 2017). Although these phenomena started to dissipate in 2016 (Ross 2017), Pacific Ocean temperatures remained much warmer than average over these years, resulting in northward transport of less nutritious, low-lipid zooplankton prey, predators 'foreign' to juvenile salmon, and competitive invertebrate populations (e.g. jellyfish, salps, etc.; Galbraith and Young 2017). These factors contribute to slow growth and high mortality for juvenile Sockeye; thus SST at ocean entry is a reasonable predictor of marine survival of Sockeye stocks, most evidently for stocks that enter directly into the CCS (Hyatt et al. 1989; 2016; 2017).

Alignment of El Niño and La Niña events from the ONI with annual B.C. Sockeye Salmon indicator stock returns indicated that:

- Large returns in the 1990s occurred for all Sockeye indicator stocks from the North Coast to the Fraser in association with a powerful 1989 La Niña event two to three years earlier. Similarly, moderate La Niñas in 1999, 2000, 2008 and 2011 were followed by above-average returns two years later, with near-record returns in 2010 and 2015 for several stocks.
- Warm ocean conditions linked to moderate El Niños through the 1990s were associated with sub-average returns late in the decade for stocks entering most directly into the CCS. A powerful El Niño event in 1997/98 likely depressed all stocks' returns in the early 2000s. Weaker El Niños in 2002/03 and 2009/10 were associated with sub-average returns for most southern and central stocks, and an El Niño event in 2015/16 – equivalent in amplitude to the 1997/98 event – was also followed by declines in all stocks to below average returns in 2017.

26.5. Implications and Outlook

Sub-average Sockeye Salmon returns in 2017 were not unexpected given the combined influence of survival-unfavourable factors operating in both freshwater and marine ecosystems from 2014-2017. Sub-average returns are anticipated to continue into 2018. In addition, the impacts of early, strong winter freshets, low snow-pack, and resulting summer drought in 2015 and 2016 (Anslow 2017) in southern watersheds may negatively impact adult production of stocks returning there through 2018 and 2019 (Hyatt et al. 2016; 2017).

However, above-average snow pack in southern B.C. and Fraser watersheds in 2017[5] should improve egg-to-smolt survival for the 2016 brood (ocean entry year 2018), and for returns in 2020. A weak La Niña that has been developing through 2016/17 and 2017/18 winters signals a

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[4] ENSO (El Niño Southern Oscillation) refers to the oscillation between multi-year 'warm-phase' (El Niño) and 'cool-phase' (La Niña) tropical water temperature events.

[5] B.C. Min. Forests, Lands and Natural Resources Operations River Forecast Centre – Basin Snow Water Index map (http://bcrfc.env.gov.bc.ca/bulletins/watersupply/SnowIndexMap.htm).

modest boost in marine survival for 2017 and 2018 sea entry years and for adult returns in 2019 and 2020.

Forecasting skill for coast-wide returns of Sockeye Salmon may be improved by accounting for ENSO effects. More research is required to fully understand the relationship between marine survival and the frequency and magnitude of ENSO events for Sockeye Salmon stocks distributed over their full range on the west coast of North America.

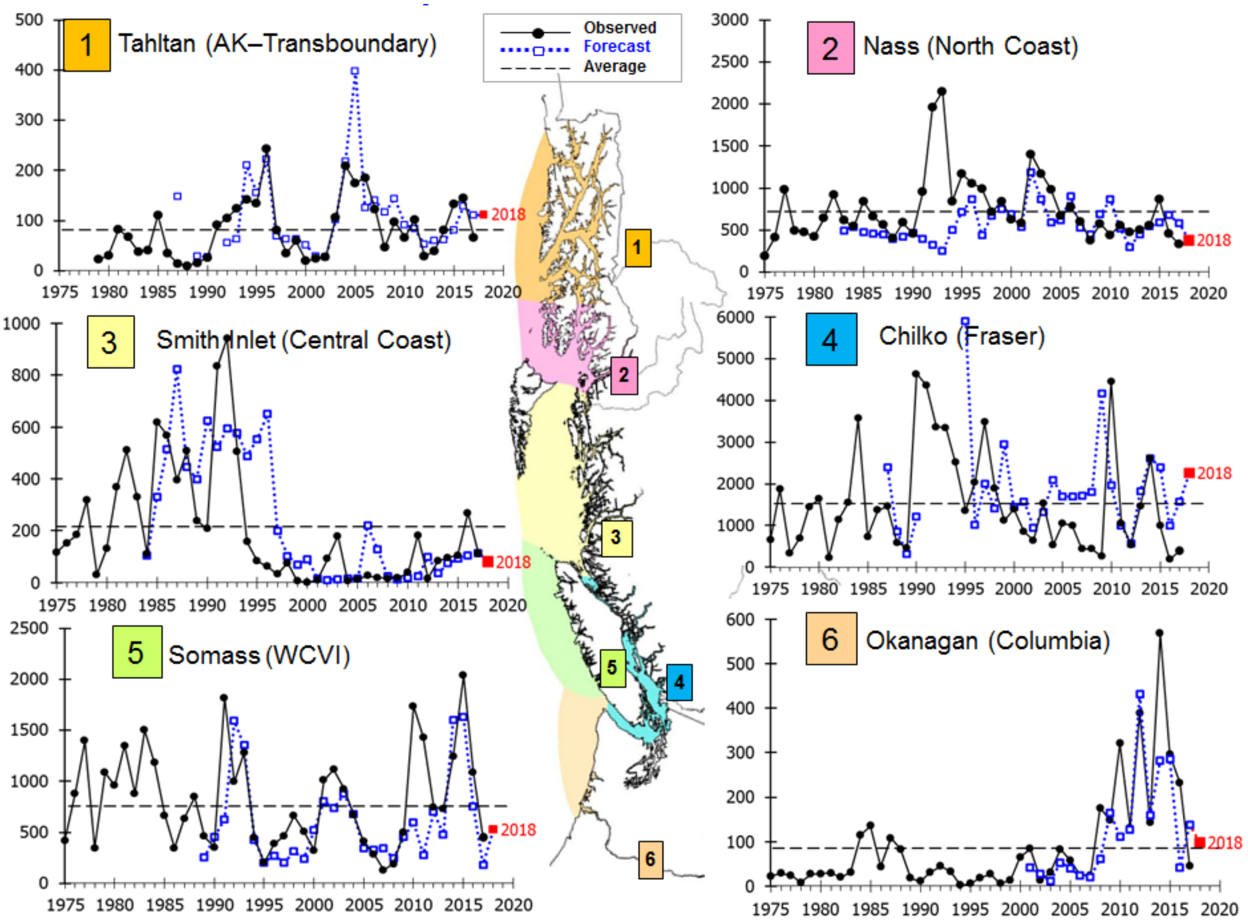

Figure 26-1. Trends in the total returns (black line) and resource manager forecasts (blue dashed line) for British Columbia Sockeye index stocks including: (1) Stikine – Tahltan; (2) Nass – Meziadin; (3) Smith Inlet – Long; (4) Fraser – Chilko; (5) Barkley Sound – Somass; and (6) Columbia – Okanagan. Y-axis represents returns in thousands of fish.

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27. ALBACORE TUNA ABUNDANCE AND TRENDS IN B.C.

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27.1. Highlights

- The North Pacific Gyre Oscillation (NPGO) index appeared to have a significant positive correlation with Albacore Tuna abundance in the Pacific Canadian exclusive economic zone (EEZ).
- Albacore Tuna annual catch from the Canadian Pacific EEZ and catch-per-unit-effort (CPUE) decreased substantially in 2016 and 2017 from high values in 2013-2015, corresponding to lower NGPO indices in the 3-4 years prior than in the 5-9 years earlier.
- Environmental conditions in the North Pacific may strongly influence albacore abundance in the Pacific Canadian EEZ.

27.2. Description of the time series

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

27.3. Status and trends

Albacore catch in the Canadian EEZ by the Canadian fishery showed substantial variation between 1995 and 2017 (Figure 27-1 A). Prior to 2010, annual catch varied, but was typically below 1000 mt. From 2010-2015, with the exception of 2011, annual catch was greater than 2000 mt. In 2016, annual catch decline by nearly a half and in 2017 was only 7.3% of the 2015 value. Although CPUE showed a similar trend to catch, they did not exactly mimic each other (Figure 27-1 B). CPUEs in the Canadian EEZ for the Canadian fishery showed a slight decline from 1995 to 1997, after which there was a general increase until 2010, reaching a maximum of 0.81 mt per vessel-day. CPUE declined by over 50% between 2010 and 2011, and remained depressed in 2012. CPUEs increased in 2013-2015, reaching the highest observed level of 0.90 mt per vessel-day in 2014. However, after 2015 there was a dramatic decline, in 2017 reaching the lowest observed level since 1995 (Figure 27-1 B).

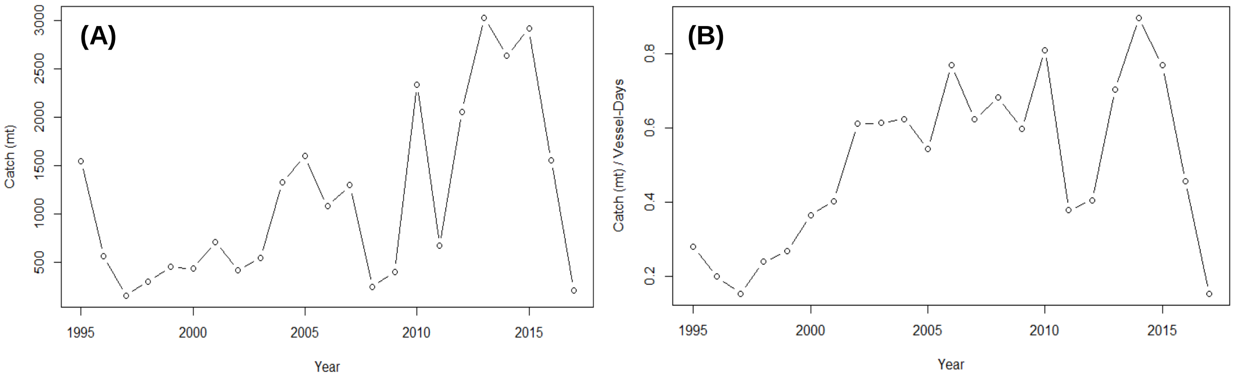

Figure 27-1. Albacore Tuna catch metric tons (A) and catch-per-unit-effort (B) in the Canadian EEZ for the Canadian fishery.

27.4. Factors influencing trends

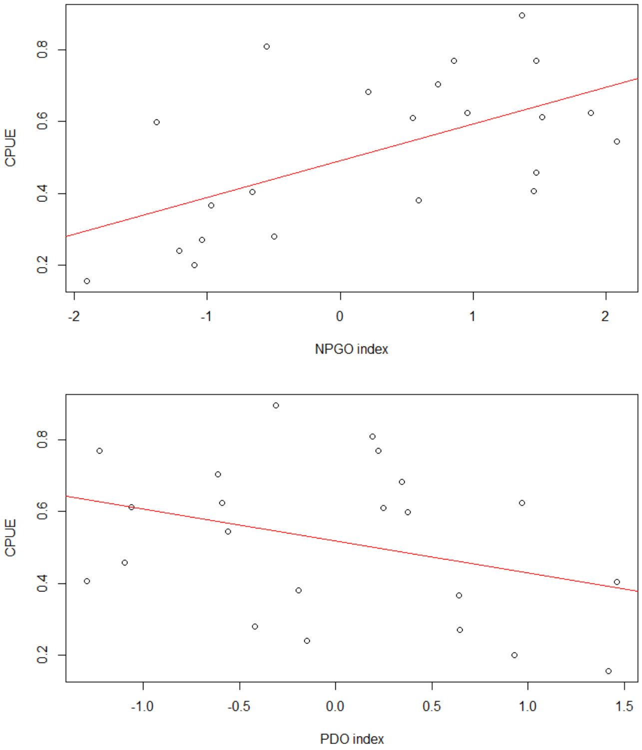

Figure 27-2. Correlation between CPUEs in the Canadian EEZ for the Canadian fishery and annual means of NPGO (top) and PDO (lower) indices four years earlier.

The North Pacific Gyre Oscillation (NPGO) was found to have a positive impact on the abundance of Albacore Tuna in the Canadian EEZ (as well as in the US EEZ). The albacore abundance time trends were significantly correlated with NPGO indices three or four years earlier. The top panel in Figure 27-2 shows the relationship between albacore abundance and the NPGO index four years earlier. In contrast, the Pacific Decadal Oscillation (PDO) may negatively affect the abundance of albacore tuna in the Canadian EEZ, although the correlation was not significant (Figure 27-2 lower plot).

The NPGO closely reflected inter-annual variations in salinity, nutrient upwelling, and surface chlorophyll-a in the ocean (Di Lorenzo et al. 2008), and was positively correlated with phytoplankton abundance off of Oregon (Menge et al. 2009) and productivity of the north Pacific albacore stock (Zhang et al. 2014). As a result, the NPGO likely has a positive influence on the survival of young-of-the-year and one-year-old albacore, which is in turn reflected in the abundance of 2-4 year-old albacore migrating into the Canadian EEZ.

27.5. Implications of those trends

Albacore is an economically important tuna species in the Pacific Ocean. Management strategy evaluation (MSE) is now under way in order to improve the management of albacore fisheries, internationally. The MSE process involves assessing biological, environmental and fishing impacts on the albacore stock to optimize catch sustainably. The correlation between albacore abundance and the NPGO indices highlights the critical importance of integrating environmental factors into the MSE.

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28. SEABIRD OBSERVATIONS ALONG THE OUTER B.C. COAST

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28.1. Highlights

- Cassin's Auklets enjoyed a good breeding season in 2017 on the world's largest colony at Triangle Island, with nestling growth rates that were well above the average compared to the years from 1996 to 2016.
- Overall, there was little juvenile salmon in diets fed to nestling Rhinoceros Auklets on Pine, Lucy, and Protection islands in 2017.

28.2. 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, 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 2017 season were well above the1996-2016 average (Figure 28-1).

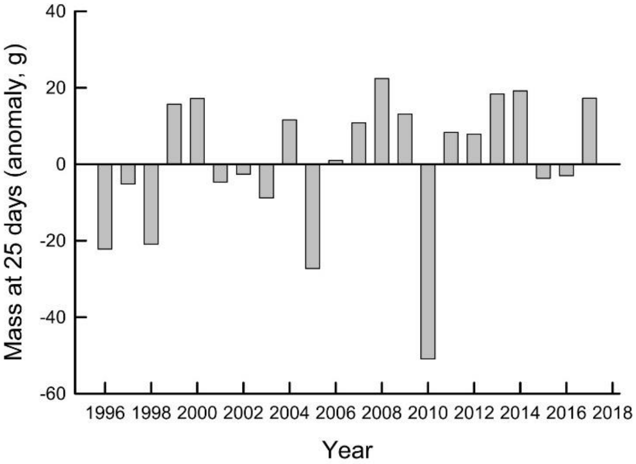

Figure 28-1. Yearly anomalies of mean 25 day mass (a proxy for growth rate) of nestling Cassin's Auklets on Triangle Island, BC, in 1996 to 2017.

28.3. Salmon in Rhinoceros Auklet diets

Pacific Salmon (*Oncorhynchus* spp.) have an anadromous life-cycle, spending a few months to two years in freshwater, followed by one to four 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 to 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 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; in 2017, the amount of salmon in diets was slightly below average there (Figure 28-2). Salmon has been less important, and less variable, in diets at Lucy Island, and the amount present in 2017 was near average. Salmon was an important component of auklet nestling diets at Triangle Island only in 2012 (largely Fraser River Sockeye), and was absent altogether in 2017 sampling. Our collaborators in Washington State have been tracking diets of Rhinoceros Auklets at Protection Island over the same time period, and salmon was uncommon in auklet nestling diets in 2017.

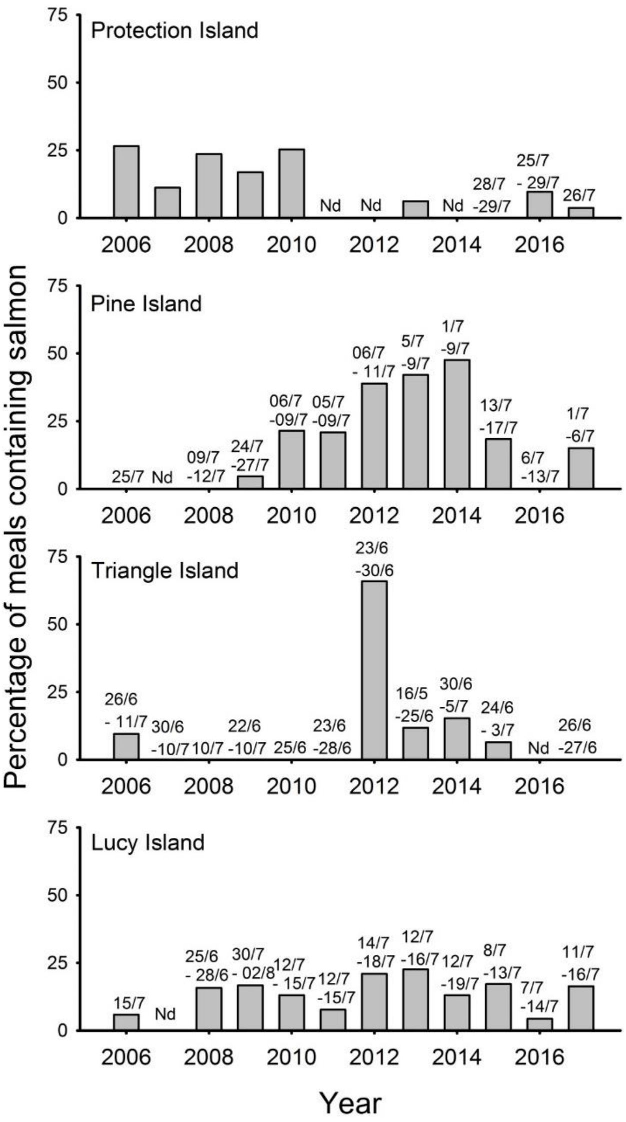

Figure 28-2. Percentage of meals delivered to nestling Rhinoceros Auklets that included one or more salmon (Pink, Chum, or Sockeye) on three colonies in B.C., Triangle, Pine and Lucy islands, and on Protection Island, WA, in 2006-2017. Dates of sampling (day/month) are indicated above the bars.

28.4. References

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Hipfner, J.M. 2008. Matches and mismatches: ocean climate, prey phenology and breeding success in a zooplanktivorous seabird. Mar. Ecol. Progr. Ser. 368: 295-304.

29. DFO SALMON NET

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29.1. Highlights

- The International Year of the Salmon (IYS; People and salmon in a changing world) will involve scientists and managers working on the current and future distributions and abundances of salmon in both the North Pacific and the North Atlantic (the Salmosphere). International and non-government funding is sought for “signature projects” that include coordinated high-seas research.
- The Canadian response to IYS includes the DFO Salmon Net, intended to encourage broader and more effective collaboration among DFO staff who are involved with salmon, across all job types and all DFO regions. A survey (2017 October) that investigated opportunities for collaboration pointed to data management as a barrier to modernizing the salmon information flow, from surveys to decisions.
- One project for IYS/Salmon Net is an experiment in knowledge management and collaboration support based on graph-database technology (*neo4j*). This will appear as a Salmon Activities Catalog (salmosphere.net), initially based on information from the Salmon Net survey. In discussion is a pilot project to encourage collaboration among DFO staff who apply acoustic technologies to salmon enumeration and salmon migrations.

29.2. The International Year of the Salmon (IYS)

Raison d’etre: “Right now, hundreds of organizations across the northern hemisphere are working on salmon issues. Yet, despite this broad and deep source of strength, we remain poorly connected and fail to take full advantage of our collective capacity to address common issues. By creating connections among these organizations and building partnerships, we can amplify this source of strength and create confidence in our ability to manage an uncertain future.” (North Pacific Anadromous Fish Commission 2017).

The intention of the IYS is, therefore, wider and more effective collaboration that will result in:

- Innovative **salmon research** to improve our ability to understand, anticipate, and respond to changing patterns in salmon distribution, abundance, and survival.
- Better informed and more nimble **salmon management**.
- Greater **public appreciation** of salmon.

IYS is an intensive burst of activity in 3 phases:

1. Plan (2016–2018): National and international planning; identify core partners; salmon networks; outreach and communication strategy; research priorities.
2. Launch (2018–2019): International kick-off event; initiate outreach and communication; design field activities.

3. Implement (2019–2022): Conduct and report research; analyze and publish results; continue outreach.

IYS activities are organized around five themes. A sixth theme, outreach, exists within each of the others (Table 29-1).

Table 29-1. International Salmon Year themes and outcomes.

Status of salmon	The present status of salmon and their environments is understood.
Salmon in a changing *salmosphere*	The effects of natural environmental variability and human factors affecting salmon distribution and abundance are understood and quantified.
New frontiers	New technologies and analytical methods are advanced and applied to salmon research and used to understand previously uncharted regions of the salmosphere.
Human dimensions	Salmon-dependent communities, indigenous peoples, youth, harvesters, academics and resource managers collaborate across the salmosphere to develop decision-making tools and arrangements that support the resilience of people and salmon.
Information systems	Freely available information systems contain historic and current data about salmon and their environment.
Salmon outreach and communication	People understand the value of healthy salmon populations and engage to ensure salmon and their varied habitats are conserved and restored against the backdrop of increasing environmental change.

29.3. DFO Salmon Net

A Canadian project for IYS is creation of a network to encourage broader and more effective collaboration among DFO staff who are involved with salmon, across all job types and all DFO regions: the *DFO Salmon Net.* The general goals are (abbreviated from the draft terms of reference):

- Obtain input on projects and priorities for Canadian salmon from DFO staff across Canada;
- Identify and close critical knowledge gaps that prevent a clear understanding of the future of salmon in a rapidly changing world;
- Assemble a legacy of knowledge, information systems, analysis tools, and new technologies for the next generation of DFO staff; and
- Develop processes to bridge gaps between science and fisheries management, e.g. management strategy evaluations.

In other words:

- Ease communication;
- Build professional relationships;
- Learn and advise of opportunities; and
- Receive and give advice and assistance.

29.4. Survey re DFO Salmon Net

A survey was conducted in 2017 October with questions in three sections: (1) your job, (2) opportunities for collaboration (by 37 topics within the 6 IYS themes), and (3) activities that would benefit from collaboration. The survey received 163 responses from 351 recipients, with 124 *thorough* responses regarding opportunities for collaboration; 90 of those 124 were from DFO’s Pacific Region. The response rate was similar across job types (~40%), but some job types were poorly represented (Figure 29-1).

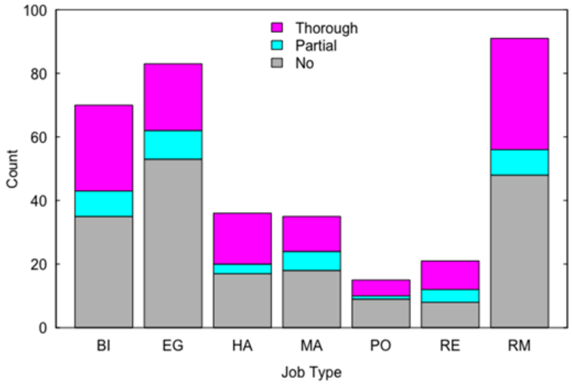


Figure 29-1. Survey response by job type, across all regions. ‘Thorough’ means most or all of the collaboration topics were addressed and ‘partial’ means that not enough topics were addressed to be useful for analysis, while ‘No’ means there were no answers to that part of the survey. The job type categories were BI: biologist in Science Branch, EG: engineers and technicians, HA: hatchery and enhancement staff, MA: administration, PO: policy and economics staff; RE: scientists; and RM: resource managers.

The 37 topics (abbreviated) for collaboration, within the six IYS themes, were:

1. Status Salmon and Habitats
1.1 Field Data
1.2 Data Analysis
1.3 Fishery Management and Assessment
1.4 Stock Status Assessment
1.5 Habitat Assessment
1.6 Population identification
1.7 Marine Survival, Growth, Migration
1.8 Interactions: Wild, Hatchery, Farmed
1.9 Toxicology

2. Effects of Changing Habitats
2.1 Freshwater habitats
2.2 Marine and Estuarine Habitats
2.3 Climate and Ecosystem Models
2.4 Adaptation
2.5 Policy and Management

3. New tech and methods
3.1 Field methods
3.2 Individual fish
3.3 Fisheries management process
3.4 New analyses
3.5 Advances genetics, genomics
3.6 Science management
3.7 Implementation

4. Connecting Salmon to People
4.1 First Nations Opportunities
4.2 Benefits from Salmon
4.3 Community engagement
4.4 Better science communication
4.5 Traditional ecological knowledge
4.6 Young scientists
4.7 Changing role of salmon in societies

5. Information Systems
5.1 Database Integration
5.2 Knowledge management
5.3 Data sharing arrangements
5.4 Data visualization

6. Outreach and Communication
6.1 International projects
6.2 Celebrating success
6.3 Outreach methods, awareness
6.4 Engage scientists with managers
6.5 Linking salmon to climate change

For each topic, recipients chose one of five answers regarding opportunities for collaboration:

0: No, or not applicable (No);
1: Yes, but unlikely at present (Pending);
2: Yes, I have an activity that would benefit from additional collaboration (Need);
3: Yes, I am keen to share data, skills, and/or knowledge with others (Share); and
4: Yes, this collaboration is vital to my work and should be a high priority for DFO (Vital).

Various analyses were applied to the 124 by 37 matrix of answers, including cluster analysis (see example, Figure 29-2) and scoring the topics as weighted means for the answers (weights 0 to 4).

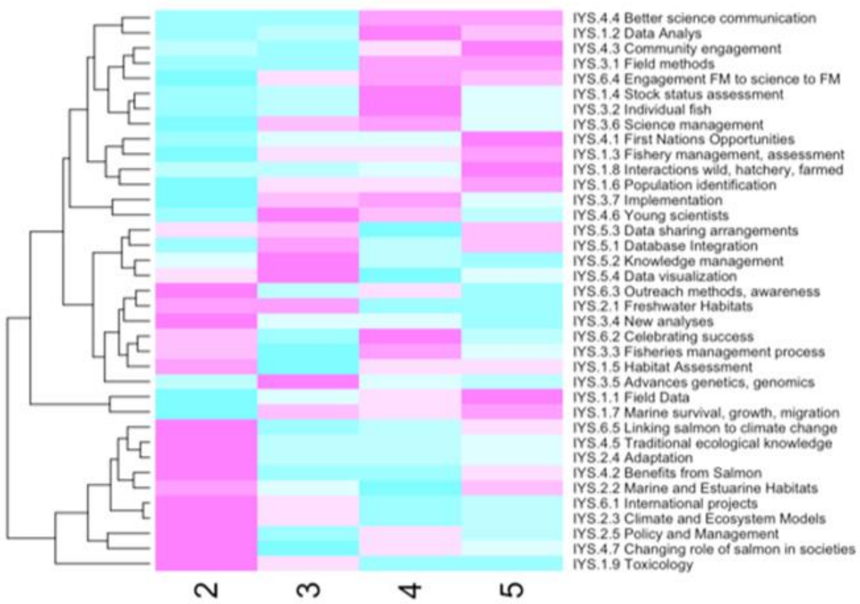


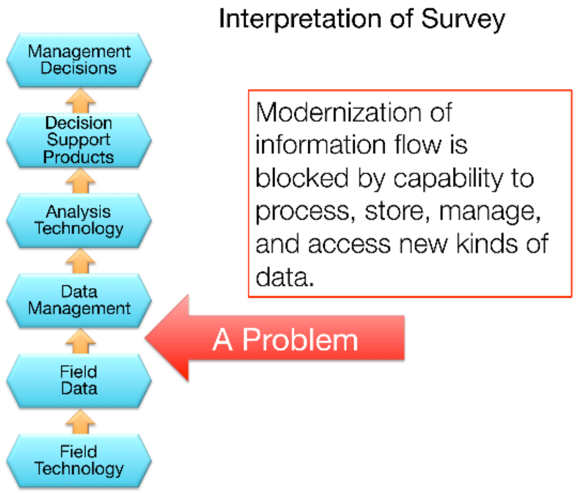
Figure 29-2. Cluster analysis of responses to opportunities for collaboration for 37 topics related to salmon. The "no" answers were deleted in this example to emphasize clusters where collaboration was favoured. Clustering is by the order of topics, the columns correspond to the available answers (0: No, 1: Later, 2: Need, 3: Have, 4: Critical). Note that choices were exclusive: indicating "critical" precluded "need."

From analysis by scoring, the top ten topics re potential for collaboration across all jobs and regions (despite important differences among job types) were:

IYS.1.1 Field Data
IYS.4.1 First Nations Opportunities
IYS.4.4 Better science communication
IYS.1.2 Data Analysis
IYS.1.3 Fishery Management, Assessment
IYS.3.1 Field methods
IYS.3.7 Implementation
IYS.4.3 Community engagement
IYS.1.7 Marine Survival/Growth/Migration
IYS.5.1 Database Integration

29.5. Interpretation of Survey Responses

Cluster and scoring results were compared by regions and job types, as the analysts struggled to understand the story behind the numbers: “What are the respondents trying to tell us?” One of the conclusions was that **modernization of information flow is blocked by capability to process, store, manage, and access new kinds of data** (Figure 29-3).



Modernization of information flow is blocked by capability to process, store, manage, and access new kinds of data.

Figure 29-3. Information flow for salmon management, from field surveys to decisions. A conclusion from examining the survey results was that desired modernizations (new technology, new processes) were hampered by the ability to manage the new types of data and the large volumes of data involved.

29.6. Knowledge Sharing and Collaboration Support

To support the DFO Salmon Network, an experiment with new technology for knowledge sharing (RoundTable™) has begun, based on the graph-database *neo4j* (neo4j.com) A prototype Salmon Activities Catalog (salmosphere.net) was developed, based on information from the 2017 October Salmon Net survey. In discussion is a pilot project with this technology, intended to encourage collaboration among the DFO staff who apply acoustic technologies to salmon enumeration and salmon migrations.

RoundTable innovations include dealing with diverse kinds of data as a network (rather than tables) where there many nodes, of many kinds (Figure 29-4), with rich links. This is referred to as a *knowledge graph*. As well as links between *things*, the concept of tagging was refined by recognizing that things are cross-linked by *ideas* (Figure 29-5). Further, the nodes representing ideas are cross-linked into a *semantic web*. The technology has an appropriate tag line: *Connect the dots. All the dots.* The user interfaces to this diversity and complexity (and realism) involve GraphView (Figure 29-5) and TableView, and potentially many other interactive data visualizations, to support discovery and sharing of knowledge. To support knowledge-rich collaboration, there are service nodes for communications support: metadata, conversation, item, request, message, and address.

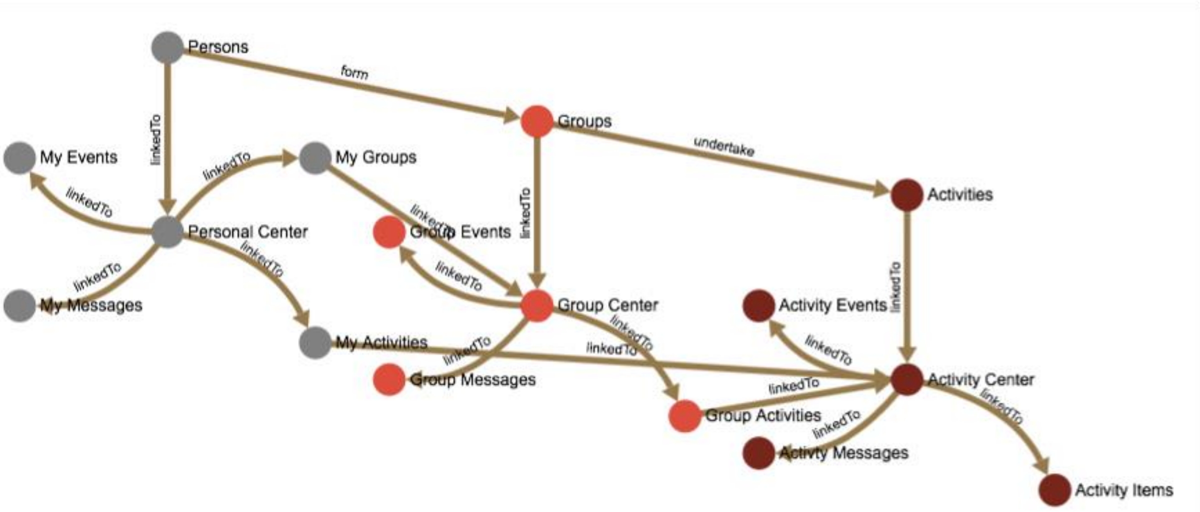


Figure 29-4. Some of the types of nodes ("resources") in the RoundTable™ technology presented as Salmosphere.net. Each type has subtypes, as do the many different kinds of links. These are customized for each community of practice.

29.7. Looking Ahead

DFO managers and staff need to know: *who is doing what, where, with whom, how, and with what results?* This requires at least a Salmon Activities Catalog, but we can do much better through a support system for knowledge sharing and collaboration that uses modern technology. The intention is to answer the call from IYS planning: "An effort beyond the capacity of any one group or country is needed to raise awareness, address knowledge gaps and devise new approaches to management." (North Pacific Anadromous Fish Commission 2018).

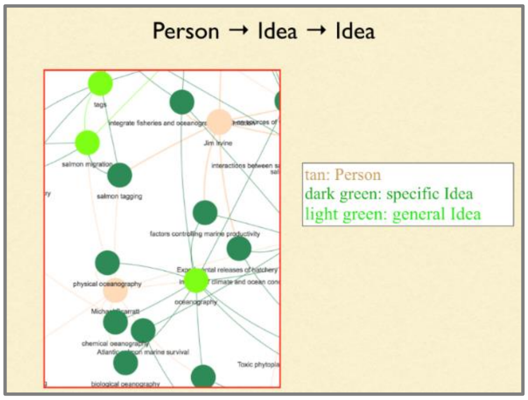


Figure 29-5. A fragment of a knowledge graph showing Persons linked to specific Ideas they proffered, with those Ideas further linked by more general Ideas. Thus two Persons are linked by chains of Ideas.

While this is a worthy goal, we have yet to discover the on-going rewards, if any, of better knowledge sharing: between job types within regions, and within job types between regions. The underlying assumption is that more and better collaboration between resource managers and scientists will produce insightful new data and valuable new decision support products that result in faster, better-informed decisions. Faster modernization should be possible by learning from others' projects: less reinventing the wheel and faster (shared) evolution of best appropriate practices. If successful, the DFO Salmon Net will quickly involve, and hopefully enrich, many non-DFO persons and agencies.

29.8. Wider Application

A Canadian Salmon Net could have broader application: making connections and establishing / supporting collaborations among scientists investigating linkages between fish stocks and oceanography, or among groups involved in integrated fish-and-forestry (watershed) management. The 2017 October survey indicated wide interest among salmon biologists and resource managers in collaboration and outreach to First Nations agencies; the Salmon Net is a vehicle to unify diverse approaches to shared goals. Collaborative development of education curricula is supported via LearningObject nodes.

The technologies within RoundTable allow linking a Model node (that invokes R, Python, C++,) to a DataSet node via MetaData nodes with information about formats and precisions. Conceptually, the time-stamp for a Document, Media, or WebPage node created by that Model can be checked against the time-stamp for the Data node, such that the Document is automatically re-created, if necessary, upon being viewed. Further information is available from the authors; collaborators welcome.

29.9. References

International Year of the Salmon Working Group. 2018. Report of the 2018 International Year of the Salmon North Pacific Steering Committee Meeting. NPAFC Doc. 1770. 57 pp. International Year of the Salmon Working Group, Committee on Scientific Research and Statistics. Available online at https://npafc.org/wp-content/uploads/1770IYSWG.pdf

30. POLLUTION TRACKER: A NEW COAST-WIDE INITIATIVE

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30.1. Highlights

- *PollutionTracker*, a long-term, coast-wide monitoring program for contaminants in sediments and mussels, was launched by the Coastal Ocean Research Institute's Ocean Pollution Research Program (OPRP) in 2015.
- *PollutionTracker* is the first integrated, coast-wide pollution monitoring program in British Columbia and Canada, and is driven by partnerships with government agencies, First Nations, port authorities, and community organizations.
- The *PollutionTracker* website was launched in February 2018, providing project information and Phase 1 summary results (2015-2017).
- Phase 2 of *PollutionTracker* began in January 2018, with sampling at existing sites on a three-year cycle, and the establishment of new sites to fill spatial gaps and meet partner interests.

30.2. Overview

PollutionTracker is a new coast-wide monitoring initiative that is generating high quality contaminant data to inform pollution priorities, source identification, best practices, restoration, and natural resource management. Prior to the launch of *PollutionTracker*, no consolidated, transparent, or sustainable pollution assessment framework existed for coastal British Columbia. *PollutionTracker* provides information to address pressing issues, including how to best conserve and protect fish and fish habitat, the assessment of risks to Species at Risk Act (SARA) -listed marine species through food web contaminant modelling, concerns of First Nations communities about the safety of traditional seafoods, oil spill preparedness, and remediation of contaminated sites.

30.3. Methods

During Phase 1 (2015-2017), 55 *PollutionTracker* sites were established coast-wide, with 51 sediment and 33 mussel samples collected (Figure 30-1). Sediment and mussels have been used internationally for several decades to monitor coastal health. Sediment can be both a contaminant 'sink' as well as a source for adjacent food webs. Mussels are useful for pollution monitoring because they are immobile, do not readily metabolize contaminants, and as filter-feeders they take in all of the contaminants in the surrounding water.

Nearshore sediment samples were collected from targeted depths of 5 to 20 m using a petite ponar grab (Figure 30-2). Depositional areas with fine-grained sediment were targeted, and the top 2 to 5 cm of sediment was taken from three to five grabs at each site and composited. Blue mussels (*Mytilus sp.)* were collected within 2 km of sediment collection locations where available.

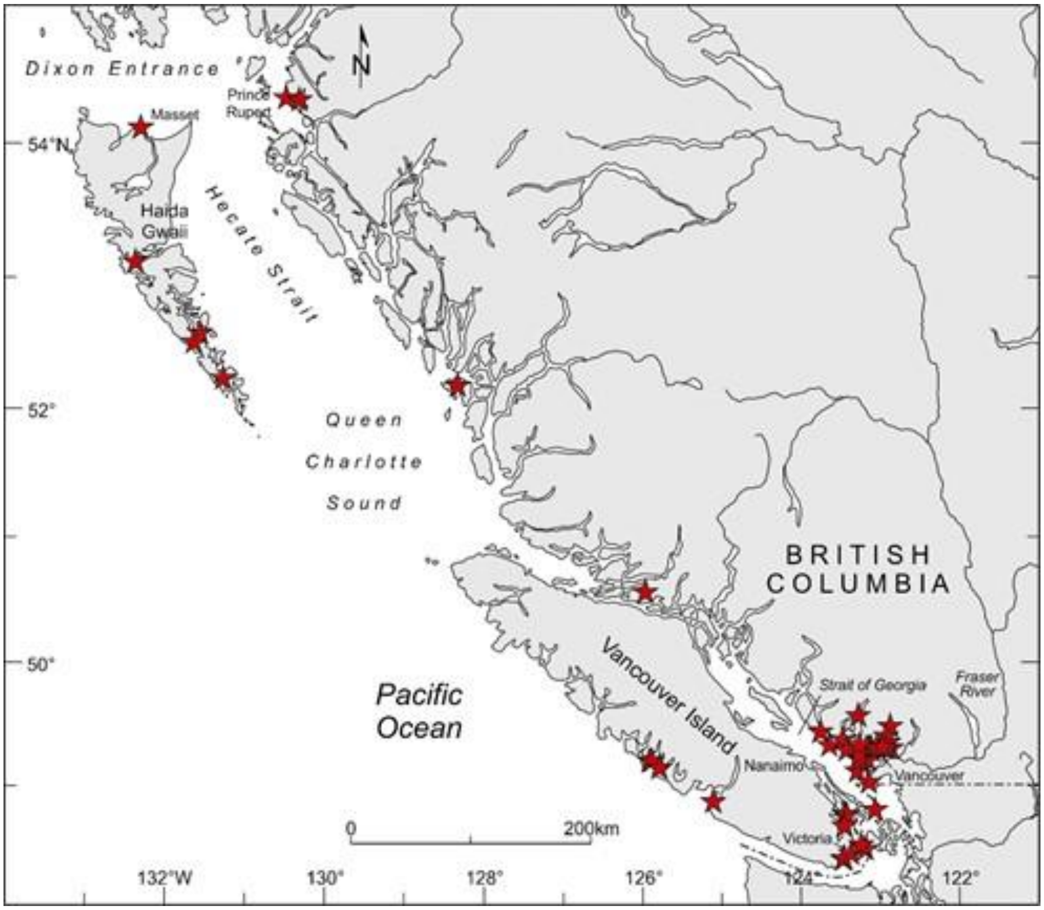

Figure 30-1. Fifty-five sites were sampled during Phase 1 (2015-2017).

Figure 30-2. Sediment samples are collected using a petite ponar grab (left), while mussel samples are collected by hand (right).

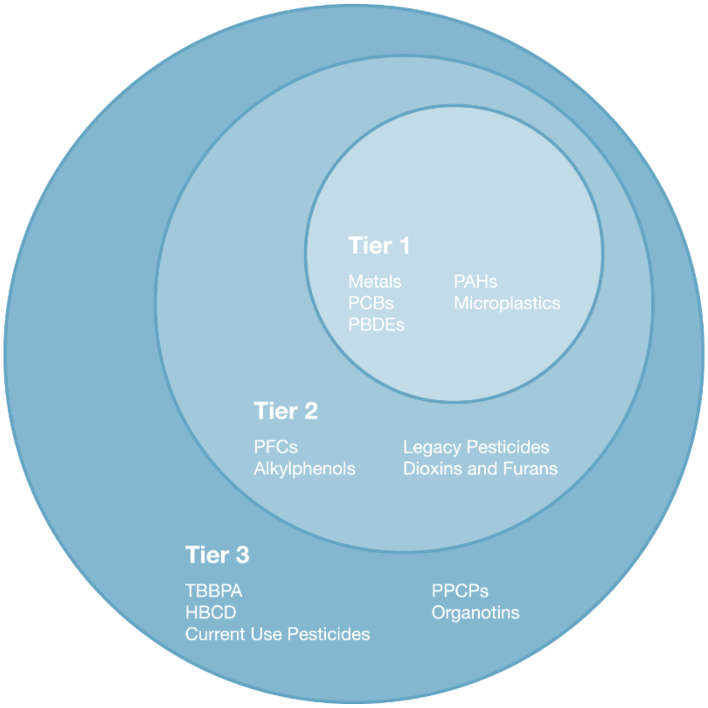

Figure 30-3. Levels of laboratory analysis, where 'Tier 3' includes all 14 contaminant classes.

