

DIVERSITY AND COMPOSITION OF COPEPODS ASSEMBLAGE ASSOCIATED WITH HYPERBENTHIC ZONE OF THE VENEZUELAN CENTRAL COAST SANDY BEACHES

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RESUMEN: Los copépodos son uno de los componentes principales de la fauna que habita en la columna de agua, siendo encontrados frecuentemente en la capa de agua adyacente al fondo. Se estudió la variación espacio-temporal de los copépodos encontrados en la zona hiperbentónica de cuatro playas arenosas de Venezuela. En cada localidad, se realizaron ocho arrastres de 5 m con un trineo hiperbentónico manual y simultáneamente fueron medidas algunas variables ambientales. Fueron identificadas nueve especies: *Acartia (O.) lilljeborgi*, *A. (A.) tonsa*, *Caligus undulatus*, *Clausocalanus arcuicornis*, *C. furcatus*, *Labidocera aestiva*, *Oithona plumifera*, *O. oswaldocruzi* y *Temora turbinata*. La especie más abundante y frecuente fue *A. lilljeborgi* (presente en >60% del periodo estudiado). La densidad de copépodos varió con máximos esporádicos. La mayor densidad fue encontrada en junio en Los Timones (71.90 ± 56.83 ind.m⁻²), seguido por Las Cabañas en mayo (31.45 ± 45.34 ind.m⁻²). Fueron detectadas diferencias significativas en el ensamblaje de la comunidad en la interacción entre playa y mes (PERMANOVA, $p = 0.0001$). Los copépodos acartidos son residentes permanentes durante el día y durante casi todo el año de la zona hiperbentónica, con patrones de variación de su abundancia no explicados por las variables ambientales locales. Se concluye que hay un bajo número de especies residentes/dependientes de la capa de agua adyacente al fondo y algunos visitantes ocasionales.

Palabras clave: Copepoda, *Acartia*, suprabentos, Venezuela, zona de rompiente

ABSTRACT: Copepods are one of the main components of the fauna that inhabits the water column. They occur frequently in the benthic boundary layer. We studied the spatial-temporal variation of the copepods found in the hyperbenthic zone of four sandy beaches in Venezuela. At each location, eight tows of 5 m were conducted with a manual hyperbenthic sledge and some environmental variables were simultaneously measured. We identified nine species: *Acartia (O.) lilljeborgi*, *A. (A.) tonsa*, *Caligus undulatus*, *Clausocalanus arcuicornis*, *C. furcatus*, *Labidocera aestiva*, *Oithona plumifera*, *O. oswaldocruzi* and *Temora turbinata*. The most abundant and frequent was *A. lilljeborgi* (present in >60% of the studied period). Copepod density varied with sporadically peaks. The highest mean density was in June in Los Timones (71.90 ± 56.83 ind.m⁻²), followed by Las Cabañas in May (31.45 ± 45.34 ind.m⁻²). Significant differences in the community assemblage were detected in the interaction of beach and month (PERMANOVA, $p=0.0001$). Acartid copepods constitute a day-time resident population almost year-round, and their population abundance pattern is not explained by the local environmental variables. We could conclude that there is a low number of resident/dependent species of the benthic boundary layer and some occasional visitors.

Key words: Copepoda, *Acartia*, suprabenthos, Venezuela, surf zone

INTRODUCTION

Hyperbenthos, also called in literature as suprabenthos or demersal zooplankton, is composed by fauna inhabiting the benthic boundary layer during different periods of their life or at different times of day, while retaining some

contact with the substratum (MEES & JONES 1997; LIGAS *et al.* 2009). Studies of copepods from the hyperbenthic community have generated important insights into the evolutionary history of the group (OHTSUKA *et al.* 2016). As the hyperbenthic community is inhabited by a mixture of basal and derived groups of copepods, it has been

suggested that the latter has secondarily colonized this habitat from the water column (OHTSUKA *et al.* 2016). Generally, peracarid crustaceans are recognized as the most abundant fauna in the hyperbenthic zone, although studies made in Greece, Canada, the United States of America and Brazil report copepods as the dominant group. Behind copepods, harpacticoids and cyclopoids are the main constituents (CAHOON & TRONZO 1992; WILDISH *et al.* 1992; KOULOURI *et al.* 2009; MELO *et al.* 2010). Some genera as *Acartia*, *Canthocalanus*, *Paracalanus* and *Temora* frequently inhabit the hyperbenthic zone. Little is known about hyperbenthic copepods, and they could dominate demersal fauna and show seasonal cycles (BLAXTER *et al.* 1998).

