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Characterization of the zooplankton in the continental shelf of the Brazilian Equatorial Atlantic

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ABSTRACT

The equatorial Atlantic is characterized by its high abundance of zooplankton. However, starting point studies concerning the species composition in the northern Brazilian continental shelf are still scarce. Species cataloging studies can help to know the diversity of this ecosystem and, consequently, develop conservation studies and strategies for natural resources management. Thus, this work aims to characterize the species composing the zooplanktonic communities present on the continental shelf of Maranhão. Ninety-six taxa distributed among the Radiolaria, Myozoa, Foraminifera, Cnidaria, Mollusca, Annelida, Arthropoda, Bryozoa, Chaetognatha, Echinodermata, Chordata, and other groups, were recorded. The composition of mesozooplankton showed a wide distribution, indicating that the species are finding the appropriate conditions for their development.

Keywords: Copepoda; Pendicularia; Maranhão State coast; mesozooplankton.

Caracterização do zooplâncton na plataforma continental do atlântico equatorial brasileiro

RESUMO

O Atlântico equatorial é caracterizado por sua alta abundância zooplanctônica, no entanto, estudos iniciais sobre a composição de espécies na plataforma continental do Norte do Brasil ainda são escassos. Pesquisas de catalogação de espécies podem auxiliar no conhecimento da diversidade desse ecossistema para, consequentemente, desenvolver estudos de conservação e estratégias para o manejo dos recursos naturais. Assim, este trabalho tem como objetivo caracterizar as espécies que compõem as comunidades zooplanctônicas presentes na plataforma continental do estado do Maranhão, localizada na porção equatorial do oceano Atlântico. A região apresentou 96 táxons distribuídos entre os grupos Radiolaria, Myxozoa, Foraminifera, Cnidaria, Mollusca, Annelida, Arthropoda, Bryozoa, Chaetognatha, Echinodermata, Chordata e outros. A composição do mesozooplâncton apresentou ampla distribuição, indicando que as espécies estão encontrando as condições adequadas para seu desenvolvimento.

Palavras-chave: copepoda; appendicularia; litoral maranhense; mesozooplâncton.

INTRODUCTION

The ecosystems of tropical areas have great diversity and are sensitive to global climate change beyond the local impacts (Oliveira-Santos et al., 2016). In these ecosystems, zooplankton biodiversity is central to the welfare of coastal and oceanic environments (Bucklin et al., 2019). The diversity of species may fluctuate along the coast-ocean gradient, and studies on the region observe that zooplankton species diversity tends to increase toward the outer platform and open ocean waters (Neumann-Leitão et al., 2018).

In contrast, high biomass values and the abundance of organisms tend to escalate on the inner platform due to upwelling areas or the influence of estuarine systems (Lopes et al., 2006). In addition, the tropical region is subject to seasonal dynamics marked by high rainfall rates, upwelling, and climatic events (such as El Niño events on an interannual scale) that shape tropical zooplankton communities, especially in neritic ecosystems (Ambriz-Arreola et al., 2018).

The zooplankton reacts quickly to environmental changes, playing an important role in aquatic environment dynamics through its connection with primary producers, justifying its importance for the structure of the food web (Porto Neto et al., 1999; Bi et al., 2014). In the productive basis of this system, zooplankton communities are the main intermediate components of the pelagic food web, transferring energy and phytoplankton matter to higher trophic levels (Oliveira et al., 2015; Cepeda et al., 2018). Secondary production measures can be used to characterize the functional role of zooplankton and evaluate the impacts on ecosystem processes and services (Araújo et al., 2017; Isinibilir; Dogan, 2019; Setubal et al., 2020).

Understanding the dynamics and trophic relationships among different groups and the ecosystem services provided can increase awareness of the importance of preserving marine environments (Lomartire et al., 2021). Therefore, knowledge about the composition of the biota through species lists can help understand the occurrence of organisms at different scales and can be applied as an impact assessment tool. These data allow the improvement of conservation strategies and management efforts (Melo et al., 2014) and additional information on species diversity for each environment (Magurran, 2013).

