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Composition and distribution of the zooplankton community along the west coast of Baja California peninsula and its relationships with the environment variables

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A B S T R A C T

The year 2014 is between one of the coldest La Niña events (2011−2012), and one of the most intense warming events between (2013–2016) in the California Current System (CCS). The information provided in this work documents part of the missing information about zooplankton and oceanographic features for the year 2014 along the southern portion of the CCS off the western Coast of Baja California Peninsula (WBCP). The statistical analysis of environmental variables during the summer of 2014 distinguished three regions off the WBCP (north, transitional, and south), in coincidence with changes in zooplankton groups composition. Thermal and saline oceanic fronts off the central region coincided with an increasing abundance of gelatinous zooplankton, where two cold core eddies were present. These mesoscale structures represent physical barriers that seem to determine the distribution limits of planktonic communities. Since no day/night statistical differences in zooplankton composition were found, zooplankton community changes seem more related to the latitudinal environmental changes and mesoscale semi-permanent structures in the middle peninsula.

1. Introduction

The West Coast of Baja California Peninsula (WBCP) in the Mexican Pacific, constitutes the southern limit of the California Current System (CCS), and is one of the most extensive and productive marine ecosystems in the region (Espinosa-Carreón et al., 2007). Here, various physical processes occur (coastal upwelling, advection, turbulent mixing, internal waves, and mesoscale eddies) that modify the supply of nutrients in the euphotic zone and determine the variability of the biomass and productivity of phytoplankton (Gaxiola-Castro et al., 2010), as well as the distribution and abundance patterns of zooplankton organisms.

The central region of the WBCP is a convergence zone for the Subarctic, Central Pacific, and Tropical Pacific water masses (Durazo, 2009), which form the eco-regions of the California Current, North Central Pacific, and Eastern Tropical Pacific (Sutton et al., 2017). The area off Punta Eugenia and Bahía Sebastián Vizcaíno, in the central region of the WBCP, represents the boundary between the San Diego and Mexican biogeographical provinces (Briggs and Bowen, 2012). It is a faunal transition zone where temperate-subarctic and tropical species coexist, and where many of them reach their latitudinal distribution limits (Moser and Smith, 1993; Aceves-Medina et al., 2018; Bautista-Romero et al., 2018; Aceves-Medina et al., 2020). This transition zone seems to be associated with the presence of oceanic fronts and semi-permanent mesoscale eddies (Aceves-Medina et al., 2019) which interrupt the hydrodynamic interconnection between the northern and southern regions, notably affecting the southern transport of biological populations (Durazo et al., 2010).

Changes in atmospheric pressure, current strength and direction, water masses, and winds, determine the seasonal climatic variability (Durazo, 2009). The subarctic water mass (SAW) prevails in the area during the winter, spring, and early summer, this is because it is associated with the California Current, of greater intensity, that flows

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southward along the peninsula, as well as strong winds that cause intense coastal upwelling during spring and early summer. The California Current weakens between summer and fall, and due to this, a northward flow of warm water occurs mainly south of Punta Eugenia, where tropical surface water (TSW) and subtropical surface water (StSW) predominate (Durazo, 2009). The water masses and wind seasonality determine the establishment of communities with less diversity but greater abundance during the cold season (winter to early summer). While from summer to fall, diversity is higher due to an increase in the number of tropical and equatorial species (Palomares-García and Gómez-Gutiérrez, 1996; Gómez-Gutiérrez et al., 1999; Hernández-Trujillo et al., 2010; Jiménez-Quiroz et al., 2019; Lavaniegos et al., 2010a, 2010b; Aceves-Medina et al., 2019).

Most studies about the composition, distribution, and abundance of zooplankton in the WBCP, and their relationship to environmental variability, focus on changes that happen within only one taxonomic group such as copepods, euphausiids, or ichthyoplankton. (Funes-Rodríguez et al., 1995, 1998; Gómez-Gutiérrez et al., 1995; Palomares-García and Gómez-Gutiérrez, 1996; Hernández-Trujillo, 1999; Lavaniegos et al., 1998, 2002; Hernández-Torre, 2004; Aceves-Medina et al., 2019; Jiménez-Quiroz et al., 2019). However, studies about zooplankton functional groups offer a broader view of the community structure in the marine pelagic ecosystem, suggesting the occurrence of spatial and temporal alternation among functional groups in relation to the climate, as has been suggested for Antarctic waters (Loeb et al., 1997). For example, the zooplankton abundance decline in southern California seems related to a decrease in the abundance of gelatinous forms (Lavaniegos and Ohman, 1999). In the WBCP, these long-term changes do not seem to be so evident, most likely due to the lack of adequate data series, although Lavaniegos et al. (2002) showed that between the fall of 1997 and 1998, the numerical abundance of copepods decreased considerably while the salp's abundance increased.

Zooplankton volumes were close to average in southern California and Baja California during the 2011–2012 La Niña event, but gelatinous organisms predominated over the copepods and euphausiids (Bjorkstedt et al., 2012). For El Niño 2015–2016, McClatchie (2016) showed that positive temperature anomalies over southern California and Baja California were associated with extremely low zooplankton volumes, resulting from low abundances of gelatinous zooplankton, copepods, and euphausiids. Although during 2014 and 2015, a significant decrease in primary production together with an increase in the copepod abundance occurred along the coasts of California (Leising et al., 2015); there is no data about the effect of The Blob (a persistent high-pressure zone pinned warm water masses along North America's west coast (Cavole et al., 2016; Reed et al., 2016; Di Lorenzo and Mantua, 2016; Jacox et al., 2016; Gentemann et al., 2017; Wells et al., 2017) in the southern region of the California Current off the Baja California Peninsula. The Marine heatwaves (MHWs) are prolonged warm water events that are increasing in frequency and magnitude due to rising global temperatures, where The Northeast Pacific Blob (the Blob) was categorized as "severe" based on a combination of magnitude, extend, and duration of the anomalies observed (Hobday et al., 2018; Holbrook et al., 2019). Therefore, this unusually widespread MHV could be a negative effect on the zooplankton community.

The main goal of the present study was to analyse the oceanographic characteristics of the area during the summer of 2014, and determine its relationship with the composition, abundance, and distribution of zooplankton groups throughout the exclusive economic zone of the West Coast of Baja California Peninsula. We propose the hypothesis that the zooplankton composition change by the latitudinal environmental changes and mesoscale semi-permanent structures in the middle peninsula during the warming events in the summer of 2014. These results complement what has been documented during this important period of environmental change in the WBCP (2011–2016) and present comparative data with other warming events (e.g. Aceves-Medina et al., 2023).

2. Material and methods

2.1. Sampling area

Zooplankton samples come from two coupled surveys on board the R/V BIPO INAPESCA within the Mexican Economic Exclusive Zone (EEZ) off the West Coast of Baja California Peninsula, between 32.5° to 23° N and 110° to 122° W covering 5173 nautical miles (nmi) (Fig. 1). The first cruise was from 15th July to 7th August, and the second one from 18th August to 5th September 2014. The study area was sampled at 191 stations, arranged into 18 transects spaced every 40 nmi, parallel to each other, and perpendicular to the coastline. The longest transect comprised 351 nmi from the shore to the oceanic area, while the shortest was 124 nmi. The location and designation of the sampling stations and transects, followed the original convention defined by the CalCOFI program (Weber and Moore, 2013).

The California Current, which flows southward, dominates the oceanic circulation. It is found between the surface and 100 m depth, and horizontally between 200 and 500 km off the coast; it transports the Subarctic Water mass (SAW), that has relatively low temperature (10–21 °C) and salinity values (33.13), and high dissolved oxygen concentration (7.5 mg/l) (Durazo and Baumgartner, 2002). The California Counter Current has a northward flow which is located between 100 and 300 m in depth (Durazo et al., 2005; Durazo, 2015). The CCC extends >100 km offshore (Lynn and Simpson, 1987) and it carries Tropical Surface Water (TSW) that is normally located from the extreme south of the peninsula to PE with relatively high temperature (> 25 °C), salinity (< 34), and low dissolved oxygen (Lynn and Simpson, 1987). Below the surface (≈100–250 m), is the Equatorial Subsurface Water mass (ESsW) that originates in the South Pacific and flows towards the pole, with temperatures that fluctuate between 8 and 15 °C, it is salty (> 34.4), low in dissolved oxygen and high in nutrients (Lynn and Simpson, 1987; Durazo and Baumgartner, 2002; Durazo, 2015).

Intense coastal upwelling occurs during spring and mid-summer mainly north Punta Eugenia, due to the increase in the strength of the northwest winds that blow parallel to the WBCP, this process brings nutrient-rich water to the surface increasing its concentration, it also causes a considerable decrease in the sea surface temperature, and an increase in primary production (Pares-Sierra et al., 1997). Mesoscale cyclonic and anticyclonic eddies are present along the peninsula, some of them with a semi-permanent presence such as those off the surrounding area of Punta Eugenia and Bahia Vizcaino (Soto-Mardones et al., 2004).