All samples were submitted to the same laboratories for high-resolution analyses. Samples were analyzed for up to 14 general contaminant classes, with a full analysis consisting of over 400 individual chemicals (Figure 30-3). The level of analysis was contingent on the availability of funding, the interests of partners, and the sampling intensity in a given region.

30.4. Phase 1 results

During Phase 1, both current-use and legacy (i.e. no longer in use) contaminants of concern were measured in samples along the B.C. coast. The pollutants detected in Phase 1 samples are a reflection of a variety of sources, including local urban and industrial inputs to the oceans (e.g. wastewater and effluent discharges, road run-off, storm-water inputs, shipping activities, pesticide use), external inputs (e.g. contaminants carried from other places via oceanic and atmospheric transport), and oceanographic factors (e.g. currents, water depth, bottom substrate). A full summary of Phase 1 results is provided at www.pollutiontracker.org.

In general, total pollutant levels were highest in industrialized and port areas (e.g. Victoria Harbour), where past and/or present inputs are relatively high, and/or the receiving environment is susceptible to accumulation (e.g. low circulation and flushing).

Pollutants known to bioaccumulate in marine food webs, such as polychlorinated biphenyls (PCBs) and polybrominated diphenylethers (PBDEs) were found coast-wide, despite the presence of regulations banning their use. Given that B.C.'s killer whales are among the most PCB-contaminated marine mammals in the world (Ross et al. 2000, Hickie et al. 2007), it is important that we give further attention to these persistent legacy contaminants in the ocean environment.

Dioxins/furans (PCDD/Fs) were also found in all samples. Prior to changes to pulp mill operations in 1989, PCDD/Fs were discharged to the marine environment in large volumes in coastal B.C. They continue to be released as by-products of the burning of chlorine-containing materials.

Polycyclic aromatic hydrocarbons (PAHs) were detected in all Phase 1 samples, with levels highest in industrialized and urban areas, reflecting the multitude of sources in these areas. Hydrocarbon fingerprinting, a tool that compares the signatures of hydrocarbons measured in environmental samples to the signatures of known hydrocarbon mixtures, is being used to identify the PAH sources for Phase 1 samples. We have used hydrocarbon fingerprinting previously to compare the ratios of alkyl-PAHs found in environmental samples to synthetic oil mixtures spilled into the marine environment (Morales-Caselles et al. 2017).

Current-use and emerging contaminants of concern, such as current-use pesticides and brominated flame retardants, and pharmaceuticals and personal care products, were also detected in Phase 1 samples, though their distribution was less widespread than their legacy counterparts.

Microplastics are structural pollutants consisting of plastic particles smaller than 5 mm in size. They do not readily biodegrade and are highly persistent in the marine environment. Using novel extraction and analysis techniques, we are currently using Fourier Transform Infrared Spectroscopy (FTIR) to identify the microplastic particles found in Phase 1 *PollutionTracker* samples.

30.5. What's next?

More detailed analysis of Phase 1 results related to contaminant sources and distributions (e.g. hydrocarbon fingerprinting analysis) will be conducted in 2018.

Phase 2 will build on Phase 1 results at dedicated *PollutionTracker* sites, expand the project's spatial coverage, and continue to lay the foundation for a coast-wide temporal trend analysis.

30.6. References

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Morales-Caselles, C., Yunker, M.B., and Ross, P.S. 2017. Identification of spilled oil from the MV Marathassa (Vancouver, Canada 2015) using alkyl PAH isomer ratios. Arch. Environ. Contam. Toxicol. 73(1): 118-130.

Ross, P.S., Ellis, G.M., Ikonomou, M.G., Barrett-Lennard, L.G., and Addison, R.F. 2000. High PCB concentrations in free-ranging Pacific killer whales, *Orcinus orca*: effects of age, sex and dietary preferences. Mar. Poll. Bull. 40: 504-515.

31. UNUSUAL EVENTS IN CANADA'S PACIFIC MARINE WATERS IN 2017

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31.1. Highlights

- Unusual events occur in Canada's Pacific marine waters every year but are often not reported on or related to the broader environmental context.
- In 2017, Pyrosomes continue to be found in huge numbers (Figure 31-1). Northern Anchovy also continue to be very abundant in the Strait of Georgia.

31.2. Description of the time series

Every year, unusual marine events occur in the Northeast Pacific. 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.

This report presents a selection of unusual events in Canada's Pacific waters in 2017 that were reported to DFO throughout 2017 (Table 31-1). The observations were presented in a poster at the State of the Pacific Ocean meeting in March 2018. Participants at the meeting (Appendix 2) were also asked to contribute any additional observations of unusual events from 2017 (Table 31-2). Some of these events are also discussed in more detail in the other individual reports, whereas other observations may not be presented in detail or at all.

Figure 31-1. Biological field technician Alaina Dowling sorting through a trawl catch of primarily pyrosomes while on board the vessel Nordic Pearl *in spring 2017. Photo by Linnea Flostrand.*

31.3. Status and trends

The most widely observed unusual event in 2017 was the explosion of the pyrosome *Pyrosoma altanticum* along the coast of B.C. Large masses of these gelatinous animals were first reported in October of 2016 (Galbraith and Young 2017) and continued to be observed along the west coast of North America through 2017 (Perry et al. 2017, Perry et al. 2018, Grupe and Norgard 2018, Galbraith and Young 2018, Brodeur et al. 2018).

Northern Anchovy continued to be abundant in the Strait of Georgia (SoG; Table 31-1). The SoG anchovy catch was historically small but the species has been found in large numbers since 2015 (Neville 2017).

Unusual species sightings included a Swordfish on the B.C. continental shelf (Table 31-1; Halpin et al. 2018) and a Black-footed albatross on La Perouse Bank (Table 31-1). During summer 2017 surveys of the Offshore Pacific Area of Interest, observations of numbers of sharks were well above normal and other rare species recorded were a basking shark, false killer whales, bottlenose dolphins, and northern right whale dolphins (Grupe and Norgard 2018).

Table 31-1. Observations of weird, wonderful and/or unusual marine events observed by or reported to DFO during 2017.

Event	**Where**	**When**	**Reported by**	**Details**
Widespread pyrosome bloom	NW coast of North America	Winter 2016 to summer 2017	Many scientists, e.g. Brodeur et al. (2018)	
Large numbers of dead/dying krill (*Thysanoessa raschii*) washing up on beaches	NW coast of North America	May, June 2017	Moira Galbraith, Jeff Aitken	 Photo: Jeff Aitken
Swordfish sighting	BC continental shelf just north of Cape Scott	Sept. 2017	Halpin et al. (2018)	Water temperature was18 C. Individual was estimated 3.5-4 meters in length.
Black-footed albatross	La Perouse	Sept. 6, 2017	Luke Halpin	Individual was banded on Tern Island (northwest Hawaiian Islands) in 1998.
High proportion of sets with Northern Anchovy	Strait of Georgia	Fall 2017	Scientists on juvenile herring survey	

Table 31-2. Observations of weird, wonderful and/or unusual marine events reported at the State of the Ocean meeting in March 2018..

Event	Where	When	Reported by	(Brief) Details
Pink Salmon in the Atlantic (not Pacific but maybe relevant)	Pink Salmon introduced by Russia in north slope rivers colonized by Norway in the past 20 years. In 2017, Pink Salmon from these introductions were reported in Britain, Newfoundland and Iceland, as well as the Clyde River (Baffin Island).		Jim Irvine	 **Pink salmon caught in N.L. likely from Russian stocking program** Pink salmon, native to Pacific areas, caught in Cartwright and Gander River recently Geoff Bartlett · CBC News · Posted: Sep 20, 2017 9:39 AM NT | Last Updated: September 20, 2017 Reported in the popular press, e.g. CBC News (Bartlett 2017)
Very high abundance of juvenile blackcod caught in prawn traps	Nootka Sound	April 2017	Kiley McFarlen	Observed by commercial prawn fishermen
Biggest oyster settlement since 1950s	Ladysmith Harbour	Spring 2016	Scott Akenhead	Intertidal rocks now covered by one and two year old oysters. Possible reasons suggested include escape from predation as a result of starfish wasting disease and warm water in 2015.
Highest water level on record (1910-2017) for the month of April (after stats quality control)	Victoria Harbour	Apr. 2017	Anne Ballantyne	
Ucluelet storm and rockfish strandings	West coast of Vancouver Island	Jan. 18, 2018	Dana Haggarty and Miriam O	Many inshore rockfishes and invertebrates washed ashore in high storm waves.

31.4. Factors influencing trends

Potential factors influencing these events include a changing climate, natural population explosions and anthropogenic pressures. Disease is a potential factor causing mortality, but is often overlooked or difficult to assess. As the climate changes, extreme weather will continue to be a factor in affecting marine biology (e.g. January 2018 storm; increasing sea-level; Table 31-2).

It is typical of gelatinous zooplankton such as Pyrosomes to have a “boom and bust” population cycle (Galbraith and Young 2018). Brodeur et al. (2018) suggested that Pyrosomes may have been advected into the area during the warm “Blob” and El Niño years and found abundant food in the following years as temperatures transitioned back to normal.

31.5. References

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

32. RIVERS INLET WATER PROPERTIES IN 2017 COMPARED TO A 1951 TO 2017 TIME SERIES

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32.1. Highlights

- A time series of temperature, salinity, pressure and oxygen from 1951 to present has been constructed.
- The time series includes data collected by the University of British Columbia, Fisheries and Oceans Canada and the Hakai Institute.
- Four water types were defined based on isopycnals.
- Deep water was 0.4 to 0.5 °C warmer than the long-term average, greater than the standard deviation, throughout 2017.

32.2. Introduction

Rivers Inlet is a fjord located on British Columbia’s central coast (Figure 32-1) that is about 45 km long and 3 km wide. At the mouth of Rivers Inlet is a sill that is approximately 137 m deep at low tide (Pickard 1961), which deepens to a basin that is about 340 m deep that shoals towards the head of the inlet. Stations DFO1, DFO2, DFO3, and DFO4 are located in the basin and station DFO5, is located on the slope near the head of the inlet.

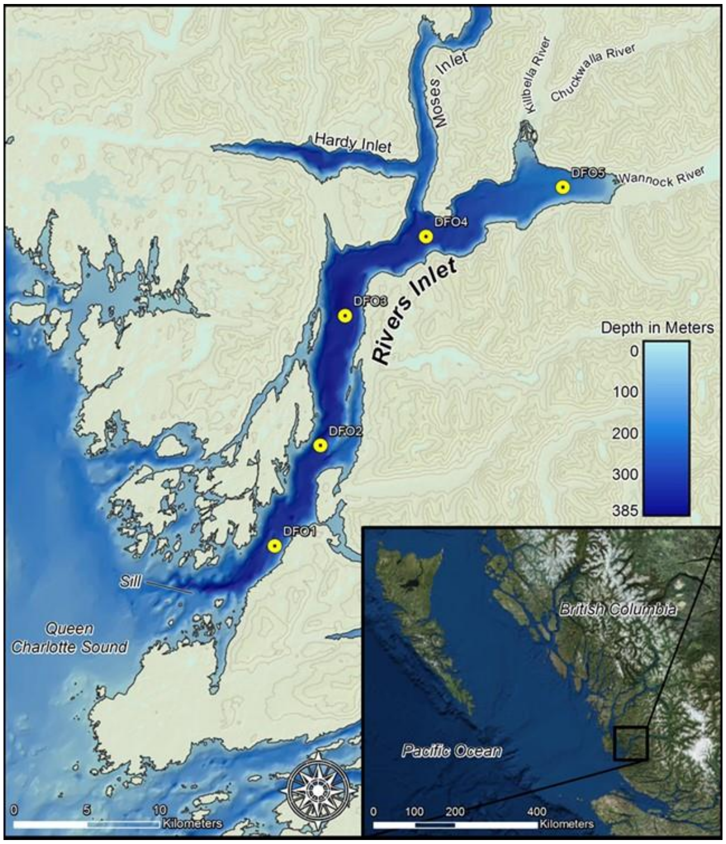

Figure 32-1. Bathymetric map of Rivers Inlet, located on British Columbia’s central coast. The five stations with historic data are labeled with yellow circles.

Once home to the third largest Sockeye Salmon run in British Columbia, persistent low salmon abundance in the early 1990s led to a closure of the commercial fishery in 1996 that has not yet re-opened. McKinnell et al. (2001) suggested that the decline in salmon abundance was due to poor early marine survival. Although concerted research and observation efforts since 2006 have advanced understanding of the Rivers Inlet ecosystem, these efforts do not inform dynamics over the period of salmon decline. In this regard, the availability of a long-term physical data set for Rivers Inlet provides an exceptional opportunity to examine historic changes in this ecosystem, including potential drivers of decreased salmon early marine survival, as well as place present-day inlet conditions in a long-term context.

32.3. Description of the time series

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

From 1951 to 1987 and from 2008 to 2010, the University of British Columbia collected data. From 1990 to present, Fisheries and Oceans Canada have collected data. From 2013 to present, the Hakai Institute has collected data. To date, 626 temperature and salinity profiles and 436 oxygen profiles have been collected in Rivers Inlet, with more than 90% of the data collected since 1998.

Four water types were defined based on potential density; isopycnals within a water type have coherent vertical displacement. These water types were surface (potential density relative to surface pressure of less than 1022 kg/m^3), near-surface (1022.5 to 1024 kg/m^3), intermediate (1024 to 1025.5 kg/m^3) and deep (greater than 1025.5 kg/m^3). There is significant seasonal variation in all water types, which normally dwarfs interannual variation. To compare 2017 to the long-term time series, first a monthly average of temperature, salinity and oxygen using all data from 1951 to 2017 was calculated for all water types. Then the monthly average from 2017 was calculated.

The monthly average salinity (Figure 32-2 top-left) showed a clear seasonal, statistically significant cycle in surface and deep water. A seasonal cycle was considered statistically significant when 1951 to 2017 standard deviation was less than the average difference between months for the same time period. Near-surface and intermediate water were variable, with no clear seasonal cycle. In 2017, surface water was saltier than average in June and fresher than average in February and August through October; near-surface water was fresher than average in June and July; intermediate water was saltier than average in July through October; and deep water was saltier than average in February through July.

The monthly average temperature (Figure 32-2 top-right) showed a statistically significant seasonal cycle in surface, near-surface and intermediate water. Deep water was variable, with no statistically significant seasonal cycle. In 2017, surface water was colder than average in February and warmer than average in August; near-surface and intermediate water were close to the average temperature; and deep water was about 0.4 to 0.5 °C warmer than the monthly average, a difference greater than the 1951 to 2017 standard deviation, in all months.

The monthly average oxygen (Figure 32-2 bottom-left) showed a statistically significant seasonal cycle in all water types. In general, oxygen concentrations were highest in spring and lowest in September or October. In 2017, oxygen was higher than average in all water types in February and March and about average during the rest of the year.

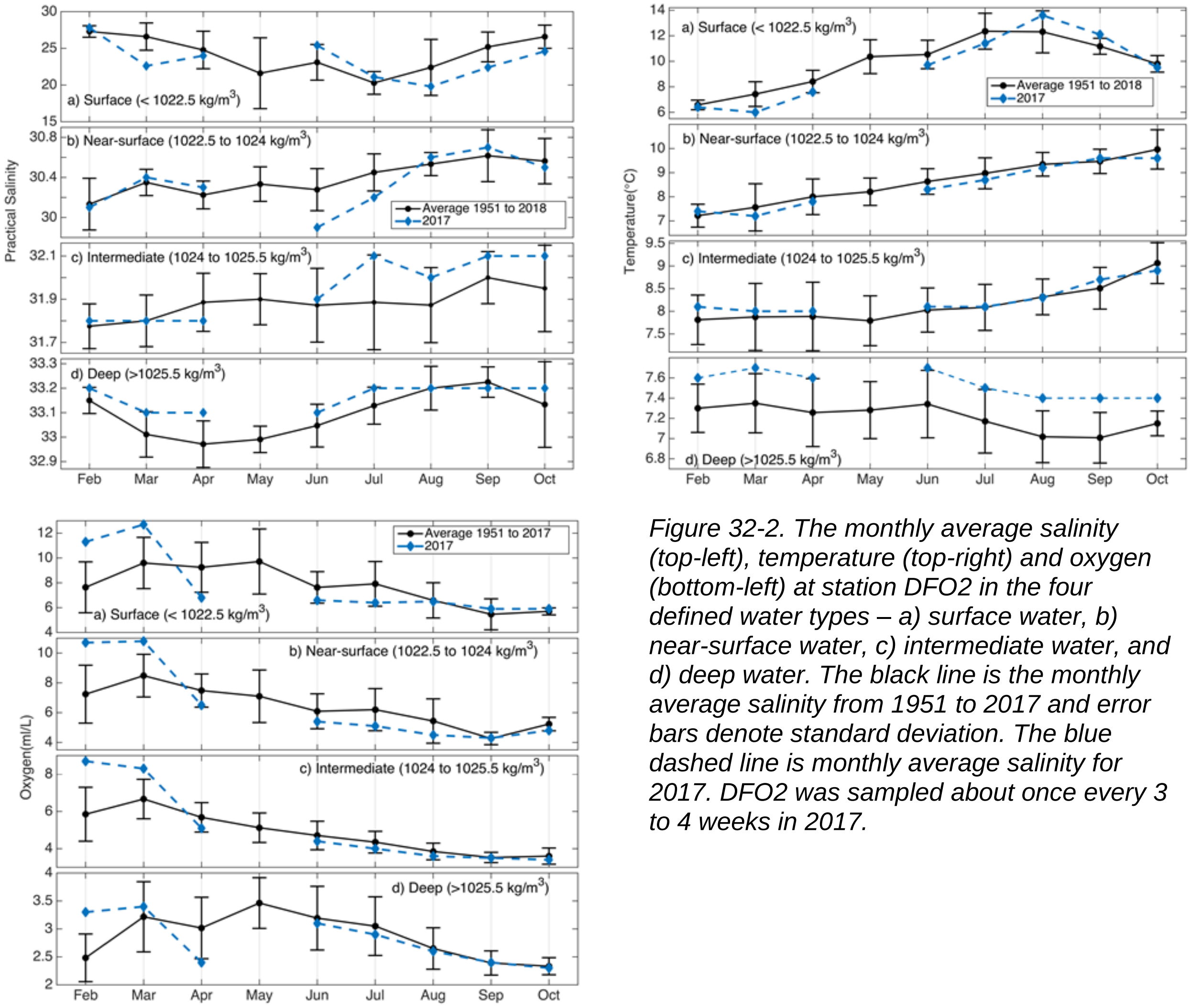

Figure 32-2. The monthly average salinity (top-left), temperature (top-right) and oxygen (bottom-left) at station DFO2 in the four defined water types – a) surface water, b) near-surface water, c) intermediate water, and d) deep water. The black line is the monthly average salinity from 1951 to 2017 and error bars denote standard deviation. The blue dashed line is monthly average salinity for 2017. DFO2 was sampled about once every 3 to 4 weeks in 2017.

32.4. Factors influencing 2017 inlet conditions

The most persistent anomaly observed in 2017 in Rivers Inlet was the temperature of deep water, which was 0.4 to 0.5 °C warmer than average from at least February to October. Deep water is renewed about once a year in summer (Hodal 2011), likely driven by upwelling-favourable winds. These results suggest that either the source of the deep water has changed or the property of the upwelled water has changed. Since neither oxygen nor salinity were anomalous during the upwelling season, it is possible that the warmer deep water was linked to the marine heatwave observed throughout the Northeast Pacific in 2014 to 2016 (Di Lorenzo and Mantua 2016). Since the marine heatwave has dissipated (Ross 2018), it is expected that deep waters in Rivers Inlet should cool in the coming year.

32.5. Implications 2017 inlet conditions

In both 2015 and 2016 the anomalously warm ocean conditions experienced on the coast of British Columbia were associated with an influx of southern copepod species and an abundance of other warm water taxa. The high deep-water temperatures observed in Rivers Inlet in 2017 indicated that Central Coast mainland fjords were similarly impacted. The warm water associated zooplankton communities are known to be lipid poor and hence of poor quality as prey for juvenile salmon and forage fish. Therefore, the 2017 inlet conditions were likely associated with reduced salmon growth during the 2017 outmigration. A second potential impact of the marine heat wave is that elevated deep-water temperatures during the winter months may significantly increase the basal metabolism of large northern copepod species that undergo winter dormancy, reducing the reproductive output of these key prey species the following spring.

32.6. References

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33. TEMPERATURE AND SALINITY OBSERVATIONS IN THE STRAIT OF GEORGIA AND JUAN DE FUCA STRAIT IN 2017

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33.1. Highlights

- The warmer than normal temperatures observed throughout the region over the past few years have diminished in most areas to levels consistent with the 1999-2017 climatology.
- Conditions in the central Strait of Georgia (near Nanoose) showed a return to winter cooling that had been absent since 2014. The depth averaged temperatures continue to be higher than the long-term average. Salinities in the upper 200 m were fresher during the spring and summer.
- The annual Fraser River discharge was near the 100 year normal; there was a larger than normal discharge in late June/early July reflected in a lower than normal salinity in the central Strait of Georgia.

33.2. Description of the Time Series

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 2017. The first is profile data collected with a SeaBird 911 CTD during the Strait of Georgia water properties survey (Figure 33-1). In 2017 surveys were carried out in mid-April, mid-June, and early October. The second dataset is provided by the Department of National Defence from the 68 temperature and salinity profiles collected in 2017 with a SeaBird 19 CTD at its Maritime Experimental and Test Range (CFMETR) near Nanoose. Data from both sources collected since 1999 are used to calculate long-term averages and identify the 2017 anomalies from these average conditions.

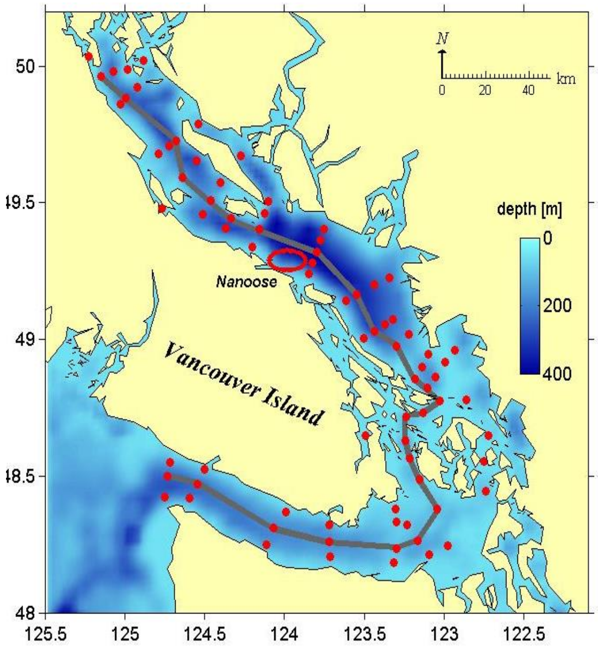

Figure 33-1. Red dots show the locations of 79 stations sampled during the water properties survey in April, June and October. The thalweg is shown as the grey line joining the deepest stations along the centreline of the survey. The red ellipse marks the area where depth profiles of temperature and salinity are collected at the Canadian Forces Maritime Experimental and Test Range (CFMETR).

33.3. Status and trends

Observations of temperature and salinity made in 2017 are compared to the 1999-2017 averages and shown as anomalies in Figure 33-2 and Figure 33-3. After recent years of above normal temperatures the surface waters have cooled but the deeper waters remain warmer than normal. In general the salinity of the region in 2017 is slightly fresher than the climatology, with a pronounced reduced surface salinity in the central Strait in summer.

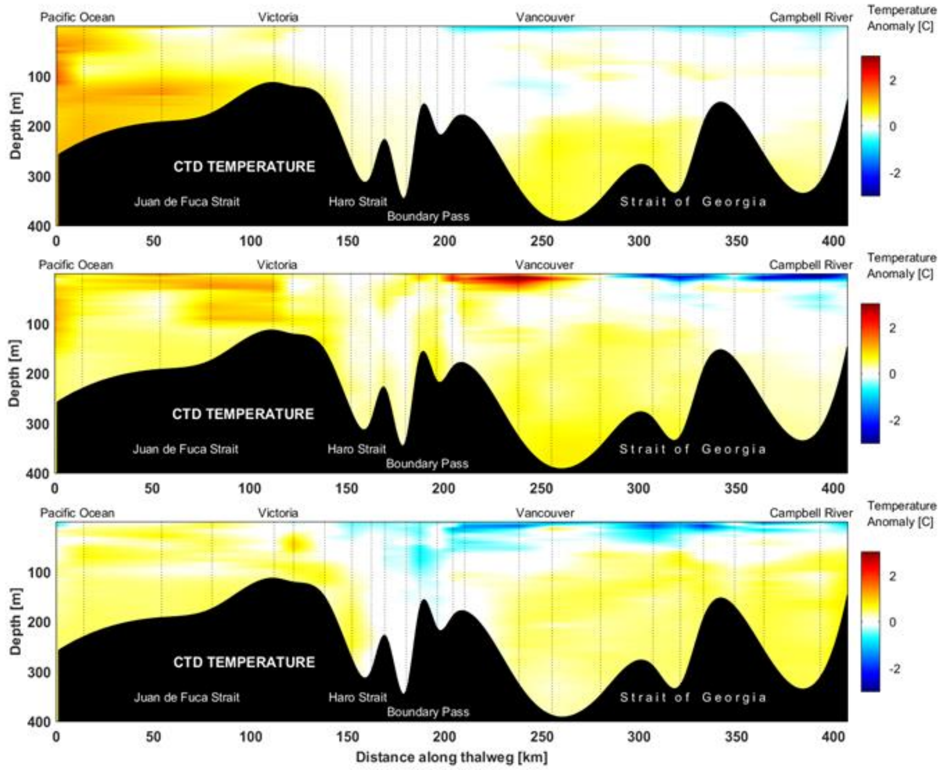

Figure 33-2. Temperature anomalies along the thalweg observed in spring (upper), summer (centre), and autumn(lower) in 2017.

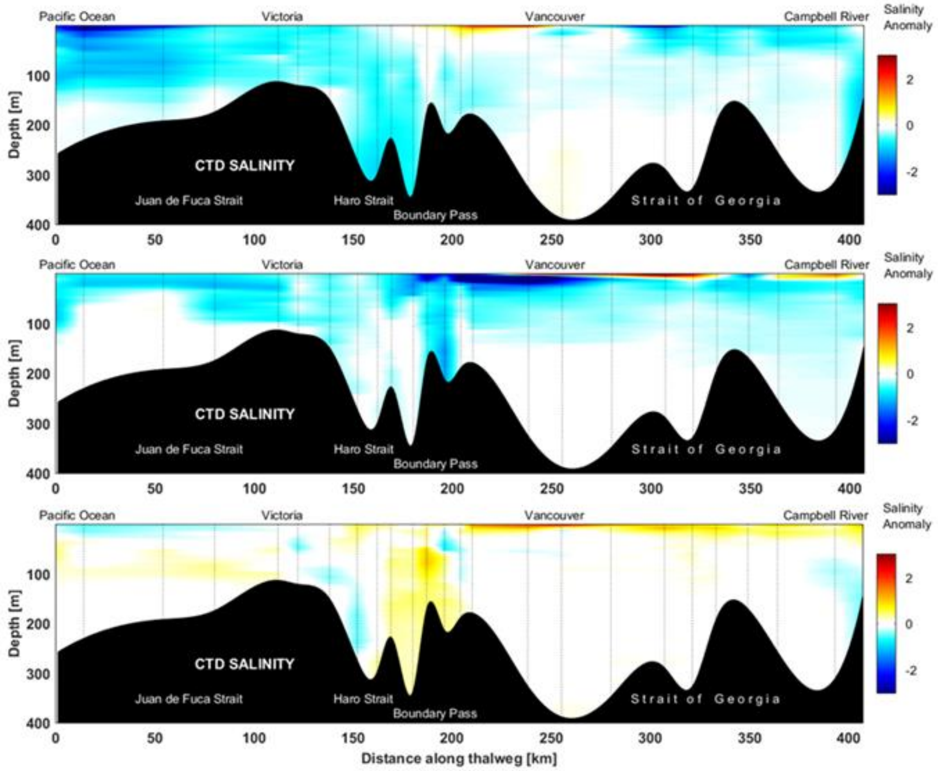

Figure 33-3. Salinity anomalies along the thalweg observed in spring (upper), summer (centre), and autumn(lower) in 2017

The interannual variations in Nanoose temperatures (Figure 33-4, upper panel) show depth averaged temperatures in 2017 at levels consistent with the long term average, and cooler than those in recent years. Comparing the 9 °C isotherm it can be seen that 2017 resembles the temperature profiles observed in 2003- 2007.

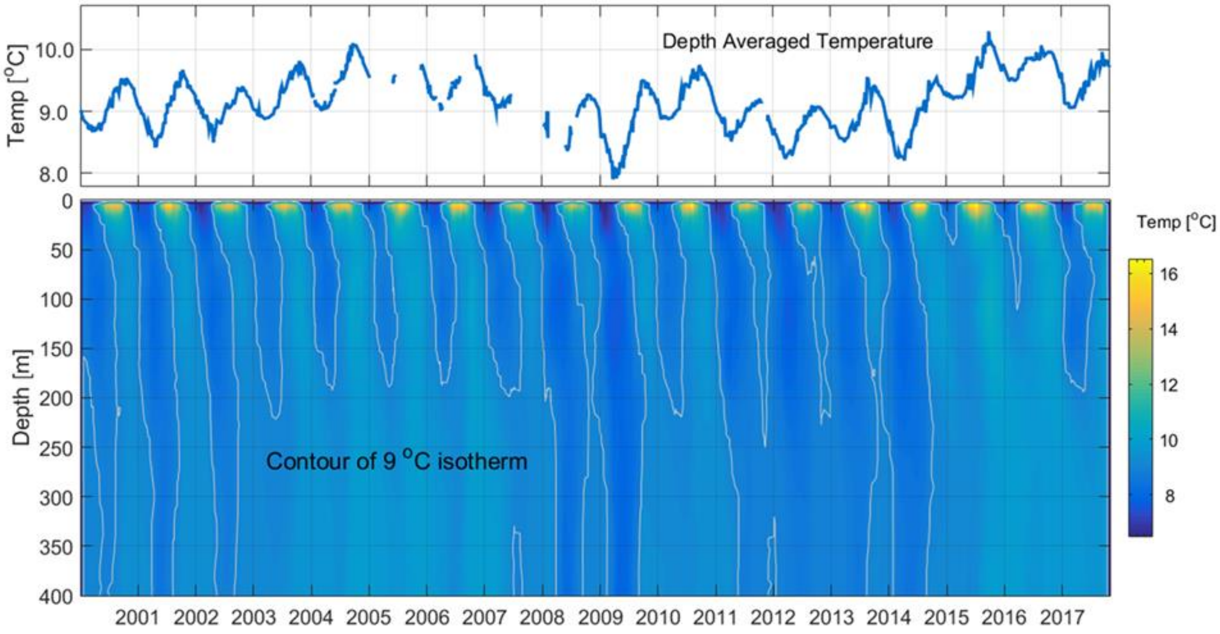

Figure 33-4. The time series of depth averaged temperature collected near Nanoose in the central Strait of Georgia (upper); the vertical distribution of these data (lower).

The influence of the Fraser River discharge is particularly evident in the salinity of the surface waters of the central and southern Strait of Georgia. While the 2017 annual discharge of the Fraser River (as measured at Hope, B.C., see Figure 33-5) was near the 100 year average there was a higher than average discharge in June that was observed as negative surface salinity anomalies (Figure 33-3).

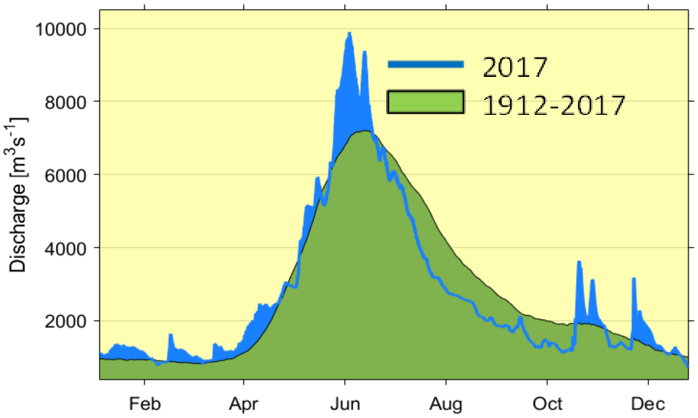

Figure 33-5. Fraser River discharge at Hope B.C.; 2017 (blue), 105 year average (green). Data source: The Water Survey of Canada).

Figure 33-6 shows the linear trend in the total volume of water discharged by the Fraser River and indicates an increase in the discharge over the past 100 years. Conditions in 2017 mark the first year since 2010 that the annual discharge has been below the long term mean. Figure 33-7 uses the same dataset to show the timing of the Fraser River discharge, specifically the day of the year when 50 percent of the annual discharge volume passes Hope, B.C. While there was significant discharge in June of 2017 the median discharge occurred later than normal due to the above normal discharge in October and November. There is a linear trend that indicates the Fraser River discharge is peaking earlier at a rate of about 1 day over 12 years.

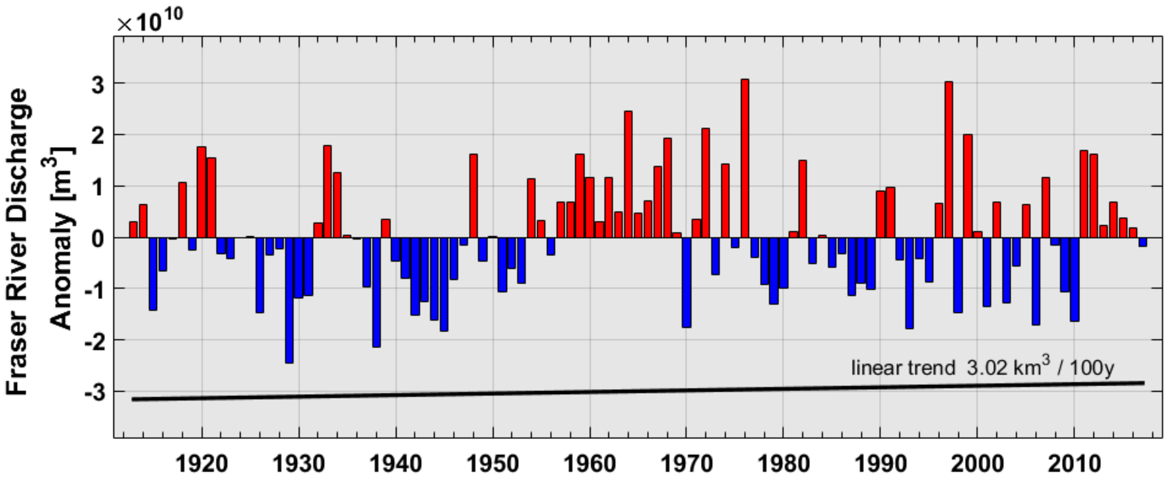

Figure 33-6. Time series of the annual volume of water discharged by the Fraser River at Hope B.C. presented as the anomaly from the long term average discharge. Data source: The Water Survey of Canada.

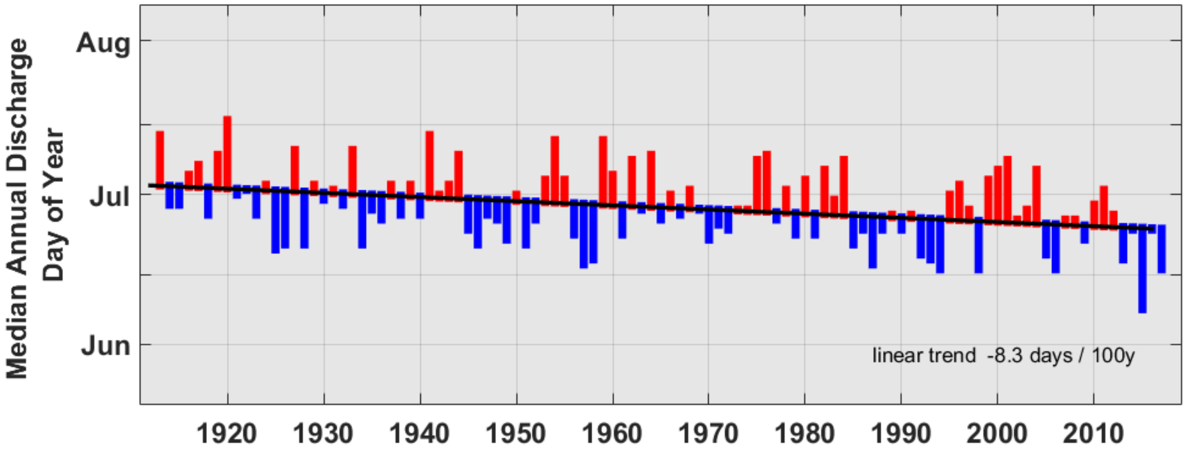

Figure 33-7. Time series of the day of year when the Fraser River discharge at Hope B.C reaches 50 percent of that year's annual discharge. Data source: The Water Survey of Canada.

34. DEEP WATER AND SEA SURFACE PROPERTIES IN THE STRAIT OF GEORGIA DURING 2017: CABLED INSTRUMENTS AND FERRIES

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34.1. Highlights

- Upwelling water at Folger Passage (97 m) was the warmest for the 8-year time series associated with slightly higher upwelling intensity.
- Limited winter (2016/17) cooling was observed at both the 170 m (East Node) and 300 m (Central Node) in the Strait of Georgia. 2017 was cooler than 2015 and 2016, but still generally warmer than average for the most of the year.
- The spring phytoplankton bloom was recorded by instrumented ferry routes in the central and southern Strait of Georgia. The bloom started outside of the Fraser River plume on March 17, followed closely by production inside the plume, and peak biomass was recorded on March 22, 2017.
- The magnitude of the 2017 spring bloom was moderate relative to the last 13 years of ferry-based measurements.

34.2. 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 (SoG; 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 $p\mathrm{CO_2}$) 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.

34.3. Status and trends

34.3.1. ONC Folger Deep:

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

The warm, fresh and oxygenated water conditions of late 2016 downwelling continued into early 2017, but the values dropped from historical extremes to closer to the time-series average (Figure 34-1). The upwelling period started a little later than the historical average in late-April (year-day 116) with a slightly higher upwelling intensity, the water was very warm/fresh relative to the time series (the warmest since 2010, Figure 34-1). The onset of downwelling associated with a rapid freshening and elevation of temperature occurred in mid-October (year-day 288), but the temperature and oxygen were lower than averages for most of the downwelling period (Figure 34-1).

34.3.2. Strait of Georgia East Instrument Platform:

Properties at the SoG East instrument platform reflect, in part, mid-water renewal to the SoG: during the 2016/17 winter, this water was cool and fresh (as expected for the season) but with frequent oscillations between high and low temperatures (±1 SD) until March. With water arriving from Strait of Juan de Fuca through deep water renewal events (Masson 2002), the temperature and salinity of this low density water increased during summer. It was cooler in 2017 compared to 2015 and 2016, but still generally warmer than average for most of the year, which suggests a continuation of warm conditions started in the late 2014 but the resumption of winter cooling after the extremely warm winter of 2016/17 (Figure 34-1). Dissolved oxygen concentrations [DO] displayed extreme oscillations between anomalously high and low concentrations from winter 2016/17 to summer 2017 (Jan-Jun), the oscillation continued from late fall into the winter of 2017 (Nov-Dec) with lower frequency (Figure 34-1).

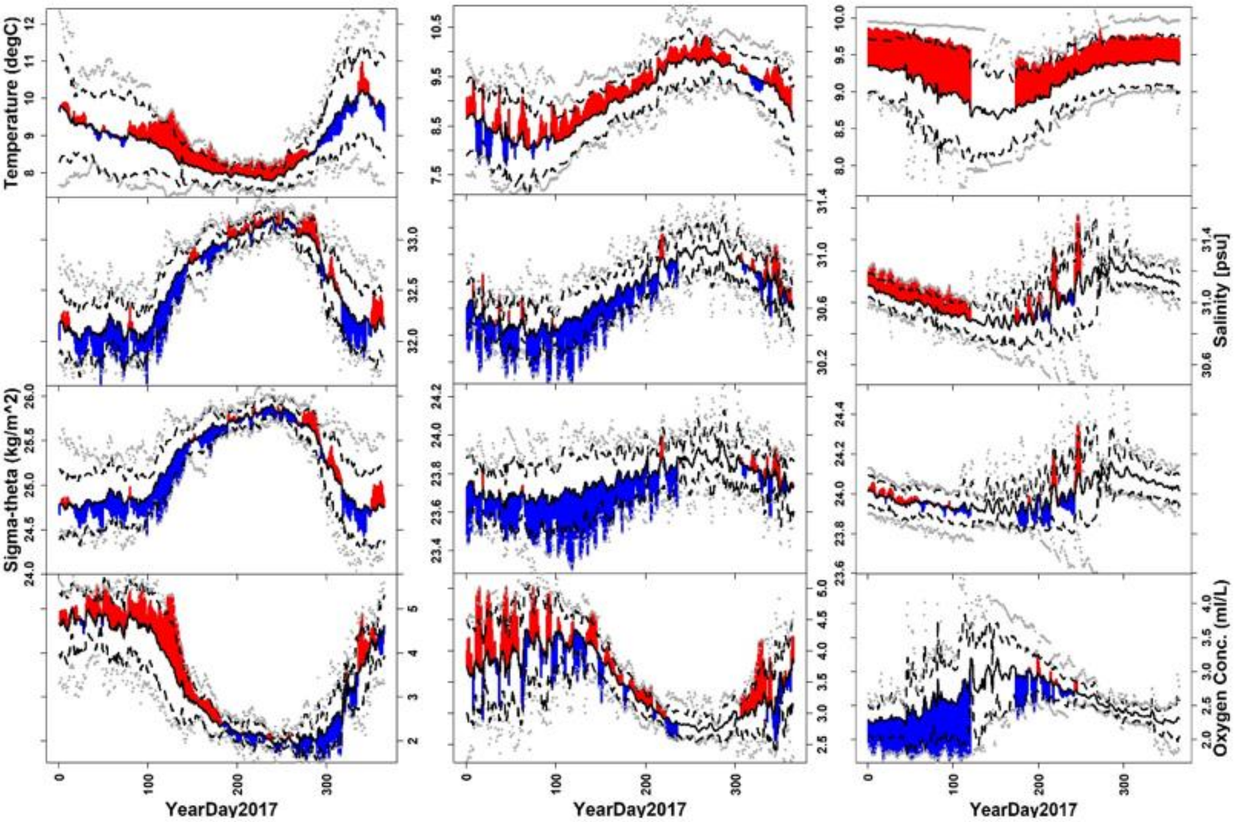

Figure 34-1. From top to bottom, mean daily temperature (°C), salinity (practical units), density (kg m^{-2}), and dissolved oxygen concentration (ml L^{-1}) for Folger Deep (left), SoG East (middle), and SoG Central (right). Red/blue bars represent values greater/less than the time series mean (solid 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.

