



## Copepod groups distribution in a cyclonic eddy in Bay of La Paz, Gulf of California, Mexico, during summer 2009

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**Abstract:** This study assessed the effects of a cyclonic eddy on copepod groups in the Bay of La Paz, Gulf of California, Mexico, during summertime. We collected high-resolution hydrographic records for conductivity, temperature and depth and performed oblique zooplankton hauls during a research cruise performed in August 2009. The results showed the presence of a cyclonic eddy with a diameter of ~30 km and velocities reaching 50 cm s<sup>-1</sup>. Copepod abundances showed differences for each group. Calanoid abundances ranged from 95 to 1019 ind 100 m<sup>-3</sup>, cyclopoids ranged from 208 to 1082 ind 100 m<sup>-3</sup> and abundance of all copepodite stages ranged from 420 to 11800 ind 100 m<sup>-3</sup>. Their horizontal distributions showed interesting patterns of variability into the eddy field. The calanoids showed high relative abundances at stations close to the center of the eddy. The cyclopoids had maximum abundances at peripheral stations, while all copepodite stages had maximum abundances at stations close to Boca Grande. A canonical correspondence analysis confirmed dependence with environmental variables. We found that copepod groups showed a clear relationship with the presence of the cyclonic eddy through and its effects on hydrographic conditions; possibly, as result of several additional processes, such as ecological interactions, population dynamics as well as feeding habits were also impacted.

**Key words:** Calanoida, Cyclopoida, Copepodites, abundance, circulation pattern.

**Distribución de los grupos de copépodos en un giro ciclónico en la Bahía de La Paz, Golfo de California, México, durante la época de verano de 2009. Resumen:** El presente estudio evalúa los efectos de un vórtice ciclónico en la distribución de los grupos de copépodos en la Bahía de La Paz, Golfo de California, México, durante la época de verano. Se adquirieron datos hidrográficos de alta resolución y se realizaron arrastres oblicuos para coleccionar organismos del zooplancton durante un crucero de investigación realizado en agosto de 2009. Los resultados mostraron la presencia de un vórtice ciclónico con un diámetro de ~30 km y velocidades de hasta 50 cm s<sup>-1</sup>. La abundancia de los grupos de copépodos mostraron diferencias. Por ejemplo, los calanoideos oscilaron entre 95 y 1019 ind 100 m<sup>-3</sup>, los ciclopoideos de 208 a 1082 ind 100 m<sup>-3</sup> y la abundancia de todos los estadios de copepoditos varió de 420 a 11800 ind 100 m<sup>-3</sup>. Su distribución horizontal mostró variabilidad en el campo del vórtice. Los calanoideos mostraron elevadas abundancias en las estaciones cercanas al centro del vórtice. Los ciclopoideos

presentaron abundancias máximas en las estaciones de la periferia, mientras que todos los estadios de copepoditos tuvieron abundancias máximas en las estaciones cercanas a Boca Grande, lo cual fue confirmado estadísticamente a través de un análisis de correspondencia canónica. Los resultados obtenidos mostraron una clara relación entre la abundancia de los copépodos con las condiciones hidrográficas, posiblemente, como resultado de diferentes procesos, como las interacciones ecológicas, la dinámica poblacional y los hábitos de alimentación de cada grupo.

**Palabras clave:** Calanoida, Cyclopoida, Copepoditos, abundancia, patrón de circulación.

## Introduction

Copepods represents the major constituent of mesozooplankton in the oceans, which exerts a fundamental part in the marine environment, contributing in the 'biological pump' that transports carbon into the ocean interior (Zuo *et al.* 2006, Brierley 2017). Although copepods have developed strategies to present both vertical and horizontal migrations, numerous studies highlight that interannual changes in their distribution, composition and abundance are influenced by physical processes at diverse scales, including eddies (Goldthwait & Steinberg 2008, Eden *et al.* 2009, Morales *et al.* 2010).

Ocean eddies, often identified as mode-water, cyclonic and anticyclonic, play a crucial role in plankton dynamics. Mode-water and cyclonic eddies induce divergent movements and produce a fertilization into the euphotic zone due to a rise of cold water enriched with nutrients, then an enhancement of biological production is present, while anticyclonic induce a convergence, and then sinking waters below the euphotic zone (McGillicuddy 2016).

To date, numerous studies concerned on the role of the physical forcing by eddies in the zooplankton and ichthyoplankton assemblages are appearing in the literature. Goldthwait & Steinberg (2008) analyzed the mesozooplankton community composition in the Sargasso Sea, a region where the presence of eddies affect the biogeochemical cycling and then resulted in changes in the community composition as well as a high zooplankton biomass inside of a mode-water eddy related with a diatom bloom. Eden *et al.* (2009), documented a maximum in copepod abundances inside of a cyclonic eddy in the Sargasso Sea, suggesting elevated food concentration influencing the zooplankton distribution. Morales *et al.* (2010), analyzed the structure of copepod assemblages off central-southern Chile, a region in which eddies are recurrent features; they documented that some

calanoid organisms were predominant inside eddies, suggesting that these physical features might advect organisms to different zones. Estrada *et al.* (2012), analyzed the zooplankton structure in the Hudson Bay (Canada), which showed a clear effect of hydrodynamic conditions, through their actions on the hydrography of the water column which in turn induce changes in the zooplankton communities.

