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Research Article

Micro- and mesozooplankton communities in the surf zone of a tropical sandy beach (Equatorial Southwestern Atlantic)

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ABSTRACT. Sandy beaches constitute important ecosystems from both ecological and socioeconomic standpoints. The ecosystems of tropical zones present a high diversity and are sensible to global climatic changes, as well as to local impacts. Despite its relevance, researches on biodiversity and existing ecological processes, like size distribution of plankton communities, in these regions are often neglected. Here, the first results of a study on the structure of zooplankton communities in a tropical sandy beach (Equatorial Southwestern Atlantic) is presented. Species were divided in two size classes (micro- and mesozooplantkon) in order to verify which possess higher diversity and abundance (ind m^{-3}). Sampling was conducted in dry and rainy season in the course of a year, aiming to cover possible variations due to weather. Data support the hypothesis that small copepod species and developmental stages of some pelagic copepods (microzooplankton) are more abundant and diverse in the surf zone of a tropical beach in both dry and rainy season. Biological characteristics of the observed species and semiarid tropical coast environmental factors, such as high and constant temperature and oligotrophic waters, explain the diversity and abundance of microzooplankton. Results suggest that a broader view of plankton communities is necessary to understand food webs and resilience in tropical ecosystems, especially concerning smaller species and those in developmental stages.

Keywords: small copepods, mesozooplankton, semiarid coast, tropical marine environments, southwestern Atlantic.

Comunidades micro y mesozooplanctónicas en la zona de rompiente de una playa de arena tropical (sudoeste del Atlántico Ecuatorial)

RESUMEN. Las playas arenosas son ecosistemas importantes desde el punto de vista ecológico y socioeconómico. Los ecosistemas de zonas tropicales tienen una elevada diversidad y son sensibles a los cambios climáticos globales, así como a los impactos locales. A pesar de su relevancia, las investigaciones sobre la biodiversidad y los procesos ecológicos, tales como la distribución por tamaño de las comunidades del plancton, en esas regiones son poco estudiados. Se presenta los primeros resultados de un estudio sobre la estructura de comunidades de zooplancton en una playa tropical (Ecuatorial del Atlántico Sudoeste). Las especies se dividieron en dos clases de tamaño (micro- y mesozooplancton), para determinar cuales tienen la mayor diversidad y abundancia (ind m^{-3}). El muestreo se realizó en la estación seca y lluviosa durante un año, para cubrir eventuales variaciones debido a las condiciones meteorológicas. Los datos obtenidos confirman la hipótesis que las especies pequeñas de copépodos y las etapas de desarrollo de algunos copépodos pelágicos (microzooplancton), son más abundantes y diversos en la zona de las rompientes de una playa tropical en las estaciones seca y lluviosa. Las características biológicas de las especies colectadas y los factores ambientales en la costa semiárida tropical, tales como temperatura alta y constante, y aguas oligotróficas, explican la diversidad y la abundancia de microzooplancton. Los resultados sugieren que se necesita una visión más amplia de las comunidades del plancton para comprender las tramas alimentarias y la resiliencia de los ecosistemas tropicales, especialmente en las especies más pequeñas y en los estadios de desarrollo.

Palabras clave: pequeños copépodos, mesozooplancton, costa semiárida, ambientes marinos tropicales, Atlántico suroeste.

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INTRODUCTION

Sandy beaches are ecologically important ecosystems and play a crucial role in the sustainable socioeconomic development of coastal zones, especially in the present context of environmental changes. They provide key ecosystem services, such as storm buffering, nutrient cycling, water purification, nursery habitats for resource species, and feeding-breeding habitats for endangered species (Defeo *et al*., 2009; Nel *et al*., 2014). Tropical ecosystems display high biodiversity and are particularly sensible to global climate changes, because of the warmth and stability of tropical oceans (Walther *et al*., 2002; Saunders *et al*., 2014). Despite its significance, a more wholly comprehension of the ecological processes and biodiversity present in this region have been neglected, especially in what sandy beaches are concerned. Ecological knowledge about sandy beaches has focused primarily on the benthic macrofauna and phyto-plankton, with few studies encompassing zooplankton (Nel *et al*., 2014; Odebrecht *et al*., 2014; Lercari & Defeo, 2015).