34.3.3. Strait of Georgia Central Instrument Platform:

Similar to SoG East, winter cooling/freshening due to top-down flux and summer warming/increasing salinity, which is more closely tied to deep-water renewal events (Masson 2002), characterize the seasonal patterns in water properties. Observations from this platform were missing from April 29 to June 23 (due to instrument failure), and measurements of salinity, density and oxygen concentration were also missing from September till the end of year (plugged pump). The water in the deep basin was characterized by limited cooling during the 2016/17 winter, the temperature was slightly cooler relative to the same period in 2016, but still approximately 1 SD greater than the time series average (remaining at 9.5-10 °C) through the year with no cooler-than-average observations (Figure 34-1). The limited observations in 2017 suggested this deep water was saltier but less oxygenated than average; with both high and low extremes, respectively, during 2016/17 winter to spring (Jan-Apr). The low time series extremes for [DO] continued during summer 2017 (Jul-Aug, Figure 34-1).

34.3.4. 2017 Spring Bloom in the Strait of Georgia:

The start and development of the spring phytoplankton bloom in 2017 was captured by two instrumented ferries: the Queen of Alberni (central route) and the Spirit of Vancouver Island (southern route) (Figure 34-2). Phytoplankton dynamics in 2017 were similar inside and outside of Fraser River plume, spring phytoplankton bloom started out side of the Fraser River plume on March 17, followed closely by production inside the plume, and then increased rapidly to peak on March 22 (Figure 34-2b) which was one day later than the bloom peak date for 2016. In addition, the temporal patterns and magnitudes of phytoplankton biomass measured from the central route were very similar to the measurements from a fluorometer mounted on the Environment Canada weather buoy at Halibut Bank (ODAS 46146; Figure 34-2b). Relative to both the instrumented ferry time-series and the long-term mean date of March 25 (Allen and Wolfe 2013), the 2017 bloom timing was average. In terms of bloom magnitude, the 2017 spring bloom was greater in terms of biomass production than 2016, but moderate relative to the last 14 years of ferry-based measurements (Figure 34-3).

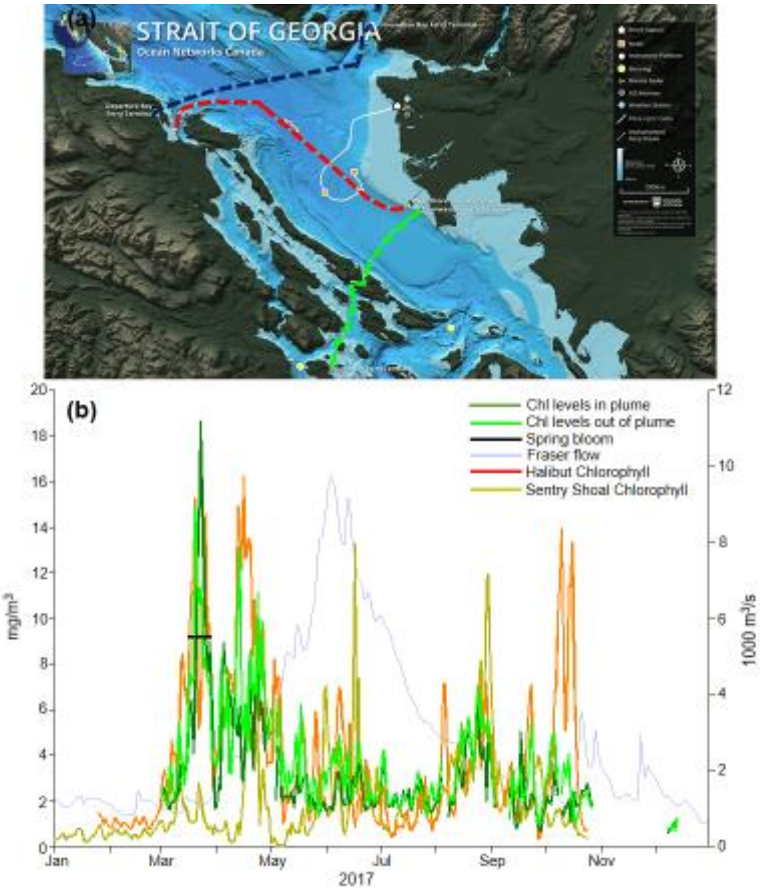

Figure 34-2. (a) Map of the central and southern Strait of Georgia indicating each of the instrumented ferry routes (coloured dashed lines; white line represents the deep-water cable connecting nodes and instrument platforms); and (b) in situ chlorophyll fluorescence (mg m^{-3}) measured at about 3m along central and southern routes and from buoys at Halibut Bank (central SoG) and Sentry Shoal (northern SoG); with colour corresponding to routes and buoys. Halibut Bank chlorophyll data were collected by S. King with funding from the Pacific Salmon Foundation.

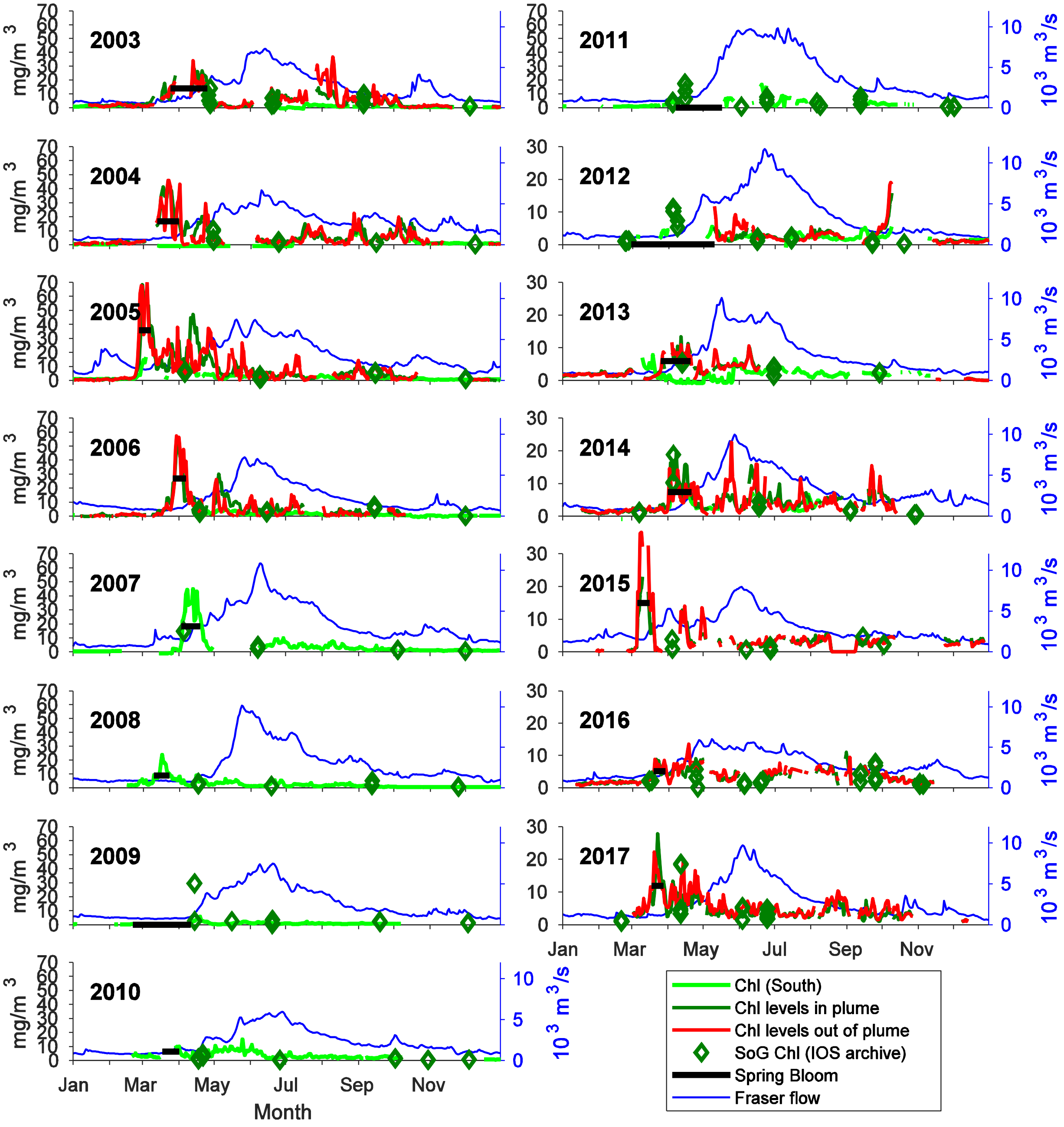

Figure 34-3. Time series of phytoplankton biomass (chlorophyll fluorescence) inside and outside of the Fraser River plume as measured from instrumented ferries transiting between Duke Point and Tsawwassen (dark green and red) and Swartz Bay and Tsawwassen (light green). Fraser River discharge (right-hand axis) is superimposed over the annual phytoplankton biomass time-series. Black lines show bloom timing (presumed in 2009, 2011 and 2012).

34.4. Factors influencing trends

Inshore deep- and intermediate water properties in the Strait of Georgia are strongly seasonal: the arrival of salty upwelled water on the shelf transiting through Juan de Fuca Strait and mixing with warm surface waters in Haro Strait cause the increasing temperature and salinity in summer water (Pawlowicz et al. 2007), while the deep mixing of local surface waters in Haro Strait/Gulf Islands cause the cooling and freshening in winter waters. 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 (Dewey et al. 2015). The anomalously warm water is thought to have transited through Juan de Fuca and mixed in Haro Strait before entering the Strait of Georgia basin. This very warm condition lasted throughout the strong El Niño years (2015-16), and then followed by seasonal winter cooling at the start of 2017 at Folger Passage Deep (more likely a consequence of the weak 2016-17 La Niña event). The warm conditions for the deep- and intermediate-depth waters of the SoG continued but to a lesser extent than 2016, suggesting limited winter cooling after 2016-17 La Niña.

The 2016 spring bloom initially started in late February under warm conditions, but several wind events disrupted and pushed a potentially early start to late March (Allen et al. 2017, Sastri et al. 2017).The 2017 spring bloom, however, started later in mid-March and grew rapidly to peak at a similar time but with higher bloom biomass production compared to 2016. In general, the 2017 spring bloom was average in timing of start and peak, short in duration, and moderate in magnitude relative to historical records.

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35. ON THE LACK OF NORTHERN SALISH SEA SUMMERTIME CO_2 OUTGASSING IN 2017

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35.1. Highlights

- Summertime wind-driven surface water pCO_2 variability was reduced in the northern Salish Sea in 2017 relative to previous years.
- Lower integrated energy transfer to the surface ocean from southward wind events and increased stratification inhibited summertime CO_2 outgassing.

35.2. Surface seawater pCO_2 time series in the northern Salish Sea

Researchers from the Hakai Institute began measuring surface water carbon dioxide partial pressure (pCO_2) in the northern Salish Sea in late 2014. This effort initiated with the installation of a CO_2 system in a flow-through setting that was capable of continuous high-speed measurements made on seawater drawn from 1 m below the surface approximately 30 m from shore in Hyacinthe Bay through a shore-side facility at the Hakai Institute's Quadra Island Field Station (QIFS; Figure 35-1). In 2016, discrete seawater sample collection began at a hydrographic station near the QIFS (QU39; 50.3007° N, 125.0992° W), and a SeaFET pH sensor was deployed on the Environment Canada Sentry Shoal weather buoy (49.92° N, 125° W) in conjunction with the Pacific Salmon Foundation's (PSF) Salish Sea Marine Survival Program. Near the end of 2017, surface pCO_2 measurement capacity was extended to the Alaska Marine Highway System M/V *Columbia* that operates on a weekly basis across the Salish Sea (Dugan et al. 2018). Therefore, the northern Salish Sea surface seawater pCO_2 time series includes data collected across four platforms.

The analytical approach used at the QIFS, as well as a regularly updated data product, is available through the Hakai Data Portal: http://dx.doi.org/10.21966/1.614670. Methods for discrete sample processing and SeaFET data handling will be presented in detail elsewhere. Briefly, discrete pCO_2 samples were processed at QIFS by headspace gas equilibration and subsequent nondispersive infrared analysis using a LI-COR LI-840A. In situ calibrated SeaFET pH data, combined with temperature and salinity data from a Sea-Bird SBE37 owned by PSF and also deployed on the Sentry Shoal mooring, was used with total alkalinity (TA) estimated from a regionally-specific TA-salinity relationship to derive seawater pCO_2.

The analysis of this time series described below incorporated wind observations from the Environment Canada Sentry Shoal weather buoy (http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/waves-vagues/data-donnees/data-donnees-eng.asp?medsid=C46131) and conductivity-temperature-depth (CTD) profiler information collected by the Hakai Institute Oceanography Program.

35.3. Status and trends

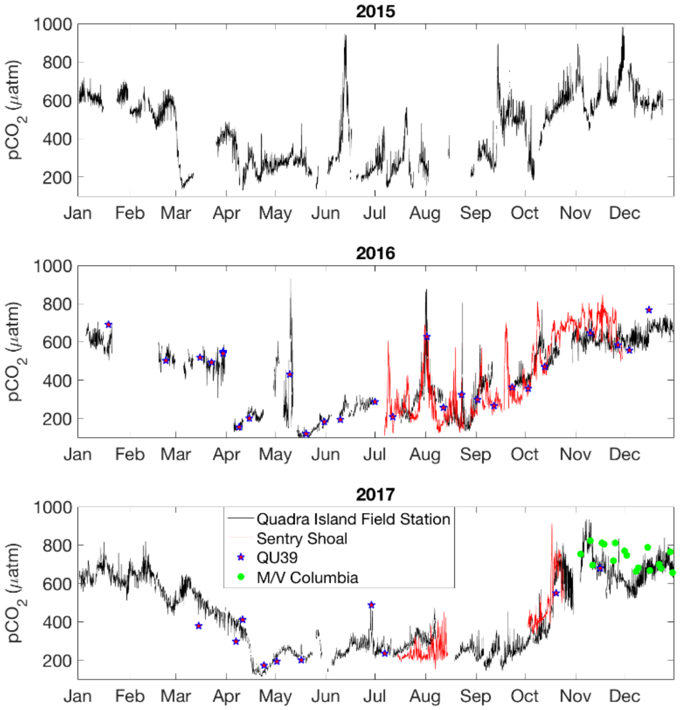

Figure 35-1. Surface seawater pCO2 in the northern Salish Sea from 2015 (top), 2016 (middle), and 2017 (bottom). Data shown were collected at the Hakai Institute's Quadra Island Field Station (black trace), the Environment Canada Sentry Shoal weather buoy (49.92°N, 125°W; red line), hydrographic station QU39 (50.3007°N, 125.0992°W; stars), and the Alaska Marine Highway System M/V Columbia (green dots).

Surface pCO$_2$ results shown here highlight a key difference that set 2017 apart from the previous northern Salish Sea surface seawater CO$_2$ observations; 2017 lacked summertime excursions to high pCO$_2$ conditions far above atmospheric levels, which were seen in previous years and supported large short-lived CO$_2$ evasion to the atmosphere (Figure 35-1; Evans and Gurney-Smith 2016, Hare et al. 2017). In 2015 and 2016, roughly week-long periods of strong (daily average > 5 m s^{-1}) southward wind speed were observed that drove mixing of the surface layer, indicated by extreme surface cooling (approximately 6 °C) and the surfacing of the 1021 kg m^{-3} isopycnal found typically at 20 m in summer months. Dissolved oxygen and pCO$_2$ changed concurrently with these conditions, with high wind speeds combined with large positive sea-air CO$_2$ gradients leading to the intense periods of CO$_2$ outgassing to the atmosphere. No summertime CO$_2$ outgassing was observed in 2017.

The question we aim to address is: were 2017 summer conditions different because of a change in wind conditions or stratification or both? Here, we attempt to address this question by assessing the balance between energy imparted on the surface ocean by the wind and the energy needed to mix the upper water column (Hauri et al. 2013).

35.4. Factors influencing trends

To compute the integrated energy input from summertime wind events into the surface ocean, we examined winds between spring and autumn transition dates that were identified by inflection points in the cumulative wind stress computed along the axis of the northern Strait of Georgia (roughly 55° rotated eastward from due south; not shown). The rate of energy transfer from the summertime winds to the water column was then computed following (Denman and Miyake 1973) and (Hauri et al. 2013):

$$\frac{\partial E}{\partial t} = \rho_a \mathrm{m} C_d u^3$$

where ρ_a is the density of air, m is an efficiency factor (~10^{-3}), and u^3 is the wind speed cubed.

The significance of an event is equal to the integrated rate of energy transfer over the duration of the event, where an event is defined as wind conditions above a threshold value. Using the observed daily average wind speeds during the 2015 and 2016 events, a threshold of 5 m s^{-1}

wind speed was used to mark the occurrence of a wind event. This wind speed threshold corresponds to a rate of energy transfer of 0.19 mJ m^{-2} s^{-1} at a mean drag coefficient of 0.00128 and an air density of 1.22 kg m^{-3}.

The integrated rate of energy transfer from the winds can then be compared with the potential energy needed to overcome stratification and mix the water column. The energy needed can be expressed in terms of potential energy needed to mix the water column given a density contrast between the upper and lower layers:

$$PE = \frac{1}{2} g h_1 h_2 (\rho_2 - \rho_1)$$

where here h_1 is the nearest surface 1 m bin of CTD data (usually 2 m) and h_2 is either the 10 m or 20 m bin, ρ_1 and ρ_2 are the corresponding seawater densities, and g is the gravitational acceleration constant. Using 2015, 2016 and 2017 QU39 CTD data, the potential energy needed to mix the upper 10 m and 20 m of the water column was computed and compared with the integrated rate of energy transfer by the winds for each wind event.

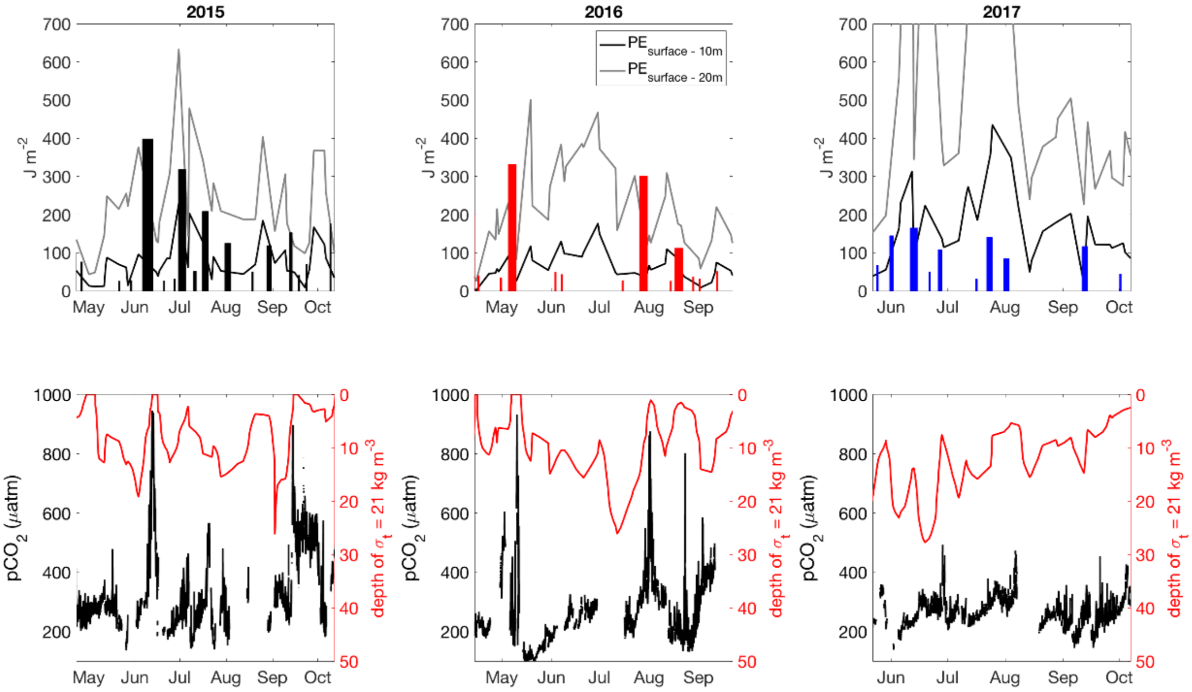

Figure 35-2. The top row is the integrated rate of energy transfer (J m^{-2}) over the duration of wind events (indicated by the thickness of the bars) between the spring and fall transitions in 2015 (black), 2016 (red), and 2017 (blue). Also shown in these panels is the potential energy needed to mix the upper water column (surface – 10 m in black, surface – 20 m in gray). The lower row is surface seawater QIFS pCO2 (black) and the depth of the 21 kg m^{-3} potential density surface (as an indication of the strength of vertical mixing). Surfacing of this density layer tends to coincide with super-saturated surface seawater pCO$_2$ with respect to the atmosphere.

During 2015 and 2016, the energy transferred to the water column during wind events surpassed the potential energy needed to mix the water column and this led to vertical mixing, high surface seawater pCO$_2$, and intense short-lived CO$_2$ outgassing to the atmosphere. In 2017, nearly twice the potential energy was needed to mix the upper 20 m than in previous years and this input was not provided during wind events. Wind events during 2017 imparted roughly 50% of the energy into the water column compared with the 2015 and 2016 events. Due to the combined impact of weaker wind events and a higher energy requirement to mix the upper water column, no CO_2 outgassing was observed in 2017. The greater potential energy needed to mix the upper water column in 2017 appeared to be due to a larger freshwater content (Proshutinsky et al. 2009) in the region compared to previous years (data not shown).

35.5. Implications of those trends

Clearly freshwater discharge impacts this setting in a number of ways, including as an amplifier for the amount of potential energy needed to mix the upper water column. This, in combination with weaker wind events, inhibited summertime CO_2 outgassing. Our focus here was on CO_2 exchange at the sea surface, but likely the more quiescent 2017 season also had implications for the phytoplankton community, by way of reduced wind-induced nutrient pulses to the sea surface, that would decrease the possibility of late season blooms with downstream impacts on the local ecosystem of the northern Salish Sea. The analysis presented here may provide a framework to asses not only CO_2 system variability but variation in ecosystem function related to wind and stratification patterns in the region.

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36. 2011 CLIMATE REGIME SHIFT REVEALED BY SEABED BIODIVERSITY

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36.1. Highlights

- A logic model based on the Oceanic Nino Index identified 1989, 1999 and 2011 as regime shifts.
- Seabed taxa show patterns of increased or decreased abundance that correspond to periods between regime shifts.
- pH data at the Vancouver Aquarium intake have been at a low plateau since the 2011 regime shift.

36.2. Description of the time series

We here define a climate regime shift as starting in the year of the end of the first La Niña closely paired with an El Niño by $\leq$2 months separation, where anomalies for both El Niño and La Niña exceed 1.0 on the Oceanic Nino Index (ONI) scale for five months or longer (available from tinyurl.com/ENSONOAA).

Using search programs for a long-term SCUBA taxonomic database (3,865 dives) for Strait of Georgia seabed sites (Lamb et al. 2011), 1,077 taxa were screened to select 23 rare or highly abundant taxa and to present the data according to the three most recent climate regime periods as defined above (Table 36-1).

Intake seawater pH is recorded for seawater pumped from 10 m below zero tide in a turbulently mixed outer sill (First Narrows) of Burrard Inlet. This intake location is shallower and more mixed than for other regular seawater sampling stations. Annual minimum and maximum pH levels were tabulated for graphing only when at least five measures at that level were recorded on different dates in a year (Figure 36-1).

36.3. Status and trends

No overall pattern exists in terms of species increasing or decreasing in abundance at climate regime shifts, but some rare taxa were entirely undetected during particular climate regimes. For the most abundant taxa, patterns of increased or decreased abundance correspond to the years defining climate regimes. Various echinoderm species increased in abundance during the millennial climate regime of 1999-2010 (Table 36-1). The sunflower star *Pycnopodia helianthoides* increased in abundance during the Millennial climate regime and then decreased after the 2011 regime shift. It was in 2013 that their numbers collapsed coincident with a seastar wasting disease (Schultz et al. 2016), and then the green urchin *Strongylocentrotus droebachiensis* increased to unprecedented abundance in absence of the key sunflower star predator (Table 36-1).

Table 36-1. Average abundance (numbers per dive) in the Strait of Georgia for selected species, with climate regimes (1989-1998, 1999-2010, 2011-2017) indicated by gray versus white shading. H. sitchensis = Heptacarpus sitchensis; Pandalus steno. = Pandalus stenolepis; Strong. droebach. = Strongylocentrotus droebachiensis; Hex. decagrammus = Hexagrammos decagrammus. Asterisk means trace, period means zero level.

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
No. Dives per Year	52	58	59	56	109	119	102	122	122	115	110	97	93	112	140	126	136	188	99	191	124	105	84	107	171	102	182	134	122
Mollusca																													
Cryptobranchia concentrica	.	.	.	.	.	.	.	.	.	.	.	1	1	*	*	*	*	2	11	6	*	*	*	*	*	*	*	1	1
Epitonium indianorum	.	.	.	*	*	*	.	*	.	*	*	*	*	*	*	.	.	*	*	*	*	*	.	.	.	.	.	.	.
Trichotropsis cancellata	*	2	2	5	32	11	12	10	1	1	2	4	1	2	8	*	2	2	1	*	*	*	*	1	1	*	1	1	*
Janolus fuscus	*	52	1	2	1	1	*	*	*	*	1	1	1	*	1	1	*	.	*	*	*	*	*	*	*	*	*	*	*
Hermissenda crassicornis	*	17	3	1	4	5	11	10	*	1	1	14	1	10	2	25	8	12	15	13	49	1	2	39	2	2	1	23	2
Flabellina verrucosa	.	1	34	.	13	29	13	*	9	*	2	32	11	*	1	*	*	*	*	17	6	2	.	*	1	.	*	*	*
Arthropoda																													
Heptacarpus kincaidi	*	*	.	.	*	*	*	*	*	1	1	2	2	1	1	2	1	1	*	1	1	1	*	*	1	.	*	1	*
Heptacarpus sitchensis	.	.	.	.	*	*	*	*	*	*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Hippolyte clarki	.	.	51	.	2	1	*	.	.	.	*	*	*	.	.	.	7	*	.	.	*	.	.	.	.	.	.	.	.
Pandalus stenolepis	*	1	1	*	2	10	1	10	10	20	4	24	15	2	1	2	42	3	5	12	3	14	4	1	7	.	2	3	11
Echinodermata																													
Dermasterias imbricata	*	3	21	9	4	7	25	6	3	2	6	7	8	9	5	14	4	22	11	16	21	12	15	11	11	20	32	19	8
Pycnopodia helianthoides	5	23	6	5	34	8	16	15	7	7	27	45	84	114	142	110	262	32	25	45	56	48	60	53	37	9	2	1	1
Ophiura luetkenii	.	18	17	*	42	30	2	2	19	3	23	58	62	115	113	182	221	193	216	187	327	190	44	40	39	90	35	11	38
Florometra serratissima	.	1	.	1	39	2	4	34	4	4	49	45	16	51	118	32	55	75	191	179	91	139	56	16	18	37	45	27	6
Strongylocentrotus droebachiensis	3	21	21	20	53	37	12	28	119	150	85	184	82	159	92	136	56	20	33	78	197	293	97	82	134	347	581	599	462
Urochordata																													
Styela gibbsii	*	21	2	4	30	19	11	2	9	1	65	4	38	39	5	28	1	2	64	38	1	24	5	1	2	1	1	1	2
Boltenia villosa	*	3	2	4	15	21	34	29	37	30	42	19	42	53	40	22	5	7	60	27	5	10	6	5	9	4	2	5	2
Metandrocarpa taylori	19	210	20	204	133	33	86	29	19	19	58	97	35	12	31	2	17	29	13	36	37	3	4	13	3	1	1	1	*
Didemnum/Trididemnum complex	.	.	.	.	.	.	*	25	.	.	10	12	1	9	15	8	1	8	52	22	37	25	5	3	1	*	*	2	*
Chordata																													
Sebastes maliger	25	3	4	26	23	3	6	4	4	2	7	7	11	6	30	27	59	20	33	30	43	32	13	18	8	3	12	3	4
Sebastes emphaeus	59	1	107	94	107	30	2	92	11	11	3	53	23	11	17	20	5	19	15	20	18	2	27	4	2	*	1	2	2
Hexagrammos decagrammus	*	4	7	6	8	6	6	5	6	2	6	10	16	12	10	9	10	9	9	15	27	30	15	19	8	5	4	3	1
Jordania zonope	22	8	27	14	29	60	4	3	1	1	4	5	6	14	5	4	12	5	6	17	24	31	7	10	7	2	3	3	2

At the 2015 State of the Pacific Ocean meeting, ocean acidification data were presented for the Vancouver Aquarium seawater intake and it was suggested that acidification appears to occur as a step function following climate regime shifts, of which 2011 thereby appears to be a regime shift (Marliave et al. 2015). A preliminary update of acidification data suggests that a new, lower plateau level of pH may be occurring after the large flux associated with the 2011 regime shift (Figure 36-1). Seawater showed a stable plateau modal value of about 7.9 from 1968-1978, then stabilized at a plateau value of about 7.7 from 1984-1997, then fluctuated from 1999-2001, stabilizing at just below 7.7 from 2004-2010, then fluctuated from 2011-2013 and may be stabilizing again at just below 7.7. Thus, 1999 and 2011 regime shifts, mark the start time of major fluctuations in pH.

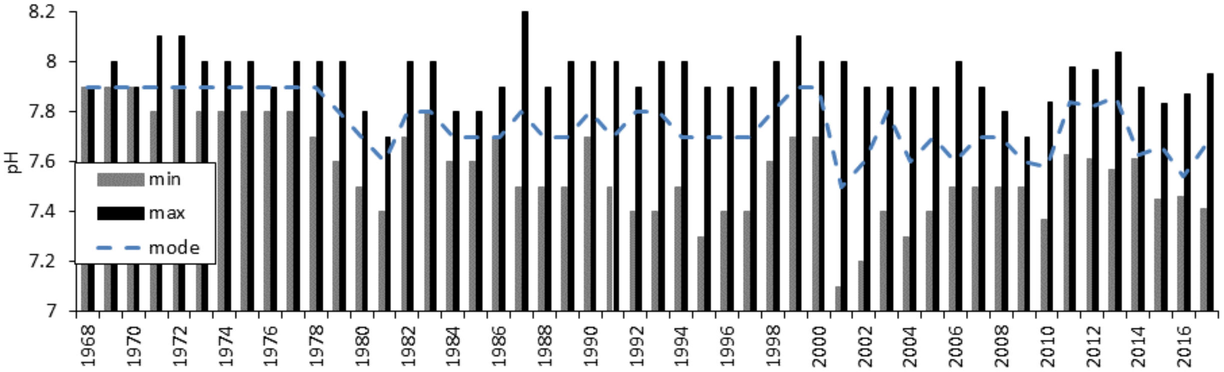

Figure 36-1. pH data for Vancouver Aquarium seawater intake, 1968-2017, with min, max and mode indicated.

36.4. Factors influencing trends

This logic model defined 1989, 1999 and 2011 as regime shifts but failed to identify 1977 as a regime shift (1974 would be indicated). A possible reason for the logic model failing for 1977 would be that the El Niño of 1972/73 was immediately preceded by an intense La Niña of 1970/71, so that La Niña conditions predominated from 1970 through 1976. There are no other climate regime shifts indicated by this model in the 67 years of the ONI database.

Hamlington et al. (2016) have indicated from satellite altimetry data that the strong La Niña of 2010/11 corresponded to a peak in their principal component time series, similar to the peak for the end of the 1998/99 La Niña. Therefore, sea level and ocean acidification trends correspond to the timing of shifts in seabed taxon abundances at climate regime shifts in accordance with this current definition for ONI climate regimes.

36.5. Implications of those trends

The biodiversity shifts that coincide with climate regime shifts do not suggest any component of global warming in terms of species loss, in that the eleven seabed species that disappeared after the 2011 regime shift were all at the center of their zoogeographic distribution in the Strait of Georgia region. An influence of warming would lend to prediction that species at their southern zoogeographic limits would be the ones to disappear from observation. Further, species also reappear after regime shifts, so that absence simply indicates abundance too low to be observed by SCUBA divers. The 2011 regime shift may be the ultimate factor in cascade effects on urchins, kelp and prawn abundance (Marliave et al. 2018).

The acidification trend may not be significant between the 1999-2010 and 2011- present regimes. The variance in pH during the current regime has not stabilized enough to reveal a precise plateau level, but it would not likely be significantly lower than in the previous regime. At this time, it appears that different plateaus could be ascribed to pre-1977, 1984-1997, 2002-2010 and 2014-2018 (present). Note that there was no pH change at the 1989 regime shift.

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

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37.1. Highlights

- The timing of the spring blooms in 2017 and 2018 was average.
- The composition of the 2017 spring bloom was typical: a mix of three species of diatoms.
- Interannual variability in summer productivity is large with distinct differences between the northern, central and southern Strait of Georgia.

37.2. Description of the time series

Using the regions of the Strait of Georgia (SoG) defined by DFO plankton investigations based on hydrographic and plankton characteristics (unpublished, Perry and Galbraith, DFO), the ferry and one-dimensional model results here pertain to the central SoG. From the three-dimensional model we show results from the southern, central and northern SoG.

37.2.1. Ferry-based measurements of chlorophyll for the spring bloom

Ferry-based chlorophyll measurements are taken underway from pumped near-surface water (Allen et al. 2017). In most years, including 2017, measurements are taken from the Tsawwassen/Duke Point route, separated into in-plume and out-plume following Halverson and Pawlowicz (2013). Ferry observations of bloom timing are defined by the period during which chlorophyll fluorescence values are more than 50% of the peak value.

37.2.2. One-dimensional biophysical model for the SoG spring bloom

The one-dimensional model is a vertical mixing model coupled to a nitrate-diatom biological model (Collins et al. 2009). All two-dimensional oceanographic processes not resolved by the model are parameterized. The model location, station S3, is on the Tswwassen/Duke Point ferry route. The model is forced by winds measured at Sand Heads, clouds and temperature measured at the Vancouver International Airport (YVR) and river flow measurements at Hope (representing the snow melt dominated part of the Fraser River) and in the Englishman River (representing all other rivers and the rainfall dominated part of the Fraser River).

The use of these measurement sites allowed us to go backward in time and produce a long time series (Allen and Wolfe 2013). However, a disadvantage is that the measurements of clouds at YVR do not always represent the clouds at S3. The timing of the spring bloom is sensitive to the incoming solar radiation. In 2017, the cumulative solar radiation at station S3 was 7% higher than that at YVR (Figure 37-1). This error led to a late model simulation for the 2017 spring bloom.

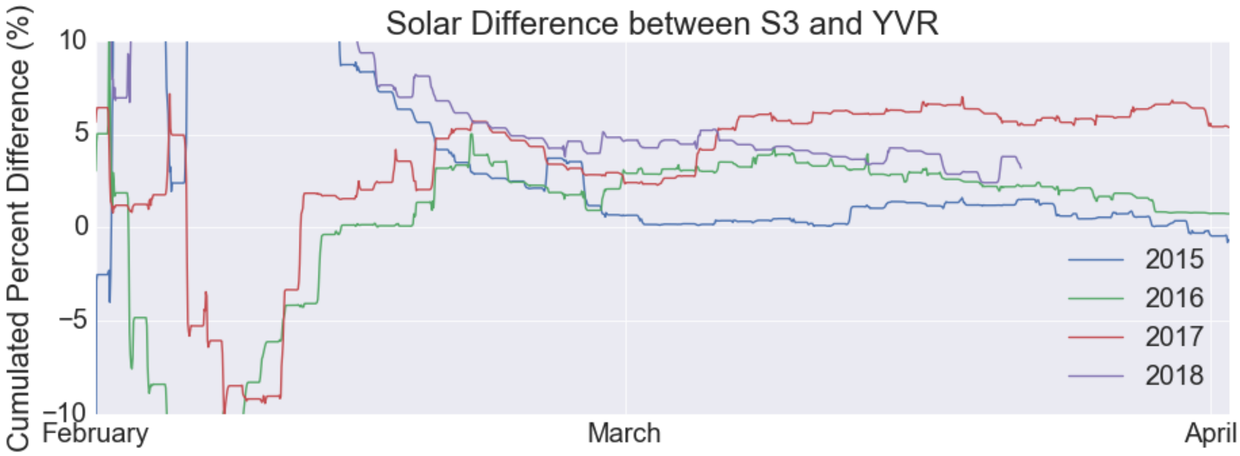

Figure 37-1. The cumulative percent difference between the solar radiation at Station S3 and at YVR airport, starting in February of each year. The solar radiation values are taken from Canada's HRDPS system (Environment Canada, 2018). In 2017, S3 was 7% brighter that YVR whereas in 2015, 2016 and 2018 the difference was less than 4%.

37.2.3. Three-dimensional biophysical model for summer productivity: SalishSeaCast

SalishSeaCast is a three-dimensional coupled bio-physical model of the Salish Sea. The physical model is based on NEMO (Madec et al. 2012), with grid resolutions of about 500 m in the horizontal and 1-22 m in the vertical (Soontiens et al. 2016). Resolution is higher near the surface. It is forced by hourly realistic winds from Environment Canada (2018), climatological rivers (Morrison et al. 2011) except for the Fraser River for which the flux at Hope is taken from observations. The biological model, SMELT, is based on the three nutrients, three phytoplankton, two zooplankton, and three detritus model described by Moore-Maley et al. (2016).

Here we present, as a new time series, the summer productivity as measured by 1) the biomass of the phytoplankton, 2) the primary productivity and 3) the grazing by the mesozooplankton.

37.3. Status and trends

37.3.1. Spring bloom

The 2017, in the central SoG, the spring phytoplankton bloom occurred between March 18 and 28 according to the ferry observations (Figure 37-2). The bloom initiated in early March. It was composed of a mix of *Thalassiosira* spp., *Skeletonema costatum, Chaetoceros* spp similar to 2016. The 2015 bloom was *Skeletonema costatum*.

The 2017 spring phytoplankton bloom occurred at a typical time (Figure 37-3); the mean-timing of the peak of the spring bloom is March 21 (Allen and Wolfe 2013). Since 2011 the spring bloom has slowly moved earlier in the season after a series of late blooms from 2006 through 2011. The timing of recent blooms has also been more similar from year to year, not having the large swings we saw in the late 1990's early 2000's.

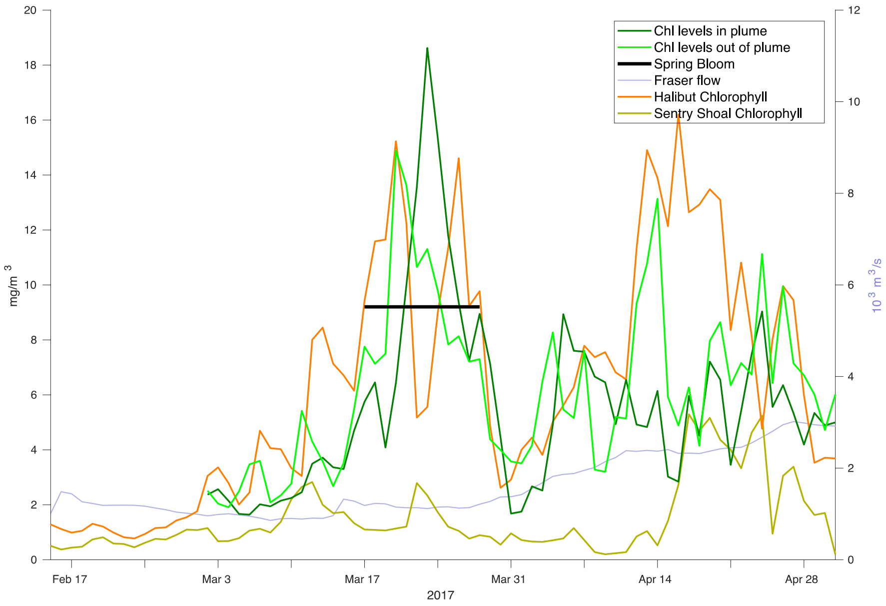

Figure 37-2. The 2017 spring bloom (black line) according to ferry and buoy observations. The bloom occurred in late March and was followed by a second bloom in mid-April. Chl levels in and out of the plume, Fraser River flow, Halibut Bank Chl, and Sentry Shoal Chl are also shown.

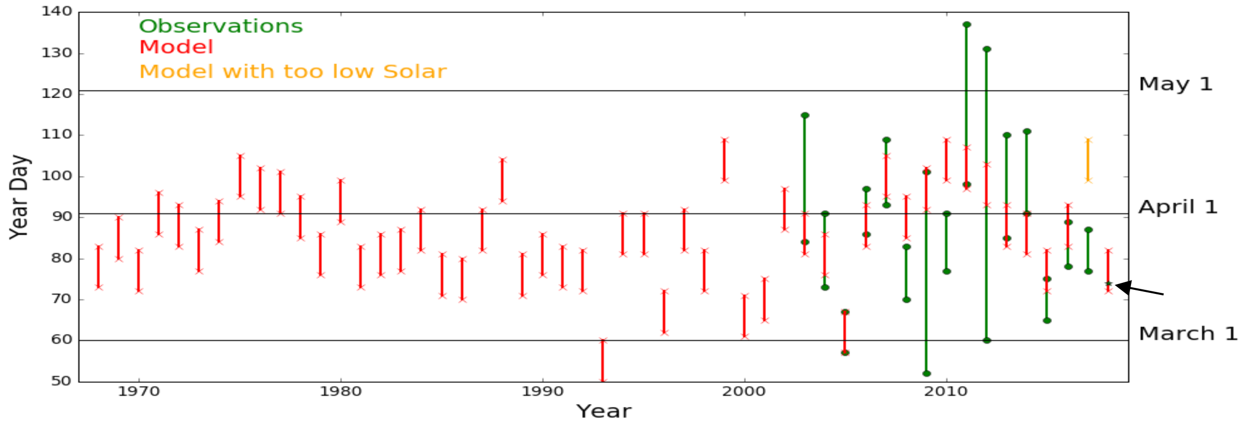

Figure 37-3. Time series of the timing of the peak of the spring phytoplankton bloom. Green – observations from the ferry systems. Black arrow – approximate value for 2018. Red – 1-D model. Orange – 1-D model with too little solar radiation.

37.3.2. Summer productivity

Summer productivity (Figure 37-4) shows similar patterns whether measured by phytoplankton, primary productivity or mesozooplankton grazing. The northern and southern SoG are more productive than the central region. Although the details of the anomalies are different among the three variables, the general trends are the same.

