Intertidal benthic macrofauna of rare rocky fragments in the Amazon region

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Received 05-IV-2013. Corrected 03-X-2013. Accepted 06-XI-2013.

Abstract: Rock fragment fields are important habitat for biodiversity maintenance in coastal regions, particularly when located in protected areas dominated by soft sediments. Researches in this habitat have received surprisingly little attention on the Amazon Coast, despite rock fragments provide refuges, nursery grounds and food sources for a variety of benthic species. The present survey describes the mobile macroinvertebrate species composition and richness of the intertidal rocky fragments in Areuá Island within the “Mãe Grande de Curuçá” Marine Extractive Reserve (RESEX) on the Brazilian Amazon Coast. Samples were collected during the dry (August and November 2009) and rainy seasons (March and May 2010) on the upper and lower intertidal zone, using a 625cm² quadrat. At each season and intertidal zone, macroinvertebrate samples were collected along four transects (20m each) parallel to the waterline, and within each transect two quadrats were randomly sampled. Macroinvertebrates were identified, density determined, and biomass values obtained to characterize benthic diversity from the rocky fragments. The Jackknife procedure was used to estimate species richness from different intertidal zones during the dry and rainy seasons. Macrofaunal community comprised 85 taxa, with 17 “unique” taxa, 40 taxa were common to both intertidal zones and seasons, and 23 taxa have been recorded for the first time on the Brazilian Amazon Coast. Species richness was estimated at 106±9.7 taxa and results suggest that sampling effort was representative. Polychaeta was the most dominant in species number, followed by Malacostraca and Gastropoda. Regarding frequency of occurrence, Crustacean species *Dynamenella tropica*, *Parhyale* sp. and *Petrolisthes armatus* were the most frequent representing >75% of frequency of occurrence and 39 taxa were least frequent representing <5% of frequency of occurrence. Occurrence of crustaceans and polychaetes were particularly noteworthy in all intertidal zones and seasons, represented by 15 and 13 taxa, respectively. The most representative class in abundance and biomass was Malacostraca that represented more than half of all individuals sampled, and was dominated by *Petrolisthes armatus*. The latter was one of the most frequent, numerous and higher biomass species in the samples. In general, results indicated greater richness and biomass in the lower zone. Additionally, richness and density increase during the rainy season. Rock fragment fields in Areuá Island are rich in microhabitats and include a diverse array of species in a limited area. Our results underline the importance of rock fragment fields in Areuá Island for the maintenance of biodiversity in the Amazon Coast. Rev. Biol. Trop. 62 (1): 69-86. Epub 2014 March 01.

Key words: macroinvertebrates, biodiversity, rocky intertidal, conservation area, Amazon Coast, tropical region.

Rocky shorelines are commonly found worldwide, forming extensive coastlines or patches along the coast (Cruz-Motta et al., 2010). Organisms of several phyla responsible for the maintenance of ecosystem functioning dwell in this important environment (Little & Kitching, 2000; Menge & Branch, 2001), and many species (e.g. algae, mussels, oysters) can be of considerable social and economic value. Rocky shores are susceptible to many impacts, and have increasingly been the focus of research and monitoring programs for biodiversity conservation (Thompson, Crowe, & Hawkins, 2002).

Rock fragment fields (comprised of varying rock sizes) are considered as an intermediate environment between soft-sediment (e.g. sand or mud) and rocky substrate (e.g. rocky shores) (Lewis, 1964; Little & Kitching, 2000). These intermediate substrates generally provide three microhabitats: the upper and lower rock surfaces and the substrate below the rocks (Motta, Underwood, Chapman, & Rossi, 2003), creating a diverse microhabitat for the establishment of a large number of species that are rarely found in other habitats (Chapman, 2002a). Thus, such three-dimensionally complex system may function as island patches for many benthic organisms (Londono-Cruz & Tokeshi, 2007), and may promote coexistence of species from rocky and soft substrates, which lead to increasing richness and diversity in these heterogeneous environments (Cusson & Bourget, 1997).

The rocky fragments are uncommon fields compared with other rocky shorelines, but highly important to local diversity (Cruz-Motta, 2005; Le Hir & Hily, 2005; Motta et al., 2003). In tropical regions, there are more studies on the structure of macroinvertebrates from coastal soft shores than rocky ones (Alongi, 1989, 1990; Neves & Valentin, 2011), largelly because tropic shores are dominated by soft-sediment habitats. The Brazilian Amazon Coast (BAC) consists mainly of mangrove forests (Souza Filho, 2005), which are habitats dominated by soft sediments with muddy and sandy areas, and few patches of rocky formations (Franzinelli, 1982, 1990). In a review conducted by Rosa Filho & Lopes (2005), no study had described the benthic macroinvertebrate diversity on rocky fields in the BAC, and to the best of our knowledge, hitherto this lack of information continues.

Measuring species richness and diversity in various habitats is a useful tool for conservation action planning of the marine and coastal biodiversity (Amaral & Jablonski, 2005; Gray, 1997). Therefore, the present study describes the species richness and composition of macroinvertebrates from rare intertidal rocky fragment habitats in Areuá Island, Northeast of Pará State, located at the Marine Extractive Reserve (RESEX) "Mãe Grande de Curuçá" on the BAC. In addition, we provide a brief account of the taxa dominance and distributional data between intertidal zones and climate seasons.

