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Original research article

# Decapod assemblages in subtidal and intertidal zones—Importance of scuba diving as a survey technique in tropical reefs, Brazil

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## HIGHLIGHTS

- The significance and importance of scientific diving to study decapods.
- Scientific diving allows access to specific decapod assemblages.
- The most endangered trade decapods can be targeted on nocturnal dives.
- We present an ecological database for subtidal and intertidal decapods.
- The first ecological baseline data for decapods in the tropical coastal reefs.

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## ABSTRACT

Decapods play a crucial role within the reef ecosystem and the development of scuba diving as a survey tool has allowed researchers the opportunity to study the decapod–reef relationship more comprehensively. The present study describes the differences in decapod assemblages in intertidal and subtidal zones at a tropical coastal reef system in the southwestern Atlantic Ocean and reports the importance of scuba diving as a survey technique. A total of 71 decapods were recorded during the research; 42 in the intertidal zone mainly formed by small endobenthic species and 39 in the subtidal zone primarily large species only 10 were found to frequent both sample zones. The study extends the range of *Brachycarpus holthuisi* Fausto Filho 1966 in Brazil; and also demonstrates how scuba diving can be used to complement traditional methodologies and vice versa. The research shows the advantages of using scuba diving when studying trade endangered decapods, as the methodology allows access to cryptic habitats such as reef caves and underwater cavities which were inaccessible when using traditional techniques. In conclusion scuba diving represents a revolutionary non-destructive survey tool allowing the researcher to directly access a specific decapod assemblage in fragile reef environments and in protected marine areas.

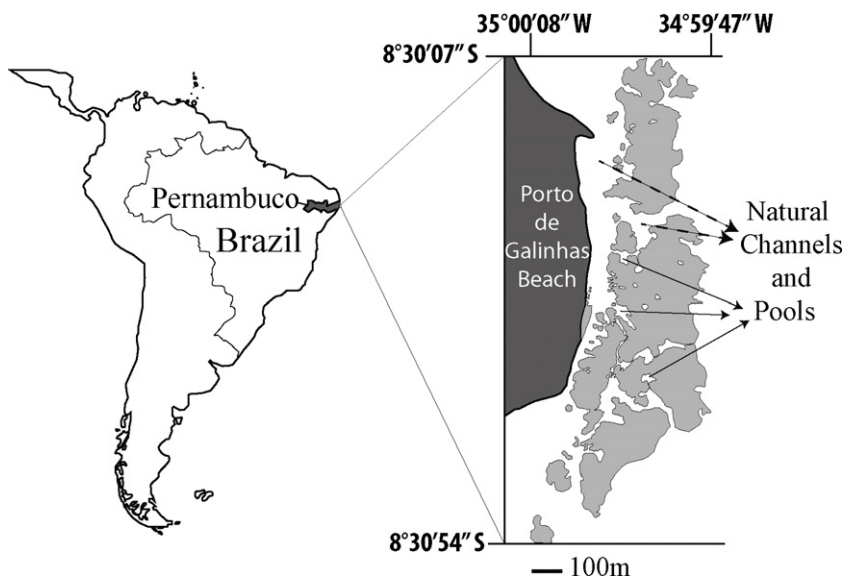
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## 1. Introduction

Within the habitats termed biogenic reefs, coral reefs in particular present some of the highest biodiversity indices recorded and as a result are one of the most important marine ecosystems in the world (Dubinsky and Stambler, 2011).

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**Fig. 1.** Map showing the location of Porto de Galinhas reefs, Pernambuco, along the Northeastern Coast of Brazil, highlighting the natural pools and channels between the reef structures.  
 Source: Adapted from Giraldes (2007, 2012).

In the majority of marine ecosystems, including coral reefs one of the key taxon are the crustaceans. In particular the decapods, which present high species diversity, are an important component in trophic dynamics and are also an important fishery resource throughout the world (Randall, 1967; Abele, 1974; Melo, 1996, 1999; Coelho et al., 2006, 2007, 2008; De Grave et al., 2009; Dubinsky and Stambler, 2011).

Decapod assemblage checklists in areas of hard substrate such as rocky reefs and coral reefs usually occur only in intertidal and at the beginning of subtidal zones. Specimens are usually sampled in association with substrate with distinct biotope markers such as algae and corals or rocks and sand (Coelho and Ramos-Porto, 1995; Masunari and Dubiaski-Silva, 1998; Melo and Veloso, 2005; Coelho-Filho, 2006; Almeida et al., 2008). However decapods in shallow subtidal waters are usually sampled with indirect methods such as drags, nets and traps and as a result numerous species elude capture and are not included in decapod checklists for coastal sites.

In recent years scientific scuba diving has revolutionized subtidal decapod research. As a result many new discoveries have been made in regards to the influence decapods exert within a subtidal ecosystem and the general ecology and biology within the order (Mantelatto et al., 2004; Bouzon and Freire, 2007; Teschima et al., 2012; Alves et al., 2012; Giraldes et al., 2012a,b; Lang et al., 2013).

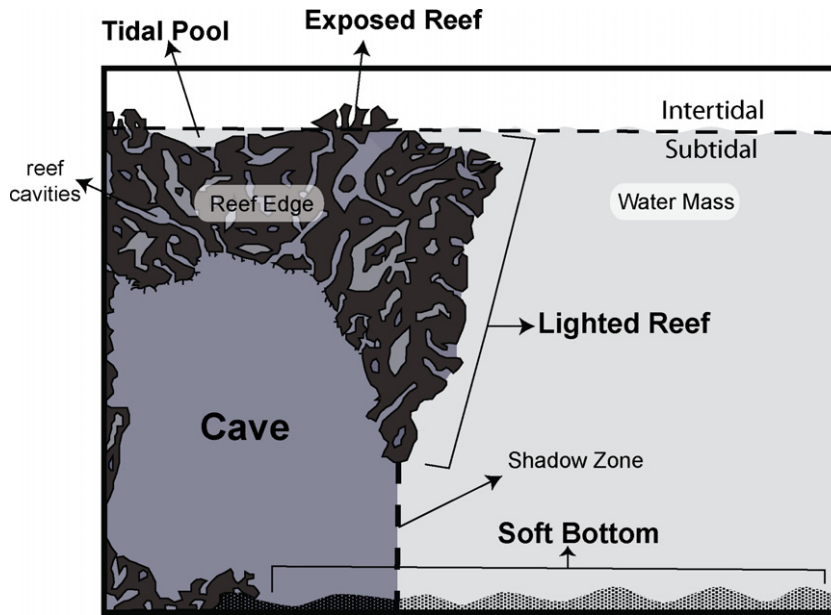
In order to create a comprehensive list of decapod assemblage for subtidal and intertidal zones in the southwestern Atlantic Ocean and highlight the importance of scientific scuba diving to study decapods, the present study aims to produce a list of species with an associated ecological database for a tropical coastal reef using recognized sampling methodologies in the intertidal zone and scientific scuba diving in the subtidal zone.