Zooplankton occupies an essential position in coastal beaches ecosystems, serving as a link between phytoplankton and higher trophic levels, in addition to working as environmental indicators. The fauna of the lower beach may extend their distribution seawards into the turbulent surf zone, where zooplankton can be abundant (Defeo *et al*., 2009). Marine plankton also responds to indirect effects of environmental changes. For example, comparatively small increases (0.6ºC) in sea surface temperature (SST) have been associated with major changes in planktonic communities in the North Atlantic over the past 50 years (Richardson & Schoeman, 2004). Given that plankton is a key food source for suspension-feeding beach species (macrofauna), changes in plankton communities would have unpredictable impacts on a sandy beach ecosystem (Defeo *et al*., 2009).

A fundamental environmental trait of marine ecology is the body size. Size structure has been considered an useful metric for monitoring changes in community structure, biodiversity and in the understanding of marine food webs (García-Comas *et al*., 2014). Small planktonic marine copepods (<1 mm in length) are undoubtedly the most abundant metazoans on Earth (Turner, 2004). Its importance in zooplankton coastal communities has already been reported from different regions and marine ecosystems (Satapoomin *et al*., 2004; Zervoudaki *et al*., 2007; Miyashita *et al*., 2009; Gubanova *et al*., 2014). However, sandy beaches are poorly studied worldwide (Delancey, 1987; Avila *et al*., 2009; Costa *et al*., 2011; Pinheiro *et al*., 2011, 2013; Nel *et al*., 2014), particularly in tropical semiarid coasts.

As previously noted, there is a gap in the scientific knowledge about the ecology of plankton communities in what concerns their structure and diversity in tropical ecosystems. This paper investigates differences between micro- and mesozooplankton communities in the surf zone of a tropical sandy beach (Equatorial Southwestern Atlantic), analyzing their total and specific abundances. The hypothesis that small copepod species and developmental stages of some pelagic copepods (microzooplankton) are more abundant than mesozooplankton was put to a test, and it is suggested that, in such environments, bigger is not better. Furthermore, this study attempts to contribute in advancing the scientific knowledge about plankton ecology and providing useful insights for the conservation of tropical marine ecosystems.

MATERIALS AND METHODS

Study area

The area studied is located in the Equatorial Southwestern Atlantic (Fortaleza, NE Brazil) on the semiarid coast. There is no coastal upwelling in the area, which is marked by its oligotrophic waters (Dias *et al*., 2013). Sampling station is located on a narrow beach strip (<50 m), adjacent to rocky outcrops, 30 m wide (average) which are submersed in high tide (3º43'28.75"S, 38º29'27.75"W). The beach is classified as intermediate (Queiroz, 2014). Specifically, it is a bay which has no direct influx of big estuaries or mangroves. The beach presents quartz sand as dominant sediment and a mesotidal regime. In the surrounding region, various types of impacting urban activities occur, such as tourism, commerce and harbor (Buruaem *et al*., 2012; Paula *et al*., 2013).

Wind regime is particularly of trade winds, whose speed varies within seasons throughout the year and is considerably slower during the first semester. Rain regime covers two periods, a rainy one (1st semester), when more than 80% of the total precipitation for the year occurs and the dry one, that spans from August to September. Brazilian northeast coastal region is marked by a tropical wet climate (Aw) due to the intertropical convergence zone (ITCZ) alternating with a semi-arid climate of low annual precipitation. The annual seawater temperature is high and constant, varying between 27 and 29ºC (Gulati, 1983; Irion *et al*., 2012; Gomes *et al*., 2014).

Data collection method, sample processing and data analysis

Zooplankton samples were collected in a fixed station using a conical-cylindrical net, equipped with a flow meter (mouth diameter of 30 cm; net length of 1 m). Two different mesh sizes were used in sampling (120 and 300 µm), with the purpose of testing the hypothesis. After the collection, samples were fixed in 4% formaldehyde and buffered in 4 g L^{-1} of sodium tetraborate. Samples were taken in spring tides, during low and high tides in 2012. Sampling was seasonal; two collections were made during rainy season (March and April, labeled C1 and C2) and the other two during dry season (October and November, labeled C3 and C4). This setting was made in order to verify possible seasonal alteration in the micro- and mesozooplankton.