MATERIALS AND METHODS

Study site: The study was carried out in Areuá Island (00º35'08.65" S - 47º50'51.97" W) located in the lower Curuçá River Estuary, within the "Mãe Grande de Curuçá" Marine Extractive Reserve in Curuçá City, Northeastern Pará State, on the Brazilian Amazon Coast (BAC). The region is under super-humid equatorial climate, with average temperature around 27ºC (SUDAM, 1984) and annual rainfall between 2 400mm and 3 330mm (Moraes, M.N. Costa, A.C.L. Costa, & M.H. Costa, 2005). There are two defined seasons: a rainy season typically from January to June, and a dry season from July to December, with annual averages of 1 657mm and 487mm, respectively (Moraes et al., 2005). Areuá Island extends over an area of 1.34km² with a variety of coastal habitats that are dominated by mangrove forests (mainly *Rhizophora mangle* and *Avicennia germinans*, and some patches of *Laguncularia racemosa*), sandy and muddy beaches, tidal flats, and a few patches of saltmarshes and rocky fragments. This region has a strong marine and freshwater influence with semi-diurnal tides showing largest spring amplitudes of more than 4m. The rock fragment fields are parallel to the shoreline and cover an area of *ca.* 0.25km². It is located approximately 170m from the minimum low water mark, and during high water spring tides, the fragments are completely immersed to a depth of *ca*. 1m. This habitat comprises mixed substrates of pebbles, cobbles and boulders, fragments of laterites, with fixed, semi-fixed or detached rocks in sandy-muddy substrate. Rocky fragments have bare surfaces often with algal or biofilm/detritus cover. Furthermore, surfaces are colonized by sessile (e.g. barnacles, anemones), sedentary (e.g. polychaetes, bivalves) and mobile fauna (e.g. crabs, amphipods, isopods, gastropods).

Data collection: Samples were collected on rocky fragments of the upper and lower intertidal zones during the dry (August and November 2009) and the rainy seasons (March and May 2010). On each month, four transects (20m each) parallel to the water line were randomly distributed on each intertidal zone examined. Along these transects, two quadrats of 25x25cm (625cm²) were randomly sampled with a distance of at least 1m between replicates. A total of 64 samples were collected. All mobile benthic organisms were collected manually at three microhabitats: the upper and lower surfaces of the rocks and in the sediment below down to 10cm deep whenever possible. The borders of the quadrats were enclosed by "tulle" cloth to avoid escaping organisms. Samples were sieved using a 0.5mm mesh-size sieve, stored in buffered 4% formalin solution in seawater and stained with Bengal Rose. Benthic samples were maintained in plastic bags and transported within plastic drums to the laboratory. Samples were transfer to 70% ethanol in the laboratory after sorting and benthic macroinvertebrates were identified to the lowest taxonomic level possible using specific identification keys for each taxa. Benthic organisms were counted and wet weights were obtained to estimate biomass on an analytical balance accurate to 0.0001g. Wet weight of gastropods and bivalves were obtained without shell, except for extreme small shell species. To estimate biomass: (1) all species from samples with <20% frequency of occurrence were weighted; and (2) at least 15% of replicates were weighted in species with >20% frequency of occurrence. The weight of the remaining samples was estimated from number of individuals. Classification and nomenclature were checked on identification keys (Blake, Hilbig, & Scott, 1995, 1996, 1997; Mugnai, Nessimian, & Baptista, 2010; Rios, 1994; Ruppert, Fox & Barnes, 2005) and taxonomic information available on-line, from the World Register of Marine Species (WoRMS-http://www.marinespecies.org), and the Index to Organism Names (ION- http://www.organismnames.com). All reported species were deposited in the Crustacean and Malacofauna Collection at the Museu de Zoologia da Universidade de São Paulo (MZUSP) and the Invertebrate Collection at the Museu Paraense Emílio Goeldi (MPEG). The Brazilian Environmental Protection Institute (IBAMA) supplied the collecting permits (n° 16346-3, 16346-4 and 16346-5).

Due to limited description available for the species in the region, benthic macroinvertebrates were classified as morphospecies when species-level identification was not possible. Nevertheless, morphological distinctions were well-defined and hereafter will be treated as taxa. Characterizations of the benthic macroinvertebrate assemblages in relation to intertidal level and sampling period were carried out using taxa richness, density, biomass and taxa dominance. The Jackknife richness estimate was obtained by the Ecological Methodology Program (Kenney & Krebs, 2000): $\hat{S}=S_{obs}+k(n\text{-}1/n)$, where $\boldsymbol{S_{obs}}$ is the observed total number of species present in **n** quadrats; **k** is the number of unique species (species found only once) and **n** is total number of quadrats sampled (Krebs, 1999). Jackknife is one of the best richness estimator, with good prediction of less biased estimates for small number of samples (Colwell & Coddington, 1994). The results of these estimates were expressed with 95% Confidence Interval: $\hat{S}\pm CI$. Taxa richness, abundance and biomass of benthic macroinvertebrates were analysed using a three-factor mixed model ANOVA (Analysis of Variance) to test for differences among intertidal zones (2 levels, fixed and orthogonal), seasons (2 levels, fixed and orthogonal) and months (2 levels, random and nested within seasons). Homogeneity of variances was checked by means of Cochran's test and data were transformed when appropriate (Underwood, 1997). Additionally, Student-Newman-Keuls (SNK) tests were used for *a posteriori* comparison of the means, following the recommendations of Underwood (1997).

RESULTS

The present study recorded 4 Phyla, 7 Classes and 85 macroinvertebrates taxa on the rocky fragments in Areuá Island (Table 1). Richness among samples varied from 2 (Upper zone; August) to 35 (Lower zone; March) taxa. According to Jackknife estimates, 81% of the total richness (106±9.7 taxa) in the intertidal rocky fragments were sampled. The observed richness in the upper and lower tidal zones were lower than confidence limits for all months sampled (Fig. 1). Nonetheless, in the upper and lower zones at least 72% and 67% of the total richness estimated in each collecting period was sampled, respectively, indicating that sampling effort was representative.