Even though the Continental Shelf of Maranhão State (CSM) is an economically important region due to fishing exploitation and the heavy ship traffic, studies that seek to understand the behavior and distribution of the zooplankton community in this ecosystem are still sparse. Thus, this study aims to characterize the species found in the zooplankton communities of the Continental Shelf of Maranhão State during the high rainfall period in the region.

MATERIAL AND METHODS

Study area

The Maranhão coast is approximately 640 km long (El-Robrini et al., 2015), while the Continental Shelf of Maranhão has almost 55.70 km^2 of surface, which is divided by the outfalls of the Gurupi and Parnaíba rivers, "offshore" limited by an 80-m isobath (Gualberto and El-Robrini, 2005). Tidal amplitudes are among the largest on the Brazilian coast, reaching up to 7 m (Coutinho and Morais, 1976). The local climate corresponds to two seasonal periods, the rainy season (comprising the months of January to June) and the dry season, including the months from July to December (Azevedo et al., 2008).

Field and laboratory procedures

An oceanographic expedition was carried out on the Continental Shelf of Maranhão State (CSM) in April 2019 with a sampling grid composed of 22 stations, and organized in three transects perpendicular to the coast (Figure 1). The transects were named according to the stalls present in the study area as transects I (São José), transects II (São Marcos) and transects III (Cumã), composed of 6, 9, and 7 stations, respectively.

For the qualitative studies of the zooplankton, conical-cylindrical plankton nets were used with a mesh opening of 120 µm. Samples were obtained by horizontal trawling on the subsurface of the water column, lasting 30 minutes each. After collection, the material was packed in 200 mL vials and fixed with formaldehyde at a final concentration of 4% for later analysis in the laboratory.

Then, a 10 mL aliquot was removed from each sample for individual counting on a Bogorov's plate, and then they were analyzed under a binocular Zeiss Stereo microscope. Regarding the taxonomic framework, we used the classification systems described by Esnal (1999), Esnal and Dalponte (1999), Pohle et al. (1999), Avila et al. (2006), Bonecker and Oak (2006), Bonecker and McC Farms (2006), Days and Araujo (2006), Fernandes et al. (2006), and others. The relative abundance (%) per group was calculated, and the species catalog was presented, discriminating the three transects.

RESULTS

The zooplankton of the Continental Shelf of Maranhão State consisted of 96 taxa distributed among Radiolaria (1.04%), Myzozoa (1.04%), Foraminifera (2.08%), Cnidaria (6.25%), Molluska (4.17%), Annelida (1.04%), Arthropoda (66.67%), Bryozoa (1.0 4%), Chaetognatha (7.29%), Echinodermata (1.0 4%), Chordata (7.2 9%), and others (1.04%) (Table 1).

Arthropoda was the phylum with the highest species richness (49 species) and the highest frequency of occurrence, represented mainly by Copepods, which were registered at all collection stations. Among the order of the copepods, there were 35 species of calanoids, 11 species of cycloids, and three species of harpacticoids. Among the other phyla found, Chaetognatha, Chordata and Cnidaria, and Mollusca presented low species richness (between seven and four species), while the phyla Radiolaria, Myzozoa, Foraminifera, Annelida, Bryozoa, and Echinodermata presented very low species richness (one or two species). According to the dwelling time in the plankton, we observed 61.79% holoplankton and 38.20% meroplanktonic species.

DISCUSSION

On the Continental Shelf of Maranhão State, oceanographic agents, such as the flow of the São Marcos and São José bays, can influence the distribution of nutrients, thus becoming a fundamental element for the maintenance of plankton communities throughout the three areas of study. According to Nogueira Júnior and Brandini (2018), plankton production tends to be more influenced by the oligotrophic tropical water of the Brazilian Current, similar to what occurs with the Northern

