CALIFORNIA CURRENT INTEGRATED ECOSYSTEM ASSESSMENT (CCIEA) CALIFORNIA CURRENT ECOSYSTEM STATUS REPORT, 2021

A report of the NOAA CCIEA Team to the Pacific Fishery Management Council, March 10, 2021.

Editors: Dr. Chris Harvey (NWFSC), Dr. Toby Garfield (SWFSC), Mr. Greg Williams (PSMFC), and Dr. Nick Tolimieri (NWFSC)

1 INTRODUCTION

Section 1.4 of the 2013 Fishery Ecosystem Plan (FEP) established a reporting process wherein NOAA provides the Pacific Fishery Management Council (Council) with a yearly update on the status of the California Current Ecosystem (CCE), as derived from environmental, biological, economic and social indicators. NOAA's California Current Integrated Ecosystem Assessment (CCIEA) team is responsible for this report. This is our 9th report, with prior reports in 2012 and 2014-2020.

This report summarizes CCE status based on data and analyses that generally run through 2020. Highlights are summarized in Box 1.1. Appendices provide additional information or clarification, as requested by the Council, the Scientific and Statistical Committee (SSC), or other advisory bodies.

Box 1.1: Highlights of this report

- West Coast research efforts in 2020 were heavily impacted by the COVID-19 pandemic. While care should always be exercised in interpreting ecosystem indicators, that is especially true this year. As always, the CCIEA team is available to advise.
- 2020 saw a transition from El Niño conditions and positive PDO signals to La Niña conditions and a negative PDO for the first time in many years. These conditions are generally associated with higher productivity in the CCE.
- The second largest marine heatwave observed in the North Pacific occurred in 2020, but mostly stayed offshore.
- The system experienced low snowpack, drought, and catastrophic wildfires in 2020.
- Strong winter upwelling preceded the start of an average to above-average upwelling season, providing a good nutrient supply to the base of the food web.
- Foraging conditions appeared to be above average, based on measures of the zooplankton community, continued high abundance of anchovies, and production of offspring at seabird and sea lion colonies.
- Signs of concern included widespread harmful algal blooms, continued presence of species associated with warmer waters, and mixed outlooks for returns of Chinook salmon in 2021.
- Fishery landings and revenues appear to be substantially lower in 2020 compared to 2019, and the COVID-19 pandemic is one of many possible contributing factors.
- We introduce or update several analyses of coastal communities, revenue dynamics, and fishing networks that may help us understand how fishing communities respond to change.

Throughout this report, most indicator plots follow the formats illustrated in Figure 1.1.

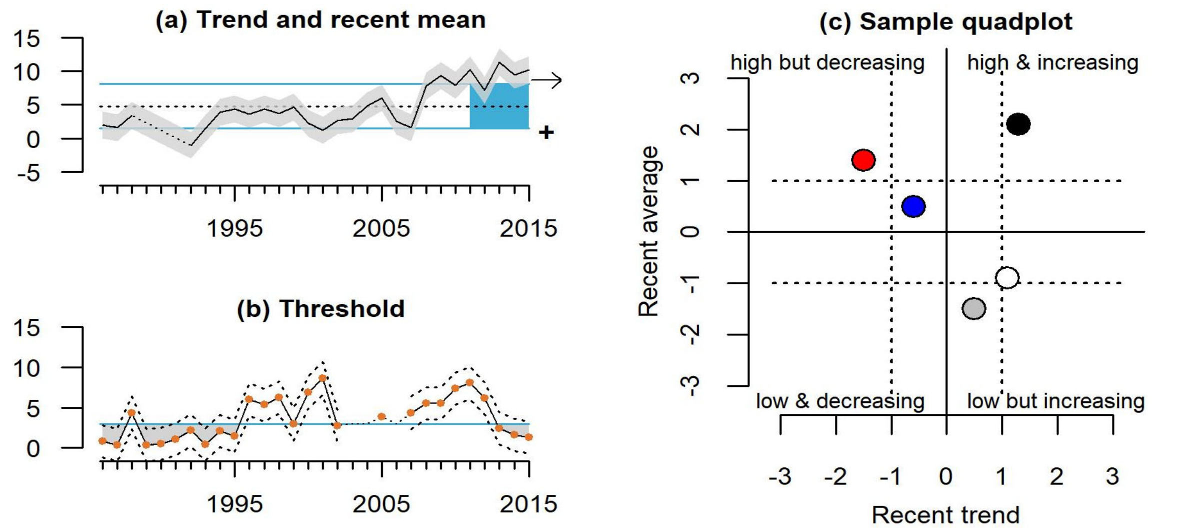

Figure 1.1 (a) Sample time-series plot, with indicator data relative to the mean (black dotted horizontal line) and 1.0 s.d. (solid blue lines) of the full time series. Dotted black line indicates missing data, and points (when included) indicate data. Arrow at the right indicates if the trend over the evaluation period (shaded blue) was positive, negative or neutral. Symbol at the lower right indicates if the recent mean was greater than, less than, or within 1.0 s.d. of the long-term mean. When possible, times series indicate observation error (gray envelope), defined for each plot (e.g., s.d, s.e., 95% confidence intervals); (b) Sample time-series plot with the indicator plotted relative to a threshold value (blue line). Dashed lines indicate upper and lower observation error, again defined for each plot. Dotted black line indicates missing data; (c) Sample quadplot. Each point represents one normalized time series. The position of a point indicates if the times series was increasing or decreasing over the evaluation period and whether the mean recent years of the time series (recent trend) was above or below the long-term average (recent mean). Dashed lines represent ± 1.0 s.d. of the full time series.

2 Sampling Locations

We generally refer to areas north of Cape Mendocino as the "Northern CCE," Cape Mendocino to Point Conception as the "Central CCE", and areas south of Point Conception as the "Southern CCE." Figure 2.1a shows sampling areas for most regional oceanographic data. Key transects are the Newport Line off Oregon, the Trinidad Head Line off northern California, and CalCOFI lines further south. This sampling is complemented by basin-scale observations and models. Figure 2.1a also shows sampling areas for most biological indicators.

Freshwater ecoregions in the CCE are shown in Figure 2.1b, and are the basis by which we summarize indicators for snowpack, flows, and stream temperatures.

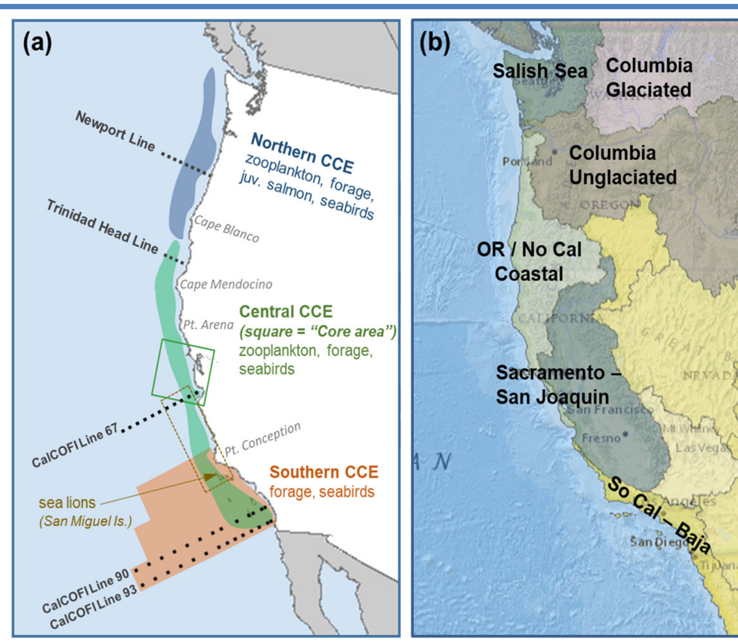

Figure 2.1. The California Current Ecosystem (CCE). (a) Sampling areas for oceanographic data (dotted transect lines) and biological data (shaded areas). Solid box = core sampling area for forage in the Central CCE. Dotted box approximates foraging area for adult female California sea lions from the San Miguel colony. (b) Freshwater ecoregions in the CCE.

***Box 2.1: COVID impacts on data*—**The COVID-19 pandemic impacted most West Coast survey programs in 2020, resulting in reduced data availability for many time series:

- Surveys that were cancelled completely in 2020 included NOAA's coastwide Coastal Pelagic Species cruise and West Coast Groundfish Bottom Trawl Survey.
- Survey efforts were severely scaled back for forage species (particularly cancellations or effort reductions of critical spring cruises) and also for marine mammals and seabirds.
- Ship-based survey reductions resulted in far fewer measurements of dissolved oxygen.
- Sample processing has been delayed for many surveys.

COVID-related effects on data are noted throughout the report, and we recommend taking additional care in interpreting findings from this year's report. As always, the CCIEA team is available to advise.

3 Climate and Ocean Drivers

Climate and ocean signals showed signs of transition in 2020. Weak El Niño conditions and a positive PDO gave way to a La Niña and a negative PDO, conditions not experienced since before the 2013-2016 marine heatwave (the "Blob"). Moderate to strong upwelling north of Point Conception expanded cool coastal waters and mostly kept a new and very large marine heatwave offshore. Harmful algal blooms were widespread, while reduced snowpack and streamflow in some regions contributed to severe drought conditions. These dynamics are detailed further in the sections below.

3.1 Basin-Scale Indicators

We use three satellite-derived indices to describe large-scale physical ecosystem states. The Oceanic Niño Index (ONI) describes the equatorial El Niño Southern Oscillation (ENSO). An ONI above 0.5°C indicates El Niño conditions, which often lead to lower primary production, weaker upwelling, poleward transport of equatorial waters and species, and more southerly storm tracks in the CCE. An ONI below -0.5°C means La Niña conditions, which usually lead to higher productivity. The Pacific Decadal Oscillation (PDO) describes north Pacific sea surface temperature (SST) anomalies that may persist for many years. Positive PDOs are associated with warmer SST and lower productivity in the CCE, while negative PDOs indicate cooler SST and higher productivity. The North Pacific Gyre Oscillation (NPGO), an index of sea surface height, indicates changes in circulation that affect source waters for the CCE. Positive NPGOs are associated with strong equatorward flow and higher salinity, nutrients, and chlorophyll-*a*. Negative NPGOs are associated with decreased subarctic source water and lower CCE productivity.

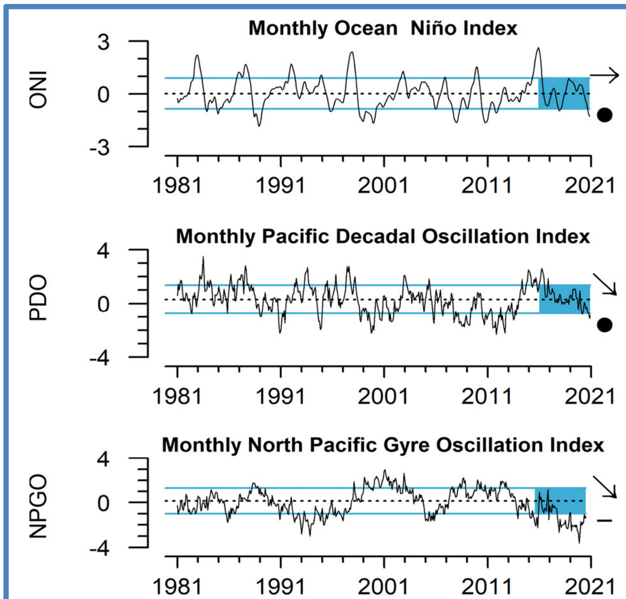

Figure 3.1.1 Monthly values of the Ocean Niño Index (ONI), Pacific Decadal Oscillation (PDO), and the North Pacific Gyre Oscillation (NPGO) from 1981-2020. Mean and s.d. for 1981-2010. Lines, colors, and symbols are as in Fig. 1.1.

