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# **Ecosystem Status Report of the California Current for 2018:**

A Summary of Ecosystem Indicators Compiled  
by the California Current Integrated Ecosystem  
Assessment Team (CCIEA)



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Cover image: Pyrosomes on a beach near Astoria, Oregon, November 2017. Photograph by R. Brodeur, NMFS/NWFSC.

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# Contents

List of Figures.....	v
List of Tables.....	viii
Dedication .....	ix
Executive Summary .....	x
Acknowledgments.....	xii
Introduction.....	1
Ecosystem-Based Fisheries Management and Integrated Ecosystem Assessment .....	1
Notes on Interpreting Time-Series Figures.....	5
Sampling Locations .....	6
Climate and Ocean Drivers.....	8
Basin-Scale Indicators.....	8
Regional Upwelling Indices .....	12
Hypoxia and Ocean Acidification .....	13
Hydrologic Indicators .....	17
Focal Components of Ecological Integrity.....	23
Northern Copepod Biomass Anomaly.....	23
Regional Forage Availability.....	24
Northern CCE.....	25
Central CCE .....	26
Southern CCE .....	27
Salmon .....	28
Groundfish Stock Abundance and Community Structure .....	31
Highly Migratory Species .....	33
Marine Mammals .....	34
Sea Lion Production.....	34
Whale Entanglement.....	35
Seabirds.....	37
Abundance.....	37
Seabird Diets .....	37
Seabird Mortalities .....	42

Human Activities.....	43
Coastwide Landings by Major Fisheries.....	43
Bottom Trawl Contact with Seafloor .....	43
Aquaculture and Seafood Consumption.....	46
Nonfishing Human Activities .....	50
Commercial Shipping .....	50
Oil and Gas Activity.....	51
Nutrient Loading.....	51
Human Wellbeing.....	52
Social Vulnerability .....	52
Fleet Diversity Indices.....	55
Synthesis .....	58
An Early Warning Index for the California Current .....	59
Identifying Ecosystem Thresholds in Indicators .....	61
Dynamic Ocean Management of Bycatch in the Drift Gillnet Fishery .....	61
References.....	63
List of Contributors.....	68
List of Abbreviations .....	69

# Figures

Figure 1. Loop diagram of the five progressive steps in iterations of the integrated ecosystem assessment process .....	2
Figure 2. Conceptual model of the California Current social-ecological system .....	3
Figure 3. (a) Sample time series plot, with indicator data relative to mean and $\pm 1$ standard deviation, of the full time series. (b) Sample time-series plot with the indicator plotted relative to a threshold value. (c) Sample quad plot .....	5
Figure 4. Maps of the California Current Ecosystem and sampling areas.....	7
Figure 5. Time–depth temperature anomaly contours for nearshore hydrographic stations NH25 and CalCOFI 93.30 .....	9
Figure 6. Monthly values of the Oceanic Niño Index, Pacific Decadal Oscillation, and North Pacific Gyre Oscillation (NPGO) from 1950 to early 2018 .....	10
Figure 7. Sea surface temperature anomalies, five-year means, and five-year trends in winter and summer.....	11
Figure 8. Cumulative upwelling index at three latitudes, 1967–2017 .....	13
Figure 9. Monthly means of daily upwelling index and anomalies for Jan 2013 to Nov 2017 .....	14
Figure 10. Dissolved oxygen at 50 and 150 m depths off Newport, OR, through 2017 .....	15
Figure 11. Monthly aragonite saturation values off Newport, OR, 1998–2017 .....	15
Figure 12. Aragonite saturation state versus depth at station NH25, 1998–2017 .....	16
Figure 13. Anomalies of 1 April snow-water equivalent in five freshwater ecoregions of the CCE through 2017. ....	18
Figure 14. Mountain snowpack on 1 April 2018 at select monitoring sites relative to values from 1981–2010.....	19
Figure 15. Anomalies of seven-day minimum streamflow measured at 213 gages in six ecoregions, 1981–2017 .....	20
Figure 16. Anomalies of one-day maximum streamflow measured at 213 gages in six ecoregions, 1981–2017 .....	20
Figure 17. Recent (five-year) trend and average of maximum and minimum streamflow anomalies in 16 Chinook salmon ESUs through 2017 .....	21
Figure 18. Mean maximum stream temperature in August measured at 446 USGS gages in six ecoregions through 2017 .....	21
Figure 19. Monthly northern and southern copepod biomass anomalies, 1996–2017 .....	24
Figure 20. Recent (five-year) trend and average of key forage species in the northern CCE through 2017 .....	25
Figure 21. Recent (five-year) trend and average of key forage species in the central CCE through 2017 .....	26

Figure 22. Recent (five-year) trend and average of the larvae of key forage species in the southern CCE through 2017 .....	27
Figure 23. Recent (10-year) trend and average of Chinook salmon escapement anomalies, with most systems updated through 2016 .....	28
Figure 24. At-sea juvenile Chinook and coho salmon catches in June, 1998–2017, off WA and OR.....	29
Figure 25. Stock status of CCE groundfish.....	32
Figure 26. Ratio of crab biomass to finfish biomass for the NWFSC West Coast Groundfish Bottom Trawl Survey from 2003–16 .....	33
Figure 27. Recent (five-year) trend and average of biomass and recruitment for highly migratory species in the CCE from the 2014–16 stock assessments .....	34
Figure 28. 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.....	35
Figure 29. Confirmed numbers of whales (by species) reported entangled in fishing gear along the U.S. West Coast from 2000–17.....	36
Figure 30. Recent (five-year) trend and average of seabird at-sea densities during the summer in three regions of the CCE through 2017 .....	38
Figure 31. Rhinoceros auklet chick diets at Destruction Island through 2017 .....	39
Figure 32. Rhinoceros auklet chick diets at Año Nuevo from 1993–2017 .....	39
Figure 33. Size of anchovy brought to rhinoceros auklet chicks at Año Nuevo from 1993–2017 .....	40
Figure 34. Common murre chick diets at Yaquina Head, OR, through 2017 .....	41
Figure 35. Encounter rates of dead birds on U.S. West Coast beaches through fall/winter of 2016–17 and late 2017.....	42
Figure 36. Annual landings of U.S. West Coast commercial and recreational fisheries, including total landings across all fisheries, from 1981–2017 .....	44
Figure 37. Annual revenue of U.S. West Coast commercial fisheries from 1981–2017 .....	45
Figure 38. Weighted distance of fishing gear contact with seafloor habitat across the entire CCE and within each ecoregion.....	47
Figure 39. Spatial representation of seafloor contact by groundfish bottom trawl gear, represented by annual distances trawled within each 2-km <sup>2</sup> grid cell from 2002–15.....	48
Figure 40. Aquaculture production of shellfish (clams, mussels, oysters) and finfish (Atlantic salmon) in CCE waters from 1986–2016 .....	49
Figure 41. Total and per capita consumption of fisheries products in the United States from 1962–2016 .....	49
Figure 42. Distance transited by foreign commercial shipping vessels in the CCE from 2001–16 .....	50
Figure 43. Normalized index of the sum of oil and gas production from offshore wells in California from 1974–2016 .....	51
Figure 44. Commercial fishing reliance and social vulnerability scores in 2015, plotted for five communities from each of five regions of the CCE.....	53

Figure 45. Recreational fishing reliance and social vulnerability scores plotted for 2015 in five communities from each of five regions of the CCE .....	54
Figure 46. Trends in average commercial fishing vessel revenue diversification, 1981–2016 .....	56
Figure 47. Trends in commercial fishing vessel revenue diversification in major ports of WA, OR, and CA, 1981–2016 .....	57
Figure 48. Early warning index model reducing 32 biological time series from the southern CCE down to two main underlying trends .....	60
Figure 49. Relationship between the atmospheric Northern Oscillation Index and California sea lion pup counts at San Miguel Island .....	62
Figure 50. Comparison of a dynamic ocean management approach to the California Drift Gillnet Fishery, relative in size to the existing static Pacific Leatherback Conservation Area closure.....	62



# Tables

Table 1. “Stoplight” table of basin-scale and local/regional conditions for smolt years 2014–17 and likely adult returns in 2018 for coho and Chinook salmon that inhabit coastal OR and WA waters during their marine phase .....30

## Dedication



**Dr. William T. Peterson**  
**1942–2017**

This work is dedicated to the memory of Dr. William T. Peterson, who worked at the Northwest Fisheries Science Center's Newport field station since 1995, and had conducted research off our coasts since the early 1970s. Bill's research on the Newport Hydrographic Line and all along the coasts of Oregon and Washington is an irreplaceable part of this ecosystem status report, and is among the most foundational work in any marine ecosystem in the world. We learned more than words could tell from Bill: about how physical and biological processes interact in these waters; about how critical copepods are to the functioning of the food web; about the conditions that lead to good years and bad years for salmon. Just as important, we learned about the essential qualities of dedication, fortitude, positivity, connecting with your fellow human, and bringing passion and a thirst for knowledge to work with you each and every day. Bill was a colleague, a mentor, an example, and a dear friend. We miss him greatly, and we will do our best to honor him, emulate him, advance his work, and tell anyone who wants to listen how truly and endlessly fascinating our oceans are.

# Executive Summary

This document is a companion to the ecosystem status report (ESR) provided by the California Current Integrated Ecosystem Assessment team (CCIEA team) to the Pacific Fishery Management Council (PFMC) in March of 2018 (Harvey et al. 2018). The CCIEA team provides ESRs annually to PFMC, as one component of the overall CCIEA goal of providing quantitative, integrative science tools, products, and synthesis in support of a more holistic (ecosystem-based) approach to managing marine resources in the California Current.

This report presents indicators codeveloped by the CCIEA team and PFMC beginning in 2009. The indicators have been refined and updated over the years to best capture the current state of the California Current ecosystem. The analyses in this document thus represent our best understanding of environmental, ecological, and socioeconomic conditions in this ecosystem roughly through 2017. Because the time required to process the data from different indicators can vary, some of the resulting time series are slightly more up-to-date than others. Some indicators (snowpack, fishery landings, and revenue) have been updated since the March 2018 report to PFMC (Harvey et al. 2018).

In terms of the natural biophysical system, we regarded 2017 as a transitional year, in which the CCE continued its recovery from the marine heat wave of 2013–16 and the major El Niño event of 2015–16. We similarly considered much of 2016 to be transitional. By “transitional,” we mean that many indicators suggest that the system has shifted away from the highly unusual conditions of the marine heat wave and El Niño events, which included very warm water temperatures, weaker-than-normal southward-flowing currents along the U. S. West Coast, and widespread occurrence of species normally associated with warmer southerly and/or offshore waters (including the pyrosomes featured on the cover of this report). However, aspects of these conditions remain in patches throughout the system, and we do not feel confident that the system has returned to a more typical regime (e.g., the relatively cool and productive periods or warm and unproductive periods governed by climate and oceanography patterns that have been observed for much of the past century). Moreover, some populations of protected species and others targeted by fisheries may show the effects of the unusual warming events at lag times of months to years, even after physical conditions and characteristics of the base of the food web have returned to average or above-average conditions.

Among the indicators that suggested a return to more typical conditions in the CCE:

- Indicators of temperature and circulation in the North Pacific Ocean and along the U.S. West Coast were closer to long-term averages for much of 2017.
- Some important forage fishes, squids, and krill increased in abundance in the central and southern regions of the system.
- Pup growth of California sea lions (*Zalophus californianus*) at the San Miguel Island colony was normal, implying improved feeding conditions for adult female sea lions in that region.
- Unlike many recent years, no mass seabird die-offs that could be attributed to poor food availability were recorded in 2017.

Other indicators, however, revealed that the CCE in 2017 was still experiencing residual effects of the recent atypical period:

- Warmer-than-normal water masses persisted into 2017, particularly in deeper waters in the northern CCE.
- Although the community of copepods (tiny free-swimming crustaceans at the bottom of the food web) off of Newport, Oregon, experienced a greater occurrence of cool-water, energy-rich species in certain sampling periods, there remained a large number of species associated with southerly or offshore water masses.
- Pyrosomes, free-swimming colonial gelatinous animals (see cover photo) that prefer warmer waters normally found further to the south, were extremely abundant in the northern and central CCE.
- Juvenile salmon catches were poor, and other indicators projected below-average Chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*) salmon returns to the Columbia River basin in 2018.
- Reports of whale entanglements in fixed fishing gear were above-average for the fourth consecutive year, possibly as a result of changes in the timing and location of food availability for the whales.

Many indicators of fishery landings and revenue have increased since a recent low point in 2015, with increases mainly attributable to Pacific hake (*Merluccius productus*), market squid (*Doryteuthis opalescens*), and Dungeness crab (*Metacarcinus magister*). Conversely, recreational fishery landings have been declining since 2015. We continued to observe a decline in the diversification of catch revenues by commercial fishing vessels of all size and revenue classes in all three coastal states; in other words, on average, vessels are relying on steadily fewer species to provide the bulk of their revenues. We are working to understand how the reliance of coastal communities on commercial and recreational fishing relates to those communities' overall social wellbeing and vulnerability.

The sections that follow will go into greater detail about the status and trends of indicators summarized here; we include sections related to Climate and Ocean Drivers, the Focal Components of Ecological Integrity, Human Activities, and Human Wellbeing, followed by a brief Synthesis.

# Acknowledgments

The time series, model simulations, and statistical analyses presented in this report come from the work of countless researchers, vessel personnel, and support staff from the federal, state, tribal, and local agencies, the nongovernmental research groups, and the academic institutions that provided information. We are gratefully indebted to them. We also thank the members of the Pacific Fishery Management Council (PFMC) Ecosystem Workgroup (Yvonne deReynier, Kit Dahl, Larry Gilbertson, Josh Lindsay, Corey Niles, Cyreis Schmitt, Richard Scully, and Deb Wilson-Vandenberg), past and present members of the PFMC Scientific and Statistical Committee (Martin Dorn, Aaron Berger, Evelyn Brown, John Budrick, Alan Byrne, John Field, Owen Hamel, Michael Harte, Dan Holland, Galen Johnson, Meisha Key, Kevin Piner, André Punt, David Sampson, Will Satterthwaite, Rishi Sharma, Ole Shelton, Cameron Speir, and Tien Shui Tsou), the many PFMC management teams and advisory panels, and PFMC itself, all of whom have provided extremely valuable feedback over the last several years to improve our annual ecosystem status reporting. Al Brown (Northwest Fisheries Science Center) provided essential comments and editorial support on earlier versions of this document. Contributing support for this work was provided by the National Oceanic and Atmospheric Administration's Integrated Ecosystem Assessment (NOAA IEA) Program; this work is NOAA IEA Program Contribution #2018\_11.

# Introduction

## Ecosystem-Based Fisheries Management and Integrated Ecosystem Assessment

Ecosystem-based management of fisheries and other marine resources has emerged as a priority in the U.S. (EPAP 1999, Fluharty et al. 2006, McFadden and Barnes 2009, NOAA 2016) and elsewhere (Browman et al. 2004, Sainsbury et al. 2014, Walther and Möllmann 2014, Long et al. 2015). The NOAA National Marine Fisheries Service (NOAA Fisheries) defines ecosystem-based fisheries management (EBFM) as:

...a systematic approach to fisheries management in a geographically specified area that contributes to the resilience and sustainability of the ecosystem; recognizes the physical, biological, economic, and social interactions among the affected fishery-related components of the ecosystem, including humans; and seeks to optimize benefits among a diverse set of societal goals (NOAA 2016).

This definition encompasses interactions within and among fisheries, protected species, aquaculture, habitats, and human communities that depend upon fisheries and related ecosystem services. An EBFM approach is intended to improve upon traditional fishery management practices that primarily are focused on individual fished stocks.

Successful EBFM requires a considerable amount of effort and coordination due to the formidable amount of information required and uncertainty involved. In response, scientists throughout the world have developed many frameworks for organizing science and information in order to clarify and synthesize this overwhelming volume of data into science-based guidance for policymakers. NOAA Fisheries has adopted a framework called Integrated Ecosystem Assessment (IEA; Levin et al. 2008, Levin et al. 2009), which can be summarized in five progressive steps (Figure 1):

1. Identifying and scoping ecosystem goals, objectives, targets, and threats.
2. Assessing status and trends of the ecosystem through the use of valid ecosystem indicators.
3. Assessing the risks of key threats and stressors to the ecosystem.
4. Analyzing management strategy alternatives and identifying potential tradeoffs.
5. Implementing selected actions, and monitoring and evaluating management success.

As shown in Figure 1, the IEA approach is iterative. Following the implementation of management actions, all other steps in the IEA loop must be revisited in order to ensure that a) evolving goals and objectives are clearly identified, b) monitoring plans and indicators are appropriate for the management objectives in mind, c) existing and emerging risks are properly prioritized, and d) management actions are objectively and regularly evaluated for success.

In 2009, NOAA line offices along the U.S. West Coast initiated the California Current Integrated Ecosystem Assessment (CCIEA). The CCIEA team focuses on the California Current ecosystem (CCE) along the U.S. West Coast. In keeping with the principles of ecosystem-based management, the CCIEA team regards the CCE as a dynamic, interactive, social-ecological system with multiple

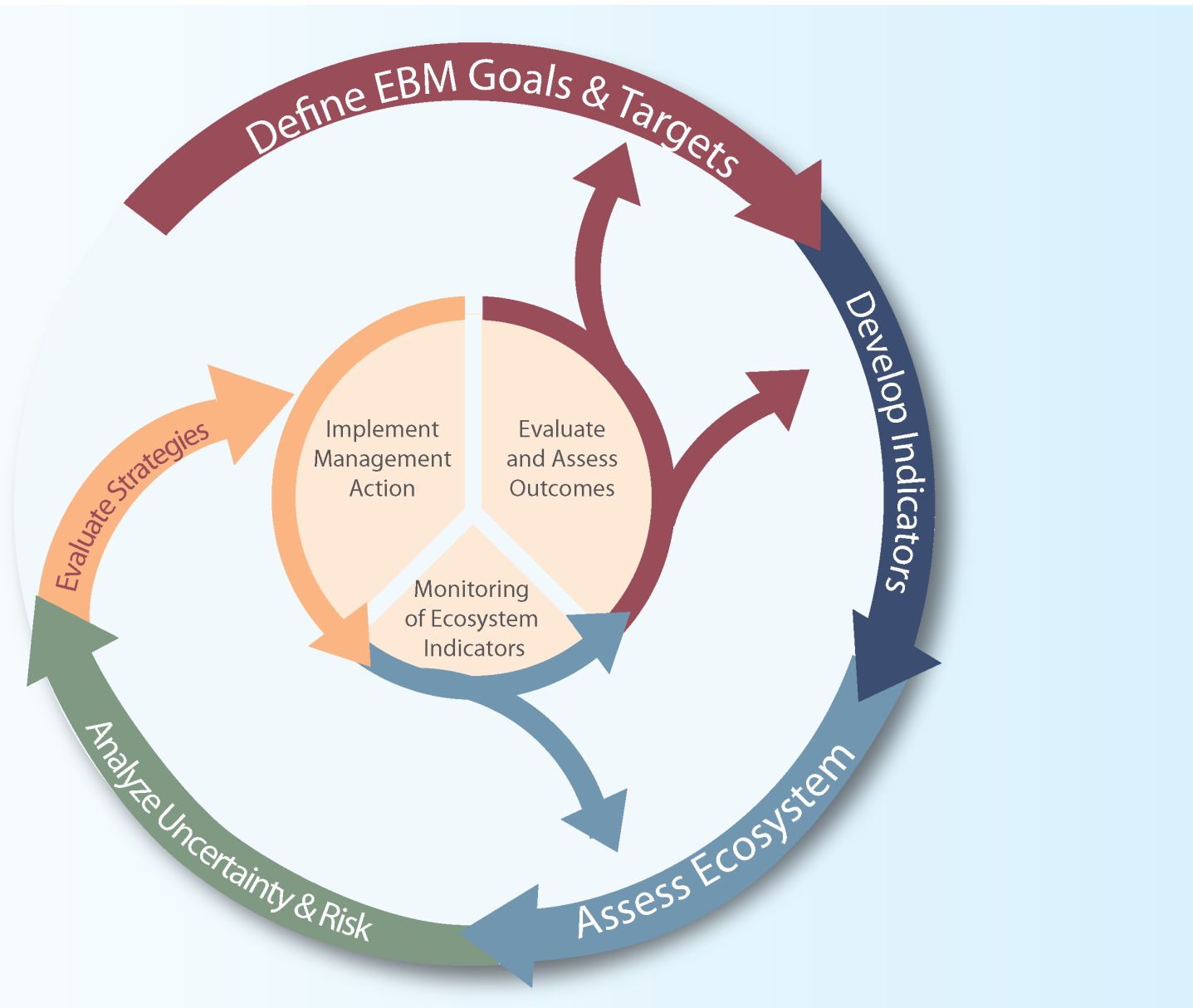


Figure 1. Loop diagram of the five progressive steps in iterations of the integrated ecosystem assessment (IEA) process. From Samhoury et al. (2014).

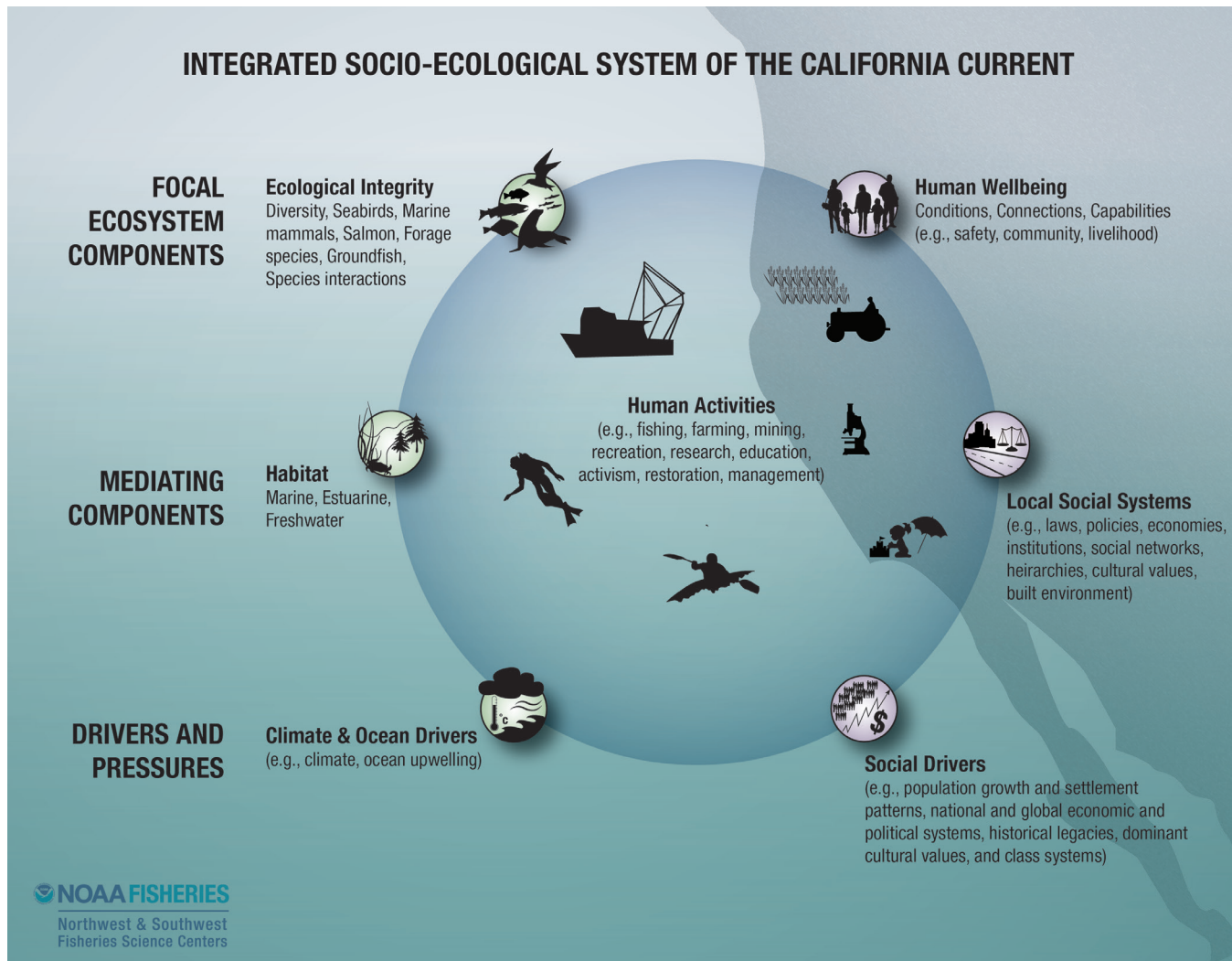


Figure 2. Conceptual model of the California Current social-ecological system. The model represents the complex and inextricable connections between natural components (left) and human components (center, right). These components are arranged in three tiers: focal ecosystem components, which are often associated with broad objectives such as ecological integrity and human wellbeing; mediating components, such as habitat and local social systems; and drivers and pressures, which are generally external forces on the ecosystem. Human activities are placed at the center to emphasize their broad extent and because they are where management actions are directly implemented in order to achieve objectives elsewhere in the system. From Levin et al. (2016).



levels of organization and diverse goals and endpoints that are both environmental and social in nature (Figure 2). The challenging task of assembling and interpreting information from this broad range of disciplines, locations, and time frames engages over 50 scientists from NOAA's Northwest and Southwest Fisheries Science Centers and other NOAA offices, as well as colleagues from other agencies, academia, and nongovernmental entities. Information on CCIEA research efforts, tools, products, publications, partnerships, and points of contact is available on the [CCIEA website](#).<sup>1</sup>

The primary management partner of the CCIEA team to date has been the [Pacific Fishery Management Council](#) (PFMC),<sup>2</sup> which oversees federally managed fisheries and implementation of the Magnuson–Stevens Fishery Conservation and Management Act in the Exclusive Economic Zone off the U.S. West Coast. PFMC manages target species directly under policies outlined in its four fishery management plans (FMPs), and may incorporate nonbinding guidance from its [Fishery Ecosystem Plan](#) (FEP; PFMC 2013).<sup>3</sup>

Section 1.4 of the FEP outlined a reporting process wherein the CCIEA team provides PFMC with a yearly ecosystem status report (ESR) that describes the current status and trends of ecosystem attributes of the CCE. The purpose of the ESRs is to provide PFMC with a general sense of ecosystem conditions as context for decision-making. ESRs include information on a range of ecosystem attributes, including climate and oceanographic drivers, status of key species groups, fisheries-related human activities, and human wellbeing in coastal communities. ESRs track ecosystem attributes through ecosystem indicators, most of which were derived through a rigorous indicator screening process developed by Kershner et al. (2011); details of specific CCIEA indicator screening exercises are documented elsewhere (Levin and Schwing 2011, Levin et al. 2013, Harvey et al. 2014).

Since 2012, the CCIEA team has provided PFMC with six ESRs, most recently in March 2018. The ESRs are available as online sections of [PFMC briefing books](#)<sup>4</sup> for the meetings at which the CCIEA team has presented the reports (November 2012, then annually in March 2014–18), and are also available on the [CCIEA website](#).<sup>5</sup> The contents of ESRs have evolved over the years through cooperation between the CCIEA team and PFMC and its advisory bodies, most notably through an [FEP initiative](#)<sup>6</sup> begun in 2015 to refine the indicators in the ESR to better reflect PFMC's needs. For example, PFMC has requested that the annual ESRs be confined to ~20 printed pages.

