STATE OF THE CALIFORNIA CURRENT 2016–17: STILL ANYTHING BUT "NORMAL" IN THE NORTH

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THE SHORT VERSION

From: Bill Peterson - NOAA Federal
<bill.peterson@noaa.gov>
Date: Mon, Apr 17, 2017 at 10:09 AM
Subject: Re: CalCOFI report 2016–17
To: Sam McClatchie - NOAA Federal
<sam.mcclatchie@noaa.gov>
Cc: Brian Wells brian.wells@noaa.gov …

Brian, Sam, and Others:

The ocean off Oregon is anything but "normal." Even though SST had cooled down a bit, we still have relatively warm/fresh water at depth as well as strong positive anomalies in copepod species richness and southern copepod biomass—all indicators that we still have a lot of "El Niño water" hanging around. And returns of adult spring Chinook past Bonneville Dam (Columbia River) are 10% of the ten-year average so far. Finally we are seeing small numbers of *Pseudo-nitzschia*. Nothing normal! The only good news is that *Euphausia pacifica* have returned.

Some years ago, we did a "warm in the north, cold in the south" (or was it the opposite title?).

Bill

ABSTRACT

This report examines the ecosystem state of the California Current System (CCS) from spring 2016–spring 2017. Basin-scale indices suggest conditions that would support average to below average coast-wide production across the CCS during this time period. Regional surveys in 2016 sampled anomalously warm surface and subsurface waters across the CCS. Chlorophyll concentrations were low across the CCS in 2016 and, concomitant with that, copepod communities had an anomalously high abundance of subtropical species. Early in 2017 conditions between northern, central, and southern CCS were dissimilar. Specifically, surface conditions north of Cape Mendocino remained anomalously warm, chlorophyll was very low, and subtropical copepods were anomalously abundant. Southern and central CCS surveys indicated that environmental conditions and chlorophyll were within normal ranges for the longer time series, supporting an argument that biophysical conditions/ecosystem states in the southern and central CCS were close to normal.

Epipelagic micronekton assemblages south of Cape Mendocino were generally close to longer-term average values, however the northern assemblages have not returned to a "normal" state following the 2014–15 large marine heatwave and 2016 El Niño. North of Cape Mendocino the epipelagic micronekton was largely composed of offshore and southern derived taxa. We hypothesize that stronger-than-typical winter downwelling in 2017 and a reduced spawning biomass of forage taxa are contributors to the anomalous forage community observed in the north. Also of note, surveys indicate northern anchovy (*Engraulis mordax*) abundance was greater than average (for recent years) and nearer shore in northern regions. Finally, record-low juvenile coho and Chinook salmon catches in the 2017 northern CCS salmon survey suggest that out-migrating Columbia Basin salmon likely experienced unusually high early mortality at sea, and this is further supported by similarities between the 2017 forage assemblage and that observed during poor outmigration survival years in 2004, 2005, and 2015.

Generally, the reproductive success of seabirds in 2016 (the most current year available) was low in the north but near average in central California. At Yaquina Head off Oregon and Castle Rock off northern California some of the lowest reproductive success rates on record were documented. In addition to reduced abundance of prey, there was a northward shift of preferred seabird prey. Seabird diets in northern areas also corroborated observations of a northward shift in fish communities. Nest failure was attributed to a combination of bottom-up and top-down forces. At Castle Rock, most chicks died of starvation whereas, at Yaquina Head, most nests failed (95% of common murre, *Uria aagle*) due to disturbance by bald eagles (*Haliaeetus leucocephalus*) seeking alternative prey. Mean bird densities at sea for the 2017 surveys between Cape Flattery Washington and Newport Oregon were the lowest observed and may indicate continued poor reproductive performance of resident breeders in 2017. South of Cape Mendocino, where forage availability was typical, seabird reproductive success was also below average for most species in 2016, but did not approach failure rates observed in the north. Finally, in 2017, abundances of seabirds observed at-sea off southern California were anomalously high suggesting an improved foraging environment in that area.

Marine mammal condition and foraging behavior were also impacted by the increased abundance and shifting distribution of the northern anchovy population. Increases in the abundance of northern anchovy in the Southern California Bight coincided with improved condition of sea lion (*Zalophus californianus*) pups in 2016. Namely, lipid-rich northern anchovy occurred in great frequencies in the nursing female diet. Increases in northern anchovy nearshore in the central and northern CCS may have also contributed to a shoreward shift in distribution of humpback whales (*Megaptera novaeangliae*) in these regions. These shifts along with recovering humpback whale populations contributed to recent increases in human-whale interactions (e.g., fixed-gear entanglements).

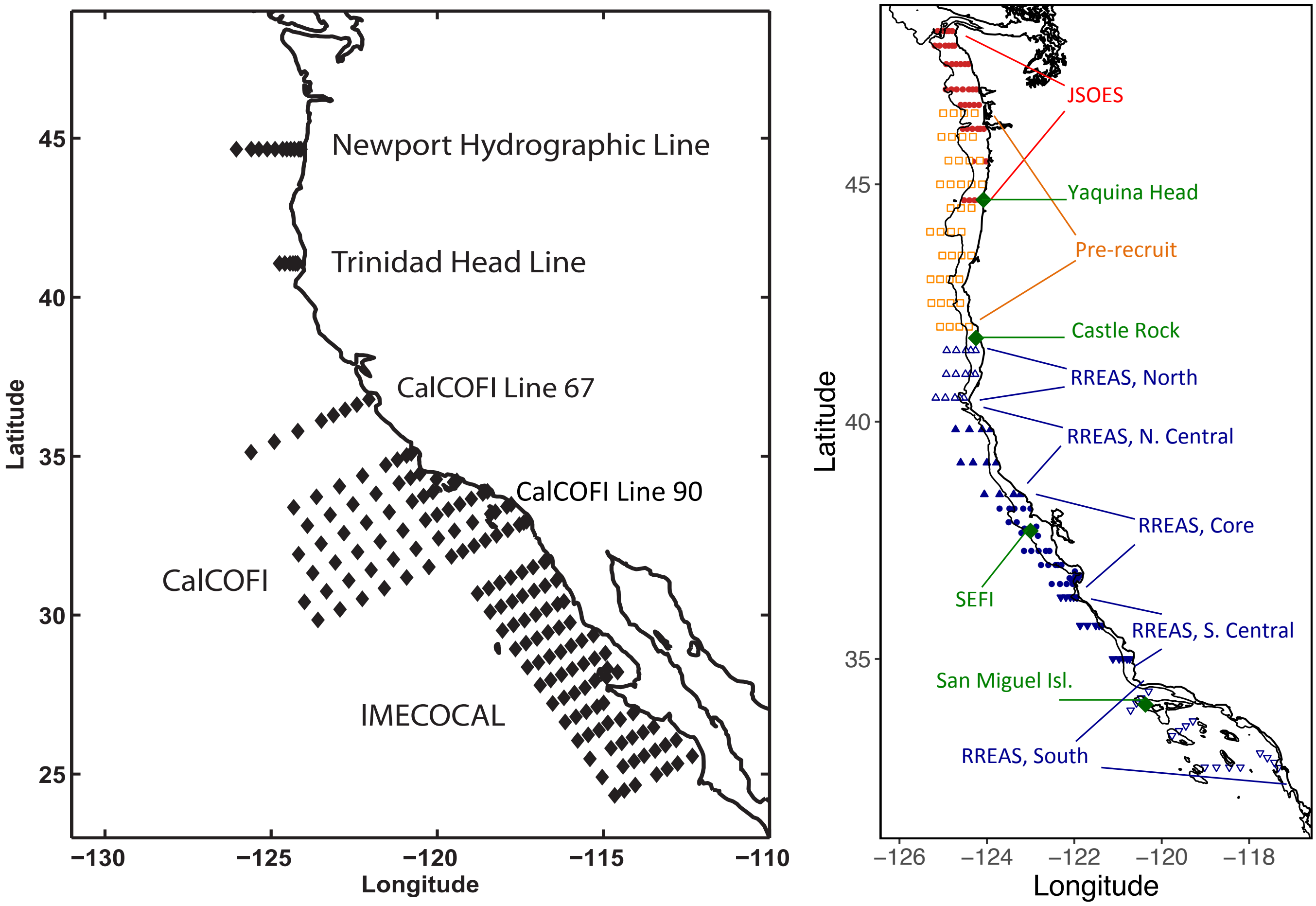


Figure 1. Left) Station maps for surveys that were conducted multiple times per year during different seasons to provide year-round observations in the California Current System. The CalCOFI survey (including CalCOFI Line 67 and 90) was occupied quarterly; the winter and spring CalCOFI survey grid usually extends just north of San Francisco. The IMECOCAL survey is conducted quarterly or semiannually. The Newport Hydrographic Line was occupied biweekly. The Trinidad Head Line was occupied at biweekly to monthly intervals. Right) Location of annual or seasonal surveys, including locations of studies on higher trophic levels, from which data were included in this report. Different symbols and colors are used to help differentiate the extent of overlapping surveys. Surveys used in this report include (Red) Juvenile Salmon and Ocean Ecosystem Survey (JSOES, NOAA/BPA rope trawl), (Orange) NWFSC Pre-recruit midwater trawl survey, and (Blue) SWFSC Rockfish Recruitment and Ecosystem Assessment Survey (RREAS) in five regions. SEFI indicates Southeast Farallon Island.

INTRODUCTION

From 2014 to 2017 the California Current System (CCS) had an unprecedented combination of warm-water conditions that may affect CCS marine life for a number of years, there was a large marine heat wave from 2014–16, influenced in part by anomalously warm conditions in the tropical Pacific that were punctuated by the 2015–16 El Niño (Leising et al. 2015; Jacox et al. 2016; Di Lorenzo and Mantua 2016; McClatchie et al. 2016; Frischkneckt et al. 2017; Peterson et al. 2017). This report revisits these years when applicable to current ecosystem conditions but primarily examines the state from spring 2016–spring 2017; this report is an extension of the previous State of the California Current report (McClatchie et al. 2016). Specifically, following on previous reports, we consolidate environmental and survey data from throughout the California Current (fig. 1). These data include indicators of basin-scale conditions, regional oceanographic conditions, and the food-web from primary production to top-predator foraging behavior, reproductive success, and condition. Although many results are preliminary and encompass dissimilar survey designs, synthesis of these diverse components provides a first approximation of the coast-wide and regional ecosystem conditions. Typical of these reports, we highlight emerging stories as supported by the available data and explore the connections between past, current, and future CCS ecosystem states. This year's report will focus on the clear disparity between ecosystem recoveries following the record 2014–16 warming of the CCS in northern and southern CCS subregions. Specifically, while the southern region trended toward a "normal" ecosystem state in 2016–17, the northern region did not (e.g., there was a persistence of the southern copepod community, limited forage availability, anomalously high salmon mortality,

TABLE 1
**State of various indicators along California Current System (CCS).
The status represents early 2017 unless otherwise stated. Grey font indicates average production/condition, red indicates below average production/condition, and green indicates above average production/condition.
Italics represent data cited from elsewhere within this report or preliminary analyses discussed in this report.
Abbreviations: Oceanic Niño Index (ONI), Pacific Decadal Oscillation (PDO),
North Pacific Gyre Oscillation (NPGO), North Pacific High (NPH), and sea surface temperature (SST).**

Indicator	Basin	Northern CCS	Central CCS	Southern CCS
ONI	Average			
PDO	Above average			
NPGO	Near average			
NPH	Below average			
Upwelling		Below average	Average	Above average
Cumulative upwelling		Average	Below average	Average
SST		Above average	Average	Average
Chlorophyll		Below average	Average	Average
Harmful algal blooms		No	No	Yes
Copepods		Southern derived and rich	—	—
Forage		offshore and southern derived assemblage	Typical assemblage	Typical assemblage along with increased anchovy abundances
Salmon survival		Below average juvenile abundance at sea	*Ecosystem indicators related to salmon suggest average*	—
Seabird productivity (2016)		Reproductive failures	Below/near average	—
Seabird at-sea abundance		Well below average	*Below/near average*	Well above average
Sea lions (2016)		Signs of recovery after the 2013 unusual mortality event		
Whales			Humpback whales distributed shoreward	

unprecedented abundance of pyrosomes, and reduced reproductive success of seabirds) (table 1).

BASIN-SCALE CONDITIONS

North Pacific Climate Indices

The CCS experienced a marine heat wave that featured record-high sea surface temperatures (SST) in 2015, with 2014–16 the warmest 3-year period on record (Jacox et al. 2017). The exceptionally high SST anomalies declined from their peak values in spring/summer 2016. The marine heatwave was first evident in the Gulf of Alaska in late 2013 (Bond et al. 2015) and by the middle of 2014, anomalously high SST anomalies were also observed in the southern CCS as far south as Baja California (Leising et al. 2015).

El Niño/Southern Oscillation (ENSO) is a mode of interannual variability in the equatorial Pacific causing physical and ecological impacts throughout the Pacific basin and CCS, though the links between ENSO and the CCS are complex (Fiedler and Mantua 2017). The Oceanic Niño Index (ONI; http://www.cpc.ncep.noaa.gov/data/indices/), a three-month running mean of SST anomalies averaged over the NINO3.4 region of 5°S–5°N and 120°W–170°W, had values exceeding the 0.5°C threshold that signifies an El Niño event from April 2015 through May 2016 (fig. 2). Peak ONI values in 2015–16 rivaled those of the record 1997–98 El Niño event, but this tropical climate event was perhaps not quite as extreme (Jacox et al. 2016). Negative ONI values, indicative of a tropical La Niña event, first appeared during July 2016, but declined only to –0.84°C indicating a modest intensity La Niña during October–November 2016. By March 2017 the ONI had transitioned to ENSO-neutral conditions, with small positive values below the 0.5°C threshold. NOAA's Climate Prediction Center [1] has issued a report stating that El Niño neutral conditions were present during the summer of 2017 and they predict that there are growing odds for a tropical La Niña event in winter 2017–18.

The Pacific Decadal Oscillation (PDO) index describes the temporal evolution of dominant spatial patterns of SST anomalies over the North Pacific (Mantua et al. 1997). Positive PDO values are also associated with a shallower upwelling cell in the northern CCS (Di Lorenzo et al. 2008). The PDO values from January 2015 to the spring of 2016 were exceptionally high. By summer of 2016 the PDO values dropped considerably and reached their lowest values since the spring of 2014 (fig. 2). However, the winter 2016–17 PDO values were slightly elevated from these, only to decline to near-zero values in July–August 2017 (fig. 2).

The North Pacific Gyre Oscillation (NPGO) is a low-frequency signal of sea surface height, indicating variations in the circulation of the North Pacific Subtropical Gyre and Alaskan Gyre (Di Lorenzo et al. 2008). Positive values of the NPGO are linked with increased equatorward flow in the California Current, along with increased surface salinities, nutrients, and chlorophyll values in the southern-central CCS (Di Lorenzo et al. 2009). Negative

[1] http://www.cpc.ncep.noaa.gov

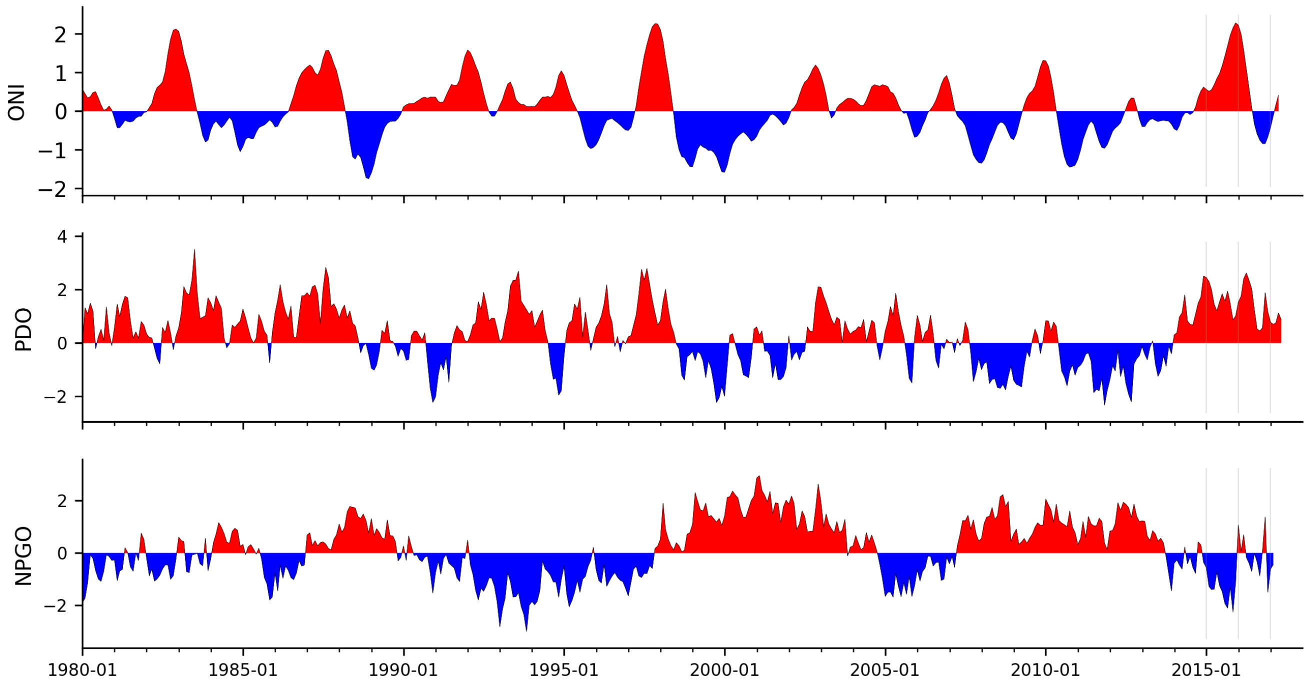


Figure 2. Time series of monthly values for three ocean climate indices especially relevant to the California Current: Oceanic Niño Index (ONI), the Pacific Decadal Oscillation (PDO), and North Pacific Gyre Oscillation (NPGO). Data are shown for January 1980 to July 2017. Vertical lines mark January 2015, 2016, and 2017.

NPGO values are associated with decreases in these variables, inferring less subarctic source waters, fewer nutrients, reduced upwelling and generally lower production in the CCS. The NPGO was negative for the entirety of 2015, with the largest negative values occurring in the fall (fig. 2). During 2016 the NPGO oscillated from positive to negative values that were very small in amplitude. The winter 2016–17 NPGO values were negative with December 2016 having the largest negative value of –1.5. Thus, NPGO index indicated that basin-scale gyre circulation favored low to neutral production across the CCS between spring 2016–spring 2017.

In summary, 2015–16 had extreme positive ONI and PDO index values, and extremely low NPGO index values, all pointing toward increased subtropical influences and reduced subarctic influences in the CCS. Summer 2016 to spring 2017 featured a modest La Niña event and reduced amplitudes in the PDO and NPGO indices, such that these basin-scale patterns were not indicating large fluctuations on the state of the CCS ecosystem over that period.

North Pacific Climate Patterns

A basin-scale examination of SST and surface wind anomalies allows for the interpretation of the spatial evolution of climate patterns and wind forcing over the North Pacific related to trends in the basin-scale and upwelling indices (figs. 3, 4). During July 2016, negative SST anomalies in the central and eastern Equatorial Pacific marked the transition between the El Niño event that peaked in winter 2015–16 and the La Niña event that peaked in winter 2016–17 (fig. 3). Tropical La Niña conditions dissipated by May 2017. During the summer of 2016, SST anomalies exceeding 1˚C were evident in the Bering Sea and the Gulf of Alaska. These positive anomalies persisted into the winter of 2016–17. The SST approached the long-term average by May 2017 in the central and southern CCS but remained warmer than average along the northern CCS.

Wind anomalies over the Bering Sea and Gulf of Alaska were anomalously eastward in July and December 2016 and a large anti-cyclonic pattern was centered at 42˚N, 160˚W due to higher than average sea level pressures during July and December 2016 (fig. 3). High SST anomalies associated with the marine heatwave had dissipated along the west coast of North America by July 2016, with only the Southern California Bight and along the Baja Peninsula showing SST anomalies greater than 1˚C. From December 2016 to May 2017 SST along the West Coast were near the long-term mean, with slightly elevated temperatures along the Washington and Oregon coasts and southern Baja California, Mexico (figs. 3, 4). Alongshore winds were average during July 2016, but strengthened in December 2017. February 2017 winds were anomalously northward, associated with an unusual number of winter storms and excessive rainfall along the West Coast (fig. 3)[2]. Upwelling-favorable (southward) winds resumed by May 2017.

[2] https://www.ncdc.noaa.gov/sotc/drought/201702

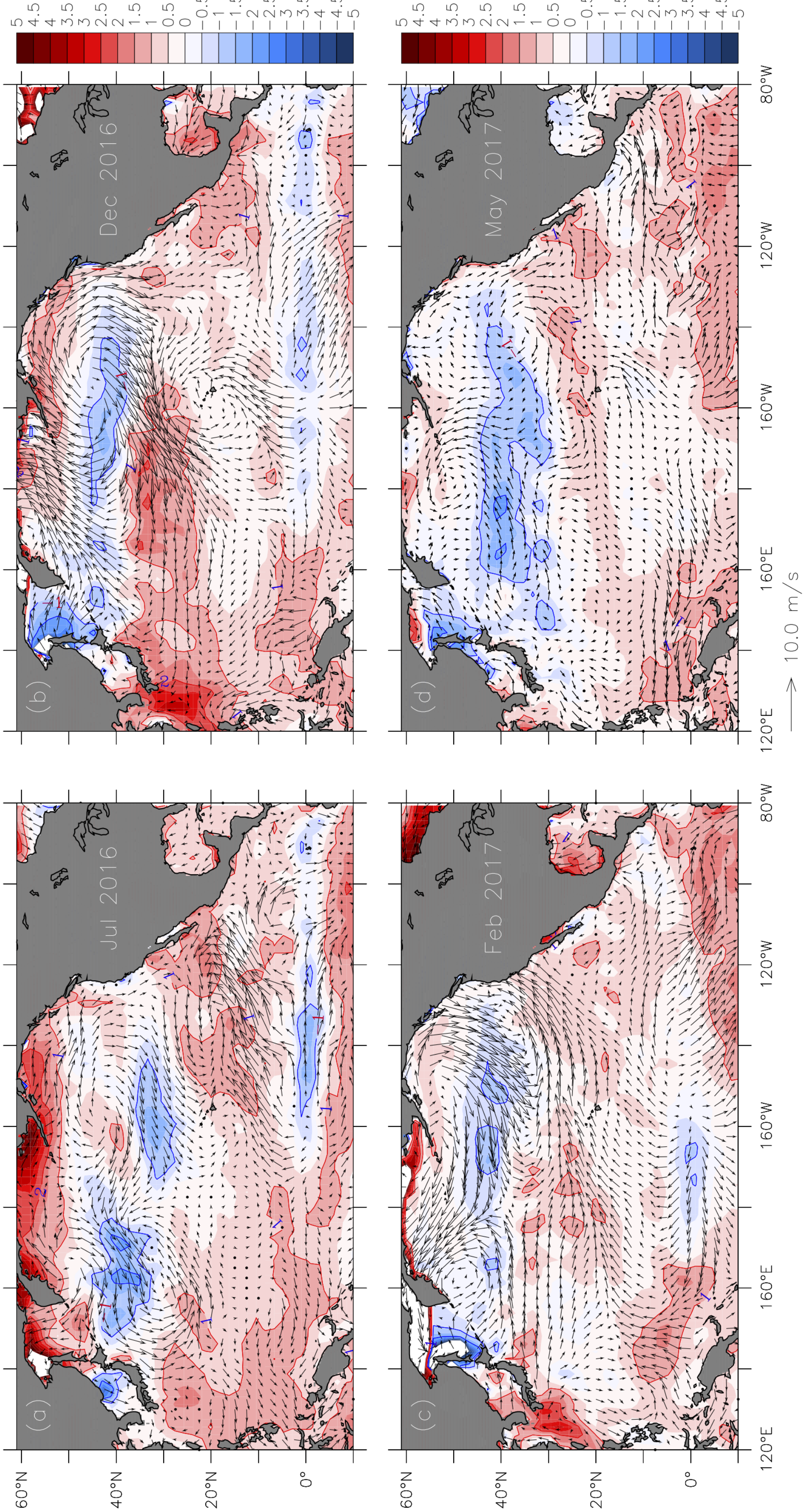


Figure 3. Anomalies of surface wind velocity and sea surface temperature (SST) in the North Pacific Ocean for July 2016, December 2016, February 2017, and May 2017. Arrows denote magnitude and direction of wind anomaly (scale arrow at bottom). Shading interval is 0.5°C and contour intervals of 1 and 2°C are shown. Negative (cool) SST anomalies are shaded blue. Wind climatology period is 1968–96. SST climatology period is 1950–79. Both SST and wind data are from NCEP/NCAR Reanalysis and were obtained from http://www.esrl.noaa.gov.

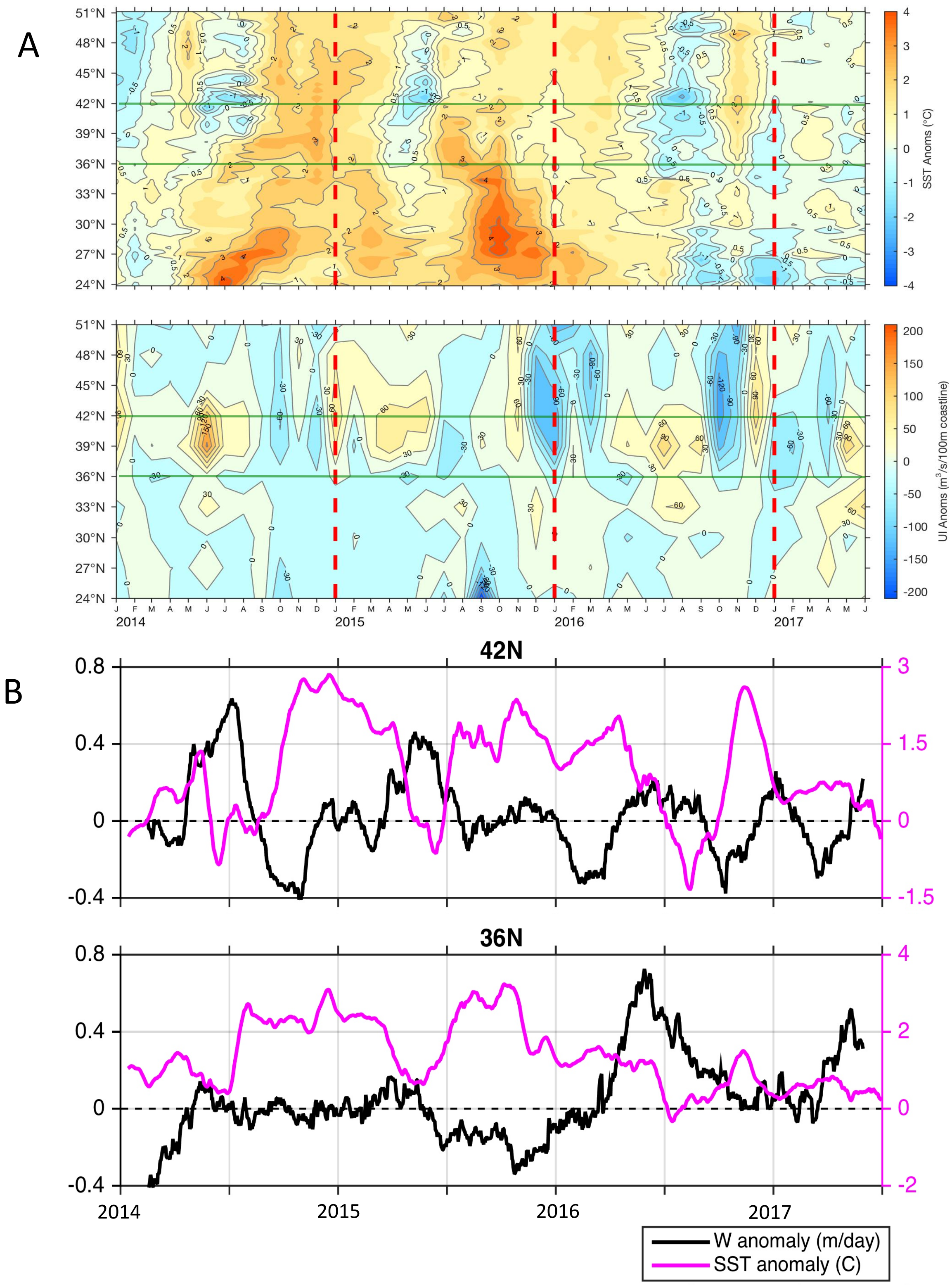


Figure 4. A) Monthly sea surface temperature (SST) anomalies (top) and upwelling index (UI) anomalies (bottom) for January 2014–June 2017. The SST anomalies are averaged from the coast to 100 km offshore. Positive and negative upwelling anomalies denote greater than average upwelling or downwelling (usually during the winter), respectively. Anomalies are relative to 1982–2017 monthly means. Daily optimum interpolation AVHRR SST data obtained from http://coastwatch.pfeg.noaa.gov/erddap/griddap/ncdcOisst2Agg. Six-hourly upwelling index data obtained from http://oceanview.pfeg.noaa.gov/erddap/tabledap/. B) Upwelling anomalies (black) and SST anomalies (magenta) relative to the 1999–2011 climatology, derived from a data assimilative ocean reanalysis of the California Current System (http://oceanmodeling.ucsc.edu/ccsnrt/), are shown at two latitudes off the US West Coast; 36°N and 42°N (indicated by horizontal green lines in A). Values are averaged from the coast to 100 km offshore. SST is smoothed with a 30-day running mean; upwelling, which is much noisier, is smoothed with a 90-day running mean.

COAST-WIDE CONDITIONS

Upwelling in the California Current

Monthly anomalies of SST (averaged from the coast to 100 km offshore) and upwelling are used to examine anomalous coastal upwelling conditions within the CCS from January 2014 to July 2017 (fig. 4). Upwelling estimates come from two sources: the Bakun upwelling index (UI; fig. 4a; Bakun 1973; Schwing et al. 1996), and a data-assimilative regional ocean model (W; fig. 4b; Jacox et al. 2014)[3]. We take this approach as the UI has long been used in studies of the California Current, but in some places, particularly south of 39˚N, it is a less reliable indicator of upwelling due to relatively poor estimation of the wind stress and modulation of upwelling by the cross-shore geostrophic flow (Bakun 1973; Jacox et al. 2014). SST anomalies along the coast are driven by upwelling, especially in northern latitudes due to a strong coupling between local winds and SST (Frischknecht et al. 2015). High SST anomalies due to the marine heat wave are evident in 2014 and 2015. Positive SST anomalies (>1˚C) during the 2015–16 El Niño event persisted during the winter and spring of 2016 especially for locations north of 42˚N. From January to May of 2017, SST anomalies north of 42˚N were near the long-term average, with the exception of a few localized periods of ~0.5˚C anomalies. UI anomalies from 39˚ to 45˚N were positive during the spring and summer of 2015, but anomalously strong downwelling occurred in the winter of 2015–16 (typical of past El Niño winters). The longest period of sustained positive upwelling anomalies during 2016 occurred from July to September for latitudes between 36˚ and 42˚N. October and November 2016 upwelling anomalies were negative north of 36˚N, followed by positive anomalies (weaker downwelling) in December. On the whole, upwelling during 2017 has been about average from 39˚ to 42˚N, weaker than average farther north, and stronger than average farther south.

The cumulative upwelling index (CUI) is the cumulative sum of the daily UI values starting January 1 and ending on December 31, and it provides an estimate of the net influence of upwelling on ecosystem structure and productivity over the course of the year (Bograd et al. 2009). In general, upwelling has been weaker for the last two years, 2016–17, than the previous two years, 2014–15 (fig. 5). During the 2016 winter, upwelling north of 39˚N was low due to the El Niño and strong upwelling only began by the summer. South of 39˚N, upwelling anomalies were neutral to positive in early 2016, counter to what would be expected from a strong El Niño (Jacox et al. 2015). Upwelling during 2017 was near the long-term average for the whole coast except for the latitudes between 36˚–42˚N. For these latitudes, the CUI curves during the winter were below the climatological curve and stronger upwelling began by the beginning of May.