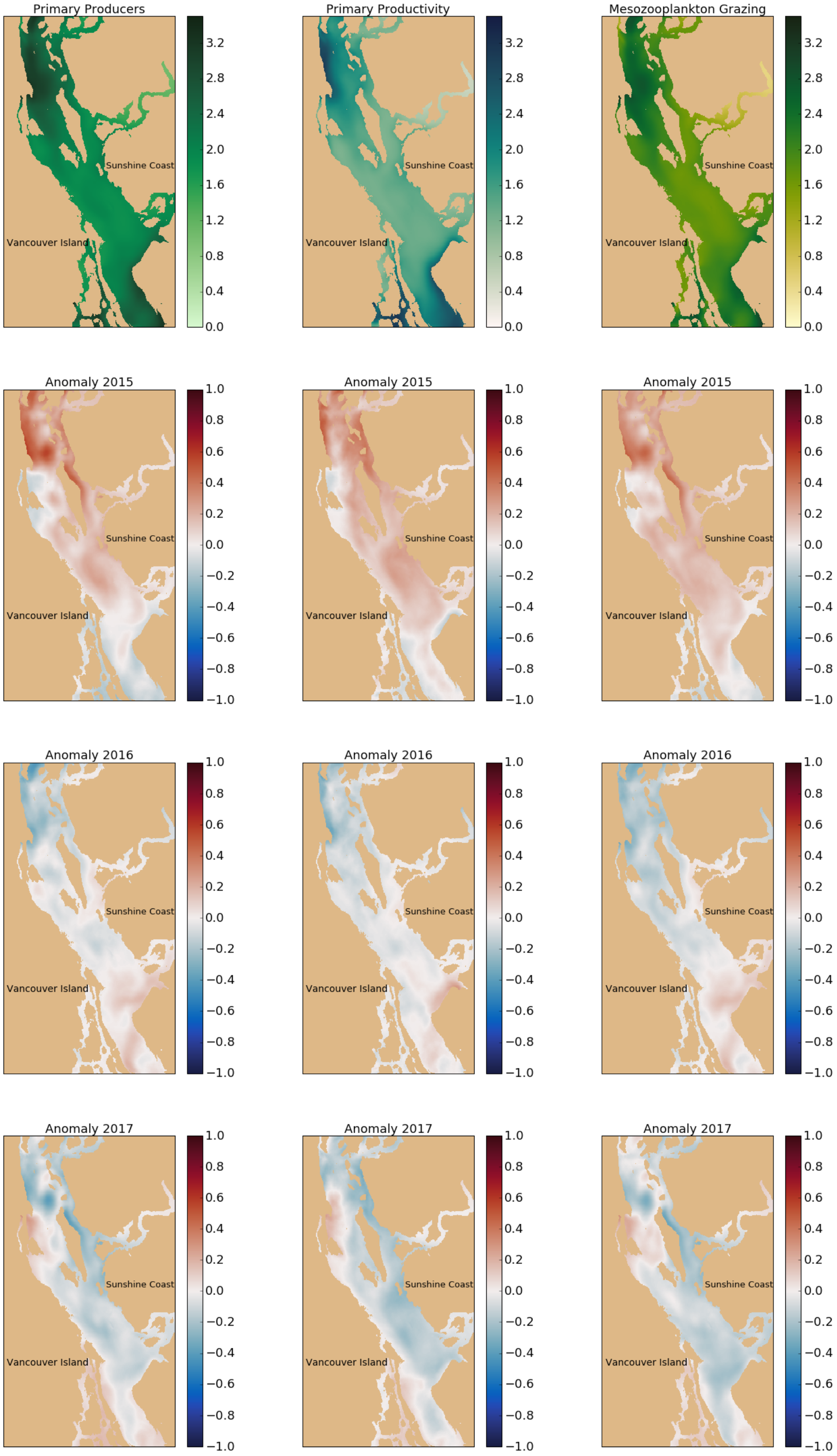

Figure 37-4. Summer productivity in the Strait of Georgia and its variation over 2015 to 2017. Values are averaged over June, July and August and integrated throughout the water column. Only water depths greater than 35 m are shown. Left column: sum of the primary producers in the model, Middle column: primary productivity in the model Right column: grazing by Mesozooplankton. Top row: mean over three years. Second, third and fourth rows: anomalies from the mean for 2015, 2016 and 2017, respectively.

Summer productivity was higher than the three year mean in the northern and central strait in 2015. In 2016, the northern strait was depressed with the central strait more neutral. In 2017, the northern strait was mixed and the central strait more clearly depressed. The southern strait had much smaller variations among the three years.

37.4. Factors influencing trends

The timing of the spring bloom is primarily driven by the amount of wind-mixing and the amount of clouds (Collins et al. 2009). These two weather-related quantities vary with the position of the jet stream. Critical timing appears to start as early as January though the importance of individual storms in March and April is clear in both model results and observational data.

Summer productivity is hypothesized to depend on nutrient availability through mixing and upwelling. We are currently analyzing the forcing processes in the model.

37.5. Implications of those trends

The timing of the spring phytoplankton bloom can impact herring recruitment, with recruitment being stronger for blooms with typical timing (Schweigert et al. 2013). Thus, the spring bloom timing in 2017 and 2018 was *good for herring recruitment.* Extreme shifts of timing have led to poor zooplankton growth (e.g. Sastri and Dower 2009). Consistent spring bloom timing seen in the 2010's should be *good for zooplankton such as copepods.*

The amount of phytoplankton biomass, primary productivity and mesozooplankton grazing should help define bottom-up food availability for higher trophic levels. Three years is a short time series and this is preliminary data but it appears that 2017 was a bit less productive than 2016 and both were less productive than 2015.

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38. CHLOROPHYLL-A PHENOLOGY IN THE SALISH SEA: SPATIAL-TEMPORAL SATELLITE OBSERVATIONS AND BUOY DATA

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38.1. Highlights

- Based on the satellite chlorophyll-a (chl-a) climatology (2003-2017) in the Strait of Georgia (SoG):
    - Spring bloom initiation occurs on average between March 22 and 30 in the Central SoG and between March 30 and April 6 in the Northern SoG.
    - Fall blooms are more prevalent in the Central SoG where chl-a exceeding 5.0 mg m^{-3} occurs after September in almost every year.
- Persistent cloud cover throughout March 2017 limited the available satellite imagery compared to other years and made interpretation of spring bloom initiation difficult. However, daily uninterpolated satellite imagery combined with *in situ* measurements suggest that spring bloom conditions were present in some areas of the Central SoG in mid-March.
- In the Northern SoG, the Sentry Shoal fluorometer measured a low concentration bloom starting on April 16. Other *in situ* measurements and daily uninterpolated satellite data suggest that the bloom was highly variable in space and time.

38.2. Summary

Spatial and interannual variability of the surface chlorophyll in the Strait of Georgia can be used as an indicator of phytoplankton biomass, 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. This report provides an analysis of annual chl-a dynamics and bloom initiation for the Central and Northern SoG (Figure 38-1) based on MODIS-Aqua imagery.

38.3. Description of the time series

MODIS-Aqua satellite data from February 2003 through July 2017 (Level 1a, 1 km^2 spatial resolution) were accessed from NASA's OceanColor web portal and atmospherically corrected using the method described in Carswell et al. (2017). The OC3M chlorophyll-a algorithm was applied, excluding pixels with standard quality-control flags. The quality control flags include pixel contamination caused by straylight and high solar and sensor zenith angles. Angular conditions result in the time series being restricted from mid-February to mid-November. The daily derived satellite chl-a products were validated with *in situ* chl-a from the DFO Institute of Ocean Sciences database and our own high-performance liquid chromatography (HPLC) measurements (Carswell et al. 2017).

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 (Alvera-Azcárate et al. 2005; Beckers and Rixen, 2003). Image interpolation criteria were defined as images containing at least 2% ocean coverage and 2% presence of individual pixels in the time series. The resulting spatially continuous, gap-filled time series was binned into weekly (8-day) composites, from which statistics for the Central and Northern SoG were recalculated based on +/- 2 median absolute deviations (MAD) chl-a for the region (Carswell et al. 2017). The time series and overall climatology for each region were then calculated.

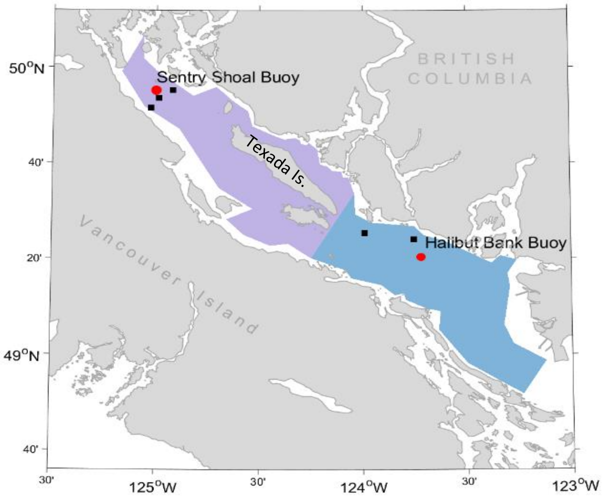

Figure 38-1. The Central (blue) and Northern (purple) regions of the SoG. Black squares are the location of in situ measurements in Figure 38-2.

Timing of the spring bloom was defined for the entire Central and Northern regions. Timing of bloom initiation was defined as the 8-day week where chl-a was greater than the annual median plus 5% (threshold value) and concentrations during one of the two following weeks were higher than 70% of the threshold value. These thresholds were defined annually based on regional statistics.

In situ measurements of chlorophyll fluorescence come from fluorometers deployed at the Environment Canada ODAS Buoys at Halibut Bank in the Central SoG and at Sentry Shoal in the Northern SoG (Figure 38-1). The fluorescence data are presented as daily averages using only nighttime values to remove the effect of nonphotochemical quenching during the day. *In situ* measurements were collected by citizen science vessels during the Pacific Salmon Foundation's Salish Sea Marine Survival Project.

38.4. Status and trends

Overall, there was a good match-up between the regional averages of satellite chl-a and chl-a from Halibut Bank and Sentry Shoal in 2015 to 2017 (Figure 38-2). Early blooms in 2015 were captured by both the satellite and buoy data in both regions. In 2016 bloom conditions were more 'normal' with bloom initiation occurring in late March.

Satellite data in the Central SoG in 2017 were sparse due to persistent cloud cover during the month of March making bloom characterization more difficult. The Halibut Bank fluorometer data show a slow increase in chlorophyll from the beginning to the middle of March (5 mg m^{-3} on March 7 to a maximum of almost 20 mg m^{-3} on March 20; Figure 38-2). This pattern was not captured by the weekly binned chl-a data. However, high chl-a concentrations were observed in some areas of the Central SoG in March when daily uninterpolated satellite images were examined (Figure 38-3). As expected, there is considerable spatial variability within the regions. Both datasets show chlorophyll peaks in the fall.

In the Northern SoG in 2017 chlorophyll measurements were highly variable in space and time. The citizen science sampling showed patchiness in chlorophyll in March (e.g. the March 20 sample of 10 mg m^3 was taken about 7 km to the south of Sentry Shoal; Figure 38-2). At Sentry Shoal concentrations were low until April 16, and then only reached about 7 mg m^3, suggesting the start of a low-magnitude spring bloom. The interpolated satellite data did not show an increase beyond threshold concentrations until the week of May 9, again due to lack of data from persistent cloud cover.

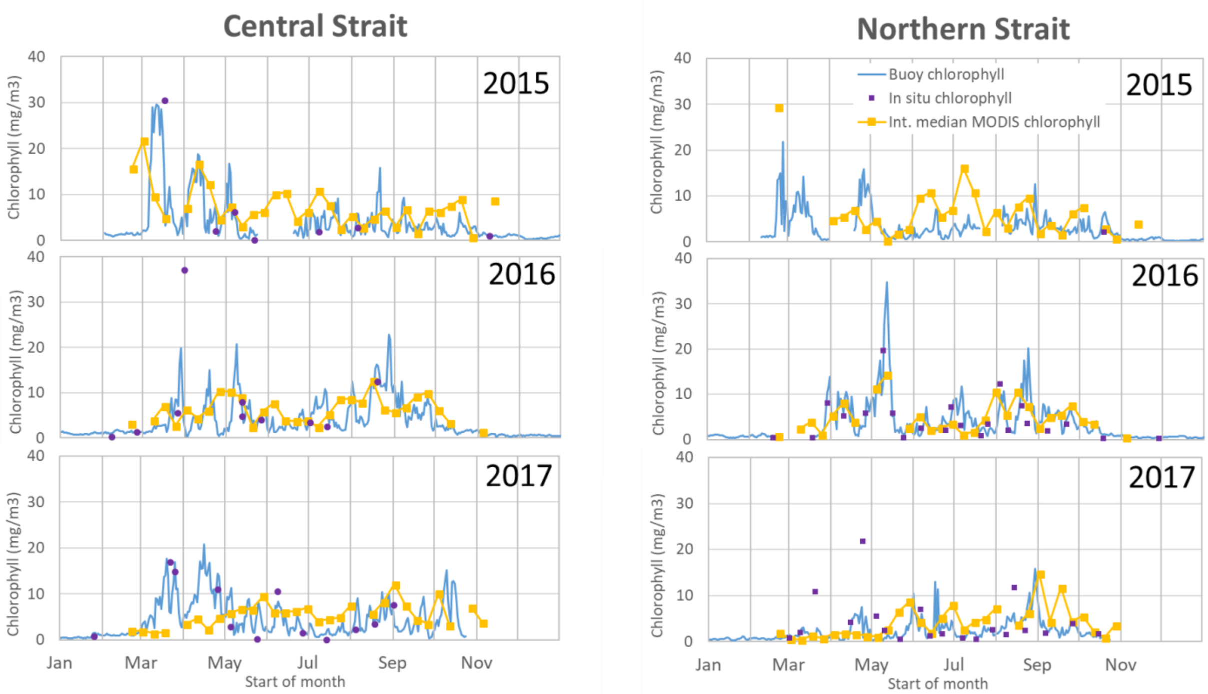

Figure 38-2. Chlorophyll time series for the Central (left) and Northern (right) Strait from deployed fluorometers (blue series), interpolated satellite data (yellow series) and nearby in situ measurements (purple squares; from locations shown in Figure 38-1).

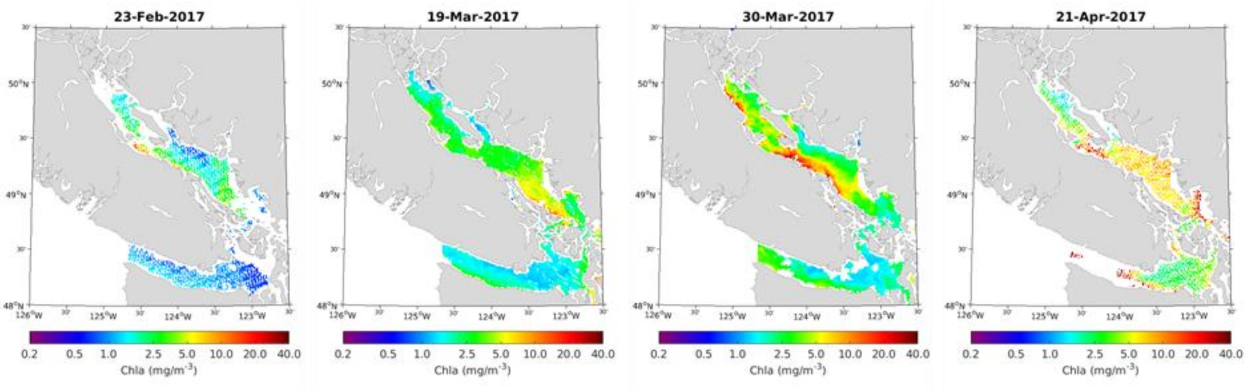

Figure 38-3. Daily MODIS uninterpolated chlorophyll for Feb 23, Mar 29, 30, and April 21, 2017 (Left to right). High chlorophyll along the Vancouver Island coast on Feb 23 are likely due to a problem with the chlorophyll algorithm.

The time series analysis of the MODIS Aqua imagery shows that, on average, the spring bloom initiation is the week of March 22 to 30 in the Central SoG. Figure 38-4 shows bloom initiation (week start day of year) from 2014 to 2017 as defined with satellite imagery for the Central SoG, Ocean Networks Canada (ONC) ferry box data, and the Halibut Bank buoy. In 2014, for the Central SoG the spring bloom initiation happened during the week of March 30 to April 6 (Days 89 to 96), similar to the *in situ* measurements; in 2015, bloom initiation in the Central SoG occurred during the week of February 18 to 25 (Days 49 to 56), two weeks earlier than the *in situ* data; in 2016, the bloom happened the week of March 14 to 21 (Day 73 to 80), similar to the *in situ* data (Sastri et al. 2016); and in 2017, satellite imagery did not capture bloom initiation until the week of May 1 to 8 (Days 121 to 128). We suspect that our regional statistics failed to capture an earlier bloom due to the persistent cloud cover that affected the quality of our weekly binned images.

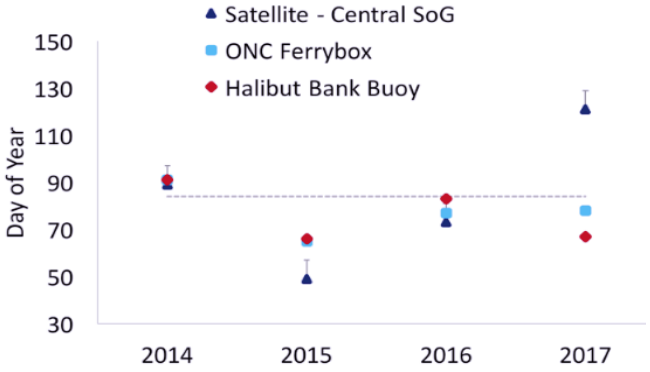

Figure 38-4. Bloom initiation dates from satellite (indicated as the start of week +8 days), the ferry box, and Halibut Bank buoy data. Dashed line is the mean start date for the Central SoG based on the climatological mean.

38.5. References

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39. NUTRIENTS, THE PHYTOPLANKTON COMMUNITY AND HARMFUL ALGAE IN THE SALISH SEA

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39.1. Highlights

- The PSF's Citizen Science Program collected thousands of samples in the Strait of Georgia and Gulf Islands from 2015 to 2017; this is an unprecedented, high-resolution dataset describing nutrients and in-situ phytoplankton dynamics in the Strait of Georgia.
- Nitrate and phosphate but not silicate at 20 m have been trending downwards over 2015 to 2017. Nitrate was limited everywhere in the Strait in 2017, but conditions were not so extreme in 2015 and 2016.
- There was remarkable temporal and spatial variation across the Strait: phytoplankton dynamics in 2016 & 2017 were similar but 2015 was very different (very early spring bloom, very low summer biomass, very low contribution of dinoflagellates, silicoflagellates, and raphidophytes); in all years, phytoplankton dynamics vary noticeably between areas.
- 2017 and 2016 had moderate levels of harmful algal species that are toxic to salmon (*Dictyocha* spp.) at the end of summer whereas in 2015 we saw very high levels of species that are mechanically harmful to salmon (*Chaetoceros concavicornis* and *C. convolutus*) in some areas; there were no significant *Heterosigma akashiwo* blooms in 2015 to 2017 in the SoG.

39.2. Citizen Science Program

The Citizen Science Program was initially proposed by Dr. Eddy Carmack, DFO. He envisioned a 'mosquito fleet' of private boats collecting data for science everywhere in the Strait of Georgia at once. Such a program was funded by the Pacific Salmon Foundation (PSF) for 2015 - 2017 as part of the Salish Sea Marine Survival Project (www.marinesurvivalproject.com). Trained members of the local communities in about 10 separate teams collected information in the Strait of Georgia every week or two between February and October at approximately 80 sites (Figure 39-1). Water samples were collected and conductivity-temperature-depth (CTD) profiling was carried out using a custom tablet system which transmitted the raw datastream to the Ocean Networks Canada (ONC) data archive. Sample/measurement processing and analysis was then carried out at the PSF, University of British Columbia (UBC), ONC, Fisheries and Oceans Canada (DFO), and the University of Victoria. The PSF Citizen Science Program is more cost effective than conventional

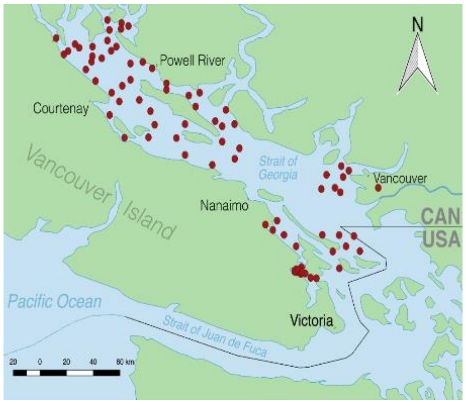

Figure 39-1. Map of the Strait of Georgia with Citizen Science Program sampling locations.

monitoring and provides unique data for the entire Strait at a resolution that had not been possible before.

Nutrients, phytoplankton, secchi disk readings and environmental databases are accessible at http://sogdatacentre.ca (all data) and http://www.oceannetworks.ca (for CTD data only). Outreach and updates on the phytoplankton component of the Program are posted on the Facebook page “Phytoplankton - Citizen Science” at https://www.facebook.com/CitizenSciencePhytoplankton.

39.3. Description of the time series

Sampling was done over the tidal cycle on a pre-planned schedule of about 20 dates per year between February and October 2015 to 2017. Nutrient samples were collected at the surface and 20 m at about 40 sites. Nutrients in 2015 were analyzed at DFO using a three channel SEAL Autoanalyzer; nutrients in 2016 and 2017 were analyzed at the University of Victoria following the methods described in Strickland and Parsons (1972).

Phytoplankton samples were collected at the surface at about 80 sites and at depth (5, 10, and 20 m) at about10 sites. Phytoplankton samples were analyzed and identified to the lowest taxonomic level possible; the enumeration (as cells mL^{-1}) was performed for the species or group that was 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).

39.4. Status and trends

In all three sampling years, the three surface nutrients (nitrate, phosphate and silicate) dropped dramatically in March/April, remained low over the summer, and then returned to winter levels at the end of the year. Surface nitrate levels in particular were very close to zero over the summer for most stations. Silicate levels dropped briefly to zero early in the summer but were generally non-zero later in the summer and fall possibly reflecting a transition from diatom-dominant spring bloom conditions to a community structure with a higher proportion of flagellates later.

Nutrient levels at 20 m did not drop to zero, although a summer decrease was visible. Overall, mean levels of nitrate and phosphate but not silicate at 20 m trended downwards from 2015 to 2017 (Figure 39-2). These interannual changes can also be seen by comparing the bubble-plot presentations of time series at all stations in Figure 39-3. Not only were the measurements at 20 m significantly lower in 2017 than in 2015 (greenish rather than red-ish in the diagrams), but the region of surface waters in which nutrient levels approach zero was far greater in 2017 than in 2015 (and 2016, not shown).

Turning to phytoplankton community structure, the spring bloom of 2017 was fairly similar to 2016 and very different from 2015. In both 2017 and 2016, the spring blooms were recorded several weeks later than in 2015; blooms were less intense but lasted longer (in some areas) and they were composed of a mixture of species (*Thalassiosira* spp., *Skeletonema costatum*, *Chaetoceros* spp.), whereas the spring bloom of 2015 was composed mostly of *Skeletonema costatum*. There were noticeable end of summer and fall blooms in 2017 and 2016, but not in 2015 (Figure 39-4). Summer and fall blooms of 2017 were lower in magnitude than in 2016. The overall phytoplankton biomass in both 2017 and 2016 had strikingly higher contributions of dinoflagellates and silicoflagellates than in 2015. There was a remarkable spatial variation across the Strait between areas and between individual sites in terms of cell densities and dominant species. On average, Irvine's and Cowichan Bay areas had higher cell densities then the other areas, whereas the northern Strait (e.g. Campbell River sites) had the lowest.

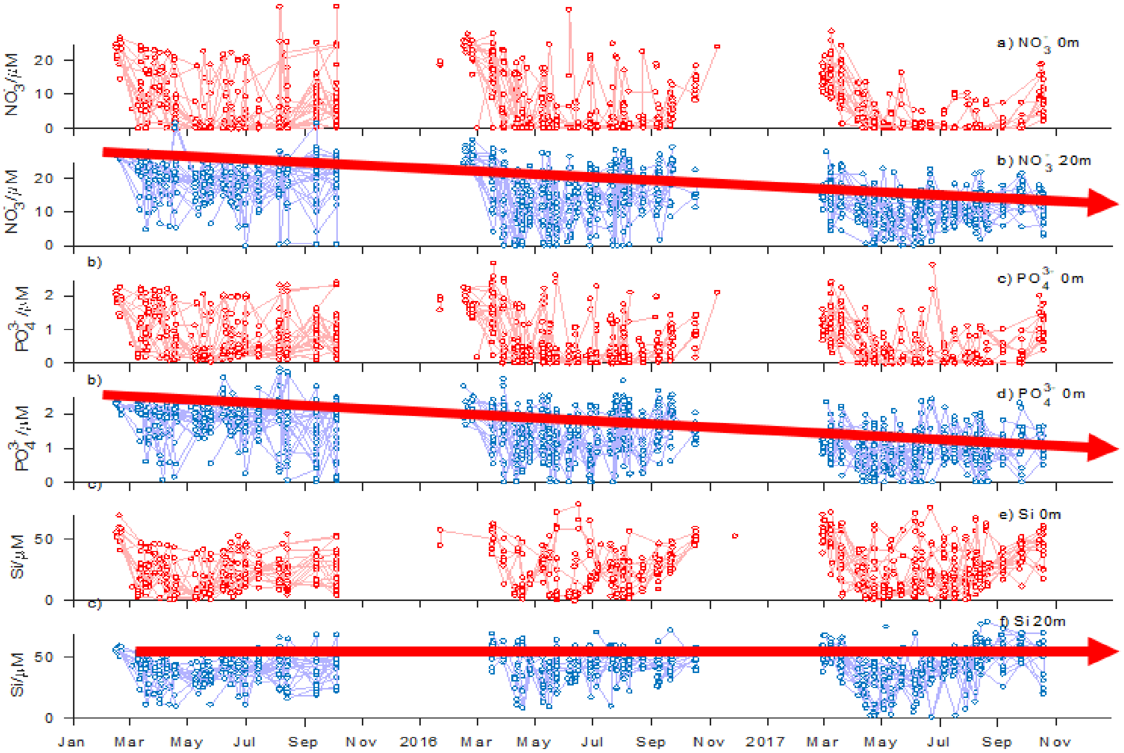

Figure 39-2. Nitrate (NO_3^-), phosphate (PO_4^-) and silicate (Si) time series 2015 to 2017 at 0 m (in red) and 20 m (in blue) in the Strait of Georgia from the Citizen Science program.

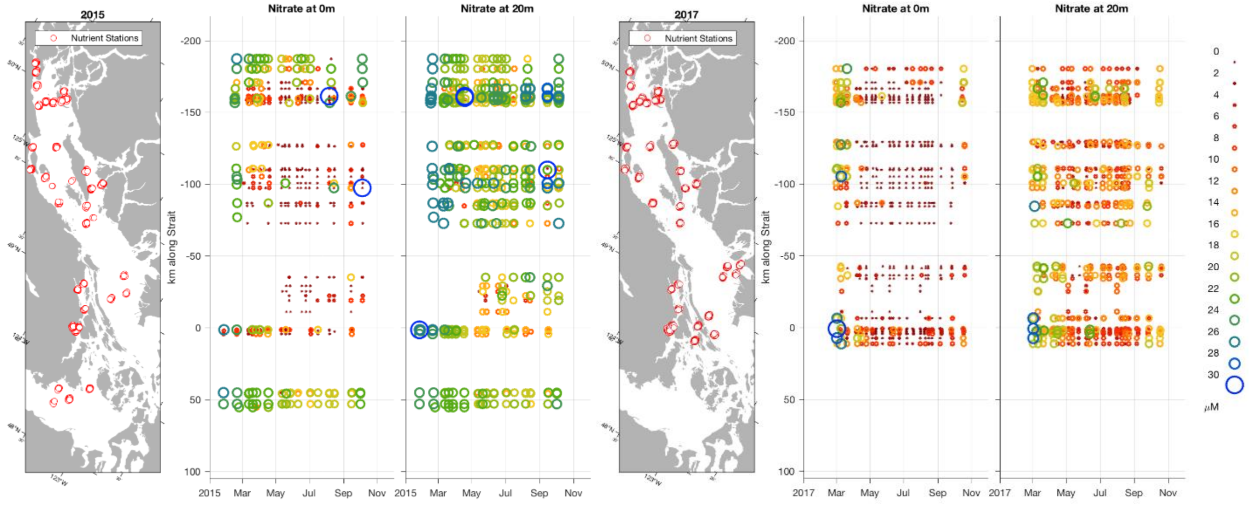

Figure 39-3. Spatial pattern of nitrate at 0 m and 20 m in the Strait of Georgia in 2015 (left bubble plots) and 2017 (right bubble plots). Measurement magnitudes are shown by the size and colour of the bubbles. Station time series appear at the same horizontal level as the station location in the map.

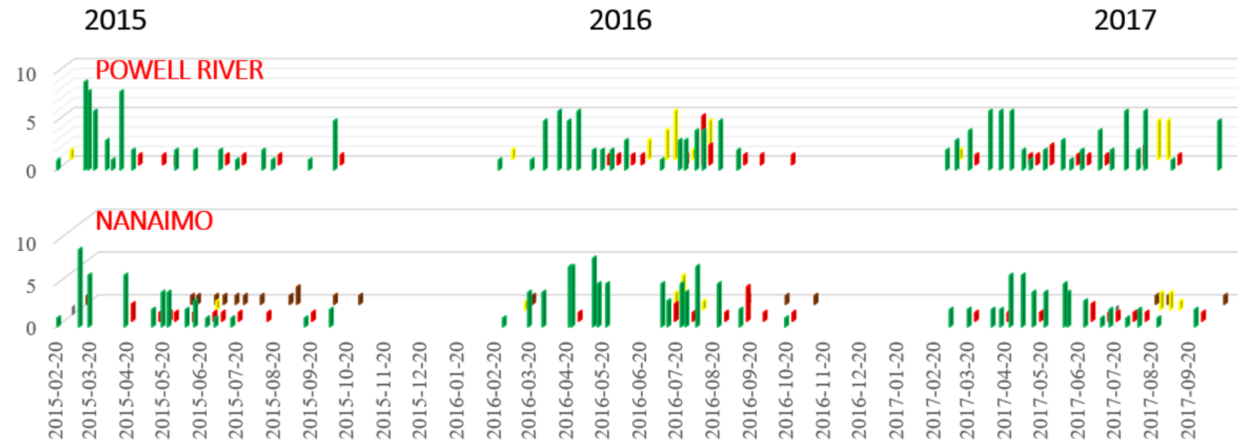

Figure 39-4. Time series of dominant algae taxa in the sample (green – diatoms, red – dinoflagellates, yellow - silicoflagellates) in 2015 to 2017, average data from Powell River and Nanaimo areas (10 and 7 individual stations), Citizen Science program. Levels on the Y axis: 1 (1-10), 2 (11-50), 3 (51-100), 4 (100-200), 5 (200-500), 6 (500-1000), 7 (1000-2000), 8 (2000-5000), 9 (5000-11000 cell mL^{-1}).

Some algae are known to cause fish kills through ichthyotoxins, mechanical damage, or hypoxia (Hallegraeff 1993). The Citizen Science Program monitors the presence and abundance of algae that are known or suspected to have a negative effect on salmonids in B.C. as well as algae causing paralytic shellfish poisoning (PSP) and diarrhetic shellfish poisoning (DSP). In 2017 and 2016 moderate levels of toxic to salmon algae (*Dictyocha* spp.) were observed at the end of summer, whereas 2015 had very high levels of algae mechanically harmful to salmon (*Chaetoceros concavicornis* and *C. convolutus*) in some areas (Table 39-1). There were no significant *Heterosigma akashiwo* blooms in 2015-2017 in the Strait.

Table 39-1. Levels of harmful to salmonids algae taxa based on the maximum count per month per area, Strait of Georgia 2015-2017, Citizen Science program. Harmful levels were established by the Harmful Algae Monitoring Program, Microthalassia Inc.: shading from white to red corresponds with 0 – not present, 1 – very low, 2 – low, 3 – moderate, 4 – high, 5 – very high. Note: at high and very high levels, mortalities of the salmon in net pens are likely to occur due to an acute harmful effect of the algae.

	2015								2016								2017							
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Chaetoceros convolutus* and *C. concavicornis																								
Baynes	4	3	4	1	0	0	0	4	4	0	0	1	0	0	0		1	0	4	0	0	0	0	4
Cowichan	4	0	4	0	0	4	4		0	0	3	0	0	3	0	0	0	0	0	4	0			
Campbell	5	0	5	4	2	0	0	4	0	0	0	2	0	0	0	0								
Irvine's	3	3	2	4	4	2		0	3	0	0	0	0	0	0		4	2	0	0	0	0	0	4
Lund	5	0	5	4	4	0	0	4	3	0	0	0	0	0	0	0	3	4	0	2	0	4	0	4
Nanaimo	1	0	0	2	0	0	0	0	3	0	0	0	2	0	0	0	3	0	0	2	0	2	0	
Powell	4	0	5	4	4	3	0	0	4	1	0	0	0	0	0	0	4	3	0	0	0	4	0	5
***Dictyocha* spp.**																								
Baynes	0	0	2	1	0	1	0	0	1	0	1	2	0	1	0		0	0	0	1	2	2	1	1
Cowichan	0	0	0	0	2	1	1		0	0	1	3	3	1	1	1								
Campbell	0	0	0	0	2	1	0	0	0	0	0	3	2	1	0	0	0	0	1	0	0			
Irvine's	2	0	0	1	1	0		0	0	0	0	3	3	3	0		1	0	0	1	2	3	2	1
Lund	0	2	0	0	1	1	1	1	1	0	2	3	3	2	0	1	1	1	1	2	1	3	2	1
Nanaimo	1	0	0	1	0	0	0	0	1	0	1	3	3	2	0	0	1	1	1	1	0	2	0	
Powell	2	0	1	1	1	0	0	1	1	1	0	2	3	3	0	1	1	1	1	1	2	3	1	0
Heterosigma akashiwo																								
Baynes	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0		0	0	0	0	0	2	0	0
Cowichan	0	0	0	0	1	0	0		0	0	0	0	0	2	2	0	0	0	0	0	0	2	0	0
Campbell	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	1	0
Irvine's	0	0	0	0	0	0		0	0	0	0	1	2	2	3		0	0	0	1	1	2	2	0
Lund	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0
Nanaimo	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	0	0	0	0	1	0	0	0	
Powell	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0	0	1	0	0	0	1	1	0

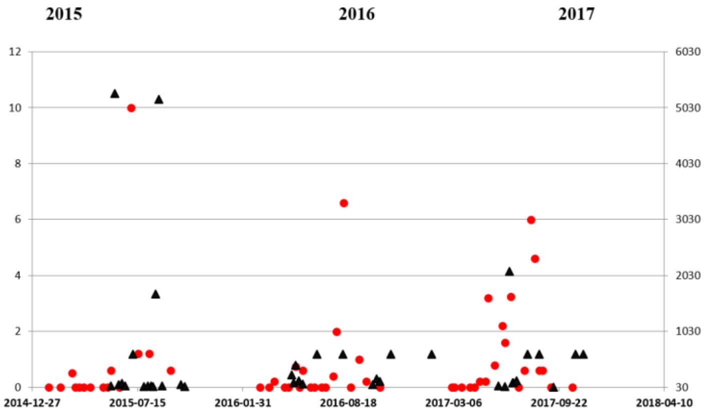

Figure 39-5. Alexandrium spp. cells mL^{-1} at 0 m, Citizen Science program (red circles, primary Y axis), and PSP-total ug PSP toxins/100 mg, Canadian Food Inspection Agency data (black triangles, secondary Y axis) at the Cowichan Bay area (18-7 DFO management area). Note: Citizen Science samples were collected ~bi-monthly whereas CFIA samples were collected ~weekly.

A number of species in the genus *Alexandrium* produce neurotoxins that are accumulated in shellfish and cause PSP. We compared in situ *Alexandrium* spp. cell density in the Cowichan Bay area with data for PSP toxins (in shellfish flesh) data and found an agreement of trends (Figure 39-5).

During the DFO September fish trawl in the Strait of Georgia led by Chrys Neville, water samples were collected for environmental DNA (eDNA) and 12 samples were analyzed in Kristi Miller's laboratory. An initial analysis targeted an amplicon from the 16S region of the DNA, and although algae were not specifically targeted, 38 algal taxa were detected. Out of these, several taxa are harmful or potentially harmful.

Comparison of current molecular results from the DFO eDNA samples with in situ data from the Citizen Science Program revealed an agreement on the presence of several species (*Dictyocha speculum*, *H. akashiwo*, *Rhizosolenia setigera*). Morphological identification was better at detecting *Alexandrium* spp. whereas this molecular technique was superior in picking up genera that are extremely challenging to identify with light microscopy due to their size, such as *Chrysochromulina* and *Prymnesium*. Some species from these genera are known fish killers (Moestrup 2009), and identification to the species level (with molecular methods or electron microscopy) is crucial in evaluating the risk to wild salmon. In the future, the combination of molecular and traditional microscopy methods could increase identification accuracy, maximize time-cost efficiency and provide fisheries researchers and managers with information on oceanographic conditions and ecosystem stressors in regards of harmful algal blooms.

39.5. Factors influencing trends

Data on environmental parameters (CTD) and nutrients collected through the Citizen Science Program along with additional data (e.g. Fraser River discharge, precipitation, winds, solar radiation, etc.) will be used for statistical analysis to establish links between harmful algal species and environmental characteristics in the Strait of Georgia.

39.6. Implications of those trends

Data sets collected through the Citizen Science Program are integrated into the Salish Sea Marine Survival Project and are used to examine potential linkages with the distribution, growth and feeding of juvenile Chinook and Coho Salmon in the Strait of Georgia. The absence of *H. akashiwo* blooms in the Strait of Georgia in 2015-2017 could be considered beneficial for juvenile salmon survival due to a potential linkage of *H. akashiwo* blooms and salmon marine survival decline (Rensel et al. 2010). It could also be beneficial for zooplankton as *H. akashiwo* blooms are known to inhibit microzooplankton growth (Kamiyama et al. 2000).

Phytoplankton is a sensitive beacon of marine ecosystem changes. Continued routine phytoplankton monitoring in the Strait can establish local baseline phytoplankton variability and, with a longer time-series, the extent to which the range of this variability can be altered as a response to climate change. It is important because phytoplankton is the first trophic level in marine environment and long term data can assist in understanding the severity of climate change impacts on the Strait of Georgia ecosystem.

Significant spatial differences in phytoplankton dynamics indicate the possibility of specific ecoregions existing within the Salish Sea. Current work, led by Dr. K.Suchy, is being done to delineate these ecoregions based on water column characteristics and both phytoplankton and zooplankton dynamics. Distinguishing subregions according to similarities and differences in bottom-up processes has important implications for higher trophic levels given that juvenile fishes occupy specific areas within the Salish Sea during their migrations.

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40. ZOOPLANKTON STATUS AND TRENDS IN THE CENTRAL STRAIT OF GEORGIA, 2017

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40.1. Highlights

- Zooplankton biomass in the central Strait of Georgia peaks in the summer months (June-July), based on bi-weekly surveys conducted in 2015 to 2017
- Zooplankton that are generally not the main prey items of juvenile Chinook and Coho Salmon (e.g. small copepods) dominated the central Strait by numbers (abundance), but 'juvenile Chinook and Coho Salmon food' plankton (euphausiids, decapods and amphipods) and gelatinous plankton were more important by weight (biomass)
- Overall zooplankton biomass in the central Strait has been trending up since 2005, with 2017 having higher than average biomass (preliminary)

40.2. Description of the time series

Historically, zooplankton sampling within the Strait of Georgia (SoG), part of the northern Salish Sea, has been spotty with little coordination among short term sampling programs. Prior to 2014, zooplankton sampling did not follow a standard grid or sampling protocols. Mackas et al. (2013) compiled data from as many sources as possible, and due to the level of taxonomic resolution performed by numerous investigators decided to merge the data into broad categories.

Since 2015 zooplankton samples have been collected in the Strait approximately every 2-3 weeks from February to October as part of the Salish Sea Marine Survival of Salmon Program (funded by the Pacific Salmon Foundation). The three main objectives of the zooplankton sampling program were to investigate: the seasonal patterns of the zooplankton community; the possible causes of those changes; and the potential consequences of those changes.

For this report, current trends of abundance (m^{-3}) and biomass (mg m^{-3} or g m^{-2}) are presented as monthly averages of all samples collected in 2015-2017 in the central Strait of Georgia (Figure 40-1). Data were restricted to the central region as it has the most complete time series available at this time. Sample processing is ongoing to fill in the other regions.

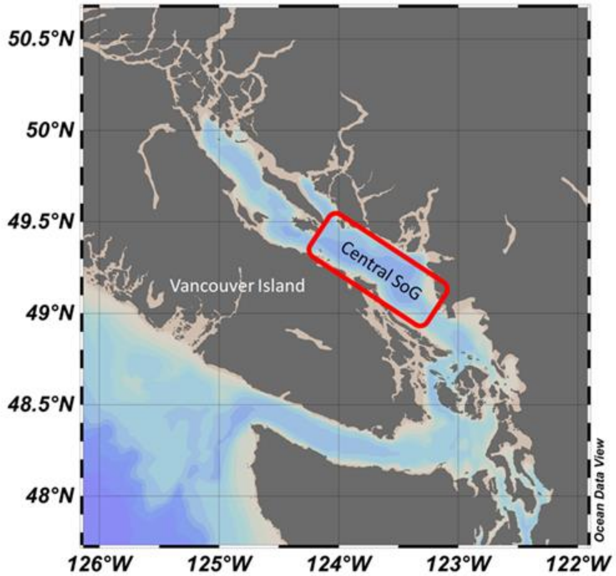

Figure 40-1. The central Strait of Georgia shown by the red box.

For historical comparison, the seasonal variability in the zooplankton data was removed by calculating a regional, log-scale biomass anomaly for selected species for a given year. A multi-year (1995-2017) average seasonal cycle ("climatology") was calculated as a baseline to compare monthly conditions during any single year. Seasonal anomalies were then averaged in each year to give an annual anomaly (see Mackas et al. 2013).

40.3. Status and trends

The total zooplankton biomass in 2015-2017 ranged from 10-60 g m^{-2}, with the lowest biomass occurring in the winter and peaking in the summer (June-July; Figure 40-2). This contrasts with the usual spring focus of most plankton studies in the Salish Sea. Overall, total biomass was above average in 2017 and has been increasing since 2015, as shown by the annual biomass anomalies (Figure 40-3).

