# CALIFORNIA CURRENT INTEGRATED ECOSYSTEM ASSESSMENT (CCIEA) CALIFORNIA CURRENT ECOSYSTEM STATUS REPORT, 2017

*A report of the NOAA CCIEA Team to the Pacific Fishery Management Council, March 8, 2017.*
*Editors: Dr. Chris Harvey (NWFSC) and Dr. Toby Garfield (SWFSC)*

## 1. INTRODUCTION

Section 1.4 of the 2013 Fishery Ecosystem Plan (FEP) outlines a reporting process wherein NOAA provides the Council with a yearly update on the state of the California Current Ecosystem (CCE), as derived from environmental, biological and socio-economic indicators. NOAA's California Current Integrated Ecosystem Assessment (CCIEA) team is responsible for this report. This marks our 5th report, with prior reports in 2012 and 2014-2016.

The highlights of this report are summarized in Box 1.1. Sections below provide greater detail. In addition, Supplemental Materials are provided at the end of this document, in response to previous requests from Council members or the Scientific and Statistical Committee (SSC) to provide additional information, or to clarify details found within this short report.

*Box 1.1: Highlights of this report*

- Following the unprecedented warm anomaly of 2013-2016 and the major El Niño event of 2015-2016, most large-scale climate indices for the Northeast Pacific (ONI, PDO and NPGO) have returned to relatively neutral values.
- Coastal upwelling was relatively weak in the northern California Current throughout 2016; upwelling along the central coast was initially weak but strengthened by summer, while upwelling on southern coast was average to above-average.
- Snowpack rebounded from the extremely low 2015, although much of the 2016 snow melted rapidly, leading to low streamflows; so far, 2017 precipitation is well above average.
- Copepod biomass off Newport, OR remains dominated by relatively energy-poor species as of fall 2016.
- The spring/summer pelagic forage community was once again highly diverse in 2016. Surveys experienced poor catches of sardine, market squid and krill. However, surveys had high but patchy catches of juvenile rockfish, juvenile hake and anchovy.
- Chinook salmon escapements through 2014-2015 varied by region and life history type. We remain concerned about environmental conditions for Chinook and coho salmon that went to sea over the past several years.
- California sea lions at the San Miguel Island colony experienced very poor foraging conditions to support pups in the 2015 cohort, though preliminary evidence suggests better conditions for the 2016 pups.
- Commercial fishing landings and revenues declined markedly in 2015, driven mainly by drops in harvest of Pacific hake, coastal pelagic species, and crabs.

### 1.1 Notes on Interpreting Time Series Figures

Throughout this report, most time series figures follow common formats, illustrated in Figure 1.1; see captions for details. In coming years we will include model fits to time series data, derived from Multivariate Auto-Regressive State Space (MARSS) models as recommended by the SSC Ecosystem Subcommittee (SSCES; see advisory body reports, Agenda Item E.1.b., March 2015).

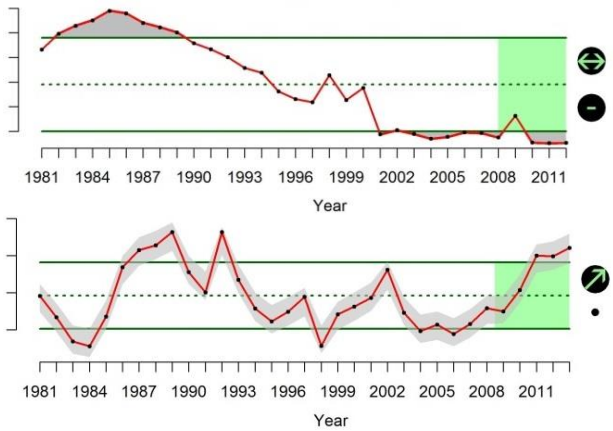


*Figure 1.1a: Sample time series plots, with indicator data relative to mean (dashed line) and ± 1 s.d. (solid lines) of the full time series. Arrow at right indicates if the trend over the most recent 5 years (shaded green) is positive (↗), negative (↘) or neutral (↔). Symbol at lower right indicates if the recent mean was greater than (+), less than (–), or within 1 s.d. (•) of the long-term mean. When possible, time series include 95% confidence intervals (gray shading, lower panel).*

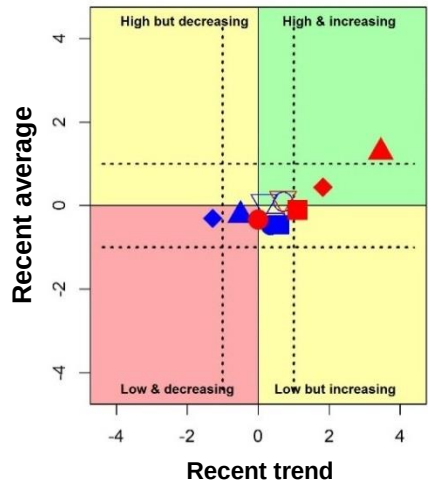


*Figure 1.1b: Sample "quad plot." Each point represents one normalized time series. The position of a point indicates if the recent years of the time series are above or below the long-term average, and if they are increasing or decreasing; quadrants are "stoplight" colored to further indicate the indicator condition. Dashed lines represent ±1.0 s.d. of the full time series.*

## 2. Sampling Locations

Figure 2.1a shows the CCE and major headlands that demarcate key biogeographic boundaries, in particular Cape Mendocino and Point Conception. We generally consider the region north of Cape Mendocino to be the "Northern CCE," the region between Cape Mendocino and Point Conception the "Central CCE," and the region south of Point Conception the "Southern CCE."

Figure 2.1a also shows sampling locations for much of the regional climate and oceanographic data (Section 3.2) presented in this report. In particular, much of our physical and chemical oceanographic data are collected on the Newport Line off Oregon and the CalCOFI grid off California. Physical oceanography sampling is further complemented by basin-scale observations and models.

Freshwater habitats worldwide can be spatially grouped into "ecoregions," according to the designations of Abell et al. (2008) (see also www.feow.org). The freshwater ecoregions in the CCE are shown in Figure 2.1b, and are the basis by which we summarize freshwater habitat indicators relating to streamflow and snowpack (Section 3.4).

The map in Figure 2.1c represents sampling for most biological indicators, including copepods (Section 4.1), forage species (Section 4.2), California sea lions (Section 4.5) and seabirds (Section 4.6). Not shown is groundfish bottom trawl sampling (see Section 4.4), which covers most trawlable habitat on the shelf and upper slope (55–1280 m depths) in US waters; the blue and green polygons in Figure 2.1c roughly approximate the areal extent of the bottom trawl survey.

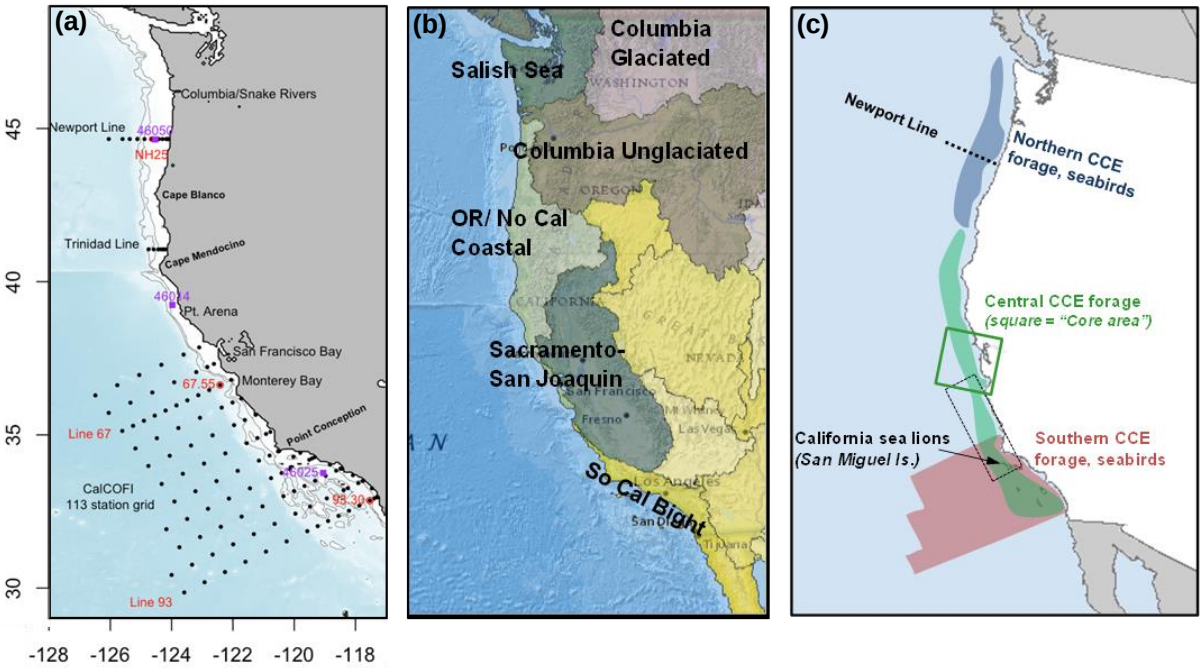


*Figure 2.1. Maps of the California Current Ecosystem (CCE) and sampling areas: (a) key geographic features and oceanographic sampling locations; (b) freshwater ecoregions, where snowpack and streamflow indicators are measured, and (c) biological sampling areas for copepods (Newport Line), pelagic forage, seabirds, and California sea lions. Solid box = the "core" sampling area for forage in the Central CCE. Dotted box approximates the foraging area for adult female California sea lions from the San Miguel colony.*

## 3. Climate and Ocean Drivers

The Northeast Pacific has experienced exceptional climate variability since 2013, reaching new extremes for many indicators. After a series of events that caused unprecedented warming in the CCE, conditions have changed since the summer of 2016 into the winter of 2016-2017, producing cooler coastal waters and a succession of winter storms with high precipitation. The strong El Niño event peaked in the tropical Pacific in the winter of 2015-2016, but its influence on the CCE was different than strong El Niño events of 1982-1983 and 1997-1998. Sea surface temperatures were exceptionally high, but the extent of heating into the water column was less than in past El Niño events (Fig. 3.1). Late winter upwelling was not as weak, and upwelling was much stronger leading into the spring.

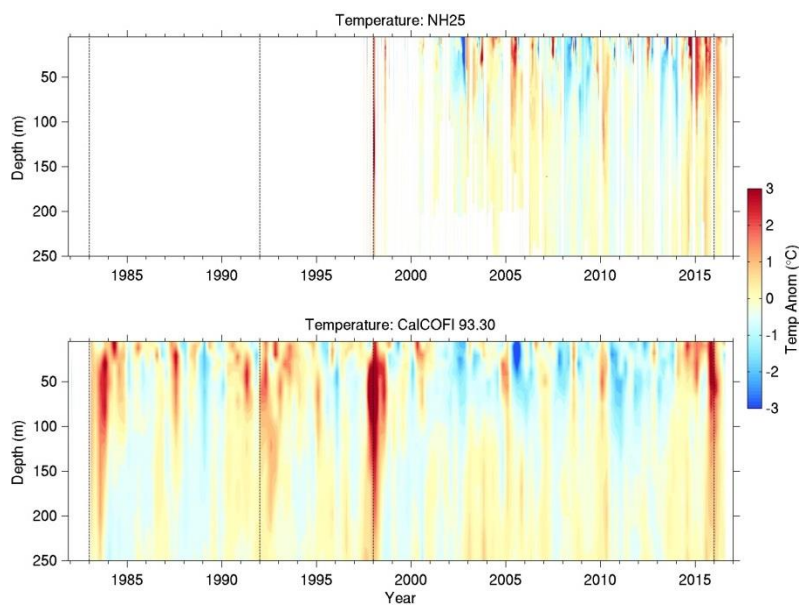


*Figure 3.1. Time-depth temperature contours from nearshore stations NH25 and CalCOFI 93.30 (see Fig. 2.1a). Vertical lines mark El Niño events (1983, 1992, 1998, 2016). Anomalies in winter/spring of 2016 are less extreme at depth than prior major El Niño events.*

### 3.1 BASIN-SCALE INDICATORS

The CCE is driven by atmosphere-ocean energy exchange that occurs on many temporal and spatial scales. To capture large-scale variability, the CCIEA team tracks three indices: the status of the equatorial El Niño Southern Oscillation (ENSO), described by the Oceanic Niño Index (ONI)[1]; the Pacific Decadal Oscillation (PDO); and the North Pacific Gyre Oscillation (NPGO). ENSO events impact the CCE by modifying the jet stream and storm tracks, deepening the nearshore thermocline, and generating coastal currents that enhance poleward transport of equatorial and subequatorial waters (and species). A positive ONI indicates El Niño conditions, which usually means more storms to the south, weaker upwelling, and lower primary productivity in the CCE. A negative ONI means La Niña conditions, which usually lead to higher productivity. The PDO is derived from sea surface temperature anomalies (SSTa) in the Northeast Pacific, which often persist in "regimes" that last for many years. In positive PDO regimes, coastal SSTa in the Gulf of Alaska and the CCE tend to be warmer, while those in the North Pacific Subtropical Gyre tend to be cooler. Positive PDOs are associated with lower productivity in the CCE. The NPGO is a low-frequency variation of sea surface height, indicating variations in the circulation of the North Pacific Subtropical Gyre and Alaskan Gyre, which in turn relate to the source waters for the CCE. Positive NPGO values are associated with increased equatorward flow, along with increased surface salinities, nutrients, and chlorophyll-*a*. Negative NPGO values are associated with decreases in such values, implying less subarctic source waters and generally lower productivity.