TABLE 1
List of benthic macroinvertebrates species from rocky fragments in the Areuá Island, considering density and biomass in the intertidal zones (Low-L and Upper-U) and seasons (Dry-D and Rainy-R)

Taxonomic Group/Species	Mean Density (ind./m^2)/Mean Biomass (g/m^2)			
	LD	LR	UD	UR
Phylum Nemertea♠	7/0.0059	52/0.0769	3/0.0031	36/0.1629
Phylum Annelida				
Class Clitellata				
Subclass Oligochaeta				
Order Enchytraeida				
Enchytraeidae●♠	0/0	0/0	0/0	36/0.0039
Order Haplotaxida				
Tubificidae sp.1♠	0/0	8/0.0009	0/0	7/0.0008
Tubificidae sp.2 ●	0/0	0/0	0/0	2/0.0002
Class Polychaeta				
Subclass Aciculata				
Order Eunicida				
Family Dorvilleidae				
Pettiboneia sp. ●▲	0/0	6/0.0011	0/0	0/0
Family Eunicidae				
Marphysa sp. ●♠	0/0	2/0.0751	0/0	0/0
Family Lumbrineridae				
Lumbrineris sp. ●	0/0	1/0.0008	1/0.0008	0/0
Family Oenonidae				
Arabella sp.★●	1/0.0166	0/0	0/0	0/0
Order Phyllodocida				
Family Polynoidae				
Subfamily Polynoinae sp.A★●	0/0	1/0.0008	0/0	0/0
Chaetacanthus sp.▲♠	0/0	9/0.0068	0/0	0/0
Family Hesionidae				
Bonuania sp.●▲♠	0/0	8/0.0033	0/0	0/0
Family Nereididae				
Ceratonereis excisa (Grube, 1874) ▲♠	1/0.0051	108/0.0956	1/0.0009	1/0.0009
Laeonereis culveri (Webster, 1879) ♠	1/0.0002	4/0.0008	3/0.0006	6/0.0012
Alitta succinea (Leuckart, 1847)♠	2/0.0004	282/0.1556	1/0.0006	35/0.02
Nereis oligohalina (Rioja, 1946)♠	1/0.0014	186/0.2604	1/0.0014	17/0.0238
Nereis sp.	0/0	17/0.0131	0/0	0/0

TABLE 1 (Continued)

Taxonomic Group/Species	Mean Density (ind./m^2)/Mean Biomass (g/m^2)			
	LD	LR	UD	UR
Perinereis sp.●	0/0	1/0.0014	0/0	1/0.0014
Family Pilargidae				
Sigambra sp.★●	1/0.0001	0/0	0/0	0/0
Family Syllidae				
Syllidae sp.A★●	0/0	1/0.0003	0/0	0/0
Syllis sp.♠	22/0.0072	264/0.0565	19/0.0043	33/0.0074
Family Phyllodocidae				
Eulalia sp.♠	0/0	6/0.0026	0/0	0/0
Phyllodoce sp.▲♠	0/0	4/0.0018	0/0	0/0
Phyllodocidae sp.A●	2/0.0009	0/0	0/0	0/0
Family Glyceridae				
Hemipodia sp.●♠	4/0.0022	1/0.0006	1/0.0006	0/0
Subclass Canalipalpata				
Order Sabellida				
Family Sabellariidae				
Sabellaria wilsoni Lana & Gruet, 1989♠	976/1.7699	978/0.6648	51/0.0636	16/0.0199
Family Serpulidae				
Hydroides sp.●▲♠	0/0	5/0.0681	0/0	0/0
Order Spionida				
Family Magelonidae				
Magelona sp.♠	0/0	3/0.03	2/0.02	0/0
Family Spionidae				
Boccardiella sp.♠	3/0.0013	6/0.0025	0/0	0/0
Spionidae sp.A★●	0/0	3/0.0013	0/0	0/0
Family Trochochaetidae				
Trochochaeta sp.★●▲	0/0	1/0.0008	0/0	0/0
Order Terebellida				
Family Ampharetidae				
Isolda pulchella Müller in Grube, 1858♠	2/0.0013	15/0.0077	6/0.0038	7/0.0063
Family Terebellidae				
Loimia sp.▲♠	0/0	9/0.6557	0/0	0/0
Subclass Scolecida				
Family Capitellidae				
Capitella capitata (Fabricius, 1780)♠	7/0.0008	7/0.0008	34/0.0042	11/0.0006
Capitella ovincola Hartman, 1947▲♠	1/0.0001	4/0.0004	0/0	2/0.0002
Mediomastus sp.♠	4/0.0049	85/0.0212	2/0.0006	2/0.0006
Family Orbiniidae				
Scoloplos (*Leodamas*) sp.♠	0/0	6/0.0214	0/0	0/0
Phylum Mollusca				
Class Bivalvia				
Subclass Heterodonta				
Order Myoida				
Family Corbulidae				
Corbula sp.★●▲□♠	0/0	1/0.0226	0/0	0/0
Family Myidae				
Sphenia fragilis (H. Adams & A. Adams, 1854)□♠	3/0.0139	254/1.1492	2/0.0093	25/0.1446

TABLE 1 (Continued)

Taxonomic Group/Species	Mean Density (ind./m^2)/Mean Biomass (g/m^2)			
	LD	LR	UD	UR
Order Veneroida				
Family Tellinidae				
Macoma pseudomera Dall & Simpson, 1901●	1/0.0013	1/0.0013	0/0	0/0
Family Ungulinidae				
Diplodonta sp.●▲♠	0/0	8/0.6889	0/0	0/0
Family Veneridae				
Petricolaria serrata (Deshayes, 1853)●▲□♠	0/0	4/0.0482	0/0	0/0
Protothaca (*Leukoma*) *pectorina* (Lamarck, 1818)□♠	11/1.9668	21/2.5769	5/0.7765	4/1.0471
Subclass Pteriomorphia				
Order Mytiloida				
Family Mytilidae				
Mytella guyanensis (Lamarck, 1819)♠	1/0.0037	30/0.0992	1/0.0031	5/0.0069
Class Gastropoda				
Subclass Caenogastropoda				
Order Caenogastropoda				
Family Epitoniidae				
Epitonium sp.□♠	0/0	6/0.0601	0/0	4/0.0309
Order Littorinimorpha				
Family Littorinidae				
Littorina sp.♠	0/0	5/0.0086	0/0	16/0.0222
Order Neogastropoda				
Family Columbellidae				
Anachis obesa (Adams, 1845)□♠	16/0.5491	171/4.6033	1/0.0276	3/0.0827
Anachis sp.▲♠	7/0.1639	55/0.7918	1/0.0154	0/0
Family Fasciolariidae				
Leucozonia sp.▲♠	18/1.9462	12/0.6582	0/0	0/0
Family Melongenidae				
Pugilina morio (Linnaeus, 1758)★●	1/0.5474	0/0	0/0	0/0
Family Muricidae				
Stramonita haemastoma (Linnaeus, 1767)□♠	23/7.774	36/2.7501	0/0	1/0.1918
Thaisella trinitatensis (Guppy, 1869)□♠	10/4.1464	4/0.8402	10/1.5922	47/8.1098
Family Nassariidae				
Nassarius polygonatus (Lamarck, 1822)★●	0/0	0/0	1/0.0533	0/0
Family Turridae				
Pilsbryspira sp.●▲♠	2/0.1208	1/0.0734	0/0	0/0
Subclass Heterobranchia				
Order Heterostropha				
Family Pyramidellidae				
Pyramidellidae sp.A●♠	0/0	5/0.0455	0/0	0/0
Subclass Neritimorpha				
Order Cycloneritimorpha				
Family Neritidae				
Nerita fulgurans (Gmelin, 1791)●□♠	2/0.922	1/0.0321	1/0.4297	0/0
Neritina virginia (Linnaeus, 1758)□♠	3/0.3942	0/0	4/0.2171	8/0.4013
Subclass Vetigastropoda				
Order Archaeogastropoda				

