CCIEA ESR Technical Documentation

California Current Integrated Ecosystem Assessment

Greg Williams Lynn deWitt Isaac Schroeder Chris Dailey
Nick Tolimieri

2026-01-30

Table of contents

Preface 5

I Introduction 6

Objective 7

Sampling Locations 8

II General Methods 10

1 Data and Code Access 11

2 Time Series and Quadplots 12

III Climate and Oceans 14

3 ONI (Oceanic Niño Index) 15

4 PDO (Pacific Decadal Oscillation) 16

5 NPGO (North Pacific Gyre Oscillation) 17

6 North Pacific High Indicators 18

7 Ocean Temperature 19

8 Marine Heatwaves 21

9 Habitat Compression Index 23

10 Upwelling 25

11 Dissolved Oxygen 28

12 Ocean Acidification 30

13 Snow-water equivalent 31

14 Maximum Stream Temperatures 33

15 Streamflow 35

IV Focal Components of Ecological Integrity 38

16 Copepods 39

17 Krill 40

18 Northern California Current Forage 43

19 Central California Current Forage 46

20 Southern California Current Forage 48

21 CPS Survey 50

22 Juvenile Salmon 51

23 Salmon Stoplight Tables 52

24 Chinook Salmon Escapement - Columbia River 54

25 Chinook Salmon Ecosystem Conditions - California 55

26 Groundfish Stock Abundance 60

27 Juvenile Groundfish Abundance 61

28 Groundfish Port Availability 65

29 HMS Spawning Stock Biomass and Recruitment 67

30 HMS Diets 69

31 Seabird Productivity 72

32 Seabird At-Sea Density 74

33 Seabird Mortality 76

34 Seabird Diet 79

35 Sea Lion Productivity 81

36 Whale Entanglement 85

37 Harmful Algal Blooms 87

V Fishing and Non-Fishing Human Activities 89

38 Fishery Landings 90

39 Commercial Fishery Revenue 98

40 Other Human Activities 100

41 Spatial Interactions with Ocean-Use Sectors 102

VI Human Wellbeing 105

42 Social Vulnerability and Fisheries Engagement 106

43 Fleet Income Diversification 109

44 Non-Fishery Income Diversification 111

45 Fishery Revenue Concentration 112

46 Fisheries Participation Networks 113

Preface

This document is our initial attempt at consolidating in one place the detailed methods used to collect and analyze the indicator data presented in the California Current Ecosystem Status Report (ESR). This online technical documentation archive is designed to serve as a repository for the methods used to access, collect, process, and analyze the indicators presented in the report, while also reducing the length of the ESR and the redundancy among the annual reports.

This repository will be provided both as an online website https://cciea-esr.github.io/ESR-Technical-Documentation-FY2026/ and a time-stamped Appendix (Appendix V) to the 2025-26 report, until it is reviewed by the SSC and Council. Thereafter, however, we intend for it to exist solely as an evolving online repository that documents changes to the indicator portfolio, the source data, and the methods used to derive them.

Chapters of this document are organized similarly to the structure of the ESR (i.e. one "chapter" of the technical documentation per section of the ESR). In some cases, we also may also include detailed methods for indicators that no longer are published in the most current version of the ESR document.

We thank the scientists at the Northeast Fisheries Science Center (DePiper et al. 2017) who provided the inspiration and initial template for some of this work https://noaa-edab.github.io/tech-doc/index.html.

Part I

Introduction

Objective

The purpose of this document is to collate the methods used to access, collect, process, and analyze derived data ("indicators") used to describe the status and trend of social, economic, ecological, and biological conditions in the California Current Large Marine Ecosystem (see Fig. 1, below). These indicators are further synthesized in Ecosystem Status Reports produced annually by the Northwest and Southwest Fisheries Science Centers for the Pacific Fisheries Management Council. The metadata for each indicator (in accordance with the Public Access to Research Results (PARR) directive) and the methods used to construct each indicator are described in the subsequent chapters, with each chapter title corresponding to an indicator or analysis present in Ecosystem Status Reports. The most recent and usable html version of this document can be found at https://cciea-esr.github.io/ESR-Technical-Documentation-FY2026/. The PDF version of this and future versions document will be archived in NOAA's Institutional Repository.

Indicators included in this document were selected to clearly align with management objectives, which is required for integrated ecosystem assessment (Levin et al. 2009), and has been advised many times in the literature (Degnbol and Jarre 2004; Jennings 2005; Rice and Rochet 2005; Link 2005). A difficulty with practical implementation of this in ecosystem reporting can be the lack of clearly specified ecosystem-level management objectives (although some have been suggested (Murawski 2000)). In our case, considerable effort had already been applied to derive both general goals and operational objectives from both US legislation such as the Magnuson-Stevens Fisheries Conservation and Management Act (MSA) and regional sources (Harvey et al. 2021).

References

Degnbol, P., and A. Jarre. 2004. "Review of Indicators in Fisheries Management – a Development Perspective." *African Journal of Marine Science* 26 (1): 303–26. https://doi.org/10.2989/18142320409504063.

Harvey, Chris J, Newell Toby Garfield, Gregory D Williams, and Nicholas Tolimieri. 2021. "Ecosystem Status Report of the California Current for 2020-21: A Summary of Ecosystem Indicators Compiled by the California Current Integrated Ecosystem Assessment Team (CCIEA).NOAA Technical Memorandum NMFS-NWFSC-170." https://doi.org/https://doi.org/10.25923/x4ge-hn11.

Jennings, Simon. 2005. "Indicators to Support an Ecosystem Approach to Fisheries." *Fish and Fisheries* 6 (3): 212–32. https://doi.org/10.1111/j.1467-2979.2005.00189.x.

Levin, Phillip, Michael Fogarty, Steven Murawski, and David Fluharty. 2009. "Integrated Ecosystem Assessments: Developing the Scientific Basis for Ecosystem-Based Management of the Ocean." *PLoS Biology* 7 (February): e14. https://doi.org/10.1371/journal.pbio.1000014.

Link, Jason S. 2005. "Translating Ecosystem Indicators into Decision Criteria." *ICES Journal of Marine Science* 62 (3): 569–76.

Murawski, Steven A. 2000. "Definitions of Overfishing from an Ecosystem Perspective." *ICES Journal of Marine Science* 57 (3): 649–58. https://doi.org/10.1006/jmsc.2000.0738.

Rice, Jake, and Marie-joelle Rochet. 2005. "A Framework for Selecting a Suite of Indicators for Fisheries Management." *ICES Journal of Marine Science* 62 (3): 516–627. https://doi.org/10.1016/j.icesjms.2005.01.003.

Sampling Locations

We generally refer to areas north of Cape Mendocino as the "Northern CCE," Cape Mendocino to Point Conception as the "Central CCE", and south of Point Conception as the "Southern CCE." Figure 1 shows sampling areas for most regional oceanographic data. Key oceanographic transects are the Newport Line off Oregon, the Trinidad Head Line off northern California, and CalCOFI lines further south, while shaded marine regions indicate sampling areas for most biological surveys. This sampling is complemented by basin-scale oceanographic observations and by outputs from various models. Figure 1 also shows sampling areas for most biological indicators. The shaded terrestrial areas in Figure 1 represent freshwater ecoregions in the CCE, and are the basis by which we summarize indicators for snowpack, flows, and stream temperatures.

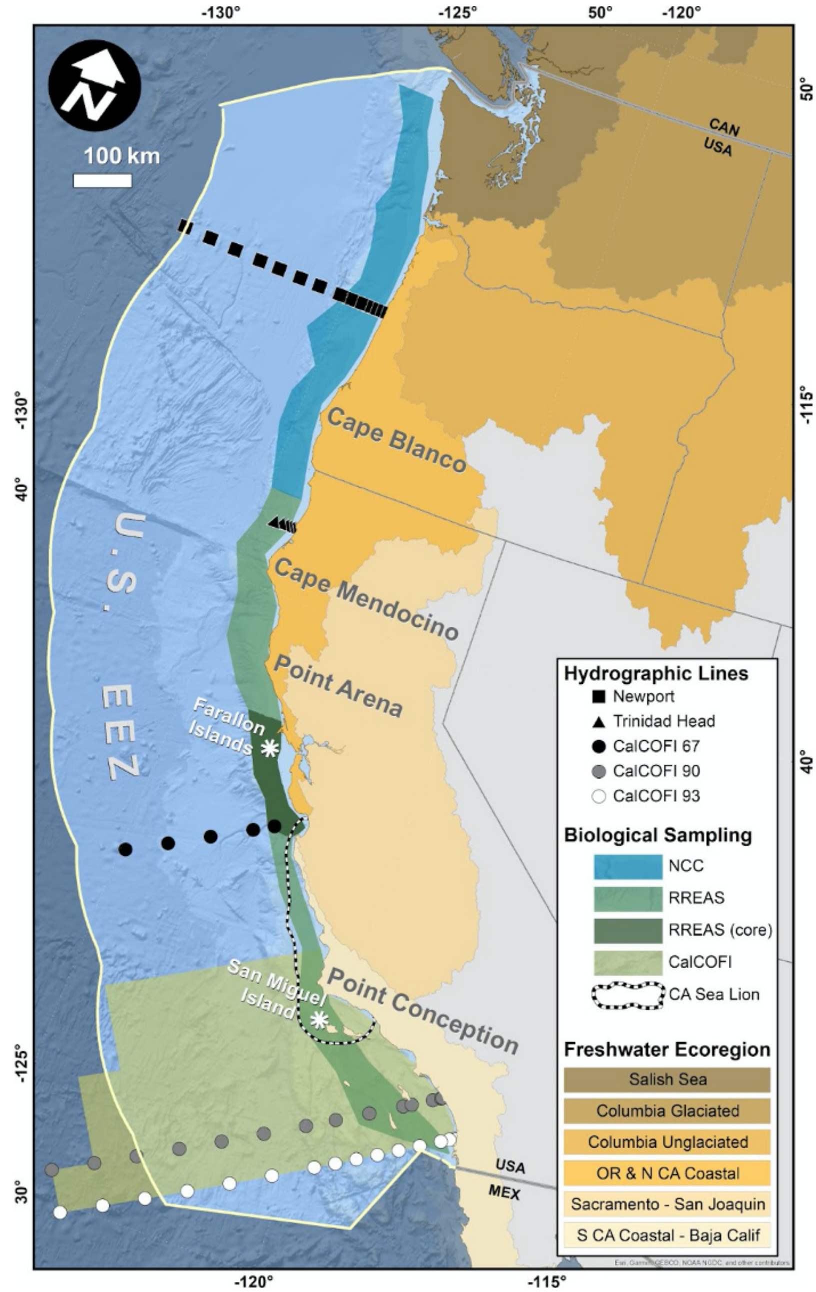

Figure 1: Map of most sampling efforts in the California Current Ecosystem (CCE) and U.S. west coast Exclusive Economic Zone (EEZ). Symbols indicate hydrographic line sampling stations for oceanographic data. Shaded ocean regions represent biological sampling areas for the Northern California Current (NCC), which includes the Juvenile Salmon and Ocean Ecology Survey (JSOES); the Rockfish Recruitment and Ecosystem Assessment Survey (RREAS), including its Core Area; and the CalCOFI sampling region. The NCC and RREAS shaded areas, combined, also approximate the survey footprints for NOAA's coastwide CPS acoustic/trawl and groundfish bottom trawl surveys. Dashed line approximates foraging area for adult female California sea lions from the San Miguel colony. Shaded terrestrial areas represent the six freshwater ecoregions in the CCE.

Part II

General Methods

1 Data and Code Access

About the CCIEA Ecosystem Status Report (ESR) The annual CCIEA Ecosystem Status Report (ESR) is a Quarto document; hosted on the NOAA Northwest Fisheries Science Center (NWFSC) Github page, and developed in R.

Indicator data Derived data sets make up the majority of the indicators presented in the CCIEA ESR. In this technical documentation, we list the derived indicators, their source, and where possible, the computations used to produce them from the raw data. This metadata is also publicly available for download. The derived indicator data can be downloaded using links in the sections of this document unless there are privacy concerns involved. In that case, it may be possible to access source data by reaching out to the Data Steward associated with that data set.

Data flow Indicator data is submitted by data providers in a standard format consisting of "long" csv files with standardized column headers and consistent file names. These requirement allow all indicators to be handled with the same R plotting code and enable automation of the data upload process.

After uploading, standardized data and metadata is organized on a private Google Drive by ESR year, and served publicly via ERDDAP™ (Simons and John 2022)

References

Simons, RA, and Chris John. 2022. "ERDDAP." NOAA/NMFS/SWFSC/ERD. 2022. https://coastwatch.pfeg.noaa.gov/erddap.

2 Time Series and Quadplots

Methods The California Current Ecosystem Status Report uses a standard time-series and quadplot format for many data streams (Fig. 2.1).

The standard time-series plot (a) shows indicator data relative to the mean and ±1.0 standard deviation of the long-term statistical evaluation period–set to a "climatology" period of 1991-2020 for all time series to match climate and oceanographic approaches. Black points (when included) indicate data, whereas dotted black lines are used to indicate missing data. The arrow at the right indicates if the trend over the evaluation period (shaded blue) is positive ( ), negative ( ), or neutral ( ). The symbol at the lower right indicates if the recent mean was greater than (+), less than (-), or within 1.0 SD of the long-term mean. When possible, times series indicate observation error (gray envelope), defined for each plot (e.g., SD, standard error, or 95% confidence intervals).

In some cases where the indicator has defined threshold values (e.g., hypoxia or domoic acid toxicity levels), the time-series plot (b) shows the indicator data relative to these threshold value, indicated with a blue line. In this case, dashed lines indicate upper and lower observation error, and the dotted black lines indicate missing data.

Sample quad plots (c) are also used in some other cases (e.g., streamflow), where each point represents one normalized time series. The position of a point indicates if the recent trend (x-axis) was increasing or decreasing over the evaluation period and whether the recent mean (y-axis) was above or below the evaluation period mean. Symbols fall therefore fall into quadrants based on recent average (high or low) and recent trend (increasing or decreasing) relative to a defined, long-term evaluation period.

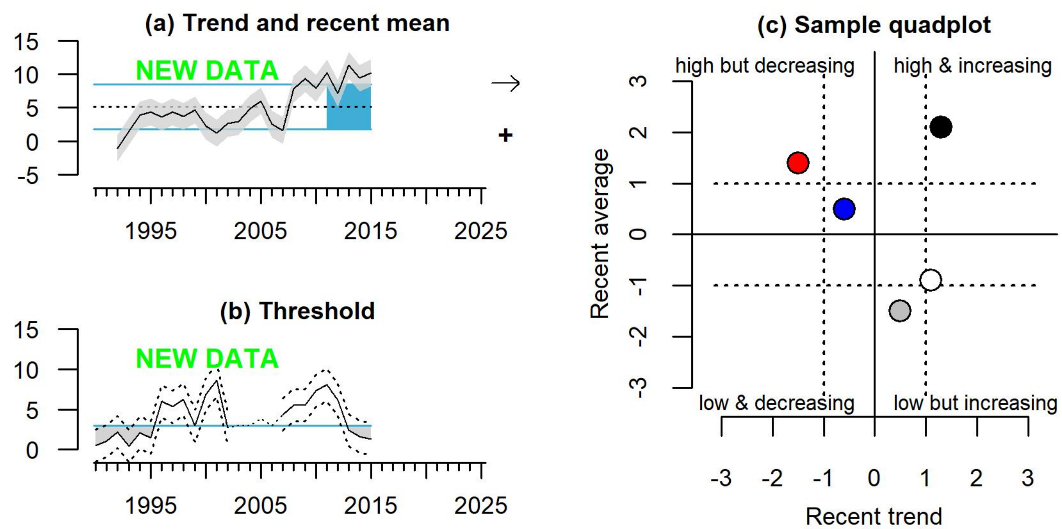

Figure 2.1: a) Sample time-series plot, with indicator data relative to the mean (black dashed horizontal line) and ±1.0 standard deviation (SD; solid blue lines) of the long-term statistical evaluation period (1991-2020). Dotted black line indicates missing data, and points (when included) indicate data. Arrow at the right indicates if the trend over the evaluation period (shaded blue) is positive ( ), negative ( ), or neutral ( ). Symbol at the lower right indicates if the recent mean was greater than (+), less than (-), or within 1.0 SD of the long-term mean. When possible, times series indicate observation error (gray envelope), defined for each plot (e.g., SD, standard error, or 95% confidence intervals). b) Sample time-series plot with the indicator plotted relative to a threshold value (blue line). Dashed lines indicate upper and lower observation error, again defined for each plot. Dotted black line indicates missing data. c) Sample quad plot where each point represents one normalized time series. The position of a point indicates if the recent trend was increasing or decreasing over the evaluation period and the position of the recent average relative to the evaluation period. Dashed lines represent +/- 1.0 SD of the full time series.

Part III

Climate and Oceans

3 ONI (Oceanic Niño Index)

Description The CCLME is driven by atmosphere–ocean energy exchange that occurs on many temporal and spatial scales. El Niño–Southern Oscillation (ENSO) events impact the CCLME by modifying the jet stream and storm tracks, changing the nearshore thermocline, and influencing coastal currents that affect poleward transport and distribution of equatorial and subequatorial waters (and species). The status of the equatorial ENSO is described by the Oceanic Niño Index, which tracks the running 3-month average sea surface temperatures in the east-central tropical Pacific between 120°-170°W. An ONI above 0.5°C indicates El Niño conditions, which often lead to lower primary production, weaker upwelling, poleward transport of equatorial waters and species, and more southerly storm tracks in the CCE. An ONI below -0.5°C means La Niña conditions, which create atmospheric pressure conditions that lead to upwelling-favorable winds that drive productivity in the CCE.

Oceanic Nino Index

- **Component Category:** Climate and Ocean Drivers
- **Time Range:** 1950 - 2025
- **CCIEA Data Contact:** isaac.schroeder@noaa.gov
- **Institution:** NOAA, Climate Prediction Center (CPC)
- **Source Data:** NOAA/CPC The ONI is the 3 month running mean of sea surface temperature anomalies in the Nino 3.4 region
- **Download data:** csv file

4 PDO (Pacific Decadal Oscillation)

Description The CCLME is driven by atmosphere–ocean energy exchange that occurs on many temporal and spatial scales. The Pacific Decadal Oscillation (PDO, Mantua et al. (1997)) describes North Pacific sea surface temperature (SST) anomalies that may persist for many years. Positive PDOs are associated with warmer SST and lower productivity in the CCE, while negative PDOs indicate cooler SST and are associated with higher productivity.

Pacific Decadal Oscillation Index

- **Component Category:** Climate and Ocean Drivers
- **Time Range:** 1950 - 2025
- **CCIEA Data Contact:** isaac.schroeder@noaa.gov
- **Institution:** NOAA SWFSC/FED
- **Source Data:** PDO index is defined as the projections of the ERSST V5 monthly SSTA onto the 1st EOF pattern of North Pacific 20N-60N. 1900-1993 DATA from ERSST V3b is used to derived the climatology and the 1st EOF pattern. Reference: Wen, C., A. Kumar, and Y. Xue, 2014: Factors contributing to uncertainty in Pacific decadal oscillation index. Geophys. Res. Lett., 41, 7980-7986, doi:https://doi.org/10.1002/2014GL061992 ERSST.V5 : Huang, B., Peter W. Thorne, et. al, 2017: Extended Reconstructed Sea Surface Temperature version 5 (ERSSTv5), Upgrades, validations, and intercomparisons. J. Climate Smith, T. M., Reynolds, R. W., Peterson, T. C., and Lawrimore, J. (2008), Improvements to NOAA's historical merged land-ocean surface temperature analysis (1880-2006), J. Clim., 21(10), 2283-2296. *Note: 2023-03-10 UW-JISAO PDO is not longer being updated. This PDO is now ERSST V5*
- **Download data:** csv file

References

Mantua, Nathan J., Steven R. Hare, Yuan Zhang, John M. Wallace, and Robert C. Francis. 1997. "A Pacific Interdecadal Climate Oscillation with Impacts on Salmon Production." *Bulletin of the American Meteorological Society* 78 (6): 1069–79. https://doi.org/10.1175/1520-0477(1997)078%3C1069:apicow%3E2.0.co;2.

5 NPGO (North Pacific Gyre Oscillation)

Description The CCLME is driven by atmosphere–ocean energy exchange that occurs on many temporal and spatial scales. The North Pacific Gyre Oscillation (NPGO, Di Lorenzo et al. (2008)) 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 CCLME. Positive NPGO values are associated with increased equatorward flow, along with increased surface salinities, nutrients, and chlorophyll-a. Negative NPGO values are associated with decreases in such values, implying less subarctic source water and generally lower productivity.

North Pacific Gyre Oscillation Index

- **Component Category:** Climate and Ocean Drivers
- **Time Range:** 1950 - 2025
- **CCIEA Data Contact:** isaac.schroeder@noaa.gov
- **Institution:** Georgia Institute of Technology (GT)
- **Source Data:** The NPGO is calculated from an Empirical Orthogonal Function analysis of sea-surface height in the Northeast Pacific. The NPGO is the second dominant mode.
- **Download data:** csv file

References

Di Lorenzo, E., N. Schneider, K. M. Cobb, P. J. S. Franks, K. Chhak, A. J. Miller, J. C. McWilliams, et al. 2008. "North Pacific Gyre Oscillation Links Ocean Climate and Ecosystem Change." *Geophysical Research Letters* 35 (8). https://doi.org/10.1029/2007gl032838.

6 North Pacific High Indicators

Description Variations in the areal extent of the North Pacific High (NPH) during the winter is predictive of winter upwelling. The January and February average of the NPH area can be used as a "preconditioning" index for ecosystem responses in the spring.

- **Indicators:**
  - North Pacific High Area
  - North Pacific High Area, January - February Mean
- **Component Category:** Climate and Ocean Drivers
- **Time Range:** 1967 - 2025
- **CCIEA Data Contact:** isaac.schroeder@noaa.gov
- **Institution:** NOAA SWFSC/ERD
- **Source Data:** Variations in large-scale atmospheric forcing influence upwelling dynamics and ecosystem productivity in the California Current System.The area of the North Pacific High (NPH) is characterized by areal extent of the 1020 Pa isobar. Winter values (January - February mean) of the NPH area can be used as an ecosystem pre-conditioning index (Schroeder et al., doi:10.1002/grl.50100).The area of the NPH are calculated from monthly mean sea level pressure (SLP) fields created by the U.S. Navy Fleet Numerical Meterology and Oceanography Center (FNMOC). Monthly SLP data available at https://coastwatch.pfeg.noaa.gov/erddap/griddap/erdlasFnWPr.html. The area is the areal extent of the 1020 hPa contour for a given month. The January - February mean is the average of the January and February areas for a given year.
- **Additional Calculations:** The NRT ROMS temperature data downloaded from the UCSC website (http://oceanmodeling.ucsc.edu/index.html) has grid points with 2 m temperature data reported as Not-A-Number, these values are 2 m temperatu. Tdata at these grid points are obtained by extrapolating the data to 2 m depth using the interp1d routine from the Python library scipy.interpolate sub-package.
- **Download data:** csv file

References

7 Ocean Temperature

Buoy Data

Indicators

- **Latitudes:**
  - 33.7 N
  - 39.2 N
  - 44.6 N
- **Component Category:** Climate and Ocean Drivers
- **Time Range:** 1982 - 2026
- **CCIEA Data Contact:** isaac.schroeder@noaa.gov
- **Institution:** NOAA NDBC, NOAA
- **Source Data:** NOAA/ERD NOAA NDBC)
- **Additional Calculations:** The National Data Buoy Center (NDBC) distributes meteorological data from moored buoys maintained by NDBC and others. This dataset is a standardized, reformatted, and lightly edited version of that source data, created by NOAA NMFS SWFSC ERD and then monthly averaged. See the summary global attribute at https://coastwatch.pfeg.noaa.gov/erddap/info/cwwcNDBCMet/index.html
- **Download data:** csv file

Satellite data

Satellite data which has been collected in a similar fashion since 1982, allows for a basin-scale view of sea surface temperature (SST) at up to daily and sub-degree (spatial) resolution.

SST anoms, 5-year means and trends

- **Description** Seasonal SST summary maps are derived from the three statistics shown in the IEA type time series (current value, mean and trend over the last 5 years). The current value is shown as an anomaly and the 5-year mean and trend are

- **Indicator Category** Climate and Ocean Drivers

- **CCIEA Data Contact** Schroeder

- **Additional Information** The seasonal averages are: winter (Jan-Mar), spring (Apr-Jun), summer (Jul-Sep), and summer (Oct-Nov). Daily SST maps are optimally interpolated, remotely sensed temperatures (Huang et al. 2021). The daily optimal interpolated AVHRR SST can be downloaded from ERDDAP, https://coastwatch.pfeg.noaa.gov/erddap/index.html, dataset ID: ncdcOisst21Agg.