## 2. Material and methods

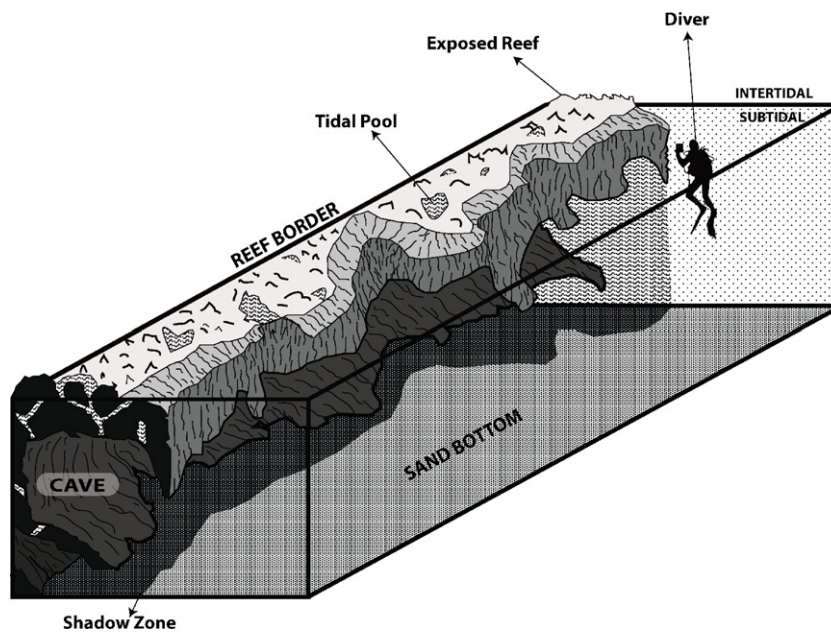
Samples were collected along the coastal biogenic reef at Porto de Galinhas beach ( $8^{\circ}30'07''$ – $8^{\circ}30'54''$ S e  $35^{\circ}00'08''$ – $34^{\circ}59'47''$ W) (Fig. 1), one of the most visited coastal reef environments in tropical Northeastern Brazil. The reef formation is a reef bank probably derived from the sandstone bedrock wall that runs parallel to the shoreline. As a result of bio-construction (as coral growing), bio-erosion (endobenthic diggers) and erosion from wave action, a cave and hollowed cavity has been formed the actual feature of the reef structure. Corals and epifaunal animals have settled on the topside and underside of the overhang and this has led to the formation of a top platform of coral structures. In areas densely aggregated the top platforms of reefs are connected forming interconnected caves below the reef surface (Dominguez et al., 1990; Maida and Ferreira, 1997; Leão et al., 2003; Manso et al., 2003) (Figs. 2 and 3).

During low tides, the intertidal zone of the reef is exposed and can be categorized as the reef top-shelf, which is clearly visible and is made up of tidal pools, natural permanent pools and channels that cross the reef structures (Fig. 1). The reef topography is populated by epibenthic flora and fauna and associated mobile fauna; macro-algae, zoanthids, calcareous algae, scleractinia corals, calcified hydroids, sponges, sea urchins, bryozoans and ascidians, while inside cave and cavities only a few sessile benthic organisms occur (Dominguez et al., 1990; Maida and Ferreira, 1997; Barradas et al., 2010).

This study is a review of data yet to be published in scientific journals, only presented as one monograph which describes sampling methodology in the intertidal zone (Austregésilo-Filho, 1992) and one dissertation and thesis were sampling



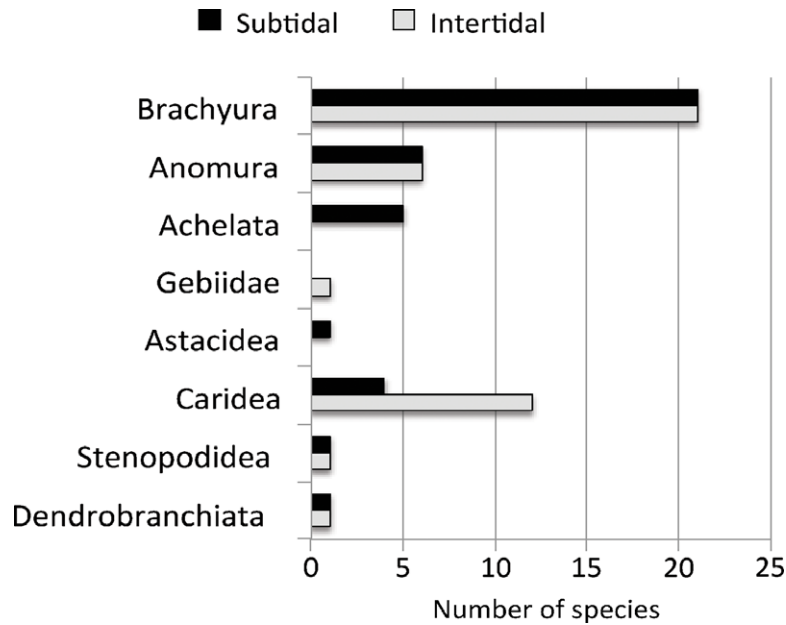
**Fig. 2.** Schematic profile of the reef edge of Porto de Galinhas reefs, highlighting: the intertidal zone, the tidal pools and the exposed reef; and the subtidal zone with the light influenced reef, the cavernous environments with the imaginary line of the shallow zone and the soft bottom surrounding the reefs.  
 Source: Adapted from Giraldes (2007, 2012).



**Fig. 3.** Schematic profile of one sample point on the reef edge (border) at Porto de Galinhas, highlighting: the intertidal and subtidal zones, the diver and the benthic features such as tidal pools, exposed reef, cave with shadow zone and the sandy soft bottom.  
 Source: Adapted from Giraldes (2007, 2012).

was carried out using scientific scuba diving and visual sampling methodology in the subtidal zone (Giraldes, 2007, 2012). Dr. Petrônio Alves Coelho from the crustacean laboratory at Federal University of Pernambuco (UFPE) guided both researches and inspired this checklist study. Specimen voucher samples were deposited in oceanographic museum of the Federal University of Pernambuco (MOUFPE) and/or identified in the laboratory using taxonomic references.

Intertidal sampling involved walking along the reef topside during low tide. Animals were collected on exposed reefs, in tide-pools and along the reef fringe until the subtidal zone lineation was met. All species were collected and identified in the laboratory due to the small size of individuals.



**Fig. 4.** Number of species inside each decapod Infraorder (Brachyura, Anomura, Achelata, Gebiidae, Astacidea, Caridea and Stenopodidea) and Suborder (Dendrobranchiata), in relation to Subtidal and Intertidal zones in Porto de Galinhas reef.

The subtidal zone was also sampled during a low tide and scuba diving was used at night to collect samples, when decapods are most. All decapods collected were identified in an improvised laboratory close to the survey reef. Large well-known decapods such as large lobsters, crabs and ornamental shrimps were visually identified in-situ and recorded on an underwater slate.