Planktonic copepods are of prime importance to marine ecosystems because many are herbivorous and feed on phytoplankton, thus forming a direct link between primary producers and higher trophic consumers (LEE *et al.* 2009). They are an important group in the second level of marine trophic food webs, being the main food item for many marine species, some of which support other species of commercial importance (MEDELLÍN-MORA & NAVAS 2010). The abundance of copepods can dramatically affect the structure of oceanic food webs because of their regulation of material and energy fluxes. Their role as secondary producers in marine ecosystems makes their potential influence on fishery resources critical. Certain copepod species are also known to be indicators of specific water masses and oceanic currents (YANG *et al.* 2000; LI *et al.* 2003). However, copepod communities may change in response to hydrographic conditions. This has been the primary reason researchers have attempted to determine how hydrographic factors affect the seasonal and/or long-term community dynamics of copepods (CLARK 2003; LEE *et al.* 2009).

Coastal and estuarine environments are typically subjected to major environmental fluctuations. These are associated with a variety of oceanographic processes: changes in bodies of water (temperature, salinity, river inputs, among others), pulses of organic matter derived from primary production, and vertical fluxes with direct influence on the suprabenthic dynamics (CARTES *et al.* 2007, 2009). Physical fluctuations such as the degree of wave exposure, sediment grain size and water transparency have a high influence in some species and may alter the composition and richness of the assemblages that inhabit the area (CLARK *et al.* 1996).

Here we address questions on copepods that inhabit the hyperbenthic zone and their seasonal community dynamics, such as the species composition, abundance, distributional pattern, parameters of biodiversity, community structure, and other issues of biological oceanography. Thus, the aim of this work was study the spatial and temporal variations in species composition of a copepod assemblage associated to the hyperbenthic zone of several beaches in the Venezuelan central coast, as well as its relationship with some environmental variables. This represents the first ecological research of copepods from the hyperbenthic zone in the Venezuelan coast.

MATERIALS AND METHODS

The studied area encompasses a large stretch of sandy beaches that extend from Cabo Codera to Barcelona in the central coast of Venezuela. Samples were collected at four beaches: Agua Sal (10°28'00" N - 66°05'04" W), Los Timones (10°28'44" N - 66°05'38" W), Las Cabañas (10°29'45" N - 66°06'27" W) and Valle Seco (10°31'19" N - 66°06'56" W). Those beaches are composed of fine sands, a dissipative profile of intermediate energy (depending on the season), and a relatively low subtidal slope (BONE *et al.* 1998). Particular details from sampling beaches include: Agua Sal receives material and sediment plume from Capaya and Tuy rivers, being the sampled point at less than 100 m from a Capaya stream mouth; the rocky jetties from the Agua Sal Club's Marine retains sticks, detritus and other fluctuating objects and makes them accumulate on this beach. Los Timones is the beach located in the other side of the rocky jetties from the Agua Sal Club's Marine, it receives freshwater discharge from the Club's Marine channel and is affected by the channel dredge with accumulation of fine sediments. Also it receives freshwater from artificial streams created for street's rain drainage. Las Cabañas receives influences from Curiepe river, which mouth discharges at 1 km from sampling point; supralittoral zone is formed by big banks of bivalves. Valle Seco is near the La Reina lagoon mouth, surf zone varied from low to high energy depending on storms and may have accumulation of bryozoans in some occasions. The median grain size is around 125 µm and remained practically constant during the sampling period. All beaches were composed by more than 60% of fine and very fine sands, and less than 10% of organic matter; with exception of Los Timones than can reach 24% of organic matter when the Club's Marine channel is dredge (ORTEGA *et al.* 2014). The temperature was characterized by variations between 26.6-33.9°C.

We collected six water samples from each beach simultaneous to faunal sampling for the analysis of the suspended organic matter percentage in the water. In addition, eight sediment samples were collected for a Total Organic Carbon percentage analysis.