TABLE 1 (Continued)

Taxonomic Group/Species	Mean Density (ind./m²)/Mean Biomass (g/m²)			
	LD	LR	UD	UR
Family Seguenziidae				
Seguenzia sp.▲♠	1/0.0028	0/0	0/0	3/0.0083
Phylum Arthropoda				
Subphylum Crustacea				
Class Malacostraca				
Subclass Eumalacostraca				
Order Decapoda				
Infraorder Caridea				
Family Alpheidae				
Alpheus cf. *chacei* Carvacho, 1979♠	1/0.0095	5/0.9529	1/0.1604	0/0
Family Palaemonidae				
Macrobrachium sp.★●	0/0	2/0.0789	0/0	0/0
Infraorder Anomura				
Family Diogenidae				
Clibanarius vittatus (Bosc, 1802)□♠	1/0.0094	23/6.4518	1/0.0094	3/0.4469
Family Porcellanidae				
Petrolisthes armatus (Gibbes, 1850)♠	324/25.5183	449/26.3004	126/3.1339	82/4.7959
Infraorder Brachyura				
Family Grapsidae				
Pachygrapsus gracilis (Saussure, 1858)□♠	3/0.3411	1/0.0003	10/0.9548	6/0.1994
Family Menippidae				
Menippe nodifrons Stimpson, 1859 ●♠	2/1.7775	2/15.5072	0/0	0/0
Family Panopeidae				
Hexapanopeus caribbaeus (Stimpson, 1871)♠	6/0.0134	139/0.4401	0/0	2/0.0063
Hexapanopeus cf. *paulensis* Rathbun, 1930 ●♠	0/0	6/0.0954	0/0	0/0
Panopeus americanus Saussure, 1857 □♠	17/25.9092	35/30.7664	5/4.0409	5/1.4404
Panopeus occidentalis Saussure, 1857 ●□♠	1/8.4525	0/0	0/0	2/11.9668
Family Portunidae				
Portunidae sp.A★●	1/0.0133	0/0	0/0	0/0
Infraorder Gebiidea				
Family Upogebiidae				
Upogebia sp.●□	2/0.0046	0/0	0/0	1/0.0023
Order Amphipoda				
Family Aoridae				
Grandidierella sp.▲♠	3/0.0008	49/0.0184	0/0	5/0.0019
Family Maeridae				
Elasmopus sp.▲♠	140/0.0441	228/0.0506	7/0.0018	11/0.0028
Family Melitidae				
Melita sp.●	0/0	2/0.0005	0/0	0/0
Family Hyalidae				
Apohyale media (Dana, 1853)★ ●▲	0/0	1/0.0005	0/0	0/0
Parhyale sp.▲♠	232/0.2074	149/0.1218	562/0.4119	1065/0.9692
Order Isopoda				
Family Munnidae				
Munnidae sp.A★●▲	0/0	0/0	4/0.0001	0/0
Family Anthuridae				

TABLE 1 (Continued)

Taxonomic Group/Species	Mean Density (ind./m²)/Mean Biomass (g/m²)			
	LD	LR	UD	UR
Anthuridae sp.A★●♠	0/0	0/0	0/0	2/0.0008
Superfamily Bopyroidea				
Bopyroidea sp.A★●	0/0	1/0.0002	0/0	0/0
Family Ligiidae				
Ligia sp.♠	24/0.0037	15/0.0096	2/0.0256	10/0.0104
Family Sphaeromatidae				
Cassidinidea fluminensis (Mane-Garzon, 1944)▲♠	83/0.0251	10/0.0021	480/0.0916	26/0.0046
Dynamenella tropica Loyola e Silva, 1960▲♠	342/0.0692	293/0.0564	547/0.1096	847/0.1628
Order Tanaidacea				
Tanaidacea sp.A♠	0/0	1/0.0004	5/0.0019	1/0.0004
Subphylum Hexapoda				
Class Collembola				
Collembola sp.A●♠				
Class Insecta	0/0	17/0.0145	0/0	0/0
Order Hymenoptera				
Larvae Hymenoptera★●	0/0	0/0	0/0	1/0.0002
Order Lepidoptera				
Larvae Lepidoptera★●	0/0	0/0	0/0	2/0.1457
Order Diptera				
Subfamily Orthocladiinae♠	1/0.0001	14/0.0015	0/0	6/0.0006

Letters indicate morphospecies within families and higher groups. (★) indicate species that were found in a single sample ("unique taxa"). (●) indicate species with < 5% frequency of occurrence. (▲) indicate new species recordings for the Pará Coast. (□) indicate specimen deposited at the Museu de Zoologia da Universidade de São Paulo. (♠) indicate specimen deposited at the Museu Paraense Emílio Goeldi.