To identify the abundance and frequency of species 12 sample events were carried out at each zone, comprising of 12 subtidal and 12 intertidal samples.

Families are presented in evolutionary order and the species in alphabetical order following De Grave et al. (2009) classification.

Data was analyzed using: Abundance (Ab)—individual average amounts per sample ( $Ab = n/s$ ) where  $n$  is the number of individuals observed and  $s$  is the number of samples held; and the frequency (Fr)—calculated by the formula:  $Fr = p \cdot 100/P$ , where  $p$  is the sample number where the species occurred and  $P$  is the total sample number analyzed as following: Constant (75%–100%); Very Common (50%–75%); Common (25%–50%); Occasional (10% ≤ 25%) and Rare (0%–10%) (Based on Dajoz, 2005; Odum and Barrett, 2007).

### 3. Results

A total of 71 decapods were recorded between subtidal and intertidal zones. Only 10 species were recorded frequenting both sample zones, 1 Anomura and 9 Brachyura (Table 1).

Forty-two decapods were recorded along the intertidal zone (Table 1), comprising of 1 Dendrobranchiata, 1 Stenopodidea, 12 Caridea, 1 Gebiidae, 6 Anomura and 21 Brachyura (Fig. 4)(Table 1). The samples mainly contained small decapod species with several endobenthic species.

Thirty-nine decapods were recorded subtidally using scuba diving (Table 1), comprising of 1 Dendrobranchiata, 1 Stenopodidea, 4 Caridea, 1 Astacidea, 5 Achelata, 6 Anomura and 21 Brachyura (Fig. 4)(Table 1). They were mainly composed of epibenthic species with large and medium sized animals, almost all with economic value.

Abundance analysis of intertidal samples recorded 5 dominant decapods that contributed 56% of the total species abundance. The most prolific species was *Palaemon northropi* with 21% ( $25.92 \pm 28.13$ ), followed by *Microphrys bicornutus* 15% ( $17.58 \pm 11.54$ ), *Clibanarius antillensis* 8% ( $10.17 \pm 9.25$ ) and *Mithraculus forceps* ( $7.83 \pm 7.14$ ) and *Alpheus cf. armillatus* ( $7.33 \pm 0.28$ ) each with 6%; the remaining 38 species contributed to 44% of the total abundance (Fig. 5)(Table 1).

Abundance within the subtidal samples recorded 5 dominant species with 92%. Being *Cinetorhynchus rigens* with 53% ( $27.92 \pm 27.43$ ), *Panulirus echinatus* 18% ( $9.59 \pm 9.19$ ), *Mithraculus forceps* 18% ( $9.38 \pm 17.13$ ), *Janicea antiguensis* 2% ( $0.81 \pm 1.48$ ) and *Stenopus hispidus* 1% ( $0.51 \pm 1.01$ ); the remaining 34 species represented 8% of the abundance (Fig. 5)(Table 1).

In intertidal samples record 12 decapod species were recorded constantly (*Palaemon northropi*, *Cuapetes americanus*, *Alpheus cf. armillatus*, *Synalpheus fritzmullerrie*, *Petrolisthes galathinus*, *Clibanarius antillensis*, *Eriphia gonagra*, *Microphrys bicornutus*, *Mithraculus forceps*, *Eurypanopeus abbreviatus*, *Panopeus hartii* and *Pachygrapsus transversus*), 5 very common,

**Table 1**

Decapod assemblage at Porto de Galinhas reefs, Northeastern Brazil. Lines present the species. Columns are of species sampled in Subtidal zone (gray) and Intertidal zone (colorless), with its corresponding values of: Abundance (Ab.) with individuals average and standard deviation; and Frequency (Fr.), being constant (CT), Very Common (VC), Common (Co), Occasional (Oc) and Rare (Rr). \* Indicates species absence.

Decapod checklist	Subtidal		Intertidal	
	Ab.	Fr.	Ab.	Fr.
<b>DENDROBRANCHIATA</b>				
<b>Penaeidae</b>				
<i>Farfantepenaeus subtilis</i> (Pérez-Farfante, 1967)	0.13 ± 0.38	Oc	*	*
<b>Sicyoniidae</b>				
<i>Sicyonia parri</i> (Burkenroad, 1934)	*	*	0.08 ± 0.28	Rr
<b>PLEOCYEMATA</b>				
<b>STENOPODIDEA</b>				
<b>Spongicolidae</b>				
<i>Microprosthema semilaeve</i> (Von Martens, 1872)	*	*	0.08 ± 0.28	Rr
<b>Stenopodidae</b>				
<i>Stenopus hispidus</i> (Olivier, 1811)	0.51 ± 1.01	Co	*	*
<b>CARIDEA</b>				
<b>Rhynchocinetidae</b>				
<i>Cinetorhynchus rigens</i> (Gordon, 1936)	27.92 ± 27.43	CT	*	*
<b>Palaemonidae</b>				
<i>Brachycarpus biunguiculatus</i> (Lucas, 1849)	0.09 ± 0.33	Rr	*	*
<i>Brachycarpus holthuisi</i> Fausto Filho, 1966	0.06 ± 0.27	Rr	*	*
<i>Palaemon (Palaeander) northropi</i> Rankin, 1898	*	*	25.92 ± 28.13	CT
<i>Cuapetes americanus</i> (Kingsley, 1878)	*	*	6.37 ± 4.86	CT
<b>Alpheidae</b>				
<i>Alpheus cf. armillatus</i> H. Milne Edwards, 1837	*	*	7.33 ± 0.28	CT
<i>Alpheus cf. formosus</i> Gibbes, 1850	*	*	2.83 ± 2.75	VC
<i>Alpheus nuttingi</i> (Schmitt, 1924)	*	*	0.5 ± 1.0	
<i>Synalpheus fritzmulleri</i> Coutière, 1909	*	*	3.42 ± 2.19	CT
<i>Synalpheus longicarpus</i> (Herrick, 1891)	*	*	0.08 ± 0.28	Rr
<b>Barbouriidae</b>				
<i>Janicea antiguensis</i> (Chace, 1972)	0.81 ± 1.48	Co	*	*
<b>Hippolytidae</b>				
<i>Hippolyte obliquimanus</i> Dana, 1852	*	*	1.25 ± 2.34	Co
<i>Latreutes parvulus</i> (Stimpson, 1866)	*	*	0.17 ± 0.58	Rr
<i>Lysmata rathbunae</i> Chace, 1970	*	*	1.5 ± 1.98	Co
<i>Thor manningi</i> Chace, 1972	*	*	0.58 ± 0.79	Co
<b>Processidae</b>				
<i>Processa fimbriata</i> (Manning e Chace, 1971)	*	*	0.08 ± 0.28	Rr
<b>ASTACIDEA</b>				
<b>Enoplometopidae</b>				
<i>Enoplometopus antillensis</i> (Lütken, 1865)	0.05 ± 0.22	Rr	*	*
<b>GEBIIDEA</b>				
<b>Upogebiidae</b>				
<i>Upogebia affinis</i> (Say, 1818)	*	*	1.67 ± 1.67	VC
<b>ACHELATA</b>				
<b>Palinuridae</b>				
<i>Palinurellus gundlachi</i> von Martens, 1878	0.17 ± 0.44	Oc	*	*
<i>Panulirus argus</i> (Latreille, 1804)	0.16 ± 0.64	Rr	*	*

