Pacific Salmon in 2022: Recent Environmental Trends Suggest Below Average Salmon Productivity (Adult Recruits produced per adult parental spawner)

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Summary

We predict that 2022 Canadian Pacific salmon productivity will generally be below historical averages. Productivity is defined as the number of adult recruits produced per adult parental spawner. This prediction is based on the environmental and biological data from 2017-2021, which coincides with parental spawning and egg incubation through to ocean rearing conditions for the 2022 salmon returns across populations.

While we do not have relevant data for each salmon population, we provide a general description of what is known about conditions experienced by Pacific salmon returning in 2022.

Specifically:

1) Higher than average river temperatures occurred from 2017 to 2020. Summer river temperatures are increasingly exceeding upper thermal tolerances for salmon in assessed systems.
2) Snow melted earlier in snow-dominated fresh water habitats. Most BC snowpacks were anomalously low by early May in 2018 and 2019, 2020 and by early June in 2017. In general, this contributed to warmer summer river and lake temperatures in snow-dominated systems in those years.
3) Record summer droughts occurred in 2017 and 2018. Lower water levels can increase temperatures, block passage to key spawning habitat, strand salmon, and increase their exposure to predators.
4) Unprecedented Northeast Pacific marine heatwaves were present during late-2013-2016 and in 2019 and 2020. This has negatively affected physical and biological ocean processes relating to salmon growth and productivity.
5) Ocean food webs shifted. Northeast Pacific Ocean zooplankton community composition continued to exhibit characteristics consistent with a warmer ocean from 2017 to 2020, contributing a higher proportion of lower quality species near the base of the salmon food web.

The effect of these challenges on 2022 returning salmon populations will depend on specific conditions encountered by each population, and their life-histories. The greatest impact will likely be felt by more southern BC populations, and species that spend more time in fresh water. Environmental conditions will interact with landscape changes in fresh water that have occurred from natural events like forest fires or mountain pine beetle kills, and human activities, such as logging, agriculture, and urban development.

General Distribution of the 2022 Pacific Salmon Returns

Five species of Pacific salmon are assessed and managed by the Department of Fisheries and Oceans: sockeye, Chinook, coho, pink and chum. Species and populations exhibit considerable variation in the habitats they occupy and the life history strategies they employ.

Most Canadian Pacific salmon returning in 2022 would have been deposited as eggs in their fresh water spawning grounds between 2017 and 2020, and will therefore return at an age falling between two and five years old (Figure 1). Many sockeye and Chinook populations, and all coho populations, rear in fresh water for one to two years as juveniles, before migrating to the ocean. Other sockeye and Chinook populations, and all chum and pink populations, migrate to the ocean shortly after hatching and emergence, with only a limited fresh water juvenile stage. Since the majority of 2022 returns would have inhabited fresh water environments between 2017 and 2020 (Figure 1), we present general fresh water conditions specific to these years.

The majority of 2022 Pacific salmon returns would have entered into the marine environment between 2019 and 2021, depending on their species and population, and will remain there until they return to fresh water in 2022. We present general marine conditions for 2019 to 2021 where available.