2.2. Collected data

At each sampling station data was recorded for vertical profiles of conductivity, temperature and depth with a calibrated SeaBird SB11 CTD, which preceded the collection of biological samples obtained with oblique zooplankton trawls (from 200 m in depth to surface) of Bongo nets with 505-μm of mesh opening (Sarmiento-Lezcano et al., 2023). The Bongo system consists of two cylindrical-conical nets (2 m in length and 71 cm of mouth diameter) each one fitted with a flexible cod end and a General Oceanics flowmeter at the mouth for the determination of the volume of water filtered. The sampling procedure and standardization of zooplankton abundance followed the method of (Smith and Richardson, 1977). Samples were fixed in 4% formalin buffered with a saturated solution of sodium borate. In the laboratory, the wet volume of zooplankton (ZV) of each sample was estimated according to the method of displaced volume (Beers, 1976). The zooplankton organisms were identified to functional taxonomic groups (e.g., copepods, euphausiids, etc.), and its abundance was standardized using the formula ($N = n \cdot 1000 / V_f$); where N is the standardized number of organisms in 1000 m^3; n is the number of organisms in the sample and V_f, is the volume of water filtered in each trawl. The normalized values were the basis for all subsequent analyses. Aliquots of 10 ml were obtained from samples with

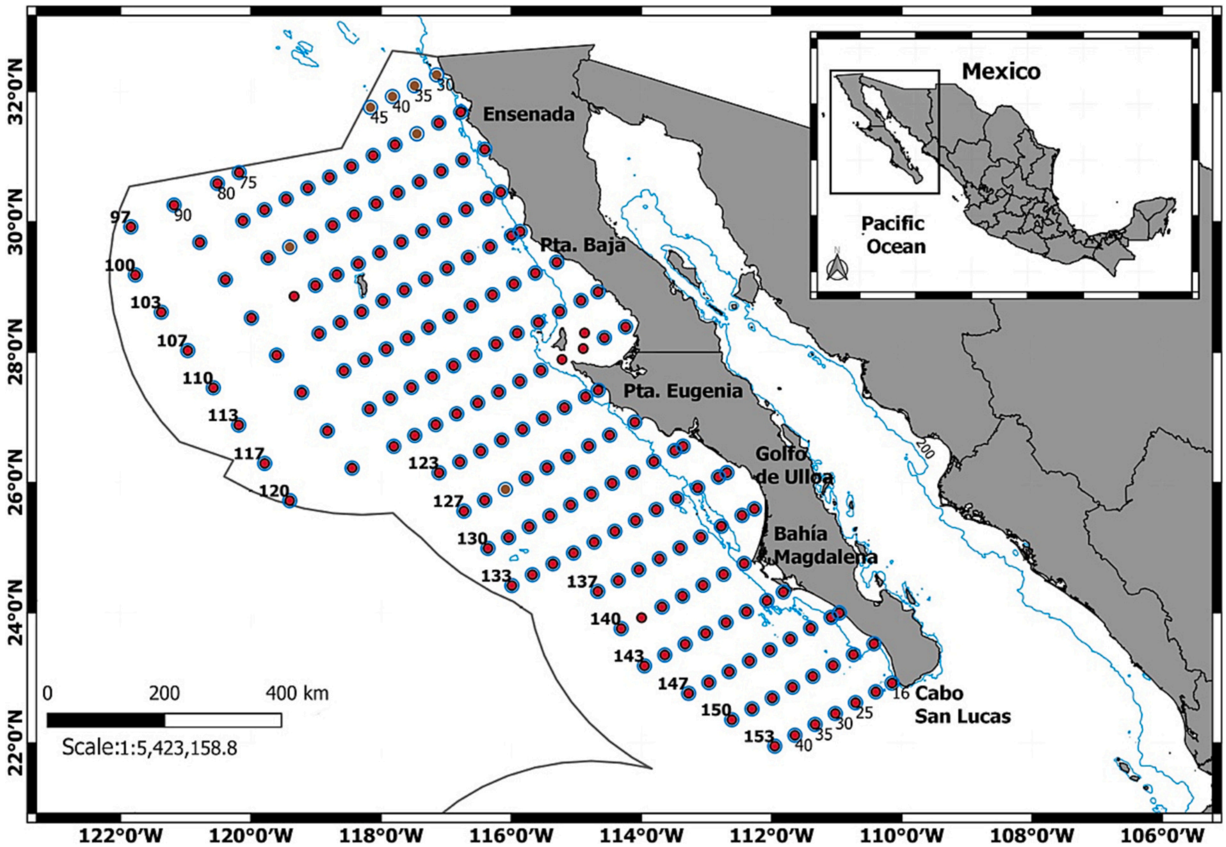

Fig. 1. Location of sampling area (Western Coast of Baja California Peninsula, Mexico). CTDs stations (red dots); biological stations (Blue empty dots); 200 m isobath (blue line). The bold numbers at the far from the coast stations designate the transect lines. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

zooplankton volume >20 ml for organism identification and counting.

The principal component analysis (PCA) was used to describe the area examined according to the environmental variables measured. Once regions were defined all analysis were made by regions. Beside the spatial differences, in order to find the diel changes in the abundance and composition of zooplankton, the stations were classified by daytime, night-time, and twilight (dawn and dusk). In the northern zone, only samples obtained during the night were analysed (n = 20). In the transition zone, 25 stations were analysed, from which 19 were at night and six during the day. In the southern zone, 40 samples were at daytime, 31 at night, and eight at twilight.

Kikvidze and Ohsawa (2002) method was used to identify the co-dominant groups within the community by geographic zones, estimated by the community model and Simpson's diversity index. Co-dominants are species that can constitute a subset, and are more abundant and more uniformly distributed than other species in a given sample.

2.3. Relationship between environmental variables and zooplankton composition and distribution

At each transect, vertical sections of temperature, salinity and dissolved oxygen were obtained with Ocean Data View software (Schlitzer, 2015). In addition, net primary production (NPP; mg $C\cdot m^{-2}\cdot d^{-1}$), and sea surface temperature (SST, °C) were obtained from remote sensors. Monthly NNP data was downloaded from the Ocean Productivity[1] website of the Oregon State University, with a spatial resolution of 9 × 9 km and processed using the Vertical Generalized Production Model (VGPM). From NASA's OceanColorWeb[2] website, the SST monthly data were obtained, in this case with a spatial resolution of 4 × 4 km and processed using the proto-algorithm from MODIS Ocean Team Computing Facility (MOTCF) based on satellite infrared retrievals of ocean temperature. The minimum oxygen depth (MOD) was downloaded from the Copernicus Marine Environment Monitoring Service (CMEMS, http://marine.copernicus.eu). Following Serrano (2012), the minimum oxygen depth was considered as the depth where the dissolved oxygen concentration is <0.5 $ml\cdot l^{-1}$. The mixed layer depth (MLD) was calculated from field data by a 2-layer model according to (Planque et al., 2006). In addition, satellite mean sea level anomalies (MSLA; cm) and their associated geostrophic flow were obtained from CMEMS and were used to portray the regional circulation patterns during the survey.

Finally, to evaluate the degree of relationship between the distribution and abundance of the zooplankton groups with the environmental variables (McCune et al., 2002), canonical correspondence analysis (CCA) was done. The abundance of the species used for the analysis was transformed to log(x + 1). Environmental variables were transformed to $(x-\overline{X})/\sigma_x$, where x is the original value of the variable, $\overline{X}$ is the average, and σ_x the standard error (standard deviation divided by the square root of the sample size). An ANOVA test was applied with a significance level of 5% ($\alpha = 0.05$) to identify which variables of those evaluated in the analysis were significant. Tukey's Honest Significant Differences Post Hoc test (HSD) was used to find differences between pairs of groups (groups of species and biogeographic zones) of the

[1] http://www.science.oregonstate.edu/ocean.productivity/index.php

[2] https://oceancolor.gsfc.nasa.gov/

analysis of variance previously applied. The statistical analysis and data processing were carried out in the R programming language environment (R Core Team, 2021). The sampling map was generated using the geographic information system QGIS (V.3.12.1) (QGIS Development Team, 2020).

3. Results

3.1. Environmental conditions

The PCA explained 81.2% of the environmental variability in the first three components (Table 1). The first component (PC1) explained 55.7% of the variance and had the highest correlation coefficient with SST, sea surface salinity (SSS), MOD, dissolved oxygen (DO) and NPP. In this case SST (15–30 °C) and SSS (33.25–34.8) increased southward (Fig. 2A–B) while MOD (30–488 m), DO (3.7–8.33 ml/l), and NPP (193–1047 mg C·m^{-2}·d^{-1}) increased northward (Fig. 2C, D, E). PC2 explained 15% of the variance (Table 1), and it was mainly correlated with zooplankton volume and the mixed layer depth, from which zooplankton volume showed the highest correlation and displayed its highest abundance values in the coastal zone (Fig. 2F), while the mixed layer depth exhibited the highest values at the north of Punta Eugenia, and in the ocean region (Fig. 2G).

The PCA reveal three aggregations (Fig. 3), one on the left side of the biplot, corresponding to the stations within the north region, between transects 96.7 and 116.7 (Fig. 3A–B). A second group was located on the positive side of the PC1 axis, corresponding to stations in the southern region between transects 136.7 and 153.3. The third group was an intermediate group found between transects 120 and 133.3 (Fig. 3A–B). Features of groups identified were described in the next section.

The T-S diagrams showed different water masses in the three regions (Fig. 3C). North of line 120 was dominated by SAW; the transitional region (transect 120 to 133) presented an overlap of SAW and TrW. This overlap was shown by an upper layer within the first 50 m depth with values corresponding to TrW, while underneath this layer SAW was predominant. South of transect 133 was already showing the influence of tropical waters, having a mixture of SAW, TrW, TssW, and TSW, although in the first 50 m depth TrW and TSsW predominated. The ESW in the northern region was only appreciable below 200 m, while in the southern region it began to be detected from 100 m depth.

The geostrophic flow (Fig. 4A) over the neritic region showed a northward direction from Cabo San Lucas to Punta Eugenia. At approximately 26° N a cyclonic eddy (E1) was occupying the oceanic area from transects 123 to 133. North of Punta Eugenia between 27 and 29° N, a second cyclonic eddy (E2) was present. Between both eddies, a front (F1) in transect 117 produced a sinking of the thermocline (Fig. 4B), halocline (Fig. 4C) and oxycline (Fig. 4D). This system of two cyclonic eddies and the front was spatially coincident with the dispersion arrangement observed in the PCA, and essentially responds to a transition zone between the cold northern ecosystem and the warm southern one.

Table 1
Principal components analysis of the environmental variables measured along the sampling area. Bold numbers showed variables with correlation greater than 60%.

	PC1	*PC2*	*PC3*
Variance explained (%)	55.7	15.1	10.4
Cumulative proportion (%)	55.7	70.8	81.2
SST	**0.9737**	0.0378	0.0001
SSS	**0.9139**	−0.0076	0.0471
MOD	**−0.8192**	−0.0223	−0.1591
DO	**−0.7652**	0.0793	0.1663
PP	**−0.6933**	0.3486	0.2068
ZV	0.0083	**0.7811**	**−0.6191**
MLD	−0.2922	**−0.6824**	**−0.5846**

Sea Surface Temperature (SST); Sea Surface Salinity (SSS); Minimum Oxygen depth (MOD); Dissolved Oxygen (DO); Primary Production (PP); Zooplankton Volume (ZV); Mixed Layer Depth (MLD).