Glider data

Glider data has also become an increasingly useful tool for analyzing trends in subsurface water temperatures over time. Subsurface gliders, which generally sample in onshore-offshore transects on a weekly to monthly basis, have been in service long enough for the development of climatologies, which are then used to compute temperature anomalies.

CUGN glider time-depth

- **Description** Time versus depth profiles of water temperatures off of Monterey (66), Pt Conception (80), and north of San Diego (90) demonstrate the extent of recent warm and cool anomalies into the water column, as well as spatial and temporal dynamics of these anomalies.
- **Indicator Category** Climate and Ocean Drivers
- **CCIEA Data Contact** Schroeder
- **Region** Lines 66, 80, 90
- **Data sources** Netcdf files of the three lines can be downloaded from https://spraydata.ucsd.edu/projects/CUGN/. The data downloaded are temperature anomalies created by CUGN.
- **Additional Information** The temperature anomaly data provided in the netcdf file has data across the line at 5 m intervals over 0-500 m and distances at 5 km from the coat out to the end of the line (66=400 km, 80=365 km, 90=530 km). Distance can be averaged using Python xarray to select specific distance ranges and then averaging over the distances. The time interval of the netcdf file is 10 days.

References

Huang, Boyin, Chunying Liu, Viva Banzon, Eric Freeman, Garrett Graham, Bill Hankins, Tom Smith, and Huai-Min Zhang. 2021. “Improvements of the Daily Optimum Interpolation Sea Surface Temperature (DOISST) Version 2.1.” *Journal of Climate* 34 (8): 2923–39. https://doi.org/10.1175/jcli-d-20-0166.1.

8 Marine Heatwaves

Description Marine heatwaves (MHW) occur when ocean temperatures are much warmer than usual for an extended period of time; they are specifically defined by the difference between the current temperature and the expected temperature for a specific location and time of year [1]. MHWs are a growing field of study worldwide because of their effects on ecosystem structure, biodiversity, and regional economies.

Indicators

Marine Heat Wave Heatwave Cover

- **Component Category:** Climate and Ocean Drivers
- **Time Range:** 1982 - 2025
- **CCIEA Data Contact:** andrew.leising@noaa.gov
- **Institution:** NOAA/SWFSC/ERD
- **Source Data:** Marine heatwaves, or MHWs, occur when ocean temperatures are much warmer than usual for an extended period of time; they are specifically defined by differences in expected temperatures for the location and time of year. MHWs are a growing field of study worldwide because of their effects on ecosystem structure, biodiversity, and regional economies. Developed by oceanographers from NOAA Fisheries' Southwest Fisheries Science Center as an experimental tool for natural resource managers, the California Current MHW Tracker is a program designed to understand, describe, and provide a historical context for the 2014-16 blob. It also produces a range of indices that could help forecast or predict future MHWs expected to impact our coast.
- **No download available**

Marine Heat Wave Maximum Area

- **Component Category:** Climate and Ocean Drivers
- **Time Range:** 1982 - 2025
- **CCIEA Data Contact:** andrew.leising@noaa.gov
- **Institution:** NOAA/SWFSC/ERD
- **Source Data:** Marine heatwaves, or MHWs, occur when ocean temperatures are much warmer than usual for an extended period of time; they are specifically defined by differences in expected temperatures for the location and time of year. MHWs are a growing field of study worldwide because of their effects on ecosystem structure, biodiversity, and regional economies. Developed by oceanographers from NOAA Fisheries' Southwest Fisheries Science Center as an experimental tool for natural resource managers, the California Current MHW Tracker is a program designed to understand, describe, and provide a historical context for the 2014-16 blob. It also produces a range of indices that could help forecast or predict future MHWs expected to impact our coast.
- **No download available**

Marine Heat Wave Maximum Intensity

- **Component Category:** Climate and Ocean Drivers

- **Time Range:** 1982 - 2025
- **CCIEA Data Contact:** andrew.leising@noaa.gov
- **Institution:** NOAA/SWFSC/ERD
- **Source Data:** Marine heatwaves, or MHWs, occur when ocean temperatures are much warmer than usual for an extended period of time; they are specifically defined by differences in expected temperatures for the location and time of year. MHWs are a growing field of study worldwide because of their effects on ecosystem structure, biodiversity, and regional economies. Developed by oceanographers from NOAA Fisheries' Southwest Fisheries Science Center as an experimental tool for natural resource managers, the California Current MHW Tracker is a program designed to understand, describe, and provide a historical context for the 2014-16 blob. It also produces a range of indices that could help forecast or predict future MHWs expected to impact our coast.
- **No download available**

Additional Information

There is growing recognition that marine heatwaves can have strongly disruptive impacts on the CCE (Morgan et al. 2019). Based on an analysis of sea surface temperature anomalies (SSTa) obtained from satellite measurements (OISST); we define marine heatwaves as 1.0 times when normalized SSTa >1.29 s.d. (90th percentile) of the long-term SSTa time series at a location, and 2. lasts for >5 days; which are analogous to the thresholds suggested in Hobday et al. (2016). Here, we further report on statistics concerning large heatwaves (LHW) which were tracked through space and time, with LHW defined as those heatwaves with an area > 400,000 km2 (these denote the top 20% of all heatwaves by area as measured since 1982 when satellite data became available for tracking.

The underlying climatology used for SST anomaly analysis has changed from 1982-2010, to now encompass 1982-2020; hence small changes in the retrospective analysis of tracked heatwaves reported more recently as compared to previous reports.

References

Hobday, Alistair J, Lisa V Alexander, Sarah E Perkins, Dan A Smale, Sandra C Straub, Eric CJ Oliver, Jessica A Benthuysen, et al. 2016. "A Hierarchical Approach to Defining Marine Heatwaves." *Progress in Oceanography* 141: 227–38.

Morgan, Cheryl A, Brian R Beckman, Laurie A Weitkamp, and Kurt L Fresh. 2019. "Recent Ecosystem Disturbance in the Northern California Current." *Fisheries* 44 (10): 465–74.

9 Habitat Compression Index

Description The Habitat Compression Index (HCI) is the area of cool habitat along the coast, which is suitable for a diverse and productive portion of the CCE food web. HCI is estimated in four biogeographic provinces along the shelf within the CCE. See (Santora et al. 2020; Schroeder et al. 2022) for more information.

Indicators

- **Latitudes:**
  - 30 - 35.5 N
  - 35.5 - 40 N
  - 40 - 43.5 N
  - 43.5 - 48 N
- **Component Category:** Climate and Ocean Drivers
- **Time Range:** 1982 - 2025
- **CCIEA Data Contact:** isaac.schroeder@noaa.gov
- **Institution:** NOAA SWFSC/FED
- **Source Data:** The habitat compression index uses 2 m temperature from the historic and NRT data assimilative ROMS physical model of the California Current system (http://oceanmodeling.ucsc.edu/index.html). Grid points between 30-48 degrees N and from the shore out to 150 km offshore are used in the analysis.
- **Additional Calculations:** In eastern boundary upwelling ecosystems the spatial footprint of cool upwelled water is regularly demarcated by the differential boundary of warmer oceanic water offshore from cooler coastal water, with upwelling conditions varying with latitude. Therefore, the goal of the habitat compression index (HCI) is to track the area of cool surface waters as an index of potential 'upwelling habitat' for assessing the spatio-temporal aspects of upwelling. Upwelling patterns of cold nutrient-rich water are clearly assessed by models and satellite observations and classified spatially by monitoring SST values less than and equal to a monthly resolved temperature threshold. The HCI tracks the amount of area, determined by the number of grid cells in the model with 2 m surface temperature values less than the monthly temperature threshold, therefore the time series reflects the area of cool water adjacent to the coastline and provides a measure for how compressed cool surface temperatures may be in a particular month. In this study (Schroeder et al. 2022), we extracted modeled 2 m temperature fields over the domain of 35.5-40 degree N for each month and tracked the amount of area with temperature values less than and equal to a monthly temperature threshold, resulting in monthly time series starting January 1980. Monthly temperature thresholds for a given month is the spatial average of 2 m temperature grid cells between 35.5-40N from shore out to 75 km for the time period 1980-2010. Cool expansion periods (low compression) are defined as months with HCI values exceeding + 1 standard deviation (SD) of the full time series, limited cool habitat (high compression) where area of cool water is less than the mean (MN) of the full time series, and periods of medium compression when the area of cool water falls between the +1 SD and the MN.

- **Download data:** csv file

References

Santora, Jarrod A, Nathan J Mantua, Isaac D Schroeder, John C Field, Elliott L Hazen, Steven J Bograd, William J Sydeman, et al. 2020. "Habitat compression and ecosystem shifts as potential links between marine heatwave and record whale entanglements." *Nature Communications* 11 (1): 1–12.

Schroeder, Isaac D, Jarrod A Santora, Nate Mantua, John C Field, Brian K Wells, Elliott L Hazen, Michael Jacox, and Steven J Bograd. 2022. "Habitat Compression Indices for Monitoring Ocean Conditions and Ecosystem Impacts Within Coastal Upwelling Systems." *Ecological Indicators* 144: 109520.

10 Upwelling

Description

The CCE is an upwelling dominated system, with the interaction between upwelling, stratification, and source water properties controlling much of coastal temperatures, nutrient input, and overall productivity.

The Coastal Upwelling Transport Index (CUTI, pronounced “cutie”) and the Biologically Effective Upwelling Transport Index (BEUTI; pronounced “beauty”) leverage state-of-the-art ocean models as well as satellite and in situ data to improve upon historically available upwelling indices for the U.S. west coast (Jacox et al. 2018). CUTI provides estimates of vertical transport near the coast (i.e., upwelling/downwelling). It was developed as a more accurate alternative to the previously available ‘Bakun Index’. BEUTI provides estimates of vertical nitrate flux near the coast (i.e., the amount of nitrate upwelled/downwelled), which may be more relevant than upwelling strength when considering some biological responses.

The historical Bakun (Bakun (1973); Bakun (1975)) upwelling indices provide long time series of upwelling, and are based on estimates of offshore Ekman transport driven by geostrophic wind stress. Geostrophic winds are derived from mean surface atmospheric pressure fields provided by the U.S. Navy Fleet Numerical Meteorological and Oceanographic Center (FNMOC), Monterey, CA.

Time series of the upwelling indices provide information on upwelling strength at sub-seasonal frequency and upwelling phenology, and allow interannual comparisons of seasonal upwelling timing and frequency. Additionally, the calculation of cumulative upwelling allows for a comparison of the total amount of upwelling a region receives during the entire course of the year. Cumulative upwelling is calculated as the daily summation of upwelling values (additive for positive upwelling, and subtractive for negative upwelling - aka downwelling) starting on Jan 1 and ending on Dec 31st.

Coastal Upwelling Transport Index (CUTI)

- **Latitudes:**
  - 33 N
  - 39 N
  - 45 N
- **Component Category:** Climate and Ocean Drivers
- **Time Range:** 1988 - 2025
- **CCIEA Data Contact:** isaac.schroeder@noaa.gov
- **Institution:** NOAA/SWFSC/ERD
- **Source Data:** CUTI is a new upwelling index that leverages state-of-the-art ocean models as well as satellite and in situ data to improve upon historically available upwelling indices for the U.S. west coast. CUTI provides estimates of vertical transport near the coast (i.e., upwelling/downwelling). It was developed as a more accurate alternative to the previously available Bakun Index. See Jacox, M. G., C. A. Edwards, E. L. Hazen, and S. J. Bograd (2018) Coastal upwelling revisited: Ekman,

Bakun, and improved upwelling indices for the U.S. west coast. Journal of Geophysical Research, doi:10.1029/2018JC014187.

- **Download data:** csv file

Biologically Effective Upwelling Transport Index (BEUTI)

- **Latitudes:**
  - 33 N
  - 39 N
  - 45 N
- **Component Category:** Climate and Ocean Drivers
- **Time Range:** 1988 - 2025
- **CCIEA Data Contact:** isaac.schroeder@noaa.gov
- **Institution:** NOAA/SWFSC/ERD
- **Source Data:** BEUTI is a new upwelling index that leverages state-of-the-art ocean models as well as satellite and in situ data to improve upon historically available upwelling indices for the U.S. west coast. BEUTI provides estimates of vertical nitrate flux near the coast (i.e., the amount of nitrate upwelled/downwelled), which may be more relevant than upwelling strength when considering some biological responses. See Jacox, M. G., C. A. Edwards, E. L. Hazen, and S. J. Bograd (2018) Coastal upwelling revisited: Ekman, Bakun, and improved upwelling indices for the U.S. west coast. Journal of Geophysical Research, doi:10.1029/2018JC014187.
- **Download data:** csv file

Bakun Upwelling Index

- **Latitudes:**
  - 33 N
  - 39 N
  - 45 N
- **Component Category:** Climate and Ocean Drivers
- **Time Range:** 1967 - 2025
- **CCIEA Data Contact:** isaac.schroeder@noaa.gov
- **Institution:** NOAA/SWFSC/ERD
- **Source Data:** Upwelling index computed from 1-degree 6-hourly FNMOC sea level pressure 33 degrees of latitude. The coastal Upwelling Index is an index of the strength of the wind forcing on the ocean which has been used in many studies of the effects of ocean variability on the reproductive and recruitment success of many fish and invertebrate species. NOAA/ERD
- **Download data:** csv file

References

Bakun, Andrew. 1973. “Coastal Upwelling Indices, West Coast of North America, 1946-71. NOAA Technical Report, NMFS SSRF-671.” Department of Commerce, National Oceanic; Atmospheric Administration.

———. 1975. “Daily and Weekly Upwelling Indices, West Coast of North America, 1967-73, NOAA Tech. Rep, 16.” Department of Commerce, National Oceanic; Atmospheric Administration.

Jacox, Michael G, Christopher A Edwards, Elliott L Hazen, and Steven J Bograd. 2018. "Coastal upwelling revisited: Ekman, Bakun, and improved upwelling indices for the US West Coast." *Journal of Geophysical Research: Oceans* 123 (10): 7332–50.

11 Dissolved Oxygen

Description Nearshore dissolved oxygen (DO) depends on many processes, including currents, upwelling, air–sea exchange, and community-level production and respiration in the water column and benthos. DO is required for organismal respiration; low DO can compress habitat and cause stress or die-offs for sensitive species. Waters with DO levels <1.4 mL/L (~ 2 mg/L, note unit change) are considered to be hypoxic; such conditions may occur on the shelf following the onset of spring upwelling, and continue into the summer and early fall months until the fall transition vertically mixes shelf waters. Upwelling-driven hypoxia occurs 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 (Chan et al. 2008).

CalCOFI Indicators

- **Locations:**
  - 150m: Line 80, Station 80 (33.5 N, -122.5 E)
  - 150m: Line 90, Station 90 (31.4 N, -122 E)
  - 150m: Line 93, Station 30 (32.8 N, -117.5 E)
- **Component Category:** Climate and Ocean Drivers
- **Time Range:** 1950 - 2025
- **CCIEA Data Contact:** isaac.schroeder@noaa.gov
- **Institution:** NOAA SWFSC
- **Source Data:** Isaac Schroeder (isaac.schroeder@noaa.gov) Dissolved oxygen is measured by an automated oxygen titrator mounted to the CTD rosette and oxygen data is sampled at depths consistent with those of temperature and salinity. Additional information can be found at http://www.calcofi.org/new.data/index.php/reporteddata/hydrographic-data/introductions.
- **Additional Calculations:** Each unique depth profile of dissolved oxygen (DO) was linearly interpolated on 1 m intervals, without any extrapolation for intervals above/below sampled depths. Outliers a profile might contain were removed by applying a Hample filter. The filter had a window size of 5 m above and below an observation, and considers the observation an outlier if a sample differs from the median by more than four standard deviations (see https://www.mathworks.com/help/signal/ref/hampel.html). Outliers are filled by linear interpolation of the points above and below. Then the DO at 150 m (DO@150) was extracted from the linearly interpolated profile. A time series of DO@150 was created using each unique profile of DO data available. A monthly mean time series was calculated from this time series. A standard deviation value was calculated if more than one profile was made during a given month, otherwise the standard deviation value was NaN (not a number).
- **Download data:** csv file

Newport Line Indicators

- **Locations:**

  - Monthly Dissolved Oxygen at 150 m: NH25 (44.65N -124.65W) (44.65 N, -124.65 E)
  - Monthly Dissolved Oxygen at 50 m: NH05 (44.65N -124.18W) (44.65 N, -124.18 E)

- **Component Category:** Climate and Ocean Drivers
- **Time Range:** 1998 - 2025
- **CCIEA Data Contact:** isaac.schroeder@noaa.gov
- **Institution:** NOAA SWFSC
- **Source Data:** Dr. Jennifer Fisher (jennifer.fisher@noaa.gov) Dissolved oxygen is measured by an automated oxygen titrator mounted to the CTD rosette and oxygen data is sampled at depths conin Peterson, J.O, Morgan, C. A., Peterson, W.T., Di Lorenzo, E. 2013) Seasonal and interannual variation in the extent of hypoxia in the northern California Current from 1998-2012, Limnology and Oceanography, 58(6):2279-2292, DOI:10.4319/lo.2013.58.6.2279.
- **Additional Calculations:** Each unique depth profile of dissolved oxygen (DO) was linearly interpolated on 1 m intervals, without any extrapolation for intervals above/below sampled depths. Outliers a profile might contain were removed by applying a Hample filter. The filter had a window size of 5 m above and below an observation, and considers the observation an outlier if a sample differs from the median by more than four standard deviations (see https://www.mathworks.com/help/signal/ref/hampel.html). Outliers are filled by linear interpolation of the points above and below. Then the DO at 150 m (DO@150) was extracted from the linearly interpolated profile. A time series of DO@150 was created using each unique profile of DO data available. A monthly mean time series was calculated from this time series. A standard deviation value was calculated if more than one profile was made during a given month, otherwise the standard deviation value was NaN (not a number).
- **Download data:** csv file

References

Chan, Francis, JA Barth, J Lubchenco, A Kirincich, H Weeks, William T Peterson, and BA Menge. 2008. "Emergence of anoxia in the California Current Large Marine Ecosystem." *Science* 319 (5865): 920–20.

12 Ocean Acidification

Description Ocean acidification (OA) occurs when atmospheric CO2 dissolves into seawater, reduces seawater pH and carbonate ion levels. Upwelling transports low oxygen, acidified waters from deeper offshore onto the continental shelf, where increased community-level metabolic activity can further exacerbate OA (Feely et al. 2008). A key measure of OA is aragonite saturation state, which is related to availability of aragonite (a form of the mineral calcium carbonate) to form or dissolve. Aragonite saturation <1.0 indicates relatively acidified, corrosive conditions that are stressful for many CCE species, particularly shell-forming invertebrates. OA impacts on these species can propagate through marine food webs and potentially affect fisheries (Marshall et al. 2017). Aragonite saturation states tend to be lowest during spring and summer upwelling, and highest in winter.

Newport Line Aragonite Saturation

- **Locations:**
  - Monthly Aragonite Saturation at 150 m: NH25 (44.65N -124.65W) (44.7 N, -124.7 E)
  - Monthly Aragonite Saturation at 40 m: NH05 (44.65N -124.18W) (44.65 N, -124.18 E)
- **Component Category:** Climate and Ocean Drivers
- **Time Range:** 1998 - 2025
- **CCIEA Data Contact:** isaac.schroeder@noaa.gov
- **Institution:** NOAA NWFSC
- **Source Data:** Data are derived from methods in Juranek et al. 2009: Juranek, L.W., Feely, R.A., Peterson, W.T., Alin, S.R., Hales, B., Lee, K., Sabine, C.L. and Peterson, J., 2009. A novel method for determination of aragonite saturation state on the continental shelf of central Oregon using multi-parameter relationships with hydrographic data. Geophysical Research Letters, 36(24).
- **Download data:** csv file

References

Feely, Richard A, Christopher L Sabine, J Martin Hernandez-Ayon, Debby Ianson, and Burke Hales. 2008. "Evidence for upwelling of corrosive" acidified" water onto the continental shelf." *Science* 320 (5882): 1490–92.

Marshall, Kristin N, Isaac C Kaplan, Emma E Hodgson, Albert Hermann, D Shallin Busch, Paul McElhany, Timothy E Essington, Chris J Harvey, and Elizabeth A Fulton. 2017. "Risks of ocean acidification in the California Current food web and fisheries: ecosystem model projections." *Global Change Biology* 23 (4): 1525–39.

13 Snow-water equivalent

Description Snow-water equivalent (SWE) is measured using data from the California Department of Water Resources snow survey program (California Data Exchange Center, cdec.water.ca.gov) and The Natural Resources Conservation Service's SNOTEL sites across Washington, Oregon, California and Idaho. Snow data are converted into SWEs based on the weight of samples collected at regular intervals using a standardized protocol. Measurements on April 1 are considered the best indicator of maximum extent of SWE; thereafter snow tends to melt rather than accumulate.

Freshwater habitat indicators are reported based on a hierarchical spatial framework. The framework facilitates comparisons of data at the right spatial scale for particular users, whether this be the entire California Current, ecoregions within the CCE, or smaller spatial units. The framework we use divides the region encompassed by the CCE into ecoregions (Fig. 1.1), and ecoregions into smaller physiographic units. Freshwater ecoregions are based on the biogeographic delineations in (Abell et al. 2008), see also www.feow.org, who define six ecoregions for watersheds entering the California Current, three of which comprise the two largest watersheds directly entering the California Current (the Columbia and the Sacramento-San Joaquin Rivers). Within ecoregions, we summarized data at scales of evolutionary significant units (ESUs) and 8-field hydrologic unit classifications (HUC-8). Status and trends for all freshwater indicators are estimated using space-time models that account for spatial and temporal autocorrelation (Lindgren and Rue 2015).

Snow water equivalent Ecoregion indicators:

- **Ecoregions:**
  - Salish Sea & WA coast
  - Columbia Glaciated
  - Columbia Unglaciated
  - Oregon and Northern California Coastal
  - Sacramento - San Joaquin
- **Component Category:** Habitat
- **Time Range:** 1910 - 2025
- **CCIEA Data Contact:** correigh.greene@noaa.gov
- **Institution:** NOAA NWFSC
- **Source Data:** Snow-water equivalent data were derived from the California Department of Water Resources snow survey (http://cdec.water.ca.gov/) and the Natural Resources Conservation Service's SNOTEL sites in WA, OR, CA and ID from sites with records that meet or exceed 30 years in duration (http://www.wcc.nrcs.usda.gov/snow/).
- **Additional Calculations:** Anomalies of April 1 snow-water equivalents (SWE) for the CCE, calculated as an area-weighted average of data from the Sacramento-San Joaquin ecoregion. SWE is a measure of the total water available in snowpack. Measurements on April 1st are considered the best indicator of maximum extent of snowpack.
- **Download data:** csv file

References

Abell, Robin, Michele L Thieme, Carmen Revenga, Mark Bryer, Maurice Kottelat, Nina Bogutskaya, Brian Coad, et al. 2008. "Freshwater ecoregions of the world: a new map of biogeographic units for freshwater biodiversity conservation." *BioScience* 58 (5): 403–14.

Lindgren, Finn, and Håvard Rue. 2015. "Bayesian spatial modelling with R-INLA." *Journal of Statistical Software* 63: 1–25.

14 Maximum Stream Temperatures

Description Mean maximum stream temperatures in August were determined from 446 USGS gauges with temperature monitoring capability. While these gauges did not necessarily operate simultaneously throughout the period of record, at least two gauges provided data each year in all ecoregions. Stream temperature records are limited in California, so two ecoregions (Sacramento/San Joaquin and Southern California Bight-Baja) were combined. Maximum temperatures exhibit strong ecoregional differences in absolute temperature (for example, Salish Sea and Washington Coast streams are much cooler on average than California streams).

Freshwater habitat indicators are reported based on a hierarchical spatial framework. The framework facilitates comparisons of data at the right spatial scale for particular users, whether this be the entire California Current, ecoregions within the CCE, or smaller spatial units. The framework we use divides the region encompassed by the CCE into ecoregions (Fig. 1.1), and ecoregions into smaller physiographic units. Freshwater ecoregions are based on the biogeographic delineations in (Abell et al. 2008), see also www.feow.org, who define six ecoregions for watersheds entering the California Current, three of which comprise the two largest watersheds directly entering the California Current (the Columbia and the Sacramento-San Joaquin Rivers). Within ecoregions, we summarized data at scales of evolutionary significant units (ESUs) and 8-field hydrologic unit classifications (HUC-8). Status and trends for all freshwater indicators are estimated using space-time models that account for spatial and temporal autocorrelation (Lindgren and Rue 2015).