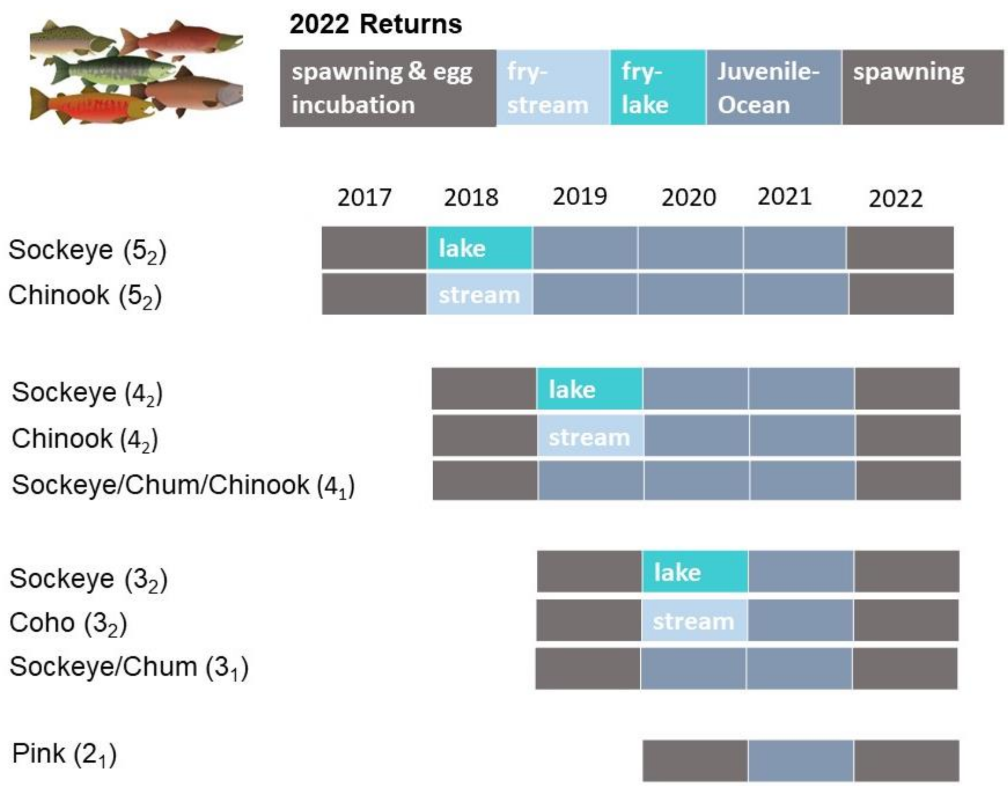

Figure 1. Timing of common age classes of Pacific salmon returning in 2022 in each habitat they occupy. For each species, the most common life-history types are presented, using the Gilbert-Rich age designation system (in brackets); the number on the left indicates the total age at return, while the subscript shows the number of winters spent in fresh water prior to migrating to the ocean. Coloured boxes show the life stage and habitat occupied by each group of animals in every year of their life, leading up to their return to fresh water in 2022.

Global and Regional Environmental Context for Salmon Outlook

The planet is warming (Figure 2). Average land-ocean temperature has risen by 1°C over the last century (IPCC 2018), and the years 2015 to 2020 were the warmest on record (NOAA National Centers for Environmental Information 2021). Canada is warming at double the rate of the global average, due to its northern latitude (Bush and Lemmen 2019). British Columbia warmed by 1.9°C between 1948 to 2016, while northern Canada warmed by 2.3°C (Bush and Lemmen 2019).