In summary the general trends are that positive MEI and PDO values and negative NPGO values usually denote conditions that lead to low CCE productivity and negative MEI and PDO values and positive NPGO values are associated with periods of high CCE productivity. These indices vary independently and so there is a wide range of observed variability in the CCE.

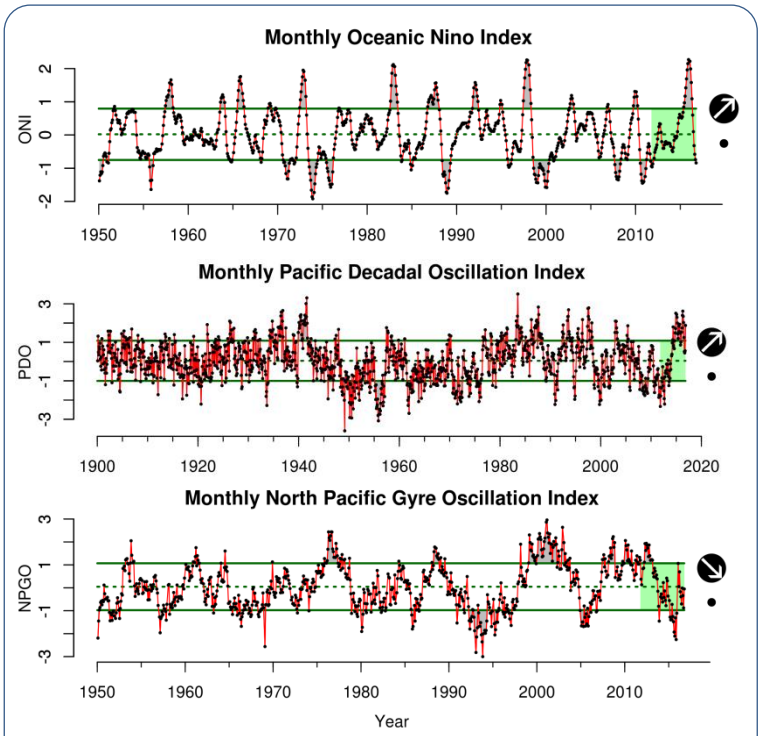


*Figure 3.1.1. Monthly values of the Oceanic Niño Index (ONI; 1950-2016), Pacific Decadal Oscillation (PDO; 1900-2016), and the North Pacific Gyre Oscillation (NPGO; 1950-2016). Lines, colors, and symbols are as in Figure 1.1a.*

#### 3.1.1 BASIN-SCALE PROCESSES, 2014-2016

This past year saw the ONI shift from El Niño to neutral and even La Niña conditions, the PDO switch from strongly positive to neutral, and the NPGO move from strongly negative to neutral (Fig. 3.1.1). Each of these indices would suggest a return to conditions of higher productivity. However, the Northeast Pacific and the CCE still show the after effects of the very anomalous conditions experienced during 2013-2016. The large marine heat wave, a.k.a. "the Blob" (Bond et al. 2015) dissipated in fall of 2016 in the Northeast Pacific, but anomalously

[1]In previous reports, the reported El Niño Index was the Multivariate El Niño Oscillation Index (MEI). The numerical and trend values for ONI and MEI are very similar, and ONI is the index supported by the NOAA Climate Prediction Center. The CCIEA report adopts the ONI as the recommended index.

warm surface waters were present in the Gulf of Alaska and immediately along the North American west coast during the winter (Fig. 3.1.2). Summer SSTa showed no lasting influence of the El Niño event, with anomalies average to slightly below average along the coast from Vancouver to San Diego. Subsurface waters, measured by ARGO floats, in the Northeast Pacific are still warm, with anomalies >1° C down to 160 m and >0.5° C down to below 200 m (Appendix E, Fig. E.6). This deep warming is interpreted as a remnant effect of the marine heat wave.

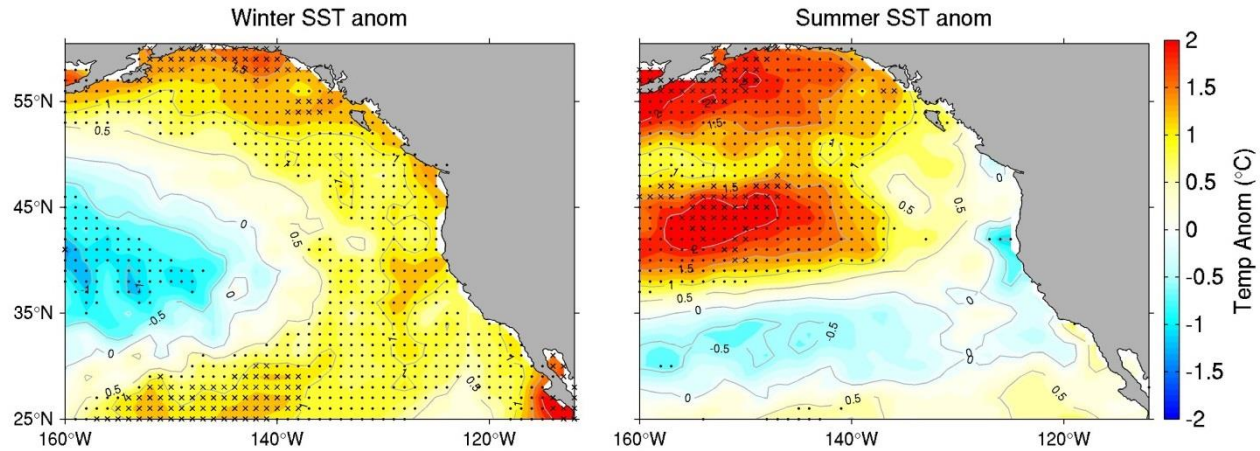


*Figure 3.1.2. Sea surface temperature (SST) anomalies in winter (Jan-Mar; left) and summer (Jul-Sep; right), 2016. The time series at each grid point began in 1982. Positive anomalies of the marine heat wave and El Niño are seen in the Gulf of Alaska in winter and summer, and off Baja California in winter. Black circles mark cells where the anomaly was >1 s.d. above the long-term mean. Black x's mark cells where the anomaly was the highest of the time series.*

Another marine heat wave formed off Baja California in 2014 and strengthened in 2015, keeping nearshore SSTs >0.5° C above normal. This event was likely caused by weaker atmospheric forcing in the Southern California Bight and along the Mexican coast (Leising et al. 2015, McClatchie et al. 2016). By summer 2016, SSTs of this region dropped to near average values (Fig. 3.1.2).

In summary, while the 2015-2016 El Niño was one of the largest recorded in terms of equatorial warming and the ONI, the large-scale environmental response of the CCE was dominated in the north by the lingering impacts of the marine heat wave, with only moderate influence from the El Niño, whereas in the south, the CCE was more strongly influenced by the El Niño. Thorough summaries of these dynamics are in Leising et al. (2015) and McClatchie et al. (2106). These large-scale forces will help explain the dynamics of biological indicators in Section 4 below.

### 3.2 Regional Climate Indicators

Seasonal high pressure over the Gulf of Alaska and low pressure over the US Southwest drive the upwelling-favorable winds that fuel the high spring-summer productivity of the CCE. Upwelling is a physical process of moving cold, nutrient-rich water from deep in the ocean up to the surface and is forced by strong northerly alongshore winds. Upwelling is critically important to productivity and ecosystem health in the CCE, as it is local coastal upwelling that allows the primary production at the base of the food web. The most common metric of upwelling is the Bakun Upwelling Index (UI), which is a measure of the magnitude of upwelling anywhere along the coast. The timing, strength, and duration of upwelling in the CCE are highly variable by region and by year. The cumulative upwelling index (CUI) is one way to display this variability. The CUI provides an estimate of the net influence of upwelling on ecosystem structure and productivity over the course of the year. The CUI integrates the onset date of upwelling favorable winds ("spring transition"), a general indication of the strength of upwelling, relaxation events and the end of the upwelling season.

### 3.2.1 Regional-Scale Processes, 2012-2016

Upwelling strength displayed significant regional variability during 2016, with the least favorable conditions in the northern CCE (Appendix E, Fig. E.7). At 45° N, strong downwelling from January through March was followed by average upwelling from April to July; CUI at this latitude was much lower than the strong upwelling of 2015 (Fig. 3.2.1), and similar to the reduced upwelling of the 1998 El Niño event (McClatchie et al. 2016). At 39° N, the spring transition to upwelling began weakly in mid-March and strengthened in May, leading to above-average upwelling by July and comparable CUI to 2015 by August. In the Southern California Bight (~33° N), the CUI was close to the long term mean during the beginning of the season, and above average after June. This is in stark contrast to the reduced upwelling seen throughout the year in 1998 following that comparably large El Niño.

Although CUI was stronger in the south than the north in 2016, productivity did not increase concomitantly as one might expect. This is likely because of increased stratification and a deeper thermocline in this region, due to the lingering effects of the marine heat wave, plus the influence of the 2015-2016 El Niño event (McClatchie et al. 2016).

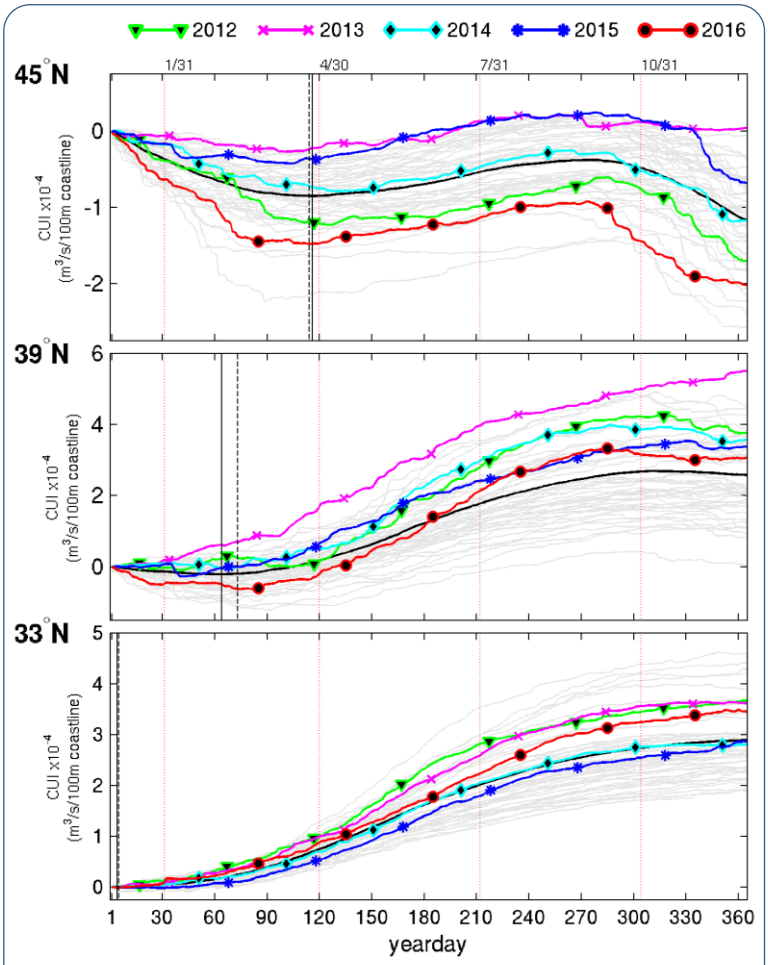


*Figure 3.2.1. Cumulative Upwelling Index (CUI) at three latitudes, 1967-2016. Black trend = long-term mean; gray trends = 1967-2011; colored trends = 2012-2016. Black vertical lines mark the 2016 spring transition date (dashed) and long-term mean spring transition date (solid). Dotted red vertical lines mark the end of January, April, July and October.*