August Mean Max stream temperature Ecoregion indicators:

- **Ecoregions:**
  - Salish Sea & WA coast
  - Columbia Glaciated
  - Columbia Unglaciated
  - Oregon and Northern California Coastal
  - Sacramento - San Joaquin & southern California Bight
- **Component Category:** Habitat
- **Time Range:** 1981 - 2025
- **CCIEA Data Contact:** correigh.greene@noaa.gov
- **Institution:** NOAA NWFSC
- **Source Data:** August mean maxium temperature is measured using active USGS gages (http://waterdata.usgs.gov/nwis/sw)
- **Additional Calculations:** Average daily values from 446 gages were used to calculate annual mean maximum Aug temp
- **Download data:** csv file

References

Abell, Robin, Michele L Thieme, Carmen Revenga, Mark Bryer, Maurice Kottelat, Nina Bogutskaya, Brian Coad, et al. 2008. "Freshwater ecoregions of the world: a new map of biogeographic units for freshwater biodiversity conservation." *BioScience* 58 (5): 403–14.

Lindgren, Finn, and Håvard Rue. 2015. "Bayesian spatial modelling with R-INLA." *Journal of Statistical Software* 63: 1–25.

15 Streamflow

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

Freshwater habitat indicators are reported based on a hierarchical spatial framework. The framework facilitates comparisons of data at the right spatial scale for particular users, whether this be the entire California Current, ecoregions within the CCE, or smaller spatial units. The framework we use divides the region encompassed by the CCE into ecoregions (Fig. 1.1), and ecoregions into smaller physiographic units. Freshwater ecoregions are based on the biogeographic delineations in (Abell et al. 2008), see also www.feow.org, who define six ecoregions for watersheds entering the California Current, three of which comprise the two largest watersheds directly entering the California Current (the Columbia and the Sacramento-San Joaquin Rivers). Within ecoregions, we summarized data at scales of evolutionary significant units (ESUs) and 8-field hydrologic unit classifications (HUC-8). Status and trends for all freshwater indicators are estimated using space-time models that account for spatial and temporal autocorrelation (Lindgren and Rue 2015).

Streamflow 1 day max Ecoregion indicators:

- **Ecoregions:**
  - Salish Sea & WA coast
  - Columbia Glaciated
  - Columbia Unglaciated
  - Oregon and Northern California Coastal
  - Sacramento - San Joaquin
  - Southern CA bight
- **Component Category:** Habitat
- **Time Range:** 1981 - 2025
- **CCIEA Data Contact:** correigh.greene@noaa.gov
- **Institution:** NOAA NWFSC
- **Source Data:** Streamflow is measured using active USGS gages (http://waterdata.usgs.gov/nwis/sw) with records that meet or exceed 30 years in duration.
- **Additional Calculations:** Average daily values from 213 gages were used to calculate annual 1-day maximum flows. These indicators correspond to flow parameters to which salmon populations are most sensitive. Standardized anomalies of time series from individual gages were then averaged to obtain weighted averages for ecoregions (for which HUC-8 area served as a weighting factor) and for the entire California current (weighted by ecoregion area).
- **Download data:** csv file

Streamflow 7 day min Ecoregion indicators:

- **Ecoregions:**
  - Salish Sea & WA coast
  - Columbia Glaciated
  - Columbia Unglaciated
  - Oregon and Northern California Coastal
  - Sacramento - San Joaquin
  - Southern CA bight
- **Component Category:** Habitat
- **Time Range:** 1981 - 2025
- **CCIEA Data Contact:** correigh.greene@noaa.gov
- **Institution:** NOAA NWFSC
- **Source Data:** Streamflow is measured using active USGS gages (http://waterdata.usgs.gov/nwis/sw) with records that meet or exceed 30 years in duration.
- **Additional Calculations:** Average daily values from 213 gages were used to calculate annual 7-day minimum flows. These indicators correspond to flow parameters to which salmon populations are most sensitive. Standardized anomalies of time series from individual gages were then averaged to obtain weighted averages for ecoregions (for which HUC-8 area served as a weighting factor) and for the entire California current (weighted by ecoregion area).
- **Download data:** csv file

Streamflow 1 day max ESU indicators:

- **ESUs:**
  - Upper Columbia Spring
  - Oregon Coast
  - S. Oregon N. California coast
  - Upper Klamath Trinity River
  - California Coast
  - Sacramento Winter
  - Central Valley Spring
  - Central Valley Fall late Fall
  - Puget Sound
  - Washington coast
  - Upper Columbia Summer Fall
  - Snake River Fall
  - Lower Columbia River
  - Mid-Columbia Spring
  - Snake River Spring Summer
  - Upper Willamette River
- **Component Category:** Habitat
- **Time Range:** 1981 - 2025
- **CCIEA Data Contact:** correigh.greene@noaa.gov
- **Institution:** NOAA NWFSC
- **Source Data:** Streamflow is measured using active USGS gages (http://waterdata.usgs.gov/nwis/sw) with records that meet or exceed 30 years in duration.

- **Additional Calculations:** Average daily values from 213 gages were used to calculate annual 1-day maximum flows. These indicators correspond to flow parameters to which salmon populations are most sensitive. Standardized anomalies of time series from individual gages were then averaged to obtain weighted averages for each of 17 Chinook salmon ESU boundaries (for which HUC-8 area served as a weighting factor).
- **Download data:** csv file

Streamflow 7 day min ESU indicators:

- **ESUs:**
  - Upper Columbia Spring
  - Oregon Coast
  - S. Oregon N. California coast
  - Upper Klamath Trinity River
  - California Coast
  - Sacramento Winter
  - Central Valley Spring
  - Central Valley Fall late Fall
  - Puget Sound
  - Washington coast
  - Upper Columbia Summer Fall
  - Snake River Fall
  - Lower Columbia River
  - Mid-Columbia Spring
  - Snake River Spring Summer
  - Upper Willamette River
- **Component Category:** Habitat
- **Time Range:** 1981 - 2025
- **CCIEA Data Contact:** correigh.greene@noaa.gov
- **Institution:** NOAA NWFSC
- **Source Data:** Streamflow is measured using active USGS gages (http://waterdata.usgs.gov/nwis/sw) with records that meet or exceed 30 years in duration.
- **Additional Calculations:** Average daily values from 213 gages were used to calculate annual 7-day minimum flows. These indicators correspond to flow parameters to which salmon populations are most sensitive. Standardized anomalies of time series from individual gages were then averaged to obtain weighted averages for each of 17 Chinook salmon ESU boundaries (for which HUC-8 area served as a weighting factor).
- **Download data:** csv file

References

Abell, Robin, Michele L Thieme, Carmen Revenga, Mark Bryer, Maurice Kottelat, Nina Bogutskaya, Brian Coad, et al. 2008. "Freshwater ecoregions of the world: a new map of biogeographic units for freshwater biodiversity conservation." *BioScience* 58 (5): 403–14.

Lindgren, Finn, and Håvard Rue. 2015. "Bayesian spatial modelling with R-INLA." *Journal of Statistical Software* 63: 1–25.

Part IV

Focal Components of Ecological Integrity

16 Copepods

Description Copepod biomass anomalies represent variation in northern copepods (cold-water crustacean zooplankton species rich in wax esters and fatty acids) and southern copepods (smaller species with lower fat content and nutritional quality). Northern copepods usually dominate the summer zooplankton community along the Newport Line, while southern species dominate winter. Positive northern copepod anomalies generally correlate with stronger returns of Chinook salmon to Bonneville Dam and coho salmon to coastal Oregon (Peterson et al. 2014). Historically, northern copepods typically have been favored by La Niña and negative PDO conditions (Keister et al. 2011; Fisher, Peterson, and Rykaczewski 2015).

Northern copepod biomass anomaly 44.6N

- **Component Category:** Ecological Integrity
- **Time Range:** 1996 - 2024
- **CCIEA Data Contact:** jennifer.fisher@noaa.gov
- **Institution:** NOAA NWFSC
- **Source Data:** Jennifer Fisher, NOAA (jennifer.fisher@noaa.gov); http://www.nwfsc.noaa.gov/research/divisio
- **Additional Calculations:** Monthly anomalies of the northern copepod biomass from 1996-present in waters off Newport, OR. See Fisher et al. 2015 for methods.
- **Download data:** csv file

Southern copepod biomass anomaly 44.6N

- **Component Category:** Ecological Integrity
- **Time Range:** 1996 - 2024
- **CCIEA Data Contact:** jennifer.fisher@noaa.gov
- **Institution:** NOAA NWFSC
- **Source Data:** Jennifer Fisher, NOAA (jennifer.fisher@noaa.gov); http://www.nwfsc.noaa.gov/research/divisio
- **Additional Calculations:** Monthly anomalies of the southern copepod biomass from 1996-present in waters off Newport, OR. See Fisher et al. 2015 for methods.
- **Download data:** csv file

References

Fisher, Jennifer L, William T Peterson, and Ryan R Rykaczewski. 2015. "The impact of El Niño events on the pelagic food chain in the northern California Current." *Global Change Biology* 21 (12): 4401–14.

Keister, Julie E, E Di Lorenzo, CA Morgan, Vincent Combes, and WT Peterson. 2011. "Zooplankton species composition is linked to ocean transport in the Northern California Current." *Global Change Biology* 17 (7): 2498–2511.

Peterson, William T, Jennifer L Fisher, Jay O Peterson, Cheryl A Morgan, Brian J Burke, and Kurt L Fresh. 2014. "Applied fisheries oceanography: Ecosystem indicators of ocean conditions inform fisheries management in the California Current." *Oceanography* 27 (4): 80–89.

17 Krill

Description Krill are among the most important prey in the CCE. The krill *Euphausia pacifica* is sampled year-round along the Trinidad Head Line off northern California (see Fig. 1 in the Introduction of this document). Mean adult length and total biomass of *E. pacifica* sampled off the Trinidad Head Line indicate productivity at the base of the food web, krill condition, and energy content for predators (Robertson and Bjorkstedt 2020; Fisher et al. 2020).

Trinidad Head krill data are provided by E. Bjorkstedt, NMFS/SWFSC SWFSC, Cal Poly, Humboldt and R. Robertson, Cooperative Institute for Marine Ecosystems and Climate (CIMEC) at Cal Poly, Humboldt.

Krill are also detected acoustically during the Joint U.S.-Canada Pacific Hake Ecosystem and Acoustic Trawl (PHEAT) Survey, conducted between June-September from Point Conception, California to Dixon Entrance, British Columbia. The coastwide nautical-area-backscattering coefficient (NASC) represents relative krill abundance observed between 50-300 m water depth (Phillips et al. 2022).

Krill biomass estimates derived from the Joint U.S.-Canada Pacific Hake Ecosystem and Acoustic Trawl (PHEAT) survey hydroacoustic data are provided by E. Phillips, NMFS/NWFSC.

Euphausia pacifica (krill) adult mean biomass

- **Component Category:** Ecological Integrity
- **Time Range:** 2007 - 2024
- **CCIEA Data Contact:** eric.bjorkstedt@noaa.gov
- **Institution:** NOAA SWFSC; Cal Poly Humboldt
- **Source Data:** Krill (Euphausia pacifica) data were provided by Dr. Eric Bjorkstedt (eric.bjorkstedt@noaa.gov), NMFS/SWFSC and Cal Poly Humboldt, and R. Robertson (roxanne.robertson@noaa.gov), Cooperative Institute for Marine, Earth, and Atmospheric Systems (CIMEAS) at Cal Poly Humboldt.
- **Additional Calculations:** Carbon biomass of krill is calculated from body length measurements following length to weight conversions in Fisher et al., 2020.
- **Download data:** csv file

Euphausia pacifica (krill) length anomaly

- **Component Category:** Ecological Integrity
- **Time Range:** 2007 - 2024
- **CCIEA Data Contact:** eric.bjorkstedt@noaa.gov
- **Institution:** NOAA SWFSC; Cal Poly Humboldt
- **Source Data:** Krill (Euphausia pacifica) data were provided by Dr. Eric Bjorkstedt (eric.bjorkstedt@noaa.gov), NMFS/SWFSC and Cal Poly Humboldt, and R. Robertson (roxanne.robertson@noaa.gov), Cooperative Institute for Marine, Earth, and Atmospheric Systems (CIMEAS) at Cal Poly Humboldt.

- **Additional Calculations:** Carbon biomass of krill is calculated from body length measurements following length to weight conversions in Fisher et al., 2020.
- **Download data:** csv file

Euphausia pacifica (krill) mean length

- **Component Category:** Ecological Integrity
- **Time Range:** 2007 - 2024
- **CCIEA Data Contact:** eric.bjorkstedt@noaa.gov
- **Institution:** NOAA SWFSC; Cal Poly Humboldt
- **Source Data:** Krill (Euphausia pacifica) data were provided by Dr. Eric Bjorkstedt (eric.bjorkstedt@noaa.gov), NMFS/SWFSC and Cal Poly Humboldt, and R. Robertson (roxanne.robertson@noaa.gov), Cooperative Institute for Marine, Earth, and Atmospheric Systems (CIMEAS) at Cal Poly Humboldt.
- **Additional Calculations:** Krill body length was measured from the back of the eye to the base of the telson.
- **Download data:** csv file

Euphausia pacifica (krill) total biomass anomaly

- **Component Category:** Ecological Integrity
- **Time Range:** 2007 - 2024
- **CCIEA Data Contact:** eric.bjorkstedt@noaa.gov
- **Institution:** NOAA SWFSC; Cal Poly Humboldt
- **Source Data:** Krill (Euphausia pacifica) data were provided by Dr. Eric Bjorkstedt (eric.bjorkstedt@noaa.gov), NMFS/SWFSC and Cal Poly Humboldt, and R. Robertson (roxanne.robertson@noaa.gov), Cooperative Institute for Marine, Earth, and Atmospheric Systems (CIMEAS) at Cal Poly Humboldt.
- **Additional Calculations:** Carbon biomass of krill is calculated from body length measurements following length to weight conversions in Fisher et al., 2020.
- **Download data:** csv file

Euphausia pacifica (krill) total mean biomass

- **Component Category:** Ecological Integrity
- **Time Range:** 2007 - 2024
- **CCIEA Data Contact:** eric.bjorkstedt@noaa.gov
- **Institution:** NOAA SWFSC; Cal Poly Humboldt
- **Source Data:** Krill (Euphausia pacifica) data were provided by Dr. Eric Bjorkstedt (eric.bjorkstedt@noaa.gov), NMFS/SWFSC and Cal Poly Humboldt, and R. Robertson (roxanne.robertson@noaa.gov), Cooperative Institute for Marine, Earth, and Atmospheric Systems (CIMEAS) at Cal Poly Humboldt.
- **Additional Calculations:** Krill body length was measured from the back of the eye to the base of the telson.
- **Download data:** csv file

References

Fisher, Jennifer L., Jennifer Menkel, Louise Copeman, C. Tracy Shaw, Leah R. Feinberg, and William T. Peterson. 2020. "Comparison of condition metrics and lipid content between Euphausia pacifica and Thysanoessa spinifera in the northern California Current, USA." *Progress in Oceanography* 188: 102417. https://doi.org/https://doi.org/10.1016/j.pocean.2020.102417.

Phillips, Elizabeth M, Dezhang Chu, Stéphane Gauthier, Sandra L Parker-Stetter, Andrew O Shelton, and Rebecca E Thomas. 2022. "Spatiotemporal variability of euphausiids in the California Current Ecosystem: insights from a recently developed time series." *ICES Journal of Marine Science* 79 (4): 1312–26.

Robertson, Roxanne R, and Eric P Bjorkstedt. 2020. "Climate-driven variability in *Euphausia pacifica* size distributions off northern California." *Progress in Oceanography* 188: 102412.

18 Northern California Current Forage

Description The Northern CCE survey (known as the Juvenile Salmon Ocean Ecology Survey, JSOES) occurs in June and targets juvenile salmon in surface waters off Oregon and Washington (Morgan et al. 2019). It also collects adult and juvenile (age 1+) pelagic forage fishes, market squid, and gelatinous zooplankton with regularity. A Nordic 264 rope trawl is towed for 15-30 min at approximately 6.5 km/hr. The gear is fished during daylight hours in near-surface (upper 20 m) waters, which is appropriate for targeting juvenile salmon.

Several other taxa (e.g., anchovy, sardine, herring and mackerels) collected by the June JSOES surface trawl are not considered to be sampled quantitatively due to their behavior (i.e., depth in the water column during daylight hours) and mesh size of sampling gear. Thus, we do not report catch-per-unit-effort (CPUE) of these species, rather noting them in terms of their relative prevalence - the proportion of stations where they were caught.

Pelagic forage data from the Northern CCE are provided by B. Burke, NMFS/NWFSC and C. Morgan, OSU/CIMRS. Data are derived from surface trawls taken during the NWFSC Juvenile Salmon & Ocean Ecosystem Survey (JSOES; https://www.fisheries.noaa.gov/west-coast/science-data/ocean-ecosystem-indicators-pacific-salmon-marine-survival-northern). Similarity analysis and cluster plot by A. Thompson, NMFS/SWFSC.

Forage Biomass:

- **Species:**
  - Market squid
  - Juvenile chum
  - Pompano
  - Subyearling Chinook
  - Yearling Chinook
  - Yearling Coho
  - Juvenile sockeye
  - Market squid
  - Aequorea Water Jelly
  - Moon jelly
  - Chrysaora Sea Nettle
  - Egg yolk jelly
- **Component Category:** Ecological Integrity
- **Time Range:** 1998 - 2024
- **CCIEA Data Contact:** brian.burke@noaa.gov
- **Institution:** NOAA NWFSC
- **Source Data:** Dr. Brian Burke (NOAA; brian.burke@noaa.gov); derived from surface trawls taken during NOAA Northwest Fisheries Science Center Juvenile Salmon & Ocean Ecosystem Survey (JSOES). Additional calculations by Cheryl Morgan (OSU - CIMERS;

cheryl.morgan@oregonstate.edu). Partial funding is from the Bonneville Power Administration (1998-014-00).

- **Additional Calculations:** To be included in this analysis, stations must have been 1) sampled during the day time, 2) on the continental shelf (greater than 200 m water depth), and 3) sampled during at least half of the years of the JSOES effort. Sampling occurs from the northern tip of Washington (48N 13.7') down to Newport, Oregon (44N 40.0') in late June. A Nordic 264 rope trawl (Nor'Eastern Trawl Systems, Bainbridge Island, WA) is towed at the surface (upper 20 m) for 15 - 30 min at approximately 6.5 km/hr. The total abundance for each nekton species caught in each haul was either determined directly or estimated from the total weight of the species in a catch and the weight and number of individuals in a subsample of that catch. Trawl catches were standardized to linear density by dividing catch of each species at a station by the distance between the start- and endpoints of the tow as determined by a global positioning system receiver and log10 transformed (Log10(no. km-1+ 1)).
- **Download data:** csv file

Forage Prevalence:

- **Species:**
  - Jack mackerel
  - Northern anchovy
  - Pacific chub mackerel
  - Pacific hake
  - Pacific herring
  - Pacific sardine
  - Pacific spiny dogfish
  - Pyrosome
  - Surf smelt
  - Whitebait smelt
  - YOY Pacific hake
  - YOY Rockfish (spp.)
  - Pyrosome
- **Component Category:** Ecological Integrity
- **Time Range:** 1998 - 2024
- **CCIEA Data Contact:** brian.burke@noaa.gov
- **Institution:** NOAA NWFSC
- **Source Data:** Dr. Brian Burke (NOAA; brian.burke@noaa.gov); derived from surface trawls taken during NOAA Northwest Fisheries Science Center Juvenile Salmon & Ocean Ecosystem Survey (JSOES). Additional calculations by Cheryl Morgan (OSU - CIMERS; cheryl.morgan@oregonstate.edu). Partial funding is from the Bonneville Power Administration (1998-014-00).
- **Additional Calculations:** To be included in this analysis, stations must have been 1) sampled during the day time, 2) on the continental shelf (greater than 200 m water depth), and 3) sampled during at least 10 of the years of the JSOES effort. Sampling occurs from the northern tip of Washington (48N 13.7') down to Newport, Oregon (44N 40.0') in late June. A Nordic 264 rope trawl (Nor'Eastern Trawl Systems, Bainbridge Island, WA) is towed at the surface (upper 20 m) for 15 - 30 min at approximately 6.5 km/hr. Prevalence is defined as the total number of stations with each nekton species present divided by the total number of stations sampled (proportion of samples present).

- **Download data:** csv file

References

Morgan, Cheryl A, Brian R Beckman, Laurie A Weitkamp, and Kurt L Fresh. 2019. "Recent Ecosystem Disturbance in the Northern California Current." *Fisheries* 44 (10): 465–74.

19 Central California Current Forage

Description The Central CCE forage survey (known as the Rockfish Recruitment and Ecosystem Assessment Survey, RREAS) samples much of the West Coast each May to mid-June, using midwater trawls sampling between 30 and 45 m depths during nighttime hours. The survey targets young-of-the-year (YOY) rockfish species and a variety of other YOY and adult forage species, market squid, adult krill, and gelatinous zooplankton. Juvenile rockfish, anchovy, krill, and market squid are among the most important prey for CCE predators (Szoboszlai et al. 2015). Time series presented here are from the "Core Area" of that survey, centered off Monterey Bay. Catch data were standardized by using a delta-GLM to estimate year effects while accounting for spatial and temporal covariates to yield relative abundance indices, shown with their approximate 95% confidence limits (Santora et al. 2021). This modeling approach was adopted in recent reports to reduce bias in 2020, when sampling effort and spatial coverage was severely constrained by the COVID-19 pandemic.

Pelagic forage data from the Central CCE were provided by J. Field, T. Rogers, K. Sakuma, and J. Santora, NMFS/SWFSC, from the SWFSC Rockfish Recruitment and Ecosystem Assessment Survey (https://go.usa.gov/xGMfR). Similarity analysis and cluster plot by A. Thompson, NMFS/SWFSC.

Indicators

- **Species:**
  - Adult Anchovy
  - Adult Sardine
  - Total Krill
  - Market Squid
  - Total Myctophids
  - Octopus
  - Pyrosomes
  - Salps
  - Thetys
  - YOY Anchovy
  - YOY Pacific Hake
  - YOY Rockfish
  - YOY Sanddabs
  - YOY Sardine
- **Component Category:** Ecological Integrity
- **Time Range:** 1990 - 2024
- **CCIEA Data Contact:** john.field@noaa.gov
- **Institution:** NOAA SWFSC
- **Source Data:** Dr. John Field (NOAA; john.field@noaa.gov) and Tanya Rogers (NOAA; tanya.rogers@noaa.gov) from the SWFSC Rockfish Recruitment and Ecosystem Assessment Survey (RREAS; https://storymaps.arcgis.com/collections/af0fa37db2bf4f1cadb024ec0ffbdfb5).

- **Additional Calculations:** Samples represent catch (individuals) per standard 15 minute trawl (CPUE) from the historical core area (36.5-38.2N) of the RREAS during late spring (May to mid-June). Data are log(CPUE+1) transformed, with geometric means calculated on non-zero data. Note: Sampling effort was greatly reduced in time and space during 2020 due to COVID restrictions, and associated data reflected substantial bias for many taxa. Catches were standardized by using a Bayesian delta-GLM to estimate year effects while accounting for spatial and temporal covariates, and to estimate approximate 95% confidence limits; see Santora et al. 2021 (https://doi.org/10.1038/s41467-021-26484-5) for model approaches used to develop alternative indices in 2020.
- **Download data:** csv file

References

Santora, Jarrod A, Tanya L Rogers, Megan A Cimino, Keith M Sakuma, Keith D Hanson, EJ Dick, Jaime Jahncke, Pete Warzybok, and John C Field. 2021. "Diverse integrated ecosystem approach overcomes pandemic-related fisheries monitoring challenges." *Nature Communications* 12 (1): 1–10.

Szoboszlai, Amber I, Julie A Thayer, Spencer A Wood, William J Sydeman, and Laura E Koehn. 2015. "Forage species in predator diets: synthesis of data from the California Current." *Ecological Informatics* 29: 45–56.

20 Southern California Current Forage

Description Abundance indicators for forage in the Southern CCE come from fish and squid larvae collected in the spring (May-June) across all core stations of the CalCOFI survey. Larval data are indicators of the relative regional abundances of adult forage fish, such as sardines and anchovy, and other species, including certain groundfish, market squid, and mesopelagic fishes. The survey samples a variety of fish and invertebrate larvae (<5 d old) from several taxonomic and functional groups, collected via oblique vertical tows of fine mesh Bongo nets to 212 m depth. In 2020, the spring larval survey was canceled due to COVID-19, and thus no data are available for that year, but survey operations resumed in 2021.