In particular, in the Bay of la Paz (BP), southern Gulf of California (GC), Sánchez-Velasco *et al.* (2006) examined the relationship between larval fish assemblages (oceanic and coastal) with the geostrophic currents and showed a correlation between the GoC and the BP, which originates an advection of the assemblages from the gulf to the interior of the bay. Duran-Campos *et al.* (2015) elucidated the relationship of the abundance of zooplankton functional groups with a cyclonic eddy, showing a radial distribution. The cyclonic eddy retained a markedly different biological composition, with herbivorous organisms close to the center, omnivorous organisms at the edge and carnivorous zooplankton organisms close to the connection with the GoC; the biomass was substantially higher inside the eddy.

While the effect of physical forcing on the abundance of phytoplankton and major zooplankton groups in the BP is relative well known since Coria-Monter *et al.* (2014) and Duran-Campos *et al.* (2015), there have been major recent developments in this area, in particular the effects on specific zooplankton groups, such as copepods.

In this study, we aimed to assess the effects of a cyclonic eddy on the distribution and abundance of the groups of copepods (calanoid, cyclopoid and all stages of copepodite) in BP, GoC. We hypothesized differences in copepod groups into the eddy field derived from the thermal/density gradient from the center of the eddy toward the edge. This study is inspired by the need to understand the processes associated with the copepod variability and their implications in the dynamics of BP during summertime. This work contributes to the efforts to

improve the knowledge of the influence of physical processes on particular zooplankton groups, such as copepods.

### Materials and methods

**Study area:** The BP is situated in the southwestern margin of the GoC, approximately 200 km from the Pacific Ocean, and represent one of the most important ecosystems due to its high biodiversity and productivity; it also serves as an area of refuge for different species (Fig. 1A). The BP has a maximum depth of 420 m in Alfonso Basin, with a connection with the GoC through two openings: a deep and wide connection located to the north, named as Boca Grande, and a shallow and narrow connection in the southern portion, named as the San Lorenzo Channel (Fig. 1B). Along Boca Grande, a bathymetric sill partially isolates the BP from the GoC and inhibits water masses interchange below 250 m depth (Molina-Cruz *et al.* 2002). In the region, the wind field present important seasonal changes, with northwest winds in winter and southeast winds in summer (Monreal-Gómez *et al.* 2001). The circulation inside the BP is controlled by a quasi-permanent cyclonic eddy (Monreal-Gómez *et al.* 2001) which promotes an Ekman pumping with high velocities ( $\sim 0.4 \text{ m d}^{-1}$ ) rising up the nutricline, fertilizing the surface layer (Coria-Monter *et al.* 2017). Also, differential distributions of diatoms and dinoflagellates (Coria-Monter *et al.* 2014) and zooplankton aggregations have been observed during summer (Durán-Campos *et al.* 2015).

**Sampling:** High-resolution hydrographic records for conductivity, temperature and depth were acquired using a CTD probe (Sea-Bird SBE-19 plus) improved with dissolved oxygen and active fluorescence sensors attached in a General Oceanics rosette system, at 55 hydrographic stations, including both the interior of the BP as well as the connection with the GoC (Fig. 1B). Samples were obtained during the multidisciplinary scientific expedition “DIPAL-III” onboard of the research vessel “El Puma” during August of 2009. Each CTD cast was close to the bottom ( $\sim 5 \text{ m}$ ), lowered at 1 m/s and storing data at 24 Hz. The sensitivity of CTD sensors was  $0.005^\circ\text{C}$  for temperature and  $0.0005 \text{ S m}^{-1}$  for conductivity.

