CALIFORNIA CURRENT INTEGRATED ECOSYSTEM ASSESSMENT (CCIEA) CALIFORNIA CURRENT ECOSYSTEM STATUS REPORT, 2018

A report of the NOAA CCIEA Team to the Pacific Fishery Management Council, March 9, 2018.

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1 INTRODUCTION

Section 1.4 of the 2013 Fishery Ecosystem Plan (FEP) established 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 6th report, with prior reports in 2012 and 2014-2017.

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 report.

Box 1.1: Highlights of this report

- **Climate, oceanographic and streamflow indicators suggest that the physical system is transitioning toward average or even La Niña conditions, following the marine heat wave ("Blob") and major El Niño events of 2014-2016**
- **Several ecological indicators in 2017 also point toward more average conditions:**
  - The copepod community off Newport saw an increase in cool-water, lipid-rich species that are better for production of salmon
  - Some important forage species increased in the central and southern CCE
  - Sea lion pup growth at San Miguel Island was normal
  - There were no mass seabird mortality events
- **However, there was lingering evidence of unfavorable conditions in 2017:**
  - Persistent deep warm water remains in the northern portion of the system
  - Pyrosomes (warm-water salps) were extremely abundant in the northern and central CCE
  - Juvenile salmon catches were poor, and other indicators suggest that Chinook and coho salmon returns to the Columbia Basin will be below average in 2018
  - A major hypoxic event occurred on the shelf of the northern CCE in August-September
  - Reports of whale entanglements in fixed fishing gear were high for the fourth straight year; most reports involved crab gear, but some involved sablefish gear
- **For the first time, the report includes highly migratory species indicators, related to biomass, recruitment, and management of protected species bycatch**
- **Social vulnerability can now be compared with the dependence of coastal communities on commercial fishing and on recreational fishing**
- **We find some evidence of threshold relationships (between sea lions and upwelling), but no support yet for an "early warning index" of major ecosystem state changes**

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

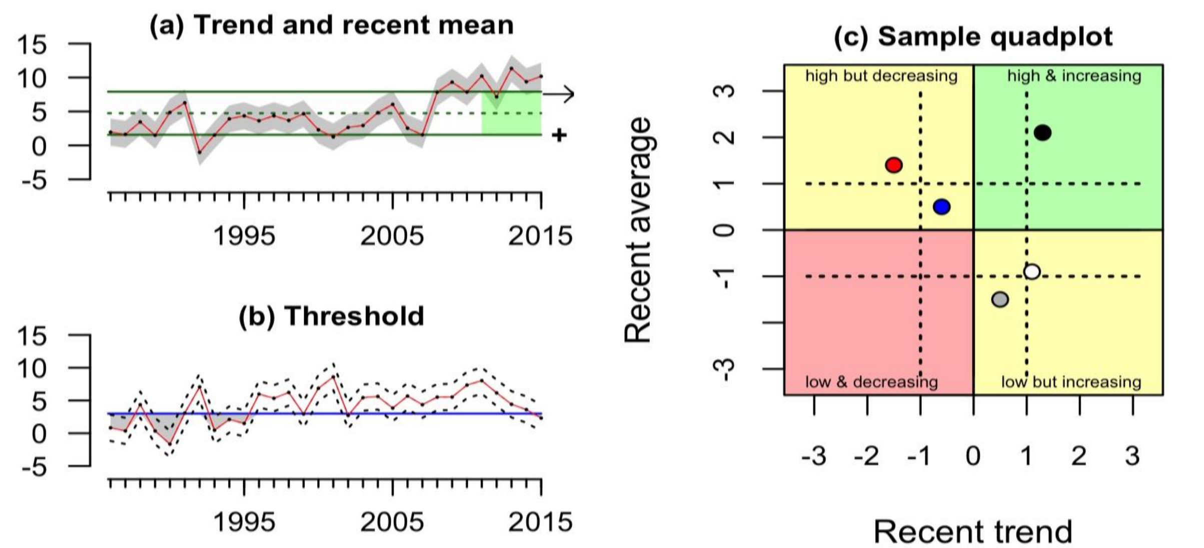

Figure 1.1 (a) Sample time-series plot, with indicator data relative to the mean (dashed line) and ±1.0 s.d. (solid lines) of the full time series. Arrow at the right indicates if the trend over the most recent 5 years (shaded green) was positive, negative or neutral. Symbol at the lower right indicates 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), which is standard error unless otherwise defined; (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; (c) Sample quad plot. 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 recent years of the time series are above or below the long-term average; quadrants are stoplight colored to further indicate the indicator condition (green = good, red = poor). Dashed lines represent ±1.0 s.d. of the full time series.

2 Sampling Locations

Figure 2.1 shows the CCE and headlands that define key biogeographic boundaries. We generally consider areas north of Cape Mendocino to be the “Northern CCE,” areas between Cape Mendocino and Point Conception the “Central CCE,” and areas south of Point Conception the “Southern CCE.”

Figure 2.1 also shows sampling locations for most regional oceanographic data in this report (Section 3.2). Much of the oceanographic data are collected on the Newport Line off Oregon and the CalCOFI grid off California. This sampling is complemented by basin-scale observations and models.

Freshwater habitats worldwide can be spatially grouped into “ecoregions” by Abell et al. (2008) (see also www.feow.org). Freshwater ecoregions in the CCE are shown in Figure 2.1b, and are the basis by which we summarize indicators for snowpack, streamflow and stream temperature (Section 3.4).

Shaded areas in Figure 2.1c indicate sampling locations for most biological indicators, including copepods (Section 4.1), forage species (Section 4.2), juvenile salmon (Section 4.3), California sea lions (Section 4.6) and seabirds (Section 4.7). The blue and green areas in Figure 2.1c also approximate the areal extent of the groundfish bottom trawl survey (Section 4.4), which covers trawlable habitat on the shelf and upper slope (55–1280 m depths) in US waters.

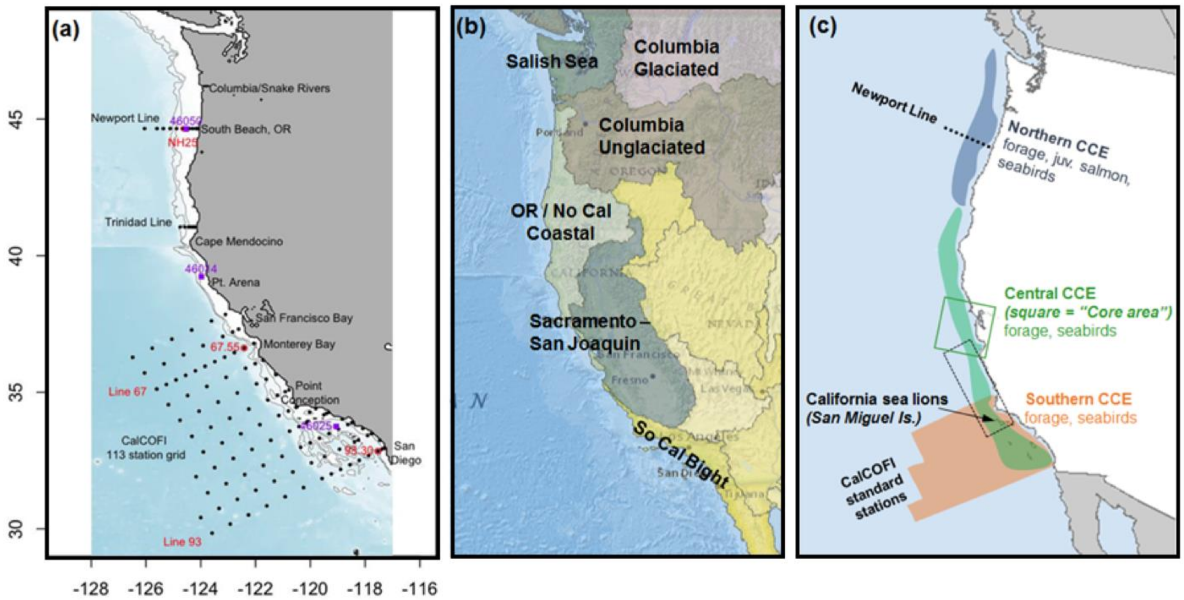

Figure 2.1 California Current Ecosystem (CCE) and sampling areas: (a) key geographic features and sampling locations; (b) freshwater ecoregions, where snowpack and freshwater indicators are measured; and (c) sampling areas for copepods (Newport Line), forage, juvenile salmon, seabirds, and California sea lions. 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.

3 Climate and Ocean Drivers

Climate and ocean indicators in the CCE reveal a climate system still in transition in 2017. The historically unprecedented marine heat wave in the CCE from 2014-2016 and the strong El Niño event in the tropical Pacific in the winter of 2015-2016 gave way to cooler coastal waters, a succession of strong storms in the winter of 2016-2017, and weak La Niña conditions by late 2017. The transition is visible in Figure 3.1 at right, where the deep and persistent red bands of above-average water temperatures from 2014-2016 return to more average or cool conditions in 2017 at the far right. We continued to see deep residual warm water and associated species from the warming events, especially in the north (Figure 3.1, top), but basin-scale indicators are trending toward average or cooler conditions. As described below, regional indicators of upwelling, water chemistry and stream conditions demonstrated their characteristically high spatiotemporal variability.

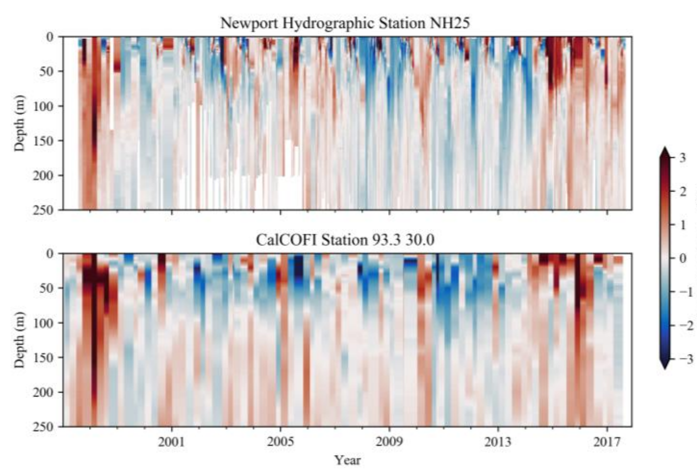

Figure 3.1 Time-depth temperature anomaly contours for nearshore hydrographic stations NH25 (August 1998 to September 2017) and CalCOFI 93.30 (January 1998 to August 2017). For location of these stations see Fig. 2.1a. Extreme warm anomalies occurred throughout the water column during El Niño events in 1998 and 2016 and at the surface in 2014-2015 during the large marine heat wave. In 2017, warm anomalies continued at the surface for both stations; anomalies at depth were warm in the north and cool in the south.

3.1 Basin-Scale Indicators

Atmosphere-ocean energy exchange is a major driver of CCE dynamics at multiple temporal and spatial scales. To capture large-scale physical variability, the CCIEA team reports three independently varying indices capable of producing a wide range of potential ecosystem states. The Oceanic Niño Index (ONI) describes the equatorial El Niño Southern Oscillation (ENSO). A positive ONI indicates El Niño conditions, which usually mean more storms to the south, weaker upwelling, increased poleward transport of equatorial waters (and species), and lower primary productivity in the CCE. A negative ONI means La Niña conditions, which usually lead to higher productivity. The Pacific Decadal Oscillation (PDO) is derived from sea surface temperature anomalies (SSTa) in the Northeast Pacific, which often persist in regimes that last for many years. Positive PDOs are associated with warmer waters and lower productivity in the CCE, while negative PDOs are associated with cooler waters and higher productivity. The North Pacific Gyre Oscillation (NPGO) is a low-frequency signal of sea surface height, indicating changes 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 and increases in surface salinities, nutrients, and chlorophyll-*a*. Negative NPGO values are associated with decreases in such values, less subarctic source water, and lower productivity.

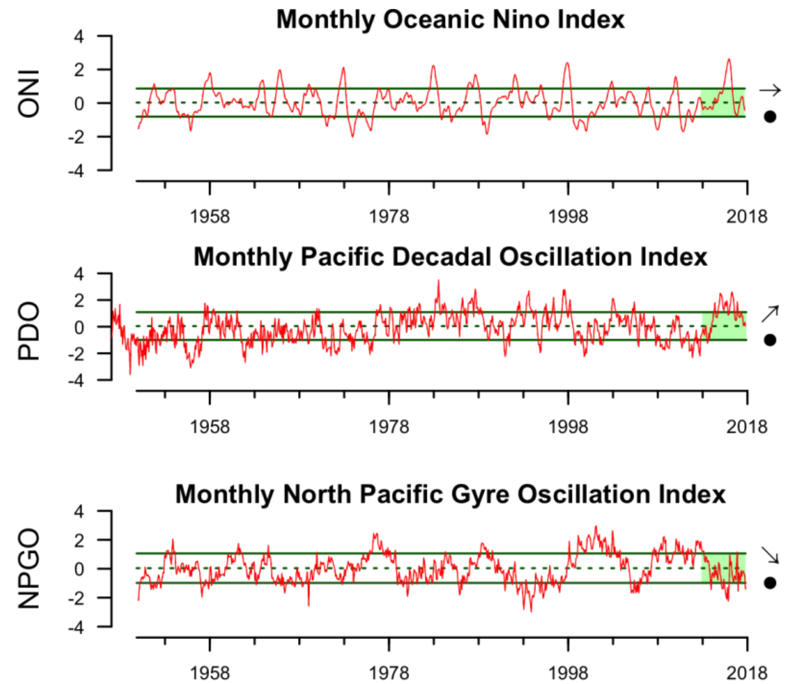

Figure 3.1.1 Monthly values of the Oceanic Nino Index (ONI), Pacific Decadal Oscillation (PDO), and the North Pacific Gyre Oscillation (NPGO) from 1950-2017. Lines, colors, and symbols as in Fig.1.

In 2017, the ONI was neutral for a majority of the year, but shifted to weak La Niña conditions in October and November (Figure 3.1.1, top). La Niña conditions are forecast to continue into the summer of 2018. PDO values were positive but declining over the course of 2017, nearing the long-term mean for the first time since winter of 2013-2014 (Figure 3.1.1, middle). NPGO values ranged between neutral and negative, with the October 2017 value being the lowest of the year (Figure 3.1.1, bottom). The ONI and PDO indices suggest a return to conditions of higher productivity following the major El Niño of 2015-2016 and the large marine heat wave, a.k.a. "the Blob" (Bond et al. 2015) of 2013-2016. However, while the Blob dissipated in fall of 2016, some slightly (<1 s.d.) anomalously warm surface water remained in the Gulf of Alaska and immediately along the West Coast in early 2017 (Figure 3.1.2, upper left). Summer SSTa generally increased, with some anomalies >1 s.d. off California and Baja California, and a negative SSTa near Cape Blanco (Figure 3.1.2, lower left). The influence of the large marine heat wave and 2016 El Niño event are especially evident in the 5-year means (Figure 3.1.2, middle) with positive anomalies in the Gulf of Alaska in the winter and expanding to the majority of the domain by the summer. The 5-year trends for SSTa are negative in the west during the winter and closer to the coast during the summer (Figure 3.1.2, right); these negative trends are a result of cooler temperatures in 2016-17 following the highs of 2014-15.

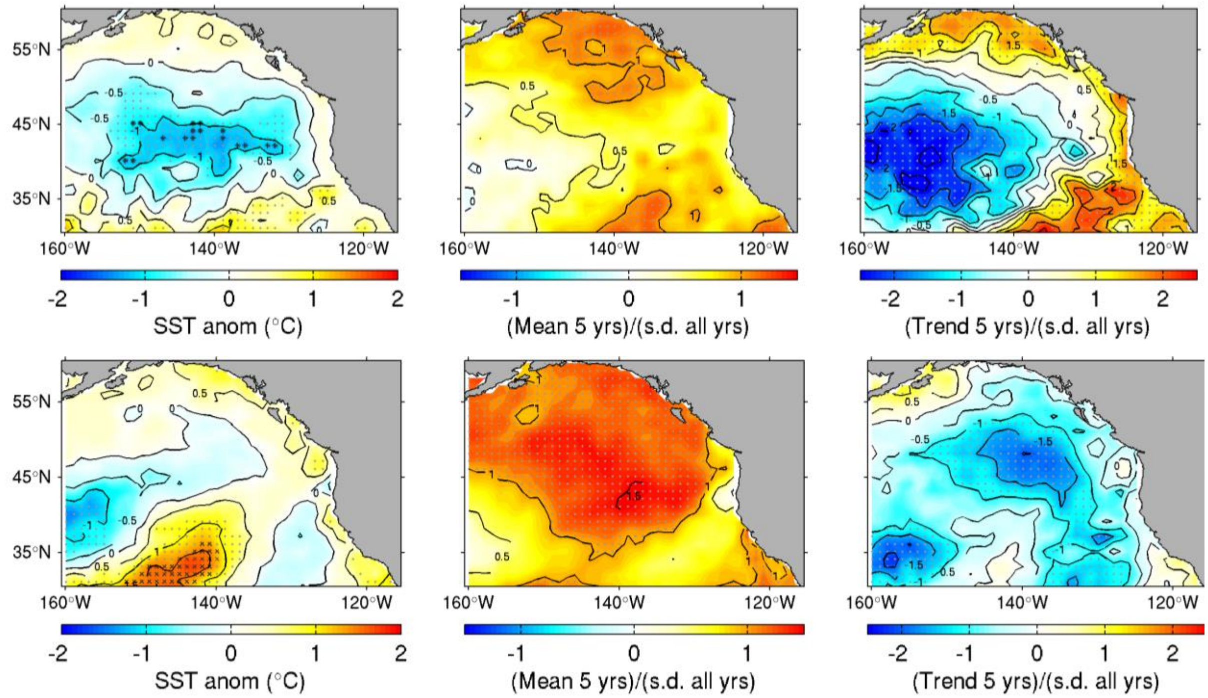

Figure 3.1.2 Sea surface temperature (SST) anomalies (2017; left), 5-year means (2013-17; middle), and 5-year trends (2013-17; right) in winter (Jan-Mar; top) and summer (Jul-Sep; bottom). The time series at each grid point began in 1982. Black circles mark cells where the anomaly was >1 s.d. above the long-term mean. Black x's mark cells where the anomaly was the highest of the time series.

In summary, while the large marine heat wave and 2015-16 El Niño event brought warm waters and associated warm water species (Barceló et al. 2017, Santora et al. 2017), temperatures moderated during 2017 and basin-scale indices are returning to neutral or La Niña conditions. However, the cooler coastal waters in the northern CCE are largely surface-oriented, with the subsurface showing lingering signs of the recent warming events (Figure 3.1). Thorough summaries of these dynamics are in Leising et al. (2015), McClatchie et al. (2016), and Wells et al. (2017). 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 produce the northerly alongshore winds that drive coastal upwelling in the CCE. Upwelling is a physical process of moving cold, nutrient-rich water from deep in the ocean to the surface, which fuels the high seasonal primary production at the base of the CCE food web. The most common metric of upwelling is the Bakun Upwelling Index (UI), derived from the US Navy Fleet Numerical Meteorology and Oceanography Center's sea level pressure product, reported at a spatial scale of 1° latitude x 1° longitude. The timing, strength, and duration of upwelling vary greatly in space and time. The cumulative upwelling index (CUI) is one way to summarize this variability at a given location over the course of a year. CUI integrates the onset of upwelling favorable winds ("spring transition"), a general indication of the strength of upwelling, relaxation events and the end of the upwelling season.

Upwelling displayed significant regional variability in 2017, with the least favorable conditions in the northern CCE (Figure 3.2.1, Appendix E, Figure E.2.1). At 45° N (near Newport, OR), average downwelling from January to April was followed by average upwelling from May to July; CUI through April was much higher than 2016, but lower than 2015, which featured strong winter upwelling (Figure 3.2.1; Appendix E, Figure E.2.1). At 39° N (near Point Arena), there was a late spring transition date in March and very little upwelling until the beginning of June, when a period of strong upwelling began that lasted until October. In the Southern California Bight (~33° N), CUI was average until April, and above average from May onward, although the Bakun UI performs poorly in this region due to the south-facing shore and complex topography.

Over the last 5 years, CUI has been below-average in the northern CCE and average to above-average in the central and southern CCE (Appendix E, Figure E.2.1). Thus, even as basin-scale indices were returning to average conditions in 2017, regional differences in upwelling may help explain why surveys found regional differences in temperature anomalies and productivity. In particular, the northern CCE experienced residual warm water (Figure 3.1), below-average chlorophyll-*a* (Wells et al. 2017), and lagging ecological conditions as described in Section 4.

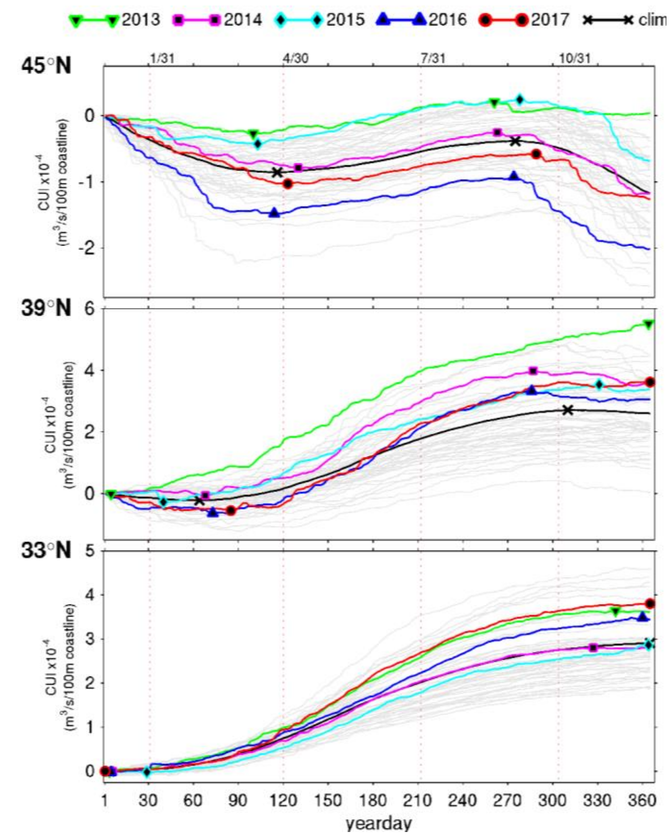

Figure 3.2.1 Cumulative upwelling index (CUI) at three latitudes, 1967-2017. Black = long-term mean; gray = 1967-2012; colored trends = 2013-2017. Symbols on trends mark the start (spring transition) and end of the upwelling season for a given year. Vertical lines mark the end of January, April, July and October.

3.3 Hypoxia and Ocean Acidification

Nearshore dissolved oxygen (DO) is dependent on many processes, including currents, upwelling, air-sea exchange, and community-level production and respiration. Low DO can compress habitat and cause stress or die-offs for sensitive species. Waters with DO levels <1.4 ml/L (2 mg/L) are considered to be hypoxic.

Low DO was a serious issue in the northern CCE in 2017. At station NH05 (5 km off of Newport, OR), water near bottom over the continental shelf was below the hypoxia threshold from late July until early September (Figure 3.3.1, top) before its seasonal rebound in fall. Though perhaps not evident from the time series, this hypoxic event was among the most serious and spatially extensive observed in the northern CCE, causing widespread die-offs of crabs and other benthic invertebrates. The primary cause is thought to be upwelled deep ocean water that was more hypoxic than normal (F. Chan, Oregon State University, pers. comm.). Seasonal trends for these stations and other stations off Southern California (where DO was well above the 1.4 ml/L threshold) are shown in Appendix E.3.

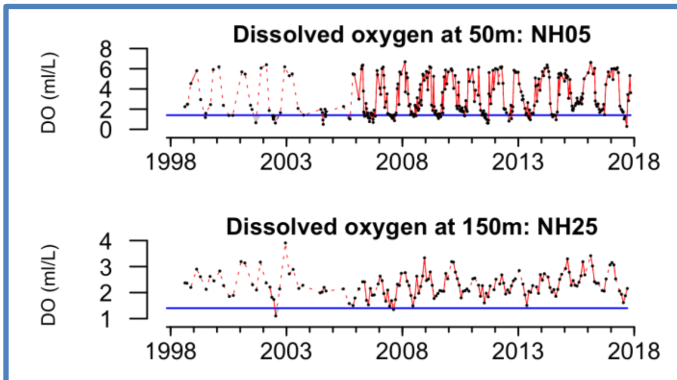

Figure 3.3.1 Dissolved oxygen at 50-m and 150-m depths off Newport, OR through 2017. Stations NH05 and NH25 are 5 and 25 km from shore, respectively. Blue line = hypoxia threshold of 1.4 ml/L. Dotted red line indicates missing data. Lines, colors, and symbols as in Fig. 1.

Ocean acidification (OA), caused by increased levels of atmospheric CO_2, reduces pH and carbonate levels in seawater. A key indicator of OA is aragonite saturation state, a measure of availability of aragonite (a form of calcium carbonate). Aragonite saturation <1.0 indicates corrosive conditions that may be stressful to shell-forming organisms. Upwelling, which drives primary production in the CCE, also transports hypoxic, acidified waters from offshore onto the continental shelf, where increased community-level metabolic activity can further exacerbate OA (Chan et al. 2008, Feely et al. 2008).

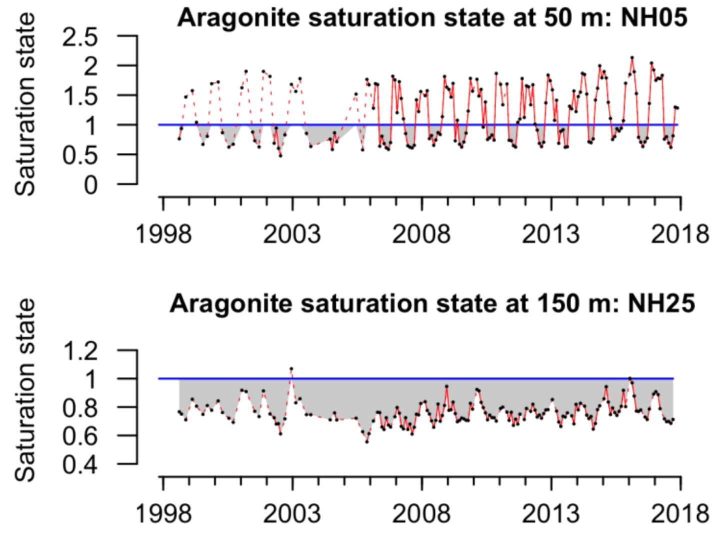

Figure 3.3.2 Monthly aragonite saturation values off Newport, Oregon, 1998-2017. Blue line = threshold value of 1.0 for aragonite saturation state. Lines, colors, and symbols as in Fig. 1.

Aragonite saturation levels off Newport in 2017 were fairly typical, and lower than in the anomalous years of 2014-2015 (Figure 3.3.2). At the nearshore station (NH05), aragonite levels at 50 m depth were saturated (>1.0) in winter and spring, then fell below 1.0 in the summer and fall, as is typical, although corrosive water was shallower in summer-fall of 2017 than in recent years, possibly related to upwelling (Appendix E.3, Figure E.3.5). At station NH25 at 150 m depths, aragonite saturation state followed the same seasonal cycle but across a narrower range; conditions at this site and depth were almost always corrosive (<1.0). Seasonal aragonite trends are shown in Appendix E.3

3.4 Hydrologic Indicators

Freshwater conditions are critical for salmon populations and estuaries that support many marine species (e.g., Appendix D). The freshwater indicators presented here focus on salmon habitat conditions as related to snowpack, streamflow and temperature. Indicators are summarized by freshwater ecoregion (see Figure 2.1b) or, where possible, by salmon evolutionarily significant units (ESUs, sensu Waples 1995). Snow-water equivalent (SWE) is the water content in snowpack, which provides freshwater in the spring, summer and fall months. Maximum streamflow in winter and spring is important for habitat formation and removal of parasites, but extreme discharge can scour salmon nests (redds). Minimum streamflow in summer and fall can restrict habitat for in-stream juveniles and migrating adults. High summer water temperatures can impair physiology and cause mortality to both juveniles and adults. All indicators are influenced by climate and weather patterns and will be affected as climate change intensifies.

As in 2016, SWE in 2017 was consistent with long-term average levels in all ecoregions, after years of steady declines and the historic low of 2015 (Figure 3.4.1). As of January 1st, SWE in 2018 is on pace to be lower than 2017, particularly in the southern Cascade Range and the Sierra Nevadas (Appendix F). However, SWE values do not typically peak until around April 1 and may be greatly influenced by precipitation until then. Thus the official measure of SWE for the year will not be until April 1, 2018.

The relatively average SWE in 2017 resulted in maximum and minimum flows that were both well within the typical historical ranges at ecoregional scales (Appendix F). We summarized streamflow with quad plots that compile recent flow anomalies at the finer spatial scale of individual Chinook

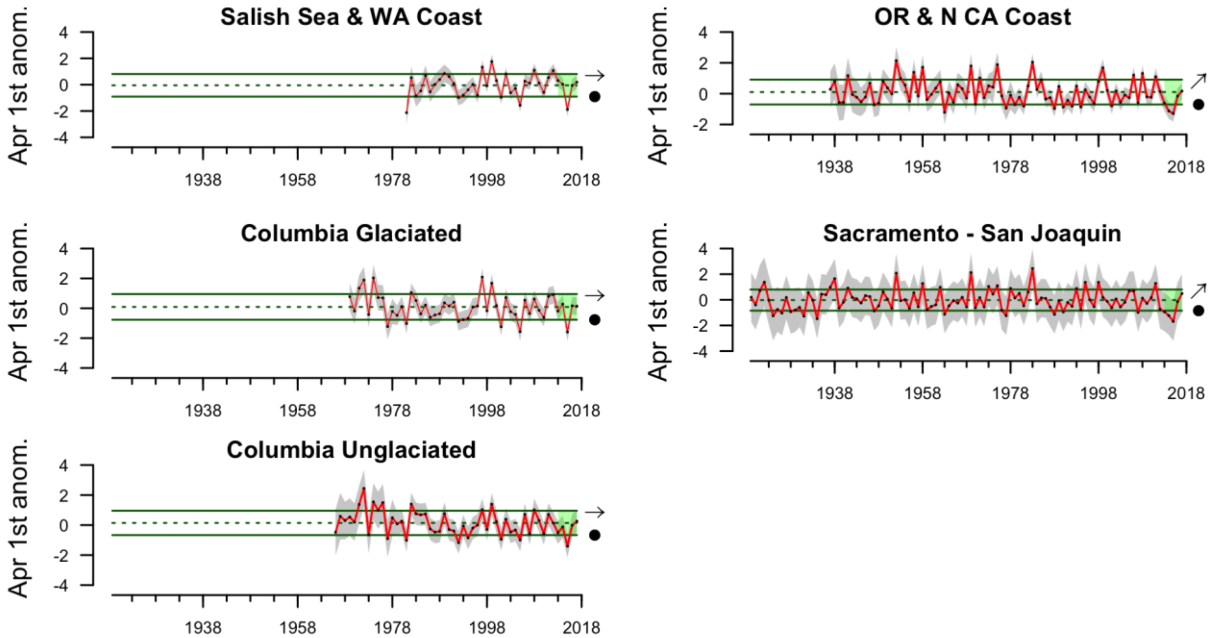

Figure 3.4.1 Anomalies of April 1st snow-water equivalent (SWE) in five freshwater ecoregions of the CCE through 2017. Lines, colors, and symbnols as in Fig.1. Ecoregions are mapped in Fig. 2.1.

salmon ESUs. Here, high and increasing maximum flows are regarded as undesirable (i.e., red quadrant of the max flow plot, Figure 3.4.2) due to redd scouring, while low and decreasing minimum flows are also undesirable (red quadrant of the min flow plot) because of the potential for stress related to temperature, oxygen, or space. The error bars describe 95% credible intervals of river flow, allowing us to determine which ESUs have short-term trends or status strongly greater than zero or the long-term mean, respectively. Maximum flow events were generally within range of long-term means and lacked strong trends, although the short-term trend for Klamath-Trinity was strongly positive (Figure 3.4.2, left). Minimum flow anomalies had worsening trends for just one ESU, Snake River fall run, which was strongly lower in both recent trend and recent average (Figure 3.4.2, right).

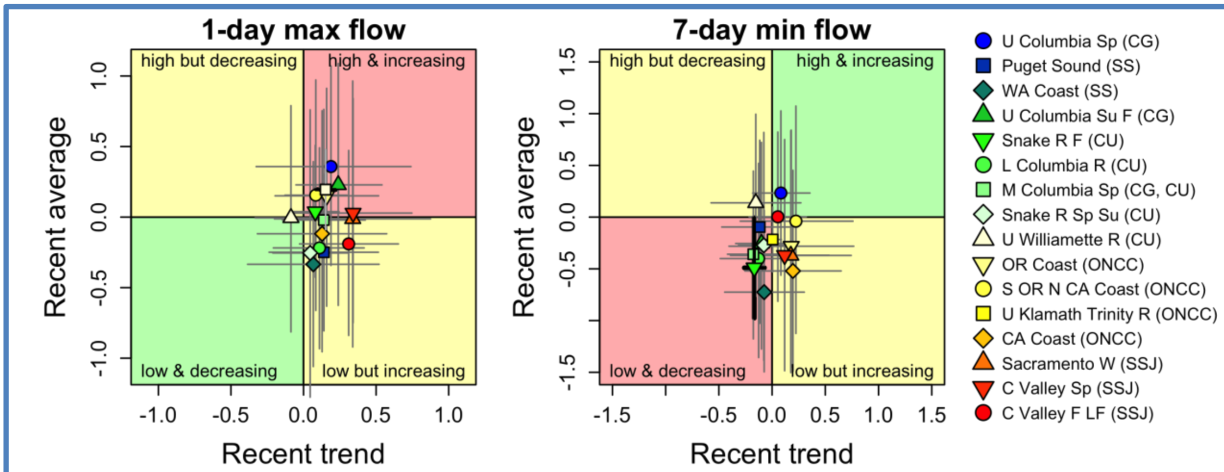

Figure 3.4.2 Recent (5-year) trend and average of maximum and minimum streamflow anomalies in 16 Chinook salmon ESUs through 2017. Symbols are color-coded from north (blue) to south (red). Error bars represent the 2.5% and 97.5% upper and lower credible intervals. Gray error bars overlap zero. Heavy black error bars differ from zero (i.e., significantly different from long-term). Note that for 1-day max flow (left), the Klamath-Trinity short-term trend was significantly positive, but the error bars are difficult to see because they are small. Lines, colors, and symbols as in Fig. 1.