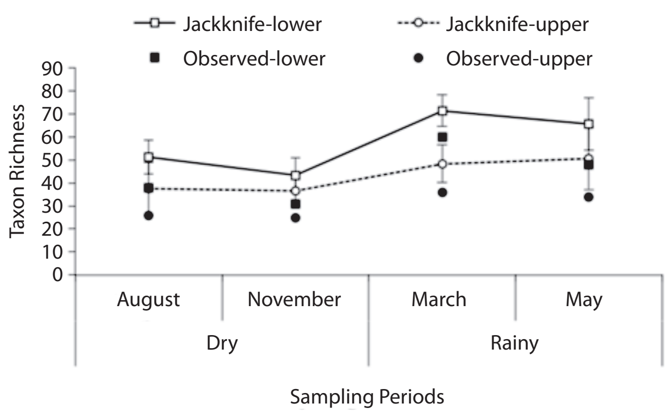

Fig. 1. Estimate taxon richness (Jackknife)±Confidence interval (95%) and Observed richness on the rocky fragments in Areuá Island during the sampling periods. The terms lower and upper refer to lower and upper intertidal zone, respectively.

Polychaeta was the most diverse class with 32 taxa, followed by Malacostraca and Gastropoda with 24 and 14 taxa, respectively. A total of 17 taxa were found only once among samples (Table 1). The taxa with highest occurrence frequency are shown in figure 3, and particularly high occurrences were observed in Crustacean taxa such as *Dynamenella tropica*, *Parhyale* sp. and *Petrolisthes armatus* that represented more than 75% in frequency of occurrence. The less frequent taxa, representing less than 5% frequency of occurrence, were 14 polychaetes, 11 crustaceans, 5 gastropods, 4 bivalves, 3 hexapoda and 2 oligochaetes (Table 1). In addition, 15 crustacean and 13 polychaete taxa occurred in both intertidal zones and seasons (Table 1).

The mean total abundance and biomass of benthic macroinvertebrates, respectively, was 2690±334ind./m² and 55.870±8.139g/m² during this study. The density and biomass by taxa between intertidal zone and sampling periods are shown in table 1. Malacostraca was the most abundant class in number of individuals corresponding to more than half of all individuals sampled (Fig. 2). Within Malacostraca, Isopoda, Amphipoda, Anomura and Brachyura represented 25%, 23%, 9% and 2%, respectively. Polychaeta was the second most abundant class (31%), followed by Gastropoda (4.5%) and Bivalvia (3.5%), with the remaining taxa adding only 1.5% (Fig. 2).

In total biomass, Malacostraca was also the most abundant (Fig. 2), with Brachyura, Anomura, Amphipoda and Caridea representing 45.5%, 30%, 0.8% and 0.5%, respectively. Gastropoda was the second most abundant class with 17% of total biomass, followed by Bivalvia (3.8%) and Polychaeta (2%), while the remaining taxa added only 0.3% (Fig. 2).

Some species were comprised of many individuals or few individuals with large biomass (Table 1), while others showed only a few individuals ("rarity of species", Table 1). *P. armatus* was one of the most representative in frequency (77% of all quadrats) (Fig. 3) and dominant in abundance (ranging from 16 to 1 600ind./m²) and biomass (ranging from 0.15 to 117.36g/m²). This species was found in all intertidal zones and sampling periods.

Besides *P. armatus*, only *Capitella capitata*, *Isolda pulchella*, *Syllis* sp., *D. tropica*, *Parhyale* sp., *Sphenia fragilis*, *Thaisella trinitatensis* and Nemertea were found in all intertidal zones and sampling periods (months). In addition, some taxa were unique for the specific rocky intertidal zone and/or season (Table 1) mainly in the lower zone during the rainy season (e.g. *Hydroides* sp., *Pettiboneia* sp., *Petricolaria serrata*, *Hexapanopeus* cf. *paulensis*, *Melita* sp. and other taxa). Furthermore, the unique taxa in the lower zone during the dry season were Portunidae, *Pugilina morio*, *Arabella* sp. and Phyllodocidae sp.A. Besides,

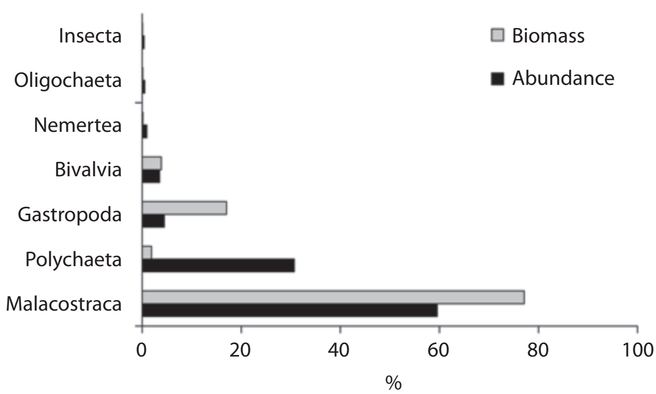

Fig. 2. Abundance and biomass (%) of macrozoobenthos taxonomic groups in the Areuá Island on rocky fragments sampled between August 2009 and May 2010. Total abundance was 10 762 individuals and total biomass was 223.32g.

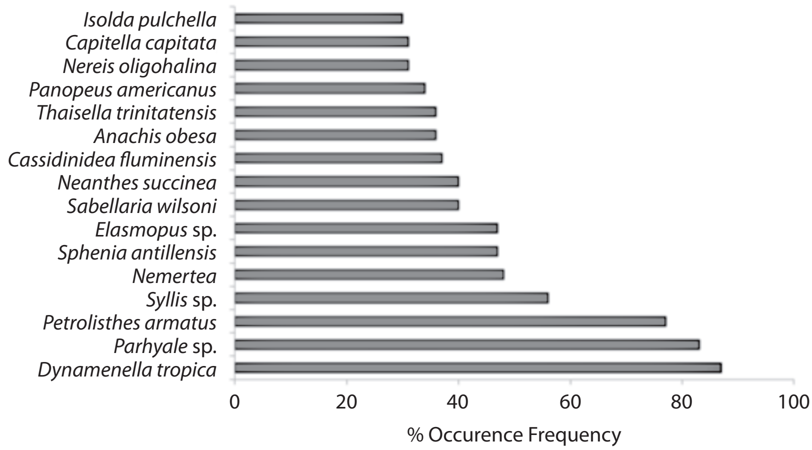

Fig. 3. Occurrence frequency (%) of macrozoobenthos in the Areuá Island on rocky fragments sampled between August 2009 and May 2010. N=64 samples.

in the upper zone during rainy season, *Nassarius polygonatus* and Munnidae were common; and in the upper zone during dry season larvae Lepidoptera, larvae Hymenoptera, Anthuridae, Enchytraeidae and Tubificidae sp.2 were found.