(continued on next page)

Table 1 (continued)

Decapod checklist	Subtidal		Intertidal	
	Ab.	Fr.	Ab.	Fr.
<i>Panulirus echinatus</i> Smith, 1869	9.59 ± 9.19	CT	*	*
<i>Panulirus laevicauda</i> (Latreille, 1817)	0.02 ± 0.15	Rr	*	*
<b>Scyllaridae</b>				
<i>Parribacus antarcticus</i> (Lund, 1793)	0.19 ± 0.44	Oc	*	*
<b>ANOMURA</b>				
<b>Porcellanidae</b>				
<i>Megalobrachium mortenseni</i> Haig, 1962	*	*	0.08 ± 0.28	Rr
<i>Petrolisthes galathinus</i> (Bosc, 1802)	*	*	4.25 ± 3.93	CT
<i>Petrolisthes rosariensis</i> Werdling, 1978	*	*	0.58 ± 2.02	Rr
<b>Diogenidae</b>				
<i>Calcinus tibicen</i> (Herbst, 1791)	0.24 ± 0.78	Oc	1.42 ± 1.16	Oc
<i>Cancellus ornatus</i> Benedict, 1901	0.07 ± 0.46	Rr	*	*
<i>Clibanarius antillensis</i> Stimpson, 1859	*	*	10.17 ± 9.25	CT
<i>Clibanarius scolopetarius</i> (Herbst, 1796)	*	*	1 ± 0.85	VC
<i>Dardanus venosus</i> (H. Milne Edwards, 1848)	0.01 ± 0.11	Rr	*	*
<i>Paguristes erythropus</i> Holthuis, 1959	0.07 ± 0.26	Rr	*	*
<i>Petrochirus diogenes</i> (Linnaeus, 1758)	0.01 ± 0.08	Rr	*	*
<b>Paguridae</b>				
<i>Pagurus provenzanoi</i> Forest e de Saint Laurent, 1968	0.43 ± 1.33	Oc	*	*
<b>BRACHYURA</b>				
<b>Dromiidae</b>				
<i>Dromia erythropus</i> (Edwards, 1771)	0.01 ± 0.07	Rr	*	*
<b>Calappidae</b>				
<i>Calappa ocellata</i> Holthuis, 1958	0.02 ± 0.13	Rr	*	*
<i>Calappa sulcata</i> Rathbun, 1898	*	*	0.08 ± 0.28	Rr
<b>Carpiliidae</b>				
<i>Carpilius corallinus</i> (Herbst, 1783)	0.01 ± 0.07	Rr	*	*
<b>Eriphiidae</b>				
<i>Eriphia gonagra</i> (Fabricius, 1781)	*	*	1.83 ± 1.4	CT
<b>Menippidae</b>				
<i>Menippe nodifrons</i> Stimpson, 1859	0.19 ± 0.49	Oc	0.08 ± 0.28	Rr
<b>Leucosiidae</b>				
<i>Lithadia conica</i> (Coelho, 1973)	0.01 ± 0.07	Rr	*	*
<b>Epialtidae</b>				
<i>Acanthonyx dissimulatus</i> Coelho, 1993	0.01 ± 0.07	Rr	0.34 ± 0.65	Oc
<i>Epialtus bituberculatus</i> (H. Milne Edwards, 1834)	*	*	0.75 ± 2.01	Oc
<i>Pelia rotunda</i> A. Milne Edwards, 1875	0.03 ± 0.2	Rr	*	*
<i>Pitho lherminieri</i> (Desbonne, in Desbonne e Schramm, 1867)	0.01 ± 0.11	Rr	0.58 ± 1.16	Oc
<b>Inachidae</b>				
<i>Stenorhynchus seticornis</i> (Herbst, 1788)	0.21 ± 0.77	Rr	*	*
<b>Majidae</b>				
<i>Macrocoeloma laevigatum</i> (Stimpson, 1871)	*	*	0.08 ± 0.28	Rr
<i>Microphrys bicornutus</i> (Latreille, 1825)	0.53 ± 1.59	Oc	17.58 ± 11.54	CT
<i>Mithraculus forceps</i> A. Milne-Edwards, 1875	9.38 ± 17.13	VC	7.83 ± 7.14	CT
<i>Mithrax braziliensis</i> Rathbun, 1892	0.4 ± 0.85	Co	0.42 ± 0.67	Co
<i>Mithrax hemphilli</i> Rathbun, 1892	0.19 ± 0.61	Oc	0.34 ± 0.65	Oc
<i>Mithrax hispidus</i> (Herbst, 1790)	0.32 ± 0.92	Oc	*	*

(continued on next page)

Table 1 (continued)

Decapod checklist	Subtidal		Intertidal	
	Ab.	Fr.	Ab.	Fr.
<i>Nemausa acuticornis</i> (Stimpson, 1870)	0.01 ± 0.07	Rr	*	*
<i>Thoe aspera</i> Rathbun, 1901	*	*	0.08 ± 0.28	Rr
<b>Pilumnidae</b>				
<i>Pilumnus dasypodus</i> Kingsley, 1879	*	*	0.5 ± 1.44	Oc
<b>Portunidae</b>				
<i>Callinectes marginatus</i> (A. Milne-Edwards, 1861)	0.02 ± 0.13	Rr	1.08 ± 1.44	Co
<i>Charybdis hellerii</i> (A. Milne Edwards, 1867)	0.02 ± 0.13	Rr	*	*
<b>Domeciidae</b>				
<i>Domecia acanthophora</i> (Desbonne, in Desbonne e Schramm, 1867)	0.22 ± 0.87	Rr	*	*
<b>Panopeidae</b>				
<i>Acantholobulus schmitti</i> (Rathbun, 1930)	*	*	3.75 ± 3.14	VC
<i>Hexapanopeus angustifrons</i> (Benedict e Rathbun, 1891)	*	*	1.67 ± 3.71	Oc
<i>Eurypanopeus abbreviatus</i> (Stimpson, 1860)	*	*	5.85 ± 3.84	CT
<i>Panopeus hartii</i> Smith, 1869	*	*	3.67 ± 4.77	CT
<i>Panopeus occidentalis</i> Saussure, 1857	*	*	0.92 ± 2.15	Oc
<b>Xanthidae</b>				
<i>Cataleptodius floridanus</i> (Gibbes, 1850)	*	*	1.83 ± 3.61	VC
<i>Platypodiella spectabilis</i> (Herbst, 1794)	0.01 ± 0.07	Rr	*	*
<b>Grapsidae</b>				
<i>Pachygrapsus transversus</i> (Gibbes, 1850)	0.01 ± 0.07	Rr	3.75 ± 3.41	CT
<i>Plagusia depressa</i> (Fabricius, 1775)	0.01 ± 0.07	Rr	*	*

(*Alpheus formosus*, *Upogebia affinis*, *Clibanarius scolopetarius*, *Acantholobulus schmitti* and *Cataleptodius floridanus*), and 5 common (*Hippolyte obliquimanus*, *Lysmata rathbunae* and *Thor manningi*, *Mithrax braziliensis* and *Callinectes marginatus*). Apart from the above species, 9 were occasional and 12 were considered rare (Table 1).