This year we added a new freshwater indicator, maximum August stream temperature, which is summarized in Appendix F. Most ecoregions in 2017 experienced maximum stream temperatures similar to historical averages, although the recent average for Salish Sea and Washington Coast streams was above the long-term mean. Long-term increases (0.01-0.04 °C/yr) in maximum August temperature starting in the 1980s and 1990s are evident in at least three ecoregions.

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 and community structure. Many CCE species and processes respond quickly to changes in ocean and climate drivers, while other responses may not manifest for many years. These dynamics are challenging to predict. Between 2014 and 2016, many ecological metrics indicated conditions of poor productivity at lower trophic levels and poor foraging conditions for many predators. In 2017 we continued to observe unexpected community structure and remnants of the recent warm anomalies in pelagic waters throughout the CCE. However, some indicators described below suggest that ecological conditions are trending toward average conditions in parts of the CCE. It remains to be seen how some species and life history strategies were ultimately affected by the period of low productivity, or whether 2018 will represent a further shift toward average or above-average productivity.

4.1 Northern Copepod Biomass Anomaly

Copepod biomass anomalies represent inter-annual variation for 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 smaller and have lower fat content and nutritional quality. In summer, northern copepods usually dominate the coastal zooplankton community observed along the Newport Line (Figure 2.1a,c), while Southern copepods dominate during winter. El Niño events and positive PDO regimes can promote 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 >0.2 are associated with better survival of coho salmon (Peterson et al. 2014).

From the start of the anomalous warm period in fall 2014 until spring 2017, copepod anomaly trends strongly favored southern copepods. However, in late June 2017 the northern copepod anomaly increased from strongly negative to relative neutral values, while the southern copepod anomaly declined from strongly positive to neutral values (Figure 4.1.1). These changes may signal a transition in 2017 from relatively unproductive to average conditions in this region of the CCE. However, the continued presence of warm water at depth (Figure 3.1) and the lack of a dominant northern copepod signal suggest that strong mixing may be required to establish an average or possibly more productive copepod community.

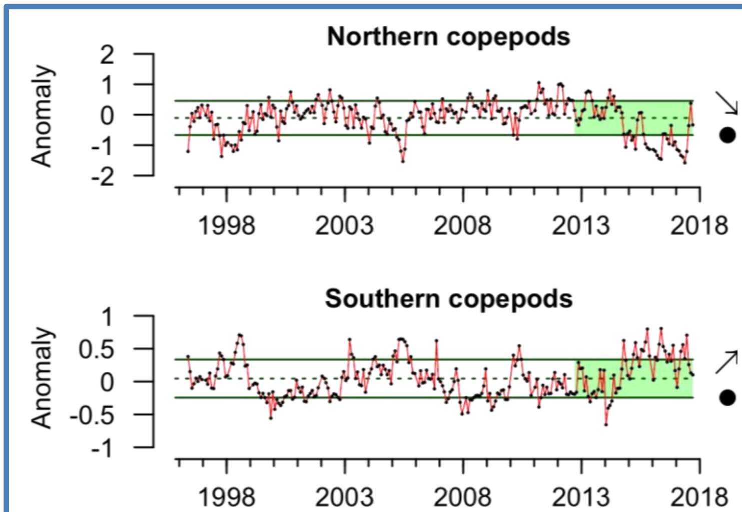

Figure 4.1.1 Monthly northern and southern copepod biomass anomalies from 1996-2017. Lines, colors, and symbnols as in Fig.1.

4.2 Regional Forage Availability

This section describes trends in forage availability, based on research cruises throughout the CCE through spring/summer 2017. These species represent a substantial portion of the available forage in the regions sampled by the cruises (see Figure 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 content, 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 forage indicators as quad plots here; time series plots for each species and region are available in Appendix G.

Northern CCE: The northern CCE survey off Washington and Oregon (see Figure 2.1c) targets juvenile salmon in surface waters, but also catches pelagic fishes, squid, and gelatinous zooplankton. Recent average catches-per-unit-effort (CPUEs) of age 1+ sardine, age 1+ anchovy, market squid and whitebait smelt were within 1 s.d. of long-term means and showed no clear short-term trends (Figure 4.2.1). Sardine and anchovy CPUE were both close to zero (Appendix G, Figure G.1.1). Jack mackerel CPUE has an increasing trend, which continued in 2017, while herring catches have decreased. Also showing a recent decline is a large jellyfish, the sea nettle *Chrysaora*. Finally, extreme numbers of pyrosomes were observed in this region (data not shown). A warm-water gelatinous salp, pyrosomes were common in the 2014-2016 warm events, but catches went up by 10-to 100-fold in 2017(Brodeur et al. 2018).

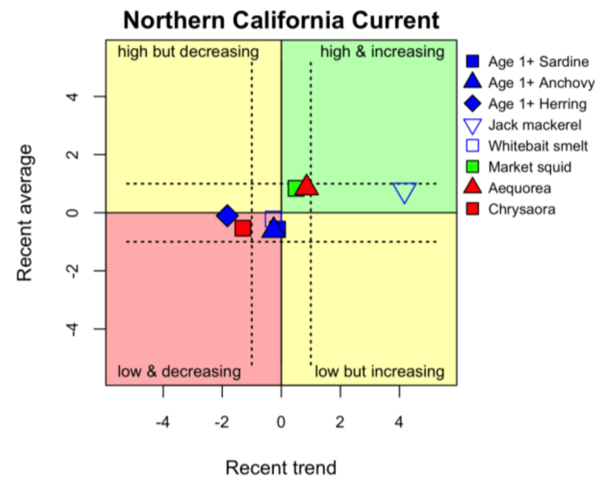

Figure 4.2.1 Recent (5-year) trend and average of key forage species in the northern CCE through 2017. Lines, colors, and symbols as in Fig. 1.

Central CCE: Data presented here are from the "Core area" of a survey (see Figure 2.1c) that targets young-of-the-year (YOY) rockfishes, but also samples forage fish, market squid and zooplankton. Adult sardine and anchovy CPUEs were within the long-term range, but remained close to zero in 2017, while YOY rockfish catch was above average for the fifth straight year (Figure 4.2.2; see also Appendix G, Figure G.2.1). Krill and market squid rebounded in 2017 from lower catches in recent years (Appendix G, Figure G.2.1). YOY hake catches have varied widely in recent years, while YOY sanddabs have declined. *Chrysaora* jellyfish have declined

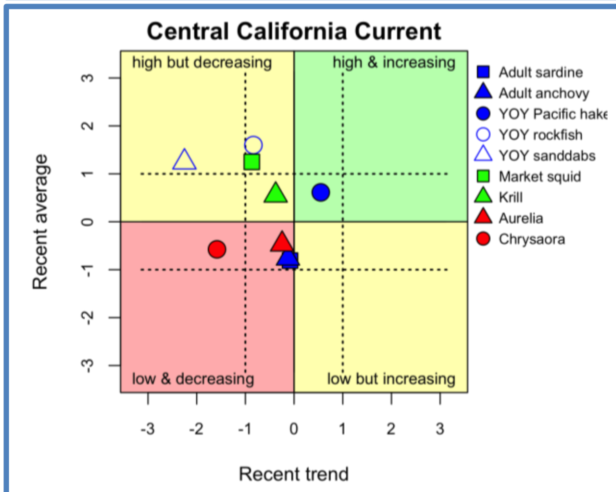

Figure 4.2.2 Recent (5-year) trend and average of key forage species in the central CCE through 2017. Lines, colors, and symbols as in Fig. 1.

recently, though that may be due in part to avoidance of sites where *Chrysaora* has fouled sampling gear in the past. Pyrosomes were relatively abundant in the Central CCE for the fourth year in a row (data not shown).

Southern CCE: Forage indicators for the Southern CCE come from CalCOFI larval fish surveys (see Figure 2.1c). Larval biomass is assumed to correlate with regional abundance of mature forage fish. Recent CPUE for species analyzed through 2017 were within ±1 s.d. of their long-term means, but several trends are evident (Figure 4.2.3). Larval anchovy and shortbelly rockfish are increasing. Larval sardine CPUE was up slightly in 2017 (Appendix G, Figure G.3.1) but remained nearly 1 s.d. below the long-term average. Larval market squid catches have declined recently and have been very low for the past 3 years. Larval jack mackerel and sanddab catches were close to average in 2017, though both species have declined from strong peaks in recent years.

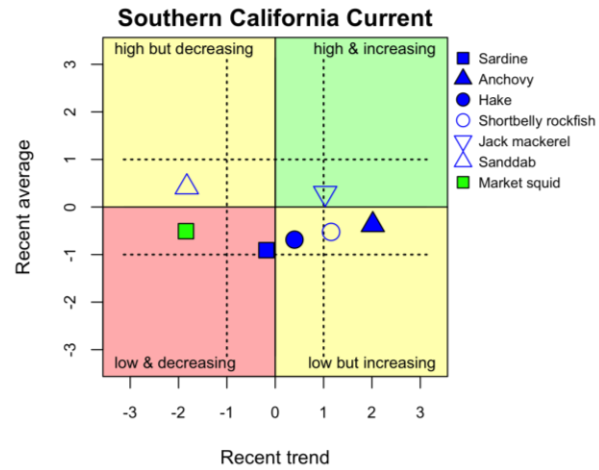

Figure 4.2.3 Recent (5-year) trend and average of the larvae of key forage species in the southern CCE through 2017. Lines, colors, and symbols as in Fig. 1.

4.3 Salmon

For indicators of the abundance of Chinook salmon, we compare the trends in natural spawning escapement from different populations to compare status and coherency in production dynamics across the greater portion of their range. We summarize escapement trends in quad plots; time series are available in Appendix H. We have also added a time series of juvenile salmon catches from a NOAA survey conducted in the Northern CCE off Oregon and Washington (see Figure 2.1c).

Most Chinook salmon escapement data are updated through 2016. Generally, escapements of California Chinook salmon over the most recent decade of data were within 1 s.d. of long-term averages (Figure 4.3.1), although recent escapements were generally near the low end of the normal range (Appendix H, Figure H.1.1). California Chinook salmon stocks have neutral trends over the last decade, and variation in escapement among years is generally relatively high (Appendix H, Figure H.1.1). For Oregon, Washington and Idaho Chinook salmon stocks, most recent escapements were close to average. The exception is Snake River Fall Chinook after a series of large escapements since 2009 (Appendix H Figure H.2.1). Ten-year trends for northern stocks were mostly neutral, but Lower Columbia and Snake River Fall both had significantly positive trends over their most recent decade of escapement data.

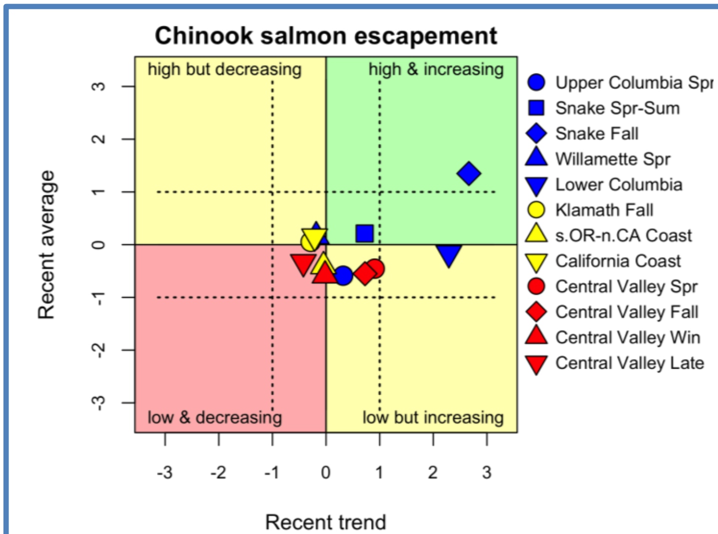

Figure 4.3.1 Recent (10-year) trend and average of Chinook salmon escapement anomalies, with most systems updated through 2016. Lines, colors, and symbols as in Fig. 1.

Catches of juvenile Chinook and coho salmon in June off the coasts of Washington and Oregon can serve as indicators of survival during their early marine phase, and are strongly correlated to later years' returns of adults to Bonneville Dam. Catches of subyearling Chinook, yearling Chinook and yearling coho in 2017 were among the lowest observed since the late 1990s (Figure 4.3.2), suggesting marine conditions in this region continued to be poor for salmon. Yearling Chinook and yearling coho catches have declined over the past 5 years, while subyearling Chinook catches have been more variable.

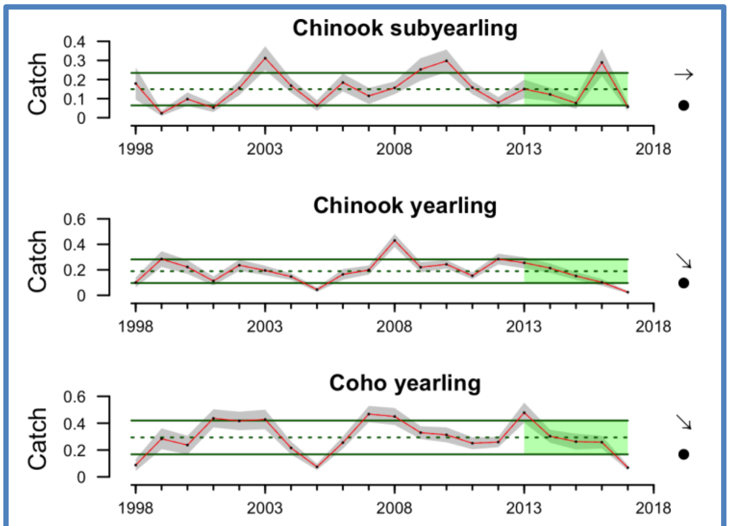

Figure 4.3.2 At-sea juvenile Chinook and coho salmon catches (Log_{10}(# km^{-1} + 1)) in June, 1998-2017 off Washington and Oregon. Lines, colors, and symbols as in Fig. 1.

Many indicators suggest below-average returns will occur for Fall Chinook, Spring Chinook and coho stocks returning to the Columbia Basin in 2018, due in part to lagged effects of the recent warm anomalies in the CCE. NOAA scientists and colleagues are evaluating long-term associations between oceanographic conditions, food web structure, and salmon productivity (e.g., Burke et al. 2013, Peterson et al. 2014). Their assessment is that indicators of conditions for smolts that went to sea between 2014 and 2017 are generally consistent with below-average returns of Chinook and coho salmon to the Columbia Basin in 2018, as depicted in the "stoplight chart" in Table 4.3.1; this includes many indicators in this report, such as PDO, ONI, Copepod Biomass Anomalies and Juvenile Salmon Catch. Recall, too, that the extremely poor freshwater conditions of 2015 (Section 3.4) affected salmon populations during this same smolt year period.

Table 4.3.1 "Stoplight" table of basin-scale and local/regional conditions for smolt years 2014-2017 and likely adult returns in 2018 for coho and Chinook salmon that inhabit coastal Oregon and Washington waters during their marine phase. Green/circles = "good," i.e., rank in the top third of all years examined. Yellow/squares = "intermediate," i.e., rank in the middle third of all years examined. Red/diamonds = "poor," i.e., rank in the bottom third of all years examined. Courtesy of Dr. Brian Burke (NOAA).

	Smolt year				Adult return outlook	
Scale of indicators	2014	2015	2016	2017	Coho, 2018	Chinook, 2018
Basin-scale						
PDO (May-Sept)	◆ (red)	◆ (red)	◆ (red)	■ (yellow)	■ (yellow)	◆ (red)
ONI (Jan-Jun)	■ (yellow)	◆ (red)	◆ (red)	■ (yellow)	■ (yellow)	◆ (red)
Local and regional						
SST anomalies	■ (yellow)	◆ (red)	◆ (red)	● (green)	● (green)	◆ (red)
Deep water temp	◆ (red)	◆ (red)	■ (yellow)	◆ (red)	◆ (red)	■ (yellow)
Deep water salinity	◆ (red)	◆ (red)	■ (yellow)	◆ (red)	■ (yellow)	◆ (red)
Copepod biodiversity	■ (yellow)	◆ (red)	◆ (red)	■ (yellow)	■ (yellow)	◆ (red)
Northern copepod anomaly	● (green)	◆ (red)	◆ (red)	◆ (red)	◆ (red)	◆ (red)
Biological spring transition	■ (yellow)	◆ (red)	◆ (red)	◆ (red)	◆ (red)	◆ (red)
Winter ichthyoplankton biomass	◆ (red)	● (green)	● (green)	● (green)	● (green)	● (green)
Winter ichthyoplankton community	■ (yellow)	■ (red)	◆ (red)	◆ (red)	◆ (red)	◆ (red)
Juvenile Chinook catch (Jun)	■ (yellow)	■ (yellow)	◆ (red)	◆ (red)	◆ (red)	◆ (red)
Juvenile coho catch (Jun)	■ (yellow)	■ (yellow)	■ (yellow)	◆ (red)	◆ (red)	■ (yellow)

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. This year's report includes updated information from several new assessments in 2017. All groundfishes assessed since 2007 are above the biomass limit reference points (LRPs); thus, no stocks are presently considered "overfished" (Figure 4.4.1, x-axis). While no longer under their LRPs, yelloweye rockfish and cowcod are still rebuilding towards their target biomasses. Three species were declared rebuilt in 2017: bocaccio, darkblotched rockfish and Pacific Ocean perch. Also of note: biomass of arrowtooth flounder (ATF, assessed in 2017) increased sharply from the prior assessment (in 2007). ATF are a predatory species with low market value, and are thought to have predatory impacts on target species in some ecosystems (e.g., Holsman et al. 2016).

Overfishing occurs when catches exceed overfishing limits (OFLs), but not all stocks are managed by OFLs. For summary purposes, our best alternative is to compare fishing rates to proxy rates that are based on a stock's spawner potential ratio (SPR; Figure 4.4.1, y-axis). Three stocks (black rockfish in California and Washington; China rockfish in California) were being fished above the fishing rate proxy in their most recent assessments (all in 2015).

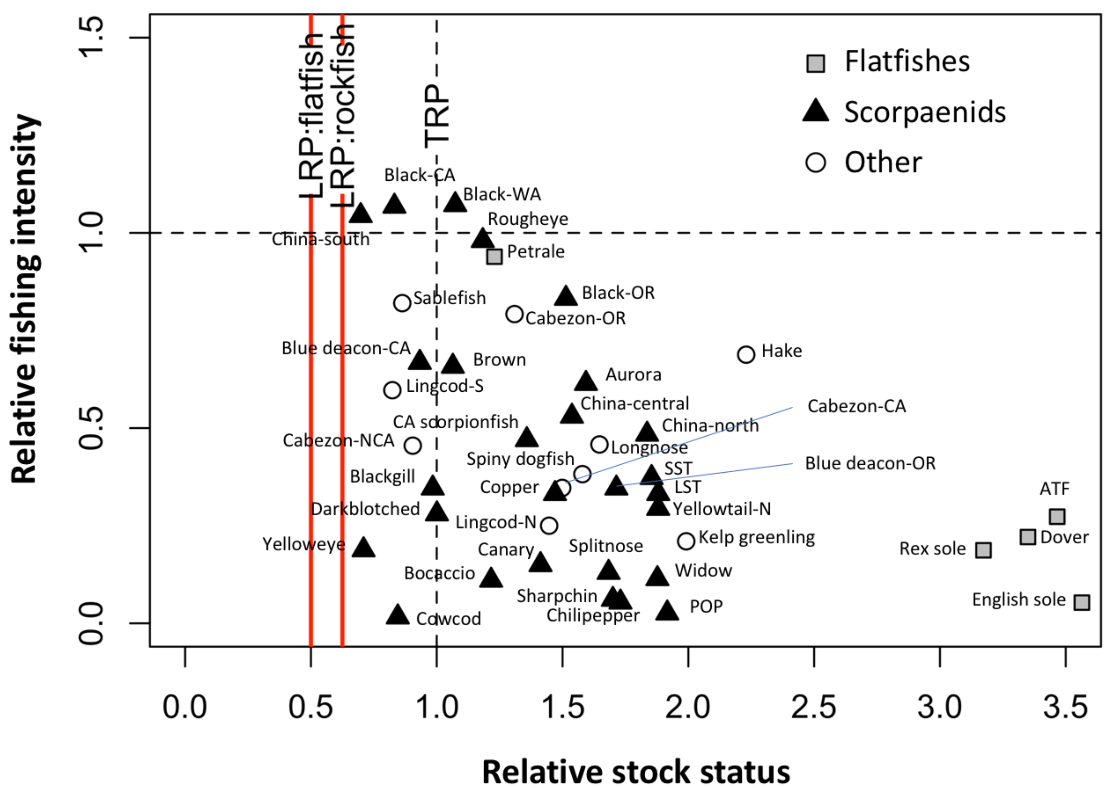

Figure 4.4.1 Stock status of CCE groundfish. X-axis: Relative stock status is the ratio of spawning output (in millions of eggs) of the last to the first years in the assessment. Y-axis: Relative fishing intensity uses the Spawner Potential Ratio (SPR), defined as (1-SPR)/1-(SPR_{MSY} proxy), where the SPR_{MSY} proxy is stock specific. Horizontal line = fishing intensity reference. Vertical lines = biomass target reference point (TRP; dashed line) and limit reference points (LRPs; solid lines; left of line indicates overfished status). Symbols indicate taxonomic group. All points represent values from the most recent Council-adopted stock assessment.

As noted in Section 4.2, YOY rockfish were highly abundant in the Central CCE in 2013-2017, and results from other NOAA surveys also revealed large numbers of pelagic and post-settled juvenile rockfish along the Washington coast in 2016. Given the warm and unproductive conditions of 2014-2016, these findings run counter to what we expected from conceptual models linking climate and productivity conditions to groundfish populations (see Appendix D, Figure D.2). These rockfish cohorts likely were not yet large enough to have been caught in bottom trawls; thus we will have to wait to determine how 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. For space considerations, and because the time series are as yet short and difficult to interpret, these indicators are located in Appendix I.

4.5 Highly Migratory Species

This marks the first year in which we include indicators of highly migratory species (HMS), most of which are managed by the Council. Here we present quad plots of recent averages and trends of biomass and recruitment from the most recent assessments of key HMS target stocks (Figure 4.5.1); time series for these indicators are found in Appendix J, with most recent assessments ranging from 2014-2016. For two stocks (swordfish and skipjack), average biomass over the most recent 5 years was substantially above the long-term average. All other assessed HMS stocks were either within ±1 s.d. of the average or were below it (e.g., blue marlin, bigeye tuna), and several stocks appeared to be near historic lows (bigeye tuna, bluefin tuna, blue marlin). Biomass trends were statistically neutral for all species, although skipjack may be increasing. Recruitment indicators varied widely: recruitment appears to be increasing for albacore, skipjack and yellowfin tuna, decreasing for bluefin tuna, and neutral for other stocks. The poor numbers for bluefin tuna may be masked by recent high bluefin catches in California, though those catches may be a result of northward and shoreward shifts by bluefin during the anomalous warm years in pursuit of prey (e.g., pelagic red crab) typically found in Baja or offshore. In future CCIEA reports, we hope to add indicators that are related to dynamics and drivers of HMS ecology and distribution.

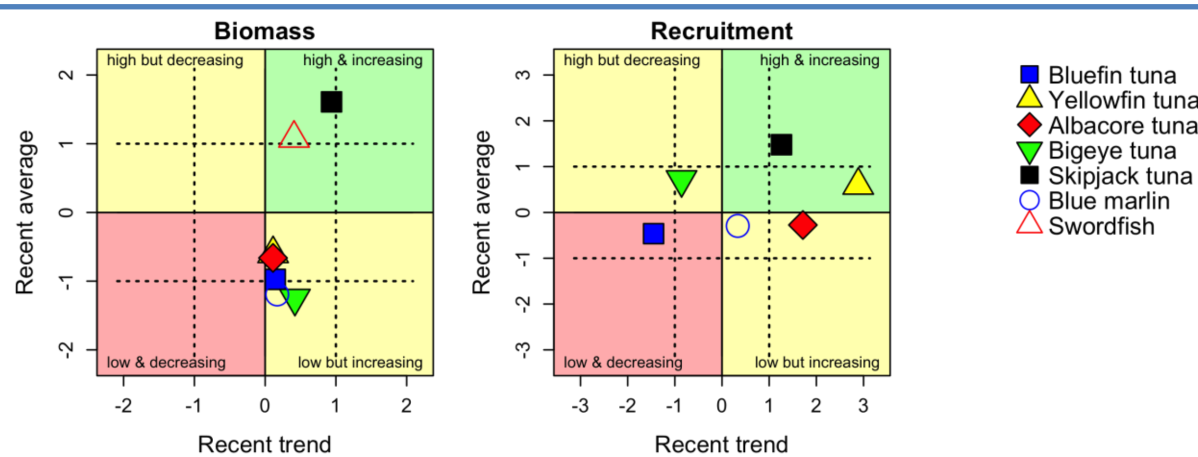

Figure 4.5.1 Recent (5-year) trend and average of biomass and recruitment for highly migratory species in the CCE from the 2014-2016 stock assessments. Data are total biomass for swordfish, relative biomass for skipjack, spawning biomass for bluefin, and female spawning biomass for all other species. Lines, colors, and symbols as in Fig. 1.

4.6 Marine Mammals

Sea lion production: California sea lions are sensitive indicators of prey availability in the central and southern CCE (Melin et al. 2012): sea lion pup count at San Miguel Island relates to prey availability and nutritional status for adult females from October to June, while pup growth from birth to age 7 months is related to prey availability to adult females during lactation from June to February.

In 2016, pup births at San Miguel Island were below the long-term mean, showing little change from 2015; the trend over the most recent 5 cohorts remained negative (Figure 4.6.1, top). The low numbers of births in 2016 reflect a reduction in the number of reproductive females in the population, due to poor feeding conditions since 2009 (Melin et al. 2012, DeLong et al. 2017). However, growth rates for the 2016 cohort were similar to the long-term average (Figure 4.6.1, bottom), a significant improvement relative to extremely low growth rates of cohorts in 2012, 2014 and 2015. Those same cohorts had experienced unusually high stranding rates, associated with poor foraging conditions for nursing females in the central and southern CCE during the period of pup nutritional dependence (Wells et al. 2013, Leising et al. 2014, Leising et al. 2015, McClatchie et al. 2016). The improved growth of pups in the 2016 cohort indicates that nursing females experienced better foraging conditions during 2016-2017, coinciding with higher frequencies of anchovy and hake in their diets, compared to a diet rich in juvenile rockfish and market squid during the periods of poor survival. If foraging conditions continue to improve, pup survival should also improve, but the effects of poor survival in five of the last seven cohorts will continue to suppress production for several more years.

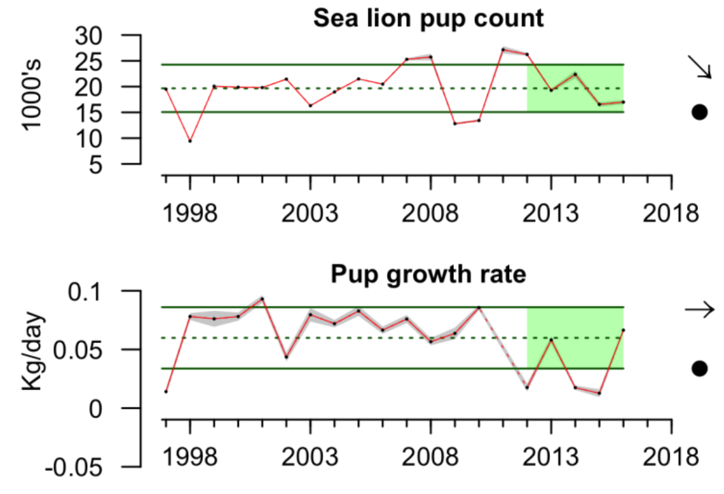

Figure 4.6.1 California sea lion pup counts, and estimated mean daily growth rate of female pups between 4-7 months on San Miguel Island for the 1997-2016 cohorts. Lines, colors, and symbnols as in Fig.1.

Whale entanglement: In this year's report, we have added a time series of reported whale entanglements in fixed gears, as a possible indicator of protected species bycatch. Coincident with the anomalous warming of the CCE in 2014-2016, observations of whales entangled in fishing gear occurred at levels far greater than in the preceding decade (Figure 4.6.2). Observed entanglements were most numerous in 2015 and 2016, with the majority involving humpbacks. Most observations occurred in California waters. Based on preliminary data, observed entanglements appeared to decline in 2017, but were still greater than in years from 2000 to 2013. The majority of entanglements occur in gear that cannot be identified visually. Of the portion that can be identified, most appears to be Dungeness crab gear. However, in both 2016 and 2017, sablefish fixed gear was identified in at least one entanglement, and gillnets were observed as entangling gear in 2015, 2016 and 2017. Many interacting factors could be causing the increased numbers of observed

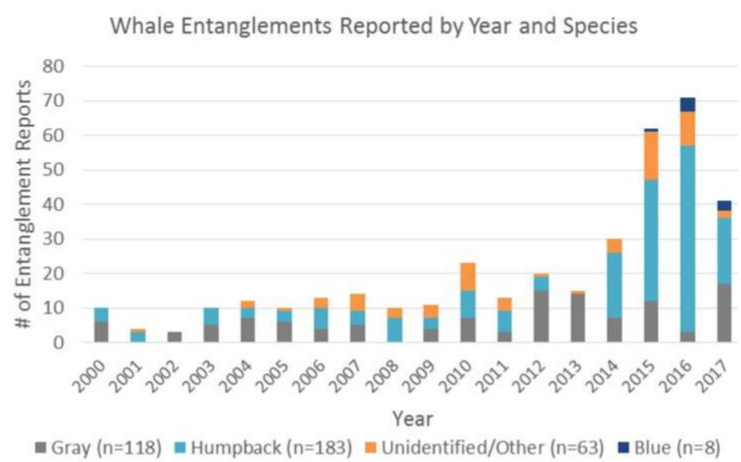

Figure 4.6.2 Numbers of whales reported as entangled in fishing gear along the West Coast from 2000-2017.

entanglements, including shifts in oceanographic conditions and prey fields that brought the whales closer to shore, as well as changes in distribution and timing of fishing effort; the NOAA West Coast Region will continue to follow this issue as conditions in the CCE change, and the CCIEA team is involved in analyses with researchers from NOAA, other agencies, and academic partners.

4.7 Seabirds

Seabird indicators are assumed to reflect regional production and availability of forage, with the three species included here representing distinct feeding strategies to take advantage of the forage portfolio. Sooty shearwaters migrate to the CCE from the southern hemisphere 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. For seabird abundance indicators, we use a quad plot to summarize regional time series for at-sea density of three key species during summer; time series are available in Appendix K.

Seabird density patterns varied within and across species. Sooty shearwater densities have undergone significant short-term declines in both the northern and central CCE, and 2017 densities in these regions were among the lowest of the time series (Figure 4.7.1; Appendix K, Figure K.1.1). In sharp contrast, sooty shearwater density in the southern CCE reached its highest recorded density in 2017, continuing a recent, significant short-term increase. Common murre density was slightly below average in the northern CCE, but 2017 common murre densities in the central and southern CCE were the highest ever recorded, resulting in significant short-term increases. Cassin's auklet density in the northern CCE was above the long-term mean in 2017, but down from a peak in 2015; however, Cassin's auklet densities were declining in the central CCE and remained just below the long-term mean in the southern CCE.

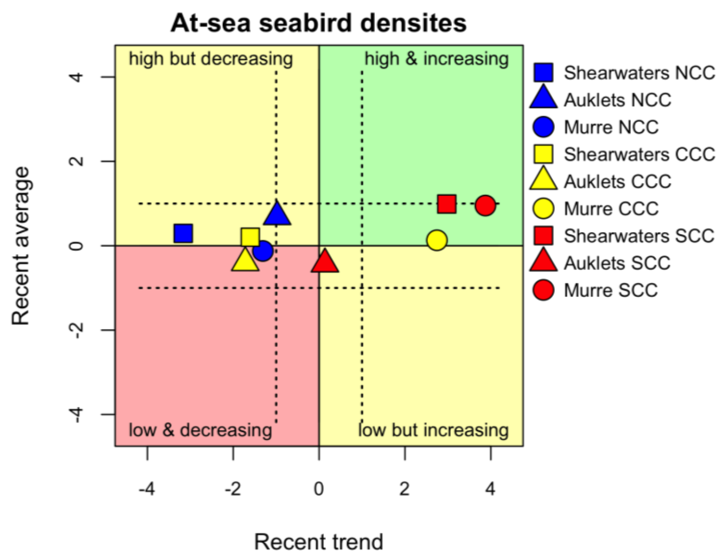

Figure 4.7.1 Recent (5-year) trend and average of seabird at-sea densities during the summer in three regions of the CCE through 2017. Lines, colors, and symbols as in Fig. 1.

The prior three CCIEA reports from the anomalously warm and unproductive years noted major seabird mortality events in each year. These "wrecks"—exceptional numbers of dead birds washing up on widespread beaches—impacted Cassin's auklets in 2014, common murres in 2015 and rhinoceros auklets in 2016. In 2017, there were no reports of widespread seabird wrecks related to low productivity; for example, the University of Washington-led Coastal Observation And Seabird Survey Team (COASST) observed average to below-average numbers of beached birds for four index species in 2017 (see Appendix K.3). (Although, we are aware of unpublished reports of localized mortality events in Southern California, possibly related to domoic acid concentrations.)

