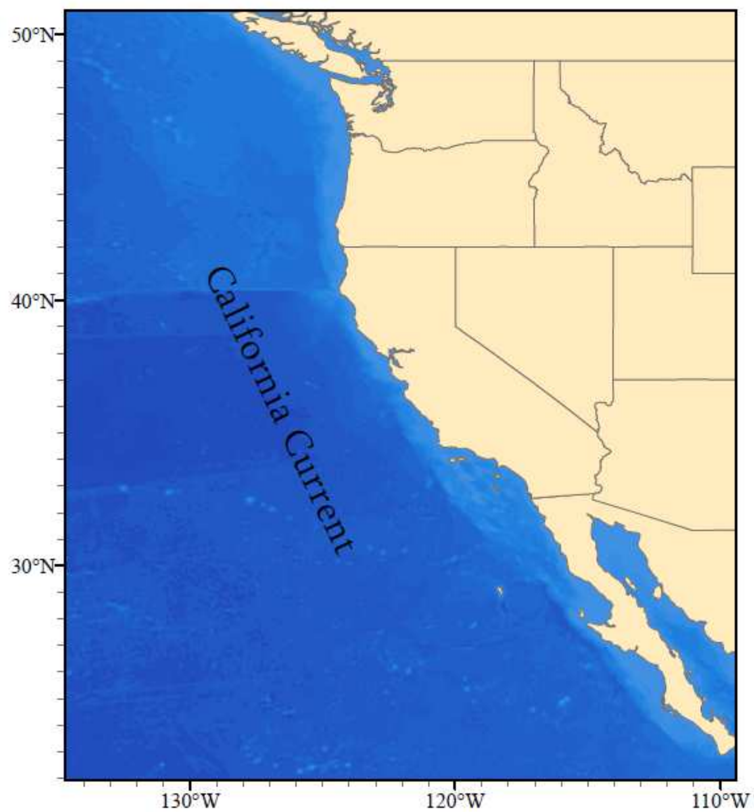
Climatic and Ecological Conditions in the California Current LME for April to June 2013

Summary of climate and ecosystem conditions for Quarter 2, 2013 (April to June) for public distribution, compiled by PaCOOS coordinator Rosa Runcie (email: Rosa.Runcie@noaa.gov).
Full content can be found after the Executive Summary. Previous summaries of climate and ecosystem conditions in the California Current can be found at http://pacoos.org/



CLIMATE CONDITIONS IN BRIEF

- **El Niño Southern Oscillation (ENSO):** ENSO-neutral conditions continue through June 2013.
- **Pacific Decadal Oscillation (PDO):** Since June 2010, the PDO has been in negative phase for all but May 2013, a value slightly above zero. This is a good indication of productive ocean conditions.
- **Upwelling Index (UI):** In the Pacific Northwest (45 °N), upwelling was not particularly strong in April-June. The average Cumulative Upwelling Index for the April-May was ninth weakest of the past 15 years. Upwelling continued to be weak through most of May (and included a two-week period in mid-June of southwesterly winds which was accompanied by a stranding of massive amounts of euphausiids on the beaches of Oregon and Northern California). Compared to other years, 2013 is similar to the years 2007-2009, years in which winter storms were infrequent, but also years in which upwelling was not particular strong. However, the indices computed for 36 °N and 39 °N indicated stronger than average upwelling at these latitudes during the second quarter.
- **Bottom Water Temperature and Salinity in Shelf Waters:** Off Newport, Oregon, deep water temperatures on the shelf in spring 2013 were the saltiest and the second coldest since first

records in 1997. Hydrographic conditions over the shelf off Trinidad, California throughout April resulted in the coldest, most saline water observed on the shelf during the Trinidad Head Line time series.

- **CalCOFI Observations:** Upwelling along the coast was strong and anomalously high in April between 32 and 42 °N. This process dominated the distribution of hydrographic and biological properties. A prominent tongue of cold water extended from north of Pt. Conception to south of the Channel Islands. The upwelling produced strong negative oxygen anomalies and strong positive nitrate anomalies. Fields of winds suggest that strong upwelling had begun at the beginning of April, thus it is not surprising that spring phytoplankton bloom had not yet set in, as concentrations of Chl a were low in most areas with high concentrations of nitrate.
- **Dissolved Oxygen Concentrations:** Oxygen concentrations measured at a depth of 50 m at mid-shelf station NH 05 (five miles off Newport, Oregon) during June (and early July) had the lowest concentrations of oxygen measured since data measurements began in 2005.

ECOSYSTEM CONDITIONS IN BRIEF

- **California Current Ecosystem Indicators:**
  1. **<u>Copepod Biomass Anomalies</u>:** Copepod species richness anomalies were moderately high in winter 2013 (January-March) but became negative in April-June. Species richness anomalies in spring turned negative in April, because of the early, April 7^{th}, spring transition.
  2. **<u>Mass stranding and mortality of euphasiids in Oregon and Northern California</u>:** A near-simultaneous mass stranding and mortality of *Thysanoessa spinifera* from at least Newport, Oregon to McKinleyville, California occurred on 15-18 June 2013. Observed strandings were preceded by a storm with southwesterly, downwelling-favorable winds, and were also coincident with unusually low dissolved oxygen including mild hypoxia. The currently hypothesized mechanism is that krill were transported shoreward by surface downwelling currents and deposited onshore by the surf; hypoxia may have contributed by driving krill shallower, making them more vulnerable to this onshore transport.
  3. **<u>Ecosystem indicators for the Central California Coast</u>:** The midwater trawl survey for juvenile rockfish and other pelagic nekton along the Central California coast in late spring (May-June) showed that trends in 2012 and 2013 were of higher productivity for the species and assemblages that tend to do better with cool, high productivity and high transport conditions, including juvenile rockfish, market squid and krill. Although northern anchovy catches in 2013 were below the long term mean, they were higher than they have been since 2007.
  4. **<u>Juvenile salmon catches</u>:** A record number of juvenile salmon were captured in June 2013 with a total of more than 2000 fish. This was due in part to the highest catches on record of Chum salmon (1000+); catches of juvenile spring Chinook and coho were high as well (but not the highest) although final numbers are not yet available.

     <u>West Coast salmonids</u>: In the second quarter of 2013, spring and summer run chinook salmon (*Oncorhynchus tshawytscha*) were ascending natal streams from California to Alaska. The spring chinook in Butte Creek, off the Sacramento River, are natural spawners and the largest naturally spawning spring chinook population in California. Butte Creek and the Feather River hatchery had excellent spring chinook returns in 2013. Because of 2013 drought conditions, naturally reproducing spring chinook may have difficulty as their spawning season approaches. Lower river flows and warmer water conditions adversely affect spawning and survival at all life stages.

CLIMATE CONDITIONS

El Niño Southern Oscillation (ENSO):

Source:**http://www.cdc.noaa.gov/people/klaus.wolter/MEI/mei.html,**
http://www.cpc.noaa.gov/products/analysis_monitoring/enso_advisory/

From January to June 2013, the Pacific Ocean exhibited ENSO-neutral conditions.

Multivariate ENSO Index (MEI) values from 2007 to June, 2013 are shown in Figure 2.

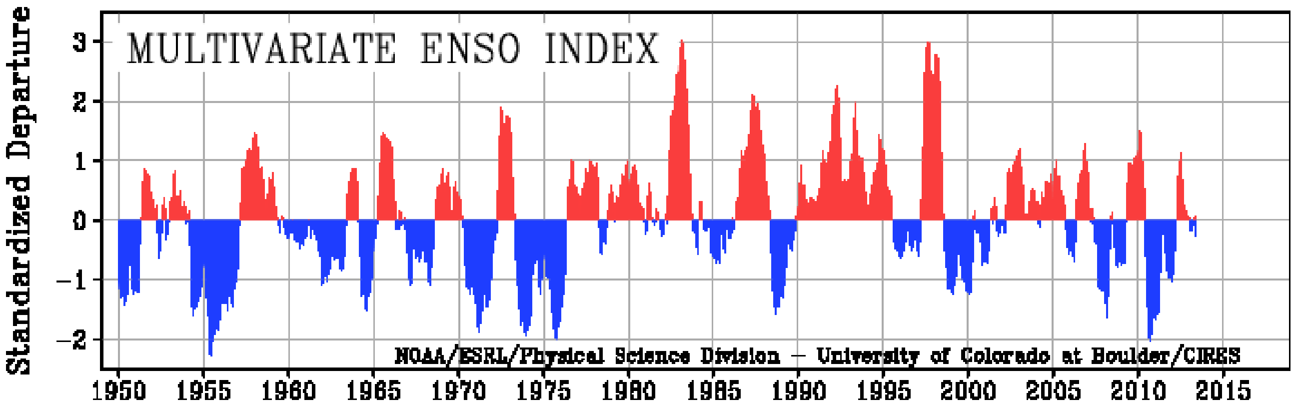


Figure 1. NOAA Physical Sciences Division monitors ENSO by basing the Multivariate ENSO Index (MEI) on the six main observed variables over the Pacific. These six variables are: sea-level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky.

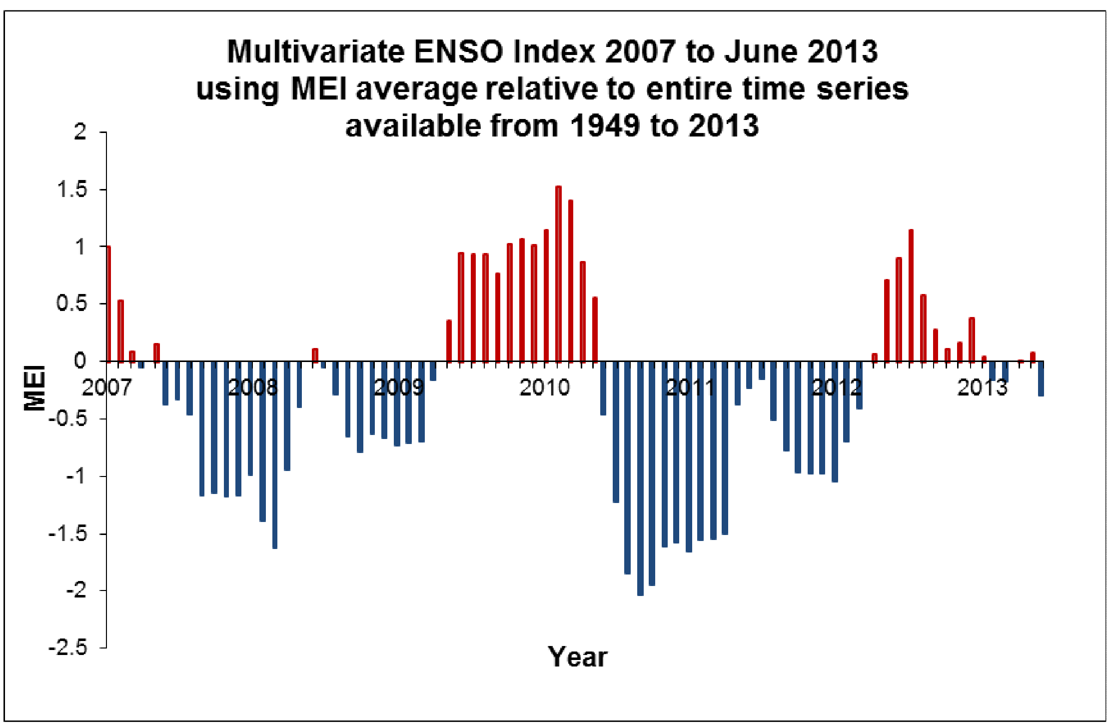


Figure 2. Multivariate ENSO Index from 2009 to June 2013. Mean used from bimonthly MEI values from the entire MEI Index time series, starting with December2006/January2007 thru May2013/June2013 (http://www.esrl.noaa.gov/psd/enso/mei/table.html).