Animals were collected monthly during 2011 from the swash zone (<1 m depth) of the four beaches, using a manual hyperbenthic sledge (mouth 50 × 20 cm), equipped with a plankton net of 500 µm mesh size. Despite copepods being usually sampled with plankton nets of 300 µm, the high content of sediment and suspended organic material in these beaches makes it impossible to tow a hyperbenthic sledge with such mesh aperture. This could lead to an underestimation of the copepod community, but as there is a scarce knowledge of the community, the seasonal variation of larger copepods is still of higher interest.

Tows were performed by a single operator wading through the swash zone parallel to the shoreline in a distance of 5 m. Distance was chosen after a pilot sampling with different towing distances and proved a good sampling of the community without the collapse of the net. Eight replicates per beach were collected and preserved in 4% buffered formaldehyde. In the laboratory, copepods were sorted and identified to the lowest possible taxonomic level. Several specimens belonging to the identified species were preserved in the collection of the Laboratorio de Zooplankton of the Universidad Central de Venezuela.

For each taxon, the total number of specimens was determined and standardized as the number of individuals per square meter (ind.m⁻²). Multivariate data was square root transformed to down-weight the importance of the highly abundant species, and similarity matrices were calculated with the Bray–Curtis similarity index. A Principal Coordinates Analysis (PCoA) was performed in order to explore and visualize similarities or dissimilarities of the community data for each beach. The statistical significance of the copepods' community structure differences, between beaches and months, was assessed using permutational analysis of variance (PERMANOVA), using 999 permutations and a p-value set on 0.05. Species compositions were compared between beaches and months using the species' total abundance, richness, evenness and the Shannon-Wiener index of species diversity. Univariate PERMANOVA analyzed differences in these factors between beaches and month, using a Euclidian distance matrix of each index. The correlation of environmental variables with the

copepod community was assessed through a Canonical Correspondence Analysis (CCA). Chi-square test verified the significance of the analysis and an ANOVA-like analysis tested the significance of the axis and terms used. All analyses were performed with the software R using the packages Vegan and Siplot (R CORE TEAM 2017).

RESULTS

A total of 2755 individuals (mean density ± standard deviation: 2.93±15.02 ind.m⁻²) in four orders were collected from all beaches (Calanoida, Cyclopoida, Poecilostomatoida and Siphonostomatoida). Between them, nine species were found: *Acartia* (*O.*) *lilljeborgi*, *Acartia* (*A.*) *tonsa*, *Caligus undulatus*, *Clausocalanus arcuicornis*, *Clausocalanus furcatus*, *Labidocera aestiva*, *Oithona oswaldocruzi*, *Oithona plumifera*, *Temora turbinata*, as well as non-identified individuals from the Poecilostomatoida order and from the *Acartia* genera. *Acartia* (*O.*) *lilljeborgi* was the most abundant species (Fig. 1).

Principal Coordinates Analysis (PCoA) showed a clear separation between studied beaches, being Los Timones and Las Cabañas the ones that differed the most (Fig. 2). Significant differences in the assemblage structure, total abundance, species' richness and species' diversity were observed in the beach-month interactions (TABLE 1). The highest total abundance and species' richness were observed in Los Timones in June. Between May and November, the highest diversity, richness and evenness for all beaches was measured. Peaks on diversity and evenness were observed in May and October, the first month for the beaches of Valle Seco and Las Cabañas and the latter for Agua Sal and Los Timones (Fig. 3).

Based on species' presence in each month, we determined its frequency of occurrence (TABLE 2). Species from the Acartidae family were common between beaches and had the highest frequency over the studied period, with values over 60%. *Caligus undulatus*, *C. arcuicornis*, *C. furcatus*, *L. aestiva*, *T. turbinata*, *O. oswaldocruzi*, *O. plumifera*, and the Poecilostomatoida morfo, were rarely observed.