5 Human Activities

5.1 Coastwide Landings by Major Fisheries

Fishery landings data are current through 2016. Total landings decreased over the last five years, driven mainly by steep declines in landings of CPS finfish, market squid and crab, along with a large decrease in shrimp landings in 2016 (Figure 5.1.1). Landings of groundfish (excluding hake) were at historically low levels from 2012-2016, while landings of hake were variable. Shrimp landings declined considerably in 2016, but remained at historically high levels from 2012-2016. Commercial landings of salmon were at the lower end of historical levels over the last five years. Landings of HMS and other species have been consistently within ±1 s.d. of historic averages over the last 20+ years. Methods for sampling and calculating mortality in recreational fisheries changed recently, leading to shorter comparable time series. Recreational landings (excluding salmon and Pacific halibut) were increasing through 2015, but a 70-80% decrease in yellowfin tuna and yellowtail landings in 2016 brought total recreational landings to within historical averages for the last five years (Figure 5.1.1). Landings for recreationally caught Chinook and coho salmon showed no trends and were within historical averages, but any further declines may result in historically low landings in subsequent years. State-by-state commercial and recreational landings are summarized in Appendix L.

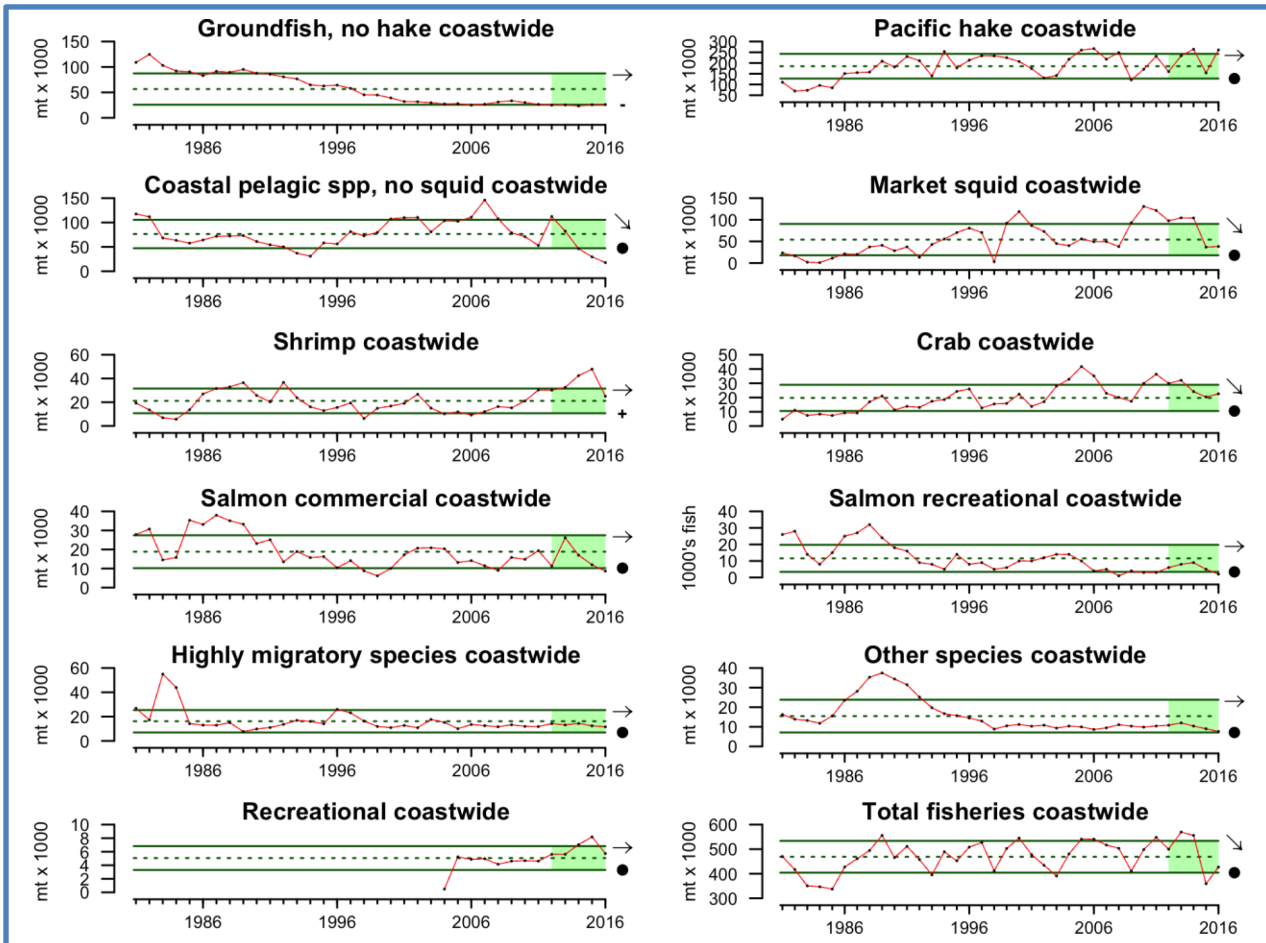

Figure 5.1.1 Annual landings of West Coast commercial (data from PacFIN) and recreational (data from RecFin) fisheries, including total landings across all fisheries from1981-2016. Lines, colors, and symbols as in Fig. 1.

Total revenue across U.S. West Coast commercial fisheries decreased from 2012–2016 (see Appendix L). This decline has been driven primarily by decreases in Pacific hake, CPS finfish, and market squid revenue over the last five years, particularly in 2015. The only fishery that increased in revenue over the last five years was shrimp, although revenue fell dramatically in 2016.

5.2 BOTTOM TRAWL CONTACT WITH SEAFLOOR

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

We estimated distance trawled on a 2x2-km grid from 2002-2015. For each grid cell, we mapped the 2015 departure (anomaly) from the long-term mean, the most recent 5-year average and the most recent 5-year trend. For example in 2015, distance trawled was above average for areas off of southern Washington and north of Cape Mendocino, but below average north of Cape Blanco (Figure 5.2.1, left). Red areas in the trend map (Figure 5.2.1, right) indicate large swaths of seafloor off Washington, southern Oregon and northern California where trawl activity increased from 2011-2015, while blue areas off Washington and central Oregon indicate areas where trawl activity declined. Because it highlights status and trends of trawling activity in specific areas, this spatial indicator may be more informative than the time series of the total coastwide distance trawled, which indicates that gear contact with seafloor was at historically low levels and had no trend from 2011-2015 (Appendix M). Subsequent efforts will incorporate other non-fishing human activities that could affect seafloor habitats.

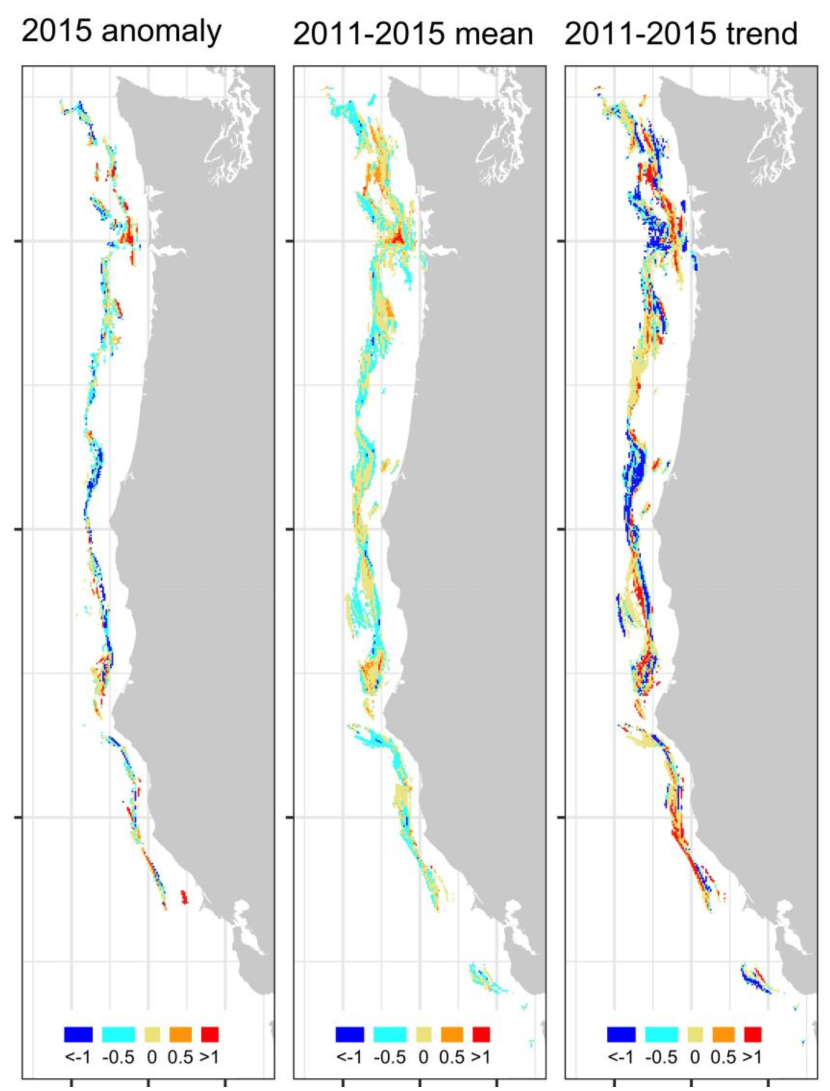

Figure 5.2.1 Values for each grid cell are relative to distances trawled using bottom trawl fishing gear in that grid cell from 2002 – 2015. Left: Annual bottom contact anomalies. Middle: Normalized mean values for the most recent five-year period. Right: Normalized trend values for the most recent five-year period. Grid cell values > 1 (red) or < -1 (blue) represent a cell in which the anomaly, 5-year mean or 5-year trend was at least 1 standard deviation away from the long-term mean of that cell.

5.3 OTHER HUMAN ACTIVITIES

The CCIEA team compiles and regularly updates indicators of human activities in the CCE, some of which may have effects on focal species, ecosystem processes and services, fisheries, and coastal communities. Some of these activities relate closely to fisheries (e.g., aquaculture) while others relate to different ocean use sectors like shipping and energy extraction. Several of these time series have recently been updated. For space considerations, we have moved these time series to Appendix N and Appendix O.

6 Human Wellbeing

6.1 Social Vulnerability

Coastal community vulnerability indices are generalized socioeconomic vulnerability metrics for 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.; see methods in Jepson and Colburn 2013). We monitor CSVI in communities dependent upon commercial fishing (Figure 6.1.1), and in this year's report we add dependence upon recreational fishing (Figure 6.1.2).

The commercial fishing *engagement* index is based on an analysis of variables reflecting commercial fishing engagement in 1140 communities (e.g., fishery landings, revenues, permits, and processing). The commercial fishing *reliance* index applies the same factor analysis approach to these same variables on a per capita basis. Figure 6.1.1 plots CSVI against commercial fishery reliance (per capita dependence) for five communities most dependent on commercial fishing in each of Washington, Oregon, and northern, central and southern California. Of note are communities that are above and to the right of the dashed lines, which indicate 1 s.d. above average levels of social vulnerability (horizontal dashed line) and commercial fishing reliance (vertical dashed line) of all West Coast communities. For example, both Moss Landing and Westport have high commercial fishing reliance (29 and 9 s.d. above average) and also high CSVI (~10 and 5 s.d. above average). Communities that are strong outliers in both indices may be highly vulnerable to commercial fishing downturns. Shocks due to ecosystem changes or management actions may produce especially high individual and community-level social stress in these communities. As we have discussed in past meetings, these data are difficult to groundtruth and require further study.

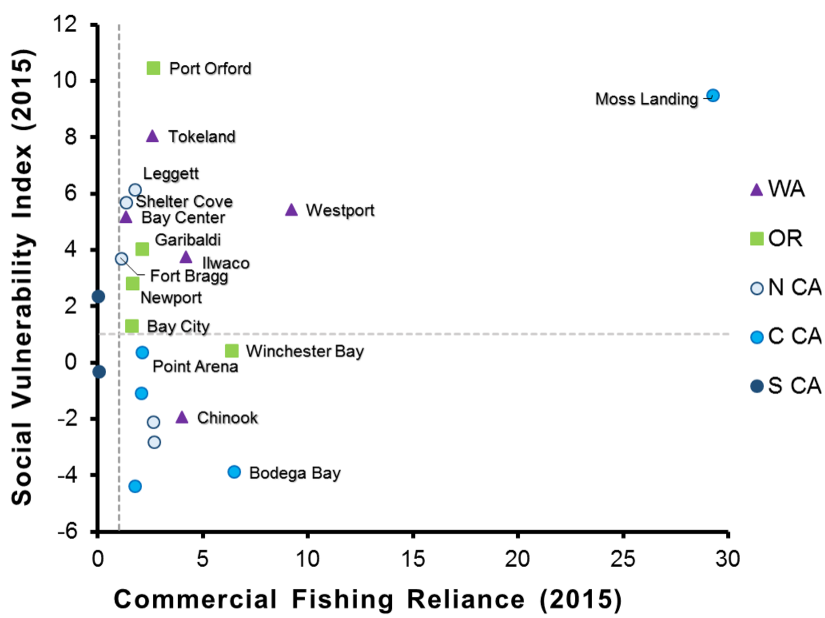

Figure 6.1.1 Commercial fishing reliance and social vulnerability scores plotted for twenty-five communities from each of the 5 regions of the California Current: WA, OR, Northern, Central, and Southern California. The top five highest scoring communities for fishing reliance were selected from each region.

The recreational fishing engagement index is based on an analysis of variables reflecting a community's recreational fishing engagement (e.g., number of boat launches, number of charter boat and fishing guide license holders, number of charter boat trips, and a count of recreational fishing support businesses such as bait and tackle shops). The recreational fishing reliance index applies the same factor analysis approach to these same variables for each community on a per capita basis. Figure 6.1.2 plots CSVI against newly available recreational fishery reliance (again, per capita dependence) for the five communities most heavily dependent on recreational fishing in each of the five geographic regions. Once again, of note are communities that appear above and to the right of the dashed lines, which indicate the 1 s.d. above average levels of recreational reliance (vertical line) and social vulnerability (horizontal line) along the West Coast. Notable communities of this type include Elkton and Westport, although there were fewer communities in this portion of the recreational reliance plot than there were in the commercial reliance plot (Figure 6.1.1). Several communities (Westport, Ilwaco, Garibaldi, Moss Landing) appear in this portion of the plot for both the commercial and recreational sectors, which may imply some potential for management-related tradeoffs in those communities. This is an emerging area of work and more research will be required to understand the importance of these relationships.

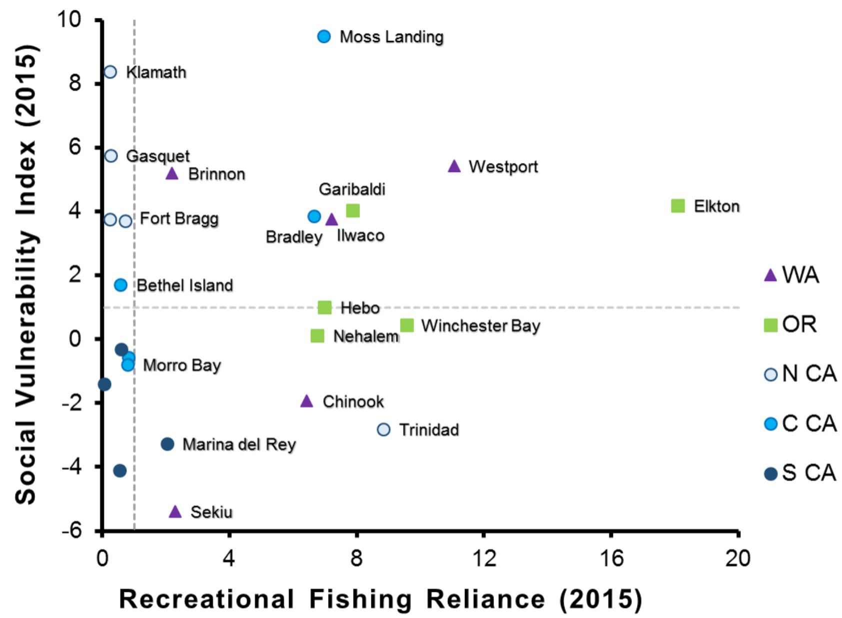

Figure 6.1.2 Recreational fishing reliance and social vulnerability scores plotted for twenty-five communities from each of the 5 regions of the California Current: WA, OR, Northern, Central, and Southern California. The top five highest scoring communities for fishing reliance were selected from each region.

6.2 Fleet Diversity Indices

Catches and prices from many fisheries exhibit high inter-annual variability leading to high variability in fishermen's revenue, but variability can be reduced by diversifying fishing activities across multiple fisheries or regions (Kasperski and Holland 2013). We use the effective Shannon index (ESI) to measure diversification among 28,000 fishing vessels on the West Coast and Alaska. The index has an intuitive meaning: ESI = 1 when all revenues are from a single species group and region; ESI = 2 if fishery revenues are spread evenly across 2 fisheries; and so on. It increases both as revenues are spread across *more* fisheries and as revenues are spread more *evenly* across fisheries. If the revenue is not evenly distributed across fisheries, then the ESI value is lower than the number of fisheries a vessel enters.

As of 2016, the fleet of vessels fishing on the West Coast and in Alaska is less diverse on average than at any time in the past 36 years (Figure 6.2.1a). All categories of vessels that fished along the West Coast decreased in average diversification from 2015 to 2016 (Figure 6.2.1b-d). The long term decline is due both to entry and exit of vessels, and to changes for individual vessels. Over time, less diversified vessels have been more likely to exit; 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 average diversification since the mid-1990s or earlier. Within the average trends, there are wide ranges of diversification levels and strategies within and across vessel classes, and some vessels remain highly diversified. Increased diversification from one year to the next may not always indicate an improvement. For example, if a class of vessels was heavily dependent on a single fishery with highly variably revenues (e.g., Dungeness crab), a decline in that fishery might force vessels into other fisheries, causing average diversification to increase. Also an increase in a fleet's diversification may be due to the exit of less diversified vessels (Appendix Q).

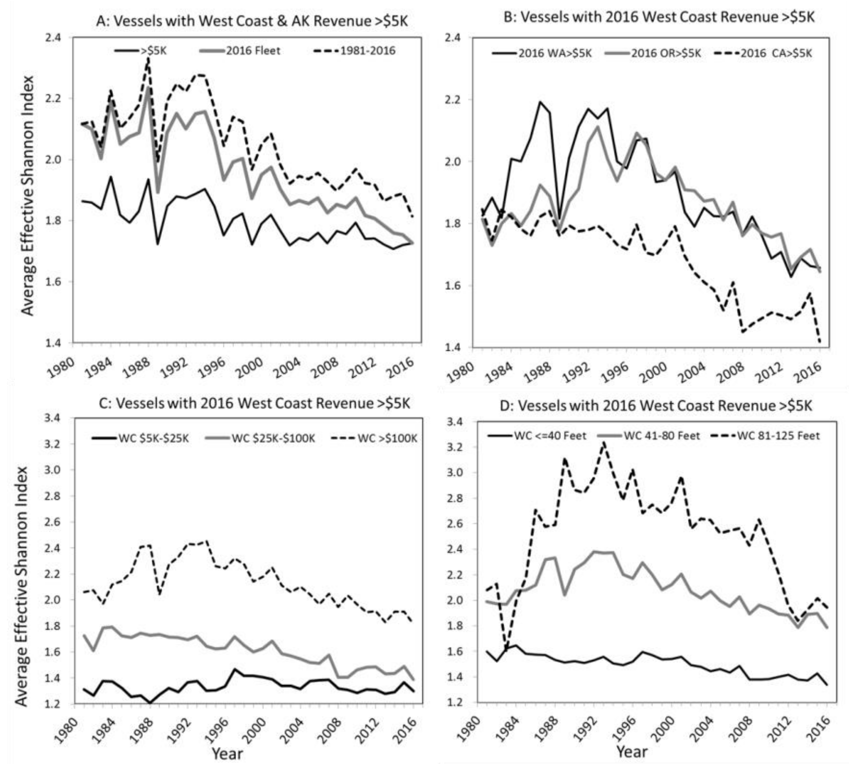

Figure 6.2.1 Trends in average diversification for US West Coast and Alaskan fishing vessels with over $5K in average revenues (top left) and for vessels in the 2016 West Coast Fleet with over $5K in average revenues, broken out by state (top right), by average gross revenue classes (bottom left) and by vessel length classes (bottom right).

7 SYNTHESIS

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 March 2017 California Current Ecosystem Status Report. Those Recommendations are generally consistent with our perspectives on ecosystem research needs in 2018; thus, rather than repeating those recommendations here (see full list in Appendix R), we offer several higher-level analysis products that CCIEA researchers are working on that illustrate several of the 2017 Research Recommendations, and that we hope are of interest to the Council in relation to: (i) continued improvements in this report; (ii) the types of analyses we can provide in other Council contexts, including the new FEP Initiative on Climate and Communities; and (iii) implementation of NOAA Fisheries efforts such as the Ecosystem-Based Fisheries Management Roadmap and the Western Regional Action Plan for the NOAA Climate Science Strategy.

The first two projects (Early Warning Index, Ecosystem Thresholds) relate most closely to Research Recommendations 2 and 3 (Appendix R), and the third project (Dynamic Ocean Management of Bycatch) relates most closely to Research Recommendation 5 (Appendix R).

7.1 AN EARLY WARNING INDEX FOR THE CALIFORNIA CURRENT

In March 2017, the Council requested that the CCIEA team report on the potential for an Early Warning Index to signal major pending changes in the state of the CCE. While past regime shifts in the North Pacific have been associated with sudden changes in the PDO, ecological theory predicts that regime shifts are also to be expected in ecosystems undergoing persistent or incremental perturbations. CCIEA scientists and colleagues used time series data and a family of statistical approaches, reviewed in September 2017 by the SSCES, to look for two indices: (1) an index of the overall ecosystem "state" of both the northern and southern CCE; and (2) an Early Warning Index that would test for impending widespread reorganizations. These methods look for shared, shifting trends in variability across the system as well as for the occurrence of rare "black swan" events that may relate to regime shifts. Preliminary results indicate that current CCE time series show no support for widespread biological reorganization as of 2016, even though the recent climate anomalies of 2014-2016 were near or beyond prior extremes for many variables (Figure 7.1.1). We will continue to revisit these analyses as time series in the CCE add further data.

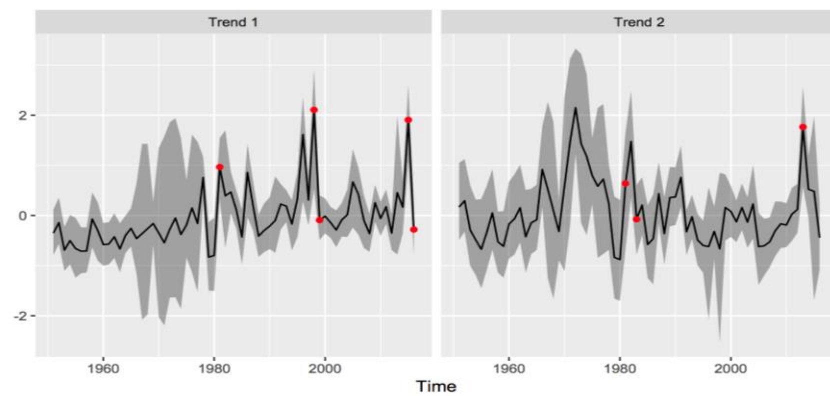

Figure 7.1.1 In this example, an early warning index model reduced 32 biological time series from the southern CCE down to two main underlying trends. Solid lines = means; shading = 95% credible intervals. Both trends showed brief departures in 2014 or 2015, followed by rapid recovery. In all cases, rare "black swan" events (red dots) were followed by returns to central tendencies, not persistent state shifts.

7.2 IDENTIFYING ECOSYSTEM THRESHOLDS IN INDICATORS

We are examining relationships between indicators of pressures and indicators of key species or processes in the CCE to determine if there are thresholds beyond which a pressure could have much stronger impacts on some part of the system. These thresholds may represent ecosystem reference points that are deserving of management attention in the future. One case study from this project, which was reviewed by the SSCES in September 2017 and recently published (Samhouri et al. 2017), was a threshold relationship between California sea lion pup counts and a large-scale oceanographic metric called the Northern Oscillation Index (NOI), which is an indicator of atmospheric processes that affect upwelling. As shown in Figure 7.2.1, sea lion pup production drops dramatically when summer NOI increases beyond a value of ~0.2,

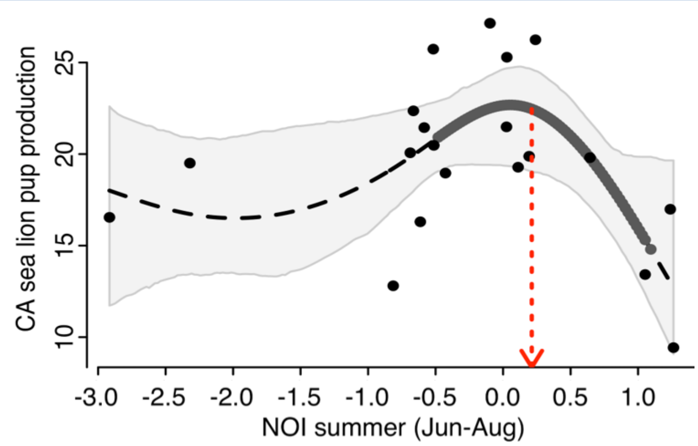

Figure 7.2.1 Relationship between the atmospheric Northern Oscillation Index (NOI) and California sea lion pup counts at San Miguel Island. Red arrow indicates best estimate of a statistical threshold, beyond which the relationship changes significantly; heavy solid trend line indicates 95% confidence around that threshold point.

based on data from 1996-2016. Many ecological time series in the CCE are just reaching a duration that allows for robust time series analyses like these, and the CCIEA team will test for other such thresholds in the near future. In particular, we will be looking at potential threshold responses by salmon populations to natural and anthropogenic pressures.

7.3 Dynamic Ocean Management of Bycatch in the Drift Gillnet Fishery

CCIEA scientists, with support from NASA, are supporting a risk analysis for bycatch species in the California Drift Gillnet fishery. This fishery is heavily managed to reduce leatherback and loggerhead sea turtle bycatch due to their endangered status, yet large-scale seasonal closures of swordfish fishing are the primary tool for avoiding bycatch. To address this, the team created the EcoCast product (http://oceanview.pfeg.noaa.gov/ecocast/), which assesses likelihood of catching swordfish relative to bycatch species in near-real time. Risk weightings were determined based on discussions with managers; leatherback turtles had the highest risk weighting among protected species included. EcoCast is available for fishery participants to inform their decisions on where and when to fish. In addition, the tool can be used to evaluate the recent warm anomalies relative to past, more normal conditions (Figure 7.3.1). The predictive model was used to examine how large, dynamically managed areas would compare to existing seasonal closures under different scenarios; for example, Figure 7.3.1 (left) was a very conservative scenario to protect the top 75% of predicted leatherback habitat, while Figure 7.3.1 (right) was a less-conservative scenario to protect the top 50% of combined EcoCast risk surfaces across turtles, pinnipeds and blue sharks. Of note, 2015 showed increased areas of high risk particularly late in the season compared to 2012. With the development of seasonal forecasting and climate-predicting ocean models, this tool could be used to proactively assess likely fishing conditions for use by the fishery.

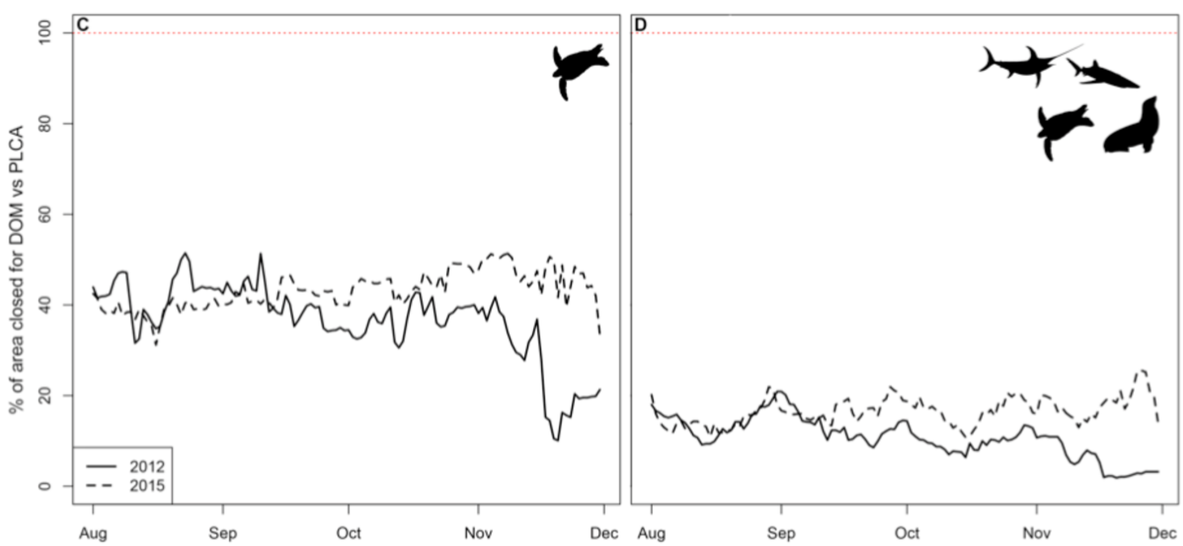

Figure 7.3.1 Comparison of a dynamic ocean management approach (EcoCast) to the California Drift Gillnet Fishery relative in size to the existing static Pacific Leatherback Conservation Area (PLCA) closure. This example tests two management objectives: (left) a dynamic closure based that protects the top 75% of leatherback habitat; and (right) a dynamic closure that protects 50% of habitat for total protected species. Scenarios were run in two years (2012 and 2015) with different climate conditions. Between-year differences were clear, but in either case, dynamic management increased fishable area by >50% (left) or >80% (right) relative to the static PLCA closure.

SUPPLEMENTARY MATERIALS TO THE CALIFORNIA CURRENT INTEGRATED ECOSYSTEM ASSESSMENT (CCIEA) CALIFORNIA CURRENT ECOSYSTEM STATUS REPORT, 2018

Appendix A LIST OF CONTRIBUTORS TO THIS REPORT, BY AFFILIATION

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Appendix B LIST OF FIGURE AND DATA SOURCES FOR THE MAIN REPORT

Figure 3.1: Newport Hydrographic (NH) line temperature data are from Ms. Jennifer Fisher (NOAA/OSU). CalCOFI hydrographic line data are from http://calcofi.org/data.html. CalCOFI data before 2016 are from the bottle data CSV database, while 2016 data are preliminary data from the CTD CSV database.

Figure 3.1.1: Oceanic Niño Index information and data are from the NOAA Climate Prediction Center (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_change.shtml). Pacific Decadal Oscillation data are from Dr. Nate Mantua (NOAA) and are served by the University of Washington Joint Institute for the study of the Atmospheric and Ocean (JISAO; http://research.jisao.washington.edu/pdo/). North Pacific Gyre Oscillation data are from Dr. Emanuele Di Lorenzo (Georgia Institute of Technology) (http://www.o3d.org/npgo/).

Figure 3.1.2: Sea surface temperature maps are optimally interpolated, remotely sensed temperatures (Reynolds et al. 2007). The daily optimal interpolated AVHRR SST can be downloaded using ERDDAP (http://upwell.pfeg.noaa.gov/erddap/griddap/ncdcOisst2Agg.html).

Figure 3.2.1: Cumulative Upwelling Index curves are calculated from the six-hourly upwelling index product (http://upwell.pfeg.noaa.gov/erddap/tabledap/erdUI216hr.html).

Figure 3.3.1: Newport Hydrographic (NH) line dissolved oxygen data are from Ms. Jennifer Fisher (NOAA/OSU). CalCOFI hydrographic line data are from http://calcofi.org/data.html. Note: CalCOFI data before 2016 are from the bottle data CSV database, while 2016 data are preliminary data from the CTD CSV database.

Figure 3.3.2: Aragonite saturation state data were provided by Ms. Jennifer Fisher (NOAA/OSU).

Figure 3.4.1: Snow-water equivalent data were derived from the California Department of Water Resources snow survey (http://cdec.water.ca.gov/) and the Natural Resources Conservation Service's SNOTEL sites in WA, OR, CA and ID (http://www.wcc.nrcs.usda.gov/snow/).

Figure 3.4.2: Minimum and maximum streamflow data were provided by the US Geological Survey (http://waterdata.usgs.gov/nwis/sw).

Figure 4.1.1: Copepod biomass anomaly data were provided by Ms. Jennifer Fisher (NOAA/OSU).

Figure 4.2.1: Pelagic forage data from the Northern CCE were provided by Dr. Brian Burke (NOAA) and Ms. Cheryl Morgan (OSU-CIMRS). Data are derived from surface trawls taken during NOAA Northwest Fisheries Science Center Juvenile Salmon & Ocean Ecosystem Survey (JSOES).

Figure 4.2.2: Pelagic forage data from the Central CCE were provided by Dr. John Field (NOAA) from the SWFSC Rockfish Recruitment and Ecosystem Assessment Survey (https://swfsc.noaa.gov/textblock.aspx?Division=FED&ParentMenuId=54&id=20615).

Figure 4.2.3: Pelagic forage data from the Southern CCE were provided by Dr. Andrew Thompson (NOAA) and were derived from spring CalCOFI surveys (http://calcofi.org/).

Figure 4.3.1: Chinook salmon escapement data were derived from the California Department of Fish and Wildlife (http://www.dfg.ca.gov/fish/Resources/Chinook/CValleyAssessment.asp), from Pacific Fishery Management Council pre-season reports (http://www.pcouncil.org/salmon/stock-assessment-and-fishery-evaluation-safe-documents/preseason-reports/2016-preseason-report-i/) and from the NOAA Northwest Fisheries Science Center's "Salmon Population Summary" database (https://www.webapps.nwfsc.noaa.gov/sps).

Figure 4.3.2: Data for at sea juvenile salmon provided by Dr. Brian Burke (NOAA) with additional calculations by Ms. Cheryl Morgan (OSU-CIMRS). Data are derived from surface trawls taken during NOAA Northwest Fisheries Science Center Juvenile Salmon & Ocean Ecosystem Survey (JSOES).

