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Research Article

Physical, chemical and zooplankton biomass variability (inshore-offshore) of Mexican Central Pacific during El Niño-La Niña 2010

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ABSTRACT. The response of zooplankton, phytoplankton biomass (Chl-*a* concentration) and nutrients to the oceanographic variability in the Mexican Central Pacific was studied over three oceanographic surveys realized in 2010 (January, May and October). The highest zooplankton biomass (48 mL 1000 m^{-3}) was registered in May when nitrites, nitrates, phosphates and silicates were also highest and mean Chl-*a* was 0.67 mg m^{-3}. The lowest zooplankton biomass was registered in October, with a mean value of 25 mL 1000 m^{-3}. Twenty-nine taxonomic groups of zooplankton were recorded, of which copepods contributed 71% of total abundance followed by chaetognaths (6%) and euphausiids (5%). Multivariate BEST test demonstrated that mixed layer depth and temperature at 25 m depth can explain the distribution of major zooplankton groups. The study area was influenced by El Niño conditions, which caused a seasonal shift. Coastal upwelling was evident until late summer, when geostrophic analysis showed a predominant SW component near the Jalisco coast. We suggest a possible top-down control of zooplankton grazing over phytoplankton, and acclimatization of both plankton groups to variability in environmental conditions induced by the transition from warm to cold ENSO phase.

Keywords: zooplankton, Chl-*a*, nutrients, mesoscale, El Niño, Mexican Central Pacific.

INTRODUCTION

Mesoscale features in the ocean constitute distribution mechanisms for inorganic nutrients and planktonic organisms. Marine zooplankton is an important link between primary producers and higher trophic levels; its spatial and temporal variability responds to the influence of physical features such as currents, wind, oceanic fronts, gyres, upwelling and downwelling (Riandey *et al.*, 2005; Yebra *et al.*, 2009). On a seasonal scale, zooplankton abundance responds to nutrient availability and phytoplankton abundance (as Chl-*a* concentrations), with a time lag of up to two months in temperate latitudes (Fernández-Álamo & Färber-Lorda, 2006). However, in tropical regions like the Mexican Central Pacific (MCP), where seasonal changes are not easily detected, the variability of zooplankton abundance is usually governed by the influence of oceanographic features (upwelling, gyres), the effect of the dominant wind in the region, or inter-annual features such as El Niño (López-Sandoval *et al.*, 2009). In the last few years the number of zooplankton biomass studies in the MCP has increased. Franco-Gordo *et al.* (2004), described the MCP as a region with a negative correlation of zooplankton biomass and temperature, based on high values of biomass associated, with the presence of low temperature water. Low abundances were observed during the El Niño period, coinciding with studies on specific taxonomic groups including copepods, euphausiids and amphipods (Ambriz-Arreola *et al.*, 2012; Gasca *et al.*, 2012; Kozak *et al.*, 2014).

Modeled dynamics in the study area show the influence of the Mexican Coastal Current, which is generated at the Gulf of Tehuantepec as a sub-thermocline flow that reaches the surface between 17º

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and 20ºN to continue northward up to the Gulf of California. The confluence of this current with a branch of California Current converts the MCP into a transition zone where mesoscale eddies, meanders and filaments are generated (Zamudio *et al.*, 2007; Godínez *et al.*, 2010; Pantoja *et al.*, 2012; Gómez-Valdivia *et al.*, 2015). In addition, the presence of a thermocline dome (106ºW, 18ºN) that plays an important role on the coastal seasonal dynamics off SW Mexico has recently been reported by Gómez-Valdivia *et al.* (2015), who proposed calling it "The Thermocline Cabo Corrientes Dome". Based on this information, the objective of this study is to provide an integrated perspective of the Mexican Central Pacific that includes the response of zooplankton, phytoplankton biomass (Chl-*a*) and nutrients to the spatial-temporal hydrological variability in the region.

MATERIALS AND METHODS

Field methods

Zooplankton and hydrographic data were obtained along a 100 nm fringe from Cabo Corrientes, Jalisco to Maruata, Michoacán, on board the "BIP XII" vessel during 15-27 January (PCM1001), 25 May-4 June (PCM1005) and 18-29 October (PCM1010) of 2010. The oceanographic surveys covered a polygonal area with 19 stations (Fig. 1). Zooplankton was sampled day or night with oblique tows using a standard Bongo net fitted with 505 µm mesh and 0.6 m mouth diameter. A calibrated digital flow meter was attached to the mouth of the net. All hauls were made at 200 m or from the bottom to the surface (Smith & Richardson, 1977). Samples were preserved in a 4% formalin solution buffered with sodium borate (Griffiths *et al.*, 1976). Nutrient and Chl-*a* samples were taken with a 5 L Niskin bottle at 0, 10, 25, 50, 75, 100, 150, 175 and 200 m depths and frozen after collection for subsequent laboratory analysis. Vertical temperature and salinity profiles of the water column were taken at each station with a Seabird model SBE-19 plus.

Laboratory analysis

A total of 57 samples were analyzed (Fig. 1). Zooplankton biomass was calculated using the displaced volume method (Beers, 1976), excluding organisms larger than 3 cm. High density samples were fractioned using a Folsom plankton splitter from ½ up to ¼, depending on the density of each sample. Biomass values were standardized to mL 1000 m^{-3} of filtered seawater. Organisms in the samples were identified to dominant taxonomic group using key sheets of Newell & Newell (1973), Smith & Johnson (1996) and Todd *et al.* (1996). The number of organisms in each functional group was standardized to 1000 m^{-3} of seawater (ind 1000 m^{-3}).

