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Abundance and diversity of deep-sea crustaceans (Decapoda and Isopoda) in the upper slope of state of Pernambuco–Brazil: With five new records

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Abstract :

In this paper the taxonomic composition, abundance, diversity and distribution of the deep-sea crustaceans collected from upper slope of Pernambuco, northeast Brazil, were described in order to provide baseline data for extend local fauna knowledge. Specimens were collected by standardized fishing sets with bottom baited traps between October 2014 to March 2018, at depths ranging from 200 to 600 m. Catch composition was consisted of 12 species (N = 690) distributed in two orders: Decapoda (57.8%) and Isopoda (42.2%). Five species were new occurrences to state of Pernambuco: three species of Cirolanidae (Bathynomus giganteus, B. miyarei and B. obtusus) and two of Paguroidea (Mixtopagurus paradoxus and Paguristes inconstans). It was observed a striking catch predominance of the soldier striped shrimp Plesionika edwardsii (CPUE 44.67 ind/trap) followed by giant isopod B. miyarei (CPUE 30.33 ind/trap) overall. In terms of latitudinal section, south coast presented the highest CPUE (10.26 ind/trap), and night period was most representative (8.58 ind/trap). Results reported herein contribute to understand abundance and distribution at depth and latitudinal features as also providing new records of deep-sea crustaceans from the state of Pernambuco.

Keywords : Depth distribution, CPUE, Atlantic Ocean, Crustacea and Trap Fishery

Introduction

The deep-sea is presumed as the place beyond the continental shelf at depths greater than 200 m, occupying 60% of the planet and is the largest marine habitat, comprising 84% of the ocean area (Gage and Tyler, 1991; Angel, 1997; Costello and

Chaudhary, 2017). However, this environment was one of the last to be explored by human being and can shelter many species still unknown. In addition, has unique characteristics such as absence of sunlight, low temperatures, high pressure and absence of primary production, except by the chemotrophic bacteria activity, which led to a specialized fauna for deep-sea environment (Drazen and Suton, 2016).

Development technologies used for prospecting life at deeper waters, such as closed-circuit rebreathers, manned submersibles, baited remote underwater stereo-videos and remotely operated vehicle adding to already known fisheries equipment as nets, traps and dredges, has shown that these regions are a potential reservoirs of biodiversity on Earth (Rex et al., 2006; Costello et al., 2010; Pinheiro et al., 2020; Sumida et al., 2020), especially due to the macro and semi-benthic fauna where crustaceans are included (Snelgrove and Smith, 2002; Kitahara, 2009; Ramirez-Llodra et al., 2010).

Currently, more than 52 thousand species of marine crustaceans were described and validated around the world, occupying fourth position in species richness (Martin and Davis, 2001; Ng et al., 2008; De Grave and Fransen, 2011; AToL, 2022; WORMS, 2022). In Brazilian deep-sea, we can highlight the performance of REVIZEE Program (Evaluation of the Sustainable Potential of Living Resources in the Brazilian Exclusive Economic Zone) between 1999 and 2005, OCEANPROF (Oceano Profundo) from 2001 – 2007, Projeto de Monitoramento Ambiental Marinho da Bacia Potiguar from 2009 – 2011, HABITATS (Heterogeneidade Ambiental da Bacia de Campos) from 2008 – 2015, and more recently the project ABRACOS (Acoustics along the Brazilian coast) from 2015 – 2017, added to other independent initiatives from research groups carried out surveys to the mid- and upper continental slope, seamounts and oceanic islands has pointed out the high diversity in deep-sea regions even in extreme environmental conditions (Silva et al., 1998; Viana et al., 2003; Coelho Filho, 2006; Pezzuto et al., 2006; Serejo et al., 2007; Melo, 2008; Arana et al., 2009; Lavrado and Brasil, 2010; Oliveira et al., 2014; Bertrand, 2015, 2017; Nilsen et al., 2015; Oliveira et al., 2015; Ferreira et al., 2016; Nunes et al., 2017; Mincarone et al., 2019; Cardoso et al., 2021).

