Conservation science
for a healthy planet.

OCEAN CLIMATE INDICATORS

STATUS REPORT – 2014

Meredith Elliott and Jaime Jahncke
California Current Group

Point Blue Conservation Science
3820 Cypress Drive # 11
Petaluma, CA, 94954

April 2015

Acknowledgments

We would like to thank our partners at Cordell Bank National Marine Sanctuary (Dan Howard and Danielle Lipski) and Gulf of the Farallones National Marine Sanctuary (Maria Brown and Jan Roletto). We also acknowledge U.S. Fish and Wildlife Service and the Farallon National Wildlife Refuge (Anne Morkill and Gerry McChesney) for partnering with Point Blue to monitor wildlife on the Farallon Islands, California Department of Public Health (Gregg Langlois) for contributing phytoplankton data, the Institute of Ocean Sciences (Moira Galbraith) for helping process zooplankton samples collected during ACCESS cruises, and Ben Saenz for helping process the acoustics data. Funders of the ACCESS Partnership include Elinor Patterson Baker Trust Fund, Boring Family Foundation, California Sea Grant, California Dept. of Fish and Wildlife, Cordell Marine Sanctuary Foundation, DJ&T Foundation, Farallones Marine Sanctuary Association, Faucett Catalyst Foundation, Firedoll Foundation, Hellman Family Foundation, McCaw Family Foundation, Moore Family Foundation, National Fish and Wildlife Foundation, Oikonos Ecosystem Knowledge, Resources Legacy Fund Foundation, Restoration Center (NOAA), and Point Blue Anonymous Donors. Results in this report would not be possible without Point Blue staff, interns and volunteers. The Southeast Farallon sea surface temperature and sea surface salinity data are provided by the Shore Stations Program with funding provided by the California Parks and Recreation, Department of Boating and Waterways, award # CA DPR-C1370020; these data are collected by research personnel with Point Blue Conservation Science.

Any reference to or use of this report, or any portion thereof, shall include the following citation:

Elliott, M. L. and J. Jahncke. 2015. Ocean Climate Indicators Status Report – 2014. Unpublished Report. Point Blue Conservation Science, Petaluma, California. Point Blue contribution number 2035.

For further information contact the director of the California Current Group at marinedirector@pointblue.org or Point Blue Conservation Science, 3820 Cypress Drive #11, Petaluma, CA, 94954.

Executive Summary

Physical ocean climate indicators illustrated weak upwelling in the region for the early months of 2014, followed by anomalously warm water conditions. Sea surface temperature data were mixed, with some sources showing cold waters in the winter and spring (possibly reflecting localized conditions), while other sources (covering a broader area) showed warm waters throughout the year. Sea surface salinities were high through March, followed by average salinities for the remaining months. Sea surface heights were anomalously high most of the year, suggesting downwelling conditions and resulting in lower than average productivity. Weak alongshore winds confirm warm water conditions, and upwelling indices (like sea surface temperature) were mixed depending on the source, which could be confounded by localized conditions. Spring transition date was average.

Climate variables showed average to warm water conditions. The Southern Oscillation Index (SOI) showed mostly average conditions for the year, with warm water periods (Mar and Sep). The Pacific Decadal Oscillation (PDO) values indicated anomalously warm water conditions for the North Pacific Ocean, while the North Pacific Gyre Oscillation showed average to less productive waters through the year.

Biological ocean climate indicators echo results from the physical indicators. Starting at the base of the marine food web, we found phytoplankton abundance (as indicated by chlorophyll a concentrations) appeared highest during the early months, coinciding with colder waters; this was followed by low phytoplankton densities for the latter half of the year. The phytoplankton community consisted mostly of diatoms; this result is confounding, as this normally indicates productive ocean conditions.

Zooplankton community composition results are not yet available for 2013-14. Results from 2011 reflect productive ocean conditions on overall zooplankton abundance, with increased zooplankton abundance compared to warm, poor productivity years (e.g. 2004-06), particularly for euphausiids and copepods. However, preliminary results from 2012 show a decline in zooplankton abundance. Intra-annual results generally show increasing zooplankton abundance in spring, peak abundance in June, and a decline in fall. Analyses of zooplankton samples show two main clusters: the first three years (2004-06), and the next six years (2007-12).

Results on various mid-trophic level species are not available for 2013-14. Similar to the zooplankton community results, copepod community composition results to date indicate large increases in the abundance of boreal copepods (i.e., species from northern latitudes which are generally considered better prey based on their larger size and greater lipid content) during cold, productive ocean conditions. Copepod species

common to mid-latitudes also became more abundant in cold water years, although not as dramatically. Equatorial copepods (i.e., copepods from southern latitudes which are smaller and have less lipid content) increased in abundance in the September cruises some years. However, declines in all copepods are evident in preliminary results for 2012. Within year results for the copepod groups generally showed peak abundances of boreal copepods in June, while the other copepod groups showed highest abundances in the fall. Pteropod abundance has remained relatively low throughout our time series, with significant increases in 2011. Euphausiid biomass results (as measured by acoustics) are not yet available for 2014, but krill densities appear to peak in late summer (July) in most years. Adult krill, which are larger and higher in lipid content than their younger counterparts, dominate the zooplankton samples during cold water years; however, with the arrival of the warm water conditions in 2014, the percentage of adult stages dramatically dropped in samples collected in July and September.

The top-level predators in our region are represented by three resident breeding seabirds and two migrant whales. Cassin's auklet, a zooplanktivorous seabird, was observed foraging close to SEFI in 2014; the average egg laying date was average for this species and it experienced high productivity. An omnivorous seabird species, the common murre, foraged more in nearshore waters and near SEFI in 2014, had an average start to breeding, experienced average breeding success, and fed mostly on rockfish. Brandt's cormorants are piscivorous and were observed in low numbers near SEFI and in nearshore waters in 2014. This species had a slightly later start to breeding, experienced very high productivity (contrary to recent years of low breeding success), and consumed mostly rockfish species in 2014.

For marine mammals in 2014, humpback whales were observed in higher numbers in the July and September cruises, and they were spotted near the shelf break, between SEFI and over Cordell Bank. Few blue whales were sighted in 2014; they were mostly observed on the shelf break in the northern part of the study region.

Introduction

The Applied California Current Ecosystem Studies (ACCESS) is a partnership between a science organization and a Federal agency to inform management in support of marine wildlife conservation in central California, encompassing NOAA – National Marine Sanctuary waters (CBNMS, GFNMS and MBNMS) and the proposed expansion area south of Point Arena, in Federal and State waters (Figure 1). The proposed expansion is anticipated to become final in July 2015, which will more than double the size of GFNMS and CBNMS, as well as extend boundaries north to Manchester Beach in Sonoma county (for GFNMS) and west to include important subsea features such as Bodega Canyon (for CBNMS). In 2014, four survey lines were added to the proposed expansion area to collect baseline information.

Our group has initiated integrated, collaborative, and multi-disciplinary research to monitor distribution, abundance and demography of marine wildlife in the context of underlying physical oceanographic processes. We are also working towards coordinated private and government research at an ecosystem scale to support a healthy marine ecosystem in the region. Effective management and conservation of natural resources requires adaptive management strategies that are informed by robust analysis of past and present data, which we intend to provide in this report.

Some of the main potential issues we aim to address include 1) water quality (ecosystem effects of freshwater outflow), 2) ocean zoning (guide human uses to provide protection of the marine ecosystem), 3) climate change (document effects of environmental change on the marine ecosystem), 4) fisheries (contribute to ecosystem-based management approaches), and 5) water quality (assess ecosystem effects of freshwater outflow).

The information we collect, while available upon request, will become available to collaborators as part of the California Avian Data Center (http://data.prbo.org/cadc).

The purpose of this report is to inform managers and policy-makers about wildlife responses to changes in ocean conditions and to mobilize public support for conservation. This effort builds off the report *Ocean Climate Indicators: A Monitoring Inventory and Plan for Tracking Climate Change in the North-central California Coast and Ocean Region* (http://farallones.noaa.gov/manage/climate/pdf/GFNMS-Indicators-Monitoring-Plan-FINAL.pdf), which was used to help prioritize indicators to include in the Point Blue report, but additional indicators were also included, as these data were readily available and provide a more comprehensive picture of regional ocean conditions. In this report, we present data collected during the ACCESS at-sea surveys which have been conducted 3-4 times a year since 2004; these data include phytoplankton composition, zooplankton composition, krill abundance from hydroacoustics, and at-sea observations of seabirds and marine mammals. We have also compiled a variety of datasets to look at long-term trends; these include climate and upwelling indices, sea surface temperature and salinity measured from the Farallon Islands, buoy data (winds, sea surface temperature), satellite data (sea surface temperature and height, and phytoplankton abundance), and seabird data (productivity and timing of breeding) on Southeast Farallon Island. While some datasets have been updated through this year, not all 2014 data are available. We have shown here what we could obtain at the time we released this report.

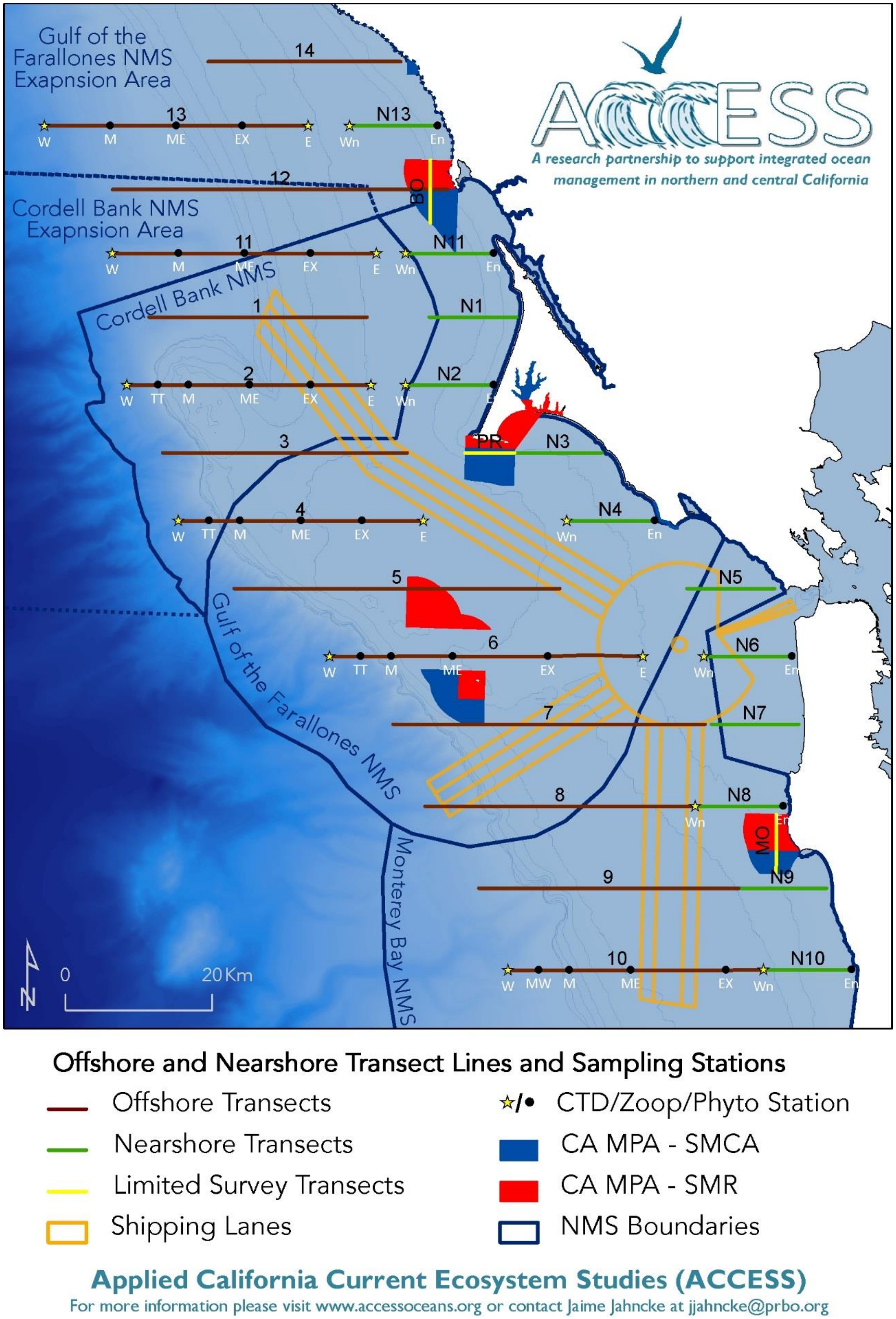

Figure 1. Applied California Current Ecosystem Studies (ACCESS) study area.

Sea surface temperature

Overview

Sea surface temperature (SST) is a way of monitoring the productivity of the ecosystem, as cold water is brought to the surface during upwelling in early spring. The surface waters eventually warm up during relaxation events that follow upwelling, typically in late summer or early fall. We used buoy and Southeast Farallon Island data for more localized observations, and satellite data (covering a 4 km^2 area) were used for a more regional perspective on SST. Each of these datasets shows an intra-annual pattern in SST: a decline during upwelling (Mar-May), then increasing SSTs through Sep (which is the peak SST for the year), followed by another decline.

Buoy data

SSTs in 2014 were cold (i.e. negative blue bars) to normal for the first half of the year, followed by anomalously warm (i.e. large positive red bars) waters for the second half (Figure 2). SSTs were close to average values in the early months of 2004. In 2005 and 2006, anomalously warm SSTs were observed in the winter and spring months. In contrast, low SSTs were noted in most months of years 2007-13; short periods of average or warm waters (e.g. late months of 2008, early months of 2010) suggest local downwelling/relaxation events.

Southeast Farallon Island data

SST data collected near Southeast Farallon Island (SEFI) shows warm (i.e., positive red bars) temperatures observed throughout 2014 (Figure 3). Short upwelling events defined by cold waters (i.e. negative blue bars) were observed in 2004, but most values were closer to the long-term averages. Warm SSTs were observed throughout 2005-06. Conversely, cold SSTs were observed throughout the early months of 2007-09. Cold temperatures appeared late (Apr and May) in 2010. SSTs in 2011 were normal to warm for most of the year, then SSTs dropped in 2012, and SSTs remained low throughout most of 2013.

Satellite data

Satellite results show warm (i.e., positive red bars) SSTs during most of 2014 (Figure 4). Temperatures in 2004 through mid-2005 were consistently warm; this differs from the buoy and SEFI data, as these other data show periods of cold (i.e., negative blue bars), upwelled water at the surface. Similar to buoy and SEFI results, 2006 had warmer SSTs in the first half of 2006, and cold SSTs in the first half of years 2007-09. Warm waters in the early months and cold waters in the later months of 2010 are also consistent with other SST results. SSTs in 2011 were average, while 2012 and 2013 showed mostly cooler SSTs.

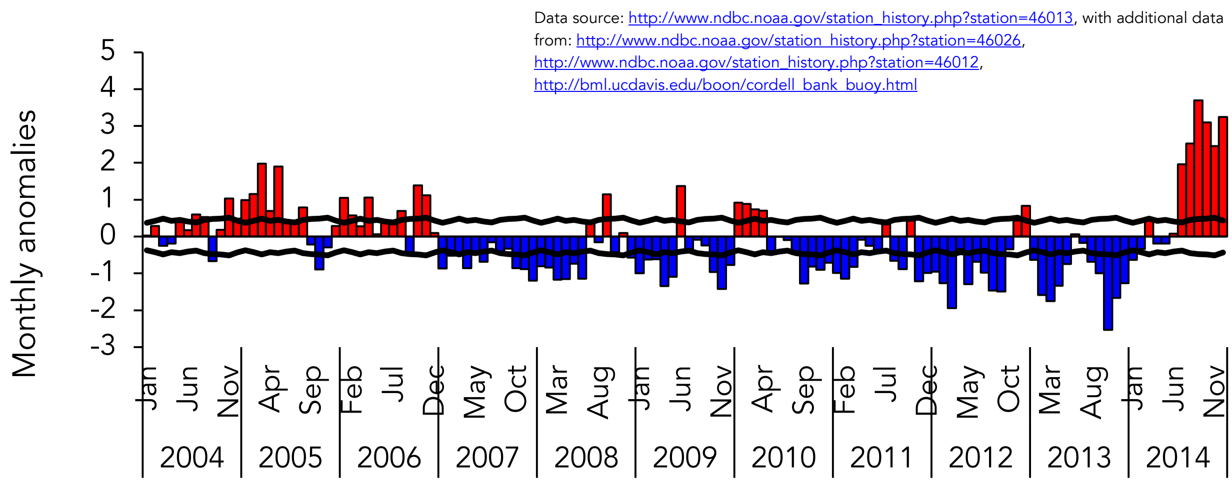

Figure 2. Monthly anomalies of SSTs, Bodega buoy, 2004–14. Black lines represent ±99% confidence intervals around the long-term monthly means.

