Flávia Rebelo Mochel
(Organizadora)

Gerenciamento Costeiro e Gerenciamento Portuário 2

Atena Editora
Ano 2019

Flávia Rebelo Mochel
(Organizadora)

Gerenciamento Costeiro e Gerenciamento Portuário 2

Atena Editora
2019

Editora Executiva: Profª Drª Antonella Carvalho de Oliveira
Diagramação: Rafael Sandrini Filho
Edição de Arte: Lorena Prestes
Revisão: Os Autores

Dados Internacionais de Catalogação na Publicação (CIP)
(eDOC BRASIL, Belo Horizonte/MG)

G367 Gerenciamento costeiro e gerenciamento portuário 2 [recurso eletrônico] / Organizadora Flávia Rebelo Mochel. – Ponta Grossa, PR: Atena Editora, 2019. – (Gerenciamento Costeiro e Gerenciamento Portuário; v. 2)

Formato: PDF
Requisitos de sistema: Adobe Acrobat Reader
Modo de acesso: World Wide Web
Inclui bibliografia
ISBN 978-85-7247-620-1
DOI 10.22533/at.ed.201191109

1. Portos – Administração. I. Atena Editora.

CDD 387.1

Elaborado por Maurício Amormino Júnior – CRB6/2422

Atena Editora
Ponta Grossa – Paraná - Brasil
www.atenaeditora.com.br
contato@atenaeditora.com.br

Atena Editora
Ano 2019

APRESENTAÇÃO

A obra “Gerenciamento Costeiro e Gerenciamento Portuário 2” é uma coletânea de trabalhos científicos que situa a discussão sobre tópicos do desenvolvimento e seus impactos socioambientais em diversas localidades da zona costeira brasileira, de maneira interdisciplinar e contextualizada.

Os capítulos abordam resultados de investigações, estudos de caso, aplicações de tecnologias, modelagens e protocolos de pesquisa, nos campos das Ciências Ambientais e Sociais, Geociências, Engenharia Ambiental, Planejamento e Gestão de atividades socioeconômicas.

Neste segundo volume, o objetivo essencial foi difundir o conhecimento adquirido por diferentes grupos de pesquisa e apresentar o que está sendo desenvolvido nas instituições de ensino e pesquisa do país no tocante às aplicabilidades desse conhecimento para a gestão das áreas costeiras e portuárias. A demanda crescente por áreas para o estabelecimento de indústrias, terminais, embarcadouros, expansão das cidades, para o incremento da economia, geração de emprego e renda, desemboca nos desafios de gerir atividades conflitantes e nas consequências sobre a sociedade e o meio ambiente. Somam-se à ocupação humana, a dinâmica natural da zona costeira, influenciada por uma indissociável interação oceano-atmosfera, por movimentos sísmicos e eustáticos, modelando ambientes de alta e baixa energia, alterando o nível dos mares e reestruturando o litoral e as populações que aí vivem.

A complexidade dos fatores intrínsecos à uma zona de interface entre moduladores continentais e marinhos remete à importância de políticas públicas específicas de gerenciamento socioambiental, debatidas e construídas em consonância com a sociedade.

Conteúdos apresentados aqui se propõem a contribuir com o conhecimento de educadores, pesquisadores, estudantes e todos os interessados na zona costeira em seus aspectos metodológicos, conceituais e operacionais, ambiente esse frágil e heterogêneo vital para a manutenção da economia, da sociedade e da vida.

A Atena Editora investe na relevância da divulgação científica ao oferecer ao público uma obra que contém registros obtidos por diversos grupos de pesquisa comprometidos com a sustentabilidade e exposta de maneira objetiva e educativa.

Flávia Rebelo Mochel

SUMÁRIO

CAPÍTULO 9

MORPHODYNAMICS AND MACROFAUNA COMMUNITIES IN 12 SANDY BEACHES OF BRAZIL NORTHEAST: A SEMIARID TROPICAL STUDY

Liana Rodrigues Queiroz
Universidade Federal do Ceará, Instituto de Ciências do Mar, Laboratório de Zoobentos
Fortaleza – Ceará - Brasil
lianarq@yahoo.com.br

Cristina de Almeida Rocha-Barreira
Universidade Federal do Ceará, Instituto de Ciências do Mar, Laboratório de Zoobentos
Fortaleza – Ceará - Brasi
cristina.labomar@gmail.com

ABSTRACT: This study aimed to verify the relationship between benthic macroinvertebrates and physical parameters of 12 sandy beaches of Ceará. More than 1500 sediment samples were collected and the benthic macrofauna was separated and identified. Wave height and period, particle size and tide were recorded. Beach slope, Dean parameter (Ω), Relative Tide Range (RTR) and Beach Index (BI) were calculated to describe morphodynamics. Ordination, Linktree and Bioenv were performed. Non-parametric variances (Kruskal-Wallis test) were verified in order to understand variations of species between beach types. Extrapolative indices of richness were calculated The beaches of Ceará tend to be more dissipative, with gentle slopes and fine grain size. There was a gradient of decreasing grain size, from east to west coast of Ceará. The total of 58 species were recorded in 6064 individuals in 12 beaches studied. Paracuru and Canto Verde beaches presented higher species richness. Dominance of crustaceans in the eastern sector (with greater particle size) and polychaetes in the extreme-western sector (finer grain size) were observed. Dissipative beaches had higher similarities in the distribution of macrofauna. According to extrapolatory estimators of species richness, beaches of Ceará are underestimated by more than 50%. This species richness is physically controlled by easily recognized abiotic factors, such as grain size and slope. However, sandy beaches are highly variable and unique environments, then looking for a large scale pattern is challenging, since several factors are involved from the natural variability, anthropogenic effects on the beaches to sampling difficulties and macrofauna estimates.

KEYWORDS: tropical beaches, macrobenthos, Brazil, beach types, morphodynamic

MORFODINÂMICA E MACROFAUNA BENTÔNICA EM 12 PRAIAS ARENOSAS DO NORDESTE DO BRASIL: UM ESTUDO NO SEMIÁRIDO TROPICAL

RESUMO: Este estudo verificou a relação entre macroinvertebrados bentônicos e parâmetros

físicos de 12 praias arenosas do Ceará. Mais de 1500 amostras de sedimento foram coletadas e a macrofauna bentônica foi separada e identificada. A altura e período das ondas, tamanho das partículas e maré foram registrados. Perfis de praia, parâmetro Dean (Ω), Intervalo Relativo da Maré (RTR) e Índice de Praia (BI) foram calculados para descrever a morfodinâmica. As análises de ordenação, Linktree e Bioenv foram realizadas. Variâncias não-paramétricas (teste de Kruskal-Wallis) foram utilizadas para entender as variações de espécies entre os tipos de praias. Índices extrapolativos de riqueza foram calculados. As praias cearenses tendem a ser mais dissipativas, com declives suaves e granulometria fina, com um gradiente decrescente de tamanho de grão, da costa leste a oeste. Foram registradas 58 espécies e 6064 indivíduos. As praias de Paracuru e Canto Verde apresentaram maior riqueza de espécies. Dominância de crustáceos no setor leste (com maior tamanho de partícula) e poliquetas no setor extremo-oeste (tamanho de grão mais fino) foi observada. Praias dissipativas apresentaram maiores semelhanças na distribuição da macrofauna. Segundo estimadores extrapolativos da riqueza de espécies, as praias do Ceará são subestimadas em mais de 50%. Essa riqueza de espécies é controlada fisicamente por fatores abióticos, como tamanho e inclinação dos grãos. Como as praias arenosas são ambientes altamente variáveis e únicos, então a busca por um padrão de grande escala é um desafio, uma vez que vários fatores estão envolvidos desde a variabilidade natural, efeitos antrópicos nas praias até as dificuldades de amostragem e estimativas de macrofauna.
PALAVRAS-CHAVE: praias tropicais, macrobentos, tipos de praia, morfodinâmica

1 I INTRODUCTION

Sandy beaches dominate the ocean shorelines of all temperate and tropical continental coasts. These ecosystems morphodynamics can be defined in terms of the following interacting factors: tides, waves, and sand particle size (Mclachlan; Defeo, 2013).

Beach models are available to predict beach state as a function of wave and sediment parameters, otherwise the models are generally representative of microtidal beaches and do not take account of the tide. In Brazil, specifically at meso and macrotidal North and Northeast beaches, the effect of tides and increasing tide range on beach morphodynamics must be considered. Indeed, fully reflective beaches will not occur when tide range exceeds 1–1.5 m. On beaches with larger tides, reflective conditions can only occur at the top of the shore (Mclachlan; Defeo 2013). According to Masselink and Short (1993), relative tide range RTR and the omega index combined are more appropriate to describe morphodynamic states regarding to meso and macrotidal beaches. McLachlan and Dorvlo (2005) developed the beach index (BI), considering the relation of the mean grain size, the maximum spring tide range and the beach face slope (dimensionless).

Physical factors, such as morphodynamics, are considered the most important factor controlling macrofauna establishment. Therefore the physical environment on the large scale mainly controls species richness. At a finer scale and under more dissipative conditions, biological factors may become important (Defeo et al. 2003, McLachlan & Dorvlo 2005). The increase of species richness, abundance and biomass from microtidal reflective to macrotidal dissipative beaches is considered a paradigm on exposed sand beaches communities' patterns (Mclachlan, 2001, Defeo & Mclachlan, 2005; Mclachlan & Brown, 2006).