Central & Eastern Equatorial Pacific Upper-Ocean (0-300 m) Heat Content Anomalies:

Source: The Coast Watch **http://coastwatch.pfel.noaa.gov/elnino.html**
http://www.cpc.noaa.gov/products/analysis_monitoring/enso_advisory/ensodisc.doc

Subsurface temperatures were above-average from April-November 2012, and below average during December 2012-early March 2013. Beginning in mid-May, subsurface temperature anaomalies increased with positive anomalies developing during June 2013.

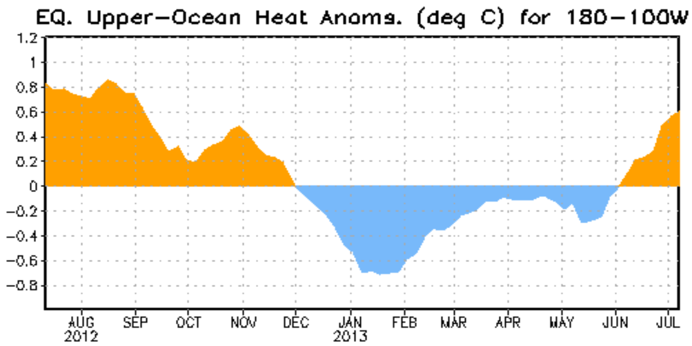


Figure 3. Area-averaged upper-ocean heat content anomalies (°C) in the equatorial Pacific (5°N-5°S, 180°-100°W). Heat content anomalies are computed as departures from the 1981-2010 base period pentad means.

PDO, ONI and SST at NOAA Buoy 46050, Newport OR:

Source: Bill Peterson (NOAA, NMFS)

Since June 2010, the PDO has been in negative phase for all but one month (May 2013, a value slightly above zero, Figure 4). This is a good indication of productive ocean conditions. The ONI has also been negative during most months since mid-2010 apart from a brief period of positive phase in mid-2012 (Figure 4) when El Niño conditions were developing at the equator, however the event never reached sufficient strength to be declared an "El Niño" and dissipated.

The first few months of the year showed slightly negative SST anomalies, approximately - 0.5°C from January to May but June showed a positive anomaly of 0.66°C (Figure 4) as a result of the lengthy period of southwesterly winds and downwelling during that month.

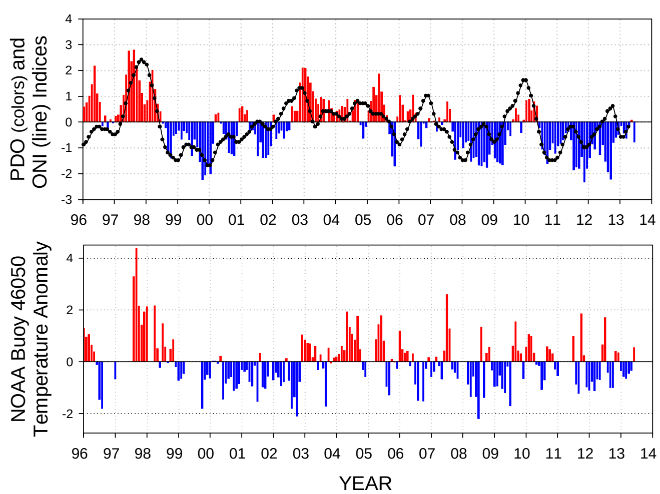


Figure 4. Time series of the PDO and ONI (upper panel) since 1996 and time series of SST measured at NOAA Buoy 46050 (located approximately 22 miles due west of Newport Oregon).

Upwelling Index:

Source: Jerrold Norton (NOAA, ERD, SWFSC (Jerrold.G.Norton@noaa.gov))

Pacific Fisheries Environmental Laboratory* http://www.pfeg.noaa.gov/products/PFEL/, *monthly surface pressure maps:* http://www.pfeg.noaa.gov/products/PFEL/modeled/pressure_maps/pressure_maps.html, *monthly IU values:

http://www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/NA/data_download.html, http://www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/upwelling.html

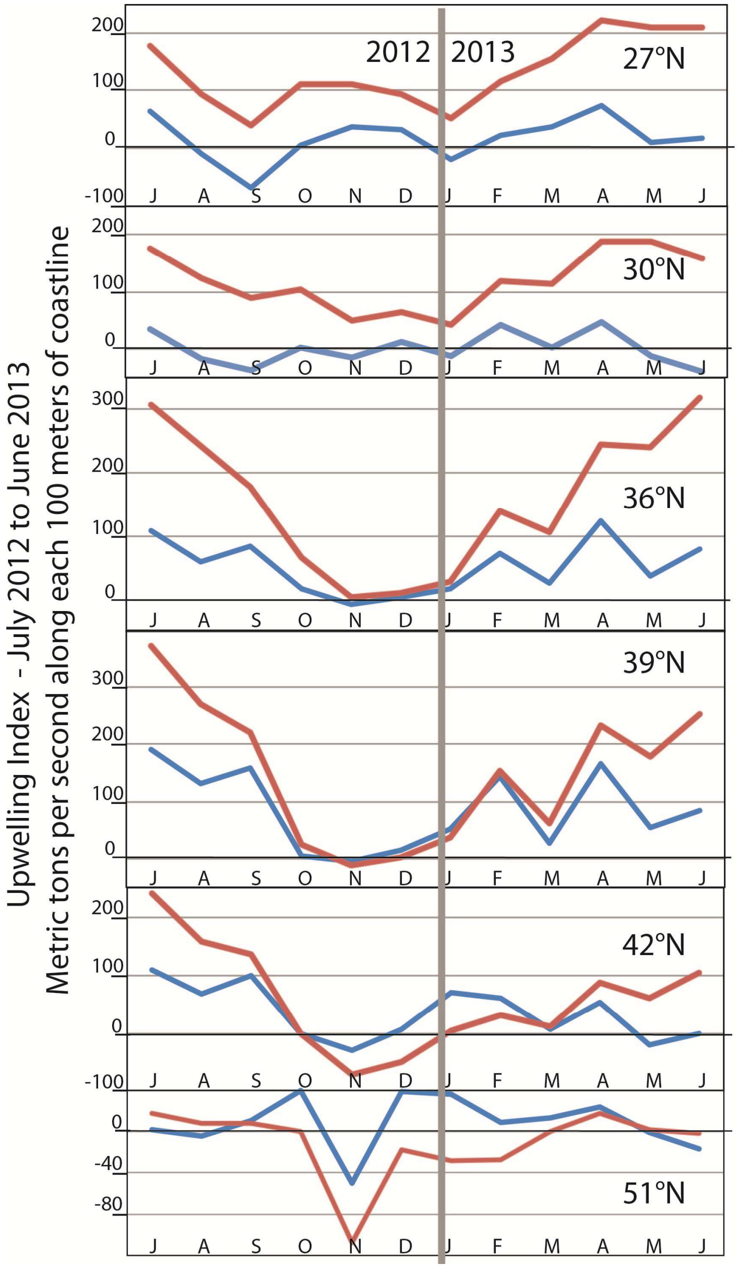


Figure 5. Time series graphs of the ERD / SWFSC upwelling index (UI) computed from monthly mean pressure fields. UI values are given for each month from July 2012 through June 2013. The computation points from the top are: 27°N and 30°N, Baja California, Mexico; 36°N, Central California; 39°N, Northern California; 42°N, Northern California Border; and 51°N, Canada. The red lines give the monthly UI and the blue lines give the UI anomaly to the same scale. All graphs, except the bottom one (51°N), are on the same scale. At 27°N, UI and UI anomaly have been positive in every month since February 2013 and the relatively large anomaly in April is seen through all the other graphs, including 51°N. The graph for 30°N shows all positive UI values, typical of these lower latitudes. At 30°N, the UI anomaly increases gradually after September 2012. The 36°N and 39°N locations are at the core of the California Current upwelling system. They have had positive UI and UI anomaly values since November 2012. In recent months the UI anomalies at 36°N and 39°N have been as high as 50% of the UI. The UI at 42°N reflects both northern and southern influences. UI anomalies at 42°N were relatively high in January, February and April. At the 51°N position, the monthly mean UI and UI anomaly values since February suggest lower atmospheric forcing, but these low UI values are due to alternating influences of high and low pressures systems and alternating winds that cause upwelling and downwelling conditions, respectively.

Coastal Upwelling at 45° N

Source: Bill Peterson (NOAA, NMFS)

The year 2013 has been characterized by a very mild and nearly storm-free winter as shown by the Cumulative (PFEL) Upwelling Index (Figure 6). In strong contrast with 2012 (Figure 6A), there were no large southwesterly storms thus almost no downwelling in January-March. The day of spring transition (based on the CUI) was on 7 April, which is the six days earlier than a 40-year climatology. However despite the "average date" of transition (which signifies the end of the winter downwelling season and beginning of the upwelling season), upwelling was not particularly strong in April-June. In fact, the average CUI for the April-May was ninth weakest of the past 15 years. Upwelling continued to be weak through most of May (and included a two-week period in mid-June of southwesterly winds which, as shown later in this report, was accompanied by a stranding of massive amounts of euphausiids on the beaches of Oregon and Northern California).

Compared to other years, 2013 is similar to the years 2007-2009 (Figure 6, right panel), years in which winter storms were infrequent, but also years in which upwelling was not particular strong.

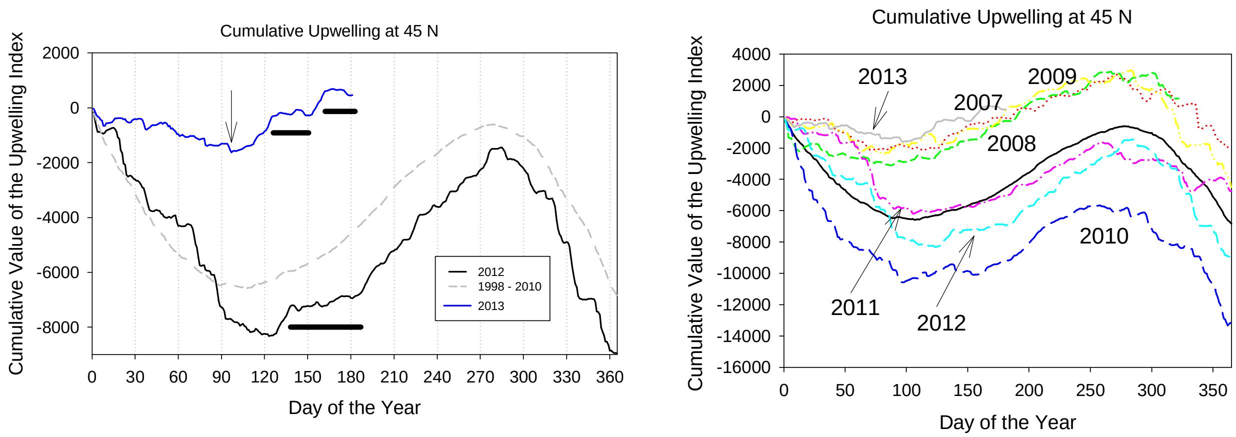


Figure 6. Left panel: Cumulative Upwelling Index for 2013 compared to 2012. Even though upwelling began early in 2012, strong persistent upwelling did not persist until late June. **Right panel:** A comparison of upwelling in 2013 to the past seven years. 2013 was similar to the years 2007-2009 all of which were characterized by a mild winter and few sinter storms.