This technical memorandum is a companion document to the ESR delivered by the CCIEA team to PFMC in March 2018 (Harvey et al. 2018), representing the status and trends of ecosystem indicators in the CCE through 2017 and, in some cases, early 2018. It is the second in an ongoing annual series of technical memorandums (following Harvey et al. 2017) that will provide a more thorough ESR of the CCE than the page limit allows us to present to PFMC. We will continue to provide the annual report to PFMC, and this technical memorandum series will largely be based on that report. However, as this series evolves, the technical memorandums will incorporate

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<sup>1</sup> <https://www.integratedecosystemassessment.noaa.gov/regions/california-current-region/index.html>

<sup>2</sup> <https://www.pcouncil.org/>

<sup>3</sup> <https://www.pcouncil.org/ecosystem-based-management/fep/>

<sup>4</sup> <https://www.pcouncil.org/council-operations/council-meetings/past-meetings/>

<sup>5</sup> <https://www.integratedecosystemassessment.noaa.gov/regions/california-current-region/publications.html>

<sup>6</sup> <https://www.pcouncil.org/ecosystem-based-management/fishery-ecosystem-plan-initiatives/coordinated-ecosystem-indicator-review-initiative/>

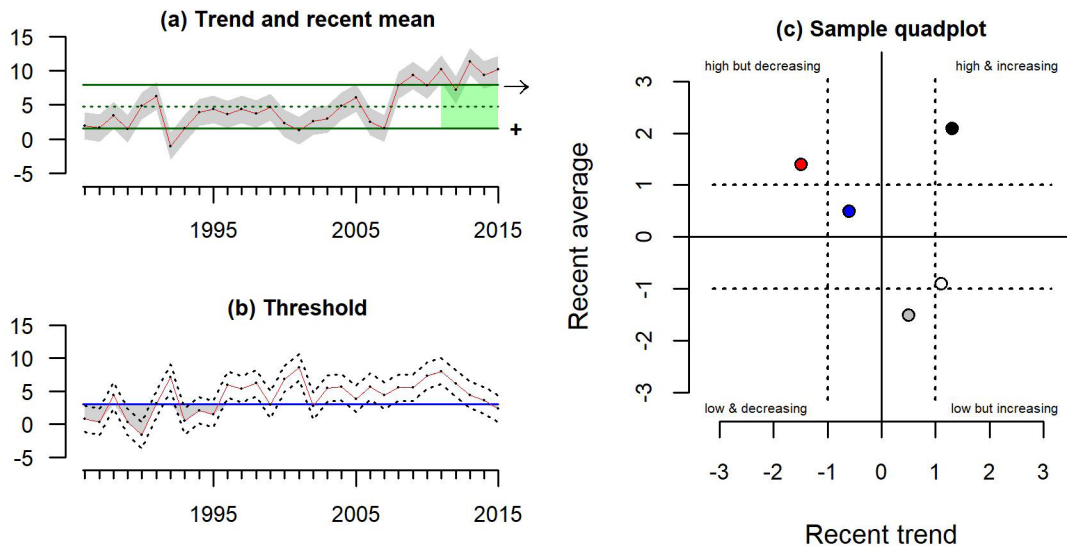


Figure 3. (a) Sample time series plot, with indicator data relative to mean (dashed line) and  $\pm 1$  standard deviation (SD; solid lines), of the full time series. Arrow at right indicates if the trend over the most recent five years (shaded green) is positive ( $\nearrow$ ), negative ( $\searrow$ ) or neutral ( $\leftrightarrow$ ). Symbol at lower right indicates if the recent mean was greater than (+), less than (-), or within 1 SD ( $\bullet$ ) of the long-term mean. When possible, time series include 95% confidence intervals (gray shading). (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 whether the recent years of the time series are above or below the long-term average, and if they are increasing or decreasing. Dashed lines represent  $\pm 1$  SD of the full time series.

more indicators and analyses covering a broader range of ecosystem attributes. This is because the CCIEA team looks to support other management partners in addition to PFMC, and our goal over the next several years is for our annual ESR to feature information in support of ecosystem-based management (EBM) in other sectors and services in addition to fisheries (Slater et al. 2017). The technical memorandum format should therefore enable increased information content, contributions from a broader range of authors, and value to a wider range of audiences. It is our hope that these improvements will lead to greater dialogue with potential partners and stakeholders; such dialogue and engagement is at the heart of the initial step of the IEA process (Figure 1), and is essential to every other step in all iterations as well.

## Notes on Interpreting Time-Series Figures

Throughout this report, many data figures will follow one of two common formats, time-series plots or quad plots, both illustrated with sample data in Figure 3; see figure captions for details. Time-series plots generally contain a single dataset, whereas quad plots are used to summarize the recent averages and trends for multiple time series in a single panel, as when we have time series of multiple populations that we want to compare in a reasonably simple manner. Some time-series plots now show thresholds beyond which we expect substantial changes in response variables, such as when a physiological tolerance to a physical or chemical variable is exceeded. Where possible,

we also include estimates of error or uncertainty in the data. Generally, error estimates are standard deviations or standard errors in the observations. In coming years, we will include model fits to time-series data where appropriate; model fits will most likely be derived from Multivariate Auto-Regressive State Space (MARSS) models, as has been recommended to the CCIEA team by the PFMC Scientific and Statistical Committee's Ecosystem Subcommittee (SSCES).

## Sampling Locations

Figure 4a shows the major headlands that demarcate potential biogeographic boundaries, in particular Cape Mendocino and Point Conception, both in California. We generally consider the region north of Cape Mendocino to be the “northern CCE,” the region between Cape Mendocino and Point Conception the “central CCE,” and the region south of Point Conception the “southern CCE.” Figure 4a also shows sampling locations for much of the regional climate and oceanographic data presented in this report. In particular, many of the physical and chemical oceanographic data are collected on the Newport Line off Oregon and the California Cooperative Oceanic Fisheries Investigations (CalCOFI) grid off California. Physical oceanography sampling is further complemented by basin-scale observations and models.

Freshwater habitats worldwide can be spatially grouped into “ecoregions” according to the designations of Abell et al. (2008). The freshwater ecoregions in the CCE are shown in Figure 4b, and are the basis by which we summarize freshwater habitat indicators relating to streamflow, stream water temperatures, and snowpack.

The map in Figure 4c represents sampling for most biological indicators, including copepods, forage species, California sea lions (*Zalophus californianus*), and seabirds. The blue-, green-, and orange-shaded regions of coastal waters refer to the extent of major survey efforts that focus on forage species, juvenile salmon, and seabirds in shelf and slope habitats; in some cases, the surveys span both sides of the major zoogeographic boundaries of Cape Mendocino and Point Conception (especially the surveys represented by green shading), although the data we use in this report for those groups are mostly subsets drawn from areas that represent status and trends specific to the Northern, Central, and Southern regions. Not shown is groundfish bottom trawl sampling, which covers most trawlable habitat on the shelf and upper slope (depths of 55–1,280 m) in U.S. waters; the blue- and green-shaded regions in Figure 4c roughly approximate the areal extent of the NOAA Fisheries West Coast Groundfish Bottom Trawl Survey (Keller et al. 2017).

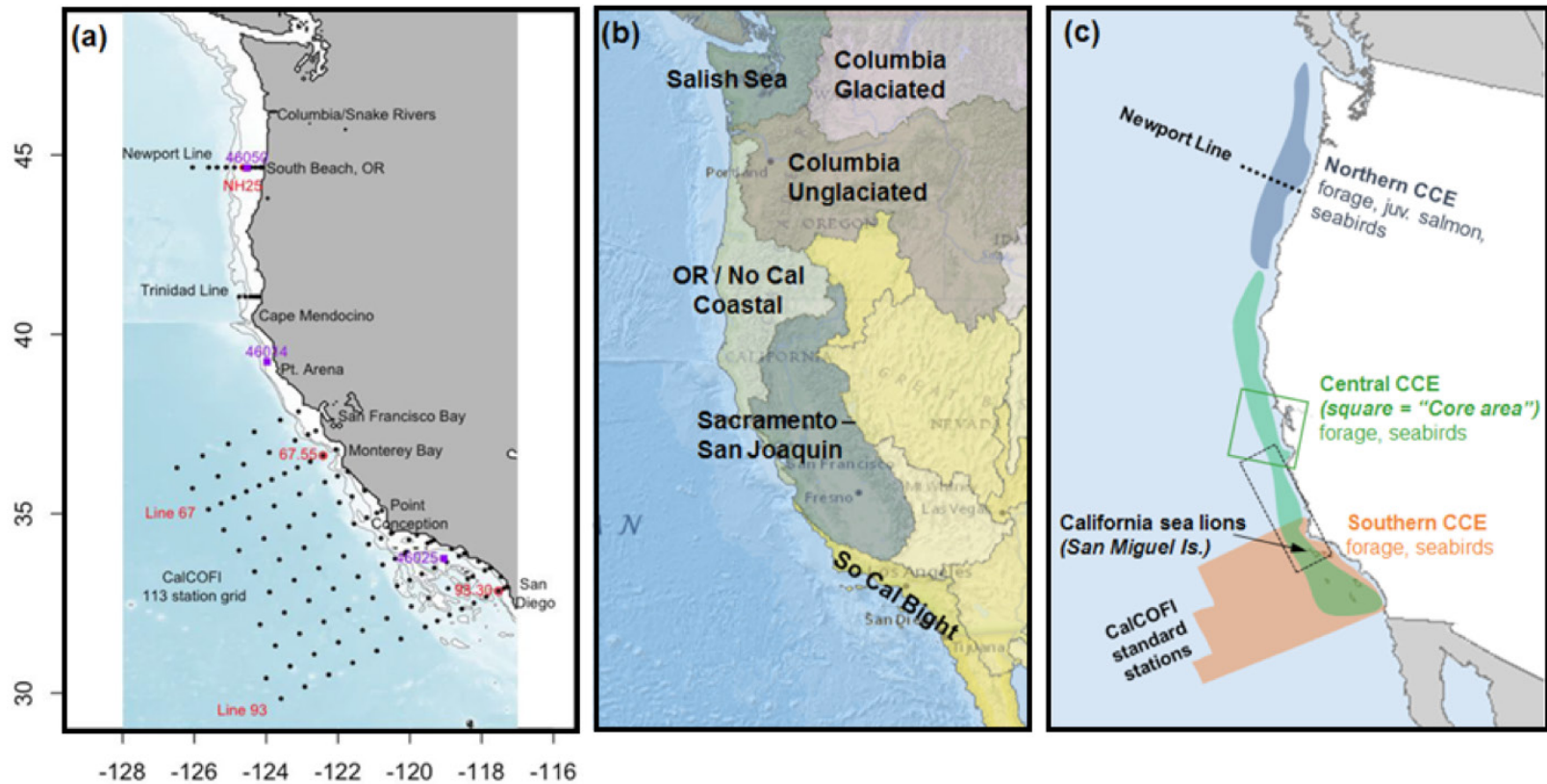


Figure 4. Maps of the California Current Ecosystem (CCE) and sampling areas. (a) Key geographic features and oceanographic sampling locations. (b) Freshwater ecoregions, where snowpack and streamflow indicators are measured. (c) Biological sampling areas for copepods (Newport Line), pelagic forage species, seabirds, and California sea lions. Solid box = the “core” sampling area for forage in the central CCE. Dotted box approximates the foraging area for adult female California sea lions from the San Miguel colony.

# Climate and Ocean Drivers

The northeastern Pacific Ocean has experienced exceptional climate variability in recent years, reaching new extremes for many indicators related to climate and ocean drivers. As we describe in the sections that follow, this variability has affected many aspects of the CCE, including water and air temperature, winds, currents, mixing of ocean waters, water chemistry, and precipitation. Climate and ocean indicators in the CCE reveal a climate system still in transition in 2017. The historically unprecedented North Pacific marine heat wave of 2013–16 and the strong El Niño event of 2015–16 gave way to cooler coastal waters, a succession of strong storms in the winter of 2016–17, and weak La Niña conditions by late 2017. The transition is visible in Figure 5, where the deep and persistent red bands of above-average water temperatures from 2014–16 return to more average or cool conditions in 2017. Deep residual warm water and associated species persisted from the warming events, especially in the north (Figure 5, top), but basin-scale climate and ocean indicators generally trended toward average conditions in 2017. As described below, regional indicators of upwelling, water chemistry, and stream conditions demonstrated their characteristically high spatiotemporal variability.

The following subsections provide in-depth descriptions of basin-scale, regional-scale, and hydrologic indicators of climate and ocean variability in the CCE.

## Basin-Scale Indicators

The CCE is driven by atmosphere–ocean energy exchange that occurs on many temporal and spatial scales. To capture large-scale variability, the CCIEA team tracks three indices: the status of the equatorial El Niño–Southern Oscillation (ENSO), described by the Oceanic Niño Index (ONI); the Pacific Decadal Oscillation (PDO); and the North Pacific Gyre Oscillation (NPGO). Positive ONI and PDO values and negative NPGO values usually denote conditions that lead to low CCE productivity, whereas negative ONI and PDO values and positive NPGO values are associated with periods of high CCE productivity. These indices vary independently, so there is a wide range of observed variability in the CCE.

ENSO events impact the CCE by modifying the jet stream and storm tracks, deepening the nearshore thermocline, and generating coastal currents that enhance poleward transport of equatorial and subequatorial waters (and species). A positive ONI indicates El Niño conditions, which usually means more storms to the south, weaker upwelling, and lower primary productivity in the CCE. A negative ONI means La Niña conditions, which usually lead to higher productivity. The PDO is related to sea surface temperature (SST), and is derived from sea surface temperature anomalies (SSTa) in the Northeast Pacific, which often persist in “regimes” that last for many years. In positive PDO regimes, coastal SSTa in the Gulf of Alaska and the CCE tend to be warmer, while those in the North Pacific Subtropical Gyre tend to be cooler. Positive PDOs are associated with lower productivity in the CCE. The NPGO is a low-frequency variation of sea surface height, indicating variations in the circulation of the North Pacific Subtropical Gyre and the Alaskan Gyre, which in turn relate to the source waters for the CCE. Positive NPGO values are associated with increased equatorward flow, along with increased surface salinities, nutrients, and chlorophyll-*a*. Negative NPGO values are associated with decreases in such values, implying fewer subarctic source waters and generally lower productivity.

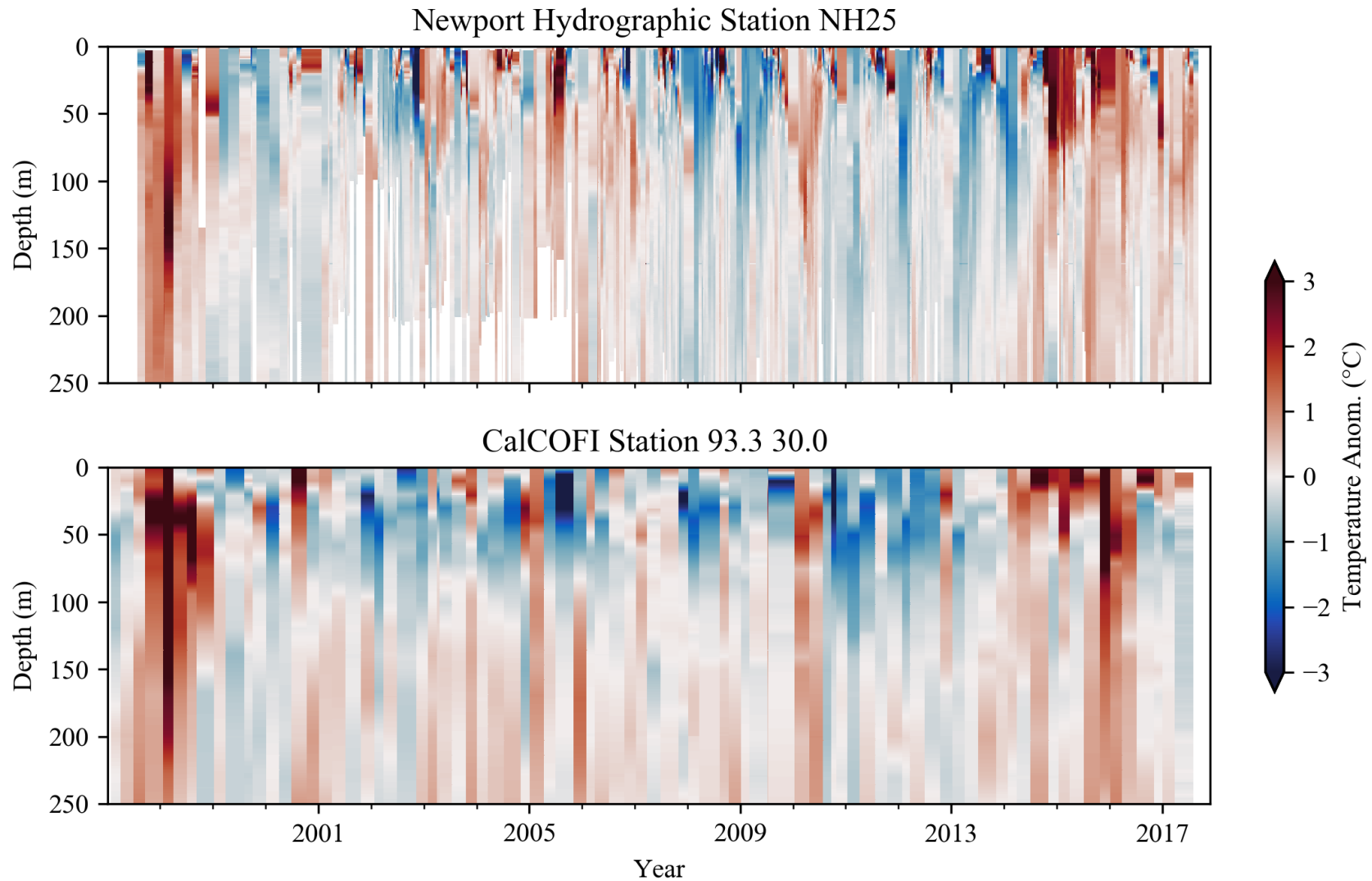


Figure 5. Time–depth temperature anomaly contours for nearshore hydrographic stations NH25 (Aug 1998 to Sep 2017) and CalCOFI 93.30 (Jan 1998 to Aug 2017). For locations of these stations, see Figure 4a. Extreme warm anomalies occurred throughout the water column during El Niño events in 1998 and 2016, and at the surface in 2014–15 during the 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. Newport Hydrographic (NH) line temperature data from J. Fisher, NMFS/NWFSC, OSU. CalCOFI hydrographic line data from <https://www.calcofi.org/>. CalCOFI data from January 1998 to February 2017 are from the bottle data database, while the remaining 2017 data are preliminary conductivity, temperature, and depth (CTD) data from the recent CTD database.

In 2017, the ONI was neutral for a majority of the year, but shifted to weak La Niña conditions in October and November (Figure 6, top); the weak La Niña conditions persisted into the first half of 2018 before shifting back to weak El Niño conditions during the summer of 2018 (Climate Prediction Center).<sup>7</sup> PDO values were positive but declining over the course of 2017, nearing the long-term mean for the first time since the winter of 2013–14 (Figure 6, middle). NPGO values ranged between neutral and negative, with the October 2017 value being the lowest of the year (Figure 6, bottom). The ONI and PDO indices suggest a return to conditions of higher productivity following the major El Niño of 2015–16 and the large marine heat wave of 2013–16. However, while the marine heat wave dissipated in fall of 2016, some slightly (<1 standard deviation [SD]) anomalously warm surface water remained in the Gulf of Alaska and immediately along the U.S. West Coast in early 2017 (Figure 7, upper left). Summer SSTa generally increased, with some anomalies >1 SD off California and Baja California, and a negative SSTa near Cape Blanco (Figure 7, lower left). The influence of the large marine heat wave and 2016 El Niño event are especially evident in the five-year means (Figure 7, middle), with positive anomalies in the Gulf of Alaska in the winter expanding to the majority of the domain by the summer. The five-year trends for SSTa are negative in the west during the winter and closer to the coast during the summer (Figure 7, right); these negative trends are a result of cooler temperatures in 2016–17 following the highs of 2014–15.

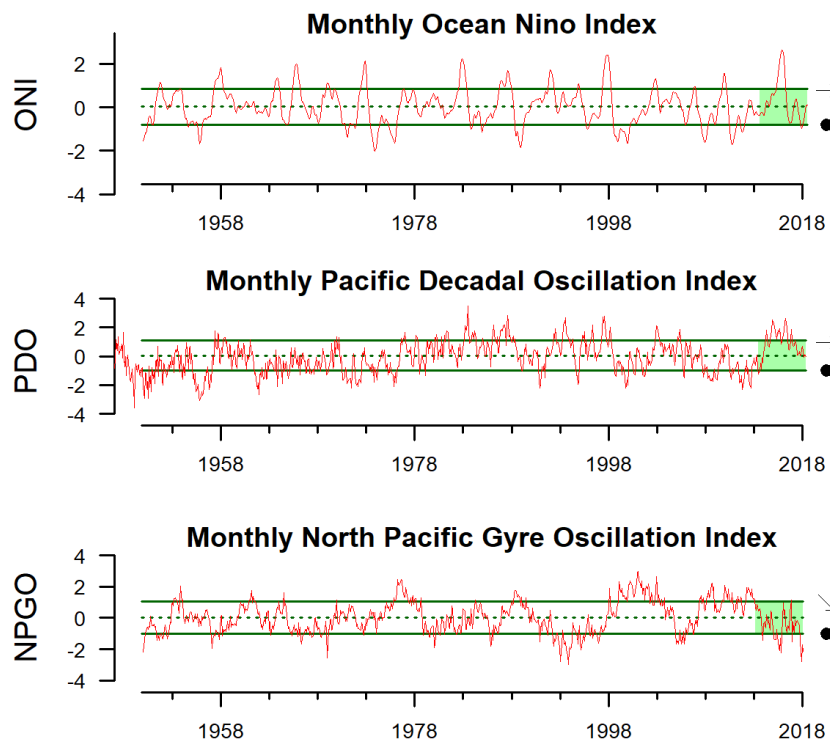


Figure 6. Monthly values of the Oceanic Niño Index (ONI), Pacific Decadal Oscillation (PDO), and North Pacific Gyre Oscillation (NPGO) from 1950 to early 2018, with lines, colors, and symbols as in Figure 3a. ONI information and data from the NOAA Climate Prediction Center ([http://www.cpc.ncep.noaa.gov/products/analysis\\_monitoring/ensostuff/ONI\\_change.shtml](http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_change.shtml)). PDO data from N. Mantua, NMFS/SWFSC, and are served by the University of Washington Joint Institute for the Study of the Atmosphere and Ocean (JISAO; <http://research.jisao.washington.edu/pdo/>). NPGO data from E. Di Lorenzo, Georgia Institute of Technology (<http://www.o3d.org/npgo/>).

<sup>7</sup> [http://www.cpc.ncep.noaa.gov/products/analysis\\_monitoring/enso\\_advisory/ensodisc.shtml](http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/ensodisc.shtml)

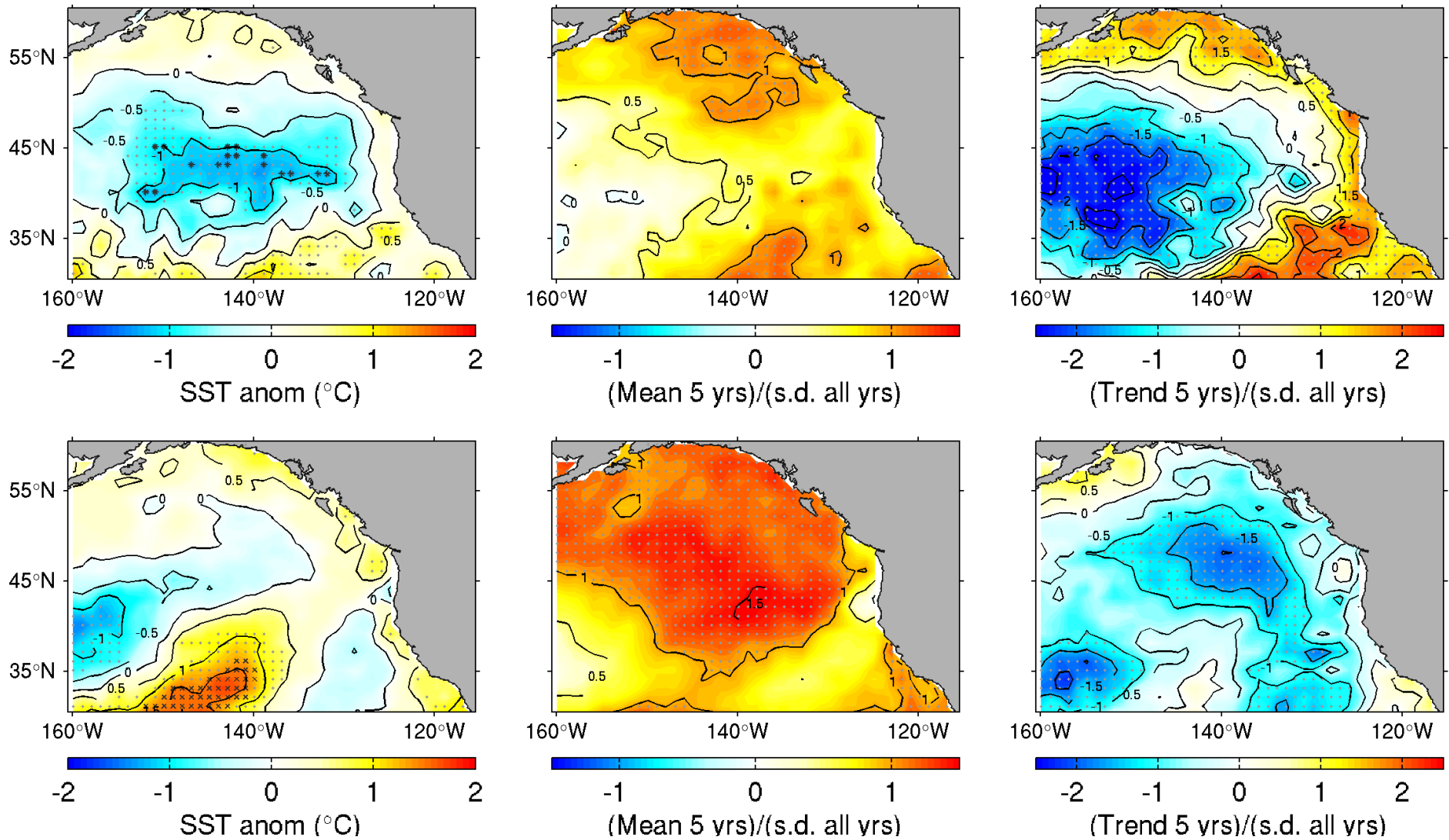


Figure 7. Sea surface temperature (SST) anomalies (2017; left), five-year means (2013–17; middle), and five-year trends (2013–17; right) in winter (Jan–Mar; top) and summer (Jul–Sep; bottom). The time series at each grid point began in 1982. Black circles mark cells where the anomaly was  $>1$  SD above the long-term mean. Black Xs mark cells where the anomaly was the highest of the time series. SST maps are optimally interpolated, remotely sensed temperatures (Reynolds et al. 2007). The daily optimal interpolated AVHRR SST can be downloaded from ERDDAP (<https://coastwatch.pfeg.noaa.gov/erddap/index.html>, dataset ID: ncdcOisst2Agg).



In summary, following the 2013–16 marine heat wave and the 2015–16 El Niño event, basin-scale climate and oceanographic indices moderated during 2017. However, the cooler coastal waters in the northern CCE were largely surface-oriented, with the subsurface showing lingering signs of the recent warming events (Figure 5). Thorough summaries of these dynamics are provided in Leising et al. (2015), McClatchie et al. (2016), and Wells et al. (2017).

## Regional Upwelling Indices

Seasonal cross-shore gradients in sea level pressure 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 U.S. Navy Fleet Numerical Meteorology and Oceanography Center’s sea level pressure product, reported at a spatial scale of one latitude degree by one longitude degree ( $1^\circ$  lat  $\times$   $1^\circ$  long). 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 (Figures 8 and 9). At lat  $45^\circ$ N (near Newport, Oregon), 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. At lat  $39^\circ$ N (near Point Arena, California), 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 (lat  $\sim 33^\circ$ 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. The CCIEA team plans to introduce improved regional upwelling indices in the near future so that all regions of the coast are represented with reasonable accuracy.

Over the last five years, CUI has been below-average in the northern CCE and average to above-average in the central and southern CCE (Figure 9). 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 5), below-average chlorophyll-*a* (Wells et al. 2017), and the lagging ecological conditions described later in this report.