Taxa richness and biomass of macroinvertebrates differed between intertidal zones (Table 2) and in general, richness and biomass on the lower zone was higher (Fig. 4A, C; SNK: $p<0.05$). In addition, there was a significantly higher taxa richness and density on March than on May during the rainy season (Fig. 4A-B, SNK: $p<0.01$).

DISCUSSION

Our results show that areas of rock fragments in Areuá Island can be considered of high conservation priority for the BAC as they represent habitats for several macroinvertebrate species. It is likely that the area has endemic species, but expertise of the

TABLE 2
Analysis of variance on the effects of Zone (Zo, fixed and orthogonal), Season (Se, fixed and orthogonal) and Month (Mo, random and nested within Season) to taxa richness, total density and total biomass of benthic macroinvertebrates from rocky fragments in the Areuá Island

Source of Variation	df	Richness		Density		Biomass	
		MS	*F*	MS	*F*	MS	*F*
Zone	1	4.14	26.73*	1064.8	1.74	75581.7	19.62*
Season	1	4.93	6.29	2044.6	0.94	4310.4	0.66
Month (Season)	2	0.78	4.99**	2173.4	5.45**	6540.0	2.2
ZoXSe	1	0.42	2.75	213.1	0.35	35.1	0.01
ZoXMo(Se)	2	0.15	0.99	610.4	1.53	3851.7	1.3
RES	56	0.15		398.6		2972.1	
Transformation		Ln(x+1)		Sqrt(x+1)		No	
Cochran's test		ns		ns		ns	

*p<0.05; **p<0.01; ns=Not significant.

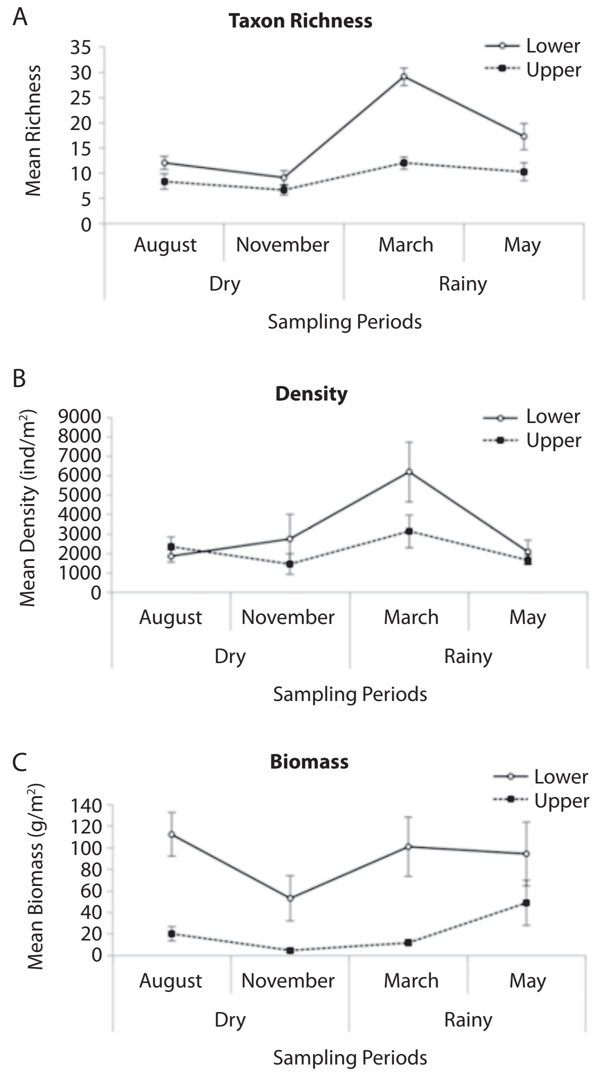

Fig. 4. Means (±SE) of density (A), biomass (B) and taxa richness (C) on the lower and upper zones from intertidal rocky fragments on Areuá Island during sampling periods.

species-level identification and more studies on description for benthic species in the region are necessary. The number of species in the present study is likely underestimated as taxonomic identification to species level is a common problem to researches on marine invertebrates (more details in Amaral & Jablonski, 2005). Many taxonomic groups were classified as morphospecies, showing a large representation of different taxa for rocky fragments in Areuá Island.

The complex three-dimensional structure of rocky fragments supplies shelter, refuge, and enhances feeding and reproduction (Cruz-Motta, 2005; Le Hir & Hily, 2005). In addition, it favours high taxon richness and the occurrence of different taxonomic groups that directly influence the biodiversity patterns.

As a result, the functioning and regulation of ecological process in the ecosystem may be affected (Lanari & Coutinho, 2010; Srivastava & Vellend, 2005).

Thus, the taxonomic dominance of Polychaeta and Crustacea in the present study is similar to rocky fragments from other coastal regions worldwide, although in some temperate regions (Canada, Ireland and Chile) and Jervis Bay-Australia, Mollusca was the most diverse and dominant phylum. Differences may be related to different environmental conditions on macrofaunal assemblage's composition and taxonomic richness or substrate type sampled. In rocky habitats, dominance in abundance and/or biomass by Malacostraca, Polychaeta and Gastropoda (Chapman, 2002b; Motta et al., 2003) is a common pattern. In the present study, Malacostraca dominated both abundance and biomass, and was comprised of small species that normally have a high number of individuals (e.g. amphipods and isopods) and large species that stood out in terms of biomass (e.g. crabs).

The dominance of Polychaeta and Crustacea is also very common to other habitats in the BAC (Table 3). This pattern may be partially attributed to the diverse feeding habits found in these taxonomic groups and the stress tolerance to natural environmental fluctuation in salinity, temperature and dissolved oxygen (Elliott & Quintino, 2007; Gray & Elliott, 2009) in the region. The tropical organisms have ecophysiological adaptability to salinity changes providing ontogenetic adaptation and distribution to the effects of salinity fluctuations in the environment (Chung, 2001). The diversity of food resources by constant input of detritus from mangrove ecosystems in the BAC is also important to the diversity and organisms coexistence (Lacerda et al., 2002).