Pelagic forage larvae data from the Southern CCE were provided by A. Thompson, NMFS/SWFSC, from spring CalCOFI surveys (https://calcofi.org/); data were not collected in 2020 due to survey cancellations associated with the COVID pandemic. Similarity analysis and cluster plot by A. Thompson, NMFS/SWFSC.

Indicators

- **Species:**
  - anchovy
  - CA smoothtongue
  - croakers
  - eared blacksmelt
  - English sole
  - Jack mackerel
  - market squid
  - northern lampfish
  - hake
  - Pacific mackerel
  - rockfishes
  - sanddabs
  - sardine
  - slender sole
  - southern mesopelagics
- **Component Category:** Ecological Integrity
- **Time Range:** 1997 - 2024
- **CCIEA Data Contact:** andrew.thompson@noaa.gov
- **Institution:** NOAA SWFSC
- **Source Data:** Dr. Andrew Thompson (NOAA; andrew.thompson@noaa.gov); derived from spring CalCOFI surveys
- **Additional Calculations:** Larval fish data summed across all stations of the CalCOFI survey in spring (units are in number under 10 sq. m of surface area; ln(abundance+1)). Note: The spring

CalCOFI cruise was not conducted in 2020 due to COVID restrictions, and winter surveys were used to develop alternative indices of larval abundance; see Appendix G.3 in Harvey et al 2021 (https://www.pcouncil.org/documents/2021/02/i-1-a-iea-team-report-2.pdf/) for methods used to develop alternative indices in 2020.

- **Download data:** csv file

21 CPS Survey

Description Acoustic-trawl method (ATM) surveys have been used by the NOAA Southwest Fisheries Science Center in most years since 2006 to map the distributions and estimate the abundances of coastal pelagic fish species (CPS) in the coastal region from Vancouver Island, Canada, to San Diego, California (Zwolinski et al. 2014; Stierhoff et al. 2024). The surveys cover waters to at least the 1,000-fathom (1829-m) isobath, or 65 km from shore.

The five most abundant CPS in this domain are Northern Anchovy, Pacific Herring, Pacific Sardine, Jack Mackerel, and Pacific Mackerel. The biomass of Pacific Sardine is calculated separately for the northern and southern stocks based on oceanographic habitat, spatial separation, and demographic structure (Zwolinski and Demer 2024). The ATM combines data from echosounders which record CPS echoes, and trawls which produce information about the composition, sizes, and ages of the fishes. This survey also samples the densities of CPS eggs at 3-m depth using a continuous underway fish egg sampler (CUFES) mounted on the ship's hull.

CPS surveys typically span the area between Cape Flattery, WA and San Diego,CA but in some years also include Vancouver Island, Canada (2015-2019) and portions of Baja CA (2021-2022).

Indicator Category Ecological Integrity

Data Steward K. Stierhoff, NMFS/SWFSC (kevin.stierhoff at noaa.gov) and J. Zwolinski, UCSC and NMFS/SWFSC

Institution NOAA SWFSC

Additional Information Data are collected and analyzed by K. Stierhoff and J. Zwolinski, who submit figures and plots to the CCIEA editorial team based on an early version of the annual CPS Acoustic Trawl survey report (preliminary until published, and subject to change), which is ultimately published as a NOAA Technical Report. For recent examples, see:
NOAA Technical Memorandum NMFS-SWFSC-676. https://doi.org/10.25923/77kp-ww39; NOAA Technical Memorandum NMFS-SWFSC-683. https://doi.org/10.25923/40x3-b146

References

Stierhoff, K. L., J. P. Zwolinski, J. S. Renfree, and David A. Demer. 2024. "Distribution, Biomass, and Demographics of Coastal Pelagic Fishes in the California Current Ecosystem During Summer 2023 Based on Acoustic-Trawl Sampling."

Zwolinski, Juan P, and David A Demer. 2024. "An updated model of potential habitat for northern stock Pacific Sardine (*Sardinops sagax*) and its use for attributing survey observations and fishery landings." *Fisheries Oceanography* 33 (3): e12664.

Zwolinski, Juan P, David A Demer, George R Cutter Jr, Kevin Stierhoff, and Beverly J Macewicz. 2014. "Building on fisheries acoustics for marine ecosystem surveys." *Oceanography* 27 (4): 68–79.

22 Juvenile Salmon

Description The Juvenile Salmon Ocean Ecology Survey (JSOES) occurs in June and targets juvenile salmon in surface waters off Oregon and Washington. A Nordic 264 rope trawl is towed for 15-30 min at approximately 6.5 km/hr. The gear is fished during daylight hours in near-surface (upper 20 m) waters, which is appropriate for targeting juvenile salmon.

Juvenile salmon data from the Northern CCE are provided by B. Burke, NMFS/NWFSC and C. Morgan, OSU/CIMRS. Data are derived from surface trawls taken during the NWFSC Juvenile Salmon & Ocean Ecosystem Survey (JSOES; https://www.fisheries.noaa.gov/west-coast/science-data/ocean-ecosystem-indicators-pacific-salmon-marine-survival-northern). Figures in the report include a cluster plot based on similarity analyses by A. Thompson, NMFS/SWFSC.

Indicators

- **Species:**
  - Subyearling Chinook
  - Yearling Chinook
  - Yearling Coho
- **Component Category:** Salmon
- **Time Range:** 1998 - 2024
- **CCIEA Data Contact:** brian.burke@noaa.gov
- **Institution:** NOAA NWFSC
- **Source Data:** Dr. Brian Burke (NOAA; brian.burke@noaa.gov); derived from surface trawls taken during NOAA Northwest Fisheries Science Center Juvenile Salmon & Ocean Ecosystem Survey (JSOES). Additional calculations by Cheryl Morgan (OSU - CIMERS; cheryl.morgan@oregonstate.edu). Partial funding is from the Bonneville Power Administration (1998-014-00).
- **Additional Calculations:** To be included in this analysis, stations must have been 1) sampled during the day time, 2) on the continental shelf (greater than 200 m water depth), and 3) sampled during at least half of the years of the JSOES effort. Sampling occurs from the northern tip of Washington (48N 13.7') down to Newport, Oregon (44N 40.0') in late June. A Nordic 264 rope trawl (Nor'Eastern Trawl Systems, Bainbridge Island, WA) is towed at the surface (upper 20 m) for 15 - 30 min at approximately 6.5 km/hr. The total abundance for each nekton species caught in each haul was either determined directly or estimated from the total weight of the species in a catch and the weight and number of individuals in a subsample of that catch. Trawl catches were standardized to linear density by dividing catch of each species at a station by the distance between the start- and endpoints of the tow as determined by a global positioning system receiver and log10 transformed (Log10(no. km-1+ 1)).
- **Download data:** csv file

23 Salmon Stoplight Tables

Description Northern California Current; Columbia Basin stocks: We use color to represent anomalous years for the stoplight tables presented in the salmon section of the report. As described in Harvey et al. (2023), we have addressed past feedback from the SSC and others by developing a more statistically based stoplight table format, which produces five bins that are determined relative to a fixed baseline reference period. In this new format, we assumed a normal distribution for each of the indicators and estimated a mean and standard deviation for the base period. For each cell within a given indicator, we determined how many standard deviations the values were from their respective base period mean and used a five-color set to indicate whether a value was >2 s.d. below the mean, 1 to 2 s.d. below the mean, within 1 s.d. of the mean in either direction, 1 to 2 s.d. above the mean, or >2 s.d. above the mean. This approach overcomes many of the issues that had been previously identified (e.g., better highlighting values that represent truly exceptional years; past values are now static and do not suddenly change colors; etc.).

Central California Current; Klamath / Sacramento / Central Valley stocks: The process of identifying key indicators for salmon habitat stoplight tables is ongoing (Munsch et al. in prep). To summarize our approach and findings to date, we used linear models to relate recruitment of SRFC, CVSC, and KRFC to salmon habitat indicators. In light of the potential for recruitment-indicator relationships to change over time, we selected indicators based on model performance metrics that suggested that the indicators were persistently or recently important to recruitment. Through preliminary analyses, we selected twelve key indicators, two of which are shared among the California Central Valley stocks (SRFC and CVSC) for a total of ten unique indicators. We note that we only found strong evidence for a linear relationship between natural spawners and future recruitment for SRFC (and thus use this indicator for forecasts below), but report natural spawner counts for other stocks for context. Our ongoing analyses will examine for evidence of a Ricker stock-recruitment relationship, which is not included here.

We also report new efforts to examine thiamine deficiency in hatchery eggs across the Central Valley in California. Some of the indicators we selected, particularly those relevant to SRFC, have been identified as important by previous research efforts (Friedman et al. 2019; Munsch et al. 2020, 2022). Indicators were indexed according to brood year or outmigration year and then adjusted to return or fishing year via the assumptions that juveniles migrated the calendar year after their brood year and that most adults were harvested or returned as spawners three years after their brood year.

[this section will require a bit more writing to incorporate evolving approaches and methods]

References

Friedman, Whitney R, Benjamin T Martin, Brian K Wells, Pete Warzybok, Cyril J Michel, Eric M Danner, and Steven T Lindley. 2019. "Modeling composite effects of marine and freshwater processes on migratory species." *Ecosphere* 10 (7): e02743.

Munsch, Stuart H, Correigh M Greene, Rachel C Johnson, William H Satterthwaite, Hiroo Imaki, Patricia L Brandes, and Michael R O'Farrell. 2020. "Science for integrative management of a diadromous fish stock: interdependencies of fisheries, flow, and habitat restoration." *Canadian Journal of Fisheries and Aquatic Sciences* 77 (9): 1487–1504.

Munsch, Stuart H, Correigh M Greene, Nathan J Mantua, and William H Satterthwaite. 2022. "One Hundred-Seventy Years of Stressors Erode Salmon Fishery Climate Resilience in California's Warming Landscape." *Global Change Biology* 28 (7): 2183–2201.

24 Chinook Salmon Escapement - Columbia River

Description In this analysis, models are fit to past smolt-to-adult return (SAR) data, and use the most recent ecosystem indicator data to predict what smolt-to-adult survival will be for cohorts that have gone to sea but not yet returned. Separate models have been developed for spring and fall Chinook salmon and steelhead from the Snake River basins and spring Chinook salmon from the Upper Columbia basin. The specific approach uses a Dynamic Linear Model, founded on linear regressions of single ecosystem indicators vs. survival rates of PIT-tagged fish that left Bonneville Dam as smolts and returned as adults. The model labeled "Stoplight PC1" uses the first principal component (PC1) from a Principal Component Analysis of the stoplight chart as a covariate. The second model, labeled "CMISST" uses a Covariance Map Index of Sea Surface Temperature (B. Burke, unpublished), which is a metric derived by calculating the similarity of sea surface temperature (SST) spatial patterns in the North Pacific Ocean to a stock-specific optimal pattern. The CMISST metric is still in development, but analyzes to date indicate that the CMISST model has better prediction skill for spring Chinook salmon and steelhead SAR, while the PC1 model has better prediction skill for fall Chinook salmon SAR.

Indicator Category Ecological Integrity

Data Steward Burke; brian.burke@noaa.gov

Additional Information Data and metrics are provided B. Burke, who submits figures and plots to the CCIEA editorial team based on unpublished model results.

References

25 Chinook Salmon Ecosystem Conditions - California

Description. Central Valley Fall Chinook salmon stoplight table: In the 2019-2020 ecosystem status report (Harvey et al. 2020), we introduced a relatively simple "stoplight" table of ecosystem indicators that were shown by Friedman et al. (2019) to be correlated with returns of naturally produced Central Valley Fall Chinook salmon. In an updated stoplight chart for adult Fall Chinook salmon returning to the Central Valley in 2024, the focal ecosystem indicators are: spawning escapement of parent generations; egg incubation temperature between October and December at Red Bluff Diversion Dam (Sacramento River); egg thiamine concentrations based on averages of samples collected from Central Valley fall run hatchery programs; median flow in the Sacramento River in the February after fry emergence; and a marine predation index based on the abundance of common murres at Southeast Farallon Island and the proportion of juvenile salmon in their diets. Reflecting discussions with the SSC-ES in September 2020, we emphasize that this stoplight chart is strictly qualitative and contextual decision-support information. Qualitative descriptors (color-coded terms like "very poor") are based on recent time series and on expert opinion of how a given indicator relates to quantitative analysis of the relationship between the indicator and life-stage specific survival (see Figure 5 in Friedman et al. 2019). For example, in the stoplight Table flows rated "very low" (<7,000 cfs) are consistent with <25% rearing/outmigration survival rates, while the flows rated "low" (7,000 to 20,000 cfs) were consistent with 25-50% outmigrant survival (see Fig. 5 in, Friedman et al. 2019). Egg incubation temperatures in the Table were consistent with egg-to-fry survival ranging from ~50% (which we rated as "suboptimal") to 0% at > 13 C ("very poor/cohort failure"). We continue to refine these qualitative categories for future reports so that their basis is more explicit.

The escapement descriptor is a qualitative evaluation of how natural-area escapement of a parent generation relates to the natural area + hatchery escapement goal of 122,000– 180,000 fish, with 122,000 spawners as the SMSY target (PFMC 2022d). Natural area escapement is relevant to the stoplight table as an indicator of total natural area egg production (Munsch et al. 2020). However, the qualification of this indicator requires future research. Obviously, using a natural+hatchery target as the qualifier for natural-only escapement is problematic. Perhaps more importantly, the SSC and STT have both recommended research and reconsideration of the Sacramento River fall Chinook SMSY objective (PFMC 2022e,f), and W. Satterthwaite (2022) has concluded that an escapement of 122,000 adults is insufficient to maximize natural production. We have not been able to fully address the SSC and SST comments yet.

The qualitative nature of this stoplight table is in part due to the fact that some of the parameters used by Friedman et al. (2019) were estimated using information from both natural-origin and hatchery-origin fish, and while it is reasonable to assume that true parameter values would be similar, given correlations between natural and hatchery escapements, additional data specific to natural-origin fish are likely necessary in order to improve model fits, evaluate other potential covariates, and support adequate testing of model predictive skill.

[include here Table J.1 which documents the habitat indicators, definitions, and key references]

Indicator Category Ecological Integrity

Data Steward Greene and Munsch; correigh.greene@noaa.gov, stuart.munsch@noaa.gov

Institution NOAA NWFSC

Additional Information Data are collected and analyzed independently by C. Greene and S. Munsch, who submitted unpublished tables and figures to the CCIEA editorial team. This work is under review by the PFMC Scientific and Statistical Committee. The complete documentation of these methods is a work in progress and will likely be completed after publication of the associated, peer-reviewed scientific manuscript.

Data sources The indicators representing Ecosystem conditions for California Chinook salmon have been shown in previous studies or were proposed in rebuilding plans to be strongly related with life-stage specific Chinook salmon productivity, and these studies helped determine expected directionality of indicators with stock productivity (see below and Harvey et al. (2020) for additional justification). Four of the five broad categories of indicators in the stoplight charts align with the simpler stoplight chart for Central Valley fall Chinook salmon presented in the main body of the report: Adult Spawners, Incubation conditions, Freshwater / Estuarine Residence conditions, and Marine Residence conditions (for the first year of marine residence). The fifth category of indicators, Hatchery Releases, expands the scope of these tables relative Table 3.2, which focuses only on natural-area fish. The habitat indicator charts also share qualities with the stoplight chart developed for Columbia Basin Chinook salmon and Oregon coast coho salmon by including regional and basin-scale oceanographic indicators as part of early marine residence conditions. Data on krill off northern California are also presented within the table for KRFC.

The indicators in Table J.1 and in the stoplight tables above have undergone several important adjustments from previous reports:

Updates to SRFC and KRFC include changes in some indicators to ensure more reliable and timely data capture. However, updates of many indicators in 2023 remain challenging due to delays in posting of online datasets, resulting in several indicators that could not be updated for this year's report and preliminary estimates for several others. These challenges underscore the importance of including multiple indicators, highlight the potential fragility of these annual summaries, and point to the importance of many individuals for maintaining the databases required for summarizing habitat indicators.

Recent analysis of krill off northern California have revealed that krill length is a much better indicator than krill biomass for predicting productivity of Klamath Fall run, so we have substituted length for this indicator.

CVSC differs from SRFC not only in migration timing but also in their behavior and spatial distribution. Habitat indicators reflect these differences, by characterizing early upstream migration starting in February, holding in pools through the summer, and spawning in a small number of creeks in the late summer and fall. Adult numbers focused on spawner counts in Butte, Mill, and Deer Creeks. Butte Creek spawners migrate from the Sacramento River through Sutter Bypass to Butte Creek, and outmigrants may rear within Sutter Bypass during outmigration. Hence, flow and temperature metrics relied on gages from these systems in addition to the Sacramento mainstem, and Sutter Bypass inundation instead of Yolo Bypass. Finally, the sole hatchery for CVSC is from Feather River, so releases and timing metrics focused on data from just this hatchery.

The stoplight tables are categorized from favorable to poor conditions using the same approach as described for the Northern California Current salmon indicator stoplight table. Specifically, after indicator datasets were collected, all indicators were "directionalized" to account for their expected relationships with stock productivity (based on the "Effect" column in (Table J.1) and converted into standardized values. These values are reported in the stoplight tables above, with colors delineating statistically meaningful departures (>2 s.d.) toward poorer (warm shades) or more productive (cool shades) conditions compared to near-average years (within ±1 s.d., yellow). The main difference for the tables shown here relative to Columbia River salmon stoplight tables is that we have not yet determined a fixed historic reference period for the SRFC, KRFC and CVSC tables, due in part to missing data from one or more indicators in large portions of the time series.

Habitat Indicator Descriptions. Adults returning and migrating to spawning grounds: Spawning adults set the cohort size (Friedman et al. 2019) and potential for density-dependent habitat limitations at future life stages (Munsch et al. 2020), so we incorporated estimated escapements from PFMC preseason forecasts. Adults must navigate multiple potential barriers to reach spawning grounds, including low river flows and high temperatures at the end of summer. We used flow and temperature measurements from the lower portions of the Sacramento and Klamath Rivers in September and October. In the Sacramento River, adults must also navigate the channel network of the delta, and the rebuilding plan proposed examining potential effects of the Delta Cross Channel as a migration barrier. We used the proportion of time the Cross Channel was closed in September and October as the indicator.

Indicators for adult migrations differ for CVSC due to their early migration timing (February to May), spring-summer holding in pools, and spawning in a small number of Sacramento tributaries. We restricted the enumerated spawner abundance to Deer, Mill, and Butte Creeks, for which records were consistently maintained throughout the 1983-present period of record. To fill in data gaps of spawner counts for Butte Creek (the largest spawning population) to complete the retrospective time series to the 1983 brood year, we used predictions from regressions of Butte Creek spawner counts and snorkel surveys. Flows and temperatures during holding were restricted to the river with the greatest spawner abundance (Butte Creek). In addition, CDFW conducts estimates of pre-spawn mortality which we added as an indicator due to CVSC's exposure to warm in-river conditions.

Incubation to emergence: After spawning, incubating eggs may be subject to dewatering in the river (Jager et al. 1997) and are sensitive to high temperatures (Friedman et al. 2019). For SRFC, the river flow indicator was derived from the seven-day 10th percentile of flow for the Sacramento River from October to December at Bend Bridge near Red Bluff. For CVSC, we used similar flow conditions for Butte Creek. For KRFC, dewatering previously was observed in various tributaries of the Klamath. Hence, minimum flows from four gages (Klamath at Iron Gate, Scott River, Shasta River, and Trinity River at Lewiston Dam) were used, and the index was calculated from the average of standardized flow values. Incubation temperature records were obtained for all three river systems, albeit for a much shorter time series in the Klamath. SRFC incubation temperature estimates are from Red Bluff Diversion Dam (data in Friedman et al. 2019), CVSC records are from Butte Creek, and Klamath records are from Seiad Valley. Egg-fry productivity as measured by migrants per spawner were initiated in the early 2000s for all stocks.

Freshwater and estuary residence: During migration to the ocean, fall Chinook salmon stocks take advantage of temporary residence in riverine and estuary habitats before transitioning to marine environments. We used a variety of indicators of habitat conditions during this stage. Freshwater conditions are set by precipitation and spring air temperatures, both of which influence snowpack salmon runs and river flow (Munsch et al. 2019) in both tributaries (important for CVSC in particular) and mainstem. In turn, flows from December to May (and their temporal variation) set conditions for rearing in river and estuary systems as fish move downstream, and have been linked to freshwater (Munsch et al. 2019) and life-cycle productivity (Michel 2019, Friedman et al. 2019). Higher flows also determine access to floodplain rearing in reaches such as the Yolo Bypass for SRFC (Limm and Marchetti 2009) and Sutter Bypass for CVSC, as well as the potential to flush polychaete hosts of the parasite Ceratomyxa shasta that infects juvenile salmon during outmigration (Jordan 2012). Flows also determine the outflow through the Sacramento delta (Reis et al. 2019), which can influence estuarine rearing opportunities (Munsch et al. 2020). To shift freshwater flows to pumping facilities, the Bureau of Reclamation opens the Delta Cross Channel, and this pathway can entrain salmon in pumps or otherwise expose them to higher mortality (Perry et al. 2013).

Magnitude and timing of hatchery releases: While much of the habitat indicators focus on natural-area fish, hatchery releases make up a significant contribution of each run and may also contribute to density dependence. We therefore included the annual total of hatchery releases, using data from up to four SRFC hatcheries on the Sacramento (San Joaquin hatcheries were not included), the Feather River hatchery for CVSC, and Trinity and Iron Gate hatcheries in the Klamath. While hatchery-origin juveniles are also sensitive to the conditions natural-origin juveniles face, they are generally raised until they are primed for rapid migration. Following concepts of match-mismatch theory (Cushing 1990), we compared release date with the date of peak spring flow in freshwater and the spring transition in the ocean, as W. H. Satterthwaite et al. (2014) showed that both timing of release relative to the spring transition and overall later release timing were positively correlated with survival rates. Fates of hatchery fish may be a consequence of release location (Sturrock et al. 2019), including locations external to the Sacramento River system, so we also included the proportion of releases that were seaward of Sherman Island in the lower delta.

Marine residence: Marine residence of 1 to 5 years completes the life cycle for fall run Chinook salmon populations. While a broad number of marine habitat indicators have been examined (Wells et al. 2008), we focused on a limited subset of possible indicators representing initial set-up of ocean entry conditions (March-May), including sea surface temperature, the North Pacific Index, and North Pacific Gyre Oscillation. We also included an index of predation by common murres nesting at Southeast Farallon Island, which was a strong predictor in Friedman et al. (2019). Unfortunately, this indicator currently cannot be updated quantitatively. On the positive side, we have updated the krill prey indicator for Klamath River fall Chinook salmon from biomass to average length to better reflect stronger correlations with recruits per spawner. Where indicators were averaged to obtain a marine habitat conditions score, hatchery release timing relative to the spring transition was also included as a marine habitat condition.

References

Friedman, Whitney R, Benjamin T Martin, Brian K Wells, Pete Warzybok, Cyril J Michel, Eric M Danner, and Steven T Lindley. 2019. "Modeling composite effects of marine and freshwater processes on migratory species." *Ecosphere* 10 (7): e02743.

Harvey, Chris J, Newell Toby Garfield, Gregory D Williams, and Nicholas Tolimieri. 2020. "California Current Integrated Ecosystem Assessment (CCIEA) California Current Ecosystem Status Report, 2020. Report to the Pacific Fishery Management Council. March 2020, Agenda Item i.1.a."

Munsch, Stuart H, Kelly S Andrews, Lisa G Crozier, Robert Fonner, Jennifer L Gosselin, Correigh M Greene, Chris J Harvey, et al. 2020. "Potential for ecological nonlinearities and thresholds to inform Pacific salmon management." *Ecosphere* 11 (12): e03302.

Satterthwaite, W. 2022. "Literature Review for Sacramento River Fall Chinook Conservation Objective and Associated SMSY Reference Point. Pages 49-75 of PFMC, 2022. 2022 Salmon Methodology Review Materials. November 2022, Agenda Item d.2, Attachment 1 (Electronic Only). Pacific Fishery Management Council, Portland, OR."

Satterthwaite, William H, Stephanie M Carlson, Shanae D Allen-Moran, Simone Vincenzi, Steven J Bograd, and Brian K Wells. 2014. "Match-mismatch dynamics and the relationship between ocean-entry timing and relative ocean recoveries of Central Valley fall run Chinook salmon." *Marine Ecology Progress Series* 511: 237–48.

26 Groundfish Stock Abundance

Description We present relative Stock Status of groundfish in the CCE as the ratio of the current year spawning biomass (in mt) or output (typically in billions of eggs) to unfished relative to the target reference point (as a percentage of unfished biomass; 0.4 for scorpaenids and other fishes; 0.25 for flatfishes). Fishing Intensity uses the fishing rate to achieve a specific spawner potential ratio (SPR), defined as F/FSPR, where SPR is the maximum sustainable yield (MSY) proxy.