The State of Ceará at Brazilian tropical zone, between 2°S–7°S and 37°W–41°W. The coastline extends for 573 km, The northern coastal zone is aligned in a general west-east direction from the estuary of the Timonha river to Itarema beach, it then trends northwest to southeast to Icapuí municipality, at the Rio Grande do Norte border (Pinheiro, et al., 2016). Municipalities bordering the sea have the highest population densities in the Ceará state, ranging between 200 and 2000 inhabitants per km^2, peaking in the city of Fortaleza, the State Capital (IPECE 2013). The climate was warm semi-arid tropical (IPECE, 2013). The intensity and frequency of the rainy season is dependent on the position of the Intertropical Convergence Zone (ITCZ), it migrates in annual cycles bringing the rainy season to Ceará between March and May (Pinheiro et al, 2016).

The Ceará coastal zone is predominantly composed of sandy sediments of Upper Terciary-Quaternary and contains several episodes of dunes, beaches, estuarine plains and active and paleo-sea cliffs, all activated during period of high sea level. Beach sediments are predominantly medium bimodal quatz sand (Morais et al., 2006) and the tides are semidiurnal mesotidal (Maia, 1998). Ceará beaches are predominantly tide-modified (RTR > 3) (Pinheiro et al. 2016). This is to be expected in a moderate wave energy mesotidal environment with a spring tide range of 3 m (Masselink & Short 1993).

This paper describes a wide range study to assess the across-shore and alongshore spatial dynamics of the physical environment and the macrobenthic community comprising 12 sandy beaches at entire coastline of Ceará, in Northeastern Brazil.

According to the theoretical frameworks developed for sandy beaches (Defeo & McLachlan, 2005), we predict: 1) a clear differentiation of morphodynamics and macrofaunal invertebrates amongst Ceará state sectors of coastal zone; and 2) a high number of species such as predicted for tropical zone.

2 I MATERIAL AND METHODS

For the present study, Ceará coastal zone was divided in three sectors according to Bensi et al. (2005). The Eastern sector is characterized by sandy-clay deposits derived from cliffs and paleocliffs. The Central-West sector is extremely urbanized and some locations are experiencing very high rates of erosion which is resulting in serious damage to urban infrastructure. The Extreme-West sector is dominated by mobile dunes, barrier islands backed by lagoons and mangrove areas. On the Extreme-West coast the presence of fine sediments is associated with proximity to the mouths of river estuaries and lagoons. It's the sector least urbanized, with strong winds and small waves (Figure 1).

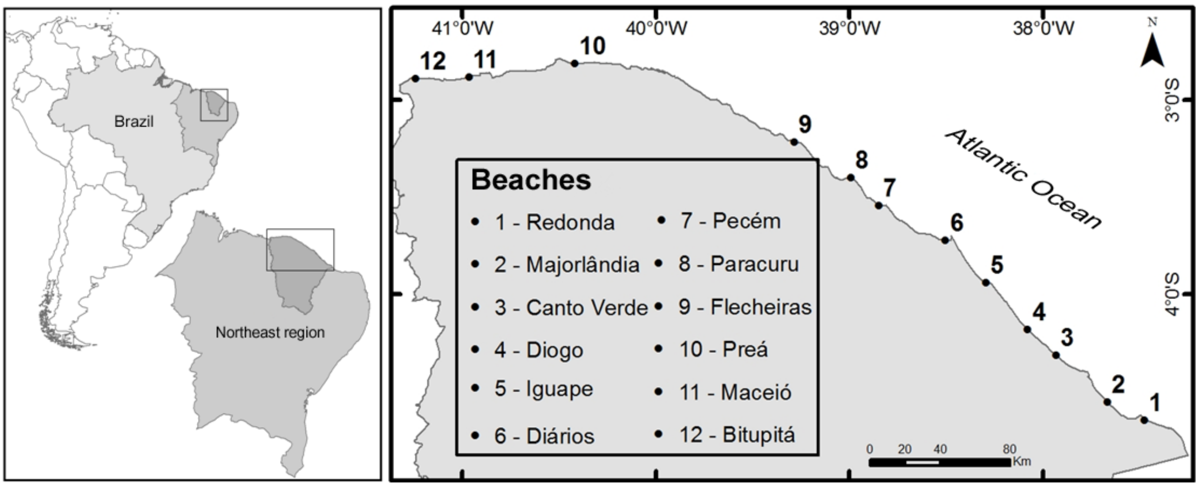

Figure 1: Map of Ceará State coast at Brazilian Northeast region showing the location of the 12 beaches studied.

All the fieldwork at 12 beaches was carried out between August 2010 and April 2011 during the low spring tide. The macroinvertebrates were collected along five transects (10 m apart) perpendicular to the coastline, except Diários beach which was collected only three transects. Each transect was divided from six to ten sampling sites covering the entire intertidal zone. A crescent numbering of sites was adopted, which 1 is the closest to supralitoral. Sediment samples were collected using a 15 cm diameter/ depth corer (0.018 m^2), sieved (0.5 mm mesh) in the field and preserved in 70% ethanol. In laboratory, the organisms were separated, identified and counted.

The standard suite of physical variables on the beach (Schlacher et al., 2008) was also measured as follows. Beach slope was determined by across-shore profiling of three transects ranging all sample station. Five sand samples were taken across-shore, washed through a 63-mm mesh sieve, oven-dried at 60º C for 24 h and sieved through a half-phi stack of sieves. The fraction of sand retained in each of the sieves was recorded, and the data were analyzed statistically using Sysgran software to determine mean sand grain size, sorting and skewness (Folk & Ward, 1957). Wave height (Hb) was visually estimated by measuring 12 breaking waves, and wave period (Tb) was recorded as the time interval between breakers. The physical variables were used to calculate the following indexes that describe beach morphodynamic type: Dean's parameter (Wright & Short, 1984); relative tide range (Masselink & Short, 1993); and beach index (McLachlan & Dorvlo, 2005).

The number of marine species recorded (termed marine species richness, MSR, showing inventory richness) is referred as the number of macrobenthic species (excluding insects) collected in a standard transect survey across the intertidal zone. MSR, total density and taxonomic group density (ind.m^{-2}) were plotted at Ceará state maps using the software Arcgis 9.3.

Data collected on density and richness did not meet assumptions of parametric ANOVA, and, therefore, nonparametric Kruskal-Wallis tests were used to compare these variables among morphodynamic types of beaches. Spearman's rank correlation was used to assess the relationships between grain size and longitude at Ceará coast. These analyses were performed using the software Statistica, v.7.0 (StatSoft, 2007).

Using the PRIMER package version 6 (Clarke & Gorley, 2006), the relationships between multivariate assemblage structure and environmental variables were assessed using the BIOENV and LINKTREE procedure (Clarke & Ainsworth, 1993). For estimation of the species richness, two non-parametrics extrapolative estimators the first-order jacknife (Jack1) and Chao 1 were calculated and compared with the observed results.

All samples in this study were conducted in accordance with applicable federal and state laws (ICMBio 19017-1). The specimens were deposited in the scientific invertebrate collections of the Instituto de Ciências do Mar (LABOMAR) of the Universidade Federal do Ceará, in Fortaleza, Ceará, Brazil.

3 I RESULTS

Physical parameters

The sandy beaches of Ceará have morphodynamic conditions quite favorable to the establishment of benthic macrofauna. With exception of the urbanized Diários beach, the studied beaches present a dissipative macromareal pattern, with Beach Index (BI)> 2.3, smooth slope (<0.06), extensive intertidal zone (Width> 77m). The beaches presented a gradient of decreasing grain size from east (383 µm in Round) to the west (96 µm in Bitupita) (Table 1).

The Beach Index (BI) found were all above 2, with an average value of 2.5, which indicates a greater proximity to the dissipative macromareal beaches.

Beach	Beach width (m)	Beach Slope	Mean grain size (μm)	Wave height (cm)	Period (s)	Dean`s parameter. (Ω)	RTR	BI
Redonda	147	0.03	383	41.8	5.0	1.5	7.9	2.4
Majorlândia	186	0.02	243	44.8	3.0	4.7	7.4	2.6
Canto Verde	123	0.04	203	37.5	10.2	1.4	7.7	2.4
Diogo	106	0.03	329	40.0	6.0	1.4	8.0	2.5
Iguape	173	0.02	291	82.0	7.0	2.9	3.7	2.6
Diários	55	0.09	262	100.0	10.0	2.8	3.1	2.0

Pecém	144	0.03	207	107.5	7.2	5.7	2.8	2.5
Paracuru	83	0.05	194	47.5	9.0	2.2	6.5	2.3
Flecheiras	159	0.03	181	50.0	6.3	3.6	5.8	2.6
Preá	77	–	173	35.0	4.4	3.9	8.9	-
Maceió	182	0.02	154	40.0	8.3	2.8	7.3	2.8
Bitupitá	288	0.01	96	10.0	4.4	3.0	31.0	3.0
Mean	144	0.03	226	53.0	6.7	3.0	8.3	2.5

Table 1: Environmental characteristics of the studied beaches (RTR - relative tide range; BI – beach index). Beaches ordered by increasing geographic longitude.

Considering that the RTR (Relative Tide Range) was higher than 3 in the studied beaches (in Pecém the RTR was 2.8, but will be considered equal to 3 by rounding), the tides have a greater contribution in the beach morphodynamics than the waves. Thus, the Dean (Ω) parameter alone does not reflect the conditions of the beach morphodynamics, so it is more appropriate to combine the RTR and Ω indexes to describe the morphodynamic features of the beach. According to these two indexes most of the studied beaches presents more dissipative character, as Pecem (dissipative); Majorlândia, Preá, Maceió (ultradissipative), and Bitupitá (flat tidal).