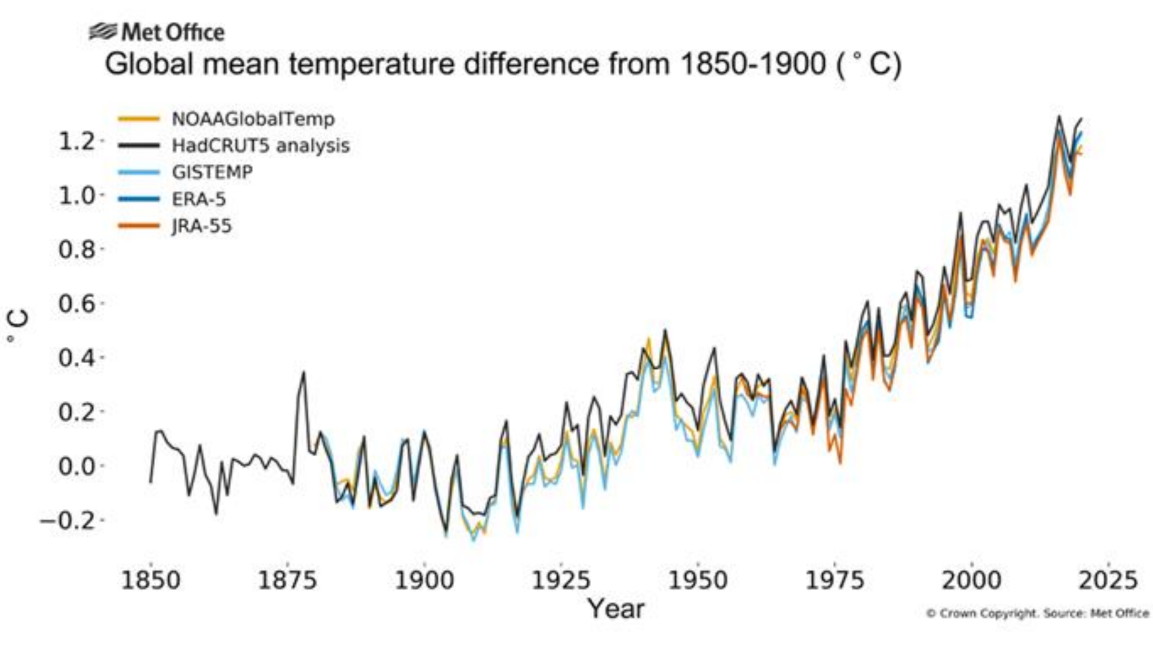

Figure 2. Global annual mean temperature difference from pre-industrial conditions (1850-1900). Canada's temperature increases are double this global rate of warming, typical of countries occupying northern latitudes. Source: Met Office Hadley Centre and the Climatic Research Unit at the University of East Anglia, UK, as it appears on the World Meteorological Organization website: https://public.wmo.int/en/media/press-release/2020-was-one-of-three-warmest-years-record. [Accessed Oct 15, 2021]

Profound environmental changes are already occurring in Western Canada as a result of the warming that has taken place to date. In B.C., average precipitation is increasing; snowpacks are melting earlier, altering the hydrographs of rivers in snow-dominated systems; lakes and rivers are becoming ice-free earlier in the spring; river temperatures are warming, and sea-surface temperatures are also warming along the coast (White et al. 2016). The Yukon has experienced accelerated warming during the winter months, increases in precipitation, melting glaciers, thawing permafrost, and earlier snowmelt over the past 50 years. Such changes are affecting the hydrologic regime in the Yukon, leading to increases in flooding and winter low flows (Streicker 2016).

Climatic conditions were unprecedented in 2021 in Western Canada. The summer of 2021 began with an extreme heatwave that blanketed Western Canada and the Pacific Northwest in late June, sending temperatures soaring well above all-time heat records across the region (Di Liberto 2021). Lytton, BC, set a record for the highest temperature ever measured in Canada, at 49.6°C on June 29, 2021, nearly 5°C higher than any temperature previously recorded in the country before this event. This heatwave was attributed to climate change; it was found to be “virtually impossible” in the absence of human-caused climate change (Philip et al. 2021). Continued warm and dry conditions over summer 2021 contributed to the third worst forest fire season in BC, with 8,800 km^2 burned; following consecutive records set in 2017 (12,161 km^2) and 2018 (13,540 km^2) (Canadian Council of Forest Ministers 2021). Moving into fall, extended periods of extreme rainfall in November 2021 caused unprecedented flooding in multiple areas of BC, and Washington State.

While the events of 2021 are unprecedented, heatwaves and heavy precipitation events are likely to become more common and more severe in the Pacific Region as global temperatures continue to rise (White et al. 2016; Philip et al. 2021). A heatwave like the one experienced in 2021 historically would have occurred once every 1,000 years. With 2°C of global warming above the pre-industrial (1850-1900) average, the frequency of such an event would increase to roughly every 5 to 10 years (Philip et al. 2021).

Global temperatures are projected to rise 1.5°C to 3.7°C above the 1850-1900 average by the end of this century. We are already approaching the 1.5°C global limit of warming that the IPCC recommends as critical if we are to avoid significant issues related to food, water, and other life support systems on the planet (IPCC 2014, 2018, UNEP 2019). Temperatures in BC are expected to increase between 1.6°C to 5.2°C above the 1986-2005 average by the end of this century, according to low (RCP2.6) or “business as usual” high (RCP8.5) emission scenarios (Bush and Lemmen 2019). These projected changes will be accompanied by further increases in precipitation, loss of glaciers, and summer/early fall drought in southern BC (White et al. 2016). Average temperatures in Northern Canada are projected to increase by 2.1 to 7.8°C by the end of the century (Bush and Lemmen 2019). Precipitation will likely continue to increase in the Yukon, and will increasingly fall as rain rather than snow, while glaciers continue to melt, and permafrost continues to thaw (Bush and Lemmen 2019).