Regional Oceanic Conditions from monthly mean AVHRR sea surface temperature:

Source: Jerrold Norton (NOAA, ERD, SWFSC (Jerrold.G.Norton@noaa.gov)),

El Niño Watch, Advisory **http://coastwatch.pfel.noaa.gov/cgi-bin/elnino.cgi**

During February and March 2013, monthly mean AVHRR sea surface temperatures (SST) and anomalies (SSTa) showed a band of negative SSTa extending from the coast of the US, southwest to beyond the Hawaiian Islands and northwest into the Gulf Alaska then westward across the Aleutian Island chain to the coast of Asia. Observations for the second quarter of 2013 involve the partial dissolution of this pattern and return to more average SST values off the coast of North America. The eastern north Pacific warmed during the second quarter. Warming was more pronounced north of 40 °N. Although SST has returned to normal ranges within 500 kilometers of the coast, the band of negative SSTa extending to the southwest across the temperate and into the tropical eastern Pacific was weaker, but remained evident through the second quarter.

In April negative SSTa (-0.5 to -1.5) persisted at the coast between Point Conception (34.5 °N) and Cape Mendocino (40.4 °N) and several hundred kilometers offshore at these latitudes. In May water warmer than 18°C was observed in the Southern California Bight (SCB) as a result of warming and influx from the southwest. Positive SST anomalies were observed in the SCB and offshore west of 130 °W between 35 °N and 45 °N. By June, average SST conditions occurred along the coast north of Point Conception. A thermal front (14° - 19 °C) developed at the northwestern end of the SCB where the warmer northwestward flowing counter current met the cooler California Current water of northern origin. Between 35 °N and 43 °N surface water with SST less than 14 °C extended 100 - 300 km seaward and delineated a well-developed coastal upwelling system in June. The upwelling system had elevated surface Chlorophyll-a concentrations. Eastern north Pacific atmospheric forcing has been dominated by the subtropical high atmospheric pressure system. Upwelling was enhanced at 36 °N and 39 °N, but apparently the coastal ocean thermal structure is compensating. By the end of the second quarter, extensive areas of negative SSTa were not seen off the west coast of the U.S. Generally, areas of nefative SSTa weakened and shrank during the second quarter.

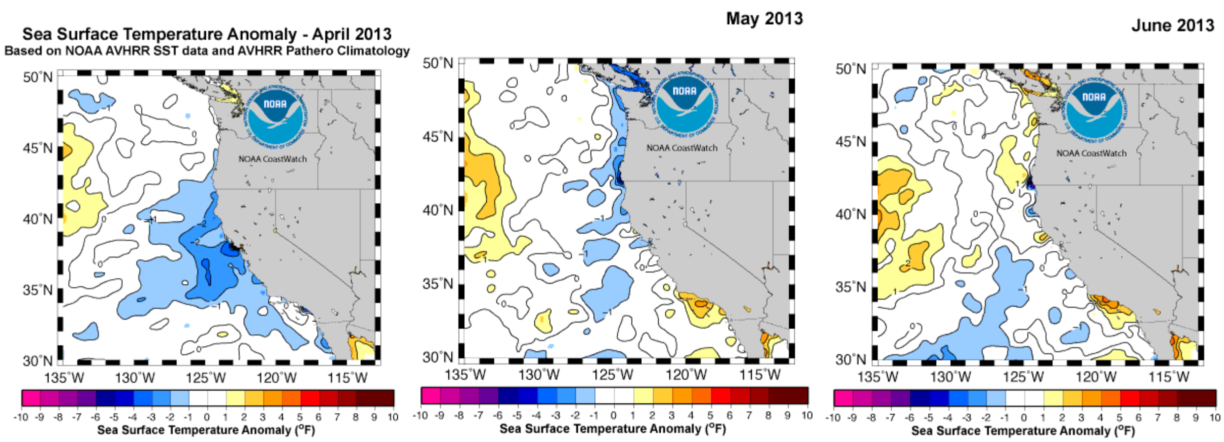


Figure 7. Regional oceanic conditions in the California Current Region.

Water Temperature and Salinity along the Newport Hydrographic Line, OR:

Source: Bill Peterson (NOAA, NMFS)

Bottom waters on the shelf at our baseline station NH 5, in spring of the year 2013, had the third highest salinity and second d coldest temperature since 1997 (Figure 8). The other "cold-and-salty" years were 2007 and 2008. Thus although upwelling was not particularly strong, anomalously cold and salty was present in deep shelf waters suggesting that had upwelling been a bit stronger, this water would have reached the sea surface.

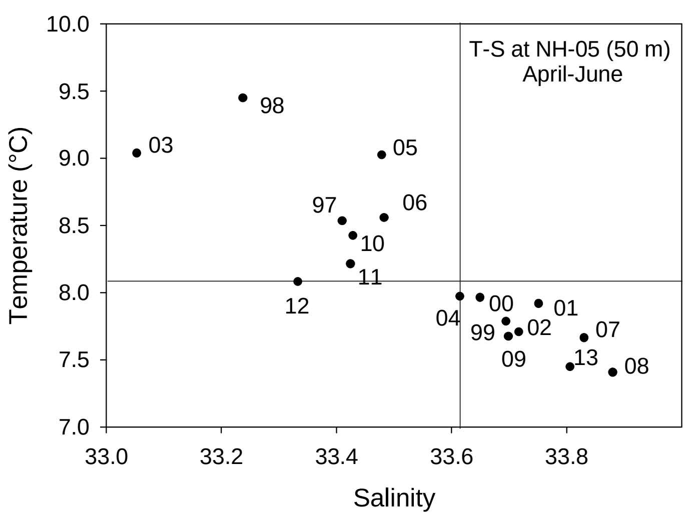


Figure 8. Temperature (T) and salinity (S) measured at a depth of 50 m at a baseline station off Newport OR (station NH 05) located 9 km west of Newport. Data reported here show that the year 2013 was nearly as cold as 2008 (the coldest year since measurements began in 1996) and the third saltiest, showing that although upwelling was not strong, cold salty nutrient rich water was present on the shelf and needed only some strong winds to bring it to the sea surface.

The lines within in the graph indicate the median values of T and S.

Observations along the Trinidad Head Line (41° 03.5' N), Second Quarter, 2013:

Source: Eric Bjorkstedt (NOAA/NMFS/SWFSC/HSU), Jeff Abell (HSU), Roxanne Robertson (HSU)

In contrast to the stormy conditions observed in early 2012, ocean conditions in early 2013 off northern California (Trinidad Head Line) reflect the effects of a relatively dry winter marked by unusually consistent, extended periods of upwelling favorable winds, and relatively infrequent storms of short duration. Intense upwelling throughout April resulted in the coldest, most saline water observed on the shelf during the THL time series (<7 C near the bottom at midshelf; Figures 9 and 10); conditions over the shelf remained cold and salty relative to spring 2012. Chl a concentrations and distributions over the shelf have been consistent with modest blooms encountered during winter cruises in early 2013. Since the onset of intense upwelling, average chl a concentrations in the upper water column have remained relatively low, in part because dense blooms have occurred in thin layers or have been concentrated inshore of station TH02 during relaxation events; broader examination of chl a concentrations across the shelf along the THL suggests comparable concentrations of chl a in spring 2013 than in 2012 (data not shown).

Dissolved oxygen concentrations in near-bottom shelf waters show expected responses to upwelling (as indexed by bottom water temperature), but reached extremely low levels in mid-June (Figures 10 and 11) see also discussion of krill mortality event below). During this event, DO concentrations (ml/l) dropped to < 0.86 ml/l in near bottom waters over the shelf; at station TH02, water with DO < 1.4 ml/l extended ~ 15 m from the bottom, and DO < 1.0 ml/l extended ~10 m from the bottom.

Observation cruises in were supported by NOAA/NMFS/SWFSC and the Ocean Protection Council.

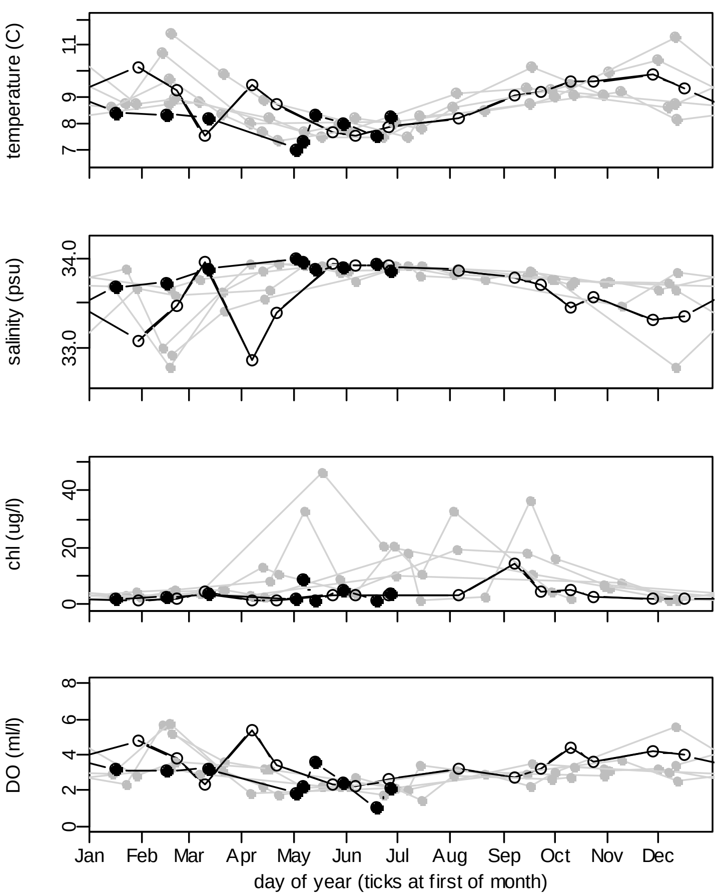


Figure 9. Ocean observations at station TH02 (approximately mid-shelf, 41° 03.5' N, 124° 16' W, 75m depth) along the Trinidad Head Line by calendar year. From top to bottom: temperature at 68 m, salinity at 68 m, mean 'chlorophyll' concentration (ug/l based on fluorometer) over the upper 30 m of the water column, and dissolved oxygen at 68 m. Dark lines indicate observations over 2012 (open black circles) and early 2013 (solid black circles); grey lines and symbols indicate observations over previous years (late 2006-2011).