Periods of upwelling or, farther north, reduced downwelling during the winter can limit stratification and facilitate introduction of nutrients to the surface acting to precondition the ecosystem for increased production in the spring (Schroeder et al. 2009; Black et al. 2010). The area of the surface atmospheric pressures associated with the North Pacific High (NPH) can be used as an index of this winter preconditioning (Schroeder et al. 2013). Since 2014 there has been a continual weak NPH during the winter (fig. 6). The January–February mean of the NPH area has been very small since the exceptionally large area during 2013, and the 2017 area was the smallest size since 2010.

Coastal Sea Surface and Subsurface Temperatures

SSTs measured by National Data Buoy Center buoys along the West Coast were mostly above long-term averages during summer of 2015 through spring of 2016 (fig. 7). For the northern buoys, this period of warm temperature was briefly interrupted by a decrease in temperatures during August or September that coincided with a strong period of upwelling favorable winds. The decrease in temperatures associated with upwelling was also evident in April and May 2016 for the buoys located off California. For all buoys, warm to exceptionally warm temperatures were recorded during October and November 2016, which decreased greatly in December and January 2017 during a period of strong southward winds. The winter storms that brought excessive rainfall to the West Coast January–February 2017 were accompanied by episodes of strong northward winds lasting approximately a week at a time (fig. 7).

Figure 8 shows January 2014–May 2017 upper ocean temperature anomalies from ROMS averaged from the coast to 100 km offshore at latitudes of 33, 36, 39 and 42˚N. From Cape Blanco (42˚N) to central California (36˚N) near-surface temperature was above average from the summer of 2014 through spring of 2016; yet, at depths greater than ~50 m, cool anomalies were often present. The exception of the warm surface and cool subsurface conditions was during winter 2015–16 when above average temperatures existed throughout the entire water column. This is

[3] A data-assimilative configuration of the Regional Ocean Modeling System (Shchepetkin & McWilliams 2005; Haidvogel et al. 2008) has been used to produce a reanalysis of the California Current circulation extending back in time to 1980 (Neveu et al. 2016) and continuing to present in near real time (http://oceanmodeling.ucsc.edu/ccsnrt).

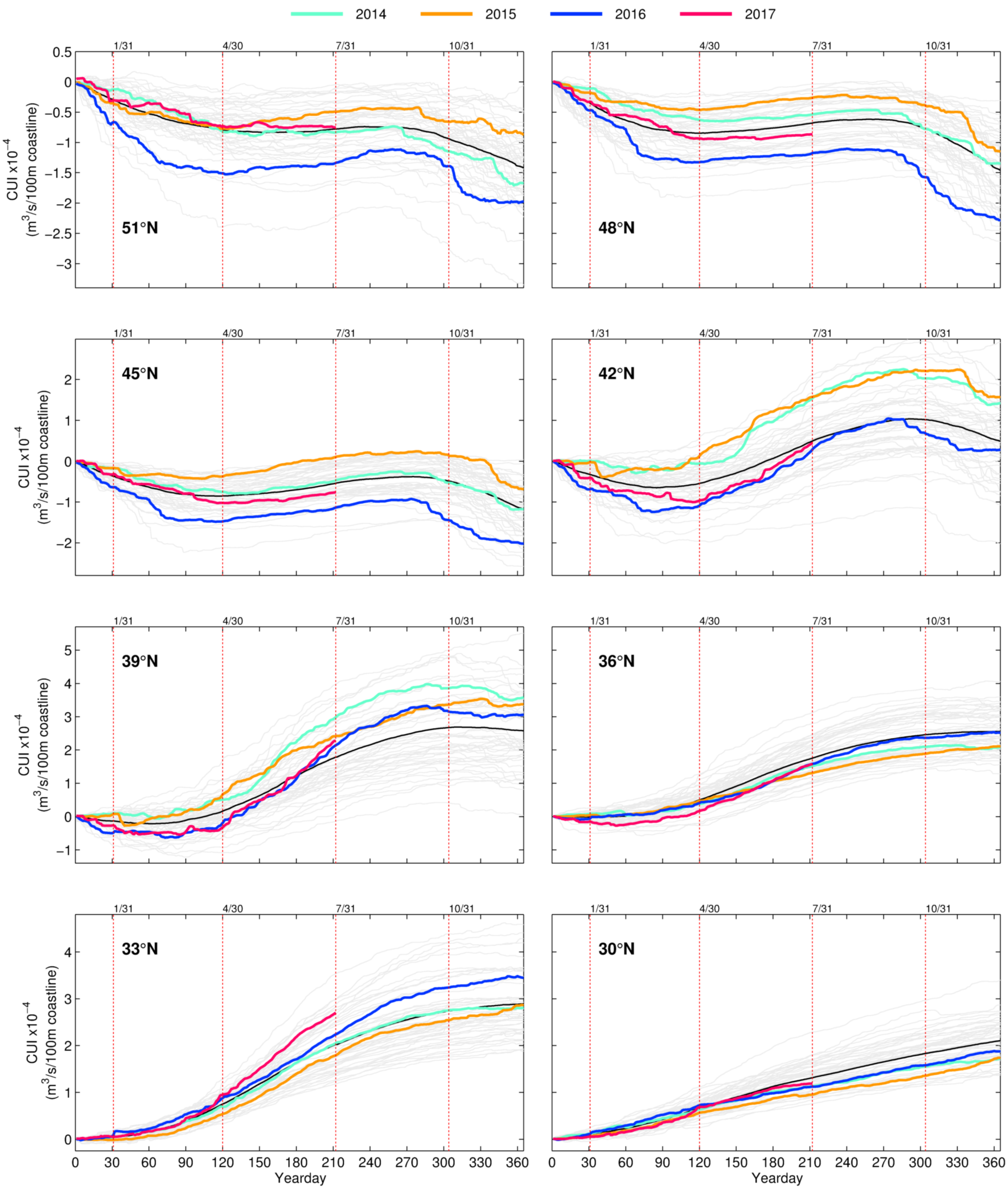


Figure 5. Cumulative upwelling index (CUI) starting on January 1 calculated from the daily upwelling index at locations along the west coast of North America. Grey lines are all yearly CUI for 1967–2016, colored CUI curves are for the years 2014–17. The climatological mean CUI is the black line. The red dashed vertical lines mark the end of January, April, July and October. Daily upwelling index data obtained from http://upwell.pfeg.noaa.gov/erddap/.

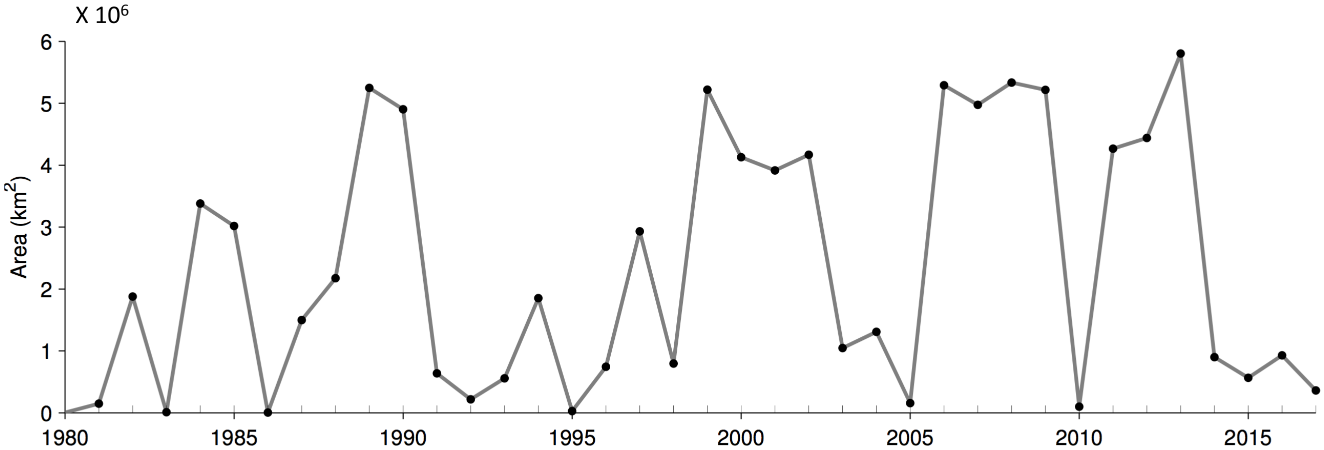


Figure 6. The area of high atmospheric pressure of the North Pacific High averaged over January and February each year (Schroeder et al. 2013). The area is the areal extent of the 1020 hPa isobar located in the eastern North Pacific.

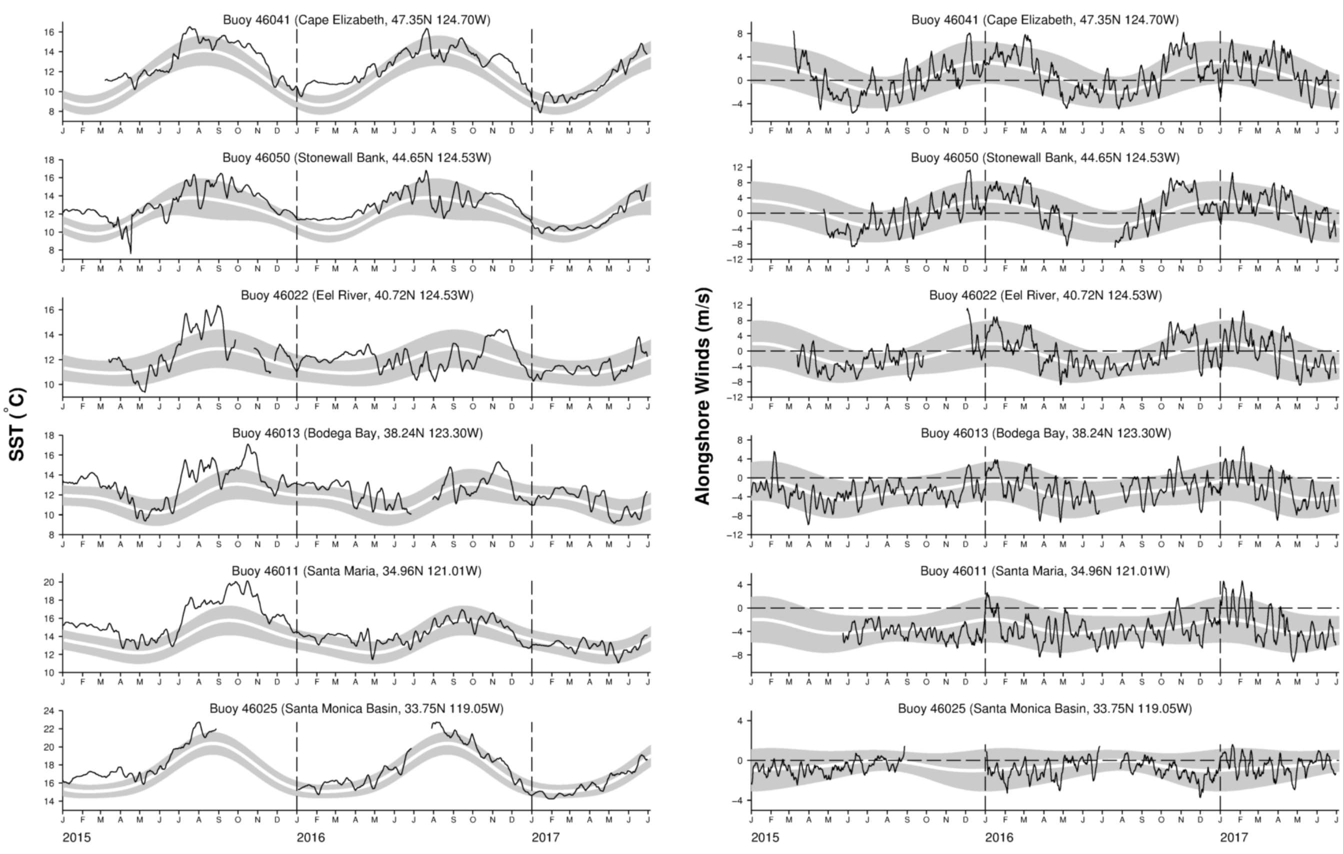


Figure 7. Time series of daily sea surface temperatures (left) and alongshore winds (right) from various National Data Buoy Center (NDBC) coastal buoys along the CCS for January 2015 to June 2017. The wide white line is the biharmonic annual climatological cycle at each buoy. Shaded areas are the standard errors for each Julian day. Series have been smoothed with a 7-day running mean. Data provided by NOAA NDBC. Additional buoy information can be found at http://www.ndbc.noaa.gov/.

especially evident in the southern bight and latitudes south of 39°N during the summer of 2015 and winter of 2015–16. In fact, for the line at 33°N the subsurface temperatures were anomalously high for the whole water column from spring of 2014 to the winter of 2016. During the winter and early spring of 2017, near-surface temperatures (0–50 m) for all the lines were slightly above average, turning below average by the late spring for depths between the surface and 150 m.

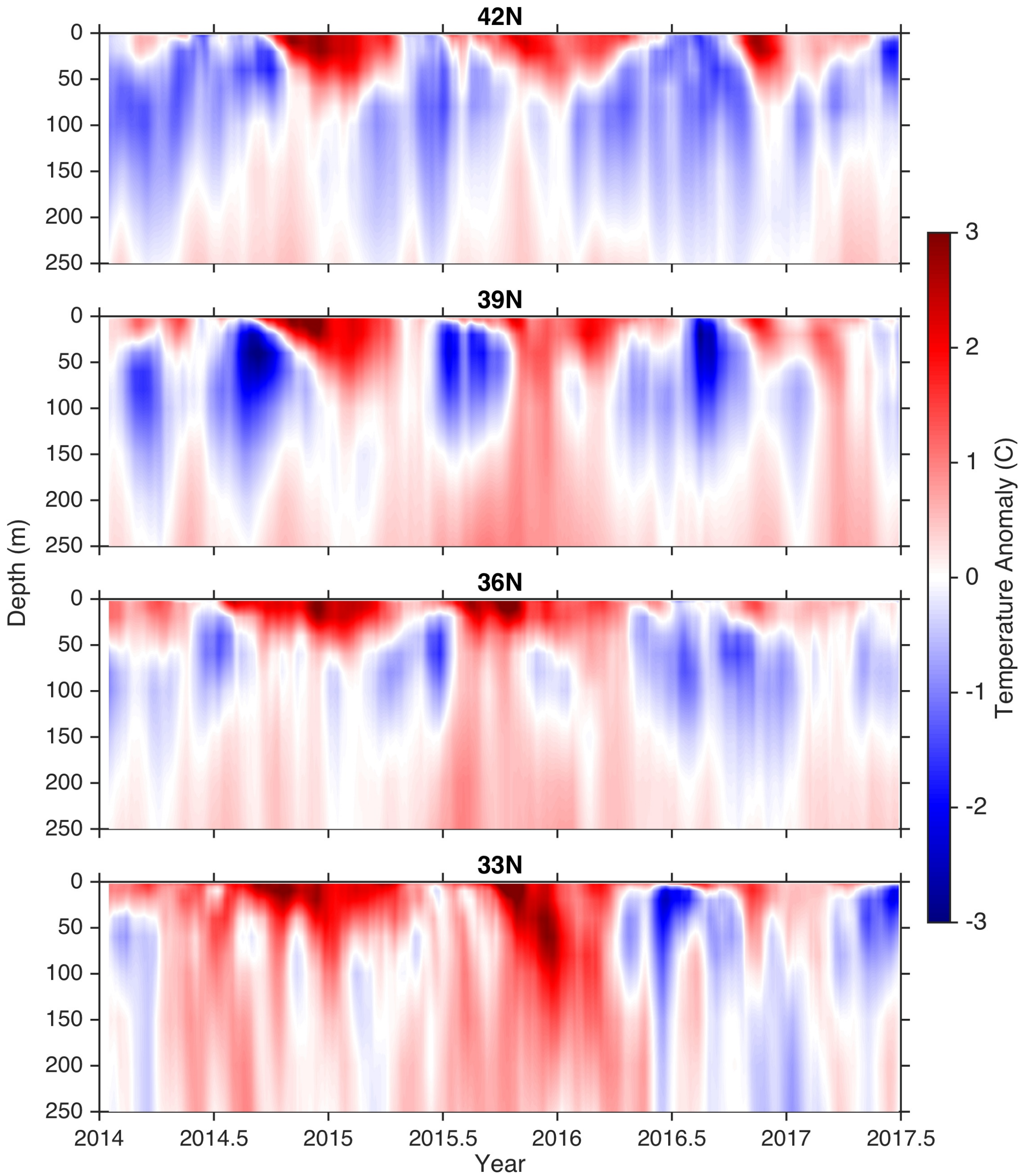


Figure 8. Temperature anomalies relative to the 1999–2011 climatology, derived from a data assimilative ocean reanalysis of the California Current System (http://oceanmodeling.ucsc.edu/ccsnrt/), are shown at four latitudes off the US West Coast. Temperatures are averaged from the coast to 100 km offshore and smoothed with a 30-day running mean.

Primary Production in the California Current System

Anomalously high chlorophyll during the spring occurred along Central California in 2014 and along the whole coast from northern Washington to Point Conception in 2015, which likely represents, to a degree, *Pseudo-nitzschia* (see McClatchie et al. 2016 for more complete description) (fig. 9)[4]. However, during these two years chlorophyll levels were below average off southern California. Spring chlorophyll levels in 2016 were below average for the whole coast except for a few localized increases along Washington and central California coasts (McClatchie et al. 2016). Spring 2017 chlorophyll values were lower than average for the majority of the CCS but showed increases in central California and around the Channel Islands. The elevated chlorophyll in spring 2017 for the Channel Islands corresponded to significant toxin event caused by *Pseudo-nitzschia* (modeled data shown in lower panels of fig. 9).

[4] https://www.nwfsc.noaa.gov/research/divisions/efs/microbes/hab/habs_toxins/hab_species/pn/index.cfm

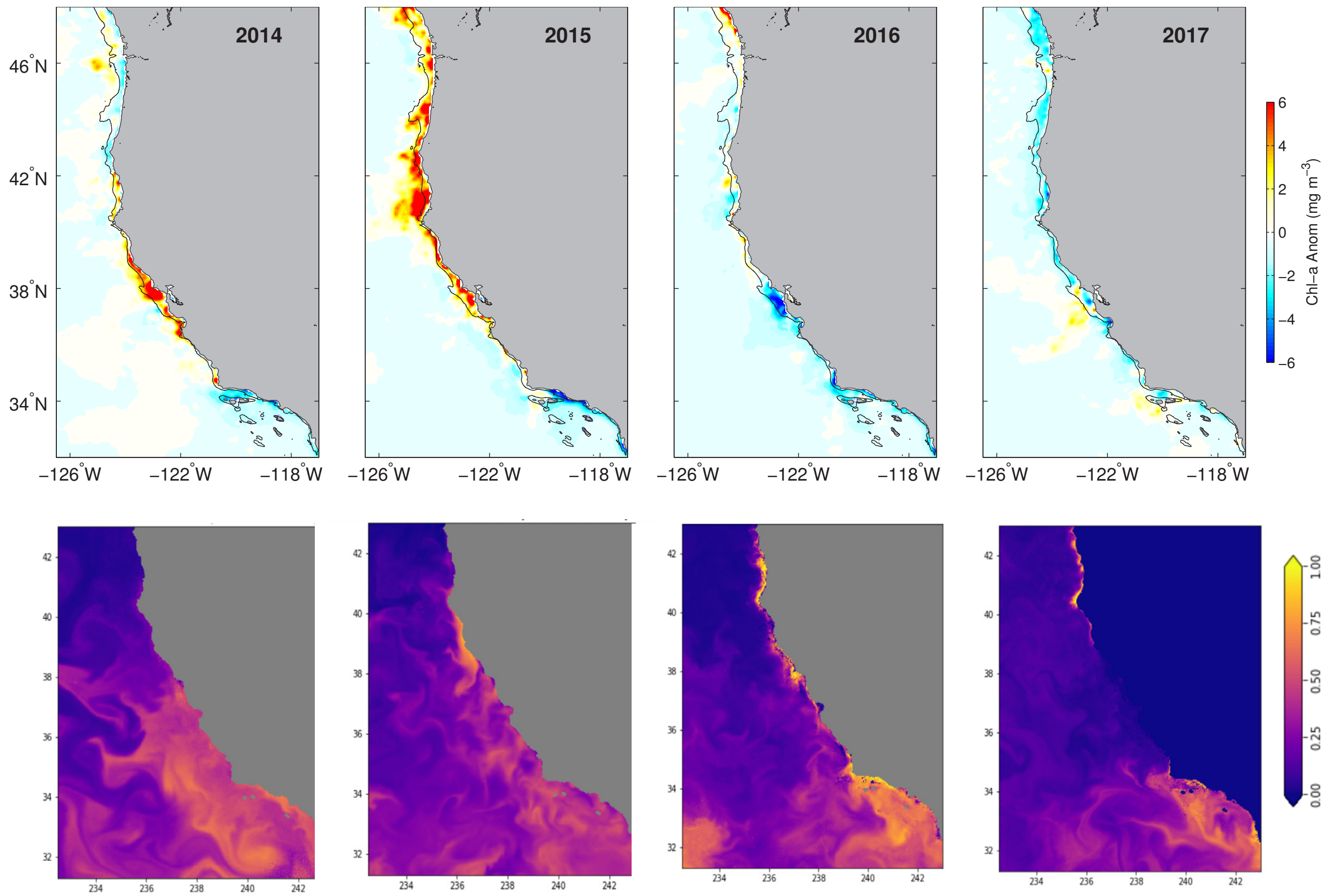


Figure 9. Top) Chlorophyll *a* anomalies from Aqua MODIS for: spring (March–May) of 2014–2017. Monthly anomalies were averaged onto a 0.1° x 0.1° grid and the climatology was based on the time period from 2002–17. The data were obtained from http://coastwatch.pfel.noaa.gov/. Bottom) predicted probability of domoic acid > 500 nanograms/L, during the same times periods as the top pane from http://www.cencoos.org/data/models/habs/previous.

REGIONAL OBSERVATIONS OF ENVIRONMENT AND LOWER TROPHIC LEVELS

Northern California Current: Oregon (Newport Hydrographic Line)

The warm anomalies that intruded onto the Oregon shelf surface waters in September 2014 remained throughout 2015, 2016, and continued into 2017, dominating the local hydrography and impacting pelagic communities. The upwelling season (spring transition) began early on 27 March 2016 and ended on 29 September 2016 (fig. 4), resulting in an upwelling season that was eight days longer than the 40-year climatology. Upwelling in 2016 cooled the warm temperatures that began during the winter of 2015–16 and continued into spring of 2016, resulting in neutral sea surface and deeper water temperatures on the shelf from June through September (figs. 7, 10). During this upwelling period, shelf waters were slightly saltier while deep waters on the slope were mostly neutral throughout 2016 and into 2017. Despite above average upwelling (fig. 4), nitrogen concentrations remained below average throughout 2016 and into 2017 (fig. 10). Following the upwelling season in 2016, the shelf waters returned to anomalously warm and fresh conditions, which were similar to the previous two years.

The zooplankton community remained in a lipid-depleted state throughout 2016 and into 2017. The zooplankton community was dominated by lipid-poor tropical and subtropical copepods and gelatinous zooplankton that generally indicate poor feeding conditions for small fishes. Pyrosomes (*Pyrosoma atlanticum*), a tropical species, were first observed in the fall of 2016 and their biomass increased greatly in the spring of 2017. With the exception of the upwelling months in 2016, the biomass of lipid-rich northern ("cold water") copepods was the lowest observed in the 21-year time series (fig. 10). During June through September, the biomass anomalies of the northern copepods were reduced slightly in response to upwelling, however the anomalies still remained strongly negative. The biomass of southern ("warm water") copepods fluctuated greatly, with

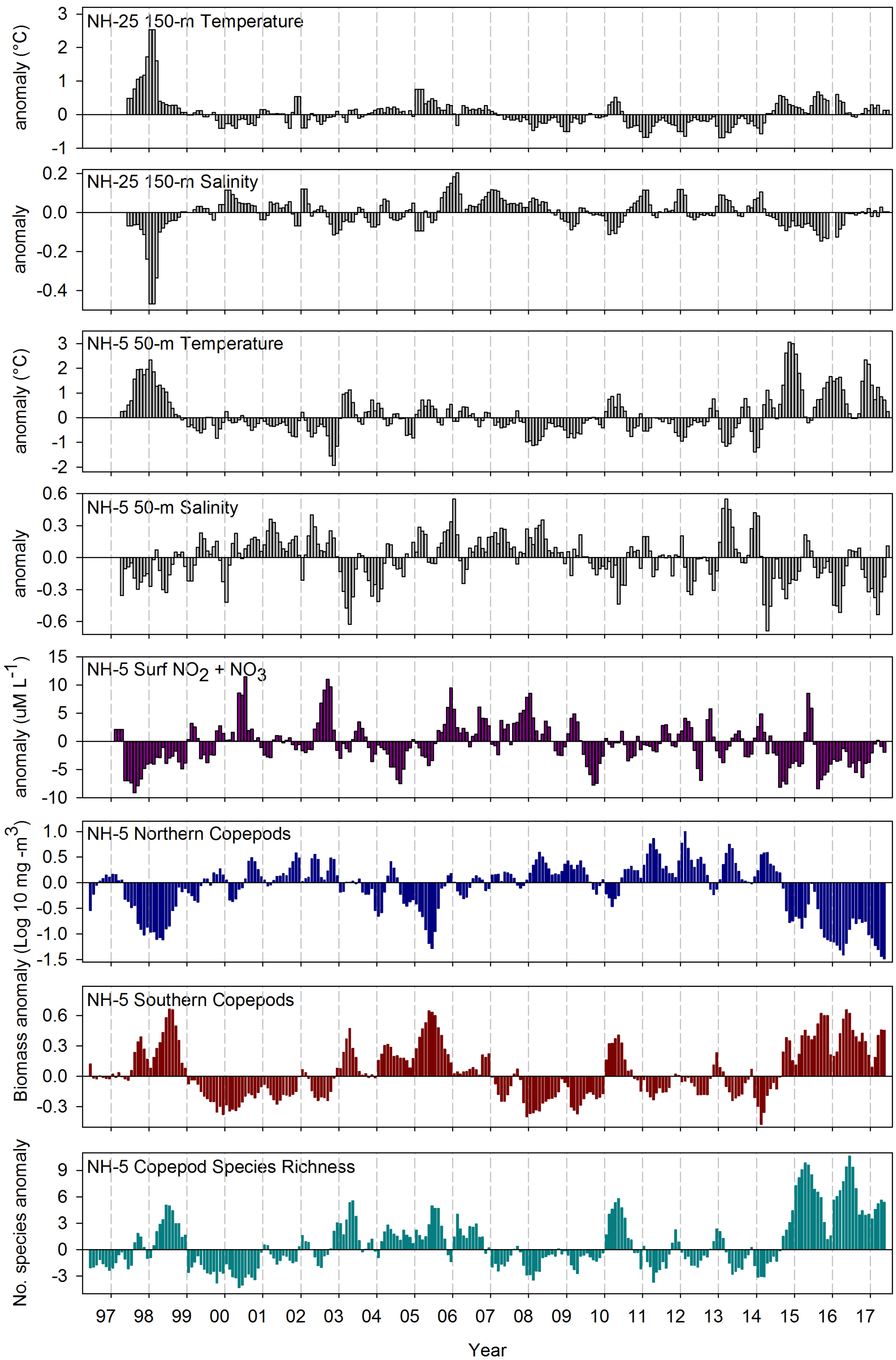


Figure 10. Time series plots of local physical and biological anomalies (monthly climatology removed) from 1997–2017 at NH-25 (Latitude: 44.6517 N Longitude: 124.65 W; top two panels) NH-5 (Latitude: 44.6517 N Longitude: 124.1770 W; lower six panels) along the Newport Hydrographic Line. Temperature and salinity from 150 m and 50 at NH-25 and NH-5 respectively, NO2 + NO3 from the surface, and copepod biomass and species richness anomalies are integrated over the upper 60 m. All data were smoothed with a 3-month running mean to remove high frequency variability.

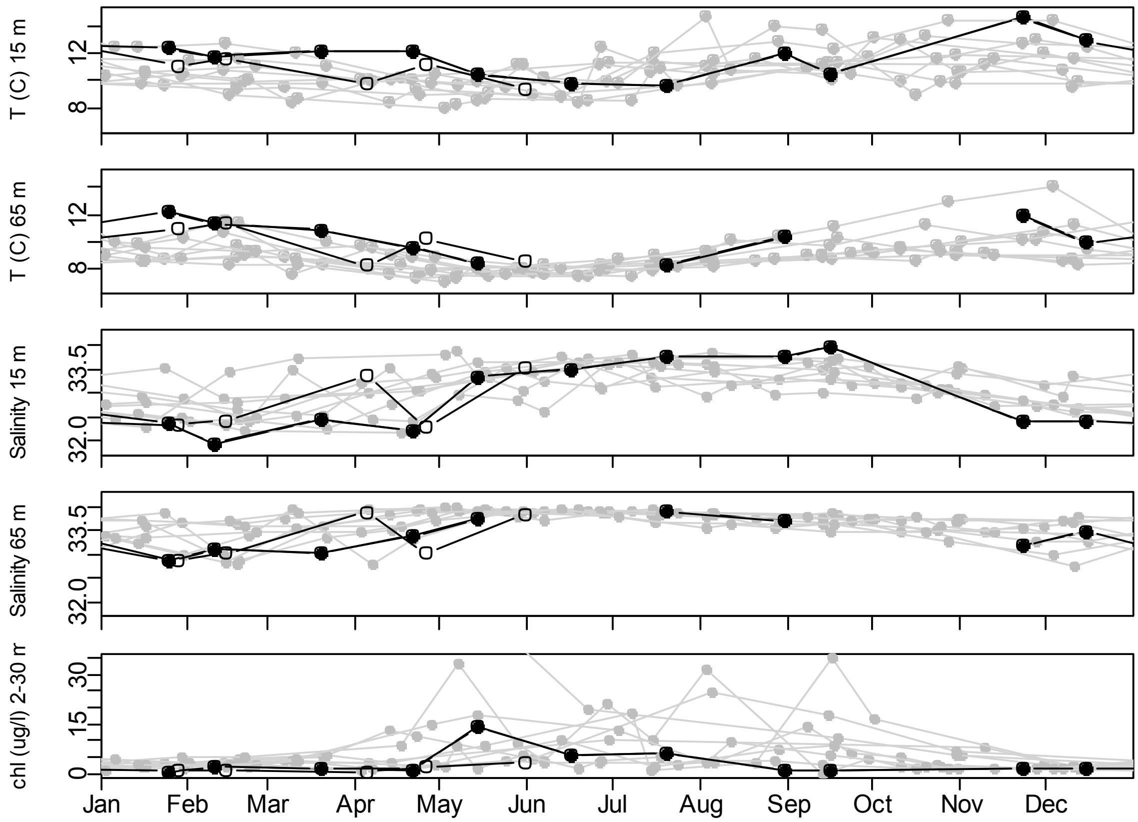


Figure 11. Hydrographic observations along the Trinidad Head (TH) Line at station TH02. Panels from top to bottom show temperature at 15 m, temperature at 65 m (near the sea floor), salinity at 15 m, salinity at 65 m, and mean (uncalibrated) chlorophyll *a* concentration from 2–30 m. Closed black circles represent 2016, open circles represent 2017, and grey time series represent previous years.

the highest biomass anomalies occurring during the upwelling months and lower anomalies during the winter (fig. 10). In 2015 and in 2016, the seasonal shift from a winter copepod community to a cold summer community that results from the Davidson Current in winter and its disappearance in spring did not happen (data not shown). This transition in the copepod community also did not occur during 1998, however it is unusual to remain in a warm-water copepod community for two consecutive years. This last occurred in 2003, 2004, and 2005 (fig. 10).