Figure 2 shows the RTR and Dean (Ω) values were plotted and it was observed that three beaches can be considered from low tide terrace (Redonda, Canto Verde and Diogo), four are low tide bar+rip (Diários, Paracuru , Flecheiras and Iguape), three are ultra-dissipative (Preá, Majorlândia and Maceió), a non-barred dissipative without a bank (Pecém) and a tidal flat (Bitupita).

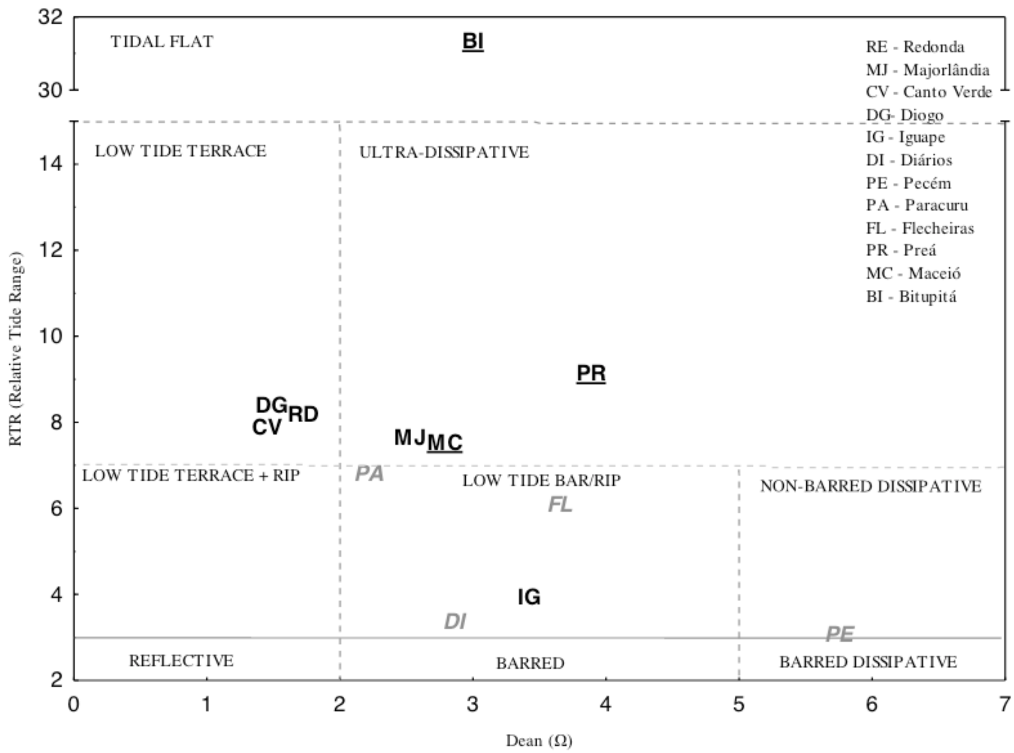

Figure 2: Scatter diagram of Dean parameter vs Relative Tide Range (RTR) according to Masselink e Short (1993) proposed model. In black letters are grouped east sector beaches; in gray letters are central-west beaches and in black underlining letters are extreme-west beaches.

The largest grain size was 383 µ in Redonda beach (extreme east) and the smallest grain size was 96 µ in the beach of Bitupitá (extreme west). By the linear regression analysis, there is a high correlation between the average grain size and the geographic longitude westward (r^2= 0,67; p=0,0011) (Figure 3).

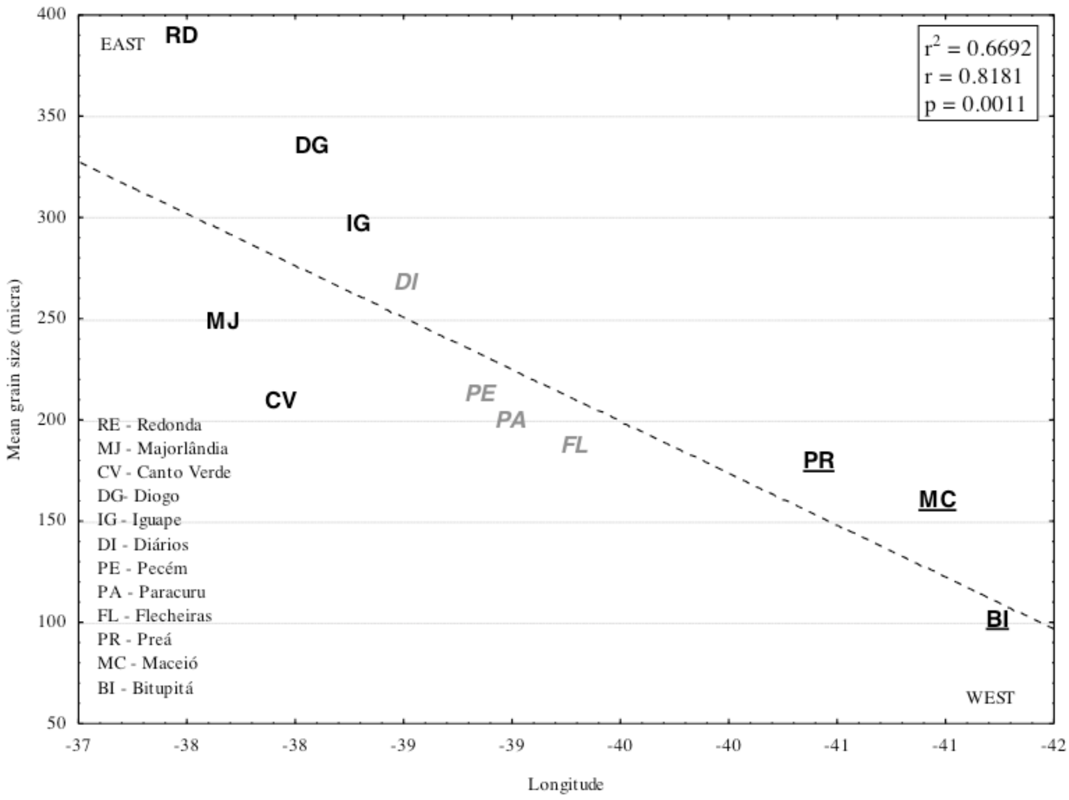

Figura 3: Linear-regression analyses of mean grain size and geographic longitude. In black letters are grouped east sector beaches; in gray letters are central-west beaches and in black underlining letters are extreme-west beaches. At upper right is present Spearman correlation analysis.

Benthic Macrofauna

Considering the 12 beaches, 6,064 individuals were collected representing 58 species (Table 2). The Pecém beach had the greatest abundance (1,780 individuals), followed by Maceió beach with 1,229 individuals. According to the number of macrobenthic species collected in a standard transect survey across the intertidal zone, MSR (marine species richness), Canto Verde beach had the highest mean value (14.0). Diários beach presented the lowest values of total richness (10) and MSR (5.3), in addition to the lower abundance and species density (Table 3).

Taxa	Redonda	Major-lândia	Canto Verde	Diogo	Iguape	Diários	Pecém	Paracuru	Flecheiras	Preá	Maceió	Bitupitá	Total Abundance
Polychaeta													
Scolelepis sp.	13	4	62	1	1	10	1486	98	14	24	447	87	2247
Paraonidae	56	33	19	0	4	1	2	8	4	12	609	150	898

Hemipodia Californiensis	1	54	61	39	1	0	128	3	12	148	45	84	576
Syllidae	2	23	0	435	60	0	2	3	1	0	6	1	533
Orbiniidae	0	2	0	1	0	0	3	10	0	134	13	51	214
Dispio sp.	0	2	34	0	0	1	0	50	2	8	1	0	98
Capitellidae	1	0	0	0	0	0	1	20	0	2	0	4	28
Onuphis cf eremita	1	0	0	0	0	0	0	0	0	3	0	11	15
Lumbrineridae	0	0	2	1	0	0	0	0	0	0	2	3	8
Spionidae	0	0	0	0	0	0	0	3	0	0	1	1	5
Goniadidae	0	0	0	0	0	0	0	0	0	0	0	4	4
Grubeulepis sp.	0	0	0	0	0	0	0	0	0	1	0	3	4
Oeonidae	0	0	0	1	0	0	0	1	0	0	0	1	3
Amphinomidae	0	0	2	0	0	0	0	0	0	0	0	0	2
Nereididae	0	0	0	0	0	0	0	1	0	0	0	0	1
Nephtydae	0	1	0	0	0	0	0	1	0	0	0	0	2
Pisione sp.	0	0	1	0	0	0	0	0	0	1	0	0	2
Paraonidae sp2	0	0	1	0	0	0	0	0	0	0	0	0	1
Polidora sp.	1	0	0	0	0	0	0	0	0	0	0	0	1
Poliqueta	1	4	2	6	1	0	2	3	0	2	5	0	26
Mollusca													
Donax Striatus	77	47	64	15	11	5	67	32	16	16	40	27	417
Donax Gemmula	43	18	39	9	0	3	4	0	17	139	43	39	354
Donax Variabilis	13	14	0	1	0	1	16	14	56	0	0	1	116
Tivela Mactroides	0	1	1	0	0	0	0	0	0	9	6	7	24
Olivella Minuta	0	0	0	0	0	0	0	16	0	0	0	0	16
Strigilla Mirabilis	2	0	0	0	0	0	0	3	0	0	0	2	7
Strigilla Pisiformis	0	0	0	0	0	0	0	2	0	0	0	0	2
Lepton Lepidum	0	0	0	0	0	0	0	0	0	0	0	1	1
Abra Aequalis	0	0	0	0	0	0	0	0	0	0	0	1	1
Anomalocardia Brasiliana	0	0	0	0	0	0	1	0	0	0	0	0	1
Crustacea													
Bowmaniella sp.	0	0	12	38	13	0	6	0	5	0	0	0	74
Excirolana Braziliensis	0	0	37	0	0	0	0	0	0	0	1	0	38
Bathyporeiapus Ruffoi	0	0	0	0	3	0	29	0	0	0	0	0	32
Metamysidopsis sp.	0	0	31	0	0	0	0	0	0	0	0	0	31
Austinixa sp.	0	4	0	0	0	1	2	11	0	2	6	4	30
Bathyporeiapus Bisetosus	0	0	1	7	1	0	11	3	0	0	0	0	23
Cheus sp.	0	0	17	1	1	0	0	0	0	0	0	0	19
Excirolana Armata	0	0	0	4	0	0	0	1	2	0	0	0	7
Caridea	0	1	1	0	0	0	1	1	0	0	0	0	4
Brachyura	0	0	2	1	0	0	0	0	0	0	1	0	4
Lepidopa sp.	1	0	1	0	0	0	1	0	0	0	1	0	4
Phoxocephalopsis sp.	0	0	0	0	0	0	1	0	2	0	0	0	3
Macrochiridotea sp.	0	0	0	0	2	0	0	0	0	0	0	0	2
Callichirus Major s.l.	0	1	0	0	0	0	0	0	0	0	0	0	1
Promysis sp.	0	0	0	1	0	0	0	0	0	0	0	0	1
Corophiidae	0	0	0	0	0	0	0	1	0	0	0	0	1