Frequency in subtidal samples resulted in only 2 constant decapods (*Cinetorhynchus rigens* and *Panulirus echinatus* Smith, 1869), 1 very common (*Mithraculus forceps*), and 3 common (*Janicea antiguensis*, *Stenopus hispidus* and *Mithrax braziliensis*); 10 species were occasional with largest amount 23 considered rare (Table 1).

#### 4. Discussion

A direct comparison cannot be made between the intertidal samples collected at Austregésilo-Filho, in 1992 and the subtidal samples from Giraldes 2007; 2012 because a different methodology was employed for each survey at different times. However the data collected is still of significant use for future research. As the same sample location along the reef system was used for both surveys and if researchers need base line data the same methodologies used in 1992, 2007 and 2012 can be adopted. The list of species presented in this research has the potential to be used as an excellent impact assessment tool in future investigations into physicochemical and anthropogenic effects of the reef system.

Dr. Petrônio Alves Coelho was one of the most renowned taxonomists in species form the northeastern Brazilian coast and presents a very thorough identification of all species listed, allowing researchers to have confidence in any identifications published in the list of species. In addition almost all the survey specimens have been deposited in his collection at the Oceanographic Museum of the Federal University of Pernambuco, providing future researchers with a valuable voucher sample library which can be accessed at anytime for a species comparison. Unfortunately some of the biological material reported in the reviewed studies was also lost in transit from the field to the Oceanographic museum and due to the length of time between surveys some samples have received new taxonomic description.

##### 4.1. Species of interest

The presence of *Lysmata rathbunae* Chace, 1970 in Porto de Galinhas, by Austregésilo-Filho (1992) and Coelho et al. (2002, 2006) needs to be confirmed as disregarded its presence on the Brazilian coast and reported the presence of two other species in its place, *Lysmata ankeri* Rhyne and Lin, 2006 and *Lysmata bahia* Rhyne and Lin, 2006. The shrimp reported by Rhyne and Lin in the 2006 study could however be *Lysmata bahia*, since it was reported to inhabit tidal-pools along the intertidal zone and displayed diurnal habit, in the same reef system sampled by Austregésilo-Filho (1992). Therefore it is

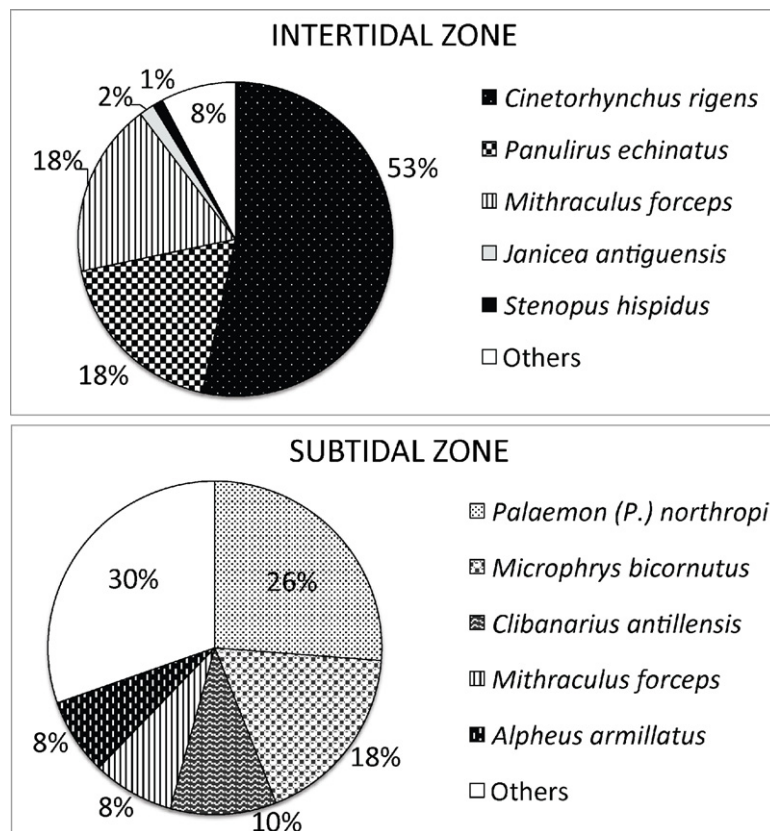


Fig. 5. Decapod abundance (%): Dominant species at Porto de Galinhas reef sampled in Subtidal and Intertidal zones.

necessary to confirm the presence of *Lysmata ankeri*, *Lysmata bahia*, and *Lysmata rathbunae* in Pernambuco coastal reefs, because according to Rhynne and Lin (2006) none of these species occur in this state. Coelho et al. (2006) reports as uncertain the presence of *L. rathbunae* in Pernambuco. It is important that the presence of any of these *Lysmata* in the studied reef system is corroborated, as this will represent a newly recorded occurrence.