Analyzing in more detail the species *A. lilljeborgi*, we could observe that it had a higher mean abundance in Los Timones in June (70.10 ± 54.14 ind.m⁻²) and in Las Cabañas in May (28.10 ± 40.80 ind.m⁻²) (Fig. 4). Corresponding the peaks of higher abundances of the specie with peaks on assemblage abundance. In the case of *A. tonsa*, abundances were low almost all year, with peaks

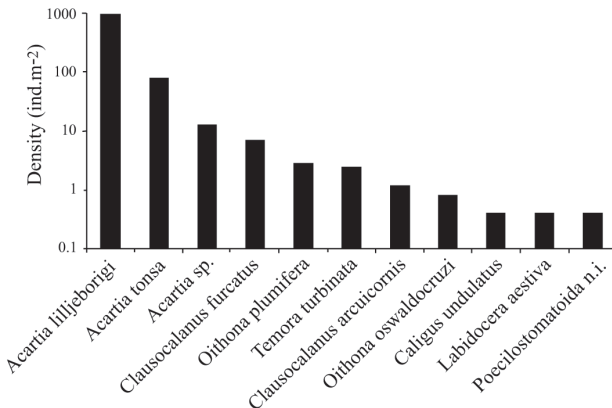


Fig. 1 Accumulated species abundance in studied area.

in May and October for Las Cabañas and in November for Valle Seco (Fig. 5). Mean density of this specie was always much lower than *A. lilljeborgi*.

Canonical Correspondence Analysis (CCA) significantly explained the relationship between the tested environmental variables and the biological data (p=0.004). Only axis 1 (CCA1) resulted significant (p=0.001). From the analyzed environmental variables, only the percentage of dissolved oxygen in water (p=0.021) and the suspended organic matter from the water column (p=0.047) significantly explained the species' abundances. Almost all the analyzed species were positively correlated with the suspended organic matter from the water column (Fig. 6). A Spearman correlation test for the most abundant species showed

that from both significant environmental variables, just the dissolved oxygen explains their abundances. *Acartia lilljeborgi* was significantly and positively correlated with the dissolved oxygen (rho=0.26, p=8.321e-07) and *A. tonsa* was negatively correlated with it (rho= -0.15, p=0.004). Dissolved oxygen levels were similar on the four beaches, varying between 1 - 7.67 mg.l⁻¹; while the suspended organic matter varied between 4.16x10⁻⁷ and 6.28x10⁻⁴ mg.l⁻¹ and salinity between 20 - 40. February was the month with higher salinity in the four beaches and December the lowest. Mean annual values are detailed on TABLE 3.

DISCUSSION

Despite the high proportion of coast presented in Venezuela, there are few studies on marine copepods (CERVIGÓN 1961, 1964; LEGARÉ 1964; MÁRQUEZ-ROJAS *et al.* 2014). In the database by RAZOULS *et al.* (2005-2016) 705 planktonic species of the Caribbean Sea, Gulf of Mexico, Florida and the Sargasso Sea are documented. Of the nine species found in this study, all have been reported in this database with the exception of *Caligus undulata*. Almost all species found in this study are an indicator of coastal waters. Species richness in the hyperbenthic zone is lower than reported for other pelagial areas in Venezuela (MÁRQUEZ-ROJAS 2011)

Caligiforms copepods are known as parasites, which are economically important in aquiculture (BOXSHALL &