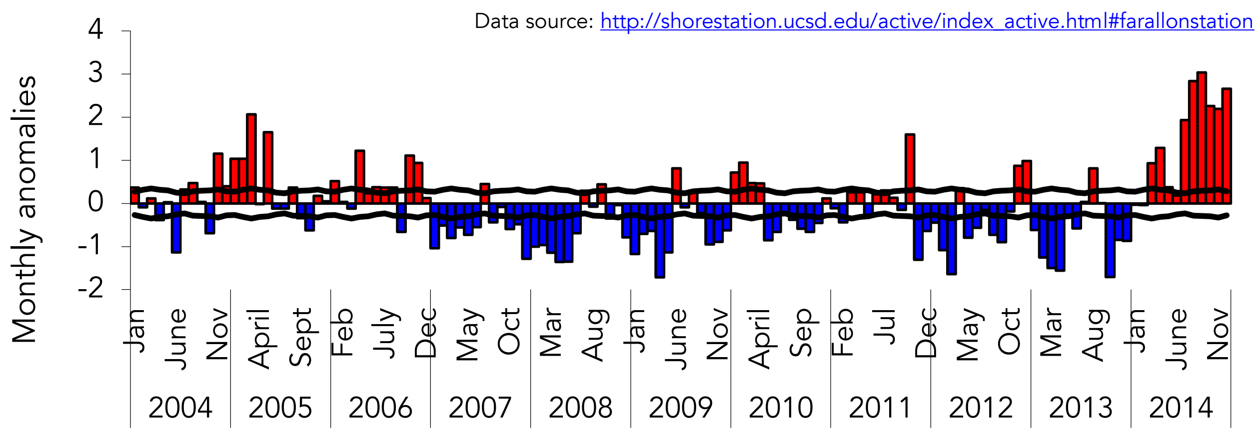

Figure 3. Monthly anomalies of SSTs, SEFI, 2004–2014.
Black lines represent ±99% confidence intervals around the long-term monthly means. NOTE: results for Nov-Dec 2014 are preliminary.

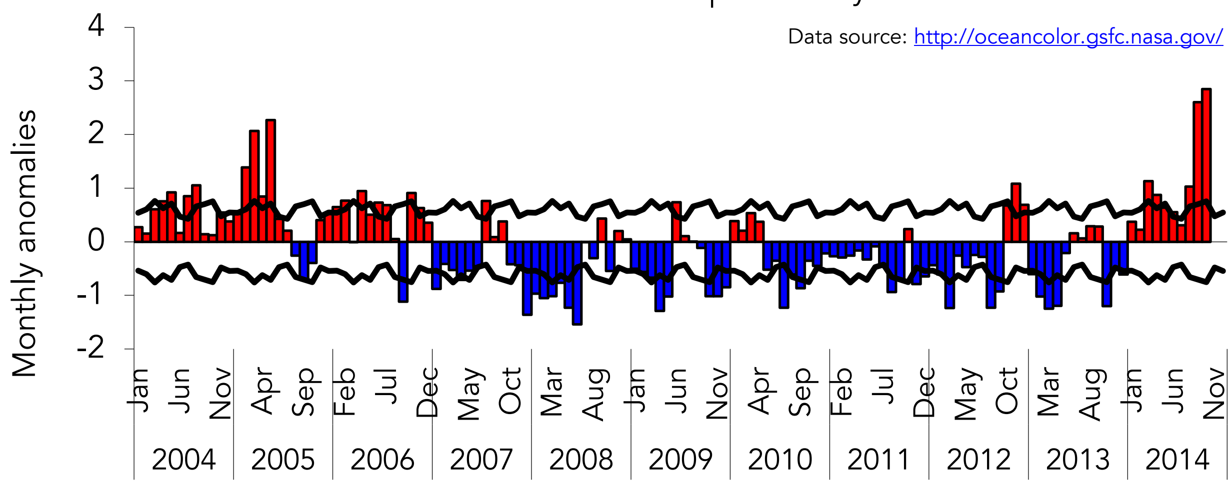

Figure 4. Monthly anomalies of SSTs, MODIS Aqua satellite, 2004-Oct 2014. Black lines represent ±99% confidence intervals around the long-term monthly means.

Sea surface salinity and height

Overview

Other variables used to estimate upwelling and productive oceanographic conditions are sea surface salinity and sea surface height. Higher salinity values can be a sign of nutrient-rich waters, which is a result of upwelling. During upwelling, surface waters along the coast are pushed offshore, causing depressed sea surface heights near the coast; the opposite is true for downwelling conditions, as offshore water returns to the coast and causes a rise in sea surface height. Salinity and sea surface height reflect these upwelling and downwelling conditions: salinity increases rapidly in the early months of the year, peaking in July, then declines slowly through the end of the year; and sea surface height declines from its highest height in Jan (indicating downwelling) through the upwelling season (lowest height observed in May), then increases through the end of the year.

Southeast Farallon Island data

Sea surface salinity data from SEFI in 2014 shows high salinity values (i.e. the positive blue bars) in the early months, indicating upwelling, followed by near-average values (and lack of upwelling) for the remainder of the year (Figure 5). Low salinity values (i.e. the negative red bars) were evident in 2004-06, indicating weak upwelling conditions. Anomalously high salinity values were observed in early months of 2007-09 and 2012. Salinity values in 2010-11 were average, indicating a lack of strong upwelling events in the early months of these years. Conversely, 2012-13 had high salinity values in the early months, suggesting upwelling during these months.

Satellite data

Sea surface height throughout 2014 was higher (i.e., positive red bars), suggesting downwelling conditions during this period (Figure 6). In general, sea surface heights were higher than average in 2004-06, indicating downwelling or relaxation conditions. From early 2007 through the first half of 2009, sea surface height declined (i.e., negative blue bars), suggesting upwelling in the region. Conditions switched in mid-2009 to higher sea surface heights (i.e., downwelling), then switched again in mid-2010 to lower surface heights, which persisted through February 2011. Weak relaxation conditions returned in May-Sep 2011, then weak upwelling conditions dominated the remainder of the year and into 2012. Weak upwelling was followed by weak downwelling in both 2012 and 2013.

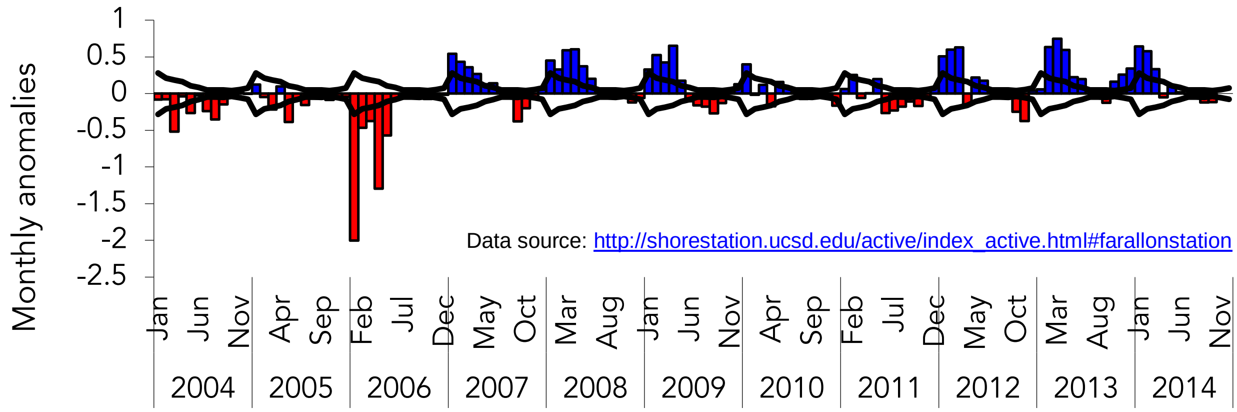

Figure 5. Monthly anomalies of sea surface salinity, SEFI, 2004 – Oct 2014.
Black lines represent ±99% confidence intervals around the long-term monthly means.

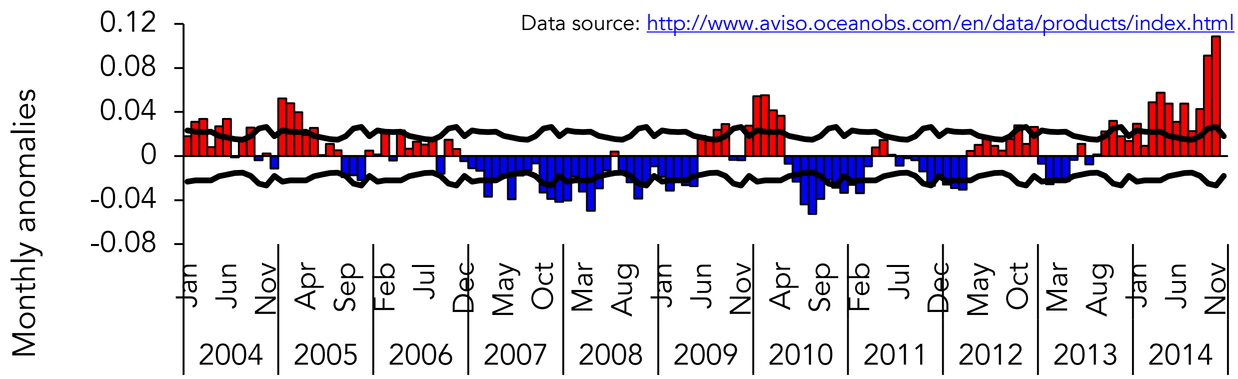

Figure 6. Monthly anomalies of sea surface heights, Aviso satellite, 2004–Nov 14.
Black lines represent ±99% confidence intervals around the long-term monthly means.

Winds, upwelling and spring transition

Overview

Upwelling is a wind-driven process where coastal winds blowing parallel to the coast result in an offshore movement of surface water drawing deep, cold, nutrient-rich waters to the surface nearshore. The strength and timing of upwelling can have significant effects on the marine ecosystem and the spring transition date; while the average spring transition date is Mar 29, the earliest date was Feb 18 (in 2007, a cold water year), and the latest date was May 11 (in 1983, an El Niño year). In addition, periods of strong upwelling should be alternated by relaxation events to allow for the spring bloom to occur. Typically, alongshore winds and upwelling values increase during the early months (both reaching a maximum in Jun), then decline through the remainder of the year.

Winds

Alongshore winds in 2014 were weak, with strong winds (i.e. negative blue bars) in Jan and May and relaxed conditions (i.e. positive red bars) for the rest of the year (Figure 7). There was moderate alongshore wind activity in 2004, followed by a lack of alongshore winds in 2005-06. Strong, upwelling-producing winds are clearly visible in the early months of 2007-09. Alongshore winds in 2010 appeared to weaken, with some strong wind activity in May-Jun and Nov. Winds continued to be moderate to weak throughout most of 2011-12, with periods of stronger winds observed in the early and later months of these years. Stronger alongshore winds were observed in 2013, with a relaxation event during the summer months.

Upwelling

Strong upwelling conditions (i.e. positive blue bars) dominated most of 2013, with a few months (e.g. Mar, May, Aug and Nov) of reduced upwelling as indicated by regional indices (Figure 8). Intermittent upwelling and downwelling (i.e. negative red bars) events were noticed in the early months of some years (e.g. 2004, 2011), while upwelling was weak and delayed in 2005-06 and 2010. Strong upwelling conditions were found in the early months of 2007-09, followed by relaxation events. Strong upwelling was noted in most of 2012 and 2013. In contrast, measurements from local buoys indicate downwelling for most of the year and do not show the stronger upwelling conditions illustrated in the regional results for 2014, which could indicate that the buoy is capturing localized conditions not observed in the monthly indices (Figure 9).

Spring transition

The spring transition date for 2014 was March 29, which is the average transition date in the time series (Figure 10). Most of the recent years (e.g. 2006-09, 2012-13) showed earlier transition dates (i.e. negative bars) and some years (e.g. 2010) had a late spring transition (i.e. positive bars). Spring transition dates calculated from Bodega Bay buoy data since 1981 show similar results as dates calculated from upwelling indices for most years, including an average date for 2014 (Figure 11). Late transition dates tend to be associated with El Niño events (e.g. 1983) and early dates with La Niña years (e.g., 2007).

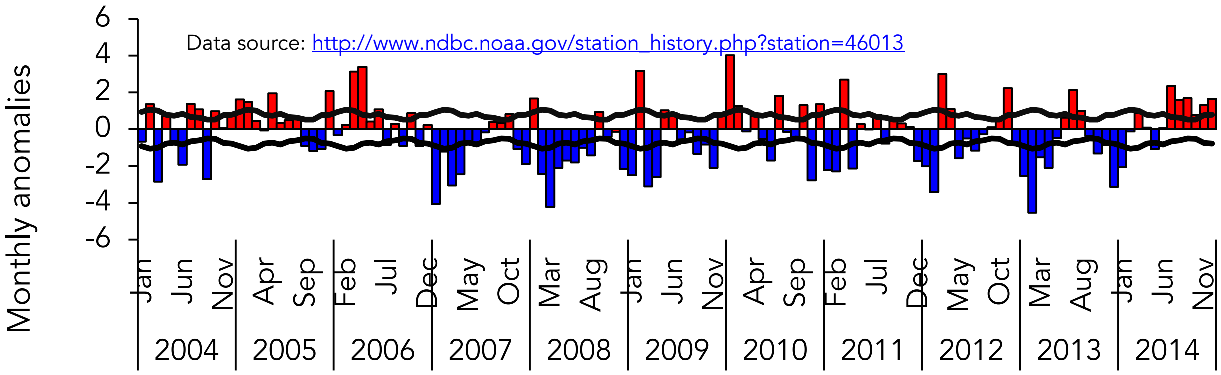

Figure 7. Monthly anomalies of alongshore winds, 2004–14.
Black lines represent ±99% confidence intervals around long-term monthly means. Red bars indicate weak winds, and blue bars indicate strong winds.

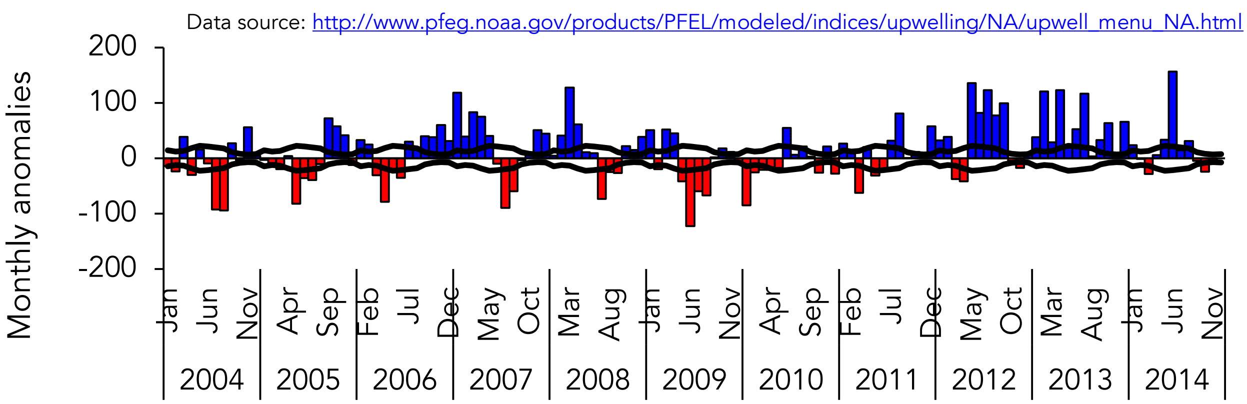

Figure 8. Monthly anomalies of regional upwelling indices, 2004 –Nov 2014.
Black lines represent ±99% confidence intervals around long-term monthly means. Red bars indicate downwelling, and blue bars indicate upwelling.

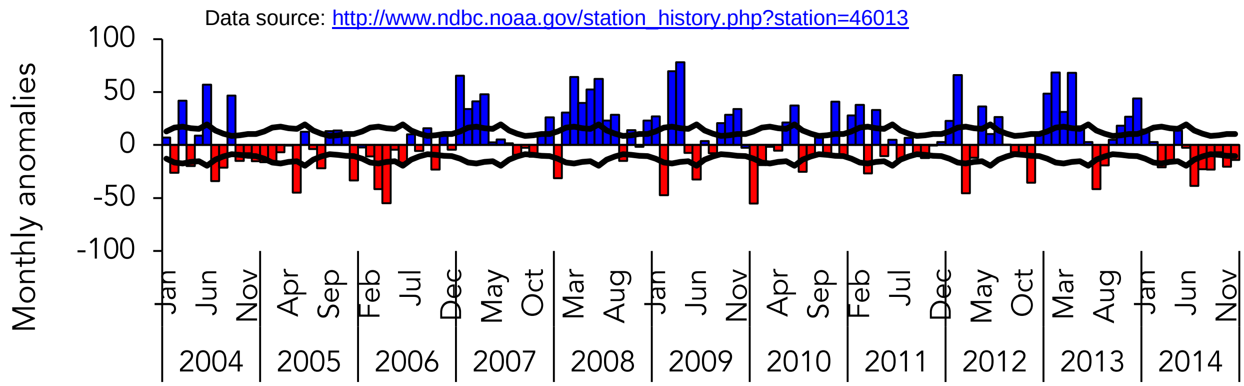

Figure 9. Monthly anomalies of local upwelling indices as calculated from the Bodega buoy data, 2004–14.
Black lines represent ±99% confidence intervals around long-term monthly means. Red bars indicate downwelling, and blue bars indicate upwelling.