Basin-scale indices suggest a return to average or above-average conditions for productivity in 2020: the ONI and PDO turned negative, while the NPGO remained negative. The ONI indicated that weak El Niño conditions, which had mostly persisted since late 2018, began to diminish in March 2020. ONI values were negative by June and La Niña conditions have existed since August 2020 (Figure 3.1.1, top). In November, ONI dropped to -1.3°C, its lowest value since 2011. NOAA forecasts a 95%

chance of La Niña remaining through winter and a 65% chance of continuing through spring 2021. The PDO continued a 5-year trend of decreasing values since 2016 (Figure 3.1.1, middle). PDO was negative for most of 2020, the longest string of negative values since before the 2013-2016 marine heatwave, and the November value (-1.12) was the lowest since 2013. NPGO remained in the negative state it has been in since late 2016, although the values were not as negative as the extreme lows at the end of 2019 (Figure 3.1.1, bottom). Seasonal values for all indices are in Appendix D.1.

The northeast Pacific continues to experience large marine heatwaves in surface waters. In January 2020, a heatwave that began in summer 2019 had receded to an offshore region in the Gulf of Alaska. A new heatwave occurred from February-June 2020 in the area where the 2019 event faltered, but it remained >1500 km from the West Coast. Then, a much larger heatwave formed offshore in June, and by mid-September it had grown to its maximum size of ~9.1M km² (Figure 3.1.2), the second largest North Pacific heatwave on record behind the 2013-2016 "Blob" (Appendix D.2). The 2020 heatwave stayed offshore until September, presumably held off by moderate to strong upwelling that occurred in the central and northern CCE for much of 2020. The heatwave lingered in coastal waters through November, particularly the northern CCE, then moved offshore, where it remains as of January 2021.

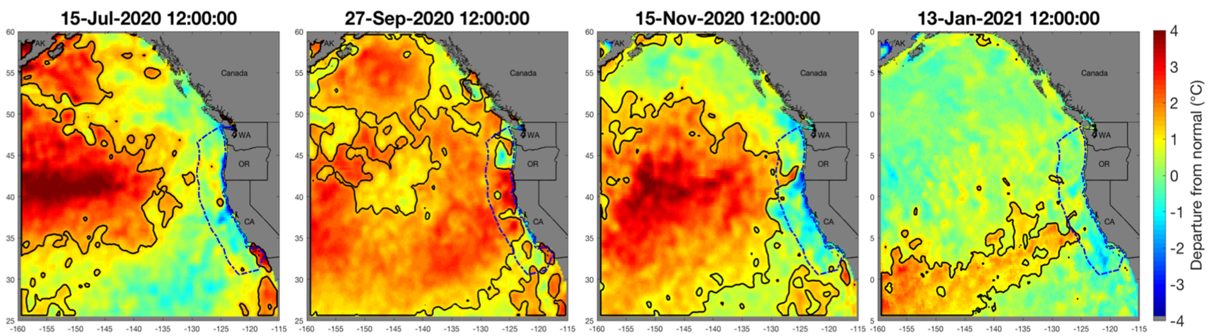

Figure 3.1.2 Progression of the 2020 marine heatwave. Colors represent standardized SST anomalies. Dark contours denote regions that meet the criteria for a marine heatwave (see Appendix D.2). Dashed line denotes EEZ boundary.

The upper portion of the water column off Newport, Oregon was relatively cool for much of 2020 (Figure 3.1.3, top). Temperatures were ~0.5°C cooler than average in the upper 50 m from winter through summer, and close to average at greater depths. The anomaly in the upper water column was the longest sustained cool period of the last 5 years. Temperatures off Newport switched to average or above-average in late summer, coincident with the arrival of the marine heatwave.

In contrast, the Southern California Bight was warm in 2020. At CalCOFI station 93.30 off San Diego, warm anomalies >1°C dominated the water column in winter and spring, particularly in the upper 50 m (Figure 3.1.3, bottom). These anomalies were likely related to the weak El Niño in early 2020. Deeper waters shifted from warm to cool anomalies in spring. Summer and fall data are as

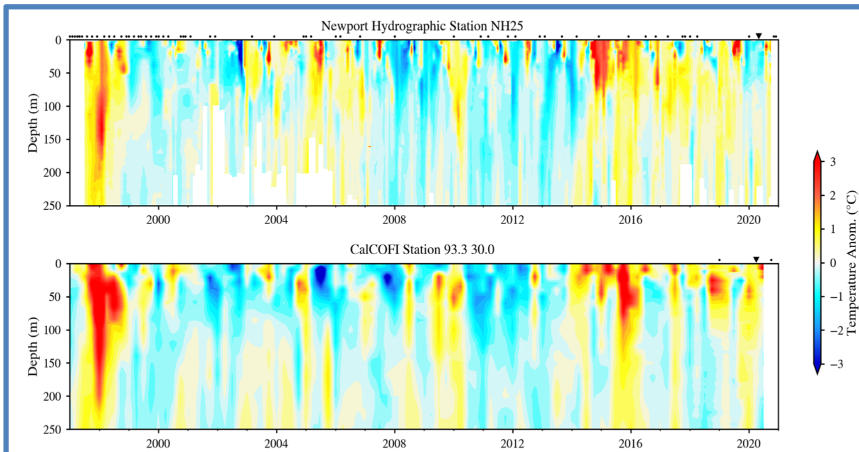

Figure 3.1.3 Time-depth temperature anomalies for stations NH25 and CalCOFI 93.30 from 1997 through October 2020. For location of transect lines, see Fig. 2.1a.

yet unavailable from this station, but wave glider data from nearby Line 90 indicate warmer-than-average waters for most of 2020 (Appendix D.2). Similarly, a wave glider off Monterey Bay recorded average or above-average temperatures down to 250 m for most of 2020 (Appendix D.2).

3.2 Regional Indicators

Upwelling in the CCE occurs when equatorward coastal winds move deep, cold, nutrient-rich water to the surface, fueling seasonal production. On average, upwelling peaks in late April at 33°N (near San Diego), mid June at 39°N (off Point Arena), and late July at 45°N (off Newport). Nutrient delivery by upwelling also varies by region: vertical flux of nitrate at 39°N is an order of magnitude greater than at 45°N or 33°N. Jacox et al. (2018) developed models to estimate the vertical fluxes of water (Cumulative Upwelling Transport Index; CUTI) and nitrate (Biologically Effective Upwelling Transport Index; BEUTI) in the CCE.

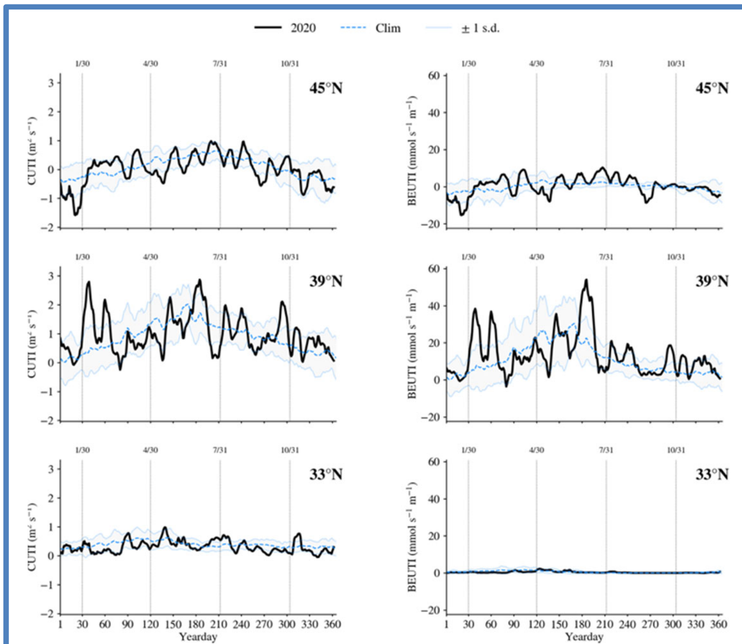

Figure 3.2.1 Daily 2020 estimates of vertical transport of water (CUTI, left) and nitrate (BEUTI, right) relative to the 1988-2019 average (blue dashed line) ±1 s.d. (shaded area), at latitudes 33°, 39°, and 45°N. Vertical lines mark the ends of January, April, July and October.

In 2020, there were frequent upwelling events at 39°N and 45°N, with peaks ≥1 s.d. above the mean, that were usually followed by relaxation events (Figure 3.2.1, left). Upwelling events provided inputs of nitrate into the surface waters, especially the strong upwelling events in February and June at 39°N (Figure 3.2.1, right). When upwelling events are followed by relaxation, as occurred in 2020, the upwelled nutrients may be more likely to be retained and spur coastal production. Also, the large upwelling events in February may have provided an early injection of nutrients before the spring transition into the productive season for the coastal food web.

The cool, productive habitat created by upwelling can be compressed along the coast by offshore impingement, marine heatwaves, or reduced upwelling conditions, with cascading ecological effects on marine species. Santora et al. (2020) developed the habitat compression index (HCI) to describe this physical process. HCI ranges from 0 (= complete intrusion of warm offshore water in a region) to 1 (= upwelled water fully extending 150 km from the coast). Off central California (35.5°N to 40°N), upwelled habitat has been expanding since 2015 (Figure 3.2.2), and winter and spring HCI values in 2020 were close to long-term means. HCI estimates for the rest of the West Coast indicate that seasonal upwelling habitat has generally been stable or expanding over the past five years for northern California, Oregon and Washington (Appendix D.3).

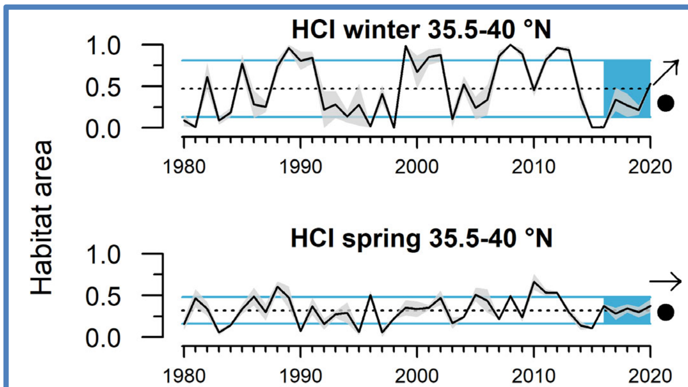

Figure 3.2.2 Mean winter (Jan - March) and spring (April - June) habitat compression index (HCI) for 35.5 - 40 °N, 1980-2020. Habitat area represents the fraction of coastal habitat that is cooler than the threshold. Error envelope indicates ± 1.0 s.e. Lines, colors, and symbols are as in Fig. 1.1.

3.3 Hypoxia and Ocean Acidification

Dissolved oxygen (DO) is dependent on processes such as currents, upwelling, air-sea exchange, primary production, and respiration. Low DO can compress habitat and cause stress or die-offs for sensitive species (Chan et al. 2008). Near-bottom DO at station NH05 off Newport, Oregon fell below the hypoxia threshold in June-August 2020, and was similar in intensity to 2019 (Figure 3.3.1, top). Off San Diego at CalCOFI station 93.30, near-bottom DO was above the hypoxia threshold in winter and summer (Figure 3.3.1 bottom; no spring data), but summer DO at CalCOFI stations further offshore was generally below average, and many stations had the lowest summer DO observed since monitoring began in 1984 (Appendix D.4). DO maps and seasonal time series from Newport and CalCOFI are in Appendix D.4.