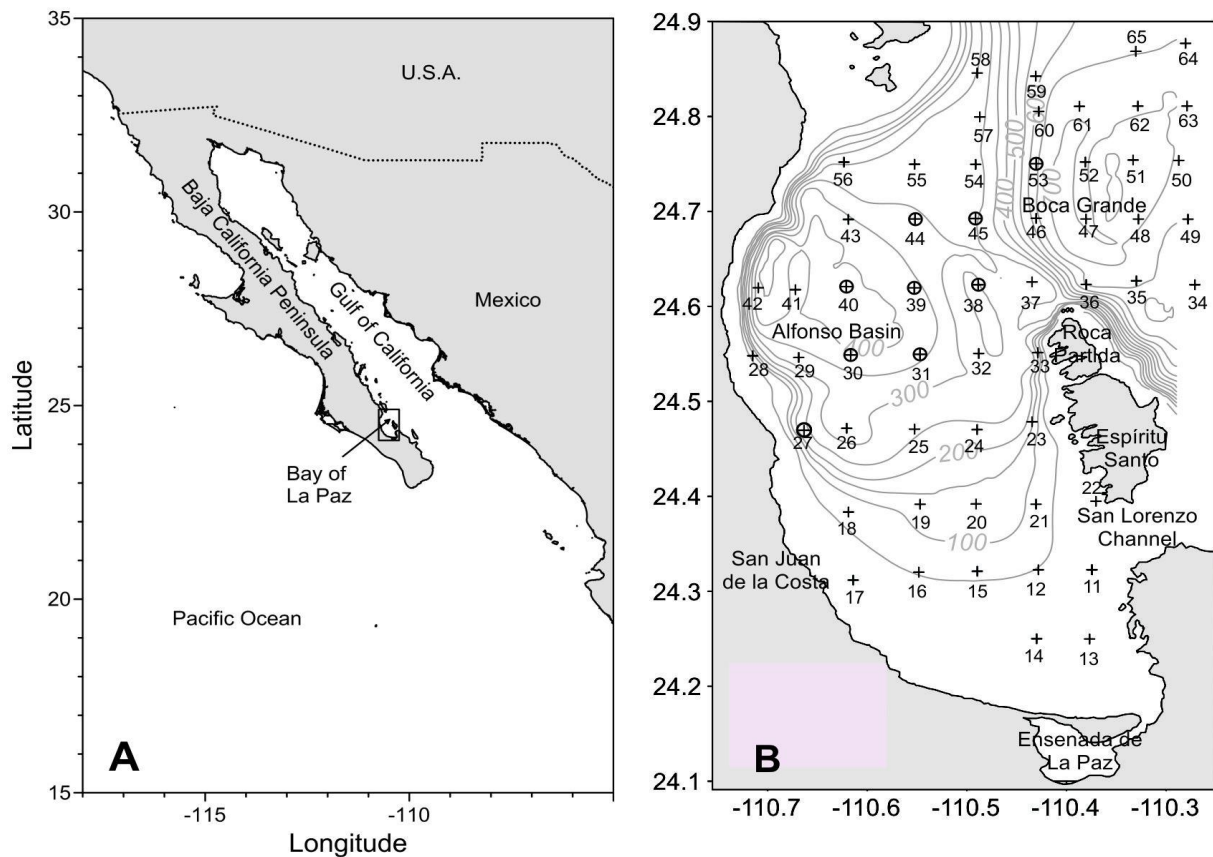
Immediately after the CTD-rosette cast, oblique hauls (day and night time) were performed with bongo nets (mesh of  $333 \mu\text{m}$ , 60 cm diameter in mouth) at nine hydrographic stations in the central portion of the BP as well in the connection with the

GoC (Fig. 1B). Zooplankton organisms were collected from 200 m depth to the surface, or near the bottom in those shallower stations. The volume of water that crossed the nets was recorded by flowmeters previously calibrated by the manufacturer (General Oceanics) which were attached to each net. Initially, the organisms captured were fixed with 4% formalin (sodium borate added) for 24 h and finally conserved in 70% ethanol. The criterion to select these specific nine stations in the central portion of the bay was owing to previous investigations that revealed the presence of a quasi-permanent cyclonic eddy (e.g. Monreal-Gómez *et al.* 2001, Coria-Monter *et al.* 2017) with which we seek to test our hypothesis on the effect of the cyclonic eddy on the copepods groups of the region.

Data of sea surface temperature (SST) and chlorophyll-*a* ( $\text{mg m}^{-3}$ ) were acquired for the days concurrent with the research cruise from the Moderate Resolution Imaging Spectroradiometer (MODIS-AQUA, <http://oceancolor.gsfc.nasa.gov>). The data, with a resolution of 1 km, were processed using SeaDAS version 7.4.

**Data processing:** The CTD data were processed by the software from the manufacturer (SBE-Data Processing V.7.26.7), averaged each dbar. The conservative temperature ( $\Theta$ ,  $^\circ\text{C}$ ), absolute salinity ( $S_A$ ,  $\text{g kg}^{-1}$ ) and density ( $\sigma_\Theta$ ,  $\text{kg m}^{-3}$ ) were derived according to the Thermodynamic Equation of Seawater-2010 (TEOS-10) (IOC *et al.* 2010). The chlorophyll-*a* concentration ( $\text{mg m}^{-3}$ ) was estimated from the *in-situ* fluorescence with the conversion factor provided by the manufacturer. Geostrophic currents were calculated from  $\Theta$  and  $S_A$  by geostrophic standard analysis (Pond & Pickard 1983). The circulation pattern was compared with the distribution of conservative temperature and density fields.

**Laboratory analyses:** Each zooplankton sample was split serially with a Folsom splitter until reaching 1/32. Then, the organisms were identified, at group level, and counted with a Carl Zeiss stereo microscope, following Boltovskoy (1999). The organisms were picked and separated into three particular groups: calanoid, cyclopoid and all stages of copepodite were pooled together. The identification of the organisms was at group level, so, we are aware that this would imply certain bias; however, several investigations have shown that the identification of marine zooplankton, at the group level, is enough to evaluate ecological aspects of the organisms, including trophic ecology aspects,



**Figure 1.** Study area: A) Geographic location of Bay of La Paz; and B) sampling stations, + represents stations with CTD casts, O represents stations with zooplankton sampling. The gray lines represent bathymetry in m.

development of communities, as well as vertical and horizontal aggregations in relationship with the physical structure of the water column, both in ocean and coastal environments (Ayon et al. 2008).