The highest representativeness of the porcelain crab *P. armatus* in rock fragments is also common to others regions. In Marapanim River Estuary, located 24km East from the present study, *P. armatus* has been found in all intertidal zones and sampling periods, where density in excess of 3800ind./m² has been recorded (D.C. Silva, 2011). This species, as well as other Porcellanidae are found usually in high abundance on rocky fragments, living in dense aggregations under rocks and coexisting with other organisms in this habitat (Emparanza, 2007; Hollebone & Hay, 2007; Masunari & Dubiaski-Silva, 1998).

Several studies showed that biotic (e.g. competition and predation) or abiotic factors (e.g. desiccation tolerance and substrate complexity) have a strong influence in the spatial and temporal patterns of porcelain crabs (Emparanza, 2007; Hollebone & Hay, 2008; Jensen & Armstrong, 1991), amphipods and isopods (Ingolfsson & Agnarsson, 2003), and on the mobile macrobenthic diversity (Davidson, Crook, & Barnes, 2004a, 2004b; Takada, 1999). In rocky shores, richness, diversity and abundance are reduced towards the upper intertidal zone, which usually has species with greater desiccation tolerance (Davidson, 2005; Reicherti, Buchholz, Bartsch, Kersten, & Gimenez, 2008; Scrosati & Heaven, 2007). In the present study, similar tendencies were observed to richness and biomass of macroinvertebrates in rocky fragments on Areuá Island. However, while mean density was not significantly different between intertidal zones, many taxa showed highest density on the lower zone than the upper zone during dry and/or rainy season (e.g. *Anachis obesa*, *Elasmopus* sp., *Petrolisthes armatus*, *Sabellaria wilsoni*).

In addition, our results suggest a positive effect of rainy season on benthic invertebrate richness and density, when highest taxa numbers and density were observed, particularly on March. There were no differences in mean biomass within sampling seasons, but some taxa showed highest total biomass on the rainy season than on the dry season (e.g. *Alitta succinea*, *Nereis oligohalina*, *Clibanarius vittatus*, *Sphenia fragilis*). However, our data differ from those found on other habitats in the BAC. Benthic invertebrate richness was higher in the dry season on Ajuruteua sand beach and Caeté River Estuary (Rosa Filho, Almeida, & Aviz, 2009; Silva, Rosa Filho, S.R. Souza, & Souza Filho, 2011); and higher during the

TABLE 3
Total taxonomic richness observed in this study of the rocky fragments on Areuá Island and other habitats on the Brazilian Amazon Coast (BAC) and rocky shores of various coastal regions worldwide

Study Site	Taxonomic Richness	Organisms	Habitat type	Reference
Areuá Island - BAC	85	Mobile and sedentary macrobenthic	Rocky fragments	This study
São Caetano de Odivelas - BAC	31	Benthic macrofauna	*Rhizophora mangle* trunks	Aviz, Mello, & P.F. Silva, 2009
Algodoal Island - BAC	37	Macrofauna	Sand beach	Rosa Filho, Gomes, Almeida, & R.F. Silva, 2011
Canela Island, Bragança - BAC	46	Epifauna and Infauna	Saltmarsh and borders without any vegetated substrate	Braga et al., 2009
Ajuruteua, Bragança - BAC	43	Infauna	Sand beach	Rosa Filho et al., 2009
Caeté Estuary, Bragança - BAC	17	Infauna	Intertidal muddy bottoms	Rosa Filho, Busman, Viana, Gregório, & Oliveira, 2006
Caeté Estuary, Bragança - BAC	34	Infauna and Sessile epifauna	Mangrove forest	Beasley et al., 2010
Caeté Estuary, Bragança - BAC	29	Brachyuran Crabs	Mangrove forest, Creek, Beach, Mudflat and Saltmarsh	Diele, Koch, Abrunhosa, Farias Lima, & Simith, 2010
Caeté Estuary, Bragança - BAC	83	Macrofauna	Soft-bottom	Silva, Rosa Filho, S.R. Souza, & Souza Filho, 2011
Pará Coast - BAC	51	Macroinfauna	Saltmarsh	Braga, Monteiro, Rosa Filho, & Beasley, 2011
Rio de Janeiro Coast - Brazil	16	Epifauna and Flora	Breakwater	Masi & Zalmon, 2008; Masi, Macedo, & Zalmon, 2009a, 2009b
São Sebastião Channel, São Paulo - Brazil	96	Sessile invertebrates	Boulder fields	Rocha, 1995
São Sebastião Channel, São Paulo - Brazil	23	Molluscs	Rock fragments	Denadai, Amaral, & Turra, 2000
Farol Island, Matinhos, Paraná - Brazil	27	Decapod crustaceans	Boulder-Pebble fields	Masunari & Dubiaski-Silva, 1998
Straits of Magellan - Chile	42	Epifauna and Infauna	Boulder-cobble fields	Rios & Mutschke, 1999
Jervis Bay - Australia	85	Mobile molluscs and echinoderms	Boulder fields	Chapman, 2002b
Sydney - Australia	183	Infauna	Sediments below boulders	Motta et al., 2003; Cruz-Motta, 2005
Cuastecomate Bay - Mexico	49	Gastropods and Bivalves	Rocky beaches with solid blocks, boulders and pebbles	Esqueda, Rios-Jara, Michel-Morfin, & Landa-Jaime, 2000
St. Lawrence - Canada	26	Fauna	Boulder fields	McKindsey & Bourget, 2001
St. Lawrence - Canada	31	Macroalga and Epifauna	Boulder fields	Guichard & Bourget, 1998
Livorno - Italy	20	Epifauna	Artificial and natural rocks	Bulleri & Chapman, 2004
Iroise Man and Biosphere - France	103	Epifauna and Infauna	Boulder fields	Le Hir & Hily, 2005
Coast of Ireland	153	Mobile and sessile fauna	Boulder fields	Davidson et al., 2004a, 2004b; Davidson 2005
Arctic and Temperate North Atlantic fjords - Europe	117	Mobile and sessile epifauna	Boulder fields	Kuklinski, D.K.A. Barnes, & Taylor, 2006

transition between rainy and dry season on saltmarshes of Canela Island, off the Caeté River Estuary (Braga, Beasley, & Isaac, 2009). These differences may be associated to larval supply, recruitment and settlement processes (López & Coutinho, 2008; Schiel, 2004) which are largely influenced by different features of each habitat (e.g. oceanic circulation and coastal currents).