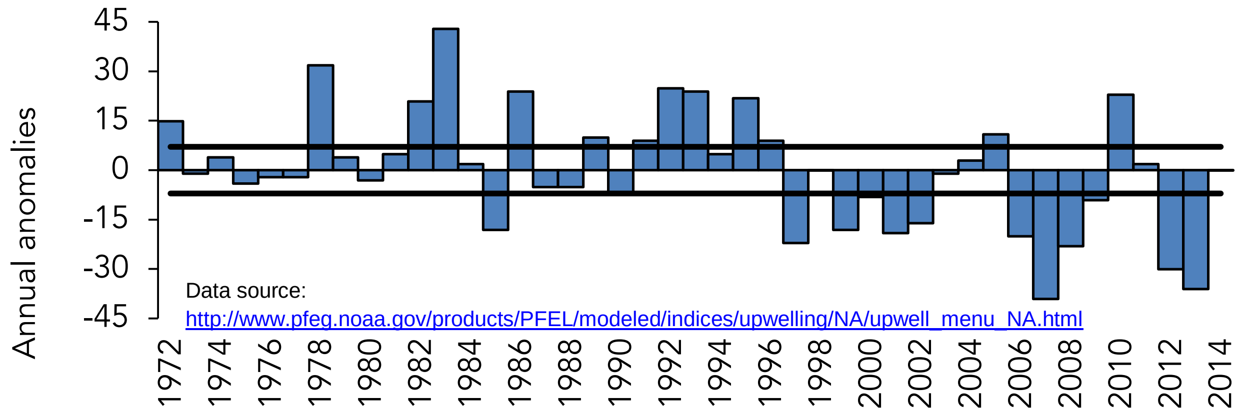

Figure 10. Anomalies of spring transition dates based on daily upwelling indices, 1972-2014.
Black lines represent ±99% confidence intervals around 43-year mean. Negative bars indicate early transition dates, and positive bars indicate late transition dates.

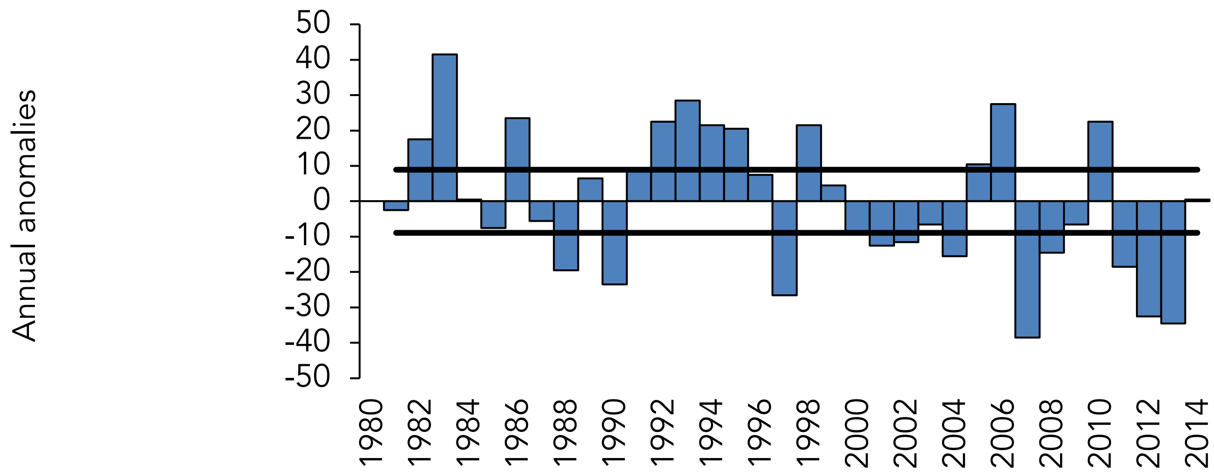

Figure 11. Anomalies of spring transition dates based on Bodega Bay buoy data, 1981-2014.
Black lines represent ±99% confidence intervals around 34-year mean. Negative bars indicate early transition dates, and positive bars indicate late transition dates.

Climate Indices

Overview

Several climate variables have been developed to understand climate effects on the basin-level scale. The Southern Oscillation Index (SOI) uses differences in mean sea level pressure anomalies between Tahiti and Darwin, Australia. Negative SOI values indicate warm ocean conditions related to El Niño, and cold water conditions are shown in positive SOI values. The Pacific Decadal Oscillation (PDO) shows changes in surface waters in the North Pacific (from 20°N to the pole) at inter-decadal scales. Positive PDO values correspond to warmer ocean waters in the eastern Pacific, and negative PDO values correspond to cold waters. The North Pacific Gyre Oscillation (NPGO) measures changes in circulation of the North Pacific gyre, and is highly correlated with nutrients and overall productivity. Similar to the SOI, negative NPGO values reflect warm water and poor productivity, while cold water and high productivity correspond to positive NPGO values.

Southern Oscillation Index (SOI)

SOI values in 2014 showed mildly warm water conditions (i.e. negative red bars) throughout most of the year, punctuated by months (Mar and Aug) of anomalously warm conditions (Figure 12). Warm waters were observed from 2004 through the first half of 2007. Cold water conditions (i.e., positive blue bars) were observed from mid-2007 through early 2009, at which point the SOI changed to negative values again. The SOI remained mostly negative throughout the later months of 2009 and early 2010, switching to positive values in Mar 2010. SOI values in 2011 showed cold water conditions, while values in 2012 were average to warm. Normal to cool conditions dominated 2013.

Pacific Decadal Oscillation (PDO)

PDO results for 2014 showed warm water conditions (i.e. positive red bars) for the year (Figure 13). Warm water conditions dominated the early years of this time series (roughly 2004-07), while cold water conditions (i.e. negative blue bars) were more prominent from late 2007 through the end of 2009. A brief period of warm water conditions returned in late 2009 and early 2010, then giving way to cold conditions from mid-2010 through 2013, where a warming trend appeared.

North Pacific Gyre Oscillation (NPGO)

NPGO values for 2014 indicate normal to mild warm water, poor productivity conditions (i.e. negative red bars; Figure 14). Warm water, poor productivity conditions were evident throughout 2005 and 2006. Normal values were observed for most of 2009, while cold, productive conditions (i.e. positive blue bars) were evident in all other years. Similar to the PDO, results for 2013 indicated a warming trend.

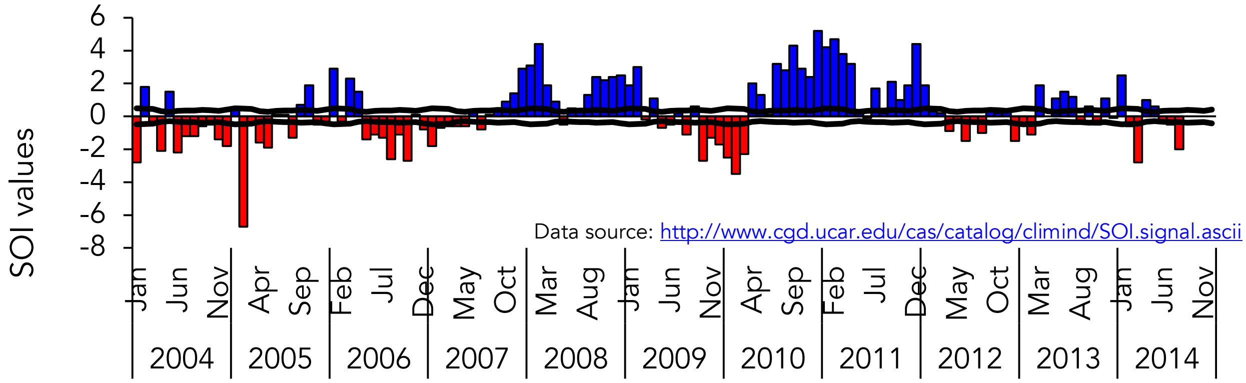

Figure 12. Southern Oscillation Index (SOI) values, 2004 – Aug 2014.
Black lines represent ±99% confidence intervals around the long-term monthly means.

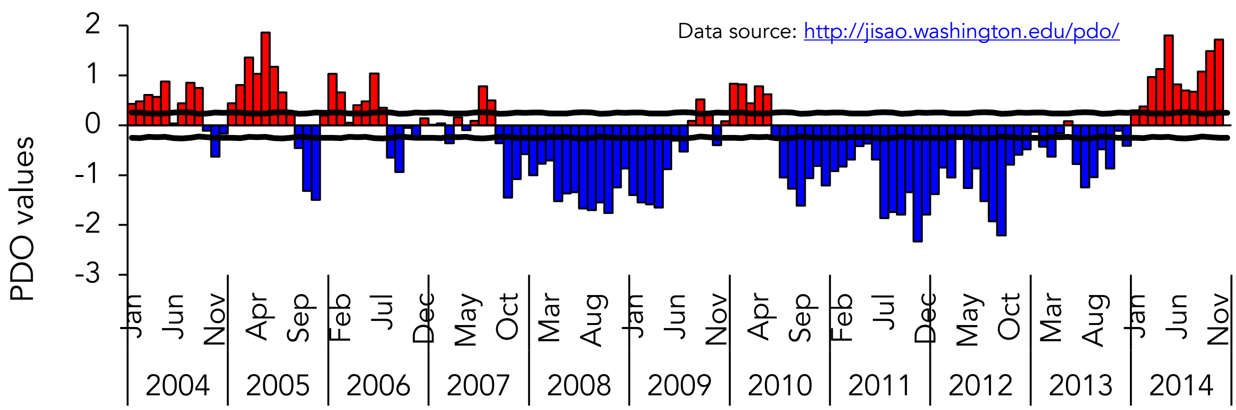

Figure 13. Pacific Decadal Oscillation (PDO) values, 2004–Nov 2014.
Black lines represent ±99% confidence intervals around the long-term monthly means.

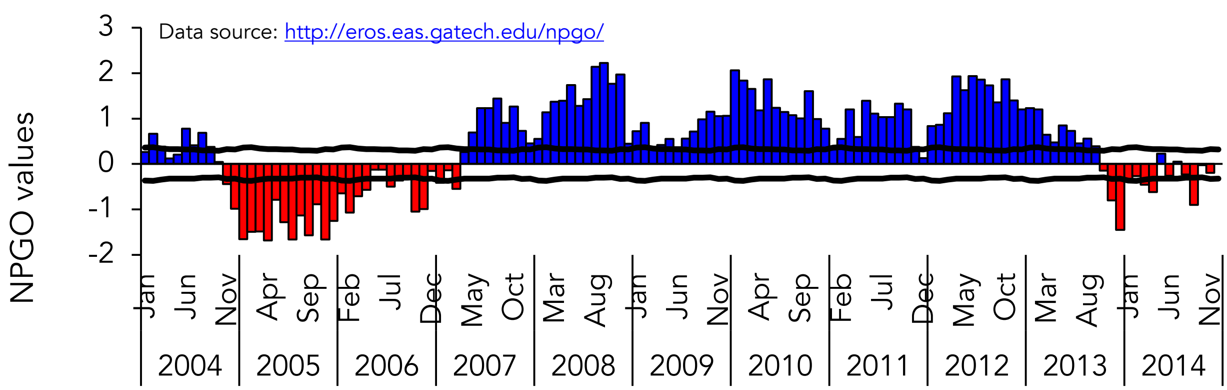

Figure 14. North Pacific Gyre Oscillation (NPGO) values, 2004–Nov 2014. Black lines represent ±99% confidence intervals around the long-term monthly means.

Chlorophyll a and phytoplankton composition

Overview

Concentrations of chlorophyll a can provide information on the amount of phytoplankton in surface waters. The timing of peak phytoplankton abundance could also have effects on how productive a marine ecosystem will be. Satellite data provide us with phytoplankton abundance estimates; long-term monthly means in abundance show increasing phytoplankton abundance in Mar-May, a slight decline through Sep, then a peak in Oct. Phytoplankton collected within and adjacent to the Sanctuaries was analyzed by the California Department of Health to help us understand the phytoplankton community composition. Composition of the phytoplankton community can provide insight into how productive an ecosystem might be. For instance, an increase in the abundance of dinoflagellates (a small organism) could signify poor ocean conditions, whereas a greater abundance of diatoms (a larger organism) could indicate more productive ocean waters.

Satellite data

Phytoplankton blooms (i.e. positive anomalies) were observed in Apr-May of 2014 (Figure 15). There is some evidence of peak chlorophyll in the spring and fall months of 2004-06, but evidence for sustained phytoplankton blooms is lacking in 2007-12. From the oceanographic results, we might have anticipated seeing anomalously high chlorophyll a concentrations in 2007-09, when upwelling conditions were good. However, blooms are known to occur after the seasonal thermocline is established, so the peak chlorophyll concentrations in later months (fall and winter) of 2005 and 2006 could be explained by the delayed upwelling in those years. Strong upwelling and a lack of relaxation could explain the average to low phytoplankton abundance in 2007-10. Blooms appeared more frequently in 2011 but were relatively small and sporadic, whereas blooms were relatively non-existent in 2012. Evidence of more substantial phytoplankton blooms were evident in the early and late months of 2013.

California Department of Health data

Phytoplankton composition in 2014 was largely dominated by diatoms throughout the year, similar to 2012-13 (Figure 16). Other years (e.g. 2006, 2007, 2009 and 2011) showed an increase in dinoflagellates from spring/summer to fall/winter, while other years (e.g. 2010 and 2012-13) showed low dinoflagellate abundance throughout the year. Dinoflagellates are most associated with warm, less turbulent waters later in the year (when diatoms sink and become scarce in surface waters) and are responsible for harmful algal blooms (e.g. red tides) common in the fall months. Contrary to most years, dinoflagellates were relatively more abundant than diatoms in the spring/summer of 2008. The greater importance of diatoms (i.e., the species most associated with cold, turbulent ocean waters) throughout the 10-year time series could indicate improved upwelling conditions through time.

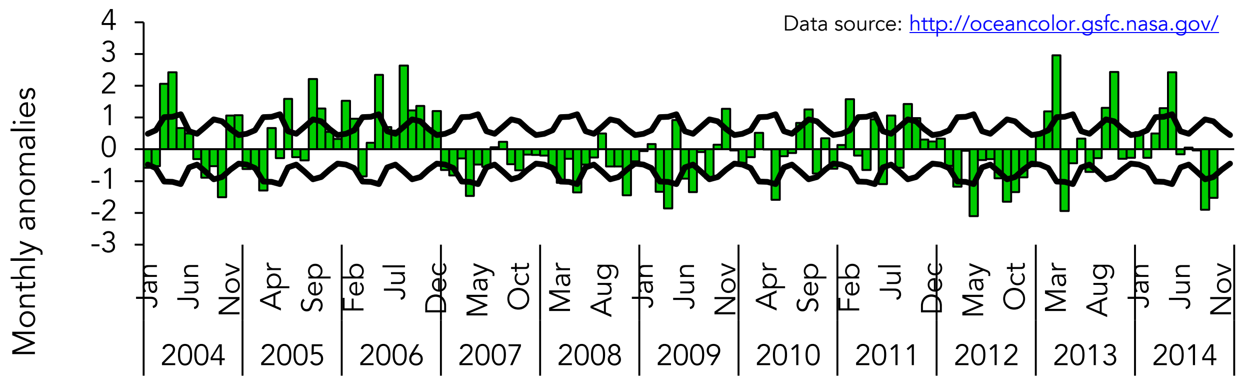

Figure 15. Monthly anomalies of chlorophyll a, MODIS Aqua satellite, 2004-Oct 2014.
Black lines represent ±99% confidence intervals around the long-term monthly means.

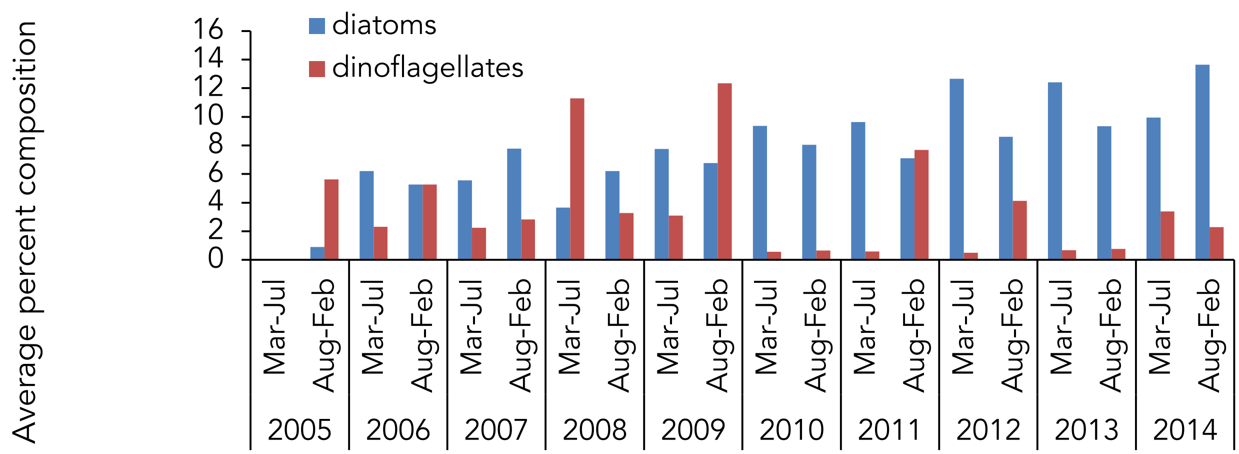

Figure 16. Average relative composition of diatoms and dinoflagellates in offshore samples, 2005-14.

