Composition and spatial distribution of subtidal Decapoda on the "Reef Coast", northeastern Brazil, evaluated through a low-impact visual census technique

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Abstract

This study investigated the composition and spatial distribution of the sublittoral decapods on the reefs of Porto de Galinhas Beach, southern coast of Pernambuco, Brazil, through the Underwater Visual Census technique. Data were collected monthly, at night during full-moon tides in low tide periods from June 2004 to May 2005, using SCUBA diving and a visual census with a fixed belt transect (20 m long). Three sampling areas were defined: Confined Waters (low hydrodynamics) with shallow sites (up to 2.5 m deep); Semi-open Water (3 to 6 m deep), influenced by waves and tidal currents (moderate hydrodynamics); and Open Water (7 to 10 m deep), in the breaker zone (high hydrodynamics). A total of 6,287 individuals of 34 species belonging to the infraorders Brachyura (19 species), Achelata and Anomura (5 species each), Caridea (3 species), and Stenopodidea and Astacidea (1 species each) were collected. Two decapod assemblages were distinguished: in a habitat with low hydrodynamics and shallow (Confined) water; and in a habitat with moderate to high hydrodynamics and depths of 3 to 10 m (Semi-open and Open water). At the sites with high hydrodynamics, i.e., the Open-water Area in the breaker zone, decapod diversity was significantly lower than in the other, protected areas on the reef bench. These results suggest that the distribution of subtidal decapods on coastal reefs is influenced by depth and exposure to water stress caused by waves and currents (hydrodynamics). The visual census technique with SCUBA proved to be suitable for ecological studies on subtidal decapods.

Key Words: decapods, ecology, reef fauna, SCUBA diver, visual census.

Introduction

Among marine ecosystems, coral reefs show the highest known diversity of species (Dubinsky and Stambler, 2011; Huang *et al.*, 2011). Brazil has the only coral reefs in the South Atlantic, and one of the best-developed reef communities is the coastal reefs of northeastern Brazil (Leão *et al.*, 2003). Described by Laborel (1970) as the "Côte des Arrecifes" or Reef Coast, these reefs are the main coral formations between 8°S and 9°S and have a distinct morphology (Dominguez *et al.,* 1990; Maida and Ferreira, 1997). The reefs are formed by rows of sandstone, generally parallel to the coast, which serve as a substrate for seaweeds and corals (Manso *et al.*, 2003). The corals grow on the sandstone line, upward (toward light) to the upper limit of the subtidal zone (often protruding from the water) and expand laterally from the top, forming densely aggregated structures and an interconnected cave system beneath the reef surface. The depth of the reef structures rarely exceeds 10 m (Laborel, 1970; Dominguez *et al.,* 1990; Maida and Ferreira, 1997). Similarly to reefs elsewhere, in Brazil these habitat is subject to intense anthropogenic pressure, aggravated by their proximity to shore (Castro and Pires, 2001; Feitosa *et al.,* 2002; Fernandes *et al.,* 2005; Barradas *et al.*, 2010; Sarmento *et al.*, 2011).

On hard bottoms such as coral reefs, the decapod crustaceans are one of the most important groups of benthic macrofauna (Abele, 1974; 1976; Abele and Patton, 1976; Martínez-Iglesias and García-Raso, 1999; Alves *et al.,* 2006). They range from inconspicuous to large forms, including shrimps, lobsters and crabs, and are distinguished by their high diversity and their importance in fisheries and trophic dynamics in these environments (Randall, 1967; Dubinsky and Stambler, 2011). The number of studies of diversity and distribution patterns of decapods on coral reefs is still relatively low, probably because these crustaceans have cryptic habits and live hidden during the day in burrows, crevices and caves (Barreto and Katsuragawa, 2008; Igarashi, 2010; Dubinsky and Stambler, 2011), limiting collection and observation.

The Underwater Visual Census (UVC) is a direct sampling technique with low impact, which has been used in several ecological and behavioral studies on marine communities (Willis, 2001; Hill and Wilkinson, 2004; Bakus, 2007; Vanderklift *et al.,* 2007; Seytre and Francour, 2008; Denitto *et al.,* 2009; Mellin *et al.,* 2009; Oliveira *et al.,* 2011), mainly in protected and fragile areas such as coral-reef environments (Edmunds *et al.,* 2005; Marshall and Schuttenberg, 2006; Wilson *et al.,* 2007; Dubinsky and Stambler, 2011).

This study investigated the composition and spatial distribution of the sublittoral decapods on the coastal reef of Porto de Galinhas Beach, northeastern Brazil, one of the main formations of the Reef Coast. The study was conducted by means of the Underwater Visual Census technique, and included areas with different depths and hydrodynamics.

Material and Methods

Study area

The study was carried out on the coral reefs of Porto de Galinhas (8°30’07” – 8°30’54”S and 35°00’08” – 34°59’47”W) (Fig. 1). These reefs have the typical characteristics described for the Reef Coast (Laborel, 1970; Dominguez *et al.*, 1990; Maida and Ferreira, 1997) (Fig. 1), and are one of the main tourist attractions on the Brazilian coast (MMA/SECTMA/CPRH, 2003). The Porto de Galinhas reef bench is in direct contact with the shore, which mixes beach and reef ecosystems during low tide when the reef bench emerges, exposing the intertidal zone. The outcropping reef acts as a barrier to the waves breaking in the outer areas. During low tide, the emerged reef bench forms the three areas sampled in this study: A) Confined Water (pools protected by the reefs); B) Semi-open Water (channels crossing the reef bench); and C) Open Water (in the breaker areas) (Fig. 2).