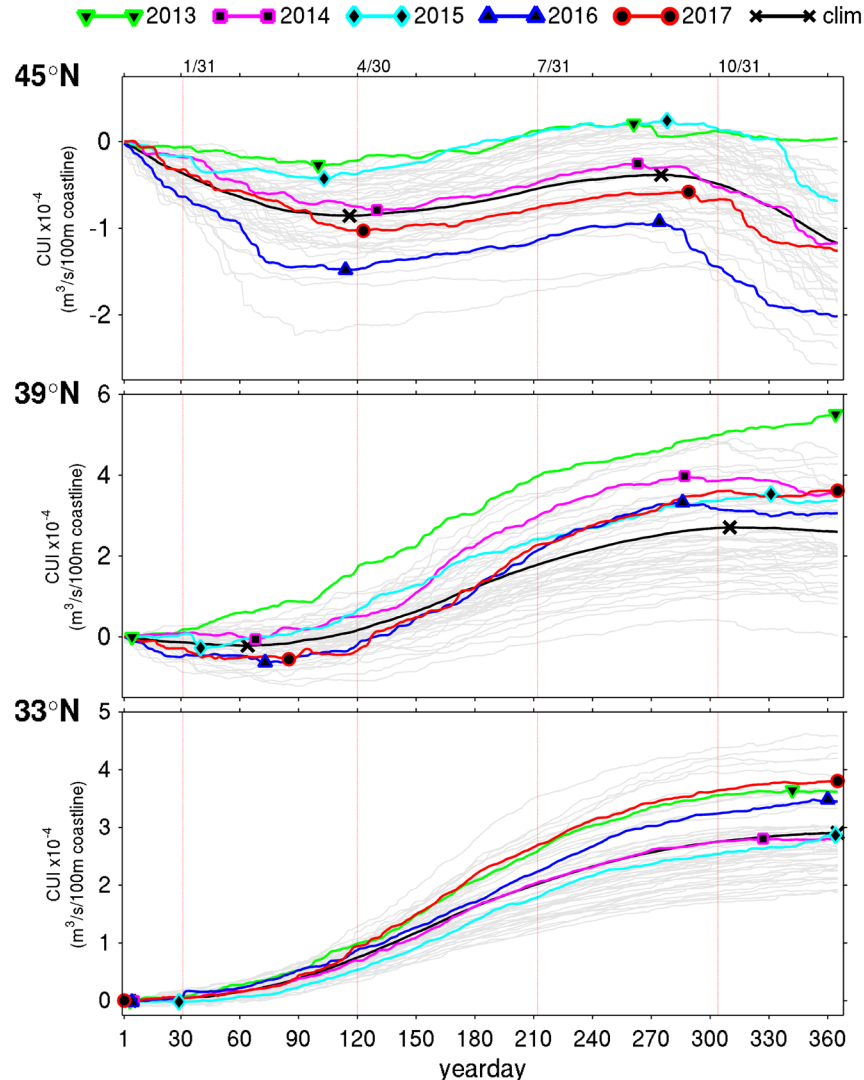


Figure 8. Cumulative upwelling index (CUI) at three latitudes, 1967–2017. Black = long-term mean; gray = 1967–2012; colored trends = 2013–17. Symbols on trends mark the start (spring transition) and end of the upwelling season for a given year. Vertical lines mark the ends of Jan, Apr, Jul, and Oct. CUI curves calculated from the six-hourly upwelling index product (<https://coastwatch.pfeg.noaa.gov/erddap/index.html>, dataset ID: erdUI216hr).

## 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. DO is required for organismal respiration, and 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; such waters are most likely to occur following the onset of spring upwelling and continuing into the summer and early fall months. This is because upwelled water from deeper ocean sources tends to be low in DO, and microbial decomposition of organic matter in the summer and fall increases overall system respiration and oxygen consumption, particularly closer to the seafloor.

Low DO was a serious issue in the northern CCE in 2017. At station NH05 (5 km off of Newport, Oregon), water near bottom over the continental shelf was below the hypoxia threshold from late July until early September (Figure 10, 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, personal communication). Observed DO levels further offshore at Newport (station NH25) were above the 1.4 mL/L threshold (Figure 10), as were data collected at stations in the CalCOFI region in the Southern California Bight (Appendix E.3 in Harvey et al. 2018).

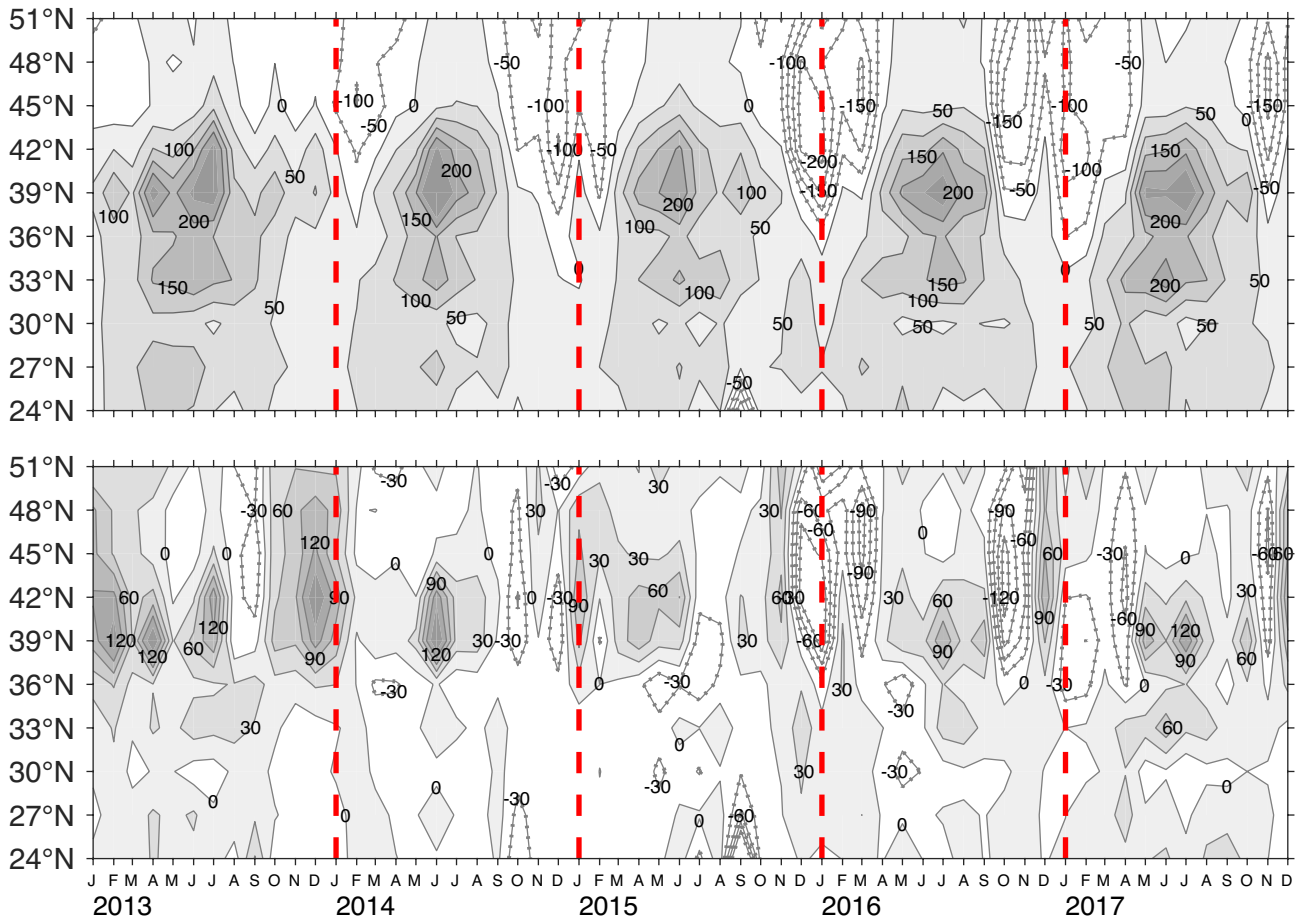


Figure 9. Monthly means of daily upwelling index (top) and anomalies (bottom) for Jan 2013 to Nov 2017. Shaded areas denote positive values (upwelling-favorable) in upper panel, and positive anomalies (generally greater than normal upwelling) in lower panel. Anomalies are relative to 1967–2015 monthly means. Units are in  $\text{m}^3/\text{s}$  per 100 m of coastline. Daily upwelling index data obtained from <https://coastwatch.pfeg.noaa.gov/erddap/index.html> (dataset ID: upwell).

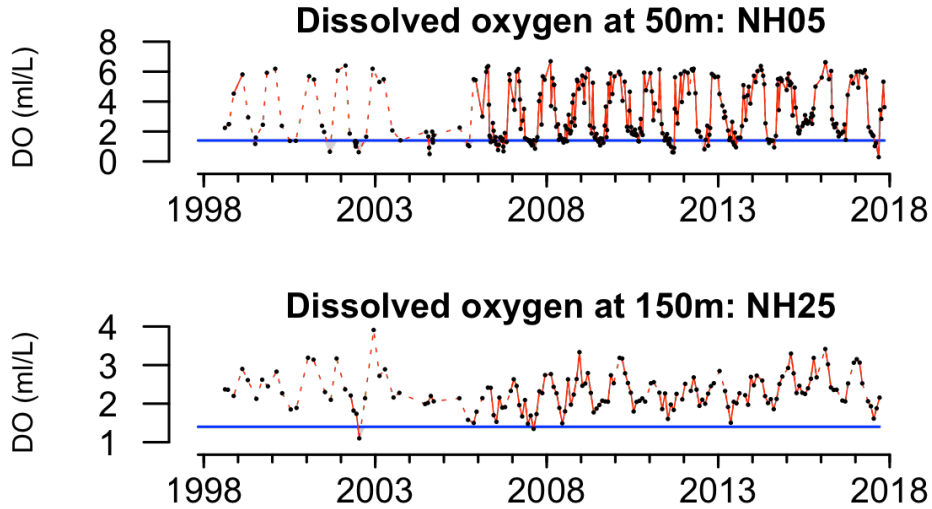


Figure 10. Dissolved oxygen (DO) at 50 and 150 m depths off Newport, OR, through 2017. Stations NH05 and NH25 are 5 and 25 km from shore, respectively. Blue line = hypoxia threshold of 1.4 mL/L. Dotted red lines indicate missing data. Lines, colors, and symbols as in Figure 3b. DO data from J. Fisher, NMFS/NWFSC, OSU.

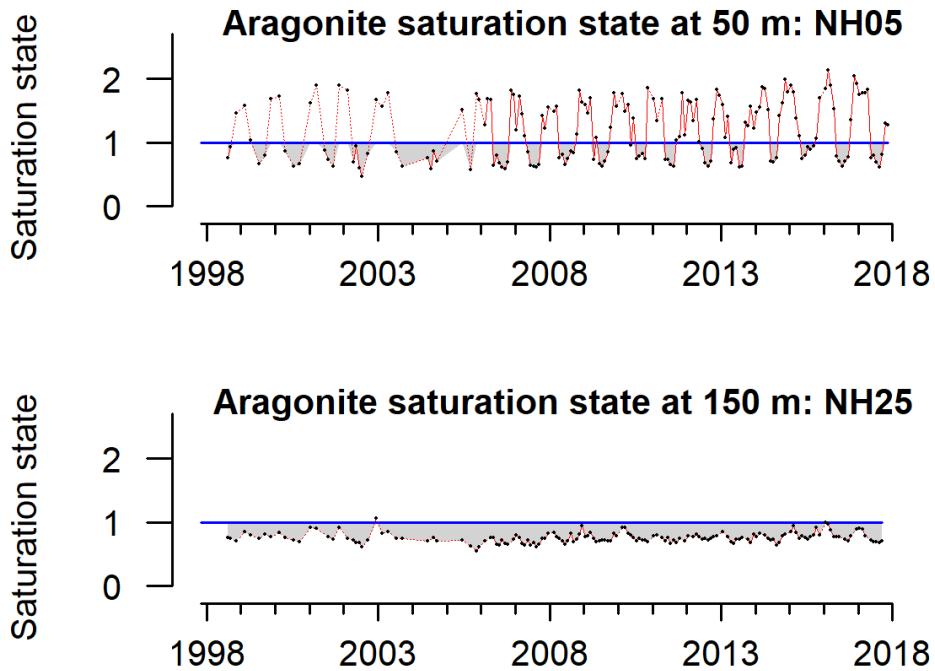


Figure 11. Monthly aragonite saturation values off Newport, OR, 1998–2017. Blue line = threshold value of 1.0 for aragonite saturation state. Lines, colors, and symbols as in Figure 3b. Aragonite saturation state data provided by J. Fisher, NMFS/NWFSC, OSU.

Ocean acidification (OA), caused by increased levels of atmospheric CO<sub>2</sub>, 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 have been shown to be stressful for many CCE species, including oysters, crabs, and pteropods (Barton et al. 2012, Bednaršek et al. 2014, Marshall et al. 2017, Hodgson et al. 2018). 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). As a result, aragonite saturation levels tend to be lowest during and following upwelling periods in the spring and summer, and highest during the winter.

Aragonite saturation levels off Newport in 2017 were fairly typical, and lower than in the anomalous years of 2014–15 (Figure 11). 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. At station NH25, aragonite saturation state at 150 m depth followed the same seasonal cycle but across a narrower range; conditions at this site and depth were almost always corrosive (<1.0). The isocline for corrosive water was shallower in summer and fall of 2017 than in any other year on record, although it was comparable to many other years in recent decades (Figure 12).

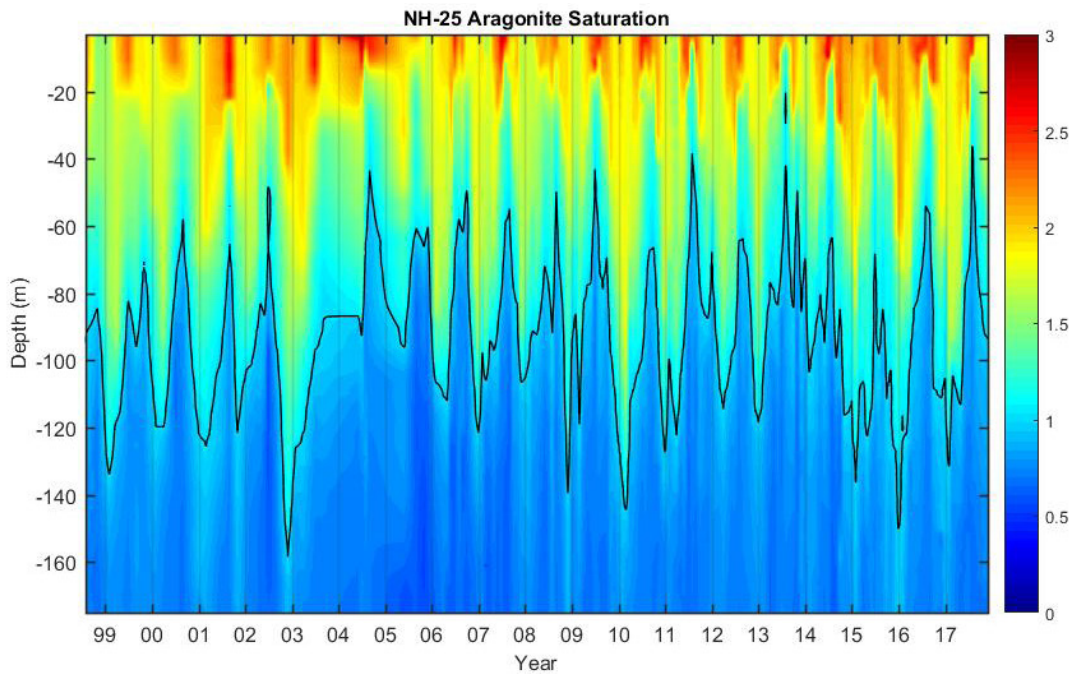


Figure 12. Aragonite saturation state versus depth at station NH25 along the Newport Line, 1998–2017. Dark line indicates the depth at which aragonite saturation state is at threshold value (= 1.0). Aragonite saturation state data provided by J. Fisher, NMFS/NWFSC, OSU.

## Hydrologic Indicators

Freshwater habitat conditions are critical for salmon populations, and for estuaries that support many marine species. Indicators are reported based on a hierarchical spatial framework and are summarized by freshwater ecoregion (Figure 4b, as derived from Abell et al. [2008] and [Freshwater Ecoregions of the World](#)<sup>8</sup>) or, where possible, by salmon evolutionarily significant units (ESUs, sensu Waples 1995). Within ecoregions, we summarized data using evolutionary significant units. Status and trends for all freshwater indicators are estimated using space–time models (Lindgren and Rue 2015), which account for temporal and spatial autocorrelation.

The freshwater indicators presented here focus on salmon habitat conditions as related to snowpack, streamflow, and temperature. Snow-water equivalent (SWE) is the total water content in snowpack, which provides a steady source of freshwater into the summer months. Maximum streamflows in winter and spring are important for habitat formation, and in California can be important for removing a polychaete worm that is the obligate host of the salmon parasites *Ceratonova shasta* and *Parvicapsula minibicornis* (Alexander et al. 2014, True et al. 2017); however, high flows can also cause scouring of eggs from salmon redds (DeVries 1997), thereby reducing abundance and productivity (Greene et al. 2005, Zimmerman et al. 2015). Minimum streamflows in summer and fall can restrict habitat for instream juveniles and migrating adults (Bradford and Heinonen 2008), and high summer water temperatures can cause impaired physiology and mortality to both juveniles (Marine and Cech 2004, Richter and Kolmes 2005) and adults (Jeffries et al. 2012). All freshwater indicators are influenced by climate and weather patterns, and intensifying climate change is expected to exacerbate high temperatures, low SWEs, and extreme flow events.

As it was 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 13). The official SWE estimate is made on 1 April for each calendar year, which is after our annual report to PFMC and thus is not represented in Figure 13; however, Figure 14 indicates that peak SWE in 2018 was below average in much of the region, particularly in the southern Cascade Range and the Sierra Nevadas.

Streamflow indicators are derived from active U.S. Geological Survey (USGS) stream gages with records of at least 30 years' duration. Daily means from 213 gages were used to calculate annual one-day maximum and seven-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. The relatively average SWE in 2017 was consistent with maximum and minimum flows that were within, or in some cases above, the typical historical ranges at ecoregional scales (Figures 15 and 16). All ecoregions experienced variability in both minimum and maximum streamflow anomalies in the most recent five years, although not significantly outside of the historical range. Minimum stream flows exhibited fairly consistent patterns across all ecoregions: most ecoregions demonstrated declining minimum flows over the last five to eight years, with an uptick in 2017—although little variation exists for rivers in the Southern California Bight (Figure 15). Here, we must also note that members of PFMC expressed concern that the minimum annual flow estimates could be derived from winter conditions when streams were frozen. A follow-up analysis of data from the Salish Sea and Snake River catchments

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<sup>8</sup> <http://www.feow.org>

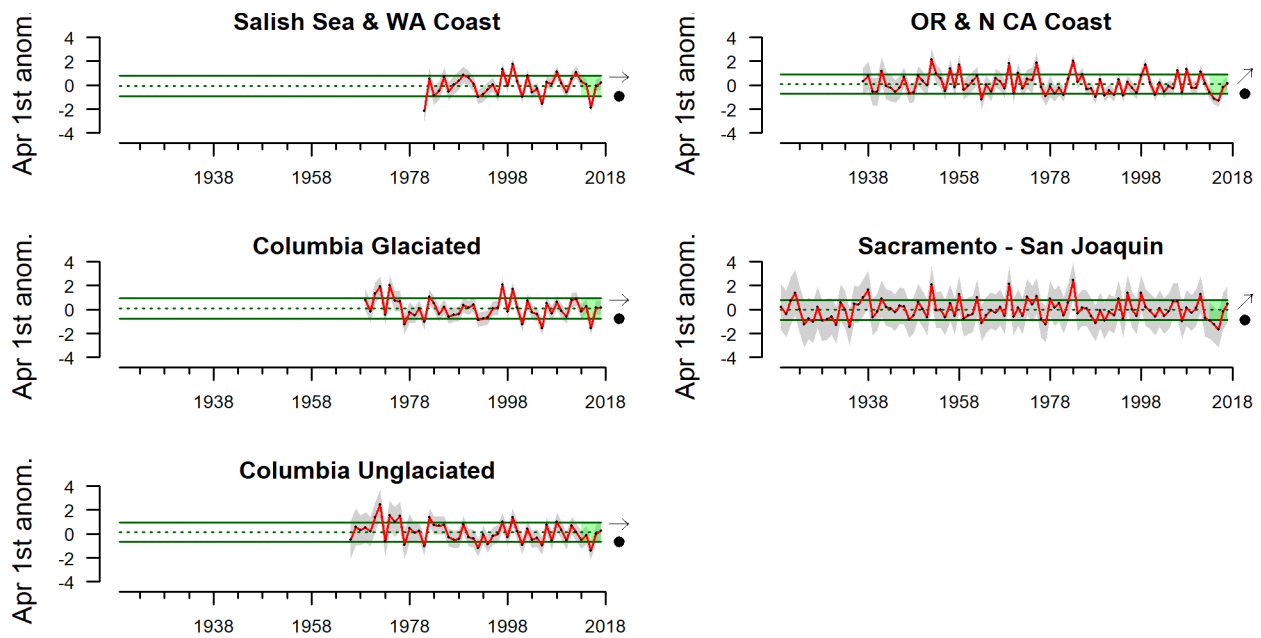


Figure 13. Anomalies of 1 April snow-water equivalent (SWE) in five freshwater ecoregions of the CCE through 2017. Lines, colors, and symbols as in Figure 3a. Ecoregions are mapped in Figure 4b. SWE data derived from California Department of Water Resources snow survey (<http://cdec.water.ca.gov/>) and Natural Resources Conservation Service’s SNOTEL sites in WA, OR, CA, and ID (<http://www.wcc.nrcs.usda.gov/snow/>).

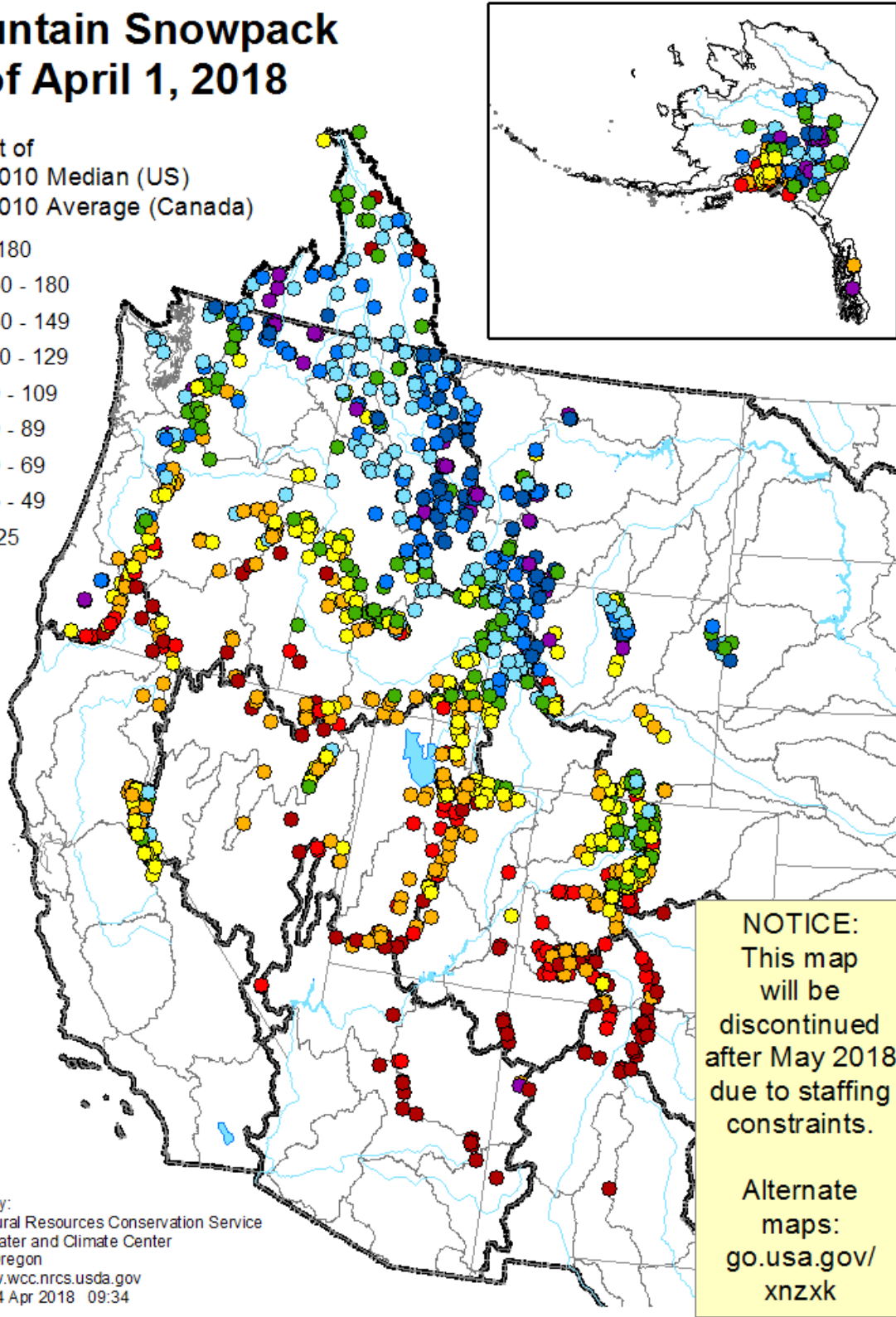
indicates the majority of low flow data came from fall (S. Munsch, NOAA, unpublished data), so we believe these results to be robust (though imperfect) indicators of low-flow events that could be detrimental to juvenile and adult salmon due to constrained habitat, warm water, and hypoxia. In future reports, we will work to further refine these indicators to best represent late-summer and fall low-flow periods. For maximum flows, five-year trends were particularly pronounced for the Sacramento–San Joaquin and Oregon and Northern California ecoregions (increased high flows), and all regions except Salish Sea and Washington Coast experienced greater maximum flows in 2017 than in 2016 (Figure 16).

We also summarized streamflow with quad plots that compile recent flow anomalies at the finer spatial scale of individual Chinook salmon ESUs. The error bars describe 95% credible intervals of river flow, allowing us to determine which ESUs have short-term trends or averages 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 17, left; yellow square symbol). While increasing maximum flow can be of concern in some catchments due to the threat of scouring, in this case, high spring flushing flows are important for reducing the occurrence of parasites in juvenile salmon (True et al. 2017). Minimum flow anomalies, which may signal the potential for stress related to temperature, oxygen, or space, had decreasing trends for just one ESU, the Snake River fall run, which was strongly lower in both recent trend and recent average (Figure 17, right). As noted in the previous paragraph, a subsequent analysis of low-flow data for the Snake River fall Chinook salmon ESU confirmed that these minimum flow events primarily occurred during the fall (S. Munsch, NOAA, unpublished data). Importantly, the averages and slopes of the plots in Figures 15 and 16 were estimated with different statistics than the quad plots in Figure 17; we will resolve this difference in the future.

# Mountain Snowpack as of April 1, 2018

Percent of  
1981-2010 Median (US)  
1981-2010 Average (Canada)

- > 180
- 150 - 180
- 130 - 149
- 110 - 129
- 90 - 109
- 70 - 89
- 50 - 69
- 25 - 49
- < 25



Prepared by:  
USDA Natural Resources Conservation Service  
National Water and Climate Center  
Portland, Oregon  
<https://www.wcc.nrcs.usda.gov>  
Created: 4 Apr 2018 09:34

NOTICE:  
This map  
will be  
discontinued  
after May 2018  
due to staffing  
constraints.  
  
Alternate  
maps:  
[go.usa.gov/  
xnzxc](https://go.usa.gov/xnzxk)

Figure 14. Mountain snowpack on 1 April 2018 at select monitoring sites relative to values from 1981–2010. Source: U.S. Department of Agriculture, National Water and Climate Center.



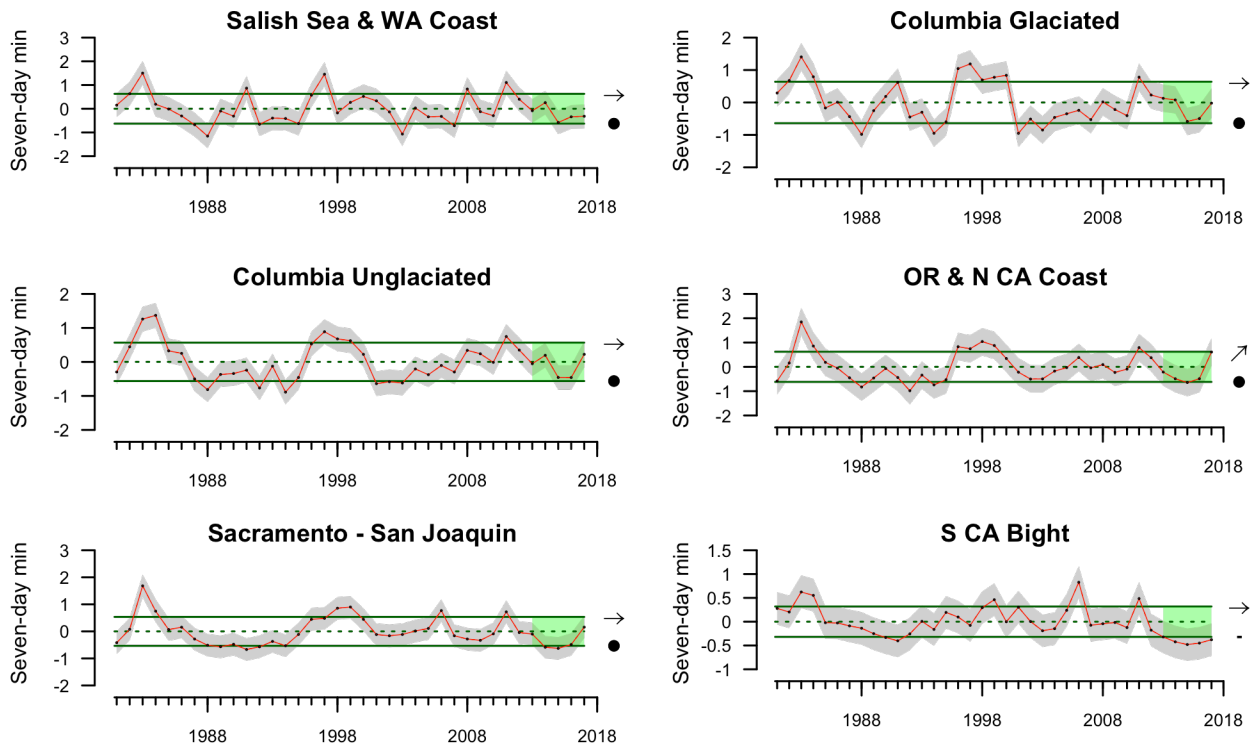


Figure 15. Anomalies of seven-day minimum streamflow measured at 213 gages in six ecoregions, 1981–2017. Gages include both regulated (subject to hydropower operations) and unregulated systems; trends were similar when these systems were examined separately. Lines, colors, and symbols as in Figure 3a. Streamflow data provided by U.S. Geological Survey (<http://waterdata.usgs.gov/nwis/sw>).