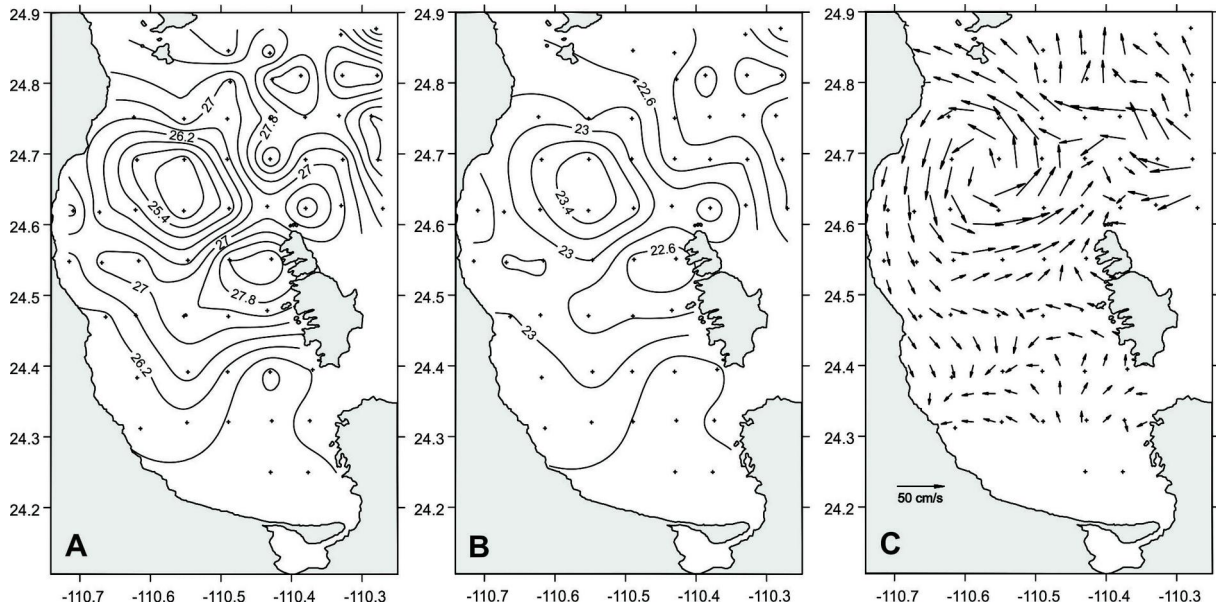
For the quantification of the biomass (expressed in wet weight,  $\text{mg m}^{-3}$ ) for each target group, a Millipore system was used to remove the excess of ethanol of the samples by manual pump, through membrane filters ( $0.45 \mu\text{m}$ , 47 mm in diameter, Millipore Corp, USA) previously weighed. The differences in weight were obtained with an analytical balance (Sartorius BP211D, 0.1 mg/210 g in resolution). Finally, the biomass ( $\text{mg m}^{-3}$ ) was calculated following Duran-Campos *et al.* (2015).

**Statistical analyses:** The statistical analyses for this study included a canonical correspondence analysis (CCA) in order to explore the effect of the physical variables on the abundance of each copepod group (ter Braak 1986, Pappas 2010). The CCA is a multivariate technique widely used in aquatic ecology to elucidate relationships between biological communities and their environment, and basically the method was designated to extract synthetic environmental gradients from ecological matrices

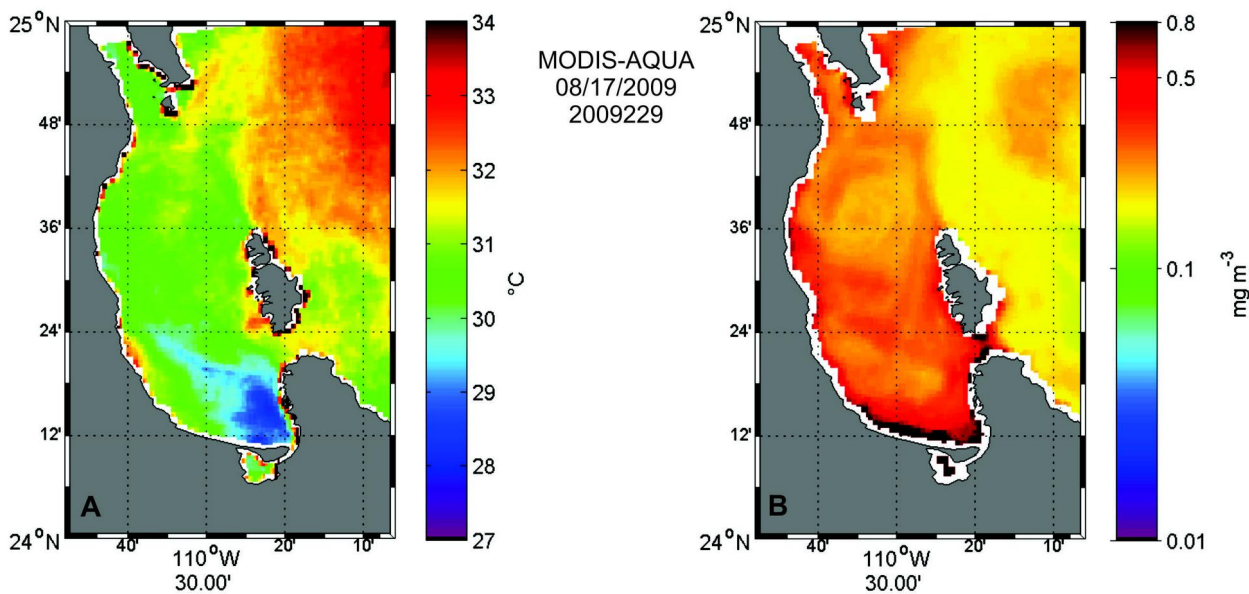
and be visualized through an ordination diagram (ter Braak & Verdonschot 1995). We performed the CCA using two matrices: 1) the abundance data for each copepod group by sampling station, prior a square-root transformation and 2) the hydrographic data obtained from the CTD probe, including conservative temperature, absolute salinity, density and chlorophyll-*a* concentration; additional information was used in order strengthen this data set, including phytoplankton groups abundances (diatoms, dinoflagellates and silicoflagellates) as described by Coria-Monter *et al.* (2014). Finally, the analysis was carried out following standard routines with CANOCO software (v4.5) (ter Braak & Smilauer, 2002).