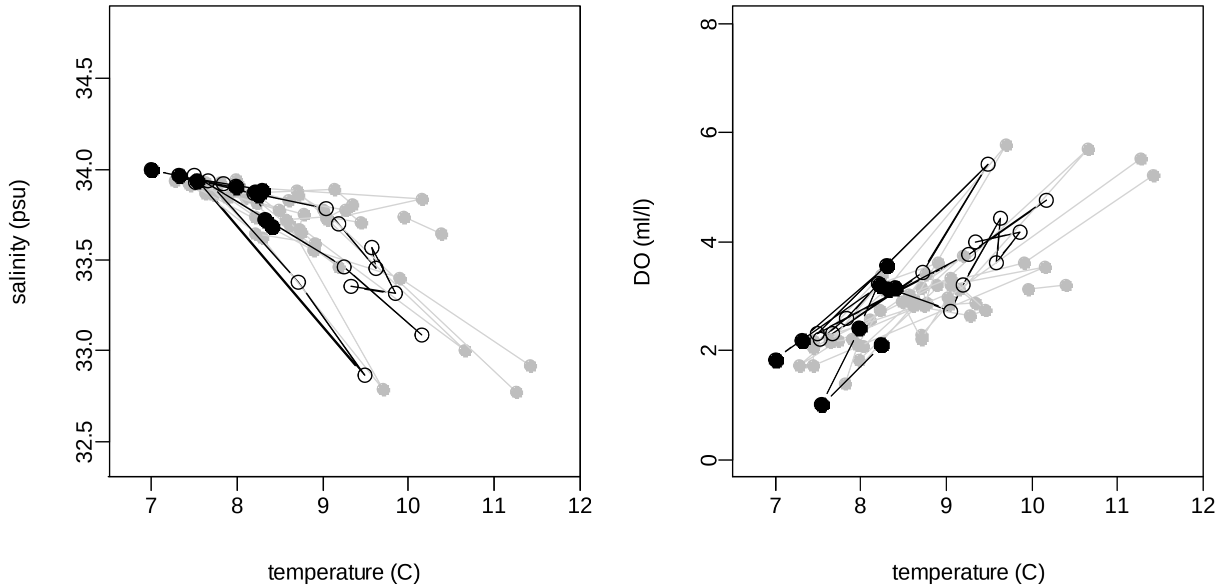


Figure 10. Temperature-salinity (left panel) and temperature-DO (right panel) relationships at 68m depth at TH02 (approximately mid-shelf, 41° 03.5’ N, 124° 16’ W, 75m depth) along the Trinidad Head Line. Dark lines indicate observations over 2012 (open black circles) and early 2013 (solid black circles); grey lines and symbols indicate observations over previous years (late 2006-2011). Extreme cold-saline water was observed on 2 May 2013 following intense upwelling throughout much of April. Extreme low DO levels encountered on 18 June 2013.

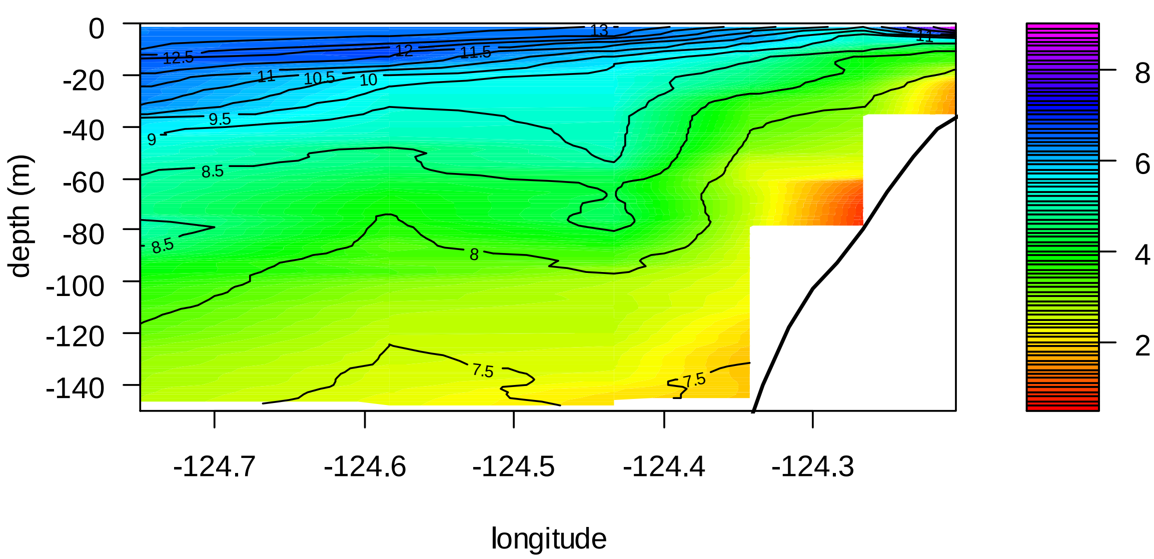


Figure 11. Dissolved oxygen (ml/l; color) and temperature (C; lines) along the Trinidad Head Line during cruise CS130618.

CalCOFI Spring 2013 Observations:

Source: Ralf Goericke (SIO)

In the spring of 2013 the CalCOFI area was surveyed from April 4th until the 30thth. Hydrographic properties suggest that the California Current entered the CalCOFI area in the offshore portion of Line 77 and continued in a SE direction until exiting the domain through the center of Line 93. Upwelling along the coast was strong and anomalously high in April between 32 and 42 °N. This process dominated the distribution of hydrographic and biological properties. A prominent tongue of cold water extended from north of Pt. Conception to south of the Channel Islands (Figure 12A). Anomalies of temperature suggest that the N-S orientation of this tongue was unusual; normal conditions correspond to a NE – SW orientation. The upwelling produced strong negative oxygen anomalies and strong positive nitrate anomalies (Figure 12B & C). Fields of winds suggest that strong upwelling had begun at the beginning of April, thus it is not surprising that spring phytoplankton bloom had not yet set in, as concentrations of Chl a (Figure 12D) were low in most areas with high concentrations of nitrate.

Signals of strong upwelling were also observed at two inshore station on Line 93 where temperature anomalies reached -3 °C and nitrate anomalies 9 μM. It is not clear if the signal was generated locally or was advected northwards from Baja California which usually experiences strong upwelling at that time of the year.

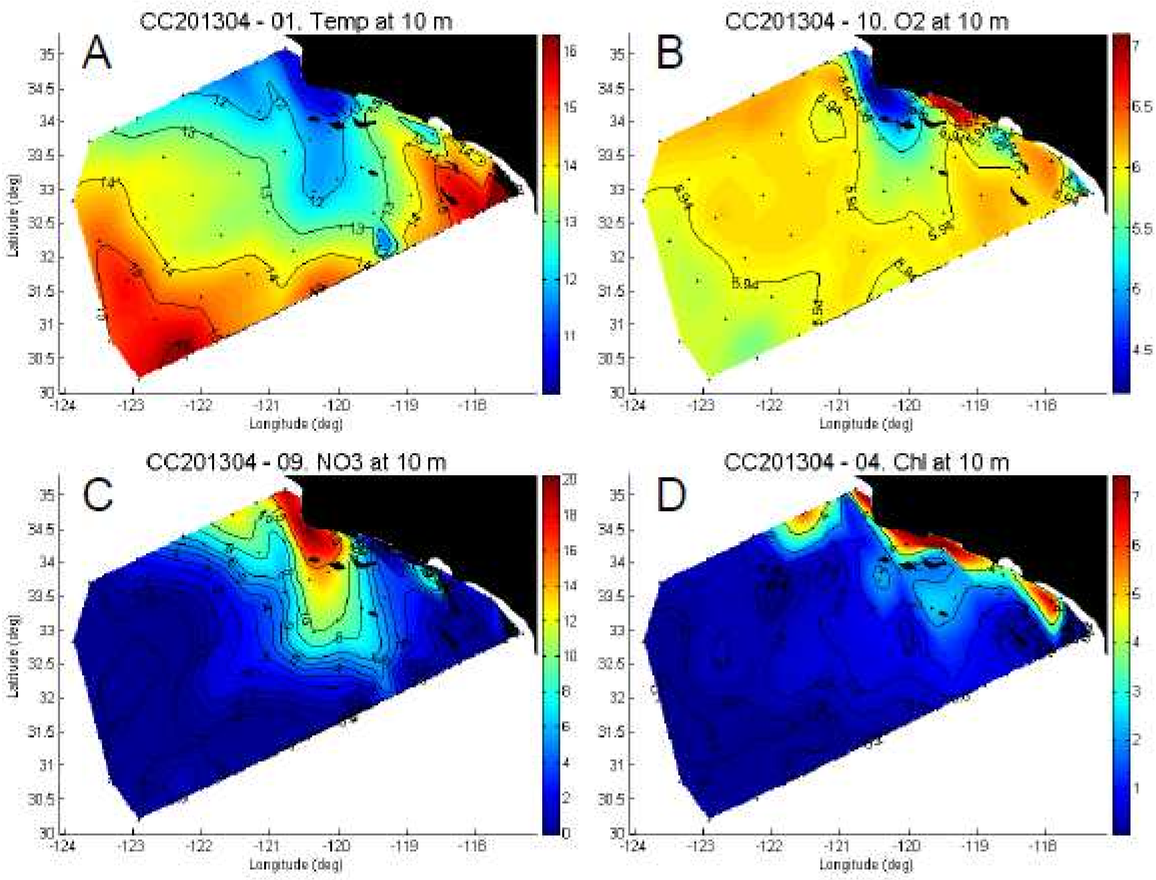


Figure 12. Hydrographic properties at a depth of 10 m off Southern California in March/April. 2012. Plotted are temperature (**A**, °C), oxygen (**B**, mL/L), concentrations of nitrate (**C**, μM) and Chlorophyll a (**D**, μg/L).

Dissolved Oxygen Concentration at station NH 05, Line, Newport, OR:
Source: Bill Peterson (NOAA, NMFS)
Oxygen concentrations measured at a depth of 50 m at mid-shelf station NH 05 (five miles off Newport, Oregon) during June (and early July) had the lowest concentrations of oxygen measured since data measurements began in 2005. Values in June on the 7 and 19 June cruises were 1.28 and 1.1 ml L^{-1}, and in early July, 0.94 ml L^{-1}. Values < 1 ml L^{-1} have in the past not been seen until August or September at station 5 along the Newport Line.

ECOSYSTEMS

California Current Ecosystem Indicators:
<u>Copepod Species Richness</u>:
Source: Bill Peterson (NOAA, NMFS)
Copepod species richness anomalies were moderately high in winter 2013 (Jan-March) but became negative in April-June (Figure 13). Positive anomalies in winter 2013 were somewhat unexpected since the PDO was in a persistently negative phase however the Oceanic Niño Index had been positive during autumn 2012 (which leads to high species richness) suggesting that a stronger than normal Davidson Current developed in autumn 2012 transporting warm water copepod species to the north and along the coast to Oregon. In other winters, species richness can be high because strong Southwesterly storms pushed offshore waters (with their subtropical species) onshore. However, the winter of 2012-13 was quiescent.
Species richness anomalies in spring turned negative in April, because of the early, April 7th, spring transition.

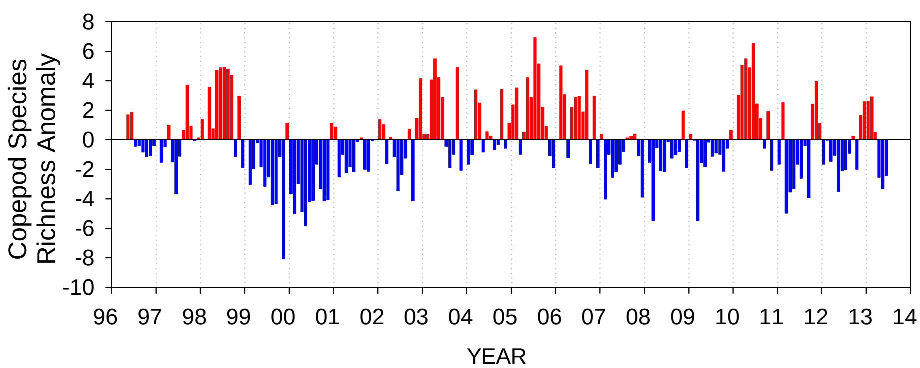


Figure 13. Tim series of copepod species richness from 1996-present. Values in winter 2012-13 were higher than average, due likely to the El Niño event that was developing at the equator. Even though the event weakened and did not become an El Niño event, a signal in the local copepods was seen nonetheless.