Ocean acidification, caused by increased anthropogenic CO_2, lowers pH and carbonate in seawater and can be stressful to shell-forming organisms and other species (Feely et al. 2008, Bednaršek et al. 2020). At station NH05 off Newport, levels of aragonite (a form of calcium carbonate) were favorable during spring, unlike in the previous two years, before waters became corrosive in summer and fall as is typical. Offshore at NH25, much of the water column in 2020 was corrosive. Details and plots are in Appendix D.4.

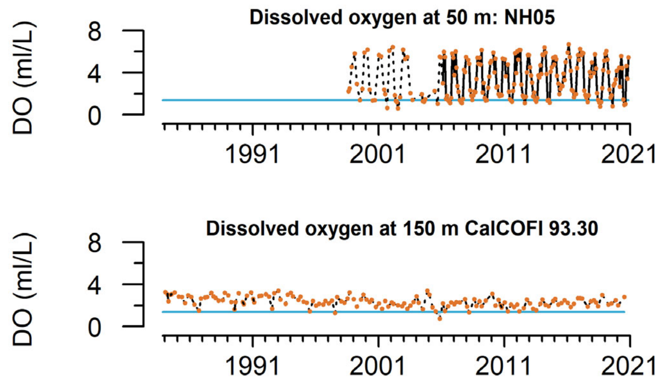

Figure 3.3.1 Near-bottom dissolved oxygen off Newport, OR (Station NH05) and San Diego, CA (CalCOFI 93.30) through 2020. The blue line is the hypoxic threshold of 1.4 ml DO/L. Lines, colors, and symbols are as in Fig. 1.1.

3.4 Harmful Algal Blooms (HABs) and "Red Tide"

Blooms of the diatom *Pseudo-nitzschia* can produce domoic acid, a toxin that can affect coastal food webs and lead to shellfish fishery closures when shellfish tissue levels exceed regulatory limits (Appendix E). In 2020, exceedances of domoic acid were detected in razor clams and crabs from northern California to the Canadian border (Figure 3.4.1), which caused protracted fishery closures and delays for much of the West Coast, many of which continued into early 2021. The razor clam fishery remained closed in northern California, as it has been since 2016. In Oregon, a statewide razor clam closure begun in 2019 was gradually lifted for northern (January), central (February), and southern beaches (August) before closing again over the course of the fall. A rapid rise of domoic acid in Washington closed recreational and Tribal razor clam harvests in October. Many crab fishery seasons were shortened, due in part to domoic acid but also to meat quality and to

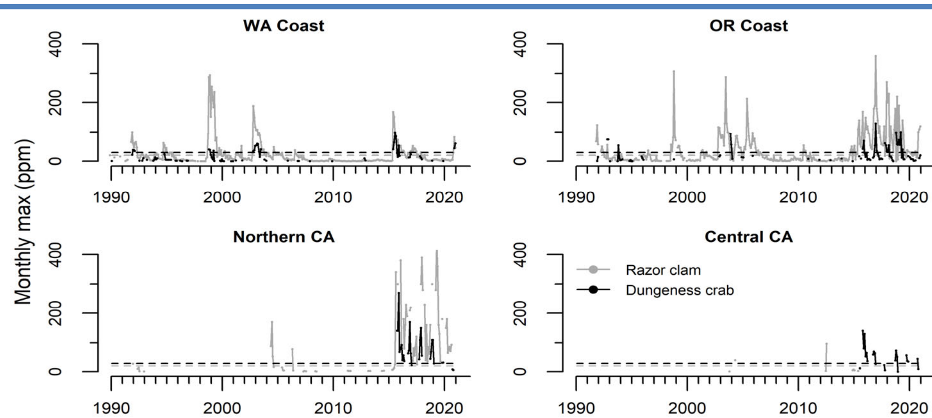

Figure 3.4.1 Monthly maximum domoic acid concentration (ppm) in razor clams (gray) and Dungeness crab viscera (black) through 2020 for WA, OR, northern CA (Del Norte to Mendocino counties), and central CA (Sonoma to San Luis Obispo counties). Horizontal dashed lines are the management thresholds of 20 ppm (clams in gray) and 30 ppm (crabs in black).

reducing risk of whale entanglement in crab gear. Domoic acid led to closure of northern California rock crab fisheries throughout 2020, and also delayed opening of the Dungeness crab fishery from Cape Falcon to the Oregon/Washington border for all of December 2020. Domoic acid also led to closures of commercial, recreational and Tribal Dungeness crab fisheries in Washington for parts of November and December 2020. Details of the causes, locations and timings of delays and closures are in Appendix E.

Further south, an extremely dense, prolonged "red tide" of the dinoflagellate *Lingulodinium polyedra* extended from Los Angeles to Baja in spring 2020. Levels of *L. polyedra* and chlorophyll at Scripps Pier were the highest ever recorded. This highly disruptive bloom caused hypoxia, fish and invertebrate kills, and respiratory irritation among surfers and beach-goers. A toxin associated with *L. polyedra*, yessotoxin, may have played a role in the die-offs. Conditions thought to have promoted the bloom included high March-April rains, stratification due to low winds, seasonal warming, and anomalous conditions in the region since 2014. Details are in Appendix E.

3.5 Hydrologic Indicators

Favorable freshwater conditions are critical for anadromous populations. Hydrologic indicators presented here are snowpack, streamflow and stream temperature, summarized by ecoregion (Figure 2.1b). Snow-water equivalent (SWE) is the water content in snowpack, which supplies cool freshwater to streams in spring, summer and fall. Maximum flows in winter and spring are important for habitat formation and removal of salmon parasites, but extreme discharge events can scour salmon redds. Below-average minimum flows in summer and fall can restrict habitat for juvenile salmon and migrating adults. High summer temperatures can impair physiology and cause mortality.

On April 1 2020, SWEs in the northern ecoregions (Salish Sea/WA Coast, Columbia Glaciated, Columbia Unglaciated) were close to long-term means (Figure 3.5.1). However, SWE were ~1 s.d. below average in 2020 for coastal Oregon and Northern California and Sacramento/San Joaquin, and were much lower than in 2019. Moderate to severe droughts were forecast for northern California, Oregon and parts of Washington in April 2020. These intensified to severe-extreme conditions in summer and triggered catastrophic wildfires throughout the West.

Maximum flows showed similar patterns to SWE for 2020 at ecoregional scales, with near-average values in the Salish Sea/WA Coast and both Columbia ecoregions, but below-average values in 2020 for coastal Oregon/Northern California and Sacramento/San Joaquin. Trends for the most recent 5 years are negative for Columbia Glaciated, OR/NoCA

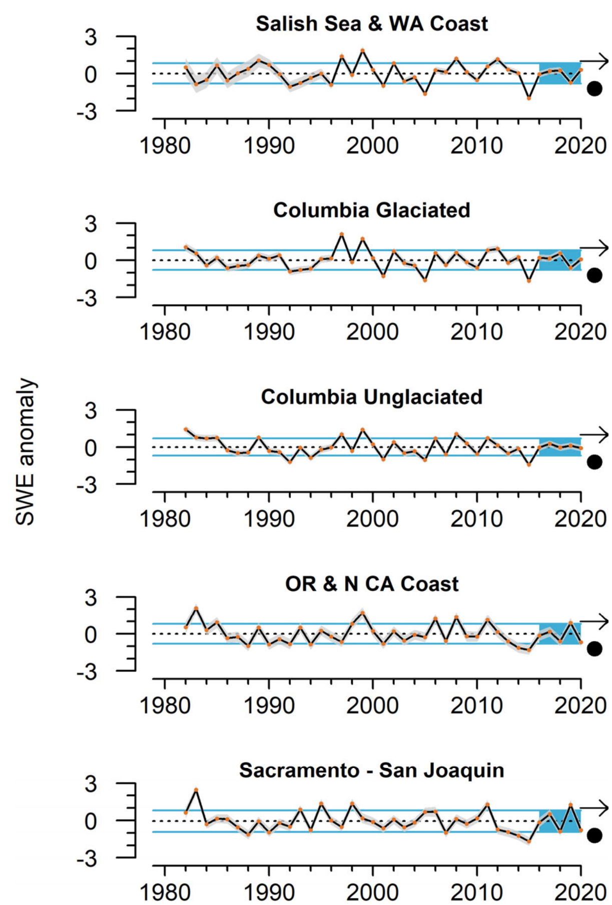

Figure 3.5.1 Anomalies of April 1st snow-water equivalent (SWE) in five freshwater ecoregions of the CCE through 2020. Ecoregions are mapped in Fig. 2.1. Error envelopes represent the 95% credible intervals (CI). Symbols follow those in Fig. 1.1.

Coast and Sacramento/San Joaquin but non-significant in other regions (see Appendix F). Minimum flows were close to long-term averages in all ecoregions in 2020, and generally have improved since 2015 (Appendix F). August stream temperatures for the Salish Sea/WA Coast were cooler in 2020 than in recent years, but the OR/NoCA Coast and Sacramento/San Joaquin ecoregions were warmer than average, and increased relative to 2019 (Appendix F).

We also summarize streamflows at the finer scale of individual Chinook salmon evolutionarily significant units (ESUs). These results are summarized in quad plots, which indicate ESUs with significant short-term trends or recent averages that differ from long-term means. With the exception of two ESUs in the Columbia system, maximum flows had either declining or non-significant trends from 2016-2020; in general, maximum flows were close to or above average during that period (Figure 3.5.2, left; Appendix F). Because high winter maximum flows are generally beneficial for juvenile salmon in southerly populations, the negative winter trends in southern ecoregions, driven by low values in 2018 and 2020, suggest worsening recent conditions for egg and alevin incubation. Minimum flows were generally close to long-term averages, but some ESUs experienced increasing minimum flows over the past five years, including the Snake River Fall and both Central Valley ESUs (Figure 3.5.2, right; Appendix F). Minimum flows in the Washington Coast and Lower Columbia ESUs have been below average in recent years.

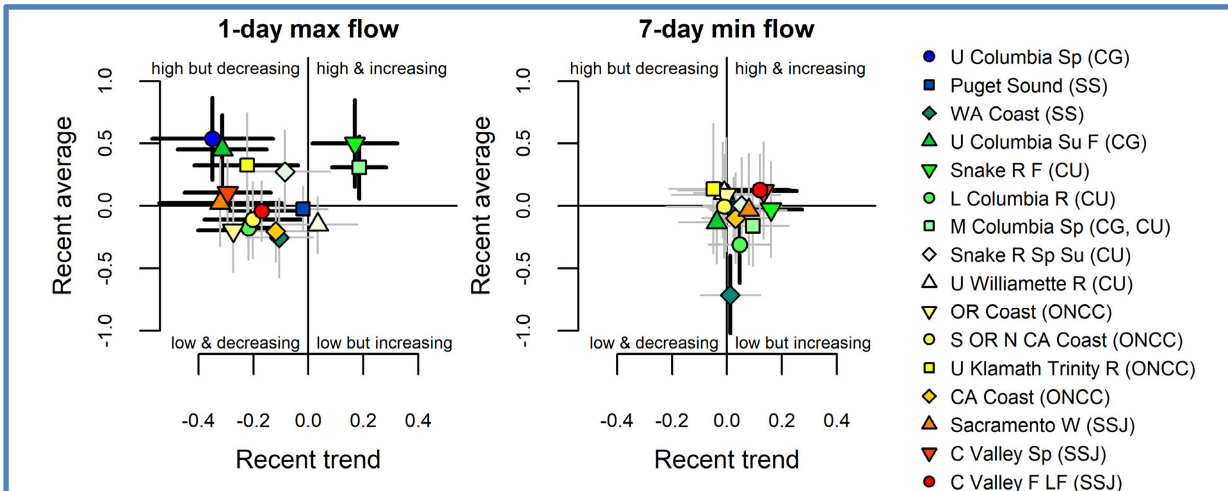

Figure 3.5.2 Recent (5-year) trend (2016-2020) and average of anomalies relative to the long-term trend (1919-2020) in maximum and minimum flow in 16 freshwater Chinook salmon ESUs in the CCE through 2020. Symbols of ESUs are color-coded from north (blue) to south (orange). Error bars represent 95% credible intervals. Gray error bars overlap zero. Heavy black error bars differed from zero.