Hyallidae	1	0	0	0	0	0	0	0	0	0	0	0	1
Amphipoda	0	0	6	8	0	2	6	3	13	0	0	0	38
Mysidacea	0	2	0	6	6	1	2	0	0	0	1	3	21
Crustacea	2	0	0	0	0	0	1	0	0	0	0	0	3
Isopoda	0	0	1	0	0	0	1	0	0	0	0	1	3
Cumacea	0	0	0	1	0	0	0	1	0	0	0	0	2
Echinodermata													
Mellita Quinquiesperforata	0	5	9	7	0	0	3	0	0	6	0	0	30
Others groups													
Nemertea	5	2	13	11	21	1	4	0	1	9	1	10	78
Chaetognata	1	0	1	0	0	0	0	0	0	0	0	0	2
Sipuncula	0	0	0	0	0	0	0	0	0	1	0	1	2
Picnogonida	1	0	0	1	0	0	0	0	0	0	0	0	2
Cephalochordata	0	1	0	0	0	0	0	0	0	0	0	0	1
Total	222	219	420	595	125	26	1780	289	145	517	1229	497	6064

Table 2: Benthic macrofauna species and their respective total abundances in the 12 beaches studied in the coast of Ceará.

	Beaches	MSR	N	S	DENS
EAST	Redonda	7.6±2.3	222	18	384.2±330.7
	Majorlândia	9.8±1.6	219	19	182.5±104.0
	Canto Verde	14.0±2.4	420	25	278.2±248.9
	Diogo	10.4±2.3	595	22	244.0±334.1
	Iguape	6.2±1.9	125	13	162.2±204.6
CENTRAL-WEST	Diários	5.3±0.6	26	10	28.3±34.5
	Pecém	11.2±1.5	1,780	24	745.5±1804.5
	Paracuru	13.2±2.0	289	24	133.9±126.8
	Flecheiras	7.2±2.0	145	13	57.9±77.4
EXTREME-WEST	Preá	11.2±1.6	517	17	218.4±128.4
	Maceió	10.0±1.2	1,229	18	572.8±406.2
	Bitupitá	13.0±1.6	500	24	190.1±240.8

Table 3: Biotic characteristics of the macrofauna community in the 12 studied beaches. Beaches ordered by increasing geographic longitude. MSR – mean and standard deviation of marine species richness per transect; N – total number of individuals; S – total number of species; DENS – mean and standard deviation of species density (ind m^{-2}**).**

The total specific richness along the levels parallel to the water line collected had an increase in sites closer to the sea. The average number of species on all beaches at level 10 (closest to the sea) was 3 times higher than level 1. The increase in specific richness at the levels closer to the sea occurred in nine of the 12 beaches studied (Majorlândia, Canto Verde, Diogo, Pecém, Paracuru, Flecheiras, Preá, Maceió and

Bitupitá).

The total density of the main species along the perpendicular levels in the beaches of Ceará is shown in Figure 4. In the upper zone (levels 1 to 4), we observed the presence of polychaete spionids *Scolelepis* sp. and syllids on most beaches. Cirolanid crustaceans, such as *Excirolana armata* and *E. braziliensis*, although in occasional occurrences, also occupied this zone. Other polychaetes like paraonids and *Hemipodia californiensis*, occupy almost all the extension of the beach. Among the donacid bivalves, *Donax striatus* and *D. variabilis* manage to inhabit the entire length of the beach, while *D. gemmula* appears in the areas closest to the water. Other taxa were also typical of moist areas such as Nemertea, the polychaetes orbiniids and *Dispio* sp., amphipods *Bathyporeiapus ruffoi* and *B. bisetosus*, in addition to the mysidaceous *Bowmaniella* sp.

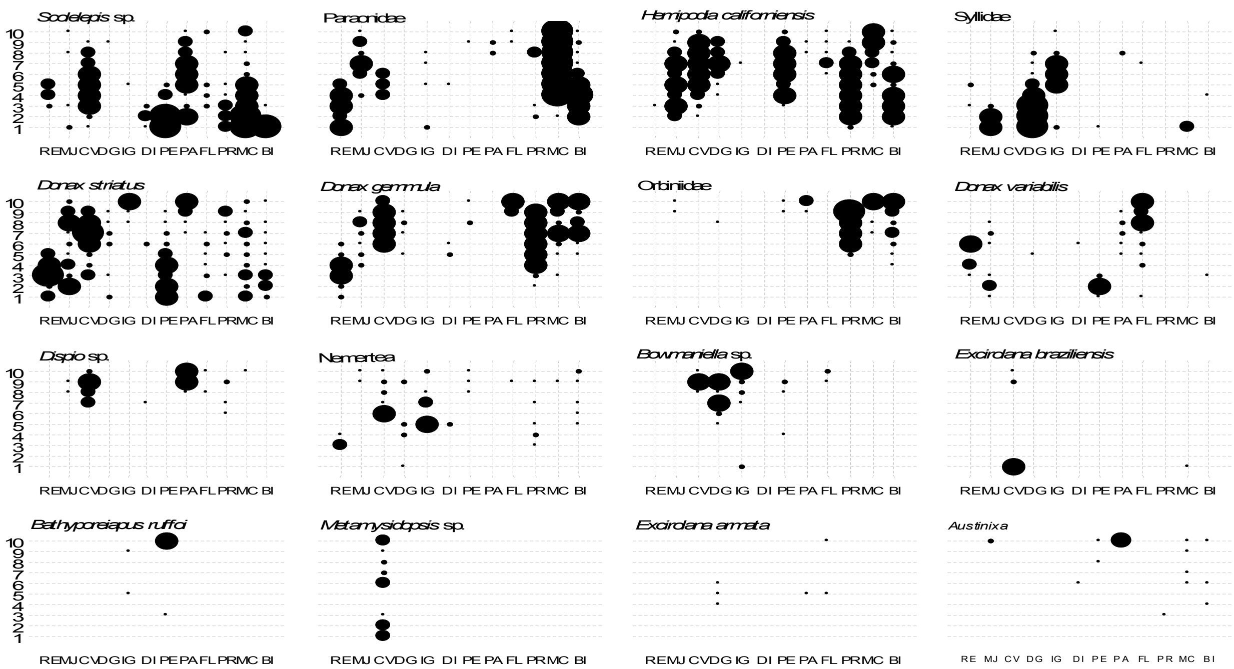

Figure 4: Zonation of 12 main species along the 12 studied beaches. Level 10 is closest to the sea. Beaches ordered by increasing geographic longitude. RE-Redonda, MJ-Majorlândia; CV-Canto Verde; DG-Diogo; IG-Iguape; DI-Diários; PE-Pecém; PA-Paracuru; FL-Flecheiras; PR-Preá; MC-Maceió; BI-Biupitá. Density classes: • 1-50 ind m^{-2} ● 50-100 ind m^{-2} ● 100-200 ind m^{-2} ● 200-1000 ind m^{-2}.

The beaches that presented richness of more than 20 species were Canto Verde, Diogo, Pecém, Paracuru and Bitupitá, and three beaches presented richness (MSR) of more than 12 species: Canto Verde (East), Paracuru (Central West) and Bitupitá (Extreme-West). In the eastern sector, with beaches with larger grain size, the polychaetes had lower densities. In contrast, mollusks had the highest densities, especially in Redonda, Majorlândia and Canto Verde beaches. Crustaceans, although higher in number of species (22 species), had low densities all over the coast. These invertebrates were practically absent on the beaches of the extreme west (Figure 5).