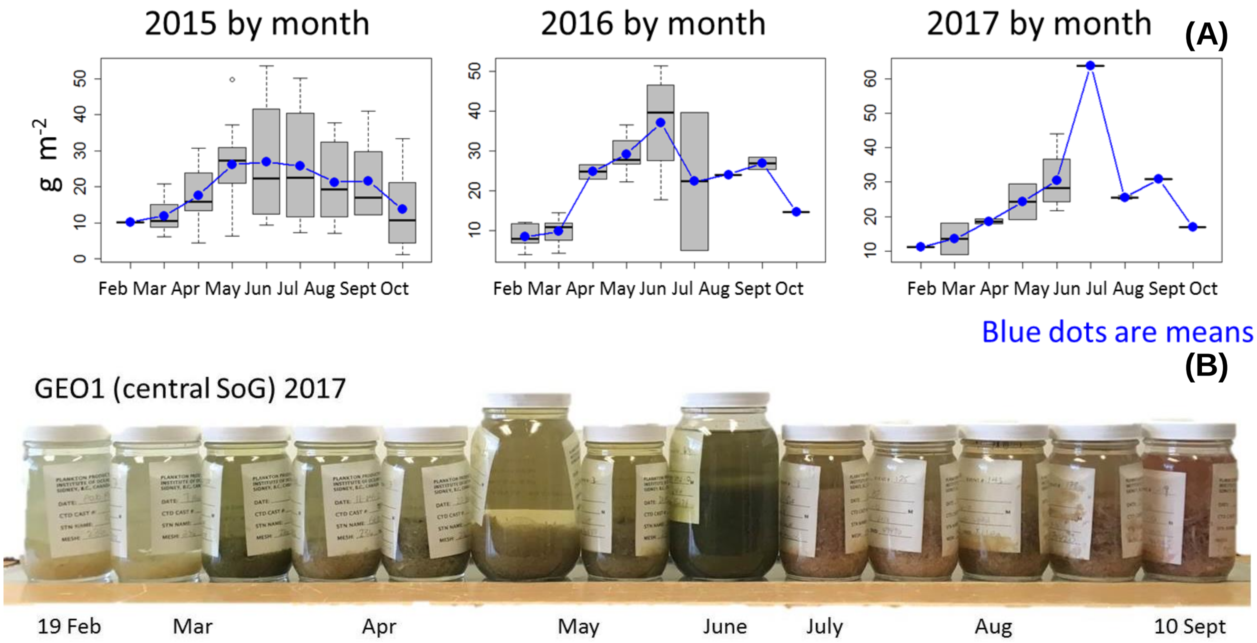

Figure 40-2. (A) Average total biomass (g m^{-2}) of zooplankton by month in the central Strait of Georgia for 2015-2017. (B) Zooplankton samples collected from one station in the central Strait of Georgia (GEO1) in 2017, clearly showing the phytoplankton blooms (green colour) in March (spring bloom) and June (summer bloom), followed by an increase in zooplankton in July (pink colour).

Copepods, in particular calanoid copepods, dominated the zooplankton by abundance, and larger crustaceans (euphausiids, amphipods and decapods) and cnidarians (hydromedusae, ctenophores and siphonophores) dominated the biomass (Figure 40-4). The peak timing of the abundance and biomass of the zooplankton in the central SoG varied by species (Figure 40-4 to Figure 40-6). Within the crustacean groups considered as food for juvenile salmon ('fish food'), euphausiid abundance

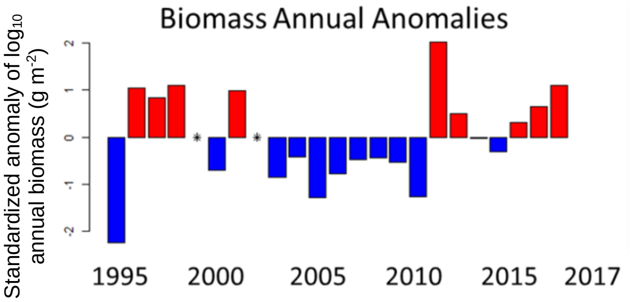

Figure 40-3. Biomass annual anomalies for total zooplankton biomass in the central Strait of Georgia, 1995-2017.

peaked in spring but biomass peaked in the fall as they grew through their larval stages into larger juveniles or adults. Decapod (mainly crab and shrimp larvae) abundance also peaked in the spring, but their biomass dropped through the spring/summer as they transitioned from planktonic larvae to benthic adults. Amphipod abundance and biomass increased in the summer-early fall (Figure 40-5). Within the ichthyoplankton, Gadiformes (mainly Hake, *Merluccius productus,* and Walleye Pollock, *Gadus chalcogramma,* previously *Theragra chalcogramma*) abundance and biomass peaked in the spring. Pleuronectiformes (Slender Sole *Lyopsetta exilis* and Rock Sole *Lepidopsetta bilineata*) biomass was highest in the springtime (Figure 40-6). Osmerid (smelts, mainly Northern Smoothtongue *Leuroglossus schmidti*) biomass increased through the spring and peaked in the summer. In 2017, Clupeiformes increased in abundance and biomass in June, mainly due to the increased presence of Northern Anchovy (*Engraulis mordax*) eggs and larvae.

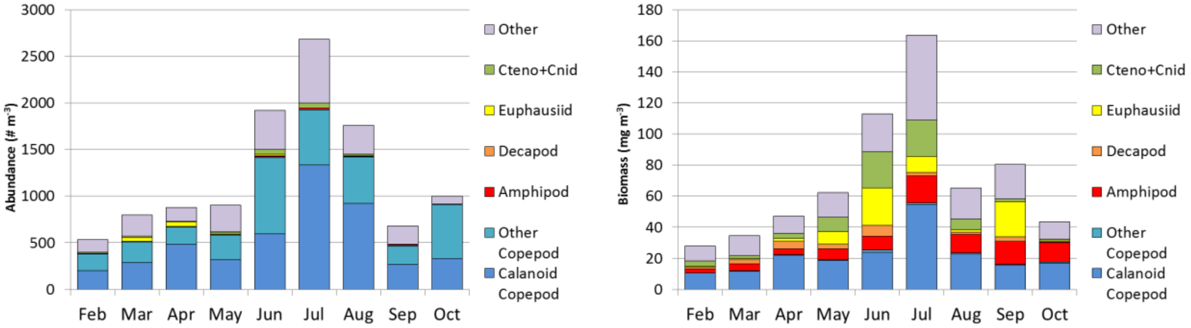

Figure 40-4. Taxonomic composition of zooplankton from central Strait of Georgia in 2017, averaged by month. Left: abundance (m^{-3}); Right: biomass (mg m^{-3}).

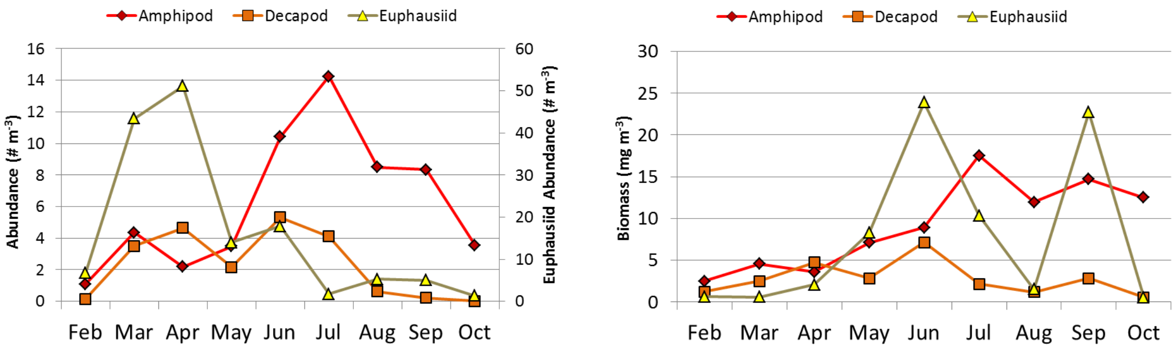

Figure 40-5. Abundance (left, m^{-3}) and biomass (right, mg m^{-3}) of 'fish food' crustaceans collected from central Strait of Georgia in 2017, averaged by month.

Neocalanus plumchrus is a large calanoid copepod that used to dominate the zooplankton biomass in the spring until their sharp decline in the early 2000's (Harrison et al. 1983, Bornhold 2000, Johannessen and Macdonald 2009, Mackas et al. 2013). In 2011, the biomass was above-average, and from 2012-2017 the biomass of the large copepods has remained average (Figure 40-7). The timing of the peak biomass has shifted to earlier in the year, potentially causing a mismatch of their growth with the spring bloom (Table 40-1). The timing of the peak biomass of *N. plumchrus* was calculated assuming it occurs when the abundance of C5 copepodites are 50% of the population (Mackas et al. 2012). In 2015- 2017, the timing of the peak biomass was in early April, which is later than was estimated for the early 2000's but still earlier than historical records (Table 40-1).

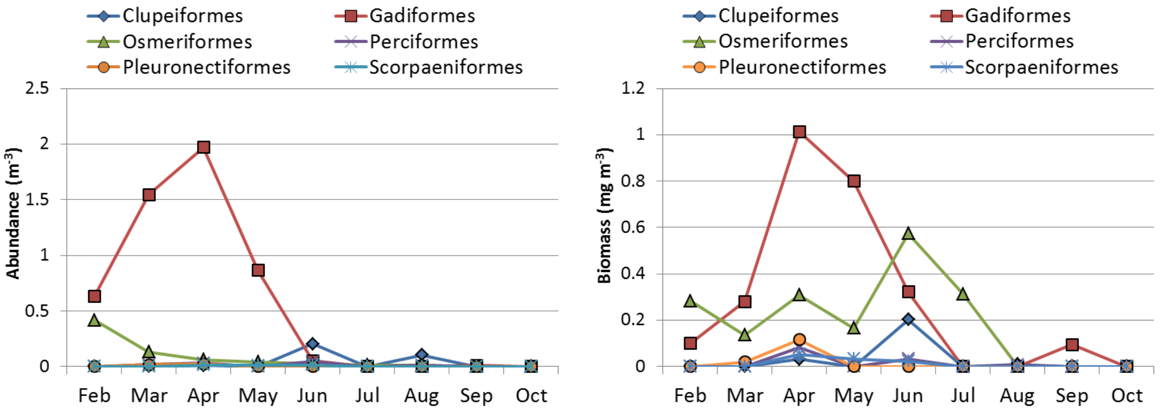

Figure 40-6. Abundance (left, m-3) and biomass (right, mg m-3) of ichthyoplankton collected from central Strait of Georgia in 2017, averaged by month.

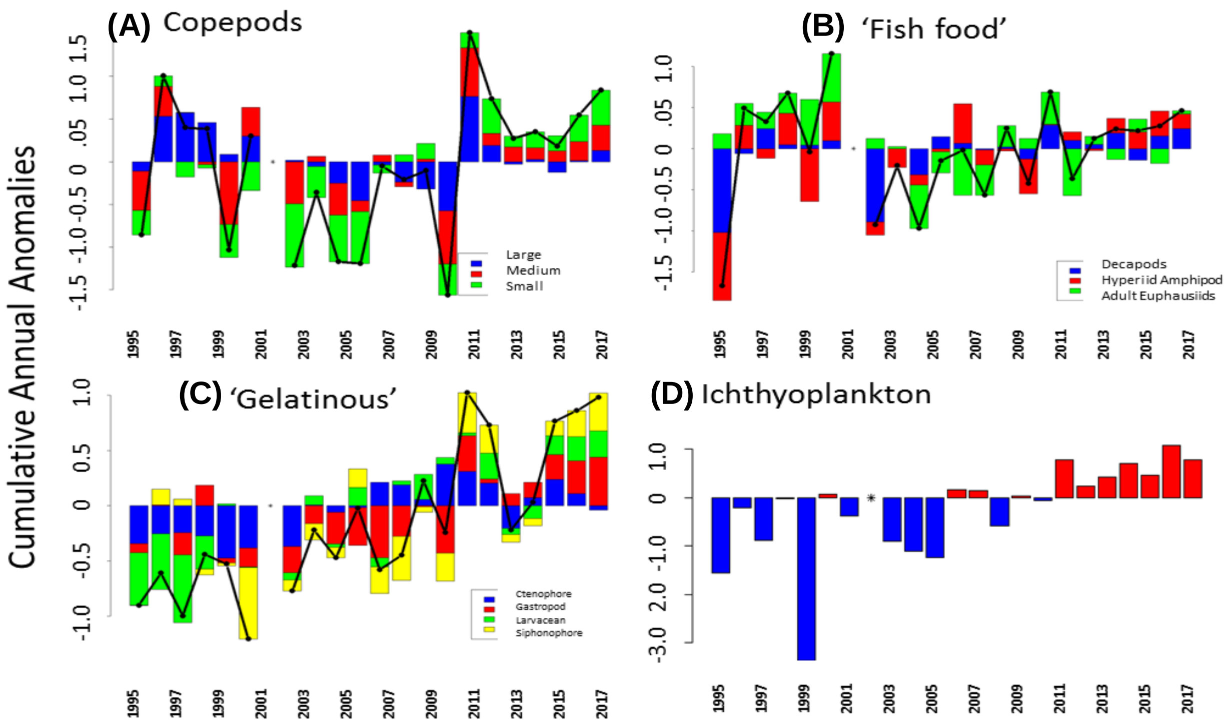

Figure 40-7. Annual biomass anomalies of (A) Copepods, separated by size; (B) 'Fish food' crustacean groups; (C)'Gelatinous' plankton groups; and (D) Ichthyoplankton. Years with no data represented by ''.*

40.4. Implications of those trends

Overall, the biomass of most zooplankton groups was above-average for 2017, and has been increasing since the mid-2000's (Figure 40-7). 2017 is among the highest positive biomass in almost all groups, gelatinous plankton and ichthyoplankton in particular. Chronological clustering (not shown) of the data using four indices of plankton community structure (cumulative anomaly index; the ratio of small to large calanoid copepods; the ratio of gelatinous to crustacean plankton; and total species turnover between adjacent years) produces four significant clusters of years: 1995-1999; 2000-2006; 2007-2012; 2013-2017.

Table 40-1. Timing of Neocalanus plumchrus peak biomass, as estimated when 50% of the population is at stage C5 (a- Bornhold, 2000; b- Johannesen and Macdonald, 2009; c- Mackas et al., 2012). na – not enough data to calculate at this time.

	DOY 50% C5	Date
2017	101	11 April
2016	103	12 April
2015	100	10 April
2010-2014	na	na
2000's[b,c]	85-100	25 Mar - 9 Apr
1990's[a,c]	115	24 April
1980's[a,c]	120	29 April
1970's[a,c]	135	4 May

Sample processing is ongoing and results are preliminary. Work is ongoing to link the trends and patterns in the zooplankton to potential environmental drivers and potential impacts to higher trophic levels, including juvenile salmon survival. A consistent zooplankton monitoring program in the Salish Sea can assist with projections of future abundances of juvenile salmon

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41. STRAIT OF GEORGIA JUVENILE HERRING SURVEY

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41.1. Highlights

- 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.
- An index of the relative biomass of age-0 herring in the SoG was lower and stable during 2013-2017, compared to the peaks within the time series.
- Age-0 herring were heavier for a given length in 2007-2017 compared to herring sampled prior to 2007.

41.2. Description of indices

The Strait of Georgia (SoG) juvenile (age-0) Pacific Herring and nearshore pelagic ecosystem survey, supported in part by the Pacific Salmon Foundation, is a 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).

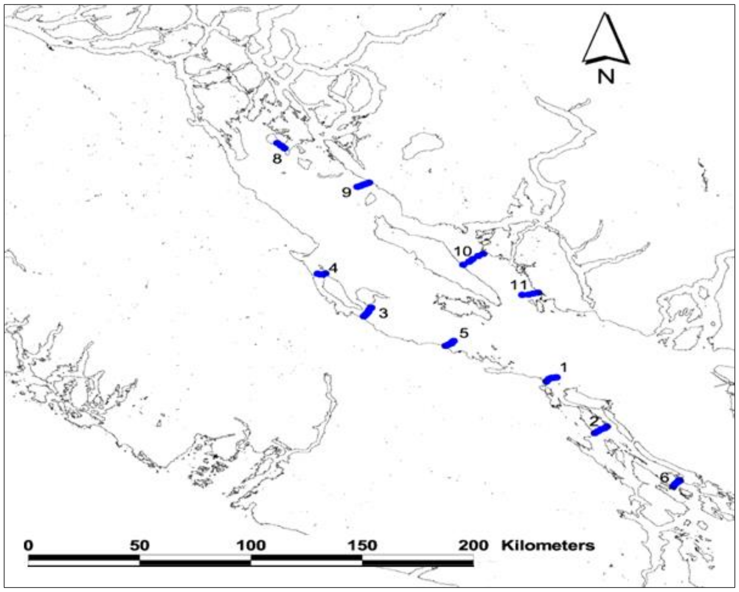

Figure 41-1. Core stations along the 10 core transects of the Strait of Georgia juvenile herring survey (there is no transect #7).

There are 10 core transects, each with three to five core stations (total 48 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 41-1). Sampling was conducted after dusk when herring were near the surface and, generally, one transect was sampled per night over the course of a four to seven 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 double-log-transformed length-weight regression.

41.3. Status and trends

In 2017, 42 of the 48 core stations were sampled (one transect was not sampled due to bad weather and one station could not be sampled due to a large amount of jellyfish preventing closure of the net). Age-0 herring were caught in all 42 stations (Figure 41-2). Estimates of age-0 catch weight CPUE (the index) varied annually, with no overall trend during 1992-2017 (Figure 41-3). The age-0 herring index tended to peak every two or three years, with the peaks occurring in even years during 2004-2012. During 2013-2017, the index was low compared to the peaks in the time series, but neutral compared to the overall median index value. High estimates of variability are associated with peak estimates; the survey CV is 0.47. Age-0 herring length-weight residuals increased during 1997-2012, and were positive in 2005 and 2007-2017 (Figure 41-4).

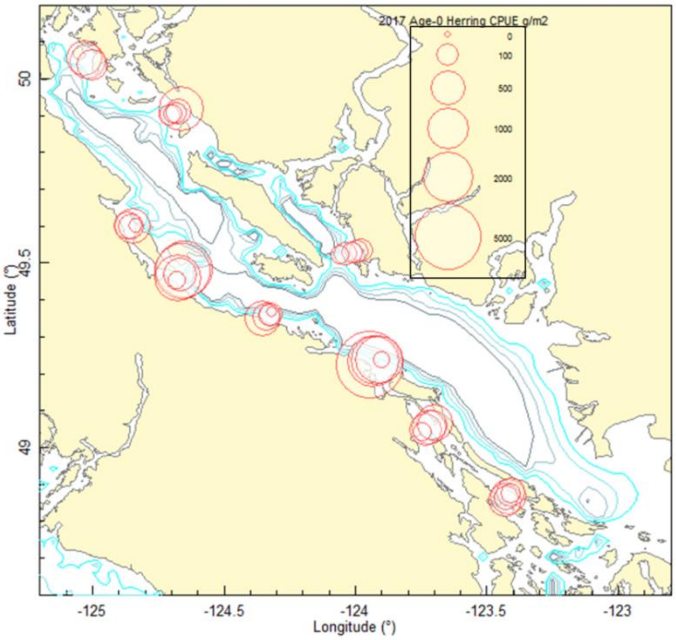

Figure 41-2. Catch weight per unit effort of age-0 herring sampled in the Strait of Georgia, 2017.

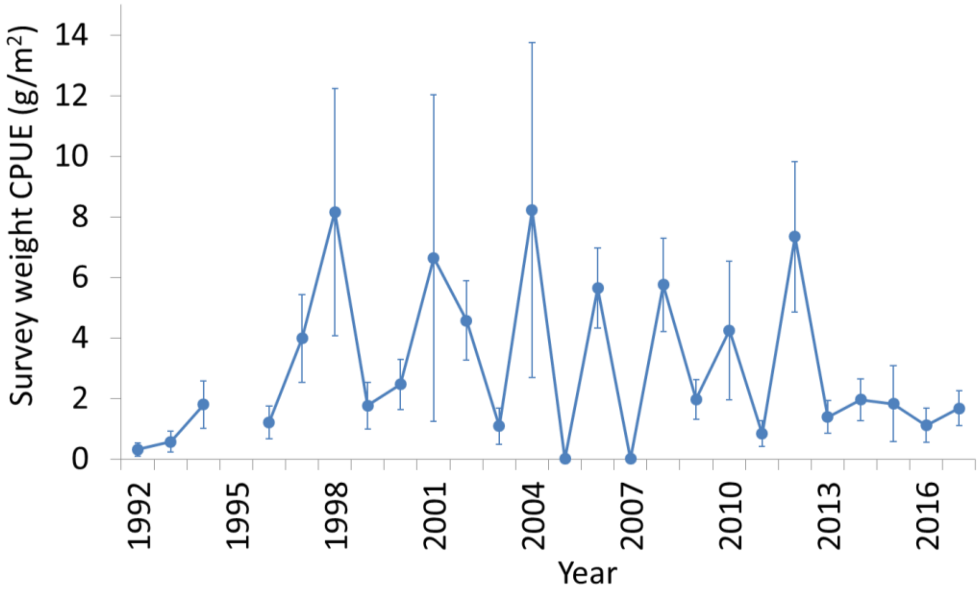

Figure 41-3. Mean catch weight per-unit-effort (CPUE) of age-0 Pacific Herring caught in the Strait of Georgia juvenile herring survey at core transects and stations during 1992-2017 (no survey in 1995; Boldt et al. 2015). Standard error bars are shown.

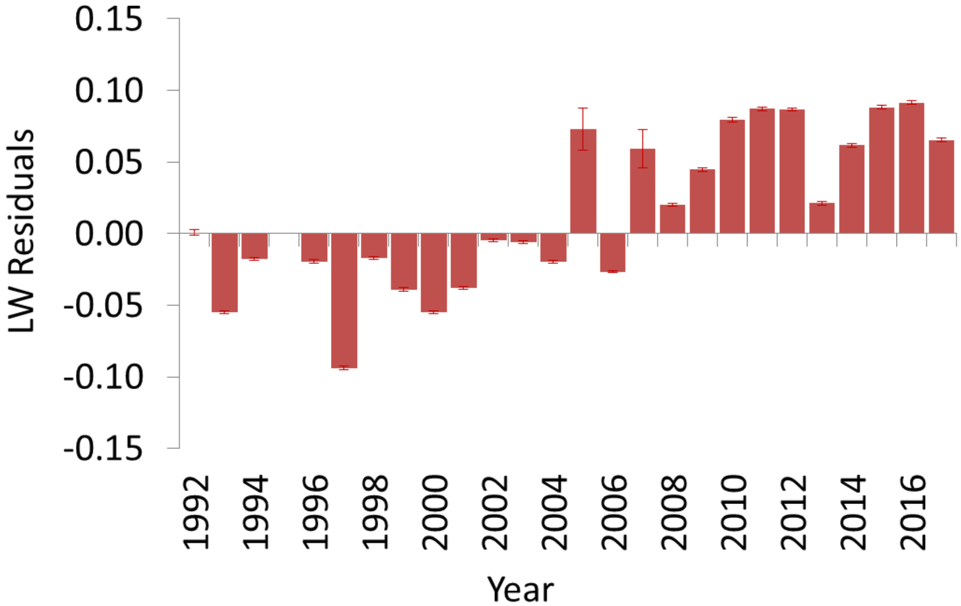

Figure 41-4. Mean age-0 Pacific Herring condition (residuals from a log-transformed length-weight regression) from the Strait of Georgia juvenile herring survey, 1992-2017 (no survey in 1995; Boldt et al. 2015). Standard error bars are shown.

41.4. Factors causing trends

Bottom-up processes (prey-driven) are the main factors affecting the interannual variability in age-0 herring abundance and condition (Boldt et al. 2018). There is some evidence that top-down (predator-driven; e.g., juvenile Coho and Chinook Salmon) processes affect age-0 herring condition. Bottom-up factors include zooplankton prey availability, 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, Boldt et al. in press). 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).

41.5. Implications of trends

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

Pacific Herring are prey for piscivorous fish, marine mammals, and seabirds and are important commercial species in British Columbia’s coastal waters. Changes in herring abundance may affect availability to commercial fisheries as well as the survival of predators, such as Coho and Chinook Salmon. 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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42. THE SAANICH INLET ROV TRANSECT 2017: DELAYED RECOVERY OF THE EPIBENTHIC COMMUNITY AFTER A SUSTAINED PERIOD OF HYPOXIA

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42.1. Highlights

- We continued an annual (2006 to present) benthic hypoxia time series in which we used remotely operated vehicles to survey seafloor fish and invertebrate abundances along a shifting hypoxia gradient from approximately 180-40 m depth in Saanich Inlet, B.C.
- The dissolved oxygen levels measured by the ONC-VENUS instrumentation at this site have continued to decrease (-0.07 ml L^{-1} $year^{-1}$) while days below ecologically relevant hypoxia thresholds have continued to increase (10-11 days $year^{-1}$).
- The 2017 state of the animal community has not recovered to the pre-2016 state: extensive die-off of the cold water coral population has occurred, overall abundance of commercial shrimp species has returned but in low numbers, and one of two 'new' species still remain in high abundance.
- This annual survey is the longest-running, ROV time series in the Pacific region of Canada.

42.2. Description of the time series

Since 2006, annual benthic visual surveys using remotely operated vehicles (ROVs) with onboard dissolved oxygen sensors and high-definition video cameras have repeated the same transect (n=14) in Patricia Bay, Saanich Inlet, B.C. (Chu and Tunnicliffe 2015, Gasbarro 2017). This annual survey is the longest-running, benthic time series in the Pacific region of Canada that was designed using standardized ROV methods. Continuation of this time series was made possible by the support of Ocean Networks Canada (ONC) and the Canadian Healthy Oceans Network to 2017. The transect transitions from the deep basin through zones of low-to-high oxygen over a gradually sloping depth gradient (180 to 40 m), and results in imagery-based soft-bottom epifauna counts with concomitant oxygen measurements made at 1 m above the seabed. Under the ecological context of this time series, hypoxia has been empirically defined by the minimum oxygen requirements of the key species living in this habitat which generally range from ~0.3-1.0 ml L^{-1} (Chu and Gale 2017). The study design allows for direct comparisons of hypoxia-induced shifts in the epibenthic animal distributions over time. Ten of the approximately fifty species that have been documented at this site have been observed in every survey from 2006-2013 (Chu and Tunnicliffe 2015, Chu et al. 2018). Of these 10 species, we used the Slender Sole (*Lyopsetta exilis*) and Squat Lobster (*Munida quadrispina*) as indicator species of the hypoxia-tolerant community, Spot Prawn (*Pandalus platyceros*) as indicator species of the hypoxia-sensitive community, and Sea Whip (*Halipteris willemoesi*) as indicator species of the sessile community. Because indicator species have high fidelity and specificity to their respective oxygen regimes, the relative depth of their occurrence can be useful in indicating the severity of hypoxia expansion events (Chu and Tunnicliffe 2015, Gasbarro et al. 2017). Seasonal variability at this site was assessed using three transects flown in the spring, summer, and fall of 2013 (Chu and Tunnicliffe 2015) and again in 2016 (Gasbarro 2017, Gasbarro et al. 2017). No transects were performed in 2014 and 2015 because of the lack of an ROV platform and personnel support. A single transect was flown in the spring of 2017. Since 2006, ONC's VENUS cabled observatory has measured 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.

42.3. Status and trends

Annual oxygen levels in this habitat have declined at a rate of -0.07 ml L^{-1} $year^{-1}$ since the beginning of the ONC-VENUS monitoring program (Figure 42-1a, data are from Feb 2006-Jan 2018). To assess the influence of climate-stressors such as hypoxia on ectotherm biology, quantifying the severity and duration of exposure is important. Figure 42-1b shows a one-year running mean applied to the per minute ONC-VENUS records which reveals the oxygen decline was primarily a result of a sustained approximately 2 year period (2015-2017) where the system remained below the ecophysiology-based hypoxia threshold established for the eastern Pacific Ocean (0.88 ml L^{-1}; Chu and Gale 2017). Consequently, this site has also experienced significant increases in the duration of hypoxia; the cumulative duration below the 0.88 ml L^{-1} and the 0.5 ml L^{-1} severe hypoxia threshold at this site has also increased by 11 days $year^{-1}$ and 10 days $year^{-1}$ respectively since 2006 (Figure 42-1c). As a result of the sustained oxygen deficiency, a notable hypoxia-induced shift in the species assemblage occurred in fall 2016 (relative to the 2006-2013 baseline) which resulted in: (1) severe habitat compression for the Spot Prawn (2016-spring, Figure 42-2), (2) shoaling of the depth distribution of the hypoxia-tolerant community, (3) anoxia extending shallower than past surveys, (4) the eventual absence of Spot Prawn and two other commercial shrimp species (*P. jordani* and *P. Hyposintus*), and (5) the increased abundance of two new species (Striped Nudibranch *Armina californica*, White Sea Cucumber *Pentamera* cf. *pseudocalcigera)* (Gasbarro 2017, Gasbarro et al. 2017).

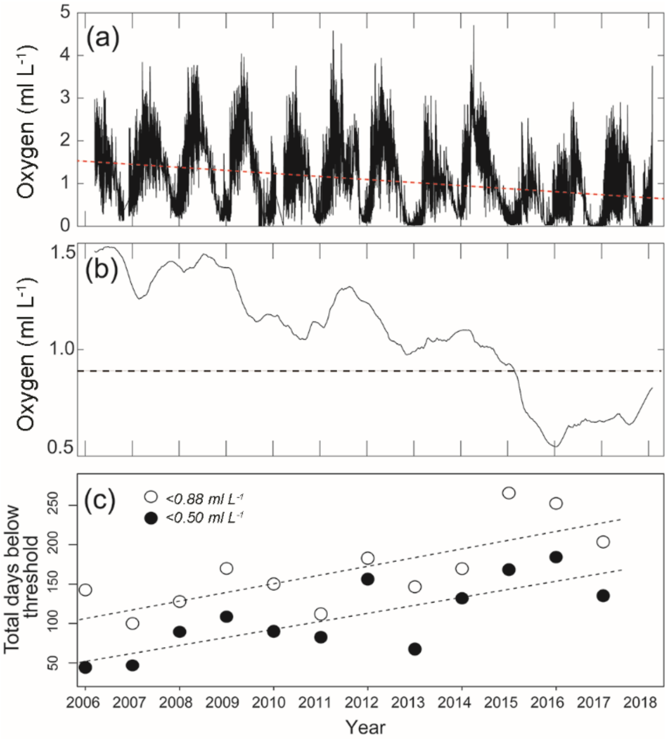

Figure 42-1. The 11-year continuous ONC-VENUS oxygen records measured at 96 m in Patricia Bay, Saanich Inlet. (a) The dissolved oxygen levels at this site have decreased over the 11-years of continuous monitoring. (b) One-year running mean through the ONC-VENUS per minute records illustrates the 2015-2017 period of sustained hypoxia. Dashed line is the 0.88 ml L^{-1} East Pacific hypoxia threshold. (c) The cumulative annual days below hypoxia thresholds have increased at this site.

As of spring 2017, the habitat remained in a state of severe oxygen-depletion. The annual oxygen levels (Figure 42-1a) and hypoxia exposure (cumulative days) have slightly improved since 2016 but are still far from recovering back to the 2006-2013 levels. The 2017-spring bottom oxygen profile appeared more similar to the 2013-spring profile; a recovery from the severe shoaling of hypoxic waters observed in 2016-spring (Figure 42-2). However, the epibenthic community has not fully recovered. Spot Prawn returned to this system, but occurred in relatively low abundance (Figure 42-3). Except for the hypoxia-tolerant species (Slender Sole, Squat Lobster), the abundance of most species was generally low (Figure 42-3). Most notable was the number of Sea Whips observed (n=80) which was the lowest recorded among surveys dating back to 2006. Only one individual of the White Sea Cucumber was observed in the 2017 survey. Striped Nudibranch numbers decreased from 2016 but their abundance was still high (n=47) relative to the period from 2006-2013 when none were observed.

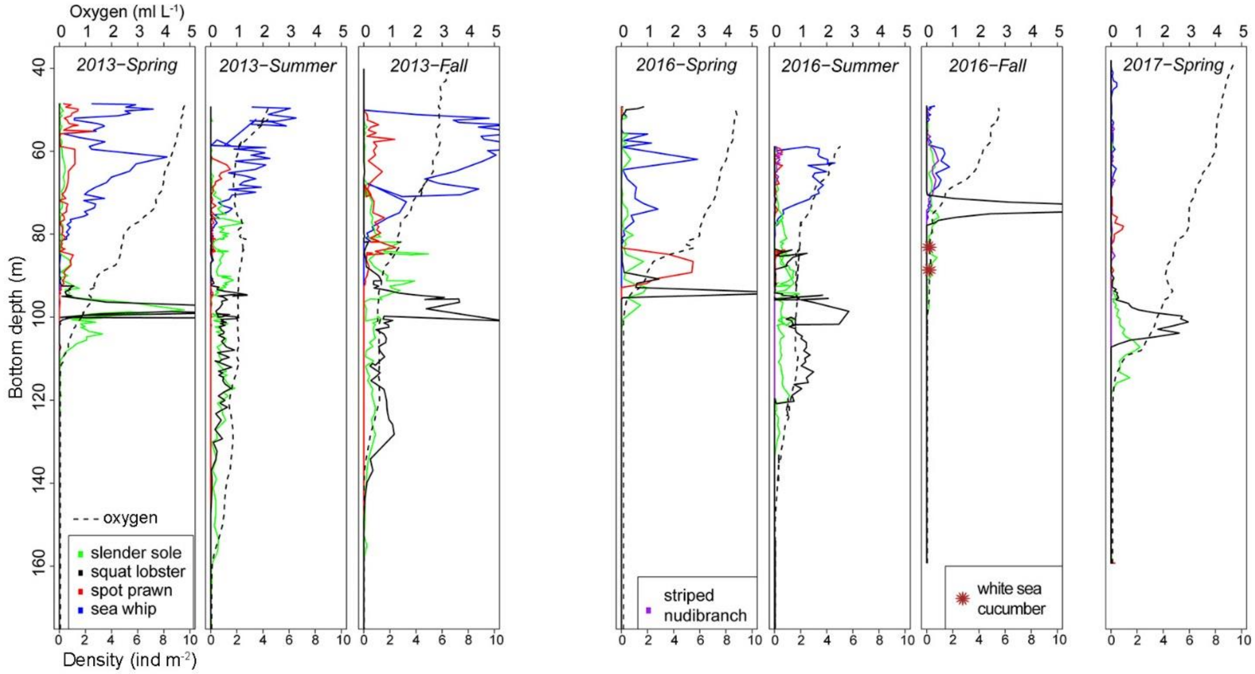

Figure 42-2. Surveys of key species distributions in Patricia Bay, Saanich Inlet relative to hypoxia gradient (dashed line) in 2013 (n=3), 2016 (n=3), and 2017 (n=1). No surveys were done in 2014 and 2015. Note that Spot Prawn and two other commercial shrimp species (Pink Shrimp Pandalus jordani, Humpback Shrimp P. Hypsinotus, not plotted) were absent in 2016-fall survey, but reappeared in 2017 in reduced densities. Overall abundance was low in 2017 with the Sea Whip population being the lowest recorded since surveys began in 2006.

42.4. Implications of these trends.

The rate of annual oxygen decline has accelerated compared to the previous rate of 0.05 ml L^{-1} $year^{-1}$ calculated for the initial eight years of the ONC-VENUS oxygen records (Chu and Tunnicliffe 2015). The continued decline in the annual oxygen levels could be a result of enhanced oxygen utilization and/or weakened oxygen renewal processes influencing the seasonal hypoxia cycle in Saanich Inlet.

The loss of commercial species, compression of habitat, invasion of new species, and loss of biomass from population shrinkage follow the general predictions of ecosystems experiencing chronic oxygen loss (Breitburg et al. 2018). However, the community turnover in the northeast Pacific region generally occurs at lower hypoxia thresholds because of the species-specific context that dictates whether the shifting oxygen regime induces a notable effect on the animal community (Chu and Gale 2017). Within a region, higher hypoxia sensitivity is also correlated with species that are commercially exploited (Chu and Gale 2017). Thus, shifts in the distribution and abundance of the more hypoxia-sensitive species (e.g. Spot Prawn) will occur at relatively high oxygen levels (~0.7-1.0 ml L^{-1}) with population mortality occurring in sustained, severely hypoxic conditions. There is less influence of severe hypoxia on the hypoxia-tolerant species (Slender Sole, Squat Lobster) because of their low critical oxygen tensions (0.3-0.4 ml L^{-1}, Chu and Gale 2017). Expanding anoxia, however, will still force populations into shallower depths because all ectotherms require some amount of oxygen to survive.

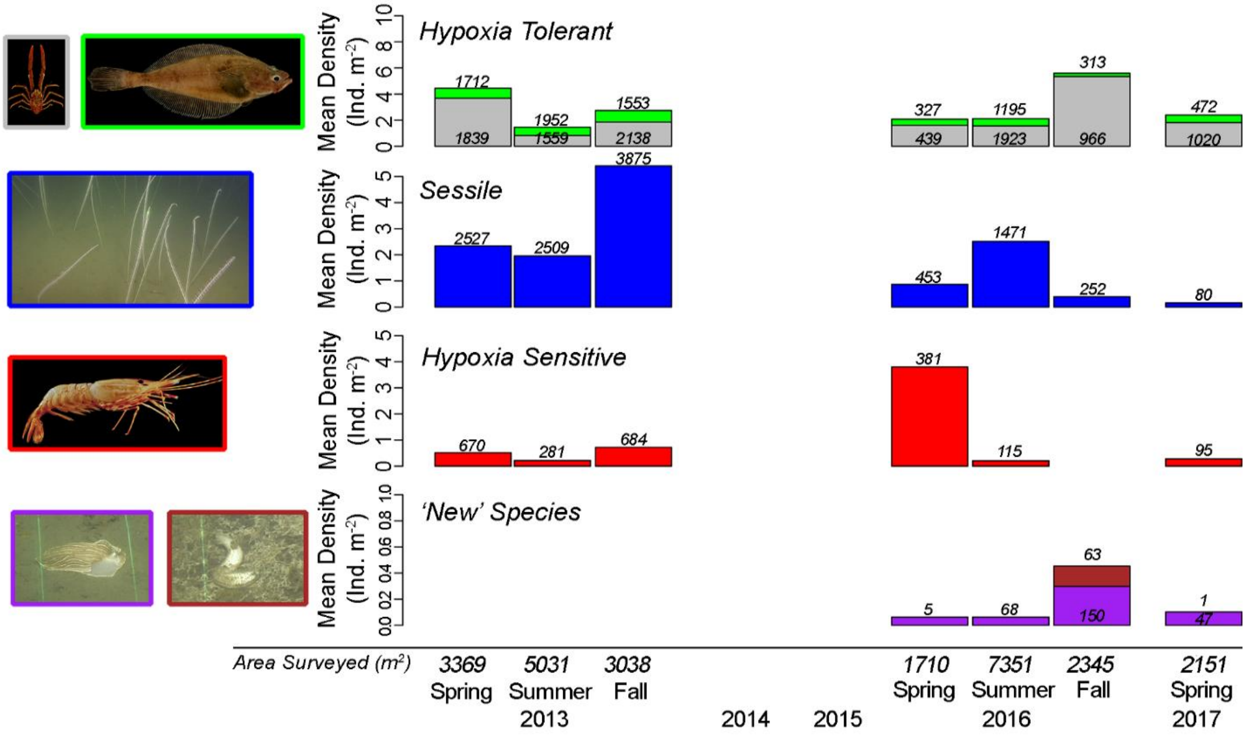

Figure 42-3. Average densities per survey for each key species presented and grouped by hypoxia tolerant (Squat Lobster, Slender Sole), sessile (Sea Whip), and hypoxia-sensitive (Spot Prawn) taxa. Total counts are indicated on each bar. Total area surveyed (m^2) for each transect is indicated on the x-axis. Differences in area surveyed among years is primarily attributed to truncation of the survey at the deeper and/or shallow portions of the transect and the field performance of the different ROV platforms (ROPOS: 2013-summer/fall, 2016-summer; Oceanic Explorer: 2013-spring, 2016-spring/fall; Hercules: 2017-spring). No surveys were performed in 2014 and 2015. 'New species' (Striped Nudibranch, White Sea Cucumber) refer to taxa that were absent from 2006 to 2013. Average densities were calculated from abundances occurring in 20 m^2 sections along each transect where species occurred and did not include sections with zero occurrences. 2013 data are from Chu and Tunnicliffe (2015). 2016 data are from Gasbarro (2017). Earlier surveys (2006-2012) are not presented but are published in Chu and Tunnicliffe (2015). Note that the 2016-spring increase in mean density of Spot Prawn (ind. m^{-2}) was because of severe habitat compression (Figure 42-2) and not a general increase in population size.

Cold-water corals, such as Sea Whip are sensitive biogenic habitat-forming species. As such, DFO has identified similar pennatulacean communities as vulnerable marine ecosystems (DFO 2012) and includes them as targets in DFO's cold-water coral and sponge conservation strategy

(DFO 2010). Spot Prawn is strongly associated with Sea Whip in Saanich Inlet (Chu and Tunnicliffe 2015) and other habitat forming species in the Salish Sea (Chu and Leys 2010). Because sessile species cannot migrate to avoid expanding hypoxia, sustained exposure inevitably results in population-level mortality with a net loss in their ecosystem service contributions (e.g. habitat provisioning). For commercial species that seek refuge in biogenic habitat, worsening hypoxia has the combined detrimental effects of reduced metabolic activity (affects individual level) and biogenic habitat loss (affects populations).

Currently, no other benthic time series exist in the coastal British Columbia, Canada that can be used to address either the long-term trends of effects of oxygen deficits or the potential for ecological recovery after sustained periods of deep-water hypoxia. Continuation of this benthic time series will determine the full recovery potential of this epibenthic community and guide ecological research in other areas in the Pacific region where oxygen regimes are also changing.

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43. JUVENILE SALMON IN THE STRAIT OF GEORGIA 2017

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43.1. Highlights

- The migration timing of juvenile Sockeye Salmon through the Strait of Georgia and into Discovery/Johnstone Strait waters was typical of observations in 2010-2014 (early June).
- The size of juvenile Pacific Salmon was above average or the largest observed in time series.
- Multiple age classes of Northern Anchovy remain present in the Strait of Georgia

43.2. 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 SoG during this first ocean summer and fall. In 2017 juvenile salmon were sampled during two trawl surveys (June 19 – July 2 and September 12 – 25). The Canadian Coast Guard research vessel *W.E. Ricker* that has conducted most of the surveys over the past 20 years, was retired from service. In its place, DFO chartered the commercial trawl vessel FV *Sea Crest* to conduct the surveys in 2017. Surveys were conducted within the time frame required and sets on the standard track lines that have been fished since 1998 following the protocol in Beamish et al. (2000) and Sweeting et al. (2003) were completed. In addition, some sets were completed in Desolation Sound, Discovery Islands, Gulf Islands and Puget Sound.

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 and distribution of juvenile salmon and size and condition of individuals in 2017 in comparison to catch levels and condition from 1998-2016.