The Confined Waters area (A) is close to the beach and shallow (to 2.5 m deep), and has almost no current and waves (hydrodynamics). This area is exposed to weak currents and waves only during high tide and neap tides (Fig. 2).

The Semi-open Waters area (B) is mainly in the channels connecting the open sea with the protected water inside the reef bench. With depths between 3 to 6 m, this area is influenced by waves and tidal currents (moderate hydrodynamics). During neap high tide, the current is strong and the area is subject to indirect wave influence (Fig. 2).

The Open Water area (C) is in the outer areas of the reef bench, exactly in the breaking-wave zone. Around 7 to 10 m deep, this area shows strong hydrodynamics during both spring and neap tides, and at high and low tide (Fig. 2).

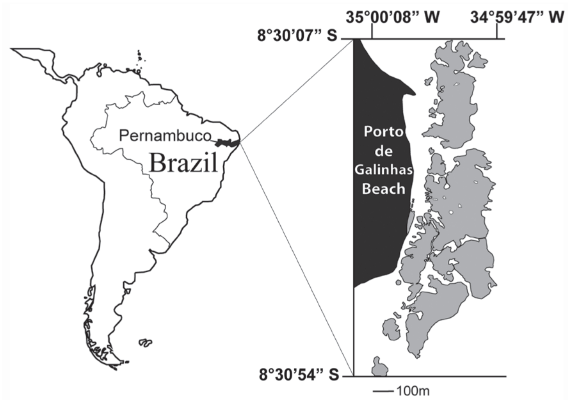

Figure 1. Reef area studied on Porto de Galinhas Beach, state of Pernambuco, northeastern Brazil.

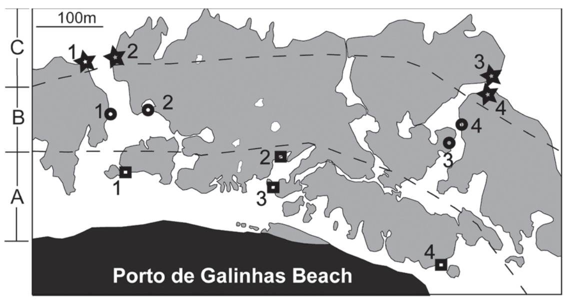

Figure 2. Reef area studied on Porto de Galinhas Beach, Pernambuco, Brazil, showing the four sampling sites in the three areas. Confined Water (sites A1 - A4) (square); Semi-open Water (sites B1 - B4) (circle); and Open Water (sites C1 - C4) (star).

Data Collection

The data were collected monthly, at night during the full-moon tide in low tide, from June 2004 through May 2005, by SCUBA diving for 3 h in each dive session (1.5 h before until 1.5 h after low tide), in three sampling areas A) Confined Waters, B) Semi-open Water, and C) Open Water. In each area, four collection points were sampled by counting all individuals by visual census, using fixed belt transects, each 20 m long, totaling 144 transects during the study period.

The chosen monitoring technique was the strip transect technique (STT) (Brock, 1954) with a 20 m-long transect. The area of this medium-scale sampling is based on the volume and size of the largest individuals covered (Hill and Wilkinson, 2004; Bakus, 2007), in this case the large reptant lobsters of the genus *Panulirus* White, 1847.

The STT is used by monitoring programs worldwide to study underwater communities (including decapods), such as the Australian Institute of Marine Science Long-term Monitoring Program (AIMS LTMP), the various Pacific monitoring programs (Lincoln-Smith transect), the Reef Check MAQTRAC (Marine Aquarium Trade Coral Reef Monitoring Protocol) Program (Hill and Wilkinson, 2004) and the Victorian Subtidal Reef Monitoring Program (Edmunds *et al.*, 2003; 2005; 2007).

Decapods were visually identified *in situ* by trained divers. The training used the following protocol: 1) each species was identified *in situ* during night dives; 2) the species was recorded on an underwater clipboard; 3) the specimen was hand-collected (with tweezers and dip nets); and 4) the species identification was confirmed through appropriate references. This procedure was repeated until the diver was confident in identifying each species.

Some decapods were not collected because their usual and known color pattern and morphological characteristics allow easy identification *in situ*. These included some commercially important species used for food (Cervigón *et al.*, 1992) or the aquarium trade (Calado *et al.*, 2003; Gasparini *et al.*, 2005).

Data analysis

The following estimated ecological indexes were based on Krebs (1994; 1998) Dajoz (2005) and Odum and Barrett (2007). Abundance – total number of individuals and Frequency of occurrence (%) – percentage of occurrence of a given species in relation to the total number of transects or areas, calculated by Fa = (Pa x 100) / P, where: Fa = frequency of the species, Pa = number of transects in which the species is present, and P = total number of samples or stations. Based on the frequency value, the species were considered rare (Fa < 10%), common (10% ≤ Fa < 50%), or constant (50% ≤ Fa ≤ 100%). Dominance (%) – expresses the ratio between the number of individuals of a given species and the number of individuals of all species, calculated by the formula Da = (Na x 100) / Nt, where Da = Dominance of the given species, Na = number of individuals of the species, and Nt = number of individuals of all species. Diversity (H') – Shannon-Wiener diversity index (Shannon and Weaver, 1949), considered slightly diverse (H' < 1 bits.ind^{-1}), diverse (1 ≤ H' < 2 bits.ind^{-1}), and very diverse (2 ≤ H' < 3 bits.ind^{-1}). Equitability (J') – the Pielou equitability index (Pielou, 1966), ranging from 0 (lowest uniformity) to 1 (maximum uniformity).