The northern region at 10 m depth (Table 2) had low average values of temperature (21.6 °C), and salinity (33.63) associated with the highest values of DO characteristic of SAW. The transition region was dominated by TrW with an average temperature of 24.7 °C and salinity of 33.94, and the southern region was dominated by TSsW with the highest values of SST (28.4 °C) and SSS (34.53), as well as the lowest values of DO (4.6 ml/l).

The monthly averages of satellite SST, from July to September (Fig. 5A), revealed that the northern region was colder (17.8–24.9 °C) than the transition region (20.3–28.1 °C) and southern region (22.8–29.6 °C). In general, the SST was lower in July, reaching the highest values in August for the three regions. There were significant differences between zones ($F_{2,639,>200} = 699.3$, $p < 0.001$), and between months ($F_{2,639,>200} = 38.08$, $p < 0.001$). Tukey's Post Hoc test between regions showed statistical differences in all cases. The difference in mean SST between zones NR and TR was 3.1 °C (95% CL: 3–4.30 °C), for NR and SR was 6.8 °C (95% CL: 6.77–8.07 °C), and between SR and TR was 3.7 °C (95% CL: 3.06–4.48 °C). According to the months sampled, the mean SST between July and August was 4.4 °C (95% CL: 3.44–5.22 °C), for July and September was 8.6 °C (95% CL: 7.27–10.06 °C), and between August and September was 4.3 °C (95% CL: 3.04–5.61 °C). However, when areas were not discriminated there were no differences between September and August ($p = 0.416$).

Regarding the NPP, July showed the highest productivity values attaining maximum values in the most coastal stations from Ensenada to Punta Eugenia (309–2400 mg C·m^{-2}·d^{-1}), covering the north and transition regions (Fig. 5B). The productivity decreased from August to September (264–1944 mg C·m^{-2}·d^{-1}), persisting in the same areas mentioned above (Fig. S1).

There were differences in the primary production values between regions ($F_{2,633,>200} = 32.64$, $p < 0.001$) and between months ($F_{2,633,>200} = 10.50$, $p < 0.001$). The difference in mean NPP between zones NR and TR was 102.1 mg C·m^{-2}·d^{-1} (95% CL: 20.4–183.8 mg C·m^{-2}·d^{-1}), for NR and SR was 230.8 mg C·m^{-2}·d^{-1} (95% CL: 151.2–310.4 mg C·m^{-2}·d^{-1}), and between SR and TR was 128.7 mg C·m^{-2}·d^{-1} (95% CL: 57–200 mg C·m^{-2}·d^{-1}). According to the months sampled, the mean NPP between July and August was 113.4 mg C·m^{-2}·d^{-1} (95% CL: 11.7–215.2 mg C·m^{-2}·d^{-1}), for July and September was 233.5 mg C·m^{-2}·d^{-1} (95% CL: 106.5–360-5 mg C·m^{-2}·d^{-1}), and between August and September was 120.1 mg C·m^{-2}·d^{-1} (95% CL: 23.8–216.3 mg C·m^{-2}·d^{-1}). However, the Tukey's Post Hoc test showed no differences between September and July ($p = 0.577$) when zones were not included in the comparison. When a distinction between zones was made, there were no differences between the north and south regions ($p = 0.067$) during July, nor in August between the north and the transition region ($p = 0.396$), and neither in September between the north and the transition region ($p = 0.743$).

In the northern region, the vertical profiles of temperature, salinity, and oxygen showed that, for the first 200 m depth, the temperature and salinity was between 10 and 18 °C and 32.5–33.75 respectively. The dissolved oxygen within the first 250 m depth ranged between 3 and 5.25 ml/l, and the minimum oxygen depth was mainly observed below 400 m.

For the transition region, the temperature in the first 100 m ranged between 15 and 22 °C, while from 200 m depth and below it was homogeneous. Salinity was between 33.5 and 33.75 in the first 100 m, increasing with depth. In general, the dissolved oxygen was found between 3 and 5.25 ml/l and the minimum oxygen depth was observed between 400 and 450 m. At the lower margin of the transition region, one mesoscale anticyclonic eddie could be observed, in which the minimum oxygen concentration was reached at 100 m depth, salinity increased between 200 and 400 m and the isotherms deepened.

Finally, in the southern region, the temperature range was between

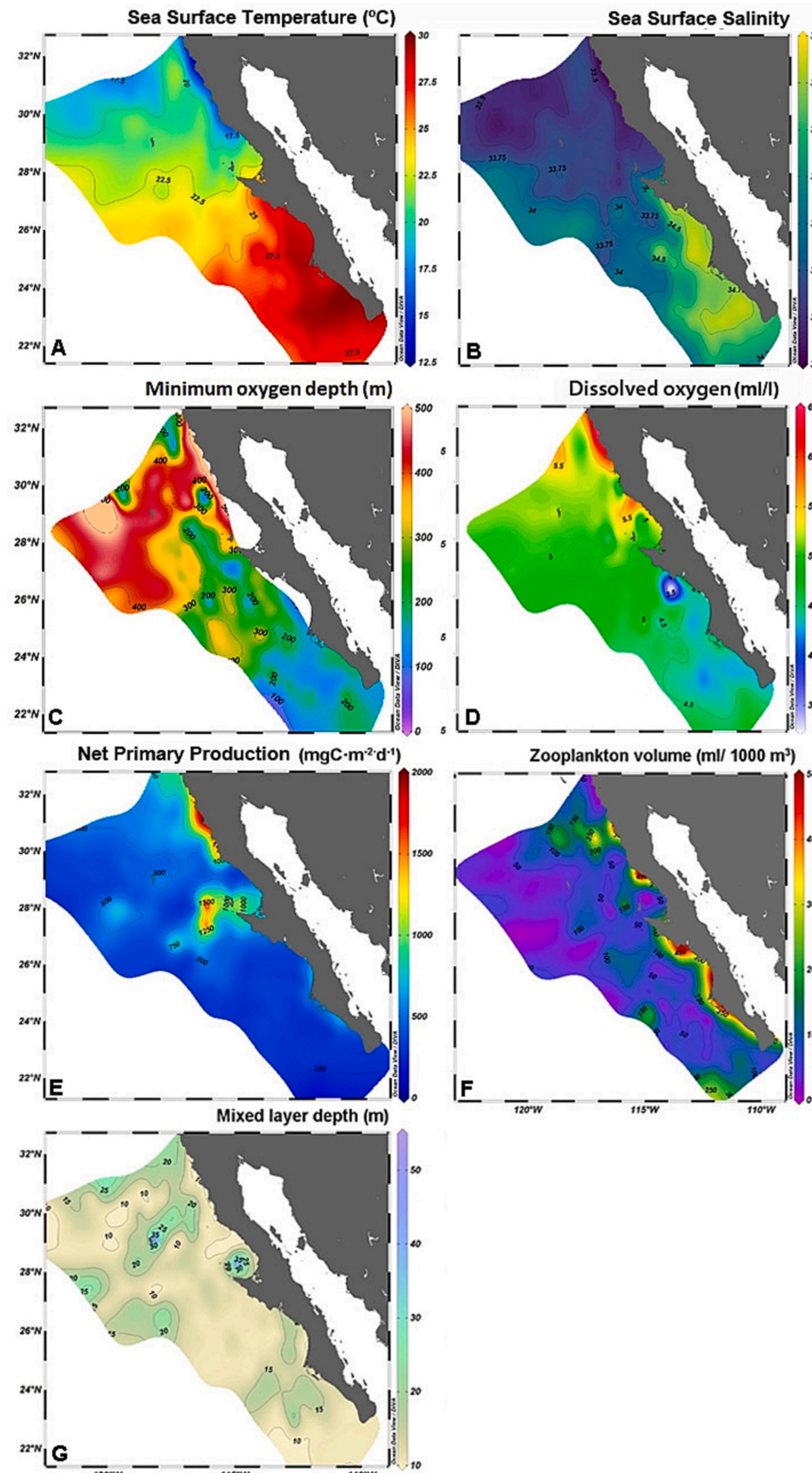

Fig. 2. Environmental variable distribution measured along the sampling area (Summer 2014). (A) Sea Surface Temperature (SST); (B) Sea Surface Salinity (SSS); (C) Minimum Oxygen Depth (MOD); (D) Dissolved Oxygen (DO); (E) Net Primary Production (PP); (F) Zooplankton Volume (ZV); (G) Mixed Layer Depth (MLD).