### 3.3 Hypoxia and Ocean Acidification

Nearshore dissolved oxygen (DO) levels and ocean acidification (OA) are related to the strength of coastal upwelling. DO is required for organismal respiration, and DO levels are dependent on a number of physical and biological processes, including circulation, air-sea exchange, and community-level production and respiration. Waters with DO levels below 1.4 ml $L^{-1}$ (2 mg $L^{-1}$) are considered to be hypoxic. Low DO can compress habitat and cause stress or even die-offs for sensitive species. OA is caused by increased levels of anthropogenic $CO_2$ in seawater, which impacts the chemical environment of marine organisms by reducing both pH and carbonate ion concentrations. A key indicator of OA effects is aragonite saturation state, a measure of how corrosive seawater is to organisms with shells made of aragonite (a form of calcium carbonate). Values <1.0 indicate corrosive conditions that have been shown to be stressful for many CCE species, including oysters, crabs, and pteropods. Upwelling, which drives primary production in the CCE, also transports hypoxic, acidified waters onto continental shelves, where increased

community-level respiration can further reduce water column DO and exacerbate OA (Chan et al. 2008, Feely et al. 2008).

At the three stations shown here, DO was seasonally variable, with peaks in the winter, but all measurements were consistently above the hypoxia threshold of 1.4 ml/L in 2016 (Fig. 3.3.1). The 5-year annual trend at each site has been stable, but there is evidence of seasonal increases in DO; seasonal time series are presented in Appendix E.3 of the Supplement. Briefly: station NH25 off Oregon has experienced increasing winter DO over the past 5 years. At the nearshore station 93.90 off Southern California, DO has declined since 1984, driven mainly by winter values, and was ~1 s.d. below the mean in winter 2016. However, the recent trend is stable and possibly increasing based on seasonal averages. At the offshore station 90.90, summer DO has increased in recent years. Nearshore DO values are almost always lower than those offshore (93.30 vs. 90.90; see Fig. 3.3.1 and Appendix E.3).

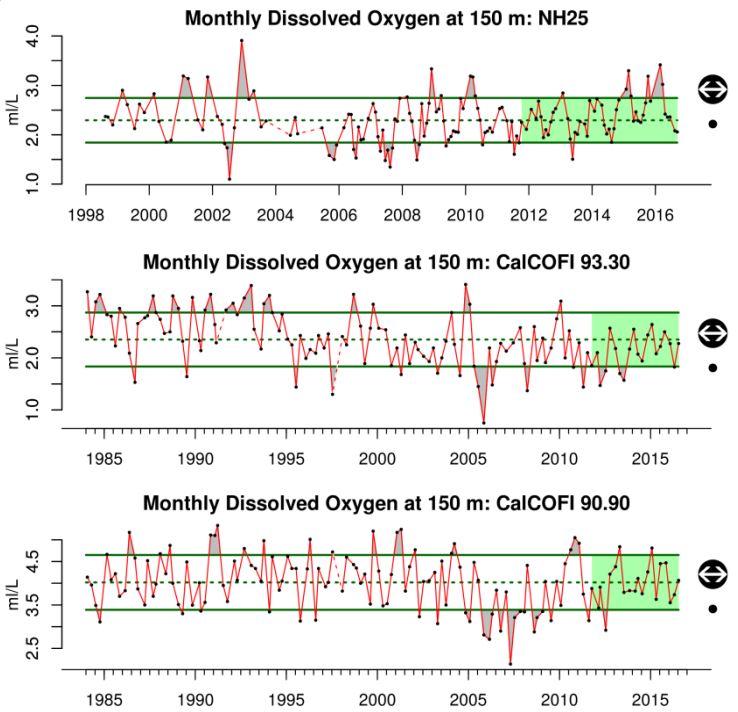


*Figure 3.3.1: Dissolved oxygen at 150-m depths off Oregon and Southern California through 2016. Stations NH25 and 93.30 are <50 km from shore; station 90.90 is >300 km from shore. Lines, colors and symbols are as in Figure 1.1a; dashed red lines indicate data gaps >6 months.*

In nearshore waters off Oregon (station NH5), aragonite levels at 40 m depth are typically saturated (>1.0) during the winter and spring, and then fall below 1.0 in the summer and fall; this was the case again in 2016 (Fig. 3.3.2). Further offshore (station NH25) and at 150 m depths, aragonite saturation state follows the same seasonal cycle but across a narrower range, and aragonite levels at this area and depth are almost always <1.0. However, aragonite levels have been elevated slightly in the anomalous conditions of the past two years. In fact, according to seasonal data, winter aragonite levels have increased over the past 5 years at both stations (Appendix E.3).

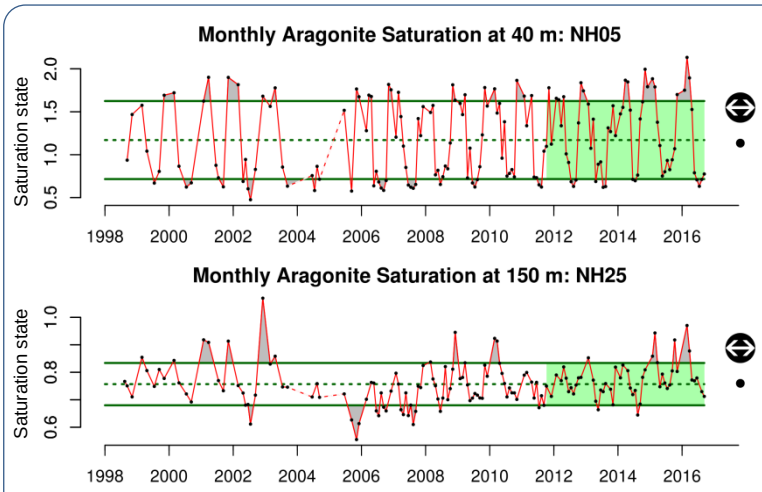


*Figure 3.3.2: Monthly aragonite saturation values off of Newport, Oregon, 1998-2016. Lines, colors and symbols are as in Figure 1.1a; dashed red lines indicate data gaps >6 months.*

## 3.4 HYDROLOGIC INDICATORS

Freshwater conditions are critical for salmon populations and for estuarine habitats that support many marine species (e.g., Appendix D). The freshwater indicators presented here focus on snowpack and streamflow, and are summarized by freshwater ecoregion (Fig. 2.1b). Snow-water equivalent (SWE) is the total water content in snowpack, which provides a steady source of freshwater into the summer months. Maximum streamflows in winter and spring are important for habitat formation, but can cause scouring of salmon nests. Minimum streamflows in summer and fall can restrict habitat for in-stream juveniles and migrating adults. All three indicators are influenced by climate and weather patterns and will be affected as climate change intensifies.

After years of steady declines and a historic low in 2015, SWE returned to average levels in all ecoregions in 2016 (Fig. 3.4.1). However, despite the rebound of SWE in early 2016, high spring and summer air temperatures resulted in rapid snowmelt. These factors led to an increase in maximum flows in 2016 (Appendix F), although not to levels considered dangerous to most salmon stocks. The early and rapid melt helped contribute to worsening trends in minimum flow in most of the ecoregions (see streamflow time series, Appendix F).

Following a series of winter storms, SWE in 2017 is on pace to exceed 2016 (see map in Appendix F, Fig. F.1) and may provide drought relief, although the official measure of SWE will not be until April 1, 2017.

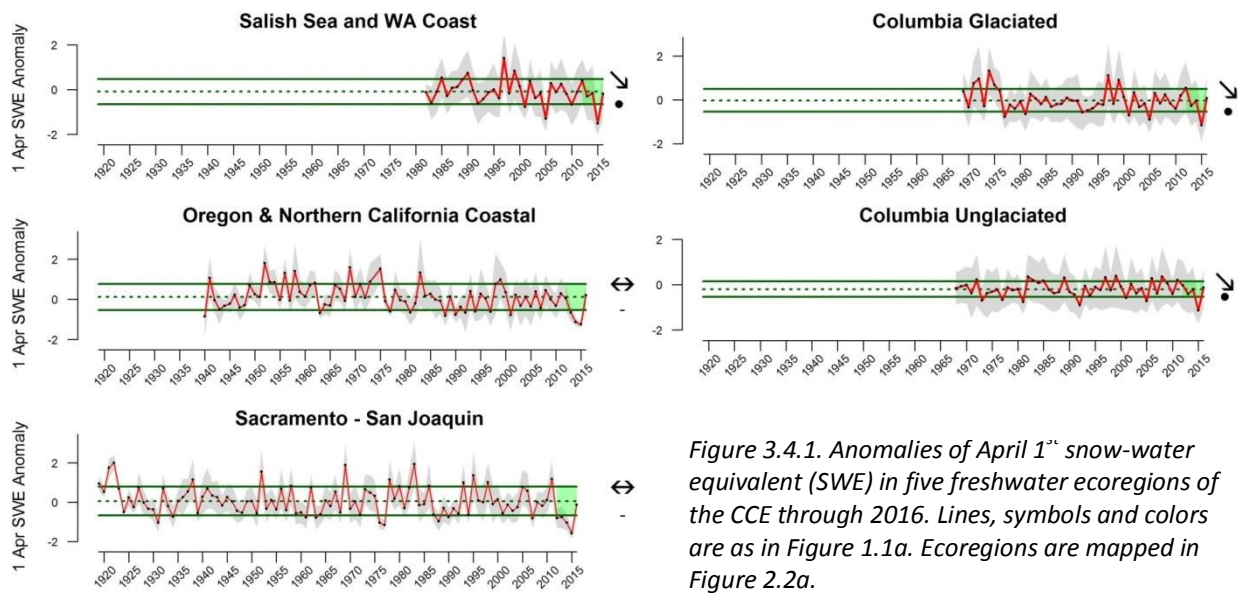


*Figure 3.4.1. Anomalies of April 1st snow-water equivalent (SWE) in five freshwater ecoregions of the CCE through 2016. Lines, symbols and colors are as in Figure 1.1a. Ecoregions are mapped in Figure 2.2a.*

We can also summarize streamflow using quad plots that summarize recent status and trends in flow anomalies at the finer spatial scale of individual Chinook salmon ESUs (Fig. 3.4.2). Here, high and increasing maximum flow is regarded as undesirable (i.e., the red quadrant of the max flow plot) due to the potential for scouring redds; low and decreasing minimum flow is also undesirable (the red quadrant of the min flow plot) because of potential for stress related to temperature, oxygen or space. The maximum flow events are within ±1 s.d. of long-term averages and generally lack signficant trends, although 4 ESUs indicate a recent increase (Fig 3.4.2, left). On the other hand, miminum flow anomalies have worsening trends for many ESUs, particularly those sensitive to low flow conditions, such as the Sacramento winter run and Klamath/Trinity ESUs. (Fig. 3.4.2, right).