Density profiles were obtained from temperature and salinity in order to calculate the mixed layer depth (MLD) according to Kara *et al.* (2000). Geostrophic velocity was calculated from dynamic height profiles as proposed by Talley *et al.* (2011); both parameters were processed using MATLAB 8.1.0.604 software (2009). Nutrients (NO_2, NO_3, NH_4, PO_4 and $Si(OH)_4$) were determined in a Skalar San Plus II segmented flow auto analyzer, and Chl-*a* using colorimetric techniques with a PerkinElmer´s UV/Vis spectrophotometer following Strickland & Parsons (1972) and Grasshoff *et al.* (1983).

Data analysis

Biotic and abiotic parameters were classified according to the water column structure during stratified (El Niño) and semi-stratified (La Niña) conditions. Statistical analysis did not indicate normal distribution (Kolmorogov-Smirnov and Shapiro-Wilk) so non-parametrical analyses were applied. Mean biomass values in every cruise were calculated with a 95% confidence interval. Two matrices were generated: environmental data were standardized (temperature, salinity and Chl-*a* at 25 m depth, MLD, coastal upwelling index (CUI), nutrients and zooplankton biomass) and zooplankton abundance data were transformed with $x = \log(x+1)$ to reduce the difference of scale between units and results. Differences between groups were tested with ANOVA analysis; in the case of significant results, *post-hoc* analysis defined the differences. For multidimensional analysis (MDS) and dissimilarity test, Euclidean distance index was applied to environmental and Bray-Curtis to abundance data. Differences between cruises and distance to coast were evaluated with one-way analysis of similarities (ANOSIM). To identify the variables that possibly controlled the distribution of major zooplankton groups, a biotic and environment matching test (BEST) was performed. In addition, Spearman-rank correlation test was made between zooplankton biomass, functional groups, Chl-*a*, nutrient and abiotic variables. Functional groups with less than of 1% of the total abundance were excluded from statistical analysis. Multivariate analyses were performed using PRIMER 6.0 software and non-parametric correlation was performed with STATISTICA 7 software.

RESULTS

Hydrological conditions

Sea surface temperature (SST) showed a positive gradient from north to south. During January, a range

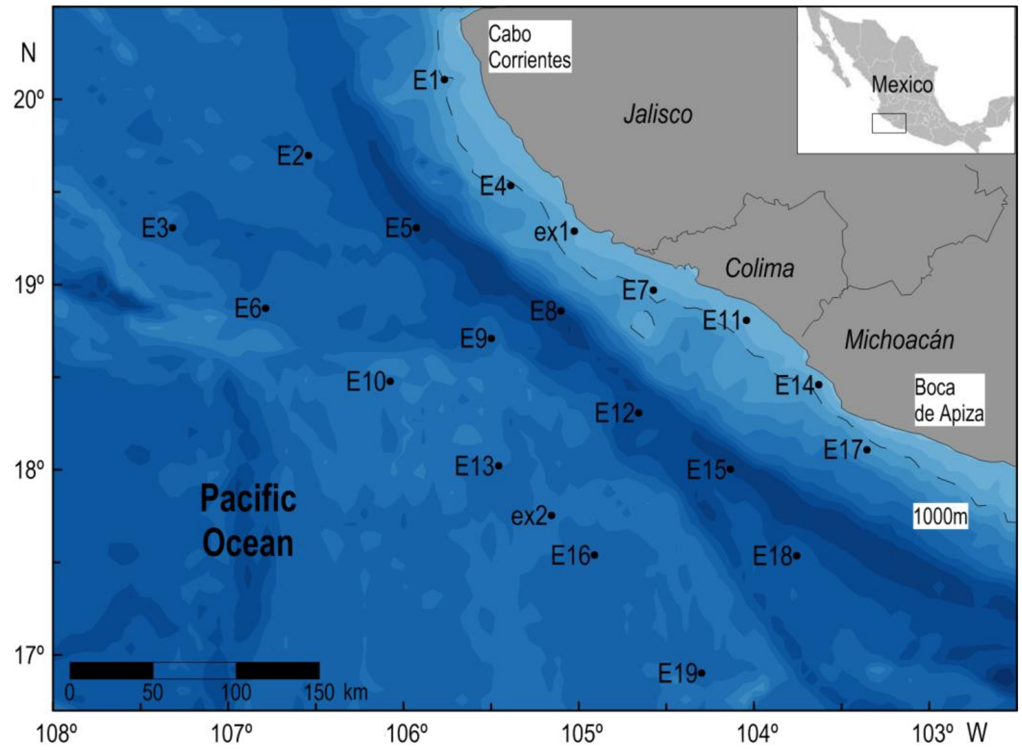

Figure 1. Position of sampling sites off the Mexican Central Pacific.

of 25.5-28.2°C was registered; May showed the lowest values of the surveyed period (24.5-28.5°C), while in October the temperature varied from 24.5 to 29.6°C (Figs. 2a-2c). Although variation between cruises appeared to be small, temperature at 25 m depth was significantly lower in May than during January and October (F = 28; $P < 0.001$). A pulse of cold water was identified in front of the Jalisco coast during the surveyed period, with the highest intensity in May, when surface temperatures of 16.7ºC were detected. This variation of temperature values across the continental shelf also showed significant differences between transects (F = 4; $P = 0.024$).