## Results

**Hydrography:** Based on the vertical distribution of conservative temperature, the average depth of the thermocline, obtained by the depth of the maximum temperature gradient ( $\delta T/\delta z$ ), was 20 m. The horizontal distribution of conservative temperature at those depths exhibited a cold core in the central region of the BP, reaching values of  $25^\circ\text{C}$  at its center, extending out with a value of  $26.8^\circ\text{C}$  (Fig. 2A). The



**Figure 2.** Horizontal distribution at 20 m depth of: A) Conservative temperature ( $^{\circ}\text{C}$ ), contour interval =  $0.4^{\circ}\text{C}$ ; B) density ( $\sigma_t$ ,  $\text{kg m}^{-3}$ ), contour interval  $0.2 \text{ kg m}^{-3}$ ; and C) geostrophic velocity ( $\text{cm s}^{-1}$ ).



**Figure 3.** MODIS-AQUA images (17 August 2009) of: A) sea surface temperature ( $^{\circ}\text{C}$ ); and B) chlorophyll-*a* ( $\text{mg m}^{-3}$ ).

density distribution was coincident with the cold core, showing a dense core with values of  $23.4 \text{ kg m}^{-3}$  at its center (Fig. 2B). The geostrophic currents indicated the existence of a well-defined cyclonic eddy, with a diameter of  $\sim 30 \text{ km}$  and velocities reaching  $50 \text{ cm s}^{-1}$  (Fig. 2C); the eddy occupied the central part of the bay along the Alfonso Basin.

Satellite observations showed a clear signal of both parameters during the research cruise. The sea surface temperature distribution by satellite evidenced an interesting contrast between the GoC and the central part of the BP, reaching values  $\geq 32$

$^{\circ}\text{C}$  and  $\sim 30 \text{ }^{\circ}\text{C}$ , respectively (Fig. 3A) whereas the chlorophyll-*a* concentration showed areas of enhancement at the southern portion of the bay and in the central region, following a circular shape in the area where the cyclonic eddy was detected, with values of  $\sim 0.2 \text{ mg m}^{-3}$ . Relatively high values were also observed at the connection with the GoC, in the Boca Grande region, at the bathymetric sill (Fig. 3B).

**Zooplankton:** The zooplankton abundance showed differences for each copepod group. Calanoid copepod abundance ranged from 95 to 1019 ind 100

$\text{m}^{-3}$ . The cyclopoid copepod abundance ranged from 208 to 1082 ind  $100 \text{ m}^{-3}$ , while the abundance of all copepodite stages ranged from 420 to 11800 ind  $100 \text{ m}^{-3}$ . Their horizontal distribution showed interesting patterns of variability into the eddy field. The calanoids showed their maximum abundance in a station over the Boca Grande region (station #53) where an enhancement zone of chlorophyll-*a* was observed; however, high relative abundances were observed at the stations inside of the eddy (Fig. 4A). The cyclopoids showed their maximum abundances in the stations along the periphery of the eddy, particularly at station #45 (Fig. 4B), while all stages of copepodites showed their maximum abundance at the stations close to Boca Grande (Table 1 in supplementary material, Fig. 4C). Even though the organisms were not identified at the species level and juvenile copepods were pooled together, as mentioned above, these results contribute to the knowledge of the ecology of these organisms and it was possible to identify patterns of distribution into an eddy system.

In terms of the biomass for each group, the calanoids ranged from 7.1 to 23.8  $\text{mg m}^{-3}$ , showing their maximum close to the coast (station # 27 and 38) proximate to San Juan de la Costa; however, secondary high values were observed at the station located at the center of the eddy (Fig. 4D). The cyclopoid copepods biomass varied from 8.8 to 39.9  $\text{mg m}^{-3}$  with a maximum at the station under the influence of the eddy periphery where also high abundance relative values were observed (Fig. 4E). Copepodite biomass showed values ranging from 15.9 to 68.1  $\text{mg m}^{-3}$  with a maximum at the station situated over the periphery of the eddy (Table 1 in supplementary material, Fig. 4F).