Figure 4.4.1: Groundfish stock status data were provided by Dr. Jason Cope (NOAA) and were derived from NMFS stock assessments.

Figure 4.5.1: Highly migratory species data provided by Dr. Barbara Muhling (NOAA). Data are derived from stock assessment reports for the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC; (http://isc.fra.go.jp/reports/stock_assessments.html) or the Inter-American Tropical Tuna Commission (IATTC; https://www.iattc.org/PublicationsENG.htm).

Figure 4.6.1: California sea lion data were provided by Dr. Sharon Melin (NOAA).

Figure 4.6.2: Data for whale entanglement provided by Dan Lawson (NMFS West Coast Region).

Figure 4.7.1: Seabird abundance data from the Northern CCE were collected and provided by Dr. Jeannette Zamon (NOAA). Seabird abundance data from the Central CCE (collected on the SWFSC Rockfish Recruitment and Ecosystem Assessment Survey) and the Southern CCE (collected on the CalCOFI surveys) are courtesy of Dr. Bill Sydeman (Farallon Institute).

Figure 5.1.1: Data for commercial landings are from PacFIN (http://pacfin.psmfc.org). Data for recreational landings are from RecFIN (http://www.recfin.org/).

Figure 5.2.1: Data for total benthic habitat distance contacted by bottom-contact fishing gears were provided by Mr. Jon McVeigh (NOAA). Weightings for benthic habitat sensitivity values come from PFMC's Pacific Coast Groundfish 5-Year Review of Essential Fish Habitat.

Figure 6.1.1: Community social vulnerability index (CSVI) and fishery dependence data were provided by Dr. Karma Norman (NOAA) and Ms. Anna Varney (PSMFC); these data were derived from the U.S. Census Bureau's American Community Survey (ACS; https://www.census.gov/programs-surveys/acs/) and PacFIN (http://pacfin.psmfc.org), respectively.

Figure 6.1.2: Community social vulnerability index (CSVI) and fishery dependence data were provided by Dr. Karma Norman (NOAA) and Ms. Anna Varney (PSMFC); these data were derived from the U.S. Census Bureau's American Community Survey (ACS; https://www.census.gov/programs-surveys/acs/) and PacFIN (http://pacfin.psmfc.org) and RecFIN (http://www.recfin.org/), respectively.

Figure 6.2.1: Fishery diversification estimates were provided by Dr. Dan Holland and Dr. Stephen Kasperski (NOAA).

Figure 7.1.1: Early warning index/dynamic factor analysis results were provided by Dr. Mary Hunsicker (NOAA), based on CalCOFI ichthyoplankton data (http://calcofi.org/) provided by Dr. Sam McClatchie (NOAA, retired).

Figure 7.2.1: Data for the atmospheric Northern Oscillation Index (NOI) were provided by Dr. Isaac Schroeder (NOAA). California sea lion pup counts were provided by Dr. Sharon Melin (NOAA).

Figure 7.3.1: Protected species bycatch model outputs were provided by Dr. Elliott Hazen (NOAA).

Table 4.3.1: Stoplight table of indicators and 2018 salmon returns provided by Dr. Brian Burke (NOAA).

Appendix C CHANGES IN THIS YEAR'S REPORT

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 Workgroup (EWG). The EWG coordinated several processes by which the CCIEA team was able to receive feedback from Council advisory bodies (including the SSC and several management teams, subcommittees and panels) and the public via direct discussions at Council meetings and through a series of webinars to provide details and discussion on key sections of the report. The EWG compiled and provided the collective feedback from these processes. We also received direct feedback from the Council following our presentations to the Council in March 2016 and March 2017. The SSCES has provided technical review of several indicators and analyses related to the Ecosystem Status Report in December 2014, September 2016 and September 2017. Finally, the CCIEA team is commited to filling key data gaps and improving information content in the report.

Below we summarize changes and improvements in the 2018 Ecosystem Status Report, in response to the requests and suggestions received from the Council, EWG, SSCES and advisory bodies, or based on gaps we have attempted to fill. We will continue to address and integrate requests and suggestions already received, as well as new requests and emerging needs in regard to this Ecosystem Status Report.

Requester	Request/Need	Response, location in document
Many advisory bodies	In conversations with many advisory bodies, CCIEA team has been encouraged to include known biological or ecological thresholds in indicator reporting	We now plot hypoxia and ocean acidification indicators (Section 3.3; Appendix E) with blue horizontal lines to denote the limits below which studies have shown levels to be harmful to many species
CCIEA team filling a gap	Freshwater ecosystem indicators have thus far not included stream temperature estimates	We added the annual maximum August temperature, averaged across freshwater ecoregions. We allude to this indicator in Section 3.3 and show data in Appendix E.
SSC and SSCES *(as part of many technical reviews, most recently September 2017)*	Include error bars around point estimates in quad plots to better distinguish significant averages and trends	We have added error bars to the points in the quad plots for maximum and minimum stream flows, according to methods outlined to the SSC-ES in September 2017. These are in Figure 3.4.2, and represent 95% credible intervals.
Ecosystem Workgroup *(as part of FEP Initiative 2 discussions)*	Graphics need to work in multiple media, sometimes in black and white. Table 4.3.1 is difficult in B&W print copy	Table 4.3.1 maintains the "stoplight" colors, but green symbols are now circles, yellow symbols are squares, and red symbols are diamonds in order to translate to B&W.

Requester	Request/Need	Response, location in document
CCIEA team filling a gap	Indicators in salmon section focused on escapement data that lag by several years; we need additional information to reflect current and future conditions	We added time series of catch-per-unit-effort of juvenile Chinook and coho salmon along the WA-OR coast during their first spring/summer at sea. These data are in Figure 4.3.2, and are also in the "stoplight table" (Table 4.3.1)
Ecosystem Workgroup *(as part of FEP Initiative 2 discussions)*	Report needs highly migratory species (HMS) information. HMS harvest levels are set internationally, so report could look at questions other than biomass, such as species' distribution in space and over time. Centers might also look at predator-prey links between HMS and CCE prey, and/or information on their co-occurrence with protected species. We are also interested in the effects of temperature shifts on HMS habitat.	We added assessment-derived indicators of HMS biomass and recruitment in Section 4.5 this year. We hope to present estimates of albacore distribution in next year's report, pending a possible technical review by the SSCES in September of 2018.
CCIEA team addressing an emerging need	Reports of whale entanglements in fishing gear have increased in recent years, possibly in relation to changing environmental conditions	We have added a time series of annual reported whale entanglements in Section 4.6.
Salmon Advisory Subpanel *(as part of FEP Initiative 2 discussions)*	We would like to see an index of seabird species diversity and density for the northern CCE and any relationships of that information to abundance and condition of salmon populations.	In Section 4.7, we now provide seabird at-sea densities for 3 species in each of the regions. We hope to include a seabird diversity index, pending discussions of data sharing among monitoring partners and determining how to standardize data across regions.
Ecosystem Advisory Subpanel *(as part of FEP Initiative 2 discussions)*	Section 5.2: We had an energetic discussion about this metric. Data do not convey variability of impacts of bottom fishing gear across gear types, habitat types, and fishing intensity; and they are not so useful in interpreting overall impact of bottom fishing gear relative to ecosystem-scale drivers.	We have added maps of bottom-fishing gear contact with the seafloor in Section 5.2. The maps illustrate recent averages and trends of seafloor contact in 2x2 km grid cells, and whether last year was above or below average in total seafloor contact.
Ecosystem Workgroup, SSC, Groundfish Management Team *(as part of FEP Initiative 2 discussions)*	Could we have a recreational fishing dependence and engagement discussion/indicator/analysis?	We have added a comparison of community-level recreational fishing dependence and community social vulnerability in Section 6.1. Additional analyses of recreational fishing dependence are in Appendix O.

Requester	Request/Need	Response, location in document
Ecosystem Workgroup *(as part of FEP Initiative 2 discussions)*	Recommend adding "Research Recommendations" section to the report or supplemental materials to comment on where future work might revise report's contents	We fulfilled this request in the 2017 report, but because our Recommendations have not changed substantively since then, we moved the list of Recommendations to Appendix R, and added a "Synthesis" section (Section 7) to this year's report, featuring integrative analyses that are related to the Research Recommendations.
Habitat Committee *(as part of FEP Initiative 2 discussions)*	Indicators are potentially valuable from a forecasting or risk-assessment perspective. HC encourages further efforts to define key indicators that can be used for forecasting.	In Section 7, we include several examples of analyses that are related to risk assessment: the Early Warning Index (preliminary analyses, reviewed by SSCES in Sept. 2017); threshold relationships between climate pressures and sea lions (reviewed by SSCES in Sept. 2017); and environmentally driven overlap between swordfish and protected species in a managed area (preliminary analyses; reviewed by SSCES in Sept. 2016). We hope to add further analyses that are more explicitly forecast-oriented.
HMS Management Team *(as part of FEP Initiative 2 discussions)*	HMSMT did express an interest in expanding the use of dynamic ocean management (e.g. EcoCast) from the current Pacific Loggerhead Conservation Area to other HMS fisheries where protected species interactions may occur.	In Section 7, we summarize a preliminary analysis of potential dynamic ocean management of protected species bycatch in the swordfish fishery within the PLCA. This analysis was done using the EcoCast tool.
CCIEA team filling a gap	Seabird indicators have been limited to abundance estimates and less directly tied to mechanisms, except for reports of mass seabird mortality events	We added some seabird diet data and time series trends of seabird mortality observations; for space considerations, these are in the Supplement (Appendix K) but we will look to build upon their utility and move them to the main report as requested
CCIEA team addressing a need	We have added many indicators and analyses to the main body of the report, but want to keep the report close to 20 pages in length	We have moved all non-fishing human activities indicators to Appendix N to save space in the main report.

Appendix D CONCEPTUAL MODELS OF THE CALIFORNIA CURRENT

The CCE is a socio-ecological system in which human and naturally occurring components and processes are inextricably linked. Recognizing these links is critical to understanding the dynamics of the CCE and to managing its resources, benefits and services in an informed way. We have developed a series of conceptual models to illustrate these key components, processes and links. The figures below show a series of conceptual models developed specifically for salmon (Figure D.1) and groundfish (Figure D.2).

The benefits of conceptual models are multifold:

- They put indicators into context; each box or line corresponds to one or more indicators.
- They facilitate discussion around which issues are thought to be most important in the CCE.
- They can be readily simplified or made more in-depth and complex as desired.
- Relating the focal component (e.g., salmon or groundfish) to its linked components and processes may help us anticipate how changes in the ecosystem will affect managed species.
- Conceptual models with up-to-date information on status and trends of relevant indicators could provide information for "ecosystem considerations" sections of stock assessments.
- They serve as consistent reminders to account for human dimensions and potential management tradeoffs in different human sectors.

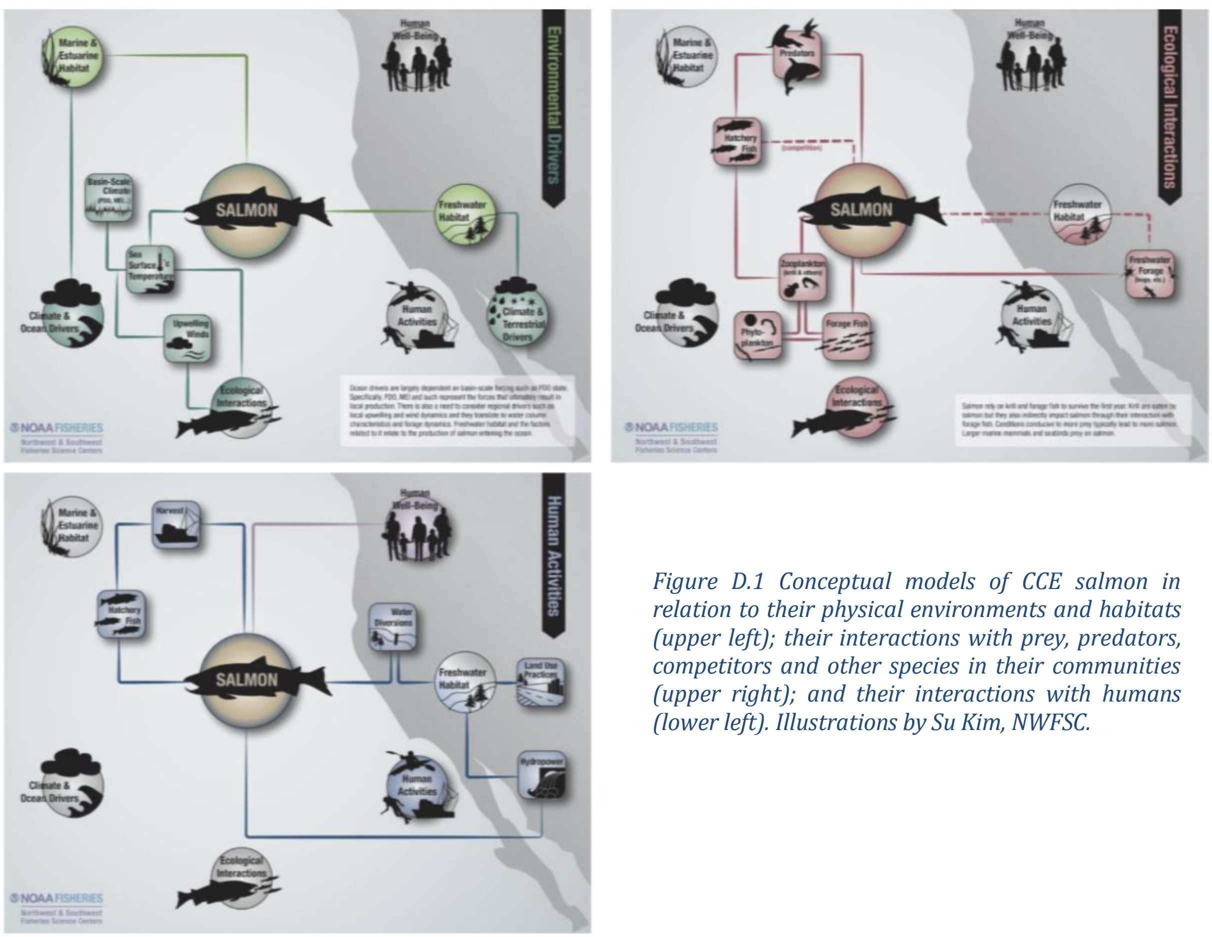
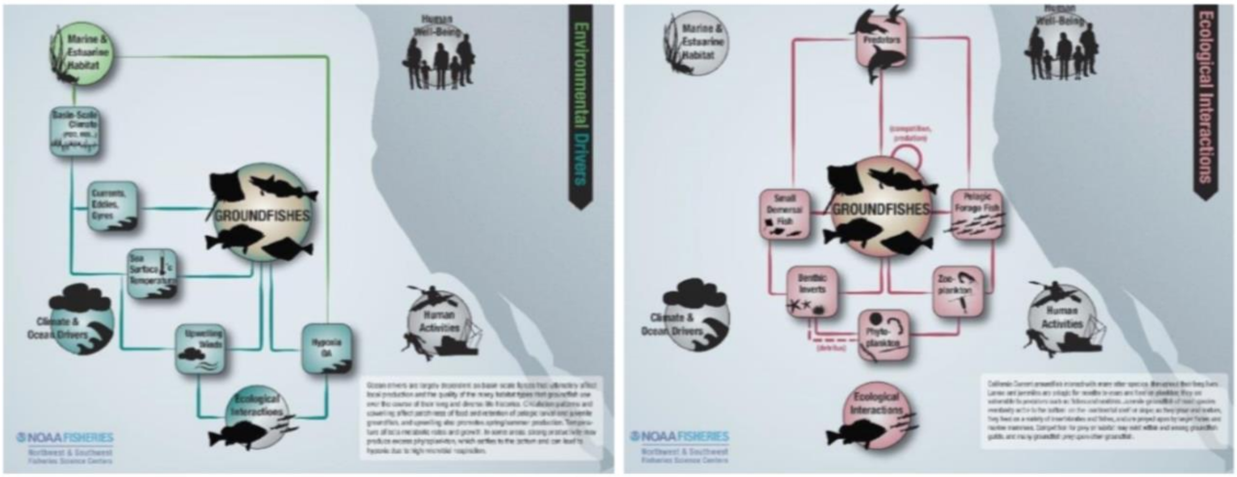


Figure D.1 Conceptual models of CCE salmon in relation to their physical environments and habitats (upper left); their interactions with prey, predators, competitors and other species in their communities (upper right); and their interactions with humans (lower left). Illustrations by Su Kim, NWFSC.



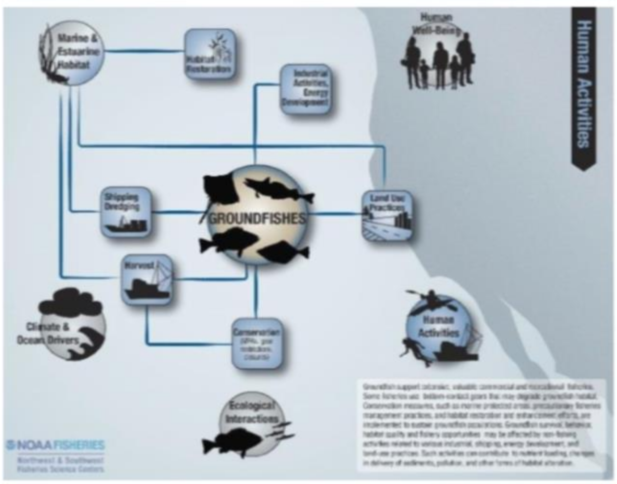


Figure D.2 Conceptual models of CCE groundfish in relation to their physical environments and habitats (upper left); their interactions with prey, predators, competitors and other species in their communities (upper right); and their interactions with humans (lower left). Illustrations by Su Kim, NWFSC.

Similar conceptual models are available for coastal pelagic species, marine mammals, seabirds, habitats, and the full socio-ecological system. For high-resolution versions of all models, please contact Su Kim (Su.Kim@noaa.gov) or Chris Harvey (Chris.Harvey@noaa.gov).

Appendix E CLIMATE AND OCEAN INDICATORS

Section 3 of the 2017 CCIEA Ecosystem Status Report describes indicators of basin-scale and region-scale climate and ocean drivers. Here we present additional plots to allow a more complete picture of these indicators.

E.1 BASIN-SCALE CLIMATE/OCEAN INDICATORS AT SEASONAL TIME SCALES

The section presents basin-scale indicators (Oceanic Niño Index (ONI), Pacific Decadal Oscillation (PDO) and North Pacific Gyre Oscillation (NPGO)), summarized by season.

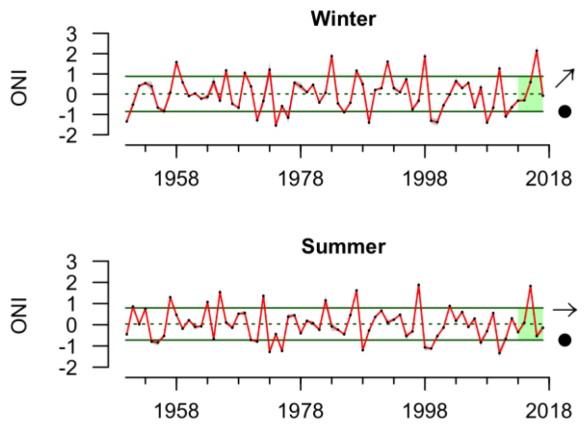


Figure E.1.1 Winter (top, Jan-Mar) and Summer (bottom, July-Sep) values of the Oceanic Niño Index. Lines and symbols as in Fig. 1.

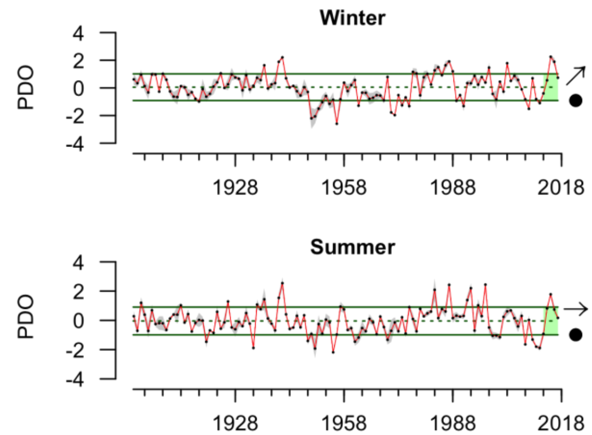


Figure E.1.2 Winter (top, Jan-Mar) and Summer (bottom, July-Sep) values of the Pacific Decadal Oscillation Index. Lines and symbols as in Fig. 1.

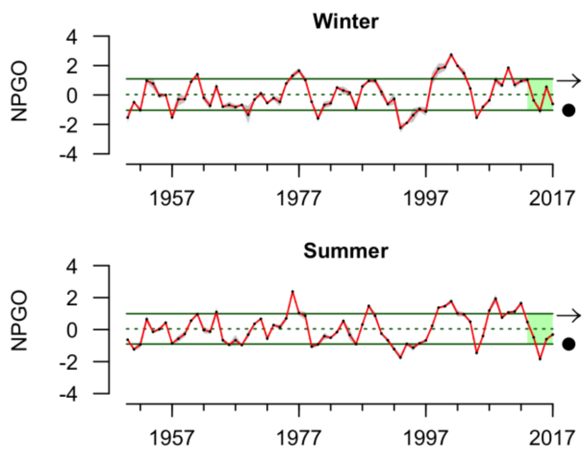


Figure E.1.3 Winter (top, Jan-Mar) and Summer (bottom, July-Sep) values of the North Pacific Gyre Oscillation Index. Lines and symbols as in Fig. 1.

E.2 REGIONAL-SCALE CLIMATE/OCEAN INDICATORS AT SPATIAL AND TEMPORAL SCALES

Figure E.2.1 shows spatiotemporal variation in upwelling intensity and anomalies from 2013-2017.

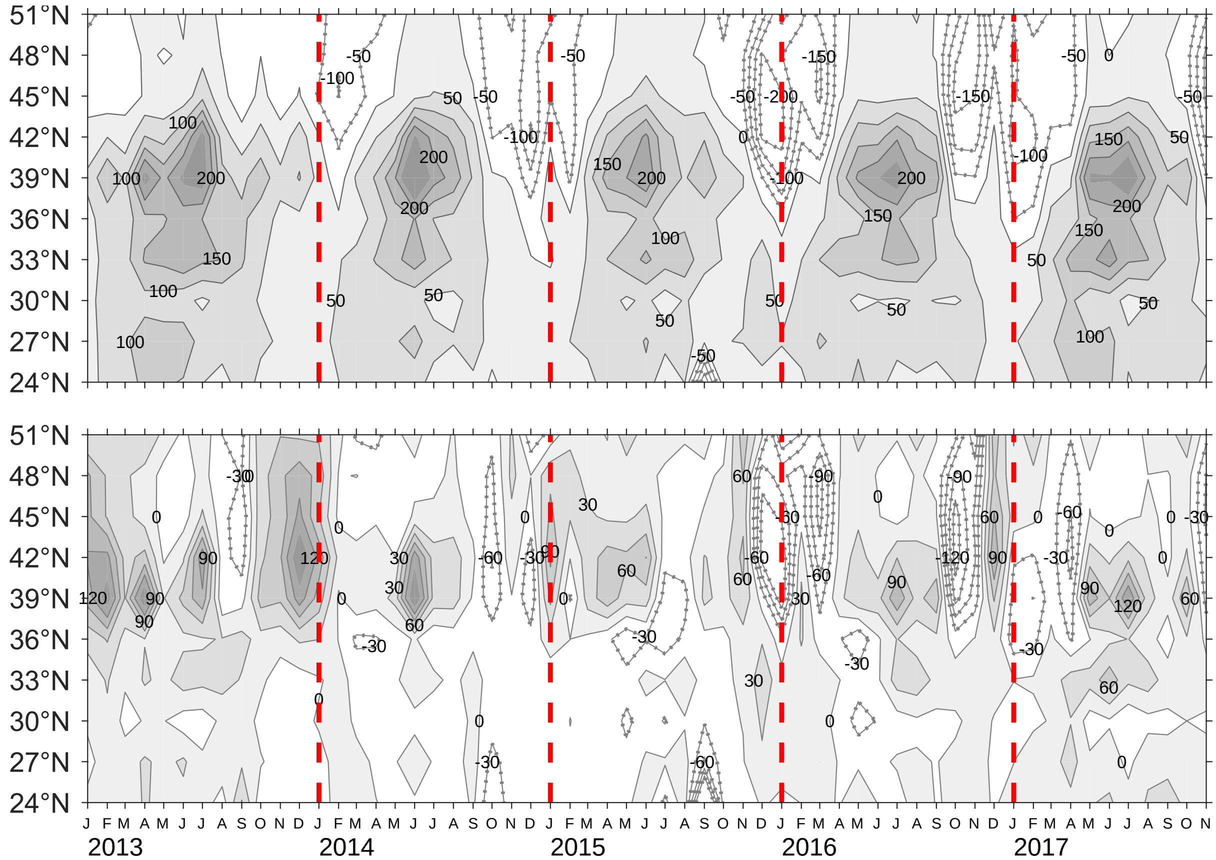


Figure E.2.1 Monthly means of daily upwelling index (top) and anomalies (bottom) for Jan 2013-Nov 2017. Shaded areas denote positive values (upwelling-favorable) in upper panel, and positive anomalies (generally greater than normal upwelling) in lower panel. Anomalies are relative to 1967-2015 monthly means. Units are in $m^3 s^{-1}$ per 100 m of coastline. Daily upwelling index data obtained from http://upwell.pfeg.noaa.gov/erddap/.

E.3 SEASONAL TRENDS IN DISSOLVED OXYGEN AND OCEAN ACIDIFICATION INDICATORS

The first series of plots in this section shows time series of summer and winter averages for dissolved oxygen (DO) data off Newport, OR (stations NH05 and NH25) and in the Southern California Bight (stations CalCOFI 90.90 and CalCOFI 93.30). The second series shows summer and winter averages of aragonite saturation state (an ocean acidification indicator) off Newport.

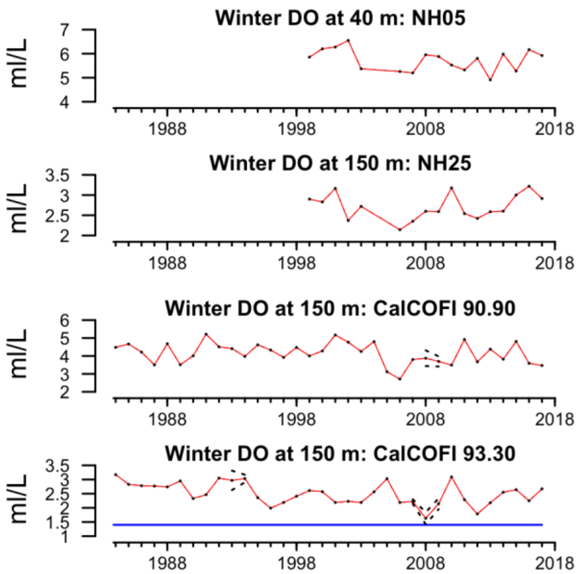


Figure E.3.1 Winter (top, Jan-Mar) dissolved oxygen (DO) at 150 m depth off of Oregon, 1999-2017 and southern California, 1984-2017. Stations NH25 and 93.30 are < 50 km from the shore; station 90.90 is >300 km from shore. Blue line indicates hypoxia threshold of 1.4 ml/L. Lines and symbols as in Fig. 1.

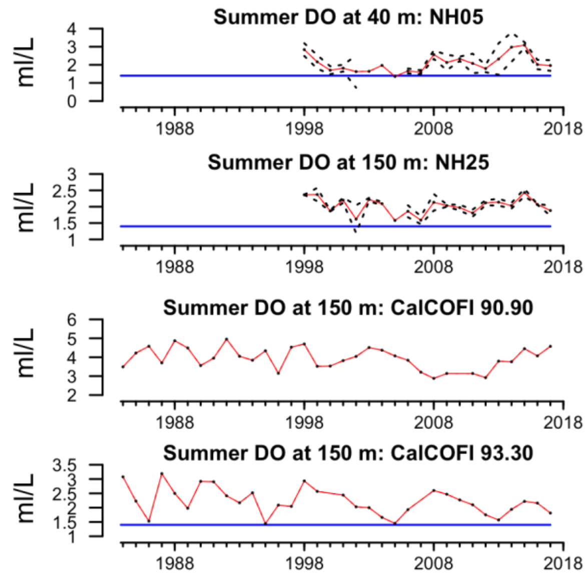


Figure E.3.2 Summer (Jul-Sep) dissolved oxygen (DO) at 50-m and 150 m depth off of Oregon, 1999-2017 and southern California, 1984-2017. Stations NH05, NH25 and 93.30 are < 50 km from the shore; station 90.90 is >300 km from shore. Blue line indicates hypoxia threshold of 1.4 ml/L. Lines and symbols as in Fig. 1.

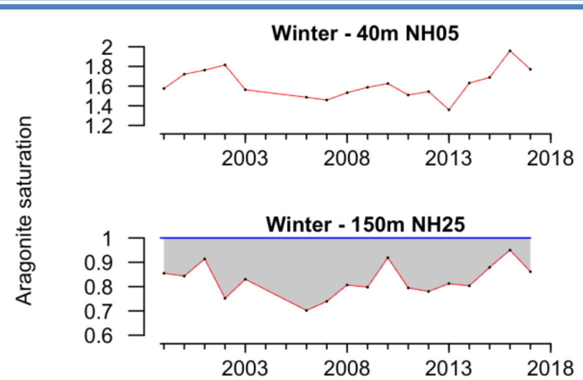


Figure E.3.3 Winter (Jan-Mar) aragonite saturation values at two stations off of Newport, OR, 1999-2017. Blue line indicates threshold aragonite saturation state = 1. Dotted lines indicate +/- 1.0 s.e. Lines and symbols as in Fig. 1.

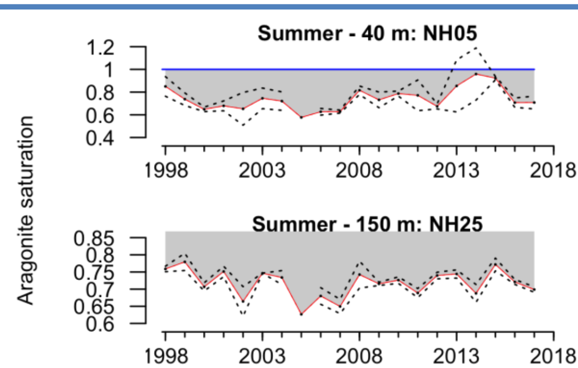


Figure E.3.4 Summer aragonite saturation values at two stations off of Newport, OR, 1998,2017. Blue line indicates threshold aragonite saturation state = 1. Dotted lines indicate +/- 1.0 s.e. Lines and symbols as in Fig. 1.

The third plot in this section, Figure E.3.5, is a time series showing the monthly aragonite saturation states at Newport Line station NH25. Warmer colors indicate higher aragonite saturation state (i.e., less stressful conditions), while cooler colors indicate lower aragonite saturation state (i.e., conditions that are more stressful and potentially corrosive to shell-forming organisms). The black line marks the point at which aragonite saturation state = 1.0, which is a proposed threshold value where values <1.0 are most stressful and corrosive. The black line demonstrates that the threshold line gets shallower in summer and deeper in winter, and also shows that in 2017, the threshold was estimated to have reached the shallowest depth on record.

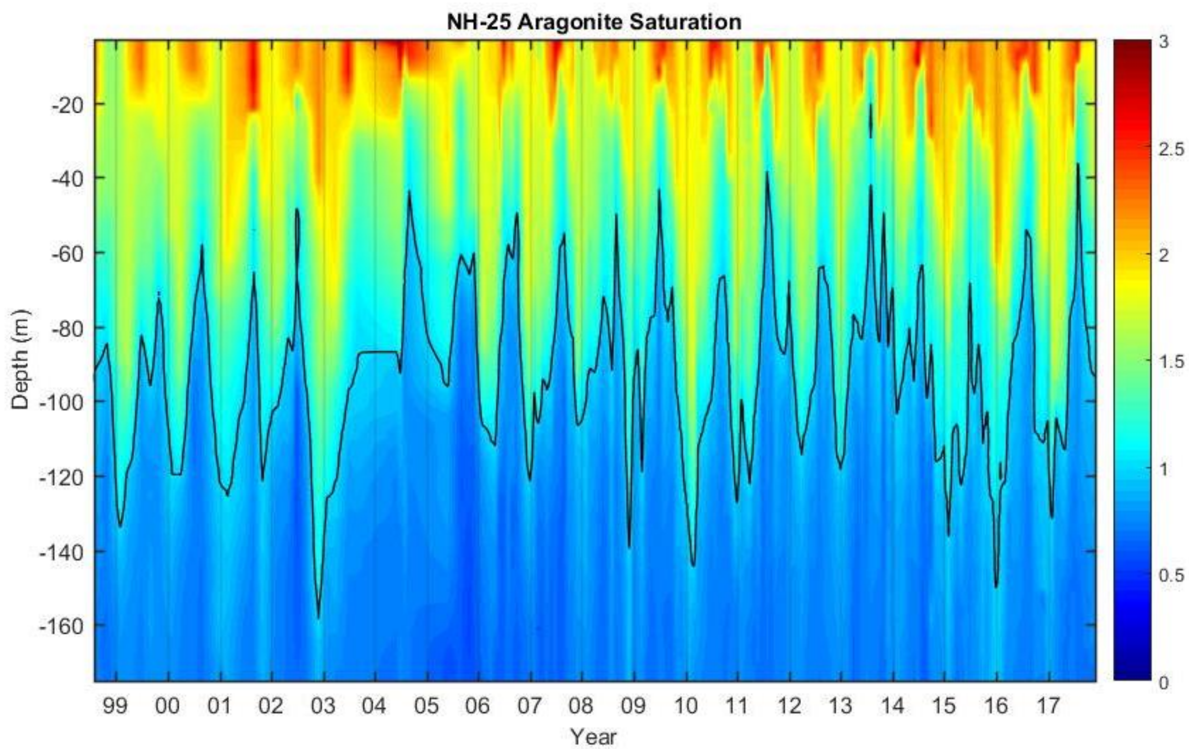


Figure E.3.5 Aragonite saturation state versus depth at station NH25 along the Newport Line, 1998-2017. Dark line indicates the depth at which the aragonite saturation state is at the threshold value (= 1.0).