Salinity was characterized by minimum values in the southern region, especially along the coastal and intermediate transects covering the central and southern regions in January. During January values ranged from 33.8 to 34.6, while May and October registered maximum salinity values (34.0-34.8) for the entire study area. The thermocline was found around 80-100 m in January, reaching the shallowest depth in October (40-70 m). Geostrophic circulation indicated the presence of a cyclonic gyre during January and a stronger one in May covering the central zone of the study area (Fig. 2). During October there was no apparent oceanographic feature that caused the thermocline to rise; in fact, the presence of an anticyclonic gyre was detected in the center of the intermediate transect (Figs. 2c and 2f). The mixed layer depth also showed significant changes between cruises (F = 31.39; $P = 0.05$); in January it was deepest (26-63 m), getting shallower during May and October with values ranging from 19 to 47 m.

Based on the ANOSIM test, environmental variables showed significant differences between climatic periods with an R = 0.579 ($P < 0.01$), presenting the most important differences during El Niño (January). Distance from the coast showed no statistically significant influence (R = 0.071; $P = 0.14$).

Nutrients and Chl-*a*

With the exception of ammonium, inorganic nutrients showed a similar distribution pattern: highest values near upwelling zones and cyclonic gyres. Median values of nitrate+nitrite (14.67 µM), phosphate (1.81 µM) and silicic acid (24.21 µM) concentrations were highest in May, when ammonium was at its lowest values. In January, ammonium (3.24 µM) showed maximum median concentration and nitrate+nitrite (2.20 µM), phosphate (0.74 µM) and silicic acid (7.09 µM) concentrations were at a minimum (Table 1).

Chl-*a* concentrations ranged from 0.01 in June to 12.91 mg m^{-3} in January. Median concentrations were: January, 2.18 mg m^{-3}; June, 0.67 mg m^{-3}; and October, 0.88 mg m^{-3} (Fig. 3).

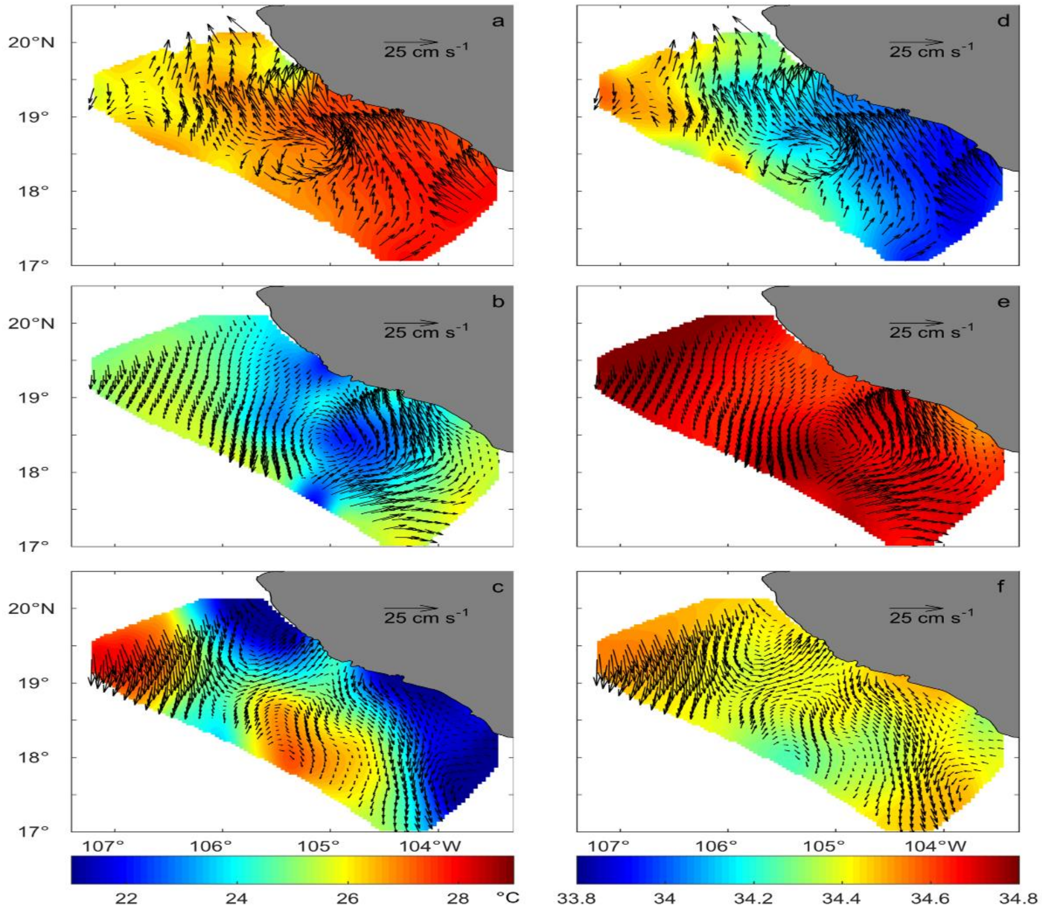

Figure 2. Spatial distribution of a, b, c) temperature and d, f, g) salinity in January, May and October 2010 along the Central Mexican Pacific. Vectors show geostrophic currents.

Values were statistically highest in the coastal zone (F = 3.57; *P* = 0.03) of the northern and southern region. Temporal distribution did not show significant differences (F = 0.60; *P* = 0.55).