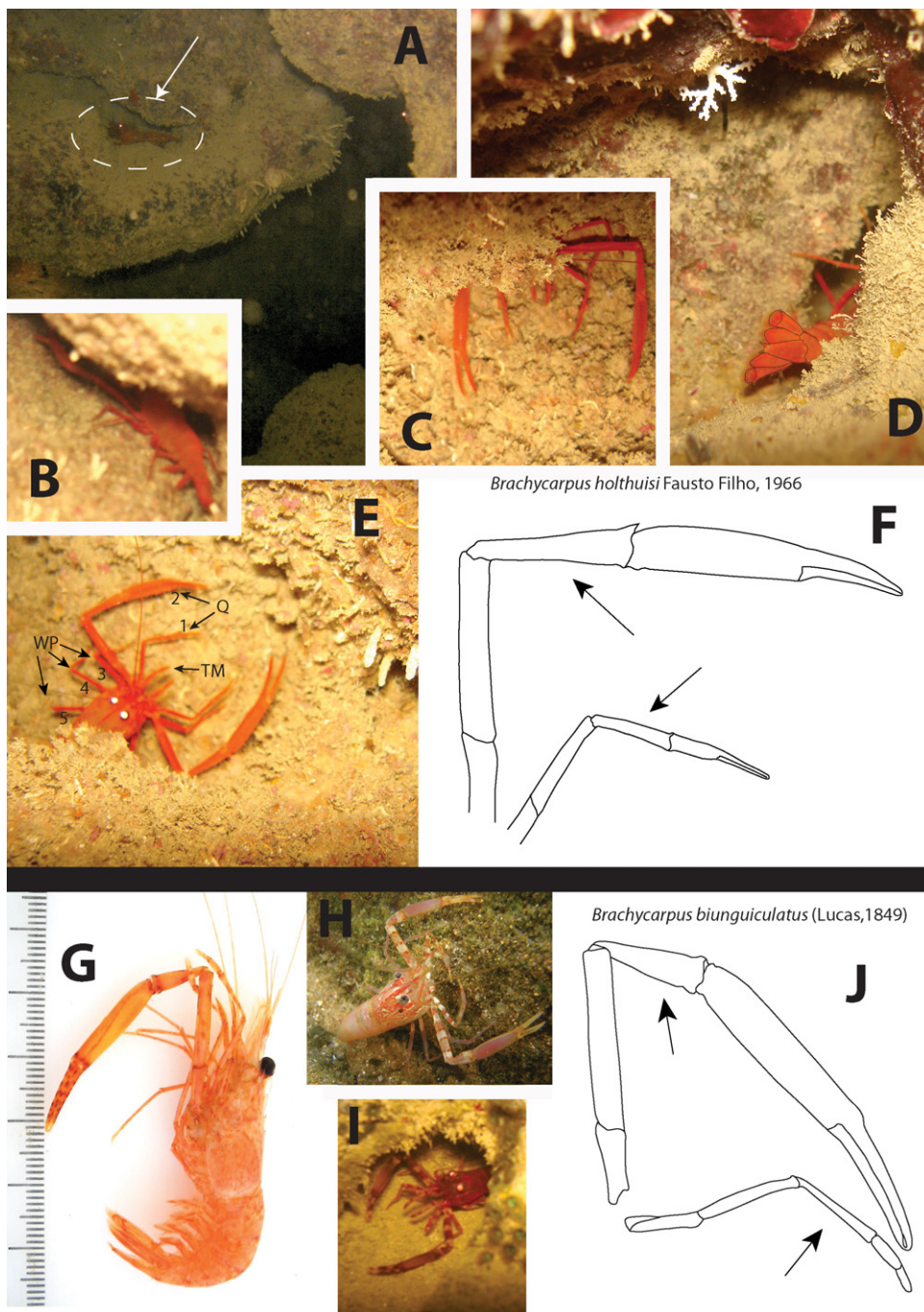
The need of a species confirmation is also presented within *Alpheus cf armillatus* H. Milne Edwards, 1837 and *Alpheus cf formosus* Gibbes, 1850, as both species recorded belong to a complex of species (Soledade and Almeida, 2013). The snapping shrimp *A. cf formosus* in the study could be *A. formosus* because Anker et al. (2008) that described the complex of this species exclude the other species from Brazilian waters and the Pernambuco state. However specimens of *Alpheus cf armillatus* described in the Pernambuco region, according with Soledade and Almeida (2013) could be two different species, *Alpheus carlae* Anker, 2012 or *Alpheus angulosus* McClure, 2002.

Caridea shrimp *Brachycarpus holthuisi* Fausto Filho, 1966 was recorded as a new occurrence for Pernambuco State, the species is endemic to Brazil but recorded only in the state of Ceará, in depths around 30–45 m without descriptions of color and habitat (Fausto Filho, 1966; Chace, 1972; Coelho et al., 2006). A reviewed study by Giraldes 2007;2012 discovered one example of *Brachycarpus holthuisi* (Fig. 6(A)–(F)) which was collected and identified during a SCUBA survey; and more individuals were observed and photographed in the reef caves. At the time it was misidentified as being *B. biunguiculatus*, however the work in this research confirmed the species as *Brachycarpus holthuisi*.

Only three species of genus *Brachycarpus* exist in the world (De Grave et al., 2009) and only two occur in Brazil (Coelho et al., 2006) all with first two pereiopods with chela and the second pair is longer, smooth and more robust. The *Brachycarpus* recorded during this research present some features described only for *B. holthuisi* by Fausto Filho (1966) and Chace (1972) such as: the carpus of first cheliped being short and thin and almost as long as the chela (Fig. 6(F)); carpus of second pereiopod is longer and slender and about half longer than the merus, and slightly as long as palm of chela (Fig. 6(F)) telson is narrower and 1,5 longer than six abdominal segment. In addition the recorded *B. holthuisi* in this study present a uniform orange colored pattern on the whole body (Fig. 6(B) and (E)). Similarly Fausto Filho (1966) recorded uniform color pattern in preserved animals without reporting the color details. It should also be noted that *B. biunguiculatus* collected in this work even after being conserved in alcohol for a long time still presented color details on the body and in the dactyl of large cheliped (Fig. 6(G)).

*B. holthuisi*, was recorded in this survey during night dives inside caves/grottos (Fig. 6(A)) around 4–8 m deep, and always inside small cavities in the substrate (Fig. 6(B) and (D)). It was noted during this research that *B. holthuisi* was a very retiring





**Fig. 6.** *Brachycarpus holthuisi* Fausto Filho, 1966 (A)–(F), photographed at night inside the cave reef in studied area, being: (A) features of cave with one specimen localized inside; (B) the uniform color; (C) chelipeds details; (D) the telson and uropods details; (E) color pattern in the anterior body part and proportion details of walking pereiopods [WP] cheliped [Q] and third maxiliped [TM]; and (F) detailed drawing from first [small] and second [large] chelipeds extracted from picture E, highlighting the size of carpus compared with chelae. *Brachycarpus biunguiculatus* (Lucas, 1849) (G)–(J) being: (G) animal photographed in laboratory, highlighting the body proportion and the color details after long time conserved in alcohol 70%; (H) photographed at day in coastal reefs of Salvador–Bahia; (I) photographed at night in reef fringe on studied area; and (J) detailed drawing from first cheliped [small] and second cheliped [large] extracted from picture G, highlighting the size of carpus compared with chelae. Photographic credits: (H) Cláudio Luis Santos Sampaio; (A–G, I, J) Bruno Welter Giraldes. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

species that immediately after being illuminated retreated back to its hiding-place, which made it extremely difficult to collect and photograph. This could explain why this shrimp was not recorded before 1966 and why only a few examples have been recorded in other states in northeastern Brazil and the Americas (Fausto Filho, 1966; Chace, 1972; Coelho et al., 2006).

The iconic species in this genus, *B. biunguiculatus* distinguished by its longer carpus in first minor cheliped; and shorter carpus in second large cheliped (Fausto Filho, 1966; Chace, 1972) (Fig. 6(J)) it also was photographed in the field during night dives. It was only found along the reef fringe near the water surface inside small cavities within the reef substrate (Fig. 6(I)). Voucher specimens were conserved in 70% alcohol and photographed in laboratory conditions (Fig. 6(G)).

This report extends the geographical range of *B. holthuisi* to 700 km south of its present documented boundaries along the Brazilian coast. The study can also confirm the presence of *B. holthuisi* at approximately a depth 25 m higher than previously recorded. The research also presents unique photographs of the species in the field and the first description of its natural color pattern in the shallow water habitat. However the only specimen collected was lost during transportation from the field to the university and, there is no deposited specimen to confirm its presence and therefore this record can be considered as uncertain.