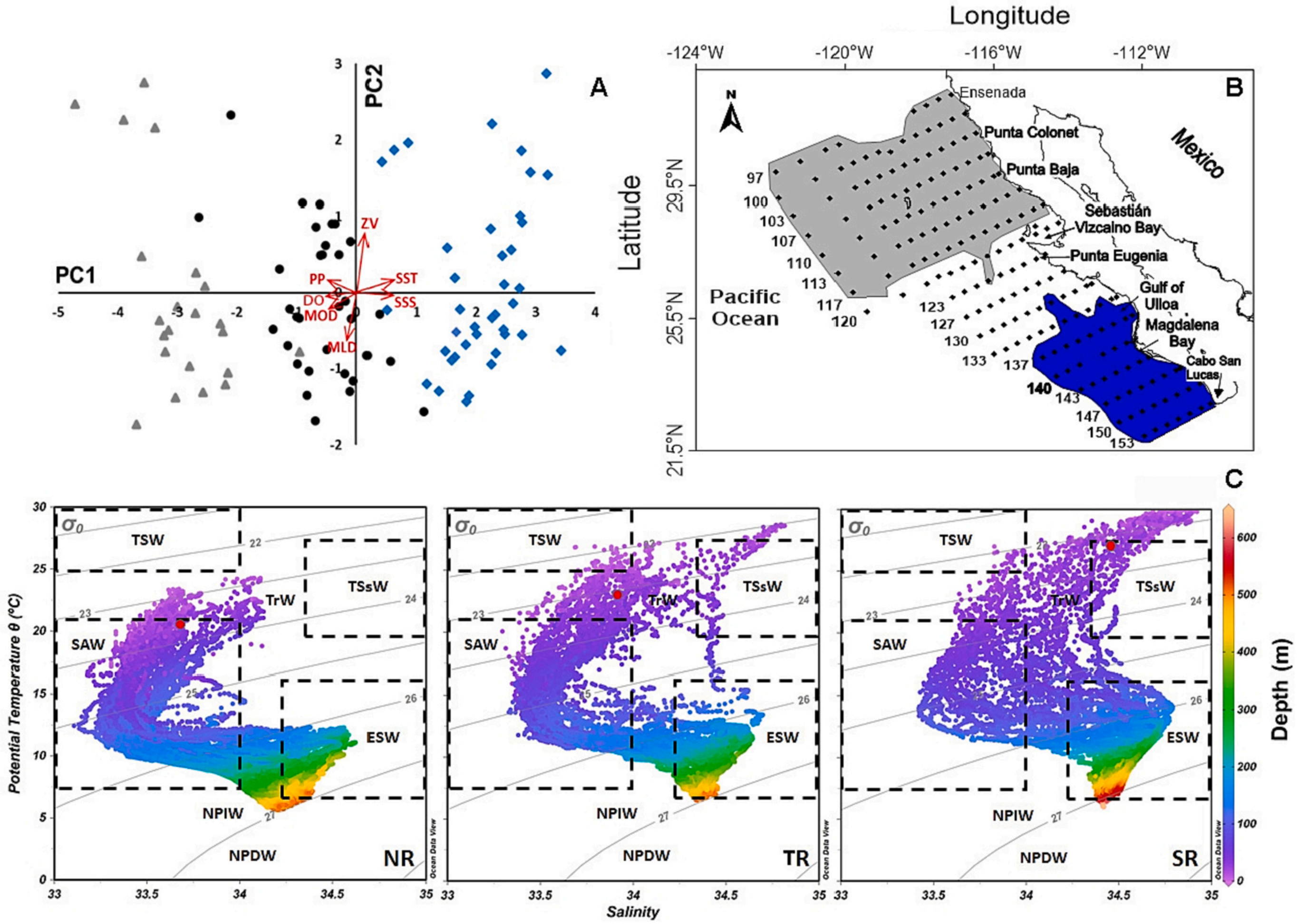

Fig. 3. (A) PCA scatter diagram from the environmental variables (SST, Sea Surface Temperature; SSS, Sea Surface Salinity; MOD, Minimum Oxygen Dissolved; DO, Dissolved Oxygen, PP, Primary Production; ZV, Zooplankton Volume; MLD, Mixed Layer Depth), the Northern station in gray triangles, central stations in black circles and southern stations in blue diamonds; (B) Spatial distribution of the station groups from the PCA scatter diagram; (C) TS diagrams for each stations group in the north (NR), transition (TR) and south (SR) regions (TSW: Tropical Surface Water; TSsW: Tropical Subsurface Water; TrW: Transitional Water; SAW: Subarctic Water; ESW: Equatorial Surface Water; NPIW: North Pacific Intermediate Water; NPDW: North Pacific Deep Water). Red dots: average of temperature and salinity in 10 m depth. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

15 and 25 °C in the first 200 m, and the salinity was variable due to the different masses of water present in the sampling area. The range of dissolved oxygen varied in all transects between 3 and 6.5 ml/l. The minimum oxygen depth from the lower boundary of this region to the Gulf of Ulloa was found between 350 and 450 m depth. However, from the Gulf of Ulloa, the minimum oxygen depth was closer to the surface, approximately at 200 m in depth.

3.2. Composition and distribution of zooplankton community

A total of 25 taxonomic groups of zooplankton were identified (Table 3), where copepods were the most numerous (> 50% of zooplankton collected), followed by the Chaetognatha, Euphausidae, Pteropoda, Siphonophora, Thaliacea, and Hydroidea groups which together accounted for >30%. Throughout the sampling area, there was a higher abundance proportion of organisms at night for most of the groups. Some groups such as Echinodermata, Cephalopoda, Cladocera, Isopoda, Nemertina, Phoronida, and Cirripedia had a relative abundance of <0.1%, although their frequency of appearance in some cases was high.

From the total, only eleven taxonomic groups had a relative abundance that was greater than or at least equal to 1% within the three regions, and together they constituted approximately 98% of the total abundance (Table 4). Copepoda was the dominant group, with a similar relative abundance within the three regions (50 to 55%); other groups with little change in relative abundance between regions were Thaliacea, Amphipoda, Larvacea, and Decapoda.

The Euphausiacea group was the second and third most abundant taxa in the northern (12.1%) and transitional regions (8.2%) but was less abundant in the southern region where it occupied the seventh place (1.4%). Similarly, Pteropoda (7.9 vs 4%) and Ostracoda (4.3 vs 2.1%) were more abundant in the northern region (Table 4). While in contrast, Chaetognatha (11.3 vs 23.2%) and Hydroidea (1.5 vs 3.2%) were more abundant in the south. In addition, the frequency of occurrence in all taxa increased significantly from north (values between 26.6 and 35%) to south (35.8 to 88.7%). Regarding the average zooplankton volume (NR = 85.13 ± 79.61; TR = 91.89 ± 96.99; SR = 108.69 ± 95.85 ml/1000 m^3), no significant differences were observed between regions ($F_{2,182} = 1.033$, $p = 0.358$), nor between daytime and night-time periods (Day = 93.02 ± 97.54; Night = 97.72 ± 82.90 ml/1000 m^3, $F_{2,168} = 0.084$, $p = 0.772$).

The relative abundance in the zooplankton groups (Fig. 6) showed that in the three regions, the dominant group was Copepoda, with a relative abundance between 48 and 56%. Except for the southern region, the northern and transitional regions showed higher relative abundance of copepods during the day than at night (Fig. 6). The Chaetognatha

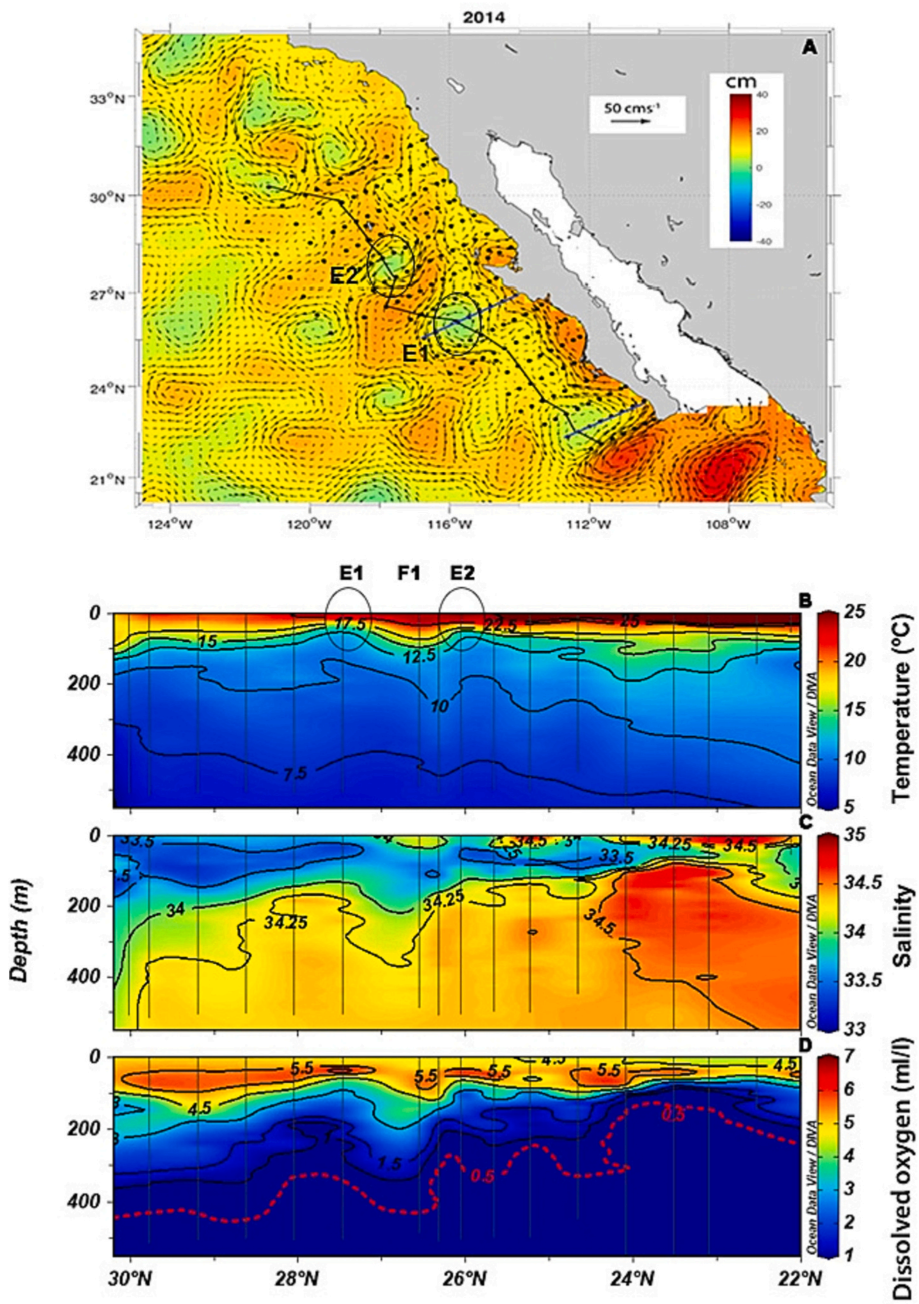

Fig. 4. (A) Direction of geostrophic flow on the surface (arrows) and mean sea level anomalies (colours) during summer 2014. The black line denoted the vertical profile section represented in the three lower panels. (B) Vertical profile section of temperature (°C), (C) salinity and (D) dissolved oxygen (ml/l). (Red dashed line: minimum oxygen depth). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Average (bold) and range values of environmental variables at 10 m depth for north (NR), transitional (TR) and south regions (SR).