In the laboratory, taxa were identified down to the lowest taxonomical level possible, using bibliographical sources of Boltovskoy (1981, 1999). Occurrence was analyzed according to the following criteria: >70% very frequent, 70-40% frequent, 40-10% infrequent, and ≤10% sporadic. Multivariate analyses were conducted for Copepod for taxonomic resolution reasons. Density data matrix was transformed to logx+1 for multivariate analysis. In order to verify similarity between samples (seasonal and mesh-size), the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) tested by the SIMPROF test ($\alpha = 5\%$) was used. Statistical significance of density differences was verified by the Mann-Whitney test, using Statistica 7.0 software.

RESULTS

Data support the hypothesis of a higher density of small copepods (U test, $P < 0.05$) when evaluating the density of meso- and microzooplankton groups (Fig. 1). Small copepods presented higher dominance and diversity in the surf zone community (Table 1). Multivariate analysis based on density divided the groups as presented in the dendrogram (Fig. 2). The first cut-off level separated the mesh-size 300 µm samples from the 120 µm samples. The microzooplankton samples formed a homogeneous significant group.

A total of 39 taxa was found, among which the copepods were dominant in richness and density. The main taxa were Paracalanidae, Acartiidae, Oithonidae, Corycaeidae and Euterpinidae, which together represented 97% (7 taxa) of total copepods. Regarding small-sized zooplankton, Calanoida represented 57.3%, followed by Cyclopoida (27.7%) and Harpacticoida (14.3%). The meroplanktonic forms were represented by gastropod and bivalve veligers, crustacean larvae (nauplii, zoea and megalopa), and Polychaeta trocophores. Among holoplankton, chaetognaths and appendicularians (*Oikopleura* spp.) were very frequent.

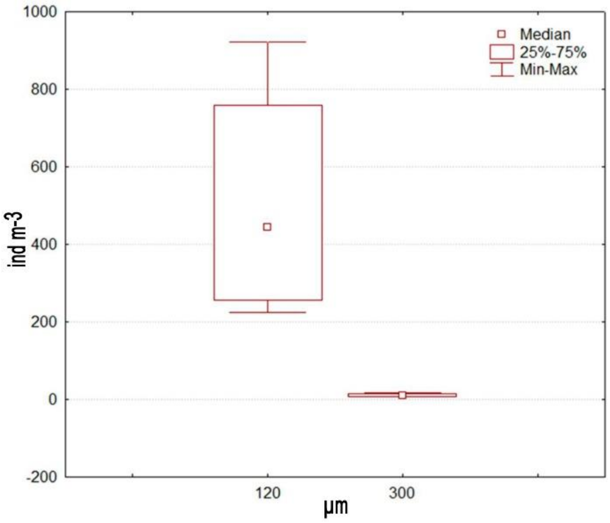

Figure 1. Abundance (ind m^{-3}) of mesozooplankton (300 µm) and microzooplankton (120 µm) groups, statistically significant (U Test, $P < 0.05$) in a tropical sandy beach.

Data suggest that the microzooplankton had a higher density in comparison to the mesozooplankton (U test, $P < 0.05$), independent of the sampling period. Therefore, during both dry and rainy season the more densely present organisms were the smaller ones (Table 2).

DISCUSSION

Results corroborated the hypothesis that microzooplankton, especially small-sized copepods, was the most abundant and diverse group. Since many authors comment on the importance of small copepods in marine food webs of temperate regions, their extreme high densities in the microzooplankton of tropical sandy beaches, in comparison to mesozooplankton, were expected but never confirmed (Marshall, 1949; Lampitt & Gamble, 1982; Hopcroft *et al.*, 1998; Turner, 2004; Calbet, 2008). We have built a conceptual model (Fig. 3) that explains the abundance of microzooplankton in the analyzed tropical sandy beach. The geographical location of the beach, in an equatorial semiarid region, suggests that the pattern found in the community structure is validated by Bergmann's rule (Bergmann, 1847). The principle states that species of smaller sizes are found in warmer regions and that an increase in the proportion of small sized species in terms of abundances of individuals and/or number of species; is the first mechanism that

Table 1. Taxa composition of a zooplanktonic community during a rainy and dry season in a tropical sandy beach.