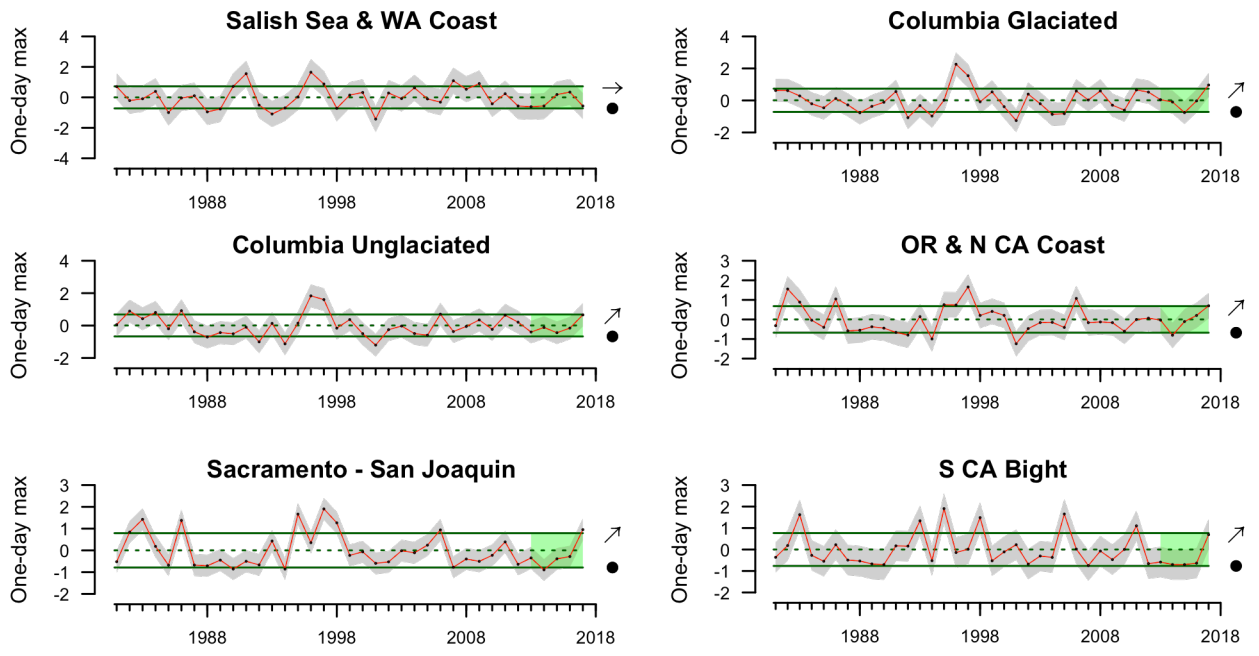


Figure 16. Anomalies of one-day maximum streamflow measured at 213 gages in six ecoregions, 1981–2017. Gages include both regulated (subject to hydropower operations) and unregulated systems; trends were similar when these systems were examined separately. Lines, colors, and symbols as in Figure 3a. Streamflow data provided by U.S. Geological Survey (<http://waterdata.usgs.gov/nwis/sw>).

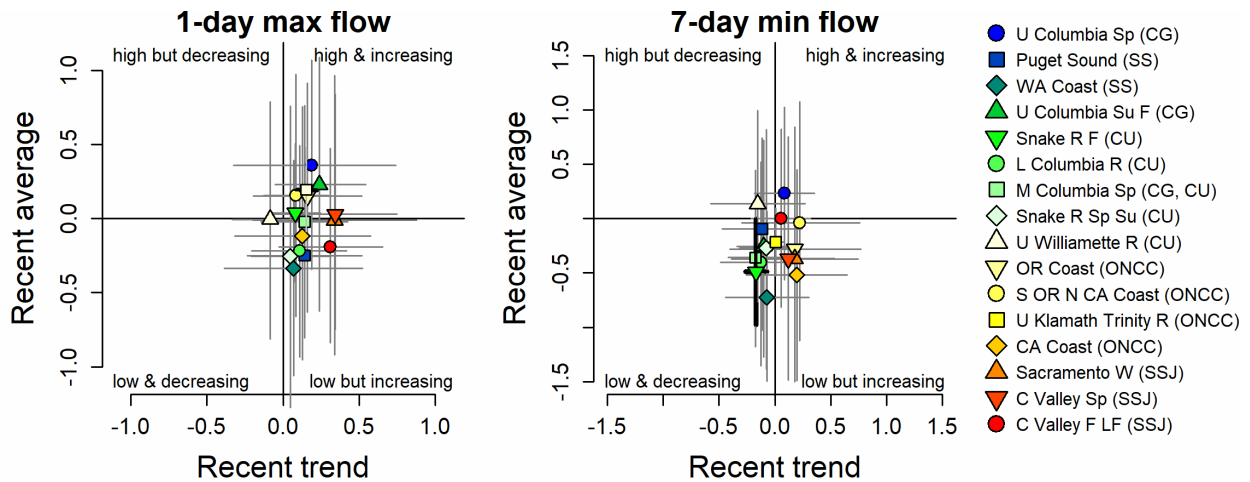


Figure 17. Recent (five-year) trend and average of maximum and minimum streamflow anomalies in 16 Chinook salmon ESUs through 2017. Symbols are color-coded from north (blue) to south (red). Error bars represent 2.5% and 97.5% upper and lower Bayesian credible intervals. Gray error bars overlap zero. Heavy black error bars differ from zero (i.e., significantly differ 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 and symbols as in Figure 3c. Streamflow data provided by U.S. Geological Survey (<http://waterdata.usgs.gov/nwis/sw>).

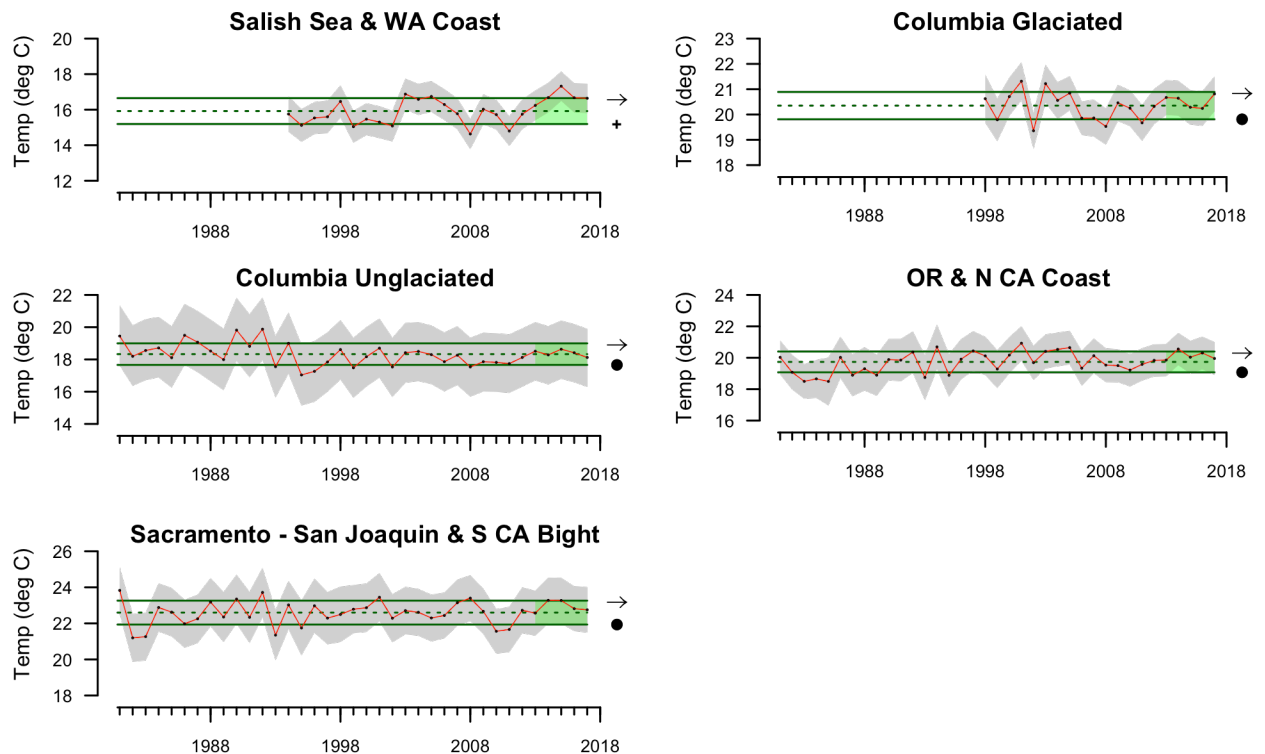


Figure 18. Mean maximum stream temperature in August measured at 446 USGS gages in six ecoregions through 2017. Gages include both regulated (subject to hydropower operations) and unregulated systems, although trends were similar when these systems were examined separately. Lines, colors, and symbols as in Figure 3a. Stream temperature data provided by U.S. Geological Survey (<http://waterdata.usgs.gov/nwis/sw>).

This year we added a new freshwater indicator, maximum August stream temperature, which is summarized in Figure 18 and derived from 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 in all ecoregions each year. Stream temperature records are limited in California, so two ecoregions were combined. For most ecoregions, the most recent five-year period was marked by largely average maximum stream temperatures. The exception is the Salish Sea and Washington Coast ecoregion, which had much higher temperatures in the last five years compared to the period of record. Long-term increases (0.01–0.04°C/year) in maximum August temperature are evident in at least three ecoregions starting in the 1980s and 1990s.

# Focal Components of Ecological Integrity

The CCIEA team examines many indicators related to the abundance and condition of key species, the dynamics of community structure, and ecological interactions. Many CCE species and processes respond very quickly to changes in ocean and climate drivers, while other responses may lag by many years. These dynamics are challenging to predict. 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, and whether 2018 will represent a further shift toward average or above-average productivity.

## Northern Copepod Biomass Anomaly

Copepod biomass anomalies represent interannual 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 4), 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 patterns strongly favored southern copepods. In late June 2017, the northern copepod anomaly increased from strongly negative to relatively neutral values, while the southern copepod anomaly declined from strongly positive to neutral values, and observations of both indicators remained within  $\pm 1$  SD of the long-term mean for the rest of the year (Figure 19). Furthermore, while several rare or previously unrecorded copepods were observed on the Newport Line between fall 2014 and spring 2015 (when the marine heat wave moved onshore) and again in 2016 (possibly related to the marine heat wave and the strong 2015–16 El Niño event), these rare and new species were absent from 2017 samples (J. Fisher, NOAA/OSU, unpublished data). While these changes may suggest a transition away from the unproductive conditions in this region of the CCE, the continued presence of warm water at depth in 2017 (Figure 5) and the lack of a dominant northern copepod signal suggest that much stronger mixing of water masses may be required to establish an average or possibly more productive copepod community.

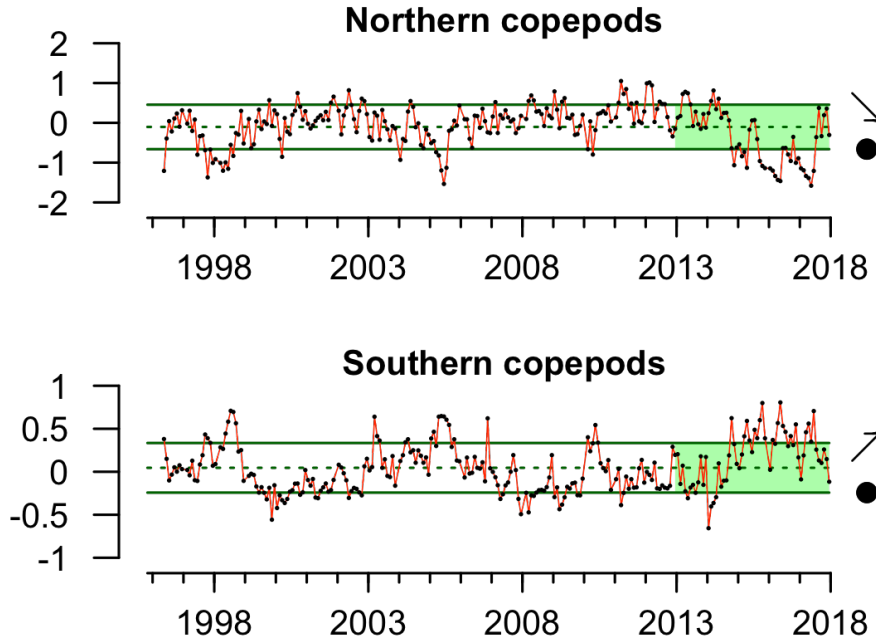


Figure 19. Monthly northern and southern copepod biomass anomalies, 1996–2017. Lines, colors, and symbols as in Figure 3a. Copepod biomass anomaly data provided by J. Fisher, NMFS/NWFSC, OSU.

## Regional Forage Availability

This section describes trends in forage availability, based on spring/summer research cruises that have been conducted independently in three different regions (Figure 4c) for decades. The species shown below represent a substantial portion of the available forage in the regions sampled by the cruises. *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 among regions. (In coming years, the CCIEA team will update the methods used to analyze these data, in consultation with the researchers who conduct the surveys and with advisory bodies from PFMC, in hopes of better associating shifts in forage community composition with environmental drivers and with the regional ecology of predatory fishes, marine mammals, and seabirds.)

The CCE forage community is a diverse portfolio of species and life-history stages, varying in behavior, energy density, and availability to predators. Years with abundant pelagic fish, market squid, and krill (e.g., *Euphausia pacifica* and *Thysanoessa spinifera*) are generally associated with cooler waters, strong upwelling, and higher productivity (Santora et al. 2014). Here, we present the forage indicators in quad plots analogous to Figure 3c; time-series data are summarized in Appendix G of Harvey et al. (2018).

## Northern CCE

The northern CCE survey off Washington and Oregon (see Figure 4c) targets juvenile salmon (*Oncorhynchus* spp.) in surface waters, but also catches pelagic fishes, squid, and gelatinous zooplankton (Brodeur et al. 2005). Recent average catches-per-unit-effort (CPUEs) of age-1+ sardine (*Sardinops sagax*), age-1+ anchovy (*Engraulis mordax*), market squid, and whitebait smelt (*Allosmerus elongatus*) were within  $\pm 1$  SD of long-term means and showed no clear short-term trends (Figure 20). Sardine and anchovy CPUEs were both close to zero (see Appendix G of Harvey et al. 2018). Jack mackerel (*Trachurus symmetricus*) CPUE had an increasing trend that continued in 2017, while herring (*Clupea pallasii*) catches decreased. Also showing a recent decline was a large jellyfish (*Chrysaora fuscescens*). Finally, extreme numbers of the pyrosome *Pyrosoma atlanticum*, a pelagic tunicate associated with warmer waters, were observed in this region (data not shown). Pyrosome observations were common during the 2014–16 marine heat wave, but catches in a related survey in this region went up 10- to 100-fold in 2017 (Brodeur et al. 2018).

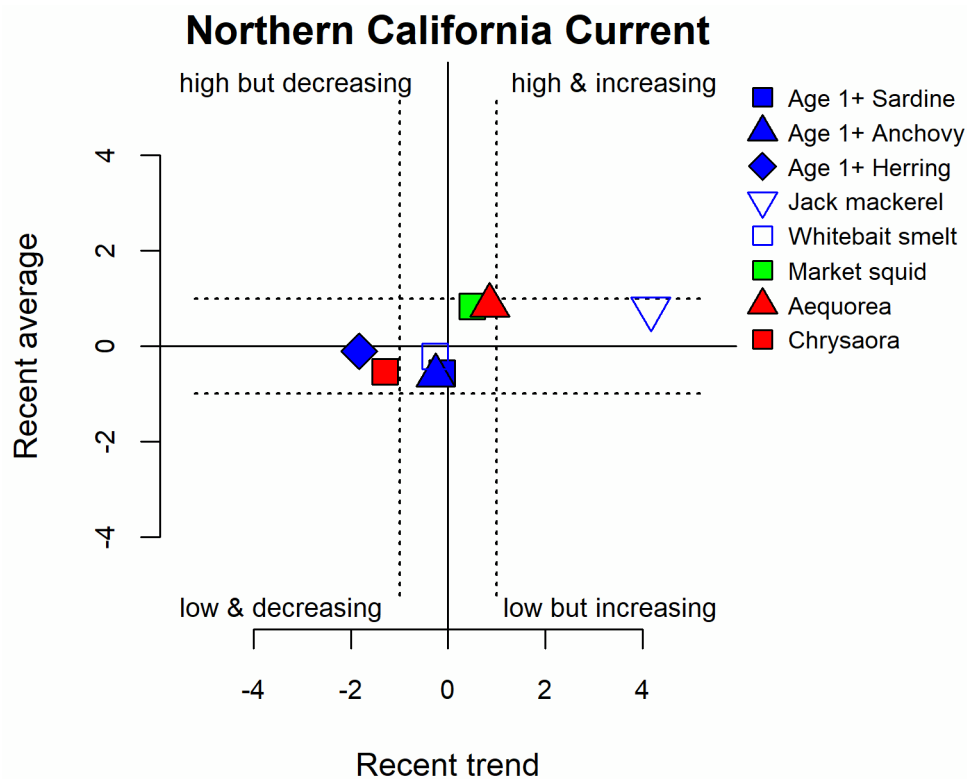


Figure 20. Recent (five-year) trend and average of key forage species in the northern CCE through 2017. Lines and symbols as in Figure 3c. Pelagic forage data from northern CCE provided by B. Burke, NMFS/NWFSC, and C. Morgan, OSU/CIMRS. Data derived from surface trawls taken during the NWFSC Juvenile Salmon and Ocean Ecosystem Survey (JSOES).

## Central CCE

Data presented here are from the “core area” of a survey (see Figure 4c) that targets young-of-the-year (YOY) rockfishes (*Sebastes* spp.), but also samples forage fish, market squid and zooplankton (Sakuma et al. 2016). 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 21; see also Appendix G of Harvey et al. 2018). Krill and market squid rebounded in 2017 from lower catches in recent years (Appendix G of Harvey et al. 2018). YOY hake catches have varied widely in recent years, while YOY sanddabs (*Citharichthys* spp.) have declined. *Chrysaora* jellyfish have declined 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).

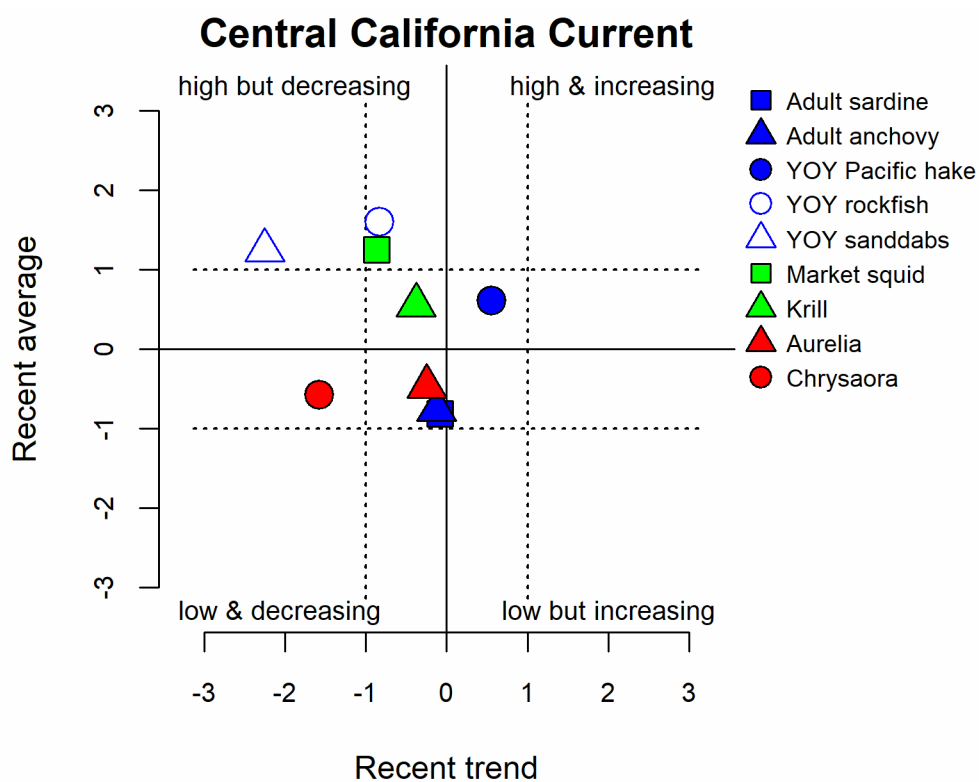


Figure 21. Recent (five-year) trend and average of key forage species in the central CCE through 2017. Lines and symbols as in Figure. 3c. Pelagic forage data from central CCE provided by J. Field, NMFS/SWFSC, from the SWFSC Rockfish Recruitment and Ecosystem Assessment Survey (<https://swfsc.noaa.gov/textblock.aspx?Division=FED&ParentMenuId=54&id=20615>).

## Southern CCE

Forage indicators for the Southern CCE come from CalCOFI larval fish surveys conducted in the spring across all core stations of the CalCOFI survey (see Figure 4c), using oblique vertical tows of fine mesh Bongo nets to 212 m depth (McClatchie 2014). The survey collects a variety of fish and invertebrate larvae (<5 days old) from several taxonomic and functional groups. Larval biomass is assumed to correlate with regional abundance of mature forage fish. Recent standardized abundances for species analyzed through 2017 were within  $\pm 1$  SD of their long-term means, but several trends are evident (Figure 22). Larval anchovy and shortbelly rockfish (*Sebastes jordani*) have been increasing. Larval sardine abundance was up slightly in 2017 (Appendix G of Harvey et al. 2018) but remained nearly 1 SD below the long-term average. Larval market squid catches have declined recently and have been very low for the past three years. Larval jack mackerel and sanddab catches were close to average in 2017, down from strong peaks in recent years.

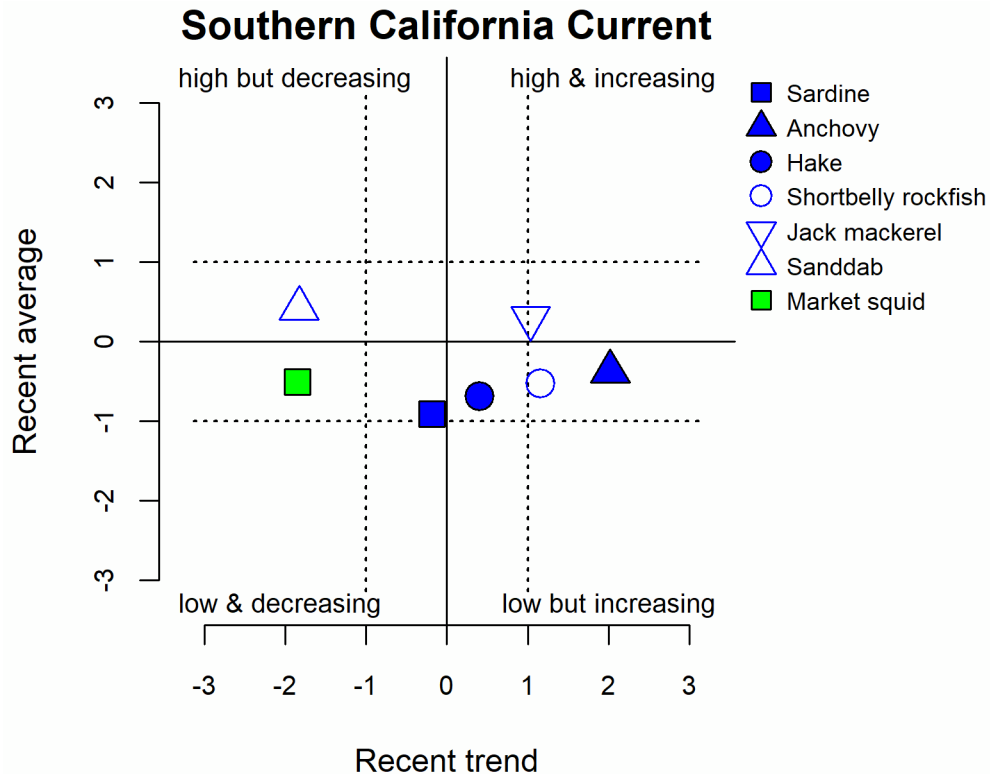


Figure 22. Recent (five-year) trend and average of the larvae of key forage species in the southern CCE through 2017. Lines and symbols as in Figure 3c. Pelagic forage data from southern CCE provided by A. Thompson, NMFS/SWFSC, and derived from spring CalCOFI surveys (<https://www.calcofi.org/>).



# Salmon

For indicators of the abundance of Chinook salmon populations, we compare the trends in natural spawning escapement along the CCE to evaluate the coherence in production dynamics, and also to get a more complete perspective of their status across the greater portion of their range. When available, we use escapement time series back to the 1970s; however, some populations have shorter time series (for example, Central Valley spring starts in 1995, Central Valley winter starts in 2001, and Coastal California starts in 1991). We summarize escapement trends in quad plots; time series are available in Appendix H of Harvey et al. (2018), and trends are evaluated for the most recent 10-year period in order to capture population dynamics across multiple generations. 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 4c).

Most Chinook salmon escapement data are updated through 2016. Generally, escapements of California Chinook salmon over the most recent decade of data were within  $\pm 1$  SD of long-term averages (Figure 23), although recent escapements were generally near the low end of the normal range (Appendix H of Harvey et al. 2018). California Chinook salmon stocks had neutral trends over

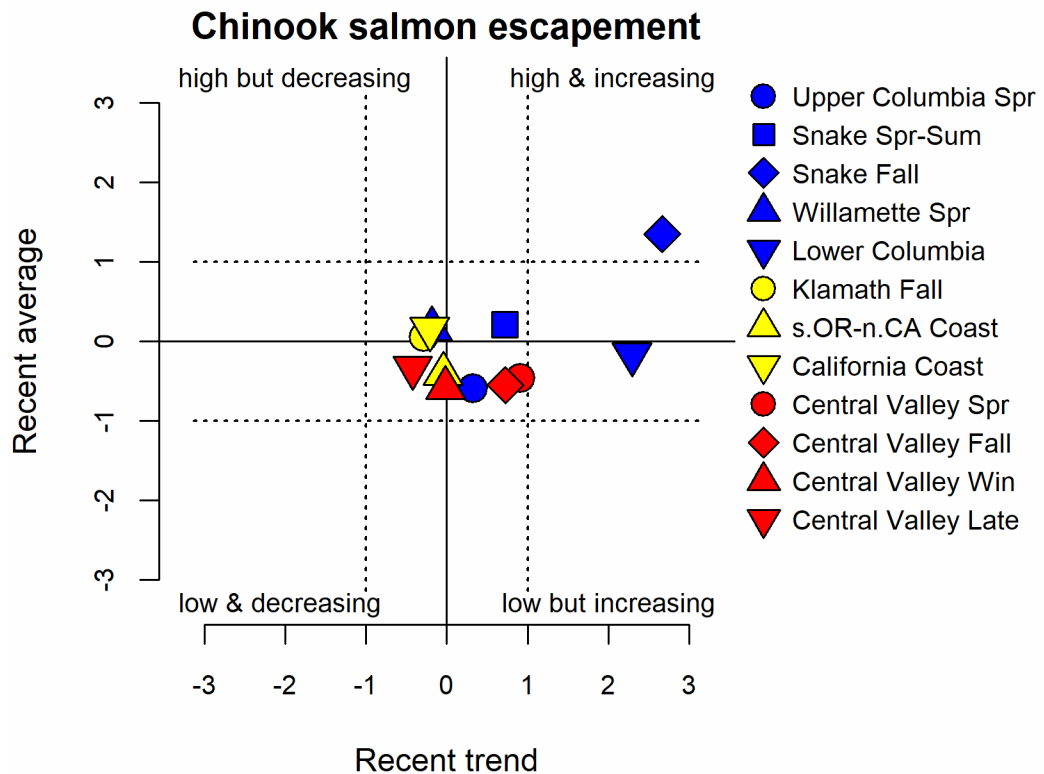


Figure 23. Recent (10-year) trend and average of Chinook salmon escapement anomalies, with most systems updated through 2016. Lines and symbols as in Figure 3c. Chinook salmon escapement data derived from California Department of Fish and Wildlife (<http://www.dfg.ca.gov/fish/Resources/Chinook/CValleyAssessment.asp>), Pacific Fisheries Management Council preseason reports (<http://www.pcouncil.org/salmon/stock-assessment-and-fishery-evaluation-safe-documents/preseason-reports/2016-preseason-report-i/>), and from the NWFSC Salmon Population Summary database (<https://www.webapps.nwfsc.noaa.gov/sps>).

the last decade, and variation in escapement among years was generally high (Appendix H of Harvey et al. 2018). For Oregon, Washington, and Idaho Chinook salmon stocks, most recent escapements were close to average (Figure 23). The exception was Snake River fall Chinook salmon, due to a series of large escapements since 2009 (Appendix H of Harvey et al. 2018). Lower Columbia and Snake River fall Chinook salmon both had significantly positive trends over their most recent decade of escapement data, while the most recent ten-year trends for the other northern stocks were neutral.