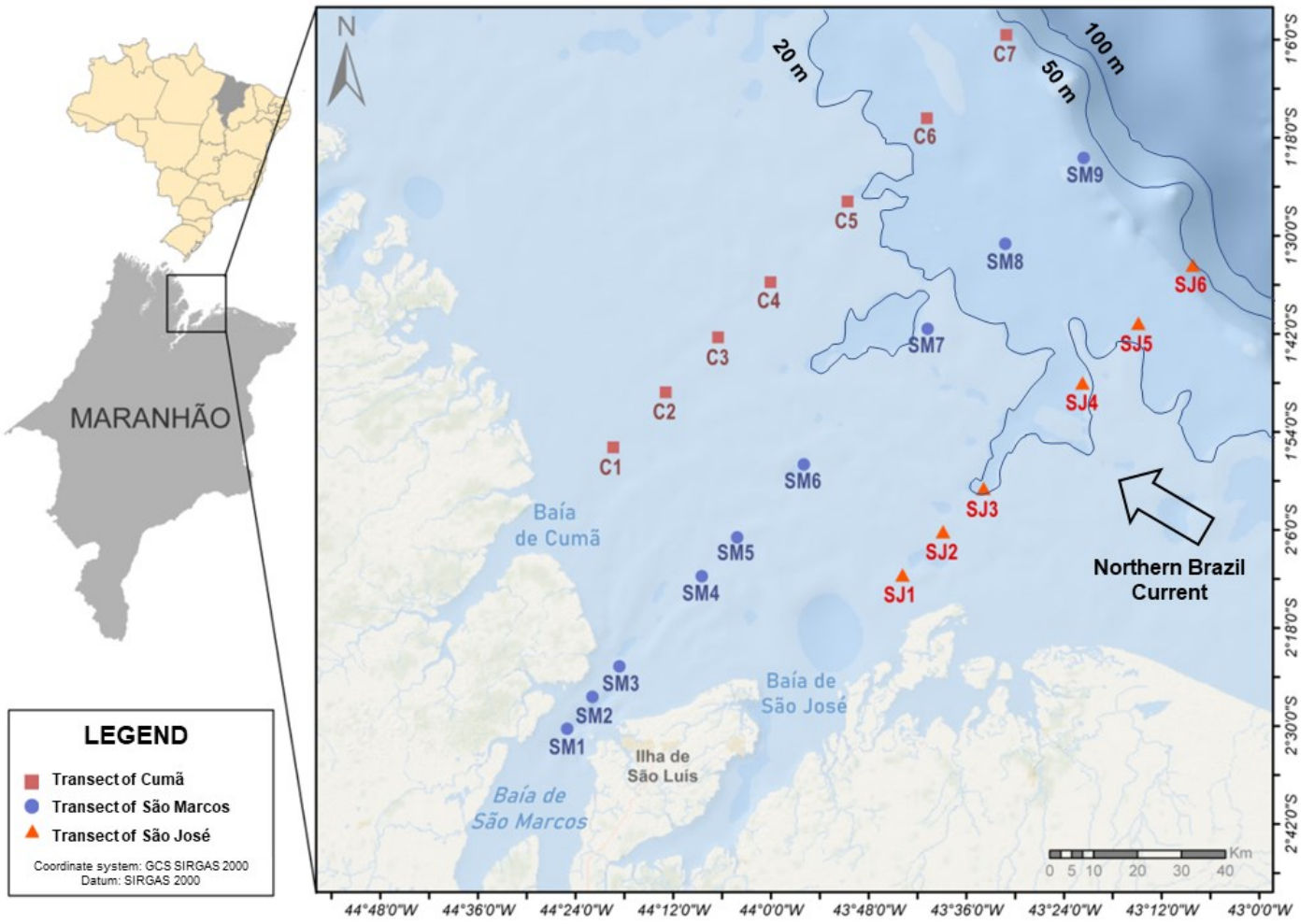

Figure 1. Sampling area on the Continental Shelf of Maranhão State (Equatorial Brazil) in April 2019.

Current of Brazil, which in turn is enriched by the advection of the central water of the South Atlantic, which is rich in nutrients.

This hydrodynamics can generate a sudden change in the pelagic community along with the breaking of the continental margin platform, related to the reduction in density and increase in biodiversity in the neritic-oceanic sense (Hopkins et al., 1981; Angel, 1996). Consequently, there is usually a gradient from the neritic to the oceanic area, where zooplankton can increase strong and constant environmental fluctuations that result from the interaction between marine and freshwater systems (Giller, 1984; Neumann-Leitão et al., 2018; Rodrigues et al., 2019).