43.3. Description of the time series

Catch-per-unit-effort (CPUE) for each survey is calculated using sets conducted on the standard track line (sets in red in Figure 43-1) and for specified habitat depths (Chinook Salmon 0-60 m; Coho Salmon 0-45 m, Pink, Chum and Sockeye Salmon 0-30 m) (Beamish et al. 2000; Sweeting et al. 2003). For the given sets, the total catch and area surveyed is used to calculate average catch per hour. In 2018 there was an issue with some of the sets conducted at depth by the charter vessel. In attempts to keep the net at a consistent depth range, the speed of the vessel fluctuated throughout the set. There is concern that the catch of the sets with variable speeds may be compromised. Due to this uncertainty; CPUE in 2017 should be considered minimum values. For Coho and Chinook salmon, the fall CPUE has been presented as a range with both the CPUE from all sets (lower value) and the CPUE from the sets with consistent speed (upper value) shown. Distribution catch maps include sets both on and off the standard track line. Although there was not consistent sampling in some of the associated areas, general patterns in overall distribution are used to provide insight. Time series of average length included salmon < 300 mm in summer survey and < 350mm in September survey in the analysis. This 20 year time series demonstrates that changes in the abundance, distribution, and condition of juvenile salmon have occurred over the past 20 years.

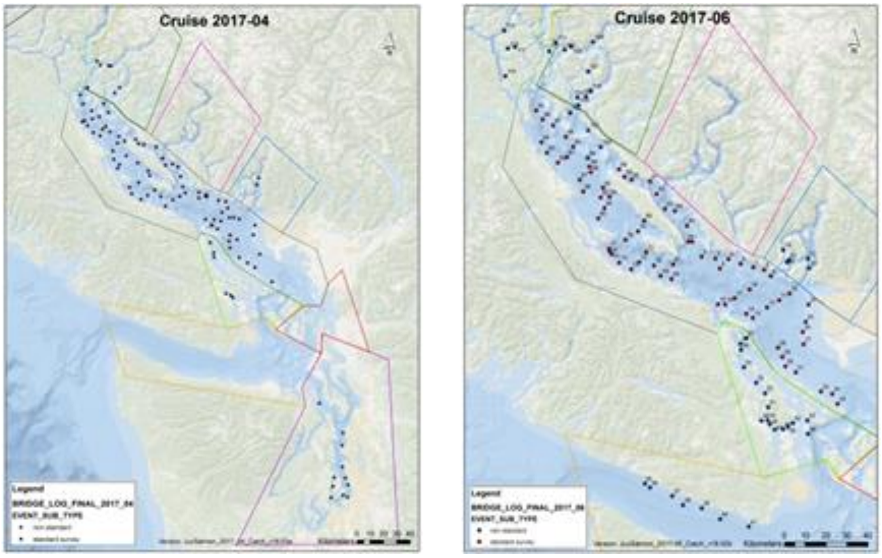


Figure 43-1. Location of sets in survey 2017-04 (June 19 - July 2, 2017) and survey 2017-06 (September 12-25, 2017).

43.4. Status and trends

The CPUE of Coho, Chinook, Chum and Sockeye Salmon was average or above average in the summer survey (Figure 43-2). Chinook Salmon CPUE was similar to values observed since 2010. Chum Salmon CPUE continued the increasing trend observed over the past 7 years. Sockeye Salmon CPUE was average but below levels observed in 2009 and 2001 (same cycle line). In the fall the CPUE of Chinook Salmon was average to above average compared to the past 20 years, the CPUE of Chum Salmon was the lowest observed and the CPUE of Coho Salmon was average to slightly above

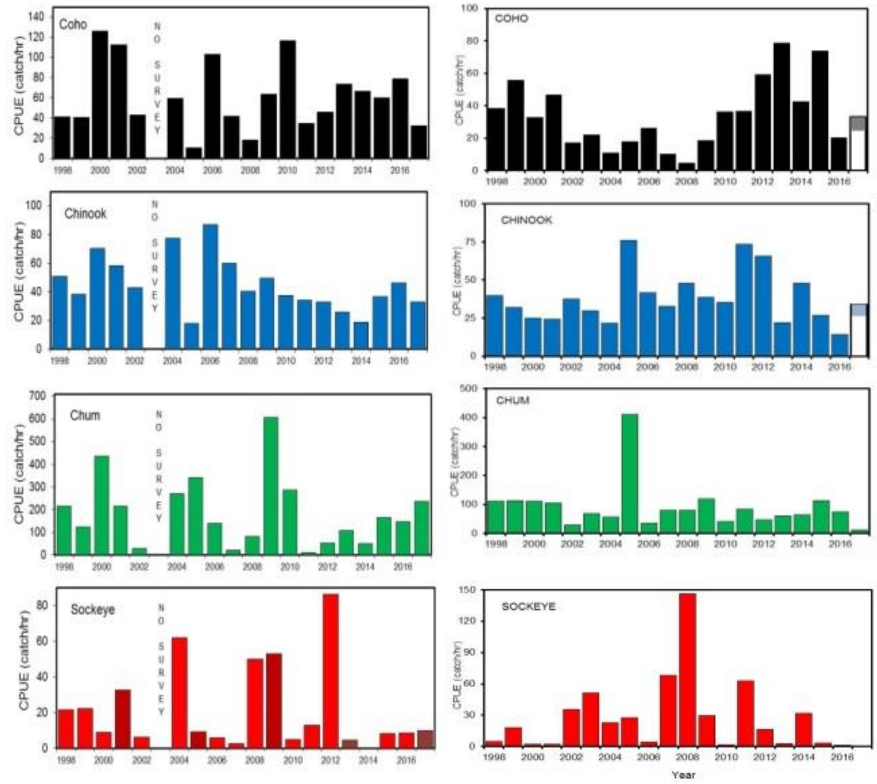
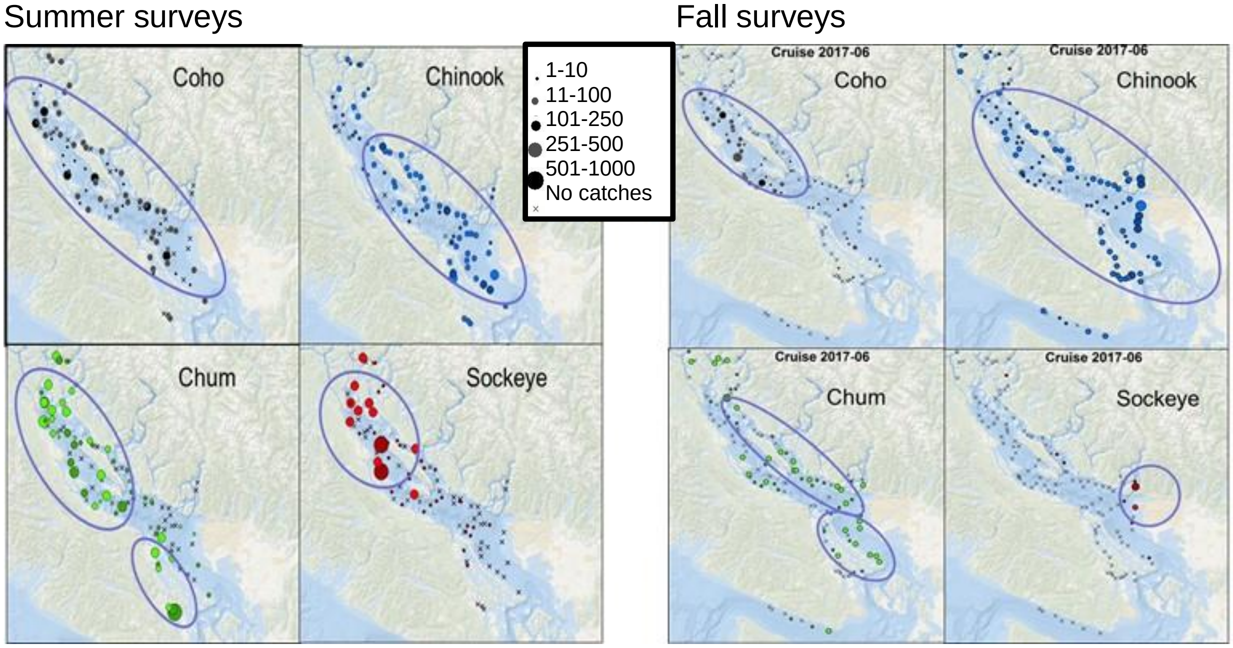


Figure 43-2. CPUE of salmon in early summer (left) and fall (right) from 1998-2017.

average depending on if the sets at depth with variable speeds were included or excluded in analysis (Figure 43-2).

During the 2017 summer survey period, the distribution of juvenile salmon was typical of the time series with the exception of juvenile Chum Salmon which was more northerly distributed with very few captured in the southern Strait of Georgia. Juvenile Sockeye Salmon continued to be observed in relatively large numbers in the northern Strait of Georgia during the summer survey period. Associated purse seines in the Discovery Island region in mid-June suggested a migration period through the Discovery Islands similar to observations 2010-2014 (Neville et al. 2013, 2015). During the fall survey, Coho Salmon were also northerly distributed. This northern distribution is typical for Coho Salmon, however, the number of sets with no Coho Salmon in the southern Strait of Georgia was anomalous to typical observations over the past 20 years. The distribution of Chinook, Chum and Sockeye Salmon was typical in September 2017 although the number of sets with no Chum Salmon was atypical.

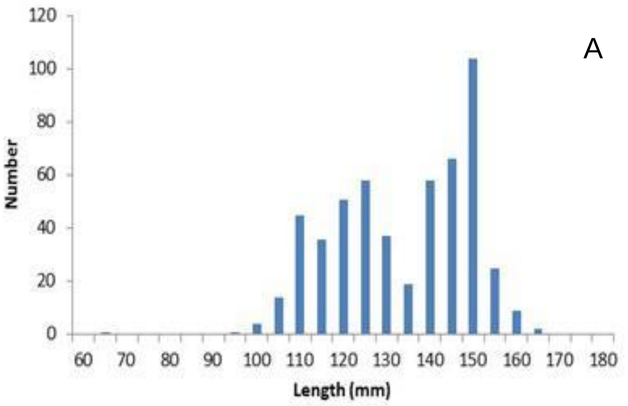
The size of the juvenile salmon captured in both surveys was above average for the time series. There proportion of empty stomachs was typical for each of the species and there was no trend in the fullness of the stomachs.


Summer surveys

Fall surveys

Figure 43-3. CPUE by set of salmon in early summer (left) and fall (right) in 2017. An x indicates a set with no juvenile salmon of given species captured

The catch of Northern Anchovy extended from Desolation Sound down to the Fraser River. The length frequency of the captured fish identified two distinct length modes (Figure 43-4). In addition, larval anchovy were identified in the diet of juvenile Coho and Chinook salmon during the summer survey. This variation in length is an indication that these fish are successfully spawning in the Strait of Georgia during 2017.



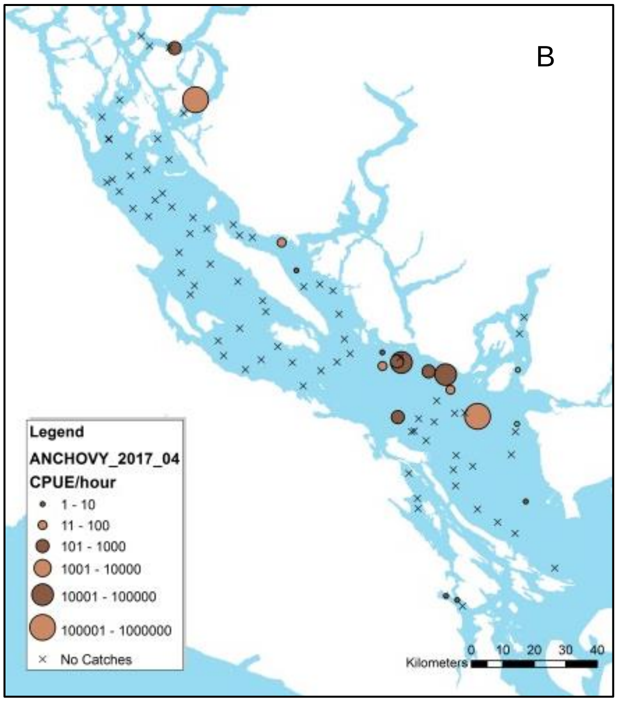


Figure 43-4. (A) Length frequency of Northern Anchovy caught in the Strait of Georgia in the summer of 2017 and (B) locations of catch. Note x indicates location of set with no anchovy in catch.

43.5. Factors influencing trends

Consideration must be given to a change in fishing vessel in 2017. Catch rates must be considered minimal due to some variation in fishing speeds that occurred throughout survey.

The sea surface temperatures in the Strait of Georgia from May to September were below the observations over the previous two years but remained above average for the past 30 years. These above average temperatures may be a contributing factor to the increased numbers of Northern Anchovy in the Strait of Georgia. This shift in ocean climate may also be affecting the distribution patterns of the juvenile salmon and resulting in lower catches in the southern Strait of Georgia. The increase in size of juvenile salmon, especially Coho Salmon, suggests good early marine growth within the Strait of Georgia. The increased size in the June survey and the consistency in the low proportion of empty stomachs in 2017 compared to most other survey years suggests that the prey availability during the juveniles first weeks to months in the ocean was good.

43.6. Implications of those trends

Uncertainty in total catch numbers resulting from the charter vessels difficulty in maintain consistent speed has limited the ability to use 2017 catch numbers to comment on forecasts of subsequent returns at present. The exception is for Coho Salmon where the combination of both catch, the large size of the juveniles and the feeding rates in the of 2017 were all positive signals. The early marine survival index (Beamish et al. 2010) indicates that the returns of Coho Salmon in 2018 should be average to above average.

The changes and trends observed in the catch rates, distribution and size of juvenile salmon in the Strait of Georgia over time indicate that these factors are not random. Therefore, it is important to understand how changes in these conditions during the first year in the ocean are related to overall marine survival.

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44. TELEMETRY-BASED ESTIMATES OF EARLY MARINE SURVIVAL AND RESIDENCE TIME OF JUVENILE SALMON IN THE STRAIT OF GEORGIA AND QUEEN CHARLOTTE STRAIT, 2017

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44.1. Highlights

- Based on acoustic tracking since 2010, the survival of Chilko Lake Sockeye during downstream migration to the Fraser River mouth ranged between 20-58%, with the highest survival in 2017.
- Early marine survival from the Fraser River mouth to northern Vancouver Island (390 km) ranged between 18-36% for age-2 Chilko Lake Sockeye, which is comparable to Cultus Lake Sockeye (20-52% from 2004-2007) and Steelhead migrating from the Seymour River (27% in 2015; ~375 km).
- Age-1 Chilko Lake Sockeye survival to the north end of Strait of Georgia in 2017 was comparable to age-2 Chilko Lake Sockeye, but travel times for age-1 fish in the Strait of Georgia were longer.
- Route preference through the Discovery Islands may differ between species and years. In 2015, almost 3/4 of tagged steelhead smolts migrated through Discovery Passage west of Quadra Island. In 2016, about half of the sockeye used this route. In 2017, we found that Sockeye were somewhat more likely to migrate east of Quadra Island.
- Juvenile Sockeye exposure time to fallowed, individual fish farms in the Discovery Islands was observed to be about 4.5 minutes. Migration speed in Hoskyn and Okisollo Channel was 18 km•d-1, or 2 body-lengths•sec-1, consistent with prior years' measurements through this region.

44.2. Description of the time series

We began estimating downstream and early marine survival of juvenile salmon in 2004 as part of the Pacific Ocean Shelf Tracking (POST) study, when acoustic telemetry arrays capable of detecting 69 kHz tags were first deployed. The first marine dual-frequency sub-arrays were deployed in 2015 in the Discovery Islands (DI) and Johnstone Strait (JS; Figure 44-1). These receivers are capable of detecting new, smaller transmitters, which transmit on 180 kHz (Figure 44-2). Receiver arrays in the lower Fraser River were compatible with both tag types until 2017; in this year, only larger 69 kHz tags could be detected.

From 2004-2007, we tracked large hatchery-reared Cultus Lake Sockeye; from 2010-2014, we tracked age-2 Chilko Lake Sockeye; in 2015, we tracked hatchery-reared Seymour River summer steelhead; and in 2016 and 2017, we tracked wild age-1 and age-2 Chilko Lake

Sockeye (Figure 44-2). Age-1 fish are more representative of the Chilko Lake population. In 2017, juvenile Sockeye were captured at the DFO managed weir at Chilko Lake and acoustic tagged as part of the thesis work of C. Stevenson and S. Johnston (UBC).

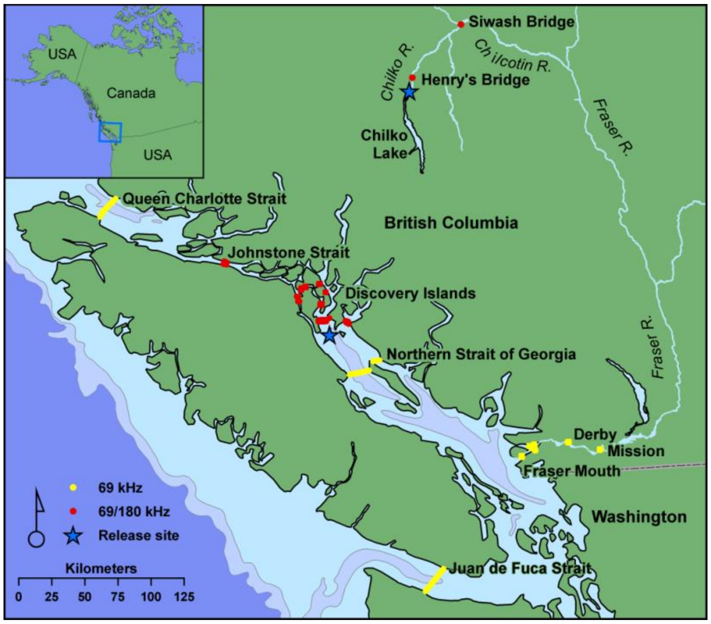

Figure 44-1. Map of the acoustic receiver array used to track juvenile salmon in 2017. Yellow lines and dots represent single frequency (69 kHz) receiver sub-arrays, while red dots and lines represent dual frequency (180 kHz) sub-arrays. Components of the array are variously managed by Kintama Research 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 sites of acoustic tagged smolts in 2017. Isobaths (200 and 500 meter) are coloured in pale blue.

We estimated survival through the Strait of Georgia (SOG) and as far as the north-east end of Vancouver Island using Cormack-Jolly-Seber models (CJS; Cormack 1964, Jolly 1965, Seber 1965). We also determined residence time (travel time), travel rate, and route selection in these areas when possible. Changes in array locations and detection frequencies prevent us from comparing survival in identical regions over all years, but we have made comparisons where possible.

Figure 44-2. Age-1 (top picture) and age-2 (bottom picture) Chilko Lake Sockeye smolts. Age-1 smolts were tagged with new, smaller transmitters (model V4; 180 kHz). Age-2 smolts were tagged with model V7 transmitters (69 kHz).

To begin to address the effect of salmon farms on wild Salmon survival, we deployed receivers in Hoskyn and Okisollo channels and at two fallowed Salmon farms (on the east and north side of Quadra Island) in 2017, to provide baseline measurements of juvenile Sockeye exposure time to a region containing salmon farms (Figure 44-3). We calculated near-field exposure as the interval between the first and last detections on a receiver located near each farm within a single passage event.

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 used to refine stock productivity and forecast models.

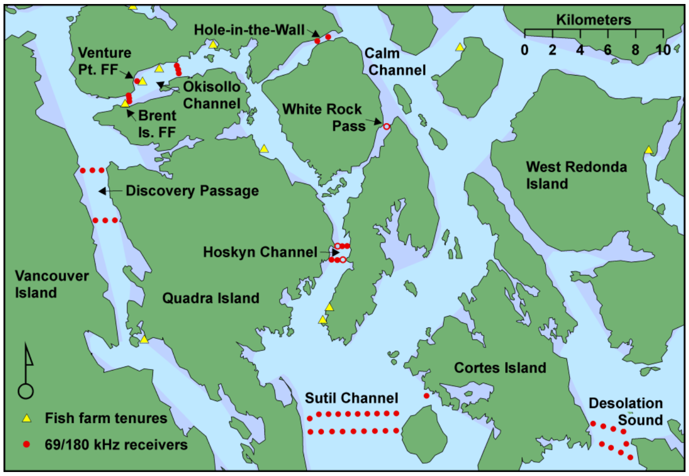

Figure 44-3. Map of the acoustic receiver array used to track juvenile salmon through the Discovery Islands and near salmon farms in 2017. Yellow lines and dots represent single frequency (69 kHz) receiver sub-arrays, while red dots and lines represent dual frequency (180 kHz) sub-arrays. Discovery Passage, Sutil Channel, and Desolation Sound were deployed 2015-2017, while Hoskyn and Okisollo channels were only deployed in 2017.

44.3. Status and trends

44.3.1. Survival

A decline in survival in the tributaries was apparent for Cultus Lake and Chilko Lake Sockeye populations in all years (except for age-2 Chilko Sockeye in 2017) followed by high survival in the Fraser River (see Rechisky et al. 2018, Clark et al. 2016, and Figure 44-4)

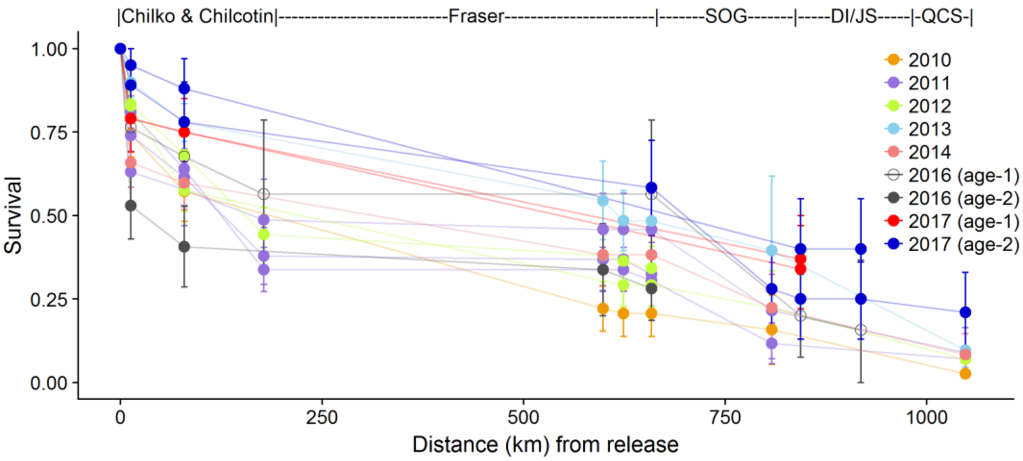

Figure 44-4. Cumulative survival of Chilko Lake Sockeye smolts 2010-2014 (age-2), 2016-2017 (age-1 and 2; Sockeye were not tagged in 2015). SOG=Strait of Georgia, DI= Discovery Islands, JS=Johnstone Strait, QCS=Queen Charlotte Strait. Note that there were two tag types (age-2) and two different tag programs (age-1) in 2017.

Survival of Cultus Lake Sockeye from release to the Fraser River mouth (~100 km) was 50-70% (Welch et al. 2009). Survival of age-2 Chilko Lake Sockeye to the Fraser River mouth (~650 kms) ranged between 22-48% from 2010-2014. In 2016, survival of age-1 Chilko Lake Sockeye was 56% (SE=11%), but only 28% for age-2 fish. Survival to the Fraser River mouth (654 km) in 2017 was 58% (SE=7%) for age-2 Chilko Lake Sockeye, the highest in the Chilko Lake Sockeye time series. Age-1 fish could not be detected on Fraser River receivers in 2017 but it was likely comparable because cumulative survival of age-1 fish to the DI array was ~36%.

Age-2 fish also had the highest overall survival to the Queen Charlotte Strait sub-array (QCS) in 2017 (21%).

Beginning in 2016, both age groups were monitored by dual-frequency receivers deployed in the Discovery Islands (DI). Survival from Chilko Lake to the DI sub-array (river + SOG) in 2016 was 20% (SE=6%) for age-1 and was unusually low for age-2- only 2% (SE=1%). In 2017, survival to DI was 35% (SE=5%) for age-1 juveniles and 25% (SE=6%) for age-2 juveniles.

Early marine survival from the Fraser River mouth to QCS (390 km) ranged between 20-52% for the Cultus Lake population, and 18-36% for age-2 Chilko Lake population (Figure 44-5). Survival of Seymour River steelhead (which enter the SOG north of the Fraser River basin) to QCS (~375 km) was 27% (SE=5.3%) in 2015 (not shown, see Healy et al. 2017).

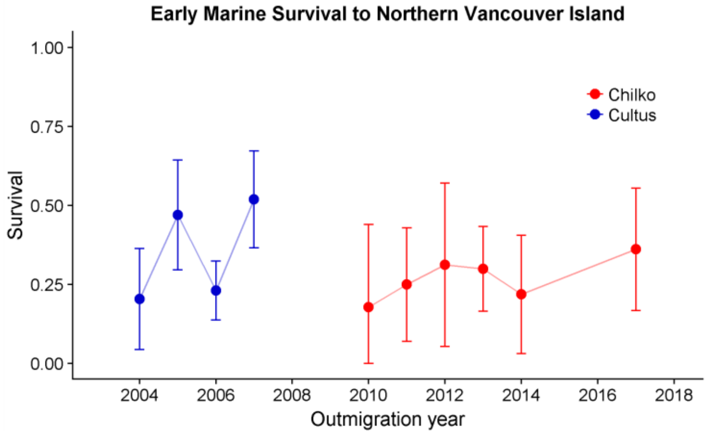

Figure 44-5. Early marine survival from the Fraser River mouth to the Queen Charlotte Strait sub-array for Cultus Lake Sockeye and age-2 Chilko Lake Sockeye Salmon tagged with 69 kHz transmitters.

We calculated daily survival rates 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 44-1). In our 12-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 and 2017 (Figure 44-6).

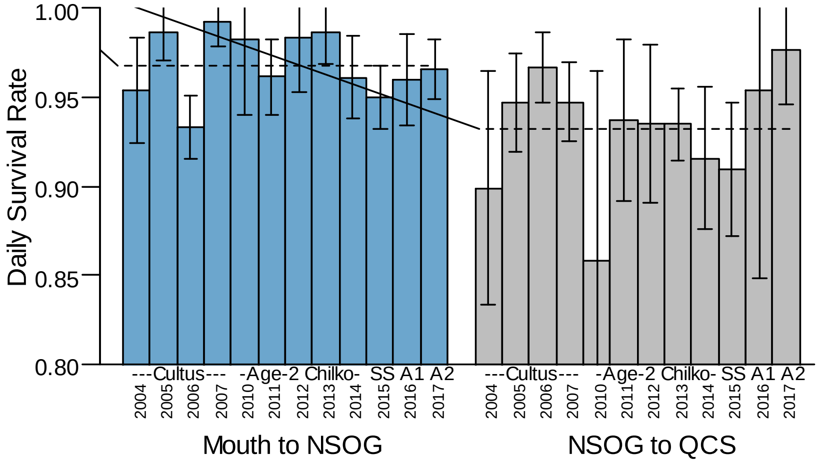

Figure 44-6. Daily survival rates for Cultus Lake Sockeye, Chilko Lake Sockeye, and Seymour River steelhead smolts (SS). The dashed line represents the mean daily survival rate for all years. A1=age-1 Chilko Sockeye, A2=age-2 Chilko Sockeye, NSOG=northern Strait of Georgia, QCS=Queen Charlotte Strait. Error bars are 95% confidence intervals. Note that A1 Sockeye survival in 2016 is from the Fraser River to DI and DI to JS.

44.3.2. Chilko Lake Sockeye travel times and rates

Travel times and rates for Chilko Lake Sockeye are reported in Table 44-1 and Table 44-2. Cumulative travel time of age-1 fish to the Discovery Islands array was 10 days longer in 2017 compared to 2016. Not surprising, travel time was relatively longer for age-1 fish compared to age-2. Too few age-2 juveniles were detected in 2016 to estimate marine travel times.

Table 44-1. Median travel time for Chilko Lake Sockeye (days). QCS=Queen Charlotte Strait sub-array, NA=not applicable, ID=insufficient data, [a]: age-1 tags could not be detected in the Fraser River in 2017 we so assumed age-1=age-2, [b]:Travel time from release to the Discovery Islands (37 days) minus travel time to the Fraser River mouth, [c]: n=2, [d]: Fraser mouth to northern Strait of Georgia sub-array (NSOG), [e]: NSOG to QCS.

Year	Age	Release to Fraser River mouth	Fraser to Discovery Islands	Discovery Islands to Johnstone Str	Johnstone Str to QCS
2017	1	6.2[a]	30.8[b]	5.4	NA
	2	6.2	25.1	3.0	3.0
2016	1	4.9	20.5	7	NA
	2	4.9	ID	ID	4.1[c]
2010-2014	2	5.2-8.4	11.9-18.6[d]	9.1-15.5[e]	

Table 44-2. 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 we could not detect age-1 fish tags at the river mouth or on QCS, ID=insufficient data, [a]: n=2, [b]: Fraser to NSOG, [c]: NSOG to QCS.

Year	Age	Release to Fraser River mouth	Fraser to Discovery Islands (SOG)	Discovery Islands to Johnstone Str	Johnstone Str to QCS
2017	1	NA	NA	2.5 (19.1)	NA
	2	9.3 (104.1)	0.6 (7.13)[b]	3.0 (33.2)	3.0 (34.1)
2016	1	17.0 (133.2)	1.3 (10.3)	1.8 (15.0)	NA
	2	12.3 (133.9)	ID	ID	2.4 (26.9)[a]
2010-2014	2	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)	

44.3.3. Migration Route Selection

In 2015, the majority (71%) of tagged steelhead with known migration routes migrated through Discovery Passage, west of Quadra Island; however, juvenile Chilko Lake Sockeye tended to use Sutil Channel east of Quadra Island (>50%) as well as Discovery Passage in 2016 and 2017. Few salmon migrated through Desolation Sound. See Figure 44-3 for a detailed map of the Discovery Islands array.

44.3.4. Exposure to salmon farms

Median near-field exposure at both Salmon farms was short, approximately 4.5 minutes. Travel time though Hoskyn and Okisollo channels (25 km) was ~30 hrs. Within Okisollo Channel, travel time from the eastern end to the western end (4 km) was ~6 hrs. Therefore, exposure times when farms were fallowed were short. This study is being repeated in 2018 when salmon farms are stocked.

44.4. Factors influencing trends

We observed three major mortality trends: high mortality in the small freshwater tributaries to the Fraser, low mortality in the Fraser River mainstem, and higher mortality in the northern marine area relative to the SOG. In the tributaries, mortality occurs very rapidly and is partially due to bull trout predation (Furey et al. 2015), vulnerability related to downstream migration timing (Furey et al. 2016) and disease (Jeffries et al. 2014). 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.

44.5. Implications of those trends

Smolt-to-adult return rates of Fraser River sockeye have declined to 2-5% in recent years (see Grant et al. 2018). Decreases in freshwater and early marine survival may have contributed to this decline; however, based on our estimates, ~1/4-2/3 of tagged fish migrating out of the array area will survive to return as adults indicating a potentially wider marine survival problem.

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45. FRASER RIVER SOCKEYE 2017 UPDATE: ABUNDANCE AND PRODUCTIVITY TRENDS

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45.1. Highlights

- Declines in Fraser River Sockeye Salmon (*Oncorhynchus nerka*) returns began in the mid-1990s. These declines dramatically reversed in 2010 and 2014, when returns hit record highs of 20 to 30 million fish. Declines resumed in 2015, set a record low in 2016 of 853,000 fish, and remained low through 2017.
- Productivity (recruits-per-spawner) across all 19 Fraser Sockeye populations largely declined from the mid-1990's to 2010 and was followed by a period of variability in individual population survivals from 2010 to 2016. Although returns were low again in more recent years, from 2015 to 2017, productivity was only consistently low across all populations in 2017.
- The consistent decline in productivity across most Fraser Sockeye populations in recent decades suggests that broad scale regional factors are affecting returns. The period of mixed productivity across populations from 2010 to 2016, however, suggests that local variations also contributed to observed trends in these particular years.
- Both freshwater and marine water temperatures have been warmer than average to exceptionally warm since 2013. Fraser Sockeye that returned in 2015 to 2017, and those that will return in 2018 have spent most of their lives in these warmer conditions.

45.2. Description of the time series

Fraser River Sockeye Salmon returns, productivity (recruits-per-spawner), and Chilko Sockeye Salmon freshwater and marine survival 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 spending their first two winters in freshwater, and their last two winters in the ocean. Therefore, total Fraser Sockeye Salmon survival is influenced by both the freshwater and marine ecosystems.

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.

45.3. Status and trends

Total Fraser Sockeye returns have historically varied (Figure 45-1A) due to the four-year pattern of abundances (cyclic dominance) exhibited by some of the larger populations, and variability in annual productivity (returns-per-spawner) (Figure 45-1B) and spawning escapements. After reaching a peak in the early 1990s, returns generally decreased, due to declines in population productivities, which reached historic lows in the 2009 return year. Subsequently, the Fraser Sockeye aggregate exhibited mixed productivities from 2010 to 2014, and again declined from 2015 to 2017. Trends in total Fraser Sockeye returns and productivity are largely determined by the populations that comprise the greatest proportion of the total abundance in each year, namely the Summer Run populations (based on return timing of adults to their spawning grounds) such as Chilko, and Late Run populations such as Late Shuswap (on dominant cycle years). Across the individual Fraser Sockeye populations there has been considerable variability in productivity (recruits-per-spawner) (Figure 45-2). Although most populations, such as Chilko and Stellako, have exhibited declining trends since the 1990’s, some populations, such as Late Shuswap, have not exhibited any systematic trends, and one population in particular, Harrison Sockeye, increased in productivity during this period (Figure 45-2). However, survival across all populations was below average in the 2005 and 2013 brood years (2009 and 2017 return years), and for many these years contained the lowest productivites on record.

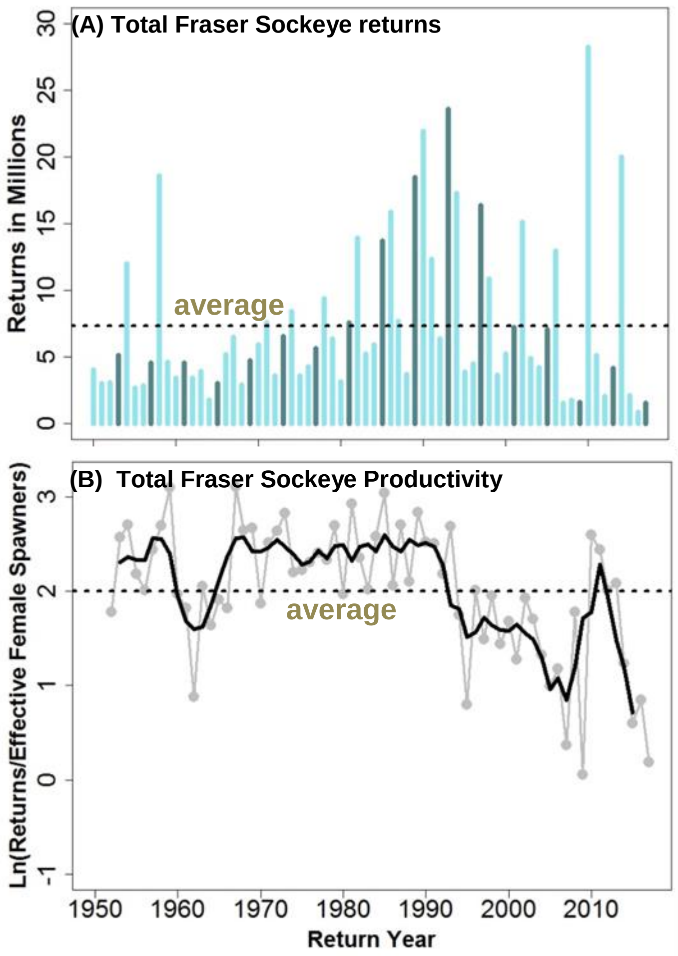

Figure 45-1. (A) Total Fraser Sockeye annual returns (dark blue vertical bars for the 2017 cycle and light blue vertical bars for the three other cycles). Recent returns from 2012 to 2017 are preliminary, and 2017 (the last data point) is an in-season estimate only. (B) Total Fraser Sockeye productivity (log$_e$ (returns/total spawner)) is presented up to the 2017 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.

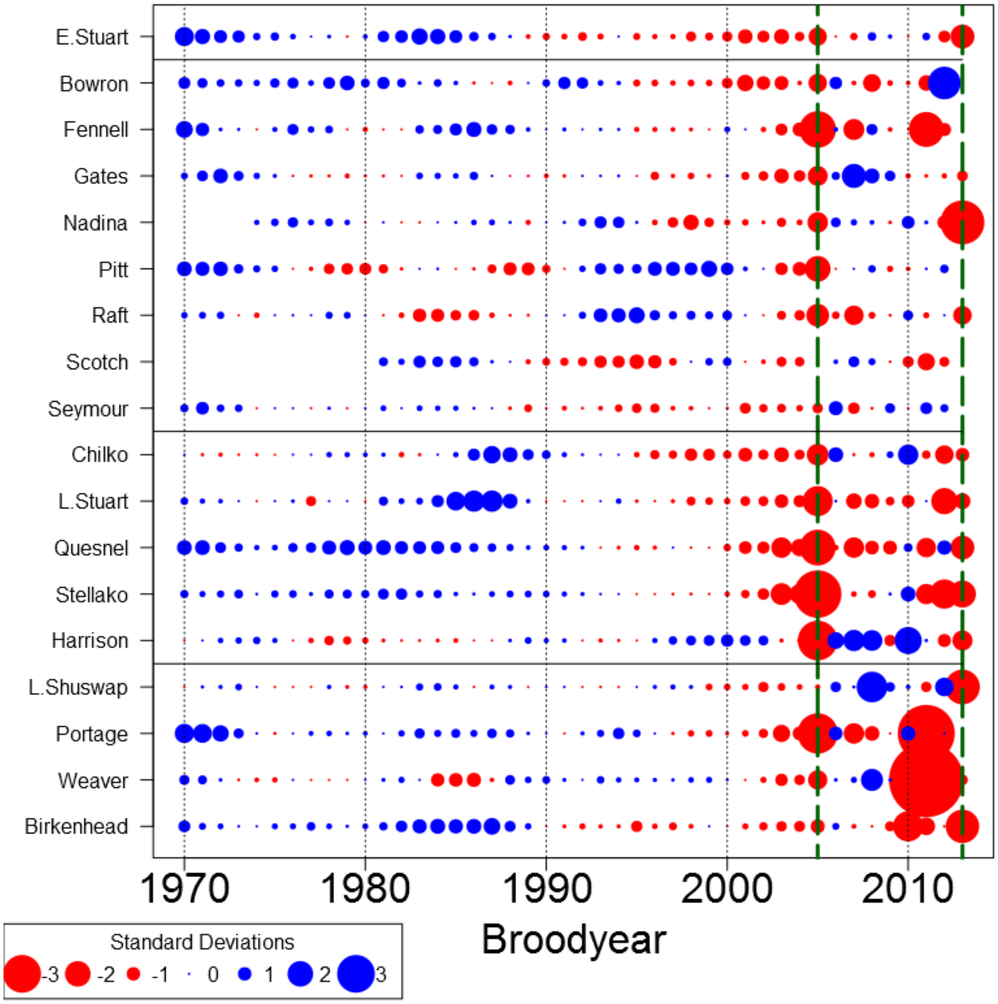

Figure 45-2. Fraser Sockeye productivity (standardized z-scores of Ricker model residuals for all populations except Scotch, Seymour and Late Shuswap, which are Larkin residuals) up to the 2012 brood year (2017 return year). Prior to the 2005 brood year, 4 year moving averages are plotted while annual estimates are provided for the more recent years. 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.

45.4. Factors influencing trends

Chilko is the only Fraser Sockeye population with a long and complete time series of freshwater and 'marine' survivals. Chilko is a key population that contributes large proportions to the annual Fraser Sockeye returns. Therefore, understanding which broad ecosystem (freshwater or marine) influences the total survival of this population explains a large proportion of the total returns. For Chilko Sockeye, freshwater survival has generally improved in recent years (Figure 45-3A). 'Marine' survival data for Chilko (Figure 45-3B) is similar to the aggregated Fraser Sockeye total survival trend (Figure 45-1B). Chilko exhibited declines in 'marine' survival in the

1990’s, which culminated in the lowest survival on record in the 2005 brood year (2009 return year). Although Chilko ‘marine’ survival improved for the 2006 to 2009 brood years (2010 to 2013 return years), in recent years marine survival has been poor.

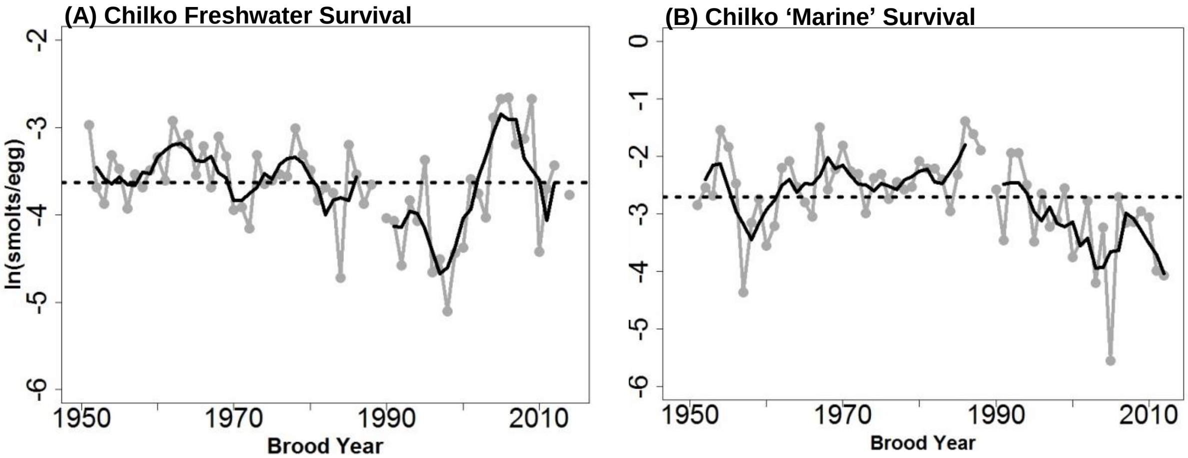

Figure 45-3. (A) Chilko River Sockeye freshwater survival (log$_e$ smolts-per-egg) and (B) ‘marine’ (log$_e$ recruits-per-smolt) annual survival. The filled grey circles and grey lines are annual values and the black line is the smoothed four-year running average survival. Freshwater survival has generally increased in the past decade, with the notable exception of 2010), 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. 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.

Note: High water levels prevented accurate counting of smolts in 2015, therefore freshwater and marine survival estimates are unavailable for the 2013 brood year (2017 return year).