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's returns of adults to Bonneville Dam. Catches of subyearling Chinook, yearling Chinook, and yearling coho salmon in 2017 were among the lowest observed since the late 1990s (Figure 24), suggesting marine conditions in this region continued to be poor for salmon. Yearling Chinook and yearling coho salmon catch trends have declined over the past five years, while subyearling Chinook salmon catches have been more variable.

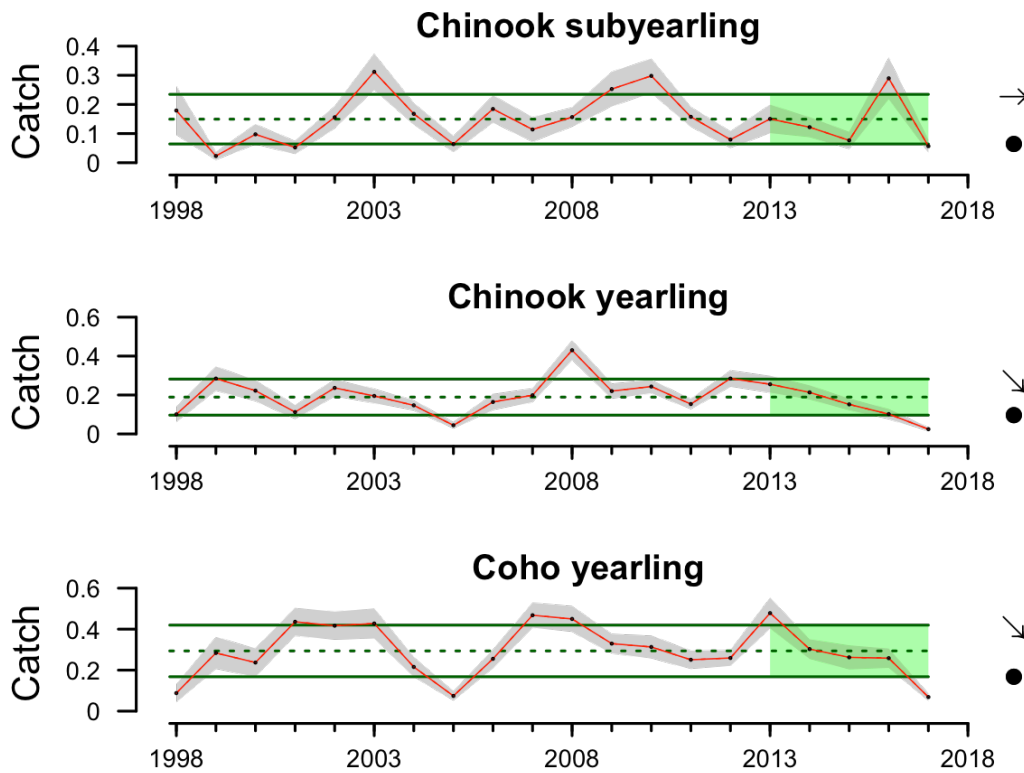


Figure 24. At-sea juvenile Chinook and coho salmon catches ( $\text{Log}_{10}(\text{number}/\text{km} + 1)$ ) in June, 1998–2017, off WA and OR. Lines, colors, and symbols as in Figure 3a. Data for at-sea juvenile salmon provided by B. Burke, NMFS/NWFSC, with additional calculations by C. Morgan, OSU/CIMRS. Data derived from surface trawls taken during the NWFSC Juvenile Salmon and Ocean Ecosystem Survey (JSOES).

Table 1. “Stoplight” table of basin-scale and local/regional conditions for smolt years 2014–17 and likely adult returns in 2018 for coho and Chinook salmon that inhabit coastal OR and WA waters during their marine phase. Green/circles = favorable conditions, i.e., rank in the top third of all years examined. Yellow/squares = intermediate conditions, i.e., rank in the middle third of all years examined. Red/diamonds = poor conditions, i.e., rank in the bottom third of all years examined. Courtesy of B. Burke, NMFS/NWFSC.

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

Many indicators suggested that below-average returns would occur for fall Chinook, spring Chinook, and coho salmon 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 (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. These indicators are depicted in the “stoplight chart” in Table 1, which includes many indicators discussed earlier in this report, such as PDO, ONI, copepod biomass anomalies, and juvenile salmon catch. Recall, too, that the extremely poor freshwater conditions of 2015 (see [Hydrologic Indicators](#) and Figure 13) affected salmon populations during this same smolt year period.

## 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; Figure 25, x-axis). Thus, no stocks are presently considered “overfished,” although yelloweye rockfish (*Sebastes ruberrimus*) and cowcod (*S. levis*), which were formerly under their LRPs, are still rebuilding toward their target biomasses. Three species were declared rebuilt in 2017: bocaccio (*S. paucispinis*), darkblotched rockfish (*S. crameri*), and Pacific ocean perch (*S. alutus*). Also of note: biomass of arrowtooth flounder (*Atheresthes stomias*; ATF in Figure 25, assessed in 2017) increased sharply from the prior assessment (in 2007). Arrowtooth flounder are a predatory species with low market value, and are thought to have predatory impacts on target species in Alaskan waters (Spencer 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 25, y-axis). Three stocks (black rockfish [*Sebastes melanops*] stocks in California and Washington, and China rockfish [*S. nebulosus*] in California) were being fished slightly above the fishing rate proxies derived in their most recent assessments (all in 2015). These three stocks’ fishing rates appear to have exceeded the targets due to recent changes in the way that the targets are calculated, rather than because of changes in management or fishery practices since the 2015 assessments.

As noted above in [Regional Forage Availability](#), YOY rockfish were highly abundant in the central CCE in 2013–17, 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 2014–16, these findings run counter to what we expected from conceptual models linking climate and productivity conditions to groundfish populations. Rockfish in these cohorts likely have not yet grown large enough to have been caught in bottom trawl surveys conducted by NOAA Fisheries or to have recruited into fisheries; 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 (*Chionoecetes* spp.) 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 26). 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  $\pm 1$  SD of the long-term mean, with a relatively stable trend.

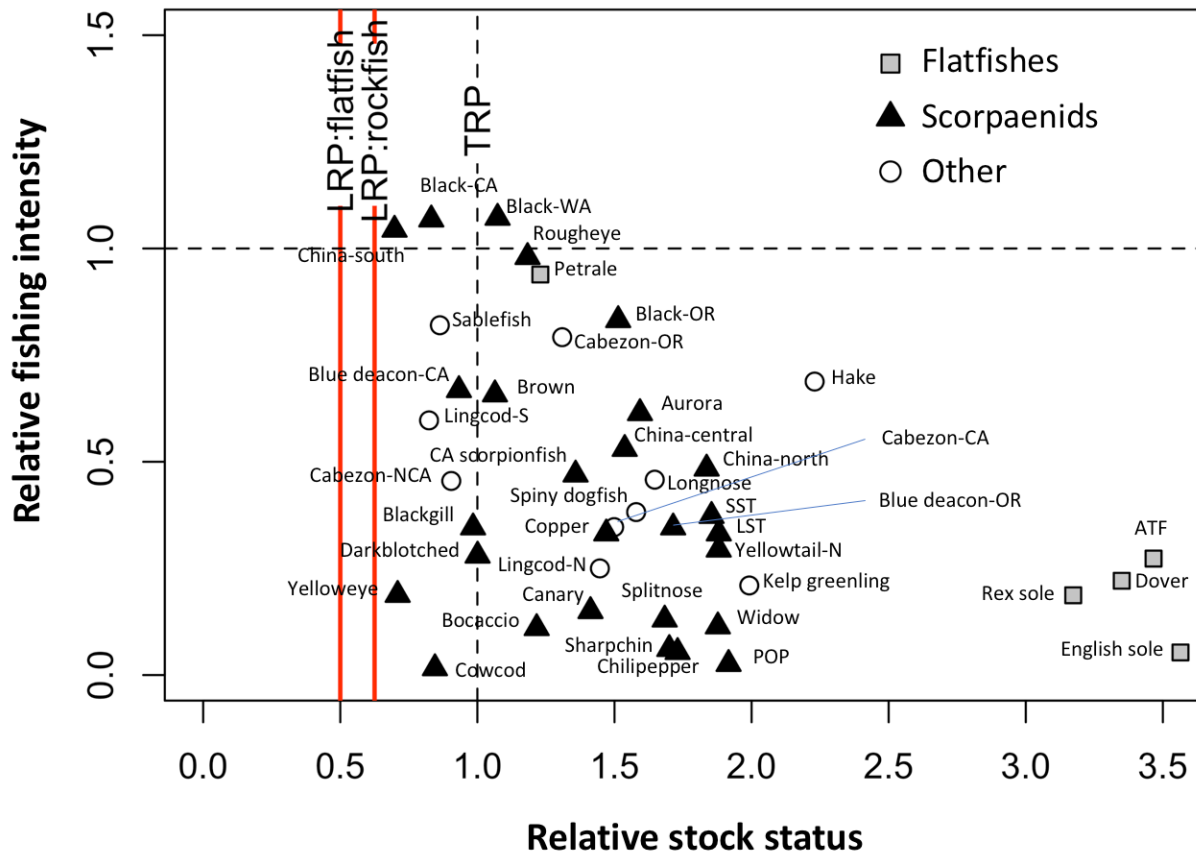


Figure 25. Stock status of CCE groundfish. X-axis: Relative stock status, the ratio of spawning output (in millions of eggs) of the last to the first years in the assessment. Y-axis: Relative fishing intensity uses the Spawner Potential Ratio (SPR), defined as  $(1 - SPR) / (1 - SPR_{MSY\ proxy})$ , where the  $SPR_{MSY\ proxy}$  is stock-specific. Horizontal dashed 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 PFMC-adopted stock assessments. Groundfish stock status data provided by J. Cope, NMFS/NWFSC, derived from NOAA Fisheries stock assessments.

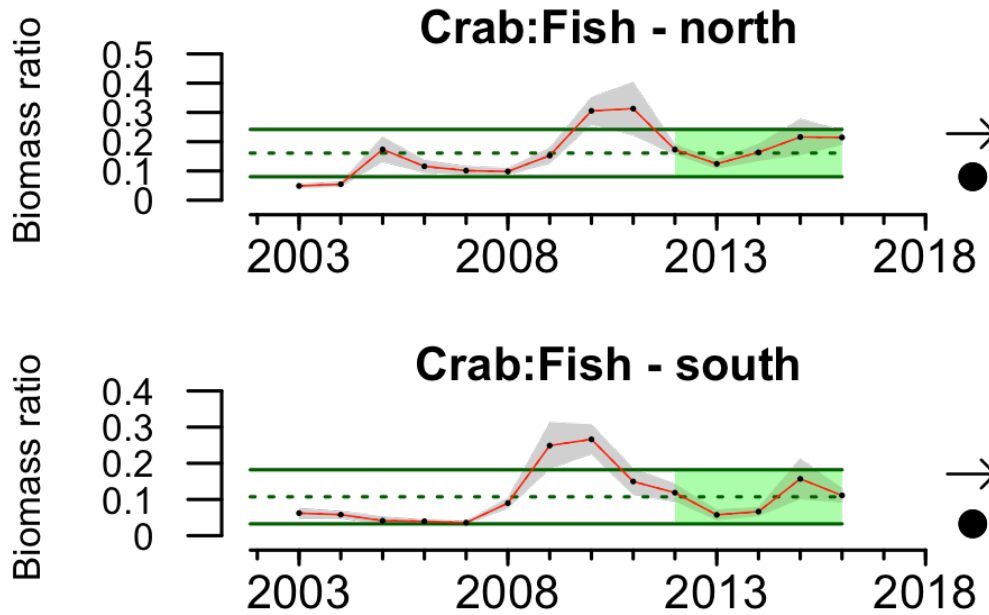


Figure 26. Ratio of crab biomass to finfish biomass for the NWFS West Coast Groundfish Bottom Trawl Survey from 2003–16. Lines, colors, and symbols as in Figure 3a.

## Highly Migratory Species

This marks the first year that the CCIEA team included indicators of highly migratory species (HMS) in our reporting. Most of the species included here are managed by PFMC. 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 27); time series for these indicators are found in Appendix J of Harvey et al. (2018), mostly derived from stock assessments conducted from 2014–16. Average biomass over the most recent five years was substantially above the long-term average for swordfish (*Xiphias gladius*) and skipjack (*Katsuwonus pelamis*). All other assessed HMS stocks were either within  $\pm 1$  SD of the average or were below it, and several stocks (bigeye tuna [*Thunnus obesus*], bluefin tuna [*T. orientalis*], and blue marlin [*Makaira mazara*]) appeared to be near historic lows. Biomass trends were statistically neutral for all species, although skipjack may be increasing. Recruitment indicators varied widely: recruitment appeared to be increasing for albacore (*Thunnus alalunga*), skipjack, and yellowfin tuna (*T. albacares*), decreasing for bluefin tuna, and neutral for other stocks. These trends reflect pan-Pacific changes in biomass and recruitment for these HMS species, not trends in their availability to fishers in the CCE. For instance, the poor numbers for bluefin tuna are inconsistent with recent high bluefin catches in California. Those high catches during the anomalous warm years may be a result of northward and shoreward shifts by bluefin tuna in pursuit of prey (e.g., pelagic red crab [*Pleuroncodes planipes*]) typically found in Baja California or offshore, rather than changes in the status of the overall bluefin population. In future CCIEA reports, we hope to add indicators that are related to the dynamics and drivers of HMS ecology and distribution in the CCE.

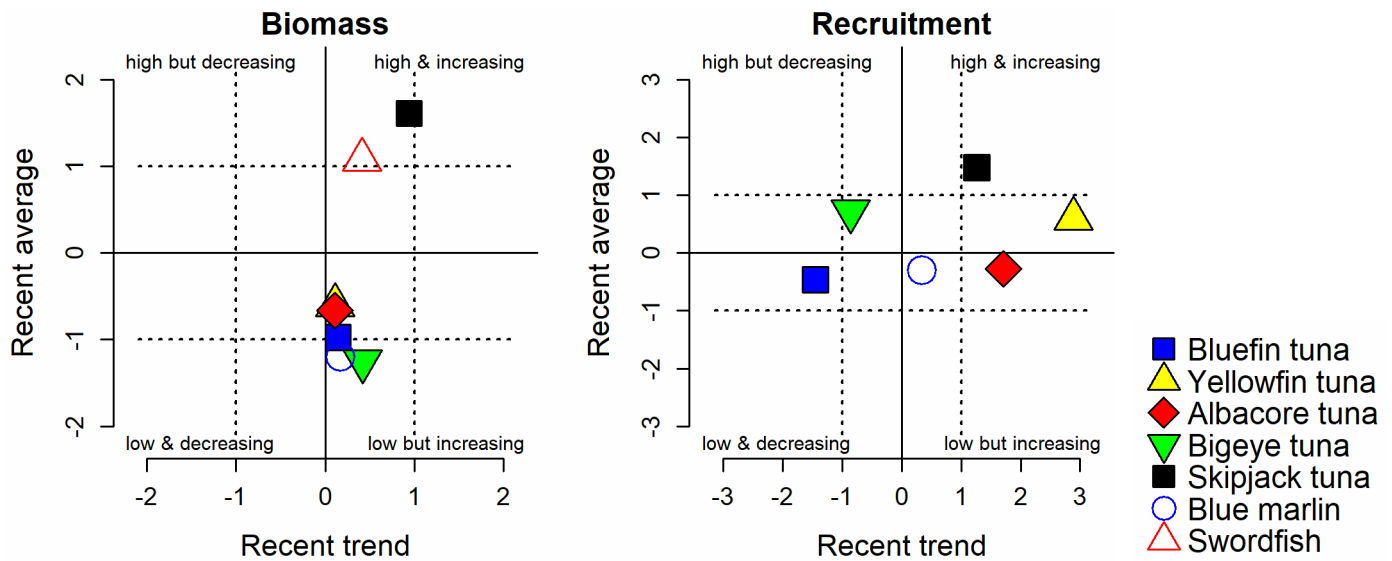


Figure 27. Recent (five-year) trend and average of biomass and recruitment for highly migratory species in the CCE from the 2014–16 stock assessments. Data are total biomass for swordfish, relative biomass for skipjack, spawning biomass for bluefin, and female spawning biomass for all other species. Lines and symbols as in Figure 3c. Highly migratory species data provided by B. Muhling, NMFS/SWFSC. Data 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](http://isc.fra.go.jp/reports/stock_assessments.html)) or the Inter-American Tropical Tuna Commission (IATTC; <https://www.iattc.org/PublicationsENG.htm>).

## Marine Mammals

### Sea Lion Production

California sea lions are permanent residents of the CCE, breeding in the California Channel Islands and feeding throughout the CCE in coastal and offshore habitats. They are also indicators of prey availability in the central and southern CCE (Melin et al. 2012). Two indices are particularly sensitive measures of prey availability to California sea lions: pup production and pup growth during the period of maternal nutritional dependence. Sea lion pup count at San Miguel Island is a result of successful pregnancies, and relates to prey availability and nutritional status for adult females from October to June. Pup growth from birth to age seven months is related to prey availability to adult females during lactation from June to February.

In 2016, California sea lion pup births at San Miguel Island were 14% below the long-term mean, showing little change from 2015; the trend over the most recent five cohorts remained negative (Figure 28, top). The low number of births in 2016 reflects 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, pup growth rates for the 2016 cohort were similar to the long-term average (Figure 28, bottom). This represents a significant improvement relative to extremely low growth rates of cohorts in 2012, 2014, and 2015; those cohorts 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.

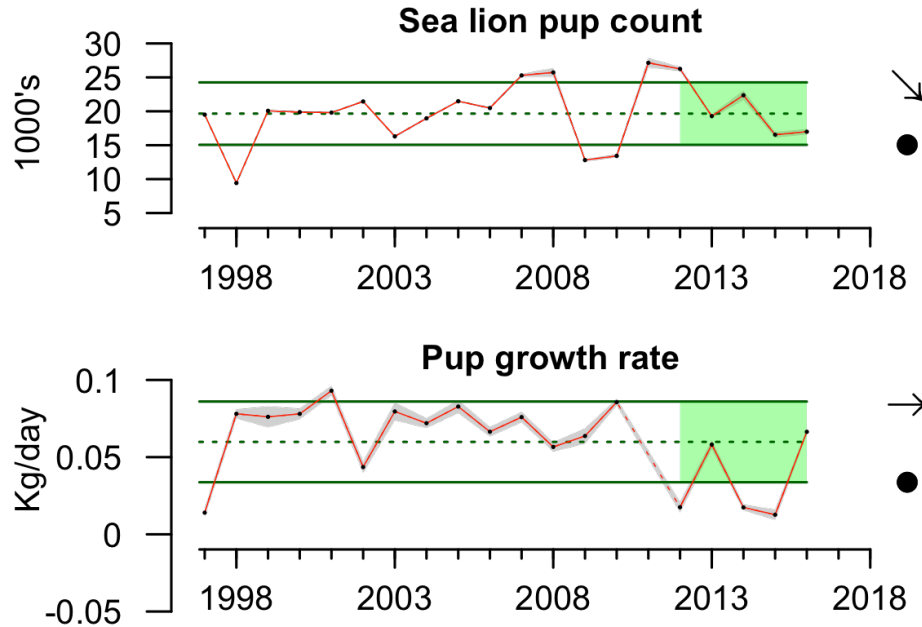


Figure 28. California sea lion pup counts and estimated mean daily growth rate of female pups between 4–7 months on San Miguel Island for the 1997–2016 cohorts. Lines, colors, and symbols as in Figure 3a. California sea lion data provided by S. Melin, NMFS/AFSC.

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 2016–17, 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.

## 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 and of changes in food web interactions along the coast. Coincident with the anomalous warming of the CCE in 2014–16, observations of whales entangled in fishing gear occurred at levels far greater than in the preceding decade. Confirmed whale entanglements on the U.S. West Coast are shown in Figure 29 (derived from NMFS 2018). A “confirmed” observation represents a unique case of an entangled whale, including resightings, where the documentation provided to the NOAA Fisheries’s West Coast Region’s Marine Mammal Stranding Response Program is complete or compelling enough for NOAA Fisheries to conclude that a whale was observed entangled in some sort of human-made material. Confirmed entanglements were most numerous in 2015 ( $n = 50$ ) and 2016 ( $n = 48$ ), with the majority involving humpback whales (*Megaptera novaeangliae*). Confirmed entanglements declined to 31 in 2017, which was still greater than the annual average of about 10 confirmed entanglements per year in 2000–13. Of the 31 confirmed entanglements in 2017, 16 were humpback whales, 12 were gray whales (*Eschrichtius robustus*), and three were blue whales (*Balaenoptera musculus*). The



majority of entanglements occurred in gear that could not be identified visually. Of the portion that could be identified by visible tags or markings, most were pots and traps targeting Dungeness crab. In both 2016 and 2017, one confirmed entanglement involved fixed gear targeting sablefish (*Anoplopoma fimbria*), and gillnets were observed as entangling gear in 2015, 2016, and 2017. As in other years, most observations of entangled whales occurred in California waters, although the time and place of the observation does not necessarily coincide with the time and place of the actual entanglement event (NMFS 2018). Many interacting factors could be causing the increased numbers of observed and reported 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. Increased public awareness to look for and properly report entangled whales may also be playing a role. NOAA Fisheries’s West Coast Region will continue to follow this issue as conditions in the CCE change, and the CCIEA team is collaborating with researchers from NOAA, other agencies, and academic partners on analyses of various biological, environmental, and anthropogenic factors that affect the dynamics of entanglement risk.

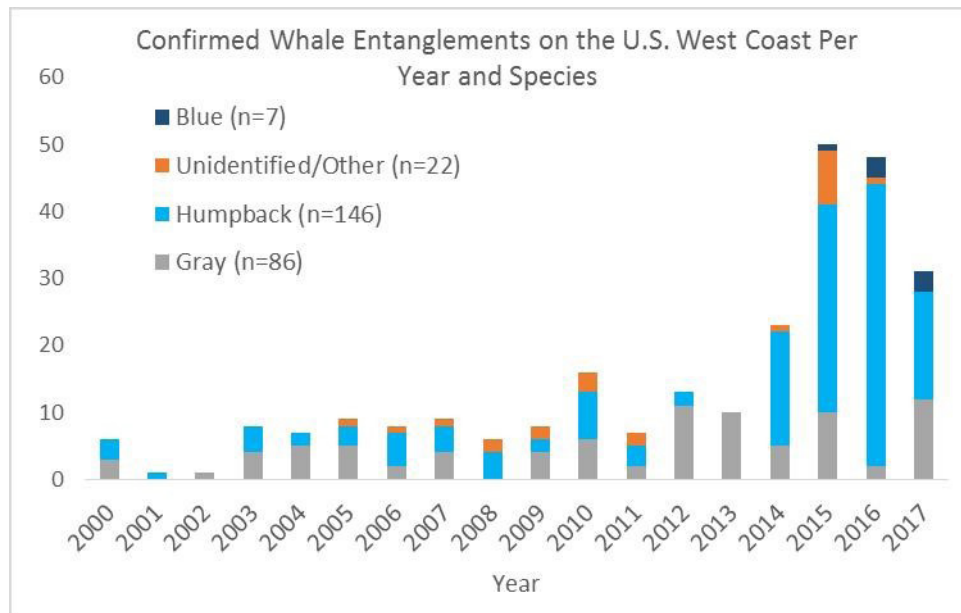


Figure 29. Confirmed numbers of whales (by species) reported entangled in fishing gear along the U.S. West Coast from 2000–17. Source: NMFS (2018).

# Seabirds

## Abundance

At-sea abundance counts of seabirds 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 (*Ardenna grisea*) migrate to the CCE from the southern hemisphere in spring and summer to prey primarily on small fish and squid on the shelf and near the shelf break. Common murre (*Uria aalge*) and Cassin's auklets (*Ptychoramphus aleuticus*) are resident species that feed primarily over the shelf; Cassin's auklets prey mainly on euphausiids, large calanoid copepods, and ichthyoplankton, while common murre target small fish and squid (see [Seabird Diets](#)).

Here, we present seabird abundance indicators in regional time series for at-sea density of three key species during summer (Figure 30). At-sea density patterns varied within and across seabird species among the three regions of the CCE. The sooty shearwater density anomalies underwent 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. In sharp contrast, sooty shearwater density in the southern CCE reached its highest recorded level in 2017, continuing a recent, significant short-term increase. The Cassin's auklet density anomaly in 2017 was nearly 1 SD above the long-term mean in the northern CCE, but Cassin's auklet densities were declining in the central CCE and remained just below the long-term mean in the southern CCE. The common murre density anomaly declined over the last five years in the northern CCE, but 2017 common murre density anomalies in the central and southern CCE were the highest of the time series, resulting in significant short-term increases in those two regions.

## Seabird Diets

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

Rhinoceros auklet diet indicator data are from colonies in the northern CCE (Destruction Island, just off the coast of central Washington) and central CCE (Año Nuevo Island, off central California). The proportion of anchovies in diets of rhinoceros auklets provisioning chicks at Destruction Island was down in 2017, as it was in 2015, and showed a significant short-term decline (Figure 31). The few anchovy that were brought back to chicks at Destruction Island 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; herring were inversely correlated with anchovy presence in chick diets, but not enough to yield a statistically significant short-term increase. The proportion of juvenile rockfish in the auklet diet returned to its normally low level from a peak in 2016, and showed no short-term trend. The proportion of smelts (family Osmeridae) was below the long-term mean in 2017 and showed no significant short-term trend.

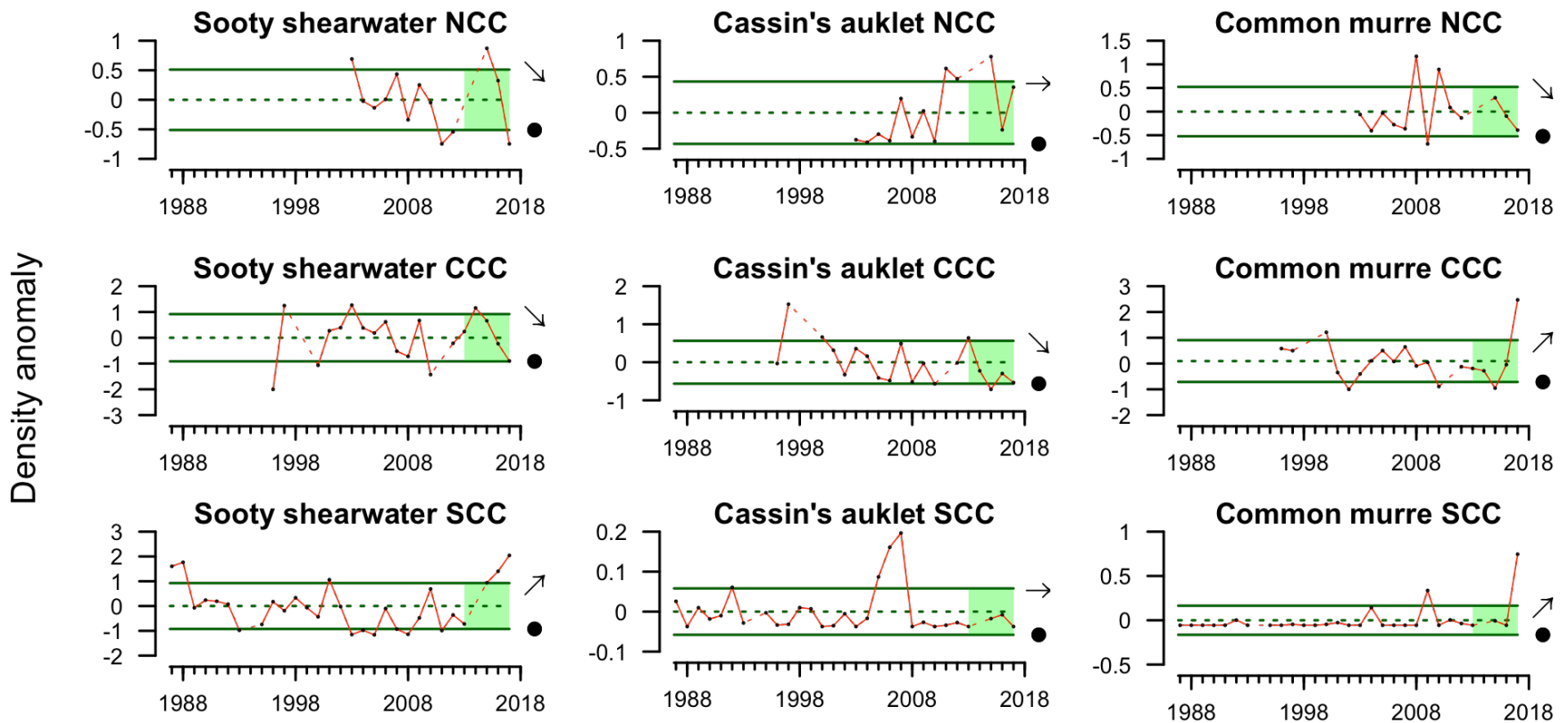


Figure 30. Recent (five-year) trend and average of seabird at-sea densities during the summer in three regions of the CCE through 2017. Lines, colors, and symbols as in Figure 3a; dashed red lines connecting data points indicate years where no data were collected. Seabird abundance data from northern CCE collected and provided by J. Zamon, NMFS/NWFSC. Seabird abundance data from central CCE (collected on the SWFSC Rockfish Recruitment and Ecosystem Assessment Survey) and southern CCE (collected on the CalCOFI surveys) courtesy of W. Sydeman, Farallon Institute.