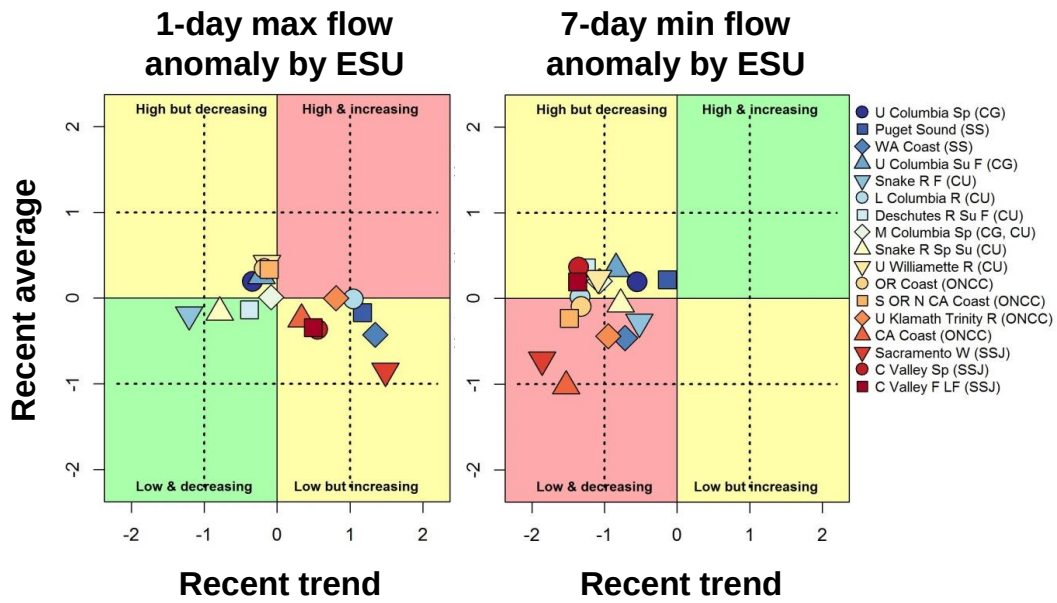


*Figure 3.4.2. Quad plots of status and trends of maximum and minimum flow in 17 Chinook salmon evolutionary significant units (ESUs) in the CCE through 2016. The 5-year status and trends of flow for each ESU are divided into green ("good" conditions), yellow ("neutral"), and red ("poor"). Symbols of ESUs are color-coded from north (blue) to south (red). Quad plot lines and base colors are as in Figure 1.1b.*

# 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 community structure and ecological interactions. Many CCE species and processes respond very quickly to changes in ocean and climate drivers, while other responses may lag by many years. These dynamics are challenging to predict. Over the last several years, many ecological integrity metrics have indicated conditions of poor productivity at low trophic levels and poor foraging conditions for many predators. In 2016 we also continued to observe unexpected community structure in pelagic waters throughout the CCE. It remains to be seen how different populations have been affected, or whether 2017 will represent a shift away from the unproductive conditions observed since 2014.

## 4.1 NORTHERN COPEPOD BIOMASS ANOMALY

Copepod biomass anomalies represent interannual variation in biomass of two groups of copepod taxa: northern copepods, which are "cold-water" species rich in wax esters and fatty acids that appear to be essential for pelagic fishes; and southern copepods, which are "warm-water" species that are generally smaller and have lower lipid content and nutritional quality. In summer, northern copepods usually dominate the coastal zooplankton community represented by collections along the Newport Line (see Fig. 2.1a,c), while Southern copepods dominate the community during winter. This pattern is often altered during El Niño events and/or when the PDO is positive, leading to higher biomass of southern copepods (Keister et al. 2011, Fisher et al. 2015). Threshold values for the anomalies have not been set, but positive values of northern copepods in summer are correlated with stronger returns of Chinook salmon to Bonneville Dam, and values greater than 0.2 are associated with better survival of coho salmon (Peterson et al. 2014).

With the exception of a brief period during summer 2015, the northern copepod anomaly has remained >1 s.d. below the long-term mean since the autumn of 2014 (Fig. 4.1.1, top). During this same period, the southern copepod biomass anomaly increased significantly and was strongly positive in much of 2016 (Fig. 4.1.1, bottom). These anomaly patterns are consistent with warm

surface waters and poor feeding conditions for pelagic fishes, and reflect a sustained departure from the generally productive ocean conditions for much of 2011-2014. Moreover, 17 species of copepods have been collected since autumn 2014 that had not been observed in these waters previously. It appears that many of these exotic copepod species were offshore, central Pacific species, not the typical southern species that are often transported northward to the Newport Line during major El Niño events.

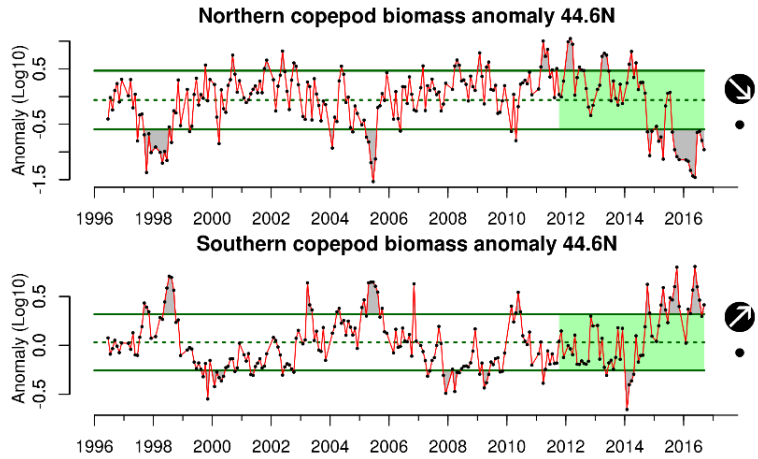


*Figure 4.1.1. Monthly northern and southern copepod biomass anomalies from 1996-2016 in waters off Newport, OR. Lines, colors and symbols are as in Figure 1.1a.*

## 4.2 Regional Forage Availability

This section describes trends in forage availability, based on research cruises throughout the CCE through spring/summer 2016. These species represent a substantial portion of the available forage in the regions sampled by the cruises (see Fig. 2.1c). *We consider these regional indices of relative forage availability and variability, not indices of absolute abundance of coastal pelagic species (CPS).* Absolute abundance estimates should come from stock assessments and comprehensive monitoring programs, which these surveys are not. Moreover, the regional surveys that produce these data use different methods (e.g., gear selectivity, timing, frequency, and survey objectives); thus the amplitudes of each time series are not necessarily comparable between regions.

The CCE forage community is a diverse portfolio of species and life history stages, varying in behavior, energy density, and availability to predators. Years with abundant pelagic fish, market squid and krill are generally associated with cooler waters, strong upwelling and higher productivity (Santora et al. 2014, McClatchie et al. 2016). For space considerations, we present the forage indicators as quad plots in the main report; time series plots for each species and region are available in Appendix G.

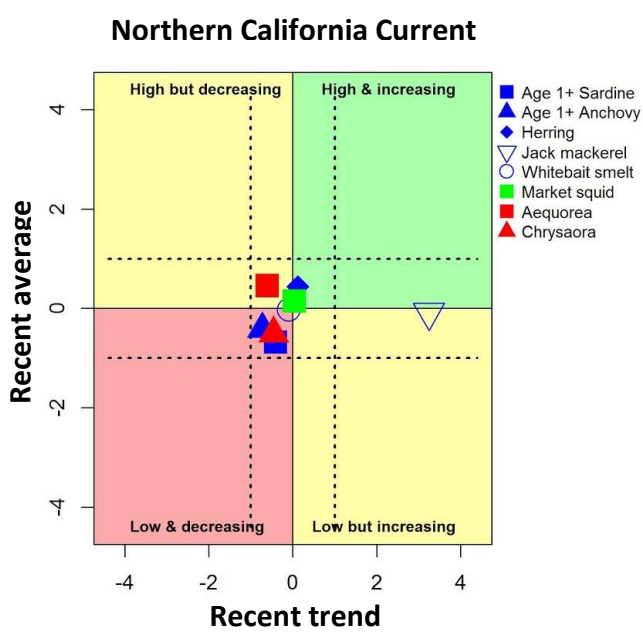


*Figure 4.2.1: Means and trends of CPUE for key forage in the Northern CCE. Means and trends are from 2012-2016 and normalized relative to the full time series (1999-2016). Lines, colors and symbols are as in Figure 1.1b.*

*Northern CCE*: The northern CCE survey targets juvenile salmon in June in surface waters, but also catches juvenile and adult pelagic fishes, market squid, and gelatinous zooplankton. Except for jack mackerel, recent average catch-per-unit-effort (CPUE) of most forage species, were within 1 s.d. of the long-term mean and showed no discernable short-term trends (Fig. 4.2.1). Sardine and anchovy CPUE remained near the lowest levels observed in the time series (Appendix G, Fig. G.1). The two main species of gelatinous

zooplankton were within the long-term mean range, although the small water jelly *Aequorea* sp. declined from 2015 and the large sea nettle *Chrysaora* was relatively uncommon. Anecdotally, a related survey in this region, which uses different methods and only began in 2011, caught many adult anchovy near the Columbia Plume, and saw evidence of anchovy spawning off Oregon in 2015 and 2016. This survey also showed a steep drop in krill in 2015 and 2016, concurrent with an increase in gelatinous salps. The survey also found young-of-the-year (YOY) rockfish and hake more abundant in 2016 than previous years.

*Central CCE*: Data presented here are from the "Core area" of a survey (see Fig. 2.1c) that targets YOY rockfishes, but also samples other forage fishes, market squid and zooplankton. The Central CCE forage community in 2016 exhibited many of the anomalous catch levels and trends observed in recent years. Adult sardine and anchovy CPUEs remained relatively low, whereas YOY rockfish CPUE was above average for the fourth year in a row (Fig. 4.2.2; see also Appendix G, Fig. G.2). YOY hake CPUE also maintained its recent increase, and YOY sanddabs remained above the long term mean. Krill and market squid CPUE have declined in recent years, particularly squid since 2014. *Chrysaora* jellyfish also declined, though that may be due to avoidance of sites where *Chrysaora* has fouled sampling gear in the past. However, salps were relatively abundant, as were warm-water species such as pelagic crabs (data not shown).

*Southern CCE*: The forage abundance indicators for the Southern CCE come from larval fish surveys conducted by CalCOFI. The larval biomass is assumed to correlate with the spawning stock biomass of forage species such as sardine, anchovy, market squid, shortbelly rockfish, and some mesopelagic species. Recent CPUE for the four species that have been analyzed through 2016 were within ±1 s.d. of their long-term means, but anchovy showed a significant increasing trend while market squid show a recent decline (Fig. 4.2.3). The increase in larval anchovy CPUE in recent years (Appendix G, Fig. G.3) is consistent with anecdotal nearshore observations of large schools of adult anchovy.

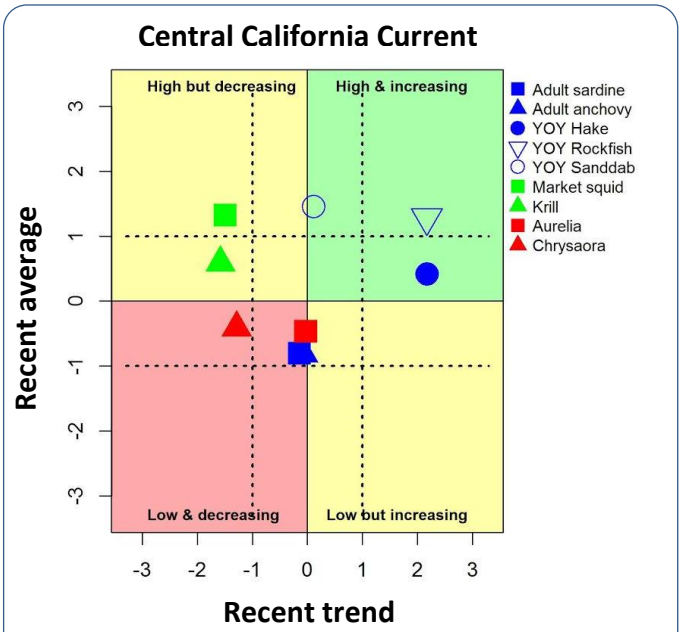


*Figure 4.2.2 Means and trends of CPUE for key forage in the Central CCE (Core area). Means and trends are from 2012-2016 and normalized relative to the full time series (1990-2016).Lines, colors and symbols are as in Figure 1.1b.*

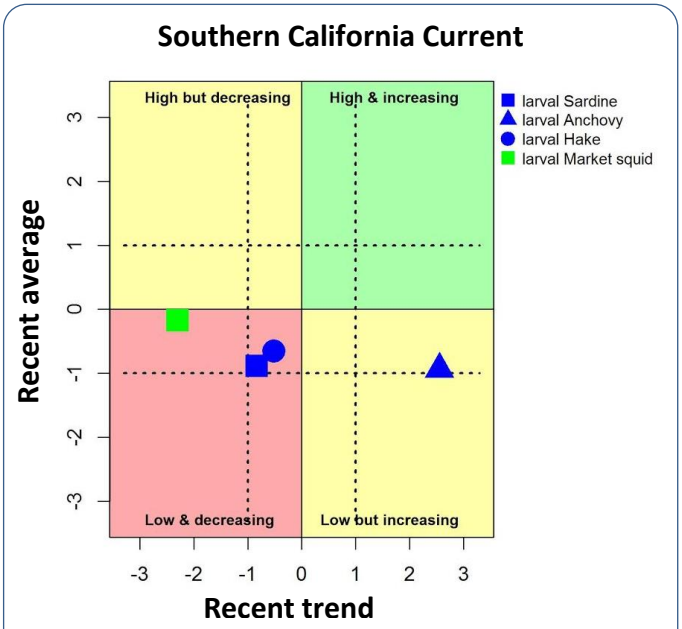


*Figure 4.2.3 Means and trends of CPUE for key forage in the Southern CCE. Means and trends are from 2012-2016 and normalized relative to the full time series (1978-2016). Lines, colors and symbols are as in Figure 1.1b.*

### 4.3 SALMON

For indicators of the abundance of Chinook salmon populations, we compare the trends in natural spawning escapement along the CCE to evaluate the coherence in production dynamics, and also to get a more complete perspective of their status across the greater portion of their range. When available, we use escapement time series back to the 1970s; however, some populations have shorter time series (for example, Central Valley Spring starts 1995, Central Valley Winter starts 2001, and Coastal California starts 1991). Here we present summary quad plots of escapements; full time series are available in Appendix H.