<u>Mass stranding and mortality of euphasiids and crustaceans in Oregon and Northern California on 15-18 June 2013</u>:

Source: Joe Tyburczy (California Sea Grant Extension, HSU), Bill Peterson (NOAA, NMFS), Jeff Abell (HSU), Eric Bjorkstedt (NOAA/NMFS/SWFSC/HSU)

Between 15 and 18 June 2013, mass strandings and mortalities of krill, *Thysanoessa spinifera*, were reported on beaches from at least Newport, OR to McKinleyville, CA (Table 1, Figures 14 and 15). A few days later on 21 June, a less dense stranding of krill occurred at Bodega Bay. Though mass stranding and mortality events in krill are occasionally observed on the West Coast, this event was unique in covering such a large stretch of coast (at least 400km from Newport, OR to McKinleyville). Additionally, mass mortalities of other crustaceans, especially smaller Dungeness crabs (*Cancer magister*) were noted around the same time as the krill strandings at Newport, OR and McKinleyville, CA; other krill stranding events have also been noted this year in Ketchikan, AK, Florence, OR, Bodega, CA and La Jolla, CA (Table 1).

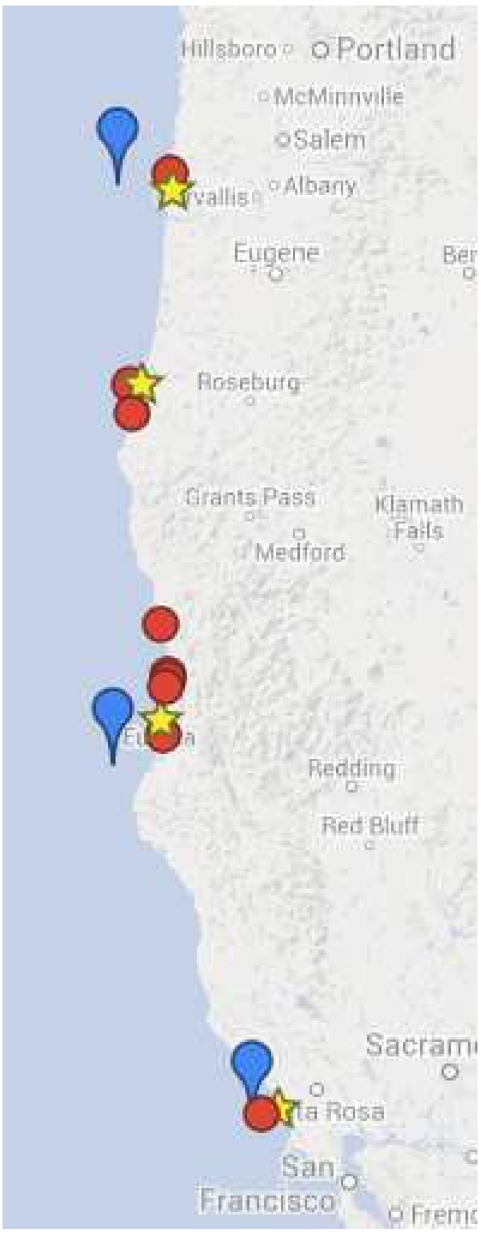


Figure 14. Locations of krill strandings (red circles) observed 15-21 June 2013, marine laboratories (yellow stars), and NOAA NDBC buoys (46050, 46022, and 46013; blue markers) in this region. Note that strandings were observed in the vicinity of all four marine stations between Portland and San Francisco (Hatfield Marine Science Center, Oregon Institute of Marine Biology, Telonicher Marine Laboratory, Bodega Marine Laboratory). [Map via Google Maps Engine, mapsengine.google.com]

Figure 15. Stranded krill. [Photo: Susannah Manning]

Table 1. Recent strandings and mass mortality events of krill and other crustaceans on the West Coast (listed from north to south).

Location of Krill Stranding	Date(s)	Reported by	Notes
Nye Beach, Newport, OR	15 June 2013	Maryann Bozza	low densities noted ~17:00, patch ~1m by ~1km long, saw no predation by birds
Nye Beach, Newport, OR	16 June 2013	Delores Williams	5 individuals examined were all female with spermatophores, photos and observers noted little predation by birds
Bastendorf Beach, Charleston, OR	week of 16 June	via Thomas Moriarty (The World, Coos Bay)	
Bullards Beach, Bandon, OR	week of 16 June	via Thomas Moriarty (The World, Coos Bay)	
Crescent Beach, Redwood National Park, CA	18 June 2013	Susannah Manning	
Gold Bluffs Beach, Redwood National Park, CA	18 June 2013	Amber Transou, Kyle Max	1m wide strand line of krill, longest stretch ~100m long, total of ~150-200m, photos and observers noted little predation by birds
Espa Lagoon to Mussel Point, Redwood National Park, CA	17 June 2013	Dave Anderson	similar, but less dense than Mussel Beach just to the south
Mussel Beach, Redwood National Park, CA	17 June 2013	Susannah Manning	*T. spinifera* including live individuals stranded for ~1.5 km along beach, little predation by birds, 5 individuals examined were all female with spermatophores but no developed eggs in ovaries
Clam Beach, McKinleyville, CA	18 June 2013	Amber Transou	
Horseshoe Cove, Bodega Bay, CA	21 June 2013	Jackie Sones	Dead krill on beach, sparser and detected because gulls were eating them

Other Krill Stranding Events	Date(s)	Reported by	Notes
Mountain Point Boat Ramp, Ketchikan, AK	7 April 2013	Joseph Piston	Tentatively identified as *Thysanoessa raschii* or *T. inermis* (Tracy Shaw)
Florence, OR	11 May 2013	Jim Ruzicka	
Horseshoe Cove, Bodega Bay, CA	30 March 2013	Jackie Sones	Dead krill on beach, sparser and detected because ravens were eating them, tentatively identified *T. spinifera* (Robin Ross)
Scripps Institute of Oceanography, La Jolla, CA	11-12 Feb. 2013	Mark Ohman	*T. spinifera*, including live individuals in the surf zone, roughly even male:female, females not recently fertilized (no spermatophores)

Mortality of other species	Date(s)	Reported by	Notes
South Beach, Newport, OR	21 June 2013	Delores Williams	crustaceans, especially small *Cancer magister*
Clam Beach, McKinleyville, CA	15-23 June 2013	Michael Ives	crustaceans, mainly small-medium (2-10 cm carapace width) *Cancer magister*

Two separate samples of five individuals each from Nye Beach, OR and Mussel Beach, CA were identified as adult female *Thysanoessa spinifera*. These krill were carrying spermatophores but their ovaries did not contain developed eggs, a situation commonly found in individuals early in their reproductive cycle. This suggests that they may have been involved in mating swarms which occur near the surface. Some observations from these strandings noted that some of the krill were still alive and moving – consistent with healthy, viable krill being stranded as opposed to krill that were already dead merely washing up onto the shore.

Our current hypothesis is that swarms of *T. spinifera* were in surface waters and driven onshore by strong southwesterly winds and resultant downwelling currents. *T. spinifera* is already among the shallowest dwelling krill species, typically found between the surface and depths of 100-200m. Stranded krill were probably at the shallower end of this range either because their normal diurnal vertical migration (DVM) drew them shallower in the water column at night, or because they were in a mating swarm. Strandings observed in the vicinity of both stations occurred immediately following a switch in wind direction from an upwelling-favorable, northwesterly direction to southwesterly, downwelling winds (based on wind data from NOAA NDBC stations 46050 and 46022 off of Newport and Eureka, respectively; Figure 16). Off Newport, winds reversed the night of 15 June with stranding first observed in low numbers beginning that evening, followed by much higher densities seen the following day, 16 June. The winds reversed on the night of 16 June off Eureka, with stranding observed in this region on 17-18 June. However, this hypothesis does not appear to be a good explanation for the stranding observed on 21 June at Bodega Bay – strong upwelling winds persisted there until the winds reversed on the night of 23 June.

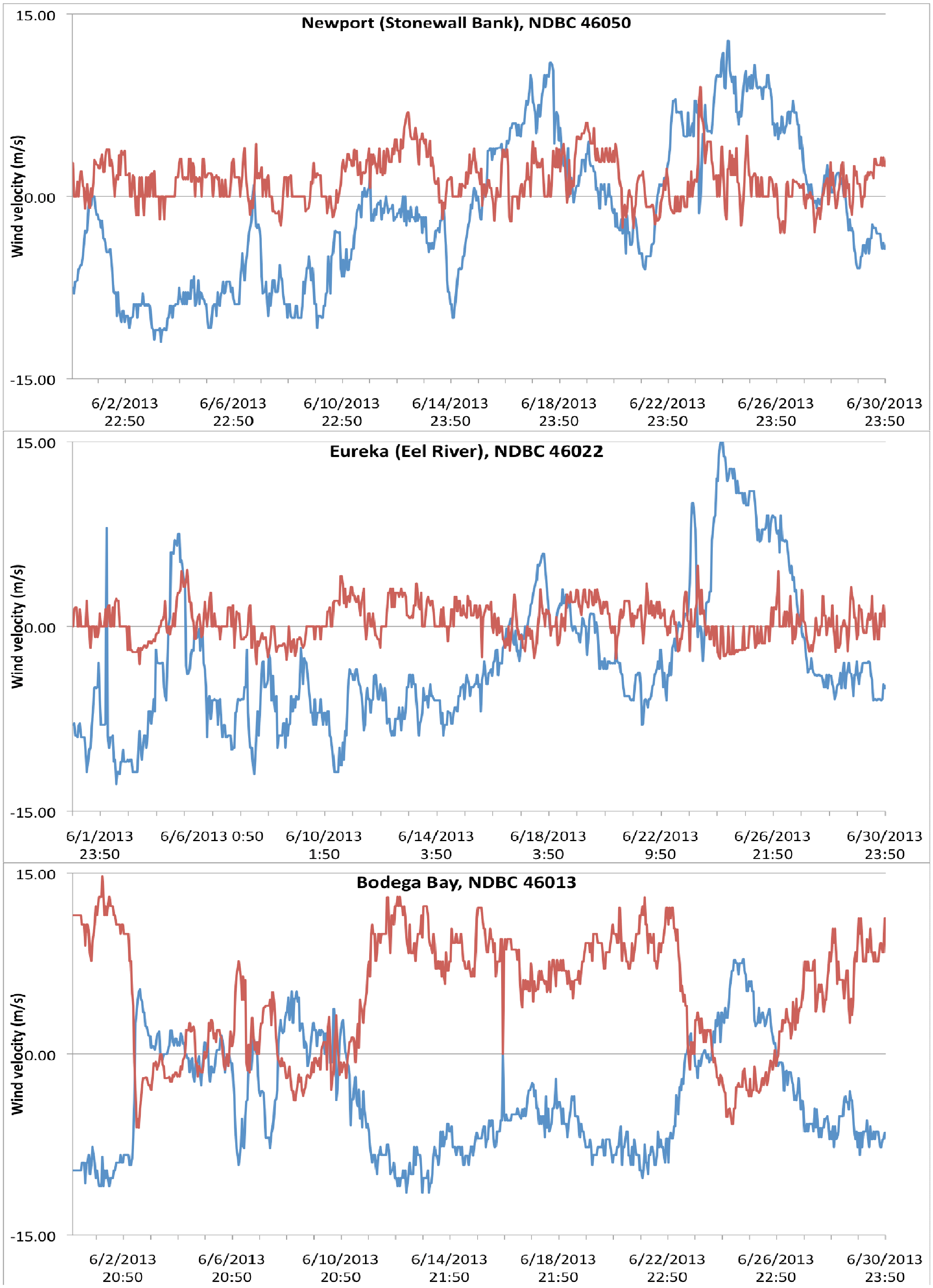


Figure 16. Wind records off of Newport, OR, Eureka, CA, and Bodega Bay, CA (NDBC 46050, 46022, 46013 respectively). Blue lines indicate the northerly(-)/southerly(+) component of the wind vector; red is the westerly(+)/easterly(-) component.