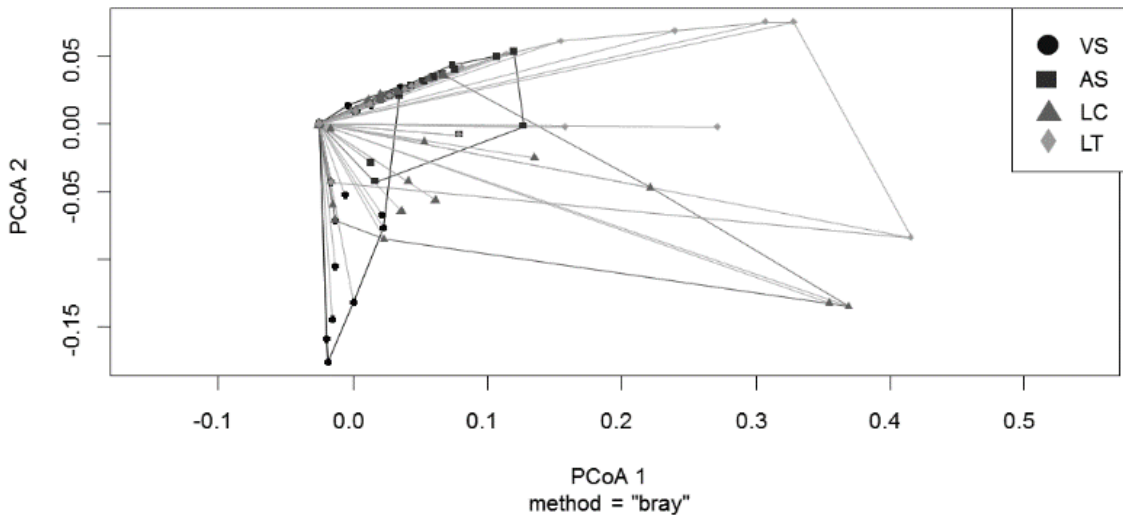


Fig. 2 Principal Coordinates Analysis (PCoA) of community structure, showing spatial differences among studied beaches. VS: Valle Seco, AS: Agua Sal, LC: Las Cabañas, LT: Los Timones.

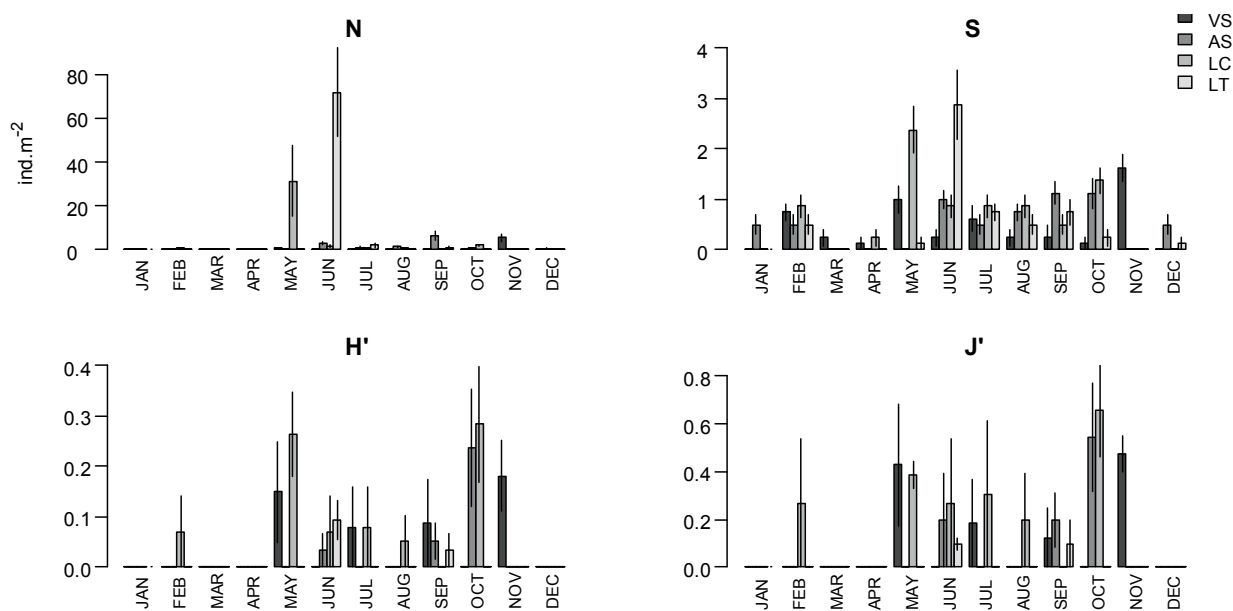


Fig. 3 Monthly variation on species total abundance (N - ind.m⁻²), richness (S), Shannon-wiener diversity index (H) and Pielou's evenness index (J) for all beaches. Vertical bars indicate confidence interval of 95%. VS: Valle Seco, AS: Agua Sal, LC: Las Cabañas, LT: Los Timones.

DEFAYE 1993). This is why its parasite stage has received much attention, while their planktonic stage has been poorly studied. Distribution of the nauplio and copepodite stages has been reported mainly in the Atlantic Ocean (COSTELLOE *et al.* 1998; PENSTON *et al.* 2004; COPLEY *et al.* 2005; TODD 2006). Many of these organisms have been collected from their host, however is not rare that caligiforms appear in plankton samples (KABATA 1979; MELO *et al.* 2010; SUÁREZ-MORALES *et al.* 2012).