"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). Our relative stock status plots present a horizontal line as the fishing intensity rate reference; above the line is above the reference level and indicates overfishing. The vertical lines in the plot represent the biomass target reference points (TRP=1; dashed line) and limit reference points (LRPs; red lines); left of the LRP indicates an overfished status. Symbols indicate taxonomic groups. All points in the plot represent values from the most recent PFMC-adopted full stock assessments. Groundfish stock status data provided by J. Cope, NMFS/NWFSC, derived from NOAA Fisheries stock assessments.

- **No data available**

Additional Information Data are collected and analyzed independently by J. Cope, who submits unpublished figures and plots to the CCIEA editorial team.

References

27 Juvenile Groundfish Abundance

Description Yearly indices of the abundances of juvenile sablefish, Dover sole, shortspine thornyhead, and longspine thornyhead along the West Coast were calculated using species distribution models. Strong year classes can determine age structure and set stock size for marine fishes, and may also indicate favorable environmental conditions, increased future catches, and impending potential bycatch issues. Here, we provide estimates of juvenile abundance for 13 species of West Coast groundfishes, including four from DTS assemblage (Dover sole, thornyheads, and sablefish) as a potential leading indicator of incoming strong year classes. The DTS assemblage is a valuable fishery, and bycatch of some species, like small sablefish, can impact other fisheries such as the at-sea hake fishery.

Indicator Category Ecological Integrity

Data Steward N. Tolimieri, NMFS/NWFSC (nick.tolimieri@noaa.gov)

Additional Information Data are collected and analyzed independently by N. Tolimieri, who submits unpublished figures and plots to the CCIEA editorial team.

Data sources Data for indicators come from the West Coast Groundfish Bottom Trawl Survey (WCGBTS) (Keller et al. 2017) for 2003-2021. There were no data for 2020 because the WCGBTS was canceled due to the COVID-19 pandemic. The survey data includes estimates of age, length, and biomass for subsamples of each haul, and occasionally for the entire haul when catch is low.

Data extraction Data were downloaded from the Fishery Resource Analysis and Monitoring data Warehouse (https://www.webapps.nwfsc.noaa.gov/data/map)

Data analysis We used species distribution models to calculate indices of abundance for juvenile groundfish. The approach follows the general approach of Tolimieri, Wallace, and Haltuch (2020) but uses the 'sdmTMB' package (Anderson et al. 2022) for R instead of the 'VAST' package (Thorson 2019). VAST was was reviewed by the SSC-ES in September 2021. The sdmTMB approach is used by many West Coast groundfish stock assessment biologists to assimilate survey data and was reviewed favorably by the SSC-Groundfish Subcommittee in summer of 2022 (PFMC 2022c).

The analyses estimate the biomass for each species by using length-age and length-weight relationships to expand the trawl data. Length is measured (cm total length) for all individuals in the subsample, but many individual fishes lack weight or age data due to time constraints in the field and ageing lab. To expand the subsample,

1. Missing weights for individuals in the subsample were obtained by first estimating the length-weight relationship from existing data and using this relationship to estimate the missing weights from known lengths. For Dover sole, sablefish and longspine thornyhead, male and female length-weight relationships were estimated separately and the average of these relationships used to determine weights for individuals where sex was not known. For shortspine thornyhead, we used a single length-weight relationship.

2. Individual fish were then allocated to age classes following Tolimieri, Wallace, and Haltuch (2020) by using length-age relationships from the WCGBTS data to determine age-class maximum lengths. See Tolimieri, Wallace, and Haltuch (2020) for more detail. The maximum lengths used here (Table 27.1) were taken from Tolimieri, Wallace, and Haltuch (2020) (Table 27.1).
3. The proportional biomass of juveniles in each subsample was calculated and used to estimate the total biomass of juvenile fishes in the full trawl.
4. Trawl biomass was then used in the following sdmTMB species distribution models.

Table 27.1: Length, age, and depth range information.

Common name	Species	Max length (cm)	Age class	Depth range (m)
Arrowtooth flounder	Atheresthes stomias	22	1	50-470
Darkblotched rockfish	Sebastes crameri	15	0-1	80-240
Dover sole	Microstomus pacificus	17	1-2	50-465
English solea	Parophrys vetulus	16	1	50-140
Lingcod	Ophiodon elongatus	25	0	50-240
Longspine thornyhead	Sebastolobus altivelis	7	<5	385-1245
Pacific grenadier	Coryphaenoides acrolepis	3	~1	490-1275
Pacific hake	Merluccius productus	15	0-1	50-700
Pacific sanddab	Citharichthys sordidus	13	0-1	50-245
Petrale sole	Eopsetta jordani	21	1-2	50-200
Sablefish	Anoplopoma fimbria	29	0	50-475
Shortspine thornyhead	Sebastolobus alascanus	8	<5	160-625
Splitnose rockfish	Sebastes diploproa	10	0-1	65-460

Coastwide juvenile groundfish abundances were estimated using a spatially explicit, species distribution model evaluated with the sdmTMB package in R. The response variable was CPUE quantified as kg of juveniles per km^2. The models included one common intercept across years, and spatial and spatiotemporal random fields, with anisotropy to account for different rates of autocorrelation with latitude versus longitude (~ depth). The common intercept prevents the model from forcing biomass to increase or decrease coastwide in a given year (thereby potentially overestimating recruitment in some areas) as would be the case for yearly intercept. Normalized depth was included to account for differences in density across depths.

To avoid projecting to areas with zero biomass, the depth range of the data used for each species in the analysis was restricted based on the distribution of positive biomass observations (Table K.1). Again, the values used here follow Tolimieri et al. (2020) with the exception that the lower depth limit for sablefish was set to 250 m, which encompasses more than 99% of their observed juvenile biomass. Pass was included as a fixed factor (as a proxy for time of year; the WCGBTS conducts two coastwide passes each year, in May-July and August-October). Models were fit with a delta-gamma distribution to account for the prevalence of zeros in the data, and the mesh was set to 10 km, resulting in 650-800 knots depending upon species. Model fits were then extrapolated to a 2x2 km grid of the West Coast to estimate total abundance in kg for juveniles in a given year. For some species, it was necessary to combine age or size classes to obtain enough data for models to converge. The resulting biomass estimate was converted to an index scaled between 0-1 by dividing all values by the maximum upper 95% confidence limit in the time series.

To address previous suggestions by the SSC-ES, we also evaluated models with year included as a fixed factor or allowed year to have a random intercept. When included as a fixed factor, models failed to converge likely due to identifiability problems due to also including the spatiotemporal random field. For sablefish and Dover sole, inclusion of year with a random intercept also created fit problems leading to very large standard errors for some estimated parameters. Therefore, we excluded the term from the final models.

2025-01 Update

Previously models for all species included a delta-poisson-link-gamma model/error structure and normalized depth as a linear variable. In 2025 models were updated to tailor model structure and the form of depth (linear, quadratic, smoothed) to individuals species. We fit models with Tweedie, delta-lognormal, delta-poisson-link-gamma, and delta-gamma model/errors. Depth was normalized and included as a linear variabe, as a quadratic, smoothed (GAM), or not included. The best model was chosen for each species based on a comparison of AIC values, QQ residual plots, and sanity (model fit) output (Table 27.2). This approach produced better residuals and tended to dampen some of the higher biomass estimates (see sablefish in the main report).

Table 27.2: Model informaiton for juvenile abundance models used in the FY2025 report.

Species	Distribution	Depth
Arrowtooth flounder	Tweedie	GAM smooth
Darkblotch rockfish	Tweedie	GAM smooth
Dover sole	delta-gamma-poisson-link	quadratic
English sole	delta-gamma	quadratic
Lingcod	Tweedie	quadratic
Longspine thornyhead	delta-lognormal	GAM smooth
Pacific grenadier	delta-gamma	GAM smooth
Pacific hake	Tweedie	GAM smooth
Pacific sandlance	Tweedie	quadratic
Petrale sole	delta-lognormal	quadratic
Sablefish	delta-lognormal	quadratic
Shortspine thornyhead	Tweedie	quadratic
Splitnose rockfish	Tweedie	GAM smooth

References

Anderson, Sean C, Eric J Ward, Philina A English, and Lewis AK Barnett. 2022. "sdmTMB: an R package for fast, flexible, and user-friendly generalized linear mixed effects models with spatial and spatiotemporal random fields." *bioRxiv*, 2022–03.

Thorson, James T. 2019. "Guidance for decisions using the Vector Autoregressive Spatio-Temporal (VAST) package in stock, ecosystem, habitat and climate assessments." *Fisheries Research* 210: 143–61.

Tolimieri, Nick, John Wallace, and Melissa Haltuch. 2020. "Spatio-temporal patterns in juvenile habitat for 13 groundfishes in the California Current Ecosystem." *PloS One* 15 (8): e0237996.

28 Groundfish Port Availability

Description We estimated the relative availability of groundfish biomass to individual ports following the methods described in Selden et al. (2020), with some exceptions. In brief, we used data from the Northwest Fisheries Science Center's West Coast Groundfish Bottom Trawl Survey (Keller, Wallace, and Methot 2017) to estimate spatial distribution of species-specific biomass (Location Biomass), and the Center of Gravity (CoG) of the Location Biomass. We then calculate the Availability Index for each port by summing the Location Biomass within a radius from that port based on the 75th quantile of the distance traveled from port to harvest of species of interest, weighted by catch, as measured from trawl logbooks. We analyzed 12 species that make up a large component of landings for vessels using bottom trawl gear along the West Coast, or that have broader management interest (e.g., shortbelly rockfish).

The present analysis differs from Selden et al. (2020) in three ways:

1- We estimated the spatial distribution of species using the R package sdmTMB (Anderson et al. 2022) instead of VAST (Thorson 2019). The sdmTMB models included Pass and normalized depth as fixed parameters. Year was a time variable and models included both spatial and spatiotemporal (iid) autocorrelation, and a delta-poisson-link-gamma error distribution (Thorson 2018).

2- We used the Location Biomass directly instead of scaling it by spawning stock biomass from the assessment. Thus, the Availability Index is a relative biomass index and not actual available biomass. Biomass was then scaled to 0-1 for presentation by dividing by the highest value in any year.

3- We used only the WCGBTS, and did not combine the Triennial survey (1980-2004) with the WCGBTS. This approach shortens the analysis period but allows us to expand the depth range to 55-1250 m.

2025-01 Update Previous sdmTMB models used a delta-poisson-link-gamma model structure/distribution and included depth a linear factor. In 2025 (for the CY2025 ESR), models were updated to use a delta-lognormal model structure, and normalized depth was included as a smoothed variable (with three knots). The delta-lognormal models produced better residuals (as evaluate with QQ-plots) than the delta-poisson-link-gamma models. The smoothed depth term allowed non-linear relationships with depth, such as higher mid-depth abundance versus shallow and deeper zones.

Indicator Category Ecological Integrity

Data Steward N. Tolimieri, NMFS/NWFSC (nick.tolimieri at noaa.gov)

Additional Information Data are collected and analyzed independently by N. Tolimieri, who submits unpublished figures and plots to the CCIEA editorial team.

Data sources Data for indicators come from the West Coast Groundfish Bottom Trawl Survey (WCGBTS) (Keller, Wallace, and Methot 2017) for 2003-2021. There were no data for 2020 because the WCGBTS was canceled due to the COVID-19 pandemic. The survey data includes estimates of age, length, and biomass for subsamples of each haul, and occasionally for the entire haul when catch is low.

References

Anderson, Sean C, Eric J Ward, Philina A English, and Lewis AK Barnett. 2022. "sdmTMB: an R package for fast, flexible, and user-friendly generalized linear mixed effects models with spatial and spatiotemporal random fields." *bioRxiv*, 2022–03.

Keller, A. A., J. R. Wallace, and R. D. Methot. 2017. "The Northwest Fisheries Science Center's West Coast Groundfish Bottom Trawl Survey: History Design, and Description." Report. U.S. Department of Commerce. https://doi.org/10.7289/V5/TM-NWFSC-136.

Selden, Rebecca L, James T Thorson, Jameal F Samhouri, Steven J Bograd, Stephanie Brodie, Gemma Carroll, Melissa A Haltuch, et al. 2020. "Coupled Changes in Biomass and Distribution Drive Trends in Availability of Fish Stocks to US West Coast Ports." *ICES Journal of Marine Science* 77 (1): 188–99.

Thorson, James T. 2018. "Three Problems with the Conventional Delta-Model for Biomass Sampling Data, and a Computationally Efficient Alternative." *Canadian Journal of Fisheries and Aquatic Sciences* 75 (9): 1369–82.

———. 2019. "Guidance for decisions using the Vector Autoregressive Spatio-Temporal (VAST) package in stock, ecosystem, habitat and climate assessments." *Fisheries Research* 210: 143–61.

29 HMS Spawning Stock Biomass and Recruitment

Description Biomass and recruitment estimates for many HMS stocks that occupy the California Current are available from stock assessments conducted by collaborators under the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) or the Inter-American Tropical Tuna Commission (IATTC).

2024-01 Update The only assessment updates since the 2023-24 ecosystem status report are for Pacific bluefin tuna, skipjack tuna, and bigeye tuna. The 2024 bigeye tuna assessment underwent several changes since the last benchmark assessment (Xu 2024). The assessment uses a risk analysis approach, encompassing three levels of hypotheses structured hierarchically to address the main uncertainties in the assessment. The time-series shown here are multi-model estimates. The 2024 skipjack tuna assessment is a significant improvement over the 2022 interim assessment (Bi 2024). It reflects major advancements in the assessment methodologies and incorporates new data sets, including tagging data. The Pacific bluefin tuna assessment also included some improvements to the model used in the last (2022) benchmark assessment (ISC 2024). One of the major changes made was to shorten the assessment time period to start in 1983 instead of 1952. This adjustment was implemented because more reliable data were available after 1983. For all species, we emphasize that the status and trends symbols shown in our status and trend figures reflect short-term patterns relative to time series averages (with a period of reference of 1991-2020), and do not necessarily reflect reference points based on, e.g., unfished stock biomass.

Indicators

- **Species:**
  - Albacore:Recruits (x1000)
  - Bigeye tuna:Recuitment
  - Blue marlin:Recruits (x1000)
  - Bluefin tuna:Recruitment
  - North Pacific swordfish:Recruits (x1000)
  - Skipjack tuna:Recruitment
  - Yellowfin tuna:Recruitment
- **Component Category:** Highly Migratory Species
- **Time Range:** 1994 - 2021
- **CCIEA Data Contact:** barbara.muhling@noaa.gov
- **Institution:** NOAA SWFSC/FRD
- **Source Data:** Estimates of annual recruitment are derived from the stock assessment model. The latest (2023) stock assessment report was completed through the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC). North Pacific albacore are considered to be one stock throughout the North Pacific Ocean. They are fished throughout their range by multiple countries, mostly using surface gear (troll and pole and line), as well as pelagic longlines and other gears. Their population dynamics are assessed using an age-, length- and sex-structured model (Stock Synthesis v3). The assessment model used was similar to that in the

2017 benchmark assessment, with four important changes: 1) adjusting coefficients of variation for the abundance index in 2020-21 to better reflect uncertainty surrounding disruptions from the COVID-19 pandemic, 2) adjustments to Japan longline fleet structure, 3) adjustments to adult abundance indices, and 4) adjustments to age selectivity. The full assessment is available from http://isc.fra.go.jp/reports/stock_assessments.html. The next benchmark assessment is expected in 2026.

- **Download data:** csv file

References

Bi, Maunder, R. 2024. "Stock Assessment of Skipjack Tuna in the Eastern Pacific Ocean: 2024 Benchmark Assessment." Inter-American Tropical Tuna Commission Document SAC-15-04 REV, 15th meeting of the Scientific Advisory Committee, La Jolla, CA.

ISC. 2024. "Stock Assessment of Pacific Bluefin Tuna in the Pacific Ocean in 2024." Annex 13, 22nd Meeting of the International Scientific Committee for Tuna; Tuna-Like Species in the North Pacific Ocean, Victoria, Canada.

Xu, Maunder, H. 2024. "Stock Assessment of Bigeye Tuna in the Eastern Pacific Ocean: 2024 Benchmark Assessment." Inter-American Tropical Tuna Commission Document SAC-15-02 REV, 15th meeting of the Scientific Advisory Committee, La Jolla, CA.

30 HMS Diets

Description Quantifying the diets of highly migratory fishes in the CCE can complement existing trawl-based assessments of the available forage, provide insight into how forage varies over time and space, as well as provide a direct metric of forage utilization.

Albacore Tuna, Bluefin Tuna, and Broadbill Swordfish are opportunistic predators that consume a wide variety of prey taxa across a range of depths and habitats. Albacore, Bluefin, and Swordfish stomachs were provided by commercial and recreational fishers, and prey were identified from whole or hard part remains and are reported as a mean percent abundance. A subset of prey species are presented here focusing on prey that are either themselves under a management plan, or considered ecosystem component species, to highlight their links to highly migratory species.

Juvenile Albacore Tuna were collected off Northern California, Oregon, and Washington during the summer and fall fishing season. Bluefin Tuna were collected by recreational fishers in the Southern California Bight from spring until early fall. Swordfish were collected off Southern and Central California during the commercial drift gillnet season (August 15th through January 31st). Swordfish stomachs are classified by the year the fishing season began (stomachs from January are assigned to the previous year's fishing season).

Albacore tuna diet

- **Species:**
  - anchovy
  - Euphausiidae
  - hake
  - jack mackerel
  - market squid
  - other
  - Pacific mackerel
  - Pacific saury
  - rockfishes
  - sardine
- **Component Category:** Highly Migratory Species
- **Time Range:** 2009 - 2024
- **CCIEA Data Contact:** antonella.preti@noaa.gov
- **Institution:** NOAA SWFSC/FRD
- **Source Data:** Diets of albacore tuna provided by C. Nickels, and A. Preti (NMFS/SWFSC). Antonella.Preti@noaa.gov Data are proportional contributions of key prey classes.
- **Additional Calculations:** Albacore stomachs were provided by commercial and recreational fishers, and prey were identified from whole or hard part remains and are reported as a mean percent abundance. Juvenile Albacore Tuna were collected off Northern California, Oregon, and Washington during the summer and fall fishing season.

- **Download data:** csv file

Bluefin diet

- **Species:**
  - anchovy
  - Euphausiidae
  - hake
  - jack mackerel
  - market squid
  - other
  - Pacific mackerel
  - Pacific saury
  - rockfishes
  - sardine
- **Component Category:** Highly Migratory Species
- **Time Range:** 2008 - 2023
- **CCIEA Data Contact:** antonella.preti@noaa.gov
- **Institution:** NOAA SWFSC/FRD
- **Source Data:** Diets of bluefin tuna provided by T. Richards, and A. Preti (NMFS/SWFSC). Antonella.Preti@noaa.gov Data are proportional contributions of key prey classes.
- **Additional Calculations:** Bluefin stomachs were provided by commercial gillnet fishery, and prey were identified from whole or hard part remains and are reported as a mean percent abundance.
- **Download data:** csv file

Swordfish diet

- **Species:**
  - anchovy
  - Euphausiidae
  - hake
  - jack mackerel
  - market squid
  - other
  - Pacific mackerel
  - Pacific saury
  - rockfishes
  - sardine
- **Component Category:** Highly Migratory Species
- **Time Range:** 2007 - 2024
- **CCIEA Data Contact:** antonella.preti@noaa.gov
- **Institution:** NOAA SWFSC/FRD
- **Source Data:** Diets of swordfish provided by A. Preti (NMFS/SWFSC). Antonella.Preti@noaa.gov Data are proportional contributions of key prey classes.
- **Additional Calculations:** Swordfish stomachs were provided by commercial gillnet fishery, and prey were identified from whole or hard part remains and are reported as a mean percent abundance.

Swordfish were collected off Southern and Central California during the commercial drift gillnet season (August 15th through January 31st).

- **Download data:** csv file

References

31 Seabird Productivity

Description Seabird population productivity, measured through indicators of reproductive success, tracks marine environmental conditions and often reflects forage production near breeding colonies. We report on standardized anomalies of fledgling production per pair of breeding adults for the Northern CCE (one species at Destruction Island, Washington and three species at Yaquina Head, Oregon) and the Central CCE (five species on Southeast Farallon Island and two species on Año Nuevo Island). Collectively, these focal species span a range of feeding habits and ways of provisioning their chicks, and thus provide a broad picture of the status of foraging conditions.

Brandt's cormorants forage primarily on pelagic and benthic fishes in waters over the shelf, generally within 20 km of breeding colonies; they return to the colony during the day to deliver regurgitated fish to their chicks. *Cassin's auklets* forage primarily on zooplankton near or on the shelf break, generally within 30 km of colonies; they forage by day and night and return to the colony at night to feed chicks. *Common murres* forage primarily on pelagic fishes in waters over the shelf and near the shelf break, generally within 80 km of colonies; they return to the colony during daylight hours to deliver single whole fish to their chicks. *Pelagic cormorants* forage primarily on pelagic and benthic fishes in waters over the shelf, generally within 20 km of breeding colonies; they return to the colony during the day to deliver regurgitated fish to their chicks. *Pigeon guillemots* forage primarily on small benthic and pelagic fishes over the shelf in the nearshore environment, generally within 10 km of colonies; they return to the colony during the day to deliver single fish to chicks. *Rhinoceros auklets* forage primarily on pelagic fishes over the continental shelf, generally within 50 km of colonies; they return to the colony after dusk to deliver multiple whole fish to their chicks.

Indicator Regions

NoCC; Yaquina Head, OR

- Species:
  - Brandts cormorant
  - Common murre
  - Pelagic cormorant
- **Component Category:** Seabirds
- **Time Range:** 2008 - 2024
- **CCIEA Data Contact:** tom.good@noaa.gov
- **Institution:** OSU Seabird Oceanography Lab
- **Source Data:** Data from Hatfield Marine Science Center Seabird Oceanography Lab Yaquina Head Seabird Studies; contact Rachael Orben (Rachael.Orben@oregonstate.edu) before citing or distributing these data.
- **Additional Calculations:** Productivity anomaly is the annual mean number of chicks fledged per breeding pair minus the long term mean, which is calculated by averaging all of the annual means prior to the most recent year (for data from 2007 to 2020, the long term mean is calculated including data from 2007-2019).

- **Download data:** csv file

NoCC; Destruction Island, WA

- Species:
  - Rhinoceros auklet
- **Component Category:** Seabirds
- **Time Range:** 2008 - 2024
- **CCIEA Data Contact:** tom.good@noaa.gov
- **Institution:** NWFSC
- **Source Data:** Data from Washington Rhinoceros Auklet Ecology Project; contact scott.pearson@dfw.wa.gov before citing or distributing these data.
- **Additional Calculations:** Productivity anomaly is the annual mean number of chicks fledged per breeding pair minus the long term mean.
- **Download data:** csv file

CeCC; Farallon Islands, CA

- Species:
  - Brandts cormorant
  - Cassins auklet
  - Common murre
  - Pigeon guillemot
  - Rhinoceros auklet
- **Component Category:** Seabirds
- **Time Range:** 1986 - 2024
- **CCIEA Data Contact:** tom.good@noaa.gov
- **Institution:** Point Blue Conservation Science
- **Source Data:** Data from Point Blue Conservation Science collected on Southeast Farallon Island in collaboration with the Farallon Islands National Wildlife Refuge (USFWS); contact Dr. Jaime Jahncke (jjahncke@pointblue.org) before citing or distributing these data.
- **Additional Calculations:** Productivity anomaly is the annual mean number of chicks fledged per breeding pair per species minus the long term mean, which is calculated by averaging all of the annual means prior to the most recent year (for data from 1986 to 2018, the long term mean is calculated including data from 1986-2017.
- **Private dataset, no download available**

References

32 Seabird At-Sea Density

Description Seabird densities on the water during the breeding season can track marine environmental conditions and may reflect regional production and availability of forage. Data from this indicator type can establish habitat use and may be used to detect and track seabird population movements or increases/declines as they relate to ecosystem change. We monitor and report on at-sea densities of three focal seabird species in the Northern, Central, and Southern CCE.

Sooty shearwaters migrate to the CCE from the Southern Hemisphere in spring and summer to forage on the shelf and near the shelf break on small fish, including northern anchovy, as well as squid and zooplankton. *Common murres* and *Cassin's auklets* are resident species in the CCE that feed primarily over the shelf. Common murres target a variety of pelagic fish, while Cassin's auklets prey mainly on zooplankton and small fish.