To analyze the main groups of species according to area (Confined, Semi-open and Open), we performed a cluster analysis and generated a dendrogram with the species and the degree of similarity of each group, using the Bray-Curtis similarity coefficient (Bray and Curtis, 1957) based on the abundance of the most important species (excluding rare species with fewer than 10 individuals found).

To evaluate differences between the means for abundance, diversity and equitability in the study areas, the nonparametric Mann-Whitney test was used (Zar, 1999), with a significance level of 5%. To check the similarity in composition and abundance with respect to the above variables, a Non-Metric Multidimensional Scaling (NMDS) ordination analysis was performed (Clarke, 1993; Clarke and Warwick, 1994).

The similarity matrix was constructed using the Bray-Curtis similarity coefficient (Bray and Curtis, 1957) based on the abundance of the most important species (excluding rare species with fewer than five individuals found). The bifactorial Analysis of Similarity (ANOSIM) evaluated the existence of significant differences in the fauna composition according to area, through the NMDS analysis matrix. R values higher than 0.5 and with a significance level less than 5% were considered statistically significant. All calculations were performed using the statistical software package Primer® 6.0 (Clarke and Gorley, 2001).

Results

Composition

A total of 34 species (5.3 ± 1.8 species/transect) were identified during the study period, belonging to infraorders Brachyura (19 species), Achelata and Anomura (5 species each), Caridea (3 species), and Stenopodidea and Astacidea (1 species each). Among the Brachyura, the family Mithracidae was the most important (5 species); among the Achelata, Palinuridae was best represented (3 species); and Diogenidae among the Anomura (4 species) (Table 1).

In all, 29 species occurred in the Confined, 25 in the Semi-open, and 22 in the Open area. The species of infraorders Stenopodidea, Caridea, Achelata and Astacidea occurred in all three areas, but were more abundant, frequent, and dominant in the Semi-open and Open areas. Anomurans were best represented in the Confined area, with the exception of *Cancellus ornatus* Benedict, 1901, which occurred only in the Semi-open and Open areas. Brachyurans were also best represented in the Confined area (16 species); the number of species declined with the distance from shore, with 11 species in the Semi-open and 9 in the Open area. The caridean *Cinetorhynchus rigens* and the lobster *Panulirus echinatus* were the dominant and abundant species in the entire reef area (Table 1).

Abundance

We observed 6,287 individuals (43.6 ± 24.9 individuals/transect) during the study. *C. rigens* was the most abundant species with 3,118 individuals (21.7 ± 9.5 per transect), followed by the brachyuran *Mithraculus forceps* with 1,357 individuals (17.3 ± 9.4 per transect) and *P. echinatus* with 1,139 (7.9 ± 7.1 per transect).

The estimated abundances in the three study areas were significantly similar (p_{AB} = 0.55; p_{AC} = 0.88; p_{BC} = 0.55). In the Confined area, 2,076 individuals were found (43.2 ± 22.7 individuals/transect); in the Semi-open, 1,986 individuals (41.4 ± 23.6 individuals/transect); and in the Open, 2,225 individuals (46.3 ± 28.2 individuals/transect) (Fig. 3). *Cinetorhynchus rigens* was the most abundant species in the Semi-open (25.8 ± 17.9 individuals/transect) and Open (31.3 ± 22.1 individuals per transect); in the Confined area,

Table 1 - Abundance, Dominance and Frequency of each species found in the subtidal of the Porto de Galinhas reef bench, Pernambuco, northeastern Brazil, by sampling areas: Confined Water (A), Semi-open Water (B), and Open Water (C). Relative abundance (Ab) with the mean number of individuals per transect. Dominance (Do) with the dominance percentage. Frequency of occurrence indicated by the color of the cells: Rare (white), Common (gray), and Constant (dark gray). *indicates absence of the species.