Copepoda	Microzzoplankton 120 (µm)			Mesozooplankton 300 (µm)		
	f (%)	Rainy	Dry	f (%)	Rainy	Dry
Acartia (Odontacartia) lilljeborgi	75	16.4 ± 15.5	0.3 ± 0.4	87.5	0.5 ± 0.5	0.0 ± 0.0
Calanopia americana	37.5	0.1 ± 0.1	0.2 ± 0.3	12.5	0.0 ± 0.0	0.0 ±0.0
Centropages velificatus	37.5	0.4 ± 0.4	0.3 ± 0.5	87.5	0.1 ± 0.1	0.1 ± 0.1
Paracalanus aculeatus	87.5	2.9 ± 3.3	3.3 ± 2.4	12.5	0.0 ± 0.0	0.0 ± 0.0
Parvocalanus spp.	100	112.5 ± 32.6	435.7 ± 237.0	12.5	0.0 ± 0.0	0.0 ± 0.1
Pseudodiaptomus acutus	87.5	1.6 ± 1.8	1.4 ± 1.8	50	0.1 ± 0.1	0.0 ±0.1
Pseudodiaptomus (copepodite)	87.5	1.1 ± 1.0	1.4 ± 1.8	100	0.2 ± 0.2	0.2 ± 0.3
Temora turbinata	87.5	1.5 ± 1.6	2.5 ± 2.2	100	0.3 ± 0.4	0.1 ± 0.2
Corycaeus spp.	75	2.4 ± 4.8	2.9 ± 1.7	75	0.1 ± 0.1	0.1 ± 0.2
Oithona spp.	100	62.3 ± 43.1	213.8 ± 186.0	12.5	0.0 ± 0.0	0.0 ± 0.0
Euterpina acutifrons	100	52.3 ± 30.1	91.1 ± 68.7	100	0.1 ± 0.1	0.0 ± 0.0
Microsetella norvegica	87.5	2.4 ± 1.2	11.6 ± 12.0	25	0.0 ± 0.0	0.0 ± 0.0
Copepoda (nauplii)	100	2.9 ± 2.1	64.7 ± 99.4	25	0.0 ± 0.0	0.0 ± 0.0
Copepoda benthic	37.5	0.1 ± 0.2	8.7 ± 10.5	12.5	0.0 ± 0.0	0.0 ± 0.0
Monstrilloida	25	0.0 ± 0.0	0.0 ± 0.0	0	0.0 ± 0.0	0.006 ± 0.0
Non-Copepoda						
Hydromedusae	37.5	0.5 ± 0.8	0.6 ± 1.1	50	0.1 ± 0.1	0.0 ± 0.0
Siphonophorae	0	0.0 ± 0.0	0.0 ± 0.0	25	0.0 ± 0.0	0.0 ± 0.0
Cyphonautes (Bryozoa-larvae)	87.5	0.6 ± 1.2	0.1 ± 0.2	100	0.0 ± 0.0	0.0 ± 0.0
Chaetognatha	25	0.2 ± 0.2	1.6 ± 2.0	100	0.2 ± 0.1	0.7 ± 1.4
Polychaeta (larvae)	62.5	0.3 ± 0.5	1.1 ± 1.4	50	0.0 ± 0.0	0.1 ± 0.1
Polychaeta (trocofora-larvae)	100	6.5 ± 6.7	14.4 ± 9.2	75	0.1 ± 0.1	0.1 ± 0.2
Cirripedia (nauplii)	75	0.9 ± 0.6	14.2 ± 13.5	62.5	0.1 ± 0.1	0.0 ± 0.0
Amphipoda	37.5	0.3 ± 0.5	0.6 ± 0.7	100	0.4 ± 0.2	0.1 ± 0.1
Brachyura (zoea)	12.5	0.0 ± 0.0	0.1 ± 0.3	100	0.1 ± 0.1	0.2 ± 0.2
Brachyura (megalopa)	0	0.0 ± 0.0	0.0 ± 0.0	50	0.1 ± 0.1	0.0 ± 0.0
Cumacea	50	1.8 ± 3.2	0.9 ± 1.5	75	0.1 ± 0.1	0.0 ± 0.0
Isopoda	0	0.0 ± 0.0	0.0 ± 0.0	100	0.1 ± 0.1	0.0 ± 0.0
Lucifer faxoni	12.5	0.0 ± 0.0	1.2 ± 2.4	50	0.1 ± 0.1	0.0 ± 0.0
Lucifer faxoni (protozoea)	75	0.2 ± 0.3	0.8 ± 0.8	50	0.0 ± 0.0	0.0 ± 0.1
Mysidacea	25	0.0 ± 0.0	6.6 ± 12.7	100	1.3 ± 1.2	3.9 ± 7.7
Ostracoda	37.5	0.1 ± 0.1	0.3 ± 0.5	87.5	0.0 ± 0.1	0.0 ± 0.0
Decapoda (larvae)	0	0.0 ± 0.0	0.0 ± 0.0	50	0.0 ± 0.0	0.0 ± 0.0
Mollusca (Bivalvia-veliger)	75	1.4 ± 1.9	1.7 ± 1.2	100	0.3 ± 0.2	0.6 ± 0.6
Mollusca (Gastropoda-veliger)	75	1.3 ± 1.8	1.2 ± 1.2	100	0.1 ± 0.1	0.1 ± 0.1
Ophiopluteus	25	0.1 ± 0.1	0.1 ± 0.1	12.5	0.0 ± 0.0	0.0 ± 0.0
Oikopleura spp.	75	3.2 ± 2.2	1.6 ± 2.0	75	0.4 ± 0.7	0.1 ± 0.3
Ascidiacea (larvae)	50	0.4 ± 0.5	0.3 ± 0.4	100	0.1 ± 0.1	0.0 ± 0.0
Teleostei (larvae)	25	0.1 ± 0.2	0.2 ± 0.4	62.5	0.1 ± 0.3	0.0 ± 0.0.
Teleostei (eggs)	12.5	0.0 ± 0.0	0.2 ± 0.3	87.5	0.0 ± 0.1	0.0 ± 0.0