California Chinook salmon data are updated as of 2015. Generally, California Chinook salmon escapements were within 1 s.d. of their long-term averages (Fig. 4.3.1), although 2015 escapements were generally near the low end of the normal range (Appendix H, Fig. H.1). Most California stocks have neutral trends over the last decade, which is a noteworthy change from our last report: trends that had been positive for Central Valley Fall, Klamath Fall, California Coast and Northern CA/ Southern OR are now neutral after poor escapements in 2013, 2014 and/or 2015 (Appendix H, Fig. H.1). Central Valley Winter Run Chinook salmon have had relatively low escapements since 2007 following high escapements in 2005-2006, leading to the recent negative trend.

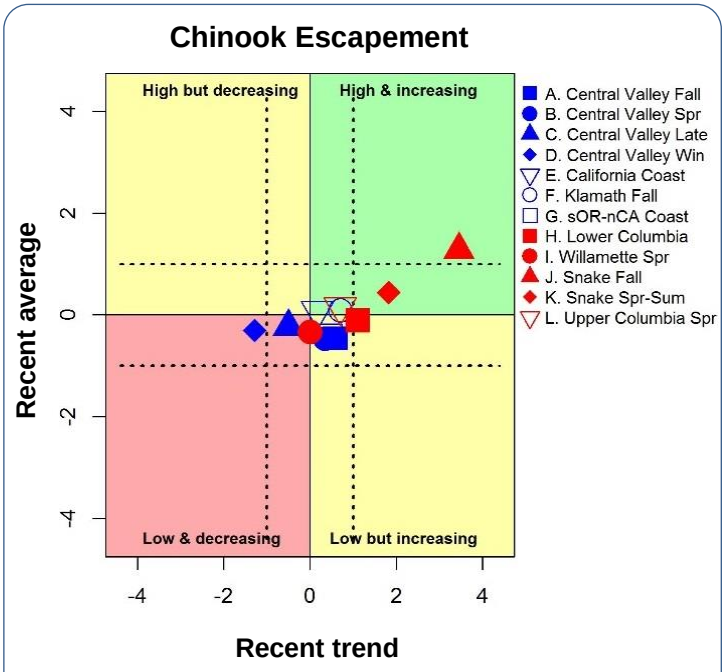


*Figure 4.3.1. Chinook salmon escapement anomalies through 2015. "Recent average" is mean natural escapement (includes hatchery strays) from 2006-2015, relative to the mean of the full time series. "Recent trend" indicates the escapement trend from 2006-2015. Base colors and lines are as in Fig. 1.1b.*

For Oregon, Washington and Idaho Chinook salmon stocks (updated through 2014), most recent escapements were close to average (Fig. 4.3.1). The exception is Snake River Fall Chinook after a series of large escapements since 2009 (Appendix H, Fig. H.2). Ten-year trends for northern stocks were either neutral or positive, with three (Lower Columbia, Snake River Fall and Snake River Spring) having significantly positive trends from 2005-2014.

Predicting exactly how the climate anomalies of 2013-2016 will affect different brood years of salmon from different parts of the CCE is difficult, despite concerted efforts by many researchers (e.g., Burke et al. 2013, Wells et al. 2016). However, many signs do suggest below-average returns may occur for Fall Chinook, Spring Chinook and coho stocks returning to the Columbia Basin. The poor hydrological conditions of 2015 (Section 3.4) were problematic for both juvenile and adult salmon. As noted above in Section 4.1, the Northern Copepod Biomass Anomaly is positively associated with Chinook and coho salmon returns in the Columbia River basin (Peterson et al. 2014), and its low levels in recent years do not portend well. The Northern Copepod Biomass Anomaly is just one part of a long-term effort by NOAA scientists to correlate oceanographic conditions and pelagic food web structure with salmon productivity (e.g., Burke et al. 2013). Their assessment is that physical and biological conditions for smolts that went to sea between 2013 and 2016 are generally consistent with poor returns of Chinook and coho salmon to much of the Columbia Basin in 2017, as depicted in the "stoplight chart" in Table 4.3.1.

*Table 4.3.1. "Stoplight" table of basin-scale and local-regional conditions for smolt years 2013-2016 and likely adult returns in 2017 for coho and Chinook salmon that inhabit coastal Oregon and Washington waters in their marine phase. Green = "good," yellow = "intermediate," and red = "poor." Courtesy of Dr. Bill Peterson (NWFSC).*

| | Smolt year | | | | Adult return outlook | |
|---|---|---|---|---|---|---|
| **Scale of indicators** | **2013** | **2014** | **2015** | **2016** | **Coho, 2017** | **Chinook, 2017** |
| **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) | 🟩 | 🟨 | 🟨 | 🟨 | 🟡 | 🟡 |

## 4.4 Groundfish: Stock Abundance and Community Structure

The CCIEA team regularly presents the status of groundfish biomass and fishing pressure based on the most recent stock assessments. Because 2016 was not a groundfish assessment year, we have no update from last year's report. Most of the recently assessed groundfish are near or above the biomass limit reference point, and are thus not in an "overfished" status (Fig. 4.4.1). The only exceptions were yelloweye rockfish and Pacific ocean perch, both last assessed in 2011.

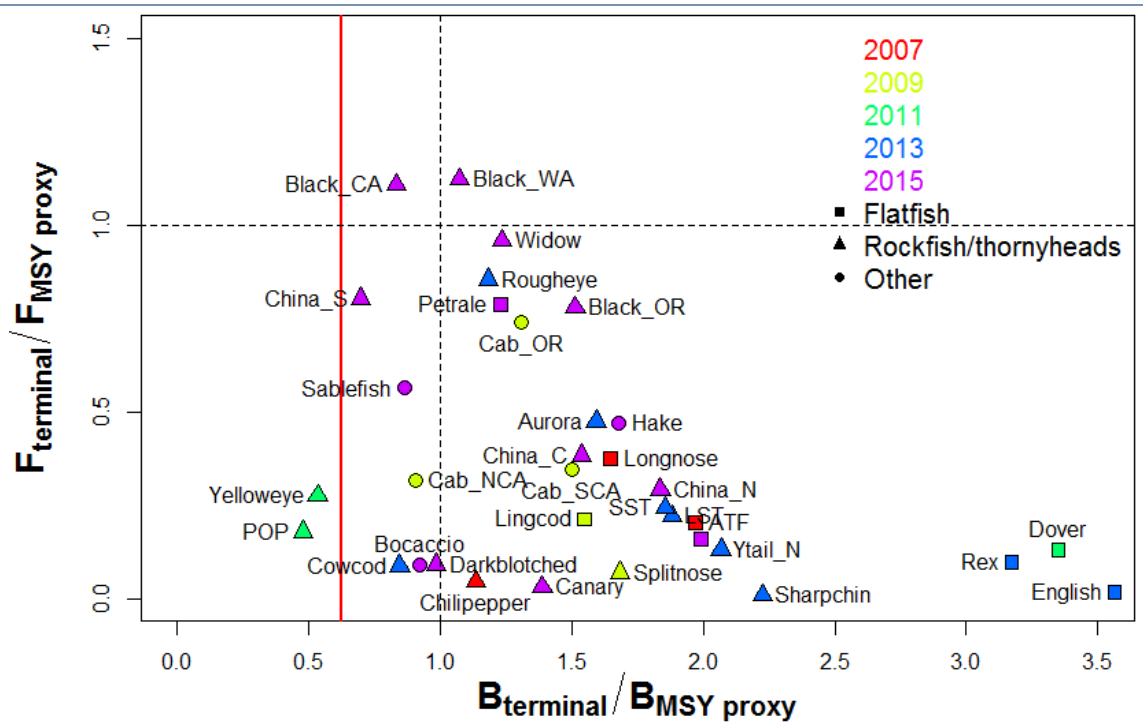


*Figure 4.4.1. Stock status of CCE groundfish. Horizontal line = fishing rate reference. Vertical lines = biomass target reference point (dashed line) and limit reference point (solid line; left of this line indicates overfished status). Symbols indicate taxa; colors indicate year of most recent assessment.*

"Overfishing" occurs when catches exceed overfishing limits (OFLs), but not all assessed stocks are managed by individual OFLs. Our best alternative is to compare fishing rates to proxy fishing rates at maximum sustainable yield ($F_{MSY}$), which are used to set OFL values. Only two stocks (black rockfish in California and Washington, both assessed in 2015) were being fished above $F_{MSY}$ in their most recent assessments.

As noted in Section 4.2, YOY rockfish were highly abundant in the Central CCE in 2015 and 2016, and results from both shipboard and scuba surveys also revealed large numbers of pelagic and post-settled juvenile rockfish along the Washington coast in 2016. Given the anomalously warm and unproductive oceanographic conditions of 2013-2016, these findings run counter to what we might have expected from conceptual models linking climate and productivity conditions to groundfish populations (see Appendix D, Fig. D.2). It will be several years before these fish are large enough to be caught in bottom trawls; thus we will have to wait to determine how affect groundfish populations respond long-term to the recent climate anomalies.

We are also tracking the abundance of groundfish relative to Dungeness and Tanner crabs as a metric of seafloor community structure and trophic status. Due to space considerations, and because the time series are as yet short and difficult to interpret, we have moved these indicators from the main body to the Supplementary Materials, Appendix I.

### 4.5 Marine Mammals

California sea lions are permanent residents of the CCE, breeding on the Channel Islands and feeding throughout the CCE, and so are good indicators for the population status of pinnipeds in the system. California sea lions may also be sensitive indicators of prey availability in the central and southern CCE: sea lion pup count in the San Miguel Island breeding colony relates to prey availability for adult females during gestation (October-June), while pup growth is related to prey availability to adult females during the 11-month lactation period.