Indicator Regions

Cape Flattery, WA to Newport, OR

- Species:
  - Cassins auklet, Summer
  - Common murre, Summer
  - Sooty shearwater, Summer
- **Component Category:** Seabirds
- **Time Range:** 2003 - 2024
- **CCIEA Data Contact:** tom.good@noaa.gov
- **Institution:** NOAA NWFSC
- **Source Data:** Data from Jen Zamon (jen.zamon@noaa.gov). Data are shipboard counts conducted during the NOAA Northwest Fisheries Science Center's Juvenile Salmon & Ocean Ecosystem Survey (JSOES).
- **Additional Calculations:** Data are shipboard counts, transformed as ln(bird density/km-2 +1) and expressed as an anomaly of log density relative to the long-term mean.
- **Download data:** csv file

N of Bodega Bay, CA to south of Monterey Bay, CA

- Species:
  - Cassins auklet, Summer
  - Common murre, Summer
  - Sooty shearwater, Summer
- **Component Category:** Seabirds
- **Time Range:** 1996 - 2024
- **CCIEA Data Contact:** tom.good@noaa.gov

- **Institution:** Farallon Institute
- **Source Data:** Data are from the SWFSC Rockfish Recruitment and Ecosystem Assessment Survey), courtesy of Dr. Bill Sydeman of the Farallon Institute (wsydeman@faralloninstitute.org)..
- **Additional Calculations:** Data are shipboard counts, transformed as ln(bird density/km-2 +1) and expressed as an anomaly of log density relative to the long-term mean.
- **Download data:** csv file

CalCOFI lines 76 to 93

- Species:
  - Cassins auklet, Spring
  - Common murre, Spring
  - Sooty shearwater, Spring
  - Cassins auklet, Summer
  - Common murre, Summer
  - Sooty shearwater, Summer
- **Component Category:** Seabirds
- **Time Range:** 1987 - 2025
- **CCIEA Data Contact:** tom.good@noaa.gov
- **Institution:** Farallon Institute
- **Source Data:** Data are from CalCOFI surveys, courtesy of Dr. Bill Sydeman of the Farallon Institute (wsydeman@faralloninstitute.org).
- **Additional Calculations:** Data are shipboard counts, transformed as ln(bird density/km2 +1) and expressed as an anomaly of log density relative to the long-term mean.
- **Download data:** csv file

References

33 Seabird Mortality

Description Monitoring of dead beached birds provides information on the health of seabird populations, ecosystem health, and unusual mortality events, and previous ESRs from the anomalously warm and unproductive years of 2014–2016 noted major seabird mortality events in each year.

In the Northern CCE, the Coastal Observation and Seabird Survey Team (COASST) at the University of Washington monitors beaches in Washington, Oregon, and northern California.

In the Central CCE, the Beach Watch program monitors beaches from Point Arena to Point Año Nuevo, California.

The BeachCOMBERS program conducts surveys of beached seabirds on central and southern California beaches from Point Año Nuevo to Malibu.

Indicator Regions

Ce/So CC

- Species:
  - Brandts cormorant encounter rate (Ce CC)
  - Cassins auklet encounter rate (Ce CC)
  - Common murre encounter rate(Ce CC)
  - Northern fulmar encounter rate (Ce CC)
  - Sooty shearwater encounter rate (Ce CC)
  - Brandts cormorant encounter rate (Ce/So CC) Central
  - Cassins auklet encounter rate (Ce/So CC) Central
  - Common murre encounter rate(Ce/So CC) Central
  - Northern fulmar encounter rate (Ce/So CC) Central
  - Sooty shearwater encounter rate (Ce/So CC) Central
  - Brandts cormorant encounter rate (Ce/So CC) North
  - Cassins auklet encounter rate (Ce/So CC) North
  - Common murre encounter rate(Ce/So CC) North
  - Northern fulmar encounter rate (Ce/So CC) North
  - Sooty shearwater encounter rate (Ce/So CC) North
- **Component Category:** Seabirds
- **Time Range:** 1997 - 2024
- **CCIEA Data Contact:** tom.good@noaa.gov
- **Institution:** BeachCOMBERS
- **Source Data:** Data from BeachCombers, who coordinate a team of trained volunteers that collect effort-controlled survey data on an approximately monthly basis, recording beached bird numbers and identity from survey locations in Central/Southern California. Contact BeachCombers for details on calculations before citing or distributing these data.

- **Additional Calculations:** Annual mean encounter rates (bird carcasses/km surveyed) aggregated from May to October (inclusive) for each surveyed beach location, and then averaged across all beaches surveyed in that year.
- **Download data:** csv file

Cape Blanco, OR to Cape Flattery, WA

- Species:
  - Northern fulmar (No CC Oct - Feb)
- **Component Category:** Seabirds
- **Time Range:** 2001 - 2023
- **CCIEA Data Contact:** tom.good@noaa.gov
- **Institution:** COASST
- **Source Data:** Data from the Coastal Observation and Seabird Survey Team (COASST), who coordinate a team of trained volunteers that collect effort-controlled survey data on an approximately monthly basis, recording beached bird numbers and identity from survey locations in Northern California through to Northern Washington and into Alaska and the Bering Sea. Contact COASST for details on calculations before citing or distributing these data.
- **Additional Calculations:** Annual mean encounter rates (bird carcasses/km surveyed) aggregated from October to April (inclusive, with years labelled according to the convention that Oct 2014 to Apr 2015 are labelled as 2014) for each surveyed beach location, and then averaged across all beaches surveyed in that year.
- **Download data:** csv file

CA-OR border to Cape Flattery, WA

- Species:
  - Cassins auklet (No CC Oct - Feb)
- **Component Category:** Seabirds
- **Time Range:** 2001 - 2023
- **CCIEA Data Contact:** tom.good@noaa.gov
- **Institution:** COASST
- **Source Data:** Data from the Coastal Observation and Seabird Survey Team (COASST), who coordinate a team of trained volunteers that collect effort-controlled survey data on an approximately monthly basis, recording beached bird numbers and identity from survey locations in Northern California through to Northern Washington and into Alaska and the Bering Sea. Contact COASST for details on calculations before citing or distributing these data.
- **Additional Calculations:** Annual mean encounter rates (bird carcasses/km surveyed) aggregated from October to February (inclusive, with years labelled according to the convention that Oct 2014 to Feb 2015 are labelled as 2014) for each surveyed beach location, and then averaged across all beaches surveyed in that year.
- **Download data:** csv file

Eureka, CA to Cape Flattery, WA

- Species:
  - Common murre (No CC Jun - Dec)

  - Sooty shearwater (No CC May - Oct)

- **Component Category:** Seabirds
- **Time Range:** 2001 - 2024
- **CCIEA Data Contact:** tom.good@noaa.gov
- **Institution:** COASST
- **Source Data:** Data from the Coastal Observation and Seabird Survey Team (COASST), who coordinate a team of trained volunteers that collect effort-controlled survey data on an approximately monthly basis, recording beached bird numbers and identity from survey locations in Northern California through to Northern Washington and into Alaska and the Bering Sea. Contact COASST for details on calculations before citing or distributing these data.
- **Additional Calculations:** Annual mean encounter rates (bird carcasses/km surveyed) aggregated from May to October (inclusive) for each surveyed beach location, and then averaged across all beaches surveyed in that year.
- **Download data:** csv file

References

34 Seabird Diet

Description Seabird diet composition during the breeding season often tracks marine environmental conditions and reflects production and availability of forage within regions of the CCE. We present seabird diet data from the northern and central regions to help shed light on foraging conditions on an annual basis.

Indicator Regions

NoCC; Destruction Island, WA

- Species:
  - Rhinoceros auklet diet - Anchovy
  - Rhinoceros auklet diet - Herring
  - Rhinoceros auklet diet - Rockfish
  - Rhinoceros auklet diet - Sandlance
  - Rhinoceros auklet diet - Smelt
- **Component Category:** Seabirds
- **Time Range:** 2008 - 2024
- **CCIEA Data Contact:** tom.good@noaa.gov
- **Institution:** NOAA NWFSC
- **Source Data:** Data from Washington Rhinoceros Auklet Ecology Project; contact tom.good@noaa.gov before citing or distributing these data
- **Additional Calculations:** Diets of rhinoceros auklet chicks (% occurrence) calculated from bill loads of returning adults to the colony at Destruction Island, WA.
- **Download data:** csv file

NoCC; Yaquina Head, OR

- Species:
  - Common murre diet - Flatfish
  - Common murre diet - Herring/Sardines
  - Common murre diet - Rockfish
  - Common murre diet - Sandlance
  - Common murre diet - Smelt
- **Component Category:** Seabirds
- **Time Range:** 1998 - 2024
- **CCIEA Data Contact:** tom.good@noaa.gov
- **Institution:** OSU Seabird Oceanography Lab
- **Source Data:** Data from Hatfield Marine Science Center Seabird Oceanography Lab Yaquina Head Seabird Studies; contact Rachael Orben (Rachael.Orben@oregonstate.edu) before citing or distributing these data.

- **Additional Calculations:** Diets of common murre chicks (% occurrence) observed as bill loads of returning adults to colonies at Yaquina Head, OR.
- **Download data:** csv file

CeCC; Farallon Islands, CA

- Species:
  - Brandt's cormorant diet - Anchovy
  - Brandt's cormorant diet - Rockfish
  - Cassin's auklet diet - Euphausia
  - Cassin's auklet diet - Mysids
  - Common murre diet - Anchovy/sardine
  - Common murre diet - Rockfish
  - Common murre diet - Salmon
  - Pigeon guillemot diet - Rockfish
  - Rhinoceros auklet diet - Anchovy
  - Rhinoceros auklet diet - Rockfish
- **Component Category:** Seabirds
- **Time Range:** 1987 - 2024
- **CCIEA Data Contact:** tom.good@noaa.gov
- **Institution:** Point Blue Conservation Science
- **Source Data:** Data from Point Blue Conservation Science collected on Southeast Farallon Island in collaboration with the Farallon Islands National Wildlife Refuge (USFWS); contact Dr. Jaime Jahncke (jjahncke@pointblue.org) before citing or distributing these data.
- **Additional Calculations:** Diet is percent occurrence of fish species in the diets of adult birds that are provisioning chicks calculated from bill loads of adults returning to the colony at Southeast Farallon Island, CA.
- **Private dataset, no download available**

References

35 Sea Lion Productivity

Description California sea lion pup counts and pup growth rates are sensitive indicators of prey availability and composition in the Central and Southern CCE.

Pup count and pup growth as indicators of foraging conditions: The San Miguel Island California sea lion indicators of pup births, pup condition, pup growth and nursing female diet are linked to the availability (a combination of abundance and distribution) and composition of the coastal pelagic forage community to nursing California sea lions foraging in the CCE from the northern California Channel Islands to Monterey Bay throughout the year. Nursing California sea lions are central place foragers for 11 months of the year, traveling to and from the breeding colonies in the Channel Islands, where their pups reside, to foraging areas within 200 km of the colonies. Consequently, they are sampling the coastal pelagic forage community throughout the year and their diet and resultant reproductive success measured by pup metrics depends on the availability of that forage community.

Nursing California sea lions consume a variety of fish and cephalopods but have a core diet of only seven taxa: Pacific hake, Pacific sardine, northern anchovy, rockfish, jack mackerel, Pacific mackerel, and market squid S. Melin, DeLong, and Siniff (2008); S. R. Melin, Orr, et al. (2012)]. These taxa vary annually and seasonally in the diet. The nursing female diet index is based on the frequency of occurrence of these seven core taxa in scats collected at the San Miguel colony during the early lactation period (June-September). This index provides a relative measure of the availability of each prey taxa to nursing females within their foraging range because California sea lions consume prey relative to its abundance in the environment (Thompson et al. 2019) but not necessarily proportionally. For example, an increase in the frequency of occurrence of anchovy from 5% in 1995 diets to 90% in 1996 diets means that almost no females consumed anchovy in 1995 because it was not available to them but almost all females consumed it in 1996; it does not necessarily mean that the biomass of anchovy increased nearly 20-fold in the CCE, just that the availability increased in the foraging range of nursing females. Nonetheless, it indicates that a change in the forage community occurred between the two years. A weakness of this index is that it only indicates presence or absence of a taxa in the diet; when sardine occurs in high frequency, it could be that sea lions are exploiting a small population of fish or it could be that sardine are ubiquitous in the environment. It also is a retrospective rather than forecasting index. It is thus important to view this as part of a suite of indicators about the prey community, along with ship-based catch or acoustic estimates of forage fish biomass. Strengths of the sea lion diet index are that it is easy to update annually and the core taxa comprise the core diet of many other top predators in the CCE that are difficult to sample or observe. Consequently, the annual variability and trends in the California sea lion diet can inform us on unusual patterns in the coastal pelagic forage community that may affect other top predators in the CCE.

Each of the pup indices in the report represents a different aspect of reproductive success that relies on successful foraging by reproductive females. As such, they are indirect qualitative measures of the forage available to reproductive females and do not provide specific forage community information. The annual number of pup births is an index of successful pregnancies, which are dependent on the nutritional condition of the female, which in turn, is dependent on the quality and quantity of prey available during the gestation period. Higher numbers of pup births indicates that females consumed a diet that provided sufficient quantity and nutrition to support the energetic cost of gestation. Pup condition and growth are dependent on milk intake. The more milk consumed the greater the better condition and growth rate. The amount of food consumed by a female on a foraging trip determines the amount of milk she has to deliver to the pup when she returns. Better pup condition and higher growth rates indicate abundant prey for nursing females during the lactation period.

Declines in pup births and pup growth have been associated with environmental events that reduced marine productivity at all trophic levels in the CCE for prolonged periods supporting the link between these indices and the status of the forage community (R. DeLong et al. 1991; Iverson, Oftedal, and Boness 1991; S. Melin et al. 2010; S. R. Melin, Laake, et al. 2012; R. L. DeLong et al. 2017). Other factors such as diseases (e.g., hookworm, Lyons et al. 2005), immune suppression from pollution (R. L. DeLong, Gilmartin, and Simpson 1973; Gilmartin et al. 1976) and natural environmental toxins (Goldstein et al. 2009) may affect pup growth or births, but these factors are likely to have less of a population level effect than large-scale food supply issues that accompany anomalous oceanographic conditions.

The influence of population abundance and carrying capacity on these indicators: In discussions related to past reports, some Council advisory bodies expressed concerns that sea lion pup counts and growth may become less effective indicators when the population is close to carrying capacity, which it was in the 2010s: according to population modeling work by Laake et al. (2018), the San Miguel colony at that time had an estimated carrying capacity of ~275,000 animals (including pups), and annual population estimates between 2006 and 2014 ranged from 242,000 to 306,000 animals. Advisory bodies were concerned that changes in pup count or growth could be due to density dependent mechanisms within the sea lion population, rather than to changes in the prey community.

A linear mixed effects model of California sea lion pup growth that includes environmental variables, sea lion abundance, fish abundance and nursing female diet revealed that the abundance of California sea lions was not a significant factor in annual variability of pup growth rates (Melin et al. in preparation). The model also did not detect a declining trend in pup growth as the population size increased, which might occur if competition among nursing females for limited forage was affecting the ability of females to support the energetic demands of their pups. Elevated SST explained the greatest amount of variability for pup growth rates in the models: a 1°C increase in SST resulted in a 7% decline in the population growth rate, even when the population was much smaller (<100,000 animals) in the 1980s (Laake et al. 2018). The reverse effect was not apparent when SST decreased by 1°C. These analyses indicate that pup count and pup growth are not compromised as indicators by population size, but rather reflect the dynamic relationship between environmental conditions and California sea lion reproduction. We believe the key underlying mechanism is that elevated SST affects the distribution and abundance of the sea lion prey community thereby reducing access to food for nursing females, such that they cannot support the energetic demands of pregnancy, resulting in fewer births, or lactation, resulting in slower pup growth.

2023 Methods Update To reduce disturbance to California sea lions and to improve the accuracy of our pup counts, we transitioned to using small drones (Aerial Imagery Systems' APH-28 and the Parrot Anafi) for our pup census in 2023. A pilot study in 2017 and 2018 that paired drone surveys and ground counts for the same areas showed no significant differences in counts determined from drones or ground counts. The drone surveys were flown at an altitude of 46 m over small or narrow sections of coastline or in transects over large areas. The images were stitched together using DigiKam software and pups were counted using DotDotGoose software that automatically entered the counts into a data file for analysis. In 2023, weather conditions precluded using the drones for the entire count so we conducted ground counts for about 20% of the colony and used drones for 80%.

Indicators

Female sea lion pup growth rate

- **Component Category:** Marine Mammals
- **Time Range:** 1997 - 2023
- **CCIEA Data Contact:** sharon.melin@noaa.gov
- **Institution:** NOAA AFSC/MML
- **Source Data:** AFSC/NMML)
- **Additional Calculations:** Predicted average (+/-1 s.e.) daily growth rate of female California sea lion pups at San Miguel Island between 4-7 months of age for cohorts from 1997-present. (Note: In 2020, data was not collected due to COVID-19 restrictions to field operations.)
- **Download data:** csv file

Female sea lion pup weight index

- **Component Category:** Marine Mammals
- **Time Range:** 1997 - 2023
- **CCIEA Data Contact:** sharon.melin@noaa.gov
- **Institution:** NOAA AFSC/MML
- **Source Data:** AFSC/NMML)
- **Additional Calculations:** Predicted average pup weights for female California sea lion pups born at San Miguel Island, California. Pups are weighed in September or October each year and weights are adjusted using a mixed effects model to a 1 October weighing date. (Note: In 2020, data was not collected due to COVID-19 restrictions to field operations.)
- **Download data:** csv file

Sea lion pup count, San Miguel Isl.

- **Component Category:** Marine Mammals
- **Time Range:** 1997 - 2024
- **CCIEA Data Contact:** sharon.melin@noaa.gov
- **Institution:** NOAA AFSC/MML
- **Source Data:** AFSC/NMML)
- **Additional Calculations:** Average number of California sea lion pups at San Miguel Island for cohorts from 1997-present. (Note: In 2020, data collection was limited to estimates from aerial surveys due to COVID-19 restrictions to field operations. M. Ball [Wildlands Conservation Science] conducted the aerial surveys and E. Jaime [AFSC] interpreted images to derive counts.)
- **Download data:** csv file

References

DeLong, RL, GA Antonelis, CW Oliver, BS Stewart, MC Lowry, and PK Yochem. 1991. "Effects of the 1982–83 El Nino on Several Population Parameters and Diet of California Sea Lions on the California Channel Islands." In *Pinnipeds and El Niño: Responses to Environmental Stress*, 166–72. Springer.

DeLong, Robert L, William G Gilmartin, and John G Simpson. 1973. "Premature Births in California Sea Lions: Association with High Organochlorine Pollutant Residue Levels." *Science* 181 (4105): 1168–70.

DeLong, Robert L, Sharon R Melin, Jeffrey L Laake, Patricia Morris, Anthony J Orr, and Jeffrey D Harris. 2017. "Age-and Sex-Specific Survival of California Sea Lions (Zalophus Californianus) at San Miguel Island, California." *Marine Mammal Science* 33 (4): 1097–1125.

Gilmartin, WG, RL Delong, AW Smith, JC Sweeney, BW DeLappe, RW Risebrough, LA Griner, MD Dailey, and DB Peakall. 1976. “Premature Parturition in the California Sea Lion.” *Journal of Wildlife Diseases* 12 (1): 104–15.

Goldstein, Tracey, Tanja S Zabka, Robert L DeLong, Elizabeth A Wheeler, Gina Ylitalo, Sibel Bargu, Mary Silver, et al. 2009. “The Role of Domoic Acid in Abortion and Premature Parturition of California Sea Lions (Zalophus Californianus) on San Miguel Island, California.” *Journal of Wildlife Diseases* 45 (1): 91–108.

Iverson, SJ, OT Oftedal, and DJ Boness. 1991. “The Effect of El Niño on Pup Development in the California Sea Lion (Zalophus Californianus) II. Milk Intake.” In *Pinnipeds and El Niño: Responses to Environmental Stress*, 180–84. Springer.

Laake, Jeffrey L, Mark S Lowry, Robert L DeLong, Sharon R Melin, and James V Carretta. 2018. “Population Growth and Status of California Sea Lions.” *The Journal of Wildlife Management* 82 (3): 583–95.

Melin, Sharon R, Jeffrey L Laake, Robert L DeLong, and Donald B Siniff. 2012. “Age-Specific Recruitment and Natality of California Sea Lions at San Miguel Island, California.” *Marine Mammal Science* 28 (4): 751–76.

Melin, Sharon R, Anthony J Orr, Jeffrey D Harris, Jeffrey L Laake, and Robert L DeLong. 2012. “California Sea Lions: An Indicator for Integrated Ecosystem Assessment of the California Current System.” *California Cooperative Oceanic Fisheries Investigations Reports* 53: 140–52.

Melin, SR, RL DeLong, and DB Siniff. 2008. “The Effects of El Niño on the Foraging Behavior of Lactating California Sea Lions (Zalophus Californianus Californianus) During the Nonbreeding Season.” *Canadian Journal of Zoology* 86 (3): 192–206.

Melin, SR, AJ Orr, JD Harris, JL Laake, RL DeLong, F Gulland, and S Stoudt. 2010. “Unprecedented Mortality of California Sea Lion Pups Associated with Anomalous Oceanographic Conditions Along the Central California Coast in 2009.” *California Cooperative Oceanic Fisheries Investigations Reports* 51: 182–94.

Thompson, Andrew R, Chris J Harvey, William J Sydeman, Caren Barceló, Steven J Bograd, Richard D Brodeur, Jerome Fiechter, et al. 2019. “Indicators of Pelagic Forage Community Shifts in the California Current Large Marine Ecosystem, 1998–2016.” *Ecological Indicators* 105: 215–28.

36 Whale Entanglement

Description The number of large whale entanglements confirmed by NOAA Fisheries has increased off the U.S. West Coast in recent years. This alarming pattern has mobilized efforts to understand and address factors that contribute to whale entanglement in fishing gear. The dynamics of entanglement risk and reporting are complex, and are affected by shifts in ocean conditions and prey fields, changes in whale populations, changes in distribution and timing of fishing effort, and increased public awareness.

NOAA Fisheries is responsible for recovering and protecting these whales under the Marine Mammal Protection Act and Endangered Species Act. The states are responsible for managing many of the fisheries that interact with these whales. Whale entanglement data is compiled by NOAA Fisheries West Coast Region. The CCIEA website (https://www.integratedecosystemassessment.noaa.gov/regions/california-current/the-ecosystem-context-reducing-west-coast-whale-entanglements) serves some of these data in an interactive map, which can be used to view the spatial distribution of entanglement records by species, gear type, and year.

Indicators

- **Species:**
  - Blue Whale
  - Fin Whale
  - Gray Whale
  - Humpback Whale
  - Killer Whale
  - Minke Whale
  - Sperm Whale
  - Grand Total
  - Unidentified Other
  - Unidentified Whale
- **Component Category:** Ecological Integrity
- **Time Range:** 2000 - 2024
- **CCIEA Data Contact:** dan.lawson@noaa.gov
- **Institution:** NOAA SWFSC
- **Source Data:** Whale entanglement data provided by D. Lawson and L. Saez, NMFS/WCR. For more information, consult: https://www.fisheries.noaa.gov/west-coast/marine-mammal-protection/west-coast-large-whale-entanglement-response-program#reportsy
- **Additional Calculations:** NOAA Fisheries collects, verifies, documents, and responds to reports of large whale entanglements that originate from a variety of sources including boaters, fishermen, law enforcement, marine resource agencies, and the public. NOAA Fisheries confirmed the reports based upon the documents submitted, follow-up sightings, and entanglement response information provided to us from our West Coast Region Marine Mammal Stranding Network partners.
- **Download data:** csv file

References

37 Harmful Algal Blooms

Description Harmful algal blooms (HABs) of diatoms in the genus *Pseudo-nitzschia* have been a recurring concern along the West Coast. Certain species of *Pseudo-nitzschia* produce the toxin domoic acid, which can accumulate in filter feeders and extend through food webs to cause harmful or lethal effects on people, marine mammals, and seabirds (Lefebvre et al. 2002; McCabe et al. 2016). Because domoic acid can cause amnesic shellfish poisoning in humans, fisheries that target shellfish (including razor clam, Dungeness crab, rock crab, and spiny lobster) are delayed, closed, or operate under special orders or health advisories when domoic acid concentrations exceed regulatory thresholds for human consumption. Fishery closures can cost tens of millions of dollars in lost revenue, and cause a range of sociocultural impacts in fishing communities (Dyson and Huppert 2010; Ritzman et al. 2018; Holland and Leonard 2020; Moore et al. 2020), including a “spillover” of fishing effort into other fisheries.