Appendix F SNOW-WATER EQUIVALENT, STREAMFLOW AND STREAM TEMPERATURE

Development of habitat indicators in the CCIEA has focused on freshwater habitats. All habitat indicators are reported based on a hierarchical spatial framework. This spatial framework facilitates comparisons of data at the right spatial scale for particular users, whether this be the entire California Current, ecoregions within the CCE, or smaller spatial units. The framework we use divides the region encompassed by the CCE into ecoregions, and ecoregions into smaller physiographic units. Freshwater ecoregions are based on the biogeographic delineations in Abell et al. (2008; see also www.feow.org), who define six ecoregions for watersheds entering the California Current, three of which encompass the two largest watersheds directly entering the California Current (the Columbia and the Sacramento-San Joaquin Rivers). Within ecoregions, we summarized data using evolutionary significant units and 8-field hydrologic unit classifications (HUC-8). Status and trends for all freshwater indicators are estimated using space-time models (Lindgren and Rue 2015), which account for temporal and spatial autocorrelation.

Snow-water equivalent (SWE) for each ecoregion is measured using two data sources: a California Department of Water Resources snow survey program (data from the California Data Exchange Center http://cdec.water.ca.gov/) and The Natural Resources Conservation Service's SNOTEL sites across Washington, Idaho, Oregon, and California (http://www.wcc.nrcs.usda.gov/snow/). Snow data (Figure F.1) are converted into SWEs based on the weight of samples collected at regular intervals using a standardized protocol. Measurements at April 1 are considered the best indicator of maximum extent of SWE; thereafter snow tends to melt rather than accumulate. While previous reports used standardized anomalies of SWE, this report includes actual measurements of SWE ($\log_e$ transformed) where snow was present on April 1. This revised measure effectively deals with the measurements that do not meet standard assumptions of a normal distribution in anomaly space. Data for each freshwater ecoregion are presented in Section 3.4 of the main report.

The outlook for 2018 is limited to examination of current SWE, an imperfect correlate of SWE in April due to variable atmospheric temperature. SWE as of January 1, 2018 was reduced in depth and spatial extent compared to January 1 of 2016 and 2017, and more closely resembles the drought year of 2015, which suggests that aquatic conditions may be poorer in 2018 compared to the previous two years.

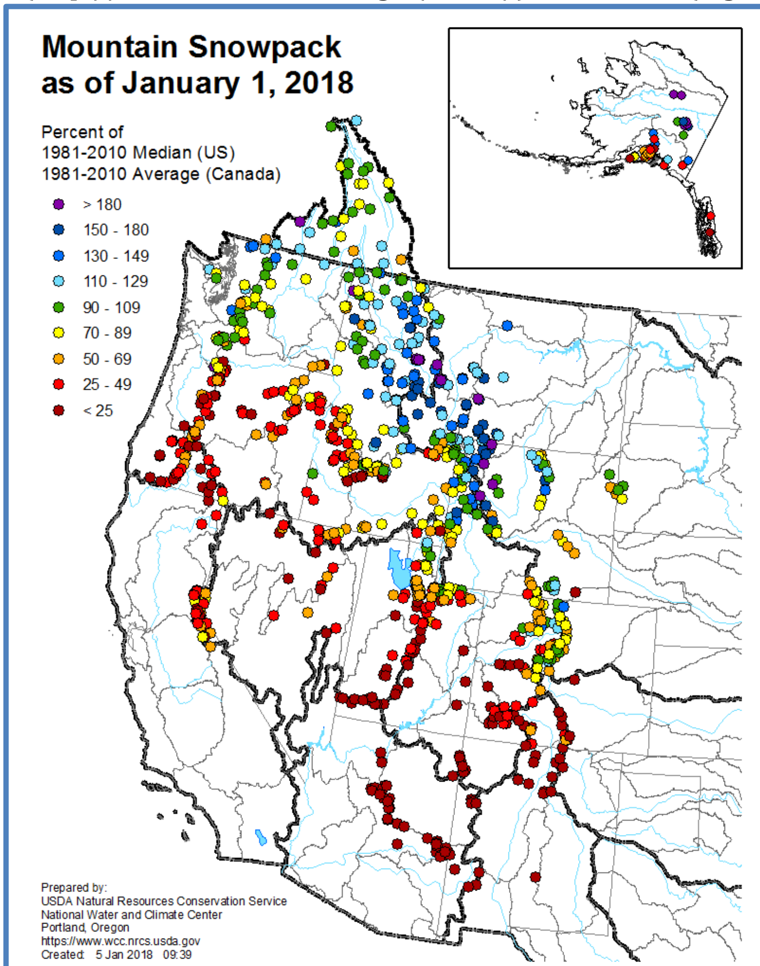


Figure F.1 Mountain snowpack as of January 1, 2018.

Streamflow is derived from active USGS gages (http://waterdata.usgs.gov/nwis/sw) with records of at least 30 years duration. Daily means from 213 gages were used to calculate annual 1-day maximum and 7-day minimum flows. These indicators correspond to flow parameters to which salmon populations are most sensitive. We use standardized anomalies of streamflow time series from individual gages.

Across ecoregions of the California Current, both minimum and maximum streamflow anomalies have exhibited some variability in the most recent five years, although not out of the historical range. Minimum stream flows have exhibited fairly consistent patterns across all ecoregions (Figure F.3, see Figure F.5 for flows by ESU). Most all ecoregions demonstrated a decline in low flows over the last 5-8 years with an uptick in 2017, although little variation exists for rivers in the Southern California Bight. For maximum flows (Figure F.4; see Figure F.6 for flows by ESU), 5-year trends were particularly pronounced for Sacramento-San Joaquin and Oregon and Northern California ecoregions (increased high flows), and all regions except Salish Sea and Washington Coast experience an uptick in high flows in 2017. (Importantly, the averages and slopes of the ESU-scale plots in Figures F.5 and F.6 were estimated with different statistics than the quad plots in Section 3.4, Figure 3.4.2; we will resolve this difference in the future.)

This year, we have added an additional freshwater indicator – mean maximum temperature in August. This was determined for 446 USGS gages with temperature monitoring capability. While these gages did not necessarily operate simultaneously throughout the period of record, at least two gages provided data each year in all ecoregions. Stream temperature records are limited in California, so two ecoregions were combined. For most ecoregions, the recent 5 years has been marked by largely average maximum stream temperatures. The exception is the Salish Sea and Washington Coast, which has much higher temperatures in the last five years compared to the period of record (Figure F.2). Most ecoregions exhibit long-term increasing trends in maximum temperature going back to the 1980s and 1990s.

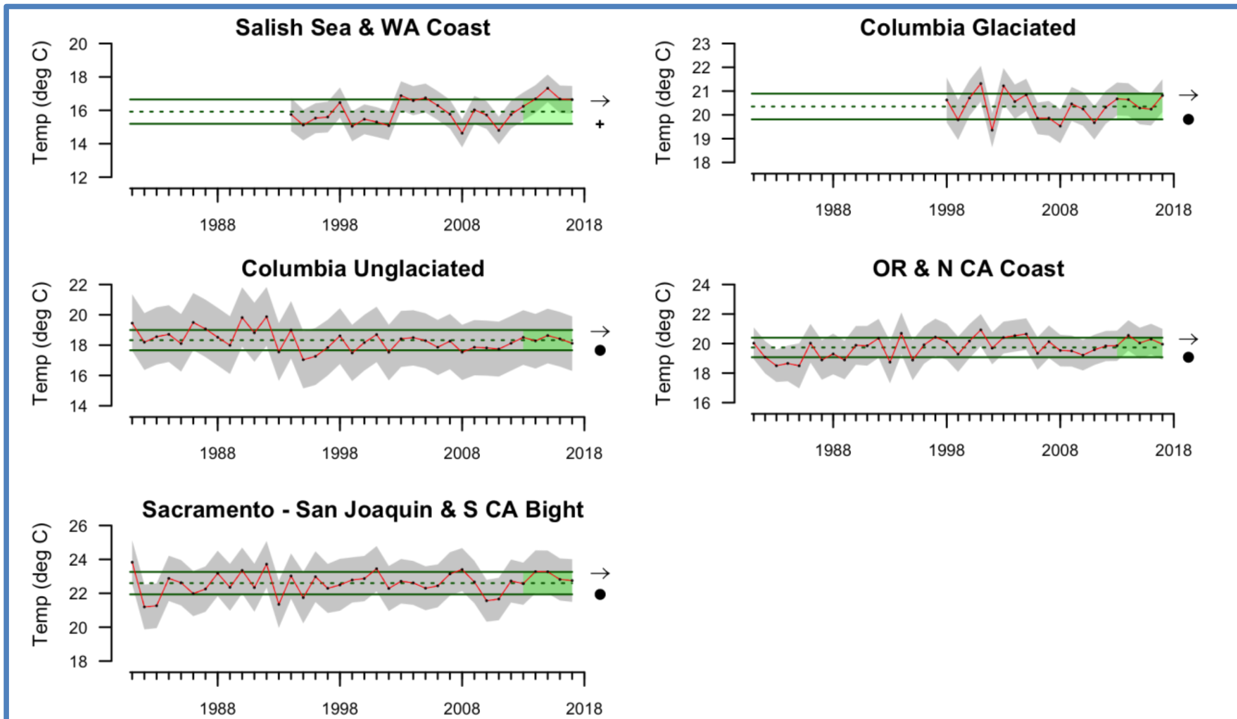


Figure F.2 Mean maximum stream temperature in August measured at 466 USGS gages in six ecoregions from 1981-2017. Gages include both regulated (subject to hydropower operations) and unregulated systems, although trends were similar when these systems were examined separately. Lines and symbols as in Fig. 1.

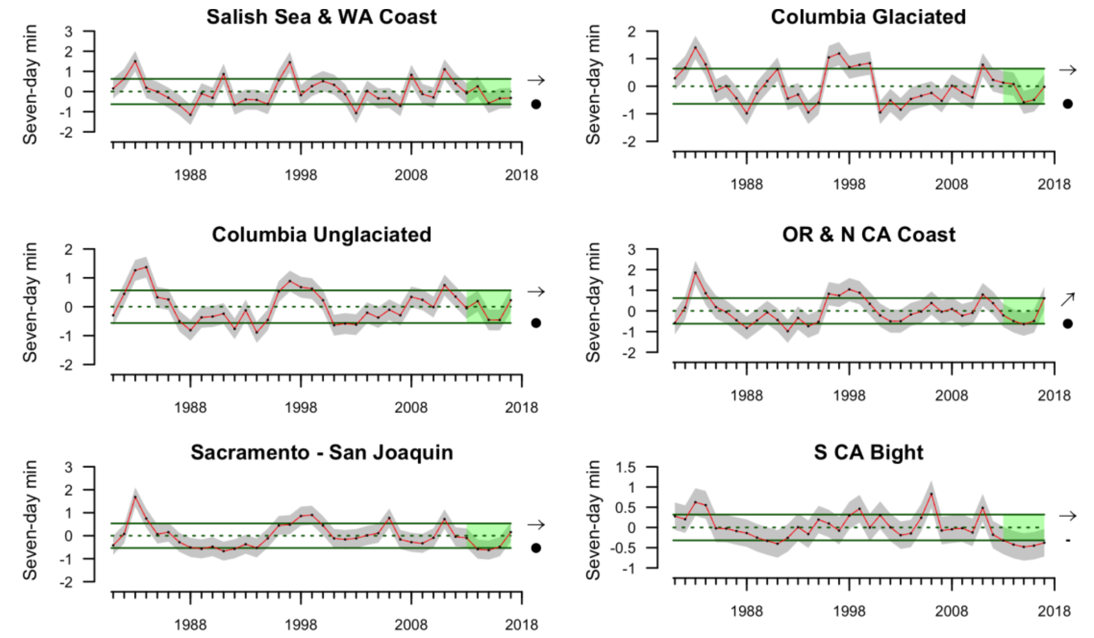


Figure F.3 Anomalies of the 7-day minimum streamflow measured at 213 gages in six ecoregions. Gages include both regulated (subject to hydropower operations) and unregulated systems, although trends were similar when these systems were examined separately. Lines and symbols as in Fig. 1.

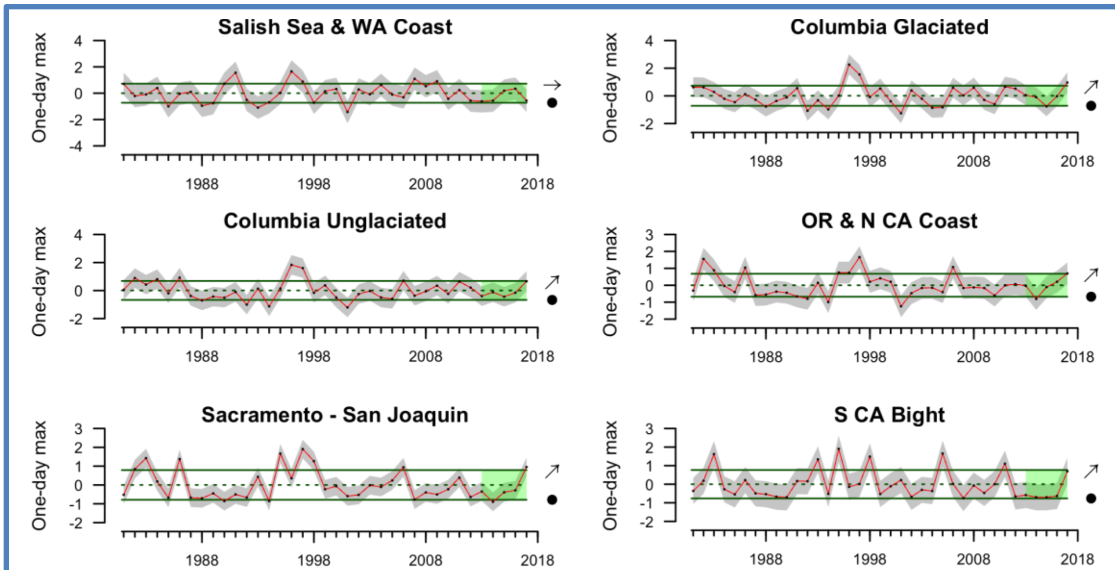


Figure F.4 Anomalies of the 1-day maximum streamflow measured at 213 gages in six ecoregions. Gages include both regulated (subject to hydropower operations) and unregulated systems, although trends were similar when these systems were examined separately. Lines and symbols as in Fig. 1.

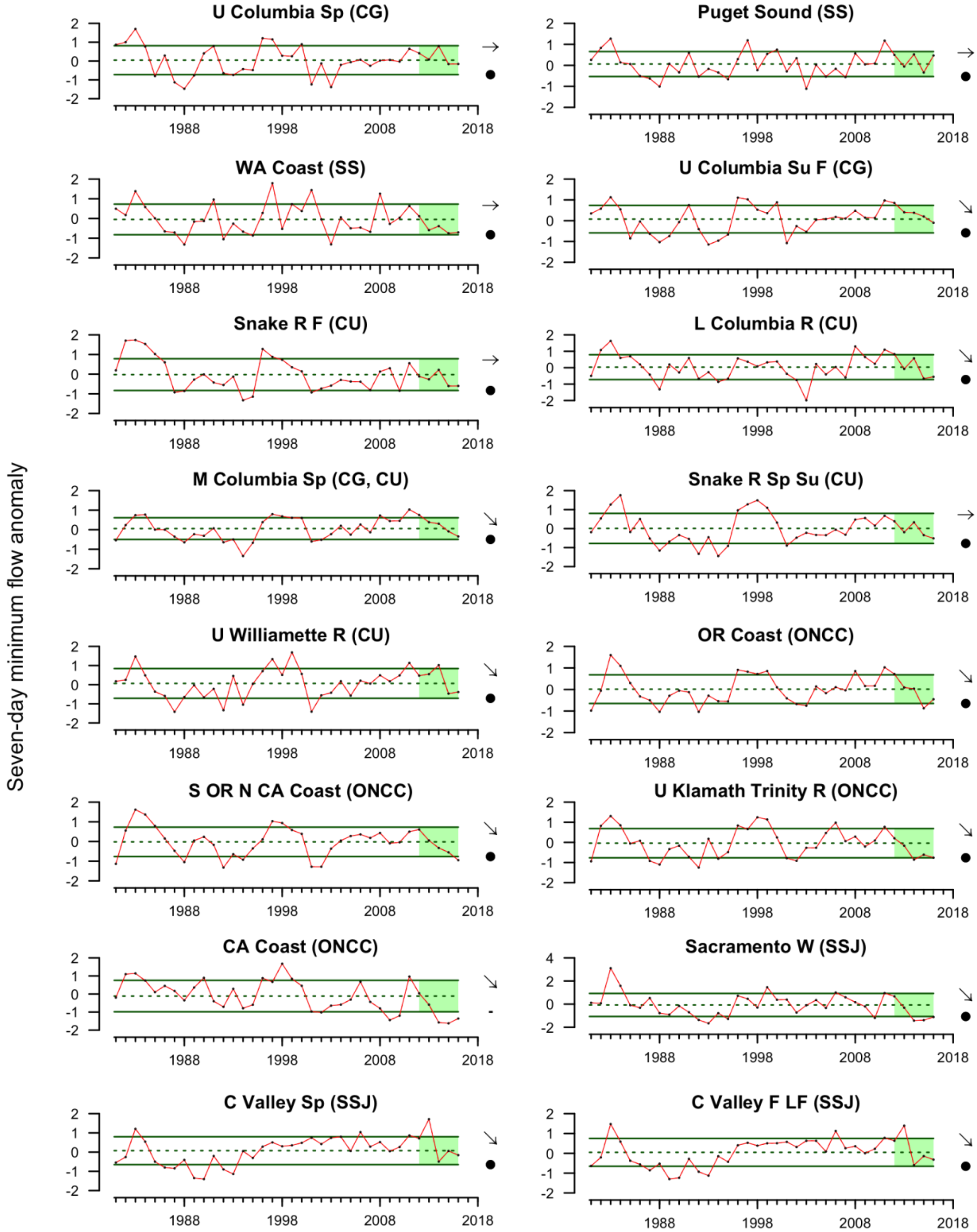


Figure F.5 Anomalies of the 7-day minimum streamflow measured at 213 gages in 16 Chinook salmon ESUs. Gages include both regulated (subject to hydropower operations) and unregulated systems, although trends were similar when these systems were examined separately. Lines and symbols as in Fig. 1.

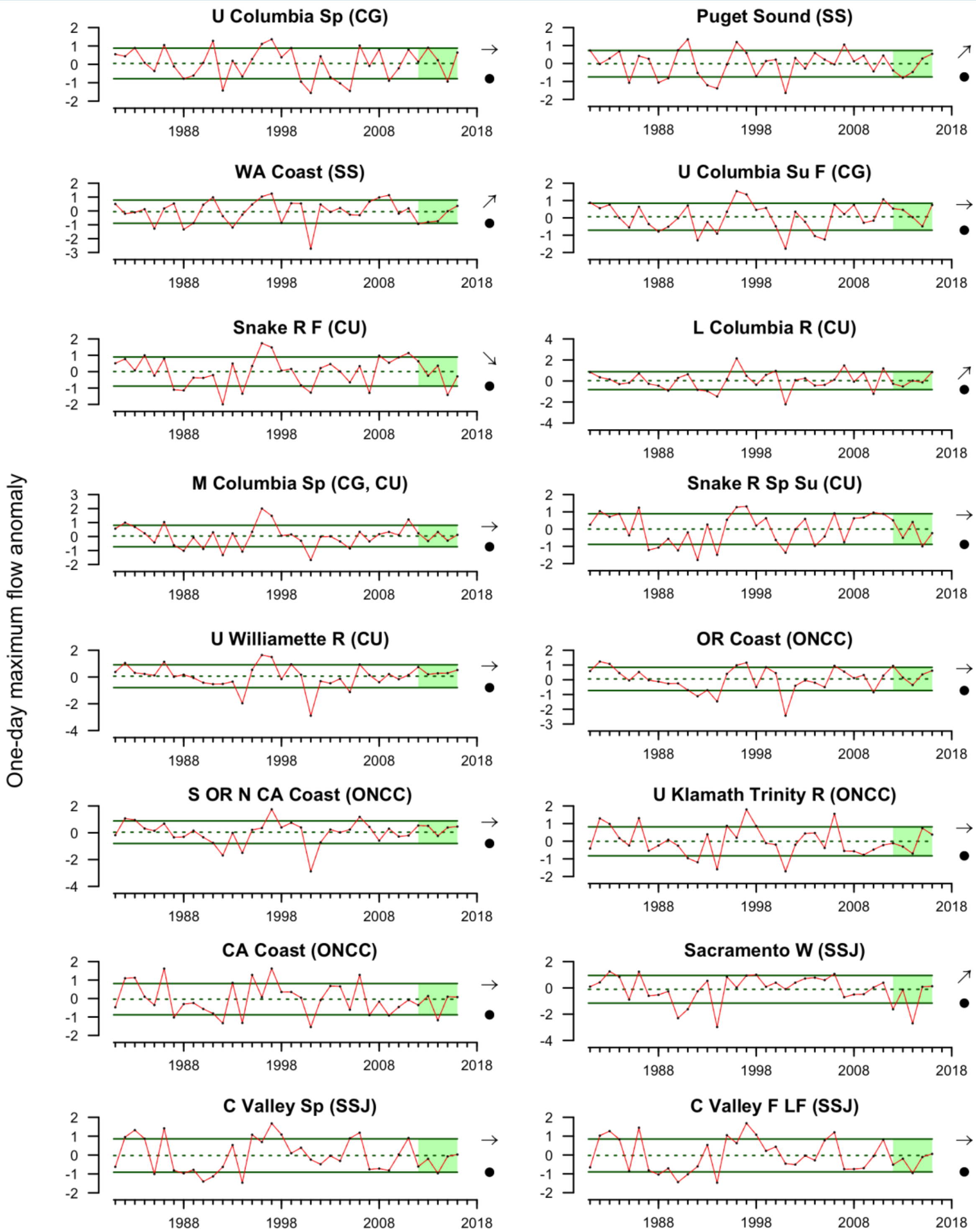


Figure F.6 Anomalies of the 1-day maximum streamflow measured at 213 gages in 16 Chinook salmon ESUs. Gages include both regulated (subject to hydropower operations) and unregulated systems, although trends were similar when these systems were examined separately. Lines and symbols as in Fig. 1.

Appendix G REGIONAL FORAGE AVAILABILITY

Species-specific trends in forage availability are based on research cruises in the northern, central, and southern portions of the CCE (Figure 2.1). Section 4.2 of the main body of this report describes forage community dynamics using quad plots to summarize recent status and trends relative to full time series. These plots are useful for summarizing large amounts of data, but they may hide informative short-term variability in these dynamic species. The full time series through 2017 are therefore presented here. As noted in the main report, we consider these to be regional indices of relative forage availability and variability; these are not indices of absolute abundance of coastal pelagic species (CPS). Collection details and format are indicated in the respective figure legends.

G.1 NORTHERN CALIFORNIA CURRENT FORAGE

The Northern CCE survey (now known as the "JSOES Survey") occurs in June and targets juvenile salmon in surface waters off Oregon and Washington, but also collects adult and juvenile (age 1+) pelagic forage fishes, market squid, and gelatinous zooplankton (*Aequorea* sp., *Chrysaora* sp.) with regularity. In 2017, most forage taxa were caught at levels within the long-term range of the survey (Figure G.1.1). One exception was jack mackerel catch, which exceeded long-term averages for the third year in a row. Catches of age 1+ sardine, anchovy, and herring were low and near the lower standard deviation of the long-term average. Catch rates of both gelatinous zooplankton taxa in 2017 were below or near long term averages.

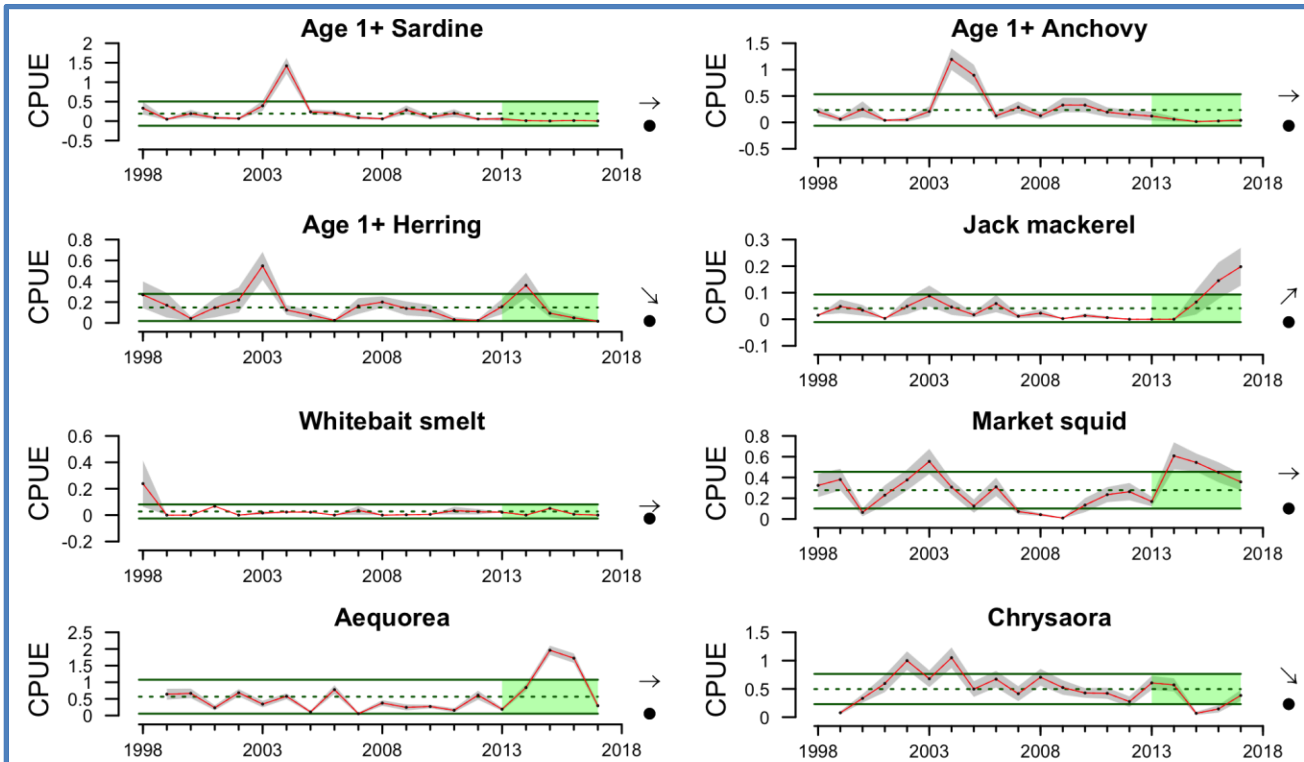


Figure G.1.1 Geometric mean CPUEs (Log_{10}(no. km^{-1}+ 1)) of key forage groups in the Northern CCE, from surface trawls conducted as part of the BPA Plume Survey, 1998-2017. Lines and symbols as in Fig. 1.

G.2 CENTRAL CALIFORNIA CURRENT FORAGE

The Central CCE forage survey (known as the "Juvenile Rockfish Survey") samples this region using midwater trawls, which not only collect young-of-the-year (YOY) rockfish species, but also a variety of other YOY and adult forage species, market squid, adult krill, and gelatinous zooplankton. Time series presented here are from the "Core Area" of that survey (see Figure 2.1c in the Main Report). In 2017, catches of adult anchovy and sardine remained near zero, whereas YOY rockfish and market squid continued recent patterns of exceptionally high catch (Figure G.2.1). Note: YOY anchovy and sardine are not included in the data below. YOY hake and YOY sanddabs catch declined to near long-term averages into 2017, while krill rose to above-average catch rates. Finally, two jellyfish taxa (*Aurelia* sp., *Chrysaora*) enumerated over most of this survey appeared to show average to below-average catch rates, although these signals may actually be masked by abandonment of tows at stations where exceptional catches of jellyfish and tunicates (pyrosomes and salps, not presented here) have clogged survey nets in the past.

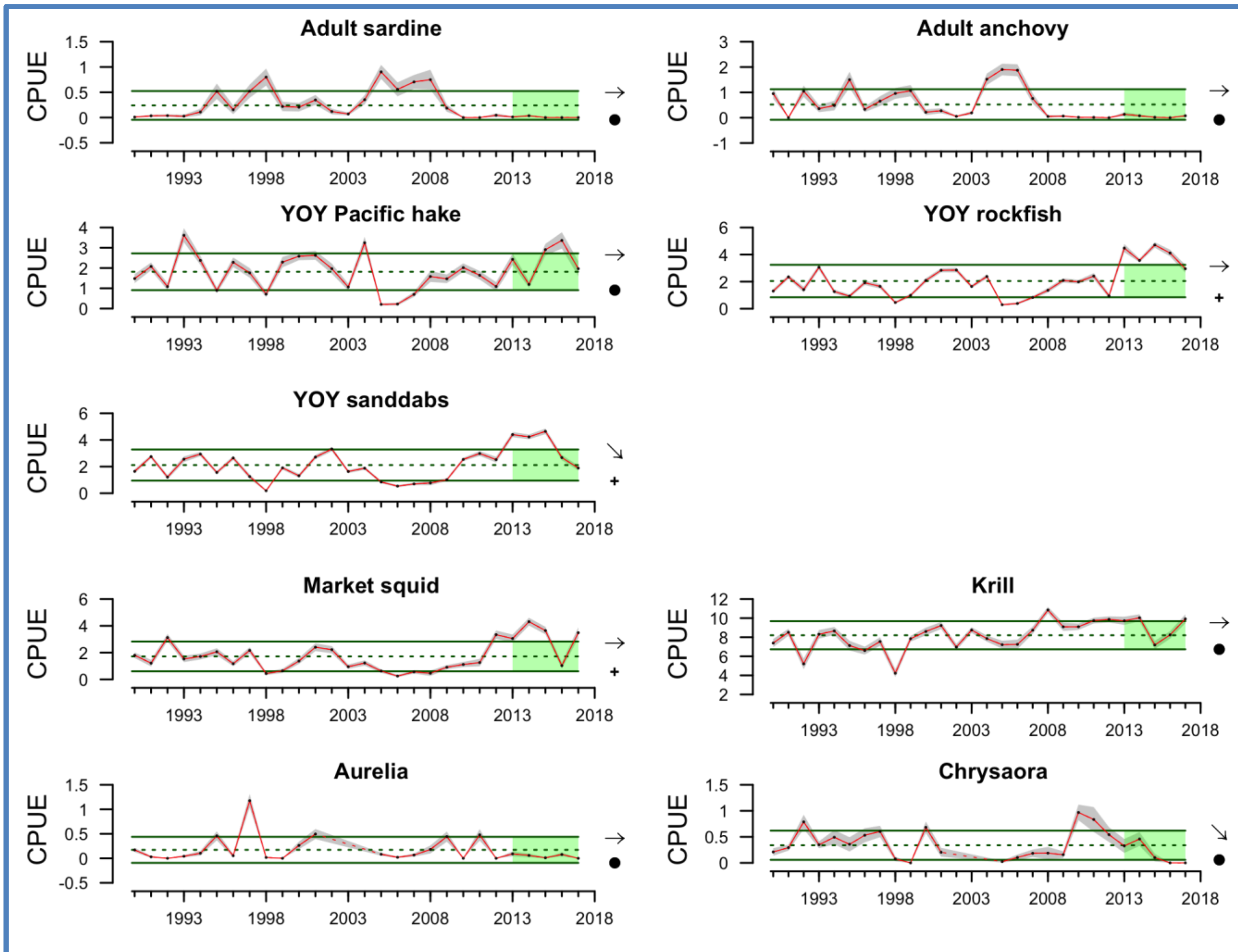


Figure G.2.1 Geometric mean CPUEs (mean (ln catch+1)) of key forage groups in the Central CCE, from the SWFSC Rockfish Recruitment and Ecosystem Assessment during 1990-2017. Lines and symbols as in Fig. 1., with the exception that shaded errors in these figures represent standard deviations of log transformed catches.

G.3 SOUTHERN CALIFORNIA CURRENT FORAGE

The abundance indicators for forage in the Southern CCE come from fish and squid larvae collected in the spring across all core stations of the CalCOFI survey using oblique vertical tows of fine mesh Bongo nets to 212 m depth. The survey collects a variety of fish and invertebrate larvae (<5 d old) from several taxonomic and functional groups. Larval data are indicators of the regional biomass of adult forage species such as anchovy and sardine. They likely also reflect the relative abundance of some other fish species, including mesopelagic species. Noteworthy observations from 2017 surveys include the increase in relative abundance of anchovy, shortbelly rockfish, and jack mackerel, the near-zero catch of sardine for the 6th year in a row, and the decline of sanddab and market squid (Figure G.3.1).