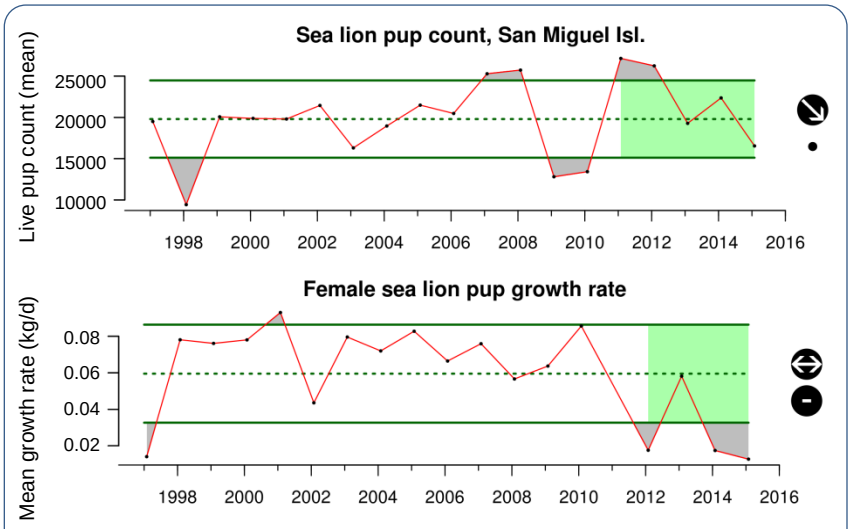


*Figure 4.5.1. California sea lion pup counts at San Miguel Island and estimated mean daily growth rate of female pups between 4-7 months, for the 1997-2015 cohorts. Lines, colors and symbols are as in Fig. 1.1a.*

Over recent years, California sea lion adult females experienced extremely poor feeding conditions (Fig. 4.5.1). Pup counts declined from 2011-2015, and pup growth was near historic lows in at least three of the last five cohorts. These results, coupled with high rates of springtime pup stranding and mortality in 2013-2016, reflects the extent of poor foraging conditions for pinnipeds in the central and southern CCE and may foretell a decrease in the California sea lion adult population. Other pinniped species that breed in this region but forage further offshore (Guadalupe fur seals and northern fur seals) also experienced poor pup growth in the same time period.

Preliminary results suggest that the 2016 cohort of California sea lion pups at San Miguel was more abundant and experienced better early growth than the preceding four cohorts, implying that foraging conditions may have improved over the past year.

## 4.6 SEABIRDS

Seabird species richness data were unavailable for this report, so we instead present regional time series for three key species. Sooty shearwaters migrate from the southern hemisphere to the CCE in spring and summer to prey on small fish and zooplankton near the shelf break. Common murres and Cassin's auklets are resident species that feed over the shelf; Cassin's auklets prey on zooplankton, while common murres target small fish.

In the northern sampling area (Fig. 2.1c), all three species exhibited temporal variability, particularly since the mid-2000s (Fig. 4.6.1). Sooty shearwaters have increased in recent years, while Cassin's auklets declined in 2016, possibly related to an exceptional mortality event in 2014-2015. Common murre counts showed no trend. (Note: no data were collected in 2013 or 2014.)

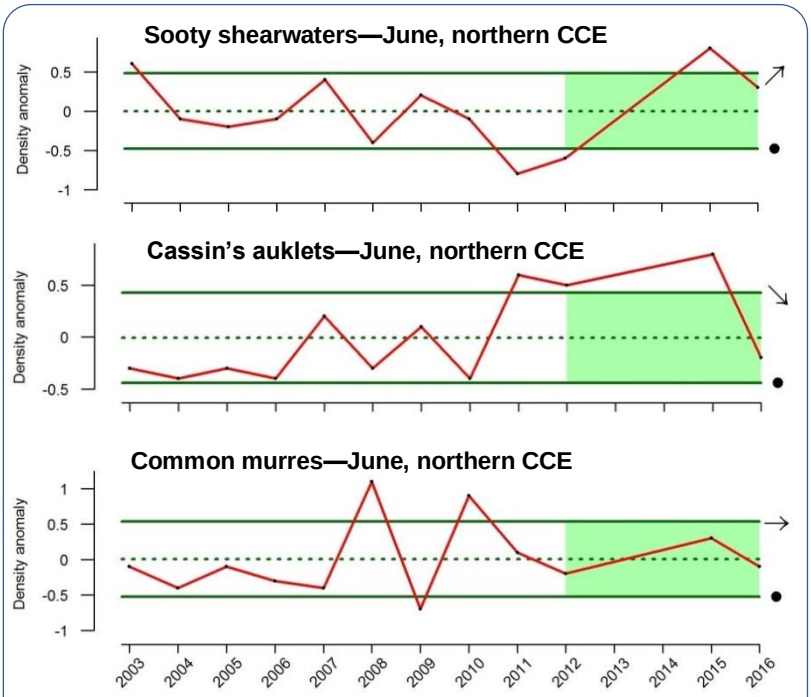


*Figure 4.6.1. Anomalies in at-sea densities of sooty shearwaters, Cassin's auklets and common murres in June in the northern CCE through 2016. Lines, colors and symbols are as in Figure 1.1a.*

In the longer southern time series, sooty shearwaters had increasing springtime density trends over the past five years (Fig. 4.6.2), which represents a return to densities observed in the late 1980s. Common murre densities had been minimal since data collection began in 1987 until an uptick in 2011, followed by strongly positive anomalies in 2015 and 2016. By contrast, Cassin's auklets in the southern CCE have been just below average density over the last 10 years.

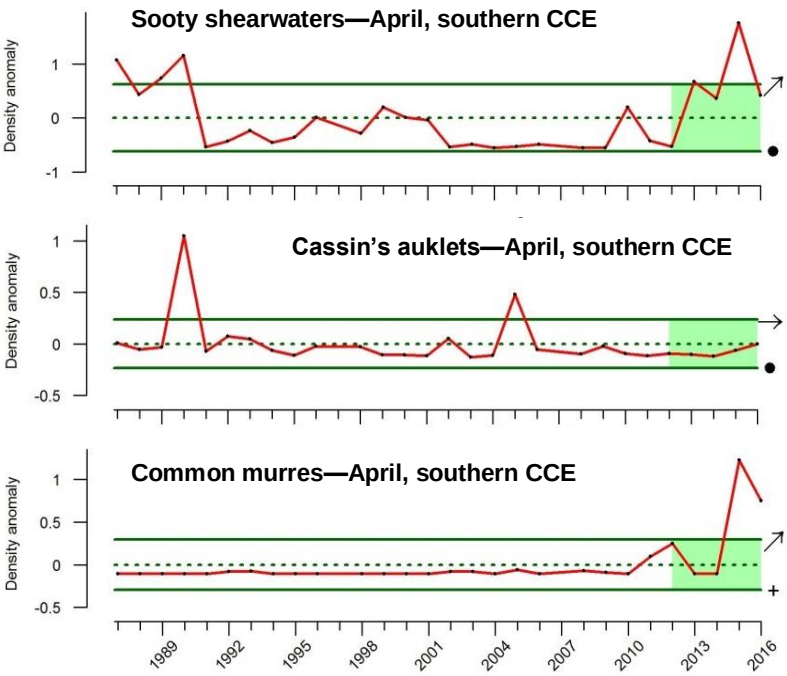


*Figure 4.6.2. Anomalies in at-sea densities of sooty shearwaters, Cassin's auklets and common murres in April in the southern CCE through 2016. Lines, colors and symbols are as in Figure 1.1a.*

The positive density anomalies in recent years are surprising, given the recent and persistent warm conditions; for example, sooty shearwaters increased despite their cold-water affinities. These are abundance indicators of long-lived birds, however, and we may need condition indicators like diet, hatching rates, fledgling success, or others to fully understand recent seabird dynamics. To illustrate this, in each of the past several

years, at least one seabird species has experienced a "wreck"—anomalously large numbers of dead birds washing up on beaches throughout much of the CCE (e.g., Cassin's auklets in 2014, common murres in 2015). In the summer of 2016, rhinoceros auklets experienced a wreck, although it was largely confined to the northern CCE. The rhinoceros auklet wreck is described in Appendix J.

## 5. Human Activities

### 5.1 Coastwide Landings by Major Fisheries

Data for fishery landings are current through 2015. Overall, total landings decreased over the last five years, driven mainly by steep declines in landings of Pacific hake, CPS and crab in 2015 (Fig. 5.1.1). Landings of groundfish (excluding hake) were historically low from 2011-2015, while hake landings were highly variable. Landings of CPS fishes and market squid decreased over the last five years. Shrimp landings increased to historic highs, particularly from 2013-2015, whereas crab declined sharply from a peak in 2013. Salmon landings were highly variable, while highly migratory species (HMS) landings were relatively consistent; both were within ±1 s.d. of historic averages. Recreational landings were historically low from 2004-2015, and showed no recent trend. State-by-state commercial and recreational landings are summarized in Appendix K.

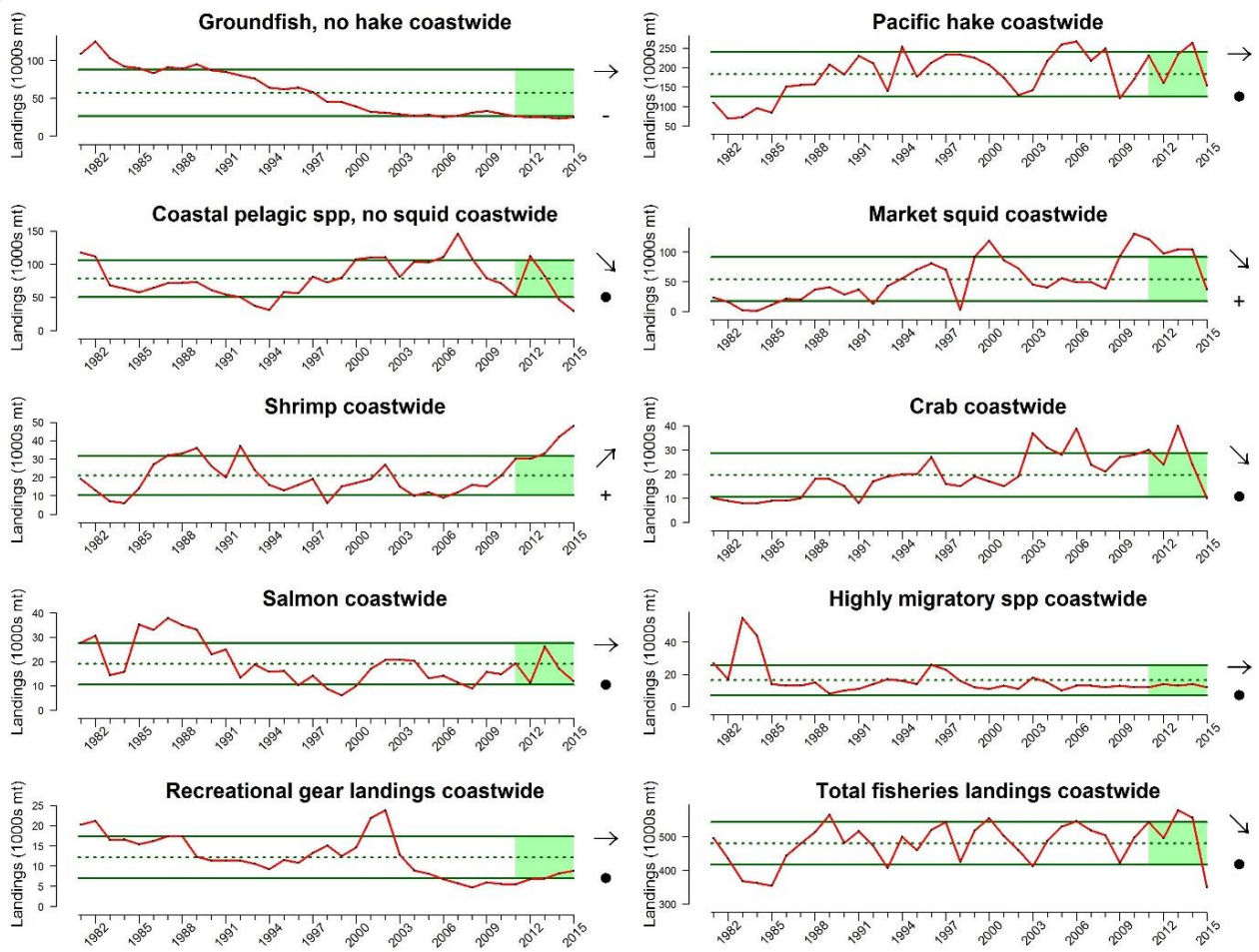


*Figure 5.1.1: Annual landings of West Coast commercial (data from PacFIN) and recreational fisheries (data from RecFIN), including total landings across all fisheries from 1981-2015. Lines and symbols are as in Figure 1.1a.*

Revenues from commercial fishing, broken out by state and FMP, are also presented in Appendix K. Total commercial fishery revenues (in adjusted 2015 dollars) have declined sharply since 2013, driven by declines in landings of crab, market squid and hake (Appendix K, Figs. K.5-K.8).