Oceanographic observations

Observations of unusually low dissolved oxygen (DO) levels from Oregon and California suggest the possibility that hypoxia may have been a contributing factor to krill strandings. By pushing the distribution of krill to shallower depths where DO was less depleted, hypoxia may have made them more vulnerable to being driven onshore by the reversal of wind-driven surface currents. A similar mechanism was proposed for a mass stranding and mortality of another species of krill (*Nematoscelis difficilis*) in the Gulf of California in 2003 (López-Cortés et al. 2006). This subtle potential role for hypoxia contrasts with severe hypoxia events (with DO <0.7mg/L – much lower than observed here) in which mass mortality of marine organisms may result directly from their inability to obtain oxygen.

OREGON OCEANOGRAPHIC OBSERVATIONS

Newport Hydrographic Line

During cruises on the Newport Hydrographic Line in Oregon, Bill Peterson found the lowest recorded DO levels for June since he began sampling in 2005 (see also his report). Minimum DO values below 1.9 and 1.6mg/L were recorded from cruises on 7 and 19 June, respectively.

PISCO Nearshore Moorings

Additional data from Oregon came from Francis Chan and Jack Barth who provided a summary of recent (through 18 June) preliminary data from PISCO instrumented moorings. They observed near-bottom DO levels below the threshold of hypoxia (~2mg/L) at moorings in 15m of water both north (Cape Foulweather) and south (Cape Perpetua) of Newport. Dissolved oxygen was lower at Cape Perpetua, where a near-bottom instrument at ~70m had declined to around 1.5mg/L. Though these observations are well above the threshold of severe hypoxia that may kill organisms outright, they were atypically low for this early in the upwelling season.

CALIFORNIA OCEANOGRAPHIC OBSERVATIONS

Data from the CeNCOOS instrument on the Trinidad pier and oceanographic cruises on the Trinidad Head Line (THL) by Jeffrey Abell and Eric Bjorkstedt (see also his report above on observations from the THL) indicate the development of unusually low levels of DO, including hypoxia off Northern California. Dissolved oxygen levels at the CeNCOOS instrument on the Trinidad pier (~3m depth and within 100m of shore) were below 2 mg/L for extended periods between 14 and 16 June, but had increased substantially by the time of Eric Bjorstedt's cruise on Trinidad Head Line (18-19 June). Though this cruise occurred after DO levels had increased significantly at the Trinidad pier, it still recorded some of the lowest levels observed on the TH Line to date. This includes extensive areas of the shelf with DO below 3 mg/L and levels below 1.5 mg/L in the bottom water at the midshelf station in ~75m of water.

Trinidad pier

Data from the CeNCOOS (Central and Northern California Ocean Observing System) instrument (YSI Sonde 6600v2) deployed at a depth of ~3m on the end of the Trinidad pier shows a pattern indicative of a upwelling event beginning in the morning of 7 June and continuing until around midnight 16 June (Figure 17).

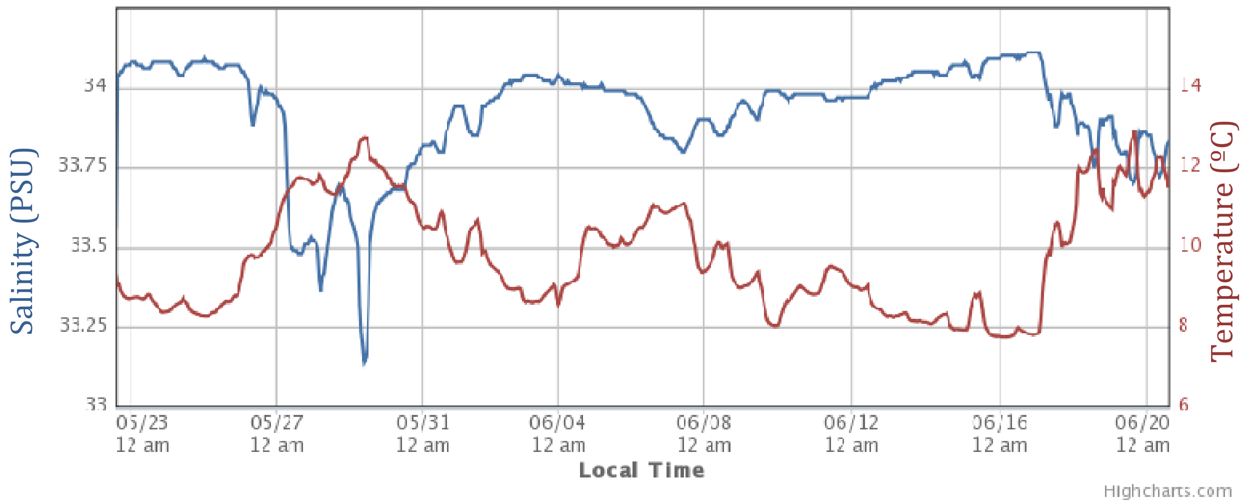


Figure 17. Salinity (blue, left axis) and temperature (red, right axis) from the CeNCOOS Trinidad pier station. An upwelling event occurred from the morning of 7 June until around midnight 16 June, indicated by increasing salinity and decreasing temperature.

Dissolved oxygen levels at the station dropped below 2mg/L; from 18:45 on 14 June through 01:45 on 15 June, from 14:45 on 15 June until 11:45 on 16 June, and reached a minimum of 1.64 mg/L at 06:45 on 16 June (Figure 18). These are surprisingly low values given that this is a shallow, nearshore station on the open coast. During the upwelling event, pH declined with DO, reaching 7.4 or lower for similar periods, and a minimum of 7.38 from 08:45-10:45 on 16 June. Waters further offshore likely exhibited a similar pattern: declining DO during upwelling, followed by a rapid increase with the onset of southwesterly storm winds. In this scenario, krill could migrate into shallower waters as DO levels fell, only to be swept onshore by the arrival of southwesterly storm winds.

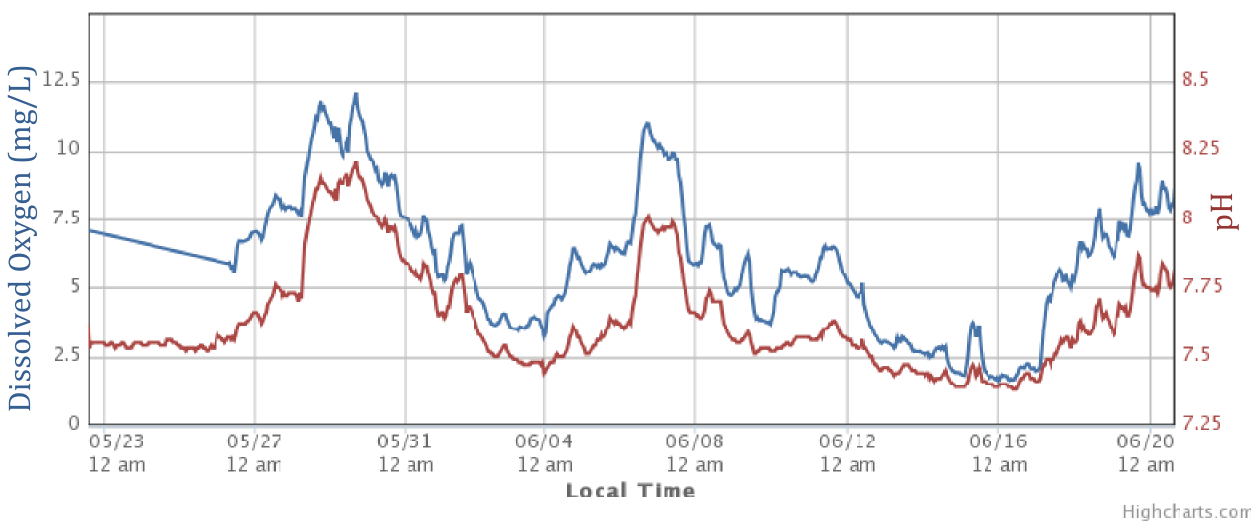


Figure 18. Dissolved oxygen (blue, left axis) and pH (red, right axis) from the CeNCOOS Trinidad pier station. During the upwelling event from 7 June until around midnight 16 June, DO levels dropped below 2 mg/L and pH below 7.4 was observed.

By the time Eric Bjorkstedt's oceanographic cruise on the Trinidad Head Line commenced around 16:00 on 18 June, DO at the Trinidad pier had already increased to 7.22mg/L and pH had increased to 7.67. This suggests that the oxygen levels observed during the oceanographic cruise on the THL were significantly higher than had existed during the prior 3-4 days. Nevertheless, the cruise captured the lowest DO levels observed since sampling began in 2010.

Trinidad Head Line (THL)

An oceanographic cruise led by Eric Bjorkstedt (NOAA/HSU) on the Trinidad Head Line was conducted from 16:30 18 June through 04:30 the following day. They found DO < 3 mg/L over shelf and very low DO (< 1.5 mg/L) in bottom water at their midshelf station (TH02, ~124.27 W) with water depth ~75m. Though analysis of plankton samples collected during this cruise has been prioritized, it is not yet complete. However, initial observations during the plankton tows noted that they were "pretty empty" compared with the cruise in May (Roxanne Robertson, *pers. comm.*). Though the data from the Trinidad pier CeNCOOS instrument suggests that the lowest DO levels occurred well prior to this cruise, they were still the lowest recorded since these cruises began in 2010. For more information including DO profile, see the THL report.

On cruises conducted on the THL by Jeff Abell since 2010, DO less than 3 mg/L was observed at the nearshore station, TH01, only once (May 2010). Dissolved oxygen concentrations less than 3 mg/L were observed only three times at the midshelf station, TH02 (May 2010, Jul 2011, Aug 2011). Before 18 June 2013, DO lower than 1.4 mg/L had not been documented on the THL. Near-bottom water was not exceptionally cold at the two innermost stations (TH01, TH02) during the 18 June 2013 cruise, however DO reached the lowest levels observed to date (Figure 19). Plots of temperature versus DO for the two furthest offshore stations, TH04 and TH05 (roughly 30 and 40km offshore, past the shelf break) reveal that in the deeper parts of the water column, DO for a given temperature has actually been slightly higher this year than previously (Figure 20). Likewise, examining data from recent cruises (6 and 29 May 2013) versus this time last year (22 May 2012) reveals that the 2mg/L isocline for DO was actually 100m deeper this year (Figure 21). These data suggest that the system was not primed with anomalously low DO offshore that was merely advected onshore by upwelling. Instead this data, along with the gradual decline observed at the Trinidad pier station, suggest that the hypoxia likely resulted from some combination of persistent upwelling, increased respiration, and retention. Interestingly, however, no signal of decreased DO was detected in Humboldt Bay at the Wiyot Tribe's station on Indian Island. Apparently gas exchange at the surface of the shallow bay was sufficient to prevent noticeable depletion of DO.