Species	Confined		Semi-open		Open	
	Ab	Do	Ab	Do	Ab	Do
STENOPODIDEA						
Stenopodidae						
Stenopus hispidus (Olivier, 1811)	0.2	<1	0.7	2	0.5	1
CARIDEA						
Rhynchocinetidae						
Cinetorhynchus rigens (Gordon, 1936)	**7.8**	**18**	**25.8**	**62**	**31.3**	**68**
Palaemonidae						
Brachycarpus biunguiculatus (Lucas, 1849)	0.1	<1	0.2	<1	0.3	1
Barbouriidae						
Janicea antiguensis (Chace, 1972)	0.3	1	**0.9**	**2**	1.1	2
ASTACIDEA						
Enoplometopidae						
Enoplometopus antillensis (Lütken, 1865)	<0.1	<1	<0.1	<1	0.1	<1
ACHELATA						
Palinuridae						
Palinurellus gundlachi von Martens, 1878	0.1	<1	0.2	1	0.2	<1
Panulirus argus (Latreille, 1804)	<0.1	<1	0.2	<1	0.4	1
Panulirus echinatus Smith, 1869	**2.8**	**7**	**10.1**	**24**	**10.8**	**23**
Panulirus laevicauda (Latreille, 1817)	<0.1	<1	<0.1	<1	<0.1	<1
Scyllaridae						
Parribacus antarcticus (Lund, 1793)	0.2	1	0.2	<1	0.1	<1
ANOMURA						
Diogenidae						
Calcinus tibicen (Herbst, 1791)	0.5	1	<0.1	<1	0.1	<1
Cancellus ornatus Benedict, 1901	*	*	<0.1	<1	<0.1	<1
Dardanus venosus (H. Milne Edwards, 1848)	<0.1	<1	*	*	*	*
Paguristes erythrops Holthuis, 1959	<0.1	<1	0.1	<1	*	*
Paguridae						
Pagurus provenzanoi Forest and de Saint Laurent, 1968	0.8	2	0.1	<1	<0.1	<1
BRACHYURA						
Dromiidae						
Dromia erythropus (Edwards, 1771)	<0.1	<1	*	*	*	*
Calappidae						
Calappa ocellata Holthuis, 1958	*	*	<0.1	<1	<0.1	<1
Carpiliidae						
Carpilius corallinus (Herbst, 1783)	*	*	<0.1	<1	*	*
Menippidae						
Menippe nodifrons Stimpson, 1859	0.2	<1	0.2	<1	0.1	<1
Leucosiidae						
Lithadia conica (Coelho, 1973)	<0.1	<1	*	*	*	*
Epialtidae						
Acanthonyx dissimulatus Coelho, 1993	<0.1	<1	*	*	*	*
Pelia rotunda A. Milne-Edwards, 1875	0.1	<1	<0.1	<1	*	*
Pitho lherminieri (Desbonne, in Desbonne and Schramm, 1867)	<0.1	<1	*	*	*	*
Inachidae						
Stenorhynchus seticornis (Herbst, 1788)	0.1	<1	0.2	1	0.5	1
Majidae						
Microphrys bicornutus (Latreille, 1825)	1.6	4	<0.1	<1	<0.1	<1
Mithraculus forceps A. Milne-Edwards, 1875	**26.2**	**61**	**1.9**	**4**	0.3	1
Mithrax braziliensis Rathbun, 1892	0.7	2	0.2	<1	0.2	<1
Mithrax hemphilli Rathbun, 1892	0.5	1	<0.1	<1	<0.1	<1
Mithrax hispidus (Herbst, 1790)	0.4	1	0.2	1	0.2	<1
Portunidae						
Callinectes marginatus (A. Milne-Edwards, 1861)	0.1	<1	*	*	*	*
Charybdis hellerii (A. Milne-Edwards, 1867)	<0.1	<1	<0.1	<1	*	*
Domeciidae						
Domecia acanthophora (Desbonne, in Desbonne and Schramm, 1867)	0.4	1	0.1	<1	*	*
Xanthidae						
Platypodiella spectabilis (Herbst, 1794)	*	*	*	*	<0.1	<1

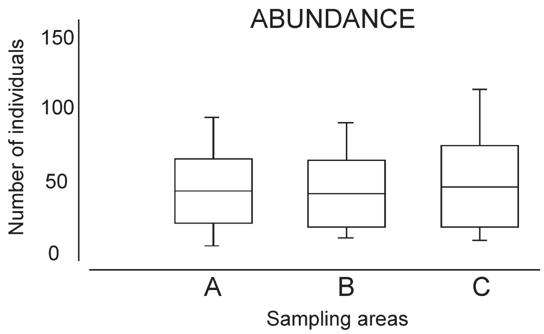

Figure 3. Abundance box plot of decapod species in Porto de Galinhas, Pernambuco, Brazil, showing the values for the three sampling areas: Confined Water (A), Semi-open Water (B) and Open Water (C).

Mithraculus forceps was the most abundant species (26.2 ± 21.9 individuals/transect) (Table 1).

Frequency

Three species were constant in the entire study (*Cinetorhynchus rigens*, *Panulirus echinatus* and *Mithraculus forceps*), 14 species were common (the stenopodidean *Stenopus hispidus*, the carideans *Janicea antiguensis* and *Brachycarpus biunguiculatus*, the lobsters *Panulirus argus*, *Parribacus antarcticus* and *Palinurellus gundlachi*, the anomurans *Calcinus tibicen* and *Pagurus provenzanoi* and the brachyurans *Microphrys bicornutus*, *Mithrax brasiliensis*, *Mithrax hemphilli*, *Mithrax hispidus*, *Stenorhynchus seticornis* and *Menippe nodifrons*. The other 17 species were rare (Table 1).

In the Confined area (A), 3 species were constant (*Cinetorhynchus rigens*, *Panulirus echinatus* and *Mithraculus forceps*), 11 common (*Stenopus hispidus, Janicea antiguensis, Parribacus antarcticus*, *Palinurellus gundlachi, Calcinus tibicen, Pagurus provenzanoi, Microphrys bicornutus, Mithrax brasiliensis*, *M. hemphilli*, *M. hispidus*, and *Menippe nodifrons*), and 15 were rare, especially the anomuran *Dardanus venosus* and the brachyurans *Dromia erythropus*, *Pachygrapsus transversus*, *Pitho lherminieri*, *Acanthonyx dissimulatus* and *Lithadia conica* which were rare and exclusive to this tide area.

In the Semi-open area (B), four were constant (*Janicea antiguensis, Cinetorhynchus rigens, Panulirus echinatus* and *Mithraculus forceps*), eight common (*Stenopus hispidus Brachycarpus biunguiculatus, Panulirus argus, Parribacus antarcticus, Palinurellus gundlachi, Menippe nodifrons, Stenorhynchus seticornis, Mithrax brasiliensis* and *M. hispidus*), and 13 species were rare, particularly the brachyuran *Carpilius corallinus*, which was found exclusively in this area.