Environmental Conditions are Affecting the Salmon Outlook for 2022: Why does this matter?

Pacific salmon are already responding to environmental changes driven by climate change and other human activities (Grant et al. 2019). Though there are exceptions, Chinook salmon abundances have declined throughout their range across BC and the Yukon, while sockeye and coho populations have declined in Southern BC (Grant et al. 2019). Pink and chum salmon generally have not exhibited declines, though Chum returns were poor in both 2019 and 2020 (Grant et al. 2019, 2020, 2021).

This qualitative outlook attempts to describe broad-scale patterns in fresh water and marine conditions to provide an indication of overall conditions for salmon survival, specifically for the 2022 returns. Physical changes in fresh water and marine environments affect Pacific salmon through their habitats and food availability, and salmon respond through their behaviour, growth rates, and overall survival (NOAA Fisheries 2021). While we do not have relevant data for all species in all locations, we provide a general description of what is known about environmental conditions experienced by the 2022 returns, in relation to historical conditions.

We predict that 2022 Canadian Pacific salmon productivity will generally be below average, given the environmental information available. Salmon populations returning in 2022 will have been exposed to varying fresh water and marine conditions during the years 2017-2021, usually reflected through warmer than average water temperatures. However, the specific environmental conditions experienced by each population are determined by their spawning and juvenile rearing distributions, age of return, and other characteristics such as migration timing. Additional factors can also contribute to salmon productivity, including habitat alteration from natural and human activities, particularly in fresh water, hatchery contributions, disease, contaminants, predation, competition, and other local environmental conditions.

Given the environmental changes already being observed and predicted for the future in BC and the Yukon, we do not anticipate that general salmon survival patterns will return to what we have seen historically. Climate vulnerability assessments for Pacific salmon on the west coast of the US indicate that vulnerability to climate change varies across Pacific salmon species and populations, determined by their unique combinations of geographical distribution and life history characteristics (Crozier et al. 2019). Climate vulnerability is largely higher for southern and interior populations, and this interacts with fresh water and estuary residence times (Crozier et al. 2019). These patterns corroborate some of the general trends that have already been observed across Pacific salmon populations in Canada (Grant et al. 2019).

As environmental conditions continue to change, we see climate vulnerability assessments as a valuable tool for providing a longer-range outlook for Canadian Pacific salmon. Such assessments will provide a more detailed understanding of the distribution of climate vulnerabilities across Pacific salmon populations in Canada, to better inform current and future management decisions.

Fresh Water Indicators of Health for Spawning, Egg Incubation, and Juvenile Rearing Life Stages between 2017-2020

Air Temperature

Air temperature is an important determinant of river temperature, and therefore an important indicator of health for salmon in the fresh water stages of their lifecycle. Canadian Pacific salmon returning in 2022 have lived during three of the five hottest years on record (NOAA National Centers for Environmental Information 2021). Though the annual data are still being collated for 2021, so far the year has seen well above average global temperatures (NOAA 2021). More locally, air temperature has been warmer than average in BC and the Yukon in recent decades (Figure 3). Warm temperature anomalies have been even greater in the Yukon than BC, due to its more northern location (Figure 3; Bush and Lemmen 2019). Spring and summer months were notably warmer from 2017 to 2019, with the exception of summer 2019, which was more variable and at times cooler than average (PCIC 2020). In 2020, B.C. experienced near normal maximum daily temperatures and above normal minimum daily temperatures.