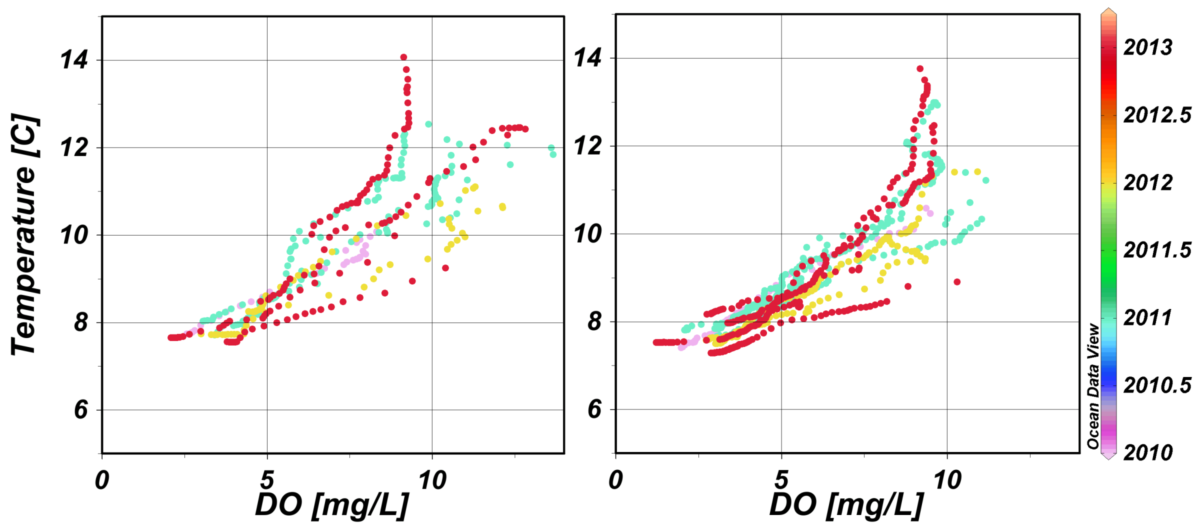


Figure 19. DO vs. temperature plots for the inshore (TH01) and the midshelf (TH02) stations for 2010-2013. Color indicates year of data collection.

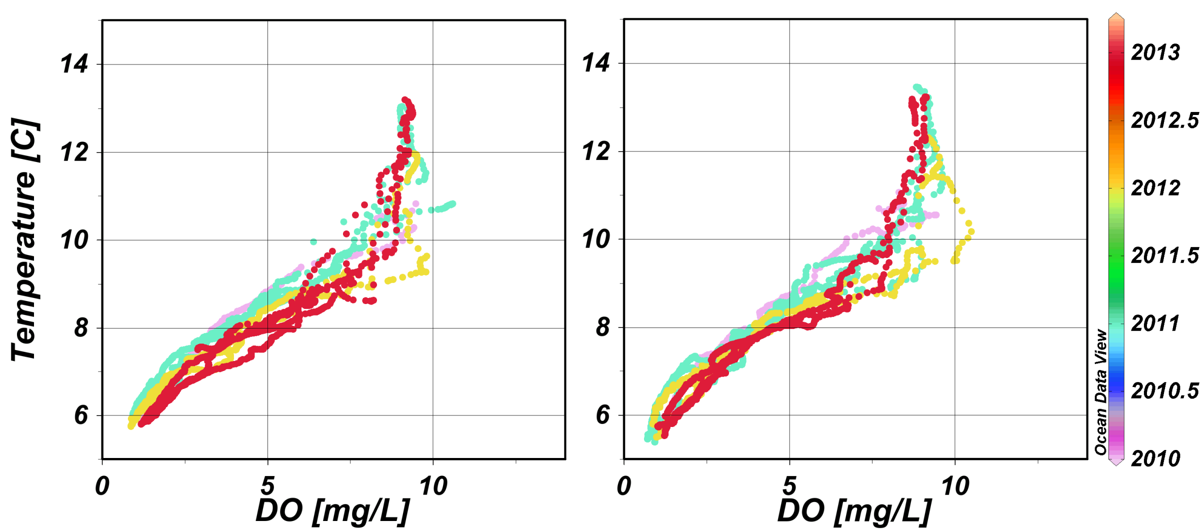


Figure 20. DO vs. temperature plots for the furthest offshore stations (TH05 and TH05) for 2010-2013. Color indicates year of data collection.

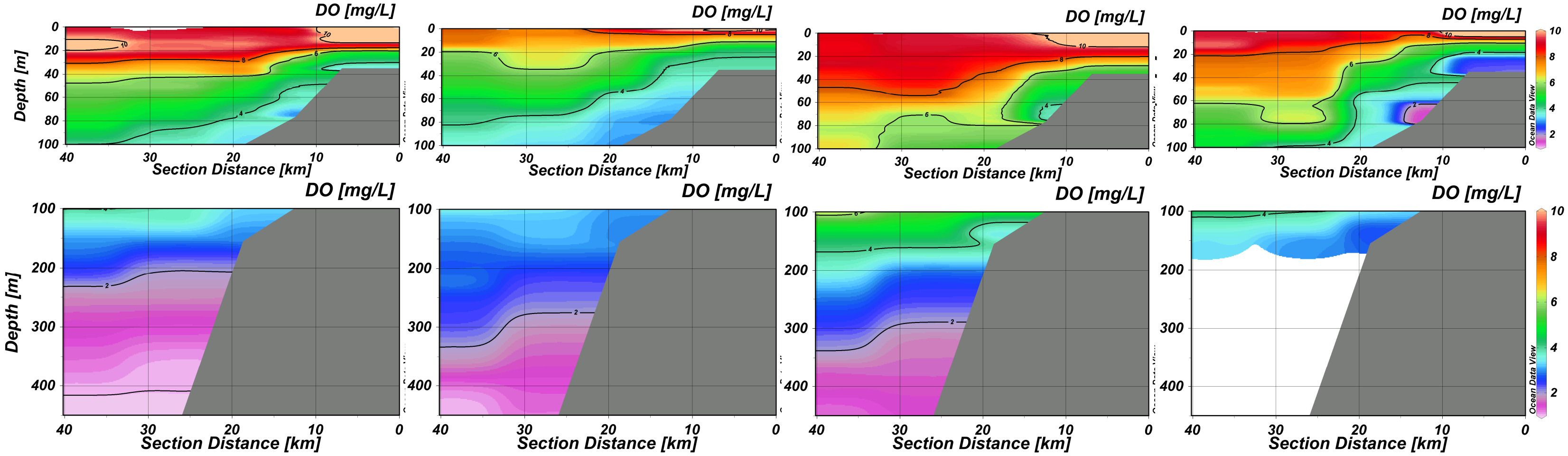


Figure 21. Cross shelf sections of DO at the TH Line for 22 May 2012 (last year), 6 & 29 May, and 18 June 2013. Note that the cruise on 18 June only conducted CTD casts to ~200m.

Discussion

Krill strandings have long been documented on the West Coast, including an event on Oregon beaches (Pearcy and Hosie 1985) and one as far back as 1948 in La Jolla, CA (Brinton 1962). However, the event on 15-18 June 2013 from central Oregon to northern California was unusual in its geographic extent of at least 400 km. Common environmental factors throughout the region that provide insight into potential causes include a switch from upwelling-favorable, northwesterly winds to downwelling, southwesterly winds immediately preceding strandings, as well as unusually low DO levels. This switch in wind direction (and even the relaxation of northwesterly upwelling winds) could have transported shoreward krill entrained in the upper water column. The krill could have migrated shallower for the nocturnal phase of their DVM or as part of mating swarms. Unusually low DO levels may have caused the krill to migrate to especially shallow depths, or to remain shallow for longer, making them more susceptible to onshore transport and stranding. This combination of physical transport and hypoxia is proposed by López-Cortés et al. (2006) to explain a krill stranding event in 2003 in the Gulf of California, though De Silva et al. (2004) suggest physical transport alone as the cause.

Bianchi et al. (2013) have found that vertically migrating animals, including krill, generally do not descend below the upper margin of oxygen minimum zones – and may intensify DO depletion at these depths. While *T. spinifera* is capable of decreasing its metabolic rate in response to low DO (Tremblay and Abele 2012), at least one species of krill accumulates lactate and oxygen debt when DO falls too low and it must resort to anaerobic respiration (Spicer et al. 1999). Accumulated oxygen debt could drive krill to remain in shallower water where DO is higher. Biochemical analysis of krill metabolite levels (including lactate) would be very helpful for understanding their physiological tolerance of hypoxia and whether low DO was an important exacerbating factor in their stranding.

Given that all ten individuals examined were female, it is likely that females made up a large proportion of the stranded *T. spinifera*. Work on another species (*Meganyctiphanes norvegica*) found that females tend to migrate closer to the surface at night than males (Tarling 2003). Modeling suggested that while this likely incurs increased risk of predation, females undertake it in order to meet the energetic demands of egg production. Females could also have consequently higher metabolic demand for oxygen. Regardless, the finding that most (or all) of the stranded *T. spinifera* were female is consistent with the hypothesis that shallow depth distribution contributed to the stranding.

The proposed krill stranding mechanism (that they were transported onshore by downwelling surface currents) appears to be consistent with some, but not all of the other stranding events observed this year:
Florence, OR, 11 May – Regional winds (NDBC 46050) were strongly upwelling 9 May through midday 10 May, relaxed, and then switched to strong downwelling starting just after midnight on the morning of 11 May.
Bodega Bay, CA, 30 March – There were mild upwelling winds offshore (NDBC 46013) during the day of 29 March, switching to downwelling winds around midnight.
Ketchikan, AK, 7 April – Winds from the land-based station (NOAA KECA2) exhibit a strong diurnal signal with southeasterly winds on the nights of 5 and 6 April, prior to the observed stranding on 7 April.

However, other krill stranding events did not seem to fit this pattern:
Bodega Bay, CA, 21 June – Strong regional winds (NDBC 46013) from the northwest persisted through 23 June, with downwelling winds out of the southeast commencing on 24 June.
La Jolla, CA, 11-12 Feb. – The offshore winds (NDBC 46086) remained northwesterly but weakened to 4-5m/s starting early on 10 February, however they did not switch to a downwelling-favorable direction.
We have not yet obtained DO data to evaluate whether hypoxia may have been a contributing factor in any of these additional krill stranding events. The mortality of small crabs noted around the same time as the krill strandings in Newport, OR and McKinleyville, CA could be the consequence of more severe hypoxia that

occurred over the seafloor. Juvenile *Cancer magister* may be more susceptible than adults to hypoxia since their hemolymph has lower oxygen-carrying capacity (Brown and Terwilliger 1998).

In addition to physical transport possibly exacerbated by hypoxia, pathogens or parasites are another potential cause or contributing factor. We have no data on whether a disease or parasite contributed to strandings, though the ten individuals examined did not have obvious signs of such. Since some krill were still alive when stranded, disease or parasitism did not kill them outright, but it could have compromised their health and ability to avoid stranding. Close examination and dissection of many individuals by a disease expert could fully evaluate this possibility.

This krill stranding event was unusual for its spatial extent, and was likely primarily the result of transport by wind-driven currents. It appears at least plausible that mild hypoxia played a contributing role by causing the krill to remain shallower than they would have otherwise. If hypoxia is indeed a part of the cause, such indirect impacts may grow in frequency and/or severity as climate change proceeds since oxygen minimum zones are expected to expand to shallower depths (Bianchi et al. 2013).

Juvenile Salmon catches during the June survey:

Source: Bill Peterson (NOAA, NMFS)

A record number of juvenile salmon were captured in June 2013 with a total of more than 2000 fish. This was due in part to the highest catches on record of Chum salmon (1000+); catches of juvenile spring Chinook and coho were high as well (but not the highest) although final numbers are not yet available.