	NR	TR	SR
SST	**21.6** (19.3–23.4)	**24.7** (22.1–29.1)	**28.4** (24.6–30)
SSS	**33.63** (33.40–34.06)	**33.94** (33.61–34.79)	**34.53** (33.90–34.89)
DO	**5.3** (4.1–5.7)	**4.9** (3.9–5.3)	**4.6** (3.8–4.9)
MOD	**542** (325–1047)	**453** (288–836)	**291** (193–339)
MLD	**383** (162–488)	**255** (93.7–375)	**179** (106–326)
ZV	**118** (84–156)	**108** (40–140)	**107** (44–136)
NPP	**522** (325–1047)	**419** (283–836)	**291** (193–339)

SST: Sea Surface Temperature; SSS: Sea Surface Salinity; DO: Disolved Oxigen; MOD: Minimum Oxygen Depth; MLD: Mixed Layer Depth; ZV: Zooplankton Volume; NPP: Net Primary Production.

represented between 11 and 27% of the relative abundance and seemed to be slightly more abundant during the day, this was particularly notorious in the southern region where it changed from 17.5% at night to 27.1% during the day. The Euphausiacea was the third most abundant group and showed an inverse pattern (Fig. 6), being consistently more abundant during the night than during the day in the three regions (northern region: 12.1 vs. 7.3%; transitional region: 11 vs. 3.7%; southern region: 2.3 vs. 0.8%).

The proportion of Pteropoda abundance was also higher at night than during the day in the three regions; in the northern (8.1 vs. 4.5%); transitional (6.2 vs. 4%); and southern (4.8 vs. 3.6%) region. For the Ostracoda, the relative abundance was greater during the day than at night in the northern region (8.3 vs. 4.3%) and in the transitional region (2.3 vs. 1.4%), while the opposite was observed in the south (1.8 vs

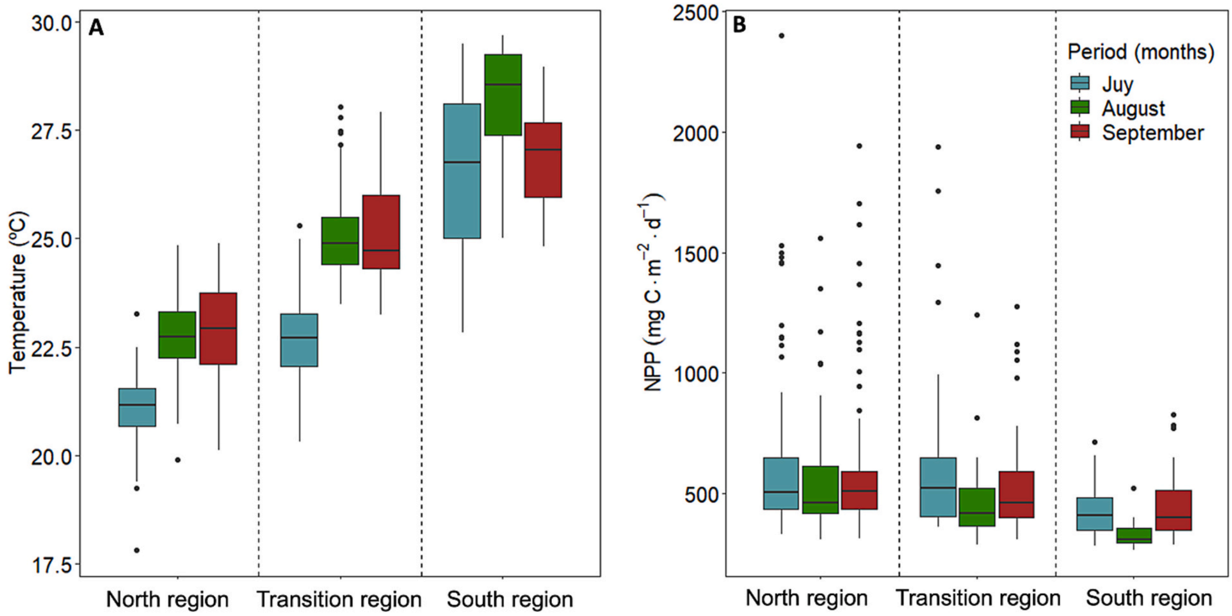

Fig. 5. Values range of (A) Sea Surface Temperature (°C) and (B) Net Primary Production (mg C·m^{-2}·d^{-1}) along the sampling area obtained from satellite data. (Based of ach boxes represent the 25% of data, horizontal black line, 50% and the upper line 75%).

Table 3
Relative abundance (A) and frequency of occurrence (O) of groups of species collected along the west coast of Baja California peninsula, for all the stations, and separated by day and night stations.

	Global	Day	Night	Global	Day	Night
	A (%)	A (%)	A (%)	O (%)	O (%)	O (%)
Copepoda	52.7	54.7	51.2	32.7	36.5	97.2
Chaetognata	19.4	24.5	15.8	32.7	36.5	97.2
Euphausiacea	5.9	1.9	9.1	32.2	27	95.8
Pteropoda	5.4	3.7	6.5	32.2	34.1	95.8
Ostracoda	2.5	2.1	2.7	29	34.9	86.1
Thaliacea	3.4	2.3	4	29.9	34.5	88.9
Siphonophora	2.4	2	2.6	32.2	35.7	95.8
Amphipoda	1.2	0.7	1.5	27.1	19	80.6
Larvacea	1.1	1.3	1	27.1	31	80.6
Hydroidea	2.6	3.3	2.3	30.4	34.9	90.3
Decapoda	1.8	1.6	1.6	26.2	20.6	77.8
Annelida	0.3	0.3	0.3	25.2	27	75
Mysidacea	0.8	0.9	0.7	16.8	30.2	50
Estomatopoda	0.2	0.3	0.2	11.7	15.9	34.7
Ctenophora	0.1	0.2	0.1	9.8	6.3	29.2
Heteropoda	0.2	< 0.1	0.3	18.2	3.2	54.2
Gasteropoda	0.1	< 0.1	0.1	7.9	0.8	23.6
Cladocera	< 0.1	< 0.1	< 0.1	7.9	1.6	23.6
Isopoda	< 0.1	< 0.1	< 0.1	7.5	1.6	22.2
Cephalopoda	< 0.1	< 0.1	< 0.1	6.1	0.8	18.1
Nemertina	< 0.1	< 0.1	< 0.1	0.5	0.8	1.4
Phoronida	< 0.1	< 0.1	< 0.1	0.5	0.8	1.4
Cirripedia	< 0.1	< 0.1	< 0.1	8.9	0.8	26.4
Echinodermata	< 0.1	< 0.1	< 0.1	6.5	0.8	19.4

Table 4
Relative abundance (A) and frequency of occurrence (O) of groups of species collected along the west coast of Baja California peninsula in the North, transition and south regions.

	NR	TR	SR	NR	TR	SR
	A (%)	A (%)	A (%)	O (%)	O (%)	O (%)
Copepoda	50.6	51.3	54.7	35.1	70.6	88.7
Chaetognatha	11.3	19.6	23.2	35.1	70.6	88.7
Euphausiacea	12.1	8.2	1.4	35.1	68.6	66.1
Pteropoda	7.9	5.4	4.0	35.1	68.6	83.0
Ostracoda	4.3	1.7	2.1	30.8	60.8	86.8
Thaliacea	3.2	3.0	3.6	34.0	64.7	81.1
Siphonophora	3.6	1.3	2.7	35.1	70.6	84.9
Amphipoda	1.5	1.1	1.1	34.0	39.2	56.6
Larvacea	1.1	1.5	0.8	26.6	66.7	71.7
Hydroidea	1.5	2.8	3.2	30.8	66.7	86.8
Decapoda	1.4	2.0	1.4	35.1	52.8	35.8
Annelida	0.3	0.2	0.3	28.7	52.9	64.1
Mysidacea	< 0.1	1.6	0.5	3.2	62.7	73.6
Estomatopoda	0.1	0.1	0.5	8.5	17.6	52.8
Ctenophora	< 0.1	< 0.1	0.3	9.6	8.6	30.1
Heteropoda	0.7	0.1	< 0.1	32.9	15.7	7.5
Gasteropoda	0.3	< 0.1	< 0.1	18.1	1.9	< 0.1
Cladocera	0.1	< 0.1	< 0.1	12.7	7.8	5.6
Isopoda	< 0.1	< 0.1	< 0.1	9.6	7.8	9.4
Cephalopoda	< 0.1	< 0.1	< 0.1	9.6	7.8	1.9
Nemertina	< 0.1	< 0.1	< 0.1	< 0.1	1.9	1.9
Phoronida	< 0.1	< 0.1	< 0.1	< 0.1	3.9	< 0.1
Cirripedia	< 0.1	< 0.1	< 0.1	19.1	3.9	< 0.1
Echinodermata	< 0.1	< 0.1	< 0.1	14.9	1.9	< 0.1

NR: north region; TR:, transitional region; SR: south regions.

2.5%).

The relative abundance of Thaliacea was similar between day and night in the northern and central regions (2.1 and 3.3%), so it became difficult to define a change associated with the time period. However, in the southern region its abundance was greater during the night (6.4%) than at the day (1.7%). The Siphonophora group had low and very similar values between day and night. In the northern region, it was 3.6% during the night vs. 4.2% during the day, in the transitional 1.2% at night and 1.5% during the day. In the southern region it was 3.4% at night and 2.2% during the day. The rest of the groups had relative abundances <2% with slight changes between day and night.

In general, in the transitional and southern regions, most of the groups showed higher absolute abundance values than in the northern zone (Fig. 7). Although higher abundance values were observed at night, there were no significant differences associated with the daytime ($p > 0.05$) among the three sampling regions. Chaetognatha, Pteropoda, and Thaliacea were more abundant in the central region, although still less than copepods.

