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Introduction to collection of papers on the response of the southern California Current Ecosystem to the Warm Anomaly and El Niño, 2014–16

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ABSTRACT

This contribution provides an introduction to a sequence of five papers (CCE I- CCE V) that describe the impact of the Warm Anomaly of 2014–15 and El Niño 2015–16 on the pelagic food web of the southern California Current Ecosystem. These contributions analyze the influence of these two warm water perturbations on satellite-based measures of ocean fronts, export efficiency out of the euphotic zone, copepod egg production, mesozooplankton community structure, and a synthesis of primary production, mesozooplankton grazing, and gravitational fluxes of organic carbon.

Major temperature anomalies were expressed in the Northeast Pacific ocean during 2014–16 that had significant consequences for marine ecosystems. First, in winter 2013–14, a pronounced Warm Anomaly developed in the Subarctic Pacific that was memorably christened The Blob by Bond et al. (2015). Warm anomalies were subsequently detected in multiple regions of the Northeast Pacific in 2014–15, ranging from the Bering Sea to the coasts of Washington, Oregon, California, and Baja California (Di Lorenzo and Mantua, 2016). It appears that these geographically disparate anomalies were forced by regionally different balances of atmosphere/ocean processes rather than by a single perturbation that was advected through the ocean from the Subarctic Pacific. Normal upwelling then resumed along the California coast in northern spring 2015 (Jacox et al., 2016), to be followed by the development of a significant El Niño that persisted until the northern spring of 2016 (http://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_disc_mar2016/ensodisc.html). The term ‘marine heat wave’ has been applied to encompass both events, implying related physical forcing (e.g., Di Lorenzo and Mantua, 2016), although the Warm Anomaly first appeared in high-to-mid latitudes while the subsequent El Niño originated along the equator.

Apart from the physical manifestations of these two warm events, a larger issue is their ecological and biogeochemical consequences, as well as the possible interactive effects of these major perturbations occurring in rapid succession. There are widespread reports of anomalous ecological conditions that coincided with these events, ranging from increased Harmful Algal Blooms associated with the diatom *Pseudo-nitzschia* spp. with consequences for Dungeness crab, razor clam, and other populations (Mccabe et al., 2016), poleward displacements of planktonic organisms (Mcclatchie et al., 2016), alterations of seabird reproductive success and brood size (Mcclatchie et al., 2016), severe declines in California sea lion pup growth and survivorship (Mcclatchie et al., 2016), and other effects (Ohman et al., 2017), although the direct cause and effect relationship between a physical perturbation and a specific biotic response can be difficult to discern.

The southern California sector of the California Current Ecosystem has a rich observational record that dates to the founding of CalCOFI in 1949. More recently, the NSF-supported *California Current Ecosystem* Long-Term Ecological Research (CCE-LTER) site was initiated in late 2004. The combination of the interdisciplinary CalCOFI time series with the process-oriented studies of CCE-LTER (which began in May 2006), provides an excellent basis for measuring and understanding the causal mechanisms underlying ecosystem changes, such as those during the 2014–16 anomalies. The CCE-LTER site makes a comprehensive series of measurements of phytoplankton and microbial growth rates, grazing rates, Fe limitation effects, measures or proxies of secondary production, particle export out of the euphotic zone, and other processes, accompanied by knowledge of community structure spanning the entire planktonic food web. These studies are carried out on Lagrangian-design process cruises (Landry et al., 2009; Ohman et al., 2013).

The following five papers in this issue, each with the prefix CCE, represent a series of studies analyzing perturbations to the planktonic ecosystem in the CCE-LTER region in 2014–2016, measured against directly comparable previous measurements made by the same groups

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of investigators. The initial catalyst for this work was a RAPID grant from the U.S. NSF to quantify the effects of El Niño on the pelagic ecosystem during a process cruise in spring 2016. Although the physical signals of El Niño had begun to relax along the equator by spring 2016, the biological consequences of El Niño often lag changes in physical forcing. Furthermore, previous evidence of strong springtime expressions of El Niño from the CalCOFI time series (e.g., Rebstock, 2001; Brinton and Townsend, 2003; Ohman et al., 2012) made this a desirable time of year for measuring biotic impacts. As research progressed, it was clear that El Niño 2015–16 could not be evaluated in the absence of attention to the pre-existing Warm Anomaly, which may have preconditioned the water column.