Zooplankton composition

Overview

Information on the abundance and species composition of zooplankton are also indicators of the productivity of an ecosystem. For example, an overabundance of gelatinous species can signify poor productivity, and a highly productive ecosystem may have high abundances of euphausiids (which are important prey for fish, seabirds, and marine mammals).

Relative composition

While all years of data are not yet available, we can see variability in zooplankton abundance and composition in years 2004-12 (Figure 17). Anecdotal observations of zooplankton samples taken during 2014 ACCESS cruises appeared to be dominated by gelatinous zooplankton. From Sep 2004 through Oct 2006, the overall average abundance of zooplankton is greatly reduced and never reaches over 30 individuals per cubic meter of water sampled. The trend changed in 2007, when overall zooplankton abundance increased dramatically, and this overall increase in zooplankton abundance is sustained for most surveys in 2007 and 2008. This is mainly attributed to increases in euphausiid and copepod abundance. The first half of 2009 shows high zooplankton abundance (especially euphausiids and copepods), followed by a return to low zooplankton densities. Results from 2010 show increasing zooplankton abundances through the year, with a significant increase (particularly for copepods) in Sep. Zooplankton increased in abundance considerably in 2011, particularly euphausiids. However, preliminary results for 2012 reveal a drastic decline in zooplankton. While we do not have samples from each month of the year, our results show increasing zooplankton abundance in spring, a peak in Jun, and a decline in fall; however, not all years show this pattern (e.g. 2010, 2011).

Community analysis

We looked for similarities between different years based on the zooplankton data by performing a non-metric multi-dimensional scaling analysis for samples collected in the spring and summer months (Apr-Jul; Figure 18). In general, there appear to be two main groups that cluster together: years 2004-06, and years 2007-12. A scattering of samples in the upper left corner are largely from samples collected in July 2009, and June and July 2010. Conditions in mid-2009 changed from cold waters to warm waters, which revealed a change in the zooplankton community (Fontana *et al*., in review), and this could be one reason for the departure of these samples from the others in the 2007-12 group.

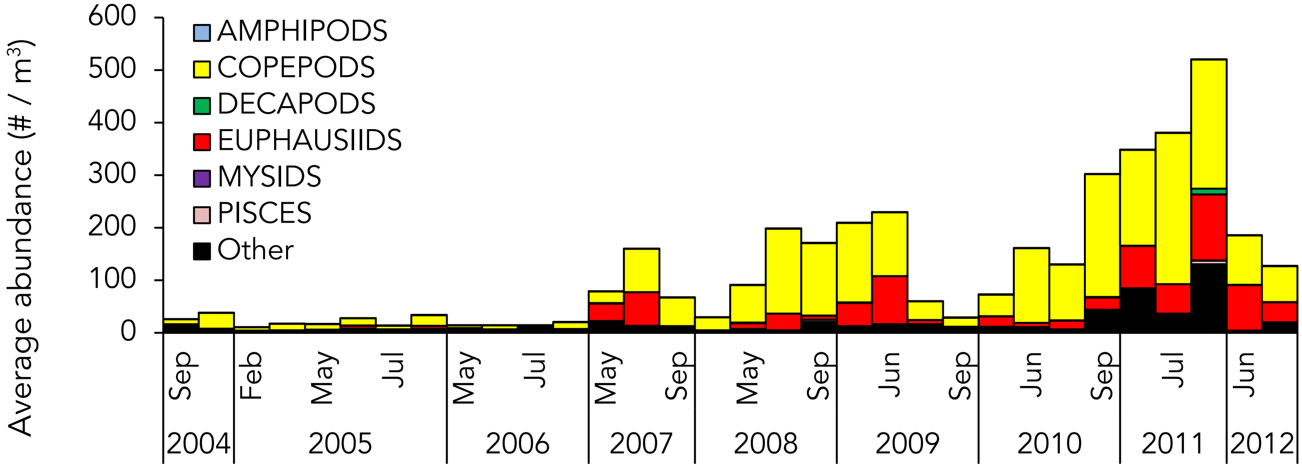

Figure 17. Zooplankton composition in the upper 50 m of the water column determined from hoop net samples, 2004- Jul 2012.
NOTE: Euphausiid abundances include all life stages *except* eggs. Data are not complete for 2012.

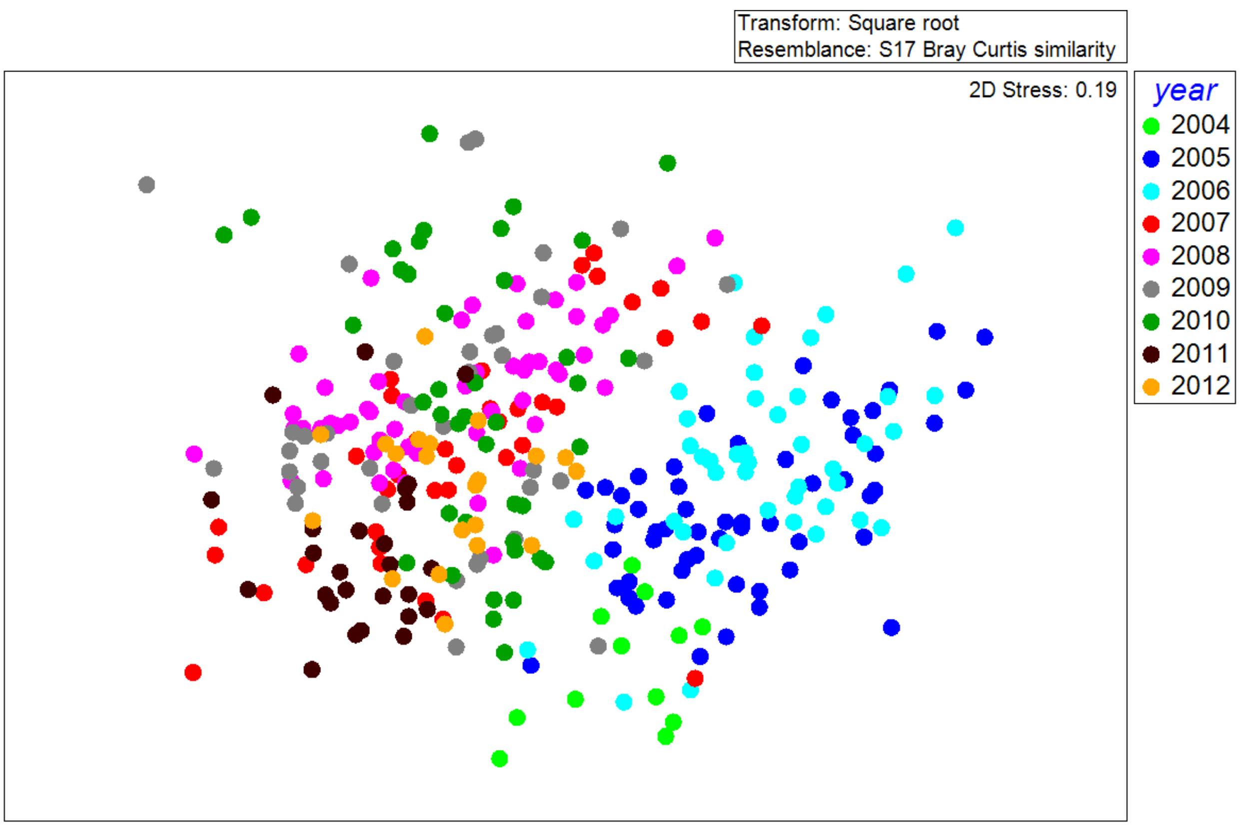

Figure 18. Non-metric multi-dimensional scaling analysis of zooplankton results, Apr-Jul samples, 2004-12.
NOTE: Data are not complete for 2012.

Copepods

Overview

Copepods are mid-trophic level organisms, and they are the most abundant and diverse zooplankton taxon, constituting the largest source of protein in the marine environment. Copepod communities change in response to changing oceanographic conditions, and the presence and absence of key species can indicate these changes. Copepods that are common to northern latitudes (called boreal species) become more abundant in colder, productive ocean waters. Transition zone species are common species to this region, yet they can become more abundant in colder waters and less abundant in poor ocean conditions. Equatorial species (i.e., species from tropical or subtropical regions) can be found during warm water intrusions (e.g., El Niño events) from southern latitudes.

Relative composition

While we do not yet have data for all years, the results we do have indicate changes in the copepod species composition, the most notable in the boreal species (Figure 19). These species were largely absent for the first three years of data (2004-06), and abundance increased significantly in 2007-08; boreal species declined again in the latter half of 2009, but a dramatic increase was observed in 2010 and 2011. Preliminary results for 2012 illustrate another sharp reduction in boreal species. While we do not have samples from each month of the year, our results for boreal copepods generally show increasing abundances in spring, peak abundance in Jun, and declining densities in fall, but this varies with ocean conditions (e.g. 2009, 2010). Species common to mid-latitude areas were in relatively low abundances throughout the time series, with peaks in abundance in the latter months (especially Sep) in 2007-08 and 2010-11 (Figure 20). While we do not have samples from each month of the year, our within year results varied greatly, with peak abundances in Jun for some years (e.g. 2007, 2009) and Sep/Oct for others (e.g. 2005, 2006, 2010, 2011). Equatorial copepods remained in low abundances throughout the eight years, except for the increases in abundance during Sep cruises of 2007-09, and an apparent increase in Jul 2011; equatorial copepods have, so far, been absent in 2012 samples (Figure 21).

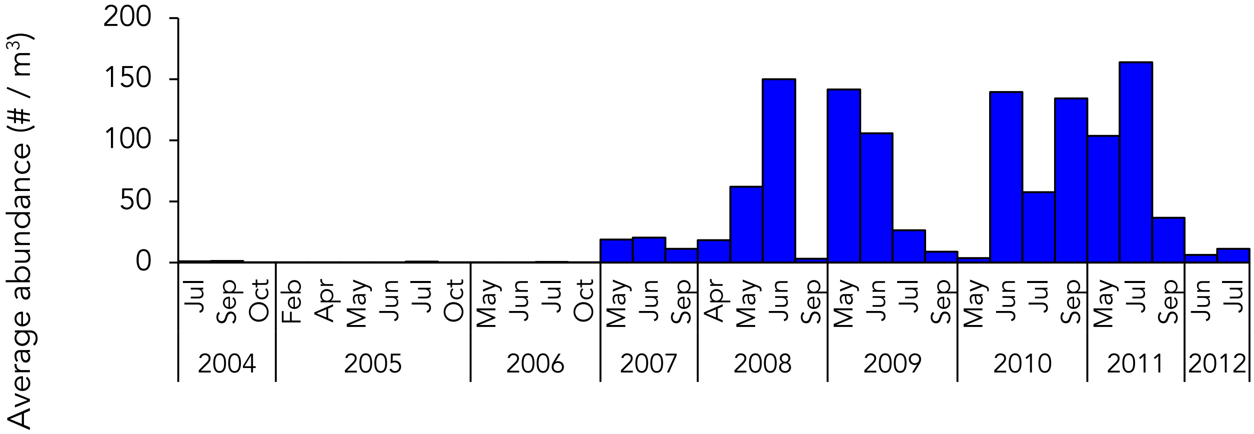

Figure 19. Average abundances of boreal copepod species, 2004–Jul 2012.
NOTE: Data are not complete for 2012.

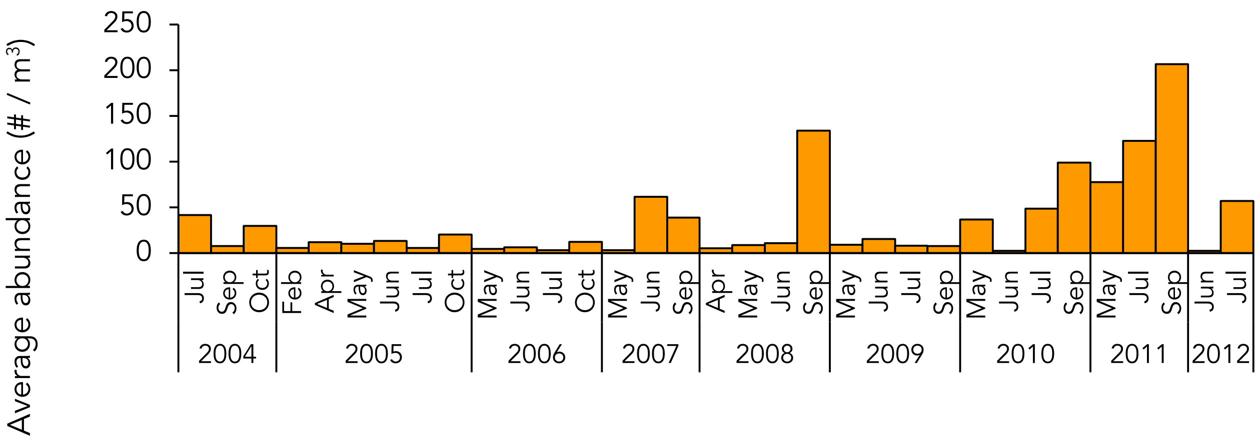

Figure 20. Average abundances of transition zone copepod species, 2004–Jul 2012.
NOTE: Data are not complete for 2012.

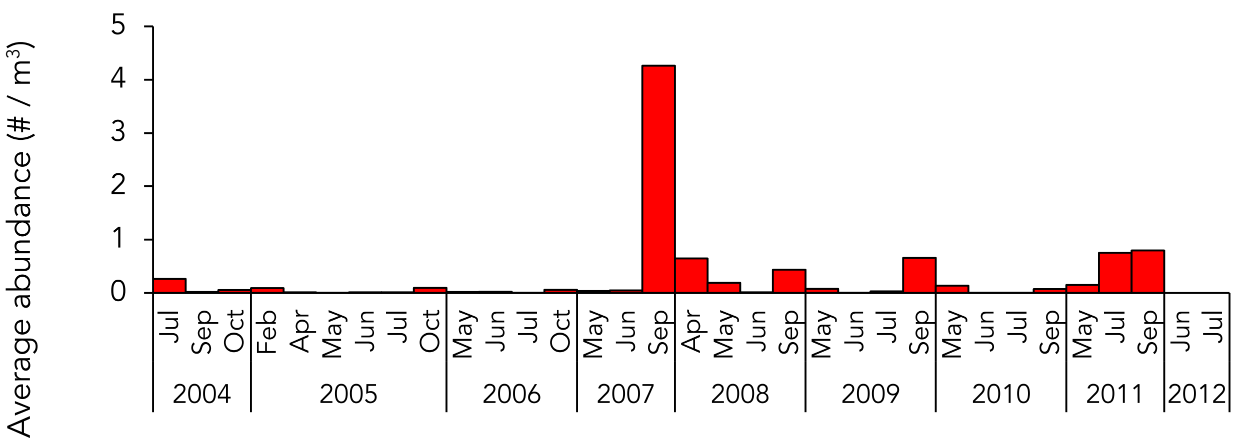

Figure 21. Average abundances of equatorial copepod species, 2004–Jul 2012.
NOTE: Data are not complete for 2012.

Pteropods

Overview

Pteropods are pelagic marine gastropods and are commonly known as sea butterflies. There are two orders of these mid-trophic level organisms: Thecosomata and Gymnosomata; the former contains a shell while the latter does not. One species belonging in the order Thecosomata, *Limacina helicina*, has been used to study the effects of ocean acidification. This species' calcium carbonate shell is sensitive to dissolution in acidic conditions, and shell thickness can be measured on this species to assess ocean acidification and its effects on the marine environment. *L. helicina* has been classified as a key indicator species of ocean acidification.

Abundance

We do not yet have results from 2013-14. However, results we have so far reveal very low abundances of *L. helicina* in our region, particularly in the first two years (Figure 22). Increases were first noted in Jun 2006 (which may have coincided with the beginning of the delayed upwelling in that year). Abundances have remained at low levels since, with dramatic increases noted in the 2011 cruises. Preliminary results from 2012 reveal very low abundances of pteropods in Jun and an increase in Jul. The significance of these results so far are still being discussed.

Future work is being planned to measure the shell thickness of this species from the ACCESS cruise samples.

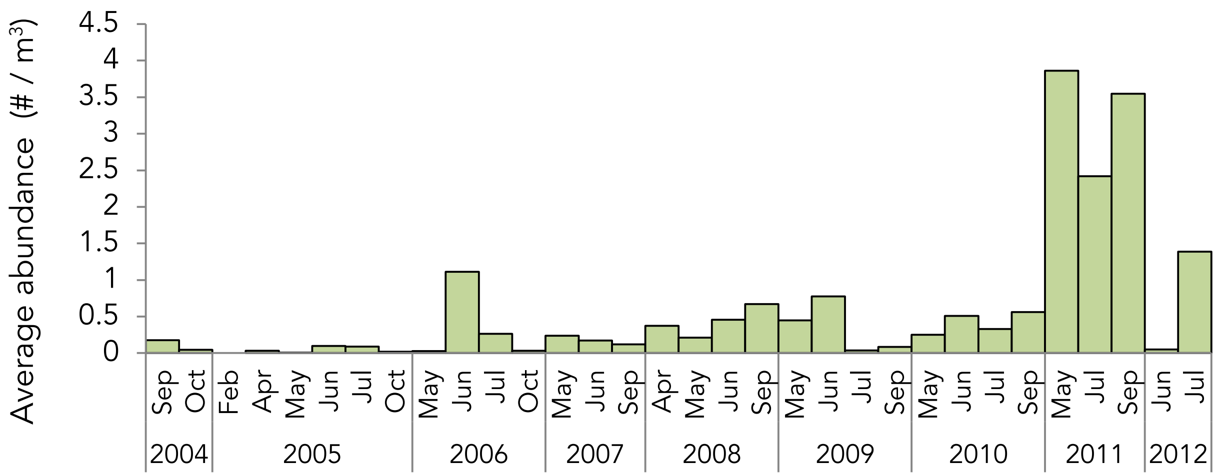

Figure 22. Average abundance of the pteropod *Limacina helicina*, 2004-12. NOTE: Data are not complete for 2012.