3.3. Zooplankton distribution during diurnal and nocturnal period

The dominant groups were Copepoda, Chaetognatha, Euphausiacea,

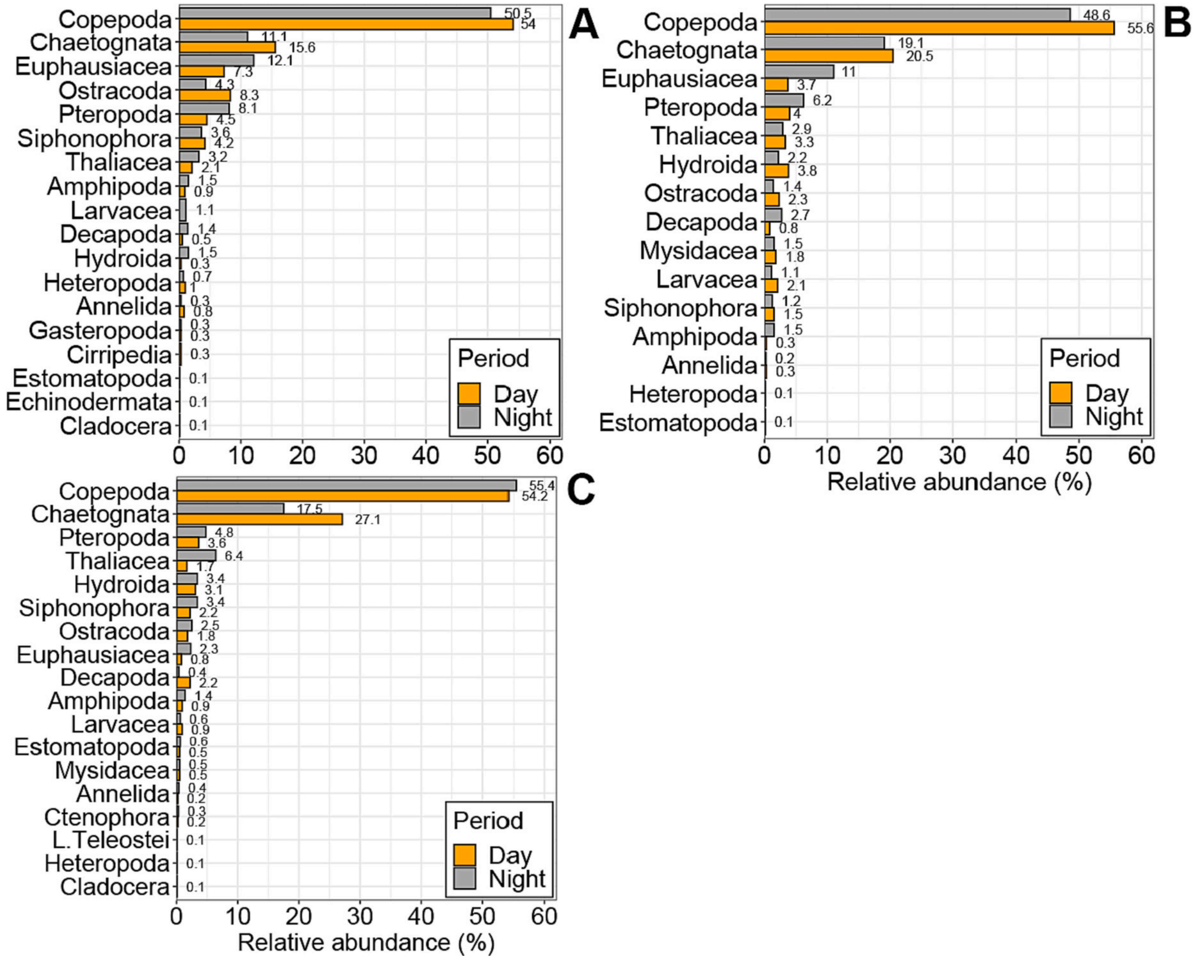

Fig. 6. Zooplankton relative abundance for each sampling area (A) North region; (B) transitional region and (C) South region (Black bars: night casts; Orange bars: day casts).

Pteropoda, Ostracoda, and Thaliacea along the WBCP (Fig. 8). Copepods were the dominant group in all regions (Fig. 8A). Euphausiids were predominantly dominant from Ensenada to Punta Eugenia (during the night, Fig. 8B) and Thaliacea from Punta Eugenia to Cabo San Lucas (during the day, Fig. 8F). Ostracods were dominant in the northern region, with the highest abundance values at night for stations from Ensenada to Punta Eugenia (Fig. 8D). Copepods, Chaetognats, and Pteropods were dominant during the night at stations within the transition and southern region (Fig. 8A, C, E). However, in the diurnal stations, Pteropods showed higher abundance than Euphausiids in the transition region (Fig. 8B, E). It should be noted, that near the coast of Punta Eugenia, Euphausiids abundance was higher in comparison to the rest of the groups, except for copepods. In the southern region in diurnal stations, the groups of Copepods, Chaetognats, and Thaliaceans were dominants (Fig. 8A, C, F). For both periods, the proportion of organisms was higher in the stations close to the coast.

3.4. Effects of the environmental variables on the zooplankton distribution

The canonical correspondence analysis showed that the first three axes explained 23.7% of the accumulated variance (Fig. 9). In Axis 1 (13.7%), the Pearson correlation value was 0.6, and the variables determining the distribution were temperature ($r = 0.9$), salinity ($r = 0.8$), density ($r = -0.9$), oxygen ($r = -0.7$) and the minimum oxygen depth ($r = -0.6$). In the second axis (8.8%), the Pearson correlation value was 0.5, in which NPP ($r = -0.8$) presented the highest correlation values (Table 5). The dispersion diagram showed that Chaetognatha and Copepoda were related to high values of temperature and salinity. Pteropods and euphausiaceans were related to high values of net primary production and oxygen, while taliaceans were associated to the MOD.

The ANOVA test showed differences in the zooplankton abundance between regions (north, transition, and south) ($F_{2,93,<200} = 13.42$, $p \leq 0.001$). Tukey's Post-Hoc test showed differences within the subset of north vs south region ($p = 0.0002$) and transition vs south region ($p = 0.005$).

4. Discussion

The year 2014 is placed between one of the coldest La Niña events (2010–2012) (Bjorkstedt et al., 2011, 2012), and one of the most extreme warming periods recorded to date (2013–2016) (Fiedler and Mantua, 2017). Both events had a strong impact throughout the California Current System with unprecedented effects on the phenology and distribution of organisms from the base of food chains to top predators (Cavole et al., 2016). During this period, studies in different areas of the North Pacific have been gathering information to obtain an integrated view of the effects caused by these processes. This work presents a part of the environmental conditions information that took place in the year 2014 within the southern portion of the California Current System.

In the Western Coast of Baja California Peninsula, between the summer of 2010 and the winter of 2012, La Niña event registered intense negative SST anomalies, while positive anomalies in the upwelling index, accompanied by values of primary productivity and the

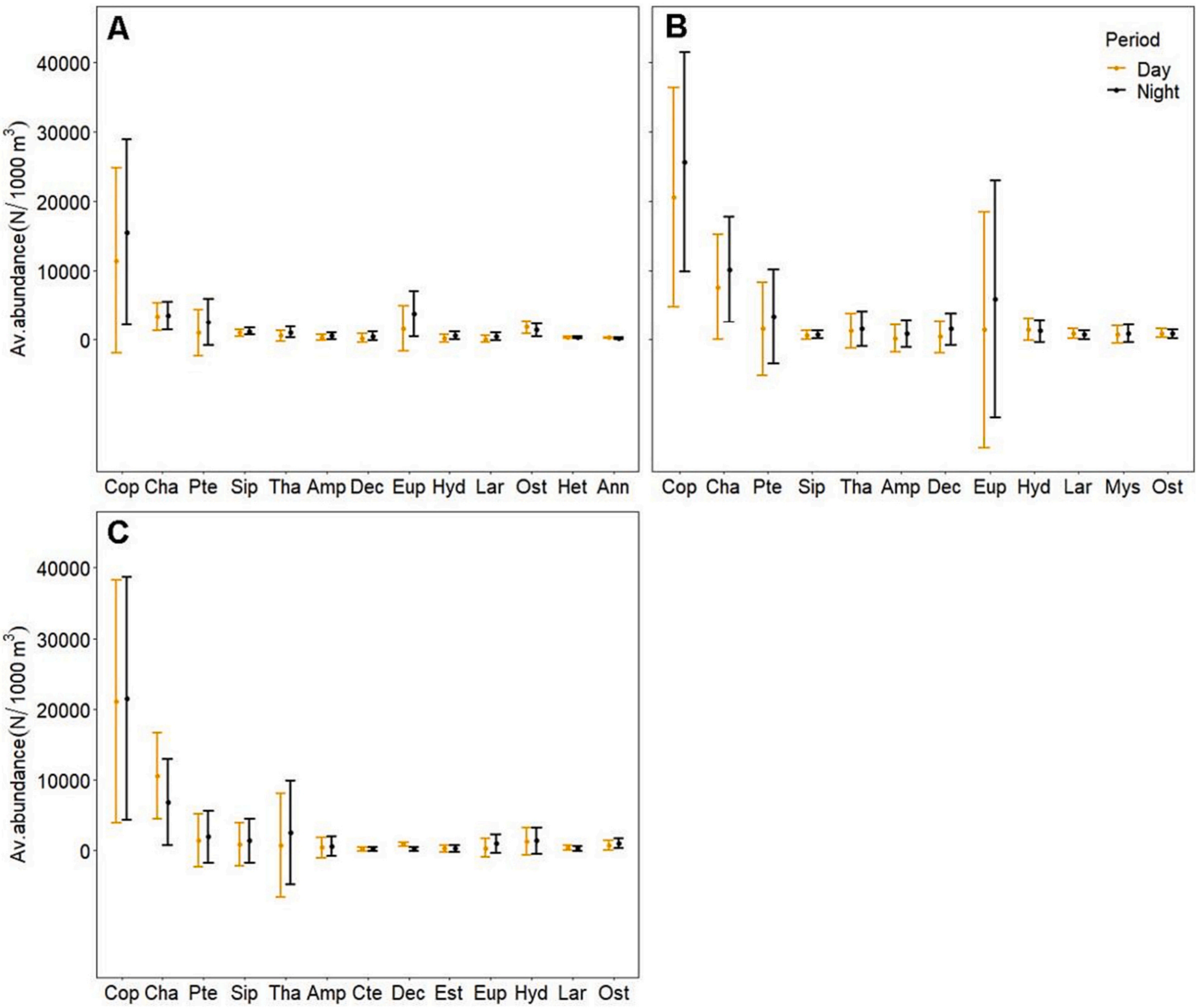

Fig. 7. Average and standard deviation of zooplankton group abundance (N/1000 m^3) for each sampling area (a) North region; (b) transitional region and (c) South region. Black bars: night casts, orange bars: day casts. (Cop: Copepoda; Cha: Chaetognata; Pte: Pteropoda; Sip: Siphonophora; Tha: Thaliacea; Amp: Amphipoda; Dec: Decapoda; Cte: Ctenophora; Eup: Euphausiacea; Hyd: Hydroidea; Lar: Larvacea; Ost: Ostracoda; Het: Heteropoda; Ann: Annelidae; Mys: Mysidacea).

zooplankton volume well above the average, as well as the predominance of gelatinous organisms (particularly siphonophores), but the decline in copepods and euphausiid's density (Bjorkstedt et al., 2012; Wells et al., 2013). For the second half of 2012 and during 2013, climatic conditions were close to average, and during this time herbivorous tunicates showed medium abundance, but carnivorous forms of tunicates and jellyfish continued to show high abundance values, on the contrary, Chaetognatha maintained constant negative anomalies since 2010 (Wells et al., 2013).