Because SWE typically peaks in early spring, the last official measure of SWE will be on April 1, 2021. As of January 31st 2021, SWE is mixed. Most stations in northern Washington and northern Idaho are average or above average, while eastern Oregon and central/southern Idaho are mixed. Stations in western Oregon and in California are mostly below average. Drought persists in nearly all of California, much of Oregon, and parts of Idaho and Washington (Appendix F).

4 Focal Components of Ecological Integrity

The CCIEA team examines many indicators related to the abundance and condition of key species and the dynamics of ecological interactions. Preliminary data suggest average to above-average feeding conditions in 2020 in much of the CCE, with signs of improved abundance of nutritious zooplankton, high abundance of anchovy, and positive productivity signals for top predators. Signals for Chinook salmon returns in 2021 are mixed. Sections below should be interpreted with care because survey effort was reduced in 2020 due to COVID-19, and many samples have yet to be processed.

4.1 Copepod Biomass and Krill Size

Copepod biomass anomalies represent variation in northern copepods (cold-water zooplankton species rich in wax esters and fatty acids) and southern copepods (smaller species with lower fat content and nutritional quality). In summer, northern copepods usually dominate the zooplankton community along the Newport Line (Figure 2.1a), while southern copepods dominate in winter. Positive values of northern copepods correlate with stronger returns of Chinook salmon to Bonneville Dam and coho salmon to coastal southern Oregon (Peterson et al. 2014). El Niño events and positive PDO regimes can increase southern copepods (Keister et al. 2011, Fisher et al. 2015).

In 2020, northern copepods continued an overall increasing trend since the extreme lows during the 2014-2016 heatwave. They were >1 s.d. above the mean in spring-summer 2020 before their regular seasonal decline in the fall (Figure 4.1.1, top). The spring-summer anomaly was among the highest of the time series. Southern copepods were below-average for much of 2020, continuing a decline since the heatwave (Figure 4.1.1, bottom). These values suggest above-average feeding conditions for pelagic fishes off central Oregon in 2020, with late-spring/summer copepod ratios the most favorable observed since before the 2014-2016 heatwave, and in nearly a decade. The biweekly survey that collects these data lost only two sampling dates due to COVID-19, both in spring.

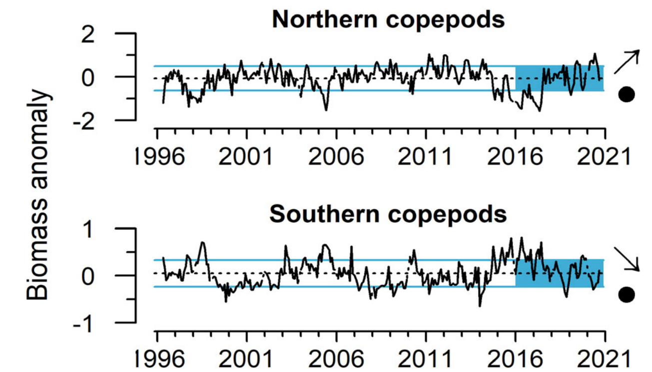

Figure 4.1.1 Monthly northern and southern copepod biomass anomalies from station NH05 1996-2020. Lines, colors, and symbols are as in Fig. 1.1.

Krill are among the most important prey for fishes, mammals and seabirds in the CCE. The key species *Euphausia pacifica* is sampled year-round off Trinidad Head (Figure 2.1a). Mean length of adult *E. pacifica* is an indicator of krill as a prey resource. *E. pacifica* grow from short individuals in winter to longer individuals by summer. *E. pacifica* lengths in spring and summer of 2020 were above average (Figure 4.1.2), and much greater than in 2019 when krill growth may have been negatively affected by El Niño conditions in the 2018-2019 winter. The overall trend for krill lengths has been increasing since poor growth at the onset of the 2014-2016 heatwave. COVID-19 led to some cancelled cruises and delayed sample processing at Trinidad Head, but the 2020 data are from stations that are highly representative of *E. pacifica* lengths in the region (Robertson and Bjorkstedt 2020). A spring survey that has produced estimates of krill biomass and distribution off Oregon and Washington since 2011 (Brodeur et al. 2019) was cancelled in 2020 due to COVID-19.

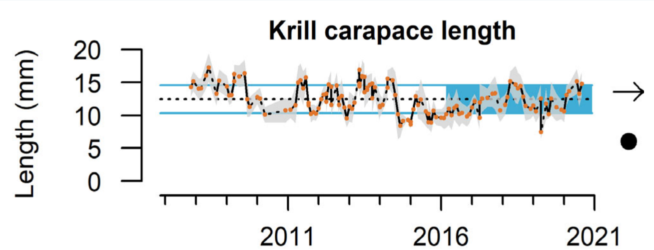

Figure 4.1.2 Monthly mean krill carapace length (mm) off of Trinidad Head, CA from 2007-2020. Gray envelope indicates ± 1.0 s.d. Lines, colors, and symbols are as in Fig. 1.1.

4.2 Regional Forage Availability

Our ability to understand dynamics of the CCE's diverse forage community was impacted by COVID-19, which disrupted regional forage surveys and sample processing. We typically use multivariate analyses to compare the timing and nature of forage community shifts across the three regions, but are unable to do so this year, due to data limitations. Instead, we present some time series that we believe to be most representative of times and locations that were surveyed in 2020, with additional time series in Appendix G along with explanations of methodological changes, which were reviewed by the Council SSC-Ecosystem Subcommittee in January 2021.

Northern CCE: The Northern CCE survey off Washington and Oregon (Figure 2.1a) targets juvenile salmon in surface waters, and also samples surface-oriented fishes, squid and jellies. Due to COVID-19, processing of samples from 2020 was delayed and only recently completed. Among 2020 samples that we have had time to evaluate, the most striking observation is unprecedented catches of YOY sablefish (Figure 4.2.1). Other time series for this survey are in Appendix G.1. Juvenile salmon data are shown in the next section.

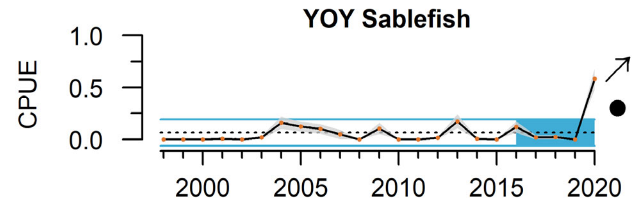

Figure 4.2.1 CPUE (log10(no/km+1)) of YOY sablefish in the Northern CCE, 1998-2020. Lines, colors, and symbols are as in Fig. 1.1.

Central CCE: Data shown here are from the "Core area" of a survey (Figure 2.1a) that targets pelagic juvenile rockfishes, but also samples other pelagic species. Due to COVID-19, survey effort in 2020 was sharply reduced (15 trawls, compared to the usual >60 trawls). We analyzed data from 1998-2020 at just these stations (see methods in Appendix G.2). Adult anchovy remained highly abundant at these stations in 2020, while YOY rockfish catches were well below average and continued declining recent trends (Figure 4.2.2). Other available time series are in Appendix G.2.

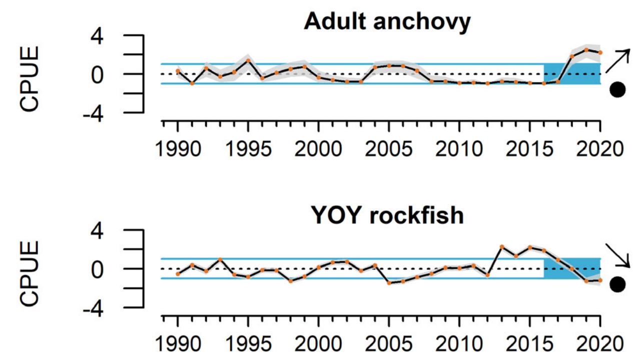

Figure 4.2.2CPUE (delta-glmm index and 95% CL) anomalies of a subset of key forage groups in the Central CCE, 1990-2020. Lines, colors, and symbols are as in Fig. 1.1.

Southern CCE: Forage data for the Southern CCE (Figure 2.1a) come from CalCOFI larval fish surveys. The spring larval survey was cancelled in 2020 due to COVID-19, so here we present results from winter larval surveys, conducted annually in January-February (see Appendix G.3). The southern forage community appeared to experience a shift from 2019 to 2020. Larval anchovy decreased from 2019 to 2020, but were still above the long-term average (Figure 4.2.3). Southern mesopelagic fishes also decreased from 2019 to 2020. Rockfishes were uncommon in 2020, as were larval flatfishes and sardines (Appendix G.3).

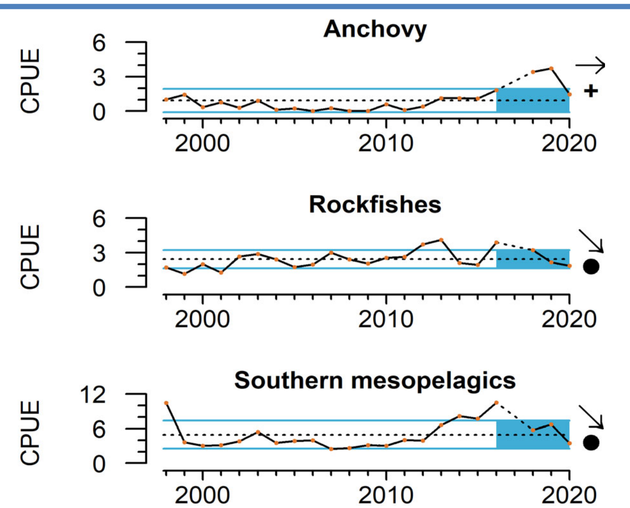

Figure 4.2.3 Mean abundance (ln(x+1)) of the larvae of key forage species in the southern CCE, from winter CalCOFI surveys during 1998-2020. Lines, colors, and symbols are as in Fig. 1.1.

Pyrosomes: Pyrosomes, a warm-water pelagic tunicate, were highly abundant in the Central CCE and as far north as Trinidad Head in 2020, as they have frequently been since anomalous warming began in 2014. Small pyrosomes began to show up on the Newport Line and on Oregon beaches in late 2020, possibly after being forced north by seasonal currents and early winter storms.

4.3 Salmon

Escapement: We examine trends in natural escapement from different populations of Chinook and coho salmon to compare status and coherency in production dynamics across their range. We summarize escapement in quad plots; time series are shown in Appendix H. Chinook salmon escapements are updated through 2018, while coho data mostly are updated through 2019.

Escapements of California Chinook salmon from 2009-2018 were within 1 s.d. of long-term means (Figure 4.3.1, top), though 2018 escapements were among the lowest on record in several ESUs, especially in the Central Valley (Appendix H.1). California escapement trends were neutral for the last decade, though those trends mask increases followed by declines during that time period (Appendix H.1). In the Northwest, most mean escapements in the past decade were within 1 s.d. of average (Figure 4.3.1, top); the exception was above-average Snake River Fall Chinook escapements. Escapement trends over the past decade were neutral for most Northwest ESUs except for Willamette Spring Chinook (increasing) and Snake River Spring-Summer Chinook (decreasing). Details are in Appendix H.2.

Escapement data available for coho salmon show a declining trend for Oregon Coast coho and neutral trends for other ESUs (Figure 4.3.1, bottom). Available ESUs have recent averages that are close to time series averages. Details are in Appendix H.3.