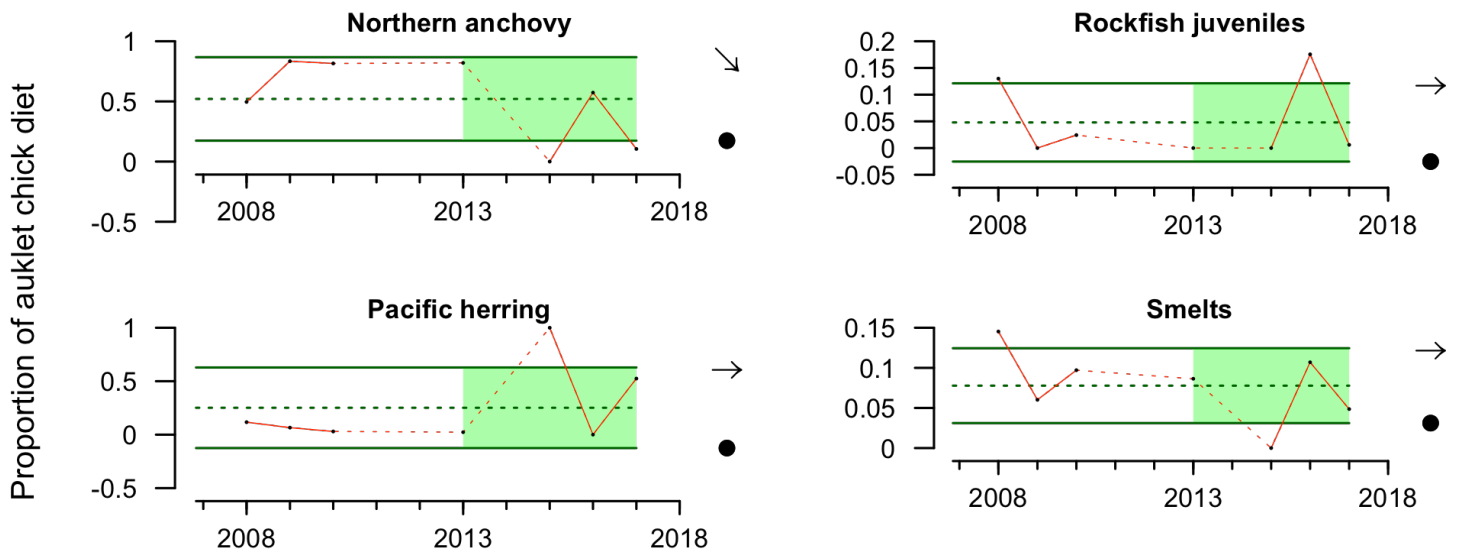


Figure 31. Rhinoceros auklet chick diets at Destruction Island through 2017. Lines, colors, and symbols as in Figure 3a. Data courtesy of the Washington Rhinoceros Auklet Ecology Project (scott.pearson@dfw.wa.gov).

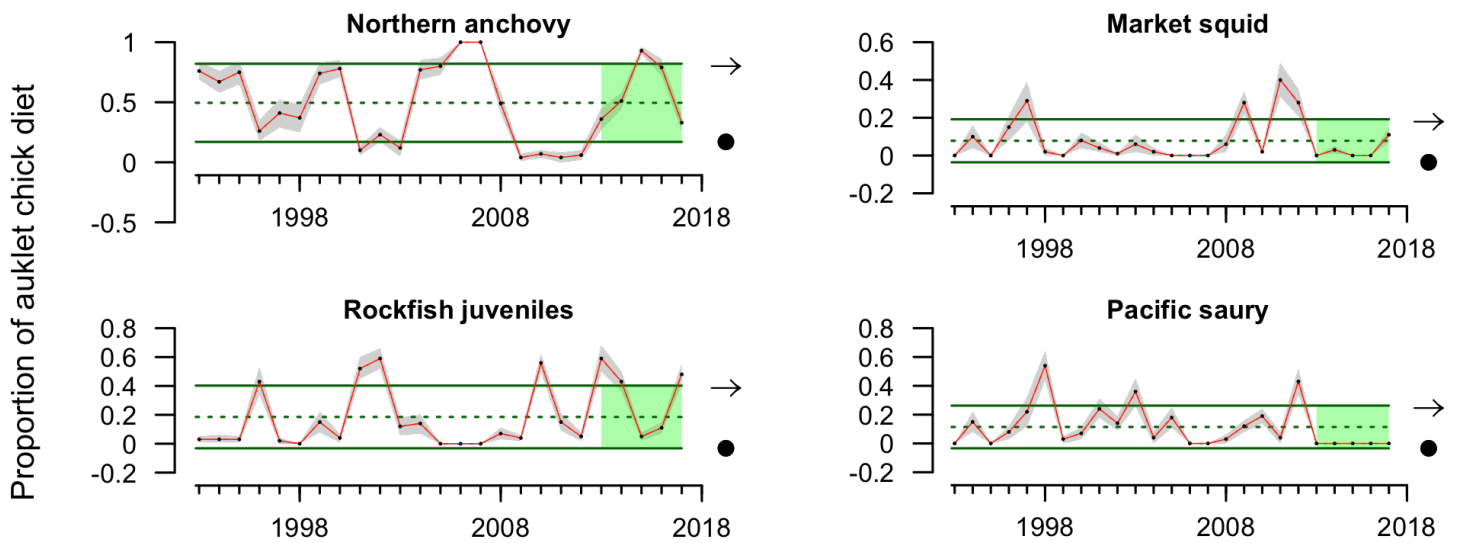


Figure 32. Rhinoceros auklet chick diets at Año Nuevo from 1993–2017. Lines, colors, and symbols as in Figure 3a. Data provided by Oikonos/Point Blue (ryan@oikonos.org).

The proportion of anchovy in diets of rhinoceros auklets provisioning chicks at Año Nuevo Island, California, was below the long-term mean in 2017 after peaking in 2015–16, but showed no significant short-term trend (Figure 32). The proportion of rockfish in the auklet diet was above the long-term mean in 2017, but has been highly variable in recent years. The proportion of squid in the auklet diet returned to its average level in 2017 after four years of relative scarcity, but showed no short-term trend. Pacific saury (*Cololabis saira*) have not appeared in the observed rhinoceros auklet diet at Año Nuevo since 2013. The anchovies that were brought back to chicks at Año Nuevo in 2017 were close to the long-term mean after three years of well below-average size (Figure 33).

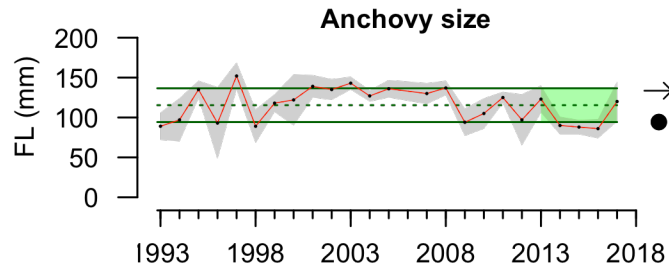


Figure 33. Size of anchovy brought to rhinoceros auklet chicks at Año Nuevo from 1993–2017. Error envelope shows  $\pm 1.0$  SD. Lines, colors, and symbols as in Figure 3a. Data provided by Oikonos/Point Blue (ryan@oikonos.org).

Common murre diet data are from a colony at Yaquina Head, along the central coast of Oregon in the northern CCE. The proportion of smelts in the diets of murre provisioning chicks was above the long-term mean in 2017, as it has been since 2012, but showed no significant short-term trend (Figure 34). The proportions of herring and sardines in murre diets in 2016–17 were the lowest seen in the time series, and the data showed a significant short-term decline. The proportion of sandlance (*Ammodytes* spp.) in the murre diet in 2017 was above the long-term mean and showed a short-term increase. The proportion of flatfishes was above the long-term mean in 2017, but showed no significant short-term trend. The proportion of juvenile rockfish in the murre diet in 2017 was zero for the third straight year, but, as rockfish are only occasionally observed in the diet of murre at this colony (peaks in 2008 and 2010), the data showed no significant short-term trend.

Collectively, these seabird diet plots likely reflect both the variability of forage community composition and the plasticity or opportunistic nature of predator foraging and diet. Each diet features shifts in dominant prey species on time scales ranging from one to as many as five years. This is perhaps most clear in the rhinoceros auklet diets on Año Nuevo (Figure 32), where anchovy are between 50% and 100% of the chick diet in many years, while a mix of juvenile rockfish, market squid, and Pacific saury becomes important in years when anchovy are less prominent. The plots also suggest that diversity in key prey is a function of both the predator (e.g., common murre vs. rhinoceros auklet) and location (e.g., rhinoceros auklet at Destruction Island vs. rhinoceros auklet at Año Nuevo). In coming years, the CCIEA team will work to better align forage indicators (see [Regional Forage Availability](#)) to the different types of predators for which they are important, so that we can better understand the functional importance of forage abundance and composition to population dynamics and distribution of piscine, avian, and mammalian predators. For example, there are published studies relating the nesting success of seabirds in the CCE to the abundance and/or composition of their prey (Ainley et al. 1996, Abraham and Sydeman 2004, Thayer and Sydeman 2007, Wells et al. 2008, Santora et al. 2014). Still, these relationships are complex, owing to the many species interactions, behaviors, feeding modes, and spatial differences involved among predators throughout the CCE.

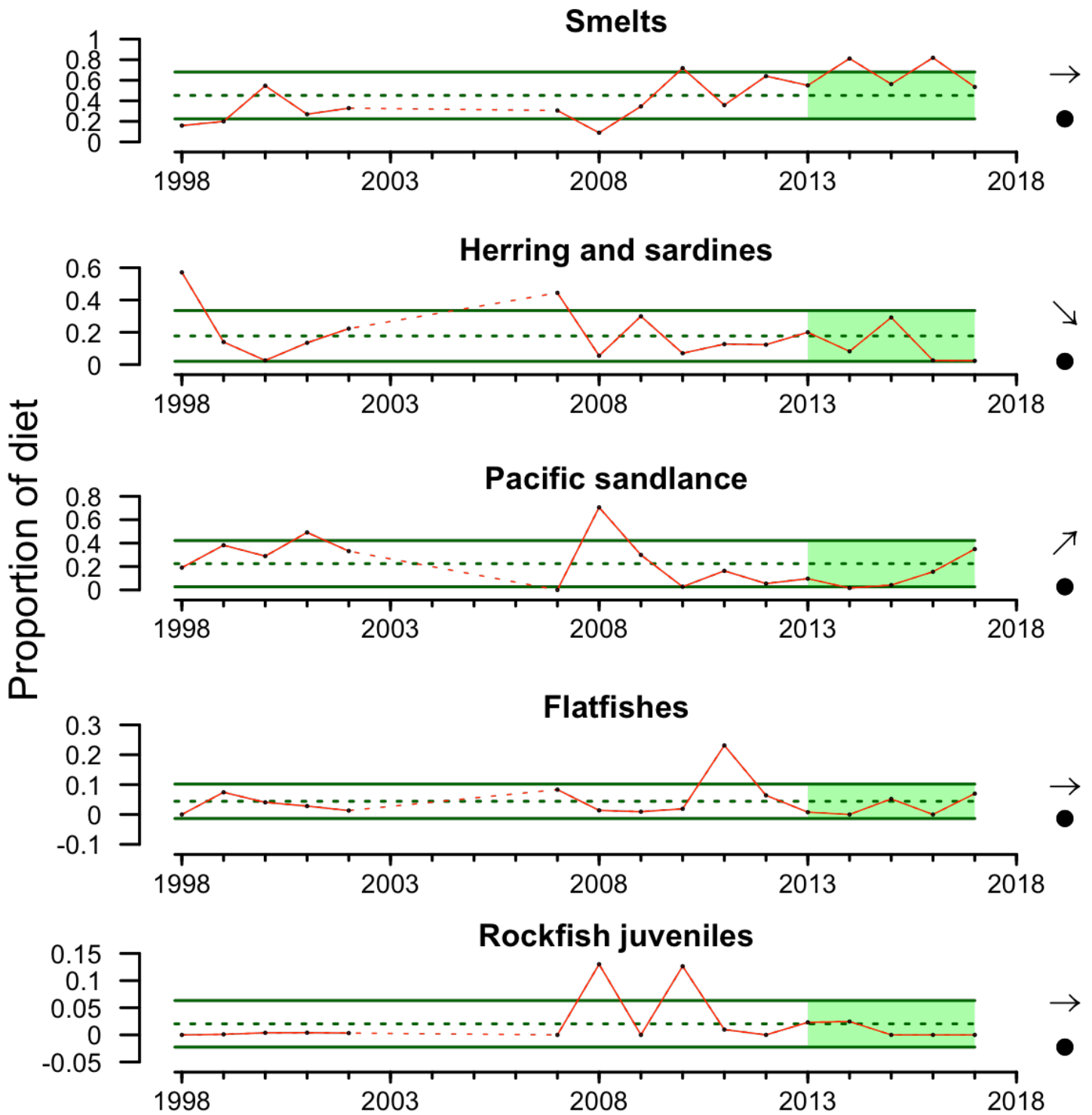


Figure 34. Common murre chick diets at Yaquina Head, OR, through 2017. Lines, colors, and symbols as in Figure 3a. Data provided by the Yaquina Head Seabird Colony Monitoring Project (rob.suryan@noaa.gov).

## Seabird Mortalities

The prior three CCIEA reports from the anomalously warm and unproductive years of 2014–16 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. While seabird die-offs were observed in the Bering and Chuckchi Seas in 2017, there were no reports of widespread seabird wrecks related to low productivity in the CCE (although there were reports of localized mortality events in Southern California, likely related to domoic acid concentrations; see Wells et al. 2017). 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 the period of October 2016 to February 2017 (Figure 35). The encounter rate of Cassin’s auklet remained at baseline levels in the fall/winter of 2016–17, where it has been since the large die-off in 2014. The encounter rate of northern fulmars (*Fulmarus glacialis*) has been just below the long-term mean since 2011, and the data showed no significant short-term trend. The encounter rate of sooty shearwaters was low relative to the long-term mean in 2017, and has declined significantly following a spike in mortality in 2011–13. The encounter rate of common murres in 2017 was close to the long-term average, following the large die-off in 2015 and a low encounter rate in 2016.

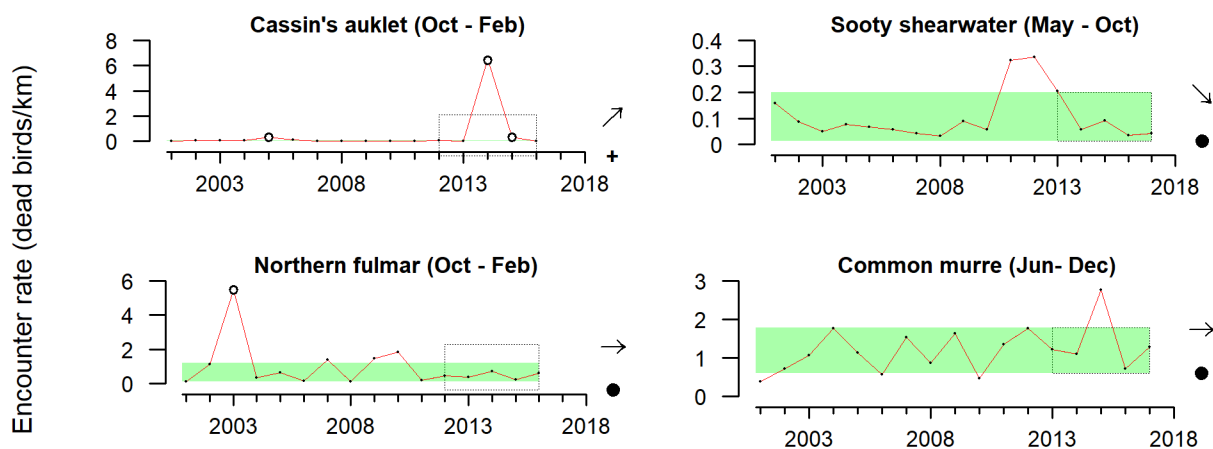


Figure 35. Encounter rates (birds/km) of dead birds on U.S. West Coast beaches through fall/winter of 2016–17 (left) and late 2017 (right). The mean and trend of the last five years are evaluated versus the mean and SD of the full time series (but with outliers removed). Open circles indicate outliers, and the green box indicates the upper and lower SD. Dotted lines indicate the evaluation period. Note variability was low for Cassin’s auklet, and the SD range is very small. Data provided by the Coastal Observation and Seabird Survey Team (COASST; <https://depts.washington.edu/coasst/>).

# Human Activities

## Coastwide Landings by Major Fisheries

Fishery landings data are current through the end of 2017. Total landings have increased sharply since 2015, although the steep decline in 2015 landings resulted in an overall negative trend for the past five years (Figure 36). Landings of groundfish (excluding hake) remained near historically low levels from 2013–17, while landings of hake increased over the past five years and reached an all-time high in 2017. On the other hand, commercial landings of CPS (excluding market squid) declined over the last five years and were at their lowest level of the time series in 2017. Market squid have declined since a peak in 2010, although landings of market squid in 2017 were close to the long-term average. Shrimp landings declined in 2017, continuing the considerable decline from 2015, while crab landings in 2017 were greater than the long-term average. Commercial landings of salmon have declined since 2013, and were near the lower end of historical levels over the last several years. Landings for recreationally caught Chinook and coho salmon showed no trend, but were statistically below the long-term averages in 2016 and 2017 (note that recreational salmon landings in Figure 36 are in thousands of fish landed). Landings of HMS and other species have been consistently within  $\pm 1$  SD 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 [*Hippoglossus stenolepis*]) declined in 2016–17 after a period of steady increases, although at the time of writing this report, we lacked species-level recreational landings data to further analyze this decline. Additional information on state-by-state landings (through 2016 only) are available in Appendix L of Harvey et al. (2018).

Total revenue from all U.S. West Coast commercial fisheries in 2017 was \$657M. Revenue has increased over the past two years following a drop in 2015 (Figure 37; all data adjusted to 2017 dollars). The recent increase was driven by increased landings revenue for crab, Pacific hake, and market squid since 2015. Revenues from other commercial fishing target species groups remained fairly stable from 2013–17 with the exception of shrimp, which spiked in 2015 but then fell sharply in 2016 and further in 2017.

## Bottom Trawl Contact with Seafloor

Benthic marine habitats can be impacted by geological events (e.g., earthquakes, fractures, and slumping), oceanographic processes (e.g., internal waves, sedimentation, and currents), and human activities (e.g., bottom contact fishing, mining, and dredging). Such disturbances 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 sediments) and be particularly dramatic in sensitive environments (e.g., seagrass, algal beds, coral and sponge reefs, or rocky substrates) relative to soft sediments.

We are developing indicators of the relative amount of bottom contact by commercial fishing gear in the CCE, both at the coastwide level and this year, for the first time, at finer spatial scales. At the broad scale, we used estimates of coastwide distances trawled along the ocean bottom from 1999–2015. Estimates from 2002–15 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



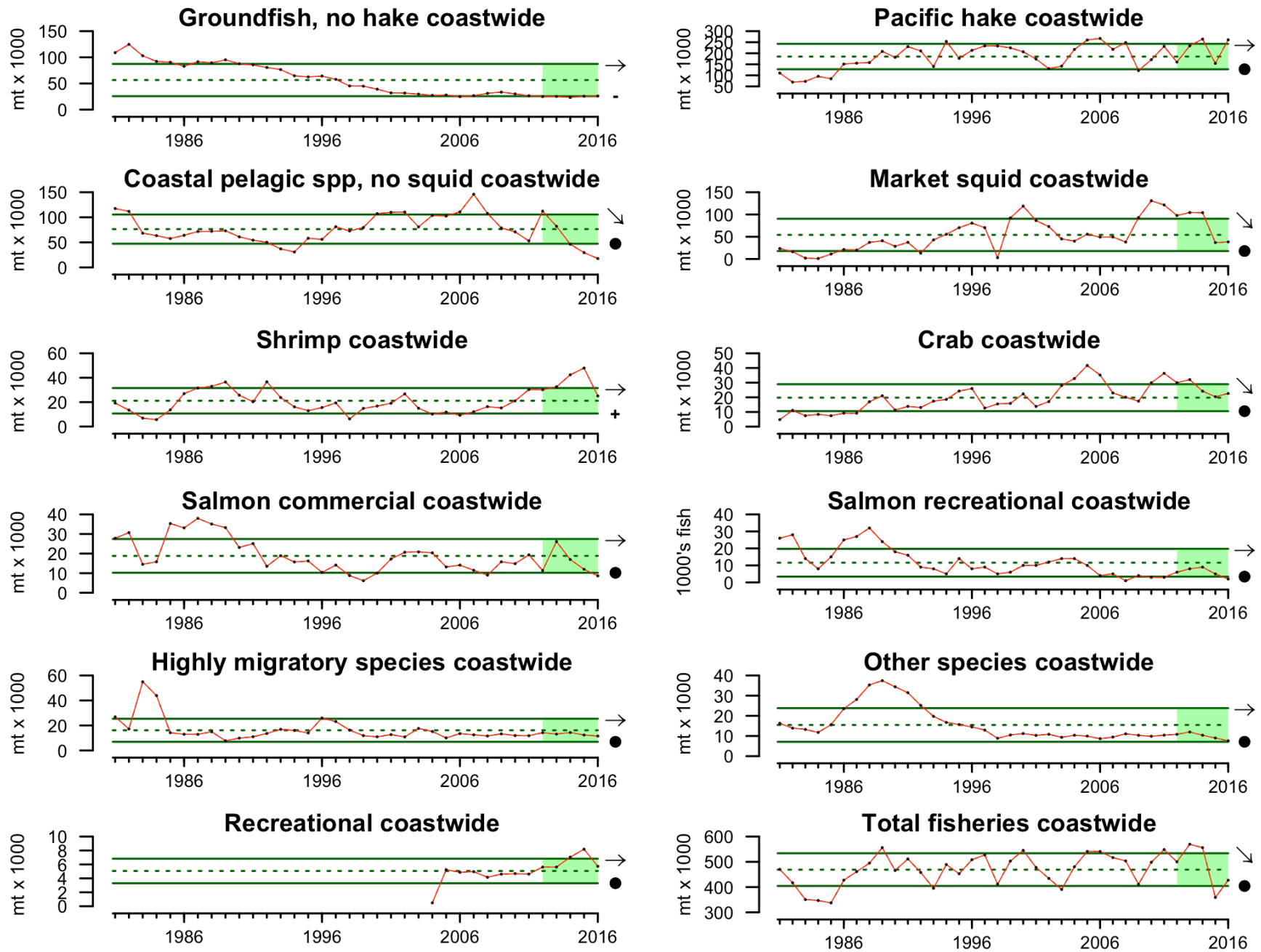


Figure 36. Annual landings of U.S. West Coast commercial (data from PacFIN; <http://pacfin.psmfc.org>) and recreational (data from RecFin; <http://www.recfin.org/>) fisheries, including total landings across all fisheries, from 1981–2017. Lines, colors, and symbols as in Figure 3a.

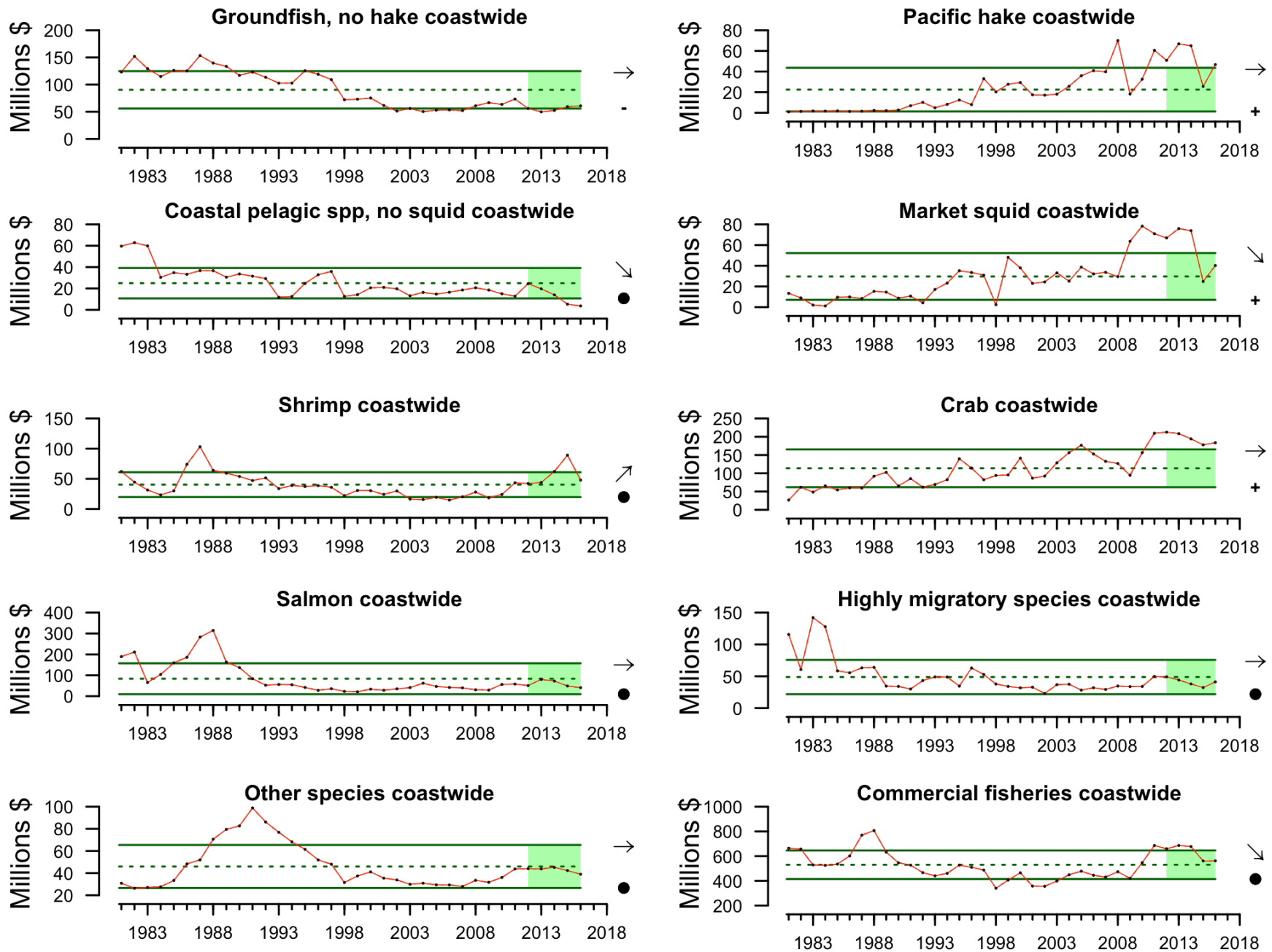


Figure 37. Annual revenue (ex-vessel value, adjusted to 2017 dollars) of U.S. West Coast commercial fisheries (data from PacFIN) from 1981–2017. Pacific hake revenue includes shore-side and at-sea hake revenue values from PacFIN, NORPAC (North Pacific Groundfish Observer Program), and NMFS Office of Science and Technology. Lines, colors, and symbols as in Figure 3a.

