



Interannual summer variability in oceanic euphausiid communities off the Baja California western coast during 1998–2008

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ABSTRACT

Euphausiids are a major component of the zooplankton biomass due to their large size, contributing with high carbon content to other trophic levels in the pelagic ecosystem. We analyzed the summer interannual variability in euphausiid species composition based on carbon mass of the Baja California oceanic domain during 1998–2008. Selection of one exclusive season allowed the emphasis of interannual changes in order to research possible biological impacts. During the period 1998–2008 prevailed intense interannual activity, with four El Niño events, two of them (1997–1998 and 2006–2007) with SST anomalies propagating toward the eastern Pacific (EP-El Niño), while the other two (2002–2003 and 2004–2005) had SST anomalies limited to the central Pacific (CP-El Niño). There were also La Niña events in 1998–2000 and 2007–2008. The species with higher biomass contribution off Baja California were *Nematoscelis difficilis*, *Euphausia gibboides*, *Thysanoessa gregaria*, *Euphausia eximia*, *Nyctiphanes simplex*, and *Euphausia pacifica*, with a global geometric mean of 156, 66, 38, 30, 21, and 13 $\mu\text{g C m}^{-3}$ respectively. *N. difficilis* and *E. pacifica* were dominant in the northern area (29.5–32°N), *N. difficilis* and *E. gibboides* in the central area (27–29.5°N), and *E. eximia* dominated in the southern area (24.5–27°N). 1998–2008 biomass anomalies showed a variety of patterns by species with the clearest footprint, in most of the species, during the strong EP-El Niño 1997–1998. CP-El Niño events also left a footprint in the biomass of some species but this was not always by anomalies of the same nature as EP-El Niño. The best examples were *N. difficilis* and *N. simplex*, which presented lightly positive anomalies during July 1998 but were strongly negative in the summer of 2003 and 2004. The opposite was observed in *E. recurva*, with a negative anomaly in July 1998 but positive in 2004 and 2005. The biophysical coupling between the species assemblage and environmental variables, using canonical correspondence analysis (CCA), explained 22% of the biomass variability. The first axis was responsible for thermal conditions in the upper layer (temperature at 10 m, 50 m, and the gradient between 10 and 100 m depth), while the second axis concentrated the oxygen gradient, oxygen and salinity at 50 m depth, and 200 m temperature. A large group of tropical-subtropical species showed covariance with axis-1, while *E. pacifica* and *T. spinifera* had an inverse covariance. The equatorial species *E. distinguenda* and *E. lamelligera* were close to axis-2, though the stations were limited to slope water where intense upwelling bring oxygen depleted deep water. Transition zone species (*E. gibboides*, *N. difficilis*, *T. gregaria*, and *N. simplex*) were relatively inert to both axes. Their response to climatic variability was less predictable and new variables should be explored, including bottom-up and top-down mechanisms.

1. Introduction

During the last decades the knowledge of how zooplankton communities change through long-term scales has considerably increased (Beaugrand, 2003; Bograd et al., 2003; Mackas et al., 2012). Long-time series are necessary to evaluate interannual anomalies, decadal regime shifts and climate change. With that purpose the Baja California region of the California Current System (CCS) has been the subject of intense sampling since the end of the past century (Baumgartner et al., 2008;

Lavaniegos, 2009; Lavaniegos et al., 2015). Baumgartner et al. (2008) created a summary of the thermohaline conditions, chlorophyll concentration and zooplankton biomass during 1997–2007, while Lavaniegos (2009) analyzed the abundance of functional zooplankton groups from the same period. Furthermore, Lavaniegos et al. (2015) updated the time-series of zooplankton functional groups for an extended period (1997–2013). However, in those studies euphausiids and other zooplankton were analyzed per major taxonomic group, but without any distinction between species.

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Long-term changes in euphausiid species abundance off Baja California and California were formerly investigated by Brinton and Townsend (2003), who analyzed the winter and spring variability through decadal periods during 1951–2002. Among the dominant species in the CCS, *Euphausia pacifica* and *Thysanoessa spinifera* were associated to low temperature, decreasing their abundances during warm El Niño events, while *Euphausia recurva*, *Euphausia eximia*, and *Euphausia gibboides* increased (Brinton and Townsend, 2003). In the southern California region, where the longest time-series was available, *Nyctiphanes simplex* and *E. eximia* presented decadal variability with a positive response during 1976–1998. However, the time-series for the Baja California sectors were shorter and with temporal gaps (surveys during 1951–1985 in the north and 1951–1981 in the central region), making the verification for a decadal response impossible (Brinton and Townsend, 2003).

Subsequently, Lavaniegos et al. (2010) and Lavaniegos and Ambriz-Arreola (2012) described interannual variability of the euphausiid community in Baja California waters based on 17 cruises carried out during 1997–2005. They found that *E. pacifica* and *T. spinifera* were absent during El Niño 1997–1998, reappearing in 1999, while *E. eximia* presented its highest abundance in 1997–1998. Even though this study presented gaps in 2001–2004, it was evident that typical species of the CCS as *E. pacifica*, *E. gibboides*, *Nematoscelis difficilis*, and *Thysanoessa gregaria* were abundant during the subarctic water intrusion occurring during July 2002 (Wheeler et al., 2003; Gómez-Gutiérrez et al., 2007; Lavaniegos, 2009). In addition, the high abundance of *E. pacifica* and *T. spinifera* drew attention during April and July of 2005, contrasting with observations in the northern sectors of the CCS. However, Lavaniegos and Ambriz-Arreola (2012) did not analyze CP-El Niño events of 2002–2003 and 2004–2005, due to missing data. In the present study, we display a more continuous and extended time-series based on biomass of summer euphausiid species collected during 1998–2008, to do a more complete analysis of interannual variability and possible long-term tendencies. This longer time-series will enable a more robust statistical analysis due to the possibility of estimating biomass anomalies.