### 5.2 Gear Contact with Seafloor

Benthic marine species, communities and habitats can be disturbed by natural processes as well as human activities (e.g., bottom contact fishing, mining, dredging). The impacts of fishing likely differ by gear and by habitat type, with hard, mixed and biogenic habitats needing longer to recover than soft sediments.

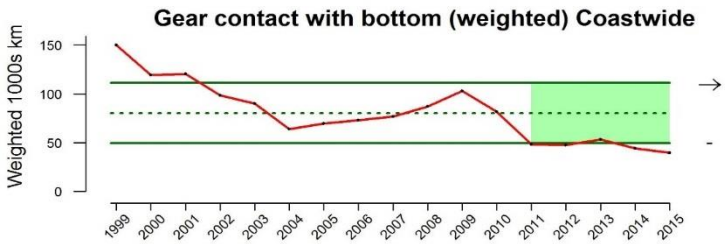


*Figure 5.2.1. Cumulative weighted distance of fishing gear contact with bottom habitat across the entire CCE, 1999-2015. Lines, colors and symbols are as in Fig. 1.1a.*

We compiled estimates of coast-wide distances affected by bottom-contact gear from 1999–2015. Estimates from 2002–2015 include bottom trawl and fixed gear, while 1999–2002 includes only bottom trawl data. We calculated trawling distances based on set and haul-back points, and fixed gear distances based on set and retrieval locations of pot, trap and longline gear. We weighted distances by gear and habitat type, according to sensitivity values described in Table A3a.2 of the 2013 Groundfish EFH Synthesis Report. Gear contact with the seafloor was at historically low levels over the most recent 5-year period (Fig. 5.2.1). The dominant signal is bottom trawl contact with soft sediments on the shelf and upper slope of the northern CCE (see Supplement, Appendix L). There is uncertainty in the estimation of bottom contact among fixed gear types (e.g. longline vs. pot and trap gear), but this uncertainty is minor compared to the signal from bottom trawl gear.

### 5.3 Aquaculture and Seafood Demand

Aquaculture activities are indicators of seafood demand and also may be related to benefits (e.g., water filtration by bivalves, nutrition, income, employment) or impacts (e.g., habitat conversion, waste discharge, species introductions). Shellfish aquaculture production in the CCE has been at historically high levels in recent years (updated through 2014 as of this report), and finfish aquaculture has been near the upper limits of historical averages (Fig. 5.3.1). Demand for seafood products increasingly is being met by aquaculture and may be influencing the increases in production.

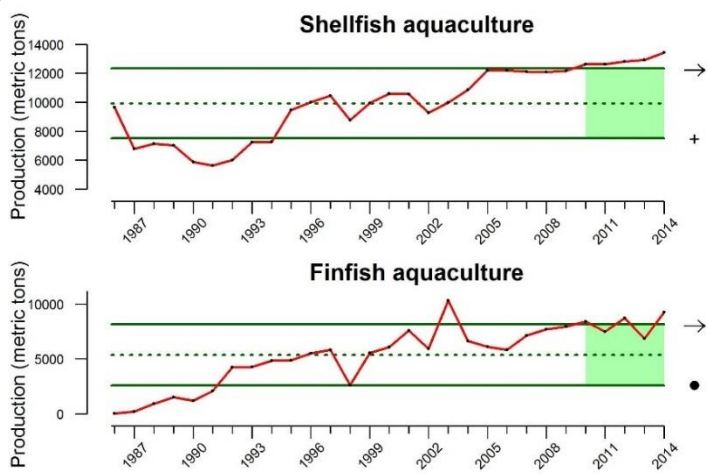


*Figure 5.3.1. Aquaculture production of shellfish (clams, mussels, oysters) and finfish (Atlantic salmon) in CCE waters. Lines, symbols and shading are as in Figure 1.1a.*

Seafood demand in the U.S. was relatively constant from 2011-2015, and had largely recovered from decline late in the previous decade (Fig. 5.3.2). The recent average total consumption was above historical averages, while per capita demand was within the historic range. With total demand already at historically high levels, increasing populations and recommendations in U.S. Dietary Guidelines to increase seafood intake, total demand for seafood products seems likely continue to increase for the next several years.

## 5.4 NON-FISHING ACTIVITIES

The CCIEA team compiles indicators of non-fisheries related human activities in the CCE, some of which may have effects on marine ecosystems, fisheries, and coastal communities. Among these activities are commercial shipping, nutrient inputs, and oil and gas activity. Since our last report in March 2016, we have received little new data for these three activities, and thus have placed information on them in the Supplementary Materials (Appendix M). It suffices to say that commercial shipping and oil and gas activity were at relatively low, stable levels through 2013-2015, while data on nutrient inputs are only available through 2012 and thus are not reliable for assessing present status and trends.

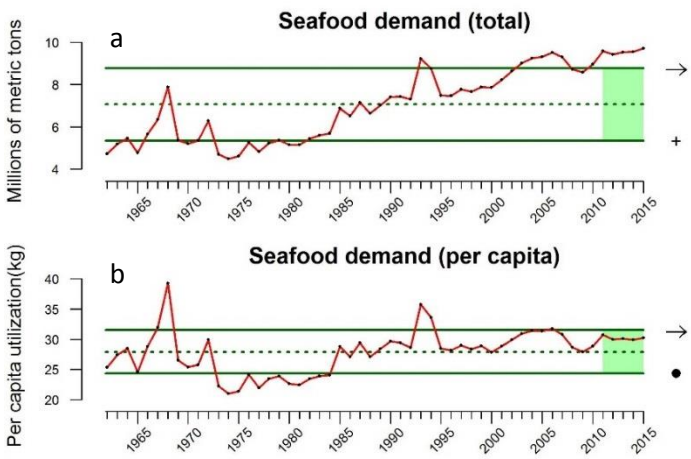


*Figure 5.3.2. a) Total and b) per-capita use of fisheries products in the U.S., 1962-2015. Lines, symbols and shading are as in Figure 1.1a.*

# 6. HUMAN WELLBEING

## 6.1. SOCIAL VULNERABILITY

Coastal community vulnerability indices are generalized socioeconomic vulnerability metrics for communities involved in commercial fishing. To assess social vulnerability in fishery-dependent communities, we use community-level social data, port-level fish ticket data, and a factor analysis approach to generate composite social vulnerability and commercial fishing indices for 1139 coastal communities. The Community Social Vulnerability Index (CSVI) is derived from social vulnerability data (demographics, personal disruption, poverty, housing characteristics, housing disruption, labor force structure, natural resource labor force, etc.). The fishing dependence composite index is based on commercial fishing engagement in a community (including fishery landings, revenues, permits, and processing) and commercial fishing reliance (per capita enagagement). Figure 6.1.1 shows both indices for 25 highly fishing-dependent communities in five regions of the West Coast. Scores are relative to the entire CCE; for example, in 2014 the commercial fishing dependence of Moss Landing was ~33 standard deviations greater than the average community. The ten most fishery-dependent communities and their vulnerability scores are presented in Appendix N.

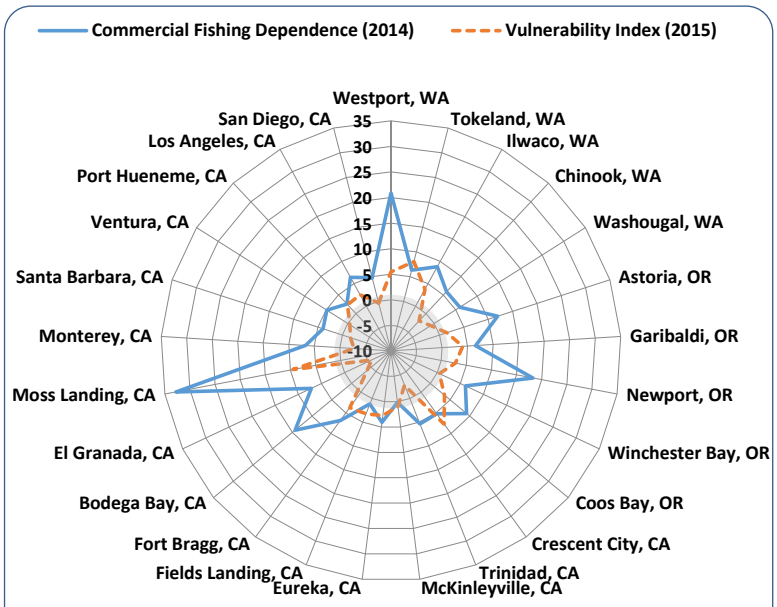


*Figure 6.1.1. Commercial fishing dependence in 2014 (solid) and social vulnerability index in 2015 (dashed) for the five most fishing-dependent communities in Washington, Oregon, and northern, central and southern California, expressed as standard deviations relative to all CCE communities. Shaded region is ≤1 s.d.*

Figure 6.1.2 shows the two indices in x-y space, allowing us to readily identify fishing-dependent communities with high social vulnerability. Of note are communities like Moss Landing and Westport, which have relatively high commercial fishing dependence (~33 and 21 s.d. above average) and also a high CSVI (~10 and 5 s.d. above average). Communities that are strong outliers in both indices may be particularly socioeconomically vulnerable to a downturn in commercial fishing. Exogenous shocks of a management-related or ecosystem-related nature may produce especially high individual and community-level social stress in these communities.

We now have enough data from the US Census and the American Community Survey for a 2000-2015 time series of community vulnerability in relation to commercial fishery dependence. This time series focuses on ten commercial fishing-dependent communities that consistently scored among the most socially vulnerable in all years. Because this time series has only four data points, it remains volatile and difficult to interpret, and is thus in the Supplement (Appendix N). We will further develop this time series, although doing so is constrained by the fact that census data are only collected every five years.

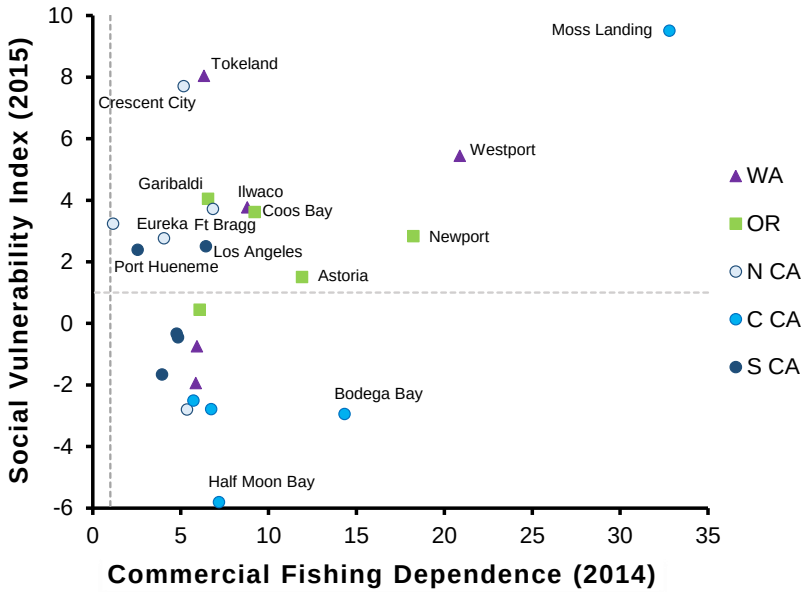


*Figure 6.1.2. Social vulnerability and commercial fishing dependence data for the same communities and time periods as in Figure 6.1.1, but as x-y data color-coded by region. Dashed lines indicate 1 s.d. above the coastwide means, i.e., communities above and right of the two dashed lines have significantly greater social vulnerability and commercial fishing dependence than average communities in the CCE.*

