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Short Note

Changes in phytoplankton vertical distribution during an El Niño event

Anxo Conde*, Mónica Prado

Instituto Nacional de Pesca, Letamendi 102 y la Ría, 090314 Guayaquil, Ecuador

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ABSTRACT

The west coast of South America is a very productive oceanic region due to cold, nutrient-rich upwelled waters. This region experiences periodic El Niño events that cause a deepening of the thermocline along with the prevalence of warm nutrient-poor superficial water. Sampling conducted during a weak El Niño event in 2014 allowed us to identify changes in phytoplankton vertical distribution at superficial waters along 8 miles offshore the Ecuadorian coast. As such, it was found that phytoplankton mainly occurred at near-surface waters rather than at 10 m depth after the onset of El Niño in terms of both abundance and species richness. The shift in vertical distribution was interpreted as a result of the trapping of cells in a surface layer formed by the stratification of the water column associated with El Niño events. This finding opens the possibility of developing a potential new El Niño indicator.

1. Introduction

1.1. General overview

Phytoplankton contributes significantly to net primary production worldwide. Primary production in the ocean maintains metazoan food webs, fuels fisheries and pumps organic carbon towards the sea bottom (Duarte and Cebrián, 1996). Mixed layer depth, temperature, solar radiation and nutrients availability are key factors driving primary productivity in oceans (Henson et al., 2013). These environmental factors are regularly subjected to seasonal cycles that may be disrupted by major climatic events such as El Niño-Southern Oscillation (ENSO; McPhaden et al., 2006; Racault et al., 2012).

ENSO is a manifestation of a heat flux interaction between the ocean and the atmosphere, implying pressure gradients, in the Pacific Ocean. It comprises cycles of warm and cold events of varying intensity, sometimes with worldwide effects at the environmental and economic levels (McPhaden et al., 2006). The warm phase of ENSO is simply known as El Niño and is manifest by warmer sea surface temperatures and low sea level pressure anomalies in the equatorial eastern Pacific (Wang and Fiedler, 2006). More precisely, during El Niño, the trade winds weaken along the equator as atmospheric pressure rises in the western Pacific while falls in the eastern Pacific. The thermocline is then deeper because of the arrival of warm superficial water from the west (McPhaden et al., 2006). Hence, ENSO results in a basin-wide, southern equatorial Pacific atmosphere–ocean coupling while El Niño is mainly related to a particular ENSO phase in the equatorial eastern Pacific. However, recent investigations support the existence of a similar warm El Niño manifestation in the central tropical Pacific, triggered by different causes than the eastern Pacific El Niño (local air-sea interactions are the base of sea surface temperature anomalies in the former; Kao and Yu, 2009).

El Niño events affect population dynamics and/or distribution of a variety of marine organisms such as zooplankton species, scallops, shrimps, fishes, pinnipeds, sea birds including penguins and cetaceans in the eastern Pacific (Wang and Fiedler, 2006 and references therein). The irruption of an El Niño event may interrupt a normal seasonal cycle in phytoplankton with consequences at higher trophic levels (Henson et al., 2013). In fact, the surface ocean warming during an El Niño prevents the nutrient-rich upwelling water from reaching the surface, resulting in a decrease in primary production that affects the transfer of energy to higher trophic levels (Bakun et al., 2015). Additionally, the reduction in available nutrients is linked to both a decrease in phytoplankton size/biovolume and more frequent occurrence of mixotroph species during El Niño events (Iriarte and González, 2004; Ochoa et al., 2010).

1.2. El Niño anomalies in the study area

The study area is located in the El Niño 1 + 2 region. This was the first oceanic region that studied the El Niño phenomenon, later extended to regions Niño 3, Niño 4 and Niño 3.4 in the Pacific Ocean (Kao and Yu, 2009). Time series of sea surface temperature and anomalies for these oceanic regions are available at the Climate Prediction Center

* Corresponding author.
E-mail address: aconde@institutopesca.gob.ec (A. Conde).

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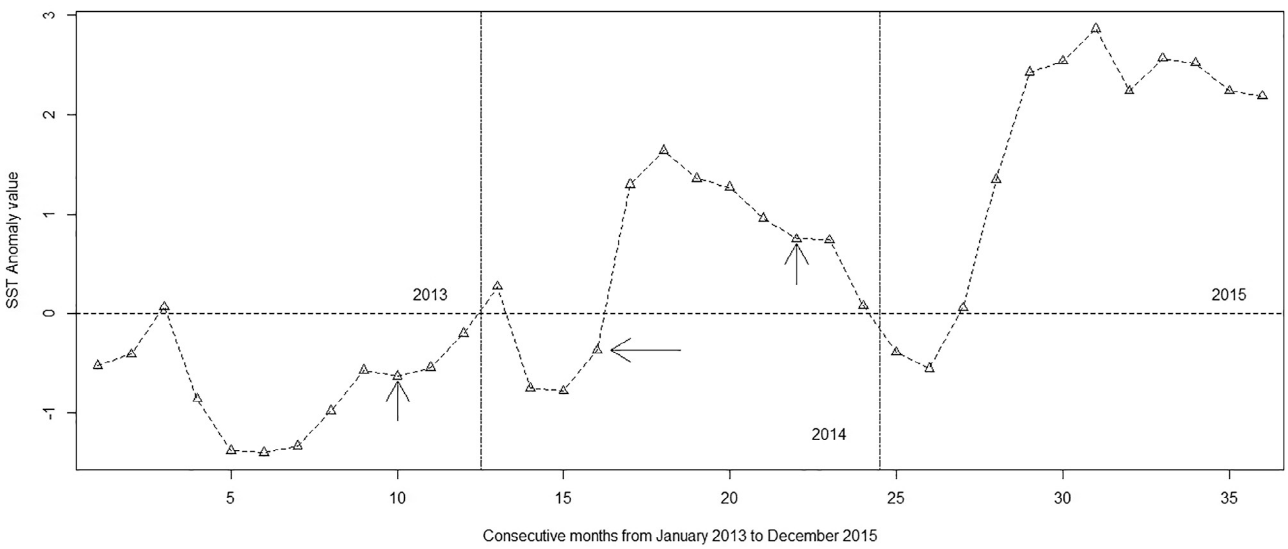