Zooplankton biomass and abundance

Mean zooplankton biomass varied from 25 mL 1000 m^{-3} in October to 47.8 mL 1000 m^{-3} in May (Fig. 4a). Mean biomass in May was significantly higher than January and October (F = 11.06; $P < 0.05$). Distribution showed a tendency to decrease offshore, but it was not statistically significant (F = 1.81; *P* = 0.170) because of the presence of some high values along the oceanic transect. In general, the highest values of biomass (56-95 mL 1000 m^{-3}) over the entire study period were observed in front of northern Michoacán on the coastal transect. During January, coastal station E1 also showed major biomass with a value of 30.22 mL 1000 m^{-3}. Zooplankton biomass in May was high in E6 (66.49 mL 1000 m^{-3}). In October, zooplankton biomass showed a decrease in all areas, especially in the northern region.

The zooplankton community was composed of 29 functional groups, which varied temporally. Eight groups accounted for 95% of total abundance both in January (copepods, chaetognaths, euphausiids, amphipods, polychaetes, pteropods, fish larvae and decapods) and May (copepods, amphipods, chaetognaths, euphausiids, decapods, pteropods, fish larvae and gasteropods). By October, ten taxonomic groups contributed 95% of the zooplankton community: copepods, chaetognaths, euphausiids, fish larvae, amphipods, siphonophores, cladocerans, polychaetes, medusas and ostracods (Fig. 4).

The remaining 5% of the zooplankton community was composed of cladocerans, ostracods, doliolids, polychaete larvae, medusae, fish eggs, ctenophores, salps, cephalopod paralarvae, bivalves, isopods, appendicularians, pyrosomes, mysiids, heteropods and echinoderms larvae, stomatopods and cirripeds.

Distribution of major groups

Copepods, chaetognaths, euphausiids and amphipods were the most abundant groups during the study period, accounting for 87% of the total abundance (Fig. 5b).

Maximum median value of copepod abundance of 10,939 ind 1000 m^{-3} was recorded in May while the minimum of 9,297 ind 1000 m^{-3} was recorded in October. The January cruise registered a density of 9,900 ind 1000 m^{-3}. In October, 20% of the stations located in the center of the study area were characterized by the lowest values (0-5,000 ind 1000 m^{-3}). The largest aggregation of this group during the entire surveyed period was observed at the inshore southern region, particularly in station E14 where abundances up to 48,711 ind 1000 m^{-3} were found (Fig. 5).

Table 1. Mean concentration and standard error of nutrients in the Mexican Central Pacific during January, May-June and October 2010.

	Jan	May-Jun	Oct
NO_3+NO_2	2.20 ± 0.44	14.67 ± 1.13	11.02 ± 1.62
NH_4	3.24 ± 0.18	2.27 ± 0.17	2.25 ± 0.14
PO_4	0.72 ± 0.14	1.81 ± 0.27	1.17 ± 0.15
Si $(OH)_4$	7.09 ± 0.91	24.21 ± 2.29	9.29 ± 1.52

The average abundance of chaetognaths over the entire study period was 823 ind 1000 m^{-3}. High abundances of this group were observed in the southern study area except in January, when the northern zone registered the highest abundance of 1,150 ind 1000 m^{-3}. During October, cruise values inshore of the central and northern zone were lower than the oceanic region (Fig. 5).

Median abundance of euphausiids varied from 595 ind 1000 m^{-3} in January to 860 ind 1000 m^3 in May. 36% of stations during January showed values in the range of 200-400 ind 1000 m^{-3}. Spatial distribution during January and May showed high abundance in the southern inshore region and low in the northern, while in October high abundance was observed in the central-oceanic zone (Fig. 5). Except for October, amphipod abundance was high in the southern inshore zone, in May it was 14,599 ind 1000 m^{-3} at station E17, but typical values during this cruise were between 600 and 800 ind 1000 m^{-3}. Cross shelf distribution was characterized by high values near the coast that decreased in the oceanic region, except for oceanic station E3 that registered high values with respect to those near the coast during January and October (Fig. 5). Average abundance of amphipods was 845 ind 1000 m^{-3} in October.

No significant differences between samples from different coastal or oceanic transects were found in ANOSIM analyses of biotic variables (R = 0.078; P = 0.08), while a marginally significant seasonality was evident between each oceanographic cruise with an R = 0.468 ($P < 0.01$).

Zooplankton *vs* abiotic features

Biota and environment matching test (BEST) showed minor influence of environmental variables on taxonomic zooplankton groups. Temperature and MLD were the main variables explaining zooplankton group distribution in the study area (Rho = 0.38; P = 0.01). Spearman correlation analysis also showed low rank values between abiotic variables and abundance of zooplankton groups and biomass (Table 2).

Chl-*a* had no statistical correlation with zooplankton biomass, and was negatively correlated with chaetognaths, ctenophores and doliolids ($-0.27 < r < 0.41$), while bivalves and decapod larvae showed a positive correlation (r = 0.29, 0.30).

There was no significant correlation between temperature and zooplankton biomass. However, salinity and zooplankton biomass were positively correlated (r = 0.27). Most of the major zooplankton groups did not show any significant correlation with temperature or salinity. Minor groups like bivalves and pyrosomes were positively related with temperature and negatively with salinity. Pteropods and gasteropods showed positive correlation with temperature (r = 0.28, 0.44). Ostracods and doliolids showed negative correlation with salinity (r = -0.26, -0.31), while siphonophores had a positive correlation (r = 0.28; P <0.05). Negative correlations were found between temperature with fish larvae and medusae (Table 1).

The MLD was not significantly correlated with zooplankton biomass, but was positively related with 9 zooplankton groups including copepods, amphipods and chaetognaths ($0.27 < r < 0.60$). Other less abundant groups (<1%) such as siphonophores, medusae, cladocerans, heteropods, appendicularians and echinoderm larvae showed a negative correlation ($-0.64 < r < -0.28$; $P < 0.05$).