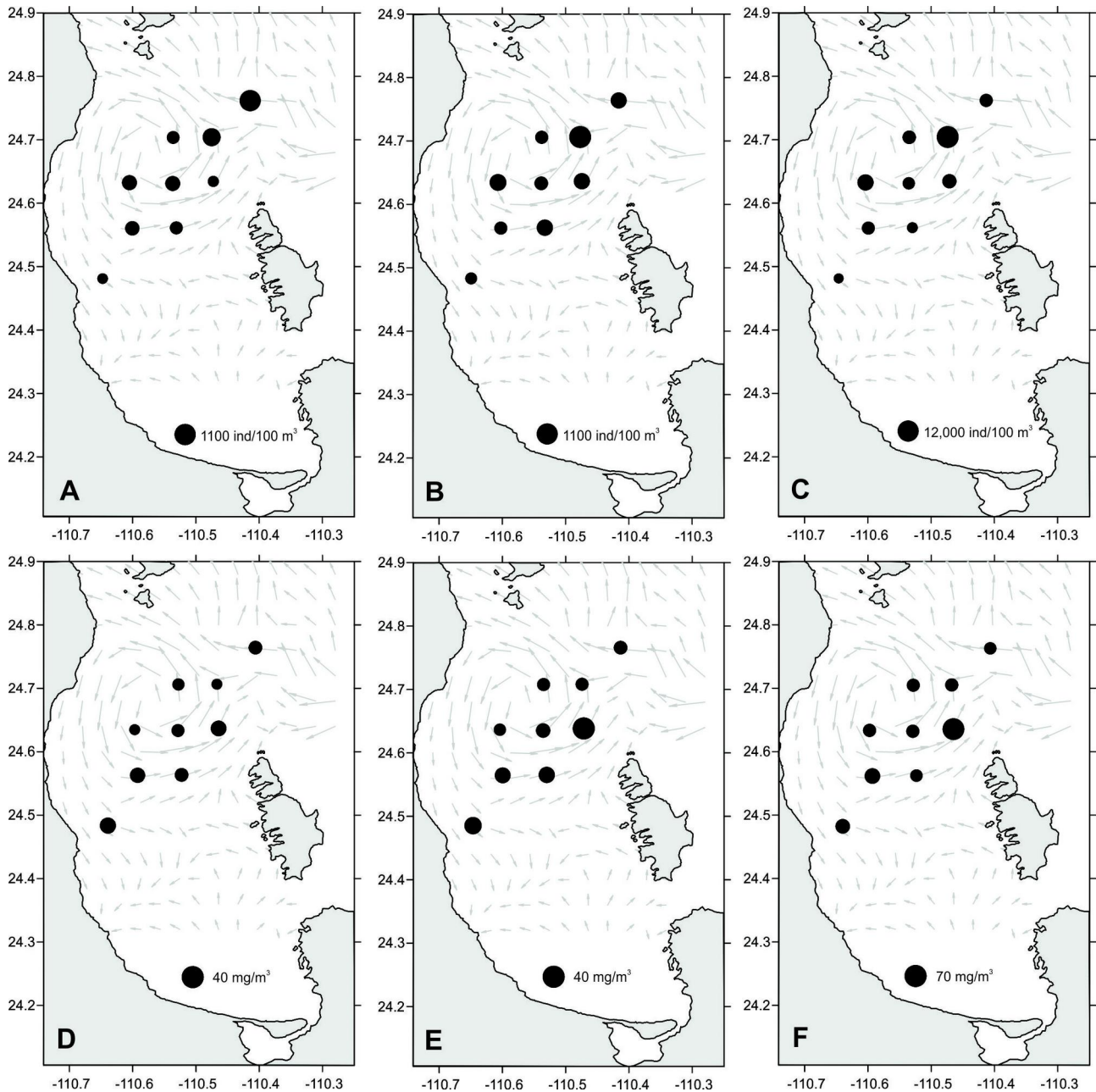
The CCA ordination diagram showed that the first two axes explained the 90.2% of the total variance (Axis 1 = 61.1%; Axis 2 = 29.1%), with clear dependences for the three zooplankton groups with respect to environmental variables (Fig. 5). As expected, the calanoid copepods showed a relationship with conservative temperature, due to the thermal gradient generated by the eddy, whereas the cyclopoid copepods apparently showed a close relationship with the abundance of diatoms and silicoflagellates.

## Discussion

The physical oceanography of the BP for summertime has been relative well described before (Coria-Monter *et al.* 2014, Durán-Campos *et al.* 2015), then only a short summary is presented here.

The analysis of zooplankton distribution in relation to hydrography and hydrodynamic processes, such as eddies, has become an innovative interdisciplinary approach for understanding plankton ecology. Particularly in the BP, the presence of a cyclonic eddy has been detected on multiple times during different research cruises from 1997 to 2009 (Monreal-Gómez *et al.* 2001, Sánchez-Velasco *et al.* 2006, Coria-Monter *et al.* 2014, Durán-Campos *et al.* 2015). Therefore, Coria-Monter *et al.* (2014) proposed that this eddy is a quasi-permanent feature of the BP and an interesting case study of an eddy confined within a bay with high biological significance. The possible mechanism of generation of the cyclonic eddy in the BP has been discussed in few previous reports (Monreal-Gómez *et al.* 2001, Coria-Monter *et al.* 2014). Coria-Monter *et al.* (2017) elucidated that the physical forcing into the eddy field is the local wind, causing an upwelling that promotes the enhancement of nutrients and chlorophyll-*a* levels; the Ekman pumping reaches high velocities ( $\sim 0.4 \text{ m d}^{-1}$ ), ensuring an enhancement of productivity by means of nutrient injection into the euphotic zone. Satellite observations obtained fit well with the horizontal distribution evidenced by *in-situ* measurements. The circular pattern in the chlorophyll-*a* concentrations detected in this study, which presents low levels at the center of the eddy, was associated with the presence of dinoflagellates in the region (Coria-Monter *et al.* 2014). Areas of enhancement were observed at the periphery of the eddy as well as in the Boca Grande where the bathymetric sill is present.