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 Essential Fish Habitat (EFH) Synthesis Report (PFMC 2013).<sup>9</sup> Data come from logbook entries collected and reported by the Northwest Fisheries Science Center's West Coast Groundfish Observer Program. Gear contact with seafloor habitat remained at historically low levels from 2011–15 at a coastwide scale (Figure 38, top). During this period, the vast majority of fishing gear contact with seafloor habitat occurred in soft-bottomed, upper slope and shelf habitats. The northern ecoregion experienced the most fishing gear contact with seafloor habitat, with nearly four times the magnitude 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 (Figure 38, bottom). A shift in trawling effort from shelf to upper slope habitats was observed during the mid-2000s, which in part corresponded to depth-related spatial closures implemented by PFMC. When compared to the mean for the entire time series, gear contact with seafloor habitats across all habitats has been within historic levels (not shown; K. Andrews, NOAA, unpublished data). Recovery time from reduction in fishing gear contact is likely to differ among habitat types (e.g., hard and mixed habitats will take longer to recover than soft habitat).

To examine finer-scale bottom contact by fishing gear, we used the same logbook data to estimate distances trawled on a 2-km<sup>2</sup> grid from 2002–15. For each grid cell, we mapped the 2015 departure (anomaly) from the long-term mean, the most recent five-year average, and the most recent five-year trend. For example, in 2015, distance trawled was above-average for areas off of southern Washington and north of Cape Mendocino, California, but below-average north of Cape Blanco, Oregon (Figure 39, left). Red areas in the trend map (Figure 39, right) indicate large swaths of seafloor off Washington, southern Oregon, and northern California where trawl activity increased from 2011–15, 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 the seafloor was at historically low levels and had no trend from 2011–15 (Figure 38). Subsequent efforts will incorporate other nonfishing human activities that could affect seafloor habitats.

## Aquaculture and Seafood Consumption

Aquaculture activities are indicators of seafood demand, and also may be related to some benefits (e.g., water filtration by bivalves, nutrition, or income and employment) or impacts (e.g., habitat conversion, waste discharge, or nonindigenous species introductions). Shellfish aquaculture production in the CCE was stable and at historically high levels from 2012–16 (Figure 40). These patterns are driven by production in Washington state, which is home to nearly 80% of the coastwide shellfish production. Finfish aquaculture (of Atlantic salmon [*Salmo salar*]) has been variable, but remained above historical averages over the last five years.

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<sup>9</sup> [http://www.pcouncil.org/wp-content/uploads/D6b\\_SUP\\_NMFS\\_SYNTH2\\_APPENDICES\\_ELECTRIC\\_ONLY\\_APR2013BB.pdf](http://www.pcouncil.org/wp-content/uploads/D6b_SUP_NMFS_SYNTH2_APPENDICES_ELECTRIC_ONLY_APR2013BB.pdf)

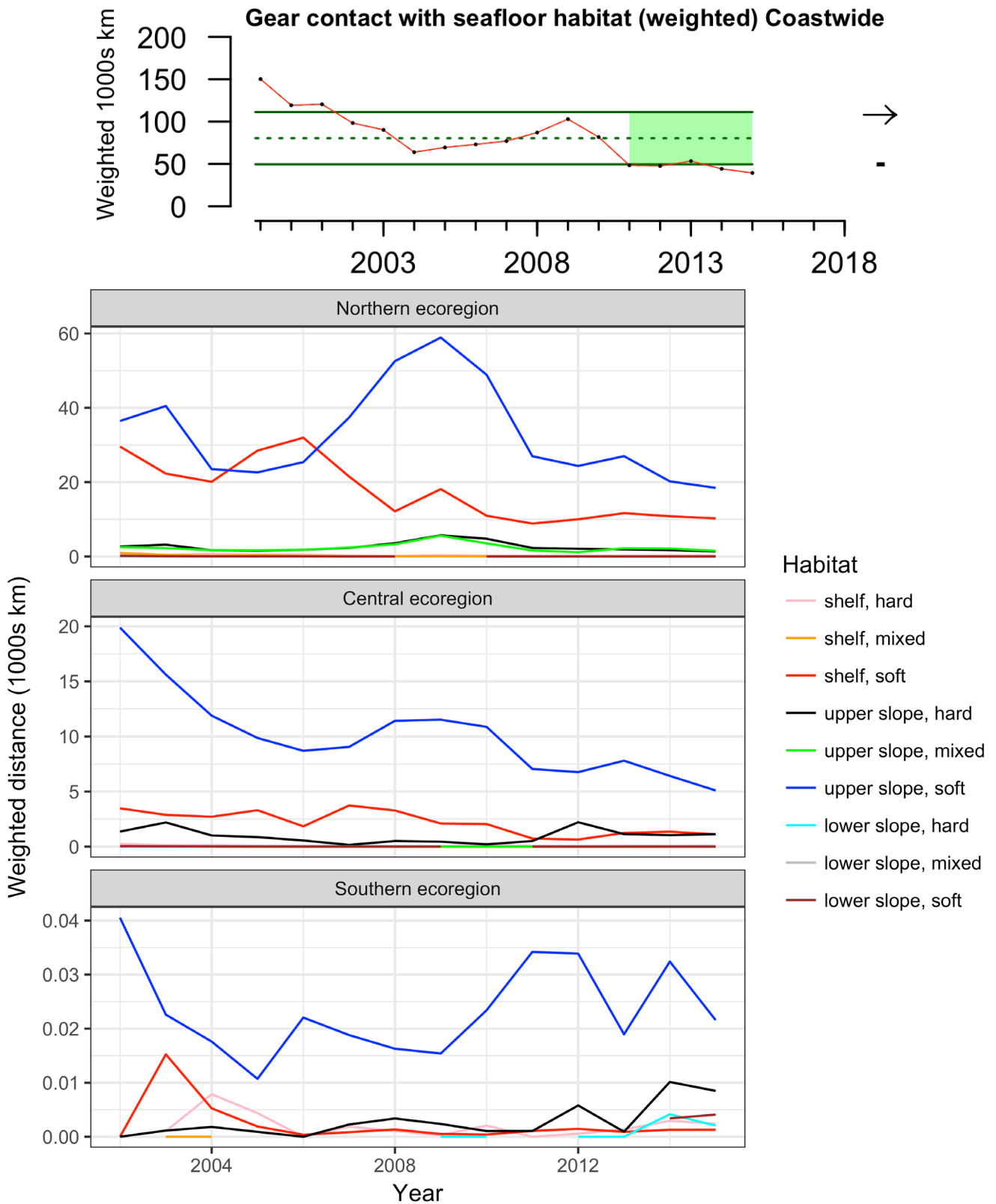


Figure 38. Weighted distance (in thousands km) of fishing gear contact with seafloor habitat across the entire CCE (top; 1999–2015) and within each ecoregion (bottom three panels; 2002–15). Lines, colors, and symbols in top panel as in Figure 3a. Data for total benthic habitat distance contacted by bottom-contact fishing gears provided by J. McVeigh, NMFS/NWFSC. Weightings for benthic habitat sensitivity values from PFMC’s Pacific Coast Groundfish 5-Year Review of Essential Fish Habitat.

2015 anomaly

2011-2015 mean

2011-2015 trend

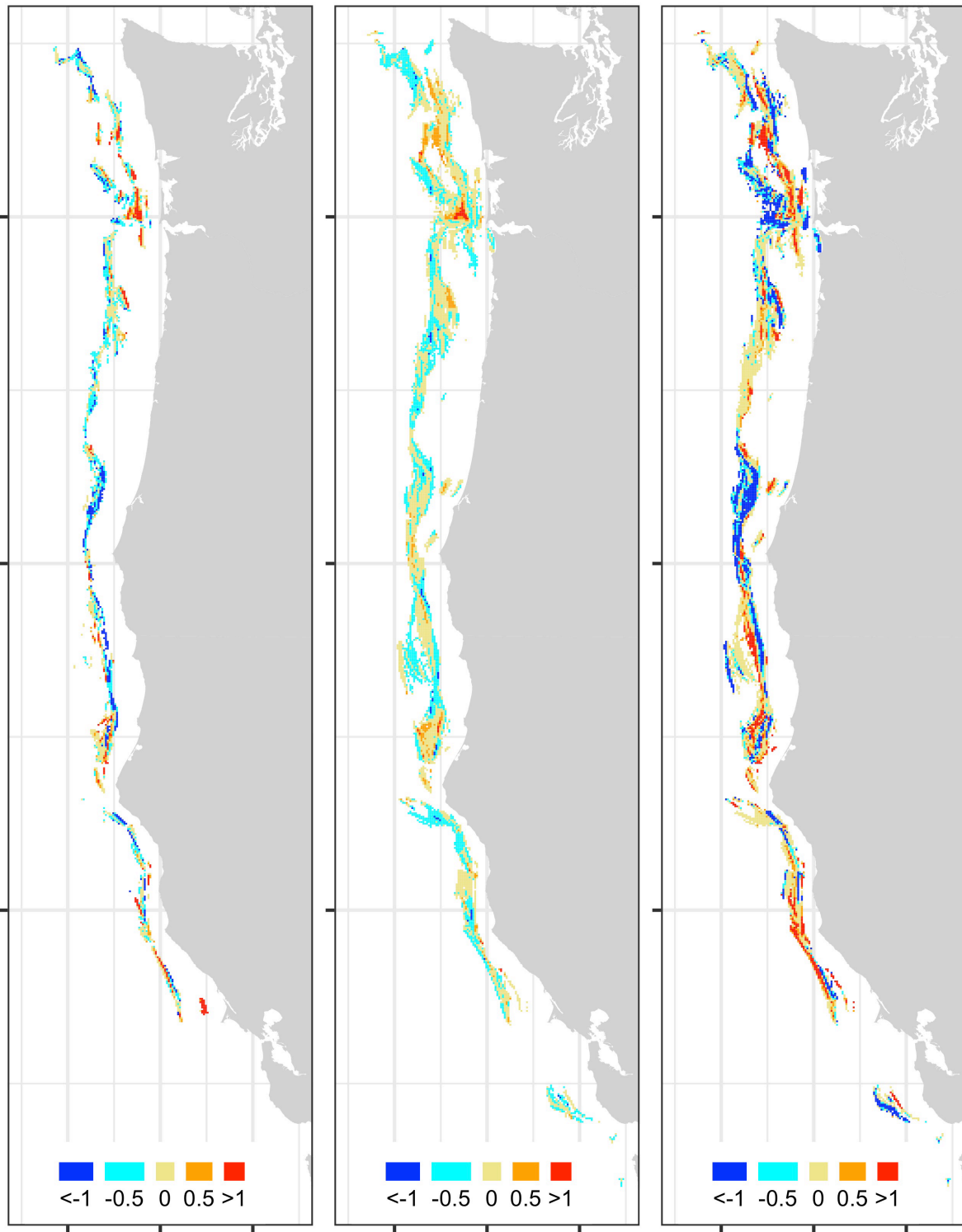


Figure 39. Spatial representation of seafloor contact by groundfish bottom trawl gear, represented by annual distances trawled within each 2-km<sup>2</sup> grid cell from 2002–15. Left: annual bottom contact anomalies. Middle: normalized mean values for the most recent five-year period. Right: normalized trend values for the most recent five-year period. Grid cell values >1 (red) or <-1 (blue) represent a cell in which the 2015 anomaly, five-year mean, or five-year trend was at least 1 SD away from the long-term mean of that cell.

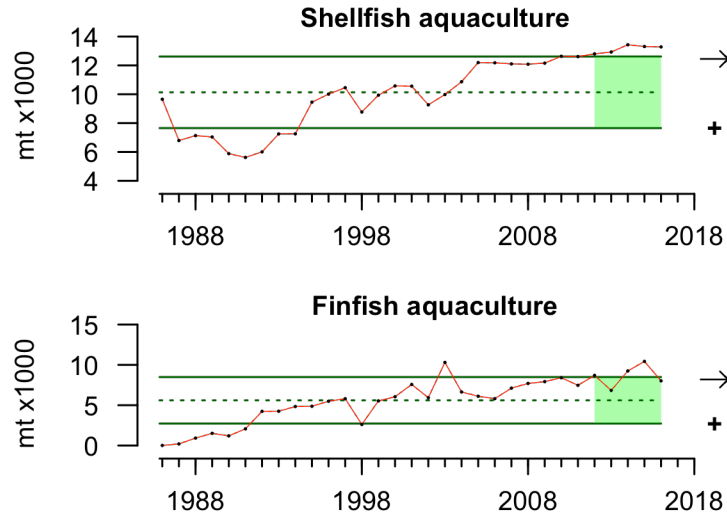


Figure 40. Aquaculture production of shellfish (clams, mussels, oysters) and finfish (Atlantic salmon) in CCE waters from 1986–2016. Lines, colors, and symbols as in Figure 3a. Shellfish production data retrieved and summed together from Washington Department of Fish and Wildlife’s Commercial Harvest Data Team (CHDT), Oregon Department of Agriculture, and California Department of Fish and Game; finfish production data from CHDT.

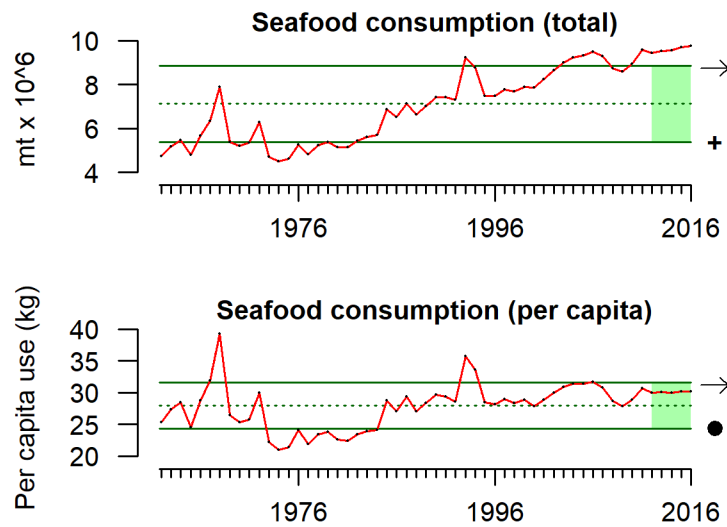


Figure 41. Total (millions of metric tons) and per capita (kg) consumption of fisheries products in the United States from 1962–2016. Lines, colors, and symbols as in Figure 3a. Data can be found in NOAA’s annual *Fisheries of the United States* reports (<http://www.st.nmfs.noaa.gov/st1/publications.html>).

Seafood consumption in the U.S. was relatively constant from 2012–16, and had largely recovered from declines in the previous decade (Figure 41). Total consumption in 2012–16 was above the historic average, while per capita consumption was within the historic range. With increasing human populations and U.S. Dietary Guidelines<sup>10</sup> recommending increased seafood intake, total consumption of seafood products seems likely to continue increasing for the next several years, barring major changes in national or global economic drivers.

## Nonfishing Human Activities

The CCIEA team compiles and regularly updates indicators of nonfishing human activities in the CCE, some of which may have effects on focal species, ecosystem processes and services, fisheries, and coastal communities. These activities relate to different ocean-use sectors like shipping and energy extraction, or to terrestrial sectors that result in nutrient inputs to coastal waters. We update many of these indicators annually, although some are updated less frequently due to the time required by the source agencies to release their data.

### Commercial Shipping

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 reproduction, recruitment, migration, behavior, and communication of target and protected species. 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 update than international data. Commercial shipping activity in the CCE was at the lowest levels of the available time series over the last five years (Figure 42). 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.

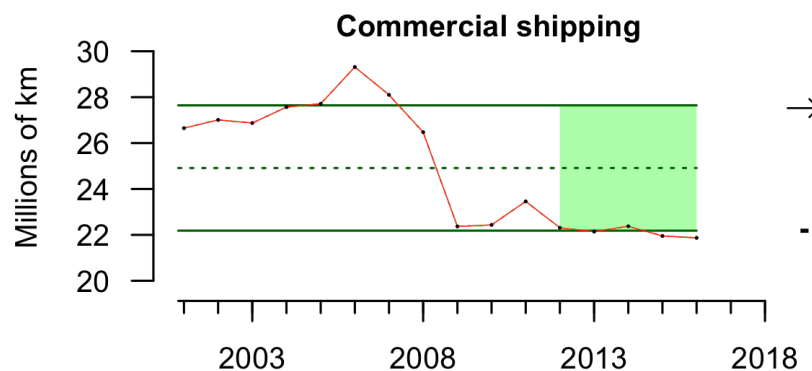


Figure 42. Distance transited by foreign commercial shipping vessels in the CCE from 2001–16. Lines, colors, and symbols as in Figure 3a. Data from U.S. Army Corps of Engineers Navigation Data Center: <https://www.iwr.usace.army.mil/about/technical-centers/wcsc-waterborne-commerce-statistics-center/>.

<sup>10</sup> <https://health.gov/dietaryguidelines/2015/guidelines/chapter-2/a-closer-look-at-current-intakes-and-recommended-shifts/#food-groups>

## Oil and Gas Activity

Oil and natural gas are extracted in offshore drilling in the CCE, with all active leases located in Southern California in the region of Point Conception and landward of the Channel Islands. Offshore oil and gas activity in the CCE has declined and was below historical levels over the last five years (Figure 43). Offshore oil and gas production has been decreasing steadily since the mid-1990s. 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 polycyclic aromatic hydrocarbons (PAHs), which may impact marine fish health and reproduction. The effects of the physical presence of oil rigs on fish stocks are less conclusive, as rig structures may provide some habitat benefits.

## Nutrient Loading

Nutrient input into coastal waters occurs through natural cycling of materials, as well as through loadings derived from human activities. Nutrient loading is a leading cause of contamination, eutrophication, and related impacts in streams, lakes, wetlands, estuaries, and groundwater throughout the United States. Nutrient input data into all CCE waters have not been updated since 2012, and are thus not presented here.

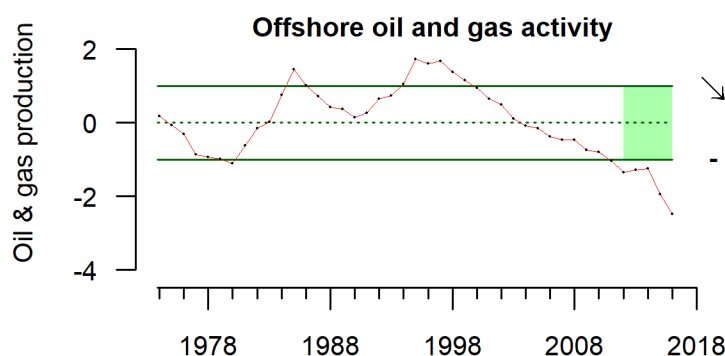


Figure 43. Normalized index of the sum of oil and gas production from offshore wells in California from 1974–2016. Lines, colors, and symbols as in Figure 3a. Oil production data come from annual reports of the California State Department of Conservation’s Division of oil, gas, and geothermal resources ([ftp://ftp.consrv.ca.gov/pub/oil/annual\\_reports/](ftp://ftp.consrv.ca.gov/pub/oil/annual_reports/)), while natural gas production data come from the U.S. Energy Information Administration ([http://www.eia.gov/dnav/ng/ng\\_prod\\_sum\\_dcu\\_rcatf\\_a.htm](http://www.eia.gov/dnav/ng/ng_prod_sum_dcu_rcatf_a.htm)).



# Human Wellbeing

## 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). The CCIEA team has been monitoring CSVI in communities dependent upon commercial fishing, and in this year's report, we expand to include dependence upon recreational fishing.

The commercial fishing *engagement* index is based on an analysis of variables reflecting commercial fishing engagement in 1,140 communities (e.g., fishery landings, revenues, permits, and processing). The commercial fishing *reliance* index applies the same factor analysis approach to these variables on a per capita basis; thus, in two communities with equal engagement, the community with the smaller population would have a higher reliance on its fisheries activities. Similarly, 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 represents these variables for each community on a per capita basis. The plots shown in this report focus on indicators of fishing reliance (per capita dependence) within focal communities; for engagement plots, see Appendix P of Harvey et al. (2018).

Figure 44 plots CSVI against per capita commercial fishery reliance for 2015 in five communities most dependent on commercial fishing in 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 SD above average levels of social vulnerability (horizontal dashed line) and commercial fishing reliance (vertical dashed line) of all U.S. West Coast communities. For example, both Moss Landing, California, and Westport, Washington, have high commercial fishing reliance (29 and 9 SD above average, respectively) and also high CSVI (~10 and 5 SD above average, respectively). Commercial fishing downturns due to ecosystem changes or management actions may produce especially high individual- and community-level social stress in communities that are strong outliers in both indices. However, as we have discussed in past reports and discussions with PFMC, these data are difficult to ground-truth and require further study. We also lack data for many communities altogether, including many tribal communities.

Figure 45 plots CSVI against the newly available per capita recreational fishery reliance index for 2015 in 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 SD above average levels of recreational fishing reliance (vertical line) and social vulnerability (horizontal line) along the U.S. West Coast. Notable communities of this type include Elkton, Oregon, and Westport, although there were fewer communities in this portion of the recreational reliance plot than there were in the commercial reliance plot (Figure 44). Several communities (Westport; Ilwaco, Washington; Garibaldi, Oregon; and 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 ground-truth information and to understand the importance of these relationships.

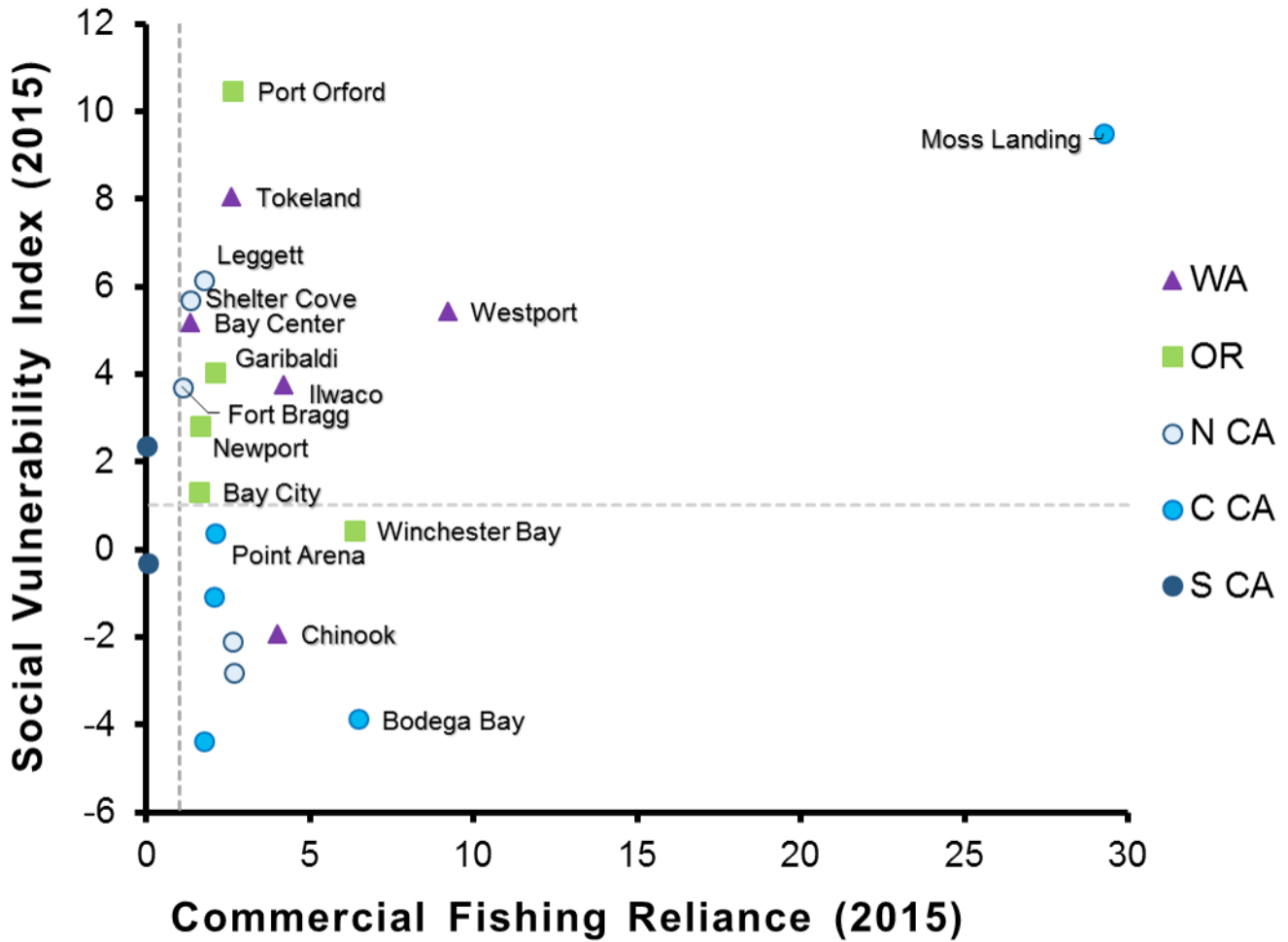


Figure 44. Commercial fishing reliance and social vulnerability scores in 2015, plotted for five communities from each of five regions of the CCE: WA, OR, and Northern, Central, and Southern CA. The top five highest-scoring communities for commercial fishing reliance were selected from each region. Community social vulnerability index (CSV) and fishery dependence data provided by K. Norman, NMFS/NWFSC, and A. Varney, PSMFC, with data 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.

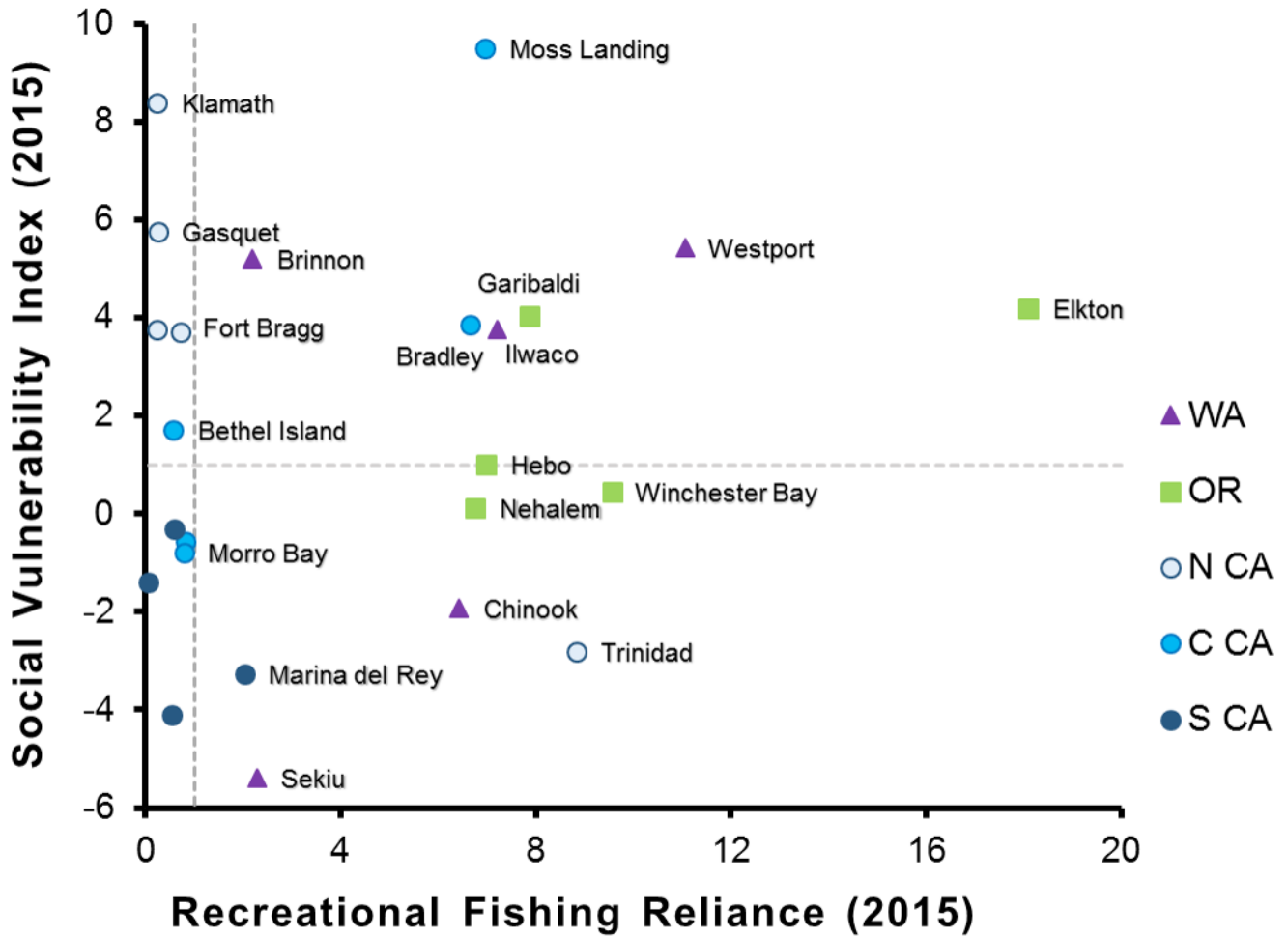


Figure 45. Recreational fishing reliance and social vulnerability scores plotted for 2015 in five communities from each of five regions of the CCE: WA, OR, and Northern, Central, and Southern CA. The top five highest-scoring communities for recreational fishing reliance were selected from each region. Community social vulnerability index (CSVI) and fishery dependence data provided by K. Norman, NMFS/NWFSC, and A. Varney, PSMFC, from data derived from the U.S. Census Bureau's American Community Survey (ACS; <https://www.census.gov/programs-surveys/acs/>) and from PacFIN (<http://pacfin.psmfc.org>) and RecFIN (<http://www.recfin.org/>), respectively.