acts in the scale of a community. Moreover, metabolic rates are elevated at higher temperatures, and larger organisms, which require more energy to maintain their basal metabolism, cannot proliferate as fast as smaller organisms with lower metabolic demands (García-Comas *et al.*, 2014). For example, plankton communities are predicted to shift toward dominance by smaller-sized individuals in response to global warming (Daufresne *et al.*, 2009).

The lack of upwelling and of estuaries/mangroves in the area, as well as the low annual precipitation, very common in the semiarid (Fig. 3), generate an oligotrophic pelagic environment of low-productivity, which favors microzooplankton. Eutrophication is expected to favor larger organisms, according to allometric scaling of basal metabolism in size-based food chains (Fuchs & Franks, 2010; García-Comas *et al.*, 2014).

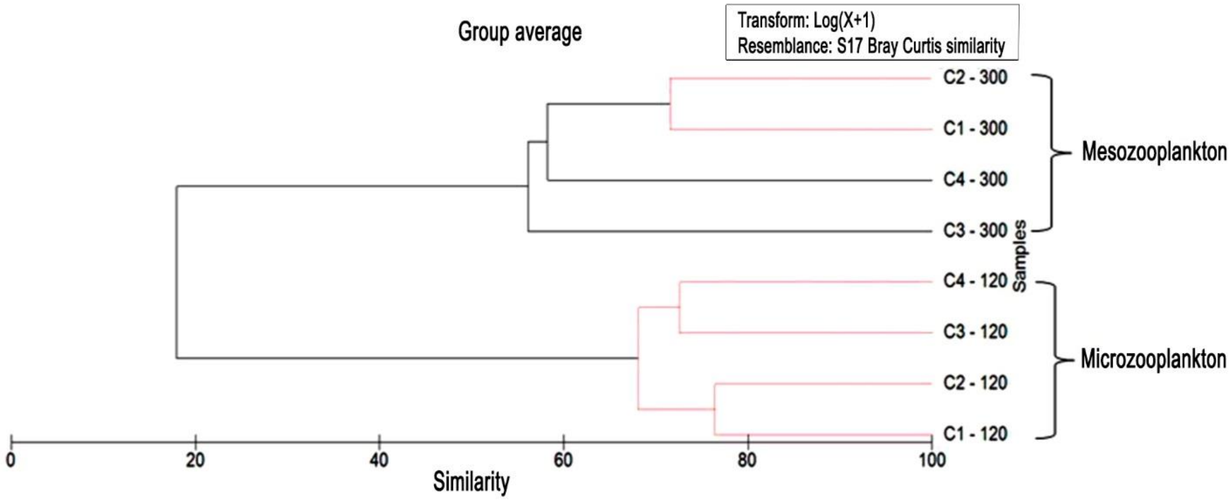

Figure 2. Dendrogram based on Bray-Curtis similarity, setting apart micro and mesozooplankton in a tropical sandy beach. Samples C1 and C2 (rainy season) and C3 and C4 (dry season). Red highlights statistically significant groups (SIMPROF).

Table 2. Average abundance and standard deviation of the taxa identified in a tropical sandy beach.