Euphausiids

Overview

Euphausiids (commonly known as krill) are important mid-trophic level organisms, feeding mainly on phytoplankton and then becoming prey for many marine top predators (e.g., salmon, seabirds, and humpback whales). There are two main species found in the Gulf of the Farallones: *Euphausia pacifica* and *Thysanoessa spinifera*, the former being more abundant than the latter. Adult and immature stages of these species are known to be the primary prey items of the Cassin's auklet, a zooplanktivorous seabird species breeding on the Farallon Islands.

Abundance

Acoustic biomass results for 2014 are not yet available, although observations of acoustic biomass during 2014 ACCESS cruises indicated low krill biomass. Results to date show the abundance of euphausiids down to 200 m below the surface were lower in the first 5 years (2004-08) with seasonal peaks in spring/summer, followed by increased abundance in 2009-13 (Figure 23). Krill abundance appears to be slowly declining since 2011. While we do not have samples from each month of the year, our results indicate annual peaks in euphausiid abundance appeared to occur mostly during Jun cruises through 2008, then Jul cruises in the latter years of our time series. The large 2006 densities are likely due to salps and other gelatinous zooplankton that were abundant that year, as these species can confound acoustic results.

Euphausiid age classes

Adult *E. pacifica* were more abundant in Tucker trawl samples (i.e., sampling down to 200 m) during the Jun cruise of 2014, then younger life stages dominated samples in Jul and Sep (Figure 24). Adult krill were more abundant during the cold, productive conditions of 2007-08, as well as average conditions in 2010-11, while younger stages dominated during the warm, less productive conditions observed of 2005-06 and the latter part of 2009. Adults were abundant for most of 2010-13, although percentages appear to be declining through time, with fall cruises (Sep) usually show higher percentages of the younger life stages.

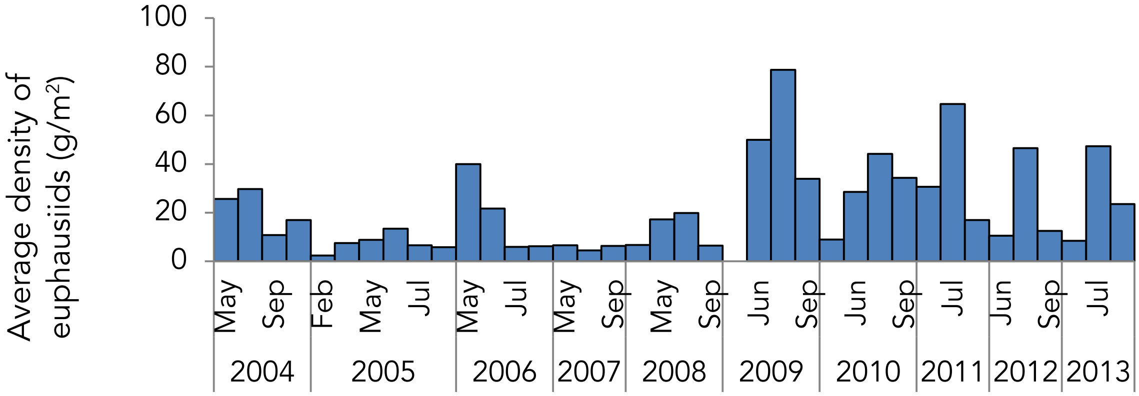

Figure 23. Acoustic biomass of euphausiids down to 200 m, 2004-13.

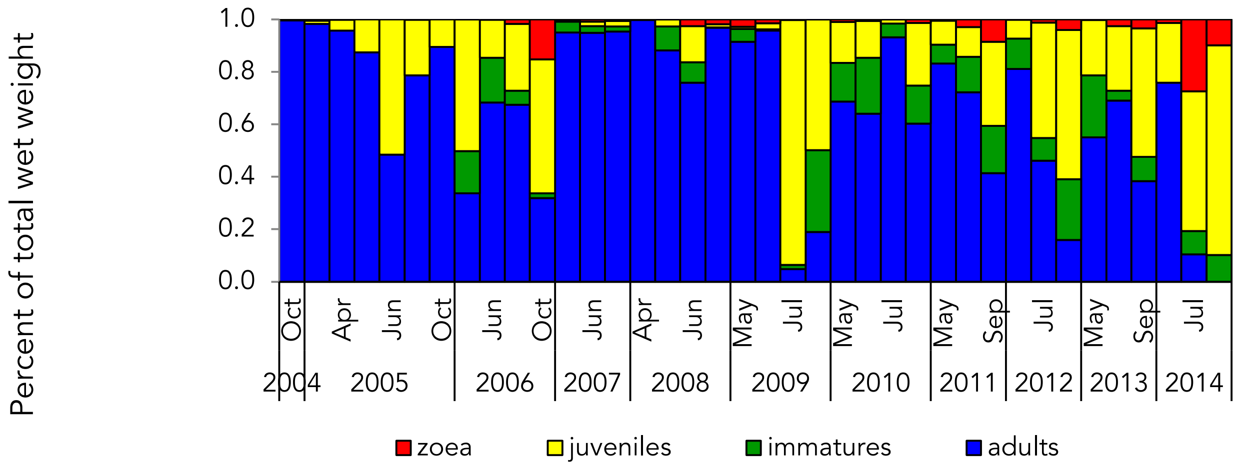

Figure 24. Percent composition of different age classes of *Euphausia pacifica*, 2004-14.

Birds

Overview

Seabirds are top marine predators that feed on a variety of marine organisms. Some species breed within our study area, while other species migrate great distances to spend their non-breeding period in the central California Current. The abundances and distributions of marine birds have been linked to bathymetric and hydrographic features which aggregate prey; many seabirds live in or travel to the central California Current because of the highly-productive waters common to the region.

Relative composition

There were a total of 46 species of seabird identified during at-sea cruises (Table 1). When looking at the top ten most abundant seabird species, six of these are known to breed on SEFI or other areas within the central California Current. Sooty and pink-footed shearwaters overwinter in the study area, while phalarope species can be found here as they make their way from their Arctic breeding grounds to tropical waters for the non-breeding period.

The next few sections will concentrate on the information available on some of these abundant species, particularly three species which breed on SEFI: common murre, Cassin’s auklet, and Brandt’s cormorant.

Table 1. Seabird species and average densities per cruise, 2004-14.

Common Name	Average density (number of animals observed per km^2 of survey area)	Common Name	Average density (number of animals observed per km^2 of survey area)
common murre	18.476341	common loon	0.002278
Cassin's auklet	9.038014	elegant tern	0.002112
sooty shearwater	8.721836	unidentified storm-petrel	0.001937
western gull	1.369590	Laysan albatross	0.001461
pink-footed shearwater	1.368163	South Polar skua	0.001102
Brandt's cormorant	1.071310	Canada goose	0.001051
rhinoceros auklet	0.922131	unidentified duck	0.001051
red-necked phalarope	0.774239	peregrine falcon	0.001051
unidentified phalarope	0.590596	parasitic jaeger	0.001049
California gull	0.370853	Thayer's gull	0.001049
northern fulmar	0.296723	unidentified loon	0.001049
black-footed albatross	0.242449	mottled petrel	0.000961
pigeon guillemot	0.218970	red-throated loon	0.000961
red phalarope	0.174622	black scoter	0.000926
fork-tailed storm-petrel	0.146405	black storm-petrel	0.000820
unidentified gull	0.113689	herring gull	0.000597
Buller's shearwater	0.090481		
Heermann's gull	0.055771		
unidentified shearwater	0.049163		
ashy storm-petrel	0.047425		
black-legged kittiwake	0.036723		
pelagic cormorant	0.028890		
brown pelican	0.022524		
tufted puffin	0.018683		
Sabine's gull	0.016828		
Pacific loon	0.015279		
unidentified alcid	0.013268		
Bonaparte's gull	0.013147		
unidentified dark shearwater	0.011549		
Scripps's murrelet	0.011123		
short-tailed shearwater	0.010360		
pomarine jaeger	0.008196		
Arctic tern	0.007140		
surf scoter	0.005330		
unidentified auklet	0.004991		
double-crested cormorant	0.003642		
flesh-footed shearwater	0.003628		
glaucous-winged gull	0.003060		
ancient murrelet	0.002929		

Cassin's auklet

Brief species account

The Cassin's auklet is a small burrowing seabird that breeds on the Farallon Islands. This is a zooplanktivorous species, with the majority of their diet consisting of euphausiids.

Abundance

In 2014, the highest number of Cassin's auklets (1043 auklets) was observed in July (Figure 25). The highest number of Cassin's auklets in the time series was found in May 2004 (2683 auklets). After this, less than half this peak number was observed in any cruise. In general, counts were higher during the breeding season (Mar-Aug). The lowest number of auklets was found in 2006, the year with delayed and weak upwelling conditions. Numbers rebounded to some degree in 2009-13. Intra-annual results track the krill acoustic results, with peak numbers occurring during Jun for most years through 2008, then peak auklet counts shifted to Jul for the remaining years.

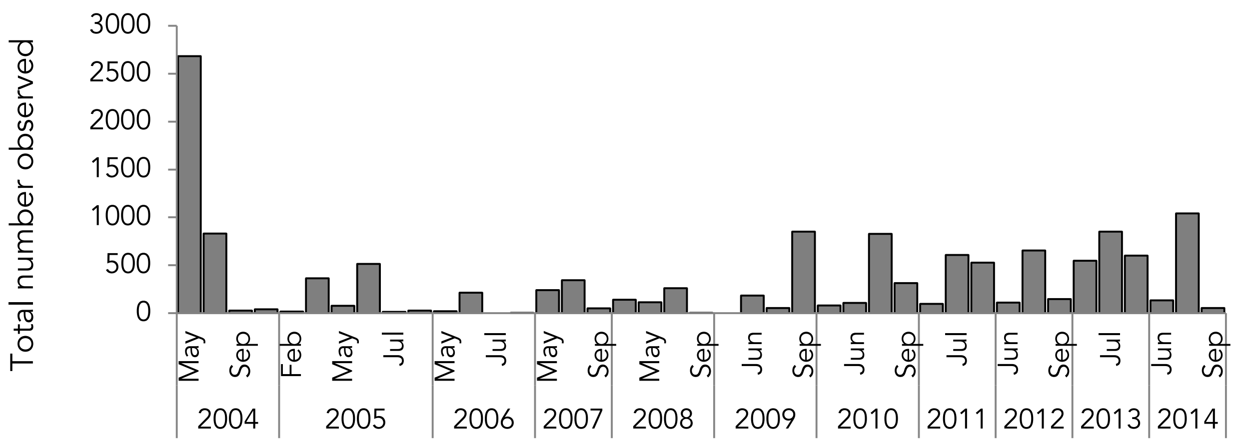

Figure 25. Abundances of Cassin's auklets observed during each cruise, 2004-14.

Distribution

Cassin's auklets were observed in the northern part of the study area in Jul 2014; this is where Cassin's auklets are observed in most years during May and Jun (Figure 26). Cassin's auklets are raising chicks during the months of May and Jun, which is why they were found close to SEFI in some years (e.g., 2012). While not shown here, poor upwelling years (e.g. 2005-06) were characterized by smaller auklet flocks, and they ventured farther north and inland. Improved ocean conditions returned in 2007, and auklets were observed over Cordell Bank, along the shelf break and closer to SEFI, but not in the large flocks noted in 2004.

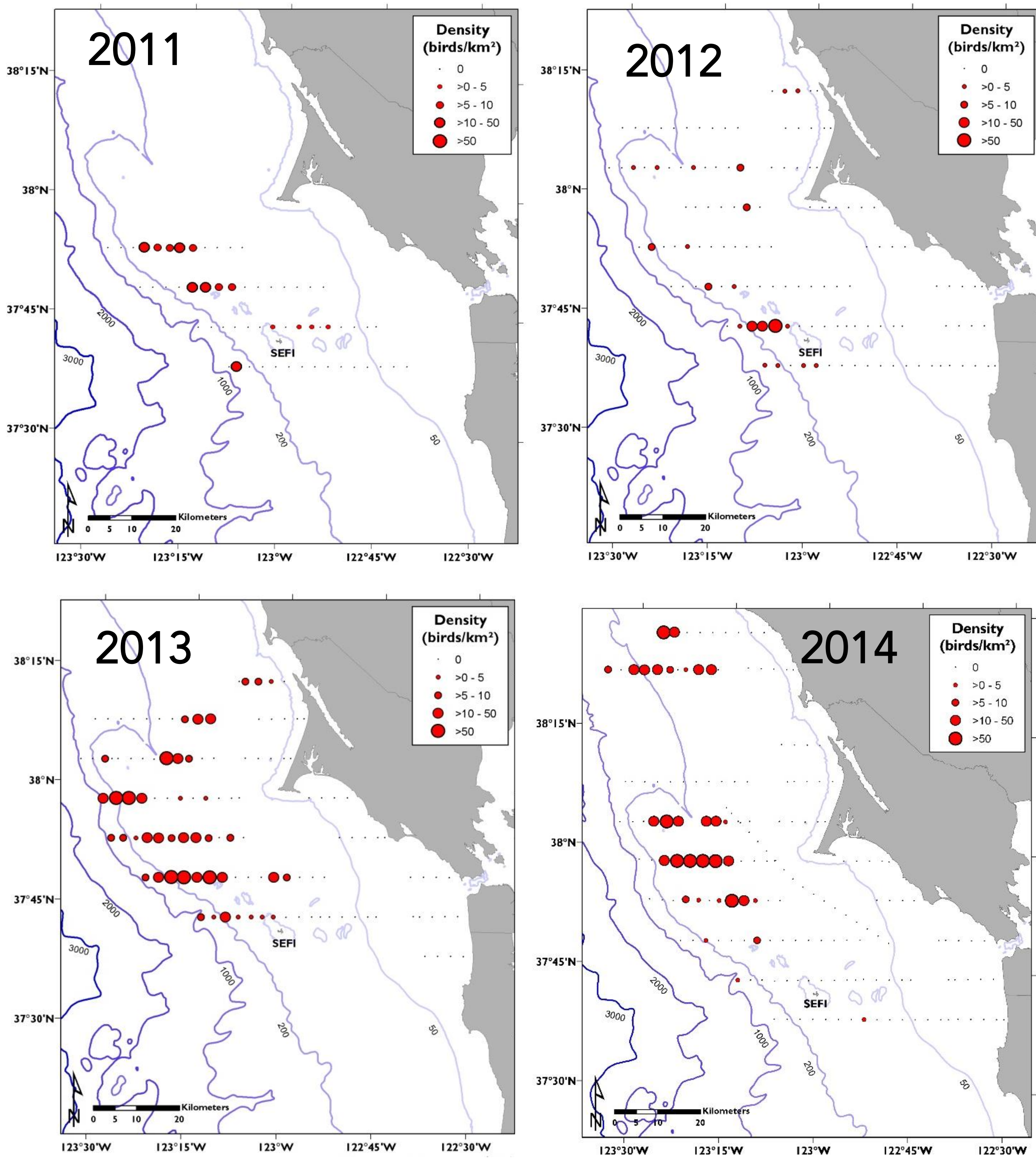

Figure 26. Cassin's auklet distributions during May or June 2010-14.
NOTE: July 2014 is shown here, as the June survey only covered a small area.

Cassin's auklet

Timing of breeding

The Cassin's auklet median egg lay date for 2014 was near the 43-year average on SEFI (Figure 27). Anomalously late lay dates correspond to El Niño events (e.g., 1982, 1992, 1998), when ocean conditions were poor. Since 2004, lay dates for Cassin's auklets have been average or earlier than the long-term average, with only 2005 (i.e., a poor ocean condition year) being later. There is a slight trend towards later lay dates through the time series, but this is not significant.

Breeding success

Breeding success for the Cassin's auklet on SEFI was higher than average in 2014, plotting above the 44-year mean but within the 80% confidence interval (Figure 28). The anomalously low productivity years have occurred during El Niño years (e.g., 1983, 1992) and generally correlate with years of later egg laying (Figure 27); years 2005 and 2006 are exceptions, as these were not El Niño years and lay dates were near the average, but they were the worse productivity years on record. Conversely, earlier lay dates (e.g., 2009-13; Figure 27) were linked to better productivity, indicating that an earlier start to breeding can lead to higher breeding success.