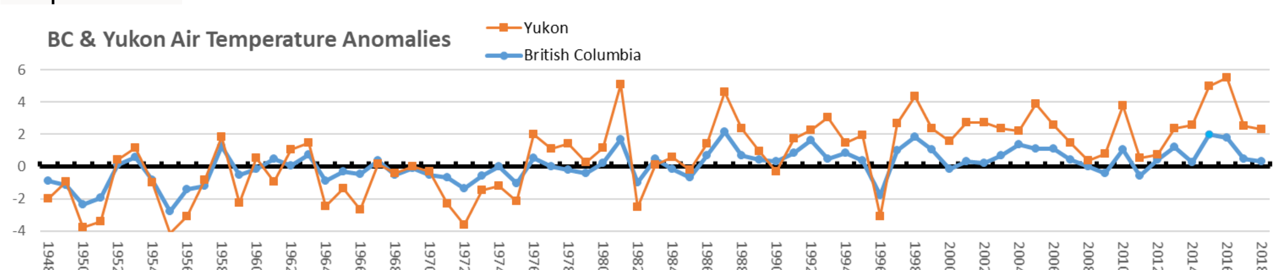

Figure 3. Canadian gridded temperature and precipitation anomalies (CANGRD) from the Government of Canada: https://climate-change.canada.ca/climate-data/#/historical-gridded-data. Temperatures for 2017 to 2020 coincide with the fresh water residence period of 2022 salmon returns. These data are interpolated from adjusted and

homogenized climate station data at a 50km resolution. Anomalies represent the departure from a mean reference period (1961-1990). Temperature anomalies are expressed as degree Celsius (C).

River Temperatures

Salmon have challenges migrating upstream to their spawning grounds when rivers are too warm. Annual river temperatures are not available for most BC/Yukon systems, but in the Fraser River system, where data are available, summer temperatures regularly exceeded upper thermal thresholds for salmon from 2017 to 2019.

Fisheries and Oceans Canada Fraser River environmental watch reports: https://www.pac.dfo-mpo.gc.ca/science/habitat/frw-rfo/reports-rapports/archives-eng.html. [Accessed December 10, 2020]

In 2020, river temperatures were relatively average, except for a short period at the end of July where they exceeded 18°C.

Fisheries and Oceans Canada Fraser River environmental watch reports: https://www.pac.dfo-mpo.gc.ca/science/habitat/frw-rfo/index-eng.html. [Accessed October 12, 2021]

Peak summer water temperatures in the Fraser River increased by greater than 1.8 °C in the fifty years preceding 2008 (Farrell et al. 2008). It is now common each year to have days where river temperatures exceed 18°C at some point in the spring/summer. Temperatures above 18°C can result in decreased adult salmon swimming performance, and above 20°C can increase adult mortality, adult disease, egg viability, and cause legacy effects that have negative impacts on juvenile condition (Tierney et al. 2009; Burt et al. 2011; Eliason et al. 2011; Sopinka et al. 2016). High in-river spawning and incubation temperatures can have population-specific negative effects on fertilization success and embryo survival, affect timing of hatch (Whitney et al. 2014), emergence (Macdonald et al. 1998), and reduce swimming endurance and impair swimming behavior of fry (Burt et al. 2012). For juveniles that rear in fresh water, warmer temperatures can improve juvenile growth rates when prey are not limiting (Brett 1971, Edmundson & Mazumder 2001), and also increase the length of the growing season in some areas (Schindler et al. 2005). The exposure of a salmon population to these various temperature-related fresh water conditions will vary by system. However, as temperatures continue to increase from global climate change, the net effect is expected to be negative (Crozier et al. 2019).

Snowpack

The timing and rate of snowpack loss are significant factors in the volume and timing of spring freshets. The size and melting rate of winter snowpack in the mountains is a strong indicator of river water volume, flow rates and temperature in the summer months. Early loss of snowpack reduces the cool water inputs into rivers and lakes from snowmelt in warmer summer months.

In 2018 and 2019, the onset of snowmelt began several weeks earlier than normal. In these years, most regions of BC had below-average snowpacks by the second week of May. In 2017, the onset of snowmelt began several weeks later than normal, with extreme hot temperatures resulting in rapid snow melt in the second half of May. By June 2017, snowpacks were anomalously low for this month in northern latitudes and were closer to average in southern latitudes of BC. The 2020 season had a mix of snowmelt conditions, with early melt in low and mid-elevation areas and a delay in the melt of high elevation snowpacks.