## Fleet Diversity Indices

Catches and prices from many fisheries exhibit high interannual 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 U.S. 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 two fisheries; and so on. It increases both as revenues are spread across *more* fisheries and as revenues are spread *more evenly* across fisheries.

As of 2016, the fleet of vessels fishing on the U.S. West Coast and in Alaska is less diverse on average than at any time in the past 36 years (Figure 46a). All categories of vessels that fished along the U.S. West Coast decreased in average diversification from 2015 to 2016 (Figure 46b–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, which would have a positive effect on diversification; however, vessels that remain in the fishery have also become less diversified, at least since the mid-1990s, and newer entrants have generally been less diversified than earlier entrants. The net 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 variable revenues (e.g., Dungeness crab), a decline in that fishery might force vessels into other fisheries, causing average diversification to increase.

As is true with individual vessels, greater diversification of landings should reduce the variability of landed value at the port level. Diversification of fishing revenue has declined over the last several decades for some ports (Figure 47). 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 and San Francisco, where declines were greater than twice the standard deviation of ESI for those ports over the last 15 years (Figure 47). Several California ports had shown increasing trends in ESI prior to the 2016 drop.

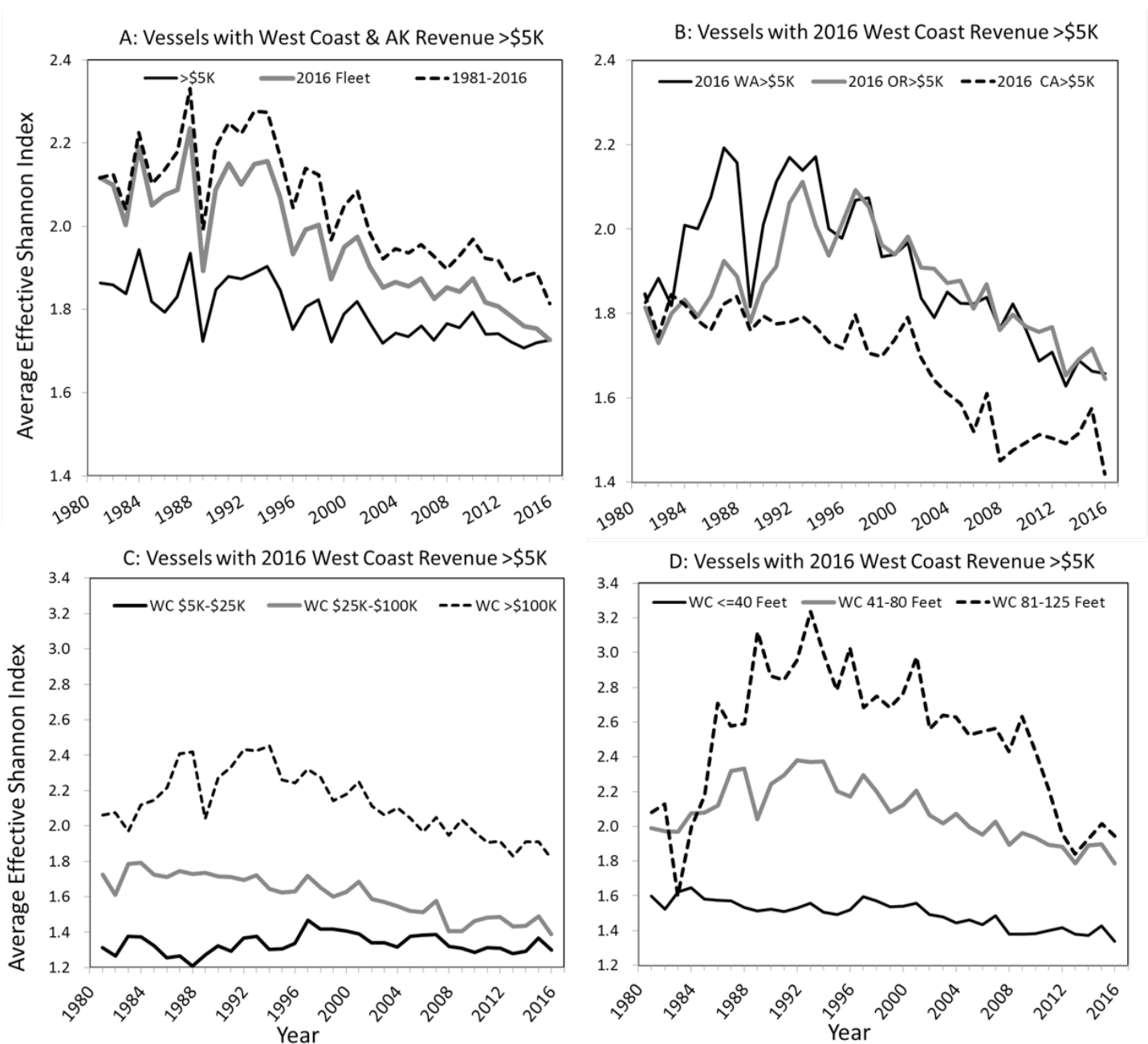


Figure 46. Trends in average commercial fishing vessel revenue diversification, 1981–2016. (A) Revenue diversification for U.S. West Coast and Alaskan fishing vessels with over \$5K in average revenues. (B–D) Revenue diversification for vessels in the 2016 U.S. West Coast Fleet with over \$5K in average revenues, broken out by: (B) state, (C) average gross revenue class, and (D) vessel length class. Fishery diversification estimates provided by D. Holland, NMFS/NWFSC, and S. Kasperski, NMFS/AFSC.

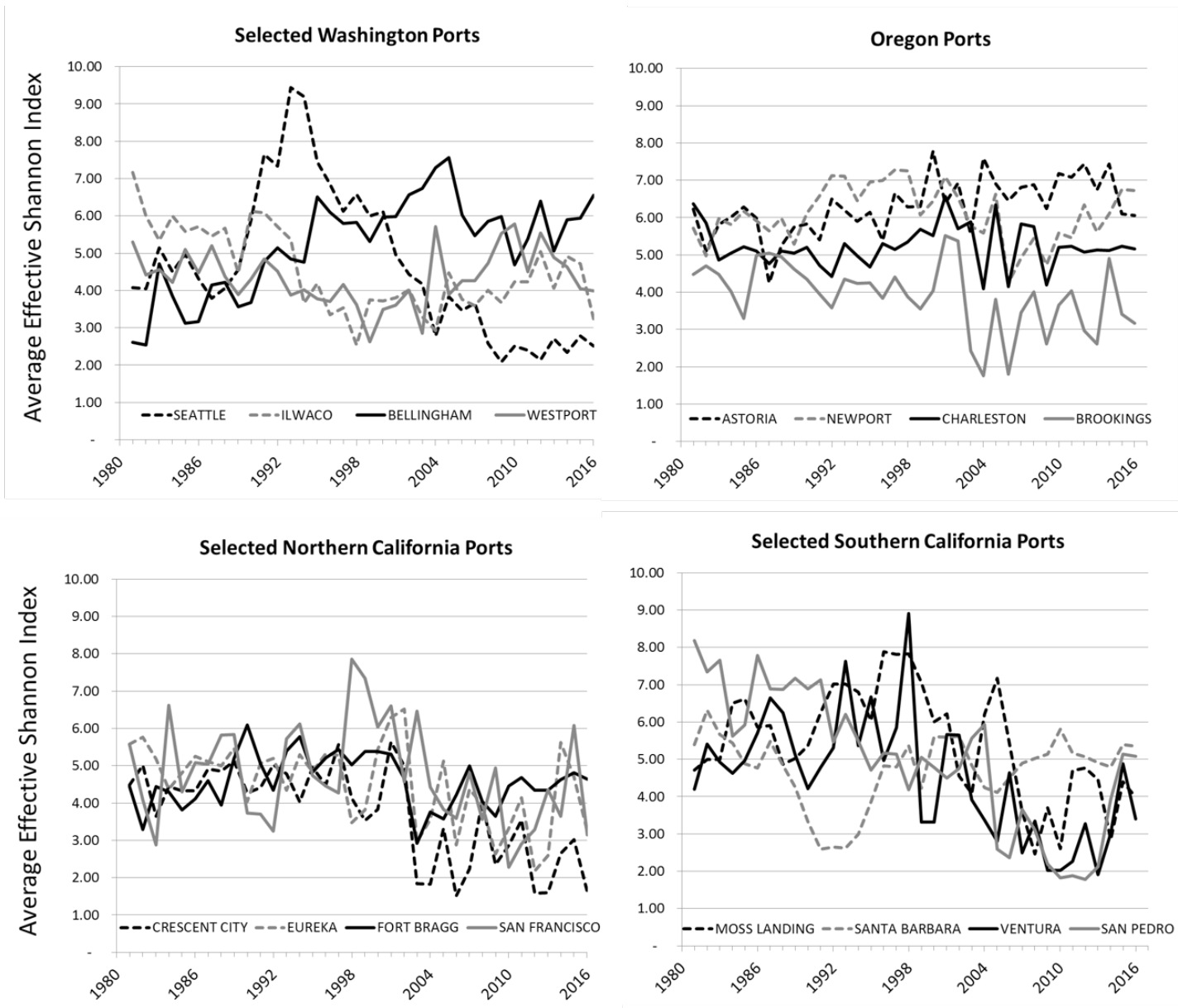


Figure 47. Trends in commercial fishing vessel revenue diversification in major ports of WA, OR, and CA, 1981–2016. Fishery diversification estimates provided by D. Holland, NMFS/NWFSC, and S. Kasperski, NMFS/AFSC.

## Synthesis

As outlined in the Executive Summary, many indicators from the California Current Ecosystem in 2017 pointed toward a natural system that was no longer experiencing the extreme warming of the recent marine heat wave and El Niño, but neither had it recovered unequivocally to long-term average conditions, much less to the highly productive regime that prevailed in the three to four years preceding the marine heat wave. Indicators of the natural system also remind us that the California Current is a spatially diverse ecosystem: in the central and southern regions, important forage and target species such as anchovy and market squid showed increases in abundance; elsewhere, in the northern region, above-average water temperatures, warm-water copepods, and large catches of pyrosomes were evidence of remnant effects of the marine heat wave. Meanwhile, indicators of the human system suggest that commercial fishery landings and revenue have begun to recover from the impact of the marine heat wave, buoyed largely by Pacific hake, market squid, and Dungeness crab. The diversification of fishery species providing revenue to the commercial fishery as a whole continued to decrease, which may indicate that fishery sectors are more vulnerable to high interannual variability in landings and price. The extent of the impacts of such vulnerability may differ across individual communities, depending on the diversification of their fleets and processing capabilities as well as the overall social vulnerability of each port, though this is an area where more information and dedicated research effort is needed.

At the time of publication, it remained to be seen if 2018 conditions will again resemble a “transitional” year, which is how we have characterized both 2016 and 2017. It also remains to be seen how the effects of the recent anomalous years will manifest themselves in the condition of different marine populations. For example, many stocks of Pacific salmon were likely affected during one or more life-history stages in fresh, estuarine, or marine waters, and our ability to detect the effects on individual stocks will be a function of the severity of impacts at different stages as well as the time lags between when the impacts occurred and when the salmon can be sampled effectively. For longer-lived species, we may need years to understand the population responses. Rockfish appear to have had successful reproduction during the anomalous years, based on high catches of YOY (e.g., Figure 21), but those year classes have yet to reach the size at which they would recruit into the fishery, so the next few years will be telling. Another long-lived species, California sea lion, has experienced poor pup survival (Figure 28); coupled with an aging adult population, this may reduce its abundance over the next several years (DeLong et al. 2017).

In March 2015, PFMC approved FEP Initiative 2, “Coordinated Ecosystem Indicator Review,”<sup>11</sup> by which PFMC, advisory bodies, the public, and the CCIEA team would work jointly to refine the indicators in the annual ESRs to better meet PFMC objectives. Many of the recommendations that came out of Initiative 2 have been incorporated into this technical memorandum and also into the ESR that the CCIEA team presented to PFMC in March 2018 (see Appendix C in Harvey et al. 2018). We will continue to update and improve future ESRs and technical memorandums in collaboration with PFMC, as well as other end users with fisheries or other resource management mandates. The CCIEA team (and many other research teams) will also continue to focus research on how the recent anomalous conditions compare to historic conditions for key species and

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<sup>11</sup> <https://www.pcouncil.org/ecosystem-based-management/fishery-ecosystem-plan-initiatives/coordinated-ecosystem-indicator-review-initiative/>

ecosystem processes in the CCE. Such work may help us identify ecosystem reference points in our indicators, i.e., points at which important ecosystem metrics experience disproportionate change that may require changes in management to mitigate impacts to ecological, economic, or social endpoints.

In the 2017 ESR to PFMC (Harvey and Garfield 2017) and the first technical memorandum in this series (Harvey et al. 2017), we included a list of six general research recommendations that a) we believe are important, b) we could provide to PFMC in a reasonable time frame (e.g., one to three years), c) should support regional implementation of the NOAA EBFM Policy (NOAA 2016), and d) would provide added value to ecosystem indicators as they relate to management of FMP stocks and protected species. The recommendations also relate to key elements in the IEA framework (Figure 1). The research recommendations were:

1. Continue an ongoing scoping process between PFMC and the CCIEA team.
2. Continue making improvements to indicator analysis.
3. Assess dynamics of fisheries adaptation to short-term climate variability.
4. Assess vulnerability of communities at sea to long-term climate change.
5. Use dynamic ocean management methods to reduce bycatch in HMS fisheries.
6. Assess the ecological and economic impacts of ocean acidification.

The CCIEA team is conducting research and outreach activities related to each of these recommendations and will include outcomes in future reports as various activities are completed. We conclude this report with three examples of ongoing projects that support the recommendations. The first two projects (Early Warning Index and Ecosystem Thresholds) relate most closely to research recommendations 2 and 3, and the third project (Dynamic Ocean Management of Bycatch) relates most closely to research recommendation 5.

## **An Early Warning Index for the California Current**

In March 2017, PFMC 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 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 2014–16 were near or beyond prior extremes for many variables (Figure 48). We will continue to revisit these analyses as time series in the CCE add further data.



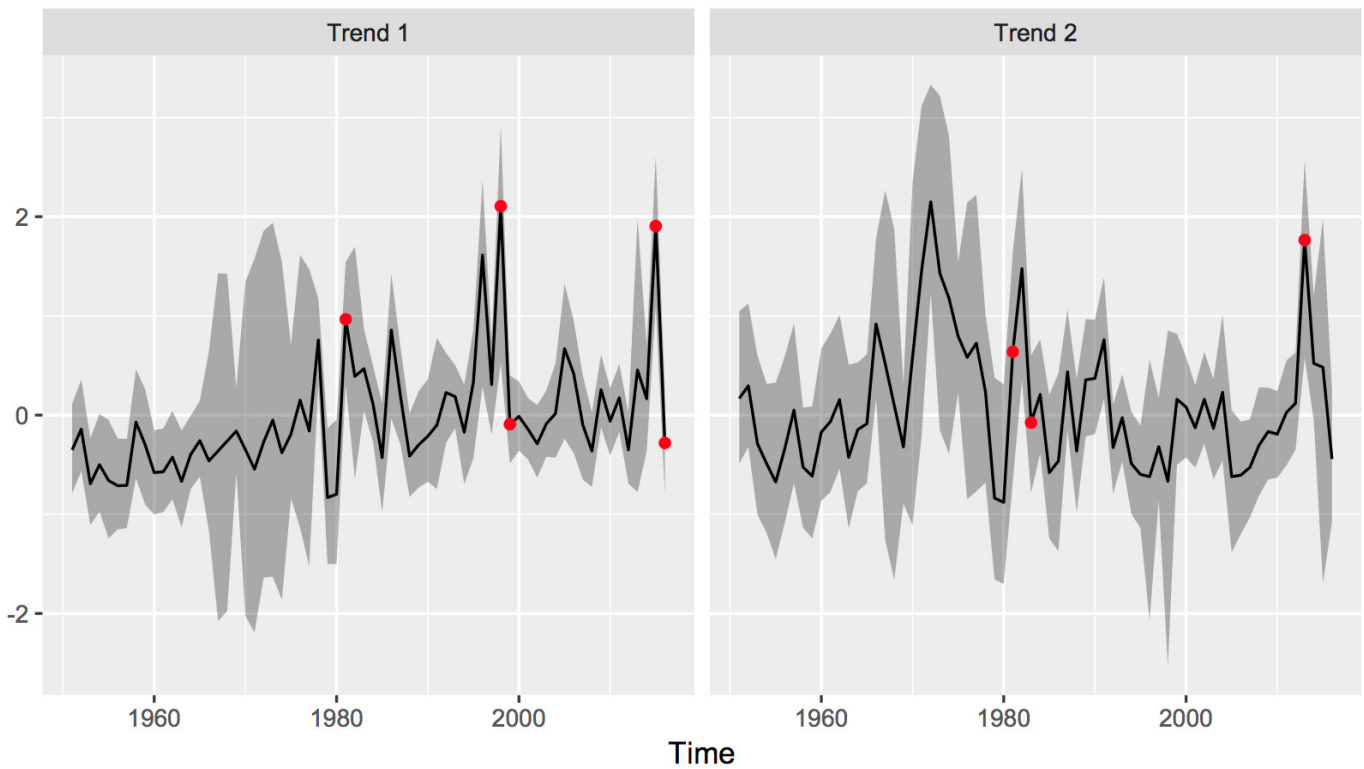


Figure 48. In this example, an early warning index model reduced 32 biological time series from the southern CCE down to two main underlying trends. Solid lines = means; shading = 95% Bayesian credible intervals. Both trends showed brief departures in 2014 or 2015, followed by rapid recovery. In all cases, rare “black swan” events (red dots) were followed by returns to central tendencies, not persistent state shifts. Early warning index/dynamic factor analysis results provided by M. Hunsicker, NMFS/NWFSC, based on CalCOFI ichthyoplankton data (<https://www.calcofi.org/>) provided by S. McClatchie, NMFS/SWFSC (retired).

## 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 inform ecosystem reference points deserving of management attention in the future. One case study from this project, which was reviewed by 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 49, sea lion pup production drops dramatically when summer NOI increases beyond a value of  $\sim 0.2$ , based on data from 1996–2016; this was counterintuitive, because positive NOI values are associated with La Niña conditions that we generally assume to be more productive (Samhouri et al. 2017). This mismatch may indicate that the sea lion pup production response to changes in environmental pressure lags by some time period related to sea lion life-history constraints, and highlights the need for further mechanistic studies. Many ecological time series in the CCE are just reaching a sufficient 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.

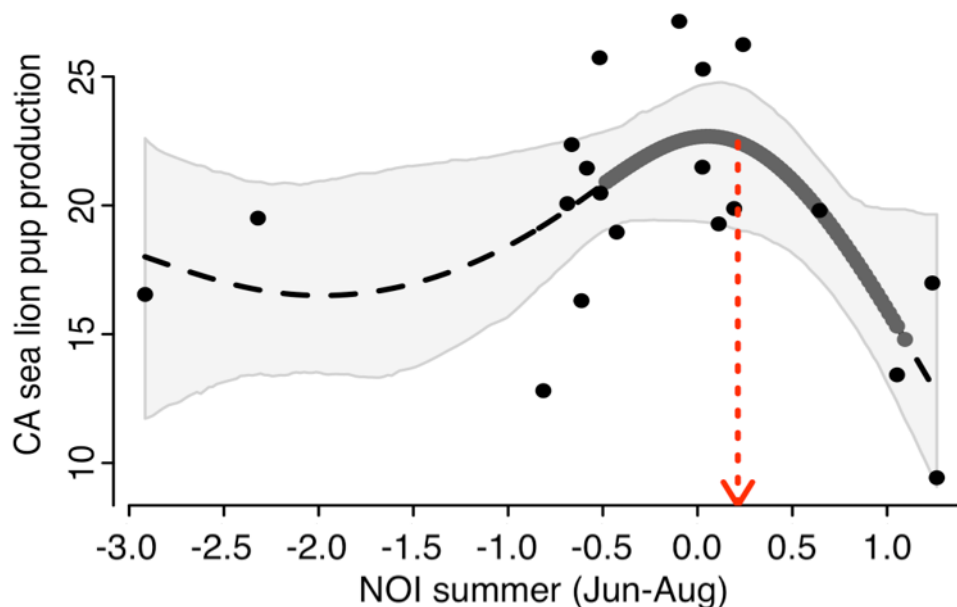


Figure 49. Relationship between the atmospheric Northern Oscillation Index (NOI) and California sea lion pup counts at San Miguel Island. The red arrow indicates the best estimate of a statistical threshold, beyond which the relationship changes significantly; the heavy solid trend line indicates 95% confidence around that threshold point. Figure provided by J. Samhouri, NMFS/NWFSC (Samhouri et al. 2017).

## 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 (Hazen et al. 2018). This fishery is heavily managed to reduce bycatch of endangered leatherback turtle (*Dermochelys coriacea*) and loggerhead turtle (*Caretta caretta*), yet large-scale seasonal closures of swordfish fishing are the primary tool for avoiding bycatch. To address this, the team created the EcoCast product,<sup>12</sup> which assesses the 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 50). The predictive model was used to examine how large, dynamically managed areas would compare to existing seasonal closures under different scenarios; for example, Figure 50 (left) was a very conservative scenario to protect the top 75% of predicted leatherback habitat, while Figure 50 (right) was a less-conservative scenario to protect the top 50% of combined EcoCast risk surfaces across turtles, pinnipeds, and blue sharks (*Prionace glauca*). Of note, 2015 showed increased areas of high risk, particularly late in the season compared to 2012 (Hazen et al. 2018). 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.

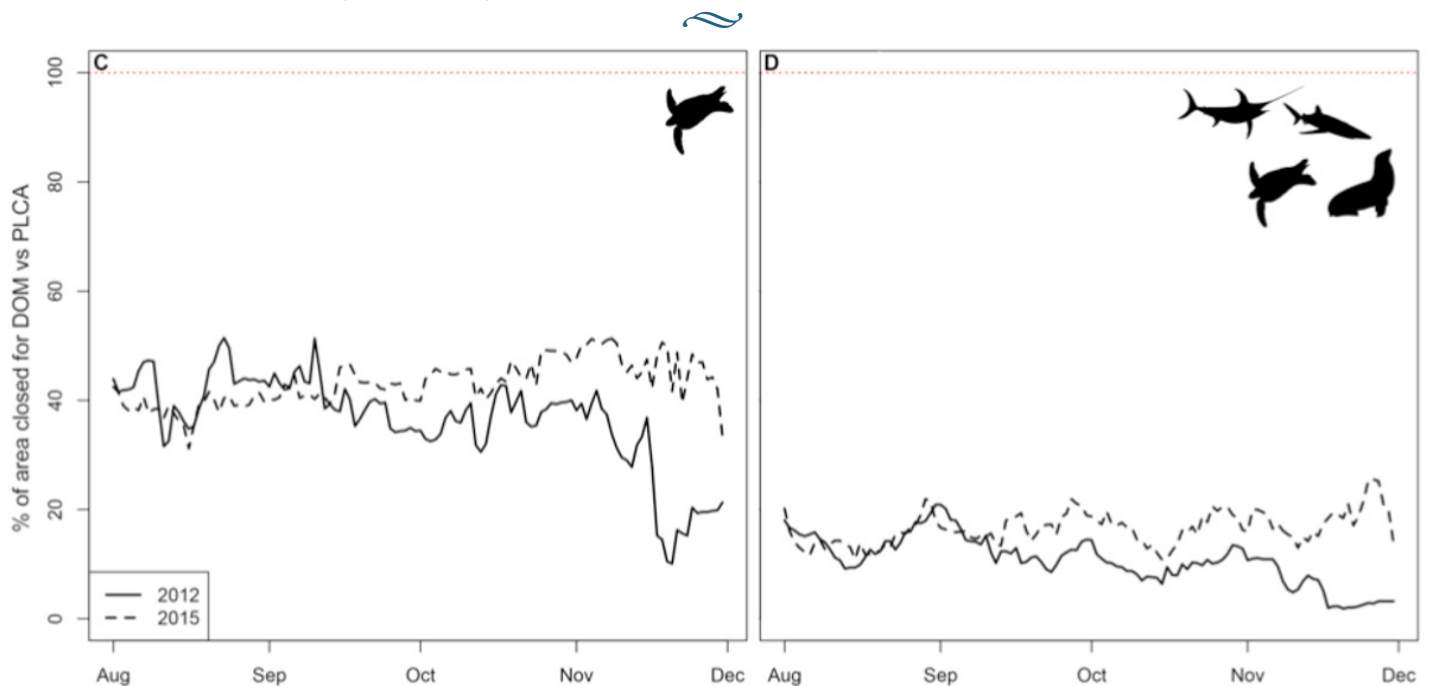


Figure 50. Comparison of a dynamic ocean management approach (EcoCast) to the California Drift Gillnet Fishery, relative in size to the existing static Pacific Leatherback Conservation Area (PLCA) closure. This example tests two management objectives: (left) a dynamic closure that protects the top 75% 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. Figure provided by E. Hazen, NMFS/SWFSC (Hazen et al. 2018).

<sup>12</sup> <http://oceanview.pfeg.noaa.gov/ecocast/>

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## List of Abbreviations

AFSC	Alaska Fisheries Science Center (NMFS)	MARSS	multivariate auto-regressive state space
AMC	American Community Survey	NH	Newport Hydrographic Line
ATF	arrowtooth flounder	NMFS	National Marine Fisheries Service (NOAA)
AVHRR	advanced very high resolution radiometry	NOAA	National Oceanic and Atmospheric Administration
CalCOFI	California Cooperative Oceanic Fisheries Investigations	NOI	Northern Oscillation Index
CCE	California Current ecosystem	NORPAC	North Pacific Groundfish Observer Program (NWFS)
CCIEA	California Current Integrated Ecosystem Assessment	NPGO	North Pacific Gyre Oscillation
CHDT	Commercial Harvest Data Team (WDFW)	NWFSC	Northwest Fisheries Science Center (NMFS)
CIMRS	Cooperative Institute for Marine Resources Studies (OSU)	OA	ocean acidification
COASST	Coastal Observation and Seabird Survey Team (UW)	OFL	overfishing limit
CPS	coastal pelagic species	ONI	Oceanic Niño Index
CPUE	catch per unit effort	OSU	Oregon State University
CSVI	community social vulnerability index	PacFIN	Pacific Fisheries Information Network (PSMFC)
CTD	conductivity, temperature, and depth	PDO	Pacific Decadal Oscillation
CUI	cumulative upwelling index	PFMC	Pacific Fishery Management Council
DO	dissolved oxygen	PLCA	Pacific Leatherback Conservation Area
EBFM	ecosystem-based fisheries management	POP	Pacific ocean perch
EBM	ecosystem-based management	PSMFC	Pacific States Marine Fisheries Commission
EFH	essential fish habitat	RecFIN	Recreational Fisheries Information Network (PSMFC)
ENSO	El Niño–Southern Oscillation	SD	standard deviation
EPAP	Ecosystem Principles Advisory Panel (NMFS)	SNOTEL	snow telemetry
ERDDAP	Environmental Research Division Data Access Program	SPR	spawner potential ratio
ESI	effective Shannon index	SSCES	Scientific and Statistical Committee, Ecosystem Subcommittee (PFMC)
ESR	ecosystem status report	SST	sea surface temperature
ESU	evolutionarily significant unit	SSTa	sea surface temperature anomaly
FEP	fishery ecosystem plan	SWE	snow-water equivalent
FMP	fishery management plan	SWFSC	Southwest Fisheries Science Center (NMFS)
HMS	highly migratory species	TRP	target reference point
IATTC	Inter-American Tropical Tuna Commission	UI	upwelling index
IEA	integrated ecosystem assessment	USGS	U.S. Geological Survey
ISC	International Scientific Committee	UW	University of Washington
JISAO	Joint Institute for the Study of the Atmosphere and Ocean (UW)	WDFW	Washington Department of Fish and Wildlife
JSOES	Juvenile Salmon and Ocean Ecosystem Survey	YOY	young-of-the-year
LRP	limit reference point		

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