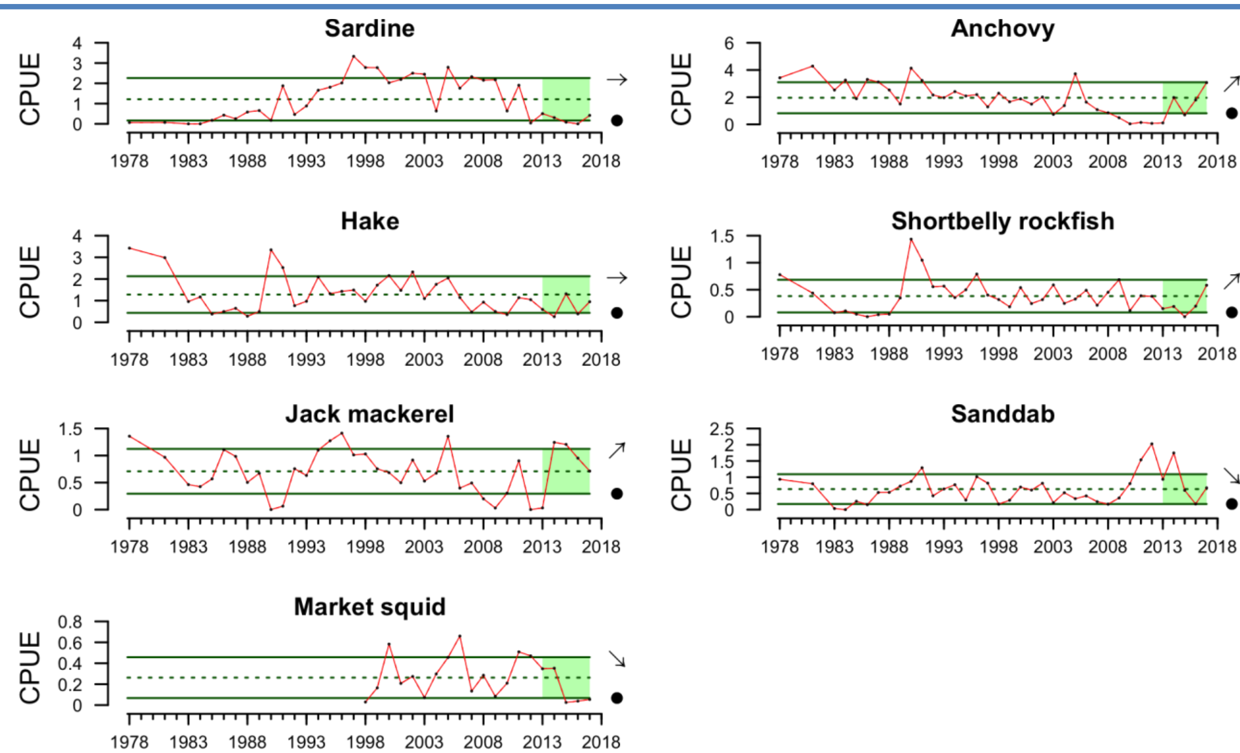


Figure G.3.1 Mean abundance (ln(abundance+1)) of the larvae of key forage species in the southern CCE, from spring CalCOFI surveys during 1978-2017. Lines and symbols as in Fig. 1.

Appendix H CHINOOK SALMON ESCAPEMENT INDICATORS

Population-specific status and trends in Chinook salmon escapement are provided in Section 4.3 of the Main Report. Figure 4.3.1 uses a quad plot to summarize recent escapement status and trends relative to full time series. These plots are useful for summarizing large amounts of data, but they may hide informative short-term variability in these dynamic species. The full time series for all populations are therefore presented here. We note again that these are escapement numbers of wild spawning fish, not run-size estimates, which take many years to develop. Status and trends are estimated for the most recent 10 years of data (unlike 5 years for all other time series in this Report) in order to account for the spatial segregation of successive year classes of salmon.

H.1 CALIFORNIA CHINOOK SALMON ESCAPEMENTS

The Chinook salmon escapement time series from California include data from as recent as 2016 extending back over 20 years, with records for some populations (Central Valley Late Fall; Southern Oregon/Northern California Coastal; Klamath Fall) stretching back to the 1970s. No population showed near-term trends (Figure H.1.1), and escapement estimates for all populations in 2016 were below the long-term mean for their respective time series (but by <1 s.d.). However, several populations have experienced lower escapements in 2013-2016 than in the late 1990s to mid 2000s.

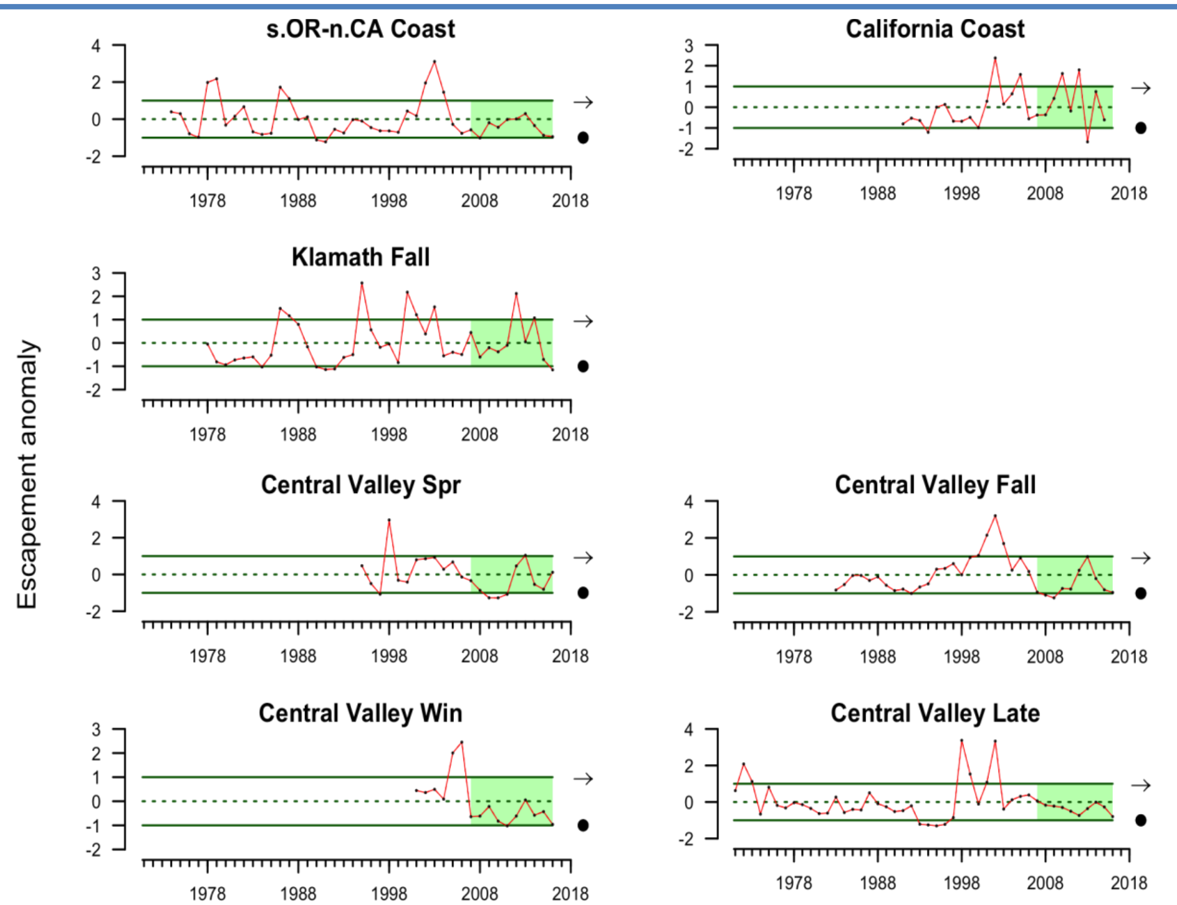


Figure H.1.1 Anomalies of escapement of wild Chinook salmon in California watersheds through 2016. Lines and symbols as in Fig. 1.

H.2 WASHINGTON/OREGON/IDAHO CHINOOK SALMON ESCAPEMENTS

The escapement time series used for Chinook salmon populations from Washington, Idaho, and Oregon extend back over 40 years, but because the stocks are often co-managed and the surveys conducted by a variety of state and tribal agencies, the most recent data are currently only available through 2016 (Figure H.2.1). Two of the five stocks examined (Snake River Fall and Lower Columbia) have shown improving escapement trends in the last ten years. Snake River Fall Chinook in 2016 were significantly above the long-term mean for the sixth year in a row, and the recent 10-year average is significantly greater than the long-term mean. Other populations' recent averages are within 1 s.d. of long-term mean.

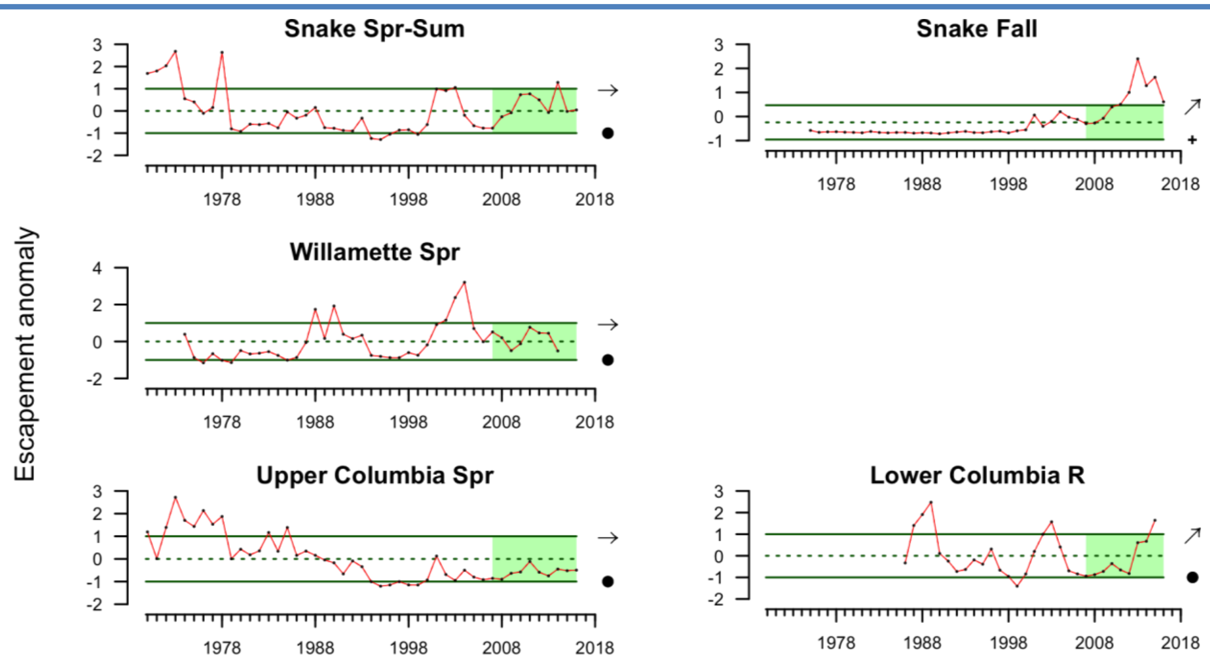


Figure H.2.1 Anomalies of escapement of wild Chinook salmon in Washington, Oregon, and Idaho watersheds through 2016. Lines and symbols as in Fig. 1.

Appendix I DEMERSAL COMMUNITY STRUCTURE

We are tracking the abundance of groundfish relative to Dungeness and Tanner crabs as a metric of seafloor community structure and trophic status. This ratio may also relate to opportunities for vessels to participate in different fisheries.

Data are area-weighted mean crab:finfish biomass ratios from NMFS trawl survey sites north and south of Cape Mendocino (Figure I.1). The ratio has varied by region and time, and peaked in the south in 2010, a year earlier than in the north. Following those peaks, the crab:finfish ratio declined, but increases in 2015 stabilized the recent trend in the south. As of 2016 (most recent data), the ratio remains at or slightly above and within one s.d. of the long-term mean, with a relatively stable trend.

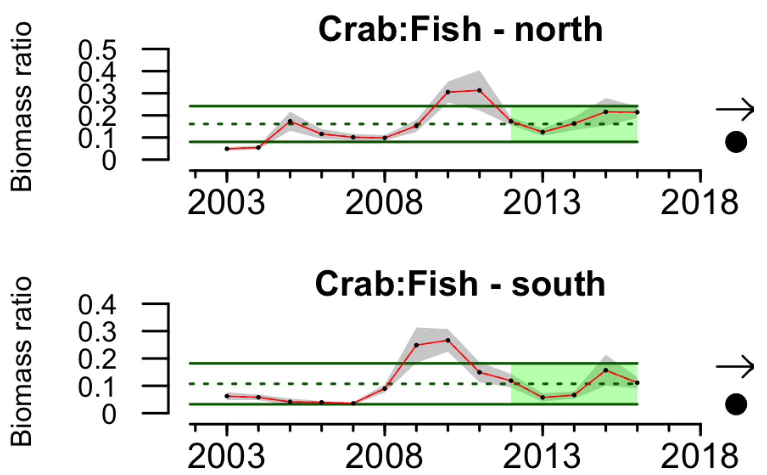


Figure I.1 Ratio of crab biomass to finfish biomass for the NMFS West Coast Groundfish Bottom Trawl Survey through 2016. Lines and symbols as in Fig. 1.

Appendix J HIGHLY MIGRATORY SPECIES

Highly migratory species are discussed in Section 4.5 of the main document, and summarized via quad plot in Figure 4.5.1. The time series for biomass (Figure J.2.1) and recruitment (Figure J.2.2) from HMS stock assessments are plotted here for reference.

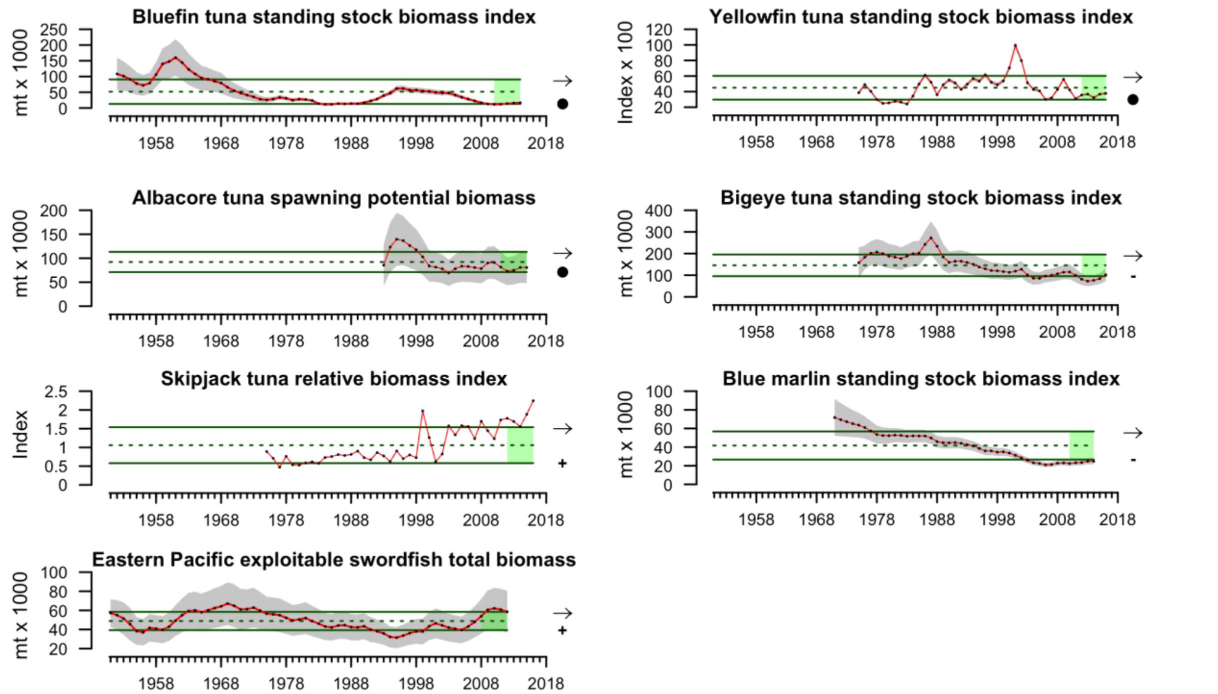


Figure J.2.1 Biomass for highly migratory species (HMS) that occur in the California Current to 2016. Lines and symbols as in Fig. 1.

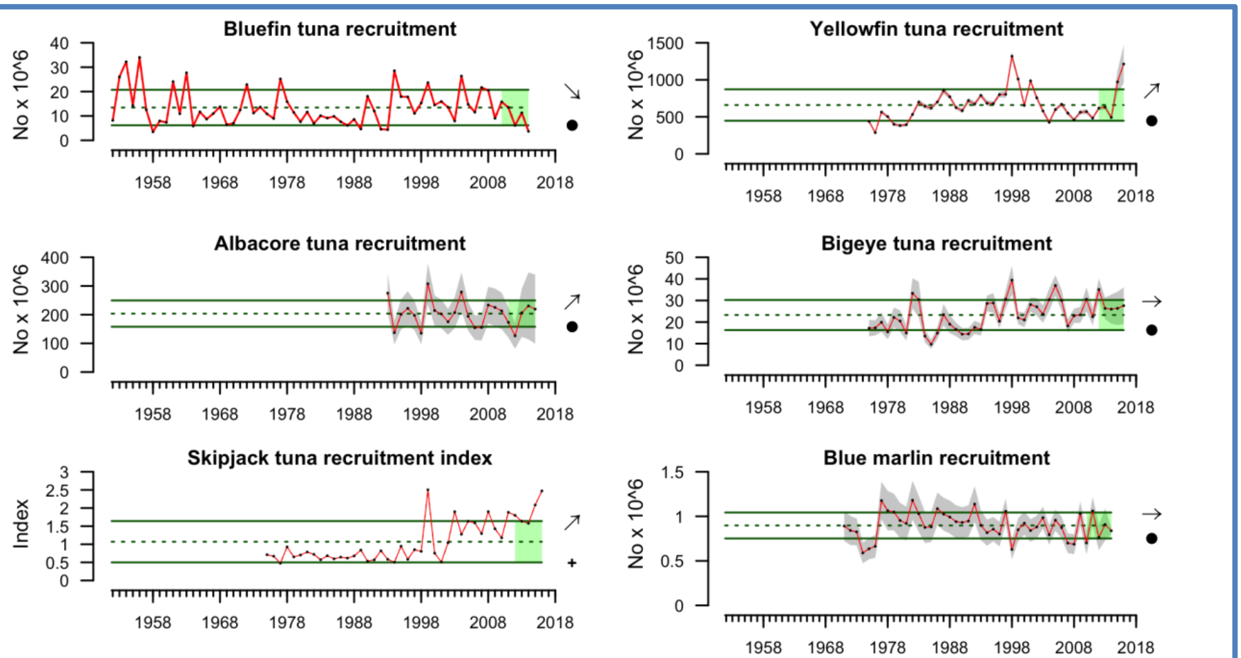


Figure J.2.2 Recruitment for highly migratory species (HMS) that occur in the California Current through 2016. Lines and symbols as in Fig. 1.

Appendix K SEABIRD DENSITY, DIET AND MORTALITY

K.1 SEABIRD AT-SEA DENSITIES

At-sea densities of seabirds are discussed in the main report. Figure 4.7.1 shows the trends in a quad plot. In Figure K.1.1 we replot the trends in standard time-series figures for more complete reference.

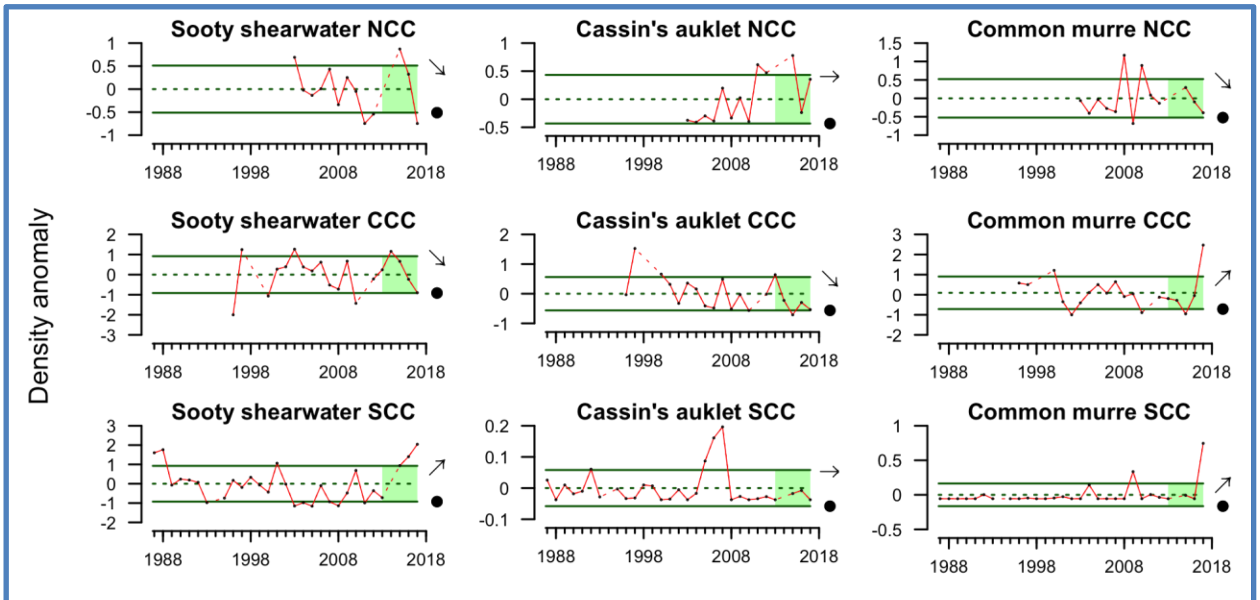


Figure K.1.1 Recent (5-year) trend and average of seabird at-sea densities during the summer in the California Current in three regions through 2017. Lines and symbols as in Fig. 1.

K.2 SEABIRD DIET

Seabird diet composition can track marine environmental conditions and the relative availability of prey. Rhinoceros auklets primarily forage on pelagic fishes in shallow waters over the continental shelf, generally within 50 km of breeding colonies during chick-rearing. They return to the colony at dusk to deliver multiple whole prey (fish or cephalopods) to their chicks. Common murres forage on pelagic fishes in deeper waters over the shelf and near the shelf break, generally within 80 km of breeding colonies during chick-rearing. They return to the colony during daylight hours to deliver single whole fish to their chicks.

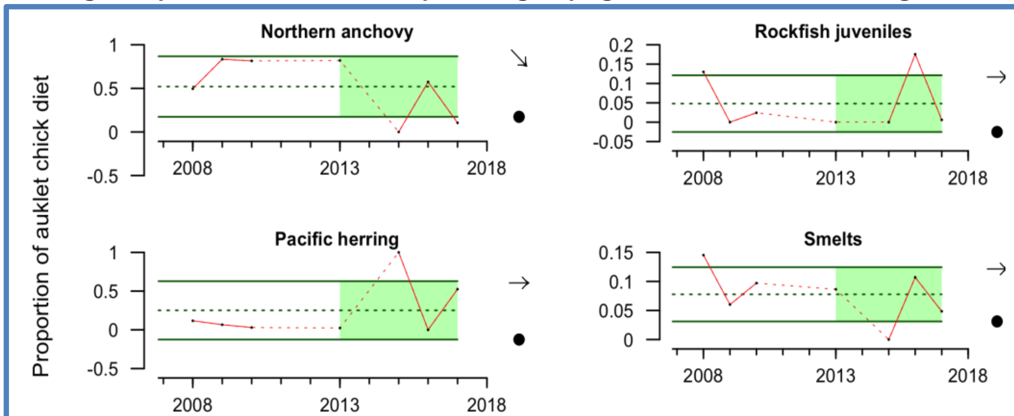


Figure K.2.1 Rhinoceros auklet chick diets at Destruction Island through 2017. Lines and symbols as in Fig. 1. Data courtesy of the Washington Rhinoceros Auklet Ecology Project (scott.pearson@dfw.wa.gov). Lines and symbols as in Fig. 1.

Rhinoceros auklet diet indicators are from colonies in the northern and central CCE. The proportion of anchovies in diets of rhinoceros auklets at Destruction Island, WA was down in 2017, as it was in 2015, and showed a significant short-term decline

(Figure K.2.1). The few anchovy that were brought back to chicks in 2017 were the largest recorded in the time series (data not shown). The proportion of herring in the auklet diet was above the long-term mean in 2017; it was the mirror image of anchovy presence but not enough to show a significant short-term increase. The proportion of rockfish in the auklet diet returned to its normally low level after a peak in 2016, and showed no short-term trend. The proportion of smelts in the auklet diet was below the long-term mean in 2017 and showed no significant short-term trend.

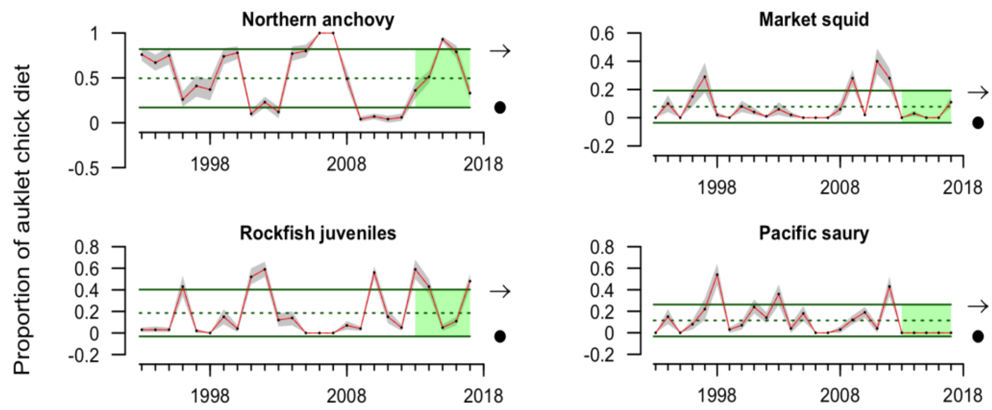


Figure K.2.2 Rhinoceros auklet chick diets at Año Neuvo through 2017. Data provided by Oikonos/Point Blue (ryan@oikonos.org). Lines and symbols as in Fig. 1.

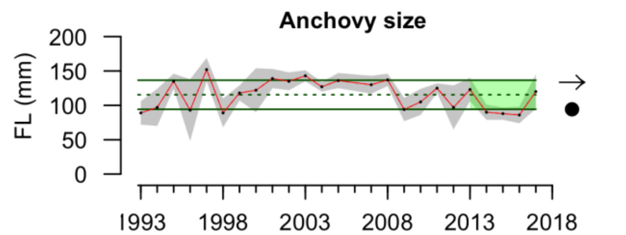


Figure K.2.3. Size of anchovy brought to rhinoceros auklet chicks at Año Nuevo from 1993-2017. Error envelope shows ± 1.0 s.d. Data provided by Oikonos/Point Blue (ryan@oikonos.org). Lines and symbols as in Fig. 1.

The proportion of anchovy in rhinoceros auklet chick diets at Año Neuvo Island, CA was below the long-term mean in 2017, down from a recent peak from 2014-2016, but showed no significant short-term trend (Figure K.2.2). The anchovies that were brought back to chicks in 2017 returned to the long-term mean range after three years of well below average size (Figure K.2.3). The proportion of rockfish in the auklet diet was above the long-term mean in 2017 but variable enough in recent years to not show a significant trend. The proportion of squid in the auklet diet returned to its average level in 2017 and showed no short-term trend. The proportion of Pacific saury in the auklet diet in 2017 continued to be well below the long-term mean and has disappeared from the observed diet since 2013.

Common murre diet indicators exhibited variable patterns at a colony in Oregon (Figure K.2.4). The proportion of smelts in the murre diet at Yaquina Head, OR was above the long-term mean in 2017, as it has been since 2012, but showed no significant short-term trend. The proportions of herring and sardines in the murre diet in 2016-2017 were the lowest seen in the time series, and the data showed a

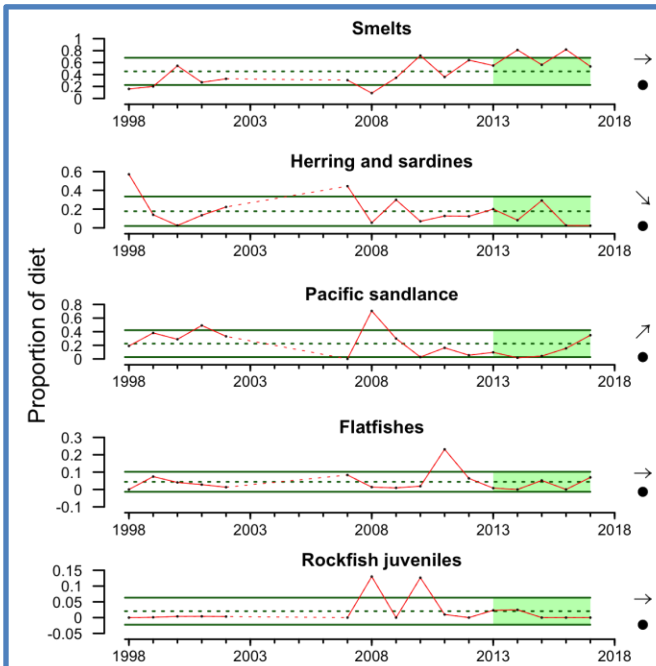


Figure K.2.4 Common murre chick diets at Yaquina Head through 2017. Data provided by the Yaquina Head Seabird Colony Monitoring Project (rob.suryan@noaa.gov). Lines and symbols as in Fig. 1.

significant short-term decline. The proportion of sandlance in the murre diet in 2017 was above the long-term mean and showed a short-term increase. The proportion of flatfishes in the murre diet was above the long-term mean in 2017 but showed no significant short-term trend. The proportion of rockfish in the murre diet in 2017 was zero for the third straight year but, as rockfish are only occasionally observed in the diet (peaks in 2008 and 2010), the data showed no significant short-term trend.

K.3 SEABIRD MORTALITY

Seabird mortality indicators in the northern California Current exhibited variable patterns on beaches from Washington to Northern California. In 2017, beached birds documented through the COASST program showed average to below average levels for the four focal species (Figure K.3.1). The encounter rate of Cassin's auklet returned to baseline levels in 2015 and 2016 after the large die-off in 2014, and the data showed a significant short-term decline (note: annual data for this species are calculated through February of the following year and so are summarized through 2016). The encounter rate of common murres in 2017, which had spiked due to a large die-off in 2015 and was low in 2016, returned to the long-term average in 2017 and showed no significant short-term trend. The encounter rate of sooty shearwaters, which had spiked from 2011-2013, continued to be low relative to the long-term mean in 2017 such that the data show a recent short-term decline. The encounter rate of northern fulmars has been just below the long-term mean since 2011, and the data showed no significant short-term trend (Note: annual data for this species are calculated through February of the following year and so are summarized through 2016).

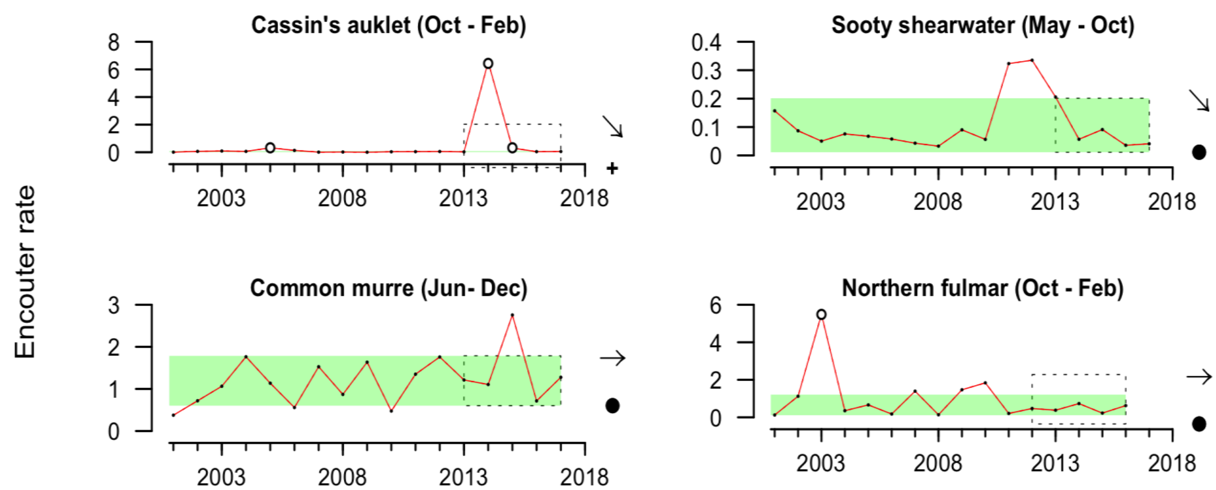


Figure K.3.1 Encounter rates (birds/km) of dead birds on West Coast beaches through 2017. The mean and trend of the last five years is evaluated versus the mean and s.d. of the full time series but with the outliers removed. Open circles indicate outliers, and the green box indicates the upper and lower s.d. Dotted lines indicate the evaluation period. Note variability was low for Cassin's auklet and the s.d. range is very small. Data provided by the Coastal Observation and Seabird Survey Team (https://depts.washington.edu/coasst/).

Appendix L STATE-BY-STATE FISHERY LANDINGS AND REVENUES

The Council and the EWG have requested information on state-by-state landings and revenues from fisheries; these values are presented here. Fishery landings and revenue data are best summarized by the Pacific Fisheries Information Network (PacFIN, http://pacfin.psmfc.org) for commercial landings and by the Recreational Fisheries Information Network (RecFIN, http://www.recfin.org) for recreational landings. Landings provide the best long-term indicator of fisheries removals. Revenue was calculated based on consumer price indices for 2016.