Characteristic	Microzooplankton	Mesozooplankton
Taxa	29	25
Species	11	8
Holoplankton min -max (ind m^{-3})	0.00 - 487.46	0.00 - 15.46
Meroplankton min - max (ind m^{-3})	0.00 - 26.34	0.00 - 0.34
Average ±standard deviation - holoplankton (ind m^{-3})	20.97 ± 63.69	0.19 ± 1.14
Average ± standard deviation - meroplankton (ind m^{-3})	1.73 ± 4.74	0.03 ± 0.07
Average + standard deviation (rainy season)	6.918 ± 19.38	0.11 ± 0.31
Average + standard deviation (dry season)	22.14 ± 70.87	0.16 ± 1.24
Copepods (Average ± standard deviation; frequency in %)		
Calanoid copepod (ind m^{-3})	32.30 ± 79.50; 56.50	0.09 ± 0.20; 86.07
Cyclopoid copepod (ind m^{-3})	70.36 ± 102. 9; 27.35	0.05 ± 0.09; 10.18
Harpacticoid copepod (ind m^{-3})	39.36 ± 49.80; 15.30	0.02 ± 0.03; 3.66
Monstrilloid copepod (ind m^{-3})	0.00; 0	0.001 ± 0.002; 0.09
Benthic copepod (ind m^{-3})	4.42 ± 8.29; 0.86	0.00; 0

Another factor contributes to the importance of microzooplankton is the marine food webs. By feeding on particles smaller than those preferred by larger copepods, nauplii (Roff *et al*., 1995) and small copepodites move microbial food web energy, normally unavailable to larger metazoans, into the classical food web (Hopcroft *et al*., 2001). Small copepods are also prey items to larger zooplanktivores like chaetognaths, ctenophores and medusae, in addition to being cannibalized by larger copepods as well (Turner, 2004). Reviewed information published between 1918 and 1983 on gut contents of 76 species of fish larvae revealed that small copepods and their developmental stages were usually the most frequently recorded prey of larval fish (Turner, 1984). According to the author, the food sources of fish larvae include adults, copepodites and particularly nauplii of the copepod genera *Acartia*, *Calanus*, *Centropages*, *Paracalanus*, *Temora*, *Corycaeus*, *Oithona*. *Oncaea* and *Microsetella*. In Japanese surf zone, the most abundant fish feeding guild was that of zooplankton feeders, depending mainly on planktonic copepods (Inoue *et al*., 2005). Some characteristics of these crustaceans that might explain their environmental success are cited: low respiration (Lampitt & Gamble, 1982), reproductive success (development and growth) (Liang & Uye, 1996; Uye & Sano, 1998) and food resources (Almeda *et al*., 2010; Zamora-Terol *et al.*, 2014).

Some Copepoda genera mentioned were also observed in the studied tropical sandy beach. *Acartia* (*Odontacartia*) *lilljeborgi* is coastal and estuarine