In the Open area (C), only *Cinetorhynchus rigens* and *Panulirus echinatus* were constant, 11 species were common (*Stenopus hispidus, Janicea antiguensis*, *Brachycarpus biunguiculatus, Panulirus argus*, *Parribacus antarcticus*, *Palinurellus gundlachi*, *Menippe nodifrons, Stenorhynchus seticornis, Mithraculus forceps, Mithrax brasiliensis* and *M. hispidus*), and 9 were rare, with the brachyuran *Platypodiella spectabilis* exclusive to the Open area (Table 1).

Dominance

Three species dominated, comprising almost 90% (89.3%) of the total individuals: *Cinetorhynchus rigens* (49.6%), *Mithraculus forceps* (21.6%) and *Panulirus echinatus* (18.2%). Seven species showed dominances around 1% and together accounted for 6.8% of the individuals found: *Stenopus hispidus* (1.03%), *Janicea antiguensis* (1.8%), *Pagurus provenzanoi* (0.7%), *Microphrys bicornutus* (1.3%), *Mithrax brasiliensis* (0.8%), *M. hispidus* (0.6%) and *Stenorhynchus seticornis* (0.56%). The 24 remaining species showed dominance lower than 0.5%, and together accounted for 3.9% of the total number of individuals (Table 1).

Mithraculus forceps was the dominant species in Confined Waters (A) (60.5%), followed by *Cinetorhynchus rigens* (18%), *Panulirus echinatus* (6.5%), *Microphrys bicornutus* (3.8%), *P. provenzanoi* (1.9%), and *Mithrax brasiliensis* (1.5%); the other 24 species together comprised 7.7% of the total individuals (Table 1).

Cinetorhynchus rigens (62.4%) and *Panulirus echinatus* (24.3%) dominated the Semi-open Waters (B), followed by *Mithraculus forceps* (4.5%), *Janicea antiguensis* (2.2%), and *Stenopus hispidus* (1.6%); the other 21

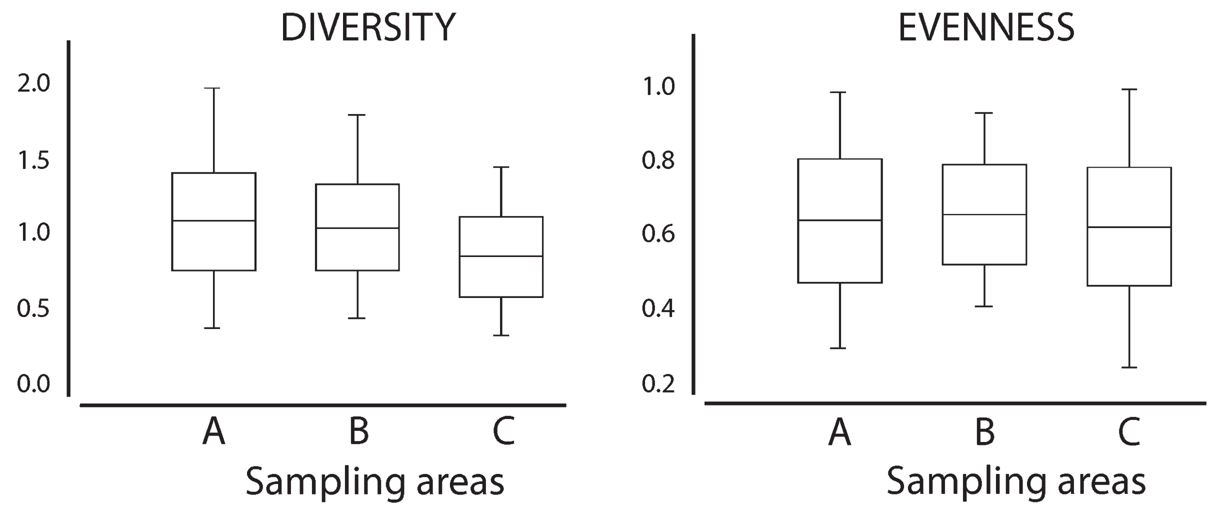

Figure 4. Diversity and equitability box plot of decapod species in Porto de Galinhas, Pernambuco, Brazil, showing the values for the three sampling areas: Confined Water (A), Semi-open Water (B) and Open Water (C).