Copepod species richness was the highest in the time series during the summer of 2016[5]. Many of the rare species observed during this period had Transition Zone and North Pacific Gyre affinities and many of the species have never (or rarely) been observed off Newport since sampling began in 1969 (Peterson et al. 2017). The presence of these species greatly increased the species richness, which exceeded the number of species observed during the strong El Niño in 1998 (fig. 10). Like cold-water copepods, euphausiid biomass during 2016 was among the lowest in 21 years and the coastal euphausiid, *Thysanoessa spinifiera*, was largely absent (data not shown; Peterson et al. 2017).

Northern California Current: Northern California (Trinidad Head Line)

Coastal waters off northern California were warmer and fresher than usual during early 2016, but cooled in response to strong upwelling during summer. Warmer, fresher water was again observed over the shelf following relaxation from upwelling in early fall 2016. Coastal waters were slightly cooler in early 2017 relative to early 2016 (figs. 8, 11), yet remained higher than most previous observations in the record, which is consistent with larger scale patterns in the CCS (figs. 3, 8). These patterns manifested throughout the water column over the inner to midshelf (fig. 11), and extended to surface waters offshore, but did not have a strong signal at depth over the outer shelf (fig. 8). Upwelling in spring 2016 led to a phytoplankton bloom that peaked in late spring and persisted through the summer (figs. 9, 11). *Pseudo-nitzschia* were a major component of this bloom, leading to low to moderately high concentrations of particulate domoic acid (the neurotoxin produced by

[5]Copepod data were based on samples collected with a 0.5 m diameter ring net of 202 µm mesh, hauled from near the bottom to the sea surface. A TSK flowmeter was used to estimate volume of water sampled.

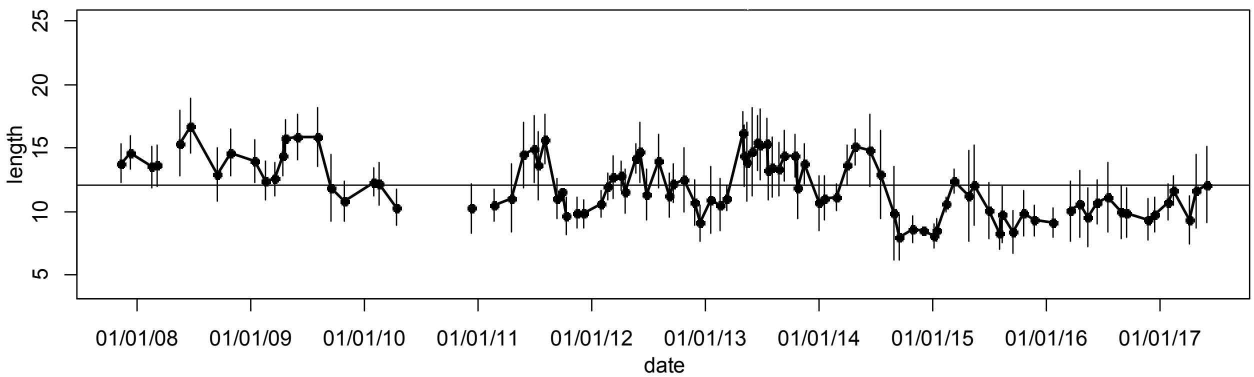


Figure 12. Density-weighted mean (points) and standard deviation (whiskers) of rostral-dorsal length of adult *Euphausia pacifica* collected along the Trinidad Head Line (aggregated over stations TH01 to TH05). Horizontal line indicates mean length taken over entire time series. Samples are collected by fishing bongo nets (505 µm mesh) obliquely from a maximum depth of 100 m (or within a few meters of the sea floor in shallower areas) to the surface.

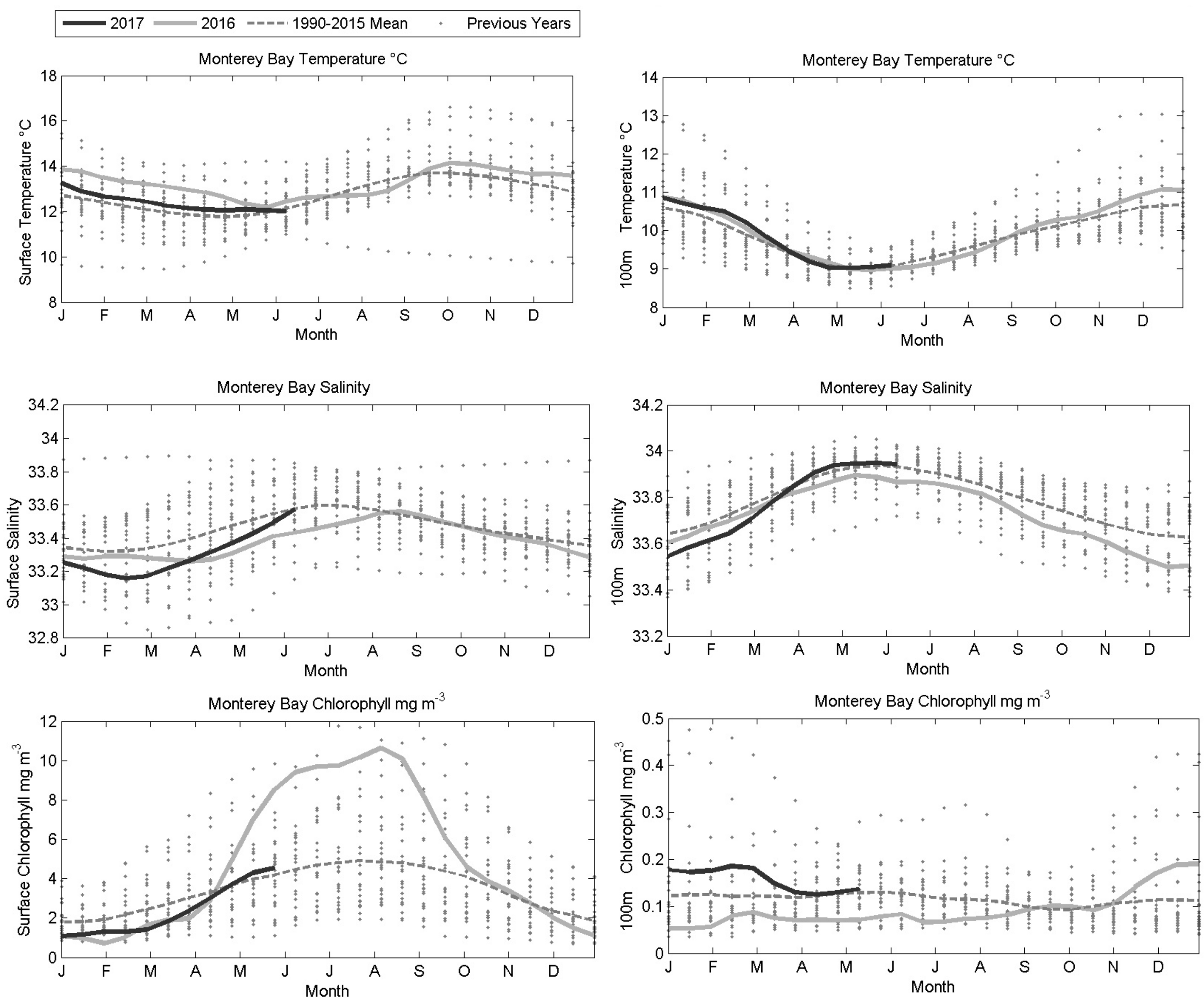


Figure 13. Temperature (top panels), salinity (middle panels) and chlorophyll *a* concentration (bottom panels) at the surface (left-hand column) and at 100 m (right hand column) observed at the M1 mooring in Monterey Bay, CA.

Pseudo-nitzschia; 0 to > 16,000 ng l^{-1}) in June 2016 that declined over the course of the summer. Chlorophyll concentrations have remained low through spring 2017 (figs. 9, 11). No hypoxic events were observed during 2016 and early 2017.

Zooplankton population and community data reflected the ongoing biological response to the persistence of warmer-than-usual water masses off northern California. For example, mean length of adult *Euphausia pacifica* collected along the Trinidad Head Line has remained consistently smaller than usual (fig. 12). Larger individuals were captured during periods of upwelling-driven cooling, and have been more consistently encountered during 2016 and early 2017, but the population continues to be dominated by smaller adults. The warm-water euphausiids *Euphausia recurva* and *Nyctiphanes simplex* were captured during winter and early spring 2016. Both species also occurred in winter samples from 2016–17, suggesting that warm-water zooplankton communities remained in the region but were displaced from coastal waters during periods of sustained upwelling. Copepod community data have not been updated through this period, but cursory inspection of samples and anecdotal observations made during analysis of krill samples suggest that cold-water copepods remain relatively rare or absent. Pyrosomes were present at unusually high densities throughout 2016 and early 2017, with the greatest abundance occurring during spring 2017. Large pyrosomes (i.e., individuals too large to be retained in preserved samples) were much more frequently and consistently encountered during 2016 and early 2017 than in previous years. Salps were abundant for a brief time during summer and fall 2016.

Central California Current: Monterey Bay

Temperatures at the surface and 100 m recorded at M1 (36°45'0" N 122°1'48" W) mooring in Monterey Bay were near average in 2017 and similar to the values from 2016. Surface salinities were also near the climatological average during this time period, although in early 2017 surface waters were somewhat fresher (fig. 13). Chlorophyll at the surface was low during winter 2016 but increased concomitantly with increased upwelling during summer and stayed elevated until October when upwelling weakened (fig. 4). Chlorophyll remained slightly below average until May 2017. At 100 m, chlorophyll remained below average during 2016 through November, at which point, it was near average until April 2017. Generally, aside from extremely elevated surface chlorophyll during June–September 2016 associated with anomalously strong upwelling (fig. 4), conditions at M1 were typical. In contrast to other regions, there were no significant toxic blooms in Central California, but there were a series of "red tide" events in the nearshore caused by the dinoflagellate *Akashiwo sanguinea*.

Southern California Current: CalCOFI Survey[6]

Over the last 12 months, mixed layer temperature anomalies remained above the long-term average (fig. 14) but were 1 to 1.5°C cooler than those observed during the marine heatwave in 2014–15. The cooling of surface waters since 2015–16 is clearly shown in the Hovmoeller plots of 10 m temperatures along CalCOFI line 90, and temperatures at 100 m depth had returned to the long-term average (figs. 8, 15).

Over the last three years water column stratification in the upper 100 m was primarily driven by high surface ocean temperatures (McClatchie et al. 2016), and this trend continued over the last year (fig. 14). Mixed layer salinity was slightly below long-term averages for the last three years (fig. 14). Temperature-salinity distributions for the offshore, California Current, upwelling, and Southern California Bight areas were not dramatically different from previous years, and neither region showed the pronounced warming of the surface layer seen in 2015–16.

The depth of the σ_t 26.4 isopycnal (fig. 16), which can indicate nutrient availability and transport, was close to its long-term average over the last 12 months, contrasting with high (deep) values observed during the previous two years. Bjorkstedt et al. (2012) speculated that concentrations of oxygen at depth had been declining since the year 2000 to values not observed previously. It appears that this trend has ended (fig. 16). Indeed, one could argue that there is no trend in the O_2 time series at σ_t 26.4 from 2003 until the present (fig. 16). The same is true for the nitrate time series (fig. 16). Changes in N*, which is a biogeochemical indicator which reflects the deficit of nitrate in a system relative to concentrations of phosphate, over the last year have also been small (fig. 16).

Mixed layer concentrations of chlorophyll were extremely low during the marine heat wave and the 2015–16 El Niño. Chlorophyll concentrations returned

[6] These results are based on four seasonal CalCOFI cruises (Ohman and Venrick 2003) in July and November of 2016 and January and April of 2017. The sampling domain encompasses the southern California Current, the Southern California Bight, the coastal upwelling region at and north of Pt. Conception and an offshore area at the edge of the North Pacific Gyre.

Results are presented as time series of averages over all 66 standard CalCOFI stations covered during a cruise or as anomalies of such values with respect to the 1984–2012 time period. When appropriate, averages from selected regions are used based on a subset of the 66 standard CalCOFI stations. The buoyancy frequency was calculated for all depths and averaged for the upper 100 m of the water column. The nitracline depth is defined as the depth where concentrations of nitrate reach values of 1 µM, calculated from measurements at discrete depths using linear interpolation. Mesozooplankton displacement volumes for the last 12 months are not yet available. Methods used to collect and analyze samples are described in detail at www.CalCOFI.org/methods. At each station a CTD cast and various net tows were carried out. This report focuses on the hydrographic, chemical and biological data derived from ~20 depths between the surface and ~515 m, bottom depth permitting.

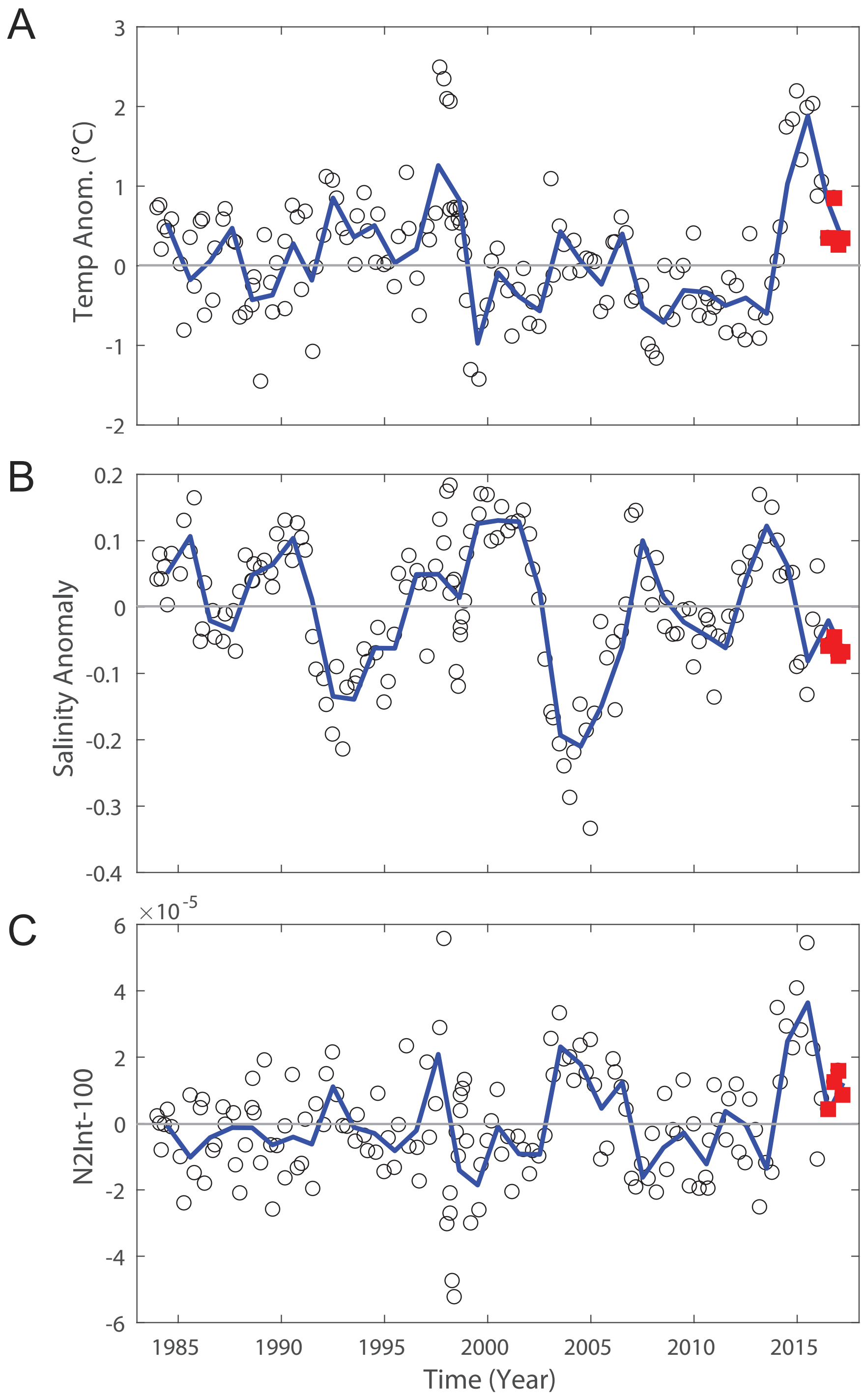


Figure 14. Cruise averages of property anomalies for the mixed layer (ML) of the 66 standard CalCOFI stations (Figure 1) for 1984 to the spring of 2017. A) ML temperature, B) ML salinity. C) buoyancy frequency squared (N2) in the upper 100 m. Data from individual CalCOFI cruises are plotted as open circles; data from the four most recent cruises, 201607 to 201704, are plotted as solid red symbols. Blue solid lines represent annual averages, grey horizontal lines the climatological mean, which is zero in the case of anomalies. Anomalies are based on the 1984 to 2012 time period.

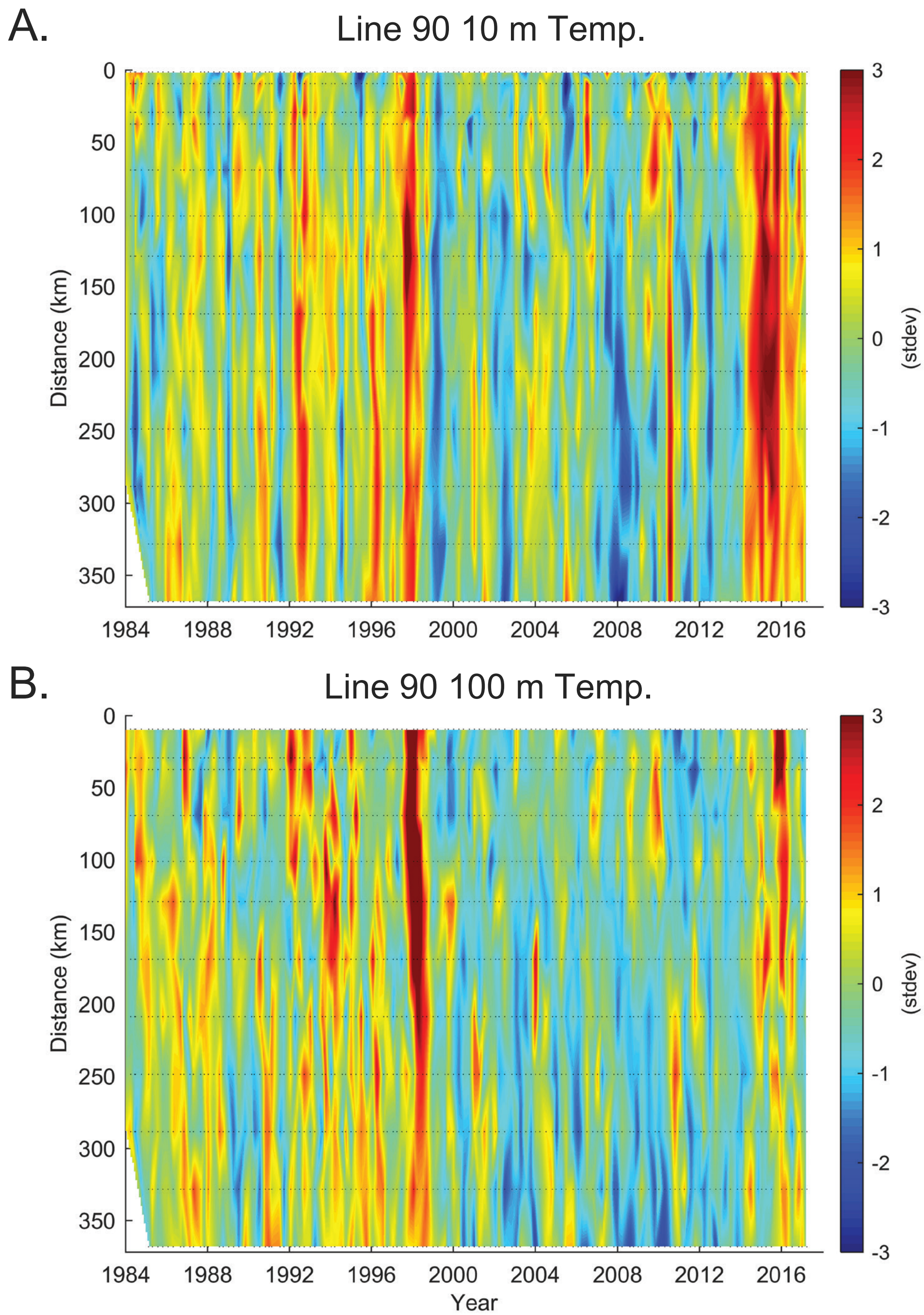


Figure 15. Standardized temperature anomalies for CalCOFI line 90 plotted against time and distance from shore for a depth of 10 m (A) and 100 m (B). Plotted data are deviations from expected values in terms of standard deviations in order to illustrate the strength of the relative changes at different depths.

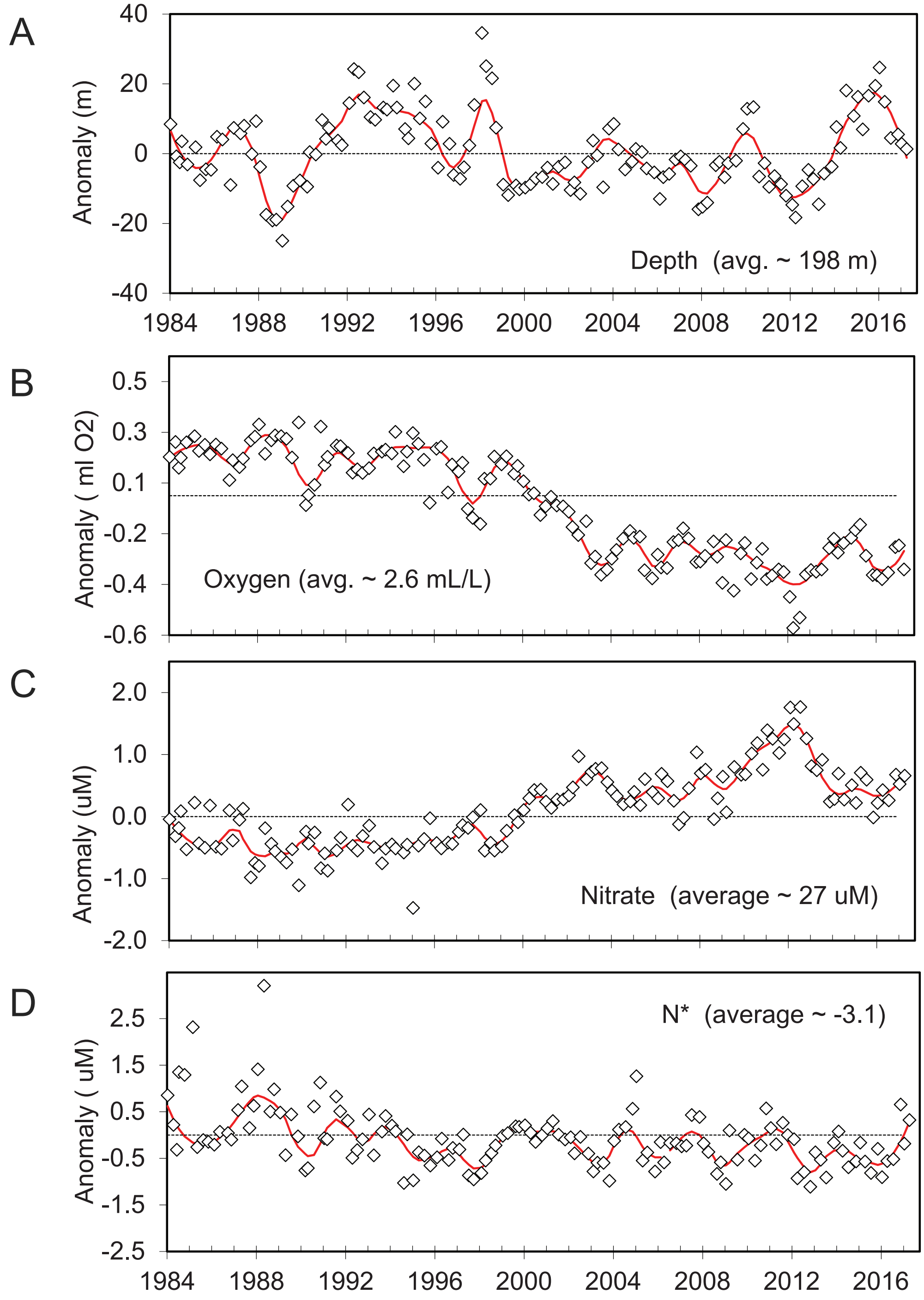


Figure 16. Anomalies of hydrographic properties at the σt 26.4 isopycnal (open diamonds) averaged over the 66 standard CalCOFI stations. Shown are anomalies of isopycnal depth, oxygen, nitrate, and N*, which is a biogeochemical indicator which reflects the deficit of nitrate in a system relative to concentrations of phosphate (Gruber & Sarmiento 1997). The solid red line represents a LOESS fit to the data; average values for the properties are listed. Anomalies are based on the 1984 to 2012 time period.

to the long-term average over the last 12 months (fig. 17). Values of mixed layer nitrate concentrations and nitracline depth (fig. 17) were also close to their long-term average, consistent with the hypothesis that phytoplankton biomass in the CalCOFI study area is primarily controlled by the availability of inorganic nutrients such as nitrate, which in turn is controlled by stratification. The depth distributions of chlorophyll in the offshore, California Current, and upwelling areas were similar to those observed between 1984 and 1997 (http://calcofi.

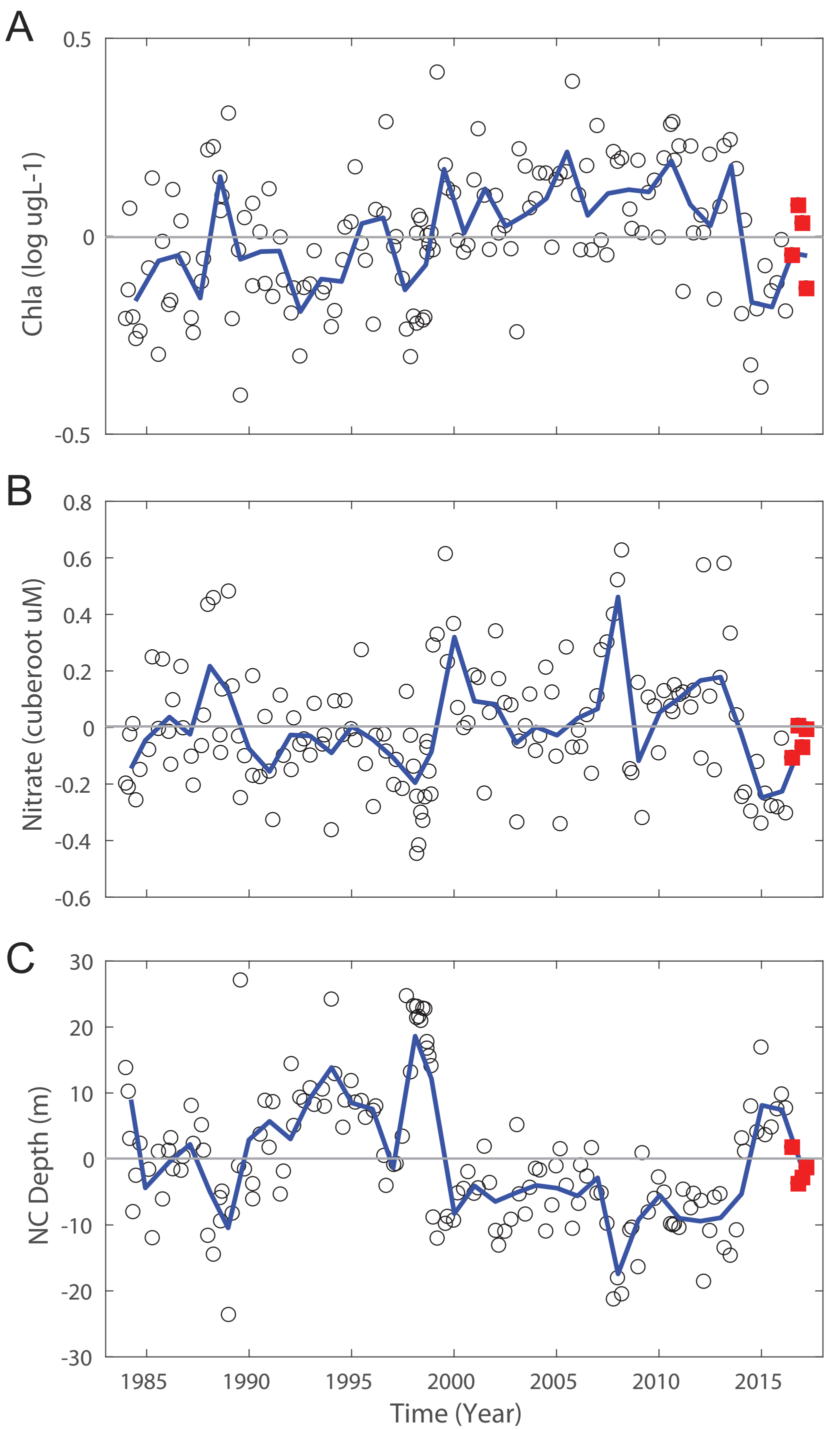


Figure 17. Cruise averages of properties for a depth of 10 m for the CalCOFI standard grid plotted as anomalies relative to the mean of the time series. A) The log10 of chlorophyll *a*, B) the cube root of nitrate, and C) nitracline depth.

org/cruises.html). The chlorophyll maximum in the offshore and California Current region was 10 to 20 m deeper than during the last decade. In the Southern California Bight the chlorophyll maximum was substantially stronger than maxima observed over the last 15 years but the mechanism driving these changes is unknown.