Zooplankton biomass and doliolids were positively correlated with nitrates+nitrites, phosphates and silicates, however, none of most abundant groups (copepods, chaetognaths, amphipods, euphausiids) were significantly correlated with nutrients. In spite of this, maps of spatial distribution showed concordance of high abundance values of copepods with nitrate+ nitrite during January in the central zone of the oceanic transect and during October in the southeast region.

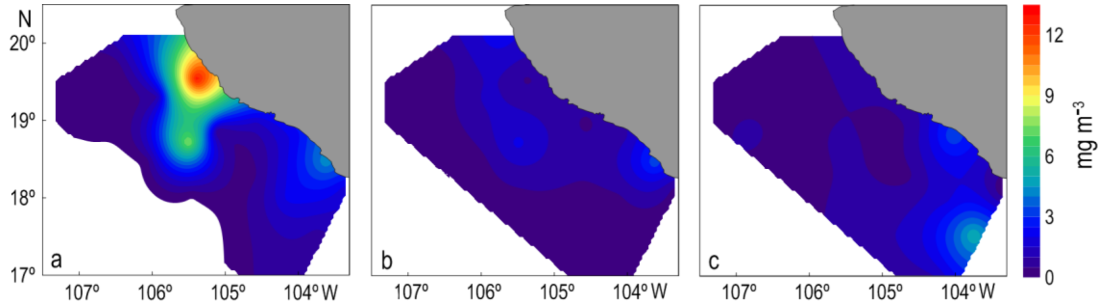

Figure 3. Spatial distribution of Chl-*a* in a) January, b) May and c) October 2010 in the Central Mexican Pacific.

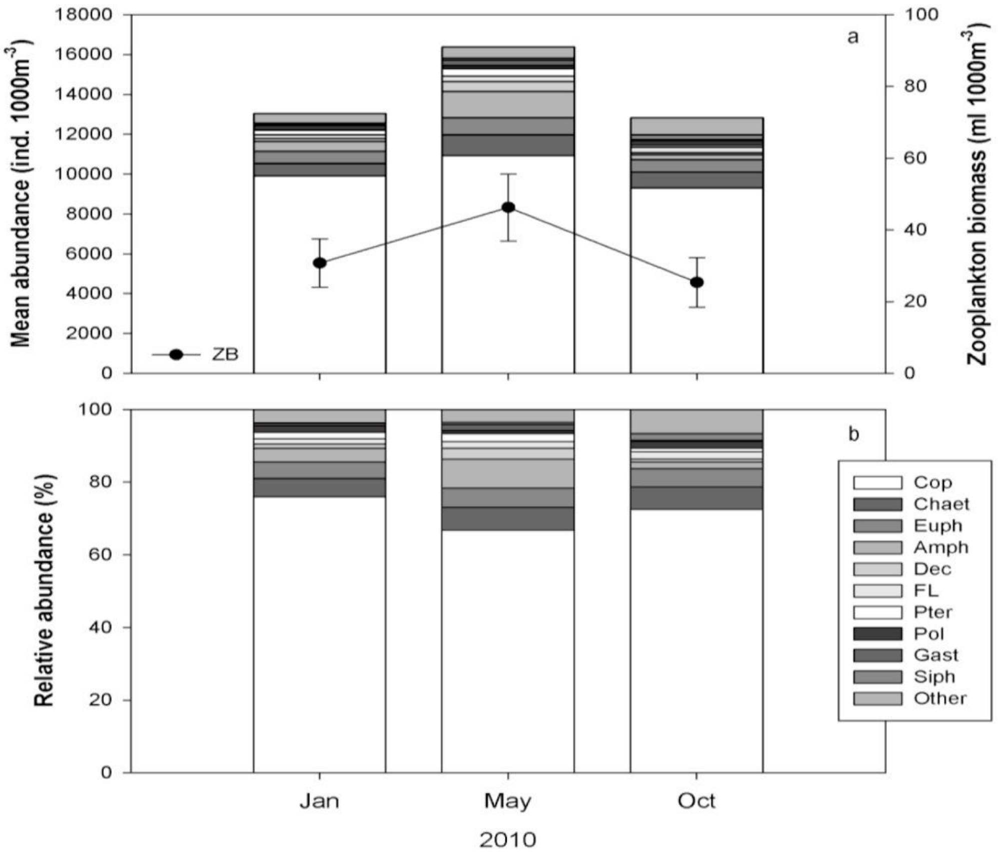

Figure 4. Temporal variation of a) mean abundance, and b) mean relative abundance of dominant taxa (>95%) of zooplankton community colected in the Central Mexican Pacific, dots in a) represent mean zooplankton biomass and bars the 95% confident interval. Cop: copepods, Chaet: chaetognaths, Euph: euphausiids, Amph: amphipods, Dec: decapod larvae, FL: fish larvae, Pter: pteropods, Pol: polychaetes, Gast: gasteropods, Siph: siphonophores.