Between sampled copepods, the Calanoida order has the highest richness, similarly with found on the Cariaco Basin, Venezuela (MÁRQUEZ-ROJAS 2011). Within this, *A. lilljeborgii* was the most abundant and frequent in

the whole studied area. This species is distributed over tropical and subtropical estuarine waters, but it can be found in a range of salinity between 8.8-30 (TUNDISI & MATSUMURA-TUNDISI 1968). MONTÚ (1980) classified *A. tonsa* as euryhaline and eurythermic, which explains their wide latitudinal amplitude. In this study, both species altered they dominance, with the exception of May in Las Cabañas where both species had an increment, being higher for *A. lilljeborgii*. Sporadic peaks of *A. tonsa* occurred in months with low abundances of *A. lilljeborgii* in all the beaches. Copepods of the genus *Acartia* inhabit many coastal and offshore environments, where they are usually among the most abundant zooplankton taxa (GREENWOOD

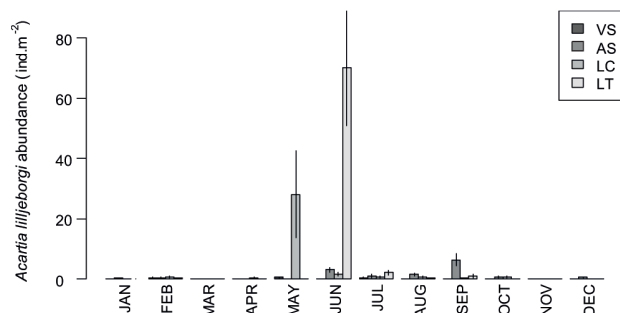


Fig. 4 Mean mensal density (ind.m⁻²) of *Acartia lilljeborgii* in each sampled beaches. Vertical bars indicate confidence interval of 95%. VS: Valle Seco, AS: Agua Sal, LC: Las Cabañas, LT: Los Timones.

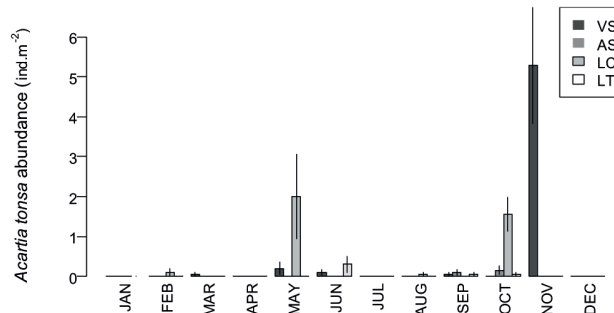


Fig. 5 Mean mensal density (ind.m⁻²) of *Acartia tonsa* in each sampled beaches. Vertical bars indicate confidence interval of 95%. VS: Valle Seco, AS: Agua Sal, LC: Las Cabañas, LT: Los Timones.