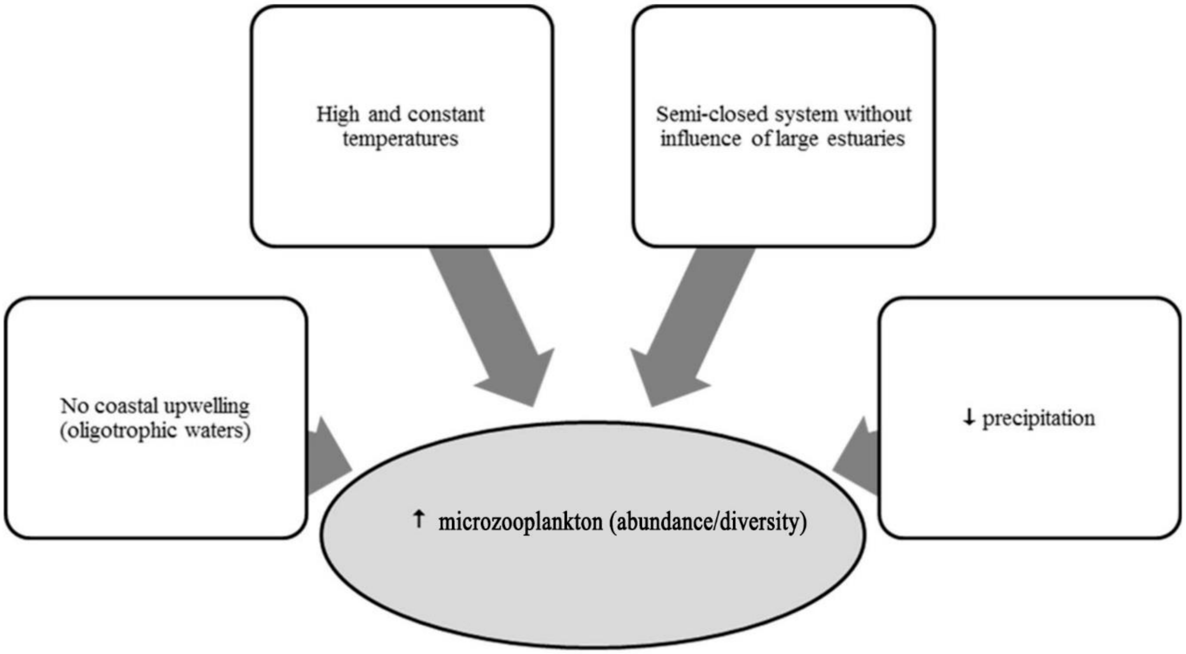

Figure 3. Schema emphasizing the environmental factors that may have led to higher abundance and diversity of microzooplankton in a tropical sandy beach (Equatorial Southwestern Atlantic).

Table 3. SIMPER analyses for plankton communities in a tropical sandy beach.

Group 1	Contrib%	Cum %	Group 2	Contrib%	Cum %
Average similarity: 80,36			Average similarity: 35.52		
Species			Species		
Parvocalanus spp.	20.71	20.71	*Pseudodiaptomus* (copepodite)	25.09	25.09
Oithona spp.	19.68	40.39	*Temora turbinata*	19.32	44.41
Clausocalanus furcatus	17.61	58.00	*Acartia lilljeborgi*	17.80	62.20
Euterpina acutifrons	17.08	75.08	*Corycaeus* spp.	15.27	77.47
Microsetella norvegica	5.70	80.78	*Centropages velificatus*	14.64	92.12
Paracalanus aculeatus	4.73	85.51			
Temora turbinata	3.63	89.14			
Corycaeus spp.	3.12	92.26			

(Björnberg, 1981; Bradford-Grieve *et al*., 1999), very common in South Atlantic coastal areas (Silva *et al*., 2003; Marcolin *et al*., 2010). *Centropages velificatus* and *Temora turbinata* are coastal and oceanic species (Björnberg, 1981; Bradford-Grieve *et al*., 1999). *T. turbinata* is exotic, did not occur in northeastern Brazil before 1993 (Araújo & Montú, 1993) and now dominates several coastal areas and estuaries of Brazil (Ara, 2002; Silva *et al*., 2003, 2004; Sterza & Fernandes, 2006). *Euterpina acutifrons* is neritic (Villate, 1997) and lives in ecosystems with high concentration of particulate suspended matter (Sautour & Castel, 1993).

Our unpublished data presented here support the hypothesis that small copepod species and the developmental stages of some pelagic copepods are important components (high diversity and abundance) in tropical sandy beach ecosystems. Therefore, for a broader view of the zooplankton community, careful attention to smaller species and copepod developmental stages is needed. Thus, it is our intention to propose here that reduction of the size distribution of plankton communities stimulated by the increase of sea surface temperature, as well as shifts in their prey availability and composition would become, in a near future, a major cause of an ecosystem shift in tropical marine ecosystems. More detailed ecological studies (such as nictemeral sampling; and also a larger series of temporal data, such as decades) are needed to elucidate the role of the species and predict the effects of climate

Table 4. Dunn analyses of multiple comparisons between micro- and mesozooplankton.

Multiple comparisons	Dunn	Significance ($P < 0.05$)
Microzooplankton (rainy season) *vs*. Microzooplankton (dry season)	-34.16	No
Microzooplankton (rainy season) *vs*. Mesozooplankton (rainy season)	62.66	Yes
Microzooplankton (rainy season) *vs*. Mesozooplankton (dry season)	83.74	Yes
Microzooplankton (dry season) *vs*. Mesozooplankton (rainy season)	96.81	Yes
Microzooplankton (dry season) *vs*. Mesozooplankton (dry season)	117.9	Yes
Mesozooplankton (rainy season) *vs*. Mesozooplankton (dry season)	21.08	No

change (high sea surface temperature, changes on precipitation, etc.), on the biodiversity and ecosystems services.

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