Submesoscale processes (e.g., ageostrophic secondary circulation) that are present at the periphery of eddies contribute to plankton productivity (Mahadevan 2016) and could be linked with the high abundance of cyclopoid copepods observed at the stations in the eddy periphery. The calanoid peak observed at the station at Boca Grande (station #53), coincident with a high chlorophyll-*a* area, suggests high food concentration in this region, which could influence the zooplankton distribution. Elevated chlorophyll-*a* concentrations could be strongly related to the bathymetric sill where important processes, such as hydraulic jumps and upwelling, took place and subsequent zooplankton aggregations were observed (Salas-Monreal *et al.* 2012). Our observations pointed out that the copepod groups analyzed showed a clear dependence on the presence of the cyclonic eddy, due to their effects on the hydrographic conditions



**Figure 4.** Horizontal distribution of: A) Calanoid copepods abundance (ind  $100\text{ m}^{-3}$ ); B) Cyclopoid copepods abundance (ind  $100\text{ m}^{-3}$ ); C) all stages of copepodites abundance (ind  $100\text{ m}^{-3}$ ); D) Calanoid copepods biomass ( $\text{mg m}^{-3}$ ); E) Cyclopoids copepods biomass ( $\text{mg m}^{-3}$ ); and F) all stages of copepodites biomass ( $\text{mg m}^{-3}$ ). Note the change in scales.

and as a result of supplementary processes, including intra and interspecific interactions, feeding habits and population dynamics. Batten & Crawford (2005) showed a high abundance of zooplankton, mainly copepods, inside eddies in the Gulf of Alaska. Similarly, Morales *et al.* (2010) studied the effects of cyclonic eddies on copepod assemblages and showed that some species, mostly calanoids, had large abundances inside cyclonic eddies off central-southern Chile, as a consequence of the advection of waters as well as the evolution and life-cycle of the

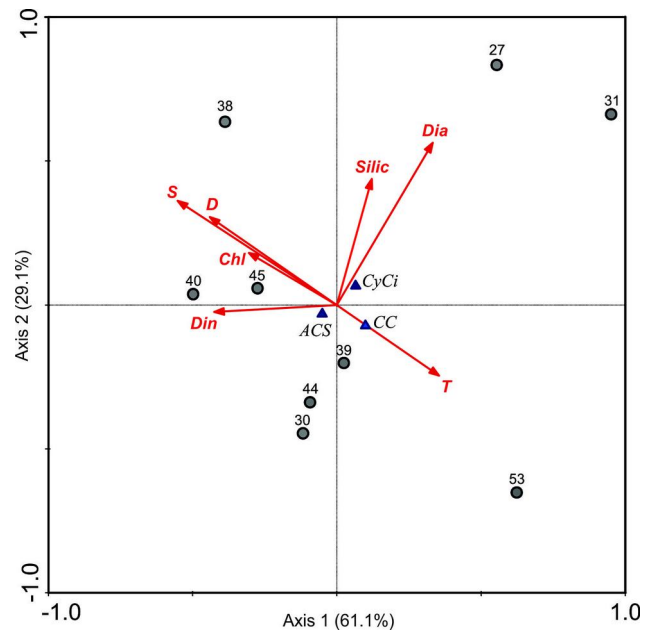
eddies over the time due to differences in hydrographic properties. Eden *et al.* (2009) documented a high abundance of copepods inside a cyclonic eddy, suggesting elevated food concentration due to fertilization by the eddy.

In particular in BP, it has been shown that zooplankton functional groups respond to the relative vorticity induced by a cyclonic eddy, while the abundance of herbivorous organisms was correlated to the water density gradient due the physical feature. An inverse correlation of

carnivorous organisms with the density of the water was associated with negative vorticity in the GoC (Durán-Campos *et al.* 2015). More recently, Rocha-Díaz *et al.* (2021) demonstrated a strong relationship between the horizontal distribution of copepods and the presence of the cyclonic eddy inside the bay during the winter season, which generates an arrangement of copepods around the physical structure, which the authors called "copepod belt".

Some studies reported temperature as a crucial physical factor affecting zooplankton distribution. For example, Lin *et al.* (2011) used CCA ordinations to visualize biotic and abiotic parameters that describe the distribution of calanoid copepods in Pearl River Estuary (China) during summer; the environmental variables temperature, salinity and nutrients, especially nitrogen, influenced the distribution of the organisms. The results presented here are consistent, considering the correlation between conservative temperature with the abundance of calanoid copepods. According to White *et al.* (2006), zooplankton assemblages, particularly cyclopoid copepods, are related with temperature, which is in agreement with our observations. Besides, in our case, the CCA ordination diagram (Fig. 5) showed that the calanoid copepods presented a relationship with conservative temperature, while the cyclopoid copepods apparently presented a close relationship with the abundance of diatoms and silicoflagellates; although they are strictly carnivores, some species at some stages could feed phytoplankton, particularly diatoms (Turner 1986, Paffenhöfer 1993). Copepodites appear to have a relationship with many of the environmental variables analyzed due to the wide spectrum of feeding habits during its life cycle. The diagram also showed a relationship with the sampling stations in coincidence with the center of the eddy.