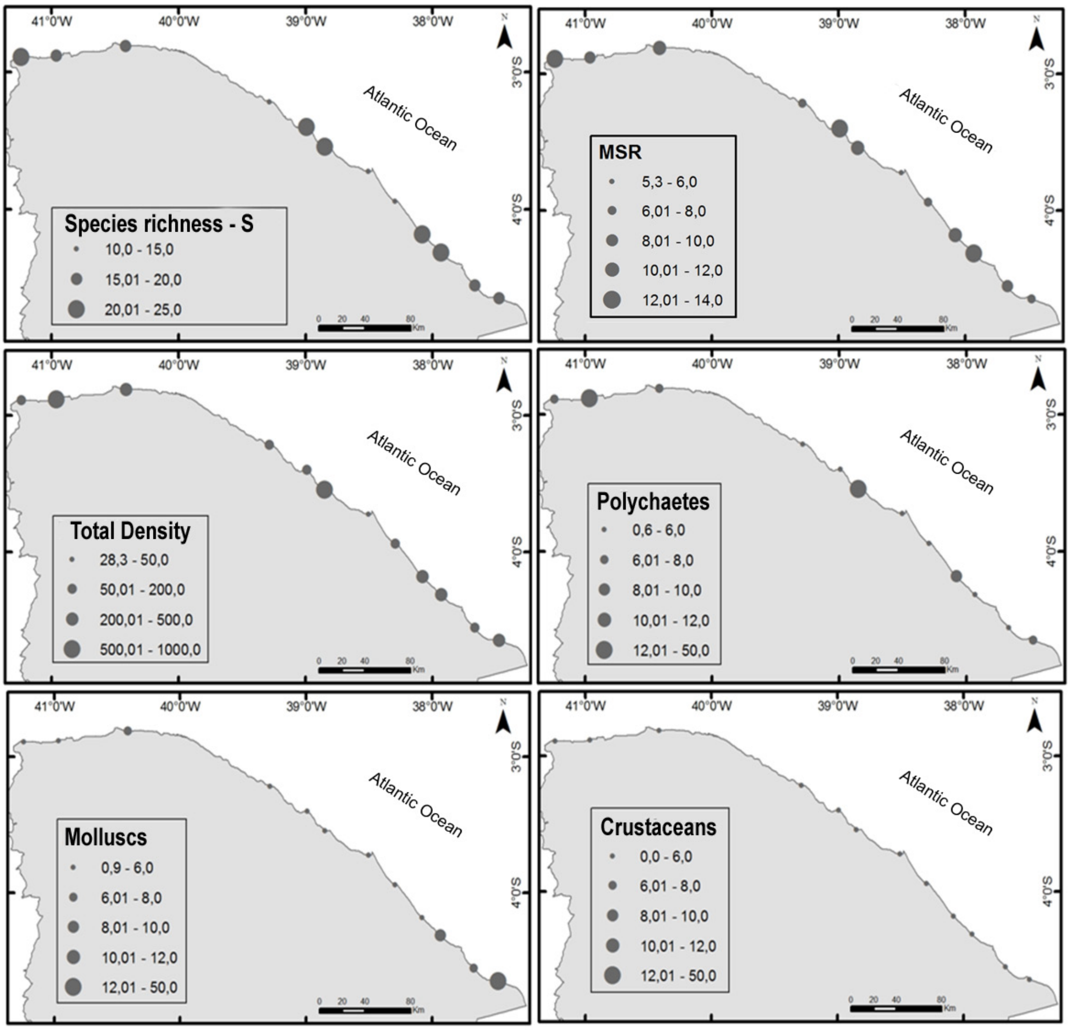

Figure 5: Map showing the 12 beaches studied across the coast of Ceará state. The total species richness (S); Marine Specie Richness per transect (MSR), total density and densities of polychaetes, mollusks and crustaceans at each beach are represented.

Relationship between physical environment and benthic macrofauna

BIOENV analysis, using the Spearman correlation method, showed that grain size and slope together were the variables that best explained the differences in benthic macrofauna (r = 0.353). However, the low p values suggest a more cautious interpretation of the results.

The LINKTREE routine combines the environmental variables with the similarities between the benthic macrofauna generating a divisive grouping of the beaches in order to describe biological and environmental relationships more effectively. Unlike BIOENV, environmental variables are non-additive, conferring an advantage in identifying an important variable under one aspect of macrofauna distribution, although it does not explain others. BIOENV, on the other hand, examines the situation in a broad way. Under this analysis, an initial division (A) separated Diarios beach from the others, due to being characterized by the low beach index (BI <1.99); high slope (> 0.09) and small width beach (<55m). The second division (B) separated beaches with different grain sizes. The beaches with the largest grain size in descending order were Redonda, Diogo and Iguape (Grão> 290.8µ) (east sector). The beaches with the finest sand grain (<242.8µ) were Majorlândia and Canto Verde, both of the eastern sector, and all other beaches of the central-west and extreme-west sectors (Figure 7).

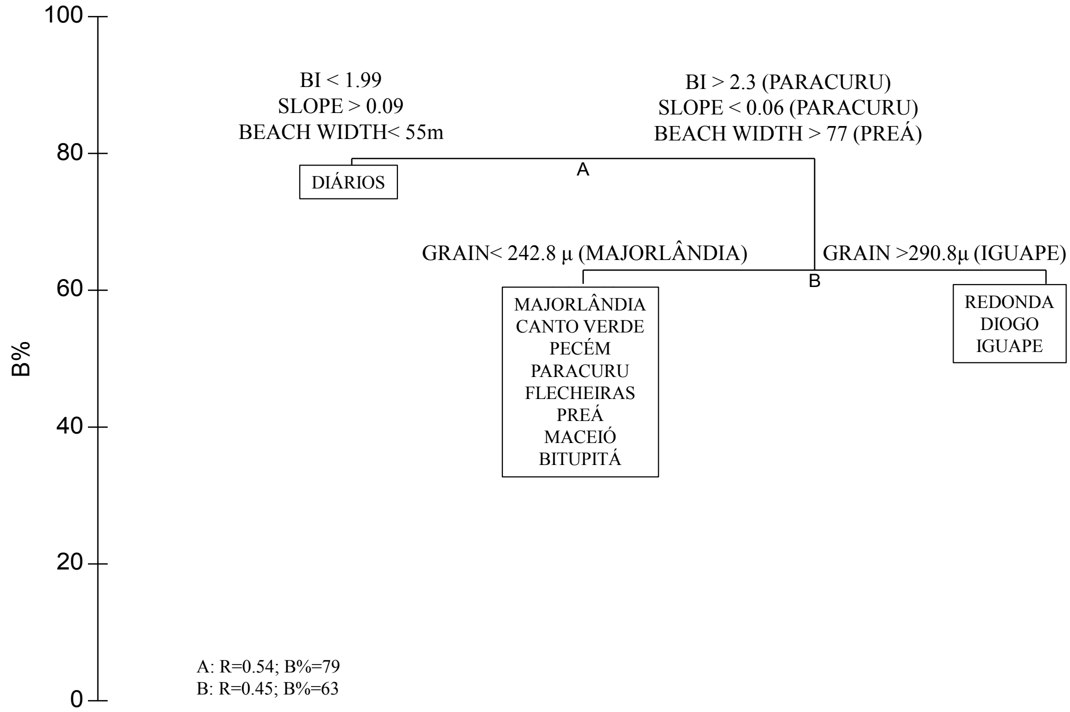

Figure 7: Linkage tree analysis (LINKTREE) showing divisive clustering of beaches from species compositions, arranged by inequalities on one or more abiotic variables. For each split (A and B), R is the optimal ANOSIM R value (relative subgroup separation). The B% statistic shows the absolute measure of group differentiation, and considers the ranks from the original resemblance data. The significant environmental variable(s) (SIMPROF, $p < 0.05$) that define each division are listed at each branching point. BI=beach index – Índice da Praia.

Two non-parametric estimators for species richness were calculated. The Jacknife 1 and Chao 1 indexes projected richness values higher than that observed on all beaches. According to these indexes, the richness of Ceará beaches would be between the lowest 15.9 (Flecheiras) and the highest 34.7 (Paracuru) by the Jacknife 1; and between the lowest 13.7 (Flecheiras) and the highest 62.5 (Diogo) according to Chao1 (Table 4). Thus, the observed macrofauna richness of the sandy beaches of Ceará is underestimated on average three times less than predicted. The extreme example was found at Diogo Beach, where the richness estimated by Chao 1 would be up to six times greater than that observed. The smallest differences were found in Prea beach, and even then, wealth would still be underestimated by almost two times less than the observed value.

Estimator	Beach	RE	MJ	CV	DG	IG	DI	PE	PA	FL	PR	MC	BI
	Observed MSR	7.6	9.8	14	10.4	6.2	5.3	11.2	13.2	7.2	11.2	10	13

Jacknife 1	27.5	25.8	32.8	31.8	17.8	15.7	33.8	34.7	15.9	20.9	25.8	32.8
Chao 1	31.5	22.1	33	62.5	25.5	28.0	28.9	48.5	13.7	18.5	42.5	56

Table 4: Values of observed marine species richness per transect (MSR) as well as the calculated Jacknife1 and Chao1 extrapolative estimators, in each studied beach.

RE-Redonda, MJ-Majorlândia; CV-Canto Verde; DG-Diogo; IG-Iguape; DI-Diários; PE-Pecém; PA-Paracuru; FL-Flecheiras; PR-Preá; MC-Maceió; BI-Bitupitá.

4 I DISCUSSION

Physical environment

The physical environment of the sandy beaches of Ceará can be characterized as follows: (1) there is a gradient of decrease in the grain size of the sand from the east to the extreme-west coast of Ceará; and (2) there is predominance of beaches with dissipative characteristics with BI Index> 2.3, smooth slope and wide beach width.