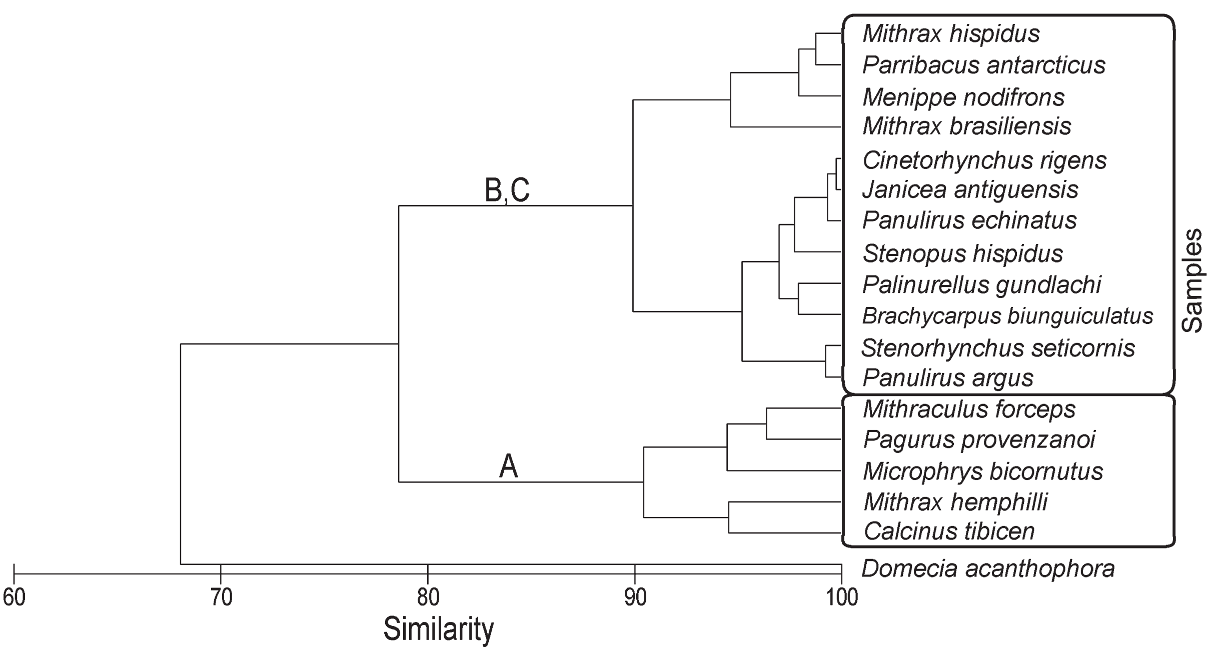

Figure 5. Dendrogram of similarities for the most numerous decapod species in Porto de Galinhas, Pernambuco, Brazil, based on analysis of the three sampling areas: Confined Water (A), Semi-open Water (B) and Open Water (C).

species together comprised 4.9% of the total individuals. The Open Water area (C) was mainly dominated by *Cinetorhynchus rigens* (67.6%) and *Panulirus echinatus* (23.4%); the other 20 species contributed 9% of the total (Table 1).

Diversity and Equitability

Diversity ranged from 0.4 to 2.0 bits.ind^{-1}. In the Confined Water (A) (1.1 ± 0.33 bits.ind^{-1}) and in the Semi-open Water (B) (1.0 ± 0.29 bits.ind^{-1}), the diversity was similar (p_{AB} = 0.5), but significantly higher than in the Open Water (C) (0.8 ± 0.27 bits.ind^{-1}) (p_{AC} = 0.005 and p_{BC} = 0.014) (Fig. 4).

Equitability was relatively high (mean 0.65 ± 0.1), ranging from 0.25 to 1, but was similar among the three areas and showed no statistical difference between (A) and (B) (p_{AB} = 0.5701), (A) and (C) (p_{AC} = 0.6029), or (B) and (C) (p_{BC} = 0.2295) (Fig. 4).

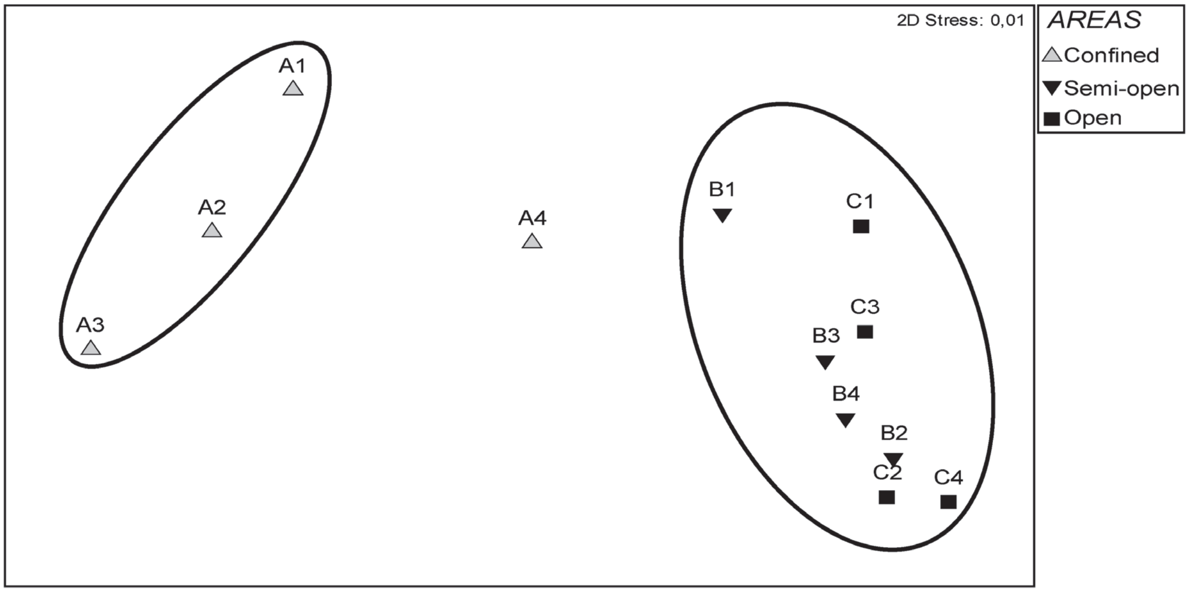

Figure 6. Non-parametric multidimensional scaling (nMDS) based on the similarity matrix of each sampling site per area: Confined Water (sites A1 - A4), Semi-open Water (sites B1 - B4), and Open Water (sites C1 - C4).

Multivariate analysis

Despite the high similarity (>70%) indicated by the cluster analysis, three distinct groups were apparent (Fig. 5). The first group was formed by *Pagurus provenzanoi*, *Calcinus tibicen*, *Mithraculus forceps, Microphrys bicornutus* and *Mithrax hemphilli* and was characteristic of the Confined Water (A). The second group was formed by species characteristic of the Semi-open Water (B) and Open Water (C) together: *Stenopus hispidus, Janicea antiguensis, Brachycarpus biunguiculatus*, *Cinetorhynchus rigens, Palinurellus gundlachi, Panulirus echinatus, Panulirus argus*, *Parribacus antarcticus*, *Menippe nodifrons, Stenorhynchus seticornis, Mithrax brasiliensis* and *M. hispidus*. The third group was formed only by the brachyuran *Domecia acanthophora*.