A recent publication compiled information on the richness of decapod crustaceans species from native deep-sea in Brazilian waters reporting increase the number of species to 181, distributed in two suborders, Dendrobranchiata (32) and Pleocyemata (149) (Cardoso et al., 2021). For the Isopoda, studies showed results about biology and ecology in catches from continental slope of southern Brazil (Boos et al., 2021).

Nonetheless, despite ecological and fishing importance of deep-sea crustaceans, which play a key role in the balance of marine ecosystems, information provided by these initiatives remains incipient and this biota still neglected (Longhurst and Pauly, 2007). Focused to fill this gap and extend the fauna knowledge off Brazilian slope, specifically in Brazilian northeast, surveys using baited traps were carried out to investigate diversity, abundance and distribution at depth and latitude features of deep-sea crustaceans off state of Pernambuco slope, including specific records than those previously performed for the region.

Material and Methods

Ethics statement

Data used in this research were obtained with full approval of the Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) of the Brazilian Ministry of the Environment (permit no. 53702-3). The Commission of Ethics on the Usage of Animals from the Federal Rural University of Pernambuco (license no. 044/2016; protocol no. 23082.025800/2015) approved capture methods.

Study area

This study was conducted on the outer margin of the continental shelf of Pernambuco state, northeast Brazil, characterized by reduced width (average of 35 km), gentle slope, shelf break between 50 – 60 m depth, relatively warm waters, high salinity and algal limestone dominating the bottom up to 100 m depth (Manso et al., 2006). On the other hand, leaning of upper part of the continental slope is very abrupt, assuming the smoothest slope from 500 m onwards (Kempf, 1970). Continental rise, corresponding to the plateau of Pernambuco, slope reaches 46 km in width, with a minimum declivity of 1.5 m/km, an upper level between 700 and 1,250 m in depth and a lower level between 2,000 and 2,400 m.

Fishing and sampling methods

Exploratory fishing sets using bottom baited traps were carried out in the upper slope off Pernambuco state, aboard the research vessel "Sinuelo" which is 13 m long and 3.40 m of maximum breadth. Sampling were accomplished between 07°50'S/34°27'W and 08°52'S/34°47'W, from October 2014 to March 2018 (Figure 1). Three different types of bottom baited traps were set up and deployed as fishing gear far 20 m apart from each other: big rectangular, 2.0 x 0.9 m, with 30 cm opening; medium rectangular, 2.0 x 0.6 m, and 20 cm opening; and circular, with 60 cm diameter and 30 cm opening (Figure 2). Traps were covered by a 25 mm plastic mesh and were baited with 500 g of *Scomber japonicus*. All traps were set at depths ranging from 200 to 600 m and a mean immersion time of 13.5 h (ranging from 6 to 27 h).