The decrease in the intensity of coastal upwellings, low values of primary production, and a progressive invasion of oligotrophic waters in 2014 were associated with marine heat wave events during 2013–2015, known as The Blob, along with a weak El Niño in 2014 (Jacox et al., 2016; Wang and Hendon, 2017). The average seasonal temperature anomaly for 2014 was of the order of +2 °C, which was raised in 2015 (+4 °C) and decreased again in 2016 (McClatchie, 2016; Gómez-Ocampo et al., 2018). The results of this study showed that this sustained warming caused a drastic decrease in the zooplankton volume since 2014, which subsequently continued decreasing during the summer of 2015 (see Aceves-Medina et al., 2023). For example, Table S1 from the data recorded by the IMECOCAL program (see in Aceves-Medina et al., 2023), shows that in the northern region of Baja California (from Ensenada to Punta Eugenia) the zooplankton volume dropped from an average of 175 ml/1000 m^3 in the autumn of 2011 to 81 ml/1000 m^3 in 2014, and presented a value of 74 ml/1000 m^3 in 2015. However, the most intense change was within the southern region (from Punta Eugenia to Cabo San Lucas), where the average values went from 240 ml/1000 m^3 in 2011 to 112 ml/1000 m^3 in 2014 and registered 56 ml/1000 m^3 in 2015, which means a reduction of 77% by 2015 compared with the average registered in the fall of 2011.

Zooplankton composition showed that in addition to the reduction in the zooplankton volume, there was significant change in the composition of functional groups, since dominance by gelatinous forms in 2011 and 2013 (Bjorkstedt et al., 2012; Wells et al., 2013) changed in 2014 when dominance was attained by crustaceans, mainly copepods (52%), and euphausiids (12%), while the gelatinous Thaliacea, Siphonophora, Larvacea, and Hydroidea did not represent >3% from the total organisms of this year. Another important change signal was the fact that while chaetognaths remained with low abundance anomalies from 2011 to 2013 (Wells et al., 2013), by 2014 they constituted the second largest group of the WBCP zooplankton contributing between 11 and 23% of the abundance depending on the region (Table 4). The general decrease in the abundance of zooplankton groups and the dominance by crustaceans found in this work during summer of 2014, became even more evident during the summer-autumn of 2015 (McClatchie, 2016). Accordingly to this distinctive reduction in zooplankton abundance, in the coastal

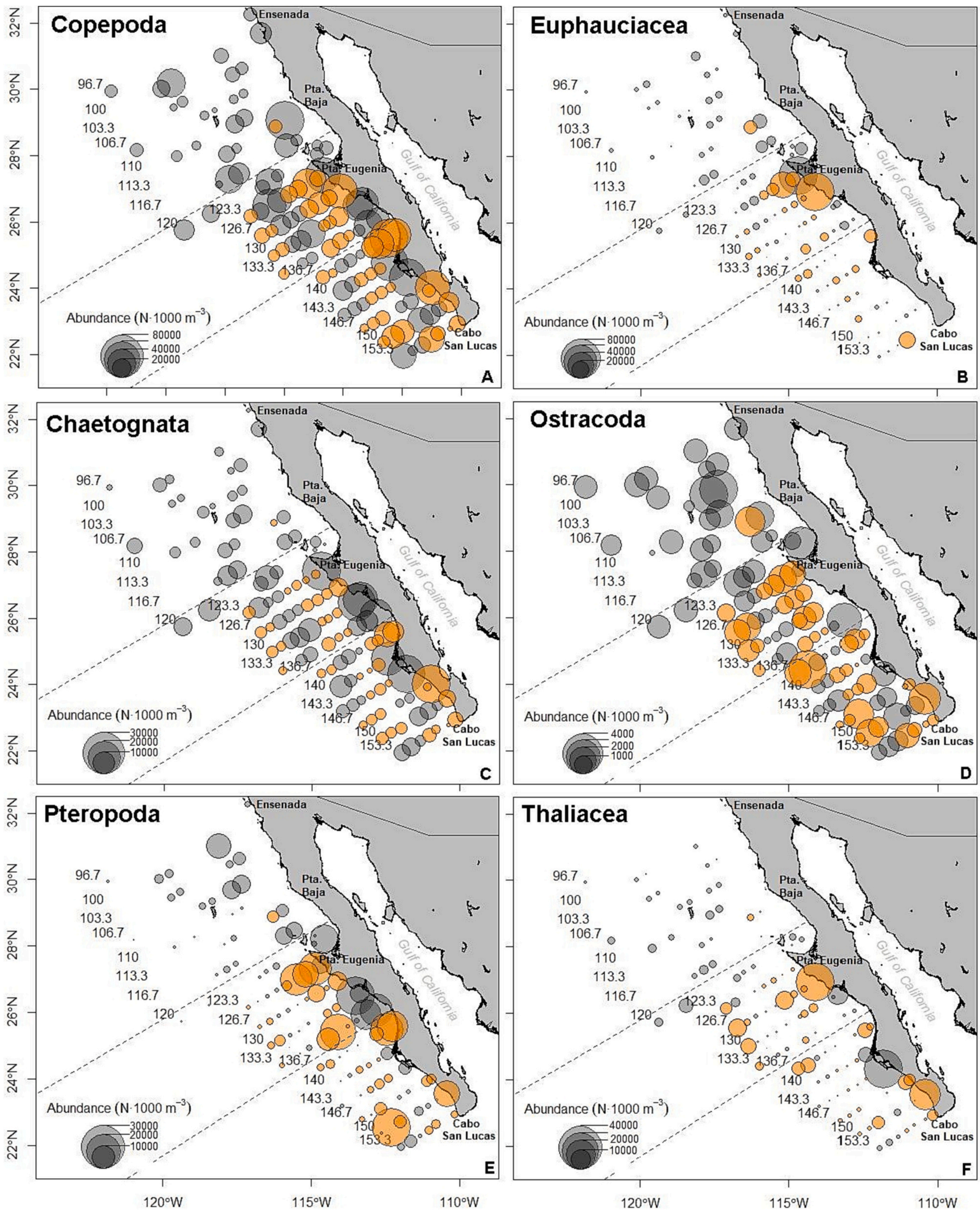

Fig. 8. Dominant zooplankton groups along the sampling region. (A) Copepoda; (B) Euphauciacea; (C) Chaetognata; (D) Ostracoda; (E) Pteropoda; (F) Thaliacea. Night casts: gray bubbles; day casts: orange bubbles.

region between Ensenada to Cabo San Lucas, La Rosa Izquierdo et al. (2022) reported a decrease by 80% in the average abundance of copepods between 2014 (7658 organisms/1000 m^3) and 2015 (1588 organisms/1000 m^3). Similarly, in the El Niño 2015–2016 event, the euphausiids also presented the lowest negative anomalies since 1998 in the central and southern regions of the WBCP, mainly related to the abundance decrease of the species *E. pacifica* and *N. difficilis* (Lavaniegos et al., 2019).

The sequence of events already reported, in addition to the data shown in this work, reveal that the warming processes between La Niña

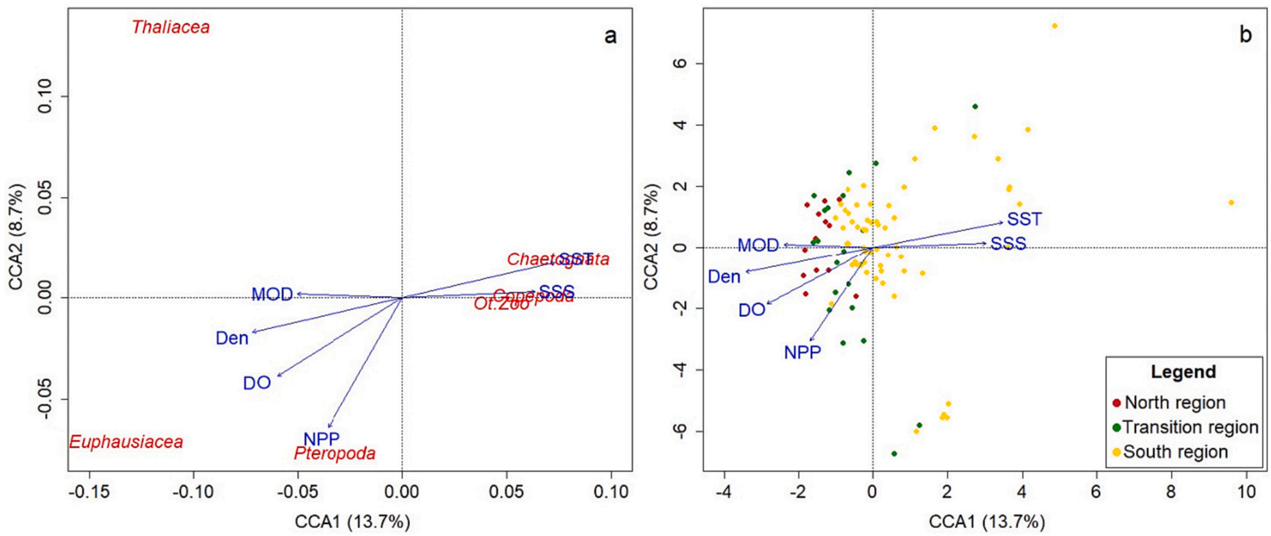

Fig. 9. Canonical correspondence analysis for (a) zooplankton groups and (b) sampling area. Ot. zoo (other zooplankton groups). SST: Sea Surface Temperature; SSS: Sea Surface Salinity; DO: Disolved Oxigen; Den: Density; MOD: Minimum Oxygen Depth; NPP: Net Primary Production.

Table 5
Results of the Canonical Correspondence Analysis between the dominant groups of zooplankton and the sampling stations in relation to the measured environmental variables. Bold numbers showed variables with correlation greater than 60%.