Although it is unknown what factors drive the observed patterns in survival, some of the variability observed in recent years may be associated with specific events affecting particular populations. Birkenhead and Weaver Sockeye experienced a major landslide upstream of their freshwater rearing habitat, which coincided with exceptionally poor survival in recent years. A mine breach (Mount Polley) in the Quesnel system dumped mine tailings into the west arm of Quesnel Lake, the effect of which is currently unclear with regards to the productivity of Quesnel Sockeye. Finally, populations that rear in the Shuswap Lake complex (Scotch, Seymour and Late Shuswap) appear to have experienced lagged density-dependent effects in recent years, due to the high density of juvenile sockeye in this lake from the large 2010 brood year.

45.5. Implications of the observed trends

Understanding factors that contribute to Fraser Sockeye Salmon return trends can increase the certainty associated with the pre-season return forecasts (DFO 2017a). 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. Currently, these forecasts are associated with high uncertainty (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 2018 forecast process (DFO 2016b). This supplement provides additional information on the condition and abundance of various populations from the 2014 brood year escapement through to 2017 jack returns. It currently provides supplemental information on the survival conditions Fraser Sockeye populations experienced throughout their life-history, from their brood year as eggs in the gravel, up to the return year.

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Individual reports on the special session

46. ASSESSMENT AND MONITORING OF THE GLASS SPONGE REEFS

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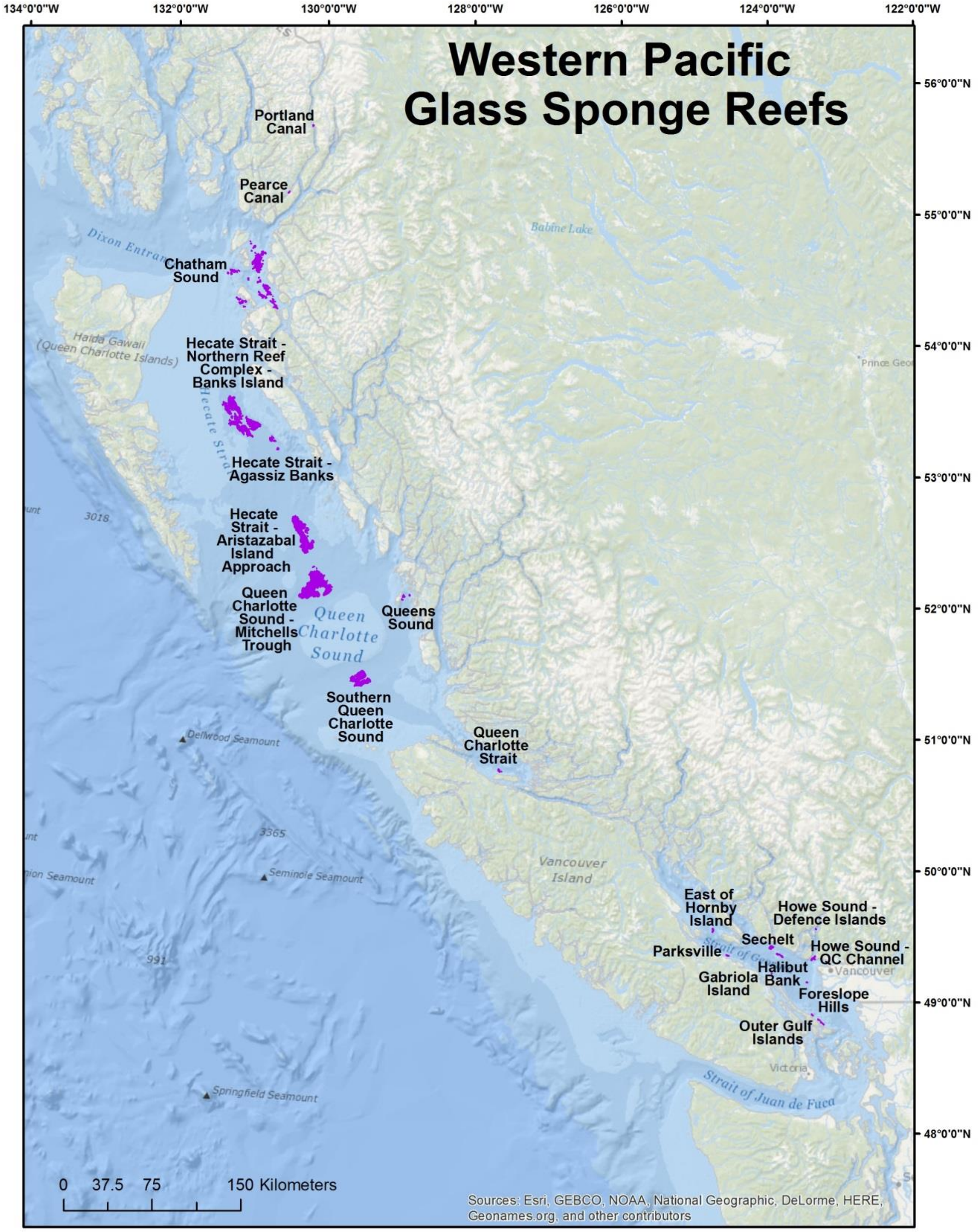
46.1. Highlights

- Glass sponge reefs are unique ecosystems found along the Pacific coast of Canada and the United States.
- Research by DFO Science and collaborators is focusing on understanding the relationship between the reefs' geomorphic expression and ecological status, constructing reef food webs, experimentally testing reef-building glass sponge sensitivity and resilience to ocean acidification, determining larval settlement timing, developing novel approaches to monitor reef communities, and optimizing monitoring survey designs.
- This research contributes to reef delineation, assessment, and monitoring, and informs management and policy decisions.

46.2. Overview of the glass sponge reefs

Glass sponge bioherms, or reefs, are unique biogenic habitats found along the coasts of western Canada and the United States. Sponge reefs were known only from fossil records until analogous live reefs were discovered in Hecate Strait and Queen Charlotte Sound in the 1980s using remote sensing techniques (Conway et al. 2001). More recently, the reefs were found in Portland Canal between Southeast Alaska and British Columbia (Stone et al. 2014) and in Chatham Sound (Shaw et al. 2018). A number of smaller reefs have also been discovered in the Strait of Georgia and Howe Sound (Conway et al. 2005, 2007, Cook et al. 2008, Clayton and Dennison 2017, DFO 2018a) (Figure 46-1).

Several studies have provided insight into the ecosystem function of the glass sponge reefs. The reefs contribute to the productivity of benthic ecosystems by forming habitat for diverse communities of invertebrates and fish (Cook et al. 2008, Marliave et al. 2009, Chu and Leys 2010, Dunham et al. 2015, 2018, DFO 2018a), act as regionally important silica sinks (Chu et al. 2011), and, being one of the densest known communities of deep-water filter feeders, link benthic and pelagic environments through carbon and nitrogen processing (Kahn et al. 2015). Yet, many aspects of the reefs' function are not yet fully understood, partially due to most reefs occurring deeper than safe SCUBA limits and thus being difficult to access.



Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors

Figure 46-1. Glass sponge reef locations along the Pacific Coast. Reef names in the Strait of Georgia correspond to fishing closure nomenclature in DFO Fishery Notice FN0415. Reefs in Howe Sound are not shown here, but can be found in DFO (2018a).

46.3. Summary of ongoing research

Over the last five years, we completed standardized Remotely Operated Vehicle (ROV) surveys of most known glass sponge reefs along B.C. coast. We developed methods for quantitative assessment of reef status and applied them to the reef complexes in the Strait of Georgia (Dunham et al. 2018) and in Howe Sound (DFO 2018a) to enable comparisons over space and time.

Our ongoing research to understand reef function is multifaceted and highly collaborative. We are currently working on understanding the relationship between the reefs' geomorphic expression and ecological status (with Kim Conway, John Shaw, and Rob Kung, NRCan), constructing reef food webs (with the Leys Lab, University of Alberta), experimentally testing reef-building glass sponge sensitivity and resilience to ocean acidification (with Angela Stevenson and Chris Harley, UBC), conducting an *in situ* field study to determine larval settlement timing (with Marine Life Sanctuaries Society), and developing novel approaches to monitor reef communities using passive acoustics (with the Juanes Lab, UVic). Research is underway to optimize monitoring survey designs by maximizing power to detect change in the ecosystem while minimizing costs and time requirements. This work would not be possible without active participation from past and current Habitat Ecology Program staff (Sarah Davies, Janet Mossman, and Lily Burke), DFO ROV team (James Pegg and Wolfgang Carolsfeld), other DFO Science collaborators, and many students and volunteers.

46.4. Application of research to management and policy

Our work on delineation of reef polygons based on ecological and geological evidence has informed spatial management decisions. Nine reefs in the Strait of Georgia have been protected by the bottom-contact fishing closures since 2015; these closures are part of the Other Effective Area Based Conservation Measures, or marine refugia, contributing towards the Convention on Biological Diversity Aichi Biodiversity Target 11. The reefs in Hecate Strait became a Marine Protected Area (MPA) in February 2017. Multiple reefs in Howe Sound were recently delineated (DFO 2018a) and are under consideration for spatial protection.

Building understanding of the structure and the function of the reef ecosystems allows us to advise managers on monitoring approaches, including indicators of reef status. To enable ecologically relevant monitoring of the glass sponge reefs and the assessment of the effectiveness of reef protection measures, we are creating reef status summaries (Dunham et al. 2018, DFO 2018a). These one to two-page summaries highlight baseline levels of monitoring metrics based on best available knowledge to date. We are also creating decision trees to aid in interpretation of assessment and monitoring results.

Knowledge of sponge reef ecology also contributes to decision-making on authorizing activities within MPAs and other protected areas through the MPA Activity Application process and other departmental guidance (DFO 2018b).

46.5. Future directions

How can we balance human use and healthy ecosystems? How can we define the “health” of sponge reefs and other biogenic habitats? Well-designed long-term monitoring programs that are consistent, but iterative − allowing incorporation of new knowledge − will be instrumental for answering these big-picture research and management questions.

As our understanding of sponge reefs expands, we will be able to determine and quantify the role the reefs play in the functioning of the larger ecosystems in which they occur. A critical gap in our knowledge is an understanding of the natural variability in healthy reef systems. For example, we know that the sponges can recover from small, but not large physical disturbances (Dunham et al. 2015, Kahn et al. 2016), but we have limited data on how sponge abundance changes in an undisturbed healthy system. Additionally, we know the reefs support high diversity of megafauna (>100 species) (Cook et al. 2008, Marliave et al. 2009, Chu and Leys 2010, Dunham et al. 2015, Dunham et al. 2018), but no data exists on temporal patterns in the abundance and diversity of megafauna associated with the reefs. Future work should be directed at filling these knowledge gaps in order to inform the frequency and timing of monitoring activities. Finally, the potential impact of additional stressors to reef ecosystems, including microplastics accumulation and anthropogenic noise, should be evaluated.

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47. OFFSHORE PROTECTED AREAS: CANADA'S OLDEST MARINE PROTECTED AREA AND NEWEST AREA OF INTEREST

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47.1. Highlights

- The Marine Spatial Ecology and Analysis (MSEA) section undertook cruise surveys in 2016 and 2017 using deep-sea technology to collect baseline data and conduct ecological research in two offshore protected areas.
- In 2016, the remotely operated vehicle (ROV) ROPOS conducted four dives in the Endeavour Hydrothermal Vents Marine Protected Area (EHV MPA) and two at the Middle Valley sedimented hydrothermal vent fields, including experimental sampling at large hydrothermal vent edifices, surveys in rarely observed minor vent fields, and initial exploration of extinct sulfide chimneys.
- In 2017, a seamount survey within the large Offshore Pacific Area of Interest (OP AOI) performed the first explorations of Dellwood, Union, Curtis, and one unnamed seamount, while discovering a total of seven previously unknown seamounts (including the latter two)(Table 47-1). The first imagery from these surveyed seamounts, which fall within recent bottom-contact fishing closures, revealed dense populations of rockfish, thornyhead, corals, sponges, and many other invertebrates.

47.2. Brief overview of the Endeavour Hydrothermal Vents MPA and Offshore Pacific Area of Interest

Recently, the MSEA section has led cruises to the two protected areas that lie in Canadian Pacific offshore waters: the EHV MPA in 2016 and the OP AOI in 2017. Hydrothermal vents and chemosynthetic ecosystems were discovered along the Juan de Fuca Ridge in the early 1980s (DFO 2018a). After two decades of active research at the vents, scientists encouraged DFO to consider protecting these unique environments under the *Ocean's Act* to ensure they would not be over-sampled or degraded by human activities. The EHV MPA was created in 2003 and became Canada's first MPA, the first deep-sea MPA in the Pacific Ocean, and the first MPA globally designed to protect chemosynthetic ecosystems. It covers approximately 100 km^2 of seafloor, of which about 1 km^2 is made up of major vent fields where scientific activities are closely managed. Its conservation objective is to manage human activities such that environmental impacts are less than what would be expected due to natural dynamic processes (eruptions, tectonics, etc.).

The OP AOI was formally announced in May 2017 (DFO 2018b). It encompasses 140,000 km^2 of seafloor, which is 2.4% of Canada's exclusive economic zone (EEZ), and encompasses the EHV MPA. The basis for its designation was the large numbers of ecologically and biologically significant areas (EBSAs) in this area, especially seamounts and hydrothermal vents. Seamounts are underwater volcanic mountains that rise at least 1000 meters from the seafloor, and are hotspots of biological productivity and benthic diversity (Figure 47-1). They also tend to host Vulnerable Marine Ecosystems (VME) consisting of sponges, corals, anemones, and other structure-forming invertebrates that are easily damaged by bottom fishing. This large area will greatly assist Canada in meeting Aichi targets (10% seafloor protection by 2020). An advisory committee was formed in 2017, which is currently working to develop a regulatory approach. A November 2017 bottom-contact fisheries closure affected 60% of the OP AOI, largely around known seamounts. Further advisory committee meetings will discuss conservation objectives, risk assessments, and possible management measures before an official MPA is designated, potentially in 2019 or 2020.

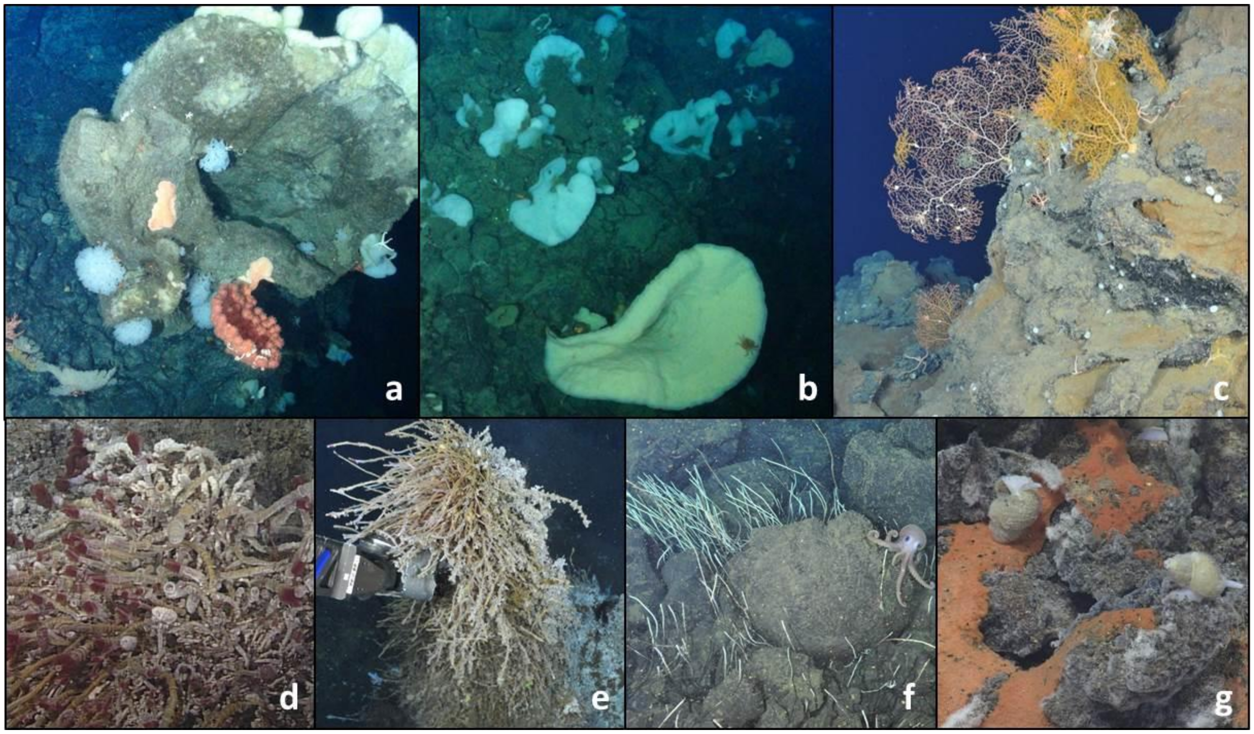

Figure 47-1. Vulnerable Marine Ecosystem (VME) species at seamounts (a-b) and extinct vent chimneys (c); microhabitats sampled within EHV MPA include high-flow tubeworms (d), low-flow tubeworms (e), basalt-hosted tubeworms (f), and active bacterial mats at the base of chimneys (g).

47.3. Summary of cruise research

47.3.1. Endeavour Hydrothermal Vents Marine Protected Area

In August 2016, DFO led a survey of the EHV MPA aboard CCGS *J.P. Tully*, collaborating with scientists from University of Victoria (UVic) and Memorial University of Newfoundland (MUN). The ROV *ROPOS* performed dives at four vent fields inside the EHV MPA, and two vent fields at Middle Valley. Additionally, one dive was conducted in Saanich Inlet as part of a CHONe project led by Verena Tunnicliffe (UVic), and two short dives were conducted at 160-200 m near Barkley Sound to explore a region where methane seep bubble plumes had been observed by Natural Resources Canada. The main objectives for the vent dives included surveying several hydrothermal vent fields that had been visited rarely, and for which DFO had no baseline habitat data (Sasquatch, Raven, Clam Bed and Middle Valley), sampling of different tubeworm habitats to study functional traits of animal and microbial communities, geological sampling to investigate the evolution of hydrothermal chimneys after they cease to be active, and the initiation of an experiment to compare invertebrate recruitment patterns among vent fields and microhabitats in EHV MPA.

Previous research at EHV MPA has largely been focused on hydrothermal vent chimneys, the extremely active and dynamic seafloor features that include black smokers, huge sulfide edifices standing tens of meters tall, and dense aggregations of tubeworms and other fauna. These are clustered into large, “active” vent fields, but we know little about the EHV MPA habitats outside of these areas. Our baseline surveys were intended to use *ROPOS’* high definition cameras while transecting through less active vent fields, sometimes driving transects away from active vents. By collecting observations and geological samples from inactive chimneys along these transects, we hope to learn more about the communities using these structures that may stand for thousands of years. Sulfides will be aged with radioisotopes and analyzed in terms of mineralogy, geochemistry, and biology, to improve our understanding of the long-term evolution of hydrothermal vent habitats in EHV MPA.

Another main goal of the survey was a CHONe project led by UVic investigating the functional traits of species living in different types of tubeworm bushes. *Ridgeia piscesae*, the dominant habitat-forming megafaunal tubeworm at active vents, grows in different morphologies depending on its flow environment. Short, fat tubeworms only grow in vigorous, hot hydrothermal flow, and are the least common morphology. Longer, skinnier tubeworms are common where hydrothermal flow is diffuse. And very long (~1.5-2 m) tubeworms appear living around basalt substrate where there is very little hydrothermal flow. A better understanding of the diversity of species and functional traits associated with each of these tubeworm morphologies will enhance our view of community structure in these distinct microhabitats, and it will improve the ability to adaptively manage vent ecosystems.

47.3.2. Large Offshore Pacific Area of Interest

The key survey tools used during the July 2017 large offshore AOI cruise were the Bathyal Ocean Observation and Televideo System (“BOOTS”, a frame containing cameras and instruments that was dropped to collect imagery and physical and chemical seawater data on four seamounts), single-beam acoustics for collecting seafloor topographical data from ten seamounts, a CTD rosette, and plankton nets (Table 47-1, Figure 47-2). Typically, BOOTS was deployed on the slope of a seamount, and was pulled by the Tully toward the summit. An altitude of 2-3 m was maintained while holding the video camera at constant angle and taking still images at regular intervals. This cruise also contained a strong outreach component, as the BOOTS surveys were live-streamed onto the internet and were viewed in 69 countries. This was promoted with a social media campaign and website facilitated by DFO Communications and Outreach.

A key finding from this cruise was a dramatic increase in our knowledge of the number of seamounts in the AOI. Prior to the cruise, there were thought to be about a dozen seamounts in the area, based on old, poorly resolved bathymetry (multibeam data had never been collected on most of the AOI). By using newer bathymetry, some available multibeam data, and predictions from satellite altimetry, we took the *Tully* across seven places with “bumps” on the seafloor, and all of them turned out to be seamounts. We now believe there are at least 40 seamounts in the AOI, including 87% of all known seamounts in Canadian waters.

Table 47-1. Seamount surveys conducted in July 2017 in Offshore Pacific AOI.

Seamount	Latitude	Longitude	Summit depth (m)	Survey dates	Surveyed depths (m)	Surveyed transects (km)
Union	49.546	-132.703	285	21-24 July	300-2118	21.40
Curtis	49.884	-132.113	1100	25 July	1106-2054	2.73
Dellwood	50.747	-130.896	535	26-28 July	548-2069	19.10
UN18	49.938	-130.902	1555	29 July	1615-2145	2.99
Seamounts for which bathymetry was surveyed acoustically, but BOOTS was not deployed.						
Oglala (East)	50.349	-131.566	1600	26 July		
UN23	50.640	-131.130	1560	26 July		
UN19	49.992	-130.905	2200	29 July		
UN27	50.094	-130.148	1690	30 July		

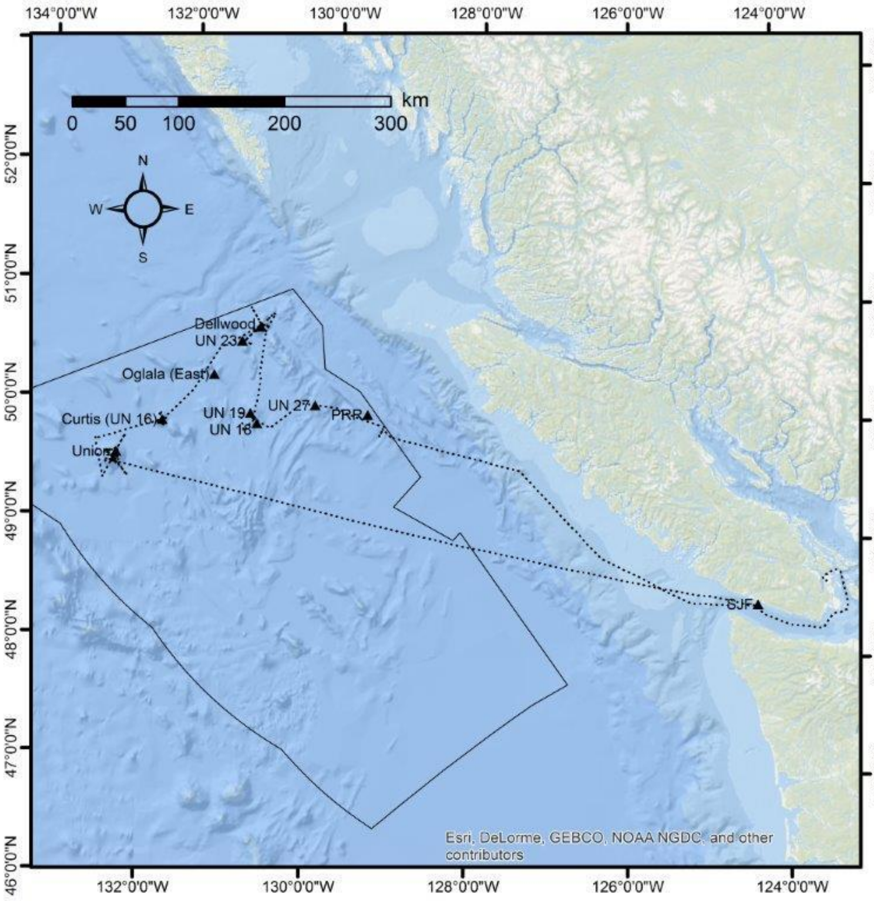

Figure 47-2. Location of the eight survey sites in the Pacific large offshore Area of Interest (AOI) and the test dive site in the Strait of Juan de Fuca. The Pacific large offshore Area of Interest is indicated by the solid line and the ship track is indicated by the dotted line

Every seamount imaged with BOOTS was characterized by VME species. Union seamount had a particularly diverse and dense assemblage of corals, while Dellwood seamount had more sponges. In fact, sponges in some of the gardens on Dellwood were in found in very high densities. Benthic fish observed included many rockfish species, thornyhead, sablefish, flatfish, ratfish, and others. Union seamount clearly had the densest rockfish populations, likely because it was the only surveyed seamount whose summit (285 m) extended above the oxygen minimum zone (OMZ) and nearly into sunlit waters. On the West of Vancouver Island, the OMZ lies between approximately 500-1100 m, and seamount benthic assemblages at these depths were dominated by coral, sponge, and had few fish other than thornyhead. Depth zonation of species was observed on all the seamounts, often seeming to correlate with levels of dissolved oxygen. Only a handful of sablefish were observed, despite the prevalence of a deep-water longline fishery for sablefish on Dellwood and Union seamounts (that is, up until the fishery closure was put into place in 2017). Derelict fishing gear was observed on two of the four seamounts imaged with BOOTS.

One of the notable events of 2017 in the Northeast Pacific Ocean was large scale blooms of pyrosomes, gelatinous colonial ascidians that are effective filter feeders of microplankton larger than 5 µm. Pyrosomes were frequently sampled in plankton nets, and dead pyrosomes were commonly observed on the seafloor. In fact, the frequency of benthic invertebrates scavenging dead pyrosomes, which has also been observed in the Gulf of Mexico, represents a potential major transfer of organic carbon from the upper ocean to the deep sea (Archer et al. 2018).

Another interesting observation from the OP AOI survey concerns possible hydrothermal venting at Dellwood. At this site, a BOOTS transect targeted an area believed to have once been a site of hydrothermal activity, thought long extinct. However, observations of yellow sediments and peculiar seafloor structures spread across several hundred meters of seafloor suggested Dellwood’s hydrothermal venting may have ceased recently or might still be ongoing.

Seabirds and marine mammals were also surveyed whenever the ship was moving. A wide variety of species were seen including both common and rare seabirds, whales, dolphins, and sharks. Notably, the numbers of sharks observed (especially blue sharks) were well above normal for B.C. offshore waters (pers. comm. Luke Halpin). Rare species for the region that were observed included a basking shark, false killer whales, bottlenose dolphins, and northern right whale dolphins (Halprin et. al 2018).

47.4. Ongoing research questions

Most of the data collected from these cruises are still in the process of being analyzed. The surveys from EHV MPA will eventually be used to conduct spatial analyses of indicator species and significant ecosystem components, which are important in the ecosystem-based management framework. Invertebrates collected from different habitats at different vent fields will be identified, addressing questions of how species composition at active vents varies across spatial scales. Bare pieces of basalt were also deployed at four sites as an experiment intended to measure recruitment. A future cruise with *ROPOS* or another ROV may be used to collect these experiments, allowing MSEA to address whether invertebrate recruitment patterns operate in a similar way throughout EHV MPA, or if there is variability among sites or habitats.

Future work in the OP AOI will ideally include additional baseline surveys at more seamounts. Data analysis may center around modeling biodiversity and species distributions, as relationships between observed fauna and environmental variables are used to improve predicted species distribution maps, as well as our picture of how unique different seamount assemblages are. A question with more far-reaching implications is whether seamounts may act as refugia for continental margin populations. Most (possibly all) of the fish observed at seamounts were not endemic species, but have been seen along B.C. shelf and slope habitats, where fishing pressure has been greater historically. If larvae released by fish on seamounts drifts eastward and subsidizes continental margin populations, it is conceivable that seamount protection could offer benefits for fisheries on the margin. This is a speculative hypothesis, but one that could possibly be addressed in the future.

47.5. Acknowledgements

This report represents at-sea research and post-cruise analyses conducted by members of the Marine Spatial Ecology and Analysis (MSEA) section including Jackson Chu, Cherisse Du Preez, Katie Gale, Sharon Jeffrey, Jessica Nephin, James Pegg, Candice St. Germain. Other collaborators include DFO Ocean Sciences Division (Moira Galbraith, Stephen Romaine, Chelsea Stanley, Mary Thiess), DFO Oceans Branch (especially Joy Hillier), Luke Halpin, and scientists from the University of Victoria (Rachel Boschen, Kim Juniper, Sheryl Murdock, Verena Tunnicliffe) and Memorial University of Newfoundland (John Jamison, Stephen Pearcy). We express our gratitude for the professional expertise demonstrated by Keith Tamburri, Keith Shepherd, and the rest of the ROPOS team during the EHV MPA survey, Kim Wallace and Jonathan Zand on the AOI survey, as well as that of the officers and crew aboard the CCGS *J.P. Tully* on cruise legs 2016-26 and 2017-36. Finally, the groundwork for these surveys was laid by Janelle Curtis, previous section head for MSEA, who helped conceive of BOOTS, initiated much of DFO's research on offshore seamounts, and planned much of the 2016 EHV MPA survey.

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48. SGAAN KINGHLAS–BOWIE SEAMOUNT MPA

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48.1. Highlights

- SGaan Kinghlas-Bowie Seamount Marine Protected Area (SK-B MPA) protects 6,000 km^2 of Canada's exclusive economic zone.
- To date, 341 taxa from 10 phyla and 30 orders have been identified in the MPA.
- SK-B MPA was completely closed to bottom contact fishing in January 2018.
- Upcoming survey (July 2018) on the *E/V Nautilus* will initiate a pilot project for monitoring benthic communities in SK-B MPA.

48.2. Overview

The SGaan Kinghlas-Bowie Seamount Marine Protected Area (SK-B MPA) encompasses 6,000 square kilometres of Canada's exclusive economic zone (Figure 48-1). Located 180 km west of Haida Gwaii, the MPA includes three seamounts at the southern end of the Kodiak-Bowie seamount chain: Davidson (a.k.a. "Pierce"), Hodgkins, and SGaan Kinghlas-Bowie (SK-B). As the shallowest seamount in the Northeast Pacific, SK-B seamount reaches well into the photic zone at its summit, 24 m below the surface (Canessa et al. 2003). Consequently, it supports an abundant algal community and a unique assemblage of species found outside their typical depth ranges (e.g. squat lobsters at uncharacteristically shallow depths and benthic algae at greater depths than usual; Canessa et al. 2003). Seamount communities like those on SK-B also benefit from increased primary production, driven by the upwelling of cold, nutrient-rich waters, as deep-sea currents interact with the seamount's steep slopes and water is forced upwards (Dower and Fee 1999).

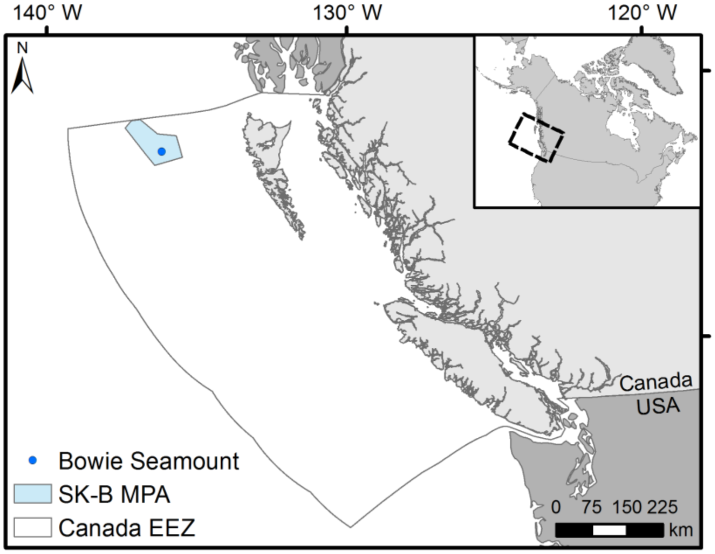

Figure 48-1. Location of Bowie Seamount and SGaan Kinghlas-Bowie Marine Protected Area (SK-B MPA) within Canada's EEZ (Exclusive Economic Zone). Reprinted with permission from Gale et al. (2017).

SK-B seamount lies within the territory claimed by the Haida First Nation, who have long valued the seamount and were instrumental in establishing the MPA in 2008. Their name for the seamount, SGaan Kinghlas, means "Supernatural Being Looking Outward". In January 2018, the Haida Nation joined the Government of Canada in an agreement to close the entire MPA to bottom-contact fishing. Prior to this date, bottom-contact fishing was permitted only in Zone 2, which includes SK-B seamount below 457 m depth (Figure 48-2). The complete closure to bottom fisheries is intended to protect sensitive benthic species, in alignment with the MPA's conservation objective to "conserve and protect the unique biodiversity and biological productivity of the area's marine ecosystem, which includes the [SK-B], Hodgkins and Davidson seamounts and the surrounding waters, seabed and subsoil" (Thornborough et al. 2016).

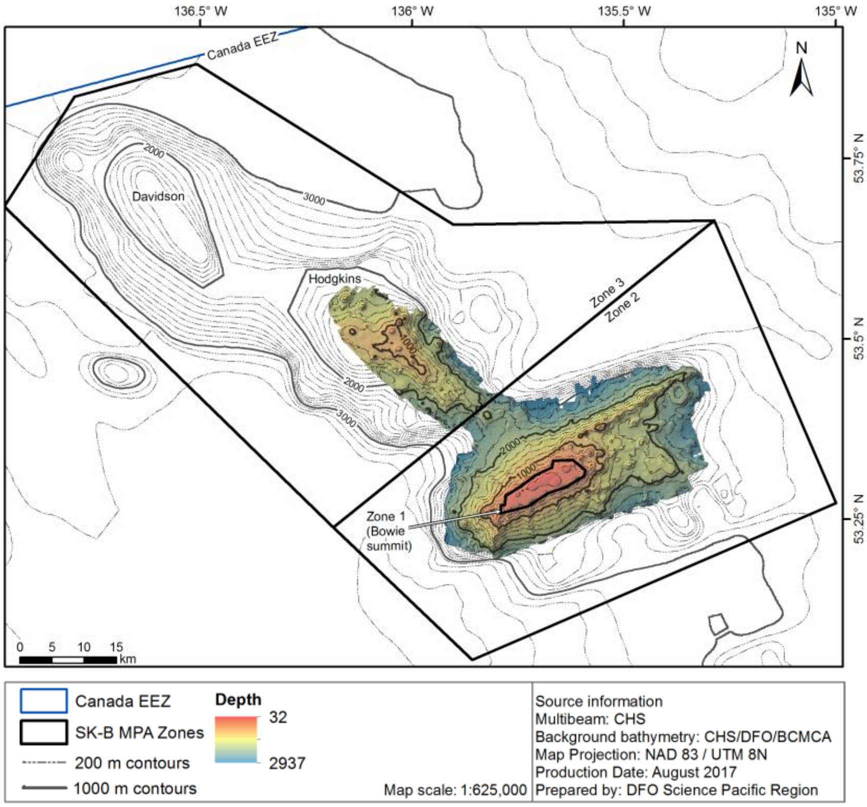

Figure 48-2. SGaan Kinghlas-Bowie Marine Protected Area (SK-B MPA) boundaries. Zone 1 covers the peak of SGaan Kinghlas-Bowie Seamount to approximately the 250 fathom (457 m) bathymetric contour. Zone 2 covers the rest of SGaan Kinghlas-Bowie Seamount, and was open to bottom contact fishing, prior to January 2018. Zone 3 encompasses Hodgkins and Davidson Seamounts. High-resolution bathymetry from the Canadian Hydrographic Service (10–50 m resolution, color-shaded area on map) is only available for SGaan Kinghlas-Bowie Seamount and part of Hodgkins Seamount and does not align perfectly with the less accurate 100 m resolution bathymetry available for the remainder of the area. Reprinted with permission from Gale et al. (2017).

48.3. Visual Surveys of SK-B MPA

Most of what we know about the biodiversity of the MPA is informed by SK-B seamount, which was the focus of a handful of scuba surveys between 1969 and 2003 and three DFO-led surveys of the benthos in 2000, 2011, and 2015 (see Gale et al. 2017 for a full list of surveys). In 2000, the two-person submersible DELTA was used to complete 20 transects over 10 dives at SK-B seamount, at depths ranging from 53 to 306 m (Yamanaka 2005). Later surveys were completed with ROV and AUV to depths up to 933 m (in 2011; Gale et al. 2017) and with the BOOTS drop-camera system to depths up to 1246 m (2015 survey; Gale et al. 2017). The objective of the 2015 survey was to characterize the biodiversity, benthic community structure, and habitat in Zones 2 and 3 (Figure 48-2), which had never before been surveyed. A total of 17 transects of the sea floor were completed, resulting in over 42 hours of HD video and 3,546 high-resolution photos. Over twelve hours of imagery have been annotated to identify the macrofauna observed, along with the associated substrate type and complexity. This expedition also included hydro-acoustic surveys, plankton tows, CTD (conductivity/temperature/depth) probe deployment, and observations of marine mammals and seabirds both inside and outside the MPA (Gale et al. 2017).

48.4. Biodiversity

To date, 341 taxa from 10 phyla and 30 orders have been identified in the MPA. These include multiple species on the International Union for Conservation of Nature (IUCN) Red List (e.g. Bocaccio Rockfish, Ocean Sunfish, and Basking Shark) and/or listed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC; e.g. Yelloweye Rockfish and Longspine Thornyhead). Generally, SK-B seamount is populated by abundant red and brown seaweeds at its summit, large populations of rockfish, and a great diversity of invertebrates, including molluscs, arthropods, cnidarians, echinoderms, sponges and bryozoans (McDaniel et al. 2003, Gale et al. 2017). Structure-forming species, such as glass sponges and red tree corals, are relatively abundant and provide shelter, feeding, and refuge habitat for many other species (Buhl-Mortensen et al. 2010). Comprehensive photo observations from the 2011 survey are publicly available on the iNaturalist “Marine Life of the Northeast Pacific” project site (Du Preez 2017), while the full species inventory of the 2015 research cruise is available from Gauthier et al. (2017a, b & c).

48.5. Ongoing research of the Marine Spatial Ecology and Analysis Section

Having obtained hundreds of observations of benthic species on SK-B seamount, efforts are now underway to develop distribution models for species of interest, such as cold-water corals and sponges. By modelling the relationship between individual occurrences and environmental variation (e.g. substrate type, complexity, oxygen levels), we can map the potential distribution of these species across the entire seamount. This map may be used to prioritize areas for monitoring or additional management actions, and will be ground-truthed and refined over future years. We will also develop detailed descriptions of benthic communities on SK-B seamount, in a similar manner as for Cobb Seamount (Du Preez et al. 2016).

In July of 2018, DFO Science will lead an expedition to SK-B MPA on board the *E/V Nautilus*. With access to the remotely operated vehicle (ROV) *Hercules*, which is capable of working at depths up to 4,000 metres, we will survey depths of SK-B MPA that have never been observed before. If time permits, ROV surveys of Davidson seamount may also be conducted, which would provide the first-ever look at the seamount and its habitat. New and additional species observations made in 2018 will be used to validate existing species distribution models and benthic community descriptions. The 2018 expedition will also function as a pilot monitoring year for the MPA. DFO Science will identify and survey potential long-term transects to facilitate assessments of temporal variation in species abundance, distribution, and community composition.

48.6. Acknowledgments

The research described here was informed and advanced by many scientists at DFO, including, but not limited to: K. Gale, D. Haggarty, M. Gauthier, M. O, J. Pegg, J.M.R. Curtis, L. Burke, and K.L. Yamanaka. The work would also not be possible without collaborations and support from the Council of Haida Nation, the University of Victoria, Oceans Network Canada, the U.S. National Oceanic and Atmospheric Administration, and the Canadian Coast Guard.

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49. MARINE PROTECTED AREA NETWORK PLANNING IN THE NORTHERN SHELF BIOREGION

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Marine Protected Area Technical Team (MPATT); technical guidance team for the MPA network planning process which is co-led by Canada, B.C. and 17 partner First Nations. info@mpanetwork.ca

49.1. Highlights

- A Marine Protected Area (MPA) network planning process is underway for the Northern Shelf Bioregion (NSB).
- Several key components of the MPA network planning process were reviewed through the Canadian Science Advice Secretariat (CSAS) including the identification of ecological conservation priorities, MPA network design strategies, and an assessment of Ecologically and Biologically Significant Areas in the NSB.
- A draft MPA network scenario is expected to be complete by the Fall 2018.

49.2. Summary

Following Canada's commitment to the 2020 Biodiversity Goals and Targets adopted under the Convention on Biological Diversity (CBD 2011) and the development of the National Framework for Canada's Network of MPAs (Government of Canada 2011), the Government of Canada and Province of British Columbia jointly produced the *Canada-British Columbia Marine Protected Area Network Strategy* (2014; herein, the Strategy). In 2015, the Marine Protected Area Technical Team (MPATT) was formed, under the direction of an MPA Network Committee, to develop a network of MPAs in the Pacific Northern Shelf Bioregion (NSB, Figure 49-1) by 2019. MPATT is the technical guidance team made up of the NSB MPA network planning partners – Canada, BC and 17 First Nations. Using the Strategy as guidance and the best available data and traditional and local knowledge, MPATT is working with stakeholders, local governments and experts to develop a MPA network design that aims to meet network goals, objectives and principles.

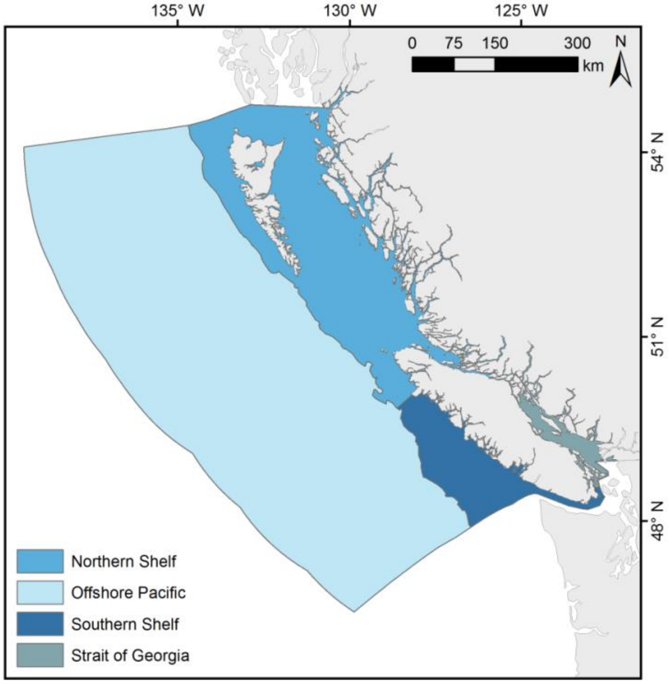

Figure 49-1. Bioregions in the Pacific Region. The current MPA network planning process is underway in the Northern Shelf Bioregion.