In paper **CCEI**, Kahru et al. (2018) show that the incidence of satellite-detected ocean fronts plummeted during both the Warm Anomaly and El Niño, interrupting an 18–33 year increasing trend. Because of the recently documented importance of frontal regions for phyto- and zooplankton aggregations (Powell and Ohman, 2015) and carbon export (Stukel et al., 2017) in this region, the decline in fronts has consequences for predator-prey interactions and ocean biogeochemistry. Changes in frontal frequency associated with the Warm Anomaly and El Niño were accompanied by the strongest negative chlorophyll anomalies and strongest positive Sea Surface Temperature anomalies in the satellite record.

In **CCEII**, Kelly et al. (2018) find that, contrary to expectations from previous global export models, *e*-ratios (i.e., export/net primary production) in the CCE-LTER region increased with distance offshore and in less productive waters. This pattern is attributed to the dominance of lateral, rather than vertical export, in the nearshore upwelling zone and to heterogeneity in particle sinking speeds and organic matter residence time in the euphotic zone. These authors also found, surprisingly, that *e*-ratios vary positively with temperature as a consequence of the association between temperature and water mass age. This result also points to the importance of cross-shore advection in displacing sites of vertical C export far offshore from the sites of net primary production. Although satellite-inferred Net Primary Production decreased during the Warm Anomaly and El Niño, *e*-ratios increased rather than decreased during these events. This study underscores the importance of horizontal advection and departures from the common steady-state assumptions that are usually invoked in studies of the biological carbon pump.

CCEIII analyzes the effect of the two warm events on daily egg production rates of the three dominant species of calanoid copepods in the CCE-LTER region. Copepod egg production is a key process initiating population growth, reflects an integrative measure of recent nutritional history, and can, with certain assumptions, be used as a proxy for secondary production. Nickels and Ohman (2018) found that during both of the warm events, egg production rates and other measures of fecundity were in the lower half of previous measurements, but egg production and egg hatching success corresponded to what was expected for the ambient food concentrations. This continuity of functional relationships implies that the fecundity relationships determined in El Niño-neutral conditions can also be used to predict responses in warm anomalies. This is sometimes referred to as a 'space-for-time exchange' and is a useful principle to invoke when parameterizing ecosystem models.

Lilly and Ohman (2018), in **CCEIV**, capitalize on the 70-year CalCOFI record to evaluate the responses of different mesozooplankton taxa to seven El Niños and the 2014–15 Warm Anomaly. They find that total zooplankton C biomass is only modestly influenced by El Niño and the Warm Anomaly, while community composition is substantially altered. At least five major taxa (euphausiids, calanoid copepods, hyperiid amphipods, appendicularians, and polychaetes) are typically suppressed in C biomass during such events. The most pronounced community changes occur at the species level, where euphausiids and, to a lesser extent, copepods show substantial community rearrangements. Distinguishing between Eastern Pacific (EP) and Central Pacific (CP) El Niño events (Capotondi et al., 2015), species changes tend to be more pronounced in EP events. The zooplankton assemblage is remarkably resilient to El Niño and Warm Anomalies to date, since up to the present time, the assemblage usually recovers to a pre-perturbation state within a year.

In **CCEV**, the final paper in this cluster, Morrow et al. (2018) present a synthetic analysis of the effects of both warming events on phytoplankton primary production, mesozooplankton grazing, and gravitationally-mediated carbon export (measured both by ^{238}U-^{234}Th disequilibrium and sediment traps). They find that during the Warm Anomaly and El Niño chlorophyll-specific primary production decreases 2–3 fold relative to El Niño-neutral years at similar nitrate concentration and photosynthetically active radiation. While absolute grazing rates by mesozooplankton conformed to pre-existing expectations based on available food supply, there was a suggestion that mass-specific grazing (which adjusts for changes in zooplankton biomass) may be somewhat suppressed during the Warm Anomaly and El Niño. Vertical C export in relation to primary production and in relation to mesozooplankton grazing changed little in response to the anomalous conditions. A consistent pattern across both warm and neutral years was the dominance of mesozooplankton fecal pellets as a contribution to C export in more productive waters, but dominance by slowly sinking, degraded particles with minimal pigment content in more offshore waters.

The results presented here, together with additional related studies to appear in the future, provide an invaluable framework for building ecosystem forecast models. Our intent is to embed these functional relationships and rate processes into a modeling framework that forecasts the ecosystem consequences of El Niño in the CCE region (*cf.* Di Lorenzo and Miller, 2017). The objective is to understand El Niño-related perturbations and their potential interactions with other warming events that are expected to become increasingly common in the future.

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References

Bond, N.A., Cronin, M.F., Freeland, H., Mantua, N., 2015. Causes and impacts of the2014 warm anomaly in the NE Pacific. Geophys. Res. Lett. 42. https://doi.org/10.1002/2015GL063306.