Rock fragments are considered habitats of high richness, abundance and endemism of benthic organisms and represent important habitats for coastal biodiversity conservation (Cusson & Bourget, 1997; Londono-Cruz & Tokeshi, 2007), comparable to oceanic islands that are susceptible to the extinction risks. The rock fragment areas in Brazil are still poorly known, in spite of their occurrence between Areuá Island-Curuçá-Northern Brazil (00º35'08.65" S - 47º50'51.97" W, present study) and Farol Island-Matinhos-Southeastern Brazil (25º50'55.13" S - 48º32'09.13" W). The scarce studies available focused generally on few specific groups (mainly epibenthic organisms) and complete macrobenthic diversity of rock fragments remains largely unknown.

The present study is the first record of benthic assemblages on rocky substrate in the BAC. This research also represents an important contribution for understanding global patterns of macroinvertebrates diversity of rock fragments. Although the rocky fragments in Areuá Island are an uncommon habitat on the BAC, this survey recorded high taxonomic diversity, which highlights the importance of this habitat for maintenance and conservation of coastal biodiversity. The Areuá Island is located in the Mãe Grande Extractive Reserve created in 2002 which continues to have no management plan, an indispensable tool for the sustainable use and conservation of natural resources. This study will, therefore, provide relevant baseline information for the design and creation of a future monitoring program in the region.

ACKNOWLEDGMENTS

The authors thank the Brazilian National Research Council (CNPq) for a grant to G. C. Morais (Master Scholarship, Process nº: 132420/2009-0). This work received financial support from the Fundação de Amparo à Pesquisa do Estado do Pará (FAPESPA, Project nº: 137/2008 – Universal). The authors would like to thank researchers for helping with species identification: Marcos Tavares, Gustavo Melo and Luis Simone (MZUSP); José S. Rosa Filho, Daiane E. Aviz, Roseanne F. Silva e Allan J. Jesus (UFPA); Cleverson R. M. Santos (MPEG); and Jesser F. Souza Filho (UFPE). We are grateful to A. M. Magalhães, A. Nagata, C. Silvestre, C. Lobato, E. Monteiro, J. B. Almeida, J. Galvão, P. Vilela, R. Bastos, R. R. Oliveira and S. Cayres for field and laboratory assistance. We also thank two anonymous reviewers and the editor for helpful comments on our manuscript.

RESUMEN

Macrofauna bentónica intermareal de los fragmentos rocosos raros en la región Amazónica. Los fragmentos rocosos comprenden un hábitat importante para el mantenimiento de la biodiversidad en las regiones costeras, particularmente cuando estos se encuentran en áreas protegidas dominadas por sedimentos blandos. A pesar de que los fragmentos rocosos proporcionan refugio, zonas de crianza y fuentes de alimento para una gran variedad de especies bentónicas, las investigaciones sobre este hábitat en la costa de la Amazonia han recibido poca atención. El presente estudio describe la composición de macroinvertebrados vágiles y la riqueza de especies en los fragmentos rocosos del intermareal de la isla Areuá en la Reserva Marina Extractiva (RESEX) "Mãe Grande de Curuçá", en la costa brasileña de la Amazonia. Las muestras fueron recolectadas durante la estación seca (agosto y noviembre 2009) y de lluvias (marzo y mayo 2010) en dos zonas del intermareal (superior e inferior), con un cuadrante de 625cm². En cada zona del intermareal y por temporada se tomaron muestras de macroinvertebrados a lo largo de cuatro transectos (20m cada uno) dispuestos paralelamente a la línea de costa. Dos cuadrantes se muestrearon al azar dentro de cada transecto. Los macroinvertebrados recolectados fueron identificados y se determinó la densidad y

la biomasa de organismos para caracterizar la diversidad bentónica de los fragmentos rocosos. La riqueza de especies de las dos zonas del intermareal durante las estaciones seca y de lluvias se estimó por el método de Jackknife. La comunidad de macroinvertebrados estuvo compuesta por 85 taxones, con 17 taxones "único", 40 taxones fueron comunes para ambas zonas del intermareal y temporadas, y 23 taxones se reportaron por primera vez para la costa brasileña de la Amazonia. La riqueza de especies se estimó en 106±9.7 taxones, por lo que los resultados sugieren que el esfuerzo de muestreo fue representativo. La Clase Polychaeta dominó en número de especies, seguida por Malacostraca y Gasteropoda. Los crustaceos *Dynamenella tropica*, *Parhyale* sp. y *Petrolisthes armatus* fueron las más frecuentes, con una frecuencia de presencia >75% mientras que 39 taxones fueron los menos comunes, con una frecuencia de presencia <5%. La presencia de crustáceos y poliquetos fue particularmente notable en las dos zonas y temporadas, incluyeron 15 y 13 taxones, respectivamente. La Clase Malacostraca fue la más conspicua en términos de abundancia y biomasa, representó más de la mitad de todos los individuos recolectados, con dominio de *Petrolisthes armatus*. Esta especie fue una de las más numerosas, frecuentes y de mayor biomasa en las muestras. En general, los resultados indican que hay una mayor riqueza y biomasa en el intermareal inferior mientras que la riqueza y la densidad aumentan en la estación lluviosa. Los sectores con fragmentos rocosos en la isla Areuá son ricos en microhábitats e incluyen una gran variedad de especies en un área limitada. Nuestros resultados enfatizan la importancia de los sectores con fragmentos rocosos en la isla Areuá para el mantenimiento de la biodiversidad en la costa de la Amazonia.

Palabras clave: macroinvertebrados, biodiversidad, intermareal rocoso, área de conservación, costa Amazónica, región tropical.

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