Our results showed a high relative abundance of calanoid copepods at the stations close to the center of the eddy. However, contrary to our observations, Cruz-Hernández *et al.* (2017) documented a decrease in the abundance of calanoid copepods towards the center of a cyclonic eddy located in the southern GoC. Nevertheless, Coria-Monter *et al.* (2014) discussed the possible temporal evolution (or life-cycle) of the eddy and concluded that inside BP, during summer, the eddy had reached maturity and that it had started decaying. However, recent evidence suggests that upwelling and nutrient enhancement stages likely occur earlier during the spring (Coria-Monter *et al.* 2017).



**Figure 5.** CCA ordination diagram. Red vectors indicate environmental variables: T = conservative temperature; S = absolute salinity; D = density; Chl = chlorophyll-*a* concentration; Dia = diatoms abundance; Din = dinoflagellates abundance; Silic = silicoflagellates abundance. Blue triangles represent abundance for each group: CyC = cyclopoid copepods; CC = calanoid copepods; ACS = all copepodite stages. Gray circles represent sampling stations (see Fig. 1).

In terms of zooplankton biomass, higher concentrations in cyclonic eddies have been previously recognized. Similar to our observations, Beckmann *et al.* (1987), documented higher values in cold cores eddied in the North Atlantic, with copepods as the principal groups in the zooplankton community across the eddy field, ranging from 24 to 156 mg m<sup>-3</sup> in the surface layers (200 m of the water column). Zooplankton biomass was also observed to be considerably higher inside a cyclonic eddy than at its periphery (Durán-Campos *et al.* 2015). Similar observations have been reported in different regions of the world. For example, in the Canary Islands it has been documented that the presence of cyclonic and anticyclonic eddies regulates the zooplankton biomass values in the region, being generally higher on the periphery of anticyclonic eddies (Hernández-León *et al.* 2001). In the Algerian Basin (western Mediterranean Sea) the presence of cyclonic eddies regulates the chlorophyll-*a* concentration which influences the composition and zooplankton biomass (Riandey *et al.* 2005).

Finally, the results presented here allowed us to visualize a pattern of progressive changes in the



composition of the organisms into the field of the cyclonic eddy observed during the summer of 2009 within the BoP, even though the organisms of interest were not identified at species level. Besides, this study highlight the influence of physical processes on the copepods organisms which are inspiring and motivate the implementation of more in-depth studies that cover additional seasons of the year. The last poses big challenges to understand how organisms benefit from ocean currents. More complete *in situ* observations are needed in order to improve the evaluation of different aspects of eddies, including differences in hydrographic parameters and dynamics, that could affect zooplankton communities that support many commercially important pelagic fish species (which usually predate on zooplankton, particularly copepods, and micronekton). Finally, an understanding of zooplankton ecology is key to understanding fisheries production and achieving better management of marine resources.

#### Ethical statement

The present investigation did not involve the manipulation of regulated animals and did not require approval by an Ethical Committee.

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## Copepod groups distribution in a cyclonic eddy in Bay of La Paz, Gulf of California, Mexico, during summer 2009

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### Supplementary material

**Table S1.** Abundance (ind 100 m<sup>-3</sup>) and biomass (mg m<sup>-3</sup>) observed for each copepod group at each station in Bay of La Paz during summer 2009.

Station	Longitude (W)	Latitude (N)	Abundance (ind 100m <sup>-3</sup> )				Biomass (mg m <sup>-3</sup> )			
			Calanoids	Cyclopoids	All stages of copepodite	Total abundance	Calanoids	Cyclopoids	All stages of copepodite	Total biomass
27	110°39'36"	24°28'12"	95	208	420	723	23.8	25.0	28.2	77

Station	Longitude (W)	Latitude (N)	Abundance (ind 100m <sup>-3</sup> )				Biomass (mg m <sup>-3</sup> )			
			Calanoids	Cyclopoids	All stages of copepodite	Total abundance	Calanoids	Cyclopoids	All stages of copepodite	Total biomass
30	110°37'12''	24°33'0''	424	306	3308	4038	21.0	20.2	33.8	75
31	110°33'0''	24°33'0''	299	588	1250	2137	16.1	21.4	16.5	54
38	110°29'24''	24°37'12''	139	581	4503	5223	22.3	39.9	68.1	130.3
39	110°33'0''	24°37'12''	475	359	2687	3521	13.7	15.6	20.4	49.7
40	110°37'12''	24°37'12''	480	632	6367	7479	7.2	8.8	20.4	36.4
44	110°33'0''	24°41'24''	285	310	3761	4356	11.2	11.1	19.6	41.9
45	110°29'24''	24°41'24''	740	1082	11800	13622	7.1	10.9	20.3	38.3
53	110°25'48''	24°45'0'	1,019	568	3450	5037	16.0	13.0	15.9	44.9