L.1 STATE-BY-STATE LANDINGS

Total fisheries landings in California decreased over the last five years and these patterns were driven by steep decreases in landings of market squid and crab from 2012-2016 (Figure L.1.1). Landings of groundfish (excluding hake) and coastal pelagic species (excluding squid) have been consistently below historical levels over the last five years, while crab landings remained above historical levels despite the recent decline. Landings of Pacific hake, shrimp, salmon, highly migratory species and other species have been relatively unchanged over the last five years. Methods for sampling and calculating total mortality in recreational fisheries changed recently, leading to a shorter comparable time series than shown in previous reports. Recreational landings in California (excluding salmon and Pacific halibut) were increasing through 2015, but a 70-80% decrease in yellowfin tuna and yellowtail landings in 2016

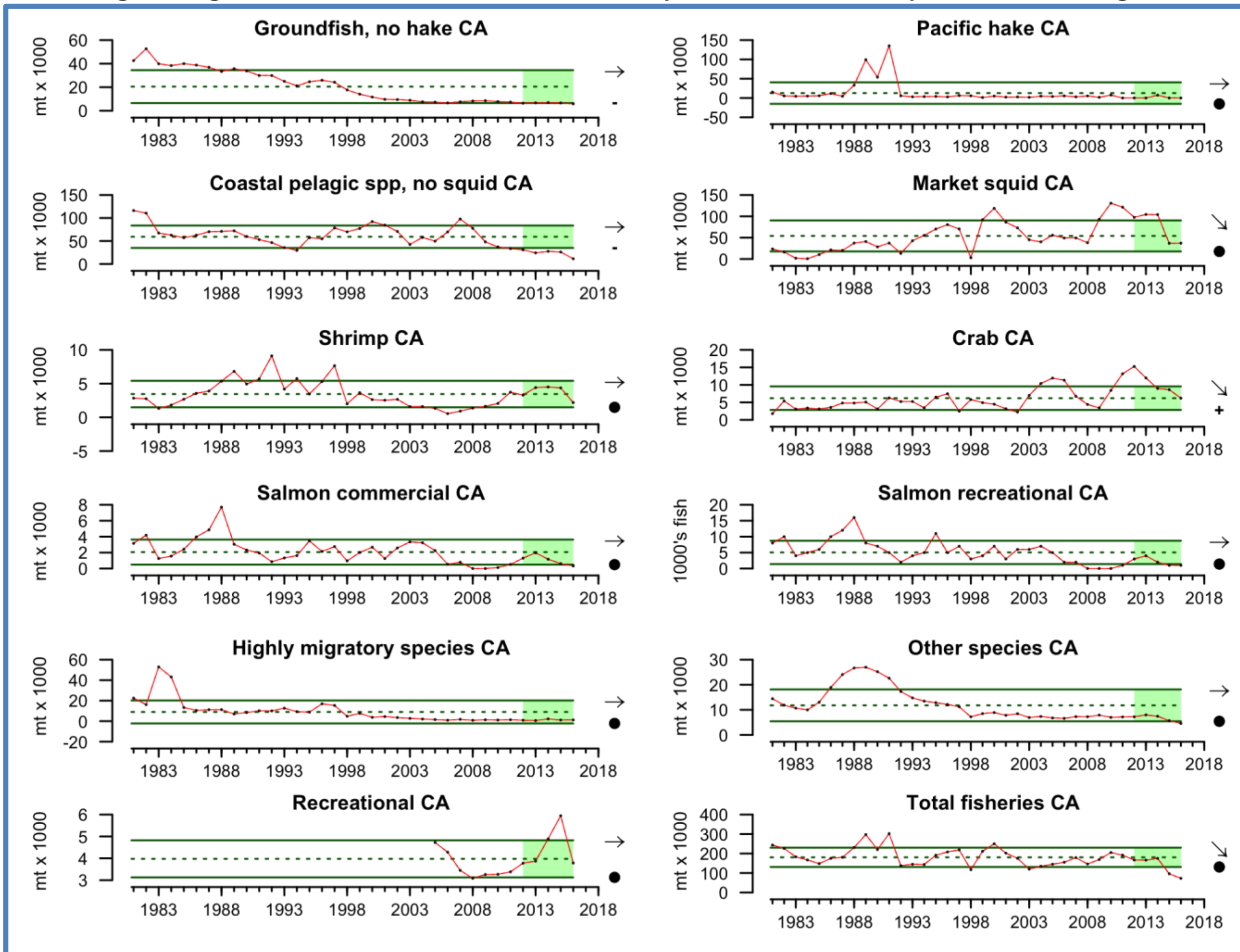


Figure L.1.1 Annual landings of West Coast commercial (data from PacFIN) and recreational (data from RecFIN) fisheries, including total landings across all fisheries from 1981-2016 in California (CA). Lines, colors, and symbols as in Fig. 1.

brought recreational landings within historical averages over the last five years (Figure L.1.1). Recreational salmon landings (Chinook and coho) were relatively unchanged and within historical averages from 2012-2016.

Total fisheries landings in Oregon have varied but were above historical levels from 2012-2016 (Figure L.1.2). These patterns were driven by interactions in landings of Pacific hake, which had a similar variance pattern over the last five years, and coastal pelagic species (excluding squid) which decreased over the last five years. Landings of groundfish (excluding hake) have been consistently near historically low levels in recent years, while landings of Pacific hake and shrimp were at historically high levels over the last five years. Landings of crab, salmon (commercial and recreational), highly migratory species and other species landings have been within historical averages over the last five years.

Methods for sampling and calculating total mortality in recreational fisheries changed recently, leading to a shorter comparable time series than shown in previous reports. Recreational fisheries landings (excluding salmon and Pacific halibut) in Oregon showed no significant trends and were within historical averages from 2012-2016 (Figure L.1.2). Salmon recreational landings (Chinook and coho) also showed no recent trends and were within historical averages over the last five years.

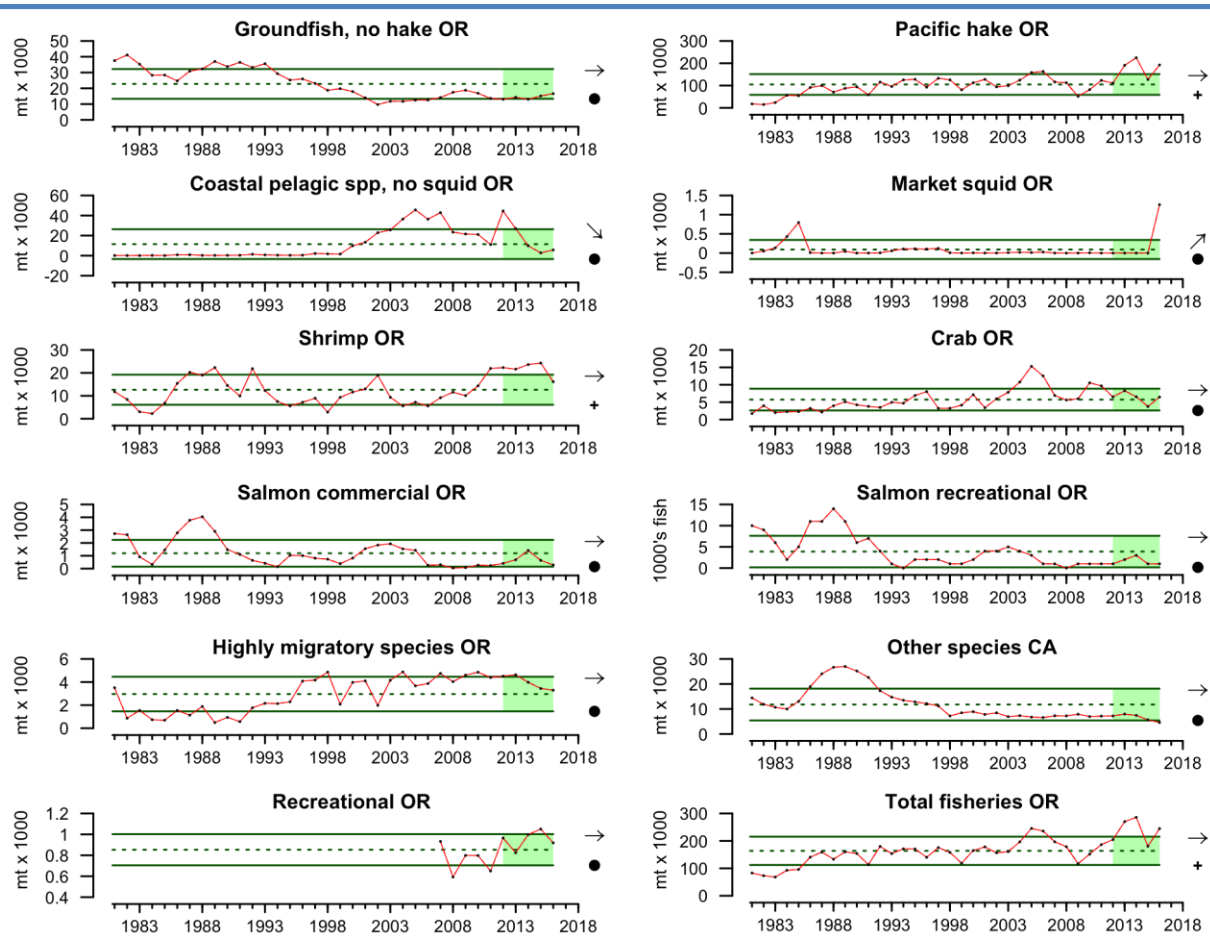


Figure L.1.2 Annual landings of West Coast commercial (data from PacFIN) and recreational (data from RecFIN) fisheries, including total landings across all fisheries from 1981-2016 in Oregon (OR). Lines, colors, and symbols as in Fig. 1.

Total fisheries landings in Washington decreased from 2012-2016, with particularly low landings in 2015 (Figure L.1.3). These patterns were driven primarily by large decreases in the landings of coastal pelagic species (excluding squid) commercial salmon over the same period and a dramatic decrease in shrimp landings in 2016. Landings of groundfish (excluding hake) were consistently below historical averages from 2012-2016, while landings of coastal pelagic species (excluding squid), shrimp and highly migratory species were above historical averages. Pacific hake, crab and other species landings showed no current trends and were within historical averages over the last five years.

Methods for sampling and calculating total mortality in recreational fisheries changed recently, leading to a shorter comparable time series than shown in previous reports. Total landings of recreational catch (excluding salmon and halibut) in Washington state were relatively unchanged at levels above historical averages from 2012-2016 (Figure L.1.3). Recreational landings of salmon (Chinook and coho) showed no trends and were within historical averages over the last five years; however, if the recent decreases in landings since 2014 continue, salmon recreational catch seems likely to go below historical averages.

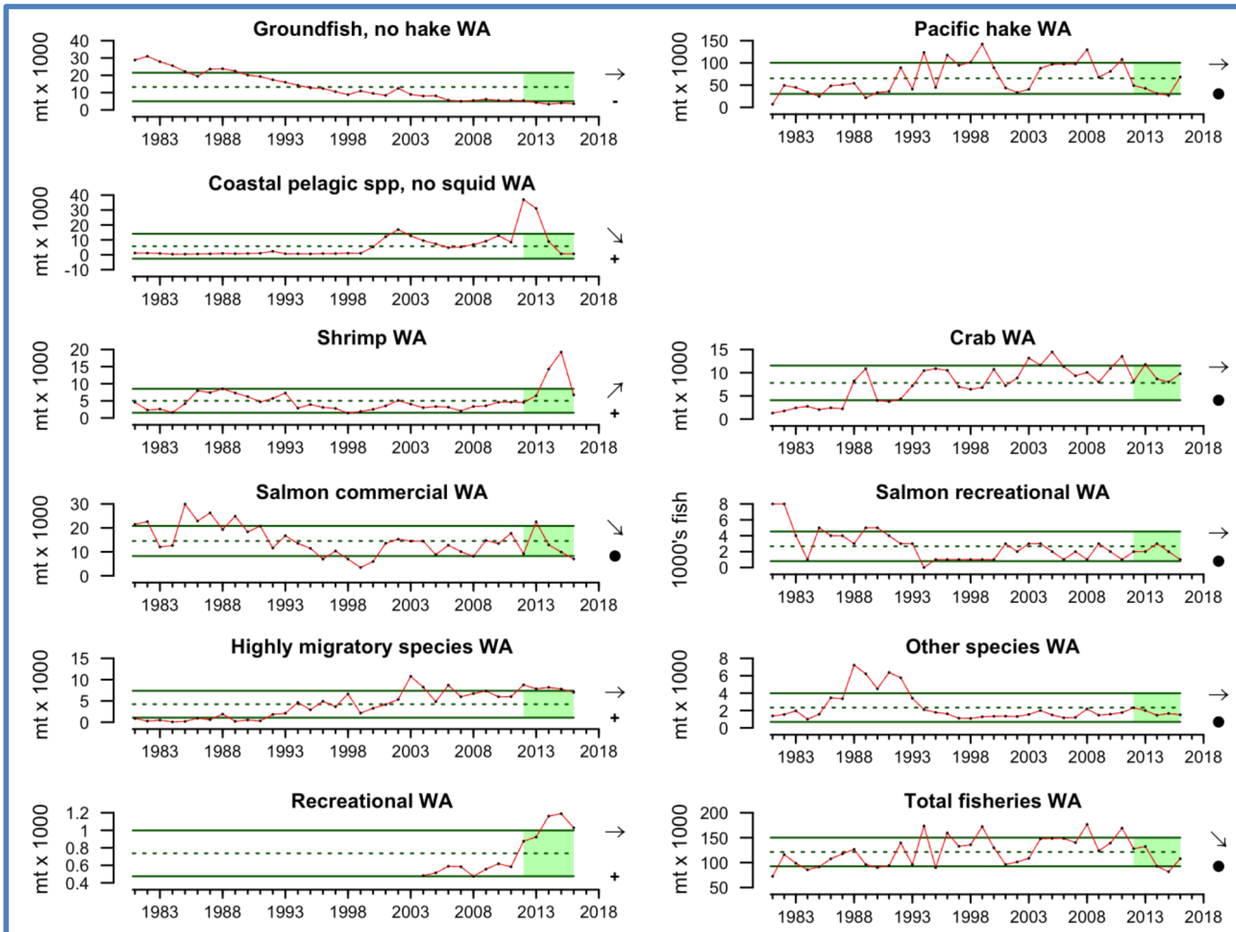


Figure L.1.3 Annual landings of West Coast commercial (data from PacFIN) and recreational (data from RecFIN) fisheries, including total landings across all fisheries from 1981-2016 in Washington (WA). Lines, colors, and symbols as in Fig. 1.

L.2 RECREATIONAL TAKE BY STATE AND FMP

We further broke down the available RecFIN data on state-by-state recreational take (landings plus dead discard) and summarized them by how the species group under the FMPs. Methods for sampling and calculating total mortality in recreational fisheries changed recently, leading to shorter comparable time series than shown in previous reports. In addition, data for recreational salmon landings are no longer contained within RecFIN databases and has been incorporated into previous coastwide and state-by-state figures (Figure 5.1.1, Figure L.3.1-Figure L.3.4). Comparable data are available for Washington since 2004, Oregon since 2007 and California since 2005. Below, we compare data from 2005 – 2016 to account for these differences.

California was the state with the clear majority of recreational take in all species groupings (Figure L.2.1). Recreational take of CPS has declined slightly since 2005, while take of groundfish has been increasing since 2008. Recreational HMS take has been highly variable; most recently, it rose sharply from 2011-2015 and then decreased dramatically in 2016 due to 70-80% decreases in catch of yellowfin tuna in California. Recreational take of "other" species that do not fall directly under an FMP was dominated by take in California (Figure L.2.1). Key species in the most recent year include yellowtail, barred surfperch, kelp bass, Pacific bonito, California halibut and striped bass. Take of these "other" species declined steeply between 2005 and 2013, then increased until 2015 before a large decrease in 2016.

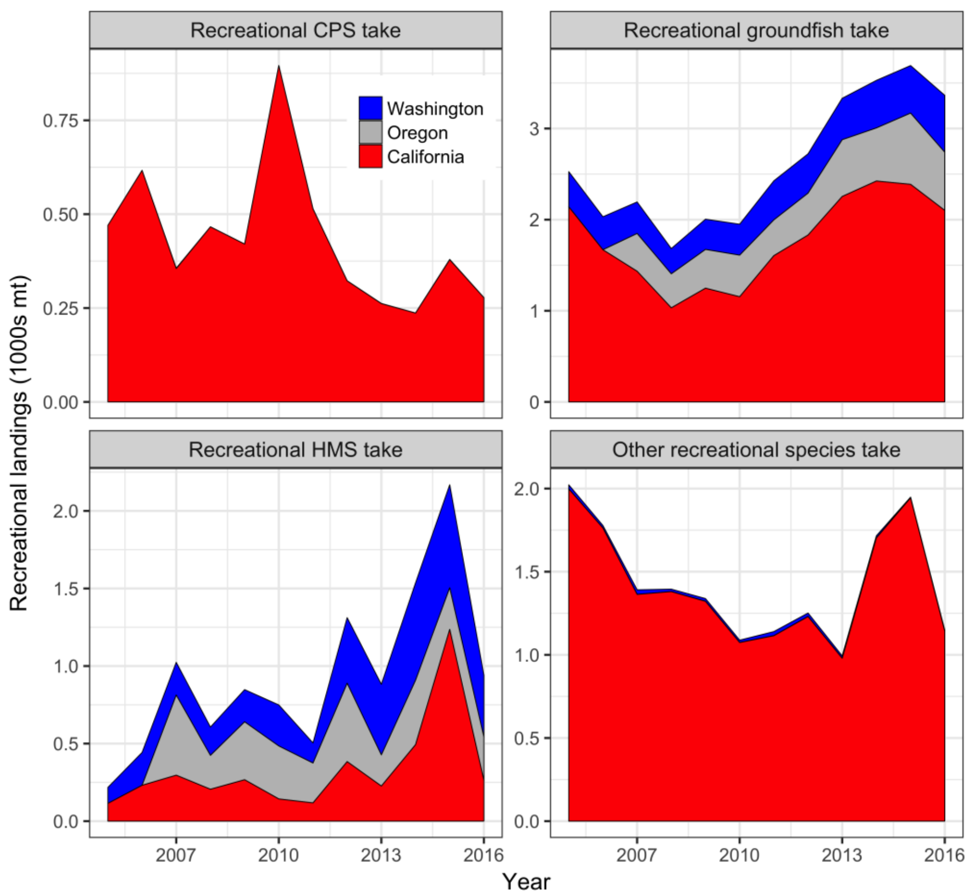


Figure L.2.1 Annual take by recreational fisheries (landings plus dead discard; data from RecFIN) from 2005-2016, summarized by state and by species groupings under the FMPs.

L.3 COMMERCIAL FISHERY REVENUES

Total revenue across U.S. West Coast commercial fisheries decreased from 2012–2016 (Figure L.3.1). This pattern was driven primarily by decreases in Pacific hake, coastal pelagic finfish species and market squid revenue over the last five years, particularly in 2015. The only fishery that increased in revenue over the last five years was shrimp, although revenue fell dramatically in 2016. Revenue from groundfish (excluding hake) remained consistently below historical averages from 2012-2016, while revenue from market squid and crab were above historical averages. Revenues from commercial salmon, highly migratory species and other species were relatively unchanged and within historical averages over the last five years.

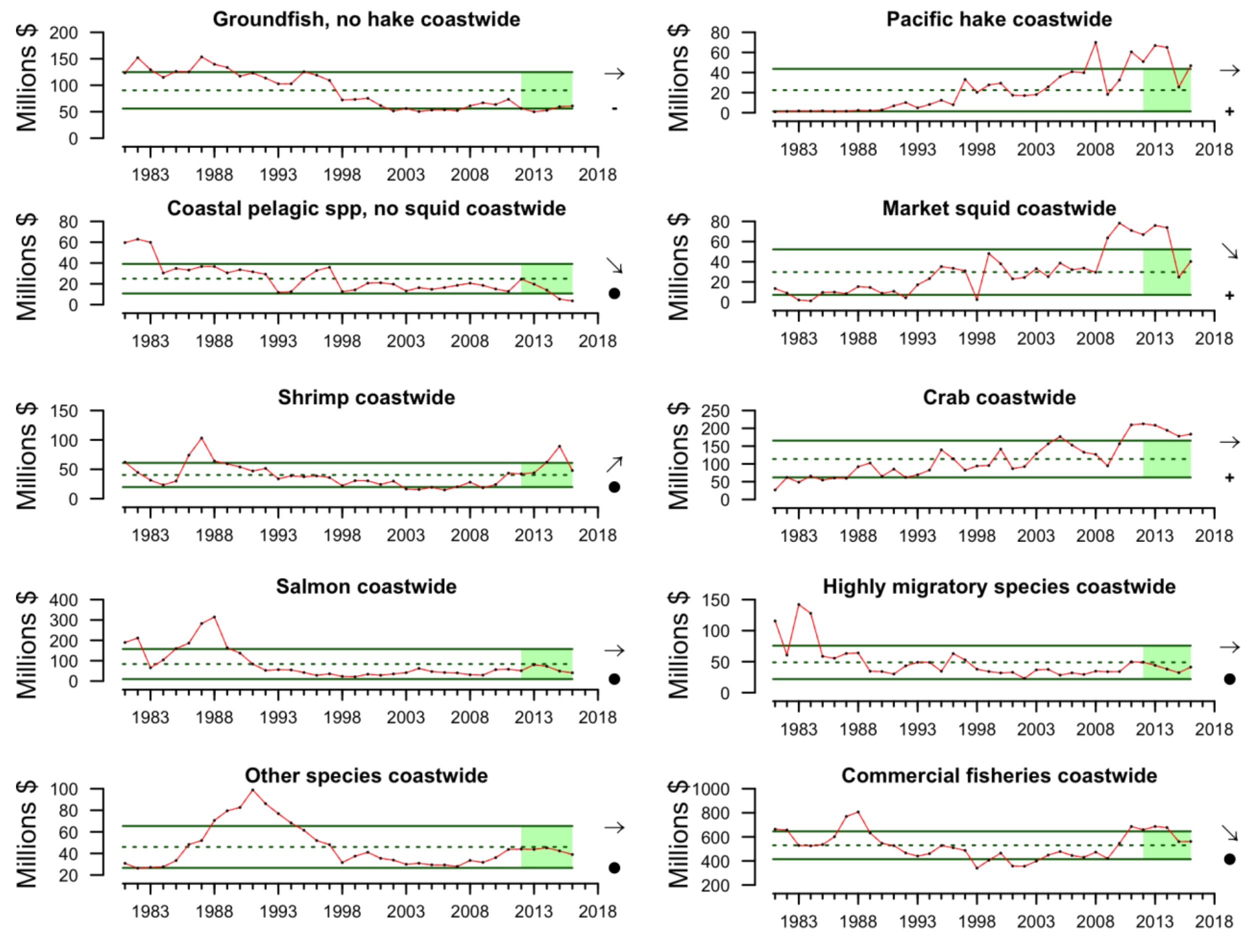


Figure L.3.1 Annual revenue (Ex-vessel value in 2015 dollars) of West Coast commercial fisheries (data from PacFIN) from 1981-2016. Pacific hake revenue includes shore-side and at-sea hake revenue values from PacFIN, NORPAC (North Pacific Groundfish Observer Program) and NMFS Office of Science & Technology. Lines and symbols as in Fig. 1.

Total revenue across commercial fisheries in California decreased from 2012–2016 (Figure L.3.2). This pattern was primarily driven by decreases in market squid and crab revenue over the last five years, particularly market squid in 2015. There were no fisheries that increased in revenue over the last five years – shrimp had been increasing until a large decrease in revenue in 2016. Revenue from coastal pelagic species (excluding market squid) was below historical averages from 2012-2016, while market squid and crab revenue was above historical averages. Revenue of groundfish (excluding hake) and highly migratory species remained consistently near historically low levels over the last five years, while revenue from Pacific hake, shrimp, salmon and other species were relatively unchanged and within historical averages over the last five years.

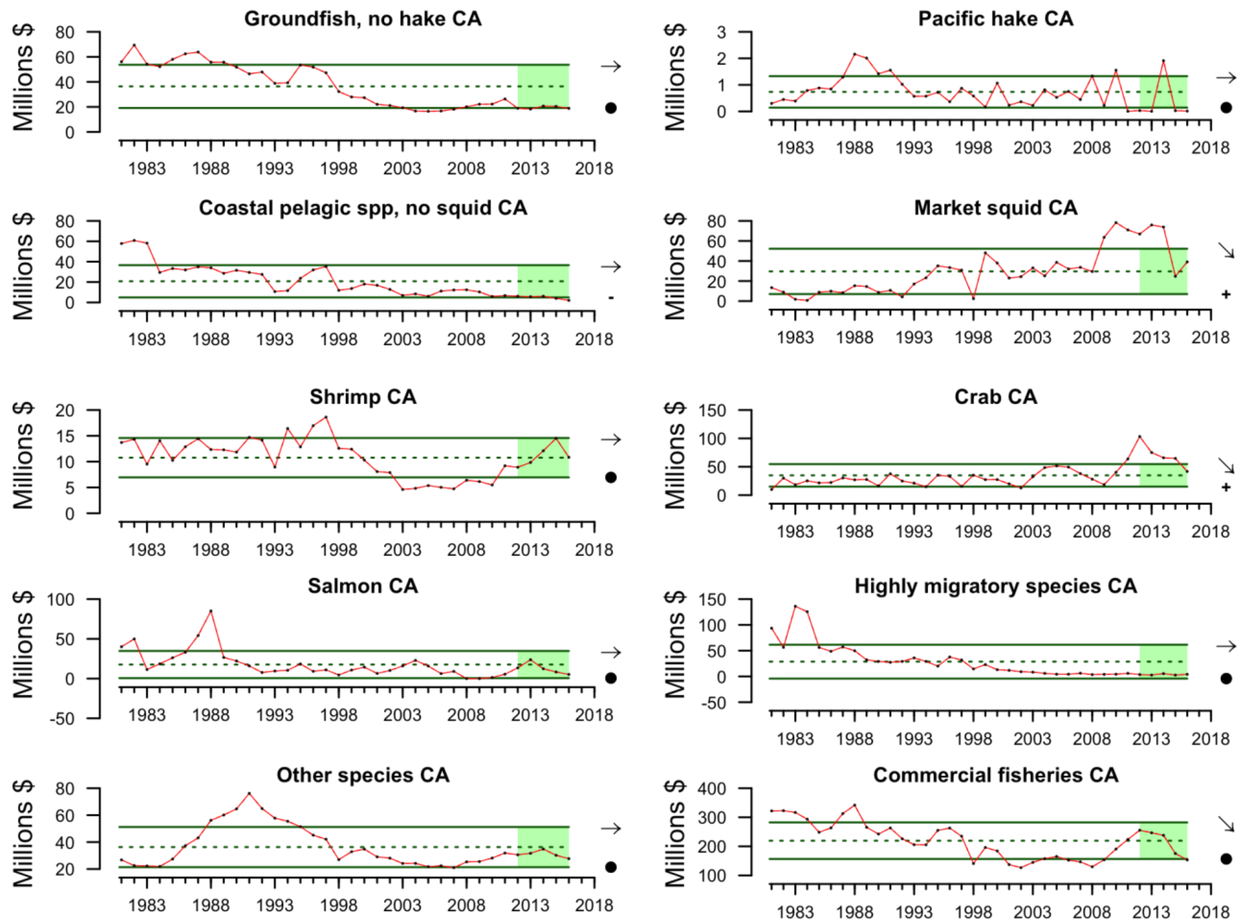


Figure L.3.2 Annual revenue (Ex-vessel value in 2015 dollars) of West Coast commercial fisheries in California (CA) (data from PacFIN) from 1981-2016. Pacific hake revenue includes shore-side and at-sea hake revenue values from PacFIN, NORPAC (North Pacific Groundfish Observer Program) and NMFS Office of Science & Technology. Lines and symbols as in Fig. 1.

Total revenue across commercial fisheries in Oregon was at historically high levels from 2012–2016 (Figure L.3.3). This pattern was driven by the amount of and variation in Pacific hake and crab revenues over the last five years. The only fishery that increased in revenue over the last five years in Oregon was market squid, due to an abnormally large catch in 2016. This may be related to unusual oceanographic conditions in 2016 that may not return, and although the magnitude of revenue gained in Oregon was relatively low (~$1 million), this trend may help explain potential changes in the distribution of market squid revenue among West Coast states. Revenue from coastal pelagic species (excluding market squid) and highly migratory species decreased from 2012-2016. All other fisheries showed no trend and were within historic averages in revenue over the last five years. It may be notable that revenue for groundfish (excluding hake) was closer to the historic mean in 2016 after several years of being near historically-low levels.

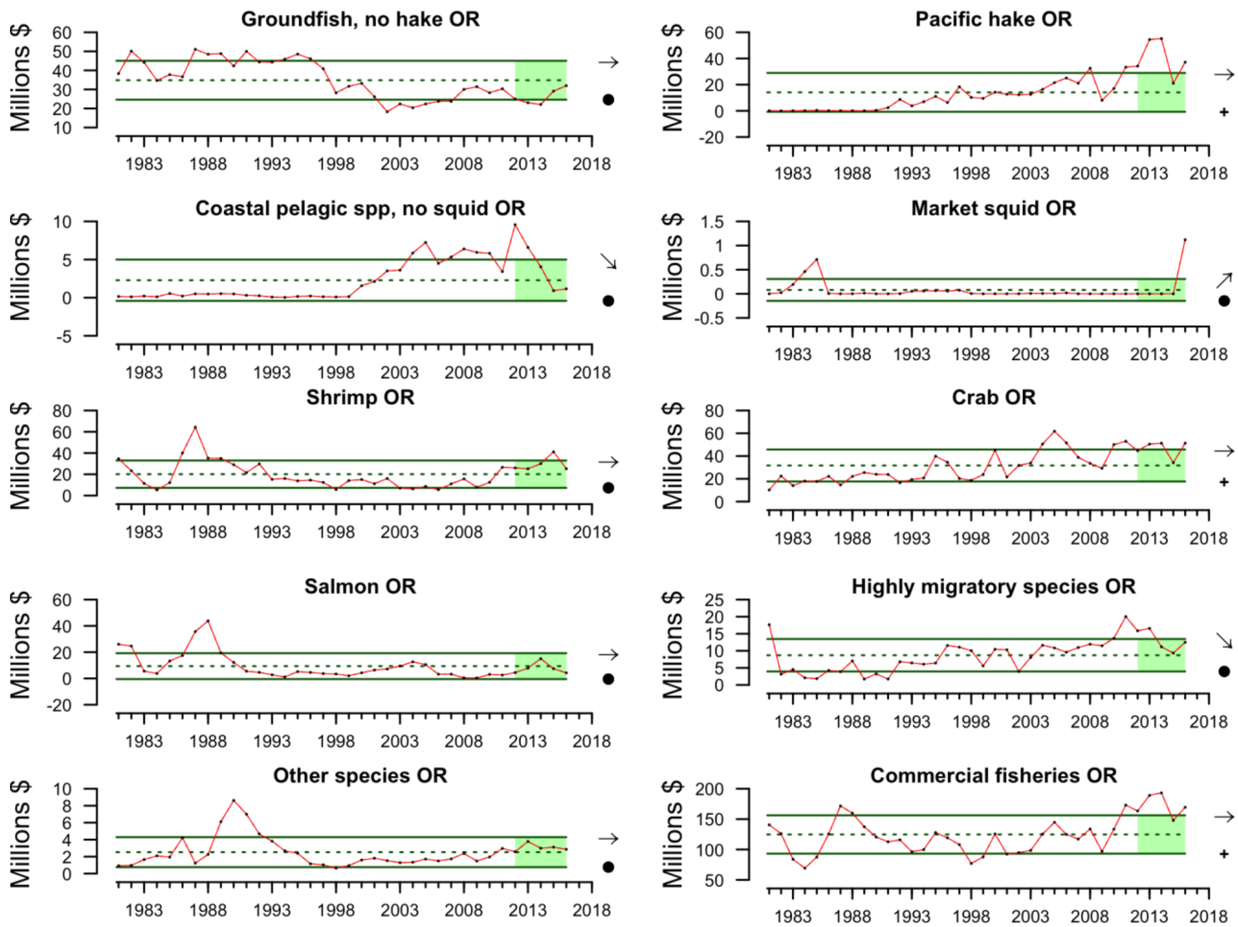


Figure L.3.3 Annual revenue (Ex-vessel value in 2015 dollars) of West Coast commercial fisheries in Oregon (OR) (data from PacFIN) from 1981-2016. Pacific hake revenue includes shore-side and at-sea hake revenue values from PacFIN, NORPAC (North Pacific Groundfish Observer Program) and NMFS Office of Science & Technology. Lines and symbols as in Fig. 1.

Total revenue across commercial fisheries in Washington remained relatively unchanged and at historically high levels from 2012–2016 (Figure L.3.4). This pattern observed in Washington (and in Oregon (Figure L.3.3)) is in sharp contrast with the decreases in revenue observed at the coastwide scale and in California over this same time period (Figure L.3.1& Figure L.3.2). This pattern is complicated but the relatively consistent and above historic levels of revenue for crab in Washington and Oregon provide a constant base of revenue, as opposed to the steady decline in crab revenue and the large decrease in revenue from market squid in California.

Revenue for Pacific hake and coastal pelagic species fisheries decreased from 2012-2016, while shrimp revenue increased and was above historic averages over the same time period despite a dramatic decrease in 2016. Revenue of groundfish (excluding hake) remained consistently below historic averages from 2012-2016, while revenue from highly migratory species was above historic averages. Revenue from salmon and other species were relatively unchanged and within historical averages over the period.