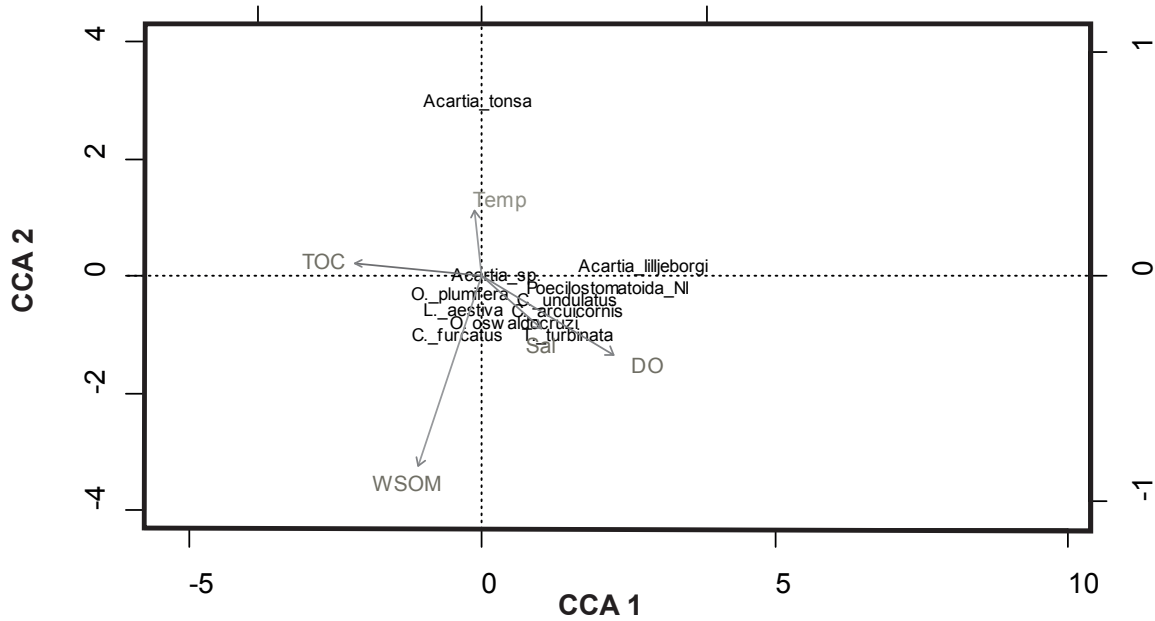


Fig. 6 Canonical Correspondence Analysis of copepods species and environmental variables. Temp= temperature, Sal= salinity, DO= dissolved oxygen, TOC= total organic carbon in sediment, WSOM= suspended organic matter on water column.

1981; HUBAREVA *et al.* 2008; MÁRQUEZ-ROJAS *et al.* 2011; MAGALHÃES *et al.* 2015). This was also confirmed in the present study, given the predominance of *A. lilljeborgii* over all the sampled copepods.

In addition, other species reported as estuarine were found, as *Oithona oswaldocruzi* and *Temora turbinata*

(SILVA *et al.* 2003), but less abundantly. The presence of estuarine species may be explained by the fact that sampling year was very rainy and as all sampling points are near rivers' mouth they could simulate in some periods estuarine conditions. Species from genera *Oithona* are frequently dominant in the estuarine plankton of South

TABLE 1. The results of PERMANOVA analysis of variance on the community structure, total abundance, species richness, and diversity index (Shannon-Wiener index) respectively. The critical values are for alpha = 0.05.

Item	Source of variation	Df	SS	MS	Pseudo-F	P(perm)
Community Structure	Beach	3	0.05	0.019	13.06	0.001
	Month	11	0.28	0.025	17.08	0.001
	Beach*Month	32	0.62	0.019	12.85	0.001
Total Abundance	Beach	3	2190	729.94	6.3903	0.001
	Month	11	10862	987.47	8.6450	0.001
	Beach*Month	32	33881	1058.78	9.2692	0.001
Species richness	Beach	3	2.69	0.89	2.63	0.045
	Month	11	44.76	4.06	11.94	0.001
	Beach*Month	32	91.96	2.87	8.43	0.001
Diversity index	Beach	3	0.16	0.053	3.68	0.010
	Month	11	0.63	0.057	3.96	0.001
	Beach*Month	32	1.12	0.035	2.40	0.001

TABLE 2. Frequency of occurrence (%) of copepods by beach during studied period. VS= Valle Seco, AS= Agua Sal, LC= Las Cabañas, LT= Los Timones

Specie/taxa	VS	AS	LC	LT
<i>Acartia (O.) lilljeborgi</i>	66.67	66.67	75.00	72.73
<i>Acartia (A.) tonsa</i>	41.67	16.67	33.33	27.27
<i>Acartia</i> sp.	16.67	8.33	8.33	9.09
<i>Caligus undulatus</i>	0.00	0.00	8.33	0.00
<i>Clausocalanus arcuicornis</i>	0.00	0.00	0.00	9.09
<i>Clausocalanus furcatus</i>	0.00	0.00	0.00	9.09
<i>Labidocera aestiva</i>	0.00	0.00	0.00	9.09
<i>Oithona oswaldocruzi</i>	0.00	0.00	0.00	9.09
<i>Oithona plumifera</i>	8.33	8.33	16.67	9.09
<i>Temora turbinata</i>	16.67	0.00	16.67	9.09
Poecilostomatoida n.i.	8.33	0.00	0.00	0.00

America and Central America (FALAVIGNA1985). This same author found *O. oswaldocruzi* as a dominant species in the low salinity water of Brazilian estuaries. LOPES (1994) also recorded a higher density of this species in the oligohalines and mesohalines regions of an estuary. This species was found in the present study only in June in Los Timones, month that had the highest precipitation values. Nevertheless, *T. turbinata* has also being reported in high abundances, constituting a dominant species in marine areas as the Cariaco Basin (MÁRQUEZ-ROJAS *et al.* 2011).