Ministry of Forests, Lands, Natural Resource Operations, and Rural Development, River Forecast Center, Snow Conditions & Water Supply Bulletin: https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/drought-flooding-dikes-dams/river-forecast-centre/snow-survey-water-supply-bulletin

Spring freshets were close to normal in 2017, 2018, 2019. In 2020, earlier seasonal melt and lower peak snow accumulation in some areas of the province saw some rivers trend towards an earlier freshet and below seasonal stream flow, while others remained close to normal or slightly above.

Ministry of Forests, Lands, Natural Resource Operations, and Rural Development, River Forecast Center, Snow Conditions & Water Supply Bulletin: https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/drought-flooding-dikes-dams/river-forecast-centre/snow-survey-water-supply-bulletin

Summer drought

Drought can result in lower river and lake levels, deteriorate water quality, block access to spawning habitat, strand salmon, increase exposure to predators and increase the risk of low oxygen levels in some fresh water systems. Recent years hit records for summer droughts in BC; 2017, and 2018 were both particularly dry years. The most significant drought occurred in 2017, during which records were set for the driest season, with almost no rain falling in southern BC from June to late October, and peak drought occurring in October. In 2018, a heatwave in early spring depleted snowpacks, and lack of precipitation from July to November created extensive dry conditions from July to November. In 2019, a spring heatwave created dry conditions across the province, and drove down streamflow levels. Heavy rains in July began to help relieve the drought. Most of the province experienced average rainfall in 2020, with the exception of Vancouver Island and some southern watersheds that were very dry by late summer. In both 2019 and 2020, by October, most of the province had returned to average.

British Columbia Drought Information Portal:
https://governmentofbc.maps.arcgis.com/apps/MapSeries/index.html?appid=838d533d8062411c820eef50b08f7ebc

Marine indicators of Health for Juvenile Rearing to Adulthood Life Stages between 2019-2021

Ocean Temperature

Salmon metabolic demands increase with temperature. Without a concurrent increase in prey quality or quantity, salmon growth and productivity will decrease under warming conditions (Holsman et al. 2018). In recent years Chinook body weight for a given length declined (Daly et al. 2017). Sizes of mature Fraser River sockeye declined from the 1970s to the early 1990s, increased in the early 2000s, then again decreased through the 2010s. Lake-type Fraser Sockeye were amongst the smallest on record in 2019 and 2020 (Latham et al. 2021). Predation also can intensify in warmer ocean conditions, increasing salmon mortality (Holsman et al. 2012).

Sea surface temperatures have been warmer than average in the Northeast Pacific Ocean in recent decades (Figure 4) and have increased linearly by 0.88°C over the past 100 years (Chandler 2021). Following the notable “The Blob”, the North Pacific marine heatwave of 2013 to 2016, there was a return to near-average sea-surface temperatures in 2017 and 2018. However, this was likely due to the cooling effect of the La Niña that persisted until the second half of 2018 (Ross and Robert 2018, 2019). New heatwaves were observed in the late summer and fall of 2018 and throughout most of 2019 and 2020 (Hannah et al. 2019; Ross and Robert 2020, 2021). The 2019 and 2020 heat waves were the second and third most expansive, respectively, in recorded history (NOAA Fisheries 2020), though neither reached the water column depths of The Blob. The cooling influences of a La Niña that emerged in the latter half of 2020 kept extreme warm ocean temperatures away from coastal B.C. waters (Boldt et al. 2021). At the time of writing, this La Niña is expected to continue through the Northern Hemisphere winter of 2021-2022 (~95% chance), and there is a 60% likelihood it will transition to neutral conditions during spring 2022 (NOAA National Weather Service 2021).