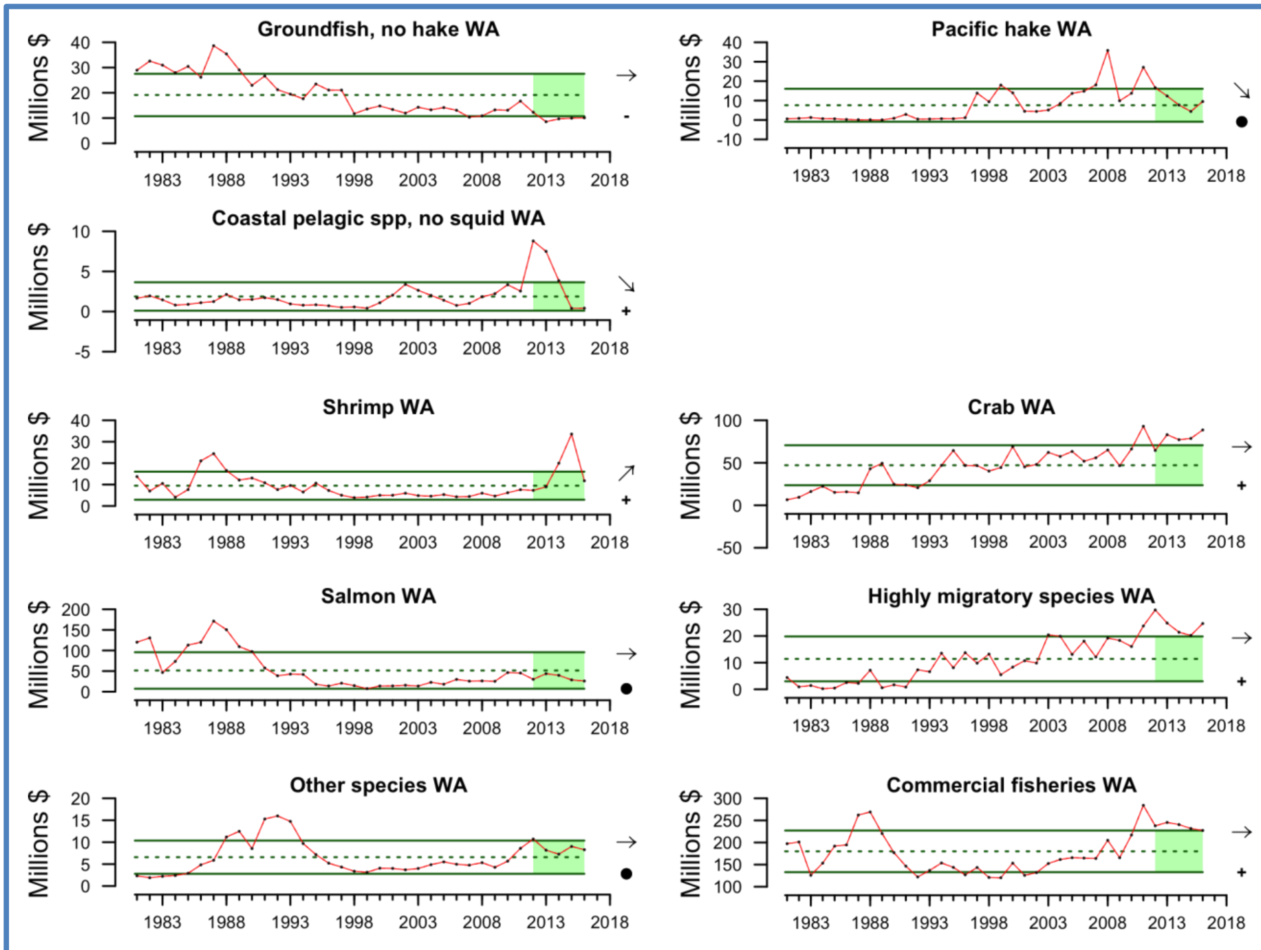


Figure L.3.4 Annual revenue (Ex-vessel value in 2015 dollars) of West Coast commercial fisheries in Washington (WA) (data from PacFIN) from 1981-2016. Pacific hake revenue includes shore-side and at-sea hake revenue values from PacFIN, NORPAC (North Pacific Groundfish Observer Program) and NMFS Office of Science & Technology. Lines and symbols as in Fig. 1.

Appendix M FISHING GEAR CONTACT WITH SEAFLOOR HABITAT

In the main body of the report (Section 5.2), we presented a spatial representation of the status and trends of habitat disturbance as a function of distances trawled. Here, we present time series representations of the data at a coastwide scale and broken out by regions ("Northern": north of Cape Mendocino; "Central": between Cape Mendocino and Point Conception; and "Southern": south of Point Conception), substrate types (hard, mixed, soft) and depth zones (shelf, upper slope, lower slope).

Benthic marine habitats can be disturbed or destroyed by geological events (e.g., earthquakes, fractures and slumping) and oceanographic processes (e.g., internal waves, sedimentation and currents) as well as various human activities (e.g., bottom contact fishing, mining, dredging), which can lead to mortality of vulnerable benthic species and disruption of food web processes. These effects may differ among physiographic types of habitat (e.g., hard, mixed or soft) and be particularly dramatic in sensitive environments (e.g., seagrass, algal beds and coral and sponge reefs). Exploration for resources (e.g., oil, gas and minerals) and marine fisheries often tend to operate within certain habitat types more than others, and long-term impacts of these activities may cause negative changes in biomass and the production of benthic communities. We used estimates of coastwide distances trawled along the ocean bottom from 1999 – 2015. Estimates from 2002 – 2015 include estimates of gear contact with seafloor habitat by bottom trawl and fixed fishing gear, while estimates from 1999 – 2002 include only bottom trawl data. We calculated trawling distances based on set and haul-back locations and fixed gear distances based on set and retrieval locations of pot, trap and longline gear. We weighted distances by gear type and fishing habitat according to sensitivity values described in Table A3a.2 of the 2013 Groundfish EFH Synthesis Report to PFMC. Data come from logbook data collected and reported by the Northwest Fisheries Science Center's West Coast Groundfish Observer Program.

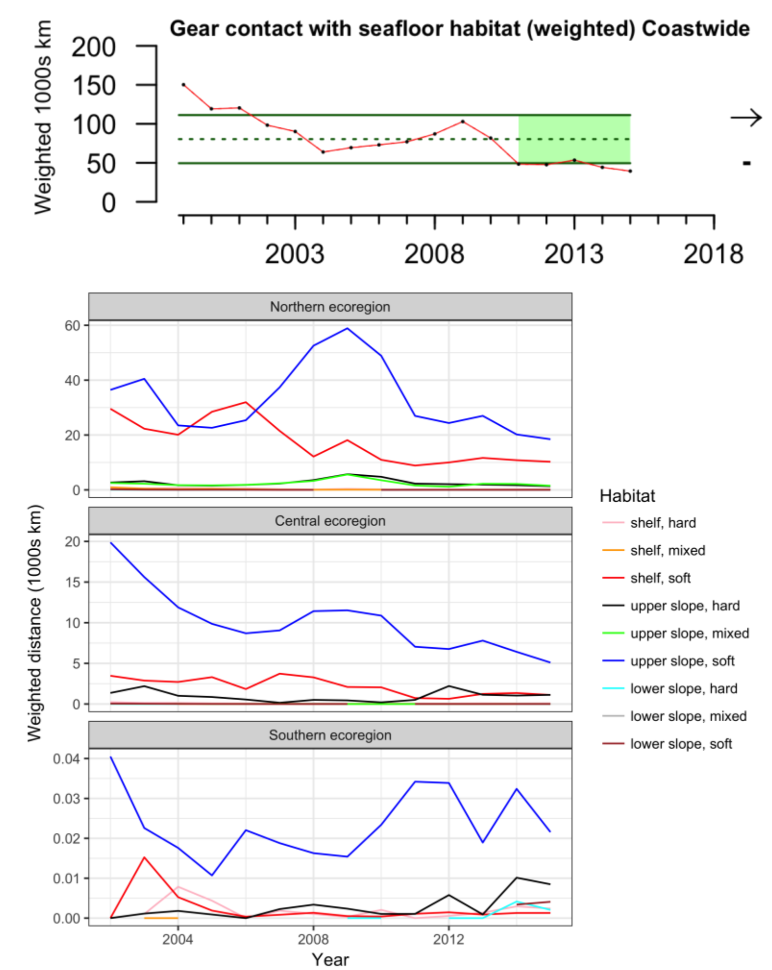


Figure M.1 Weighted distance (1000s km) of fishing gear contact with seafloor habitat across the entire CCE (top; 1999-2015) and within each ecoregion (bottom three panels; 2002-2015). Lines, colors and symbols in top panel are as in Fig. 1.1a.

At the scale of the entire U.S. West Coast, gear contact with seafloor habitat remained at historically low levels from 2011–2015 (Figure M.1, top). During this period, the vast majority of fishing gear contact with seafloor habitat occurred in soft, upper slope and shelf habitats. The Northern ecoregion also has seen the most fishing gear contact with seafloor habitat with nearly four times the magnitude as observed in the central ecoregion and >40 times the magnitude observed in the southern ecoregion, where very little bottom trawling has occurred within the time series. A shift in trawling effort from shelf to upper slope habitats was observed during the mid-2000's, which in part corresponded to depth-related spatial closures implemented by the Pacific Fishery Management Council. When compared to the mean for the entire time series, gear contact with seafloor habitats across all habitats has been within historic levels (statistics not shown due to space limitations). Reduced fishing gear contact may not coincide with recovery times of habitat depending on how fast recovery happens, which is likely to differ among habitat types (e.g., hard and mixed habitats will take longer to recover than soft habitat).

Appendix N AQUACULTURE AND SEAFOOD DEMAND

Aquaculture activities are indicators of seafood demand and also may be related to some benefits (e.g., water filtration by bivalves, nutrition, income and employment) or impacts (e.g., habitat conversion, waste discharge, species introductions). Shellfish aquaculture production in the CCE has been consistently at historically high levels from 2012-2016 (Figure N.1). These trends are driven by production in Washington state, with nearly 80% of the coastwide production. Finfish aquaculture has been variable but remained above historical averages over the last five years. Demand for seafood products increasingly is being met by aquaculture and may be influencing the increases in production.

Seafood demand in the U.S. was relatively constant from 2012-2016, and had largely recovered from declines late in the previous decade (Figure N.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 to increase for the next several years.

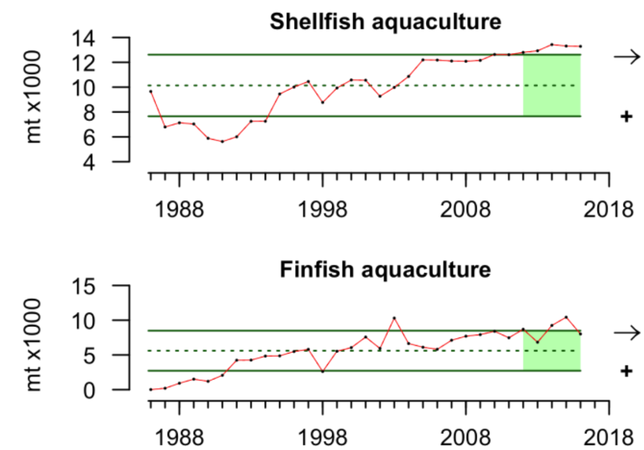


Figure N.1 Aquaculture production of shellfish (clams, mussels, oysters) and finfish (Atlantic salmon) in CCE waters from 1986-2016. Lines, colors, and symbols as in Fig. 1.

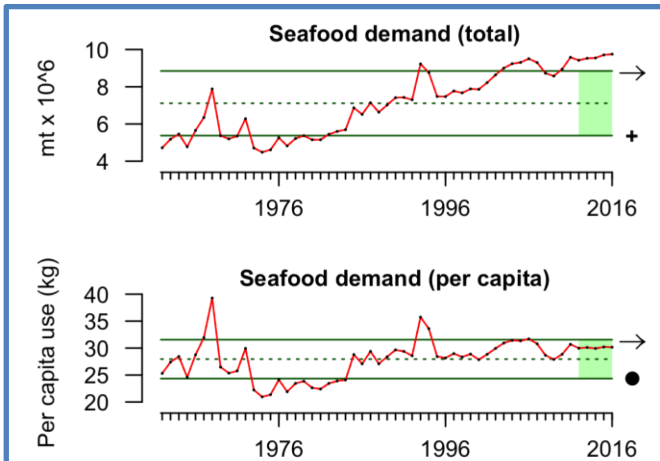


Figure N.2 Total (metric tons) and per capita use (kg) of fisheries products in the U.S., 1962-2016. Lines, colors, and symbols as in Fig. 1.

Appendix O OTHER NON-FISHERIES HUMAN 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, oil and gas activity, and nutrient inputs.

Approximately 90% of world trade is carried by the international shipping industry. Fisheries impacts associated with commercial shipping include interactions between fishing and shipping vessels; ship strikes of protected species; and underwater noise that affects fish spawning, recruitment, migration, and communication.

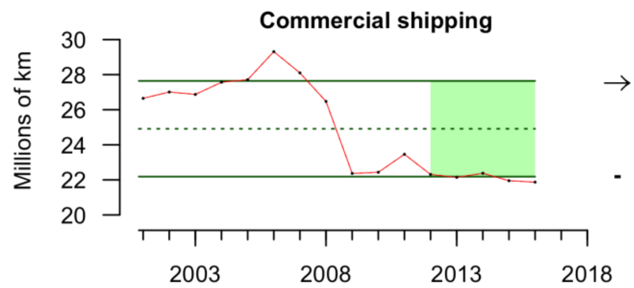


Figure O.1 Distance transited by commercial shipping vessels in the CCE from 2001-2016. Lines, colors, and symbols as in Fig.1.

Commercial shipping activity is measured by summing the total distances traveled by vessels traveling internationally within the CCE. Domestic traveling vessels are not included in this calculation because they make up only 10% of distances traveled, have no effect on the overall status and trend, and are more difficult to get up-to-date domestic data. Commercial shipping activity in the CCE was at historically low levels over the last five years of the dataset (Figure O.1). This contrasts with global estimates of shipping activity increasing nearly 400% over the last 20 years. Regional differences, lagging economic conditions and different data sources may be responsible for the observed differences.

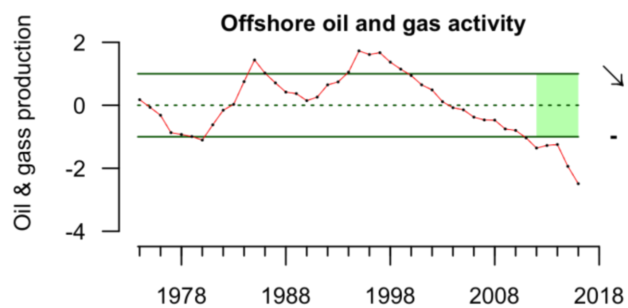


Figure O.2 Normalize index of the sum of oil and gas production from offshore wells in CA from 1974-2016. Lines, colors, and symbols as in Fig.1.

Risks posed by offshore oil and gas activities include the release of hydrocarbons, smothering of benthos, sediment anoxia, benthic habitat loss, and the use of explosives. Petroleum products consist of thousands of chemical compounds, such as PAHs, which may impact marine fish health and reproduction. The effects of oil rigs on fish stocks are less conclusive, as rig structures may provide some habitat benefits.

Offshore oil and gas activity in the CCE occurs only off the coast of California and has declined and was below historical levels over the last five years (Figure O.2). Offshore oil and gas production has been decreasing steadily since the mid 1990's.

Nutrient loading is a leading cause of contamination, eutrophication, and related impacts in streams, lakes, wetlands, estuaries, and ground water throughout the U.S. Nutrient input was relatively constant and within historical averages over the last five years of the available dataset (2008–2012), but has not been updated recently. Please refer to past reports for data.

Appendix P SOCIAL VULNERABILITY OF FISHING-DEPENDENT COMMUNITIES

In Section 6.1 of the main report, we present information on the Community Social Vulnerability Index (CSVI) as an indicator of social vulnerability in coastal communities that are dependent upon commercial fishing in the CCE. As a reminder: fishery *dependence* can be expressed by two terms, or by a composite of both. Those terms are engagement and reliance. *Engagement* refers to the total extent of fishing activity in a community; engagement can be expressed in terms of commercial activity (e.g., landings, revenues, permits, processing, etc.) or recreational activity (e.g., number of boat launches, number of charter boat and fishing guide license holders, number of charter boat trips, number of bait and tackle shops, etc.). *Reliance* is the per capita engagement of a community; thus, in two communities with equal engagement, the community with the smaller population would have a higher reliance on its fisheries activities.

In the main body of the report, Figure 6.1.1 and Figure 6.1.2 plot CSVI against commercial and recreational fishing reliance, respectively, for the five most dependent communities in each sector from each of five regions of the CCE. Those plots are based on data from 2015. Here, we present similar plots of CSVI relative to commercial and recreational fishing engagement scores. We then compare communities based on their relative commercial:recreational fishing reliance and engagement.

Figure P.1 shows commercial fishing-engaged communities and their corresponding social vulnerability results. Of note are communities like Westport and Newport, which have relatively high commercial fishing engagement results and also a high CSVI composite result.

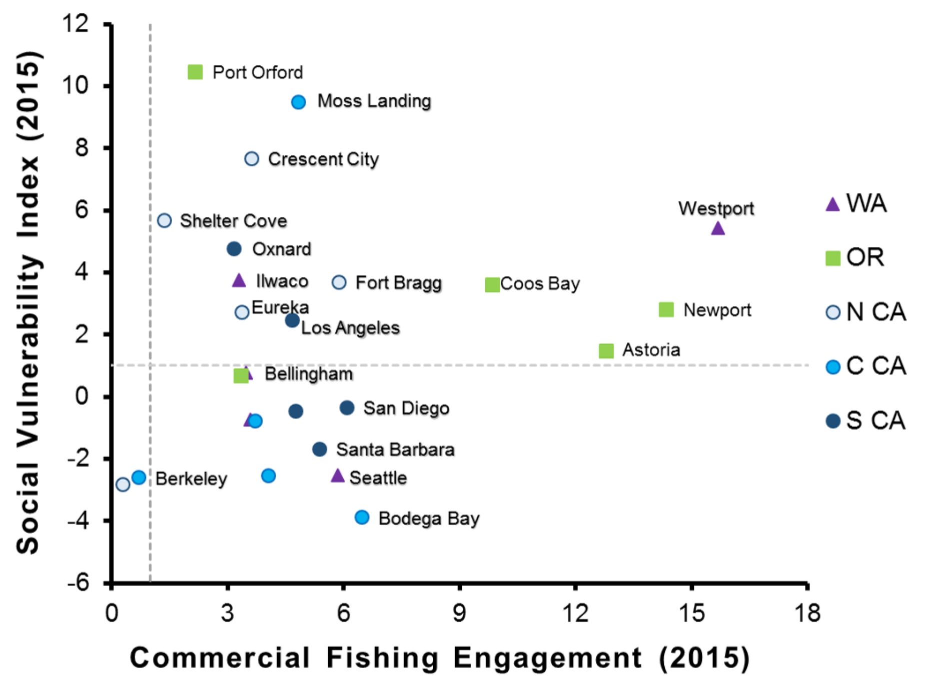


Figure P.1 Commercial fishing engagement and social vulnerability scores plotted for twenty-five communities from each of the 5 regions of the California Current: WA, OR, Northern, Central, and Southern California. The top five highest scoring communities for fishing engagement were selected from each region.

Figure P.2 shows recreational fishing-engaged communities with their corresponding social vulnerability results. Of note are communities like Los Angeles and Westport, which have relatively high recreational fishing reliance results and also high CSVI composite results. In contrast, San Diego has very high recreational fishing engagement, but relatively low social vulnerability. It is also notable that many (but not all) of the communities in Figures P.1 and P.2 are different from those in Figures 6.1.1 and 6.1.2, because these are total community engagement plots, not per capita reliance plots.

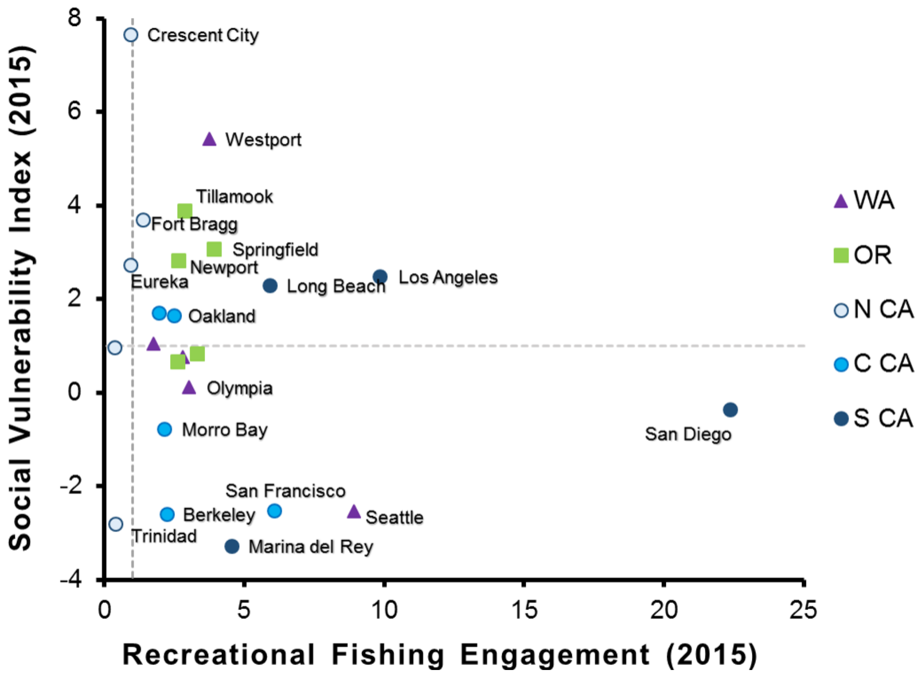


Figure P.2 Recreational fishing engagement and social vulnerability scores plotted for twenty-five communities from each of the 5 regions of the California Current: WA, OR, Northern, Central, and Southern California. The top five highest scoring communities for fishing engagement were selected from each region.

Figures P.3 and P.4 are intended to show that some communities are more dependent upon one sector (commercial or recreational) than the other, while also accounting for CSVI. Figure P.3 plots each community's recreational fishing engagement level against its commercial fishing engagement. The size of the plot point for each community is scaled to approximate the level of social vulnerability for each community. All of the communities from Figures 6.1.1., 6.1.2, P.1 and P.2 are included here; it is thus possible for regions to have more than five communities in these plots. San Diego demonstrates a disproportionately high level of engagement in recreational fishing relative to commercial fishing engagement, while Westport and Newport demonstrate a similarly high level of engagement with commercial fishing relative to recreational engagement.

Figure P.4 plots each community's results for recreational fishing reliance against each community's results for commercial fishing reliance. Of particular note are the communities of Westport and Ilwaco, which exhibit relatively high levels of commercial fishing reliance, recreational fishing reliance and general social vulnerability. Moss Landing and Elkton both present high social vulnerability, and appear as examples of communities that are both outliers in terms of their degrees of reliance on commercial fishing (Moss Landing) and recreational fishing (Elkton).

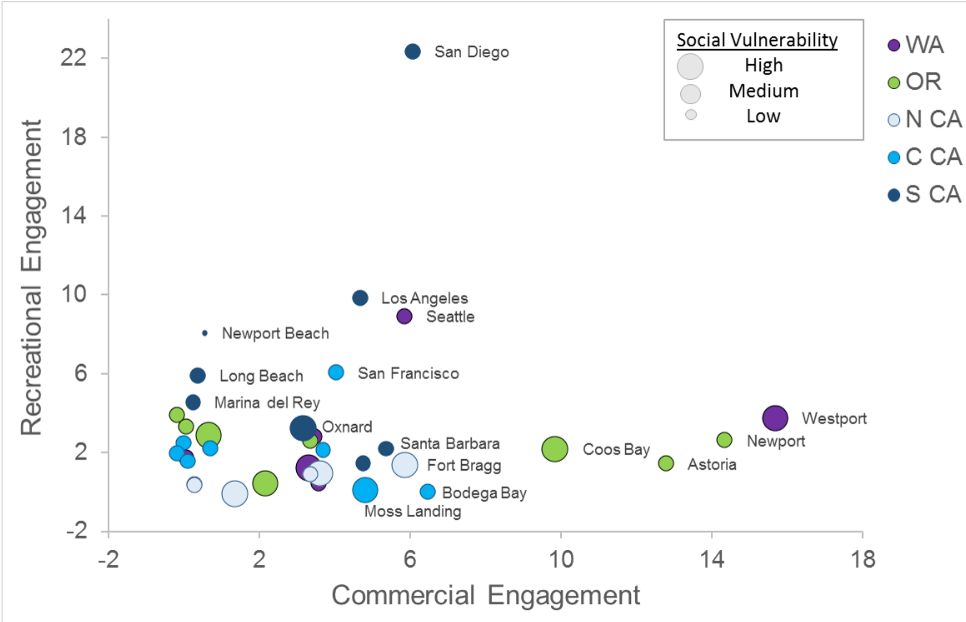


Figure P.3 Communities with the top five highest scores for commercial fishing and recreational fishing engagement from each of the five regions of the California Current are plotted. Bubble size indicates a high, moderate, or low social vulnerability score.

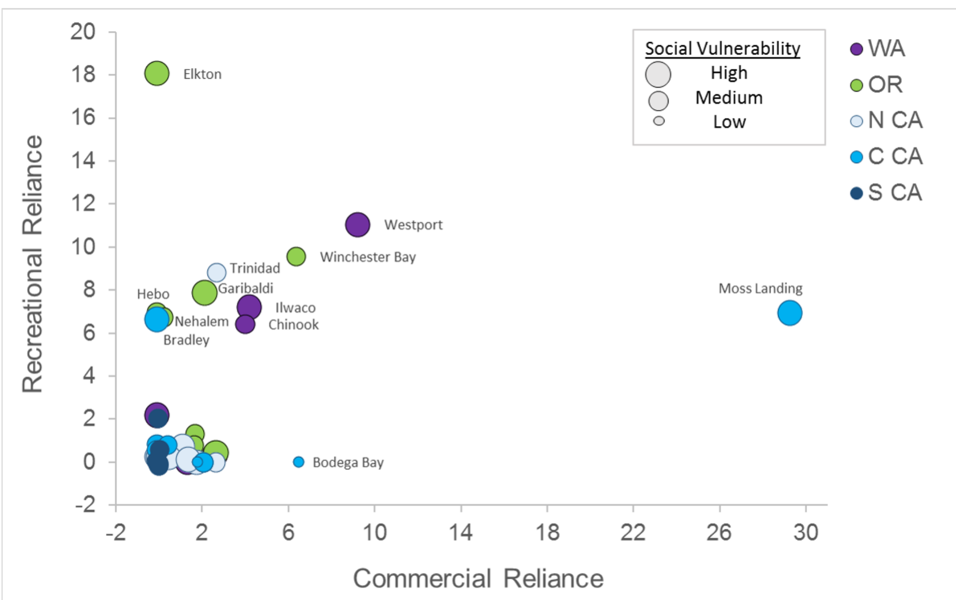


Figure P.4 Communities with the top five highest scores for commercial fishing and recreational fishing reliance from each of the five regions of the California Current are plotted. Bubble size indicates a high, moderate, or low social vulnerability score.

Appendix Q FLEET DIVERSIFICATION INDICATORS FOR MAJOR WEST COAST PORTS

As is true with individual vessels, the variability of landed value at the port level is reduced with greater diversification of landings. Diversification of fishing revenue has declined over the last several decades for some ports (Figure Q.1). Examples include Seattle and most, though not all, of the ports in Southern Oregon and California. However, a few ports have become more diversified including Bellingham Bay and Westport in Washington and Astoria in Oregon. Diversification scores are highly variable year-to-year for some ports, particularly those in Southern Oregon and Northern California that depend heavily on the Dungeness crab fishery which has highly variable landings. Most major ports saw a decrease in diversification between 2015 and 2016. The drop was most dramatic for Ilwaco, WA and San Francisco, CA where declines were greater than twice the standard deviation of ESI for those ports over the last 15 years. Several California ports had shown increasing trends in ESI prior to the 2016 drop.

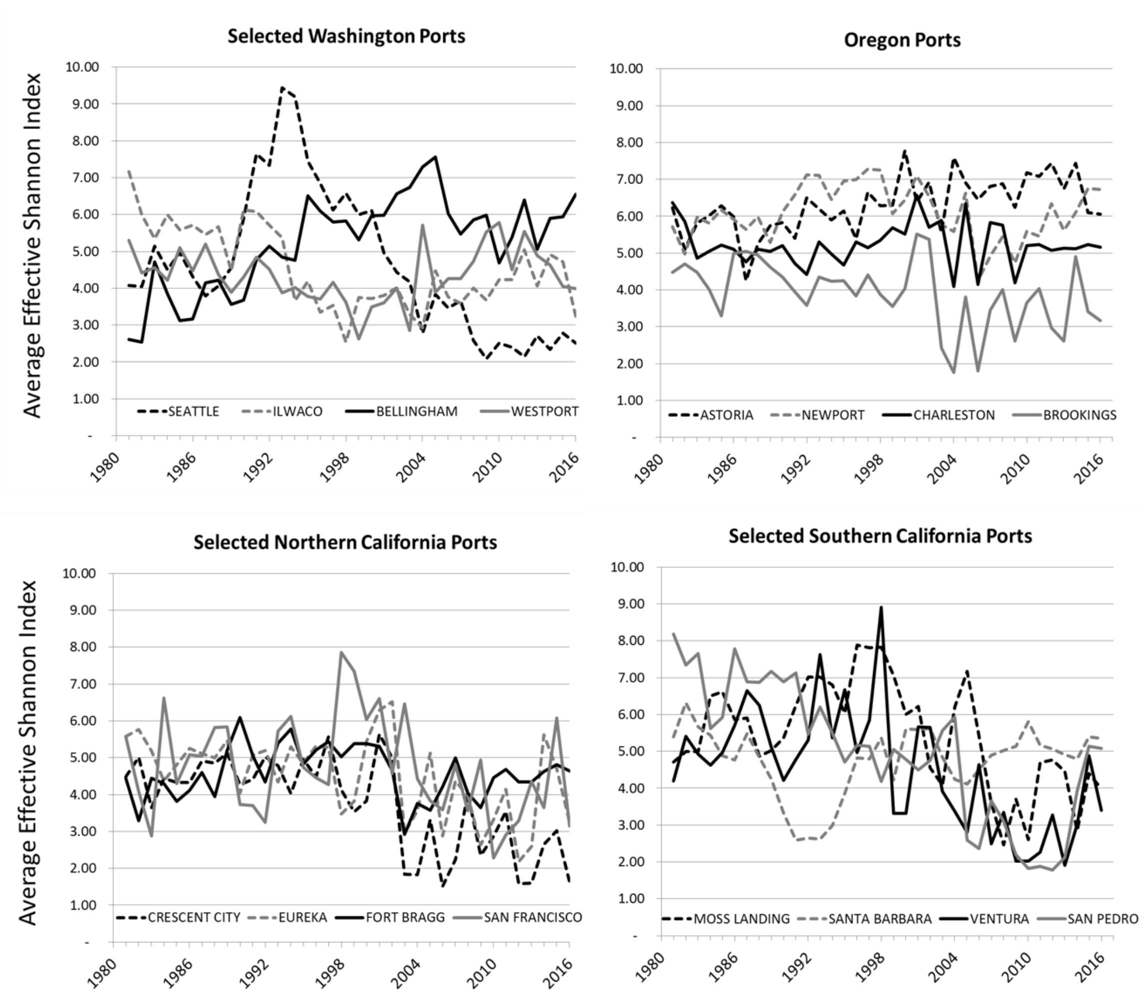


Figure Q.1 Trends in diversification in major west coast ports for Washington, Oregon, and California.

Appendix R RESEARCH RECOMMENDATIONS FROM THE 2017 REPORT

As noted in Section 7 of the main report, the CCIEA team was asked by the EWG to include a short section of "Research Recommendations" in the 2017 Ecosystem Status Report. The six Recommendations that we proposed in the 2017 report are listed here:

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 <u>opportunity to further scope</u> CCIEA work with the Council and its advisory bodies, to ensure that our work is aligned with the Council's ecosystem science needs.*

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 <u>existing indicators</u> in this report, to better meet Council needs;*
- *Identifying and prioritizing <u>indicator gaps</u>, 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 <u>estimate trends</u> in our indicators, separate from the observation error inherent in field sampling;*
- *Analyzing time series to (1) determine if <u>threshold relationships</u> exist between stressors and indicators, to inform risk assessments; and (2) to detect <u>early warning indicators</u> of major shifts in ecosystem structure or function.*

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 <u>productivity of key species</u> 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 <u>models of individual fishing participation</u> choices;*
- *Construct an <u>integrated model of several CCE fisheries</u> (e.g., salmon, Dungeness crab, albacore, groundfish, shrimp) that determines participation and effort in each fishery;*
- *<u>Model how climate variability affects fisheries</u> both directly via environmental effects and indirectly via participation decisions, and explore what types of <u>fishing portfolios</u>, for individuals or ports, result in lower variation in income and higher quality of life.*

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.*

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.*

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.*

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Appendix T LIST OF ACRONYMS USED IN THIS REPORT

ATF	Arrowtooth flounder
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CCC	Central California Current
CCE	California Current Ecosystem
CCIEA	California Current Integrated Ecosystem Assessment
COASST	Coastal Observation And Seabird Survey Team
CPS	Coastal Pelagic Species
CPUE	Catch Per Unit Effort
CSVI	Community Social Vulnerability Index
CUI	Cumulative Upwelling Index
DO	Dissolved Oxygen
EBFM	Ecosystem-Based Fisheries Management
ENSO	El Niño Southern Oscillation
ESI	Effective Shannon Index
ESU	Evolutionarily Significant Unit
EWG	Ecosystem Workgroup
FEP	Fishery Ecosystem Plan
FMP	Fishery Management Plan
HABs	Harmful Algal Blooms
HMS	Highly Migratory Species
IEA	Integrated Ecosystem Assessment
MARSS	Multivariate Autoregressive State Space model
MSY	Maximum Sustainable Yield
NCC	Northern California Current
NH	Newport Hydrographic Line (or, “Newport Line”; Fig. 2.1 and elsewhere)
NOAA	National Oceanic and Atmospheric Administration
NOI	Northern Oscillation Index
NPGO	North Pacific Gyre Oscillation
NWFSC	Northwest Fisheries Science Center
OA	Ocean Acidification
OFL	Overfishing Limit
ONI	Oceanic Niño Index
PacFIN	Pacific Fisheries Information Network
PDO	Pacific Decadal Oscillation
PFMC	Pacific Fishery Management Council
PLCA	Pacific Leatherback Conservation Area
RecFIN	Recreational Fisheries Information Network
SCC	Southern California Current
s.d.	standard deviation
s.e.	standard error
SPR	Spawner Potential Ratio
SSC	Scientific and Statistical Committee
SSCES	Scientific and Statistical Committee Ecosystem Subcommittee
SST	Sea Surface Temperature (except Fig. 4.4.1, shortspine thornyhead)
SSTa	Sea Surface Temperature anomaly
SWE	Snow-Water Equivalent
SWFSC	Southwest Fisheries Science Center
UI	Bakun Upwelling Index
YOY	Young-of-the-Year