The detection of a clear gradient of decrease in grain size from the east to the west end of the Ceará coast is related to the types of adjacent coastal ecosystems. In the east coast, there is a great presence of beaches with cliffs, which are known to supply sediments of the beaches of Ceará. The beaches of this sector were characterized by coarse sand. In the west coast, dune fields are more frequent, and constitute a deposition zone that receives the finest sediments in the coastal drift (Bensi et al., 2005).

According to Pinheiro et al. (2016), the sediment size distribution along beaches of Ceará showed that fine sediments dominates 32% of the beaches, very fine sands occurs at 15% , while medium size sand is the most dominant on 45 % of Ceará beaches. In the present study, a decrease in sand grain size from the east to the extreme west of the coast of Ceará was evidenced, which is related to the types of adjacent coastal ecosystems and the longshore sand transport pattern.

On the west coast, the presence of fine sediments is associated with proximity to the mouths of river estuaries and mangroves (Bensi et al., 2005, Pinheiro et al 2016), that contribute to the most flat beaches observed in the extreme-west coast, such as Maceió and Bitupitá. Dune fields are also common in this sector, and constitute a deposition zone that receives the finest sediments in the coastal drift (Bensi et al., 2005). In the other hand, along east coast, there are significant higher grain size sediments originated by sand-clay cliffs. Besides, longshore sand transport is driven by east-southeast currents (Pinheiro et al., 2016), which contributes to remove fine sediments at east and deposit at extreme-west side. At extreme-west side, where the coastline has an east-west direction, the waves affect the coast in a right angle, the wind takes an offshore component, and the flow of water has a tendency to move away from the coast creating optimal conditions for sedimentation (Bensi et al., 2005).

The wave pattern observed in the present study (mean Hb = 53cm and t = 6.7s) are within the characteristics expected for the coast of Ceará. According to Carvalho et al. (2008), 80% of the waves incident on the coast are sea waves (1 ≤ T ≤ 9 s) and 20% are swell waves, with periods> 10 s. The wave height is attenuated in embayed beaches and crossing longitudinal bars and rock outcrops (Pinheiro, et al., 2016).

Tides in Ceará are semidiurnal mesotidal with a maximum amplitude of 3.2 m (Morais, 1981; Maia, 1998). The studied beaches of Ceará had very similar tidal amplitudes (from 2.9m to 3.3m), so the variation in wave height seems to influence RTR values, and consequently their morphodynamics.

The incident waves at high tide and at low tide were also different along the studied beaches. At low tide, the swash acts gently on the intertidal zone, with a typical swash lenght of dissipative environments. Already at high tide, reflective wave-dominated conditions predominate with a high set-up of the swash and with waves breaking directly on the beach face. These morphodynamic conditions agree with the statements of Pinheiro et al. (2016).

The tides effect should be considered when establishing morphodynamic patterns on the sandy beaches of Ceará. Some researchers have already classified the morphodynamics of sandy beaches by the parameter Ω (Maia, 1998; Branco et al., 2005; Albuquerque et al., 2009; Dias & Rocha-Barreira, 2011; Moura, 2012). However, few studies have used the RTR, which considers the tidal effect, and which would be adequate for the Ceará coast (Albuquerque et al., 2009; Pinheiro et al., 2016).

A combination of the Dean (Ω) and RTR parameters was used to classify the 12 beaches studied in five distinct morphodynamic states: tidal flat, ultradissipative, dissipative, low tide terrace and low tide bar / rip. In all the beaches, beach index (BI) was superior to three, which indicates that the beaches present more dissipative conditions, with the smooth slope and width of the wide beach.

Latitudinal changes in climate cause changes in physical factors impinging on sandy beaches and the most significant change is an increase in wave energy from the tropics toward cold temperate areas, which causes a shift in beach type (Mclachlan & Defeo, 2018). Despite these evidences, latitudinal patterns of beach morphodynamics should be considered with caution, since the selection of sampling sites and the particularities of beaches reported in different researches may lead to mistaken generalizations. According to Soares (2003) and McLachlan and Dorvlo (2005), tropical areas tend to have a greater proportion of marine biogenic calcareous sands and lower waves, which promotes a preponderance of reflective beach types. This argument may be valid on tropical beaches associated with coral reefs, which provide biogenic sediments. However, without biogenic reefs, dissipative beaches may predominate. Most of the sediments of the shallow internal continental shelf of Ceará have terrigenous origin, transported from the coastal plains and cliffs (Muehe, 2005). In this way, the predominance of dissipative conditions was already expected. Defeo and Mclachlan (2013) argued that the trend of reflective beaches in tropical environments might have no connection with latitudinal gradients, but only because of the choice of small, compartmentalized beaches and the presence of coral reefs that dissipate wave energy.

Another aspect contrary to this generalization is that according to the classification proposed by Masselink and Short (1993) beaches with RTR> 3, characteristically mesotidal and macrotidal beaches, reflective morphodynamic types are not contemplated. In these beaches, the reflective condition will occur only at the time of high tide.

Other tropical environments such as the northern region of Brazil also present beaches with dissipative character. Alves and El-Robrini (2004) and Monteiro et al. (2009) applied the RTR and Ω parameters to characterize the behavior of the macrotidal beach of Ajuruteua at Pará state, evidencing its dissipative slope.

Benthic macrofauna: spatial distribution

The occurrence of benthic macrofauna in Ceará beaches followed some patterns already reported by other authors (Rocha-Barreira et al., 2001; 2005; Viana et al., 2005). The spatial distribution of the benthic macrofauna of Ceará beaches is characterized by the preferential occurrence of mollusks and crustaceans in the eastern littoral and polychaetes on the western and extreme west coast.

Dexter (1992) evidenced the preference of polychaetes for more sheltered beaches. The polychaetes are more sensitive to changes in the state of the beach and are absent or rare in reflective beaches or of coarser granulometry. On low energy and fine sand coasts, polychaetes can be especially abundant and include predators, deposit feeders and suspensivores (Mclachlan and Defeo, 2013). On the coast of Ceará, the beaches with finer granulometry (extreme-west sector) presented high abundances of polychaetes, mainly *Scolelepis* sp., Paraonidae, Orbiniidae; *Hemipodia californiensis*.

Scolelepis spp. are abundant in intermediate and dissipative sandy beaches of all the continental coasts (Souza and Gianuca, 1995, Borzone et al., 1996, Barros et al., 2001, Queiroz 2006, Rodil et al., 2013). This polychaete was especially abundant on the beach of Pecém, the only beach considered properly dissipative. The occurrence of *Scolelepis* sp. in other beaches may have been limited by the high occurrence of the polychaete Paraonidae. An interspecific competition for space and food due to this co-occurrence may have limited the abundance of *Scolelepis* sp. on other beaches. Although the competition on sandy beaches is little evident, since most sandy-beach animals are opportunistic in their feeding and this decreases the likelihood of competition, there are some studies at fine scales under dissipative/sheltered conditions where competition has been indicated, if not conclusively demonstrated (Mclachlan & Defeo, 2018). Franklin Jr. (personal communication) also reported that Paraonidae were the most abundant and most frequent taxa on the shallow continental shelf west of Ceará. In the present study, the beaches adjacent to this region, such as Redonda, Maceió and Bitupitá, presented high abundance of Paraonidae.

Olivella minuta was captured only at Paracuru Beach. This gastropod is common on sandy beaches protected by sandstone reefs on the coast of Ceará (Rocha-Barreira et al., 2001; 2005; Viana et al., 2005; Araújo and Rocha-Barreira, 2012). Paracuru Beach is a vast sandy beach interspersed with sandstone reef formations (Viana et al., 2005). This protection to the beach also favored the occurrence of several species, mainly polychaetes, which contributed to higher species richness of this beach. Other studies have also shown that the degree of protection on the beach favors the establishment of a diverse fauna on sandy beaches (Dexter, 1992).

In the present study, the occurrence of bivalves *Donax gemmula* and *Donax variabilis* was widely recorded. Barroso et al. (2013) only recently recorded the occurrence of *D. gemmula* for the sandy beaches of Ceará. The bivalve *D. variabilis*, despite having a record in the Malacological Collection Prof. Henry Ramos Mathews, of the Universidade Federal do Ceará, had not been reported on the sandy beaches of Ceará in previous studies. An analysis of the donacids cataloged in this malacological collection revealed that many of the individuals captured in Ceará were erroneously identified as *D. striatus*, being in fact specimens of *D. gemmula* and *D. variabilis*, contrary to the invasion hypothesis raised by Barroso et al. (2013).

Based on three extensive studies that are representative of a wide range of beaches (McLachlan & Jaramillo, 1995; McLachlan & Dorvlo, 2005; Defeo & McLachlan, 2005; 2013) that crustaceans typically correspond to half of the species on sandy beaches, followed by polychaetes and mollusks (Mclachlan & Defeo, 2018). On the beaches of Ceará, however, they were represented by peracarids (especially isopods, amphipods, and mysids), but both abundance and species richness were not very representative. Crustaceans were practically absent on beaches with fine sediments, mainly in the western-western sector. Several authors, who reveal that crustaceans are common across all beach types and are usually dominant toward reflective beaches (Defeo et al., 1997; Mclachlan and Brown, 2006), have already, recognized this pattern of occurrence. The highest richness and abundance of amphipods was found mainly at the swash zone, as postulated by Degraer et al. (2003).

The absence of the *Emerita portoricensis* in the samples of the 12 studied beaches reveals a marked decrease of its occurrence on the coast of Ceará. This sand crab was common in high abundances on beaches of Ceará, being exploited and consumed by fishing communities (personal observation). This species was frequent at the swash zone of Futuro beach (Rocha-Barreira et al., 2001). Therefore, a more detailed study is necessary to clarify the spatial distribution of this species and the causes of a possible population decline on the coast of Ceará.