The mesozooplankton of the CSM state were composed mainly of Copepoda (49 species), Chaetognatha (seven species), and Cnidaria (six species). The relative abundance of meroplankton in CSM was 38.20%. According to Fanjul et al. (2018), individuals who present this life cycle play a fundamental role in the formation of the zooplankton community and may highlight the influence of benthic dynamics on the pelagic community. Finally, the holoplankton had a record of 61.79% — for according to Brandini et al. (1997), the most numerous representatives of the marine holoplankton are the Copepoda, other crustacea, the appendicularia, and some plankton predators, such as the Hydromedusae and the Chaetognatha.

This large number of Copepoda recorded in the CSM is similar to that in other tropical regions of Brazil. Araujo and Ribeiro (2008) found 51 species on the Continental Shelf of Sergipe State; Salvador and Bersano (2017) identified 22 species in Paranaguá Bay, and Conceição et al. (2021) found 62 Copepoda on the Continental Shelf of Salvador State. Our data confirm the dominance and importance of this group throughout the Brazilian coast. In this regard, Sun et al. (2010) say that large, medium, and small crustacean copepods are the main food resources for fish, while carnivorous individuals (such as gelatinous individuals) compete with other organisms to obtain food, and their energy may not be efficiently transferred to higher trophic levels.

Among the main species of Copepoda found in CSM, we can highlight the species *Undinula vulgaris*, *Nannocalanus minor*, *Corycaeus speciosus*, *Euchaeta marina*, and *Temora stylifera* as indicators of oligotrophy, according to Cavalcanti and Larrazábal (2004), in the Economic Exclusive Zone of the

Table 1. Spatial distribution of zooplankton taxa on the continental shelf of Maranhão State (Equatorial Brazil).

GROUPS/SPECIES	Transect I	Transect II	Transect III	N° of species	%
RADIOLARIA				1	1.04
Radiolaria	X	X	X		
MYZOA				1	1.04
Nematodes sp.			X		
FORAMINIFERA				2	2.08
Globigerinoides ruber (D'Orbigny, 1839)	X	X	X		
Globorotalia scitula (Brady, 1882)	X		X		
CNIDARIA				6	6.25
Eutima gracilis (Forbes & Goodsir, 1853)		X	X		
Aglaura hemistoma (Péron & Lesueur, 1810)		X	X		
Liriope tetraphylla (Chamisso & Eysenhardt, 1821)	X				
Chelophyes contorta (Lens & Van Riemsdijk, 1908)	X		X		
Cytaeis sp.		X	X		
Agalma sp.	X	X	X		
MOLLUSCA				4	4.17
Limacina sp.	X	X	X		
Creseis acicula (Rang, 1828)	X	X	X		
Bivalvia (larvae)	X	X	X		
Cephalopoda (paralarvae)	X	X	X		
ANNELIDA				1	1.04
Annelida (Nectochaeta and Metatrochophora)	X	X	X		
ARTHROPODA				64	66.67
Cumacea	X	X			
Isopoda	X	X	X		
Amphipoda	X		X		
Cirripedia		X	X		
Mysida	X	X	X		
Euphausiacea	X	X	X		
Ostracoda					
Conchoecia sp.		X	X		
Cladocera					
Pseudevadne tergestina (Claus, 1877)	X	X	X		
Copepoda					
Acartia tonsa (Dana, 1849)		X			
Acartia danae (Giesbrecht, 1889)		X			
Acartia lilljeborgii (Giesbrecht, 1889)		X			
Agetus typicus (Krøyer, 1849)	X	X	X		
Brachycalanus bjornbergae (Campaner, 1978)		X			

Continue...

Table 1. Continuation.