The remainder of species sampled in Pernambuco state—Brazil (Coelho et al., 2002, 2006, 2007, 2008) reported here have specimens deposited at the oceanographic museum in Dr. Pertonio Alves Coelho collection at the Federal University of Pernambuco (MOUFPE).

#### 4.2. Habitat and environmental divisions

This study was carried out in a reef bank along a large coastal reef ecosystem in the northeast coast of Brazil and the notable differences were recorded between decapod assemblages in relation to shore zones (intertidal and subtidal). The results suggest a natural habitat restriction for certain decapod assemblages in relation to shore zones along the whole coastal reef ecosystem (Dominguez et al., 1990; Maida and Ferreira, 1997; Leão et al., 2003).

Some characteristics were common when targeting decapod assemblages in the intertidal zone or subtidal zones. Using the removal of substrate for a *a posteriori* identification of the targeted species in intertidal samples (Table 1) were small and or very small decapods such as; *Pitho lherminieri*, *Eurypanopeus abbreviatus*, *Hexapanopeus angustifrons*, *Acantholobulus schmitti*, *Panopeus hartii* and *Panopeus occidentalis* (Melo, 1996); others have a definite association with epilithic algal matrix (EAM), that cover some lighted areas in the studied reefs; such as *Cataleptodius floridanus*, *Macrocoeloma laevigatum*, *Microphrys bicornutus*, *Mithraculus forceps*, *Mithrax braziliensis*, *M. hemphilli*, *Acanthonyx dissimulatus*, *Epialtus bituberculatus* and *Pilumnus dasyopodus* (Melo, 1996; Melo and Veloso, 2005; Blanco et al., 2011).

Others were have endobenthic behavior such as *Upogebia affinis* (Melo, 1999) and the Alpheoidea species such as *A. armillatus*, *A. formosus*, *A. nuttingi*, *S. fritzmuelleri*, *S. longicarpus* (Coelho et al., 2002; Almeida et al., 2008; Soledade and Almeida, 2013); or can be associated with the tidal-pool habitat of the intertidal zone such as; *Paleomon northropi*; *Clibanarius antillensis*, *C. sclopettarius*, *Pachygrapsus transversus* and *Eriphia gonagra* (Melo, 1996, 1999; Pralon and Negreiros-Fransozo, 2006; Coelho et al., 2002).

In comparison the samples in the subtidal zone which were observed during nocturnal scuba diving could target large decapods that displayed nocturnal habits and are traded as ornamentals in aquarium stores or as commodities in fish markets; species that inhabited cryptic ecotypes such as caves and grottoes in hard substrate; and possessed colors and features that enabled visual identification *in situ*. Decapods displaying these characteristics included the fished lobsters *Panulirus argus*, *Panulirus echinatus* and *Panulirus laevicauda*; the bycatch species *Parribacus antarcticus*, *Palinurellus gundlachi*, *Dardanus venosus*, *Petrochirus diogenes*, *Dromia erythropus*, *Mithrax hispidus*, *Mithrax braziliensis*, *Mithrax hemphilli*, *Mithraculus forceps*, *Menippe nodifrons*, *Carpilius corallinus*, *Calappa ocellata* and *Plagusia depressa*; and ornamental decapods used in the aquarium trade such as; *Brachycarpus biunguiculatus*, *Calcinus tibicen*, *Cinetorhynchus rigens*, *Dardanus venosus*, *Enoplometopus antillensis*, *Palinurellus gundlachi*, *Petrochirus diogenes*, *Platypodiella spectabilis*, *Stenopus hispidus*, *Mithraculus forceps* and *Stenorhynchus seticornis* (Cervigón et al., 1992; Rocha et al., 1997; Melo, 1999; Calado et al., 2003; Gasparini et al., 2005; Corrêa et al., 2007; Freitas and Santos, 2007; Silva and Fonteles-Filho, 2011).

Species with wide distribution inhabit the same intertidal zone in different biogeographic regions as in subtropical rocky reefs in southern and southwestern Brazil, and also are captured using the same methods described here such as *Pachygrapsus transversus*, *Microphrys bicornutus*, *Mithraculus forceps*, *Eurypanopeus abbreviatus*, *Panopeus occidentalis*, *Pilumnus dasyopodus*, *Petrolisthes galathinus*, *Clibanarius antillensis*, *C. sclopettarius* *Cuapetes americanus* (as *Periclimenes americanus*) and *Synalpheus fritzmuelleri* (Masunari and Dubiaski-Silva, 1998; De Szechy et al., 2001; Turra and Denadai, 2001). In addition, following the functional equivalence, ecological equivalence or niche convergence theories (Hubbell, 2005, 2006), different species with the same genus but occurring in different biogeographic regions are reported as occupying the same habitat as species reported here: *Pachycheles haigae* Rodrigues da Costa, 1960, *Pachycheles monilifer* Dana, 1852, *Megalobrachium roseum* Rathbun, 1900, *Acanthonyx petiverii* H. Milne Edwards, 1834, *Hexapanopeus paulensis* Rathbun, 1930 and *Epialtus brasiliensis* Dana, 1852 reported to subtropical rocky reefs in intertidal zone at south and southern Brazil (Masunari and Dubiaski-Silva, 1998; De Szechy et al., 2001).

The same is true for widely distributed species that inhabit cryptic habitats in the subtidal zones that have also been studied using scuba diving in temperate subtropical waters along rocky reefs in southern and southwestern Brazil, such as *Mithraculus forceps*, *Mithrax hispidus*, *Pelia rotunda*, *Stenorhynchus seticornis*, *Menippe nodifrons*, *Calappa ocellata*, *Platypodiella spectabilis*, *Panulirus argus*, *Panulirus laevicauda*, *Enoplometopus antillensis* and *Stenopus hispidus*. Also, species of the same genus that occur in cold subtropical waters were likewise reported using scuba diving as a sampling methodology in subtropical rocky reefs: *Mithrax tortugae* Rathbun, 1920, *Calappa gallus* (Herbst, 1803) and *Dardanus insignis* (de Saussure, 1858) (Gregati et al., 2006; Bouzon and Freire, 2007; Teschima et al., 2012).

Therefore it is possible to find the same wide distribution of species inhabiting the same habitat and zone using the same sampling methodologies in different ecoregion (Spalding et al., 2007). According with each biogeographic ecoregion it is possible to find different species occupying the same habitat and niche and even within the same genus due to different environmental conditions and trophic pressures, (Hubbell, 2005, 2006) and certainly this mosaic of species distribution, biodiversity and biocenosis will oscillate according with several abiotic and biotic ranges.

The present study revealed an interesting result with regards to the proportion of decapods in suborder and Infraorder because they present similar numbers of suborder with 1 Dendrobranchiata for each zone and 41 Pleocyemata in intertidal and 38 in subtidal zone; and the same number of species in some Infraorder as 21 Brachyura, 6 Anomura, and 1 Stenopodidea for each zone. Even with a similar proportion of Infraorder the composition of species was totally different highlighting the amazing specificity of habitat for decapod species.