Southern California Current: Harmful Algal Blooms (HAB)

As part of the 2016 CalCOFI surveys, near-surface samples were collected for domoic acid to see if there would be an HAB response to the El Niño conditions. Toxin concentrations were negligible during 2016. In

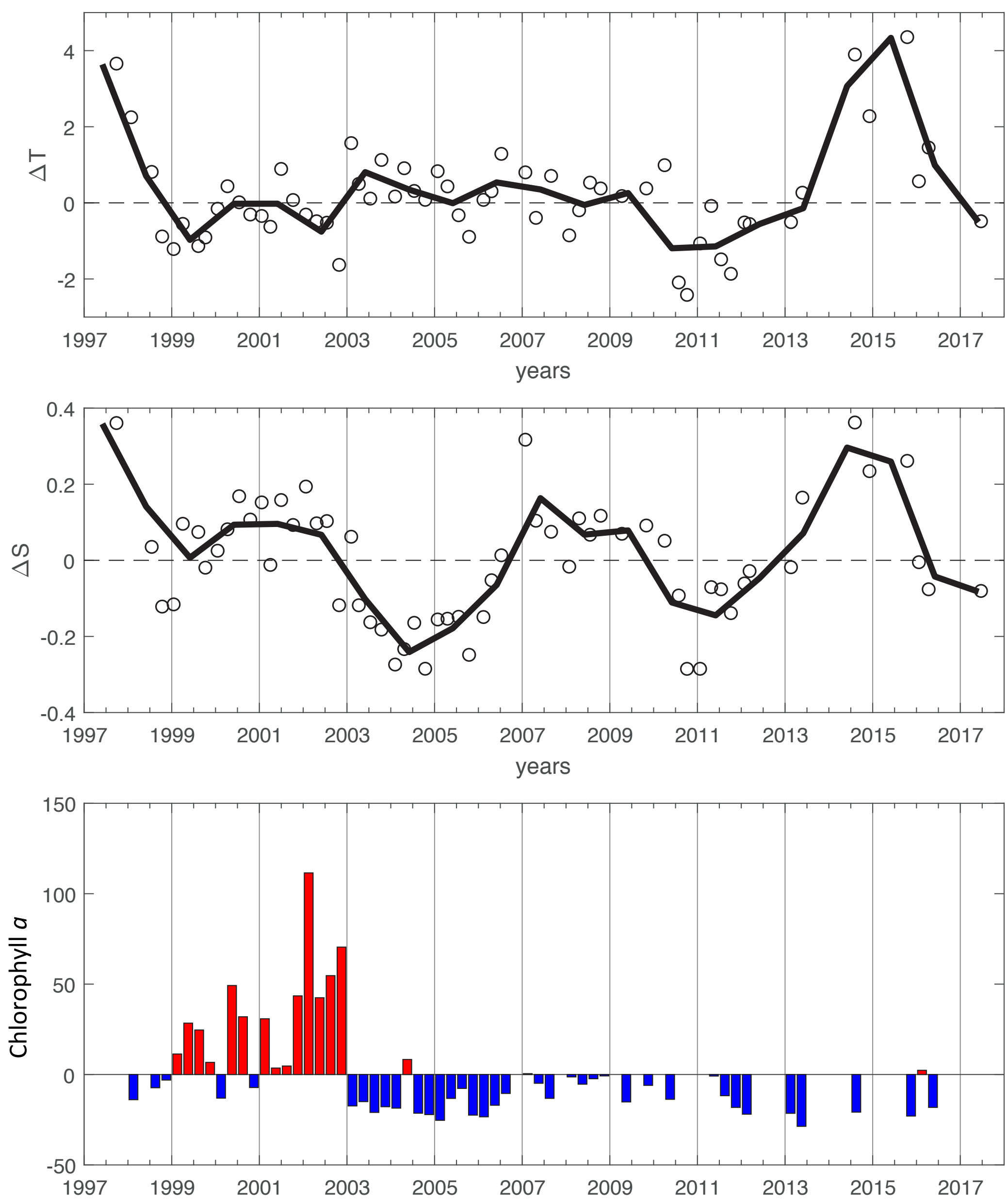


Figure 18. Interannual variability of the mixed layer temperature anomalies (˚C) and salinity anomalies in the IMECOCAL region for the period 1997–2017 (white circles) and the mean of each year (thick line). Depth-integrated (0–100 m) chlorophyll *a* anomalies (mg m^{-2}) in the IMECOCAL region.

contrast, a significant bloom developed in April–May 2017, with numerous bird mortalities and marine mammal strandings. The bloom was localized to the Southern California Bight region, but achieved very high particulate domoic acid concentrations (exceeding 50,000 ng/L). This caused an unusual mortality event for multiple marine bird species, dominated by loons (*Gavia* spp., 75% of strandings). Sixteen loons were sampled for toxins, and all were positive for domoic acid. One loon had a sardine in its gullet at the time of death, which contained 681 ppm domoic acid. Concentrations in the loons (liver, kidney, bile) tested as high as 88 ppm (the regulatory limit for human consumption of fish and shellfish is 20 ppm). The bloom region corresponded to the elevated chlorophyll in Figure 9.

Southern California Current: Baja California (IMECOCAL)[7]

Similar to other areas in the California Current, the magnitude of anomalously warm conditions of 2014–

[7] The IMECOCAL program conducts quarterly cruises off the Baja California peninsula since 1997–98 El Niño. However, during 2012–17 the sampling frequency has been more sporadic and the last two years the surveys have been carried out exclusively off north Baja California.

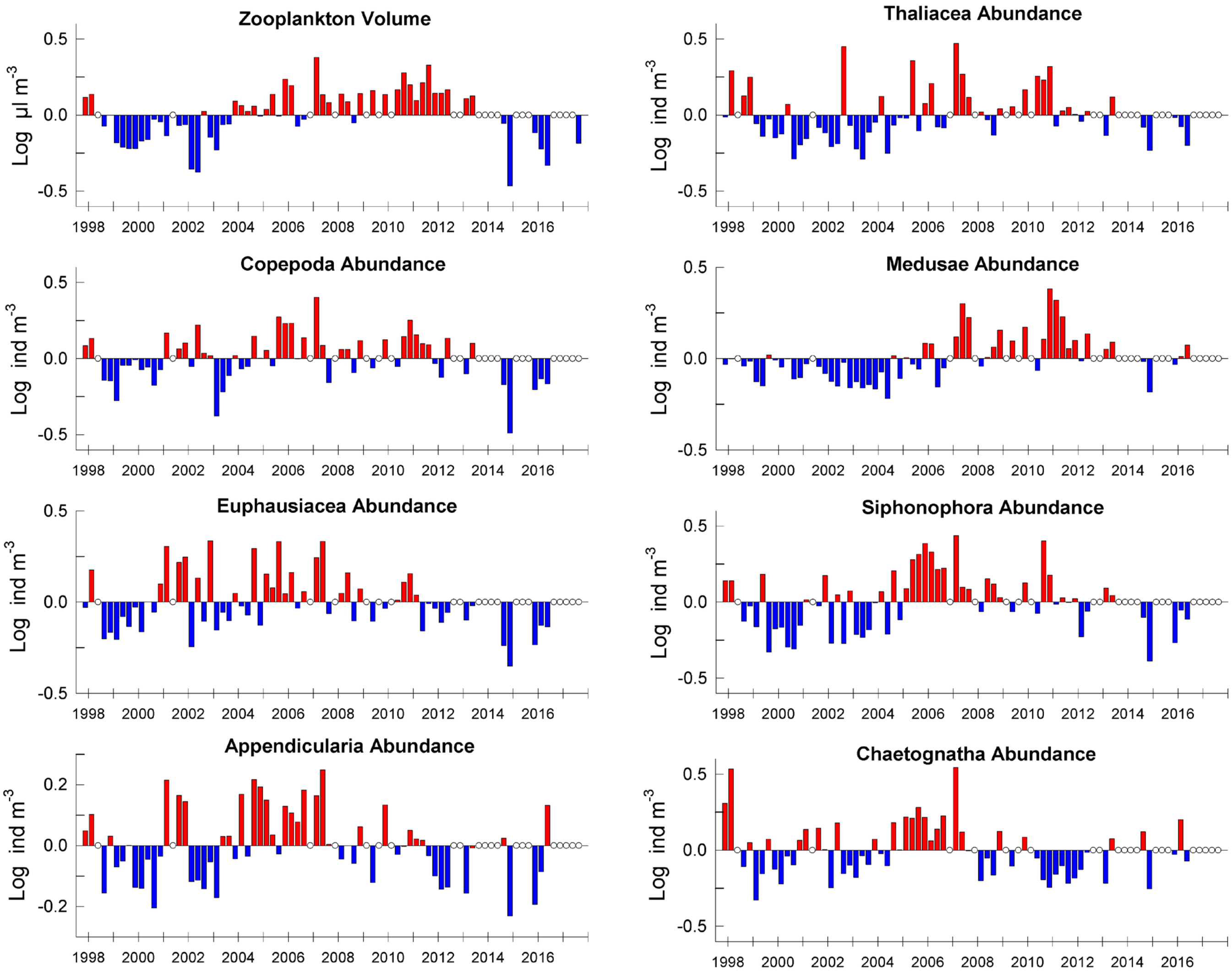


Figure 19. Zooplankton volume anomalies and abundance anomalies of zooplankton groups for the Baja California Peninsula (IMECOCAL) region. Each bar represents a single cruise and open circles represent cruises that did not take place or were omitted due to limited sampling. Data were converted to logarithms.

15 was reduced in 2016 off Baja California (fig. 18)[8]. By June 2017, surface waters transitioned to slightly cooler than average. The last result should be taken with caution because the cruise was carried out in early summer during overcast conditions. Similar to temperature, salinity anomalies of the mixed layer in April 2016 shifted from more saline waters associated with 2014–15 to fresher than average water, and remained this way into 2017 (fig. 18).

Chlorophyll from 2003-2016 remained anomalously low (fig. 18)[9]. However, there were data missing for the most productive season (spring) in recent years 2015–17. It is worth noting that anomalies presented in this updated figure differ from the figure reported in McClatchie et al. (2016) for the time interval 2008–16. This is due to a methodological error found and the application of a correction factor to values collected after 2008.

Zooplankton biomass anomalies have only recently tracked chlorophyll anomalies in this region (fig. 19)[10].

[8] The hydrographic data were collected using seabird sensors factory calibrated prior to each cruise. CTD data were computed by Seasoft based on EOS-80. After that, the thermodynamic variables were processed using Matlab functions from SEA-MAT. The mixed layer depth was estimated following the methodology by Jeronimo and Gomez-Valdes (2010) for the IMECOCAL grid. Harmonics were computed for mixed layer properties for all stations for which sufficient data exists. Our approach to obtain the long-term variability follows that of Bograd and Lynn (2003).

[9] Phytoplankton chlorophyll-*a* data were analyzed from water collected at discrete depths in the upper 100 m, filtering water onto Whatman GF/F filters, following the fluorometric method. Integrated chlorophyll anomalies were estimated removing seasonal means. Chlorophyll was not measured in the cruise performed in 2017.

[10] Zooplankton was sampled with oblique tows of a bongo net (500 µm of mesh width) from 210 m to the surface. Displacement volume was measured in all samples and zooplankton taxa were counted in nighttime samples only. For more reference about water samples collections and zooplankton techniques visit the IMECOCAL Web page: http://imecocal.cicese.mx.

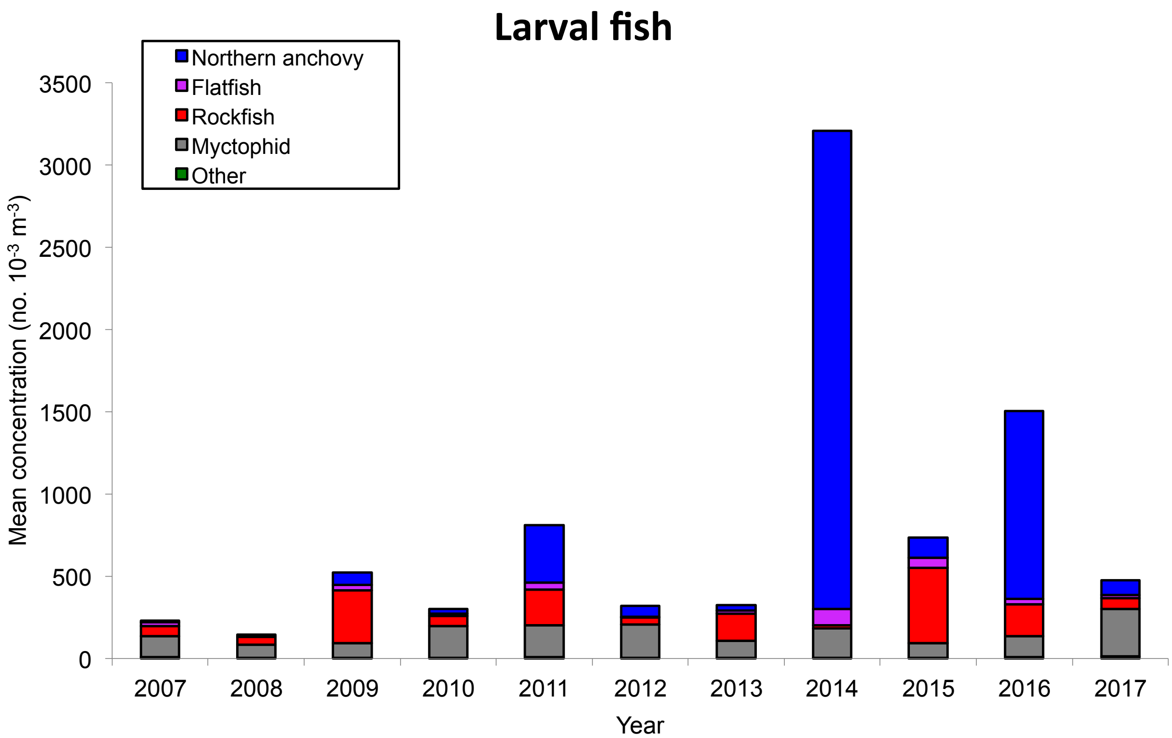


Figure. 20. Mean concentrations (no. 10^{-3} m^{-3}) of the dominant larval fish taxa collected during June–July in 2007–17 along the Newport Hydrographic (NH; 44.65˚N, 124.35–125.12˚W) and Columbia River (CR; 46.16˚N, 124.22–125.18˚W) lines off the coast of Oregon.

During 2014–16, an anomalously low biomass of zooplankton coincided with low chlorophyll concentrations. Prior to this (2003–13), zooplankton biomass tended be greater than average despite the anomalously low concentration of chlorophyll over this same period. In June 2017, zooplankton biomass remained anomalously low despite cooling water temperatures. The main crustacean grazers (copepods and euphausiids) as well as gelatinous groups (tunicates, siphonophores, and medusae) may have contributed to the extremely low biomass of zooplankton observed (fig. 19). The negative anomalies of zooplankton biomass and abundances of functional groups during El Niño 2015–16 are in contrasts with El Niño 1997–98 when positive anomalies of copepods, euphuausiids, tunicates, and siphonophoes were observed. The unique coincidence between zooplankton in the two periods were positive anomalies of chaetognaths abundance during both the 2015–16 and the 1997–98 El Niño.

It is difficult to distinguish the contribution of the marine heat wave or El Niño on the low abundance of zooplankton in the Baja California. An increase in temperature could be the result of either, producing a similar effect on subtropical species, which usually are dominant in the region (Jiménez-Pérez and Lavaniegos 2004; Lavaniegos and Ambriz-Arreola 2012). Also, negative anomalies in some groups, such as euphausiids, appendicularians, and chaetognaths, occurred since 2011, previous to the marine heat wave event.

REGIONAL EPIPELAGIC MICRONEKTON AND SALMON OBSERVATIONS

Northern California Current: Washington and Oregon

Newport Hydrographic Line and Pre-recruit Survey The larval epipelagic micronekton community along the central-northern coast of Oregon in June 2017 was similar to the average community structure found in the same area and season during the previous ten years in terms of composition and relative concentrations of the dominant taxa (fig. 20)[11]. The exception was unusually

[11] Micronekton samples were collected from 3–4 stations representing coastal (<100 m in depth), shelf (100–1000 m), and offshore (>1000 m) regions along both the Newport Hydrographic (NH; 44.65˚N, 124.35–125.12˚W) and Columbia River (CR; 46.16˚N, 124.22–125.18˚W) lines off the coast of Oregon during June–July in 2007–17 (See Auth 2011 for complete sampling methods). In addition, post-larval (i.e., juvenile and adult) fish were collected using a modified-Cobb midwater trawl (MWT) with a 26 m headrope and a 9.5 mm codend liner fished for 15 min at a headrope depth of 30 m and ship speed of ~2 kt. MWT collections were made at 4–6 evenly-spaced, cross-shelf stations representing coastal, shelf, and offshore regions along nine (five in 2017) half-degree latitudinal transects between 42.0 and 46.0˚N latitude in the northern California Current region during June–July in 2011–17 (although no sampling was conducted in 2012). Sampled volume was assumed to be uniform for all hauls. All fish collected were counted and identified to the lowest taxonomic level possible onboard, although pre-recruit rockfish were frozen and taken back to the lab for identification using precise meristic and pigmentation metrics.

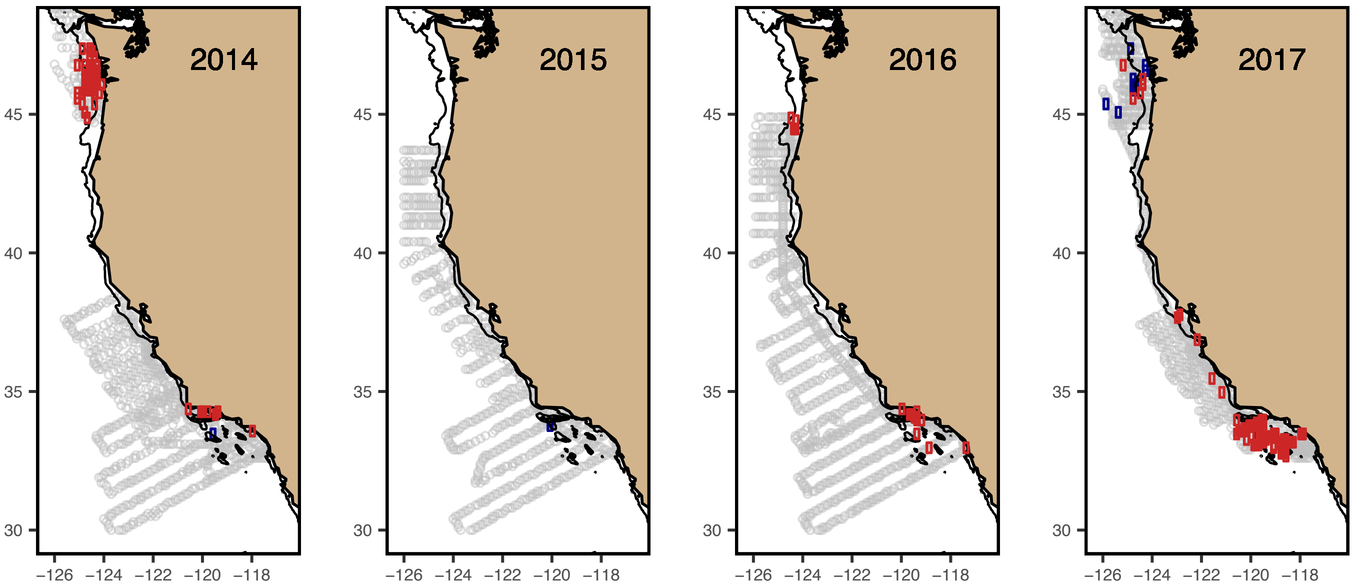


Figure 21. Northern anchovy egg density anomalies from continuous underway fish egg sampler (CUFES) surveys March–July 2014–17. Anomalies are shown for values greater than 2 eggs/m³ (red, Observation − Mean) or less than −2 eggs/m³ (blue) based on 0.1˚ bin spatial averages. North of 44˚N there were only 12 years of data: 2003, 2004, 2006, 2007, 2008, 2010, 2011, 2012, 2013, 2014, 2016, and 2017. Note that central California southward has been surveyed since 1997.

high concentrations of larval northern anchovy (*Engraulis mordax*) in 2014 and 2016 resulting from anomalously high spawning activity in the region (fig. 21)[12]. Total mean larval concentration was near average based on the 11-year time series. Larval myctophids in 2017 were found in the highest concentration since sampling began in 2007 as were "other" taxa, although other taxa still only accounted for <3% of the total mean larval concentration.

The post-larval fish community in the northern California Current in June 2017 was similar to the community structure found in the same area and season during the previous two years primarily due to the continued dominance of Pacific hake (*Merluccius productus*), which comprised 83% of the mean abundance of "other" taxa and ~ 60% of the total mean abundance of all post-larval fish (fig. 22). The abundance of smelt in 2017 was tied with that in 2016 for the lowest of the six-year time series, while the abundance of clupeiformes in 2017 was tied with that in 2016 for the highest, primarily due to the high concentration of northern anchovy collected just off the mouth of the Columbia River. Rockfish abundance in 2017 was the second highest of the time series, with the dominant species consisting of shortbelly (*S. jordani*; 50% of total rockfish), blue (*S. mystinus*), darkblotch (*S. crameri*), and widow (*Sebastes entomelas*). In addition, medusafish (*Icichthys lockingtoni*) were collected in far higher numbers than ever before in the six-year time series, probably due to their affinity for pyrosomes which were present in unprecedented numbers throughout the sampling area.

Columbia River plume region: Juvenile Salmon and Ocean Ecosystem Survey The June fish and invertebrate assemblage in the northern California Current during 2017 was unusual and dominated by species that normally occur in warmer ocean waters to the south of the study area[13]. A nonmetric multidimensional scaling (NMDS) ordination clearly showed that the 2015–17 assemblages were outliers, distinct not only from the 1999 La Niña assemblages, but also from the assemblage sampled during the 2005 warm event in the northern California Current (fig. 23).

The fish and invertebrate community in 2017 was similar to the past two warm years of 2015 and 2016 (fig. 23). Taxa indicative of 2017 included the pyrosome, Pacific pompano (*Peprilus simillimus*), Pacific chub mackerel (*Scomber japonicus*), and jack mackerel (*Trachurus symmetricus*). Pyrosomes are tunicates that are normally

[12] Egg data is from continuous underway fish egg sampler (CUFES). While the southern/central region has been surveyed since 1997, the survey expanded north of 44˚N only in 12 years: 2003, 2004, 2006, 2007, 2008, 2010, 2011, 2012, 2013, 2014, 2016, and 2017. Spatial anomalies are estimated on 0.1˚ bins.

[13] Pelagic fish and invertebrate catch data were collected by the Juvenile Salmon and Ocean Ecosystem Survey (JSOES, NWFSC NOAA/Bonneville Power Administration) surveys using surface trawls on standard stations along transects between northern Washington and Newport, OR, in June from 1999 to 2016. All tows were made during the day at predetermined locations along transects extending off the coast to the shelf break (Brodeur et al. 2005). We restricted the data set to stations that were sampled consistently over the sampling time period (>9 y). Numbers of individuals were recorded for each species caught in each haul and were standardized by the horizontal distance sampled by the towed net as CPUE (number/km towed). A log(x+1) transformation was applied to the species at each station and then averaged by year for each species. The species data matrix included the 27 most abundant species captured over the 18 years sampled years (27 species x 18 years). A nonmetric multidimensional scaling (NMDS) ordination was used to describe the similarity of each year's community in species space.

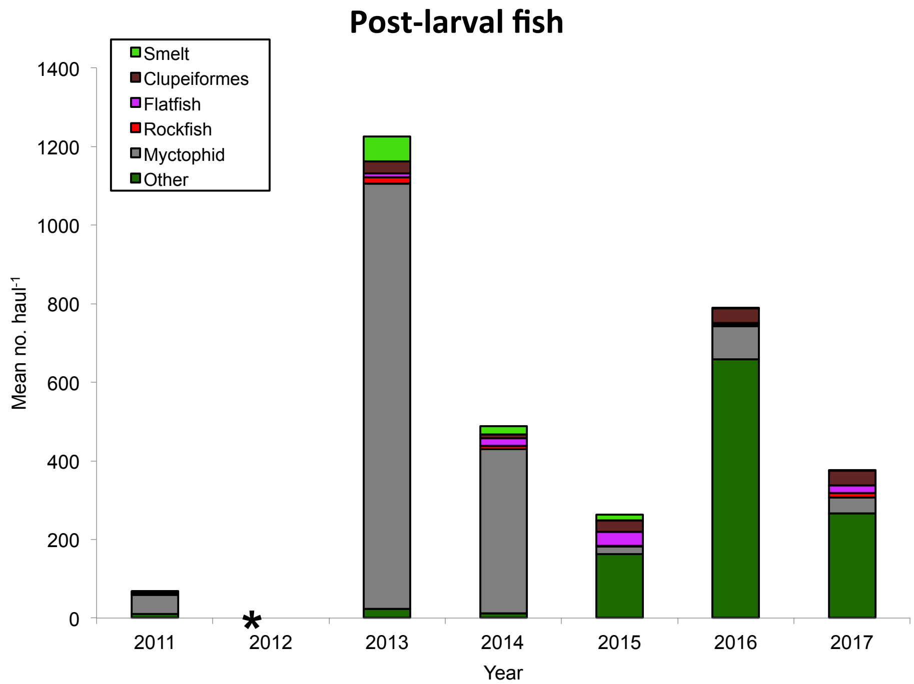


Figure 22. Mean catches (no. haul^{-1}) of the dominant post-larval fish taxa collected during June–July in 2011–17 along nine half-degree latitudinal transects between 42.0° and 46.0°N latitude in the northern California Current region. * = no samples were collected in 2012.

Figure 23. NMDS ordination of northern California Current pelagic assemblages. The NMS ordination explained 80.8% of the total variability in the first two dimensions. Pelagic fish and invertebrate catch data were collected by the NWFSC NOAA/Bonneville Power Administration surveys using surface trawls on standard stations along transects between northern Washington and Newport, OR, in June from 1999 to 2016. All tows were made during the day at predetermined locations along transects extending off the coast to the shelf break (Brodeur et al. 2005).

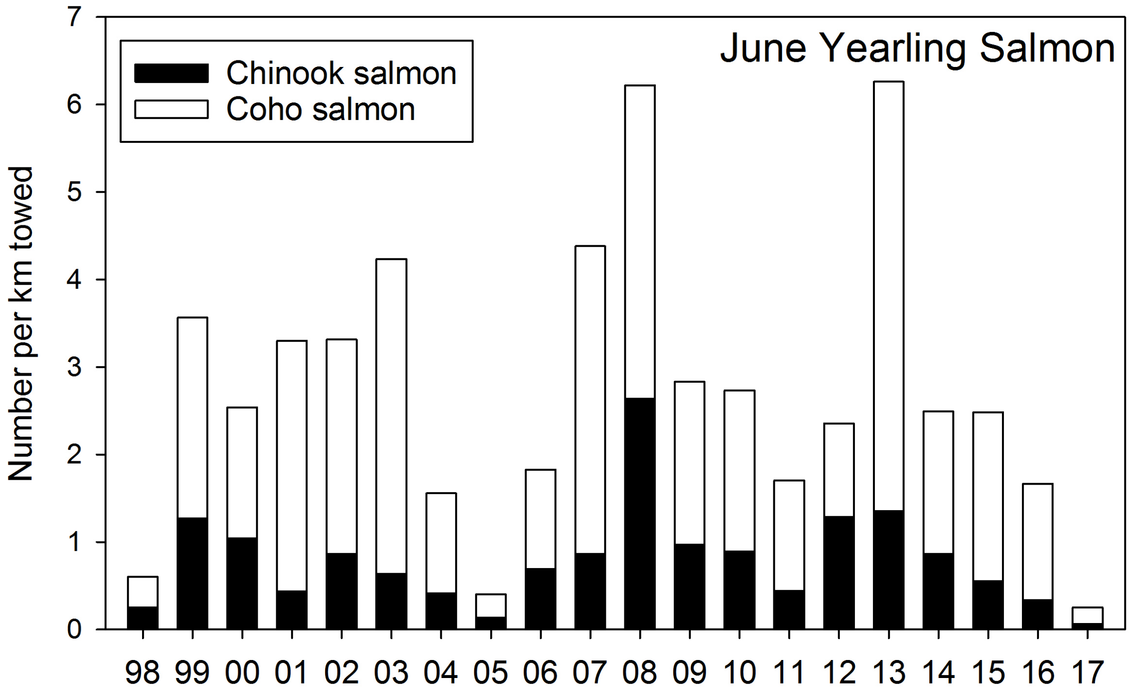


Figure 24. Catches of juvenile coho (black bars) and Chinook (white bars) salmon off the coast of Oregon and Washington in June from 1998–present.

found in the tropics, and have never been captured on the continental shelf during this survey or any previous surveys off central Oregon to northern Washington to our knowledge, although in recent years it has been found increasingly farther north off the shelf in other surveys[14]. But during June 2017 pyrosomes were present in 37% of the hauls, sometimes exceeding hundreds of individuals.

The jellyfish community off Washington and Oregon was also quite different than previous years. The usual numerically dominant large jellyfish is a cool-water associated scyphozoan species, sea nettle (*Chrysaora fuscescens*). However, during the warm ocean years of 2015 and 2016, the more offshore taxa of Hydromedusae, the water jelly (*Aequorea* spp.) was much more abundant and densities of *Chrysaora* were low. In June 2017 both *Chrysaora* and *Aequorea* were caught in average densities.

Salmon and salmon forage indicators in northern California Current Catches of yearling salmon off Washington and Oregon in June may be a good indicator of early ocean survival of yearling Chinook (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*). The abundance of yearling Chinook salmon during June is positively related to spring Chinook jack and adult salmon counts at the Bonneville Dam (with 1 and 2 year lags, respectively), as does the abundance of yearling coho salmon to subsequent coho smolt to adult survival[15] (Morgan et al. 2017). Catch per unit effort (number per km trawled) of both yearling Chinook and coho salmon during the June 2017 survey was the lowest of the 20-year time series from 1998 to 2017 (fig. 24). This suggests that adult returns of both spring Chinook in 2019 and coho salmon in 2018 will be significantly lower than average.

The biomass of fish larvae in late winter from the Newport Hydrographic Line provides an index of fish that are the common prey of juvenile salmon when they enter the ocean in spring and summer, and correlates with juvenile salmon survival and return as adults (Daly et al. 2013, 2017)[16]. The food biomass for out-migrating juvenile salmon in winter (January–March) 2017 was the highest in the 20-year time series (fig. 25), largely attributable to presence of young-of-the-year (YOY) rockfishes.

In addition to the increased biomass of fish prey potentially available to out-migrating juvenile salmon, the type of fish prey (assemblage) that are available for salmon also influences salmon survival. Importantly, the overall community composition of winter ichthyoplankton in 2017 was similar to 2015 and 2016 and predicted a poor food community for the salmon (fig. 26).

[14] http://news.nationalgeographic.com/2017/06/pyrosome-fire-body-bloom-eastern-pacific-warm-water

[15] https://www.nwfsc.noaa.gov/oceanconditions/Juvenile Salmon Catch

[16] Ichthyoplankton samples were collected from 5 stations spaced ~9 km apart along the NH line. Sampling was conducted approximately every 2 wk between January and March. Only samples from January–March were used, assuming that larvae collected during these months would have had sufficient time to grow to the average size of prey eaten by juvenile salmon in late spring and early summer.

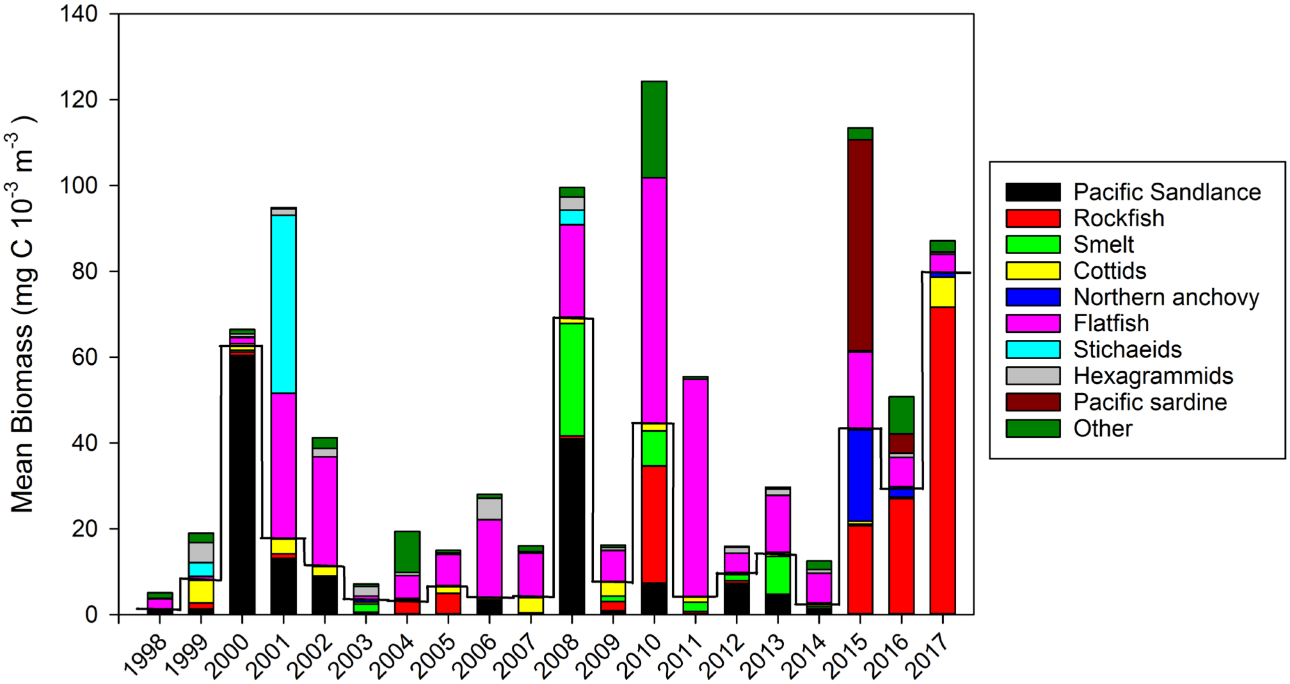


Figure 25. Annual mean biomass (mg C 10^{-3} m^{-3}) of the five important salmon prey taxa (below solid line) and five other dominant larval fish taxa (above solid line) collected during winter (January–March) in 1998–2017 along the Newport Hydrographic line off the coast of Oregon (44.65°N, 124.18–124.65°W). Figure expanded from one presented in Daly et al. (2013).