Juvenile salmon abundance: Catches of juvenile coho and Chinook salmon from surveys during June in the Northern CCE (Figure 2.1a) are indicators of salmon survival during their first few weeks at sea. In 2020, juvenile subyearling Chinook salmon catches were higher than the previous two years, but were within 1 s.d. of the long-term average (Figure 4.3.2). Juvenile yearling Chinook salmon catches declined in 2020, and were ~1 s.d. below average. Yearling coho salmon catches were similar to 2019, and were within 1 s.d. of the time series average.

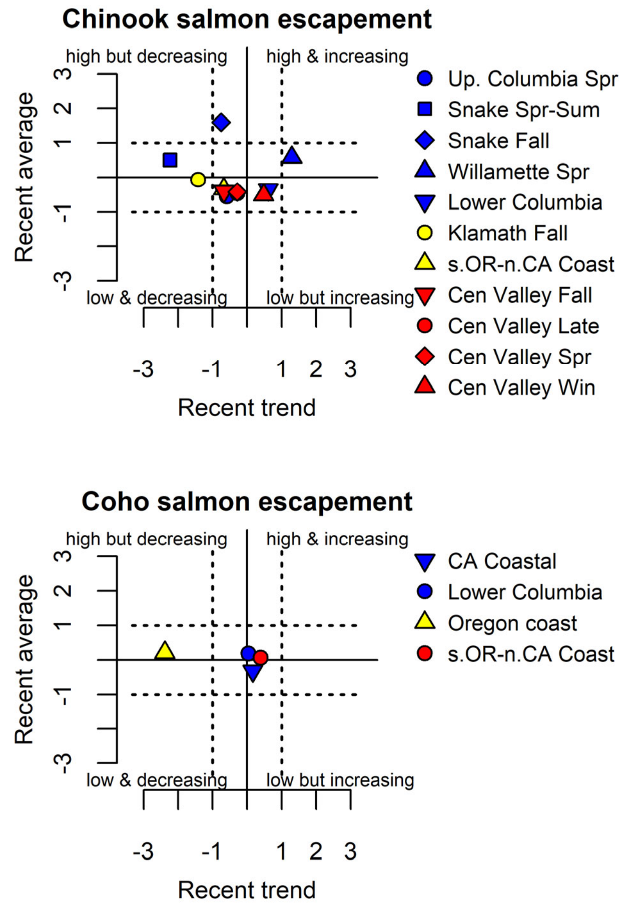

Figure 4.3.1 Recent trend and average of Chinook salmon escapement through 2018 and coho salmon through 2019. Recent trend indicates the escapement trend over the last 10 years of the time series. Recent average is mean natural escapement (includes hatchery strays) over the same time period. Lines, colors, and symbols are as in Fig. 1.1.

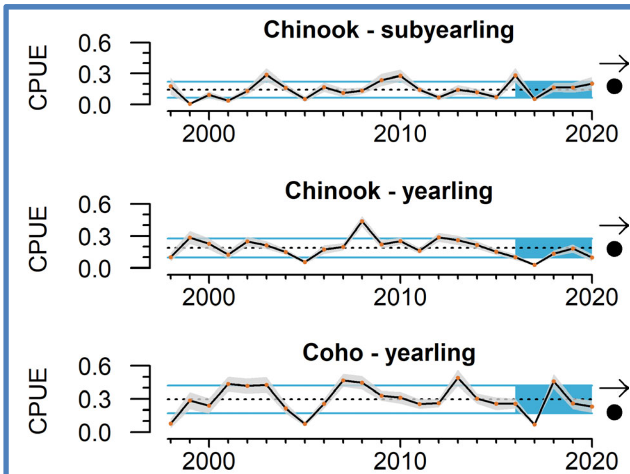

Figure 4.3.2 At sea juvenile salmon catch (Log10(no/km + 1)) from 1998 to 2020 for Chinook and coho salmon. Lines, colors, and symbols are as in Fig. 1.1.

Stoplight tables: Long-term associations between oceanographic conditions, food web structure, and salmon productivity (Burke et al. 2013, Peterson et al. 2014) support qualitative outlooks of returns of Chinook salmon to Bonneville Dam and smolt-to-adult survival of Oregon Coast coho salmon. This suite of indicators is depicted in the "stoplight chart" in Table 4.3.1, and includes many indicators shown elsewhere in this report (PDO, ONI, SSTa, deep temperature, copepods, juvenile salmon catch). For coho salmon returning to the Oregon coast in 2021, ecosystem indicators for the dominant smolt year (2020) suggest a mix of good, intermediate and poor relative conditions. For Chinook salmon returning to the Columbia Basin in 2021, indicators for the dominant smolt year (2019) mostly reflect a mix of intermediate and poor conditions. A related quantitative model that incorporates these indicators into outlooks for Chinook salmon returns estimates a probability of relatively poor counts of both Spring and Fall Chinook at Bonneville Dam in 2021 (Appendix H.4).

Table 4.3.1 "Stoplight" table of conditions for smolt years 2017-2020 and qualitative outlooks for adult returns in 2021 for coho salmon returning to coastal Oregon and Chinook salmon returning to the Columbia Basin. Green/circle = "good," yellow/square = "intermediate," and red/diamond = "poor," relative to the long-term time series.

	Smolt year				Adult return outlook	
Scale of indicators	**2017**	**2018**	**2019**	**2020**	**Coho, 2021**	**Chinook, 2021**
Basin-scale						
PDO (May-Sept)	■	■	◆	■	■	◆
ONI (Jan-Jun)	■	●	◆	◆	◆	◆
Local and regional						
SST anomalies	■	■	◆	■	■	◆
Deep water temp	◆	◆	◆	◆	◆	◆
Deep water salinity	■	●	■	◆	◆	■
Copepod biodiversity	◆	■	■	●	●	■
Northern copepod anomaly	◆	■	●	●	●	●
Biological spring transition	◆	◆	■	●	●	■
Winter ichthyoplankton biomass	■	■	◆	●	●	◆
Winter ichthyoplankton community	◆	◆	◆	■	■	◆
Juvenile Chinook catch (Jun)	◆	■	■	■	■	■
Juvenile coho catch (Jun)	◆	●	■	■	■	■

In last year's report, we introduced an indicator-based outlook for Chinook salmon in California. Friedman et al. (2019) found that Central Valley Fall Chinook salmon returns were correlated with natural-area spawning escapement of parent generations; fall egg incubation temperature and February streamflow in the Sacramento River; and a marine predation index based on the abundance and diet of common murres at Southeast Farallon Island. For adult salmon returning in 2021, signals are mixed, both within and across age classes. The dominant age class (age-3, from the 2018 brood year) experienced unfavorable parent escapement and egg incubation temperature, but favorable winter flows for newly hatched juveniles (Table 4.3.2).

Table 4.3.2 Conditions for naturally produced Central Valley Fall Chinook salmon returning in 2021, from brood years 2016-2019. Indicators reflect each cohort's parent generation escapement, egg incubation temperature, flow during juvenile stream residence, and seabird predation in the early marine phase. Heavy outline and bold type indicates age-3 Chinook salmon, the dominant age class returning to the Central Valley.

Spawning Escapement (t=0)	Incubation Temperature (Oct-Dec t=0)	February Median Flow (t+1)	Seabird Marine Predation Index (t+1)	Chinook Age in Fall 2021
2016: 56,000 (low)	11.8°C (poor)	48,200 cfs (very high)	Near average	5
2017: 18,000 (very low)	11.8°C (poor)	5,525 cfs (very low)	Near average	4
2018: 72,000 (low)	**11.7°C (poor)**	**21,700 cfs (high)**	**Near average**	**3**
2019: 120,400 (met goal)	11.2°C (suboptimal)	6,030 cfs (very low)	Near average	2

Age-4 fish are the progeny of a very low escapement year (2017) and experienced both poor egg incubation temperature in the 2017-2018 winter and very low streamflow for juveniles. Age-5 fish (produced in 2016) have mixed signals thanks to better juvenile flow regimes.

The Council's Habitat Committee, Salmon Technical Team, and others including CCIEA scientists have begun developing more comprehensive stoplight tables for Sacramento River Fall Chinook and Klamath River Fall Chinook, both of which were the focus of rebuilding plans following recent determinations of overfishing. The stoplight tables feature indicators related to the egg incubation, freshwater, early marine, and spawning phases, as well as hatchery releases. These new stoplight charts build on the effort shown in Table 4.3.2, and are presented and described in Appendix H.5. They show that both stocks experienced below-average freshwater and marine conditions in two of the three brood years defined in the rebuilding plans (2012-2014); in the years since, freshwater conditions have improved for Sacramento River Fall Chinook, but not for Klamath River Fall Chinook, while marine conditions have declined for both (Appendix H.5).

4.4 Groundfish Stock Abundance and Distribution

Except for Pacific hake, there were no groundfish assessment updates in 2020, so indices for the status of groundfish biomass and fishing pressure are essentially unchanged from last year's report. We will update that figure in next year's report following the upcoming assessment cycle.

Changes in abundance and spatial distribution of groundfish may affect fishing opportunities in different locations. We are analyzing data from the NOAA groundfish bottom trawl survey to determine if groundfish stock availability is changing at different spatial and temporal scales (Selden et al 2020; details in Appendix I). Here we focus on three key target stocks—sablefish, petrale sole and yellowtail rockfish—and how relative availability of their biomass has changed over time for four ports (Figure 4.4.1).

Availability of the three species has generally increased since ~2010, with some variability in recent years (Figure 4.4.1). These overall increases are due at least in part to increasing stock biomass. Availability of all three species was higher for Astoria than for the more southerly ports, potentially reflecting larger core habitat area farther north. The center of gravity of these three stocks varies over time, but there is no clear evidence that the populations are steadily shifting in a single latitudinal direction (Appendix I). Sablefish have experienced both northerly and southerly changes in center of gravity of 2-3° latitude in the span of years, while petrale sole and yellowtail rockfish centers of gravity have been more stable, suggesting that biomass increase is a more important cause of the availability increase (Figure 4.4.1). Future work to understand the relative roles of climate, recruitment, stock size,

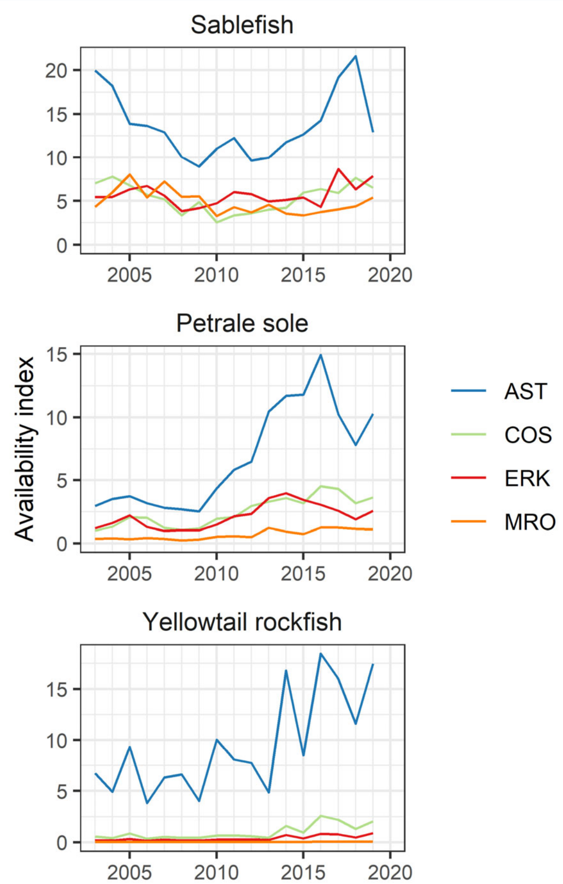

Figure 4.4.1 Index of availability for selected species to ports along the West Coast from 2003-2019. Ports are: Astoria (AST), Coos Bay (COS), Eureka (ERK), and Morro Bay (MRO).

fisheries removals, and other factors would help to explain observed variation in center of gravity. Details and analyses with additional ports and groundfish species, including lingcod, skates and other rockfishes, are in Appendix I.