DISCUSSION

Water column conditions

The confluence between the Mexican Coastal Current and the California Current in the Mexican Central Pacific (MCP) (Badan-Dangon, 1997; Kessler, 2006; Trasviña & Barton, 2008) forms a transition zone where varied physical phenomena are developed by the interact-tion of Tropical Pacific Surface Water (TPSW), Equatorial Surface Water (ESW), Subtropical Subsur-face Water (SSW) and California Current Water (CCW) (Kessler, 2006; Salas *et al.*, 2006). The thermohaline struc-ture through the water in the southern Cabo Corrientes region showed the influence of SSW (Trasviña *et al.*, 2004), while in the northeast CCW was detected. The influence of CCW is attributed to the

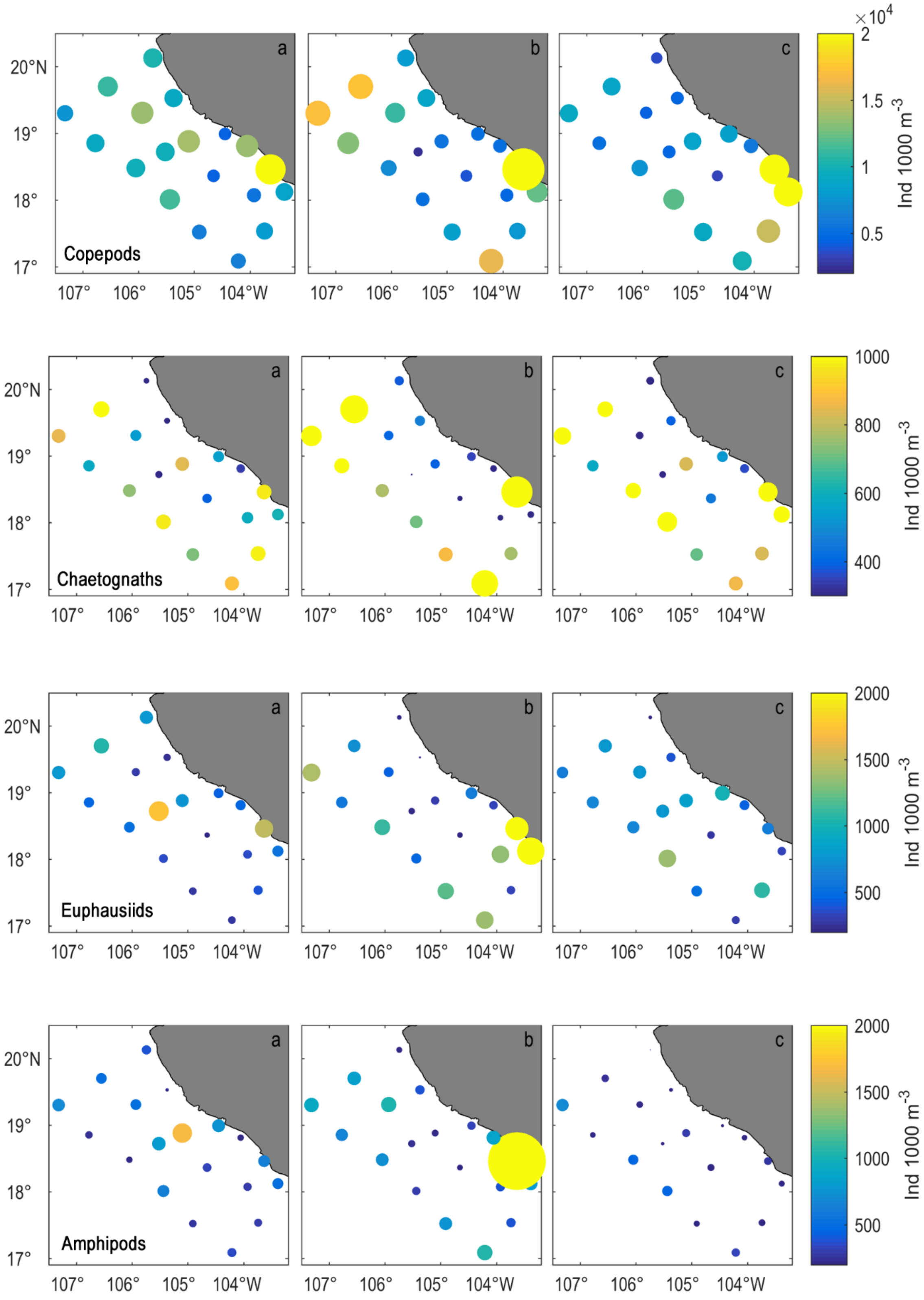

Figure 5. Spatial distribution of copepods, chaetognaths, euphausiids, and amphipods in a) January, b) May and c) October in the Central Mexican Pacific.

Table 2. Spearman rank correlations between abiotic variables and major dominant taxa (>95%) of the zooplankton community. Correlation values in bold are significant at $P = 0.05$. CUI: coastal upwelling index, MLD: mixed layer depth, T: temperature, S: salinity, Chl-*a*: chlorophyll-*a*, NO_{3}+NO_2: nitrates+nitrites, NH_4: ammonium, PO_4: phosphate, SiO_2: silicates acid, ZB: zooplankton biomass, Cop: copepods, Amph: amphipods, Euph: euphausiids, DP: decapod larvae, Pol: polychaetes, Pter: pteropods, Siph: siphonophores, Chaet: chaetognaths, FL: fish larvae, and Gast: gasteropods.