Relationship between physical environment and benthic macrofauna

Considering the physical environment and the benthic macrofauna, two main patterns can be summarized for the sandy beaches of Ceará: (1) Beach Index (BI), slope, beach width and sand grain size were environmental variables contributed to the macrofauna composition and distribution; and (2) the species richness of benthic macrofauna had intermediate values compared to the tropical patterns,

The sandy beaches of Ceará show morphodynamic conditions very favorable to the establishment of benthic macrofauna. Most of the beaches exhibited a dissipative type, with beach index BI> 2.4; slope <0.04, extensive intertidal zone (Width> 77m), as visualized through Linktree analysis. This pattern explains the greater similarities of macrofauna composition between dissipative beaches. Species richness increases in response to increasing tide range, increasing wave energy, decreasing sand particle size, and in flatter and wider beaches, meaning an increase as beaches become more tide dominated and/or dissipative (McLachlan & Defeo, 2018). Therefore, on the dissipative and/or macromareal beaches, the more stable substrate also promotes the presence of small and sedentary animals buried, enriching the typical mobile fauna of sandy beaches. Such characteristics both increase habitat complexity and species interaction.

The beach index is suggested in this study as the best in explaining macrofauna patterns in the coast of Ceará. This morphodynamic index was highlighted by the Linktree analysis to explain the macrofauna grouping, with the slope and width of the beach being also environmental variables important for the establishment of macrofauna. Brazeiro (2001) suggests that the changes in swash climate covary with changes in grain size and erosion-accretion dynamics, and given that cause-effect pathways between these factors and biological processes of the beach macrofauna. This author suggests the 'multicausal environmental severity' hypothesis, which proposes that the sum of the independent effects at least these three physical variables affect in the macrofauna distribution along the morphodynamic gradient.

Defeo and Mclachlan (2013) compiled information from more than 200 sandy beaches around the world and explore latitudinal trends in species richness, abundance and biomass. The authors have shown that tides (i.e. tide range) explain the major part of these global patterns in species richness. As the most studies to be based in regions with similar tide range, the effect of the tide in the macrofauna establishment has largely been ignored by previous workers. The increasing tide range widens to beach and also moves different hydrodynamic zones (swash, surfing and shoaling waves) across the intertidal profile, thus reducing the amount of time waves can rework to given portion of the beach (Masselink, 1993) and inhibit the formation of nearshore bar morphology (Jackson et al., 2002). This study was not displayed the differential effect of the tides on the macrofauna, however its important role on the morphodynamics is evident. These results confirm the use of the RTR parameter in the definition of the types of sandy beaches in Ceará. Once the regular tidal variations determine the duration of air exposure intertidal zone, they define abiotic stress related to temperature, drying, insolation and salinity (Valdivia et al. 2011) for which benthic macrofauna must have adaptations.

Defeo and McLachlan (2013) pointed out the need to gather additional information in the tropical region, where many studies have been deficient in coverage of macrofauna estimates and physical characteristics of the environment.

The sandy beaches of Ceará, due to low declivity, dissipative conditions, high tidal amplitude and high genetic pool, would be very favorable to the establishment of several species of benthic macrofauna. Several authors (Mclachlan & Dorvlo, 2005; 2007; Mclachlan & Defeo, 2013) have proposed such favoritism for the biota in sandy beaches, however, the results showed a species richness from moderate to low.

This study considered a maximum sampling area of 2.5 m^2 per beach studied. According to Jaramillo et al. (1995), sampling areas of 2% resulted in average 80% of the species present on the beach. The authors further claim that the total area needed to be sampled in macrofauna surveys to estimates of species richness depends on the beach type and tide range. Thus, macrotidal beaches, because they harbor more species, require a sampling effort of at least 5 m^2.

However, in practical terms, the sampling strategy on tropical meso and macrotidal beaches is different from temperate microtidal beaches. There is a limitation in field sampling time, which hinders a larger sample size to be collected. Another obstacle is that as tropical invertebrates tend to have a smaller body size (Mclachlan & Dorvlo, 2005), and therefore a 0.5 mm mesh is used for the separation of organisms from sediment, unlike 1mm mesh used on temperate beaches. The use of a smaller mesh causes a greater amount of sand also retained, which must be transported and sorted in the laboratory, increasing the time spent for macrofauna analysis.

Schooler et al. (2014) suggested the use of extrapolative species richness estimators to address these issues in comparing species richness results from two sampling designs that differed in area sampled for intertidal macroinvertebrates on exposed sandy beaches. Schoeman et al. (2008) demonstrate that the conventionally used S_{obs} (observed species richness) is statistically a poor (inaccurate) estimator of species richness, with the Jackknife1 estimator being the best estimator among all the estimators tested. Foggo et al. (2003) stated that in situations where sample effort was limited and to estimate regional diversity, Chao1 was the best estimator. Thus, as the species richness observed is almost always underestimated, and since it is not always possible to increase the sample effort, the use of extrapolation techniques has allowed a greater accuracy in the true species richness at regional scales (Foggo et al. 2003), as well as the sample size (Schoeman et al., 2008).

Although the sandy beaches of Ceará would be very favorable to the establishment of several species of benthic macrofauna, the species richness was low. The intertidal macrofauna of tropical regions is under great stress daily, being subjected very high variations in temperature and salinity. In the case of the beaches of Ceará, the diurnal spring tides occur around 10h-14h, exposing intertidal animals to extremes of temperature and insolation. Salinity may vary from zero during the rainy season to

40 after evaporation at low tide. Such conditions of intense semi-arid tropical heat, especially during tide variation, may limit the faunistic diversity.

In conclusion, we verified that the species richness of the sandy beaches of Ceará is physically controlled by easily recognized abiotic factors, such as grain size and slope. However, sandy beaches are highly variable and unique environments, so looking for a large scale pattern is challenging, since several factors are involved from the natural variability and the anthropogenic effects on the beaches to sampling difficulties and macrofauna estimates.

REFERENCES

ALBUQUERQUE, M. G et.al. **Morfodinâmica da Praia do Futuro, Fortaleza-CE: uma sintese de dois anos de estudo.** Quaternary and Environmental Geosciences, v. 01, n. 2, p. 49-57, 2009.

ALVES, M. A. M. S.; EL-ROBRINI, M. **Morphodynamics of a Macrotidal Beach: Ajuruteua, Bragança North Brazil.** Journal of Coastal Research, v. SI 39, p. 949-951, 2004.

ARAÚJO, P. H. V.; ROCHA-BARREIRA, C. A. **Population dynamic and secondary production of *Olivella minuta* (Gastropoda: Olividae) on Sandy Beach in Northeastern Brazil.** Sociedad Malacológica de Chile (SMACH): Amici Molluscarum, v. 20, n. 1, p. 7-15, 2012.

BARROS, F.; BORZONE, C. A.; ROSSO, S. **Macroinfauna of Six Beaches near Guaratuba Bay, Southern Brazil.** Brazilian Archives of Biology and Technology, v. 44, n. 4, p. 351-364, 2001.

BARROSO, C. X. et al. **An extended geographical distribution of *Donax gemmula* Morrison, 1971 (Bivalvia: Donacidae): new record from the Brazilian Northeastern coast**. Check List, v. 9, n. 5, p. 1087-1090, 2013.

BENSI, M.; MARINHO, R. A.; MAIA, L. P. **Clima de ondas e sua implicação com a erosão costeira ao longo do Estado do Ceará.** Congresso de Engenharia de Pesca. Fortaleza, CE: CONBEP: 802-815 p. 2005.

BORZONE, C. A.; SOUZA, J. R. B.; SOARES, A. G**. Morphodynamic influence on the structure of inter and subtidal macrofaunal communities of subtropical sandy beaches.** Revista Chilena de Historia Natural, v. 69, p. 565-577, 1996.

BRANCO, M. P. N. C. et al. **Morfodinâmica das Praias Arenosas à Barlamar e à Sotamar do Promontório Ponta do Iguape – Estado do Ceará - Brasil.** Revista de Geologia, v. 18, n. 2, p. 215-229, 2005.

BRAZEIRO, A. **Relationship between species richness and morphodynamics in sandy beaches: what are the underlying factors?** Marine Ecology-Progress Series, v. 224, p. 35-44, 2001. ISSN 0171-8630. Disponível em: < <Go to ISI>://000173683900003 >.

CARVALHO, A. M. et al. **Eolianitos de Flecheiras/Mundaú, Costa Noroeste do Estado do Ceará, Brasil - Registro ímpar de uma paleo-sistema eólico costeiro.** In: WINGER, M. *et al* (Ed.). Sítios Geológicos e Paleontológicos do Brasil. Brasília: CPRM, v.2, 2008. p. 121-130.

CLARKE, K. R.; AINSWORTH, M. **A method of linking multivariate community structure to environmental variables.** Marine Ecology-Progress Series, v. 92, p. 205-205, 1993.

CLARKE, K. R.; GORLEY, R. N. **PRIMER v6: user manual/tutorial computer program**. 2006.

DEFEO, O. et al. **Is Sandy Beach Macrofauna Only Physically Controlled? Role of Substrate and Competition in Isopods.** Estuarine, Coastal and Shelf Science**,** v. 45, p. 453-462, 1997.

DEFEO, O.; MCLACHLAN, A. **Patterns, processes and regulatory mechanisms in sandy beach macrofauna: a multi-scale analysis**. Marine Ecology-Progress Series, v. 295, p. 1-20, 2005. ISSN 0171-8630. Disponível em: < <Go to ISI>://000230671800001 >.