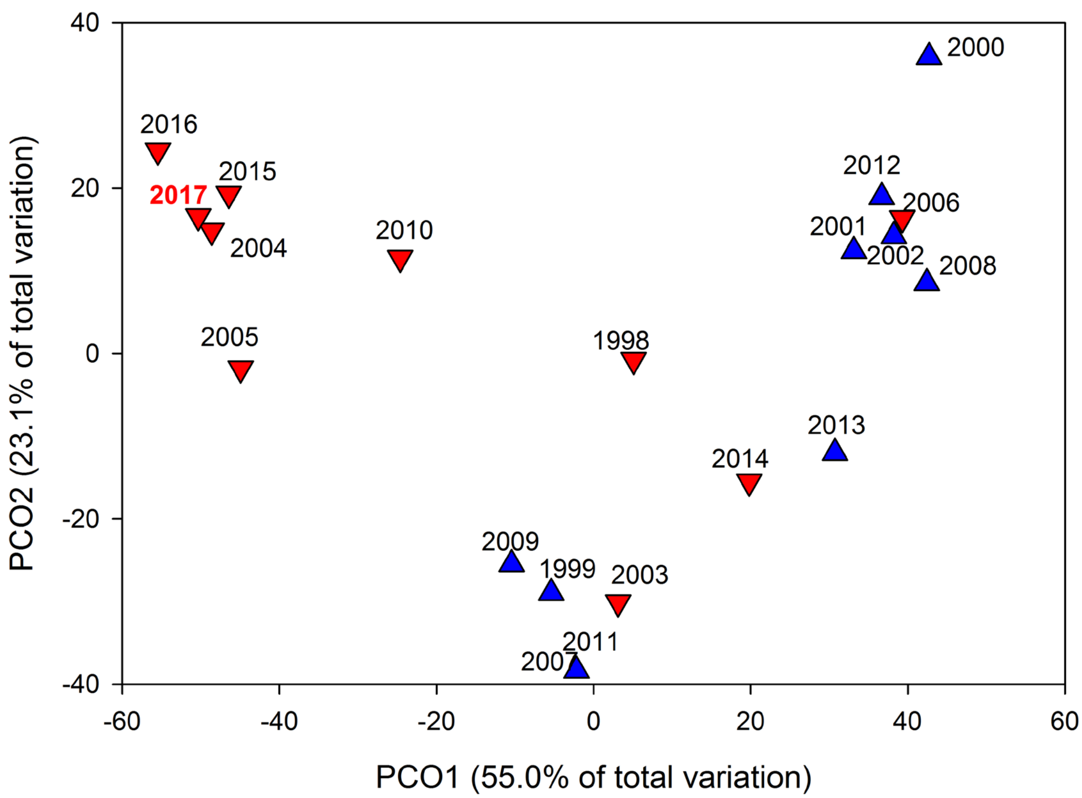


Figure 26. Principal coordinate analysis of the prey composition of winter ichthyoplankton that are important prey for out-migrating juvenile salmon (Pacific sand lance, osmerids, cottids, northern anchovy, and rockfishes). Red symbols indicate positive winter PDO (warm ocean temperatures) and blue indicates negative winter PDO (cold ocean temperatures). The larvae were collected during winter (January–March) in 1998–2017 along the Newport Hydrographic line off the coast of Oregon (44.65°N, 124.18–124.65°W). Figure expanded from one presented in Daly et al. (2017).

Based on axis 1 values (55% variance explained along this axis) from principal coordinate analysis of the prey composition of winter ichthyoplankton, the index of the 2017 prey composition predicts poor prey conditions for currently out-migrating juvenile salmon. In 2017, 90% of the winter ichthyoplankton composition was warm ocean condition taxa consisting of rockfishes and northern anchovy larvae. The relationship between the principle component 1 (PC1) axis values (prey composition) with spring Chinook salmon adult returns to Bonneville Dam two years later is: P = 0.003; R^2 = 48.0% (1998–2014; 1999 outlier year excluded). The biomass of ichthyoplankton in winter predicts returns of spring Chinook salmon to Bonneville Dam in 2019 to be just below ~230,000, and the prey composition prediction is one of the lowest of the time series at ~74,000.

Higher than average ichthyoplankton biomass but poor ichthyoplankton composition occurred in the warm ocean years 2015–17. Of particular note during January–March 2017, southern California winter-spawned larvae were present for the third winter in a row (e.g., Pacific hake and Pacific sardine [*Sardinops sagax*]; Auth et al. 2017). Sardine larvae were present in winter 2017, but not in high amounts, and were located at inshore stations (NH 1 and 10) and some were >10 mm long (Auth unpublished data). Of note, juvenile sardine were eaten for the first time in the time series by coho and Chinook salmon in May and June 2016 (Daly and Brodeur unpublished data), indicating that sardine are a new prey resource for the salmon in warm ocean conditions.

Summary of epipelagic micronekton and salmon in northern CCS Taken as a whole, the micronekton community and juvenile salmon abundance during winter to June 2017 off Washington and Oregon indicate continued perturbation from "normal" conditions. The abundance of pyrosomes may have indicated abnormal water transport in 2017. It is not yet clear whether the findings of 2017 are a result of the marine heat wave combined with the 2015–16 El Niño or whether ocean processes unique to 2017 combined with the previous warm years resulted in the altered community structure.

Central California[17]

Above average catches of YOY rockfishes were observed off central California in late spring 2017, although these catches were lower than the high catches observed in 2015 and 2016 (fig. 27). Catches in the southern region increased from below average values in 2016 to the greatest values in the (shorter) 13-year record in that region in 2017. Catches of YOY rockfish in north-central California were below average, such that there was a gradient in relative catch rates from record highs in the Southern California Bight to below average (but above historic low levels) in northern California.

In the Southern California Bight during 2017, catches of adult northern anchovy were comparable to past (2004) high levels, while catches continued to be very sparse in other regions of the California Current sampled by this survey (fig. 27). The survey also samples YOY northern anchovy and YOY Pacific sardine, for which catches of both increased during the 2015–16 warm event, and, in 2017, stayed above previous low levels in northern and central areas while continuing to increase to very high levels in the Southern California Bight (data not shown, but see Sakuma et al. 2016). Although the sparse catches for adult Pacific sardine and adult northern anchovy north of Southern California Bight indicate that the biomass of each may be too low to be meaningfully indexed by the survey, the increase in catches of YOY northern anchovy, in particular, are consistent with an increase in that population which is likely more concentrated in nearshore habitats not sampled by the survey. An increase in adult northern anchovy nearshore is also consistent with the egg enumeration data in 2017 (fig. 21) and seabird diets (presented below), both of which indicated above average adult northern anchovy abundance in the region. The abundance of both krill and market squid (*Doryteuthis opalescens*), increased significantly in all regions in 2017, both ranked at the third highest value since 1990 in the core region (fig. 27).

Thetys as well as other salps were less abundant than recent years in all but the southern region, where other salps increased relative to 2016 (fig. 28). Pyrosomes continue to be caught in very large numbers across all regions (fig. 28), with particularly high catches (of primarily very small pyrosomes) in the southern region. Catches of scyphozoan jellyfish (primarily *Aurelia* spp. and *Chrysaora* spp.) continued to be unusually low in 2017, a pattern that emerged in 2015 (fig. 28). The high numbers of pelagic red crabs (*Pleuroncodes planipes*) and California lizardfish observed in 2015 and 2016 (Leising et al. 2015; McClatchie et al. 2016) were not observed in 2017 possibly indicating cooler water regionally.

There are sharp differences in principal component (PC) loadings between coastal pelagic (Pacific sardine, northern anchovy) and mesopelagic species (myctophids) relative to most of the YOY groundfish, krill, and cephalopods. The two leading PCs for the assemblage are shown in a phase plot (fig. 29). The dramatic separation of the 2013–16 period was apparent as those years were

[17] Epipelagic micronekton samples were collected during May and June by the Southwest Fisheries Science Center Rockfish Recruitment and Ecosystem Assessment Survey and the Northwest Fisheries Science Center Pre-recruit Groundfish Survey, covering a geographic range from the US/Mexico border (32.5°N) to southern Washington (46.5°N). A modified midwater Cobb trawl (10–30 m headrope depth) was used to sample pelagic species along the CCE in the mixed layer where juvenile salmon are typically found. Methods were standardized between regions beginning in 2011 (Sakuma et al. 2016).

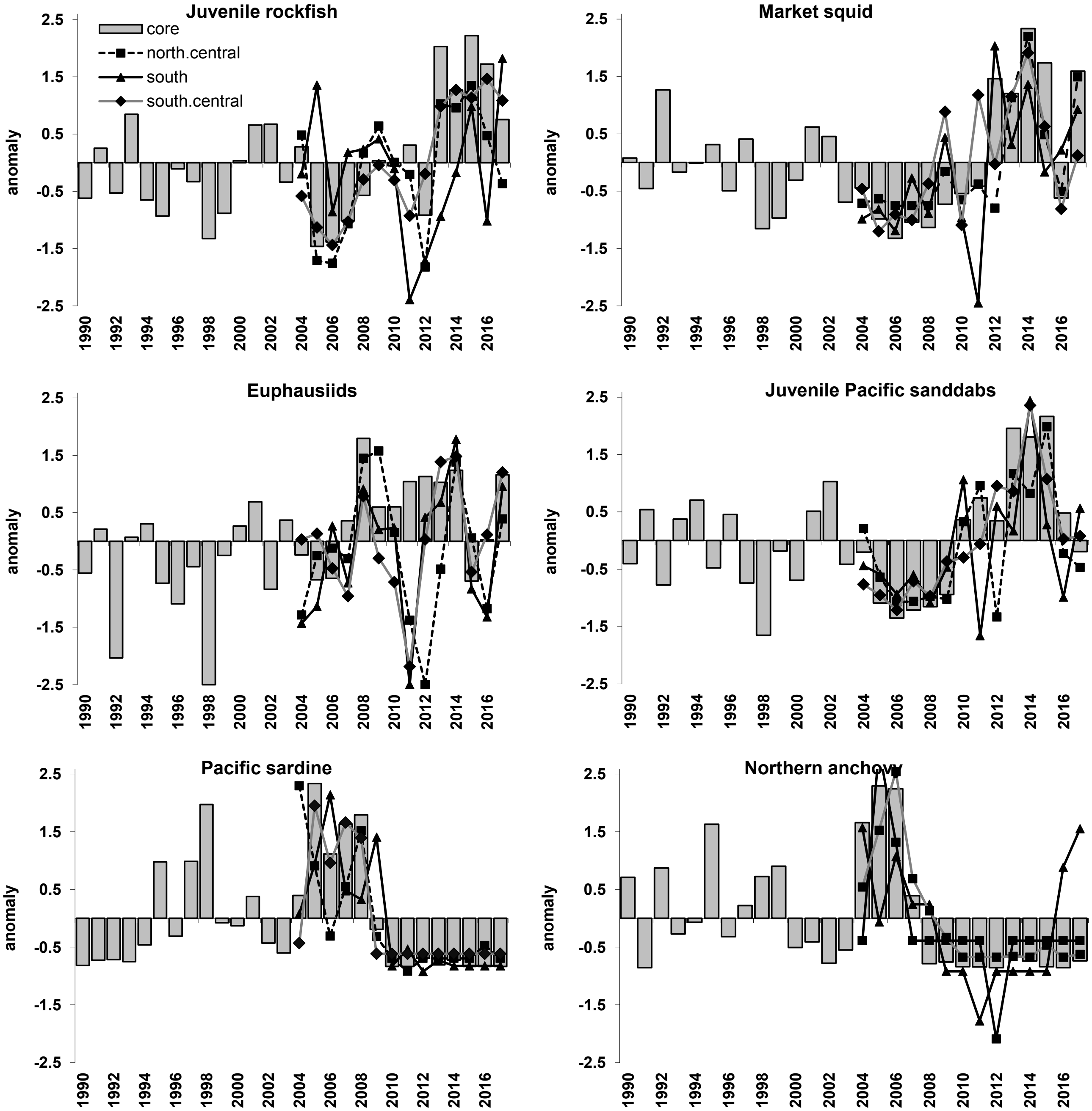


Figure 27. Long-term standardized anomalies of several of the most frequently encountered pelagic forage species from rockfish recruitment survey in the core (central California) region (1990–2017) and the southern, south-central and north-central survey areas (2004–17). Forage groups are YOY rockfish, market squid, krill (primarily *Euphausia pacifica* and *Thysanoessa spinifera*), YOY Pacific sanddab, Pacific sardine and northern anchovy.

extremely orthogonal to the low productivity years of 1998, 2005, and 2006. However, in 2017 the observed community switched to what might be considered a "normal" state, centrally located among the years 1990–2016. The switch in the forage base has important implications for seabirds, marine mammals, salmon and adult groundfish that forage primarily, or exclusively, on one or another component of the forage assemblage.

Southern California Current: CalCOFI region

The spring coastal pelagic fish survey in 2017 on NOAA ship *Reuben Lasker* was focused on northern anchovy rather than Pacific sardine and consequently the offshore extent of transects was reduced. No trawling was conducted offshore and unlike 2015 and 2016, no sampling was conducted north of San Francisco in 2017. The spring CalCOFI cruise on NOAA ship

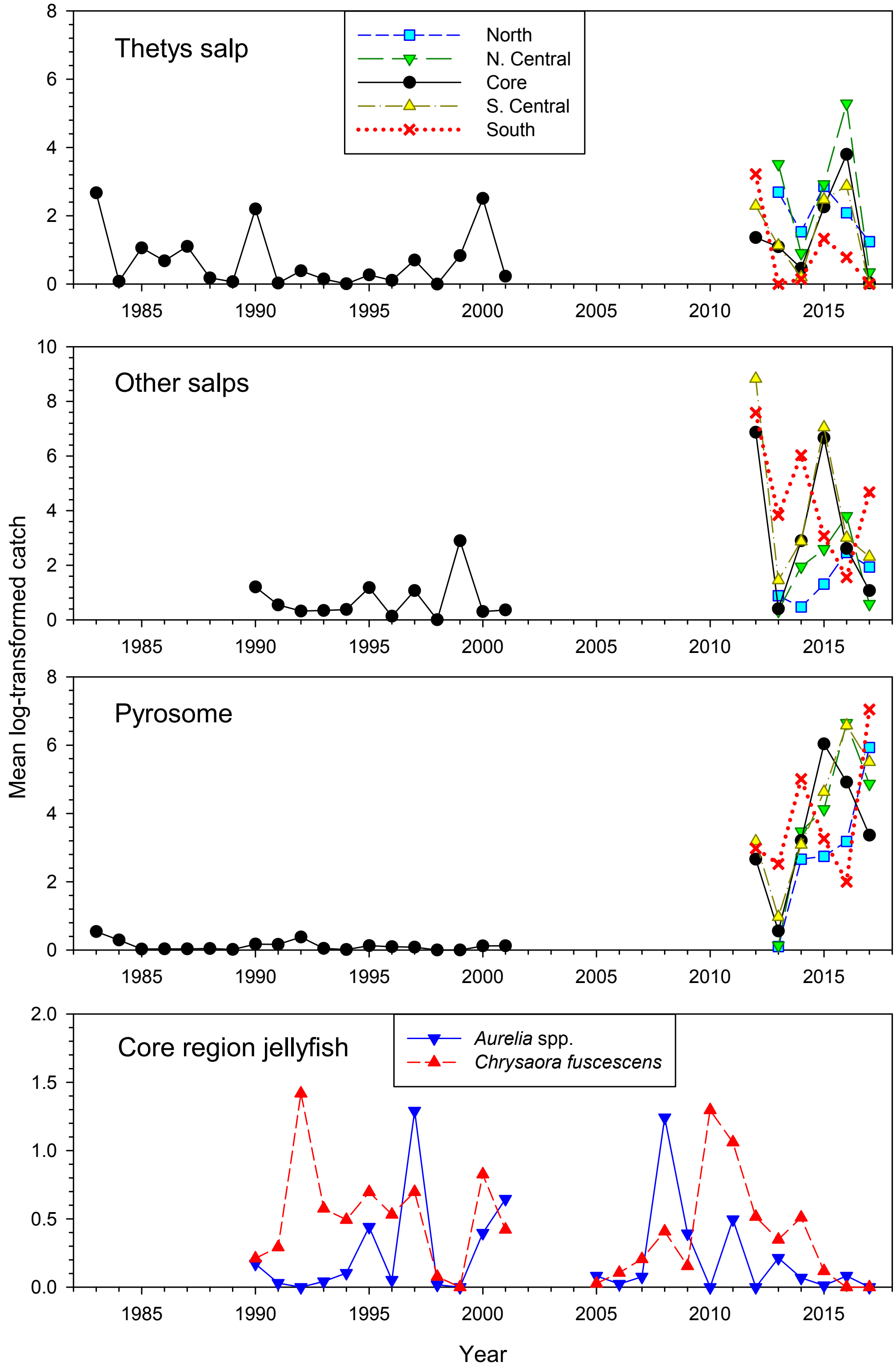


Figure 28. Standardized catches of jellyfish (*Aurelia* and *Chrysaora* spp.) and pelagic tunicates in the core and expanded survey areas.

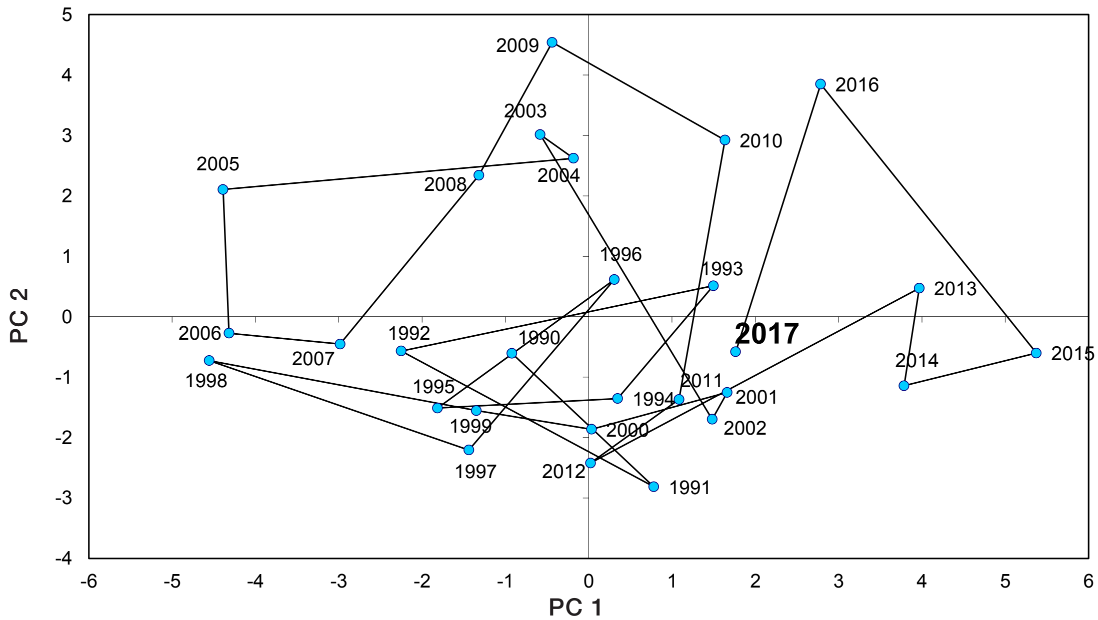


Figure 29. Principal component scores plotted in a phase graph for the nine key taxonomic groups of forage species sampled in the central California core area in the 1990–2017 period.

Bell M. Shimada sampled the usual 113-station winter and spring pattern (San Diego to San Francisco) (fig. 30).

Anchovy eggs in spring 2017 were notably more abundant than in 2016 (fig. 31). Anchovy eggs were also an order of magnitude more abundant in spring 2016 compared to 2015, but the increase was spatially restricted to small areas off Ventura, California and Newport, Oregon. By contrast, in spring 2017 anchovy eggs were widespread in the Southern California Bight, indicating that eggs were both more widely distributed and present at higher density than in 2016. It is notable that the highest egg count was very localized (again, off Ventura, California) and was associated with an extreme trawl catch of more than 600 kg of almost pure anchovy. This single catch was an order of magnitude larger than all of the other forage fish trawl catches on the entire cruise, and presumably represented a large school of northern anchovy.

In 2017, few anchovy eggs, and no adults, were collected north of Point Conception (fig. 30) although other continuous underway fish egg sampler surveys demonstrate concentrations of northern anchovy eggs off the Columbia River (fig. 21). Peak northern anchovy spawning off California generally occurs during March, so spawning patterns detected by the spring cruise may not be representative of the full northern anchovy spawning season.

Sardine and jack mackerel eggs were found at very low concentrations in the spring of 2017, consistent with the long-term trend. Sardine eggs were most abundant off the central California coast, south of Monterey, California (fig. 30). In 2016 the spawning distribution of sardine eggs was centered farther north (43°–44.5°N, off Oregon) than in spring 2015 (41°–43°N, California-Oregon border), but we are unsure if there was significant sardine spawning off Oregon in 2017 (fig. 31).

Whereas the ichthyoplankton assemblage (larval; an earlier stage than represented in fig. 27) in 2014–16 (based on spring samples from lines 80 and 90) was characterized by high abundances of southern, offshore mesopelagic fishes such as *Ceratoscopelus townsendi*, Gonostomatidae (mostly in the genus *Cyclothone*), *Triphoturus mexicanus*, and *Vinciguerria* spp. (mostly *V. lucetia*; these taxa are colored red on fig. 32), the 2017 assemblage was more "normal" (fig. 32). In multivariate space based on NMDS, NMDS 1 largely separated years when southern species (red font, fig. 32) were predominant (high NMDS 1) from years with primarily northern species (low NMDS 1; blue font on fig. 32), and NMDS 2 distinguished years with high Pacific sardine (high NMDS 2) and high northern anchovy (low NMDS 2). The 2017 assemblage fell in the middle of both NMDS axes 1 and 2, indicating that the assemblage was characterized by species with cosmopolitan distributions (colored green in fig. 32) and unexceptional abundances of both Pacific sardine and northern anchovy across the sampled region.

Evaluation of common mesopelagic taxa indicated that warm-water taxa generally declined between 2016 and 2017 while abundances of cool-water taxa were similar between these years. The southern warm-water taxa *Vinciguerria* spp. and *C. townsendi* fell to relatively low abundances in the spring of 2017 (fig. 33). The southern myctophid *T. mexicanus* declined dramatically from 2016

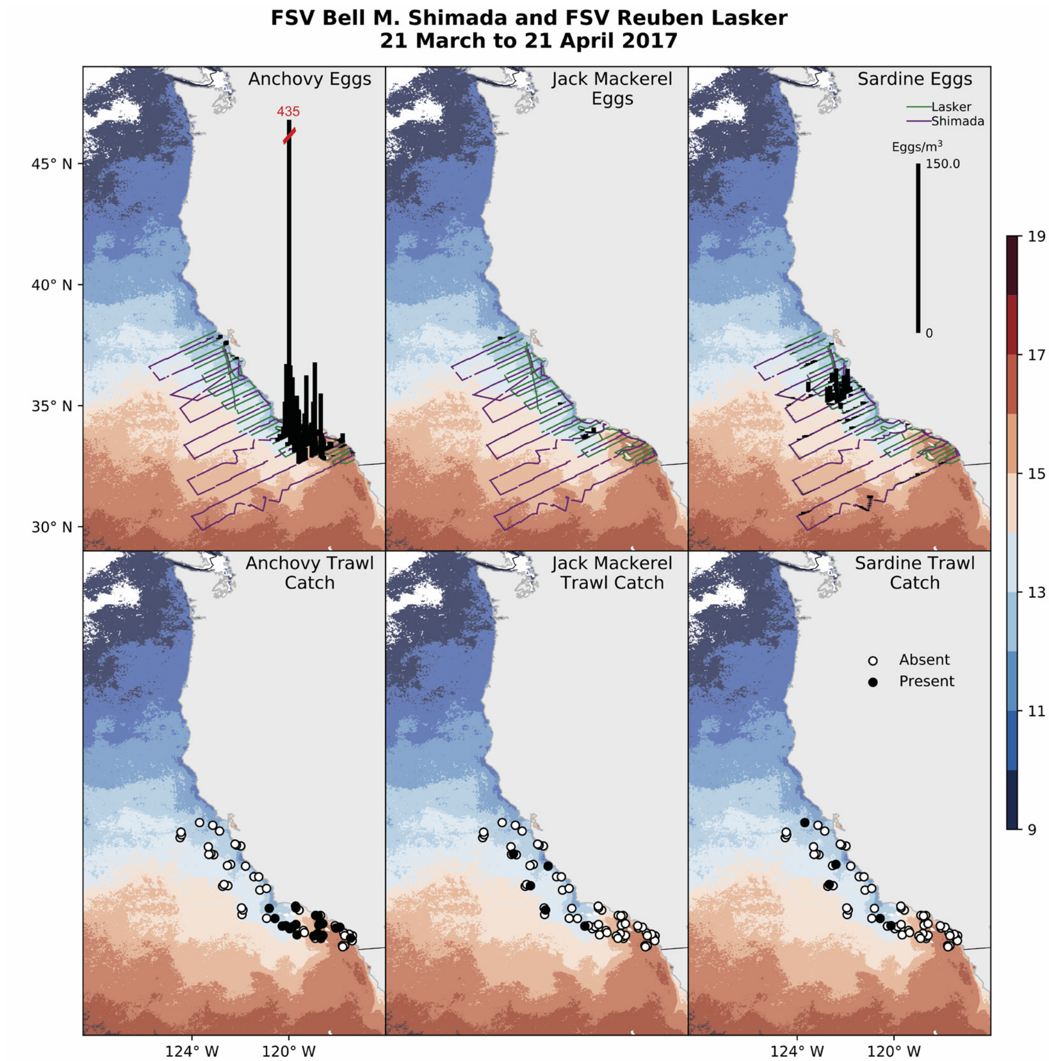


Figure 30. Density of eggs of northern anchovy, jack mackerel, and sardine collected with the continuous underway fish egg sampler (CUFES) during the spring 2017 CalCOFI and coastal pelagic fish cruises overlaid on satellite sea surface temperatures (˚C). Lower panels represent trawls in which anchovy, jack mackerel, and sardine where absent or present.

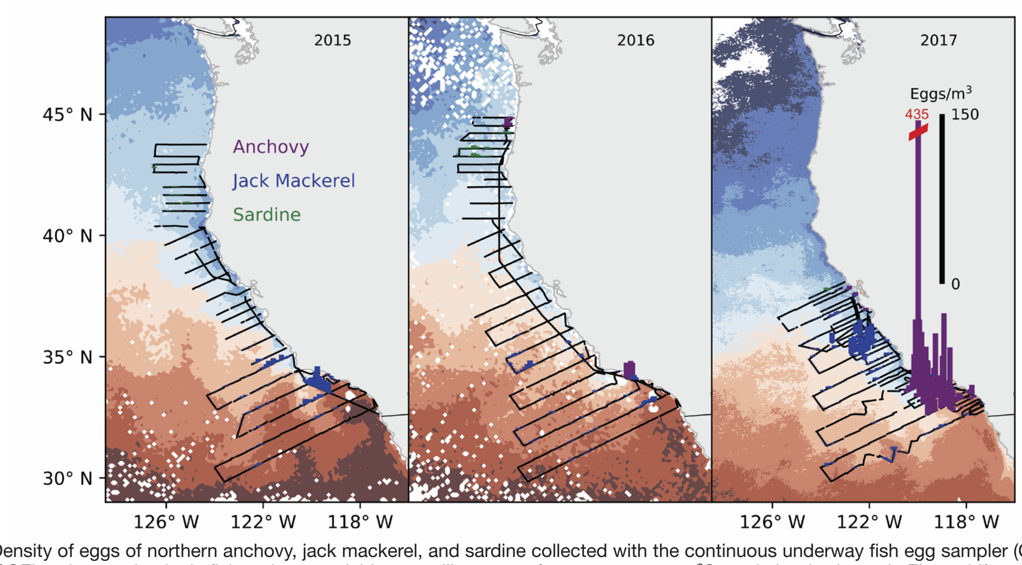


Figure 31. Density of eggs of northern anchovy, jack mackerel, and sardine collected with the continuous underway fish egg sampler (CUFES) during the spring 2015–17 CalCOFI and coastal pelagic fish cruises overlaid on satellite sea surface temperatures (˚C; scale bar is shown in Figure 30).

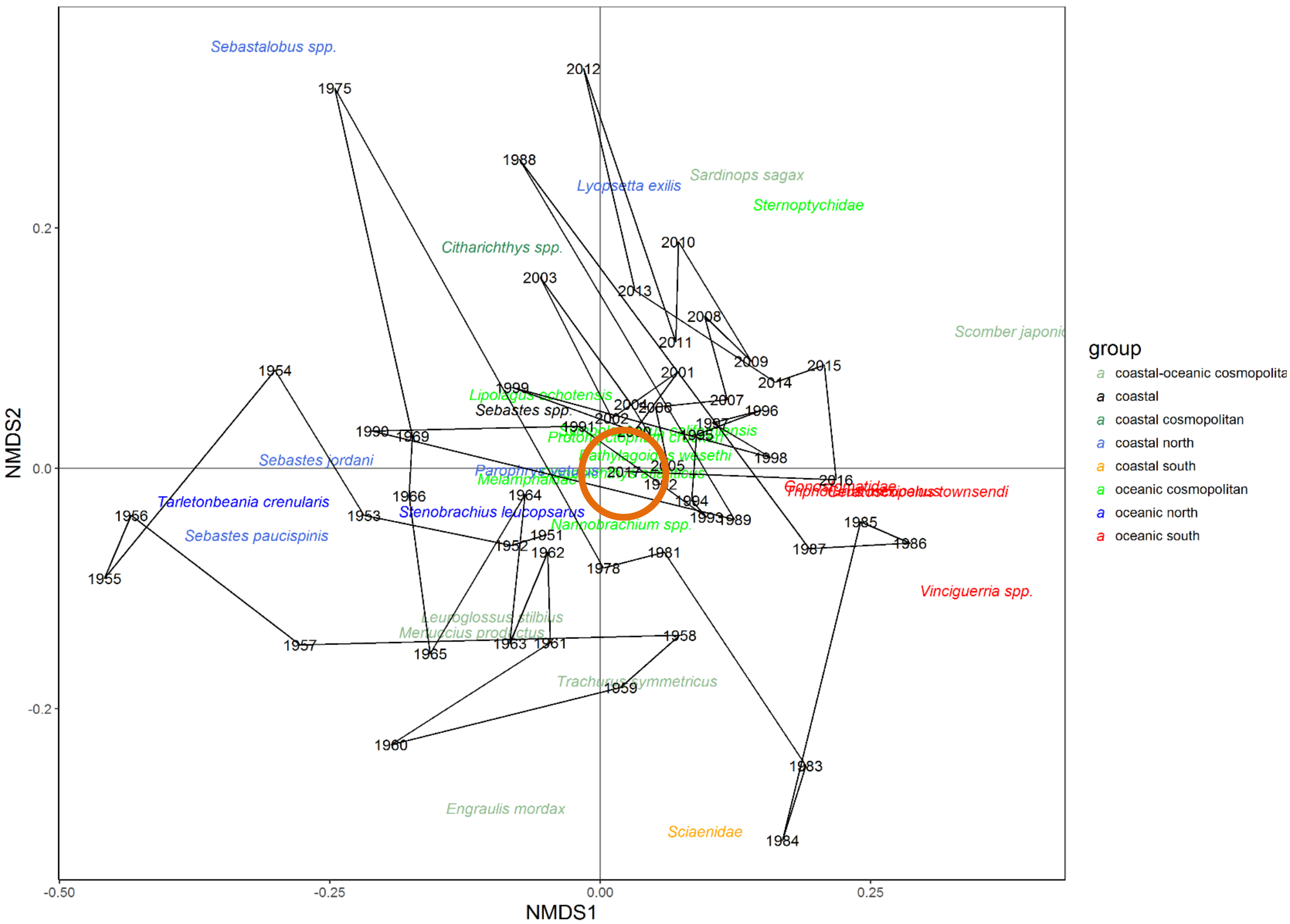


Figure 32. NMDS analysis depicting the composition of forage assemblage from lines 80 and 90 during the spring among years. The color of the species names characterizes their habitat affiliation and biogeographic range. Species in red or orange font are southern California Current, blue font are northern California Current, and green font are cosmopolitan. Open orange circle denotes the location of 2017.

but was still high relative to most years, while Gonostomatidae declined in 2017 to approximately average abundances (fig. 33). The northern cool-water myctophid *Stenobrachius leucopsarus* increased a bit relative to 2015–16 to near average levels (fig. 33), while another northern myctophid, *Tarletonbeania crenularis*, remained low (fig. 33).