Diet

The 33-year diet time series for Cassin's auklets is dominated by euphausiids, including 2014 (Figure 29). The diet in 2005 and 2006 deviate greatly from the other years, as mysids (shrimp-like marine invertebrates) comprised the entire diet of the few diet samples collected in those years. This also led to breeding failure (Figure 28), revealing the importance of krill in this species' diet, as well as the lack of krill in the region during 2005 and 2006. Since the breeding failures of 2005-06, euphausiids have increased in the auklet diet, and breeding success has also rebounded. In addition, the age class of krill being consumed matters. While SEFI auklet diet was mostly comprised of euphausiids in 2014, 75% of the krill consumed were juveniles, which are smaller and contain fewer calories than adult krill. In 2014, a large auklet die-off (mostly juveniles) was observed along the west coast; a lack of food is suspected as the cause of the high mortality, and our diet results endorse this idea. Adult krill were present near SEFI early in the season (Figure 24) and allowed Cassin's auklets to have high productivity (Figure 28); but as warm water conditions materialized, younger krill became more abundant, and young auklets could not survive.

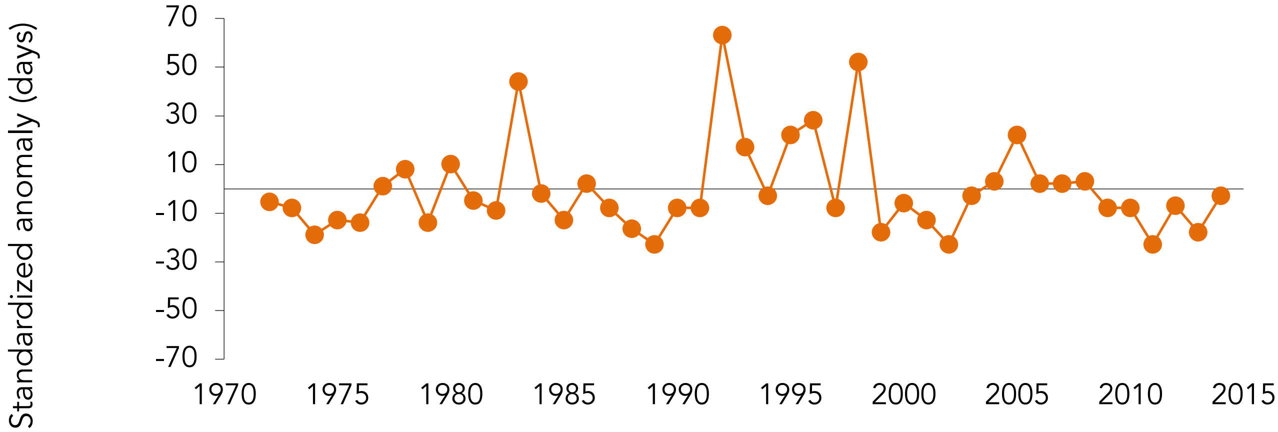

Figure 27. Cassin's auklet annual median egg lay dates on SEFI, 1972-2014.

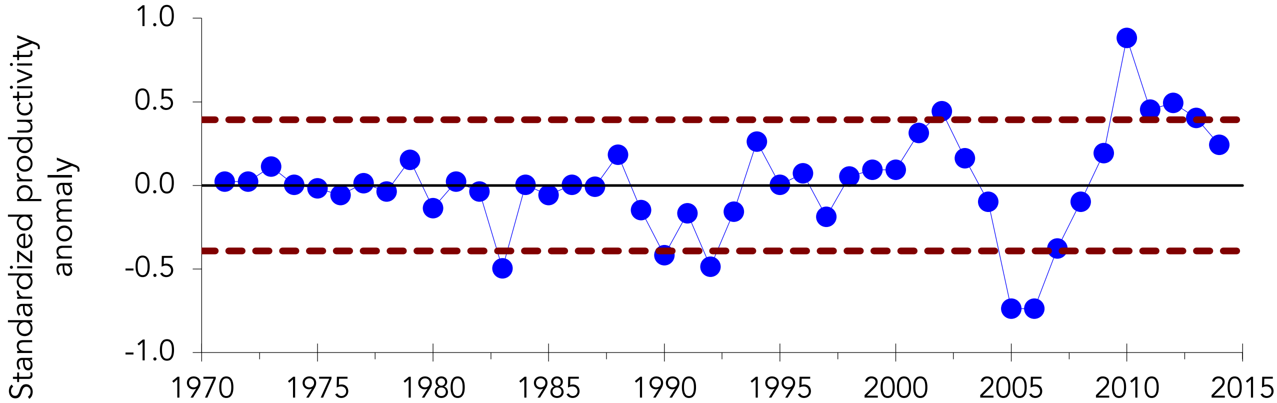

Figure 28. Cassin's auklet breeding success anomalies on SEFI, 1971-2014. Solid black line represents 44-year mean, and dotted red lines represent ±80% confidence intervals.

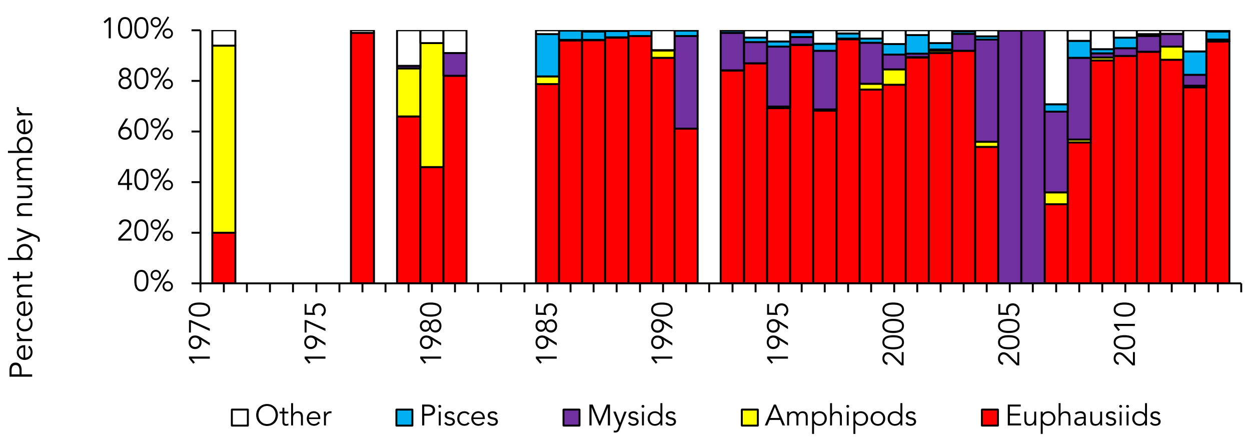

Figure 29. Cassin's auklet diet composition on SEFI, 1971-2014.

Common murres

Brief species account

The common murre is a frequently-observed seabird in the Gulf of the Farallones and breeds on the Farallon Islands. They are an omnivorous seabird feeding mainly on fish, but they also consume zooplankton.

Abundance

In 2014, common murres were observed in slightly higher abundances compared to 2013, with the highest number counted in July (Figure 30). Since 2004, the highest number of murres were seen in July 2010 (2405 murres) and April 2005 (2264 murres). This species was abundant in 2004 and early 2005, then declined in abundance in 2006. Counts of murres gradually increased over the next few years, followed by a slight decline after 2010. In general, this species was present in higher number in spring and summer (i.e., May-Jul, the breeding months) than in the fall months.

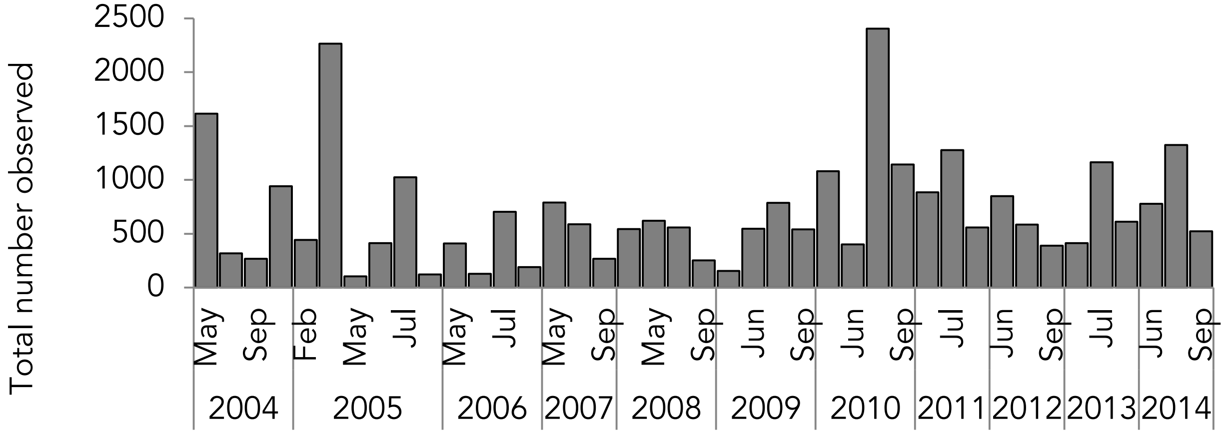

Figure 30. Abundances of common murres observed during each cruise, 2004-14.

Distribution

In 2014, common murres were observed over much of the shelf of the study area (Figure 31). In most years, murres have been observed in shelf waters near SEFI and between SEFI and Cordell Bank (e.g., 2004-06 and 2008, not shown; 2010-13, Figure 31). In some years, this species was more dispersed, with more observations in the northern parts of the study area (e.g., 2005 and 2009, not shown) or further nearshore to the southeast area of SEFI (e.g., 2007-08, not shown). Note that distributions shown here represent adult murre distributions; common murre chicks do not start appearing in the waters of the Sanctuaries until July and after.

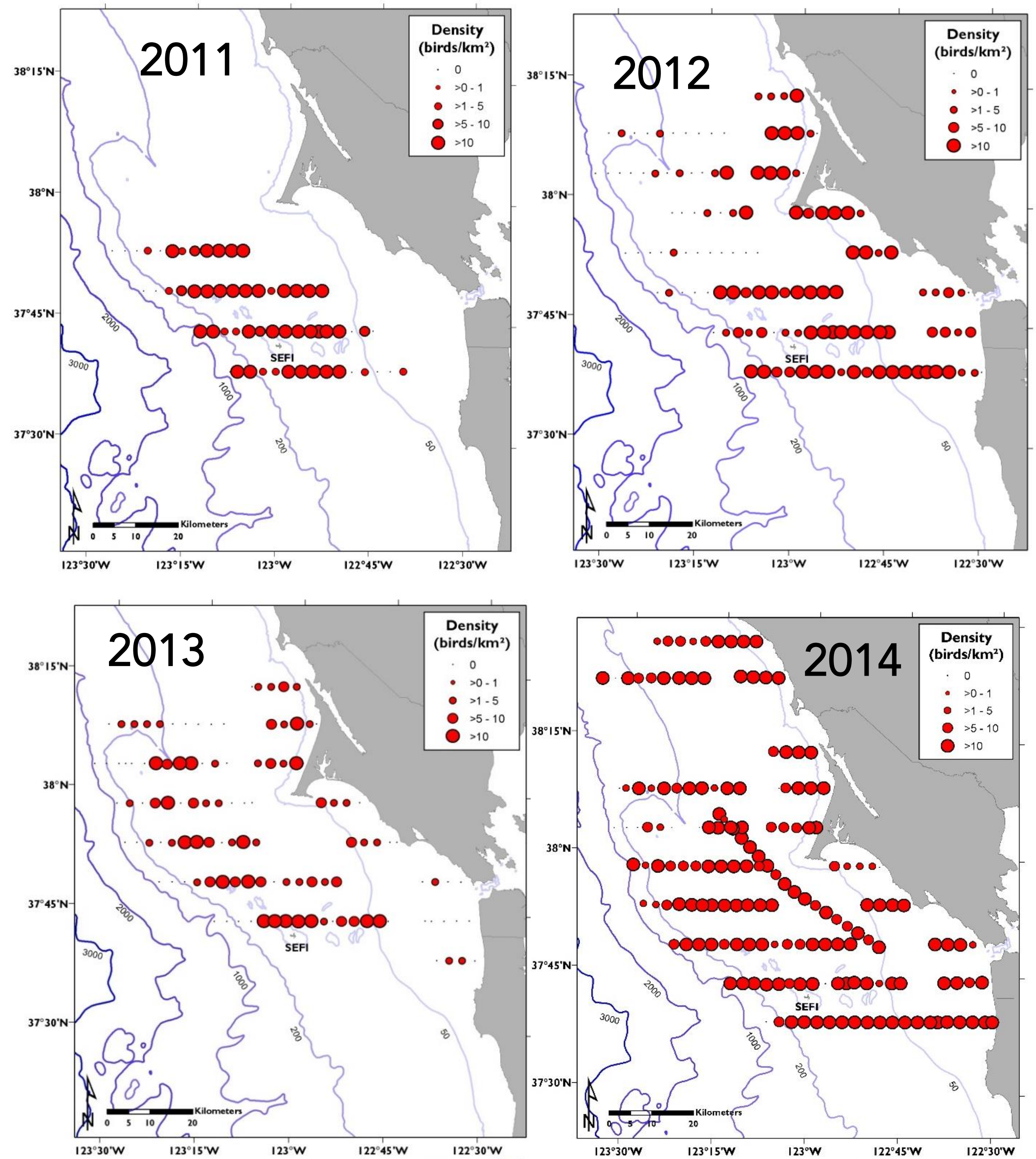

Figure 31. Common murre distributions during May or June, 2010-14.
NOTE: July 2014 is shown here, as the June survey only covered a small area.

Common murres

Timing of breeding

In 2014, common murres on SEFI had an average median egg laying date (Figure 32). Similar to the Cassin's auklet, we observed that common murres have later lay dates in poor ocean condition years (e.g., 1983, 1992, 1998). Since 2004, the annual median lay date has hovered close to the long-term mean, with some years showing earlier lay dates (e.g., 2004, 2007, 2008, 2013) and some years showing later dates (e.g., 2005, 2006, 2009-11). There has been a slight trend in earlier lay dates through time, although this is not significant.

Breeding success

Common murre breeding success in 2014 was equivalent to the 43-year mean (Figure 33). Similar to the Cassin's auklet, anomalously low productivity years (e.g., 1983, 1992, 1998) that punctuate the time series correspond to El Niño years, as well as years with late median lay dates (Figure 32). However, recent years of extremely low breeding success (i.e., 2006 and 2009) had relatively late median lay dates but were not El Niño years. Earlier lay dates (e.g., 1988; Figure 32) were linked to better productivity in some years, but this was not consistent; annual median lay dates for 2006 and 2009 were earlier compared to 2005, yet breeding success was worse. Some of these discrepancies in lay dates and productivity can be explained by low feeding rates to chicks, as observed in 2009.

Diet

In 2014, juvenile rockfish was the most common prey item being fed to common murre chicks (Figure 34). Prey items being brought to common murre chicks have varied over time, with rockfish being the main diet items in the 1970s and 1980s, then anchovy and sardine becoming the dominant prey in the 1990s. This changed again in the early 2000s when rockfish became the dominant prey, then back to anchovy/sardine in the 2004-08 period. Since 2009, rockfish has been more important in the diet. Historically, El Niño years corresponded to years with a low percentage of rockfish in the diet; these were also years of late timing of breeding (Figure 32) and low breeding success (Figure 33). However, 2005 and 2006 were not El Niño years, yet these years of poor ocean conditions yielded late breeding, low breeding success, and few rockfish in the murre diet. The 2009 results have been exceptional, as murres were eating a lot of rockfish, yet breeding success was one of the lowest years on record; as mentioned previously, low chick feeding rates can help explain the low productivity in this year.

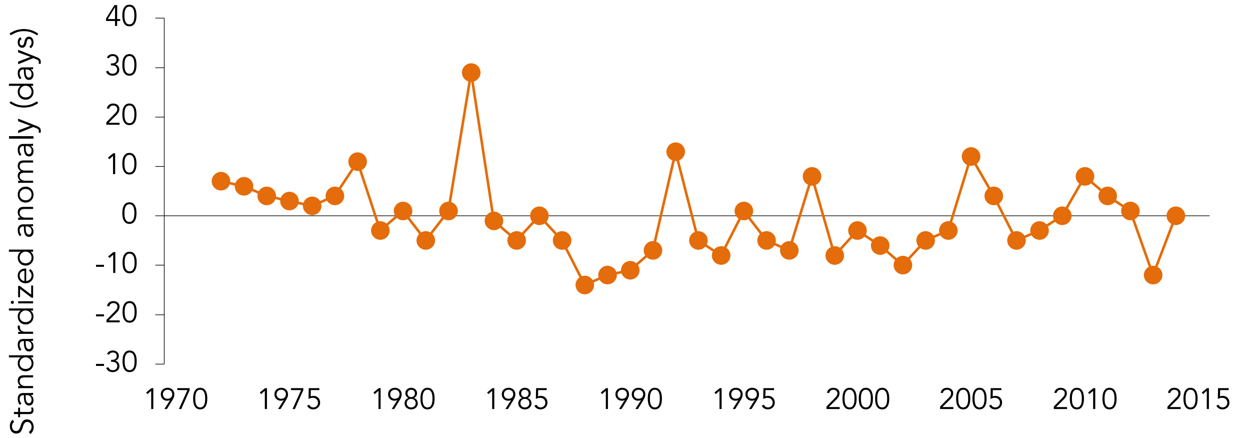

Figure 32. Common murre annual median egg lay dates on SEFI, 1972-2014.