DEFEO, O.; MCLACHLAN, A. **Global patterns in sandy beach macrofauna: Species richness, abundance, biomass and body size**. Geomorphology, v. 199, p. 106-114, 2013.

DEFEO, O.; LERCARI, D.; GOMEZ, J. **The role of morphodynamics in structuring sandy beach populations and communities: what should be expected?** Journal of Coastal Research, p. 352-362, 2003.

DEGRAER, S.; VOLCKAERT, A.; VINCX, M. **Macrobenthic zonation patterns along a morphodynamical continuum of macrotidal, low tide bar/rip and ultra-dissipative sandy beaches.** Estuarine, Coastal and Shelf Science, v. 56, n. 3-4, p. 459-468, 2003. ISSN 02727714.

DEXTER, D. M. **Sandy beach community structure: the role of exposure and latitude**. Journal of Biogeography, v. 19, p. 59-66, 1992.

DIAS, I. C. C. M.; ROCHA-BARREIRA, C. A. **Morphodynamic Behavior of Taíba Beach, Northeast Brazil.** Journal of Integrated Coastal Zone Management, v. 11, n. 4, p. 421-431, 2011.

FOGGO, A. et al. **Estimating marine species richness: an evaluation of six extrapolative techniques**. Marine Ecolgy Progress Series, v. 248, p. 15-26, 2003.

FOLK, R. L.; WARD, W. C. **Brazos river bar: a study of significante of grain size parameters.** J. Sediment. Petrol., v. 27, p. 3-26, 1957.

IPECE- Instituto de pesquisa e estrategia econômica do Ceará. **Ceará em números 2013**. http://www.ipece.ce.gov.br/categoria5/ceará-em-numeros. Accessed 10 Nov 2013.

JACKSON, Nancy L. et al. **'Low energy' sandy beaches in marine and estuarine environments: a review.** Geomorphology, v. 48, n. 1-3, p. 147-162, 2002.

JARAMILLO, E.; MCLACHLAN, A.; DUGAN, J. **Total sample area and estimates of species richness in exposed sandy beaches.** Marine Ecolgy Progress Series, v. 119, p. 311-314, 1995.

MAIA, L. P. **Procesos costeros y balance sedimentario a lo largo de Fortaleza (NE- Brasil): Implicaciones para una gestión adecuada de la zona litoral.** 1998. 256 (Tese de Doutorado). Universidade de Barcelona, Barcelona.

MASSELINK, G.; SHORT, A. D. **The Effect of Tide Range on Beach Morphodynamics Morphology: A Conceptual Beach Model.** Journal of Coastal Research, v. 9, n. 3, p. 785-800, 1993.

MCLACHLAN, A.; DEFEO, O. **Coastal beach ecosystems**. Encyclopedia of biodiversity, v. 1, p. 741-751, 2001.

MCLACHLAN, Anton; DEFEO, Omar. **The ecology of sandy shores**. Academic Press, 2018.

MCLACHLAN, A.; DORVLO, A. **Global Patterns in Sandy Beach Macrobenthic Communities.** Journal of Coastal Research, v. 214, p. 674-687, 2005. ISSN 0749-02081551-5036.

MCLACHLAN, A.; DORVLO, A. **Species – area relationships for sandy beach macrobenthos in the context of intertidal width**. Oceanologia, v. 49, n. 1, p. 91-98, 2007.

MONTEIRO, M. C.; PEREIRA, L. C. C.; OLIVEIRA, M. O. **Morphodynamic Changes of a Macrotidal Sand Beach in the Brazilian Amazon Coast (Ajuruteua-Pará).** Journal of Coastal Research, v. SI 56, p. 103-107, 2009.

MORAIS, J. O. et al. Ceará. **Erosão e progradação do litoral brasileiro. Brasília: Ministério do Meio Ambiente**, p. 132-154, 2006.

MORAIS, J. O. et al. **Erosão Costeira em Praias Adjacentes às Desembocaduras Fluviais: O Caso de Pontal de Maceió, Ceará, Brasil**. Gestão Costeira Integrada, v. 8, n. 2, p. 61-76, 2008.

MORAIS, J. O. **Evolução sedimentar da enseada do Mucuripe.** Arq Cienc Mar, v. 21, p. 20-32, 1981.

MOURA, M. R. **Aspectos climáticos versus variação sazonal do perfil morfodinâmico das praias do litoral oeste de Aquiraz, Ceará, Brasil.** Revista Brasileira de Climatologia, v. 11, p. 208-222, 2012.

MUEHE, D. **Aspectos gerais da erosão costeira no Brasil.** Mercator, v. 4, n. 7, 2005.

PINHEIRO, L. S; MORAIS, J. O.; MAIA, L. P. **The beaches of Ceará**. In: Brazilian Beach Systems. Springer, Cham, 2016. p. 175-199.

QUEIROZ, L. R. **Variação espaço-temporal da biomassa macrofaunal bentônica da zona de varrido da praia do Cassino – RS, Brasil**. 2006. (Dissertação de mestrado). Pós-graduação em Oceanografia biológica, Fundação Universidade Federal do Rio Grande, Rio Grande.

ROCHA-BARREIRA, C. D. A.; MONTEIRO, D. O.; FRANKLIN-JUNIOR, W. **Macrofauna bentônica da faixa entremarés da praia do Futuro, Fortaleza, Ceará, Brasil.** Arquivos de Ciencias do Mar, v. 34, p. 23-38, 2001. ISSN 0374-5686.

ROCHA-BARREIRA, C. A. et al. **Levantamento da macroinfauna bentônica de ambientes inconsolidados do estado do Ceará: faixa entremarés de praias arenosas.** Programa Ecológico e Econômico da Zona Costeira do Estado do Ceará, p.144 p. 2005

RODIL, I. F.; COMPTON, T. J.; LASTRA, M. **Geographic variation in sandy beach macrofauna community and functional traits**. Estuarine, Coastal and Shelf Science, v. 150, p. 102-110, 2014.

SCHLACHER, T. A. et al. **Sandy beach ecosystems: key features, sampling issues, management challenges and climate change impacts.** Marine Ecology-an Evolutionary Perspective, v. 29, n. Suppl. 1, p. 70-90, Jul 2008. ISSN 0173-9565. Disponível em: < <Go to ISI>://000256446800010 >.

SCHOEMAN, D. S.; NEL, R.; SOARES, A. G. **Measuring species richness on sandy beach transects: extrapolative estimators and their implications for sampling effort.** Marine Ecology, v. 29, n. Suppl. 1, p. 134-149, 2008.

SCHOOLER, Nicholas K.; DUGAN, Jenifer E.; HUBBARD, David M. **Detecting change in intertidal species richness on sandy beaches: calibrating across sampling designs.** Estuarine, Coastal and Shelf Science, v. 150, p. 58-66, 2014.

SOARES, A. G. **Sandy beach morphodynamics and macrobenthis communities in temperate, subtropical and tropical regions - A macroecological approach**. 2003. 171 p. Ph.D. thesis, Faculty of Science, University of Port Elizabeth, South Africa.

SOUZA, J. R. B.; GIANUCA, N. M. **Zonation and seasonal variation of the intertidal macrofauna on a sandy beach of Parana State, Brazil.** Scientia Marina, v. 59, n. 2, p. 103-111, 1995.

STATSOFT, INC. **Statistica (data analysis software system)**, version 7. 2007. <www.statsoft.com>

VALDIVIA, N. et al**. Variation in Community Structure across Vertical Intertidal Stress Gradients: How Does It Compare with Horizontal Variation at Different Scales?** PLoS One, v. 6, n. 8, p. e2462, 2011.

VIANA, M. G.; ROCHA-BARREIRA, C. A.; GROSSI HIJO, C. A. **Macrofauna bentônica da faixa entremarés e zona de arrebentação da praia de Paracuru (Ceará-Brasil).** Brazilian Journal of Aquatic Science and Technology, v. 9, n. 1, p. 75-82, 2005.

WRIGHT, L. D.; SHORT, A. D. **Morphodynamic variability of surf zones and beaches: a synthesis.** Marine Geology, v. 56, p. 93-118, 1984.

SOBRE A ORGANIZADORA

FLÁVIA REBELO MOCHEL Possui graduação em Ciências Biológicas pela Universidade Federal do Rio de Janeiro, mestrado em Zoologia - Museu Nacional / UFRJ , doutorado em Geociências pela Universidade Federal Fluminense e pós doutorado em Wageningen University, Holanda, com Recuperação de Manguezais. Atualmente é professora associada do Departamento de Oceanografia e Limnologia da Universidade Federal do Maranhão, responsável pelo LAMA- Laboratório de Manguezais e fundadora/coordenadora do CERMANGUE- Centro de Recuperação de Manguezais na UFMA. Possui experiência na área de Ecologia e Oceanografia Biológica, com ênfase em Ecologia e Recuperação Ecológica de Manguezais e em Educação Ambiental e Oceanografia Social, com ênfase em Sustentabilidade de Ecossistemas, atuando em ensino, pesquisa e extensão, principalmente nos seguintes temas: manguezais, macrofauna bêntica, sensoriamento remoto, ecossistemas costeiros, interação natureza e sociedade, educação ambiental e produção de materiais lúdico-pedagógicos.

ÍNDICE REMISSIVO

N

O

P

R

S

T

U

V

Z

Agência Brasileira do ISBN
ISBN 978-85-7247-620-1
9 788572 476201