For coastal pelagic species that are fished to varying degrees, northern anchovy abundance in spring was very similar to 2016 (fig. 34). Northern anchovy abundance from spring samples has been low since the early 1990s (with the exception of 2005), and 2017 had the third highest abundance of this species since 1994 (fig. 34). Abundance of northern anchovy in 2017, however, was still low relative to peaks between the 1950s and 1994. Pacific sardine, jack mackerel, and Pacific chub mackerel abundances were low in 2017 (fig. 34).

Shannon-Weaver diversity was almost exactly at a median level in spring of 2017 (fig. 35). This index tends to be low when coastal pelagic species are very abundant (e.g., correlation r = –.70 between Shannon-Weaver and northern anchovy) and high when southern mesopelagics are relatively abundant (e.g., r = .35 between Shannon-Weaver and *T. mexicanus*). The median diversity reflects results of the multivariate analysis on individual taxa suggesting that 2017 was characterized by having unexceptional abundances of both the southern mesopelagic taxa and northern anchovy. Overall species richness based on an estimated asymptote from bootstrap species accumulation curves was at the upper 75th quantile in 2017 and increased by approximately 8 species in comparison with 2016. Species richness also correlates positively with abundances of southern offshore species (e.g., r = .53 between Gonostomatidae and richness). Although the southern offshore species were down from 2015–16, some taxa (e.g., *T. mexicanus*, Gonostomatidae) were still relatively abundant (fig. 34). In addition, while a few commonly found taxa such as *Citharichthys* spp., shortbelly rockfish, and *Sebastes*

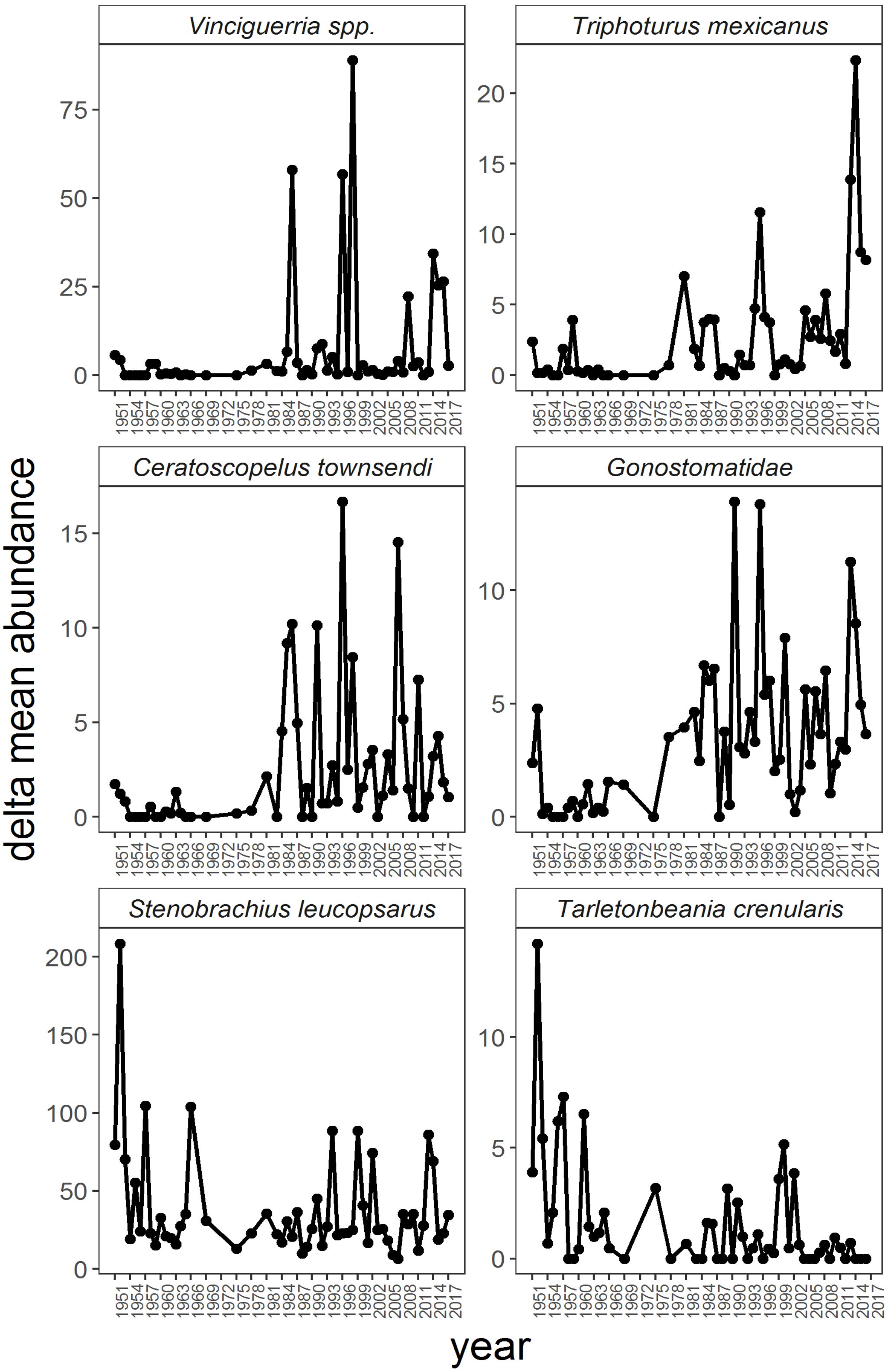


Figure 33. Delta-mean abundances of common mesopelagic taxa in spring between 1951 and 2017. Delta-mean calculations are used to estimate mean values from data with high numbers of samples that contain zero values (Pennington 1996). The four taxa in the top panels (*Vinciguerria* spp., *Triphoturus mexicanus*, *Ceratoscopelus townsendi*, and Gonostomatidae) have southern distributions relative to southern California and the two in the bottom panels (*Stenobrachius leucopsarus* and *Tarletonbeania crenularis*) are more broadly distributed to the north.

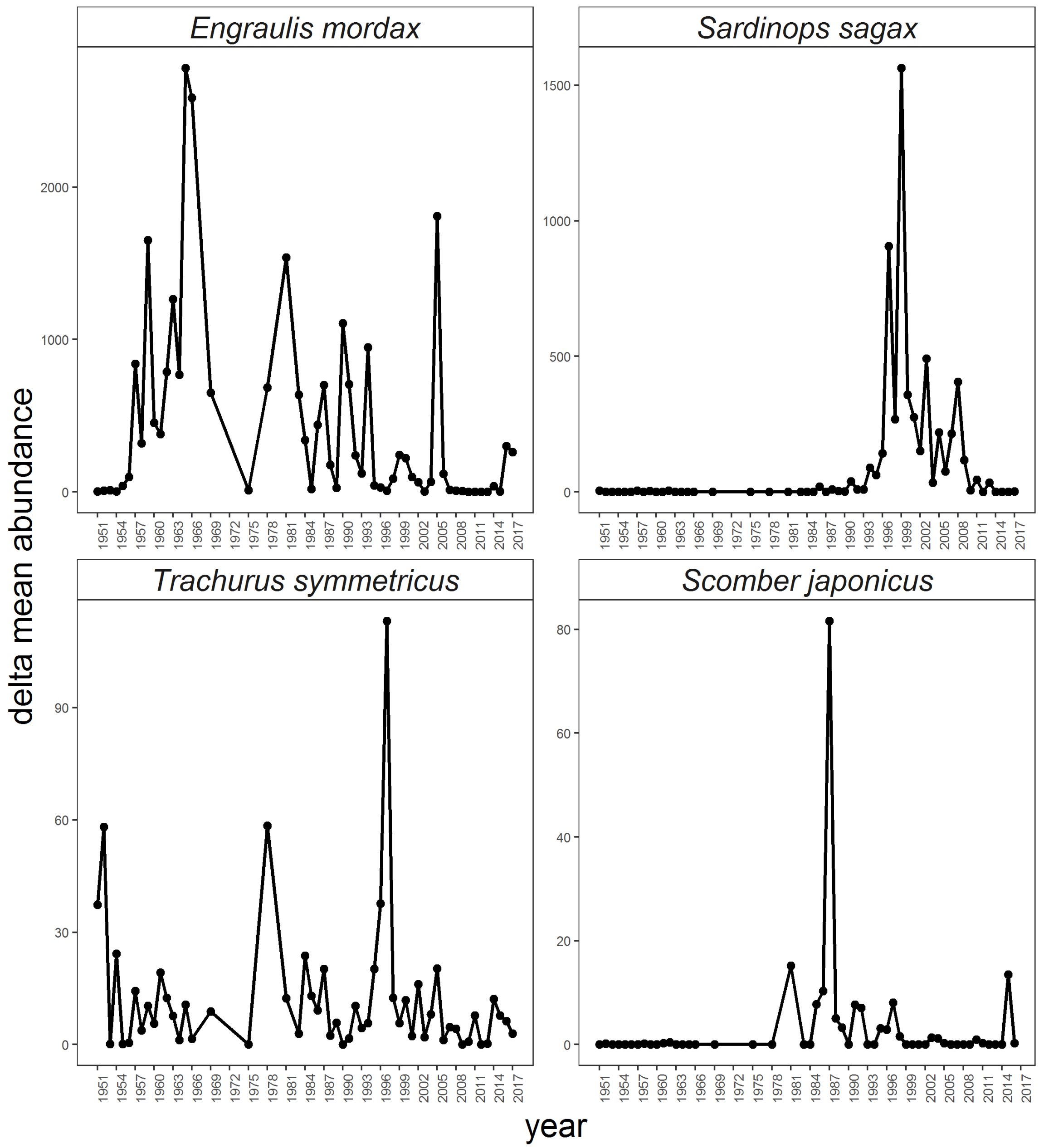


Figure 34. Delta-mean abundances of the most common coastal pelagic species that are to some extent commercially fished. Delta-mean calculations are used to estimate mean values from data with high numbers of samples that contain zero values.

paucispinis were completely absent in 2016, these taxa were again present in 2017.

REGIONAL PATTERNS IN BIRDS AND MARINE MAMMALS

Northern California Current: Yaquina Head, Oregon

Common murres (*Uria aalge*) at Yaquina Head experienced reproductive failure in 2016, as they had in 2015. Most (97%) murre eggs laid (n = 183) were not incubated long enough to hatch chicks. This was the second consecutive year of almost complete reproductive failure, and the only times this occurred during the 15 years of data collection. Murres at Yaquina Head exhibited a 6-year run (2011–16) of low reproductive success that is approximately a quarter the success of the first 9 years of our study (1998–2002, 2007–10, fig. 36). Murre reproductive success during the 2014–16 are the lowest on record. As in previous years, the reproductive failure is a combination of top-down predation and bottom-up food limitation. While the top-

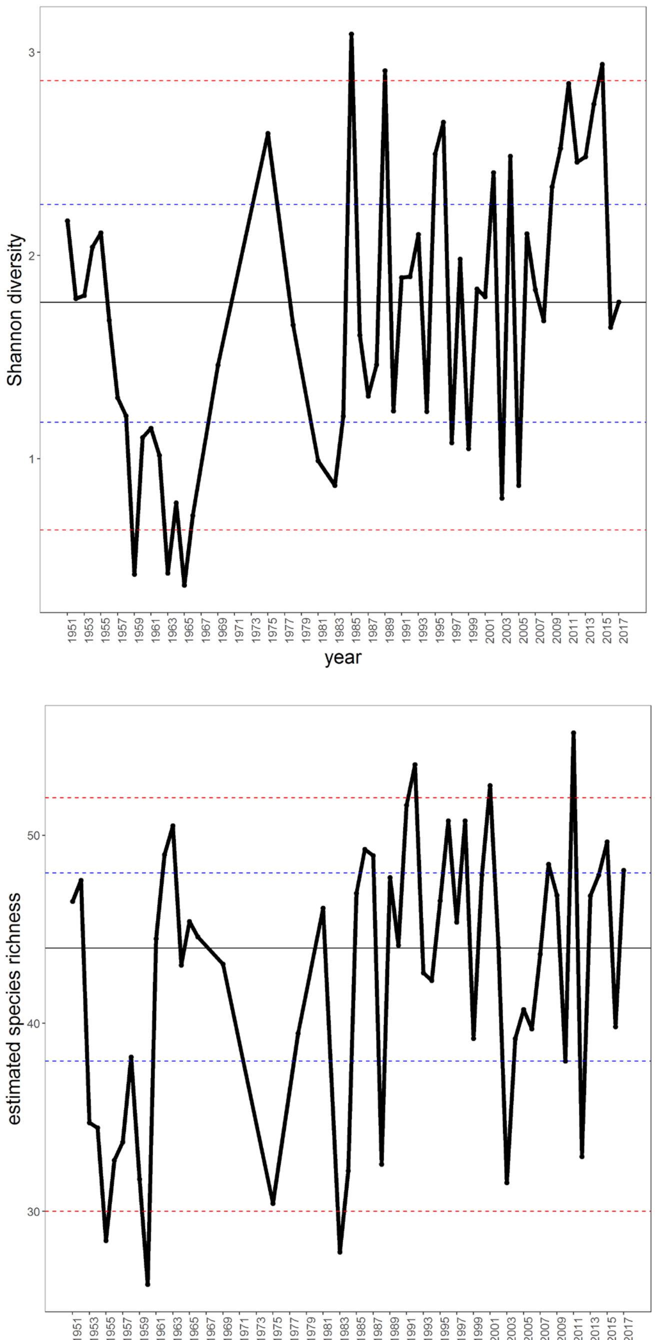


Figure 35. Shannon-Weaver diversity and estimated taxa richness of the larval assemblage. Dashed, horizontal blue lines depict 25th and 75th quantiles, dashed red lines 5th and 95th quantiles, and solid, horizontal black lines the median values.

down signal is most prominent, the bottom-up signal is evident. For example, the only location where a few murre chicks fledged in 2015 and 2016 was a small rock near sea level, not used for rearing chicks in previous years, and generally out of the way of predators. Even at this mostly predator-free site where a new study plot was added in 2016, the murre reproductive success was only 0.21 fledglings/pair, which is among the lowest recorded for the whole colony in our time series and similar to reproductive success during the 1998 El Niño (Gladics et al. 2015).

Since 2011 much of the reproductive loss for murres has been due to egg and chick predators (Horton 2014), however, 2016 had the highest rate of murre egg and adult loss, with 4.21 eggs destroyed and 0.28 adult murre fatalities per hour of observation (n = 243 hours). As in 2015, the disturbance by primarily bald eagles (95%; *Haliaeetus leucocephalus*) in 2016 was so intense early in the breeding season that most eggs were not incubated long enough to hatch chicks. Persistent eagle disturbance early season is also in part responsible for the later chick hatching dates of murres.

Brandt's (*Phalacrocorax penicillatus*) and pelagic (*P. pelagicus*) cormorant were both successful at rearing young. Brandt's cormorants reproductive success (0.87 fledglings/nest) was lower than 2015 (1.70 fledglings/nest), but greater than 2014 (0.72 fledglings/nest) and overall slightly above the long-term mean (fig. 37). Median hatch date (June 27th) was among the earliest recorded in our time series (fig. 37). Average brood size (1.65 chicks) was close to the long-term average (fig. 37).

Pelagic cormorants had their second highest reproductive success (1.37 fledglings/nest), only surpassed by 2013 (2.13 fledglings/nest; fig. 36). There were 30 nests visible from observation platforms, also second only to 2013 (34 nests) and more than double 2015 (11 nests). Pelagic cormorant reproductive success has been highly variable during our time series. Median hatch date (July 13th) was close to the long-term average (fig. 37).

The three main forage fish species fed to murre chicks in the Yaquina Head region have been smelt (Osmeridae), Pacific herring or sardine (Clupeidae), and Pacific sand lance (*Ammodytes hexapterus*). The relative proportion of the three species can be similar or one species may be numerically dominant in a given year. The failure of most of the colony prior to chick rearing provided an added challenge for diet data collection in 2015 and 2016. We were able to collect diet data, however, very few of these samples were likely fed to chicks, but instead simply adults flying into the colony with fish. Diets in 2016 were again dominated by smelt (82%), continuing a trend of smelt-dominated diets for six of the past seven years (since 2010; fig. 38). Murre diets in 2016 had the highest proportion of smelt (82%) recorded in a single year, with sand lance a distant second (16%). Pacific sand lance continues to be minimal in diets since 2010. The dominance of smelt, and lack of herring and sand lance is even notably different than diets during the 1998 El Niño (fig. 38). Sand lance are generally more prom-

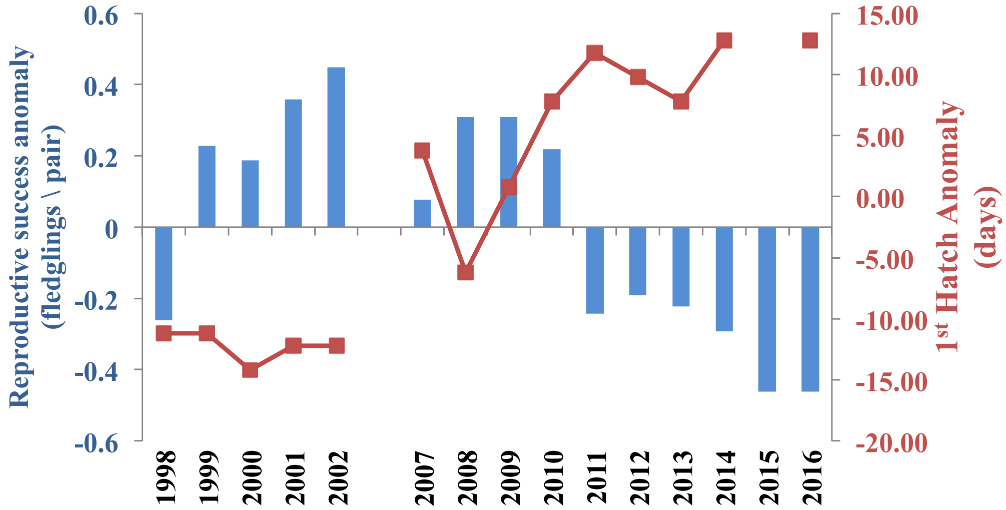


Figure 36. Anomalies of first chick hatch date and reproductive success for common murres nesting at Yaquina Head, Oregon, 1998–2016. 2016 was the second year that the colony failed to produce chicks from all but one small area where <10 chicks fledged each year.

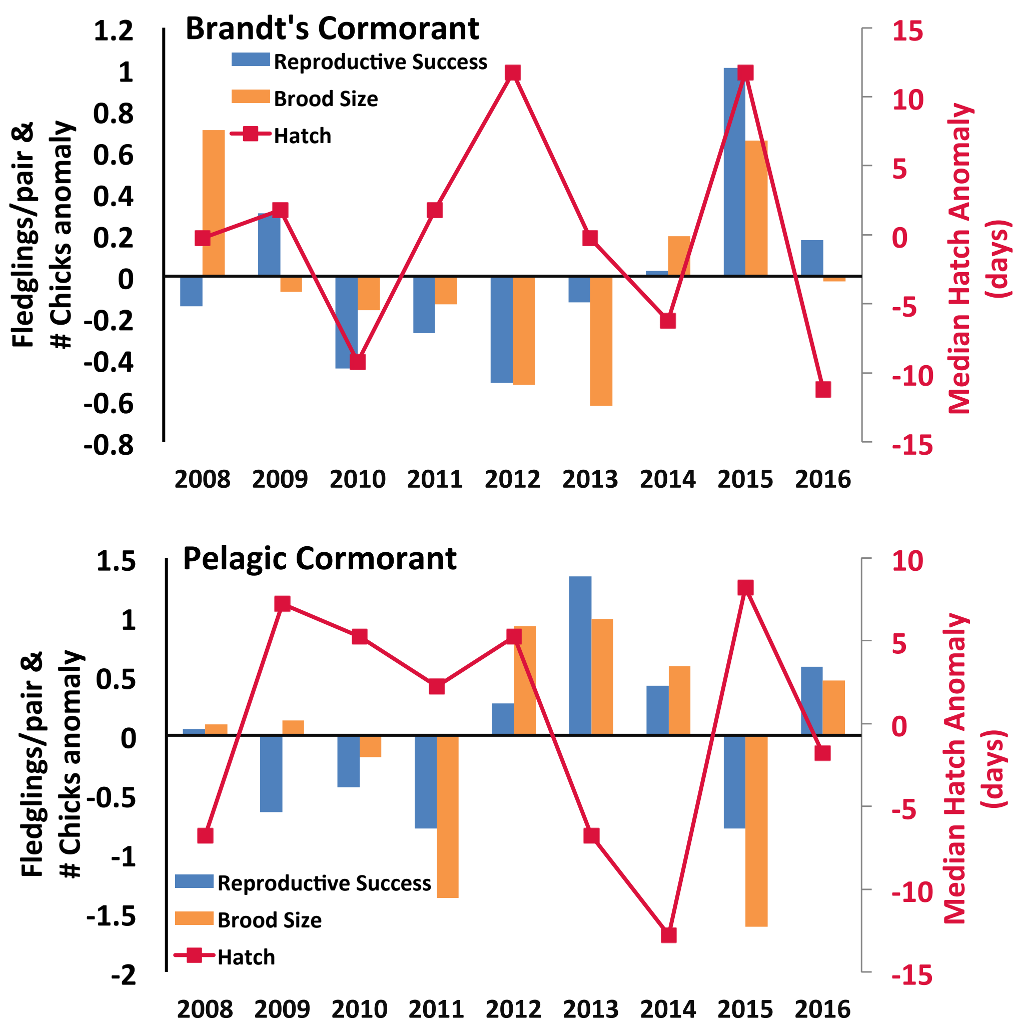


Figure 37. Anomalies of reproductive success and brood size for cormorants nesting at Yaquina Head, Oregon, 2008–16. Cormorants had average to above average reproductive success and brood size. Red lines indicate hatch date anomalies for cormorants.

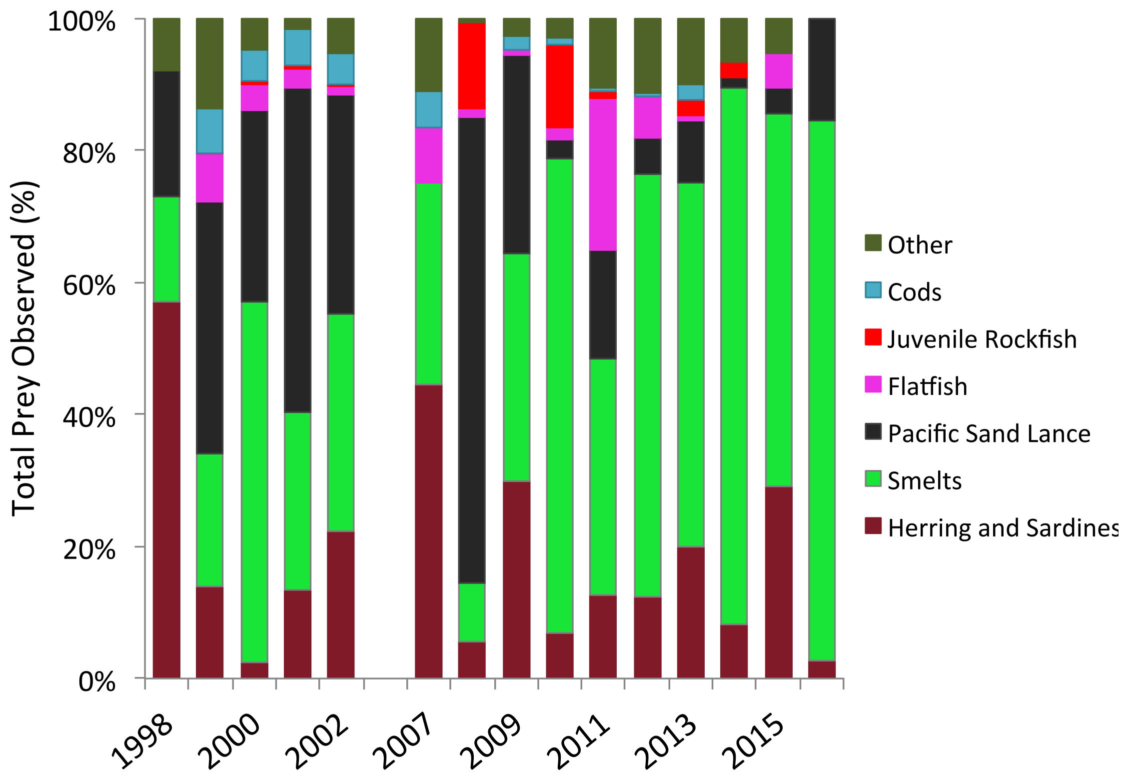


Figure 38. Prey fed to common murres chicks (% occurrence) at Yaquina Head Oregon, 1998–2016.

inent in murre diets during cold water years (Gladics et al. 2014, 2015), as highlighted by their prevalence in 2008 (fig. 38). Clupeids (primarily Pacific herring, *Clupea pallasii*), are generally associated with warmer water and positive PDO (Gladics et al. 2015), although their occurrence in recent warm water years has been lower than expected.

Northern California Current: Cape Flattery, Washington to Newport, Oregon

Notably, mean bird densities at sea for the 2017 strip transect surveys between Cape Flattery and Newport were the lowest observed during the 13-year data set and may indicate continued poor reproductive performance of resident breeders in 2017 (i.e., common murre)[18]. There was an apparent downward trend in common murre abundance at sea since 2015, with the third lowest mean density value on the record (9.27 birds per km^2) occurring in 2017 (fig. 39). This species was also aggregated near the Columbia River mouth, with 70.5% of all individuals observed on the three transects closest to the Columbia River (Willapa Bay, WA and Columbia River/Cape Mears, OR). Common murres are usually the most numerous breeding species found in the California Current during the upwelling season. Murres may have been affected by low forage fish availability beyond the Columbia River plume. The region near the Columbia River mouth where common murres were observed was also the area where northern anchovy were collected in surveys, including the same survey as the bird observations, and where above-average egg densities were observed with continuous underway fish egg sampler (fig. 21).

Sooty shearwater (*Ardenna grisea*) abundance in 2017, although very similar to that in 2011, was the lowest value yet observed in all 2003–17 June surveys (8.96 birds per km2) (fig. 39). Sooty shearwaters were highly aggregated in their distribution, with almost all (85.8%) individuals observed during the survey found on two transect lines immediately north of the Columbia River mouth (Grays Harbor and Willapa Bay, WA) where adult northern anchovy were observed during the same period. Given that sooty shearwaters are the most numerous non-breeding piscivorous species found in the California Current during upwelling season (May–September), their absence may reflect a lack of available prey in the offshore oceanic and Oregon waters found on the shelf in 2017, an hypothesis supported by the unusual micronekton assemblage observed in the same survey (fig. 23).

[18] Seabird observations from an annual June survey encompassing 8 cross-shelf transects (extending ~30–50 km offshore) between Cape Flattery, WA and Newport, OR provide information on density patterns for the northern domain of the California Current.

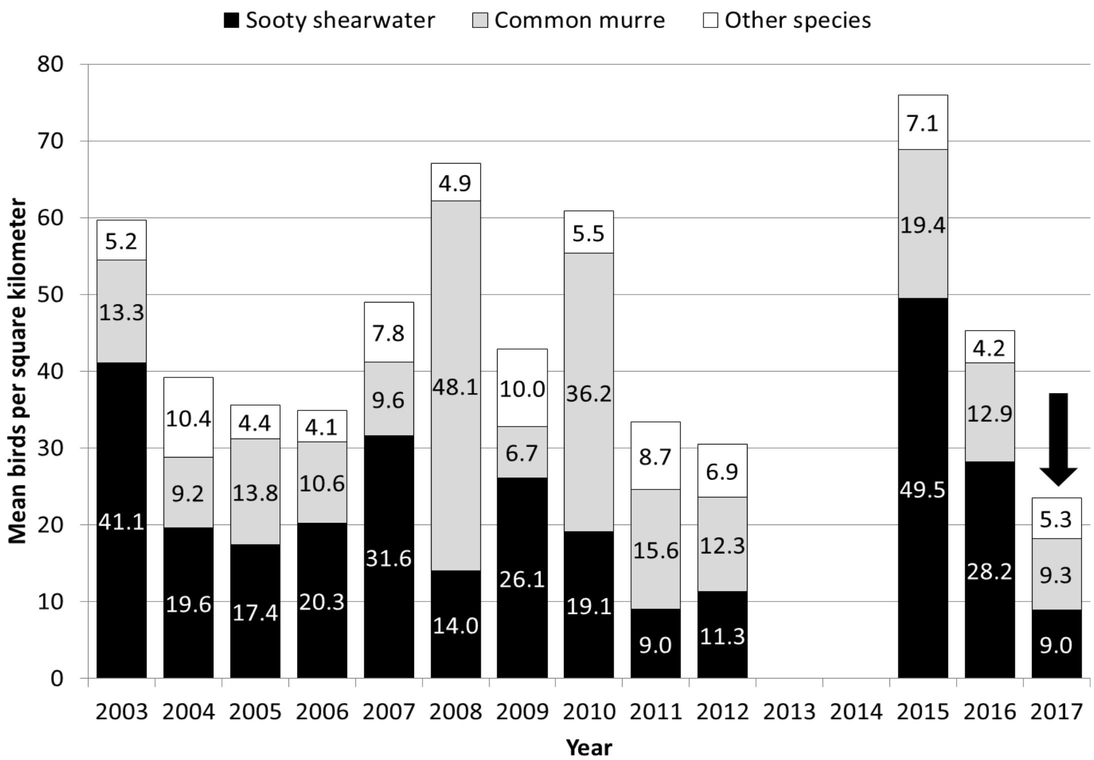


Figure 39. Seabird observations from an annual June survey encompassing 8 cross-shelf transects (extending ~30–50 km offshore) between Cape Flattery, WA and Newport, OR provide information on density patterns for the northern domain of the California Current.

Northern California Current: Castle Rock National Wildlife Refuge[19]

Common Murre are the most abundant surface-nesting seabird at Castle Rock and their reproductive success, nesting phenology, and chick diet have been studied since 2007. The percent of nesting pairs that successfully fledged young in 2016 was based on 93 breeding pairs monitored every other day for the duration of nesting. During 2016, murres only produced 0.16 fledglings per pair, which was 78% lower than the long-term average for this colony and the poorest year observed during the 10-year time-series (fig. 40). Although many murres hatched eggs (63%), chick starvation was frequent and 74% of chicks died prior to fledging. While the bottom-up food limitation was the primary cause of mortality, this food limitation caused murres to frequently leave chicks alone at the colony in search of prey, and these unprotected chicks were sometimes predated opportunistically by western gulls (*Larus occidentallis*) also nesting at the island. Reproductive failure of common murres at Castle Rock is consequential for the overall population of murres nesting in the California Current as this island is one of the most populous colonies south of Alaska (Carter et al. 2001).

In 2016, the average nest initiation date was 19 May, which was 10 days later than the long-term average at this colony (fig. 40) likely due to the later onset of upwelling-favorable winds (fig. 4) and weaker NPH and preconditioning (Schroeder et al. 2009, fig. 6). Although the timing of nesting by murres is not a direct response to the onset of upwelling, the increased availability of food associated with upwelling improves the body condition of egg-laying females and thereby influences the timing of nesting (Reed et al. 2006; Schroeder et al. 2009).