West Coast Salmonids, Second Quarter, 2013:

Source: Jerrold Norton (NOAA, ERD, SWFSC (Jerrold.G.Norton@noaa.gov))

In the second quarter of 2013, spring and summer run chinook salmon (*Oncorhynchus tshawytscha*) were ascending natal streams from California to Alaska. Winter and summer run steelhead (*Oncorhynchus mykiss*) were also returning to many coastal rivers. Sockeye salmon (*Oncorhynchus nerka*) runs are underway from Oregon to Alaska. Because of 2013 drought conditions, spring chinook in the Sacramento and Trinity drainages may have difficulty as their spawning season approaches. The spring chinook in Butte Creek, off the Sacramento River, are natural spawners and the largest naturally spawning spring chinook population in California. Butte Creek and the Feather River hatchery had excellent returns in 2013. In the wild state, spring chinook return early in the year, migrate upstream to rivers and streams fed by snow melt where they hold until spawning occurs months later. These spring chinook behaviors worked for their survival as a population until feed waters were cut off and diverted for other uses. Since 2013 was a dry year on the west coast, particularly in California, the spring chinook's pools and holding areas are warming up and need cooler water that might have come from snow melt in predevelopment days. For spring chinook, warm water is associated with poor breeding success and disease. Efforts are underway to supply additional water to spring chinook at Butte Creek, where there may be 16,000 fish preparing to spawn, and on the Trinity River, a major tributary to the Klamath River in northern California. The water shortage will also disrupt the life-histories of fall chinook when they begin their spawning runs up California Rivers. Recreational and commercial ocean fishing for chinook salmon has been fair to poor south of San Francisco and fair to good off northern California and Oregon.

The spring chinook run at the Columbia River's Bonneville fishways was 53% of last year's run and 59% of the 10-year average. However, the Bonneville run of spring chinook jacks was robust at 445% of 2012 and 166% of the 10-year average. The Columbia River spring chinook run started in May then peaked quickly and was nearly over by mid-June. Bonneville steelhead passage has also been weak at 35% of last year and 47% of the 10-year average. Sockeye salmon runs began in the second quarter and will be complete in the third quarter. On June 30 the Bonneville fishway's sockeye returns were about equal to the 10-year average. Sockeye runs monitored a Ballard Locks in northern Washington have been more robust than anticipated.

Sockeye runs on the Frazer River in southern Canada began in late June. Frazer River sockeye runs are expected to be between one and five million fish when ocean catches are included.

<u>Ecosystem indicators for the Central California Coast, May-June, 2013</u>:

Source: John Field (Fisheries Ecology Division, SWFSC) and Keith Sakuma (Fisheries Ecology Division, SWFSC)

The Fisheries Ecology Division of the SWFSC has conducted an annual midwater trawl survey for juvenile rockfish and other pelagic micronekton along the Central California coast in late spring (May-June) since 1983. The survey targets pelagic juvenile (pelagic age 0) rockfish for fisheries oceanography studies and stock assessments, while simultaneously monitoring the micronekton forage assemblage (including other juvenile fishes, krill, coastal pelagic species, and mesopelagic species) and collecting oceanographic information. The results here summarize trends in the core area since 1990, as not all species were consistently identified in earlier (1983-1989) years of the survey. From 1983 through 2008 cruises took place on the NOAA ship David Starr Jordan, but since 2009 a series of different research platforms have been utilized and the surveys have ranged in duration and spatial distribution. In 2013 the cruise took place onboard the R/V Ocean Starr, which in fact is the former NOAA Ship David Starr Jordan, renamed after decommissioning and operated by a private contractor (Stabbert Maritime). The data for the 2013 survey presented here are preliminary, and this analysis does not account for potential differences in catchability among vessels. Results from the expanded survey area (available from 2004 to the present) will be developed for future reports.

The standardized anomalies from the log of mean catch rates are shown by year for six key forage species and assemblages that are sampled in this survey (Figure 22). Trends in 2012 and 2013 were of higher productivity for the species and assemblages that tend to do better with cool, high productivity and high transport conditions, including juvenile rockfish, market squid and krill. In particular, the 2013 survey was associated with extremely high rockfish catches throughout both the core area and the expanded survey region, with the highest overall juvenile rockfish catches in the time series. Catches of more regularly encountered YOY groundfish, such as Pacific hake, were also at high (albeit, not record) levels. These observations were consistent with high reported catches of YOY rockfish and other groundfish in power plant impingement surveys, from scuba divers conducting a range of scuba surveys, and from commercial and recreational fishermen. Other key forage species, such as krill and market squid, remained at very high levels, and although northern anchovy catches in 2013 were below the long term mean, they were higher than they have been since 2007. As with the 2012 results, 2013 continued to indicate a pelagic micronekton community structure dominated by cool-water, high productivity forage species (juvenile groundfish, krill and market squid). However, based on a principle components analysis of anomalies across 15 key taxa (including the six shown in Figure 22), 2013 was also unique in many ways, as it did not load consistently with clusters of other recent years (more details provided in CalCOFI State of the California Current Reports, and in preparation). Although abundance of salps and other gelatinous zooplankton was nowhere near the high levels observed in 2012, high numbers of *Thetys vagina* were observed, particularly north of the core survey area.

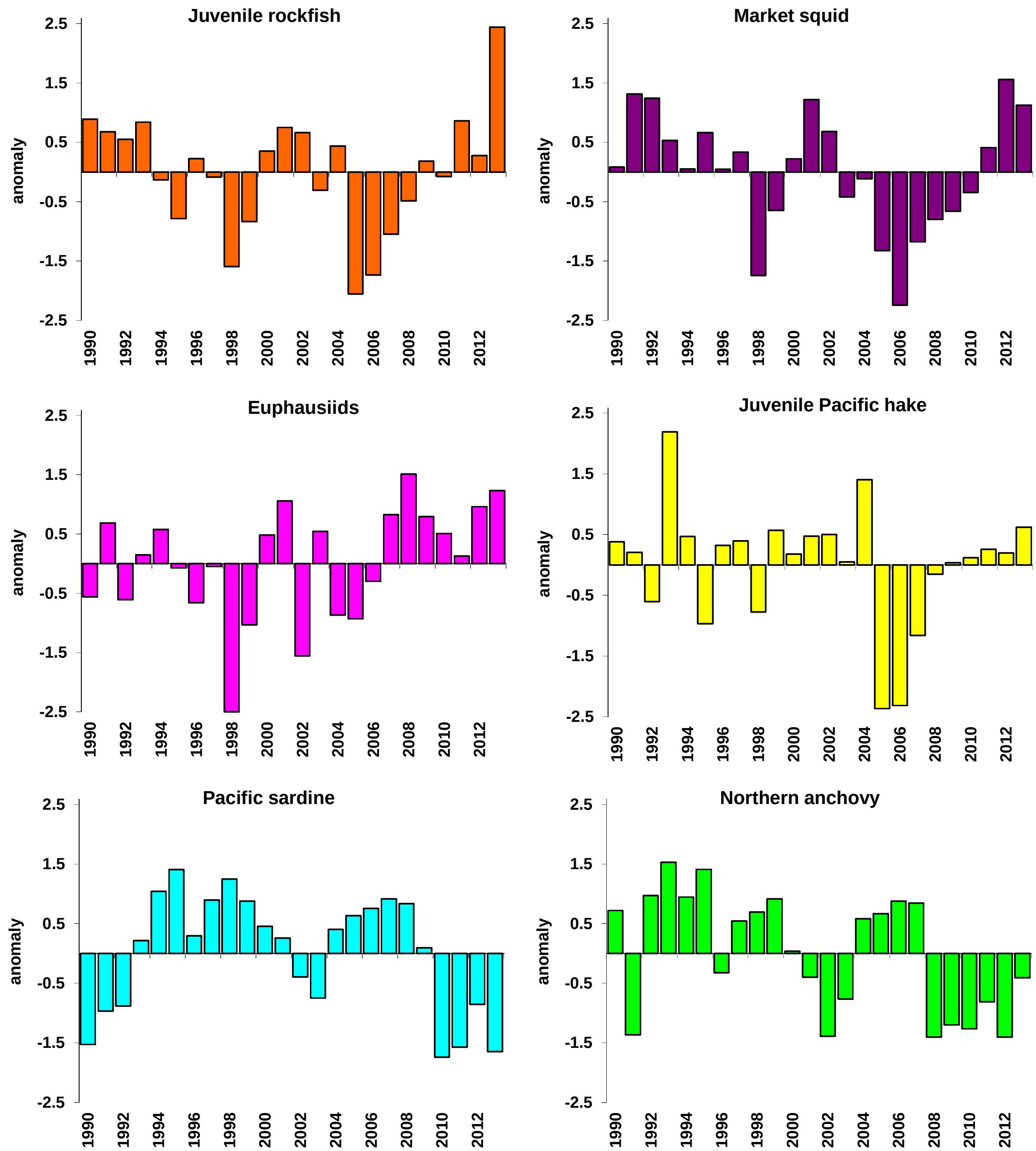


Figure 22. Long-term standardized anomalies of several of the most frequently encountered pelagic forage species from the central California rockfish recruitment survey in the core region (1990-2012).

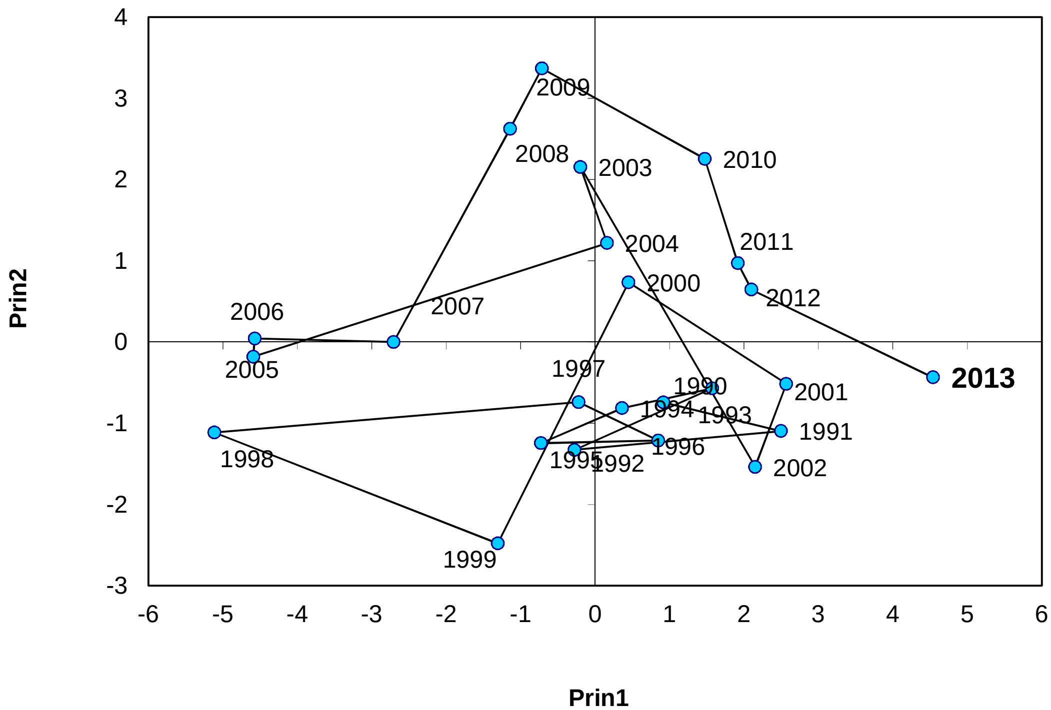


Figure 23. Principal component scores plotted in a phase graph for the fourteen most frequently encountered species groups sampled in the central California core area in the 1990-2013 period.

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