The MPATT science team, which includes biologists and spatial planners from the initiative's partner organizations, has developed several key pieces that feed into the MPA network planning process shown in Figure 49-2. The focus of this summary is on the identification of the ecological conservation priorities, design strategies, and the identification of new areas of high conservation value to support the development of a MPA network.

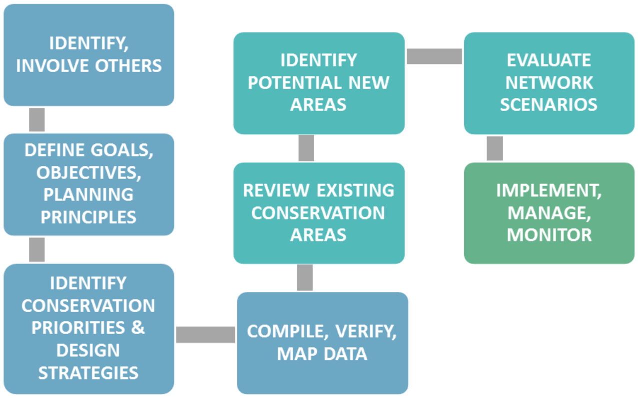

Figure 49-2. MPA network planning process diagram for the Northern Shelf Bioregion.

49.3. Description of ecological conservation priorities

Conservation priorities are the features to be protected in a MPA network, and can be ecological (e.g. ecologically significant species, habitats or areas) or cultural (e.g. species or sites of cultural significance). Ecological conservation priorities were identified by applying a systematic framework that was reviewed in a CSAS Regional Review Process in November 2016 (Gale et al. in press, DFO 2017). The framework was derived from the ecological MPA network objectives and conservation priorities were identified on their ecological role, conservation status and vulnerability. The framework was applied to species known to occur in the NSB and resulted in 195 species-based and 17 area-based ecological conservation priorities. A full list of the ecological conservation priorities is available in DFO (2017).

49.4. Description of design strategies

Design strategies for the MPA network in the NSB were developed by building on previous conservation planning analyses in the Pacific Region, MPA network design best practices, international MPA network planning processes and the literature (Martone et al. in revision). Design strategies describe how the conservation priorities will be spatially incorporated into the network (i.e. area-based targets), and provide guidance on other aspects of the network design including size, spacing, replication and protection levels. The design strategies for the NSB went through a CSAS Regional Review Process in May 2017 (Martone et al. in revision). The design strategies focus on the ecological conservation priorities and guide achievement of Goal 1 from the Strategy (2014): "to protect and maintain marine biodiversity, ecological representation and special natural features". Area-based targets, also referred to as "ecological conservation targets", are quantitative estimates of how much of each feature (the spatial datasets that represent each conservation priority) should be included in the NSB MPA Network. Examples of design strategies could be to protect a certain percentage of representative habitat types; to include a certain number of replicates of a specific habitat in the network; or to protect a proportion of a conservation priority's distribution (e.g. X % of the distribution of species A).

49.5. Analysis for highlighting areas of high conservation value

Areas of high conservation value in the NSB are being identified using the decision support software Marxan (Ball et al 2009). Globally, Marxan is the most widely used decision support software for conservation planning and it has been used in both marine and terrestrial systems (marxan.net). MPATT is using Marxan to identify areas of high ecological conservation value that can be used as a starting point for other important inputs into the planning process. These include socio-economic and cultural components which will be incorporated, in part, through stakeholder engagement. Marxan uses an optimization algorithm and attempts to meet all conservation targets for each conservation priority feature while minimizing the cost. For the initial Marxan runs with only the ecological data, the only cost that the software is minimizing is area.

49.6. Next steps

The MPA network planning process in NSB is ongoing and is expected to be complete by 2019. Once areas of high ecological conservation value are identified, the cultural conservation priorities will be integrated into the Marxan runs. Concurrent analyses using fisheries and other human use spatial data are underway to identify areas of high economic value, which will eventually be incorporated into a cost layer. MPATT's draft timeline has stakeholder workshops in May 2018 to identify areas for consideration in network planning, and is working towards a draft network design for Fall 2018.

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50. ASSESSING THE CONTRIBUTION OF ESTABLISHED PROTECTED AREAS TOWARDS MEETING MPA NETWORK OBJECTIVES IN THE NORTHERN SHELF BIOREGION

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50.1. Highlights

- As part of the marine protected area (MPA) network planning process in the Northern Shelf Bioregion of B.C. (NSB), the MPA technical team is reviewing 114 existing and 1 proposed marine protected areas to evaluate the degree to which each protected area meets ecological objectives for the network.
- Because protected areas vary in their degree of protection, ongoing threats and pressures and biological composition, the capacity of the protected areas to effectively protect the ecological conservation priorities within their boundaries needs to be assessed. To take this variability into account, our team has developed a method that considers the potential cumulative effects of allowed and/or ongoing human activities on ecological conservation priorities within existing protected areas.
- Using a set of ecological conservation targets that were developed for the network, we evaluate the proportion of the spatial area of each ecological conservation priority protected by the current and proposed MPAs, adjusted by the potential cumulative effects from allowable human activities within the planning area.

50.2. Summary

The Government of Canada, Government of British Columbia, and 17 member First Nations are collaborating on the design and implementation of a network of marine protected areas (MPAs) in the Northern Shelf Bioregion (NSB). Based on guidance provided by the Government of Canada (2011) and the Canada-B.C. MPA Network Strategy (2014), a set of goals, objectives, principles, and design guidelines provided the basis for identifying ecological conservation priorities, which are the ecological features to be prioritized for protection within the MPA

network. These elements also informed the identification of design strategies, which describe approaches for spatially incorporating ecological conservation priorities into the network, including a set of ecological target ranges (i.e. the proportion of each spatial feature representing ecological conservation priorities that will be included in the network), as well as other key variables (e.g. size, shape, spacing, and protection levels of MPAs).

To develop a network of MPAs, the first step is to identify what MPAs already exist, and how they meet the design strategies, including representation targets established for the ecological conservation priority features identified in the planning process. There are currently 114 existing MPAs and 1 proposed MPA of various designations that have been established in the NSB (Figure 50-1). They have a range of sizes, objectives, restrictions and protection status, ranging from highest restrictions on human activities within their boundaries, to MPAs that allow varying levels of resource extraction (Robb et al. 2011). Furthermore, even where MPA management plans articulate restriction of activities, including resource extraction, these objectives are not always enforced or able to be achieved with the legislation currently in place (Robb et al. 2015).

Here we present an approach for determining how effectively the existing MPAs meet the ecological conservation priority targets in the NSB, taking potential cumulative impacts from human activities into consideration. First, we examine the current suite of MPAs to ascertain how much of each spatial feature representing the ecological conservation priorities is protected within their boundaries. We then apply a scaling factor to the proportion protected, based on the potential cumulative impacts to the conservation priorities from the human activities allowed in each MPA.

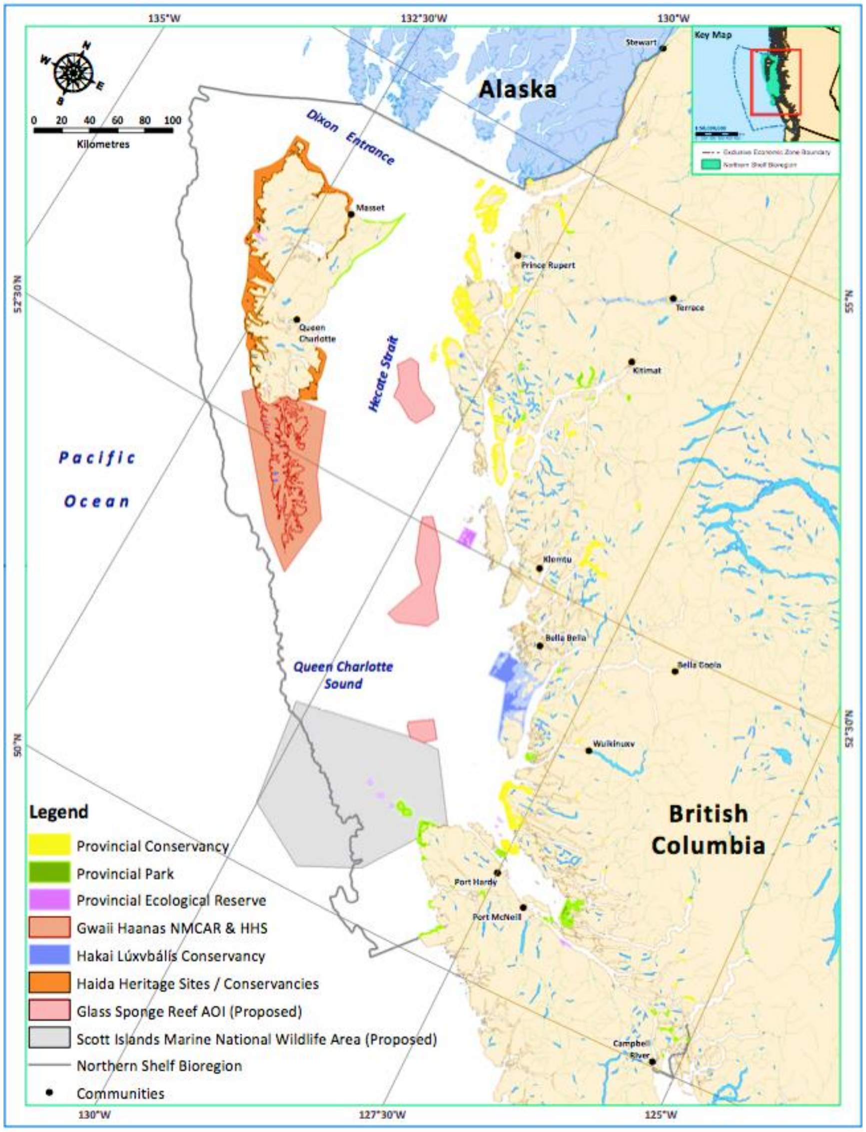
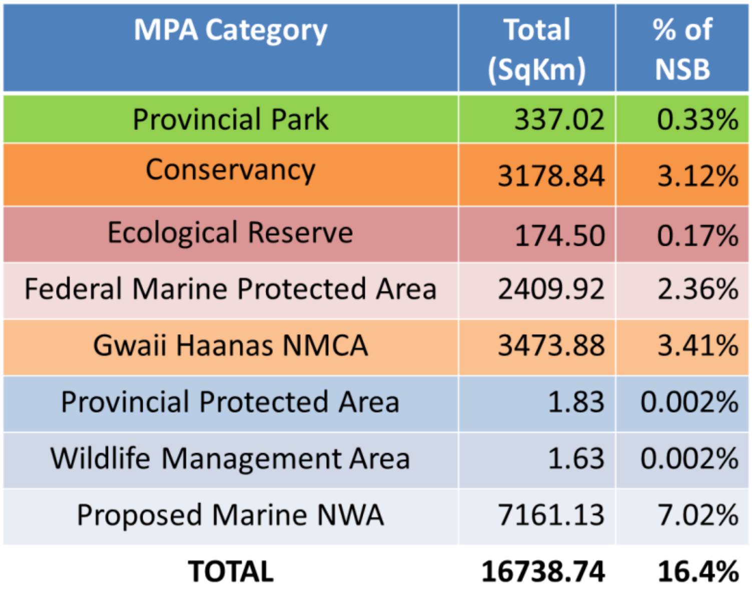


Figure 50-1. Current and Proposed MPAs in the Northern Shelf Bioregion.

50.3. Description of existing MPAs in the NSB

To assess the representation of the ecological conservation priorities in the current MPAs in the NSB, we created a spatial layer of existing MPAs using the Conservation Areas Reporting and Tracking System (CARTS) database (http://www.ccea.org/carts/). The CARTS database contains spatial data for marine and terrestrial protected areas that are updated annually by the federal, provincial, and territorial governments responsible for the management of protected areas. The MPAs represented in the database include federal *Oceans Act* MPAs, federal Migratory Bird Sanctuaries (MBS) and National Wildlife Areas (NWA), federal National Marine Conservation Areas (NMCA) and National Park Reserves (NPR), and a number of areas designated by the Province of B.C. (Ecological Reserves, Protected Areas, Provincial Parks, Wildlife Management Areas, Conservancies, and Recreation Areas) (Figure 50-1). In addition, we identified spatial boundaries for MPAs that have been proposed (e.g. Scott Islands marine NWA) or have been designated but not yet added to the CARTS database (e.g. Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs MPA) (Figure 50-1).

Table 50-1. Area and percent of the NSB in the boundaries of existing (current and proposed) MPAs.



MPA Category	Total (SqKm)	% of NSB
Provincial Park	337.02	0.33%
Conservancy	3178.84	3.12%
Ecological Reserve	174.50	0.17%
Federal Marine Protected Area	2409.92	2.36%
Gwaii Haanas NMCA	3473.88	3.41%
Provincial Protected Area	1.83	0.002%
Wildlife Management Area	1.63	0.002%
Proposed Marine NWA	7161.13	7.02%
TOTAL	**16738.74**	**16.4%**

We then analyzed the total geographic area of the NSB within the existing MPA boundaries using ArcGIS. Current and proposed MPAs cover approximately 16,738.74 km^2 (16.4%) of the NSB (Table 50-1).

50.4. Analysis of current protection of ecological conservation priorities in NSB

Ecological conservation priorities for the NSB were identified by applying a systematic framework that was reviewed in a Canada Science Advisory Secretariat (CSAS) Regional Review Process (Gale et al. in press), and include species considered ecologically important, vulnerable, or of conservation concern, as well as areas of climate resilience, degraded areas, Ecologically and Biologically Significant Areas (EBSAs; e.g. areas of high biodiversity and productivity), and representative habitats. The framework was applied to species known to occur in the NSB and resulted in 195 species-based and 17 area-based ecological conservation priorities. Spatial features representing areas of importance for each ecological conservation priority were proposed through a CSAS Regional Review Process in May 2017 (Martone et al. in revision) and the spatial features were subsequently created using recommended data sources and reviewed and revised by subject matter experts.

We intersected the spatial features representing the ecological conservation priorities with the footprint of the existing MPAs using ArcGIS. We then calculated the overlap of each of the existing MPAs with each of the ecological conservation priorities, resulting in a matrix of the percentage of the feature representing the ecological conservation priorities within each MPA.

To illustrate, we provide an example matrix of three ecological conservation priorities within three MPAs and summed across all existing MPAs (Table 50-2).

Table 50-2. Percent of the total area of each ecological feature in the NSB (3 examples: Estuaries, Harbour Seal haulouts; Black Oystercatcher nesting sites) within three example MPAs and within all current MPAs in the NSB. Blue values indicate the percent of the feature captured in existing MPAs and green values indicate percent of the feature in MPAs adjusting for potential cumulative effects of allowable human activities (described in more detail below). Note these data are not final.

	% Area in existing MPAs			% Area in existing MPAs adjusted by allowable human activities		
	Estuaries	Harbour Seal Haulouts	Black Oystercatcher Nesting Sites	Estuaries	Harbour Seal Haulouts	Black Oystercatcher Nesting Sites
Kitasoo Spirit Bear Conservancy	0.06%	0.16%	0%	0.04%	0.16%	0%
Broughton Archipelago Marine Provincial Park	0%	1.53%	0.58%	0%	0%	0.04%
Kunxalas Heritage Site/Conservancy	0%	0.23%	0.47%	0%	0.23%	0.05%
…						
Total (All Existing MPAs)	12.0%	25.4%	38.4%	0.55%	7.64%	0.19%

50.5. Accounting for potential cumulative effects of human activities on ecological conservation priorities in existing MPAs

To assess how well the current MPAs meet conservation targets for the ecological conservation priorities, we developed an approach to account for the potential cumulative effects of allowable human activities on ecological conservation priorities within current MPAs. We identified a suite of human activities occurring in the NSB and reviewed the management plans, purpose statements, or zoning plans available for the MPAs to identify which human activities are restricted within their boundaries. The final list of human activities included 31 individual activities grouped into 19 broad activity categories, including fishing, aquaculture, navigation, marine energy and other uses. Because MPAs can be designated under several different provincial and federal legislative tools, the agency developing the management plan for an MPA may not have the jurisdiction or mandate over activities recommended for prohibition. In those cases, we examined the regulations set by the agency with the appropriate authority to determine if the recommended restrictions had been implemented. All allowable activities within MPA boundaries were included, even if the activities are not currently operating. Allowable activities that could potentially occur in the future (i.e. are not currently restricted so could begin at any time) will impact the protection level of the MPAs if/when they do occur, so were included in this analysis.

We then applied a risk-based approach that derived qualitative consequence scores based on literature reviews for each human activity on ecological components identified for the NSB (Tamburello et al. 2017). The set of human activities were screened for their potential to impact each ecological conservation priority. Where potential interactions occurred, a score was developed to reflect the relative magnitude of the potential consequences of each human activity on each ecological component. Consequence was defined as the potential for long-term harm to ecological components as a result of interaction with a stressor, based on a risk assessment approach developed for the same region (O et al. 2014).

Using these individual scores, we then applied a decision framework that was developed to address the potential cumulative effects on ecological conservation priorities that could result from allowing a suite of different human activities within each MPA (Martone et al. in revision). We assigned a level of potential impact to each conservation priority within a given MPA based on the potential cumulative impacts of multiple activities. Based on the potential cumulative impact score for each conservation priority in each MPA, we then assigned a "performance scaling factor" to adjust the calculation of how much each MPA in the network contributes to the conservation targets for each ecological conservation priority (Table 50-3) (Martone et al. in revision). The performance scaling factors were adapted from global meta-analyses of fish assemblages examining effectiveness of no-take areas and partially protected marine protected areas (see Sciberras et al. 2013; Ban et al. 2014) (Table 50-3).

Table 50-3. Performance scaling factors derived from meta-analysis comparing MPAs with different International Union for Conservation of Nature (IUCN) levels of protection (Ban et al. 2014) linked to potential cumulative effects scores.

IUCN Categories	Effectiveness Scores	Performance Scaling Factors	Cumulative Effect Score
IUCN Ia, II, III (no take)	1.00	1.00	Negligible
IUCN Ib and II, with indigenous use	0.85	0.85	Low
IUCN IV	0.6 (95% CI: 0.34 - 0.89)	0.60	Moderate
IUCN VI	0.24 (95% CI: -0.12 – 0.72)	0.24	Moderate-High
Fished areas	0.00	0.00	High

We applied the performance scaling factors to adjust the percentage of each ecological conservation priority feature overlapped by each MPA based on the allowable activities within the MPAs (Table 50-2). For example, existing MPAs currently overlap with 25.4% of known harbour seal haulouts in the NSB. However, adjusting for potential cumulative effects of human uses allowed within the existing MPAs, this would be downweighted to only 7.6% of the harbour seal haulout feature protected. This allows for an identification of how much additional protection may need to be afforded to the ecological conservation priorities to meet conservation targets set for the network (e.g. 40-60% of harbour seal haulouts, Martone et al. in revision).

50.6. Next steps

This analysis identifies the amount of area of each ecological conservation priority feature that is protected by the existing MPAs. Next steps will be to identify ways to close the gaps which may include enhanced management of existing MPAs, boundary adjustments of existing MPAs, corridors to link sites, and new protected areas.

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51. STATE OF THE ATLANTIC OCEAN: INCORPORATING HABITAT AND MPAS

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51.1. Highlights

- The 2017/2018 State of the Atlantic Ocean report includes a biogeographic overview and summaries and case studies on seven theme groups: (1) oceanography (physical), (2) oceanography (lower trophic levels), (3) habitat/coastal and significant areas, (4) fish and invertebrate communities, (5) marine mammals, (6) sea turtles, and (7) seabirds, integrated over three Atlantic bioregions (Scotian Shelf, Gulf of St. Lawrence, and Newfoundland and Labrador Shelves).
- Selected habitats were intertidal flats, kelp beds, and eelgrass (coastal), corals and sponges (offshore), and sand dollars (nearshore-offshore).
- Long-term data on status and trends were generally lacking, therefore, the focus was on habitat distribution in the Atlantic, function in the ecosystem, natural variability and changes over time, threats that can lead to changes, gaps in knowledge and monitoring, and key messages.
- Due to the science, theme-based, and Atlantic-wide focus of the report, it was decided that more management-based, focused initiatives such as marine protected areas (MPAs) would not be included in this year's report. However, links and references to existing information on MPAs may be included in the frequently asked questions section of the report website.

51.2. State of the Atlantic Ocean reporting

As part of Fisheries and Oceans Canada's (DFO) commitment to report on the state of Canada's oceans and aquatic ecosystems, the Department has been tasked with Ecosystem Reporting. The goal of this new Ecosystem Reporting initiative is to inform Canadians about the current status of Canada's oceans. An initial DFO National Ecosystem Reporting Workshop was held in Montreal, QC, on January 31–February 2, 2017 to discuss reporting requirements, develop shared understanding of existing regional reporting, and to develop a national framework for reporting on the State of Canada's Oceans. DFO Ecosystem Reporting is to follow a four-year cycle with a Pacific Ocean report produced by the end of fiscal year 2016/17, an Atlantic Ocean report in 2017/18, an Arctic Ocean report in 2018/19, and a national report on the three oceans in 2019/20. The aim is to produce a plain language public report based on a scientific synthesis report. The DFO National Ecosystem Reporting Steering Committee held a second Ecosystem Reporting Workshop in Dartmouth, NS, on May 24–25, 2017 to determine the overall structure of the State of the Atlantic Ocean report, develop a timeline, and plan for a synthesis workshop in fall 2017.

The reporting structure of the present State of the Atlantic Ocean reporting initiative differs from the previously published DFO Canadian State of the Oceans' reports in that current status and trends summaries of the Atlantic Ocean is provided by theme group as opposed to being a review of ecosystem stressors and human impacts. A reporting structure including a biogeographic overview and seven theme groups [oceanography (physical), oceanography (lower trophic levels), habitat/coastal and significant areas, fish and invertebrate communities, marine mammals, sea turtles, and seabirds] was developed with integration over three Atlantic bioregions (Scotian Shelf, Gulf of St. Lawrence, and Newfoundland and Labrador Shelves) (Figure 51-1). This integrated approach required that the contents of this report be based on published or peer-reviewed data given the time constraints for the production of the State of the Atlantic Ocean Report (2017/18).

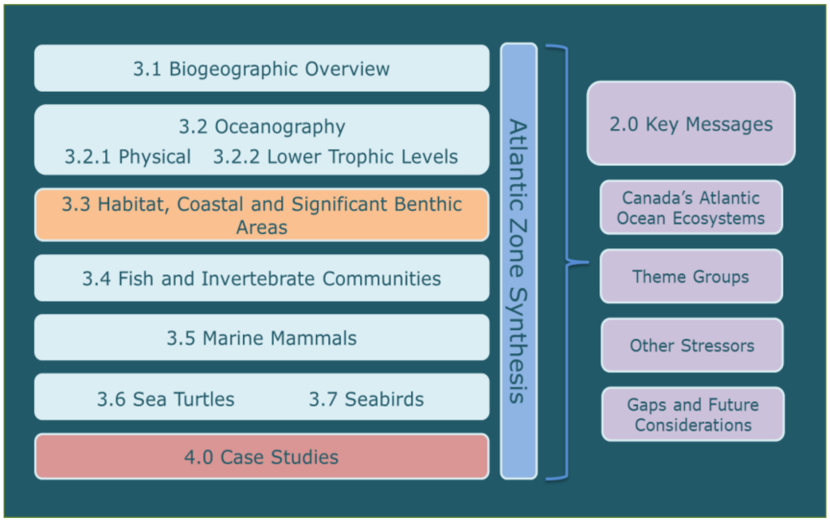

Figure 51-1.General reporting structure of the State of the Atlantic Ocean's synthesis and public reports with integration between Scotian Shelf, Gulf of St. Lawrence, and Newfoundland and Labrador Shelves.

DFO scientific experts were appointed by their regional managers for their participation in theme working groups and the subsequent drafting of theme groups' status and trend summaries for the present Atlantic Ocean synthesis report. Scientific expertise from Environment and Climate Change Canada (ECCC) was sought out for the seabirds theme group as seabirds are not within DFO's mandate.

Theme working group members as well as other DFO scientific experts working on particular ecosystem stressors (e.g. aquatic invasive species) were also invited to contribute a case study in their field of expertise. The purpose of case studies is to further explain concepts or processes, describe ecosystem stressors, or to highlight similarities across the three Atlantic bioregions that were not discussed in each theme working group's status and trends summaries.

Theme groups' status and trends summaries, as well as twelve case studies, were presented by their authors and subsequently discussed at a synthesis workshop, which was held in Moncton, NB, on December 5–6, 2017. DFO scientists from each of the four Atlantic Regions (Quebec, Gulf, Maritimes, and Newfoundland and Labrador) along with representatives from DFO Gulf Communications Branch, DFO Science Outreach, ECCC, NIVA Inc., and the DFO National Ecosystem Reporting Steering Committee were present at the workshop. The objective of the workshop was to present and synthesize scientific knowledge in seven key theme areas to provide a basis for a plain language public report.

Public reporting will take the form of a website with (1) a plain language written report that includes status and trends, key messages, and the four key case studies, (2) frequently asked questions to briefly address important themes not included in the report, and (3) additional case studies in various forms (e.g. infographics, videos, podcasts).

51.3. Habitats and MPAs

Atlantic Canada has diverse coastal and offshore environments that form habitat for all species in the ecosystem, but all were not able to be included in the report due to time constraints. To demonstrate the diversity of Atlantic habitats and the varied, important roles different habitats play in the ecosystem, we selected five representative coastal habitats (intertidal flats, kelp beds, and eelgrass), offshore habitats (corals and sponges, including Ecologically and Biologically Significant Areas), and habitats that span from the coast to the offshore (sand dollars). Habitat data are inherently spatial in nature and peer-reviewed historical data on status and trends is generally lacking due to the difficulty and expense in obtaining representative, ongoing samples. Therefore, the focus was on habitat distribution in the Atlantic, function in the ecosystem, natural variability and changes over time, threats that can lead to changes, and gaps in knowledge and monitoring. General key messages were then developed:

- Kelp beds and eelgrass habitat in Nova Scotia and in the Gulf of St. Lawrence are decreasing, but eelgrass habitat in Newfoundland is increasing. Warmer temperatures may be a contributing factor to these changes.
- Coral and sponge habitats are hotspots of biodiversity in the deep sea and are threatened by resource extraction and bottom trawling.
- Intertidal flats are ecologically and economically important habitats that may be impacted by warming temperatures and eutrophication.
- Habitat degradation and loss in coastal regions may occur with coastal development as well as sea level rise and increased storm surges caused by climate change.

To complement these habitat summaries, three case studies were selected:

- Eelgrass and Atlantic Cod recruitment
- Benthic babysitters: role of corals and sponges as nurseries in the deep sea
- Biodiversity from benthic trawl from Passamaquoddy Bay

Other case studies also included links to habitats via stressors such as nutrient input, harmful algal blooms, hypoxia, and acidification in coastal areas.

Workshops included discussions on how and if MPAs should be included in the report. Due to the science, theme-based, and Atlantic-wide focus of the report, it was decided that more management-based, focused initiatives such as MPAs would not be included in this year's report. However, links and references to existing information MPAs may be included in the frequently asked questions section of the reporting website. Inclusion of case studies on specific MPAs may also be considered in future reports.

51.4. References

Bernier, R.Y., Jamieson, R.E., and Moore, A.M. (eds.) 2018. State of the Atlantic Ocean Synthesis Report. December 5-6, 2017 – Moncton. Can. Tech. Rep. Fish. Aquat. Sci. *in press.*

Appendix 1. Review Meeting Agenda

March 7 and 8, 2018
Nanaimo River Room, Vancouver Island Conference Centre, Nanaimo, BC

Co-Chairs: Peter Chandler (Peter.Chandler@dfo-mpo.gc.ca) and
Jennifer Boldt (Jennifer.Boldt@dfo-mpo.gc.ca)
Organizer: Stephanie King (king@seathis.com, 250-734-3569)

SOPO AGENDA – Wednesday, March 7th (Conditions in the NE Pacific and outer BC coast)

Time	Name	Presentation
9:00-9:30	**Registration / settling-in**	**Refreshments provided**
9:30-9:50	Peter Chandler/Jennifer Boldt	Introduction and purpose
	Carmel Lowe	Welcome from DFO
	Elder Lolly	Welcome from the Snuneymuxw First Nation
9:50-12:00	Faron Anslow	Land temperature and hydrological conditions in 2017
	Tetjana Ross	Temperature, salinity and density of the NEP using Argo, satellite and Line P data
	Roy Hourston	Wind-driven upwelling along the Northwest coast of North America: timing and magnitude
	Peter Chandler	BC Lighthouses
	Bill Crawford	Oxygen concentrations on the WCVI
	Jim Gower	Satellite and buoy observations of BC waters
	Angelica Pena	Phytoplankton
	Robert Izett	NSERC Strategic SPEAR Project: Net Primary Protection, Net Community Production, and Phytoplankton Community Composition in the Ne Pacific
	Jennifer Jackson	Hakai Oceanography on the Central Coast
	Jennifer Jackson	Interdecadal oceanographic trends in Rivers Inlet, BC from 1951 to 2017
12:00-13:00	**Lunch**	**Not provided**
13:00-15:00	Anne Ballantyne	Water level observations
	Moira Galbraith	West coast zooplankton
	Sonia Batten	NE Pacific zooplankton
	Doug Hay	Coast-wide river-by-river on the update on the anadromous eulachon
	Ian Perry	WCVI small mesh survey
	Jennifer Boldt	Pelagic Fish
	Stephane Gauthier	Hake survey
	Greg Workman	Overview of groundfish surveys in 2017
	Dan Curtis	Update on abalone
15:00-15:30	**Break**	**Refreshments provided**
15:30-16:45	Howard Stiff	Coast-wide sockeye indicator stock returns in 2017
	Zane Zhang	Albacore Tuna
	Mark Hipfner	Seabird observations on the BC Coast
	Gwil Roberts	CHS Pacific's activities and results in 2017; also someone on water levels
	Scott Akenhead	The emerging DFO Salmon Network
	Kelsey Delisle	The Pollution Tracker program at Ocean Wise
16:45-17:00	Peter Chandler/Jennifer Boldt	Discussion
17:00-19:00	**Ocean Networks Canada Poster Session** Enjoy the posters and some light snacks. Cash bar for those who are interested.	

Group dinner at the Old City Station Pub

SOPO AGENDA – Thursday, March 8th (Inside waters and special session on marine protected areas)

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
9:15-12:00	Peter Chandler		SoG water properties in 2017
	Wiley Evans		Hakai Ocean Acidification Program data from 2017
	Jeff Marliave		The 2011 climate regime shift revealed by seabed biodiversity / Update on ocean pH
	Richard Dewey		Sea-surface and deep water properties in the SoG during 2017: cabled instruments and ferries
	Svetlana Esenkulova		The phytoplankton community and harmful algae in the Salish Sea
	Maycira Costa		Satellite observations in the Salish Sea
	Susan Allen		Spring bloom timing and interannual variations in summer productivity in the SoG
	Moira Galbraith		SoG zooplankton
	Jackson Chu		The 2017 Saanich Inlet ROV transect: Delayed recovery of the epibenthic community after a sustained period of hypoxia
	Erin Rechisky		Update on Fraser River sockeye survival through the Strait of Georgia
	Chrys Neville		Juvenile salmon in the SoG
	Sue Grant		Fraser River Sockeye: abundance and productivity trends
	Skip McKinnell		Life in the Gauntlet in 2017: physical-biological-phenological characteristics of the ocean from Chatham Point to Cape St. James
12:00-13:00	**Lunch**		**Not provided**
13:00-15:00	Lyse Godbout		Effects of early marine growth on adult Fraser sockeye salmon returns
	Special Session	Miriam O	MPA research programs in DFO's Pacific Science Branch
		Anya Dunham	Assessing and monitoring glass sponge reefs
		Ben Grupe	Offshore protected areas: Canada's oldest Marine Protected Area and newest Area Of Interest
		Kim Juniper	Remote monitoring of a deep-sea MPA - the Endeavour Hydrothermal Vents
		Kelly Swan	SGaan Kinghlas – Bowie Seamount Marine Protected Area
		Lynn Lee	State of Gwaii Haanas marine monitoring
14:45-15:15		**Break**	**Refreshments provided**
15:30-16:45		Emily Rubidge	Marine Protected Area Network planning in the Northern Shelf Bioregion
		Rebecca Martone	Conservation gaps in the Northern Shelf Bioregion: Assessing the contribution of established protected areas towards meeting MPA network objectives
		Andrea Moore	State of the Ocean – Atlantic: Incorporating habitat and MPAs
		Peter Chandler/ Jennifer Boldt	Special session discussion
16:45-17:00	Peter Chandler/ Jennifer Boldt		Take away messages and wrap-up

Posters presented in the Ocean Networks Canada Poster Session from

1. Susan Allen - 3-D model biophysical model in the Strait of Georgia
2. William Atlas - Life-cycle monitoring program on the Koeye River on the Central Coast of BC
3. Justin Belluz - Fluorescence to Chlorophyll Ratios in Coastal British Columbia Waters
4. Emily Haughton- Weather Driven Dynamics of Small Pluvial Watersheds on the Central Coast of British Columbia from 2013 to 2017
5. Margot Hessing-Lewis - Nearshore habitats
6. Brett Johnson - Hakai Institute Juvenile Salmon Program
7. Greg Jones - Assessing ocean habitat for seabirds in the proposed Scott Islands marine National Wildlife Area
8. Jackie King - Low juvenile salmon abundance off the WCVI: results from the Pelagic Integrated Ecosystem Survey 2017
9. Erika Loc - The Scott Islands: A Proposed Marine National Wildlife Area
10. Tom Okey - Indicators of marine ecosystem integrity for Canada's Pacific: An expert-based hierarchical approach
11. Shani Rousseau - Juvenile salmon acoustic monitoring in the Discovery Islands
12. Hayley Dosser - Physical and biological ocean conditions in Johnstone Strait, and their impact on migrating juvenile salmon
13. Alysia Herr - Long-term trends and patterns of DMS in the Northeast Pacific
14. William Burt - Carbon : Chlorophyll ratios and net primary productivity of Subarctic Pacific surface waters derived from autonomous shipboard sensors
15. Maria Fernanda Coló Giannini - Spatial-temporal dynamics of coastal marine biogeochemical provinces of British Columbia and Southeast Alaska using high-resolution satellite data
16. Cliff Robinson - Modeling Pacific sand lance burying habitat in the Salish Sea

Appendix 2. Review Meeting Participants

Participant	**Affiliation**
Scott Akenhead	Ladysmith Institute, Ladysmith
Hussein Alidina	WWF
Susan Allen	UBC, Vancouver
Faron Anslow	UVic, Victoria
Stephanie Archer	DFO, PBS, Nanaimo
William Atlas	Hakai Institute
Dan Baker	VIU, Nanaimo
Anne Ballantyne	DFO, IOS, Sidney
Jessy Barrette	Hakai Institute
Alexandra Barron	Canadian Parks and Wilderness Society
Sonia Batten	Sir Alister Hardy Foundation for Ocean Science, Nanaimo
Andrew Baylis	DFO
Justin Belluz	Hakai Institute
Michelle Bigg	DFO
Kelly Binning	DFO
David Blackbourn	DFO, Retired
Karin Bodtker	Coastal Ocean Research Institute at the Vancouver Aquarium
Jennifer Boldt	DFO, PBS, Nanaimo
Laura Borden	Vancouver Aquarium, Vancouver
Julia Bradshaw	DFO, PBS, Nanaimo
Tamara Brown	Microthalassia
William Burt	University of British Columbia
Katherine Butts	Lax Kw'alaams Fisheries
Sally Cargill	Province of BC, Ministry of Forests, Lands and Nat. Res.
Melissa Chancey	DFO
Peter Chandler	DFO, IOS, Sidney
Lisa Christensen	DFO
Jackson Chu	DFO, IOS, Sidney
Maycira Costa	UVic, Victoria
David Costalago	UBC, Vancouver
Paul	DFO
Bill Crawford	DFO (retired), IOS, Sidney
Terry Curran	PSF
Dan Curtis	DFO, PBS, Nanaimo
Janelle Curtis	DFO, PBS, Nanaimo
Kelsey Delisle	Ocean Wise
Hilari Dennis-Bohm	DFO
Richard Dewey	Ocean Networks Canada, Victoria
Hayley Dosser	Hakai Institute
Katarina Doughty	DFO
Sarah Dudas	VIU, Nanaimo
Stephanie Duff	VIU, Nanaimo
Kirsten Dunbar	Province of BC, Ministry of Forests, Lands and Nat. Res.
Anya Dunham	DFO, PBS, Nanaimo
Kimberley Dunn	WWF
Mairi Edgar	BC Salmon Farmers Association
Svetlana Esenkulova	UVic, Victoria

Participant	**Affiliation**
Wiley Evans	Hakai Institute
Maria Fernanda Coló Giannini	UVic, Victoria
Jessica Finney	DFO, PBS
Linnea Flostrand	DFO, PBS, Nanaimo
Bill Floyd	VIU, Nanaimo / Province of BC, Ministry of Forests, Lands and Nat. Res.
Michael Folkes	DFO, PBS, Nanaimo
Kieran Forge	DFO, PBS
Ian Forster	DFO
Cameron Freshwater	DFO
Caihong Fu	DFO, PBS, Nanaimo
Moira Galbraith	DFO, IOS, Sidney
Katie Gale	DFO, IOS, Sidney
Jessica Garzke	UBC, Vancouver
Stephane Gauthier	DFO, IOS, Sidney
Donna Gibbs	Vancouver Aquarium, Vancouver
Ian Giesbrecht	Hakai Institute
Kayleigh Gillespie	DFO
Lyse Godbout	DFO, PBS, Nanaimo
Martin Godefroid	DFO
Jim Gower	DFO, IOS, Sidney
Sue Grant	DFO, Delta
Ben Grupe	DFO, Institute of Ocean Science, Sidney
Dana Haggarty	DFO, PBS
Nicky Haigh	VIU, Nanaimo
Charles Hannah	DFO, IOS, Sidney
Lucie Hannah	DFO, IOS, Sidney
Emily Haughton	Hakai Institute
Doug Hay	DFO, retired
Melissa Hennekes	DFO, IOS, Sidney
Alysia Herr	University of British Columbia
Margot Hessing-Lewis	Hakai Institute
Joy Hillier	DFO, Prince Rupert
Mark Hipfner	Wildlife Research Division, Delta
Carrie Holt	DFO
Roy Hourston	DFO, IOS, Sidney
Ann-Marie Huang	DFO
Josie Iacarella	DFO, IOS, Sidney
Jim Irvine	DFO, PBS, Nanaimo
Robert Izett	UBC, Vancouver
Jennifer Jackson	Hakai Institute
Robyn Jamieson	DFO
Marlene Jeffries	DFO, CHS, IOS, Sidney
Stewart Johnson	DFO, PBS, Nanaimo
Brett Johnson	Hakai Institute
Greg Jones	DFO, IOS, Sidney
Kim Juniper	ONC
Jackie King	DFO, PBS
Stephanie King	Sea This Consulting, Nanaimo
Jason Ladell	DFO

Participant	**Affiliation**
Neil Ladell	DFO
Aleria Ladwig	DFO, Resource Management, Vancouver
Doug Latornell	UBC, Vancouver
Lynn Lee	Parks Canada
Joanne Liutkus	BC Salmon Farmers Association
Erika Loc	Environment Canada, Canadian Wildlife Service
Andrea Locke	DFO, IOS, Sidney
Eddie Loos	ASL Environmental Sciences, Sidney
Carmel Lowe	DFO, Regional Director, Science, Nanaimo
Amy Mar	DFO, Species at Risk Program
Jeff Marliave	Vancouver Aquarium, Vancouver
Rebecca Martone	Province of BC, Ministry of Forests, Lands and Nat. Res.
Skip McKinnell	PICES (retired)
Romney McPhie	MaPP
Katherine Middleton	DFO
Andrea Moore	DFO
Ken Morgan	Canadian Wildlife Service, Institute of Ocean Sciences, Sidney
James Mortimor	DFO, PBS, Nanaimo
Todd Mudge	ASL Environmental Sciences, Sidney
Cathryn Clarke Murray	DFO
Nina Nemcek	DFO, IOS, Sidney
Jessica Nephin	DFO, IOS, Sidney
Chrys Neville	DFO, PBS, Nanaimo
Harry Nyce	Nisg?a'a Lisims Government
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Shannon Obradovich	DFO, PBS
Mike O'Brian	DFO
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Greig Oldford	DFO, RHQ
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Rich Pawlowicz	UBC, Vancouver
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Bill Pennell	VIU, Nanaimo
Ian Perry	DFO, PBS, Nanaimo
Eric Peterson	Hakai Institute
Travis Poehlke	DFO
Mark Potyrala	DFO
Jay Pudota	Marine Harvest, water quality manager
Erin Rechisky	Kintama Research Services, Nanaimo
Luba Reshitnyk	Hakai
Tessa Richardson	DFO, Fisheries Protection Program
Carrie Robb	DFO
Gwil Roberts	DFO, CHS, IOS, Sidney
Kendra Robinson	DFO, SFU

Participant	**Affiliation**
Steve Romaine	DFO, IOS, Sidney
Sarah Rosengard	UBC
Tetjana Ross	DFO, IOS, Sidney
Shani Rousseau	DFO, IOS, Sidney
Emily Rubidge	DFO
Akash Sastri	Ocean Networks Canada, Victoria
Steven Schut	DFO
Danielle Scriven	DFO
Lara Sloan	DFO, Communications Advisor
Shona Smith	DFO, Nanaimo
Chelsea Stanley	DFO, IOS, Sidney
Kira Stevenson	Province of BC, Ministry of Environment
Hannah Stewart	DFO
Howard Stiff	DFO, PBS, Nanaimo
Megan Sullivan	Province of BC, Ministry of Environment
Kelly Swan	DFO
Greg Thomas	Herring Conservation and Research Society
Pramod Thupaki	DFO
Karen Topelko	Province of BC, Ministry of Forests, Lands and Nat. Res.
Strahan Tucker	DFO, PBS, Nanaimo
Lenora Turcotte	DFO
Brenda Waddell	DFO, PBS
Rachel Wang	WWF
Ziwei Wang	UVic, Victoria
Bill Wareham	David Suzuki Foundation
David Welch	Kintama Research Services, Nanaimo
Christie Whelan	DFO, PBS, Nanaimo
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Allison Witter	Province of BC, Ministry of Agriculture
Cecilia Wong	Environment Canada
Greg Workman	DFO, PBS, Nanaimo
Kristin Worsley	Province of BC, Ministry of Forests, Lands and Nat. Res.
Cynthia Wright	DFO, IOS, Sidney
Jennifer Yakimishyn	Parks Canada
Lynne Yamanaka	DFO
Kelly Young	DFO, IOS, Sidney
Zane Zhang	DFO