The differences in Infraorder composition in the intertidal zone in this study is accounted for by the high number of Caridea species present, the methodology involved the removal of substrate and this was reflected in the numbers of the Genus *Alpheus* and *Synalpheus* recorded during the work. These species are known for their high diversity and endobenthic behavior (De Grave et al., 2009; Soledade and Almeida, 2013); the same is true of the Gebiidae an endobenthic group (Melo, 1999).

In comparison only two Infraorder were recorded in the subtidal zone Astacidea and Achelata (Melo, 1999) and were encountered as a result of the use of scuba which allowed access to the caves and dark cavities in the subtidal reef structures were these decapods frequent. These large lobsters with cryptic behavior will not appear along the intertidal zone or tidal-pools by day.

The Brachyura followed by Caridea and Anomura represented the richest taxa in each sampled shore zone and for the studied reef system, similar to the findings described by Coelho et al. (2002) for the Pernambuco State in the northeast of Brazil (Coelho et al., 2006, 2007, 2008) and globally by De Grave et al. (2009). In addition, similar findings to those described in this research, show certain some taxa, such as; Alpheidae for Caridea and Majidae for Brachyura are prolific in numbers in Pernambuco State (Coelho et al., 2002, 2006, 2007, 2008) and in the world (De Grave et al., 2009). This proliferation has a long historical record for decapods in the ocean, with changes in speciation according ocean changes over a long period of time coupled with high adaptive values for groups with higher diversity; such as efficient body shape, productive strategies in obtaining food reproduction and defense (Távora et al., 2010). This is demonstrated within the brachyuran crabs that possess a great plasticity of shape, size and diet allowing them to live in several microhabitats (Melo, 1996), which explain their great diversity.

This study highlights the importance of a habitat specific decapod checklist with descriptions of environmental and behavior relationships specific to each species. The absence or presence of decapod species within a specific zone can be an indicator of environmental disturbance from physicochemical or anthropic inputs. Mainly because the decapods represent one of the most important taxon in the marine ecosystem, being a key group in trophic relations within all marine trophic chains (Abele, 1974; Melo, 1996, 1999; Coelho et al., 2006, 2007, 2008; De Grave et al., 2009; Dubinsky and Stambler, 2011).

Decapods are dominant within in a number of environmental niches such as; Cryptofauna that inhabit biogenic reefs (live deeply embedded within the interstitial reef spaces) and display symbiotic behavior with sessile organisms, providing important protection and defense to their hosts such as; algae, coral, zoanthid and echinoderms. They have a close trophic relationship with reef fish and provide a food source to many other species within the reef system (Randall, 1967; Wirtz et al., 2009; Stier et al., 2010; Stier and Leray, 2013).

The quantitative result that displayed only a few dominant species, but high abundance and high frequency, for both methodologies, may be the natural decapod pattern for the investigated reef system. The high dominance displayed for only a few species is a typical climax characteristic of an old established ecosystems and this has been corroborated in previous studies carried out by Leão et al. (2003), who described the corals and hydrocorals that form the studied reefs in the northeast Brazil areas as archaic animals. The same author states that due to Amazon River plume, these local reefs have been preserved and remained isolated in Northeastern Brazil since the Pleistocene.

#### 4.3. Scientific scuba diving as a research tool in decapod studies

Coelho et al. (2002) described 312 decapods for the Pernambuco state—Brazil, with a habitat division specific to each decapod assemblage which encompassed environments under a general heading such as; mangrove, marine soft bottom, coastal biogenic reefs (hard bottom), with a group of a few species occupying restricted zones and environments like the reef system described in this research. Therefore the 71 decapod species recorded during this intensive research of one reef structure could be used as a representative template for the carcinofauna for coastal reefs in the Pernambuco state. The current list of species also allows researchers to divide the species list further into habitat divisions, with 42 species listed as intertidal and 39 subtidal and with only 10 species occurring in both zones (Melo, 1996, 1999; Coelho et al., 2002; Wirtz et al., 2009).

Almeida et al. (2008) completed a similar decapod checklist performed for a hard substrate habitat at a coastal island located close to the studied reefs. Differences of decapod composition between Almeida et al. (2008) and this study have been noted and can be attributed to a mangrove area close to were the samples were collected as the collected decapods displayed characteristics synonymous with estuarine areas. This study however employed scuba diving as a collection method and allowed the scientists access to more complex reef structures and therefore encounters with more ornamental and large decapods that live in cryptic habitats. The large similarities between the decapod assemblage in Almeida et al. (2008) and

the assemblage in this present study suggest that the species reported here represent the decapod assemblage in all coastal hard substrate environments in northeastern Brazil and can only oscillate influenced by external factors such as adjacent mangrove estuarine close to reef area.

This study emphasizes the value of adopting scuba diving as a research tool when studying decapods, and agrees with Lang et al. (2013) that there has been a revolution in research and discoveries in marine sciences since the use of scuba diving within the last years. Without this tool it would have been virtually impossible to sample some of the species in this study such as: *Janicea antiguensis*, *Brachycarpus holthuisi*, *Palinurellus gundlachi* and *Enoplometopus antillensis*, and other decapods that display cryptic habits and are found in difficult to access areas of the reef. The use of scuba also allowed researchers to describe new occurrences and distribution patterns for decapods in Brazilian waters (Mantelatto et al., 2004; Bouzon and Freire, 2007; Teschima et al., 2012; Alves et al., 2012; Girdes et al., 2012a,b).

The other great advantage of using scuba diving is it allows the scientist to study the decapod *in-situ* especially species like *Panulirus argus*, *Panulirus echinatus* and *P. laeviscauda*, which are directly affected by the fishing market. The monitoring of these valuable species has the knock on effect of presenting the researcher an opportunity to study decapod species associated with the market dominant ones; *Carpilius corallinus*, *Parribacus antarcticus*, and *Plagusia depressa* usually found in local fishing markets and captured as bycatch species (Rocha et al., 1997); and some ornamental species traded and coveted by aquarium hobbyists such as *Stenopus hispidus*, *Enoplometopus antillensis*, *Calcinus tibicen*, *Mithraculus forceps* which in themselves command a high individual trade value Calado et al., 2003, Gasparini et al., 2005.

In other words to study decapods comprehensively this research advises the use of scuba diving as it allows direct contact with the ecosystem and animals being studied. It offers a means of creating a visual census to compound information on the demands of a fishing industry targeting these crustaceans. Information obtained can be used to highlight public awareness of any detrimental impacts on stocks and can be used to inform authorities on the need to police stocks and manage and monitor accordingly.

In conclusion, the use of scientific scuba diving to study decapods is an important addition to complement the traditional methodologies used when creating a decapod checklist and represents an important tool to study and monitor the decapod assemblage in reef environments in general, especially in fragile coral reefs in protected marine areas.

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