Brinton, E., Townsend, A., 2003. Decadal variability in abundances of the dominant euphausiid species in southern sectors of the california current. Deep-Sea Res. II 50, 2469–2492.

Capotondi, A., et al., 2015. Understanding ENSO Diversity. Bull. Am. Meteor. Soc. 96, 921–938. https://doi.org/10.1175/bams-d-13-00117.1.

Di Lorenzo, E., Mantua, N., 2016. Multi-year persistence of the 2014/15 North Pacific marine heatwave. Nat. Clim. Change 6, 1042. https://doi.org/10.1038/nclimate3082.

Di Lorenzo, E., Miller, A.J., 2017. A framework for ENSO predictability of marine ecosystem drivers along the U.S. West coast. variations CLIVAR OCB Newsl., 15, pp. 1–7.

Jacox, M.G., et al., 2016. Impacts of the 2015–2016 El Nino on the California Current system: early assessment and comparison to past events. Geophys. Res. Lett. 43, 7072–7080. https://doi.org/10.1002/2016gl069716.

Kahru, M., Jacox, M.G., Ohman, M.D., 2018. CCE1: decrease in the frequency of oceanic fronts and surface chlorophyll concentration in the California Current System during the 2014–2016 northeast Pacific warm anomalies. Deep-Sea Res. I (In this issue).

Kelly, T.B., Goericke, R., Kahru, M., Song, H., Stukel, M.R., 2018. CCE II: spatial and interannual variability in export efficiency and the biological pump in an eastern boundary current upwelling system with substantial lateral advection. Deep-Sea Res. I (In this issue).

Landry, M.R., Ohman, M.D., Goericke, R., Stukel, M.R., Tsyrklevich, K., 2009. Lagrangian studies of phytoplankton growth and grazing relationships in a coastal upwelling ecosystem off Southern California. Progr. Oceanogr. 83, 208–216. https://doi.org/10.1016/j.pocean.2009.07.026.

Lilly, L.E., Ohman, M.D., 2018. CCE IV: el Niño-related zooplankton variability in the southern California Current System. Deep-Sea Res. Part I (In this issue).

Mccabe, R.M., et al., 2016. An unprecedented coastwide toxic algal bloom linked to anomalous ocean conditions. Geophys. Res. Lett. 43, 10366–10376. https://doi.org/10.1002/2016gl070023.

Mcclatchie, S., et al., 2016. State of the California Current 2015-16: comparisons with the

1997-98 El Niño. CalCOFI Rep. 57, pp. 1–57.
Morrow, R.M., Ohman, M.D., Goericke, R., Kelly, T.B., Stephens, B.M., Stukel, M.R., 2018. CC V: Primary production, mesozooplankton grazing, and the biological pump in the California Current Ecosystem: variability and response to El Niño. Deep-Sea Res. I.
Nickels, C.F., Ohman, M.D., 2018. CCEIII: persistent functional relationships between copepod egg production rates and food concentration through anomalously warm conditions in the California Current Ecosystem. Deep-Sea Res. I (In this issue).
Ohman, M.D., Barbeau, K., Franks, P.J.S., Goericke, R., Landry, M.R., Miller, A.J., 2013. Ecological transitions in a coastal upwelling ecosystem. Oceanography 26, 210–219. https://doi.org/10.5670/oceanog.2013.65.
Ohman, M.D., Mantua, N., Keister, J., Garcia-Reyes, M., Mcclatchie, S., 2017. ENSO impacts on ecosystem indicators in the California Current system. variations. CLIVAR OCB Newsl., 15, pp. 8–15.
Ohman, M.D., Rau, G.H., Hull, P.M., 2012. Multi-decadal variations in stable N isotopes of California Current zooplankton. Deep Sea Res. I 60, 46–55. https://doi.org/10.1016/j.dsr.2011.11.003.
Powell, J.R., Ohman, M.D., 2015. Covariability of zooplankton gradients with glider-detected density fronts in the Southern California Current System. Deep-Sea Res. II. https://doi.org/10.1016/j.dsr2.2014.04.002.
Rebstock, G.A., 2001. Long-term stability of species composition in calanoid copepods off southern California. Mar. Ecol. Progr. Ser. 215, 213–224.
Stukel, M.R., et al., 2017. Mesoscale ocean fronts enhance carbon export due to gravitational sinking and subduction. Proc. Nat. Acad. Sci. USA www.pnas.org/cgi/doi/10.1073/pnas.1609435114.