	Axis 1	*Axis 2*	*Axis 3*
Eigenvalue	0.0062	0.0039	0.0005
Variance explained (%)	13.76	8.78	1.10
Cumulative proportion (%)	13.76	22.55	23.65
Pearson correlation	0.6137	0.4695	0.2281
SST	**0.9059**	0.2223	0.1216
NPP	−0.4382	**−0.7787**	−0.2257
SSS	**0.7975**	0.0466	0.4760
Den	**−0.8904**	−0.2137	−0.0967
DO	**−0.7371**	−0.4747	0.0071
MOD	**−0.6322**	0.0166	−0.3312
MLD	−0.1172	−0.0369	0.5698
ZV	−0.0663	−0.2081	−0.0334

SST: Sea Surface Temperature; SSS: Sea Surface Salinity; DO: Disolved Oxigen; Den: Density; MOD: Minimum Oxygen Depth; MLD: Mixed Layer Depth; ZV: Zooplankton Volume; NPP: Net Primary Production.

2010–2012 to El Niño 2015–2016, determined a drastic reduction in the zooplankton volume (77%), as well as a turnover, from a community dominated by gelatinous forms to one dominated by copepods and euphausiids in 2014, and decapods such as *Pleuroncodes planipes* in 2015 (McClatchie, 2016). Similar environmental responses were found by Smith (1985), who observed that during La Niña 1955–1956 Thaliaceans represented 75% of the zooplankton, while in El Niño 1957–1958 they only represented 7%, but Copepods and Euphausiids increased from 17% to 60% within the same period. Conversely, Hereu et al. (2006) showed that salps were particularly abundant during El Niño 1997–1998 and decreased during La Niña 1998–1999. Lavaniegos and Ohman (2003) also found salps were the most abundant group during El Niño 1982–1983, although moderately abundant in El Niño 1958–1959 and almost absent during El Niño 1997–1998, therefore they considered there was no specific response in southern California. In this study, salps only contributed 3.6% of the abundance within the gelatinous zooplankton group (summer 2014), hence our results do not sustain the hypothesis that El Niño events favour the proliferation of salps off the central region of the WBCP (Hereu et al., 2006).

Spatially, during the summer of 2014, the statistical analyses reflected a latitudinal environmental change that evidenced the presence of three substantially different regions off the WBCP (north, transitional, and south). This change was mainly related to the presence of warm and low-salinity water masses at the south (TSW, TSsW and ESW), which advanced northerly through a narrow flow along the coast towards Punta Eugenia, then a zone at the north with a cold-water mass (SAW) moving southward, and a zone of transition where there was a predominance of transitional waters. The transition zone was also characterized by two cold-core cyclonic gyres, and between them a front zone, in the Punta Eugenia transect. Prior to the analysis of the distribution of the groups, we found that although some of them showed changes in abundance between day and night, for example, copepods were apparently more abundant during the day and euphausiids at night, the statistical analyses showed there were no significant diurnal differences in abundance. However, the day/night comparison may be biased because almost no daytime samples were taken in the northern zone, even so this allowed us to assume that composition changes were more related to latitudinal environmental changes than to changes associated with day/night vertical migrations carried out by organisms such as Euphausiids (Robinson and Gómez-Gutiérrez, 1998) or Heteropods (Wall-Palmer et al., 2018).

The strongest abundance gradient for the zooplankton volume was from coast to ocean as it was expected for this study area (Cervantes-Duarte et al., 1993), but latitudinally the zooplankton volume was slightly higher in the north, although the composition of the functional groups changed. For instance, crustaceans represented mainly by copepods, were the dominant group in the entire area. However, copepods had codominance with Euphausiids, Chaetognatha, and Pteropoda in the north, while towards the south this codominance changed, with the abundance of euphausiids and pteropods decreasing significantly, but Chaetognatha increasing, occupying the second place in abundance. In the central region, euphausiids, pteropods, and thaliaceans were more abundant. In general, only copepods and chaetognaths increased towards the south.

The gelatinous organisms that increased in the central region (chaetognaths, pteropods, and some carnivorous species of thaliaceans) represent very active predators (Van der Spoel, 1996; Vdodovich et al., 2018), which in large numbers can regulate populations of copepods and euphausiids, generally dominant in WBCP zooplankton samples. Although the abundance of these predators during the summer of 2014 was not as high as in other years (except for Chaetognatha), there was a significant change in the composition of copepod species for this same area and period. La Rosa-Izquierdo et al. (2022) reported in the transition zone off Punta Eugenia, a decrease in the Shannon diversity index H′ when a community is characterized by an almost total dominance of omnivorous-herbivorous species. These results seem to indicate there is a regulatory effect due to competition or predation, since in the northern (cold-water predominate; SAW) and southern regions (warm and low-salinity water mass predominate; TSW, TSsW and ESW), while the abundance of gelatinous zooplankton predators decreased, there is an increase in the diversity and abundance of the carnivorous forms of copepods.

Hereu et al. (2006) showed that the presence of warmer and saltier waters, a deeper thermocline, and a reduction in oceanographic processes like mesoscale features, were associated with increased abundance of thaliaceans (specifically of the genus *Thalia*), making them particularly abundant in the central region of the WBCP during El Niño 1997–1998 (Hereu et al., 2006). Although during 2014 there were indications of an El Niño event, it did not developed (Wang and Hendon, 2017). However, the composition of the observed water masses, as well as the geostrophic flow, exhibited the advance of southern oligotrophic warm waters that penetrated at least as far as Bahia Vizcaíno. According to Durazo et al. (2017) and Gómez-Ocampo et al. (2018) this caused the California Current water mass to sink under the warmer surface water (particularly in the southern of California Current System), which led to the deepening of the nutricline, weak upwelling, increased stratification, elevated near-surface temperatures, and the phytoplankton biomass decrease.

It has been suggested that the thermal and saline fronts that are often recorded off Baja California may provide appropriate niches for the development of salps and other tunicates, which will find good conditions for grazing with moderate concentrations of phytoplankton in the region (Lavaniegos et al., 2015). Our results find coincidence of this thermal and saline oceanic fronts with an increase in the abundance of gelatinous zooplankton within the transition zone of the mid-peninsula, where two cold core eddies are separated by a warm waterfront. These mesoscale structures also seem to function as physical barriers that in the case of copepods (La Rosa-Izquierdo et al., 2022), heteropod holoplanktonic molluscs (Aceves-Medina et al., 2020), and fish larvae (Aceves-Medina et al., 2019) greatly determine the structure of planktonic communities. The zooplankton community can serve as indicators of climate change (Richardson, 2008), as their non-linear responses allow them to rapidly respond to change (Taylor et al., 2002), by which they may accurately reflect changes in temperature and ocean currents, since zooplankton physiological processes are sensitive to temperature (Mauchline, 1998; Richardson, 2008). In this sense, a functional zooplankton groups (functional traits defined as those morphological, physiological, and behavioural characteristics which define the functional role and ecological niche (Litchman et al., 2013)) are therefore defined as clusters of species with similar effects on ecosystem functions, which are likely to respond similarly to changes in environmental conditions (Lavorel et al., 1997). Our results showed in the north regions, that Copepods, Euphausiids, Chaetognatha, and Pteropoda abundance responded at the environmental conditions (cold-water mass (SAW) and high primary production), creating an potential niche for Carnivory/Omnivory/Herbivory species where they are the main prey items for fish, seabirds, and marine mammals in the region (Deibel, 1982). In the south region, the abundance of Euphaudiids and Pteropoda responded negatively decreasing their abundance due to the warming-salinity water masses and lower NPP. At the opposite occurred with Chaetognatha and Copepods, where their abundance increased in this region creating a special niche for this groups (being a link between primary and tertiary consumers (e.g. Escribano and Pérez, 2010; Liang and Vega-Peréz, 1995)). Finally, the predominance of transitional water and two cold-core gyre in the central region, created a special ecological niche for Euphausiids and gelatinous zooplankton (Pteropoda and Thaliacea), Omnivore-Herbivore group that they have the ability to efficiently filter very small phytoplankton and other particles (e.g. microzooplankton) including copepod eggs and juveniles from the water column (Deibel, 1982).

In summary, our results contribute to fill the gap in information of the Western Coast of Baja California Peninsula zooplankton community during the warming events in the summer of 2014, in particular within the southern portion of the California Current System. Just as changes were observed in the composition and abundance of organisms during the cold and warm events recorded before (coldest La Niña event, 2010–2012) and after (warming periods, 2013–2016), there was a significant change in the composition of functional groups of zooplankton during the summer of 2014, when crustaceans (mainly copepods and euphausiids) dominated, followed by chaetognaths, while the gelatinous (Thaliacea, Siphonophora, Larvacea, and Hydroidea) did not represented >3% from the total organisms of that year. Environmental variables distinguished three regions off the WBCP related to the presence of warm and low-salinity water masses at the south, a cold-water mass at the north, and an intermediate zone with transitional waters. In this sense, changes in zooplankton groups composition were related to three regions defined before (the latitudinal environmental changes) and mesoscale semi-permanent structures in the middle peninsula, where according to the greatest to lowest abundance, the dominant groups were Copepoda Euphausidae, Chaetognatha, and Pteropoda in the north; Copepoda, Chaetognatha, Euphausidae and Pteropoda in the south; and Copepoda, Euphausidae, Pteropoda, and Thaliacea in the transitional region. In the last mentioned region, an increase in the abundance of the gelatinous group coincided with thermal and saline oceanic fronts, where two cold core eddies were present. Therefore, these mesoscale structures represent physical barriers that seem to determine the distribution limits of planktonic communities.

Declaration of Competing Interest

Gerardo Aceves-Medina reports a relationship with Instituto Politécnico Nacional Secretaría de Investigación y Posgrado that includes: non-financial support.

Data availability

Data will be made available on request.

Acknowledgments

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Appendix A. Supplementary data

Supplementary data to this article can be found online at PANGEA platform: Sarmiento-Lezcano, A.N., Aceves-Medina, G., Villalobos, H. and Hernández-Trujillo, S. 2023. Physical oceanography during RV BIPO INAPESCA cruise along the west coast of Baja California peninsula (July–September 2014). https://doi.org/10.1594/PANGAEA.957401. Supplementary data to this article can be found online at https://doi.org/10.1016/j.jmarsys.2023.103940.

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