GROUPS/SPECIES	Transect I	Transect II	Transect III	N° of species	%
Copepoda					
Calanopia americana (Dahl, 1894)	X	X			
Calocalanus pavo (Dana, 1852)	X	X	X		
Calocalanus contractus (Farran, 1926)	X	X	X		
Candacia truncata (Dana, 1849)	X	X	X		
Candacia varicans (Giesbrecht, 1893)	X	X	X		
Centropages velificatus (Oliveira, 1947)	X	X	X		
Centropages gracilis (Dana, 1849)	X	X	X		
Copilia mirabilis (Dana, 1852)		X	X		
Corycaeus speciosus (Dana, 1849)	X	X	X		
Ditrichocorycaeus amazonicus (Dahl, 1894)		X	X		
Euchaeta marina (Prestandrea, 1833)	X	X			
Euterpina acutifrons (Dana, 1847)	X	X	X		
Farranula gracilis (Dana, 1849)	X	X	X		
Labidocera acutifrons (Dana, 1849)	X	X	X		
Labidocera fluviatilis (Dahl, 1894)	X	X	X		
Labidocera sp.	X		X		
Lucicutia flavicornis (Claus, 1863)			X		
Miracia efferata (Dana, 1849)	X	X	X		
Microsetella rosea (Dana, 1847)	X	X	X		
Nannocalanus minor (Claus, 1863)	X	X	X		
Oithona oswaldocruzi (Oliveira, 1945)	X	X	X		
Oithona nana (Giesbrecht, 1893)	X	X	X		
Oithona ovalis (Herbst, 1955)	X	X	X		
Oithona setigera (Dana, 1849)	X	X	X		
Oncaea conifera (Giesbrecht, 1891)	X	X	X		
Oncaea media (Giesbrecht, 1891)	X	X	X		
Oncaea venusta (Philippi, 1843)	X	X	X		
Onchocorycaeus giesbrechti (Dahl, 1894)	X	X	X		
Onchocorycaeus latus (Dana, 1849)	X	X	X		
Onchocorycaeus ovalis (Claus, 1863)		X	X		
Parvocalanus crassirostris (Dahl, 1894)	X	X	X		
Paracalanus aculeatus (Giesbrecht, 1888)	X	X	X		
Paracalanus indicus (Wolfenden, 1905)	X	X	X		
Paracalanus quasimodo (Bowman, 1971)	X	X	X		
Phaenna spinifera (Claus, 1863)		X	X		
Pontellopsis regalis (Dana, 1849)	X	X			
Pseudodiaptomus acutus (Dahl F., 1894)		X			

Continue...

Table 1. Continuation.

GROUPS/SPECIES	Transect I	Transect II	Transect III	N° of species	%
Copepoda					
Pseudodiaptomus gracilis (Dahl F., 1894)		X			
Pseudodiaptomus richardi (Dahl F., 1894)		X			
Pseudodiaptomus sp.		X			
Subeucalanus pileatus (Giesbrecht, 1888)	X	X	X		
Fear turbinata (Dana, 1849)	X	X	X		
Fear stylifera (Dana, 1849)	X	X	X		
Undinula vulgaris (Dana, 1849)	X	X	X		
Copepoddito	X	X	X		
Nauplius	X	X	X		
Decapoda					
Lucifer typus (Edwards, 1837)		X	X		
Belzebub faxoni (Borradaile, 1915)	X	X	X		
Brachyura		X	X		
Penaeidae (larvae)	X	X	X		
Caridae (larvae)		X	X		
BRYOZOA				1	1.04
Membranipora sp.	X	X	X		
CHAETOGNATHA				7	7.29
Flaccisagitta enflata (Grassi, 1881)		X	X		
Ferosagitta hispida (Conant, 1895)		X	X		
Sagitta bipunctata (Quoy & Gaimard, 1827)	X	X	X		
Sagitta helenae (Ritter-Záhony, 1911)	X	X	X		
Pseudosagitta maxima (Conant, 1896)		X	X		
Parasagitta tenuis (Conant, 1896)	X	X	X		
Sagittidae (others)		X			
ECHINODERMATA				1	1.04
Echinodermata (larvae)	X	X			
CHORDATA				7	7.29
Branchiostoma sp.	X	X	X		
Oikopleura (Vexillaria) dioica (Fol, 1872)	X	X	X		
Oikopleura (Coecaria) longicauda (Vogt, 1854)	X	X	X		
Thalia democratica (Forskål, 1775)		X			
Doliolum sp.		X	X		
Teleostei (larvae)		X	X		
Teleostei (eggs)	X	X	X		
OTHERS				1	1.04
Larva trocooff	X	X	X		
TOTAL	**67**	**89**	**80**	**96**	**100.00**