4.5 Highly Migratory Species

Several highly migratory species (HMS) targeted by West Coast fisheries have had recent updates to their assessments, including information on stock biomass and recruitment. Here we present stocks that have been updated as quad plots summarizing recent short-term averages and trends of biomass and recruitment; time series and summaries of stock condition for these stocks, as well as stocks that have not been recently assessed (e.g., swordfish, blue marlin, skipjack) are presented in Appendix J.

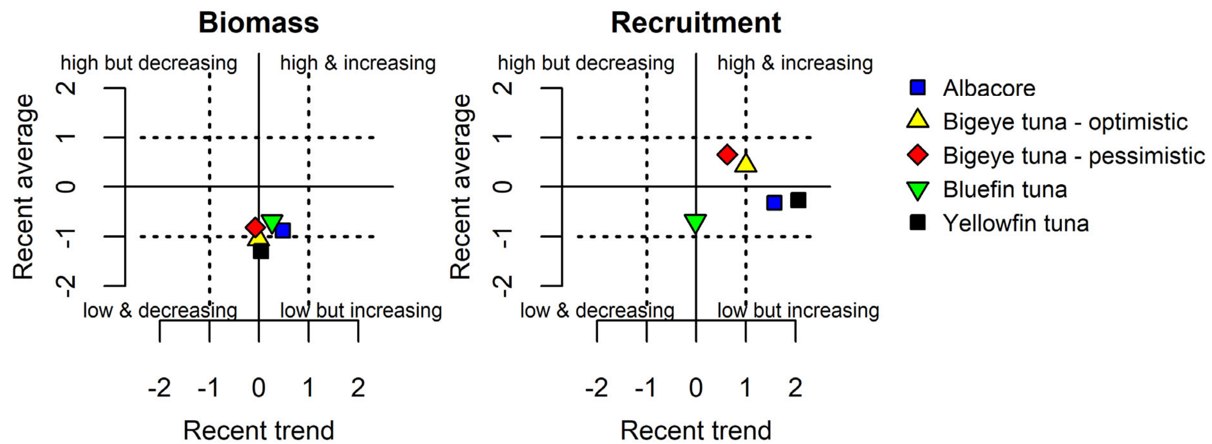

Figure 4.5.1 Recent trend and average of spawning biomass and recruitment for highly migratory species (HMS) in the California current from recent stock assessments: Albacore (2019), Bigeye tuna (2019), Bluefin tuna (2018), and Yellowfin tuna (2020). Lines, colors, and symbols are as in Fig. 1.1.

Biomasses of recently assessed HMS stocks appeared to be below average relative to the full assessment periods, and biomass trends ranged from weakly negative to weakly positive (Figure 4.5.1 left; Appendix J). HMS recruitment estimates from recent assessments are within ±1 s.d. of long-term averages, and several stocks experienced apparent increases in recruitment the most recent five years (Figure 4.5.1 right), although these estimates should be interpreted cautiously given their high uncertainty (Appendix J). The relationships between these indicators and different attributes of population condition (e.g., target and limit reference points) are complicated and differ by species, as summarized in Appendix J; for example, bigeye tuna estimates are drawn from 44 separate reference models that broadly group into two outlooks, one relatively "optimistic" and one relatively "pessimistic." We will continue to improve on HMS indicators in future reports.

4.6 Marine Mammals

Sea lion production: California sea lions are sensitive indicators of prey availability and composition in the central and southern CCE: research has shown that pup counts and condition at the San Miguel Island colony are positively correlated with seasonal prey availability, and that pup counts and growth can be especially high when higher quality prey such as sardines, anchovy or mackerels have high occurrence in adult female sea lion diets (Melin et al. 2012a). Sea lion pup count relates to prey availability and nutritional status for gestating females from October to June, while pup growth from birth to age 7 months is related to prey availability to lactating females from June to February. These metrics have been shown to be good indicators of forage quality and abundance even when the sea lion population is at or near carrying capacity (Appendix K).

In 2020, NOAA scientists were able to conduct counts of sea lion pups via aerial surveys. The 2020 cohort was the fourth consecutive year of above-average pup counts (Figure 4.6.1), and continued the positive trend since the relatively low counts in 2015-2016. The relatively high pup count in 2020 implies abundant and high-quality prey for adult female sea lions in their foraging area (rectangle in Figure 2.1a), and is consistent with the estimates of high anchovy abundance derived from the limited sampling of forage communities of the Central and Southern CCE in 2020 (Section 4.2).

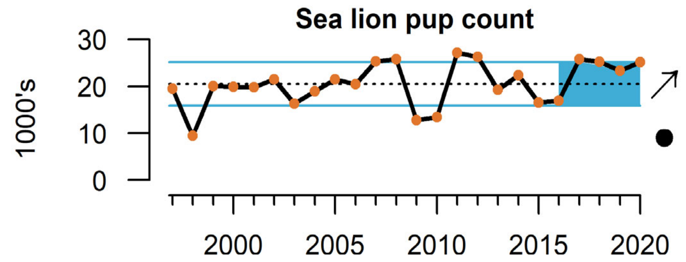

Figure 4.6.1 California sea lion pup counts on San Miguel Island for the 1997-2020 cohorts. Lines, colors, and symbols are as in Fig. 1.1.

We usually report sea lion pup growth from fall and winter, but researchers could not assess pup growth or condition in 2020 due to COVID-19 restrictions. However, based on threshold analyses relating sea lion pup growth to PDO, conditions in 2020 are consistent with normal to above-normal pup growth. Details of this analysis are in Appendix K.

Whale entanglement: Reports of whale entanglements along the West Coast increased in 2014 and even more in the next several years, particularly for humpback whales. While ~50% of reports cannot be attributed to a specific source, Dungeness crab gear has been the most common source identified in this period. The dynamics of entanglement risk and reporting are complex, and are affected by shifts in ocean conditions and prey fields, changes in whale populations, changes in distribution and timing of fishing effort, and improved reporting due to increased public awareness.

Based on preliminary data, West Coast entanglement reports were again higher in 2020 than pre-2014, although fewer confirmed reports were received than in any year since 2013 (Figure 4.6.2; note that COVID-19 reduced reporting capability, with fewer vessels available to assist with sighting and documentation). Humpback whales continued to be the most common species reported entangled. As in previous years, the majority of reports were in California, though entanglements were known to include gear from all three West Coast states. Confirmed sources included commercial and recreational Dungeness crab, commercial rock crab, and gillnet fisheries. No confirmed entanglements occurred in sablefish fixed gear. Significant actions were taken in 2020 to address entanglement risk, including closures and delays of Dungeness crab seasons in California, and late-season reductions of allowable Dungeness crab gear and new line marking requirements in Washington. In Oregon, newly adopted regulations that restrict depths and amount of Dungeness crab gear that can be fished will be implemented in 2021. While these actions are expected to reduce entanglement risks, other factors will continue to present obstacles to risk reduction. These include exposure of whales to derelict gear, foraging in nearshore waters during certain ecosystem conditions, and growth of some whale populations.

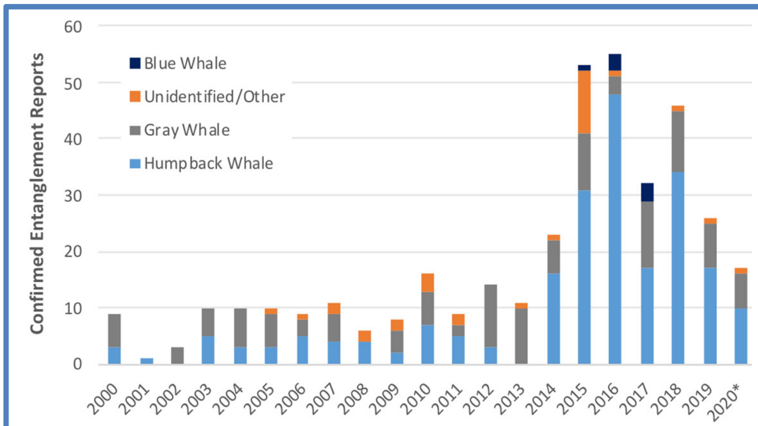

*Figure 4.6.2 Numbers of whales reported as entangled in fishing gear along the West Coast from 2000-2020. *2020 data are preliminary.*

4.7 SEABIRDS

Seabird indicators (densities, productivity, diet, and mortality) are a portfolio of metrics that reflect population health and condition of seabirds, as well as links to lower trophic levels and other conditions in the CCE. To highlight the status of different seabird guilds and their ecological relationships multiple focal species are monitored throughout the CCE. The species we report on here and in Appendix L represent a breadth of foraging strategies, life histories, and spatial ranges.

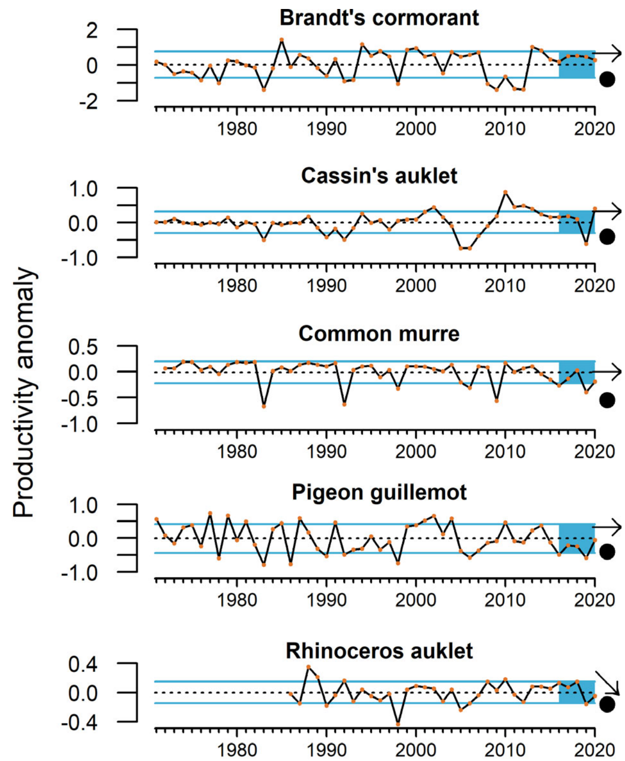

Figure 4.7.1 Standardized productivity anomalies (annual productivity, defined as the annual number of chicks fledged per pair of breeding adults, minus the long-term mean) for five seabird species breeding on Southeast Farallon Island through 2020. Lines, colors, and symbols are as in Fig. 1.1.

Seabird colonies on Southeast Farallon Island off central California experienced mixed productivity in 2020 (Figure 4.7.1). Several species experienced improved fledging production relative to 2019. Cassin's auklets, which feed on krill, bounced back strongly in 2020, consistent with higher amounts of krill in their diets (Appendix L). Pigeon guillemots and rhinoceros auklets experienced near-average productivity in 2020, an increase from 2019. Anchovies again dominated diets of piscivorous birds at this colony (Appendix L). Anchovies may have been too large for some chicks to ingest, leading to poor fledgling rates, especially in common murres. Further north at Yaquina Head, Oregon, fledgling production in 2020 was above-average for two cormorant species, suggesting good feeding conditions; colony failure of common murres at Yaquina Head was likely due to extreme disturbance by bald eagles rather than to poor feeding conditions (data not shown; see Appendix L).

Monitoring of stranded birds on beaches, often done by citizen scientists, provides information on unusual mortality events linked to ecosystem conditions. There were no reports of large mortality events ("wrecks") during 2020, although data were not available from some parts of central and southern California, and sampling was also substantially reduced due to COVID-19 (Appendix L.2).