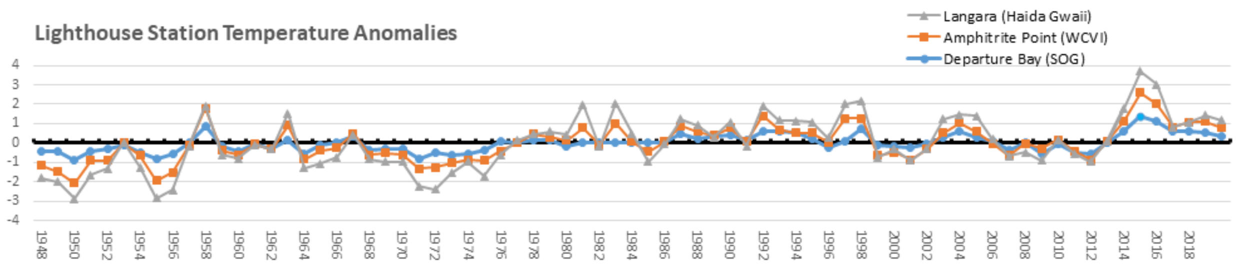

Figure 4. Annual average sea-surface-temperature anomalies from Fisheries & Oceans Canada lighthouse stations: https://www.dfo-mpo.gc.ca/science/data-donnees/lightstations-phares/index-eng.html. Anomalies represent the departure from a mean reference period (1948-2020). Temperature anomalies are expressed as degree Celsius (C).

Physical oceanography

Deep water convection is one of the major processes driving open-ocean primary productivity in the Pacific Ocean. Strong winter mixing brings more nutrients to the surface. Mixing during the 2018/2019 winter was very weak, suggesting lower than average availability of surface nutrients in early spring 2019 (Ross and Robert 2020). The mixing in the winter of 2019/20 was weak, though surface nutrients were likely not as low as they were in 2019 (Ross and Robert 2021).

Food Web: Phytoplankton

Phytoplankton are the base of the aquatic food web, feeding a host of other animals, such as zooplankton. The size and composition of phytoplankton communities affect the zooplankton that are able to feed on them, causing impacts further up the food chain (Batten and Ostle 2020).

Off the west coast of B.C. (along Line P), phytoplankton biomass was similar to previous years in spring/summer 2019, but relatively low in 2020 (Boldt et al. 2020, 2021). The phytoplankton community was composed of relatively high abundances of diatoms at several open-ocean sampling locations in June 2019, similar to 2018 (Peña and Nemcek 2020). In the winter of 2020, the phytoplankton community composition was similar to 2015 (a marine heatwave year), but in the summer it was similar to pre-marine heatwave years. There was no survey in the spring of 2020 (Boldt et al. 2021).

Food Web: Zooplankton

Zooplankton play a key role in the food web, supporting higher trophic levels. Boreal and sub-Arctic copepod species of zooplankton occur along the outer BC coast, and are lipid-rich and very nutritious. Southern copepods (which have their distributions centered off California) are less nutritious, as they are smaller and comparatively lipid-poor. Warmer ocean temperatures such as those seen in marine heatwaves like The Blob cause northward shifts in the distribution of southern copepod species to occupy habitats otherwise too cold for them (Mackas et al. 2004). Such shifts in zooplankton composition are a key pathway potentially linking reduced salmon productivity to warmer temperatures in the Northeast Pacific Ocean (Mackas et al. 2007).

From 2019 to 2020, zooplankton composition and biomass varied across regions. In general, biomass of gelatinous zooplankton, characterized by high water content and low nutritional value, were closer to average, compared to the anomalous highs observed since 2014 during the Blob (Galbraith and Young 2021). Crustacean biomass anomalies were close to average (Galbraith and Young 2021).

Among those crustaceans, though, there was a continuing trend of higher than average abundances of southern, lipid-poor copepod species, and low abundances of lipid-rich, subarctic copepods (Galbraith and Young 2021). However, sampling in the coastal waters of Vancouver Island (North and South) and Hecate Strait regions showed declining trends in southern copepods since 2017/18, with an increase in 2020 in the Southern Vancouver Island region. Southern copepod biomass has remained above average in deep oceanic waters of the NE Pacific (along Line P; Galbraith and Young 2021).

In the Strait of Georgia, zooplankton biomass has been trending upwards since 2011 (Perry et al. 2021), and was above average in both 2019 and 2020 (Young et al. 2021). Zooplankton biomass was dominated by medium and large bodied copepods and larger crustaceans (Young et al. 2021), which tend to be the preferred prey for several species of juvenile fish of commercial interest (Perry et al. 2021).

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