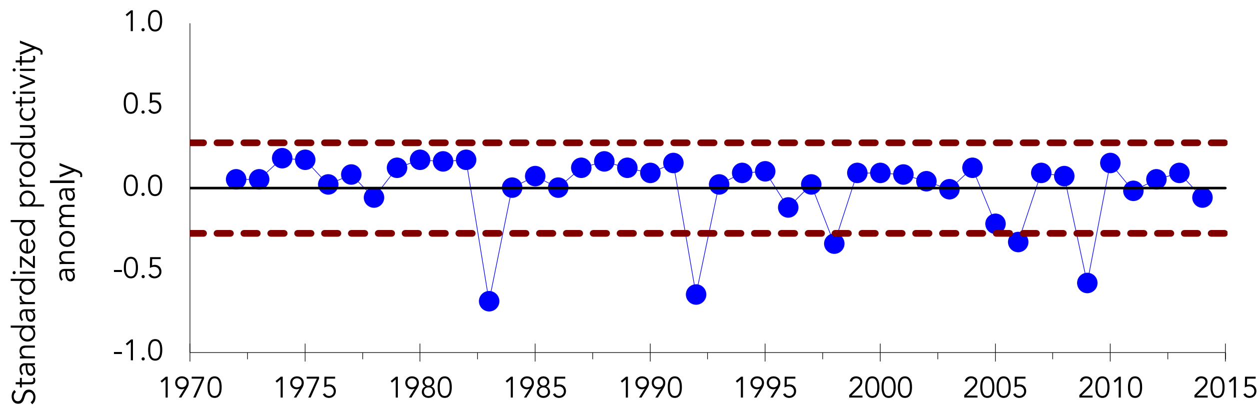

Figure 33. Common murre breeding success anomalies on SEFI, 1972-2014. Solid black line represents 43-year mean, and dotted red lines represent ±80% confidence intervals.

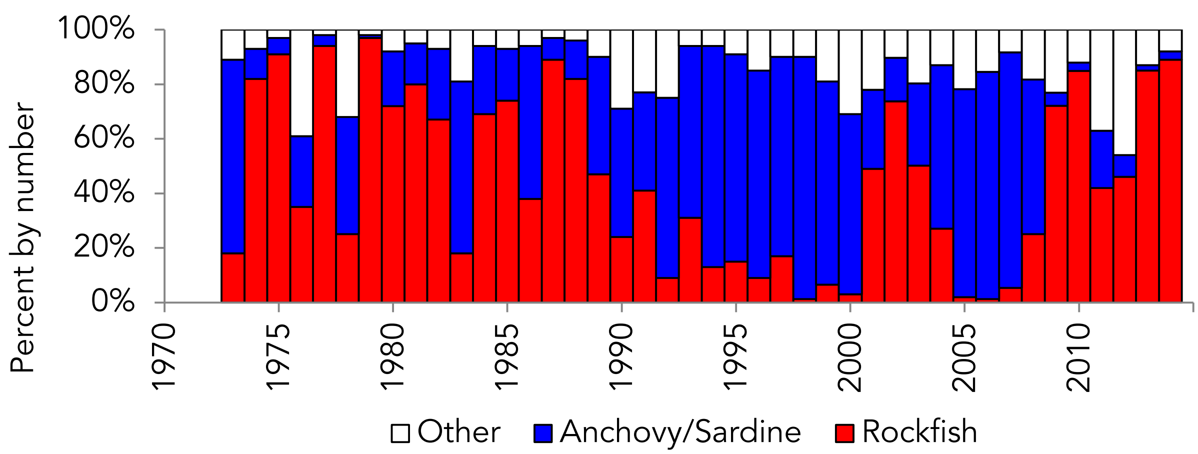

Figure 34. Common murre chick diet composition on SEFI, 1973-2014.

Brandt's cormorant

Brief species account

Brandt's cormorants are piscivorous birds found throughout the coastal areas of California. They are one of the seabirds monitored on SEFI.

Abundance

Since 2008, Brandt's cormorants were observed in very low numbers, and this trend has continued in 2014 (Figure 35). Numbers of Brandt's cormorants have declined through the time series, with the peak in October 2004 (273 cormorants); since this cruise, numbers have been less than half of this high count. The October 2004 peak was later in the year compared to the high counts of other years, which generally occurred during the summer months (i.e., the breeding season). The low abundances observed in 2008-12 correspond to poor productivity for this species in these years (Figure 38).

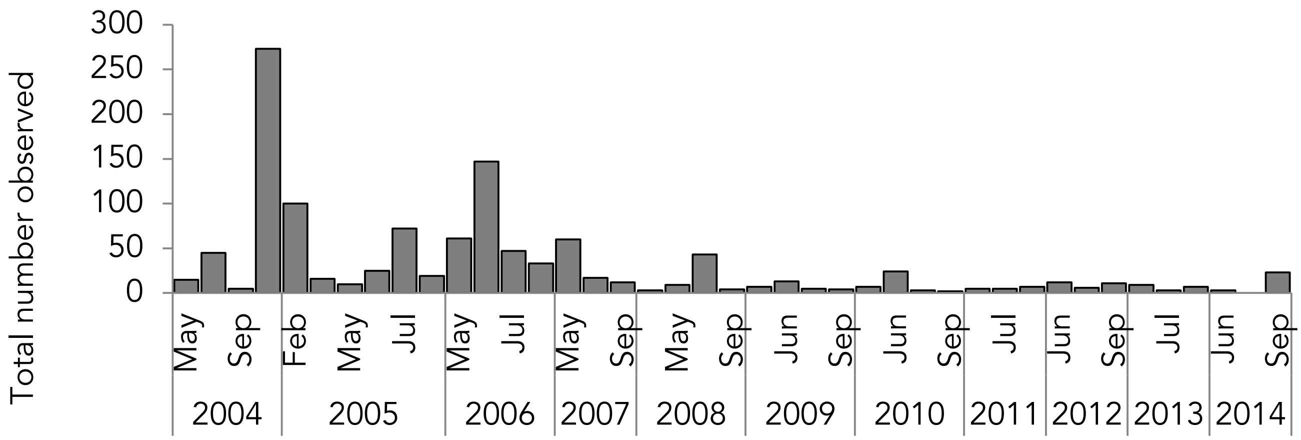

Figure 35. Abundances of Brandt's cormorants observed during each cruise, 2004-14.

Distribution

In 2014, Brandt's cormorants were observed in nearshore waters near San Francisco Bay and the Point Reyes peninsula, which could be explained by the later season (July) distribution compared to earlier distributions shown for other years (Figure 36). Brandt's cormorants have been observed near SEFI in most other years (Figure 36). In some years, this species was more scattered and observed in smaller groups or as individual birds in waters closer to shore (e.g., 2007 and 2010 (not shown), and 2012).

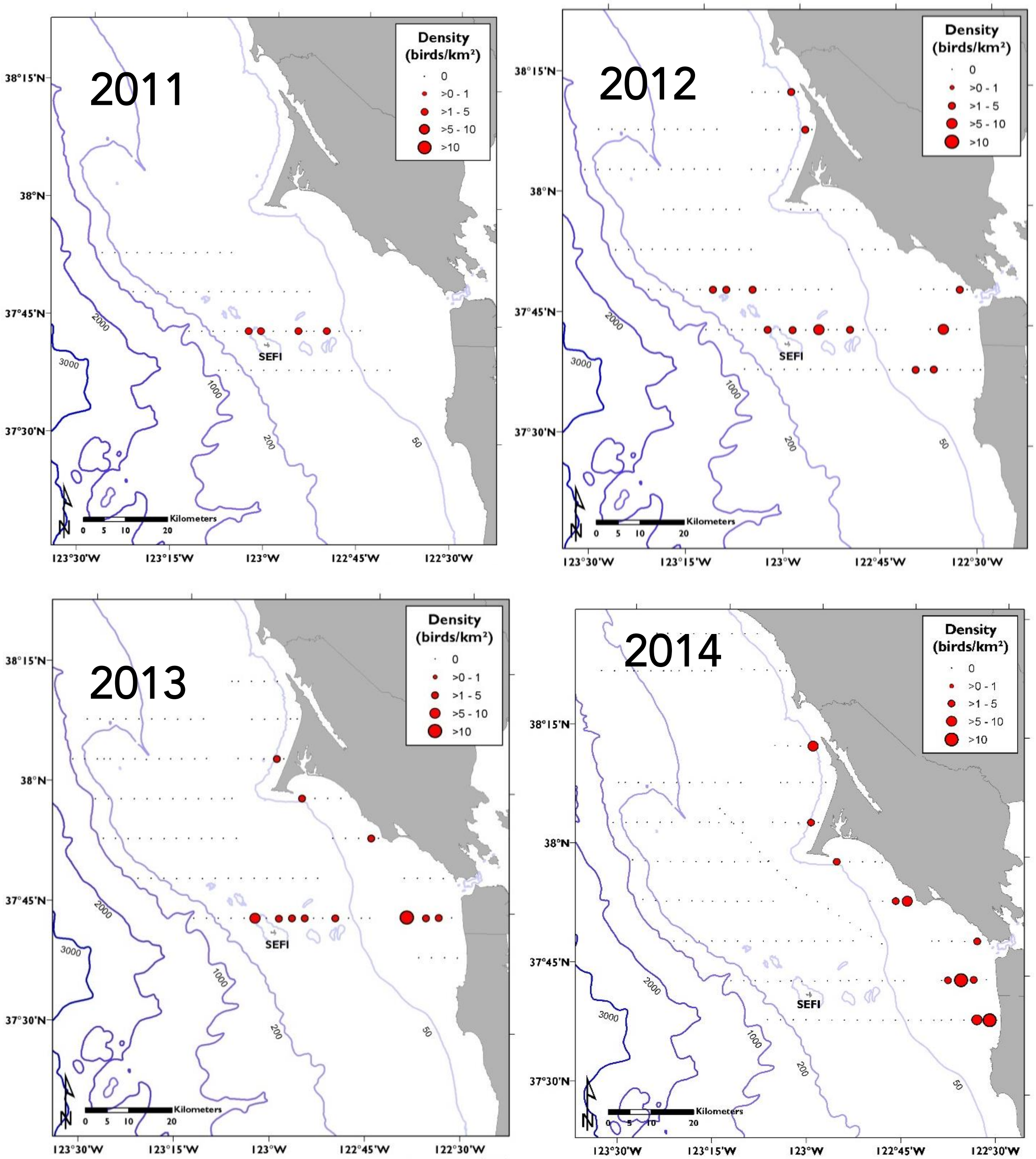

Figure 36. Brandt's cormorant distributions during May or June, 2010-14.
NOTE: July 2014 is shown here, as the June survey only covered a small area.

Brandt's cormorants

Timing of breeding

The median egg lay date for Brandt's cormorants on SEFI in 2014 was slightly later than the 43-year average (Figure 37). Timing of breeding in Brandt's cormorants isn't as clearly linked to ocean conditions as in Cassin's auklets or common murres; El Niño years (e.g., 1983, 1992, and 1998) do not show anomalously late lay dates. There has been a slight trend in later lay dates through time, although this is not significant. Since 2004, this species began breeding early for three years (2004, 2006-07), and then bred late in 2005 and extremely late in 2008-12. The return to average median egg laying dates in the past two years has corresponded to improved breeding success (see below).

Breeding success

Breeding success of Brandt's cormorants on SEFI in 2014 was one of the highest annual productivity values of this species in the 44-year time series (Figure 38). Most of the annual productivity estimates for Brandt's cormorants fall within the 80% confidence intervals around the long-term mean, similar to auklets and murres; however, unlike auklets and murres, Brandt's cormorants have experienced several years of extremely low productivity, usually corresponding to El Niño years (e.g., 1983, 1992). In looking at breeding success data since 2004, above average breeding success was observed in the first four years (2004-07), then extremely low productivity in 2007-12, and now it is very high in 2013-14.

Diet

Brandt's cormorants on SEFI in 2014 consumed almost exclusively rockfish (Figure 39). The diet of Brandt's cormorants on SEFI has consisted of forage fishes (i.e., northern anchovy, Pacific sardine), various benthic species (i.e., sculpins, gobies, rockfish, and flatfish), and cephalopods. Years with high percentages of anchovy and sardine in the diet (e.g., 2005-07) have usually corresponded to years of high productivity, with the exception of the two most recent years (Figure 38). Recent breeding success increases may be attributed to the increased abundance of more offshore-distributed rockfish species which were likely absent during the poor productivity years (Elliott *et al.* 2015).

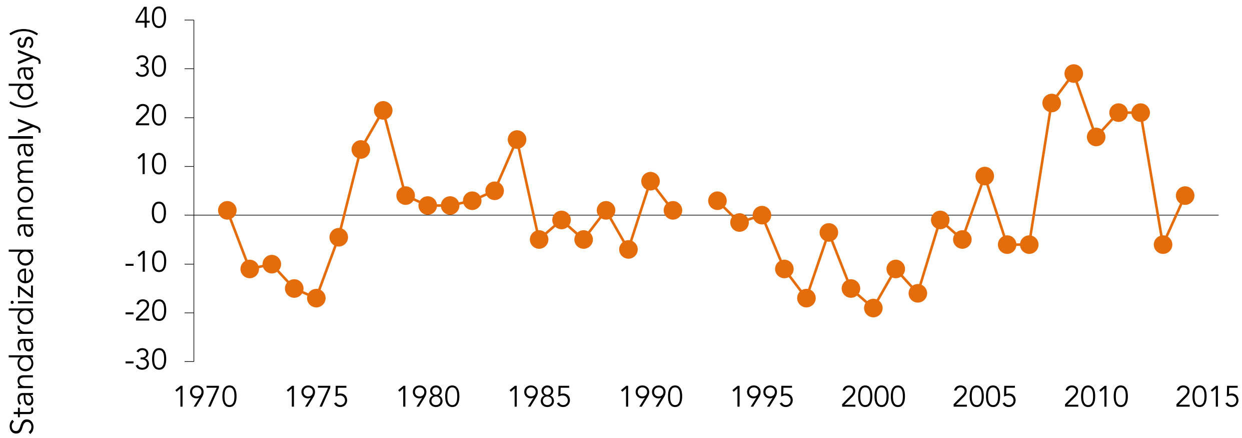

Figure 37. Brandt's cormorant annual median egg lay dates on SEFI, 1972-2014.

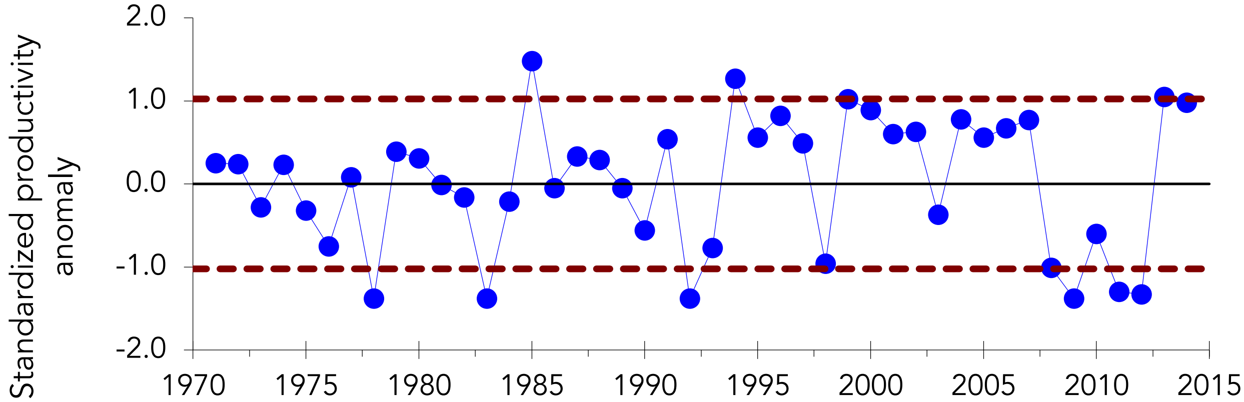

Figure 38. Brandt's cormorant breeding success anomalies on SEFI, 1971-2014. Solid black line represents 44-year mean, and dotted red lines represent ±80% confidence intervals.

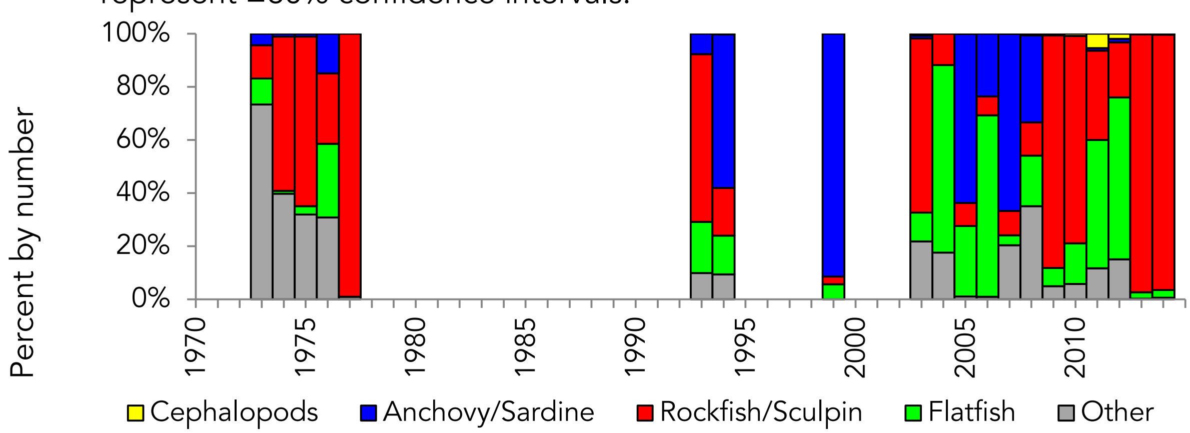

Figure 39. Brandt's cormorant diet composition on SEFI, 1994-2014. NOTE: Data for years 1973-77 from Ainley et al. 1981. Years 1999, 2004 and 2006 have low sample sizes.