In 2016, the diversity of prey fed to chicks was lower than usual, (11 of 21 prey types observed), and no new prey types were observed[20]. Proportion of northern anchovy was 23x greater than the long-term average in 2016. Despite this increased prevalence of anchovy, smelt remained the predominant prey fed to chicks (fig. 40). Notably, the total number of prey observed at the colony was much less than usual because most chicks starved

[19] In recent times, Castle Rock National Wildlife Refuge (hereafter Castle Rock) has frequently been the most populous single-island seabird breeding colony in California (Carter et al. 2001). This island is located off the coast of Crescent City, just south of Point St. George, in the northern California Current System. To facilitate long-term monitoring of seabirds nesting at this colony, a remotely-controlled video monitoring system was installed at this island in 2006. For purposes of assessing the state of the California Current, the reproductive performance of common murre and Brandt's cormorants is provided. For common murre, nesting phenology and chick diet between 2007 and 2016 is also provided.

[20] To determine prey composition fed to common murre chicks, 2-hour diet surveys were conducted 6 days per week during the murre chick-rearing period (approximately 23 hours surveyed in 2016).

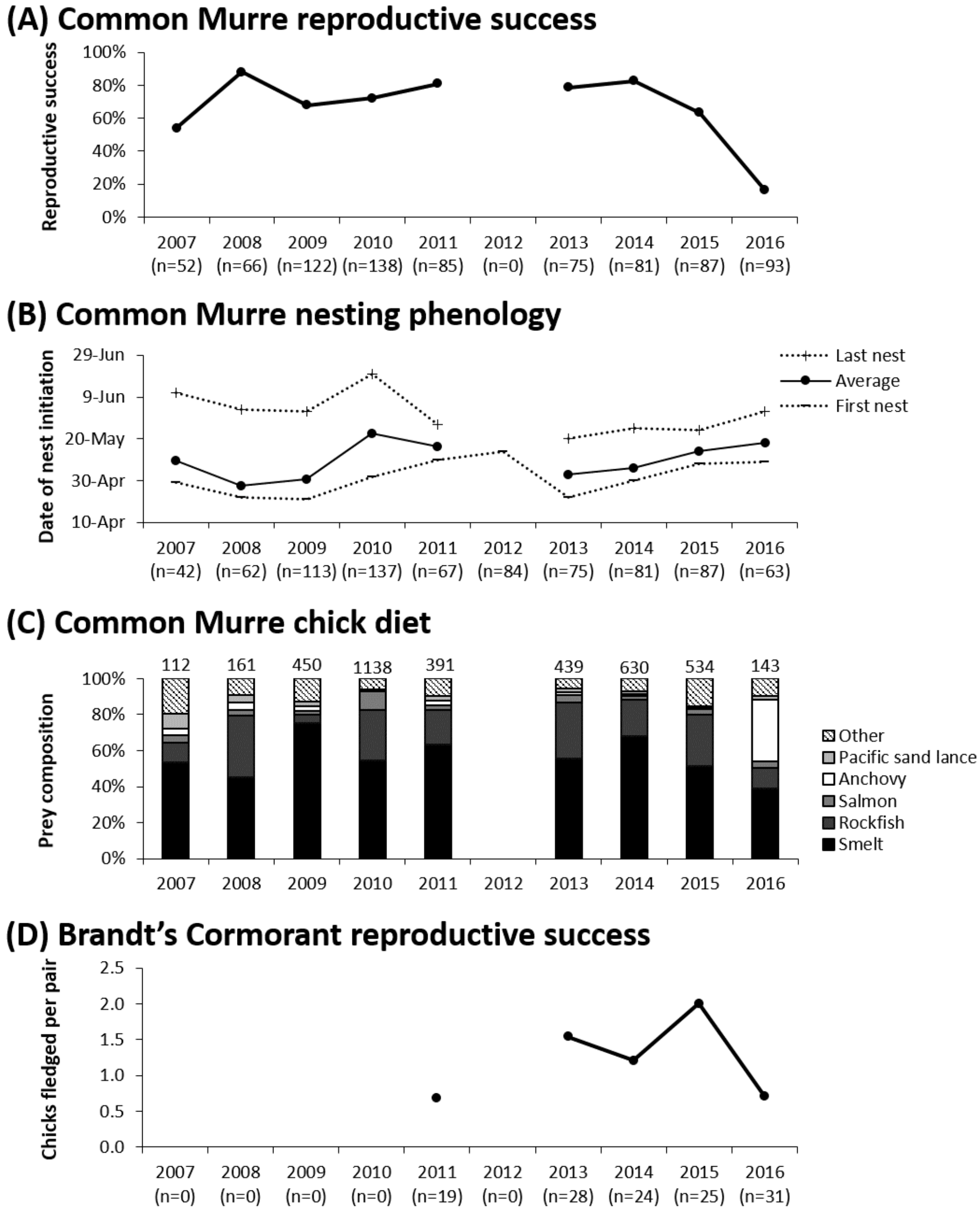


Figure 40. Reproductive data for seabirds nesting at Castle Rock National Wildlife Refuge (hereafter Castle Rock), Del Norte County, CA between 2007 and 2016; (A) Percent of common murre nesting pairs that successfully fledged young. The sample size (n) represents the total number of nesting pairs observed per year, and this figure does not include the success of replacement clutches. (B) First, average, and last dates for nests initiated by common murres. The date of nest initiation was the defined as the day that an egg was laid at a nest-site. The sample size (n) represents the total number of nests observed each year where nest initiation dates were accurate to ±3.5 days. (C) Composition of prey delivered to chicks by common murre. Numbers above each bar indicate the total number of prey identified each year. (D) Chicks fledged per nesting pair of Brandt's cormorant. The sample size (n) represents the total number of nesting pairs observed per year, and this figure does not include the success of replacement clutches. For each section, data from 2012 is lacking due to premature failure of the video monitoring system.

before they reached fledging age. Interestingly, murre diet data from Castle Rock and Yaquina Head continued to show northerly shifts in the forage fish community during 2016. Specifically, murres at Castle Rock had a dramatic increase in northern anchovy (more typical of central California colonies to the south) and Yaquina Head remain dominated by smelt (more typical of Castle Rock to the south).

Brandt's cormorant are the second-most abundant surface-nesting seabird at Castle Rock and their reproductive success has been studied since 2011. Based on 31 nests observed every three days throughout the 2016

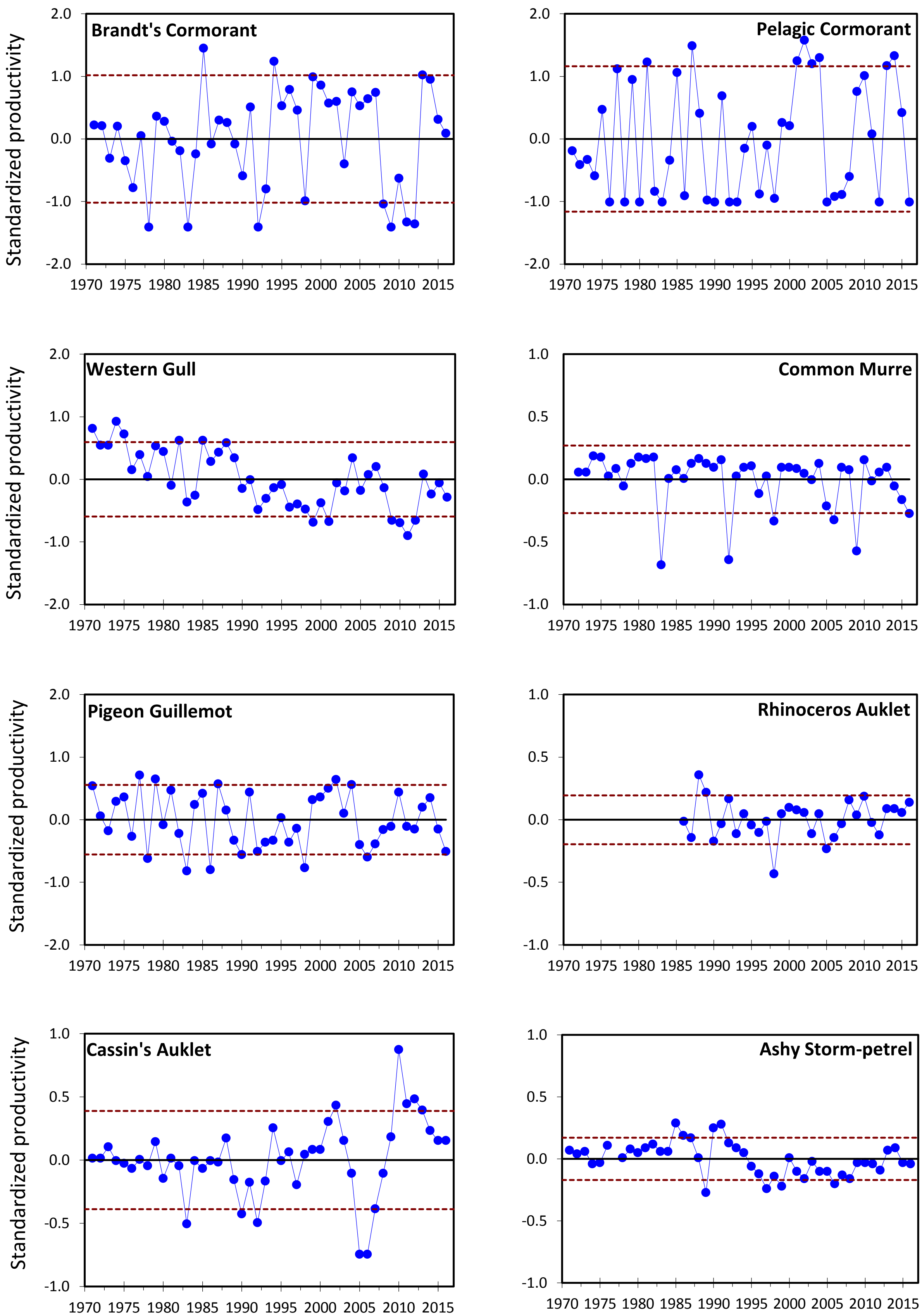


Figure 41. Standardized productivity anomalies (annual productivity minus 1971–2017 mean productivity) for 8 species of seabirds on Southeast Farallon Island.

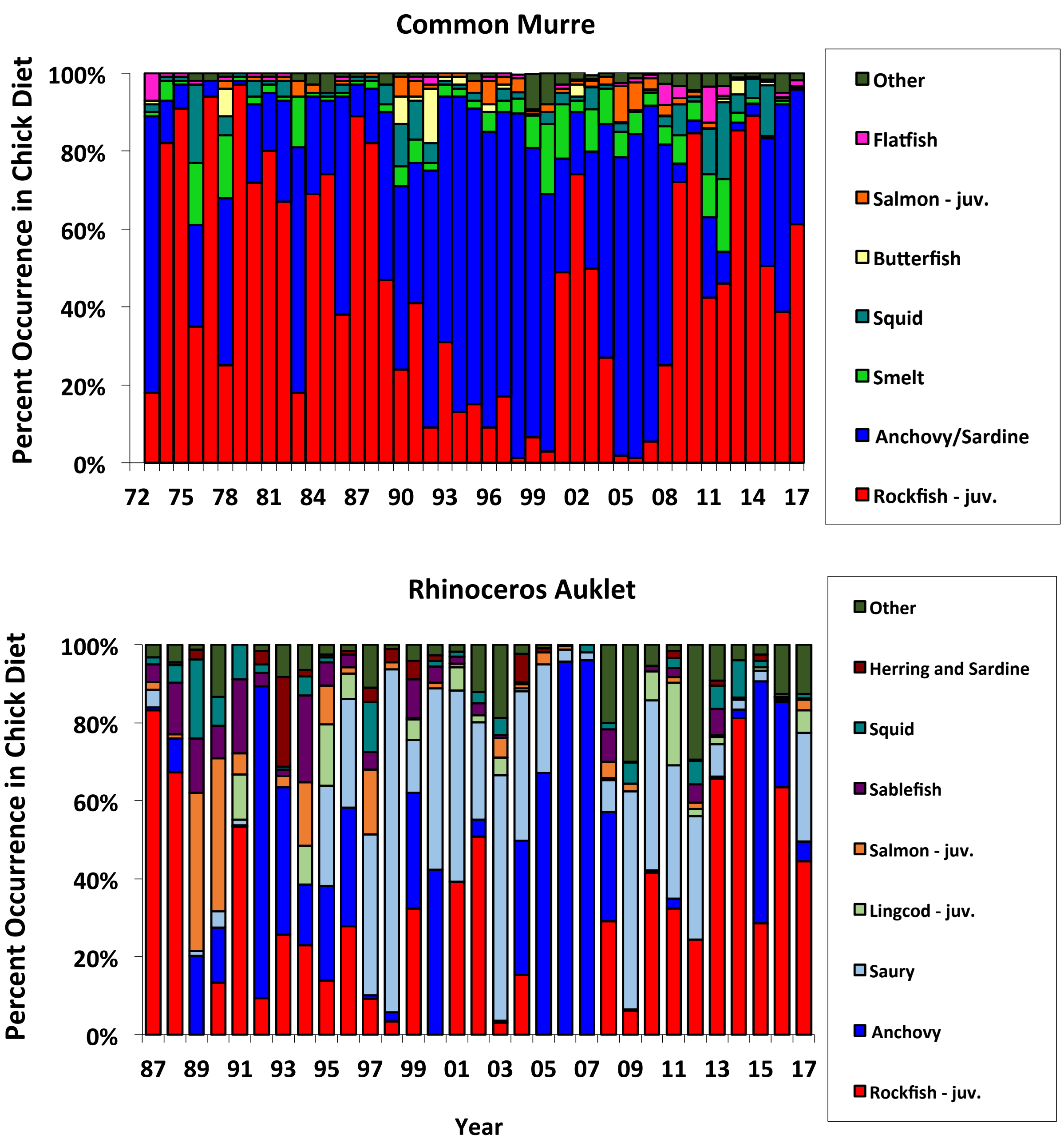
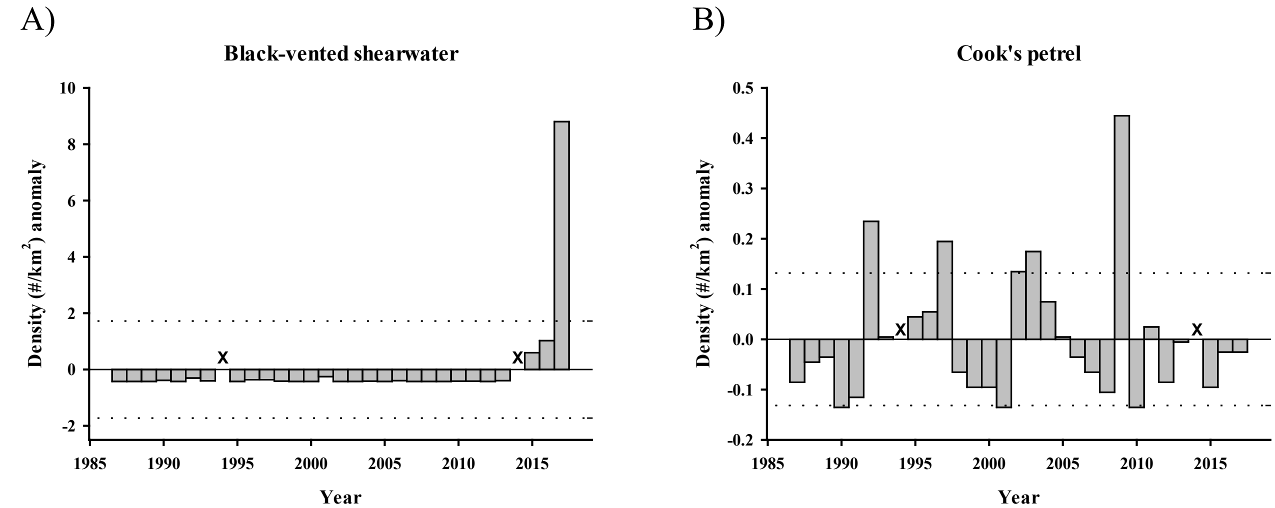


Figure 42. Diets of common murre and rhinoceros auklets returning to feed chicks 1987–2017. Note bar color differences between panels.

season, breeding pairs produced 0.71 chicks on average which was 1.9x lower than the long-term average at this colony and the second lowest observation since monitoring began (fig. 40). This reduction in success between 2015 and 2016 mirrored observations at Yaquina Head.

Central California: Southeast Farallon Island

Warm water conditions, such as those observed during the recent El Niño, typically lead to very low breeding success and even breeding failure for seabirds (fig. 41). This generally proved to be true in 2016 with reduced breeding populations and reproductive success for most species. However, the availability of common forage taxa such as rockfishes and krill muted the response relative to previous El Niño events such as 1998 during which these forage taxa were well below average (fig. 27). Overall breeding success of seabirds during the 2016 breeding season at Southeast Farallon Island can best be classified as a below average year for most species. Reproductive success was lower for most species when compared to 2015, including complete breeding failure for pelagic cormorants and the lowest success for pigeon guillemots (*Cepphus columba*) in 10 years. Common murres, Brandt's cormorant, and west-



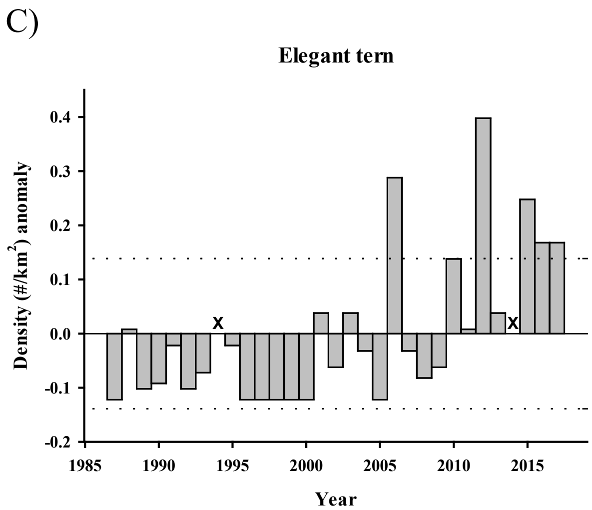


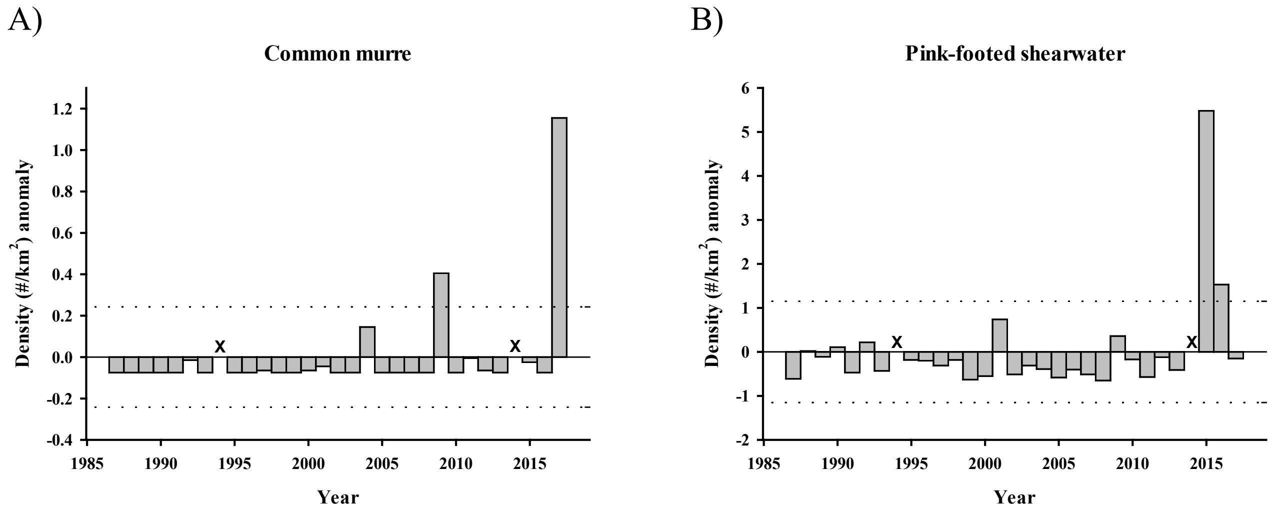
Figure 43. Density (expressed as anomalies) over summer surveys for species with warm water-affinity, core CalCOFI core survey area, 1987–2017. A) Black-vented shearwater, B) Cook's petrel, and D) Elegant tern. The "x" indicates years when no spring survey was conducted.

ern gull likewise suffered lower than average breeding success. Cassin's auklets (*Ptychoramphus aleuticus*) and rhinoceros auklets (*Cerorhinca monocerata*) were the only species to have higher than average breeding success. Cassin's auklets attempted few second broods but did manage to successfully fledge chicks from two of them, typically a sign of productive ocean conditions. Though the second broods did not significantly contribute to overall productivity this season, a high success rate for first broods resulted in an overall productive season.

Effects on breeding populations were mixed. Brandt's cormorants, Cassin's auklets, pigeon guillemots and western gulls all decreased whereas pelagic cormorants, double-crested cormorants (*Phalacrocorax auritus*) and tufted puffins (*Fratercula cirrhata*) increased. The western gull breeding population estimate was the lowest observed during our 46 years of monitoring while pigeon guillemots, Brandt's cormorants and Cassin's auklets were the lowest they have been in the last five years.

Following the strong upwelling periods in late March and April 2016 (fig. 4), zooplankton abundance (primarily krill) was average (fig. 27). Although diet analysis has not been completed, preliminary visual inspection of Cassin's diet samples indicated that krill remained the dominant item in auklet prey. This likely allowed for the higher than expected breeding in 2016 for Cassin's auklets. Similarly, the diets of common murre and rhinoceros auklet can be indicative of the current-year preyscape and resultant foraging behavior (Wells et al. 2017) and, ultimately, the reproductive success (Wells et al. 2008). Juvenile rockfish, a preferred prey, remained a significant portion of the diet fed to chicks in 2016 and 2017 (fig. 42) suggesting that significant reproductive failure is unlikely in 2017.

In general, although the 2015–16 El Niño may not have had as great an impact as previous events, the number of birds attempting to breed and their breeding success were both reduced during 2016. Chicks generally took longer to grow and fledged at lower weights



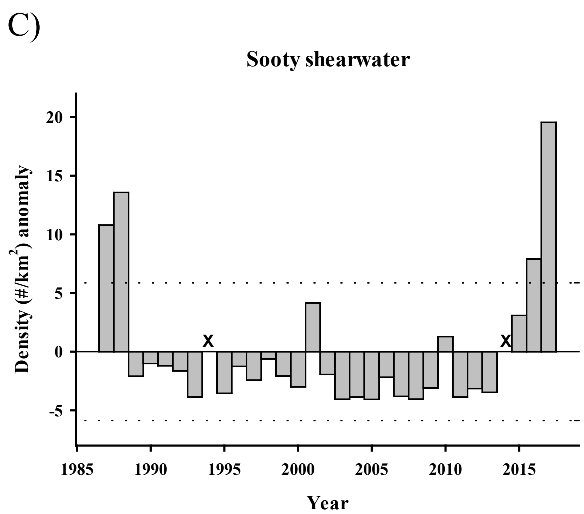


Figure 44. Density (expressed as anomalies) over summer surveys for species with cold water-affinity, core CalCOFI core survey area, 1987–2017. A) Common murre, B) Pink-footed shearwater, and C) Sooty shearwater. The "x" indicates years when no spring survey was conducted.

than in the past few seasons. Warm water continued to bring unusual species into the region. These included record numbers of brown boobies (*Sula leucogaster*), a few persistent blue-footed boobies (*Sula nebouxii*) and the first island record for least storm-petrel (*Oceanodroma microsoma*), all species that are normally found in more tropical regions.

Southern California Current: CalCOFI

Seabird distribution and abundance was surveyed during the 2017 summer CalCOFI cruise and seabird densities are presented here for the core survey area (defined here as the six CalCOFI lines, 77–93), 1987–2017. Anomalies of seabird species density in summer are indicative of species with affinities for warm and cold-water conditions (Hyrenbach and Veit 2003; Sydeman et al. 2009; Santora and Sydeman 2015). For summer, species with warm water-affinity include black-vented shearwater (*Puffinus opisthomelas*), Cook's petrel (*Pterodroma cookii*), and elegant tern (*Sterna elegans*) (fig. 43[21]). Cold water-affinity species include common murre, pink-footed shearwater (*Ardenna creatopus*), and sooty shearwater (fig. 44). Notable results from the 2017 summer survey indicate higher than average density of the warm-water species black-vented shearwater (highest density since 1992) and elegant tern. Interestingly, two of the three cool water-affinity species' (sooty shearwater and common murre) densities are well above any observed summer values since 1987. This is in stark contrast to results from northern California Current surveys that observed record low densities and may reflect superior foraging conditions within the core survey region during the 2017 spring CalCOFI cruise.

Sea Lions: San Miguel Island

California sea lions (*Zalophus californianus*) are permanent residents of the CCS, breeding in the California Channel Islands and feeding throughout the CCS

[21] https://static1.squarespace.com/static/56a6b01dd8af105db2511b83/t/5931b5aa59cc68dd30ae919b/1496429995317/FI_Report_CAC_2017_summer.pdf

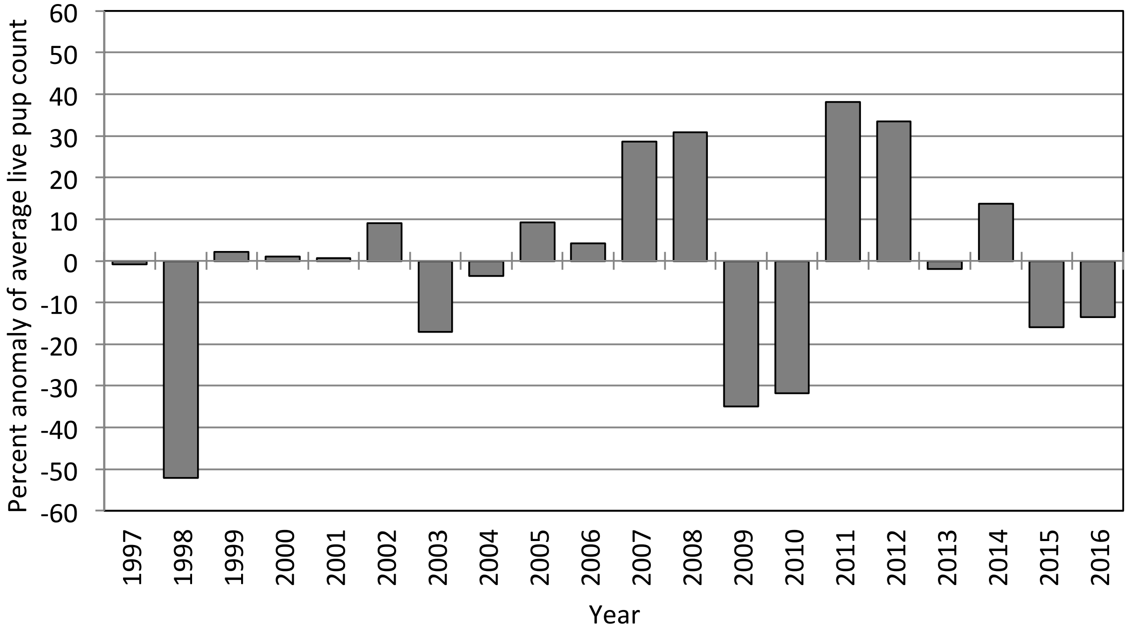


Figure 45. The percent anomaly of live California sea lion pup counts at San Miguel Island, California, based on a long-term average of live pup counts between 1997–2016 in late July when surviving pups were about 6 weeks old.

in coastal and offshore habitats[22]. They are also sensitive to changes in the CCS on different temporal and spatial scales and so provide a good indicator species for the status of the CCS at the upper trophic level (Melin et al. 2012). Two indices are particularly sensitive measures of prey availability to California sea lions: pup production and pup growth during the period of maternal nutritional dependence[23]. Pup production is a result of successful pregnancies and is an indicator of prey availability to and nutritional status of nursing females from October to the following June. Pup growth from birth to 7 months of age is an index of the transfer of energy from the mother to the pup through lactation between June and the following February which is related to prey availability to nursing females during that time[24].

In 2016, California sea lion pup births at San Miguel Island were 14% below the long-term average between 1997 and 2016 but showed a slight improvement from 2015 (16% below) (fig. 45)[25]. Pup condition and pup growth for the 2016 cohort increased from the record lows for the 2015 cohort. The average weights of three-month-old pups were 1.7 kg and 2.0 kg higher than the long-term average for female and male pups, respectively (fig. 46), representing a 10% increase in pup condition in 2016 compared to 2015. After two years of extremely low growth rates in 2014 and 2015, pup growth rates from three to seven months of age for female and male pups were similar to the 20-year average in 2016, marking a significant improvement in growth rates (fig. 47).

Since 2009, the California sea lion population has experienced low pup survival, low pup births, or both (Melin et al. 2012; McClatchie et al. 2016; DeLong et al. 2017). In March 2013, an unusual mortality event was declared for California sea lions in southern California in response to unusually high numbers of young pups from the 2012, 2014, and 2015 cohorts stranding along the coast and at San Miguel Island and other rookeries (Wells et al. 2013; Leising et al. 2014; Leising et al. 2015; McClatchie et al. 2016)[26]. The unusual mortality event was associated with poor foraging conditions for

[22] San Miguel Island, California (34.03°N, 120.4°W) is one of the largest colonies of California sea lions, representing about 45% of the US breeding population. As such, it is a useful colony to measure trends and population responses to changes in the marine environment.

[23] We used the number of pups alive at the time of the live pup census conducted in late July and the average weights of pups at 4 months and 7 months of age between 1997 and 2016 as indices of the population response to annual conditions in the CCS. The number of live pups in late July represents the number of pups that survived from birth to about 6 weeks of age. Live pups were counted after all pups were born (between 20–30 July) each year. A mean of the number of live pups was calculated from the total number of live pups counted by each observer. A long-term average live pup count based on counts between 1997 and 2016 was used to create annual anomaly percentages from the long-term average.

[24] Each year, between 200 and 500 pups were weighed when about 4 months old. Pups were sexed, weighed, tagged, branded, and released. Up to 60 pups were captured in February and weighed and measured at 7 months of age. Of the 60 pups captured in February, up to 30 pups were branded and provided a longitudinal dataset for estimating a daily growth rate between 4 months and 7 months old.

[25] We used a linear mixed-effects model fit by REML in R to predict average weights on 1 October and 1 February in each year because the weighing dates were not the same among years. The model contained random effects with a sex and days interaction (days = the number of days between weighing and 1 October and 1 February) which allowed the growth rate to vary by sex and year, and a full interaction fixed effects of sex and days. The average weights between 1997 and 2016 were compared to the long-term average for the average pup weights between 1975 and 2016.