A similar pattern was found in the MDS for the species distribution, with the formation of two statistically significant groups (Fig. 6): 1 – Open Water (C) + Semi-open Water (B), and 2 – Confined Water (A) ($p_{AB} = 0.03/R = 0.85$; $p_{AC} = 0.03/R = 0.93$; $p_{BC} = 0.46/R = -0.04$). The southernmost point in the Confined Water (A4) was distinct; this point is deeper and less confined than the other points (Fig. 6).

Discussion

Decapod composition

The brachyuran crabs are among the most abundant and diverse groups of species on coral reefs (Dubinsky and Stambler, 2011), and in this study comprised 55% of the total species on the reefs. The ornamental crab *Mithraculus forceps* was the most dominant and abundant crab, as also found on rocky shores of the southeastern and southern coast of Brazil by SCUBA divers (Gaeta *et al.*, 2011) and manual sampling (Mantelatto *et al.,* 2004; Bouzon and Freire, 2007). The dominance of *M. forceps* in shallow hard-bottom areas is probably due to: short larval stage, high survival rate of juveniles and rapid growth (Rhyne *et al.,* 2005); high reproductive effort and growth stimulated by warm water (Mantelatto *et al.*, 2004; Rhyne *et al.,* 2005; Figueiredo *et al.,* 2008); as well as herbivorous feeding habit (Figueiredo *et al.,* 2008); and possibly effective defense strategies and an absence of large predators.

In addition to *M. forceps*, other brachyurans including *Mithrax braziliensis, Mithrax hispidus, Pelia rotunda, Pitho lherminieri, Stenorhynchus seticornis, Pachygrapsus transversus* and *Menippe nodifrons* were common on the Porto de Galinhas reef. These species are commonly found associated with algae on coral reefs or rocky shores and coral reefs (Melo, 1996), and were also collected in the daytime by SCUBA divers in southeast and southern Brazil (Mantelatto *et al.,* 2004; Bouzon and Freire, 2007).

Caridean shrimps are also an important group on coral-reef and other hard-bottom ecosystems, including marine and anchialine caves (Hobbs III, 1994; Clark *et al.*, 2008). The caridean *Cinetorhynchus rigens* was the most abundant and dominant species on the Porto de Galinhas reef, comprising around 50% of all specimens found during the study. This shrimp is reported from cavernicolous marine environments (Okuno, 1997; Micael *et al.*, 2006) and on the Porto de Galinhas reef was found in crevices in the walls, on cave roofs, and in reef grottos, moving out of the caves at night. Caillaux and Stotz (2003) found a similar pattern for the shrimp *Rhynchocinetes typus* H. Milne Edwards, 1937 in cavities and caves in Chile. Another very abundant caridean shrimp on the Porto de Galinhas reef was *Janicea antiguenis*, which is often found in underwater caves and tunnels (Manning and Hart, 1984; Hobbs III, 1994; Udekem d'Acoz, 2001; Wirtz, 2004). The high abundance of *J. antiguensis* and *C.rigens* in studied reef is probably due to: the studied area present many caves and a large crevicular system below the reef structures, typical habitat for these species (Manning and Hart, 1984; Okuno, 1997; Micael *et al.*, 2006); *J. antiguensis* and *C. rigens* have nocturnal habits (Okuno, 1997).

Some species found on this reef deserve particular attention because of their economic and social importance. *Brachycarpus biunguiculatus, Cinetorhynchus rigens*, *Stenopus hispidus, Enoplometopus antillensis, Palinurellus gundlachi, Calcinus tibicen, Domecia acanthophora, Stenorhynchus seticornis*, *Pelia rotunda*, *Platypodiella spectabilis, Dardanus venosus, Petrochirus diogenes* and *Mithraculus forceps* are ornamental species popular in the aquarium trade (Calado *et al.*, 2003; Gasparini *et al.*, 2005; Balaji *et al.*, 2009), while the lobsters *Panulirus argus, P. laevicauda* and *P. echinatus* are targets of artisanal fishing (Rocha *et al.,* 1997). Many of these species were rare and in low abundance on the reefs, demonstrating the importance of developing local public policies for the management of their catches.

The portunid crab *Charybdis hellerii* was rare but present in the study area, especially in confined waters. An invasive species originally from the Indo-Pacific, *C. hellerii* is recorded from the Brazilian coast from Maranhão to Santa Catarina, in reefs and estuarine environments (Calado, 1996; Mantelatto and Dias, 1999; Bezerra and Almeida, 2005; Braga *et al.*, 2005; Feres *et al.*, 2007; Coelho *et al.*, 2008; Loebmann *et al.*, 2010; Silva and Barros, 2011). It competes for space and food with native species (Loebmann *et al.*, 2010).

Spatial distribution

The abundance of decapods showed no statistically significant differences between the sampling areas. However, we expected that decapods found in the shallower and more easily accessed areas on a reef bench that is heavily used by tourists (MMA, SECTMA and CPRH, 2003) would be less abundant and less diverse, especially species with economic value. Surprisingly, these shallower areas showed the highest diversity and abundance, suggesting that the Confined-water areas provide shelter for juveniles and young decapods, as also recorded for the spiny lobsters *Panulirus argus* and *Panulirus echinatus*, which use the crevices of coastal reefs as refuges (Barreto and Katsuragawa, 2008; Igarashi, 2010).