Mammals

Overview

Marine mammals are top marine predators that feed on a variety of marine organisms. Some species breed within our study area, while other species migrate great distances to spend their non-breeding period in the central California Current. The abundances and distributions of marine mammals have been linked to bathymetric and hydrographic features which aggregate prey; many marine mammals live in or travel to the central California Current because of the highly-productive waters common to the region.

Relative composition

There were 19 species of marine mammals observed during at-sea cruises since 2004 (Table 2). When looking at the top fifteen most abundant marine mammal species, two of these are known SEFI inhabitants: California sea lion and Steller sea lion; both of these species are piscivorous. Risso's dolphin, Dall's porpoise, northern right whale dolphin, and Pacific white-sided dolphin all consume fish and squid, and are known to inhabit offshore waters. The two whale species (humpback and blue) are both krill-consuming whales that are common to coastal and shelf waters.

In the following sections, more detailed information will be provided on the two common migrant whales observed in the region: humpback whale and blue whale.

Table 2. Marine mammal species and average densities per cruise, 2004-14.

Common Name	Average density (number of animals observed per km of survey distance)
California sea lion	0.2255
Risso's dolphin	0.14569
humpback whale	0.12862
Pacific white-sided dolphin	0.11757
Dall's porpoise	0.09597
northern right whale dolphin	0.06939
unidentified whale	0.03472
unidentified otariid	0.02937
unidentified pinniped	0.01359
blue whale	0.01344
northern fur seal	0.00866
Steller sea lion	0.00825
harbor porpoise	0.00644
killer whale	0.00356
unidentified dolphin	0.00346
northern elephant seal	0.00291
harbor seal	0.00198
unidentified cetacean	0.00073
common minke whale	0.00065
unidentified porpoise	0.00054
unidentified sea lion	0.00047
gray whale	0.00041
unidentified seal	0.00019
Guadalupe fur seal	0.00019
sperm whale	0.00011
fin whale	0.000092
bottlenose dolphin	0.000089

Humpback Whale

Brief species account

Humpback whales are found in groups along the coast of western North America. The North Pacific population spends the summer months along the coast from Alaska to California, moving south (e.g., Hawai'i and Mexico) during the winter. This species feeds mainly on krill but will also consume fish.

Abundance

In 2014, humpback whale abundance was relatively low, with a peak in July of 72 whales (Figure 40); while peak numbers of this species are typically seen in the fall (Sep-Oct), the warm-water conditions that developed in our region in late summer may have led to an earlier departure for these whales. The highest number of humpback whales was sighted in July 2010 with 204 whales. Similar to 2014, peaks of humpback whales in 2010 and 2011 were in July. The poor ocean conditions in 2005-06 could explain why there were relatively fewer whales. The improved conditions in 2007-12 have led to more sightings of this species, although fewer whales were spotted in 2013-14.

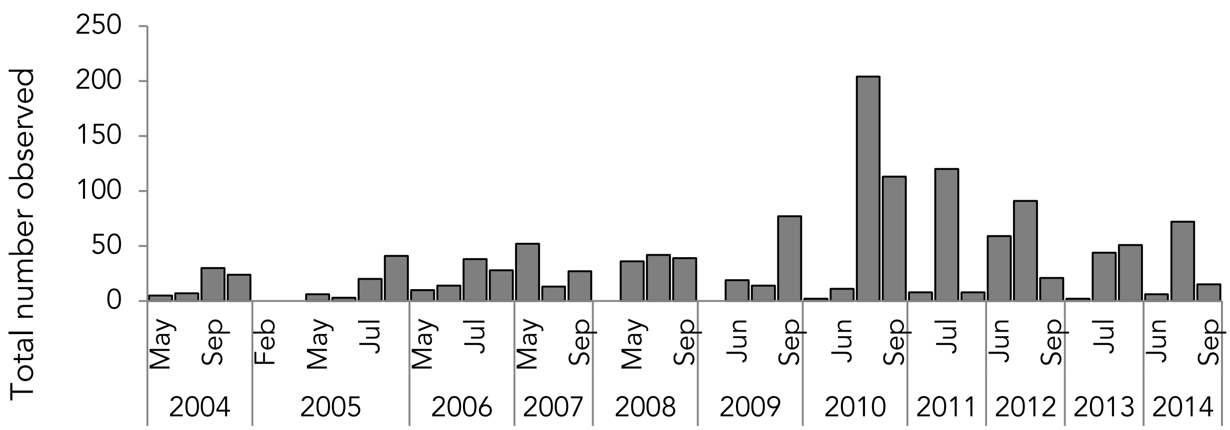

Figure 40. Humpback whale abundances, 2004-14.

Distribution

Humpback whales were sighted on the shelf and near the shelf break between SEFI and Cordell Bank in 2014 (Figure 41). In 2004-06 (not shown), this species congregated on the shelf and near SEFI in earlier months (May-Jul), and then expanded north to Cordell Bank and near the 200 m isobath in the fall (Sep-Oct). In 2007-09 (not shown), the distributions changed; humpback whales were consistently observed on the shelf throughout the study area, with some aggregations in inshore areas and near SEFI. In 2010 (not shown) and 2011-13, small numbers of this species were observed in early months (mainly near the shelf break), while greater numbers of whales were observed over Cordell Bank and on the shelf in later months (Figure 41); 2012 was an exception, with higher numbers observed in June in nearshore areas.

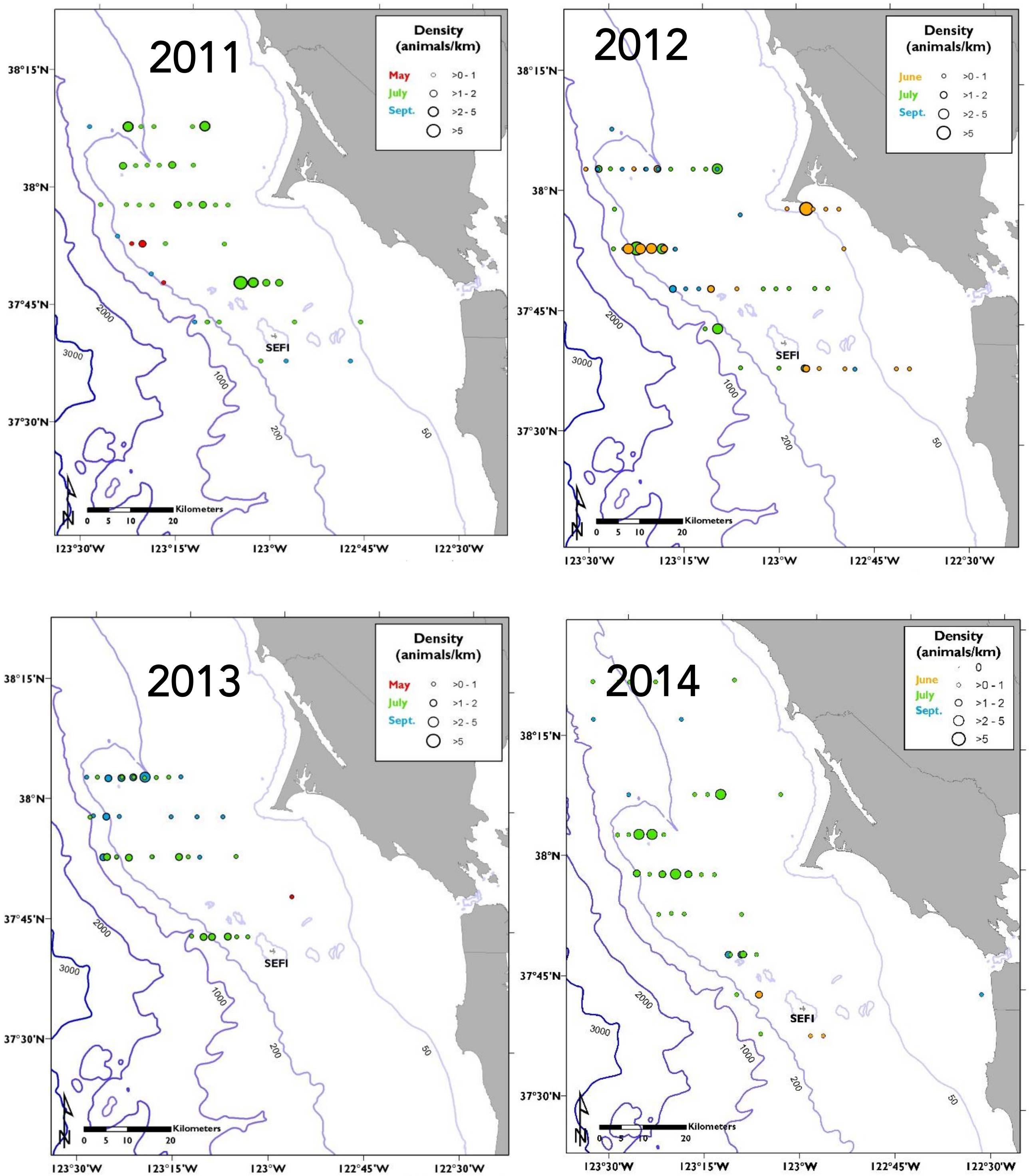

Figure 41. Humpback whale annual distributions, 2010-14.

Blue Whale

Brief species account

The blue whale is the largest animal on earth, and it feeds on krill (and occasionally other invertebrates). This species is found in all the oceans, with calving occurring in tropical and subtropical waters during winter months. This species is found off the coast of California during the summer.

Abundance

Possibly due to the warm water conditions that developed in late summer, only a few blue whale sightings were recorded in June and July of 2014, while none were recorded in September (Figure 42). The highest number of blue whales (20 whales) in our time series was recorded in July 2011. In most years, blue whales have peaked in abundance in late summer and early fall months (July-Oct). The delayed upwelling in 2005 may have led a delay in peak numbers, and the lack of blue whales in 2006 was evidence to the poor ocean conditions. Despite the improved conditions in 2007-09, observations of this species remained relatively low, but then increased in 2010-11; abundances have declined since 2011.

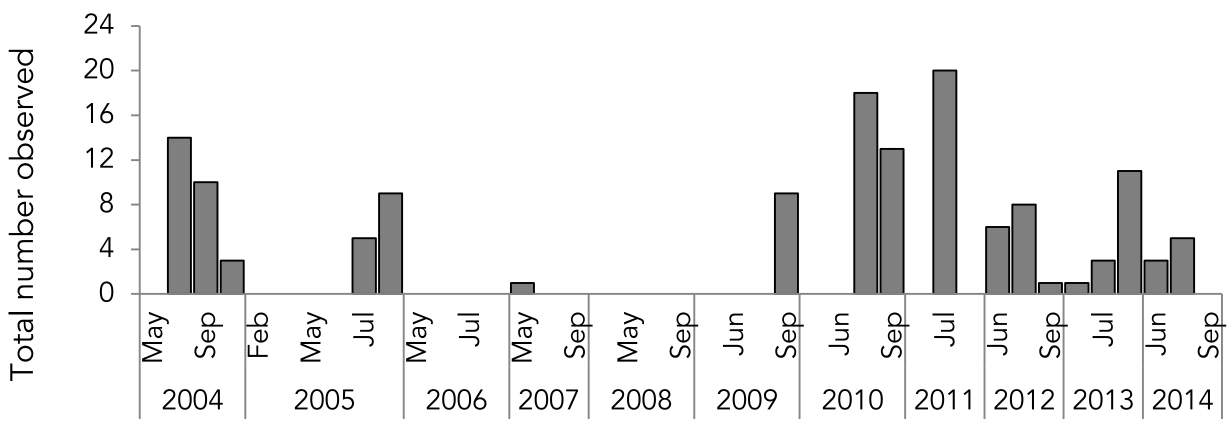

Figure 42. Blue whale abundances, 2004-14.

Distribution

The few blue whale observed in 2014 were just south of SEFI, over Cordell Bank, and to the north near the shelf break (Figure 43). These results are consistent with most other years. Blue whales have been found in the northern part of the study area (over Cordell Bank) in 2004-05 (not shown), and 2013; this species was observed closer to SEFI in 2007, 2009-10 (not shown), and 2011. Blue whale sightings were scattered on the shelf in 2012.

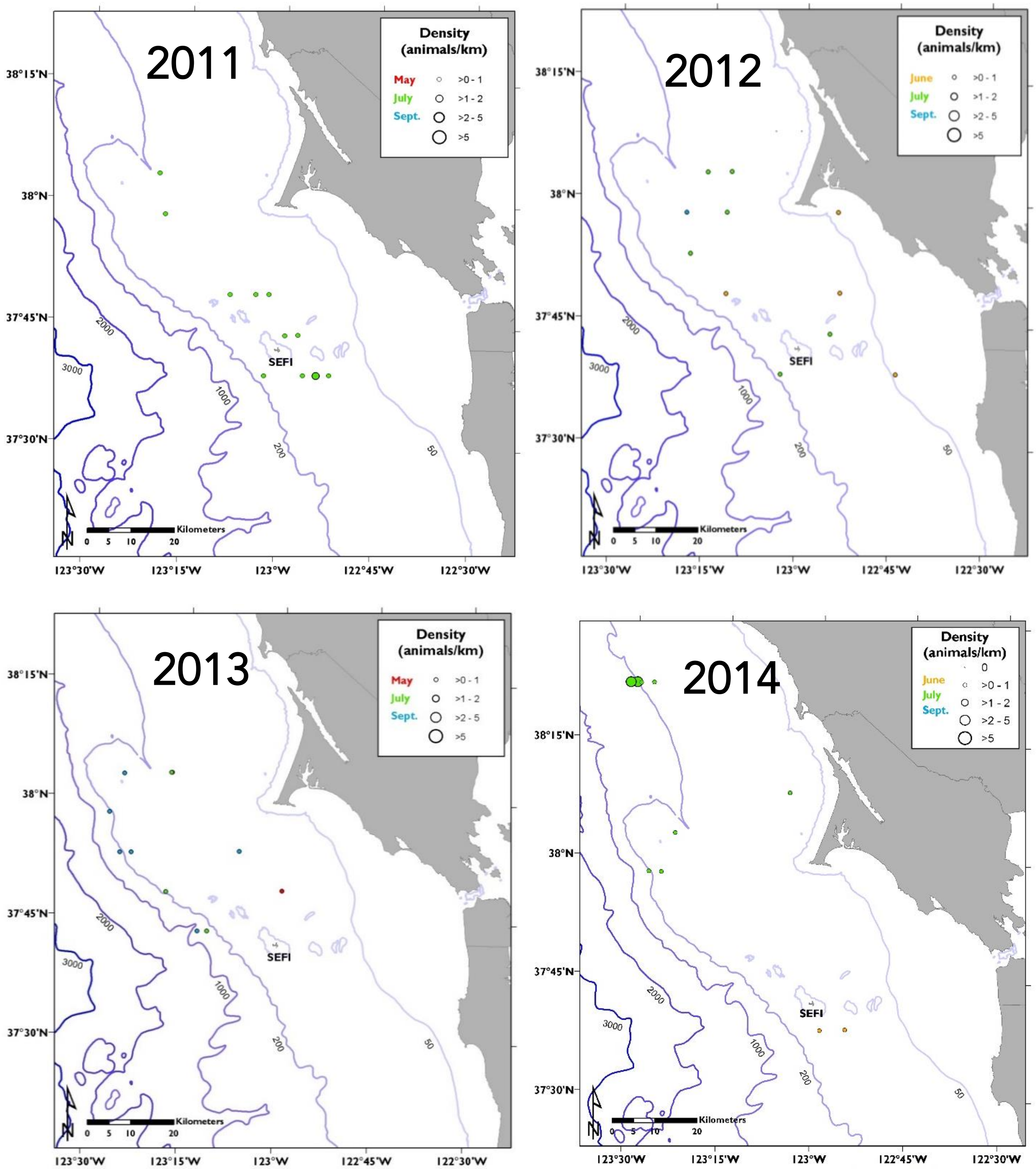

Figure 43. Blue whale annual distributions, 2010-14.

Literature Cited

Ainley, D. G., D. W. Anderson, and P. R. Kelly. 1981. Feeding ecology of marine cormorants in southwestern North America. *Condor* 83: 120-131.

Elliott, M.L., R.W. Bradley, D.P. Robinette, and J. Jahncke. 2015. Changes in forage fish community indicated by the diet of the Brandt's cormorant (*Phalacrocorax penicillatus*) in the central California Current. *Journal of Marine Systems*, in press.

Fontana, R.E., M.L. Elliott, J.L. Largier, and J. Jahncke. 2015. Temporal variation in zooplankton abundance and composition in a strong, persistent coastal upwelling region. *Progress in Oceanography*, in review.