	CUI	MLD	T	S	Chl-a	NO_3+NO_2	NH_4	PO_4	$Si(OH)_4$	ZB	Cop	Amph	Euph	DL	Pol	Pter	Siph	Chaet	FL	Gast
CUI	1.00																			
MLD	**-0.59**	1.00																		
T	**-0.27**	**0.61**	1.00																	
S	**0.61**	**-0.41**	**-0.48**	1.00																
Chl-*a*	-0.21	0.05	0.01	**-0.34**	1.00															
NO_3+NO_2	**0.63**	**-0.52**	**-0.51**	**0.55**	-0.10	1.00														
NH_4	**-0.46**	**0.39**	**0.37**	**-0.28**	0.07	-0.24	1.00													
PO_4	**0.41**	**-0.27**	**-0.40**	**0.55**	-0.15	**0.70**	0.11	1.00												
SiO_2	**0.52**	**-0.27**	**-0.38**	**0.62**	-0.11	**0.77**	-0.08	**0.58**	1.00											
ZB	**0.40**	-0.04	-0.09	**0.27**	-0.13	**0.27**	-0.09	**0.26**	**0.40**	1.00										
Cop	-0.01	**0.28**	0.05	-0.03	0.01	-0.09	0.14	-0.04	-0.05	**0.51**	1.00									
Amph	0.16	**0.30**	0.25	0.11	-0.17	-0.07	0.04	-0.08	0.16	**0.66**	**0.42**	1.00								
Euph	0.14	0.10	0.07	0.13	-0.13	-0.05	-0.23	-0.12	-0.02	**0.39**	**0.44**	**0.43**	1.00							
Dec	0.25	0.00	-0.12	0.12	**0.29**	0.08	0.00	0.09	0.17	**0.43**	**0.29**	**0.29**	**0.31**	1.00						
Pol	**-0.35**	**0.31**	0.07	**-0.51**	**0.35**	**-0.28**	**0.27**	-0.11	-0.17	0.14	**0.43**	0.23	-0.01	0.14	1.00					
Pter	-0.08	**0.28**	**0.44**	-0.22	0.06	-0.12	0.11	-0.19	-0.08	**0.43**	0.22	**0.51**	0.08	0.22	0.23	1.00				
Siph	**0.37**	**-0.39**	-0.16	**0.28**	-0.25	**0.39**	**-0.31**	0.19	0.15	0.14	0.05	0.10	**0.28**	-0.14	**-0.46**	-0.01	1.00			
Chaet	-0.08	0.23	0.22	0.00	**-0.41**	-0.11	0.09	-0.03	-0.12	**0.39**	**0.59**	**0.42**	**0.35**	-0.10	0.24	**0.29**	0.26	1.00		
FL	**0.33**	-0.16	**-0.28**	0.15	-0.01	0.24	-0.12	0.26	0.13	**0.52**	**0.39**	0.18	**0.26**	**0.47**	0.16	0.03	0.19	0.19	1.00	
Gast	0.05	**0.33**	**0.50**	-0.25	0.14	-0.12	0.09	-0.24	-0.09	**0.29**	0.08	**0.38**	0.11	0.20	0.22	**0.49**	-0.13	0.17	0.03	1.00

equatorward flow occurring mainly during winter-spring months (Ambriz-Arreola *et al.*, 2012) which may be upwelled due the presence of mesoscale features originated by the steep bathymetry of the region (Salas *et al.*, 2006; Ambriz-Arreola *et al.*, 2012).

The thermohaline structure of the water column in the study area has been described by Filonov & Tereshchenko (2010) and Ambriz-Arreola *et al.* (2012), who established three periods: 1) mixed water column from February to early June, 2) a stratified period from June to November, and 3) a semi-mixed transitional period commonly occurring in June and December/ January. In the context of our results, the influence of El Niño conditions from January to March (Blunden *et al.*, 2011) shifted oceanographic and biological conditions. Geostrophic circulation in the northern zone was dominant in the region and may have caused deepening of the MLD. Increased wind intensity in late May to June (Bulgakov & Martínez-Zartarain, 2006; Pantoja *et al.*, 2012) and the influence of La Niña conditions from July to December (Diamond, 2011) promoted intense upwelling events which were reflected in a shallow MLD in May and October; these processes lead to higher concentration of nitrites, nitrates, phosphates and silicic acids and zooplankton biomass in the coastal zone.

Chl-*a*, showed an inverse behavior with respect to nutrients and zooplankton biomass. Mean concentration of Chl-*a* in the study period was 1.24 mg m^{-3}. Concentrations in the coastal zone were statistically higher due to coastal upwelling promoted by the dominant northwestern winds in the region, especially in January. Considering phytoplankton as the major food supply for zooplankton, we expected concentrations of Chl-*a* to be positively correlated with the high abundance of zooplankton biomass registered in May, but we found the inverse. This result could be explained by two possible reasons: 1) a coastal upwelling event prior to the survey period (15 days CUI = 142 $m^3 s^{-1}$ 100 m^{-1} coastline) caused phytoplankton to bloom, producing available particulate organic matter compounds such as lipids, carbohydrates and proteins (not analyzed in this study) as food for zooplankton during the survey period (Färber-Lorda *et al.*, 2004a, 2004b); and 2) the presence of small cells of marine cyanobacteria such as *Prochlorococcus* in upwelling regions and coastal zones of tropical oceans. Although we did not analyze the concentration of this cyanobacteria, it tends to have faster nutrient uptake rates without contributing significantly to the productivity of blooms (Ward *et al.*, 2012, 2013).

Zooplankton grazing could be exerting a top-down control over phytoplankton, preventing the use of all available nutrients and therefore affecting Chl-*a*. This has been previously reported in different areas of the Central Mexican Pacific under warm conditions, in studies showing a clear association of primary productivity with higher trophic levels (Torres-Orozco *et al.*, 2005; Gaxiola-Castro *et al.*, 2008; López-Sandoval *et al.*, 2009; Ambriz-Arreola *et al.*, 2012). Although El Niño conditions registered in this study ended in April, transition into a "normal period" could have influenced phytoplankton cell acclimatization (Lluch-Cota *et al.*, 1999) and induced lower Chl-*a* production during May (Fig. 3).