Ocean conditions associated with marine heatwaves, El Niño events, or positive PDO regimes may further exacerbate domoic acid toxicity and fishery impacts, and domoic acid toxicity tracks anomalies of southern copepod biomass (Fig. 3.1) (McCabe et al. 2016; McKibben et al. 2017). The largest and most toxic HAB of *Pseudo-nitzschia* on the West Coast occurred in 2015, coincident with the 2013-2016 marine heatwave, and caused the longest-lasting and most widespread HAB-related fisheries closures on record (McCabe et al. 2016; Moore et al. 2019; Trainer et al. 2020). Closures and delays in the opening of West Coast crab fisheries resulted in the appropriation of >$25M in federal disaster relief funds (McCabe et al. 2016).

According to thresholds set by the U.S. Food and Drug Administration, domoic acid levels 20 parts per million (ppm) trigger actions for all seafood and tissues except Dungeness crab viscera, for which the level is >30 ppm (California applies this to rock crab viscera as well) (Fda 2011). Under evisceration orders, Dungeness crab can be landed when the viscera exceeds the threshold but the meat does not, provided that crab are eviscerated by a licensed processor. Oregon was the first West Coast state to pass legislation allowing evisceration, in November 2017, followed by California in October 2021. Washington adopted an emergency evisceration rule in February 2021, and is considering legislation to grant long-term authority for issuing evisceration orders.

Indicator Category Ecological Integrity

Data Steward S. Moore, NMFS/NWFSC (stephanie.moore at noaa.gov);

Additional Information Domoic acid data are collected from state partners and analyzed independently by S. Moore and C. Free, who submit unpublished figures and plots to the CCIEA editorial team. Data are plotted as monthly maximum domoic acid concentrations for both razor clams and Dungeness crab viscera relative to management thresholds (20 ppm - clams; 30 ppm - crabs).

Data sources Domoic acid data are provided by the Washington State Department of Health, Oregon Department of Agriculture, and California Department of Public Health.

References

Dyson, Karen, and Daniel D Huppert. 2010. "Regional Economic Impacts of Razor Clam Beach Closures Due to Harmful Algal Blooms (HABs) on the Pacific Coast of Washington." *Harmful Algae* 9 (3): 264–71.

Fda, Us. 2011. "Fish and Fishery Products Hazards and Controls Guidance." *Food and Drug Administration, Center for Food Safety and Applied Nutrition, US Department of Health and Human Services.*

Holland, Daniel S, and Jerry Leonard. 2020. "Is a Delay a Disaster? Economic Impacts of the Delay of the California Dungeness Crab Fishery Due to a Harmful Algal Bloom." *Harmful Algae* 98: 101904. https://doi.org/10.1016/j.hal.2020.101904.

Lefebvre, Kathi A, Sibel Bargu, Tom Kieckhefer, and Mary W Silver. 2002. "From Sanddabs to Blue Whales: The Pervasiveness of Domoic Acid." *Toxicon* 40 (7): 971–77.

McCabe, Ryan M, Barbara M Hickey, Raphael M Kudela, Kathi A Lefebvre, Nicolaus G Adams, Brian D Bill, Frances MD Gulland, Richard E Thomson, William P Cochlan, and Vera L Trainer. 2016. "An Unprecedented Coastwide Toxic Algal Bloom Linked to Anomalous Ocean Conditions." *Geophysical Research Letters* 43 (19): 10–366.

McKibben, S Morgaine, William Peterson, A Michelle Wood, Vera L Trainer, Matthew Hunter, and Angelicque E White. 2017. "Climatic Regulation of the Neurotoxin Domoic Acid." *Proceedings of the National Academy of Sciences* 114 (2): 239–44.

Moore, Stephanie K, Michael R Cline, Kathryn Blair, Terrie Klinger, Anna Varney, and Karma Norman. 2019. "An index of fisheries closures due to harmful algal blooms and a framework for identifying vulnerable fishing communities on the US West Coast." *Marine Policy* 110: 103543.

Moore, Stephanie K, Stacia J Dreyer, Julia A Ekstrom, Kathleen Moore, Karma Norman, Terrie Klinger, Edward H Allison, and Sunny L Jardine. 2020. "Harmful Algal Blooms and Coastal Communities: Socioeconomic Impacts and Actions Taken to Cope with the 2015 US West Coast Domoic Acid Event." *Harmful Algae* 96: 101799.

Ritzman, Jerilyn, Amy Brodbeck, Sara Brostrom, Scott McGrew, Stacia Dreyer, Terrie Klinger, and Stephanie K Moore. 2018. "Economic and Sociocultural Impacts of Fisheries Closures in Two Fishing-Dependent Communities Following the Massive 2015 US West Coast Harmful Algal Bloom." *Harmful Algae* 80: 35–45.

Trainer, Vera L, Stephanie K Moore, Gustaaf Hallegraeff, Raphael M Kudela, Alejandro Clement, Jorge I Mardones, and William P Cochlan. 2020. "Pelagic harmful algal blooms and climate change: Lessons from nature's experiments with extremes." *Harmful Algae* 91: 101591.

Part V

Fishing and Non-Fishing Human Activities

38 Fishery Landings

Description Fishery landings are indicators of ecosystem services provided and also reflect removals from the CCE. Commercial landings data are best summarized by the Pacific Fisheries Information Network (PacFIN; pacfin.psmfc.org), and recreational landings are best summarized by the Recreational Fisheries Information Network (RecFIN; www.recfin.org). Landings provide the best long-term indicator of fisheries removals. Status and trends are estimated relative to a frame of reference of 1991-2020. In most cases, landings data for the most recent reporting years are only complete through the latter months (e.g., October-December); these data are updated in the next annual cycle.

Commercial landings data are reported coastwide and by state (CA, OR, WA) by fishery species category; in the case of recreational landings, however, we use the same geographic reporting distinctions but differentiate only between salmon recreational and total recreational landings.

Indicators

- **Coastal pelagic spp, no squid CA**
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)
- **Coastal pelagic spp, no squid coastwide**
  - *About this indicator:* Coastal pelagic species (without market squid (Loligo opalescens)) landings (1000's of metric tons) on the U.S. West Coast. Coastal pelagic species include Pacific herring (Clupea harengus pallasii), round herring (Etrumeus teres), chub mackerel (Scomber japonicus), jack mackerel (Trachurus symmetricus), northern anchovy (Engraulis mordax), Pacific bonito (Sarda chiliensis), Pacific sardine (Sardinops sagax), and unspecified mackerel.
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)
- **Coastal pelagic spp, no squid OR**
  - *About this indicator:* Coastal pelagic species (without market squid (Loligo opalescens)) landings (1000's of metric tons) in Oregon. Coastal pelagic species include Pacific herring (Clupea harengus pallasii), round herring (Etrumeus teres), chub mackerel (Scomber japonicus), jack mackerel (Trachurus symmetricus), northern anchovy (Engraulis mordax), Pacific bonito (Sarda chiliensis), Pacific sardine (Sardinops sagax), and unspecified mackerel.
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)
- **Coastal pelagic spp, no squid WA**
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)
- **Crab CA**

  - *About this indicator:* Crab landings (1000's of metric tons) in California. Crab species include Dungeness (Metacarcinus magister), tanner (Chionoecetes spp.), rock (Cancer spp.) and unspecified crabs.
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Crab coastwide**
  - *About this indicator:* Crab landings (1000's of metric tons) on the U.S. West Coast. Crab species include Dungeness (Metacarcinus magister), tanner (Chionoecetes spp.), rock (Cancer spp.) and unspecified crabs.
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Crab OR**
  - *About this indicator:* Crab landings (1000's of metric tons) in Oregon. Crab species include Dungeness (Metacarcinus magister), tanner (Chionoecetes spp.), rock (Cancer spp.) and unspecified crabs.
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Crab WA**
  - *About this indicator:* Crab landings (1000's of metric tons) in Washington. Crab species include Dungeness (Metacarcinus magister), tanner (Chionoecetes spp.), rock (Cancer spp.) and unspecified crabs.
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Highly migratory species CA**
  - *About this indicator:* Highly migratory species landings (1000's of metric tons) in California. Highly migratory species primarily consist of tunas (Thunnus spp), swordfish (Xiphias gladius) and pelagic sharks (e.g., blue (Prionace glauca), thresher (Alopias spp), and shortfin mako (Isurus oxyrinchus).
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Highly migratory species coastwide**
  - *About this indicator:* Highly migratory species landings (1000's of metric tons) on the U.S. West Coast. Highly migratory species primarily consist of tunas (Thunnus spp), swordfish (Xiphias gladius) and pelagic sharks (e.g., blue (Prionace glauca), thresher (Alopias spp), and shortfin mako (Isurus oxyrinchus).
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Highly migratory species OR**
  - *About this indicator:* Highly migratory species landings (1000's of metric tons) in Oregon. Highly migratory species primarily consist of tunas (Thunnus spp), swordfish (Xiphias gladius) and pelagic sharks (e.g., blue (Prionace glauca), thresher (Alopias spp), and shortfin mako (Isurus oxyrinchus).

- *Time Range:* 1981 - 2024
- *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Highly migratory species WA**
  - *About this indicator:* Highly migratory species landings (1000's of metric tons) in Washington. Highly migratory species primarily consist of tunas (Thunnus spp), swordfish (Xiphias gladius) and pelagic sharks (e.g., blue (Prionace glauca), thresher (Alopias spp), and shortfin mako (Isurus oxyrinchus).
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Market squid CA**
  - *About this indicator:* Market squid (Loligo opalescens) landings (1000's of metric tons) in California.
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Market squid coastwide**
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Market squid OR**
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Non-whiting groundfish CA**
  - *About this indicator:* Non-whiting groundfish (Merluccius productus) landings (1000's of metric tons) in California. Groundfish taxa include flatfishes, rockfishes and abundant demersal roundfishes.
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Non-whiting groundfish coastwide**
  - *About this indicator:* Non-whiting groundfish (Merluccius productus) landings (1000's of metric tons) on the U.S. West Coast. Groundfish taxa include flatfishes, rockfishes and abundant demersal roundfishes.
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Non-whiting groundfish OR**
  - *About this indicator:* Non-whiting groundfish (Merluccius productus) landings (1000's of metric tons) in Oregon. Groundfish taxa include flatfishes, rockfishes and abundant demersal roundfishes.
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Non-whiting groundfish WA**

- *About this indicator:* Non-whiting groundfish (Merluccius productus) landings (1000's of metric tons) in Washington. Groundfish taxa include flatfishes, rockfishes and abundant demersal roundfishes.
- *Time Range:* 1981 - 2024
- *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Other species CA**
  - *About this indicator:* Other species landings (1000's of metric tons) in California. Other species include several taxa, but consists primarily of red sea urchin (Stronglyocentrotus franciscanus) and hagfish (Eptatretus spp.).
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Other species coastwide**
  - *About this indicator:* Other species landings (1000's of metric tons) on the U.S. West Coast. Other species include several taxa, but consists primarily of red sea urchin (Stronglyocentrotus franciscanus) and hagfish (Eptatretus spp.).
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Other species OR**
  - *About this indicator:* Other species landings (1000's of metric tons) in Oregon. Other species include several taxa, but consists primarily of red sea urchin (Stronglyocentrotus franciscanus) and hagfish (Eptatretus spp.).
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Other species WA**
  - *About this indicator:* Other species landings (1000's of metric tons) in Washington. Other species include several taxa, but consists primarily of red sea urchin (Stronglyocentrotus franciscanus) and hagfish (Eptatretus spp.).
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Pacific whiting CA**
  - *About this indicator:* Pacific whiting (Merluccius productus) landings (1000's of metric tons) in California. Pacific whiting landings include data from shoreside and at-sea processors.
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Pacific whiting coastwide**
  - *About this indicator:* Pacific whiting (Merluccius productus) landings (1000's of metric tons) on the U.S. West Coast. Pacific whiting landings include data from shoreside and at-sea processors.
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Pacific whiting OR**

- *About this indicator:* Pacific whiting (Merluccius productus) landings (1000's of metric tons) in Oregon. Pacific whiting landings include data from shoreside and at-sea processors.
- *Time Range:* 1981 - 2024
- *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Pacific whiting WA**
  - *About this indicator:* Pacific whiting (Merluccius productus) landings (1000's of metric tons) in Washington. Pacific whiting landings include data from shoreside and at-sea processors.
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Recreational CA**
  - *About this indicator:* Total landings of all species from recreational fisheries in California from www.recfin.org using weight of catch type "A + B1" metric tons.
  - *Time Range:* 2005 - 2024
  - *Source Data:* Recreational Fisheries Information Network (RecFIN)

- **Recreational coastwide**
  - *About this indicator:* Total landings of all species from recreational fisheries from www.recfin.org using weight of catch type "A + B1" metric tons.
  - *Time Range:* 2005 - 2024
  - *Source Data:* Recreational Fisheries Information Network (RecFIN)

- **Recreational OR**
  - *About this indicator:* Total landings of all species from recreational fisheries in Oregon from www.recfin.org using weight of catch type "A + B1" metric tons.
  - *Time Range:* 2005 - 2024
  - *Source Data:* Recreational Fisheries Information Network (RecFIN)

- **Recreational WA**
  - *About this indicator:* Total landings of all species from recreational fisheries in Washington from www.recfin.org using weight of catch type "A + B1" metric tons.
  - *Time Range:* 2005 - 2024
  - *Source Data:* Recreational Fisheries Information Network (RecFIN)

- **Salmon commercial CA**
  - *About this indicator:* Salmon landings (1000's of metric tons) in California. Salmon landings primarily consist of Chinook (Oncorhynchus tshawytscha), but also includes chum (O. keta), coho (O. kisutch), pink (O. gorbuscha) and sockeye (O. nerka) and steelhead (O. mykiss) .
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Salmon commercial coastwide**
  - *About this indicator:* Salmon landings (1000's of metric tons) on the U.S. West Coast. Salmon landings primarily consist of Chinook (Oncorhynchus tshawytscha), but also includes chum (O. keta), coho (O. kisutch), pink (O. gorbuscha) and sockeye (O. nerka) and steelhead (O. mykiss) .

    - *Time Range:* 1981 - 2024
    - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Salmon commercial OR**
    - *About this indicator:* Salmon landings (1000's of metric tons) in Oregon. Salmon landings primarily consist of Chinook (Oncorhynchus tshawytscha), but also includes chum (O. keta), coho (O. kisutch), pink (O. gorbuscha) and sockeye (O. nerka) and steelhead (O. mykiss) .
    - *Time Range:* 1981 - 2024
    - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Salmon commercial WA**
    - *About this indicator:* Salmon landings (1000's of metric tons) in Washington. Salmon landings primarily consist of Chinook (Oncorhynchus tshawytscha), but also includes chum (O. keta), coho (O. kisutch), pink (O. gorbuscha) and sockeye (O. nerka) and steelhead (O. mykiss) .
    - *Time Range:* 1981 - 2024
    - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Salmon recreational CA**
    - *About this indicator:* Salmon landings (1000's of metric tons) in California. Salmon landings primarily consist of Chinook (Oncorhynchus tshawytscha), but also includes chum (O. keta), coho (O. kisutch), pink (O. gorbuscha) and sockeye (O. nerka) and steelhead (O. mykiss) .
    - *Time Range:* 1981 - 2023
    - *Source Data:* Recreational Fisheries Information Network (RecFIN)

- **Salmon recreational coastwide**
    - *About this indicator:* Salmon landings (1000's of metric tons) on the U.S. West Coast. Salmon landings primarily consist of Chinook (Oncorhynchus tshawytscha), but also includes chum (O. keta), coho (O. kisutch), pink (O. gorbuscha) and sockeye (O. nerka) and steelhead (O. mykiss) .
    - *Time Range:* 1981 - 2023
    - *Source Data:* Recreational Fisheries Information Network (RecFIN)

- **Salmon recreational OR**
    - *About this indicator:* Salmon landings (1000's of metric tons) in Oregon. Salmon landings primarily consist of Chinook (Oncorhynchus tshawytscha), but also includes chum (O. keta), coho (O. kisutch), pink (O. gorbuscha) and sockeye (O. nerka) and steelhead (O. mykiss) .
    - *Time Range:* 1981 - 2023
    - *Source Data:* Recreational Fisheries Information Network (RecFIN)

- **Salmon recreational WA**
    - *About this indicator:* Salmon landings (1000's of metric tons) in Washington. Salmon landings primarily consist of Chinook (Oncorhynchus tshawytscha), but also includes chum (O. keta), coho (O. kisutch), pink (O. gorbuscha) and sockeye (O. nerka) and steelhead (O. mykiss) .
    - *Time Range:* 1981 - 2023
    - *Source Data:* Recreational Fisheries Information Network (RecFIN)

- **Shrimp CA**

- *About this indicator:* Shrimp landings (1000's of metric tons) in California. Shrimp landings consist primarily of Pacific pink shrimp (Pandalus jordani).
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Shrimp coastwide**
  - *About this indicator:* Shrimp landings (1000's of metric tons) on the U.S. West Coast. Shrimp landings consist primarily of Pacific pink shrimp (Pandalus jordani).
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Shrimp OR**
  - *About this indicator:* Shrimp landings (1000's of metric tons) in Oregon. Shrimp landings consist primarily of Pacific pink shrimp (Pandalus jordani).
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Shrimp WA**
  - *About this indicator:* Shrimp landings (1000's of metric tons) in Washington. Shrimp landings consist primarily of Pacific pink shrimp (Pandalus jordani).
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Total fisheries CA**
  - *About this indicator:* Combined commercial and recreational fisheries landings (1000's of metric tons) in California.
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Total fisheries coastwide**
  - *About this indicator:* Combined commercial and recreational fisheries landings (1000's of metric tons) on the U.S. West Coast.
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Total fisheries OR**
  - *About this indicator:* Combined commercial and recreational fisheries landings (1000's of metric tons) in Oregon.
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

- **Total fisheries WA**
  - *About this indicator:* Combined commercial and recreational fisheries landings (1000's of metric tons) in Washington.
  - *Time Range:* 1981 - 2024
  - *Source Data:* Pacific Fisheries Information Network (PacFIN)

Component Category: Human Activities

CCIEA Data Contact: kelly.andrews@noaa.gov

Institution: NOAA NWFSC

References

39 Commercial Fishery Revenue

Description Commercial fishery revenue is a direct indicator of ecosystem services provided to coastal economies of the CCE. Commercial revenue data are best summarized by the Pacific Fisheries Information Network (PacFIN; https://pacfin.psmfc.org/). Revenues are calculated based on consumer price indices in current year (e.g., 2024) dollars. Status and trends are estimated relative to a frame of reference of 1991-2020. In most cases, revenue data for the most recent reporting year are only complete through the latter months (e.g., October-December); these data are updated in the next annual cycle.

Commercial revenue data are reported coastwide and by state (CA, OR, WA) by fishery species category.

Indicators

- **Species:**
  - Coastal pelagic spp, no squid CA
  - Coastal pelagic spp, no squid coastwide
  - Coastal pelagic spp, no squid OR
  - Coastal pelagic spp, no squid WA
  - Commercial fisheries CA
  - Commercial fisheries coastwide
  - Commercial fisheries OR
  - Commercial fisheries WA
  - Crab CA
  - Crab coastwide
  - Crab OR
  - Crab WA
  - Non-whiting groundfish CA
  - Non-whiting groundfish coastwide
  - Non-whiting groundfish OR
  - Non-whiting groundfish WA
  - Highly migratory species CA
  - Highly migratory species coastwide
  - Highly migratory species OR
  - Highly migratory species WA
  - Market squid CA
  - Market squid coastwide
  - Market squid OR
  - Other species CA
  - Other species coastwide
  - Other species OR
  - Other species WA
  - Pacific whiting CA
  - Pacific whiting coastwide

  - Pacific whiting OR
  - Pacific whiting WA
  - Salmon CA
  - Salmon coastwide
  - Salmon OR
  - Salmon WA
  - Shrimp CA
  - Shrimp coastwide
  - Shrimp OR
  - Shrimp WA

- **Component Category:** Human Activities
- **Time Range:** 1981 - 2024
- **CCIEA Data Contact:** kelly.andrews@noaa.gov
- **Institution:** NOAA NWFSC
- **Source Data:** Pacific Fisheries Information Network (PacFIN)
- **Additional Calculations:** Coastal pelagic species (without market squid (Loligo opalescens)) revenue (millions of 2024 dollars) in California. Coastal pelagic species include Pacific herring (Clupea harengus pallasii), round herring (Etrumeus teres), chub mackerel (Scomber japonicus), jack mackerel (Trachurus symmetricus), northern anchovy (Engraulis mordax), Pacific bonito (Sarda chiliensis), Pacific sardine (Sardinops sagax), and unspecified mackerel.
- **Download data:** csv file

References

40 Other Human Activities

Description Human activities in, on and around the ocean are varied and growing. These activities generate many benefits, including production of food, employment, energy and livelihoods (Guerry et al. 2012). However, they are also associated with pressures on the ecosystem that have negative consequences, such as loss or modification of habitat, depletions and introductions of species, physical, visual and auditory disturbances, and toxic and non-toxic contamination (Eastwood et al. 2007). Despite the increasing urgency of these influences (Halpern et al. 2007), it is rare to have a full accounting of how anthropogenic pressures in the marine environment have changed over time.

We developed standardized time series of indicators for a variety of anthropogenic pressures (e.g., trawl bottom contact, commercial shipping, nutrient input) acting across the entire USA's portion of the California Current Large Marine Ecosystem (Andrews et al. 2015). These time series were used to quantify and evaluate the intensity and temporal trends of each pressure. Our synthesis, and corresponding methodological approaches to quantify the intensity and trends of these pressures, provide a foundation for future integrative analyses on ecological components (such as risk analysis and management strategy evaluations) across the CCE.

Indicators

- **Species:**
  - Commercial shipping - distance
  - Finfish Aquaculture
  - Nutrient Input
  - Oil And Gas Activity
  - Seafood consumption (per capita)
  - Seafood consumption (total)
  - Shellfish Aquaculture
- **Component Category:** Human Activities
- **Time Range:** 1997 - 2018
- **CCIEA Data Contact:** kelly.andrews@noaa.gov
- **Institution:** NOAA NWFSC
- **Source Data:** Domestic vessel data from U.S. Army Corps of Engineers Navigation Data Center (New Orleans, LA) and foreign vessel data from http://www.ndc.iwr.usace.army.mil/data/dataclen.htm.
- **Additional Calculations:** Commercial shipping activity (distance) was measured as the distance traveled by commercial vessels during transit within waters of the California Current. Distance traveled was calculated using distance traveled within the California Current while in transit between shipping and receiving ports
- **No download available**

References

Andrews, Kelly S, Gregory D Williams, Jameal F Samhouri, Kristin N Marshall, Vladlena Gertseva, and Phillip S Levin. 2015. "The Legacy of a Crowded Ocean: Indicators, Status, and Trends of Anthropogenic Pressures in the California Current Ecosystem." *Environmental Conservation* 42 (2): 139–51.

Eastwood, PD, CM Mills, JN Aldridge, CA Houghton, and SI Rogers. 2007. "Human Activities in UK Offshore Waters: An Assessment of Direct, Physical Pressure on the Seabed." *ICES Journal of Marine Science* 64 (3): 453–63.

Guerry, Anne D, Mary H Ruckelshaus, Katie K Arkema, Joey R Bernhardt, Gregory Guannel, Choong-Ki Kim, Matthew Marsik, et al. 2012. "Modeling Benefits from Nature: Using Ecosystem Services to Inform Coastal and Marine Spatial Planning." *International Journal of Biodiversity Science, Ecosystem Services & Management* 8 (1-2): 107–21.

Halpern, Benjamin S, Kimberly A Selkoe, Fiorenza Micheli, and Carrie V Kappel. 2007. "Evaluating and Ranking the Vulnerability of Global Marine Ecosystems to Anthropogenic Threats." *Conservation Biology* 21 (5): 1301–15.

41 Spatial Interactions with Ocean-Use Sectors

Description Below, we describe two portfolios of indicators for i) oceanographic and lower-trophic level productivity and ii) fisheries activity that can help identify ocean areas important to the overall structure and function of the CCE, and that can track potential social-ecological impacts across all stages of OWE development.

Oceanography and Productivity. Six broad-scale indicators of long-term, spatial variation in oceanography and lower-trophic level productivity are being used to inform spatial suitability analyses in areas off northern California being considered for OWE development in 2024. The ecosystem indicators include: 1. Average wind-driven upwelling during March-July, calculated at 40m depth from 1988-2012 using the Regional Ocean Modeling System (Raghukumar et al. 2023); 2. Long-term, spatial variability and hotspots in primary productivity, calculated from a biogeochemistry model as the average concentration of surface phytoplankton in May-July, 1995-2020 (Fiechter, Edwards, and Moore 2018); 3. Long-term, spatial variability and hotspots in secondary productivity from May-August, calculated as an ensemble of four different estimates of krill abundance/biomass across the West Coast (Cimino et al. 2020; Fiechter et al. 2020; Messié et al. 2022; Phillips et al. 2022); 4. Long-term, spatial variability and hotspots for young-of-year (YOY) rockfishes during their pelagic juvenile life stage in May-June from 2001-2022 (Field et al. 2021); 5.Long-term, spatial variability and hotspots for YOY Pacific hake in May-June from 2001-2022 (Field et al. 2021); 6. Long-term, spatial variability and hotspots of groundfish nursery habitat on the seafloor, based on summed average densities of juveniles from 13 groundfish species in May-October from 2003-2018 (Tolimieri, Wallace, and Haltuch 2020).