Brazilian Northeast. Meanwhile, the species *Acartia lilljeborgii*, *Acartia tonsa*, and *Acartia danae* may be largely influenced by some physical-chemical parameters, such as water surface temperature, transparency and salinity, which make them more frequent (Resgalla Júnior, 2011; Nunes et al., 2021).

The phylum Chaetognatha was the second most representative in terms of number of species (seven species). This phylum is characterized by the predominance of marine species and predators of the pelagic community (mainly Copepoda), with considerable influence on the structure of this group (Pearre, 1980; Vega-Pérez and Schinke, 2011). According to Boltovskoy (1999), *Parasagitta tenuis* and *Flaccisagitta enflata* are the most frequent Chaetognatha on the Brazilian coast due to their eurythermal and euryhaline characteristics, and they may also occur in neritic waters. Although *F. enflata* is considered a cosmopolitan organism (Melo et al., 2020), it was not recorded in transect I. The species that were most widely distributed in CSM were *Sagitta bipunctata*, *Sagitta helenae,* and *Parasagitta tenuis*.

Studies with gelatinous (Cnidaria, Ctenophora, and Tunicates) and semigelatinous (Chaetognaths and some pelagic Mollusca) are still insipid. Within this group, most Cnidaria are typically oceanic, not presenting great richness in the number of species in the platform area, as recorded by Nogueira et al. (2018), with six species of this phylum. Within the class Hydrozoa, the species of the order Siphonophorae found in CSM were *Chelophyes contorta*, *Cytaeis* sp., and *Agalma* sp. According to Lučić et al. (2005), this group is poorly influenced by marine currents and can perform great shifts, mainly to reach areas with higher primary productivity. Within the Hydrozoa, some medusoid forms of the species *Liriope tetraphylla* were registered exclusively in transect I, while the species *Eutima gracilis* and *Aglaura hemistoma* were recorded in transects II and III.

Appendicularia *Oikopleura longicauda* is a widely distributed species in tropical and subtropical waters (Esnal, 1999). Thus, Carvalho and Bonecker (2016) characterized the occurrence of Appendicularia in the Caravelas estuary and the adjacent coastal area, and revealed that, although all species are distributed along the coast, only five were recorded in the estuary (*Oikopleura rufescens*, *O. dioica, O. cophocerca*, *O. fusiformis*, and *O. longicauda*).

The zooplankton composition recorded by Nunes et al. (2020) along the coast of Maranhão State presented a wide distribution of Copepoda, Annelida, Foraminifera, Molluska, and Decapoda, which is similar to our findings. Hence, we infer that the local zooplankton is finding the appropriate conditions for their development in the continental shelf of Maranhão State and its adjacent regions.

CONCLUSIONS

The present study was the first in-depth work on the Continental Shelf of Maranhão State, characterizing the species found in zooplanktonic communities. From this, it was possible to identify that the main groups of species do not have a great variation throughout the study areas. The Copepoda are the most representative functional group in terms of species, due to evolutionary and adaptive issues that make this group unique.

CONFLICT OF INTERESTS

Nothing to declare.

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AUTHOR'S CONTRIBUTIONS

Nunes, Y.B.S.: conceptualization, project administration, data curation, software, formal analysis, investigation, methodology, writing — original draft, writing — review & editing. Cutrim, M.V.J.: supervision, data curation, formal analysis, methodology, writing — review & editing. Diaz, X.F.G.: formal analysis, methodology, writing — review & editing. Campos, P. N.: formal analysis, methodology, writing — review & editing. Palheta, G.D.A.: formal analysis, methodology, writing — original draft, writing — review & editing. Melo, N.F.A.C.: project administration, Funding acquisition, data curation, formal analysis, investigation, methodology, writing — original draft, writing — review & editing.

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