5 FISHERY LANDINGS AND REVENUE

5.1 COASTWIDE LANDINGS BY MAJOR FISHERIES

Commercial fishery landings data are >90% complete through the end of 2020 for the three coastal states. Coastwide total landings have declined by 8-9% per year each year since 2017, largely tracking changes in hake and market squid (Figure 5.1.1). Salmon, CPS, HMS, and non-hake groundfish are at or near lows for the time series. Ocean conditions, wildfires, and COVID-related effects on supply and demand all likely contributed to the overall decrease in landings in 2020. COVID-related restrictions contributed to decreased demand, particularly from restaurants and export markets. Additionally, COVID outbreaks on some Pacific hake vessels may have reduced ability to harvest available quota (NMFS 2021). State-by-state landings are presented in Appendix M. *We will provide further updates in the March 2021 presentation to the Council.*

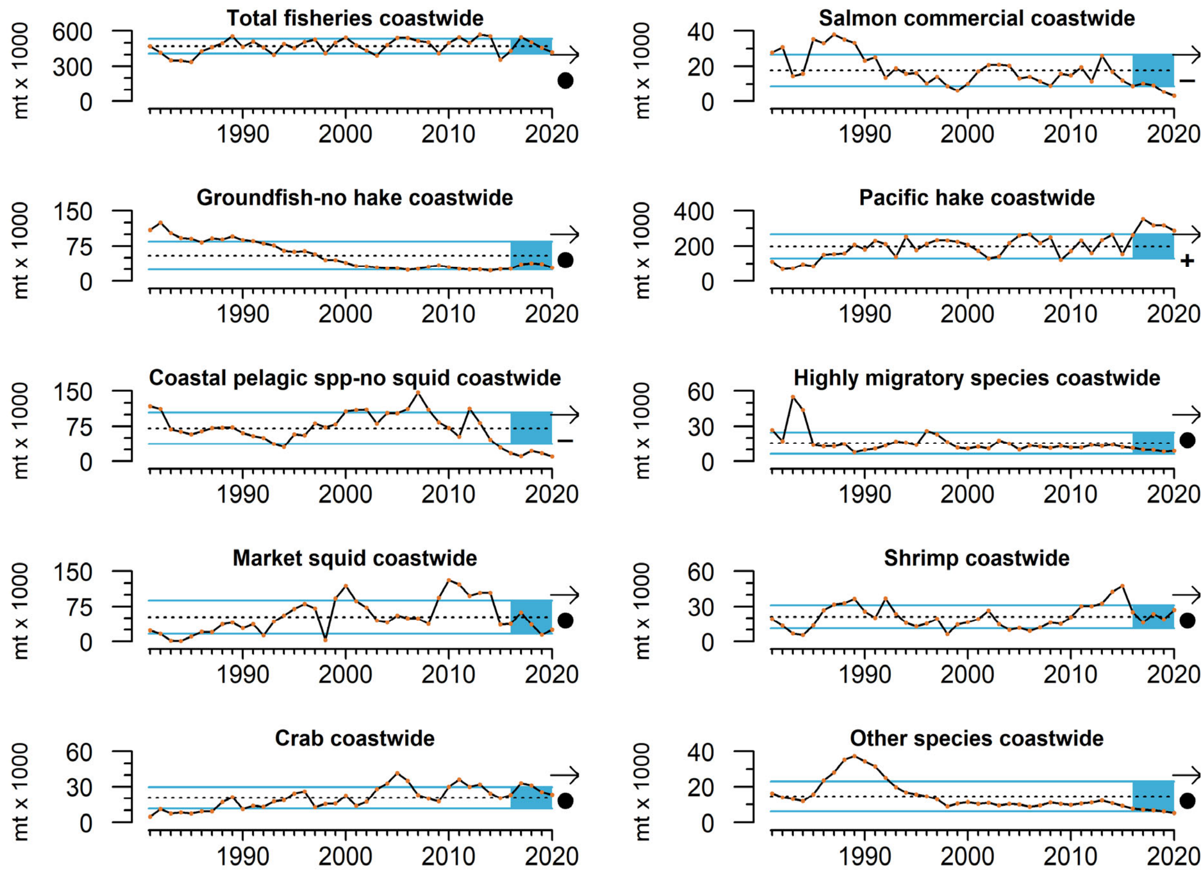

Figure 5.1.1 Annual landings of West Coast commercial fisheries, including total landings across all fisheries from 1981-2020. Data from 2020 are incomplete (see text). Lines, colors, and symbols are as in Fig. 1.1.

Recreational landings data (excluding salmon and Pacific halibut) are complete at the coastwide level through 2019, and were close to the time series average, as they had been since 2016 (Figure 5.1.2). Large increases in recreational albacore landings in 2019 contributed to an overall increase in recreational landings relative to 2018. Recreational landings of Chinook and coho salmon at a coastwide level increased each year from 2017-2019, though they remained low relative to the 1980s and 1990s. Recreational landings data available thus far for 2020 suggest declines relative to 2019, although recreational HMS landings data were not yet available for California and Washington, and albacore are a major component of recreational landings. Albacore landings in Oregon were dramatically lower in 2020, likely due in part to cool coastal conditions (see Figure 3.1.3). COVID-19 likely caused disruptions to recreational fishing opportunities, including restrictions on charter boat trips. State-by-state recreational landings and details are in Appendix M.

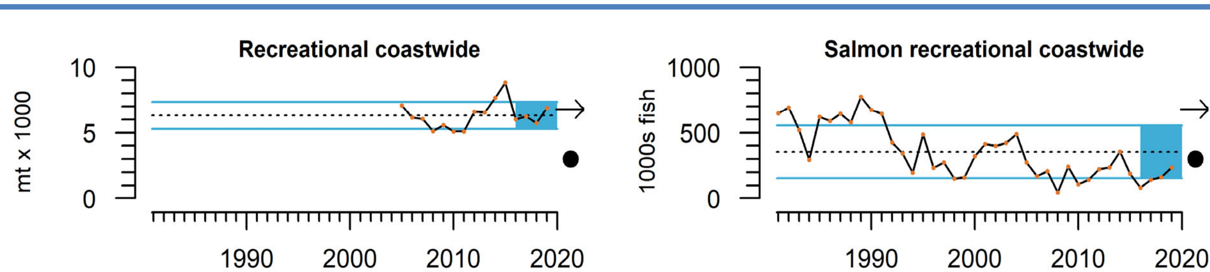

Figure 5.1.2 Annual landings of West Coast recreational fisheries for all recreational fisheries and salmon for 1981-2020. Data from 2020 are incomplete (see text). Lines, colors, and symbols are as in Fig. 1.1.

Total revenue for West Coast commercial fisheries decreased from 2016–2019, and is 22% lower in 2020 than in 2019, based on data currently available (see Appendix M.2). Revenue for 8 of 9 target groups currently show decreases in 2020 compared to 2019: CPS finfish (-45%), Pacific hake (-38%), non-hake groundfish (-37%), salmon (-33%), other species (-14%), crab (-13%), HMS (-10%), and shrimp (-6%). Market squid currently show greater revenue in 2020 than in 2019 (+91%). Ocean conditions, wildfires, compressed Dungeness crab fishing seasons, and COVID-related effects on supply and demand all likely contributed to the apparent decrease in total revenue in 2020. In addition, vessels and processors may have experienced increased operational costs due to overcoming COVID outbreaks and implementing protective measures. Coastwide and state-level revenue data are presented in Appendix M.2; *we will update these data in our March presentation*.

5.2 Gear Contact with Seafloor

We track the amount of contact by groundfish bottom trawl gear with the seafloor on the shelf and slope. For space considerations, we have moved this analysis, updated through 2019, to Appendix N.

6 Human Wellbeing

We include several indicators of human wellbeing in fishing communities, which relate to the risk profiles and adaptive capacities of coastal communities in the face of various pressures. We are working to develop a suite of indicators that helps track progress toward meeting National Standard 8 (NS-8) of the Magnuson-Stevens Act. NS-8 states that fisheries management measures should “provide for the sustained participation of [fishing] communities” and “minimize adverse economic impacts on such communities.”

6.1 Social Vulnerability

Coastal community vulnerability indices are generalized social-economic vulnerability metrics. The Community Social Vulnerability Index (CSVI) is derived from social vulnerability data (demographics, poverty, housing, labor force structure, etc.; Jepson and Colburn 2013). We monitor CSVI in communities that are highly reliant upon fishing. The commercial fishing reliance index reflects *per capita* engagement in commercial fishing (landings, revenues, permits, processing, etc.) in each West Coast fishing community (n ≈ 250).

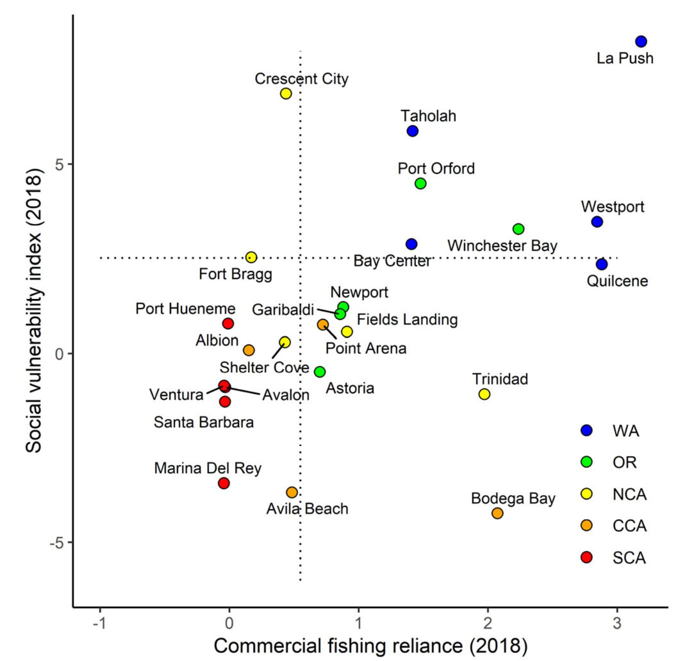

Figure 6.1.1 Commercial fishing reliance and social vulnerability scores as of 2018, plotted for twenty-five communities from each of the five regions of the California Current: WA, OR, Northern, Central, and Southern California. The top five highest scoring communities for fishing reliance were selected from each region. Black dotted lines denote one s.d. above the mean for communities with landings data. Note, the points for Avalon and Ventura overlap.

Figure 6.1.1 plots CSVI updated through 2018 against commercial fishing reliance for communities that are among the most reliant on commercial fishing in different regions of the West Coast. Communities above and to the right of the dashed lines are those with relatively high CSVI (horizontal line) and commercial fishing reliance (vertical line). Multiple ports in Washington and Oregon are in that upper right portion of the plot, scoring relatively high for both reliance and CSVI compared to other coastal communities. Communities that are outliers in both indices may be especially socially vulnerable to downturns in commercial fishing. We note, however, that commercial fishing reliance can be volatile, and communities may move left on the x-axis during years with reduced landings. The communities may thus appear to be less dependent on commercial fishing when in fact they have actually just experienced a difficult year; thus, these results should be interpreted with care, and we will work to improve this analysis in the future. Additional details are in Appendix O.