Analysis of the faunal assemblage clearly showed the formation of three well-defined groups with different spatial distributions: 1) species found in shallow waters, with maximum depth about 2.5 m and less-intense hydrodynamics (Confined area); 2) species in deeper locations (3 to 10 m), which are subject to some form of wave and tidal stress (Semi-open and Open areas). These findings suggested that hydrodynamics (water confinement) and differences in depth on shallow coastal-reef benches influence the distribution of subtidal decapods, and agree with observations by Martínez-Iglesias and García-Raso (1999) and Huang *et al.* (2011), who included these among the main factors that influence the distribution of benthic invertebrates. The third group was formed by the crab *Domecia acanthophora*, the only species found only on the fire coral *Millepora alcicornis* Linnaeus, 1758, showing the importance of inter-specific associations existing on reef ecosystems (Patton, 1967; Criales, 1984; Wirtz and Udekem d'Acoz, 2008; Wirtz *et al.*, 2009).

The assemblage in the Confined area was mainly composed of Brachyura and Anomura. The five most significant (dominant and frequent) species in this area, *Calcinus tibicen*, *Pagurus provenzanoi*, *Mithraculus forceps, Microphrys bicornutus* and *Mithrax hemphilli* are commonly associated with secondary substrates such as macrophytes, sponges and corals on reefs in northeastern Brazil, and can be collected manually during low tide (Melo, 1996; Almeida *et al.,* 2008; Garcia *et al.,* 2008; Batista *et al.,* 2009). On these reefs, the Confined area, with its shallow, well-lighted pools is favorable for the establishment of secondary substrates such as macrophytes, zooanthids and corals (Maida and Ferreira, 1997; Barradas *et al.*, 2010) and decapod crustaceans are known to be associated with these living substrates (Stevens and Anderson, 2000; Batista *et al.*, 2009; Wirtz *et al.,* 2009).

In the Semi-open area, the decapod assemblage showed intermediate characteristics between the assemblage in the Confined area, composed mainly of brachyuran crabs, and in the Open area, composed mainly by caridean shrimps, suggesting a gradual change in decapod distribution according to depth and hydrodynamics. In the Semi-open area, *Stenopus hispidus*, *Janicea antiguenis* and *Palinurellus gundlachi* were prominent; these species are commonly recorded in caves, tunnels or inaccessible cavities on coastal reefs (Manning and Hart, 1984; Williams, 1984; Melo, 1999). The ornamental shrimp *Stenopus hispidus* is the most popular shrimp among aquarists (Calado *et al.*, 2003), and probably finds refuge in the caves of the Semi-open area.

The Open-water area in the breaker zone is more exposed to wave action (with stronger hydrodynamics) and showed the lowest decapod diversity, significantly lower than the more-protected areas on the reef bench. The strong hydrodynamics limits the establishment of decapods and other benthic species such as seaweed, sponges and corals (Huang *et al.*, 2011), which serve as living substrates for some decapod species. According to Thiel and Vásquez (2000), the branches and structures of algae are important microhabitats for decapods.

The characteristic species (highest dominance and frequency) for the Open area were caverniculous or crevicular species including *Cinetorhynchus rigens, Brachycarpus biunguiculatus, Janicea antiguensis, Enoplometopus antillensis* and *Palinurellus gundlachi*, with adaptations to cave life (wine-red color and/or long tactile structures), or species with strong structures to hold themselves in the reef structures under wave and current action, such as the ornamental crabs *Stenorhynchus seticornis* and *Platypodiella spectabilis* (Hart *et al.,* 1985; Hobbs III, 1994; Iliffe and Bishop, 2007).

Stenorhynchus seticornis is commonly associated with sessile invertebrates (Hayes *et al.*, 1998; 2006; Wirtz *et al.*, 2009), and at Porto de Galinhas, was found associated with the octocoral *Carijoa riisei* Duchassaing and Michelotti, 1860 in the Semi-open and Open areas. *Stenhorhynchus seticornis* has an elongated body, which provides perfect camouflage and symbiosis among the octocoral structures. The ornamental crab *Platypodiella spectabilis* was found on the zooanthid *Palythoa caribaeorum* Duchassaing and Michelotti, 1860 that commonly covers the flat reef surface in the breaker zone (Barradas *et al.,* 2010), an association also reported by Gleibs *et al.* (1995) in the Colombian Caribbean Sea. *Domecia acanthophora*, which was found in this study only on the hydrocoral *Millepora alcicornis* Linnaeus, 1758, was also recorded on *Millepora alcicornis* at Parrachos de Maracajaú, northeastern Brazil (Garcia *et al.*, 2008), and on three acroporid corals [*Acropora cervicornis* (Lamarck, 1816), *A. palmata* (Lamarck, 1816) and *A. prolifera* (Lamarck, 1816)] in Puerto Rico (Patton, 1967). This association with cnidarians provides the reef crabs protection against predators and the strong tidal currents typical of the Open and Semi-open areas (Williams, 1984).

Acknowledgements

The authors thank the Acqua Viva Dive Center for dive support, Dr. Janet Reid for English assistance, CNPQ (Conselho Nacional de Desenvolvimento Científico e Tecnológico) and FACEPE (Fundação de Amparo à Ciência e Tecnologia de Pernambuco) for the M.Sc. and PhD scholarship awarded to B.W. Giraldes, and the anonymous reviewers for their suggestions on the text.

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Submitted 30 May 2012
Accepted 26 October 2012