Indicator Category Fishing and Non-Fishing Human Activities

Data Steward Andrews; kelly.andrews at noaa.gov

Institution NOAA NWFSC/SWFSC; WCR

Additional Information Data are collected and analyzed independently by K. Andrews and team, who submit internally reviewed figures and plots to the CCIEA editorial team.

The Bureau of Ocean Energy Management (BOEM) has been using a spatial suitability analysis developed by NOAA's National Centers for Coastal and Ocean Science (NCCOS) to identify areas BOEM may consider for OWE development. In order to inform an analysis of new areas along the northern California coast, we used BOEM's methods to calculate an overall suitability score across the six ecosystem indicators for each grid cell (Riley et al. 2021). Briefly, the raw data for each indicator was cropped to the area-of-interest, interpolated across a 2x2-km spatial grid, transformed using a z-membership function, and then geometrically averaged across all indicators for each grid cell. This geometric mean represents the suitability score of a grid cell for OWE development relative to the importance of these areas to the processes represented by each indicator; thus, a suitability score of '1' is most suitable for OWE, while suitability scores closer to 0 are less suitable. In addition to being applicable to siting of new areas, these indicators could be used to establish baseline conditions that can be used to identify potential effects resulting from OWE development and to identify relevant mitigation strategies.

Data sources

*Fisheries Indicators.** We developed seven indicators that describe spatial and temporal variation in groundfish bottom trawling activity from 2002-2021 in the same region being considered for OWE development off the coast of northern California. These indicators were presented in the 2022 ESR (Harvey et al. 2022) and are meant to capture the spatial and temporal variation in fishing effort for the groundfish bottom trawl fishery and to be used in tandem with the ecosystem indicators to identify potential interactions across the entire social-ecological system.

For the groundfish indicators herein, we used logbook set and retrieval coordinates from the limited-entry/catch shares groundfish bottom trawl fisheries to estimate total duration trawled on a 2x2-km grid. These durations were then used to calculate: 1. total duration trawled in the most recent year (2021); 2. the anomaly of the most recent year relative to the entire time series; 3. the most recent 5-year mean (2017-2021); 4. the most recent 5-year trend (2017-2021); 5. the sum of duration trawled across all years; 6. the proportion of years trawled; and 7. the number of years since trawling occurred within each grid cell.

To maintain confidentiality, grid cells with <3 vessels operating within the grid cell across the years associated with the indicator have been removed. The first four indicators are consistent with measuring the 'status' and 'trends' of other ecosystem indicators presented in this report, while the last three have been developed as indicators to use within a risk analysis framework. These indicators account for only federal limited-entry/catch shares groundfish bottom trawl fisheries from 2002-2021, but provide a useful framework for identifying the potential for overlap and conflict between day-to-day fisheries operations and OWE areas. Other fisheries were included in a similar framework and will be added as analyses are completed.

References

Cimino, Megan A, Jarrod A Santora, Isaac Schroeder, William Sydeman, Michael G Jacox, Elliott L Hazen, and Steven J Bograd. 2020. "Essential Krill Species Habitat Resolved by Seasonal Upwelling and Ocean Circulation Models Within the Large Marine Ecosystem of the California Current System." *Ecography* 43 (10): 1536–49.

Fiechter, Jerome, Christopher A Edwards, and Andrew M Moore. 2018. "Wind, Circulation, and Topographic Effects on Alongshore Phytoplankton Variability in the California Current." *Geophysical Research Letters* 45 (7): 3238–45.

Fiechter, Jerome, Jarrod A Santora, Francisco Chavez, Devon Northcott, and Monique Messié. 2020. "Krill Hotspot Formation and Phenology in the California Current Ecosystem." *Geophysical Research Letters* 47 (13): e2020GL088039.

Field, John C, Rebecca R Miller, Jarrod A Santora, Nick Tolimieri, Melissa A Haltuch, Richard D Brodeur, Toby D Auth, et al. 2021. "Spatiotemporal Patterns of Variability in the Abundance and Distribution of Winter-Spawned Pelagic Juvenile Rockfish in the California Current." *PloS One* 16 (5): e0251638.

Harvey, Chris J, Newell Toby Garfield, Gregory D Williams, and Nicholas Tolimieri. 2022. "California Current Integrated Ecosystem Assessment (CCIEA) California Current Ecosystem Status Report, 2022. Report to the Pacific Fishery Management Council. March 2022, Agenda Item i.1.a."

Messié, Monique, Diego A Sancho-Gallegos, Jerome Fiechter, Jarrod A Santora, and Francisco P Chavez. 2022. "Satellite-Based Lagrangian Model Reveals How Upwelling and Oceanic Circulation Shape Krill Hotspots in the California Current System." *Frontiers in Marine Science* 9: 835813.

Phillips, Elizabeth M, Dezhang Chu, Stéphane Gauthier, Sandra L Parker-Stetter, Andrew O Shelton, and Rebecca E Thomas. 2022. "Spatiotemporal variability of euphausiids in the California Current

Ecosystem: insights from a recently developed time series." *ICES Journal of Marine Science* 79 (4): 1312–26.

Raghukumar, Kaustubha, Timothy Nelson, Michael Jacox, Christopher Chartrand, Jerome Fiechter, Grace Chang, Lawrence Cheung, and Jesse Roberts. 2023. "Projected Cross-Shore Changes in Upwelling Induced by Offshore Wind Farm Development Along the California Coast." *Communications Earth & Environment* 4 (1): 116.

Riley, Kenneth L, Lisa Claire Wickliffe, Jonathan A Jossart, Jonathan K MacKay, Alyssa L Randall, Gretchen E Bath, Meghan B Balling, Brandon M Jensen, and JA Morris Jr. 2021. "An Aquaculture Opportunity Area Atlas for the US Gulf of Mexico." National Oceanic; Atmospheric Administration.

Tolimieri, Nick, John Wallace, and Melissa Haltuch. 2020. "Spatio-temporal patterns in juvenile habitat for 13 groundfishes in the California Current Ecosystem." *PloS One* 15 (8): e0237996.

Part VI

Human Wellbeing

42 Social Vulnerability and Fisheries Engagement

Description The Community Social Vulnerability Index (CSVI) is an indicator of social vulnerability in coastal communities that are dependent upon commercial fishing (Norman 2007). To gain further insight into community vulnerability in relation to commercial fishing, fishing dependence, which can be expressed in terms of engagement, reliance, or by a composite of both, can be considered in relation to CSVI. Engagement refers to the total extent of fishing activity in a community; it can be expressed in terms of commercial activity (e.g., landings, revenues, permits, processing, etc). Reliance is the per capita engagement of a community; thus, in two communities with equal engagement, the community with the smaller population would have a higher reliance on its fisheries activities.

Similar to the commercial fishing reliance and engagement measures produced as a part of the Community Social Vulnerability Index (CSVI), we have developed index measures for recreational fishing engagement and reliance (Lewis-Smith and Norman 2024), absent in prior versions of this report as consistent annual data had not been identified. As with the commercial fishing Index construction, following the method proposed by Jepson and Colburn (2013), data directly linking place-based communities to the economic aspects of recreational fishing, which could be attributed to specific calendar years, were compiled from six distinct sources as inputs for the measures. Charter and guide permit data collected by state managers were obtained and linked to Census-Designated Place (CDP) based communities. Additionally, historic fishing tackle business location data was compiled from Data Axel, the provider of business location data to Environmental Systems Research Institute's (ESRI) business analyst application. Marina business location data was also obtained from ESRI and ESRI's provider. These data enable interannual comparisons and allow for future replicable iterations.

Communities that score highly in either commercial or recreational reliance in addition to higher social vulnerability scores may be especially socially vulnerable to downturns in fishing. Fishing reliance can be volatile: communities can move left on the x-axis in years with reduced landings, and may thus appear to be less dependent on commercial fishing when in fact they have actually just experienced a difficult year; therefore, these results should be interpreted with care. These same qualifications apply to recreational fishing reliance measures, and several communities are among the most reliant in their respective regions for both commercial and recreational fishing. These data are difficult to groundtruth and interpreting trends requires further study.

- **Communities (ordered north to south):**
  - Bellingham, WA
  - Neah Bay, WA
  - Anacortes, WA
  - Westport, WA
  - Seattle, WA
  - Tokeland, WA
  - Shelton, WA
  - Bay Center, WA
  - Olympia, WA

- Ilwaco, WA
- Chinook, WA
- Astoria, OR
- Garibaldi, OR
- Tillamook, OR
- Beaver, OR
- Cloverdale, OR
- Newport, OR
- Florence, OR
- Coos Bay, OR
- Yachats, OR
- Port Orford, OR
- Winchester Bay, OR
- Brookings, OR
- Crescent City, CA
- Trinidad, CA
- Eureka, CA
- Shelter Cove, CA
- Fort Bragg, CA
- Point Arena, CA
- Bodega Bay, CA
- Dillon Beach, CA
- Tomales, CA
- Bolinas, CA
- San Francisco, CA
- El Granada, CA
- Half Moon Bay, CA
- Moss Landing, CA
- Monterey, CA
- Morro Bay, CA
- Santa Barbara, CA
- Summerland, CA
- San Buenaventura (Ventura), CA
- Oxnard, CA
- Port Hueneme, CA
- Marina del Rey, CA
- Los Angeles, CA
- Dana Point, CA
- Avalon, CA
- Del Mar, CA
- San Diego, CA

- **Component Category:** Human Wellbeing
- **CCIEA Data Contact:** karma.norman@noaa.gov
- **Institution:** NOAA NWFSC
- **Source Data:** Community social vulnerability index (CSVI) data were provided by Dr. Karma Norman (NOAA), and are derived from the American Community Survey (ACS) associated with the US Census (http://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml). Although decennial

census data represent an estimate at a specific date, the ACS data are period estimates, collected over an entire year and are potentially averaged over varying time periods, depending on the size of the geographic area (U.S. Census Bureau, 2009). Given that communities of interest include geographic areas with populations less than 20,000, ACS data at the Census-Designate Place level or for place-based communities, are averaged over a five-year period. Annual scores are provided as categorical rankings with high representing scores at or above 1 standard deviation, medium high as between .5 and .99 standard deviation, mediam as 0 to .49 standard deviation and low as below 0 standard deviation.

- **Additional Calculations:** The Community Social Vulnerability Index (CSVI) is derived from social vulnerability indices (e.g., personal disruption, poverty, population composition, housing characteristics, housing disruption, labor force structure, and natural resource labor force).
- **Download data:** csv file

References

Jepson, Michael, and Lisa Lynne Colburn. 2013. "Development of Social Indicators of Fishing Community Vulnerability and Resilience in the US Southeast and Northeast Regions."

Lewis-Smith, Connor, and Karma Norman. 2024. "Developing US West Coast Recreational Fishing Community Measures: Applying an Index Approach in the Context of COVID-19 and Social Vulnerability." *Ocean & Coastal Management* 255: 107236.

Norman, Karma C. 2007. "Community Profiles for West Coast and North Pacific Fisheries: Washington, Oregon, California, and Other US States."

43 Fleet Income Diversification

Description Catches and prices from many fisheries exhibit high interannual variability, leading to high variability in fisher's revenue, but variability can be reduced by diversifying activities across multiple fisheries or regions (Kasperski and Holland 2013). Individuals may have good reasons to specialize, including reduced costs or greater efficiency; thus while diversification may reduce income variation, it does not necessarily promote higher average profitability. We use the Effective Shannon Index (ESI) to examine diversification of fishing revenue for more than 28,000 vessels fishing off the West Coast and Alaska over the last 40 years. The ESI increases as revenues are spread across more fisheries, and as revenues are spread more evenly across fisheries; ESI = 1 when a vessel's revenues are from a single species group and region; ESI = 2 if revenues are spread evenly across 2 fisheries; ESI = 3 if revenues are spread evenly across 3 fisheries; and so on. If revenue is not evenly distributed across fisheries, then the ESI value is lower than the number of fisheries a vessel enters.

Diversification can take other forms. Spreading effort and catch over the year, or simply fishing more weeks of the year, can both increase revenue and decrease interannual variation of revenue just as species diversification does. In fact, Abbott, Sakai, and Holland (2023) showed that reductions in revenue variation associated with species diversification can be explained mainly by increased temporal diversification, which can be achieved by fishing in multiple fisheries but also by fishing for more weeks of the year in a single fishery. Effective Shannon Index can also be used to examine how widely and evenly vessel revenues are spread across weeks of the year as an indicator or temporal diversification. Like the species diversification metric, this index increases the more weeks of the year a vessel has revenue and the more evenly that revenue is distributed across weeks. A vessel fishing 15 weeks of the year with the same revenue each of those weeks would have a temporal ESI of 15, and that number would decline as revenue is spread less evenly over the 15 weeks.

- **Indicators:**
  - vess_rev_5k
  - vess_rev_5k_fish_2023
  - vess_rev_5k_fish_1981-2023
  - vess_rev_5k_fish_1981
  - vess_rev_5_25k
  - vess_rev_25-100k
  - vess_rev_100k
  - vess_rev_5k_len_40
  - vess_rev_5k_len_41-80
  - vess_rev_5k_len_81-125
  - vess_2023_WA_rev_5k
  - vess_2023_OR_rev_5k
  - vess_2023_CA_rev_5k
  - vess_2023_WC_rev_5k_ave_5k-25k
  - vess_2023_WC_rev_5k_ave_25-100k

  - vess_2023_WC_rev_5k_ave_100k
  - vess_2023_WC_rev_5k_len_40
  - vess_2023_WC_rev_5k_len_41-80
  - vess_2023_WC_rev_5k_len_81-125
  - Port of Bellingham, WA
  - Port of Seattle, WA
  - Port of Westport, WA
  - Port of Ilwaco, WA
  - Port of Astoria, OR
  - Port of Newport, OR
  - Port of Charleston, OR
  - Port of Brookings, OR
  - Port of Crescent City, CA
  - Port of Eureka, CA
  - Port of Fort Bragg, CA
  - Port of San Francisco, CA
  - Port of Moss Landing, CA
  - Port of Santa Barbara, CA
  - Port of Ventura, CA
  - Port of San Pedro, CA
- **Component Category:** Human Wellbeing
- **Time Range:** 1981 - 2023
- **CCIEA Data Contact:** dan.holland@noaa.gov
- **Institution:** NOAA NWFSC/AFSC
- **Source Data:** Data derived from Pacific Fisheries Information Network (PacFIN) and Alaska Fisheries Information Network (AKFIN). Fishery diversification estimates provided by D. Holland, NMFS/NWFSC, and S. Kasperski, NMFS/AFSC.
- **Additional Calculations:** Aggregation and manipulaton of vessel level annual revenue data to create effective shannon index. For details, see: Kasperski, S. and D.S. Holland 2013. Income Diversification and Risk for Fishermen. Proceedings of the National Academy of Science. 100(6):2076-2081. doi: 10.1073/pnas.1212278110; Holland, D.S. and S. Kasperski 2016. The Impact of Access Restrictions on Fishery Income Diversification of US West Coast Fishermen. Forthcoming in Coastal Management.
- **No download available**

References

Abbott, Joshua K, Yutaro Sakai, and Daniel S Holland. 2023. "Species, Space and Time: A Quarter Century of Fishers' Diversification Strategies on the US West Coast." *Fish and Fisheries* 24 (1): 93–110.

Kasperski, Stephen, and Daniel S Holland. 2013. "Income Diversification and Risk for Fishermen." *Proceedings of the National Academy of Sciences* 110 (6): 2076–81.

44 Non-Fishery Income Diversification

Description Compared to many other professions, fishers face unusually high year-to-year variability in their income levels. Diversifying fishing income can help reduce income variability and reduce financial risk, but focusing solely on diversification opportunities within the fishery misses a potentially important form of financial risk reduction - income diversification from non-fishing occupations (i.e., livelihood diversification). Livelihood diversification may actually be a more effective form of financial risk reduction for fishing households if their non-fishing income streams are unaffected by changes in fishery productivity or profitability or if they can be actively increased when fishing income is low.

Levels and trends in non-fishery income diversification have not been presented previously due to a lack of regularly collected data on non-fishery income (NFI). To address this and other informational gaps, the NWFSC began periodically surveying West Coast fishing vessel owners on a triennial basis with surveys carried out in 2017, 2020, and 2023. Surveys were sent to all vessel owners with commercial revenue from West Coast fisheries (federal and state) the prior year. Response rates were around 50% in 2017 and 2020 with over 1400 surveys returned each year. The response rate in 2023 fell to 40% with 1163 surveys returned.

Among other questions, the surveys ask fishing vessel owners what percentage of their household income came from fishing versus non-fishing sources in the prior calendar year (e.g. 2022 for the 2023 survey) and also what percentage of the income they personally contribute to the household is from non-fishery sources. The survey also asks vessel owners that personally contributed NFI to their household what type of non-fishing work they did. Treakle and Holland (2023) provides a detailed analysis of the survey data on non-fishing income from the 2017 and 2020 surveys.

Indicator Category Human Wellbeing

Data Steward Dan Holland; dan.holland at noaa.gov

Institution NOAA NWFSC/AFSC

Additional Information Data are collected and analyzed independently by D. Holland, who submits unpublished figures and plots to the CCIEA editorial team.

The West Coast Fisheries Participation Survey tool can be accessed at the following link: https://www.fisheries.noaa.go
data/west-coast-fisheries-participation-survey-results

References

Treakle, Abbott, T., and D. S Holland. 2023. "Not by Fishing Alone: Non-Fishing Employment and Income for US West Coast Fishers." *Ocean & Coastal Management* 243: 106763.

45 Fishery Revenue Concentration

Description Along with factors like processor availability and local infrastructure influence, variability in port-level landings can impact the overall distribution of fishing revenue along the coast. The Theil Index metric assesses the geographic concentration of fishing revenues, and is used to track progress toward meeting NS-8. The index estimates the difference between observed revenue concentrations and what they would be if they were perfectly equally distributed across ports; higher values indicate greater concentration in a subset of ports. Annually, we calculate the Theil Index for all fisheries and for specific management groups, at the scale of the 21 port groups previously established for the economic Input-Output model for Pacific Coast fisheries (Leonard and Watson 2011).

- **Species:**
  - All fisheries
  - Coastal pelagics
  - Crab
  - Groundfish
  - Highly migratory species
  - Other species
  - Salmon
  - Shrimp and prawns
- **Component Category:** Human Wellbeing
- **Time Range:** 1981 - 2023
- **CCIEA Data Contact:** karma.norman@noaa.gov
- **Institution:** NOAA NWFSC
- **Source Data:** Theil Index and annual commercial fishery revenue data provided by K. Norman, NMFS/NWFSC, and A. Phillips, PSMFC, with data derived from PacFIN (http://pacfin.psmfc.org).
- **Additional Calculations:** As a potential indicator to track progress toward meeting NS-8, we use a metric called the Theil Index to assess geographic concentration of fishing revenues. The index estimates the difference between observed revenue concentrations and what they would be if they were perfectly equally distributed across ports; higher values indicate greater concentration in a subset of ports. We calculate the Theil Index for total fisheries and for specific management groups, at the scale of the 21 port groups previously established for the economic Input-Output model for Pacific Coast fisheries (IO-PAC; Leonard and Watson 2011).
- **Download data:** csv file

References

Leonard, Jerry Lamar, and Philip Scott Watson. 2011. "Description of the Input-Output Model for Pacific Coast Fisheries; NOAA Technical Memorandum NMFS-NWFSC ; 111." https://repository.library.noaa.gov/view/noaa/8718.

46 Fisheries Participation Networks

Description Vessel-level fisheries participation networks (FPNs] provide a visual representation of the portfolio of fisheries that are economically-important to individual vessels within a port group and represent how diversified harvest portfolios create connections between fisheries (Fuller et al. 2017; Fisher et al. 2021). FPNs have shown how West Coast networks change over time, how groundfish fisheries are connected to other fisheries in different IO-PAC port groups (Chris J. Harvey et al. 2022), and the vulnerability of West Coast port groups to future shocks to salmon fishing, based on economic dependence (a measure of sensitivity) and a resilience index based on fisheries connectivity (a measure of adaptive capacity) (Harvey et al. 2023). More recently, we compare the number of active salmon vessels and the revenue of commercial salmon vessels between two periods (2017-2022 and 2022-2023) for West Coast port groups.

As fishers diversify their harvest portfolios, they create connections between fisheries, even when ecological links between the target species are weak or absent. In previous reports (Chris J. Harvey et al. 2021, 2022; C. J. Harvey et al. 2023; Leising et al. 2024), we used fisheries participation networks (Fuller et al. 2017; Fisher et al. 2021) as a way to represent this information about how fisheries are connected through shared participation patterns. In these networks, fisheries are depicted as nodes, and pairs of nodes are connected by lines called 'edges' that integrate information about vessels participating in both fisheries. Changes in network structure over time reflect changes in the ecology of adjacent coastal waters, as well as the legacy of management, markets, and other factors.

Indicator Category Human Wellbeing

Data Steward Samhouri; jameal.samhouri@noaa.gov

Additional Information Data are collected and analyzed independently by J. Samhouri, who submits unpublished figures and plots to the CCIEA editorial team.

Data sources The networks are derived from landings receipts and summarized annually from week 46 in one year through week 45 in the following year (e.g., November 2020 to November 2021) to capture the beginning of the Dungeness crab fishing season. Fisheries landings data were retrieved from the Pacific Fisheries Information Network (PacFIN; http://pacfin.psmfc.org) database. We note that in Washington, fish tickets include a port assigned based on the actual port of landing or derived from the license database; prior to 2018, most port data were derived.

Data extraction To focus the analysis on vessels that derive a substantial amount of income from commercial fishing, we include only vessels that generate at least $5,000 annually in total fisheries revenue. In addition, vessels must generate at least $500 of revenue from a given fishery (node) to be included as participants in that fishery. We assume that economically-important fisheries are those that contribute to at least a median of 10% of the annual revenue of associated vessels. Vessels are represented in all port groups for which their landings meet these conditions. To maintain confidentiality, we include only fisheries with at least three vessels participating in a port group.

In network graphs, node size represents the median proportional contribution of a fishery to annual vessel-level revenue; it is scaled relative to the fishery with the maximum median proportional contribution to annual vessel-level revenue in each network, summarized by port group. Therefore, node sizes are not comparable across port groups, only within them. The edges connecting pairs of nodes indicate that vessels participate in both fisheries, and the widths of these edges scale with the number of vessels exhibiting this behavior, as well as the total amount and evenness of revenue generation from each pair of fisheries. As with node sizes, edge widths are not comparable across port groups, only within them.

Data analysis

References

Fisher, Mary C, Stephanie K Moore, Sunny L Jardine, James R Watson, and Jameal F Samhouri. 2021. "Climate shock effects and mediation in fisheries." *Proceedings of the National Academy of Sciences* 118 (2): e2014379117.

Fuller, Emma C, Jameal F Samhouri, Joshua S Stoll, Simon A Levin, and James R Watson. 2017. "Characterizing fisheries connectivity in marine social–ecological systems." *ICES Journal of Marine Science* 74 (8): 2087–96.

Harvey, C. J., N. T. Garfield, G. D. Williams, and N. Tolimieri. 2023. "California Current Integrated Ecosystem Assessment (CCIEA) California Current Ecosystem Status Report, 2023. Report to the Pacific Fishery Management Council. March 2023, Agenda Item i.1.a."

Harvey, Chris J, Newell Toby Garfield, Gregory D Williams, and Nicholas Tolimieri. 2021. "Ecosystem Status Report of the California Current for 2020-21: A Summary of Ecosystem Indicators Compiled by the California Current Integrated Ecosystem Assessment Team (CCIEA).NOAA Technical Memorandum NMFS-NWFSC-170." https://doi.org/https://doi.org/10.25923/x4ge-hn11.

———. 2022. "California Current Integrated Ecosystem Assessment (CCIEA) California Current Ecosystem Status Report, 2022. Report to the Pacific Fishery Management Council. March 2022, Agenda Item i.1.a."

Leising, A., Hunsicker M., Tolimieri N., Williams G., and Harley A. 2024. "California Current Integrated Ecosystem Assessment (CCIEA) California Current Ecosystem Status Report, 2024. Report to the Pacific Fishery Management Council. March 2024, Agenda Item i.1.a."