### 6.2 Fleet Diversity Indices

Catches and prices from many fisheries exhibit high interannual variability, leading to high variability in fishers' income. Variability in annual revenue can be reduced by diversifying fishing activities across multiple fisheries or regions (Kasperski and Holland 2013). There may be good reasons for individuals to specialize, however, including reduced costs or greater efficiency. Thus, while diversification may reduce income variation, it does not necessarily promote higher average profitability. We measure diversification with the Effective Shannon Index (ESI). ESI = 1 when revenues are all from a single species group and region. It increases both as revenues are spread across *more* fisheries and as revenues are spread more *evenly* across fisheries. The index has an intuitive meaning: ESI = 2 if fishery revenues are spread evenly across 2 fisheries; ESI = 3 if revenues are spread evenly across 3 fisheries; and so on. If revenue is not evenly distributed across multiple fisheries, the ESI value is lower than the number of fisheries. As of 2015, the fleet of vessels fishing on the US West Coast and in Alaska is less diverse on average than at any point in the past 35 years (Fig. 6.2.1). Between 2014 and 2015, some categories of vessels showed a small increase in ESI, while others decreased, but absolute changes were minor. The only fleet to change by >2 s.d. were vessels 81-125 feet, for which ESI increased by about 5%; this change appears to be due to non-participation of some less-diversified vessels from West Coast fisheries in 2015. The long-term decrease in ESI over the last 35 years is due both to entry and exit of vessels and changes for

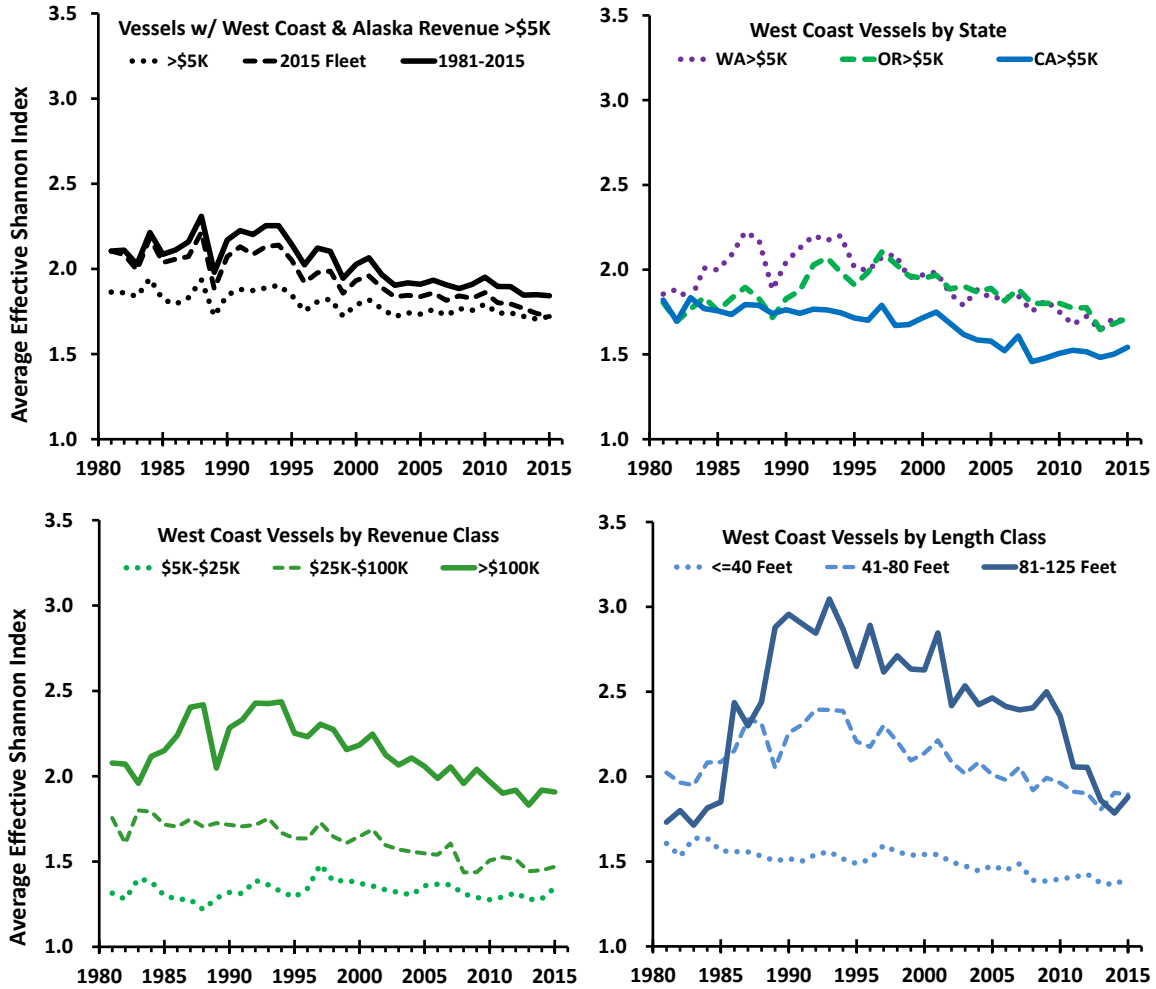


*Figure 6.2.1. Average fishing vessel diversification for US West Coast and Alaskan fishing vessels with over $5K in average revenues (top left) and for vessels in the 2015 West Coast Fleet, broken out by state (top right), average gross revenue (bottom left) and vessel length (bottom right).*

individual vessels. Over time, less-diversified vessels have been more likely to exit, which increases average diversification. However, vessels that remain in the fishery have also become less diversified, at least since the mid-1990s, and newer entrants have generally been less diversified than earlier entrants. The overall result is a moderate decline in ESI since the mid-1990s or earlier for most vessel groupings. Notwithstanding these average trends, there are wide ranges of diversification levels and strategies within as well as across vessel classes, and some vessels remain highly diversified. It should be noted that increases in diversification from one year to the next may not always indicate a positive improvement. For example, if a class of vessels was heavily dependent on a single fishery with highly variably revenues, such as Dungeness crab, an overall decline in the Dungeness crab fishery might cause ESI to increase. Also an increase in ESI may be due to the exit of less diversified vessels. Additional break-downs of diversification are in Appendix O of the Supplement.

## 7. RESEARCH RECOMMENDATIONS

In March 2015, the Council approved FEP Initiative 2, "Coordinated Ecosystem Indicator Review" (Agenda Item E.2.b), by which the Council, advisory bodies, the public, and the CCIEA team would work jointly to refine the indicators in the annual CCIEA Ecosystem Status Report to better meet Council objectives. The Initiative was implemented by an ad-hoc Ecosystem Working Group (EWG).

The EWG asked the CCIEA team to include a short section of "Research Recommendations" in the 2017 report. The Recommendations below reflect our collective assessment of science products that we believe are important; that we could provide to the Council in a reasonable time frame (e.g., 1-3 years, including technical review by the SSC Ecosystem Subcommitte); that fit with developing NOAA Ecosystem-Based Fisheries Management (EBFM) Road Map; and that would provide added value to the indicators as they relate to management of FMP stocks and protected species.

### 7.1 CONTINUE AN ONGOING SCOPING PROCESS BETWEEN THE COUNCIL AND THE CCIEA

The CCIEA team recognizes the necessity to partner directly with the Council on these Research Recommendations, in order for them to be effective and directly applicable to management. We greatly appreciated the time and effort the Council gave to scoping the contents of this annual report under FEP Initiative 2. An ongoing scoping process could give the CCIEA team clear direction on Council needs, and give the Council a clear sense of CCIEA capabilities and capacity. Therefore:

- *The Research Recommendations below are based on our current work and interests, but we would appreciate an opportunity to further scope CCIEA work with the Council and its advisory bodies, to ensure that our work is aligned with the Council's ecosystem science needs.*

### 7.2 CONTINUE MAKING IMPROVEMENTS TO INDICATOR ANALYSIS

The CCIEA team has benefited greatly from working with the EWG on the Initiative, and from the complementary support of the SSC in providing technical review of CCIEA indicators and activities. The CCIEA team recommends that this partnership continue, with emphasis on:

- *Continued refining of the existing indicators in this report, to better meet Council needs;*
- *Identifying and prioritizing indicator gaps, such as CPS, HMS, groundfish, diet information, chlorophyll, harmful algal blooms, and socioeconomic data from underreported communities;*
- *Using multivariate autoregressive state-space (MARSS) models to estimate trends in our indicators, separate from the observation error inherent in field sampling;*
- *Analyzing time series to (1) determine if threshold relationships exist between stressors and indicators, to inform risk assessments; and (2) to detect early warning indicators of major shifts in ecosystem structure or function.*

### 7.3 ASSESS DYNAMICS OF FISHERIES ADAPTATION TO SHORT-TERM CLIMATE VARIABILITY

The CCE is highly variable, driven by annual or decadal variations such as El Niño events, PDO shifts, and marine heat waves. The livelihoods of fishers in the CCE are heavily influenced by such variability. As fishers attempt to adapt to variability by switching among fisheries, their actions impact other fishers and fishing communities, and may actively influence ecosystem dynamics. This project will investigate how fisheries management and fishers' fishing strategies combine to effect social and ecological resilience to the short-term climate variability inherent to the CCE. We plan to:

- *Analyze how productivity of key species varies with climate/ocean conditions;*
- *Survey CCE fishers to determine motivations for fishery participation, and use the data from the survey and fish tickets to fit statistical models of individual fishing participation choices;*
- *Construct an integrated model of several CCE fisheries (e.g., salmon, Dungeness crab, albacore, groundfish, shrimp) that determines participation and effort in each fishery;*

- *Model how climate variability affects fisheries both directly via environmental effects and indirectly via participation decisions, and explore what types of fishing portfolios, for individuals or ports, result in lower variation in income and higher quality of life.*

### 7.4 ASSESS VULNERABILITY OF "COMMUNITIES AT SEA" TO LONG-TERM CLIMATE CHANGE

Long-term climate change has already shifted distributions of marine species in the CCE, but the socio-ecological impacts of climate change on fishing communities over the next several decades are difficult to anticipate. A major challenge remains linking vulnerability to predicted long-term changes in the marine seascape upon which each community depends, particularly because both target species and fleets from different ports form spatially and temporally dynamic "communities at sea" (e.g., Colburn et al. 2016). We plan to:

- *Develop a composite index of vulnerability for each community at sea as a function of its exposure (changes in target species biomass) and sensitivity (dependence on each target species) to long-term climate change;*
- *Assess each community at sea's adaptive capacity (e.g., mobility, target switching);*
- *Set up Environmental Competency Groups throughout the CCE, so that scientists, fishers and managers can together interrogate information about climate vulnerabilities and impacts, co-develop adaptation strategies, and proactively reveal barriers to adaptation.*

### 7.5 "DYNAMIC OCEAN MANAGEMENT" TO REDUCE BYCATCH IN HMS FISHERIES

Traditional management measures for bycatch reduction are static in space and time, despite the fact that both marine species and human users rely on dynamic environmental features. Dynamic Ocean Management (DOM) offers an ecosystem-based management approach toward addressing these dynamic issues (Lewison et al. 2015). We define DOM as management of marine systems that can change in space and time with the shifting nature of the ocean and its users. We are exploring DOM for HMS, specifically to maximize swordfish catch in the California drift gillnet fishery while minimizing bycatch of key species including leatherback sea turtles, blue sharks, and California sea lions; we will extend this to include marine mammals that are hard cap species. Our approach is to:

- *Use species-specific bycatch risk profiles to create risk-reward ratios for swordfish vessels;*
- *Track spatiotemporal changes in risk ratios as a function of management strategies and dynamic environmental conditions in the area of the drift gillnet fishery.*

### 7.6 ASSESS ECOLOGICAL AND ECONOMIC IMPACTS OF OCEAN ACIDIFICATION

The CCE is characterized by upwelling of deep, cold, nutrient-rich waters that support fish stocks and the human communities that rely on them, but that also make the area particularly at risk of OA. The CCIEA team is leading focused research to identify the species, fisheries, and ports most vulnerable to OA. This will address needs identified in PFMC Fishery Ecosystem Plan Initiative A.2.8, by the Ecosystem Advisory Subpanel, and in the NOAA Fisheries Climate Science Strategy Western Regional Action Plan (WRAP). Specifically, we will:

- *Apply an Atlantis ecosystem model, which was formally reviewed by the SSC in July 2014, and presented to the full Council in November 2014 (Kaplan and Marshall 2016);*
- *Link the Atlantis model to 1) ensembles of future scenarios for OA, warming, and species range shifts, and 2) updated information about species exposure and sensitivity to OA;*
- *Identify FMPs, ecoregions, and ports most likely affected by OA, warming, and subsequent range shifts, including both direct and indirect (e.g. food web) effects;*
- *Consider impacts on FMPs that result from changes in prey productivity, for instance impacts on rebuilding rockfish stocks.*