The knowledge of euphausiid ecology in the CCS is reported mostly based on the abundance (Brinton, 1962; Gómez-Gutiérrez, 1995; Brinton and Townsend, 2003). However, the adult component of the euphausiid populations represents substantial biomass due to their large body sizes. Large species from the CCS are *E. eximia* and *E. gibboides* with adults up to 30 mm, *E. pacifica* has an intermediate size (11–25 mm), and *N. simplex* is a small sized species (8–17 mm; Brinton et al., 2000). Diversity in species and sizes represent a broad spectrum of preys for nektonic predators. Therefore, euphausiid biomass stands out as a key link in trophic webs and carbon cycling dynamics. Consequently, our research is based on biomass estimations rather than on abundance. The study will be restricted to the oceanic region because the coastal shelf stations are too few and the previous study showed categorical differences between oceanic and neritic euphausiid communities (Lavaniegos and Ambriz-Arreola, 2012). In the neritic region, *N. simplex* is dominant, with eventual occurrence of *T. spinifera* in the upwelling region off Punta Colonet (31°N), Punta Canoas (29.4°N), and Punta Eugenia (28°N). Thus, the focus of the present study is on the oceanic latitudinal differences of the summer euphausiid communities' biomass with a more extensive sampling coverage than those previously reported.

During the study period, the CCS underwent the influence of four El Niño events; two of them (1997–1998 and 2006–2007) with high SST anomalies propagating from the central Pacific toward the Eastern Pacific (EP-El Niño). According to the Oceanic El Niño Index (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml), the EP-El Niño 1997–1998 was strong, starting in May 1997 and ending in May 1998, while the EP-El Niño 2006–2007 was weak and short (September 2006–January 2007). Other two El Niño events showed positive SST anomalies limited to the central

Pacific (CP-El Niño, also named Modoki). The CP-El Niño 2002–2003 lasted from June 2002 to February 2003 and the CP-El Niño 2004–2005, from July 2004 to April 2005 (Lee and McPhaden, 2010). Regarding the cold phase of the ENSO cycle, only two events occurred, one in 1998–2000 and another in 2007–2008. La Niña 1998–2000 started in July 1998 and ended in February 2001, with two peaks of high intensity in the winters of 1998–1999 and 1999–2000. La Niña 2007–2008 presented two cold pulses, one between August 2007 and June 2008, and another from November 2008 to February 2009 (Hu et al., 2014). Moreover, an extra-tropical cooling event occurred from 2002 to 2003, which consisted in a subarctic water intrusion (Wheeler et al., 2003, Lavaniegos, 2009). The goal of the present study is to analyze the intense interannual activity that occurred in the region during 1998–2008. We expect to find changes in euphausiid biomass as a response to climatic variability taking as a reference the biogeographic knowledge of the species (Brinton, 1962; Brinton et al., 2000).

2. Methods

The study area off Baja California pertains to the subtropical sector of the CCS. Because of the strong latitudinal gradient in temperature and increasing southward influence of tropical species, the area was divided in three sections: north, central, and south. Each sector included four transect-lines, extending 240 km from coast to offshore, with the exception of two transects in the central region (117 and 120) that were 390 km long (Fig. 1).

2.1. Sampling

Zooplankton samples were collected with a bongo net towed obliquely between the surface and 200 m depth, with a velocity of 3.7 km h^{-1} . The net had 500 μm mesh width and 71 cm of mouth diameter (61 cm before 2000). The water filtered was measured with a flowmeter located in front of the net. The plankton was preserved using 4% formaldehyde with sodium borate. Only zooplankton samples from nighttime stations were selected to avoid strong variability due to vertical migration (Brinton, 1967). To discard seasonal variability, only summer cruises were selected. This gives 338 zooplankton samples from 11 cruises performed during the summers of 1998–2008 (see Appendix 1 for the list of stations and cruise used in the present study).

In all stations CTD/rosette casts were performed to 1000 m depth. Water samples from 0, 10, 20, 50, 100, and 150 m depth were taken with 5L Niskin bottles to determine chlorophyll *a*. The water was filtered with Whatman GF/F filters and these frozen for further fluorescence analysis in the laboratory.

2.2. Taxonomic analysis

Euphausiid species were identified and counted per life phases: calyptopis, furcilia, juvenil and adult. Subsamples (1/8 or 1/16) were used to count the most abundant species or a particular life phase, but the complete sample was analyzed for the less abundant species. Taxonomic identification was done with the interactive key of Brinton et al. (2000). The larvae of *Euphausia diomedea*, *E. mutica*, *E. recurva*, and *E. eximia* were difficult to identify, and are reported as Group 1A (Brinton, 1962).

2.3. Data analysis

Euphausiid abundances were converted to carbon mass using the carbon mass-length function for *E. pacifica* estimated by Ross (1982): $Y = 0.337 (X)^{3.17}$, where *Y* is carbon mass (μg) and *X* the body length (mm) assuming all species have the same body weight-length relationship. The mean body length of each life phase was taken from Brinton et al. (2000). The biomass of all life phases was added to get the carbon mass of the total population of each species. Before the

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