Fig. 1. Monthly sea surface temperature (SST) anomalies for El Niño 1 + 2 zone recorded from January 2013 to December 2015. The horizontal line highlights the zero value that implies no anomalies. Vertical lines separate consecutive years. The anomalies profiles are more similar between 2014 and 2015, with more intense anomalies in 2015. Positive anomalies indicate El Niño conditions in the study site. Sampling occasions are identify by arrows.

website (http://www.cpc.ncep.noaa.gov/data/indices/sstoi.indices). Fig. 1 shows sea surface temperature anomalies for El Niño 1 + 2 region. Anomalies are calculated as the departure for any month in relation to the 1981–2010 monthly mean sea surface temperature values. As such, departures may be positive or negative. The profile of the anomalies is more similar between 2014 and 2015 (El Niño years) than between 2014 and 2013 (the latter was not an El Niño year, Fig. 1; Stramma et al., 2016; Yukiko et al., 2016). The profiles suggest similar oceanic processes with different intensities between 2014 and 2015. In fact a strong El Niño was expected in 2014 but an intrusion of subsurface cold water off the tropical Pacific weakened its occurrence (Yukiko et al., 2016). Anomalies increased in their values at consecutive sampling occasions (arrows in Fig. 1) suggesting a heating process through time. The difference between the value of the anomalies at the same month of consecutive years (first and last arrow in Fig. 1 corresponding to October) evidences different oceanographic conditions in the study site. The tendency evolved temporally, showing the highest anomaly values in October 2015, associated with an acuter El Niño event (Stramma et al., 2016).

Our 2014 sampling offshore coincided with an El Niño onset in the eastern Pacific (Yukiko et al., 2016). Based on data collected at the start of our sampling in 2013, we hypothesize that a distributional shift occurred in phytoplankton from a depth of 10 m to surface waters before and after the establishment of El Niño conditions. The hypothesis is directly linked to the temporal occurrence of El Niño but the actual ecological cause is not disentangled though a likely explanation is discussed.

2. Material and methods

2.1. Study site, sampling and lab procedures

Samples were collected at the early morning during the dry season (October 2013 and 2104) and in the rainy season (April 2014) at seven sampling stations eight miles off the Ecuadorian coast. The sampling sites were located at the northern (northernmost site at 01.1 N–079.8 W, close to the border with Colombia) central and southern regions of the country (southernmost site at 03.3 S–080.5 W, close to the border with Peru). The sampling sites were, from north to south, 122, 226, 332, 383, 423 and 502 miles apart from the northernmost sampling station.

Samples were taken at approximately 0.5 m depth (hereinafter referred to as "near-surface") and 10 m depth with 10 L Niskin bottles. Phytoplankton was preserved with lugol solution. A subsample of 200 mL was kept to separate an aliquot of 10 mL for cell sorting, counting and identification. We proceeded using an inverted microscope and sedimentation chambers (Utermöhl, 1958).

2.2. Data analysis

The use of samples taken from seven sites distributed along ca. 500 miles are tested here to find a potential temporal variation in phytoplankton depth distribution. Therefore, it is assumed that significant results imply an overall regional phenomenon.

Differences in both log abundances and species richness between near-surface and 10 m throughout sampling occasions were tested using a one-way ANOVA followed by a pairwise Tukey Honest Significant Difference (HSD) test with adjusted p-values (Crawley, 2007). Data was checked for normality (Shapiro test) and homoscedasticity (Fligner-–Killeen test) prior to ANOVA. The null hypothesis about the normal distribution of log abundances was at the limit of rejection ($W = 0.907$, $p = 0.048$) but the data clearly had a constant variance (chi-square = 0.269, df = 2, $p = 0.874$). Because homoscedasticity is the most important assumption underlying analysis of variance (Crawley, 2007) we proceeded with the ANOVA. Beside, differences in log abundances were correlated with species richness through time using the Pearson correlation.

Sites with more abundance of phytoplankton at near-surface than at 10 m depth were coded with 1 (0 otherwise). The same binary coding was applied to differences in species richness distribution between near-surface and 10 m depth. These binary variables were modelled using a logistic regression with a logit-link function and a binomial distribution for the error term (a type of generalized linear model –GLM–, McCullagh and Nelder, 1989). GLMs are used when the variance is not constant, and/or when the errors are not normally distributed. Overdispersion may compromise the analysis. It occurs when there is extra, unexplained variation in the response or, mathematically, when (residual deviance)/(residual degrees of freedom) > 1 (Crawley, 2007; our highest ratio was 1.18 so results were considered as valid). Logistic regression models allows calculating the probability of a success within levels of a factor (Crawley, 2007), thus we calculated the probability of phytoplankton preferring near-surface location rather than 10 m depth at a particular sampling occasion. The logistic regression was fitted using data from October 2013 plus those observations from April or