Copepod abundances vary greatly in the coastal and shelf regions of the world (MAUCLINE 1998). For instance, the average annual abundance ranged from 150 to 2000 ind.m⁻³ in a 53 m water column sampled vertically by a 200 µm mesh net in the North Sea (ROFF *et al.* 1988). In Cariaco Basin zooplankton abundances varied between 11.90 and 9669.45 ind.m⁻³ in oblique tows from 25 m depth until surface (MÁRQUEZ-ROJAS *et*

al. 2011). Fluctuations in the average seasonal abundances in this study ranged from 0.4 - 573.2 ind.m⁻², lower than other zooplankton studies. Holoplanktonic organisms that live permanently in the water column, as copepods, may have larger contributions near the substrate searching for shelter using substrate or light avoiding to protect from predators (MELO *et al.* 2010). The horizontal gradients in hydrological parameters such as salinity, temperature, and turbidity constitute a crucial determinant of the copepod distribution within estuarine environments (MAGALHÃES *et al.* 2015), and also probably between studied beaches, as there are fluctuations in those parameters as a consequence of river's discharge. It was mainly turbidity that, through personal observation, was a factor that changed between beaches and month. There were occasional arrivals of algae, bryozoa and other organic detritus that remained on the surf zone of the beaches without periodicity, mainly in Los Timones and Valle Seco. In addition, sand

TABLE 3. Mean annual values of environmental variables on the studied beaches

Beach	Dissolved oxygen		Suspended organic matter		Salinity	
	Annual Mean (mg.l ⁻¹)	Standard deviation	Annual Mean (mg.l ⁻¹)	Standard deviation	Annual Mean	Standard deviation
Agua Sal	4.75	2.23	3.26 x10 ⁻⁵	6.04 x10 ⁻⁵	31.41	3.9
Los Timones	5.11	2.12	2.60x10 ⁻⁵	2.08 x10 ⁻⁵	31.86	4.88
Las Cabañas	4.57	2.21	9.47x10 ⁻⁶	9.98 x10 ⁻⁶	31.79	3.8
Valle Seco	4.56	2.06	3.15 x10 ⁻⁵	4.58 x10 ⁻⁵	32.92	3.8

re-suspension made those beaches to usually have a brown color, but in some occasions with low tide and few waves, they were quite transparent. As these beaches are highly dynamic, a highly spatial and temporal variation in its fauna is expected.

Despite salinity not being significant in the CCA, it seems to be an important factor that allowed the presence of some species. As it was low almost all year, this probably lead that analysis to not identify it as explaining variations in species abundances. This way we highlight the resistance of estuarine species when inhabiting marine conditions. Precipitation values for this year show that 2011 was a year with high rain levels, where we can consider January to March as the dry season. This extended rainy season was occasioned by a *La Niña* event (<http://ggweather.com/enso/oni.htm>), which causes high rates of precipitation in the area. This could favor the entrance of estuarine species that come from nearby rivers in the studied areas. The concentration of dissolved oxygen is a reflection of the production and consumption processes of organic matter. High levels of organic matter or productivity demand a higher consumption of dissolved oxygen and its concentration diminishes in the water column (JULIES & KAHOLONGO 2013).

Low occurrence frequency of most species can be an indicative that they are occasional visitors of the benthic boundary layer. Probably the *Acartia* species may be resident or dependent on this environment at least during day-time. Finally, LIGAS *et al.* (2009) argued that seasonal patterns in the hyperbenthic crustacean's fluctuations might be related to biological and ecological characteristics rather than environmental factors. More studies complementing hyperbenthic samples with plankton ones are required for a better understanding of the biological interactions in coastal areas. Additionally, other environmental variables like wave action, turbidity and tide levels should be measured.

CONCLUSION

There is a low number of resident/dependent species of benthic boundary layer and some occasional visitors. The copepods assembly varies through year and between beaches in response to non-identified environmental or biological factors. Acartid copepods constitute a day-time resident population almost year-round, and their population abundance pattern is not explained by their local environmental variables.

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