Zooplankton variability: abundance and structure

In this study, temporal variations of zooplankton biomass appeared to be strongly influenced by temperature, considering that maximum values were observed in the presence of low temperatures during May. Different authors have recognized the same pattern in the MCP (Franco-Gordo *et al.* 2004) and other areas of Mexico (Hernández-Trujillo *et al.*, 2001), which could be explained by the metabolism of these organisms, where high temperatures cause their metabolic requirements to exceed available energy (primary production), resulting in low biomass development (Coyle *et al.*, 2008). Nevertheless, low zooplankton biomass values in this study probably resulted from the broader oceanic sampling area (100 nm from coast) than the other studies (<3 nm), and therefore fertilization mechanisms were less intense. Our zooplankton values were also lower in the presence of high values of nutrients and Chl-*a* during the January and October cruises, which could be due to the time lag between the transference from primary producers to zooplankter organisms. Fernández-Álamo & Färber-Lorda (2006) reported a time lag of up to two months in temperate regions, while tropical latitudes could vary temporally due the presence of local hydrographic conditions. This was the case of the May cruise, where high biomass values recorded in the oceanic region were likely due to the presence of a cyclonic gyre in the inshore region (Fig. 2).

Negative correlation of zooplankton biomass and SST has been reported by other authors (Franco-Gordo *et al.*, 2002, 2004; Fernández-Álamo & Färber-Lorda, 2006). The presence of the ENSO phenomenon during January could have affected the zooplankton community, as the lowest biomass values were recorded during that period. The influence of abnormally high temperatures could lead to lower upwelling intensity, lower concentration of nutrients and the establishment of phytoplankton species not included in the zooplankton diet, which has been reported to cause disturbances in the food chain, including uptake and utilizations, and competitive/predatory interactions (Barber & Chavez, 1983; Sebastian *et al.*, 2012).

Zooplankton structure in the all three cruises was dominated by copepods (66-76%); they are cosmopolite organisms with a great capacity of adaptation to varied environmental conditions in the same region (Hernández-Trujillo *et al.*, 2001; Lo *et al.*, 2004; Lavaniegos *et al.*, 2012). Chaetognaths were the only carnivorous zooplankton that significantly contributed to total abundance with 5-8%, in agreement with Hossfeld (1996) and Álvarez-Cadena *et al.* (2008) who reported that this zooplankton group accounted for 5-15% of total zooplankton abundance.

During January, crustacean herbivores such as euphausiids and amphipods were dominants, and other groups including polychaetes, pteropods and some groups of meroplankton such as fish and decapod larvae were also present. During the May cruise relative abundance of polychaetes diminished to <1%, while gasteropods represented >1%. Lack of significant correlation between temperature and polychaete abundance in this study demonstrates the great species diversity and affinity that can be found in the MCP, since it has been demonstrated that some species are abundant in upwelling zones while other species could be indicators of warm tropical water masses (Fernández-Álamo & Sanvicente-Anorve, 2005; Fernández-Álamo & Färber-Lorda, 2006).

Only doliolids and pyrosomes registered a positive correlation with temperature and negative with salinity, this could be explained by the influence of Tropical Pacific Surface Water (TPSW), characterized by high values of temperature, low salinity and low nutrient availability (Fiedler & Talley, 2006).

There was a correlation between the abundance of fish larvae and the relatively low SST, high productivity and high zooplankton biomass found along the coastal zone in front of Michoacán and southern Colima. This may be the influence of coastal upwelling during the May and October cruises, where the input of subsurface nutrients promotes the production of certain species of phytoplankton that serve as food for fish larvae. León-Chávez *et al.* (2010) studied the influence of circulation on larval fish assemblages in the Eastern Tropical Pacific during 2010, and proposed that distribution is controlled by large scale and mesoscale hydrodynamic processes in the Eastern Tropical Pacific. Although in this study fish larvae were not identified to species level, many individuals of this group appear to be carried by a northward current in January and May, whereas in October the abundance of fish larvae coincide with an upwelling zone in the Cabo Corrientes region and a southward current in the coastal region of Michoacán (distribution map not shown here).

The positive correlation of nitrites, nitrates, phosphates and silicates with zooplankton biomass, and nitrate+nitrite with cladocerans, medusae and siphonophores leads us to suggest that upwelled waters could favor the abundance of these groups through primary production enhancement. Although Richardson *et al.* (2012) consider that the influence of high nutrients leads to the presence of large crustaceans and carnivorous zooplankton, the energy transfer throughout trophic levels needs to be studied in order to establish the influence of inorganic compounds on specific zooplankton groups. There are few studies focused on the marine environment because of its omnivorous nature which comprises a mixture of trophic types, species, size-classes and detritus (Gentleman *et al.*, 2003). This latter could explain why, contrary to expectations and findings from previous studies (Franco-Gordo *et al.*, 2001; Lavaniegos *et al.*, 2002), in this study there was no statistical evidence of a correlation between Chl-*a*, zooplankton biomass and the principal herbivorous groups (copepods, euphausiids, ostracods, amphipods, salps). It is also important consider the dynamic nature of the marine environment, where there are no absolute distributional boundaries, particularly in a transition region such as the MCP, as well as the time lag of more or less one month for zooplankton abundance to reflect food intake (Färber-Lorda *et al.*, 2004b; Fernández-Álamo & Färber-Lorda, 2006). This study can be considered an approach to help understand the hydroclimatic influence on zooplankton groups of the Mexican Central Pacific.

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