6.2 DIVERSIFICATION OF FISHERY REVENUES

According to the Effective Shannon Index that we use to measure diversification of revenues across different fisheries (see Appendix P), the fleet of 28,000 vessels that fished the West Coast and Alaska in 2019 was less diverse on average than at any time in the prior 38 years (Figure 6.2.1a, solid gray line). Diversification rates for most categories of vessels fishing on the West Coast have been trending down for several years, but there were slight increases in 2019 for several categories of vessels with West Coast landings (Figure 6.2.1b-d). California, Oregon and Washington fleets all saw small increases in average diversification in 2019. The long-term declines are due both to entry and exit of vessels and changes for individual vessels. Less diversified vessels have been more likely to exit; vessels that remain have become less diversified, at least since the mid-1990s; and newer entrants generally have been less diversified than earlier entrants. Within the average trends are wide ranges of diversification levels and strategies, and some vessels remain highly diversified.

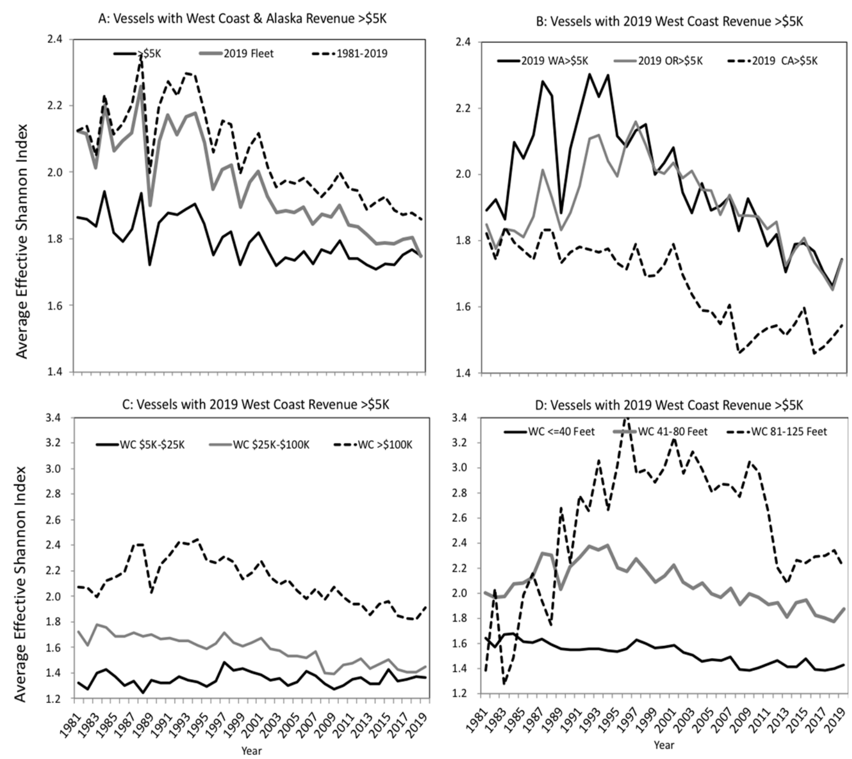

Figure 6.2.1 Average diversification for US West Coast and Alaskan fishing vessels (top left) and for vessels in the 2018 West Coast Fleet, grouped by state (top right), average gross revenue classes (bottom left) and vessel length classes (bottom right).

Port-level diversification is presented in Appendix P. Trends vary widely by port, even ports within the same region. As with individual vessels, the variability of landed value at the port level is reduced with greater diversification. Port-level diversification is variable from year to year, particularly in ports highly dependent upon Dungeness crab.

6.3 REVENUE CONSOLIDATION

In last year's report (see Harvey et al. 2020), we introduced port-level consolidation of fishing revenue as an exploratory indicator. With guidance from the SSC, we have updated that analysis for this report. The updated approach uses a metric called the Theil Index to estimate geographic concentration of revenue at the scale of the 21 port groups previously established for the economic input-output model for Pacific Coast fisheries (IO-PAC; Leonard and Watson 2011). The Theil Index estimates the difference between observed revenue concentrations and what they would be if they were distributed with perfect equality across port groups.

We produced annual Theil Index values for revenue distribution of total fisheries and of different fishery management groups. In Figure 6.3.1 top, the Theil Index for each management group is shown, where positive values indicate revenue concentration greater than the long-term average, and negative values indicate revenue concentration closer to equality across the port groups. All fisheries combined (Figure 6.3.1 top, upper left) show small deviations and little variability over time, suggesting that total revenue has not exhibited high levels or extended trends of geographic concentration. This is shown in the maps in Figure 6.3.1 bottom, where the sizes of the bubbles, representing inflation-adjusted revenue from all commercial fisheries in each port-group, are fairly consistent over time. Separate fishery management groups show much clearer fluctuations in revenue concentration (Figure 6.3.1 top). For example, Theil Index values for groundfish have been gradually increasing due to greater concentration of revenues in northern port groups (see Appendix Q). In contrast, HMS revenues present a U-shaped trend, where geographic concentration of revenues was skewed to southern ports early in the time series, then decreased through the middle part of the time period, and then increased again in recent years as revenues became more concentrated in the north (Appendix Q). CPS, salmon and shrimp show high short-term or decadal variability.

Figure 6.3.1 Top and middle: Theil Index anomalies for all West Coast commercial fisheries plus seven individual management groups. Positive values indicate above-average revenue concentration in a smaller number of port groups. Bottom: maps of 21 port groups, with bubbles proportional to Theil Index values for all fisheries revenue in a given port group for each five-year time period. See text and Appendix Q for details.

We have not attempted to interpret the Theil Index with respect to NS-8, or to link changes to specific causes. We will work with Council advisory bodies to develop recommendations for further analyses.

6.4 Fisheries Participation Networks

As fishers diversify their harvest portfolios, they create links between fisheries, even when ecological links between the harvested species are weak or absent. This creates networks of alternative sources of income, which can be described on a variety of spatial and temporal scales. Fisheries participation networks offer one way to represent this information visually, as nodes in a network represent fisheries, and pairs of nodes are connected by lines ("edges") that indicate the relative number of vessels that participate in both fisheries. These networks therefore add a level of detail to the diversification indices, and context to the Theil indices, presented earlier in this report.

In IO-PAC port groups, networks consist of 1 to 8 fisheries, with 0-16 links between the fisheries within each network (see Appendix R). Some fisheries, like crab and groundfish, are represented at nearly all port groups while others, like squid, are represented at fewer. Figure 6.4.1 shows four example networks from 2019-2020. In each network, nearly all fisheries are connected to at least one other fishery, indicating that most vessels participate in multiple fisheries over the course of a year. (Echinoderms in the North Washington Coast port group are an exception). Notably, many Council-managed fisheries connect to fisheries under state jurisdictions. The prime example from Washington south to Morro Bay is the crab fishery, which accounts for a large proportion of fishing revenue (large node size) and is highly connected to other fisheries that generate less revenue in each port group. The crab, salmon, and groundfish nodes involve consistently heavy levels of cross-fishery participation across port groups (Figure 6.4.1). In the southern three port groups (Santa Barbara, Los Angeles, San Diego; see Appendix R), echinoderms and shellfish generate the majority of revenue, but compared to crab in the northern ports, there is less connectivity between these fisheries and others in the same port group.

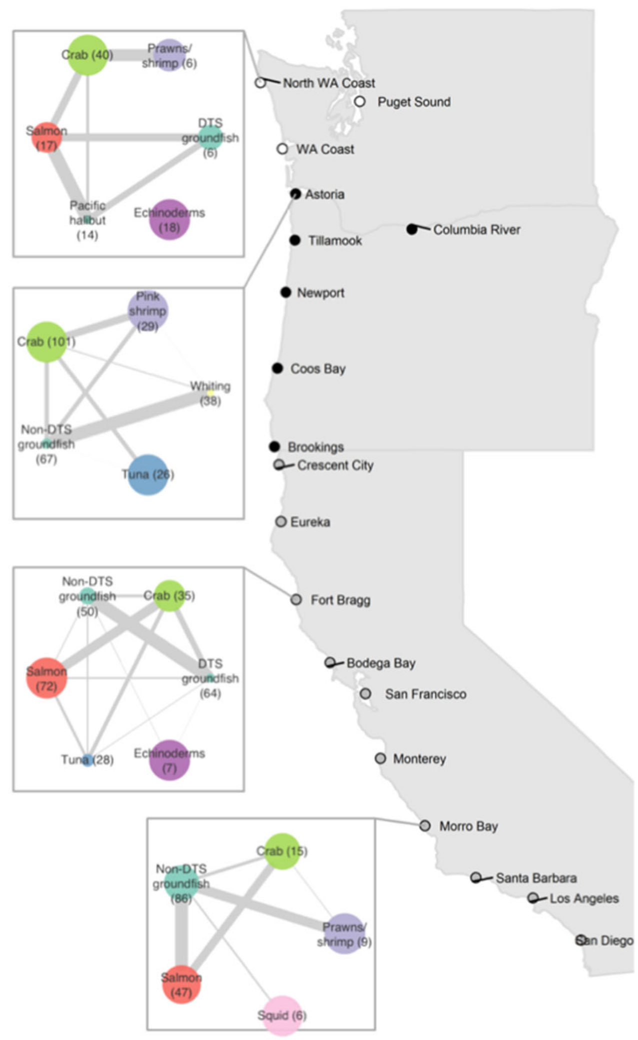

Figure 6.4.1. Fisheries participation networks for four port groups, based on November 2019-September 2020 landings. Node size is proportional to revenue from a given fishery. The thickness of lines is proportional to the number of vessels participating in both of the fisheries connected by the lines.

Differences in the make-up of port group networks in part reflect differences in the ecology of adjacent coastal habitats and waters, and in part the legacy of management, market, and other factors that vary geographically. The networks demonstrate that individual fisheries do not operate in vacuums, just as species do not, and part of an ecosystem approach to fisheries management is to consider species and fisheries as interactive entities rather than in piecemeal fashion. Thus, these networks may provide context for understanding and interpreting indicators of human activities and wellbeing presented in these reports. Further, tracking changes in the networks themselves may support the Council's Climate and Communities Initiative and other activities by providing insight into how fishing communities are changing and potentially adapting to external forces such as changing stock availabilities, climate, regulations, and economic and social systems.

7 Synthesis

Accurately summarizing the status of the CCE in 2020 will be a challenge, now and going forward, due to the negative impacts of COVID-19: fisheries that depend on California Current stocks were badly disrupted, research effort was cut or delayed, and fewer eyes from the fishing, management, research, and public sectors were on the water to develop a collective sense of the state of the system. Despite those challenges, we can best summarize the past year as follows:

Evidence points to a return to average or above-average productivity in the CCE in 2020. Many indicators suggested good foraging conditions in different regions, including the high abundance of nutritious northern copepods off Oregon, large krill in plankton nets and seabird diets in northern and central California, continued abundance of anchovies, and generally good production of offspring by seabirds and sea lions at the colonies being monitored. More information on abundance and condition of key species may come available as 2020 samples continue to be processed.

Some of these results are continuations of past years' dynamics, such as the now years-long resurgence of the anchovy population. Others may have benefited from shifts in climate and ocean conditions that occurred in 2020, including a transition to La Niña and negative PDO conditions that are often associated with cooler and more productive years in the CCE. Local upwelling/relaxation strength and timing, particularly off central California, may have helped boost productivity, and also may have helped the CCE avoid some of the effects of another very large marine heatwave in 2020. We await to see if La Niña, negative PDO and positive upwelling will persist further into 2021.

The past year was not without concerning signals: we continue to see relatively warm water, offshore in the form of heatwaves, and alongshore, particularly in the southern CCE and to a lesser extent the central CCE. Harmful algal blooms were an issue in all three coastal states. Salmon outlooks remain mixed based on past years' indicators. Much of the West is facing drought in the year ahead and recovering from traumatic wildfires. And of course, fishing communities have been through the unprecedented stress test of the COVID-19 pandemic, which affected landings, revenues, operations and markets for many fisheries, and added a new layer of uncertainty to the fishing profession. As with any ecosystem shock, this one will reverberate and its full effects will take time to understand.