[26] http://www.nmfs.noaa.gov/pr/health/mmume/californiasealions2013.htm

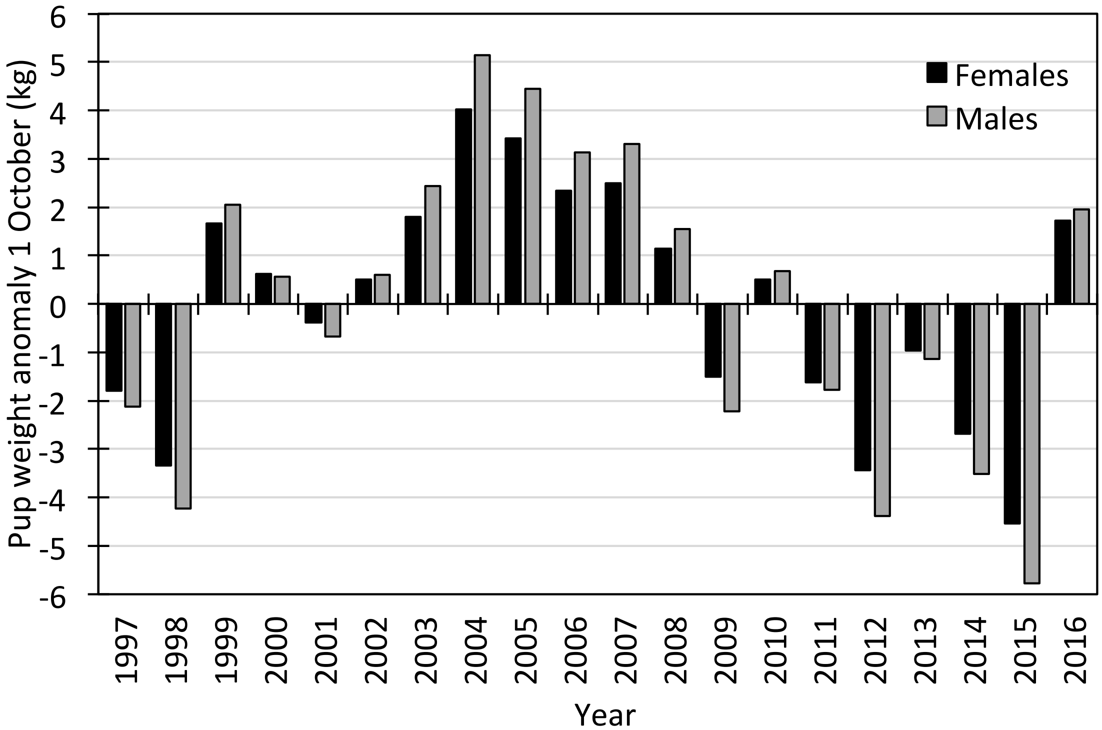


Figure 46. Average pup weight anomaly (kg) from predicted average weights of 3-month-old female and male California sea lion pups at San Miguel Island, California, from the long-term average between 1997 and 2016.

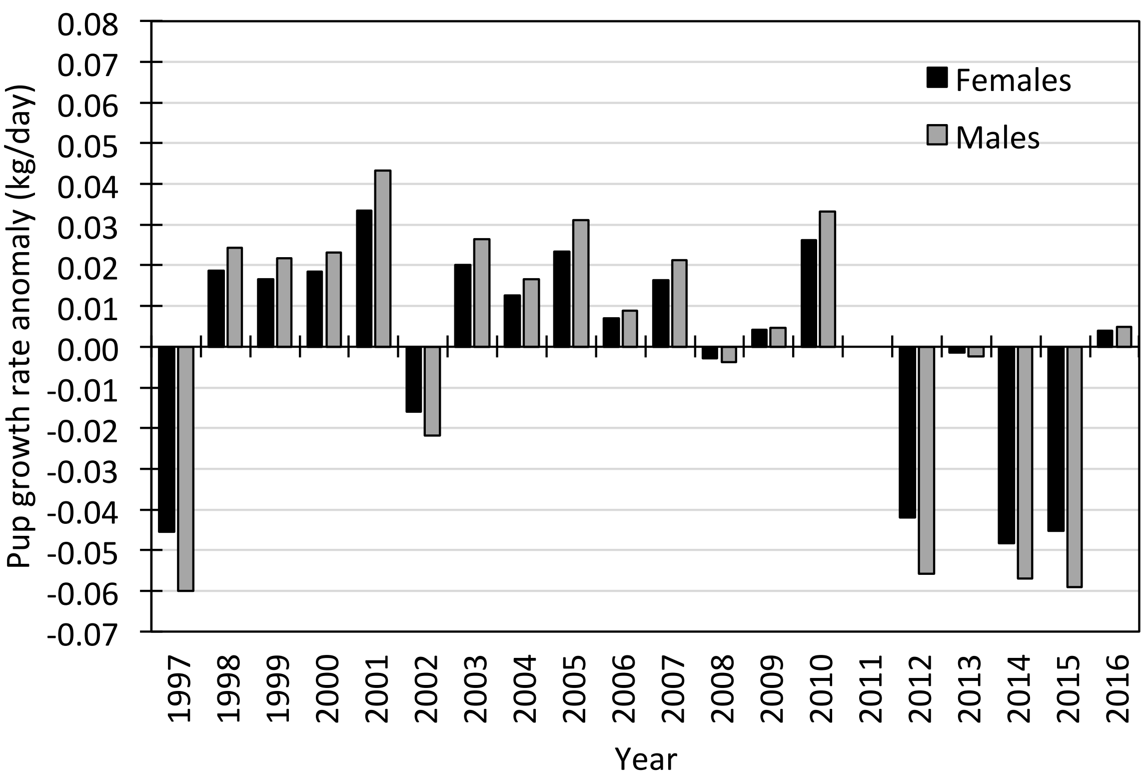


Figure 47. Average daily growth rate anomaly of female and male California sea lion pups between 3 and 7 months old at San Miguel Island, California, from the long-term average between 1997 and 2016.

nursing females due to shifts in the availability of prey and prey community composition in the central and southern CCS during the period of pup nutritional dependence. The low numbers of births in 2016 reflect the effects of low numbers of births and poor pup and juvenile survival since 2009 that have reduced the number of reproductive females in the population. However, the improved condition of pups in 2016 indicates that nursing females experienced better foraging conditions during the 2016–17 nursing period and were able to support the nutritional demands of their pups. The improved condition of pups in 2016 coincided with the return to a nursing female diet with high frequencies of northern anchovy (92%) and Pacific hake (63%) compared to a diet rich in juvenile rockfish and market squid that dominated the food habits during the unusual mortality event.

Marine Mammal Surveys: CalCOFI Surveys

On-effort visual detections of baleen whales for 2014–17 are shown in fig. 48[27]. During winter and spring cruises, most baleen whale sightings occurred within 200 nm of the shoreline. A nearshore shift in distribution of humpback whales (*Megaptera novaeangliae*) was seen during the spring in the 2016 and 2017 cruises. During summer, there were more baleen whale sightings along the continental slope and in offshore waters. During fall cruises in 2015 and 2016 baleen whale sighting were concentrated in the Channel Islands region.

Odontocete detections for 2014–17 are shown in Figure 49. In general, short-beaked common dolphins (*Delphinus delphis*) were detected offshore more frequently than inshore. In 2015, short-beaked common dolphins were not observed in the offshore areas, but they were present in the offshore areas during the summer and fall of 2016.

DISCUSSION

In this paper, we have not attempted to develop a quantitative model integrating all these data series. However, when we examine them in total, bolstered by current literature, we can make assertions about the temporal and spatial evolution of the California Current ecosystem encompassing the majority of links between environmental influences, population productivity, reproductive and foraging dynamics of top-predators, and the overall trophic structure. We finish with a comment regarding unanticipated ecosystem interactions resulting from recent anomalous ocean conditions and the realized and potential impact they have on coastal communities.

A weak La Niña in 2016, and stormy winter and sluggish upwelling in 2017

From spring 2016–spring 2017, the NPGO was at near-average values and the PDO remained positive, with values lower than the exceptionally high values of 2014–16. A weak tropical La Niña event was marked by modest negative ONI values from summer 2016–winter 2017. Together, these indices suggest that basin-scale patterns did not likely favor strong coast-wide productivity anomalies from spring 2016 to spring 2017. Above average upwelling north of 36˚N persisted from the spring to the fall of 2016 (March–September). By January and February 2017, stronger-than-average downwelling winds occurred in northern California Current (fig. 4) related to a continued weak NPH (fig. 6). As upwelling began in March and April 2017 it was weaker than typical north of 36˚N. Ultimately, chlorophyll during the March–May of 2017 was below average throughout much of the CCS with localized areas with positive chlorophyll anomalies in central California and the Channel Islands (fig. 9). The positive chlorophyll anomalies in central California may have been associated with strongly positive upwelling anomalies that began in May (fig. 4). As late-winter and spring conditions influence productivity of the forage base across the CCS (Logerwell et al. 2003; Schroeder et al. 2009, 2014) and structuring of the ecosystem (Wells et al. 2016, 2017), the observed weak upwelling conditions north of 36˚N during March–April 2017 could negatively affect the availability of forage to predators through 2017.

Dissimilar conditions emerged in the south and the north

Regional surveys during the 2016 El Niño found that surface waters were anomalously warm across the CCS and were also anomalously warm at depth south of Cape Mendocino (figs. 4, 7, 8). Through 2016, northern CCS copepod communities had an anomalously high abundance of subtropical species (fig. 10). Chlorophyll concentrations were low across the California Current in 2016. At Trinidad Head there was a *Pseudo-nitzschia* bloom in spring that abated by June. In the central and southern CCS domoic acid concentrations were negligible during 2016 (fig. 9).

Early in 2017 physical and biological conditions were dissimilar between the northern, central, and southern CCS. Surface conditions north of Cape Mendocino remained anomalously warm (fig. 4), chlorophyll was very low (fig. 9), and copepod species richness patterns

[27] Marine mammal surveys were initiated as part of the CalCOFI cruises in 2004. Visual monitoring incorporates standard line-transect survey protocol which includes two experienced observers scanning for marine mammals during transits between CalCOFI stations. Information on all cetacean sightings was logged systematically, including species, group size, reticle of cetacean position relative to the horizon, relative angle from the bow, latitude, longitude, ship's heading, behavior, environmental data and comments.

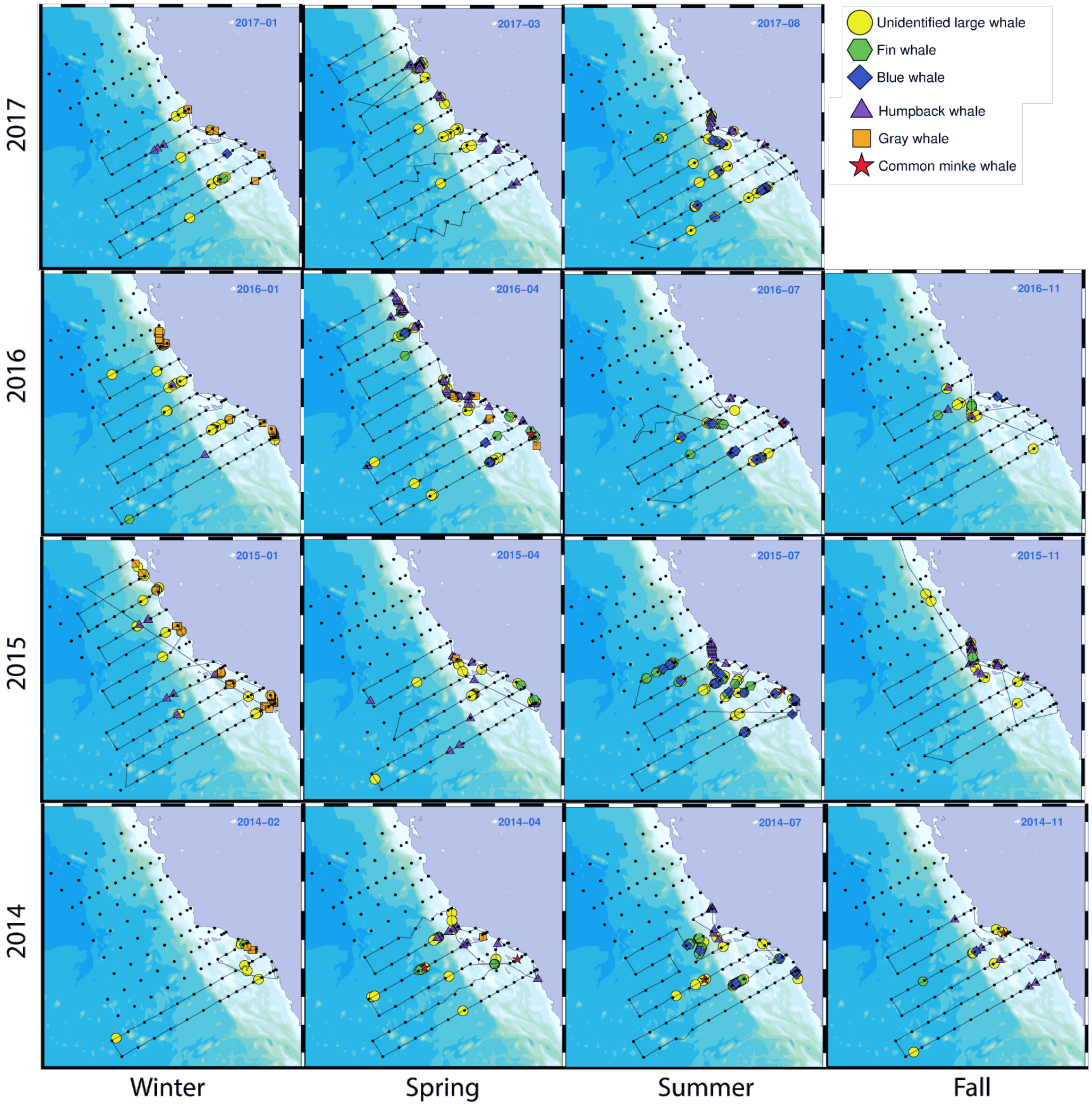


Figure 48. On-effort baleen whale sightings during CalCOFI cruises 2014–17. CalCOFI stations are represented by black dots and the ship's trackline is represented as a solid black line between stations. Symbol shapes and colors denote different species, as per legend.

were representative of southern assemblages in 2017 (table 1, fig. 10). Further, in January–April 2017 downwelling anomalies were evident along the West Coast from Monterey Bay to Vancouver Island, which were associated with increased storm events especially in California (figs. 3, 4). Southern and central regional surveys indicated that environmental conditions were typical for the longer time series, which suggests that central and southern regions may be returning to "normal." However, atypically, the increased chlorophyll in spring 2017 around the Channel Islands during April–May corresponded with a significant toxic event linked to increased estimates of *Pseudo-nitzschia* abundance (fig. 9). The event was responsible for an unusual mortality event for a number of seabirds and exceeded the regulatory limit for human consumption of fish and shellfish.

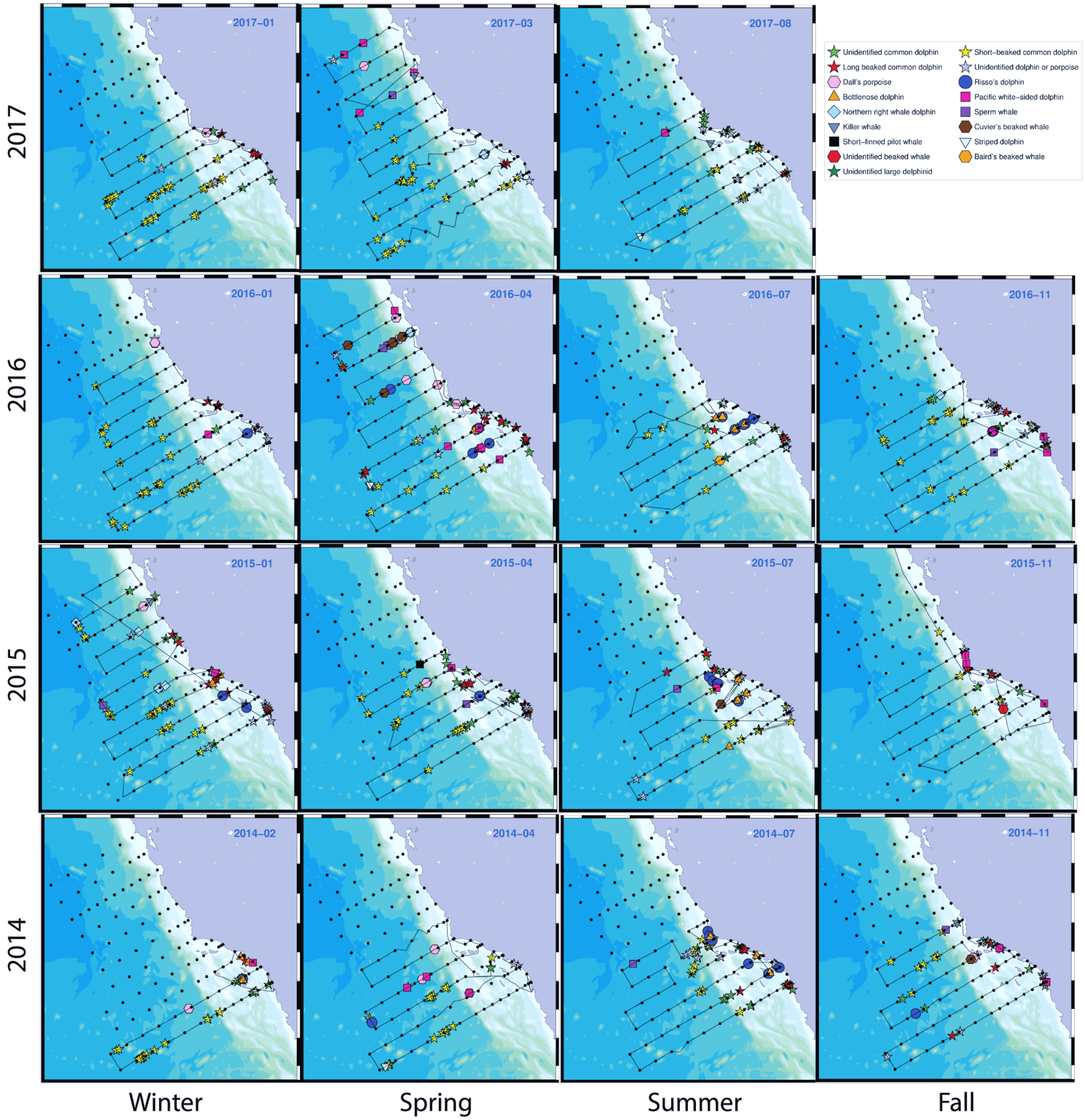


Figure 49. On-effort odontocete sightings during CalCOFI cruises 2014–17. CalCOFI stations are represented by black dots and the ship's trackline is represented as a solid black line between stations. Symbol shapes and colors denote different species, as per legend.

Micronekton communities responded to regional conditions and northern anchovy had notable spawning events

Micronekton abundance, distribution, and community structure reflect the larger patterns in environmental and zooplankton variability observed throughout the CCS. Namely, while conditions south of Cape Mendocino were typical of the longer times series, the northern regions did not return to a "normal" state following the end of the 2014–16 marine heatwave (Auth et al. 2017; Peterson et al. 2017). Specifically, the northern CCS was anomalously warm at the surface and the micronekton community was dominated by taxa originating from the south and off the shelf (e.g., pompano, myctophids, YOY Pacific hake, and YOY rockfishes) (Auth et al. 2017). In 2017 the dominant signal of warm-water taxa on the shelf included the extreme abundance of pyrosomes, which have been found with increasing frequency since 2014 in the northern California Current, but never in the extreme densities on the shelf region as observed this year (Brodeur, unpub.). The anomalously strong northward winds and the associated downwelling that occurred in the northern CCS in January–February 2017 (figs. 3, 4, 7) may have led to poor preconditioning of coastal waters (Hickey et al 2006; Logerwell et al. 2003) and directly contributed to the presence of offshore and southern taxa on the shelf in winter and spring. There may also be a biological reason for the reduction in typical fish taxa. Specifically, many of these fishes are short-lived and are regional residents. It is not unreasonable to expect that the preceding three years of poor productivity (due to the marine heat wave and El Niño) may have simply reduced their spawning stock biomass.

It is also notable that a greater than average abundance of northern anchovy has been observed in the northern CCS since 2014. As well, egg enumeration data indicates their spawning activity has been high (fig. 21). Interestingly, the most anomalous event in the southern CCS was the increased spawning activity of northern anchovy (fig. 31). While the greatest spawning activity was in the Southern California Bight and Columbia River shelf regions, greater than average spawning activity was also observed at a few isolated locations nearshore in central California (fig. 21). The mechanisms driving these dense spawning aggregations largely in the northern and southern parts of the CCS are to yet be determined, but they are consistent with the predictions of the Basin Model (MacCall 1990), which states that as the overall population abundance is reduced, as has been observed in recent years[28], dense spawning aggregations may be concentrated in areas of particularly suitable habitat. In the case of northern anchovy, they would be impinged along the remaining good habitats nearshore and expand to less optimal habitat as the population increases; such expansion may now be occurring in the core anchovy habitat within Southern California Bight.

Salmon habitat and observations

Recent climate extremes contributed to sharp downturns in the abundance (catch + escapement) of many West Coast Chinook and coho salmon populations. Historically poor freshwater conditions were caused by California's extreme "hot drought" from 2012–15. A broader "western snow drought" in 2015 related to a combination of precipitation and record high surface air temperatures contributed to extreme high freshwater temperature in many western rivers in 2015 that will impact catches and escapement during 2017–20. Record high coastal ocean temperature from 2014–16 and the associated ecosystem impacts that included shifts to more subtropical forage communities and shifting predator distributions likely contributed to sharp declines in survival rates for many US West Coast salmon populations. Fishery impacts included sharply reduced Chinook salmon landings in West Coast commercial fisheries and very low escapements in California's Klamath and Sacramento Rivers in 2016 (PFMC 2017a). The Klamath River fall Chinook ocean abundance forecast was the lowest on record (since 1985). This low abundance forecast and conservation concerns for other weak stocks led to heavily constrained or closed commercial, recreational, and tribal fisheries in California and Oregon (PFMC 2017b).

Results from northern surveys indicate that 2017 likely had anomalously high early-marine mortality for Columbia Basin origin coho and Chinook salmon. Specifically, 2017 had the lowest catch for juvenile Chinook and coho salmon in coastal surveys in the 20-year times series (1998–2017; fig. 24). The record-low catch is likely related to the forage composition (fig. 26) for out-migrants soon after they entered marine waters (Daly et al. 2017) rather than river conditions as the springtime stream flow was about average as the majority of smolts out-migrated in 2017. Early marine survival for 2017 out-migrants will influence the bulk of the adult coho salmon returns in 2018 and the bulk of the Columbia River Chinook salmon returns in 2019.

For the central CCS, environmental conditions in freshwater, estuaries and the coastal ocean from spring 2016 to summer 2017 were notably different than those during the 2012–15 hot drought and 2014–15 marine heat wave and 2016 El Niño. Out-migration flows in the Sacramento River were exceptionally low in spring 2014, 2015, and 2016. They were so low that emergency measures were taken that included trucking hatchery juveniles to the Bay-Delta for release[29,30]. By contrast, flows were high in spring 2017. Sacramento River stream temperature in 2014–15 was exceptionally high and contributed to record-low egg-to-fry survival for Central Valley winter-run Chinook salmon (Martin et al. 2016), while from spring 2016–summer 2017 stream temperatures were much more favorable for salmon. The improved freshwater conditions in 2016–17 likely resulted in improved salmon growth and condition at the time of out-migration to sea, thus improving their likelihood of survival (Woodson et al. 2013). Unfortunately,

[28] http://usa.oceana.org/sites/default/files/maccall_et_al_anch_biomass_remains_low_2012-2015.pdf

[29] https://www.fws.gov/sfbaydelta/fisheries/salmon_trucking_and_release.htm

[30] https://www.fws.gov/sfbaydelta/documents/2015_coleman_salmon_trucking_nr.pdf

at-sea observations of juvenile salmon from California are unavailable. However, ocean ecosystem indicators of early salmon survival have been developed for central California (Wells et al. 2016, 2017). For both spring 2016 and spring 2017 conditions in the Gulf of the Farallons were near normal. Likewise, the forage community supporting central California salmon in spring 2016 and 2017 was not significantly below average. Similarly, seabird diets on the Farallon Islands in springs 2016 and 2017, which have been linked to early salmon survival (fig. 42; Wells et al. 2017), were typical (i.e., largely rockfishes and northern anchovy) and did not demonstrate a significant increase in predation on juvenile salmon. Considering this suite of indicators based on ecosystem conditions related to key freshwater and marine salmon life stages, a Central Valley fall-run Chinook salmon fishery impact like that observed in 2007–08 (or 2016–17) appears to be unlikely for 2018–19.

Seabird reproductive success and foraging behavior reflect forage communities regionally

The reproductive success of seabirds in 2016 (the most current year available) was negatively related to latitude. In addition, there existed a northward shift in the prey field. In the northern California Current, at Yaquina Head and Castle Rock breeding colonies, some of the lowest reproductive success rates on record were observed. Nest failures were attributed to a combination of bottom-up and top-down forces. At Castle Rock, most chicks died of starvation, whereas at Yaquina Head, most nests failed due to predation by bald eagles seeking alternate prey. At-sea surveys of distribution and abundance of seabirds in northern California Current indicate that the reproductive success in 2017 may also be catastrophic. Namely, extremely low abundances were observed for migrant and central-place feeders. The few occurrences of common murre and sooty shearwaters observed at sea in 2017 in the north were at the locations where rare concentrations of forage (i.e., northern anchovy) were also observed, indicating close coupling of available forage patches and seabird aggregations. Preliminary observations at Castle Rock and Yaquina Head in 2017 also corroborate this speculation of catastrophic reproductive failure; fledging success of murres was 0%, with most chicks starving in the first few days, and it is likely Brandt's cormorants at Castle Rock also failed to produce young.

South of Cape Mendocino seabird reproductive success was generally below average. However, the significant decreases noted in the north were unapparent. Examination of the prey field (fig. 27) and the diets (fig. 42) indicate that the availability of primary forage taxa to seabirds remained average although the overall community was diverse (Santora et al. 2017a) and, in 2016, atypical (fig. 29) likely resulting from the inclusion of offshore forage taxa on the shelf during the El Niño event.

In 2017 the divergent characteristics of the environment, forage assemblages, and seabird abundances were apparent. For example, in southern California where forage communities were typical and the surface waters only slightly warmer than typical, the abundance of sooty shearwater was far above average. Yet, in the northern CCS abundance of sooty shearwater was the lowest in the observed record; observations also confirm lower abundance in central California (but within 1 SD of mean)[31]. As sooty shearwater migrate northward along the California Current, it is possible that they stopped their migration in southern California to benefit from persistent trophic hot spots there (Santora et al. 2017b) rather than continue to the northern California Current to lower quality forage assemblages. In addition, forage may have been reduced on their main foraging grounds in the Alaskan Bering-Sea Aleutian Islands ecosystem. Although unconfirmed, the seabirds in the south may be responding to the increased abundance of northern anchovy in the Southern California Bight (figs. 21, 27, 31); in the northern surveys the increased density of anchovy was isolated to the region of Columbia River mouth where the few seabirds were observed (fig. 21).

California sea lions show signs of recovery since the unusual mortality event

Increases in the abundance of northern anchovy coincided with improved condition of pups in 2016. Namely, lipid-rich northern anchovy and Pacific hake occurred in greater frequencies in the nursing female diet compared to the diet during the unusual mortality event that was dominated by juvenile rockfishes and market squid, which have low caloric value. The superior diet of nursing females translated into better condition of their dependent pups. If foraging conditions continue to improve, pup condition and survival should also improve. However, pup production will likely remain suppressed for several more years because the smaller cohorts produced from the unusual mortality event will comprise a greater proportion of the breeding population.

Whales shifting to nearshore habitats

There was a shoreward shift in the distribution of baleen whales. This distributional shift is quite apparent in central and southern California where there has been a recent, dramatic increase in whale entanglements with fixed fishing gears[32]. Humpback whales likely forag-

[31] https://static1.squarespace.com/static/56a6b01dd8af105db2511b83/t/59cd54e09f7456363177e20d/1506628834109/FI_Report_NMFS_JRES_2017.pdf

[32] http://www.westcoast.fisheries.noaa.gov/mediacenter/WCR%202016%20Whale%20Entanglements_3-26-17_Final.pdf

ing on the increased nearshore abundances of northern anchovy are the most at risk[33]. However, gray (*Eschrichtius robustus*) and blue (*Balaenoptera musculus*) whales have also been increasingly encountering gear. While yet to be determined, there are several potential causes for the increased interactions such as increased population abundance and increased predation on anchovy as an alternative prey. For example, humpback whales shift their foraging patterns between nearshore and offshore prey communities (Ainley and Hyrenbach 2010), focusing their foraging effort on krill during cool, productive years and on northern anchovy more inshore during years of delayed upwelling or lower productivity (Fleming et al. 2016).

Human dimensions

The ecosystem conditions observed during the last few years demonstrate the impacts that ocean variability and unanticipated environmental-food web-fishery interactions can have on coastal communities. For example, the marine heat wave was associated with coast-wide blooms of *Pseudo-nitzschia australis* that resulted in fishery season delays and closures (e.g., Dungeness crab, razor clams, rock crab) (Leising et al. 2015, McClatchie et al. 2016, McCabe et al. 2016). Further, due to increased SST, adult northern anchovy and associated spawning aggregations nearshore became more common in the northern CCS. Presumably, while foraging on the nearshore schools of northern anchovy, a dramatic increase of human-predator interactions occurred, including whale entanglements with fixed fishing gears that were deployed in greater density during the condensed and delayed Dungeness crab season of 2016. The risk for these interactions may increase if northern anchovy, a nearshore resident, continues to increase in abundance, or if there are further delays (or increased late-season effort) in Dungeness crab and other fixed-gear fisheries. Beyond fishery impacts, there could also be a need for alteration of coastal shipping lanes in trophic hot spots to reduce ship strikes on whales (Redfern et al. 2013, Santora et al 2017b).

The low catches of juvenile salmon in the northern CCS survey may indicate a significant impact on the fisheries and dependent communities. Salmon represent an example of how unanticipated, negative synergistic interactions can emerge. Salmon recruitment is reliant on ocean and river conditions the salmon experience early in life. In 2007–08, Central Valley Chinook salmon fishery collapsed requiring a Congressional appropriation of $170,000,000 from disaster relief (Lindley et al. 2009). The proximate cause of that collapse was poor ocean conditions in central California during 2005–06 (Lindley et al. 2009). Specifically, the anomalous ocean conditions and low productivity reduced forage availability that motivated a switch by predators, such as common murre, from preferred prey to adult northern anchovy nearshore. This switch in foraging behavior led to increased incidental predation on juvenile salmon as they outmigrated to sea. This interaction between ocean environment whereby bottom-up influences in the ocean environment led to top-down impacts on salmon was largely responsible for the extreme mortality of juvenile salmon and the subsequent collapse of the fishery (Wells et al. 2017). Similar mechanisms have been argued for salmon in the northern California Current (Pearcy 1992; Emmett et al. 2006; Phillips et al. 2017) and could be a contributor to the low juvenile salmon numbers observed in the northern survey during 2017. As predator populations increase, especially for potential salmon predators such as common murre (Wells et al. 2017) and humpback whales (Chenoweth et al. 2017), the impacts of poor ocean conditions on salmon may be magnified. One potential mitigation effort is to improve freshwater conditions such that more, larger, and an increased portfolio of salmon life histories contribute to increased diversity in the smolt out-migration to sea (e.g., more diversity in ocean-entry timing, smolt size, or migration routes) (Carlson and Satterthwaite 2011; Woodson et al. 2013). However, improvements to inland habitat would not be disconnected from interactions with agriculture, hydropower, and flood control. Regardless, the ocean is not always the primary determinant of recruitment. The "hot drought" affecting California from 2012–15 is considered a dominant driver of the lowest escapement to Central Valley since the collapse of the fishery a decade ago (PFMC 2017a). In such cases, recruitment of salmon to the fishery may rely on mitigation of mortality in freshwater by exceptional ocean ecosystem productivity where smaller (Woodson et al. 2013) and ill-timed (Satterthwaite et al. 2014) out-migrants have a better opportunity of survival.

Ultimately, given the highly variable CCS ecosystem and its variety of interacting components, management actions aimed at sustainability in living marine resources and resource systems will require an ecosystem-based fishery management approach. Efforts to better understand ecosystem interactions and the cascading consequences of anomalous ocean conditions will be critical to the ability of managers to respond effectively to variable ocean conditions while avoiding undesirable impacts to fisheries, protected resources and coastal communities.

Extending the empirical results of these and similar integrative programs to quantitative models capable of evaluating competing management scenarios may be a key aspect of affective management in a variable environment.

[33] http://www.sfchronicle.com/bayarea/article/Why-eye-popping-whale-shows-off-the-California-12172489.php

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