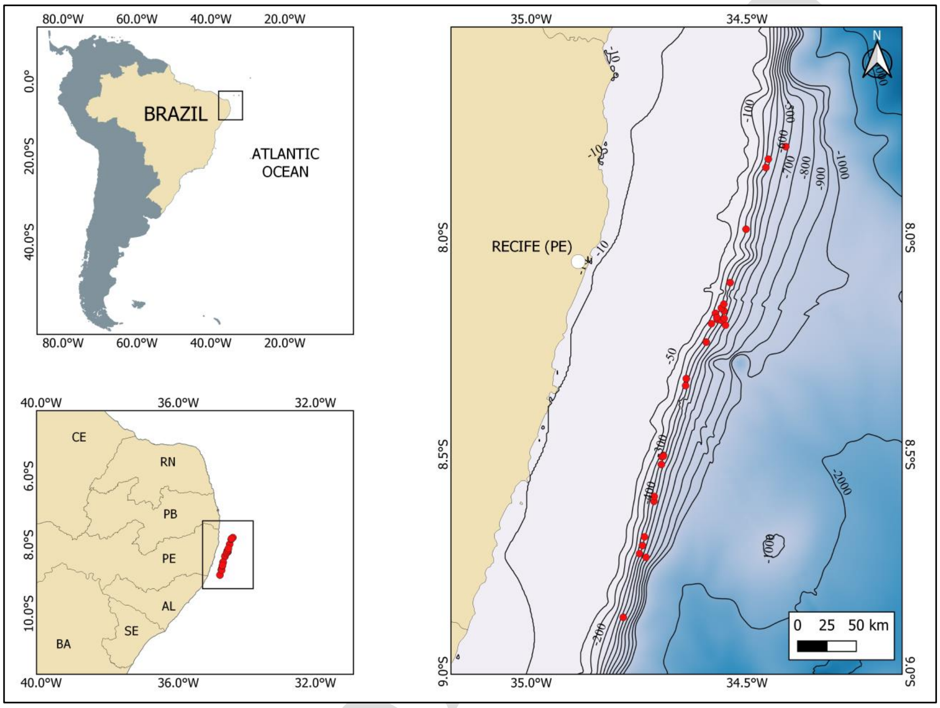

Figure 1. Study area of Pernambuco, northeast Brazil, on the upper slope of continental shelf between depths of 200 and 600 m. Red dots represent fishing set carried out.

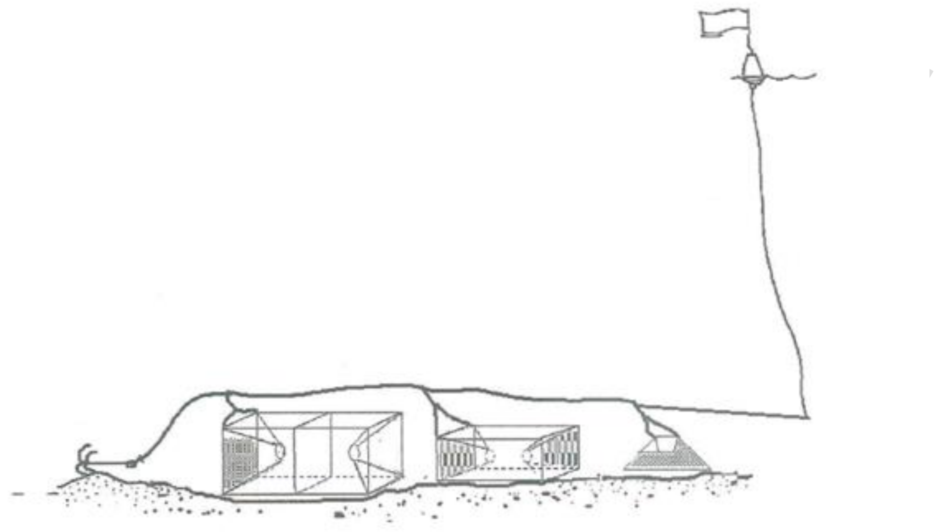

Figure 2. Traps models used to collect malacostracan from upper slope of Pernambuco state (adapted from Oliveira et al., 2015).

Species identification

Collected species were photographed, labeled and stored on ice, until transport to the Fisheries Oceanography Laboratory - LOP, at the Fisheries and Aquaculture Department of Federal Rural University of Pernambuco, where they were analyzed. All specimens were identified at the lowest taxonomic level, whenever possible, according to specific bibliography (Crosnier and Forest, 1973; McLaughlin and Provenzano, 1974; Melo, 1996; Rego and Cardoso, 2010; Paiva, 2012). Specimens were deposited at the Oceanography Museum Petrônio Alves Coelho from the Federal University of Pernambuco (MOUFPE) and in the Didactic Collection of Marine Invertebrates at LOP-UFRPE.

Data Analysis

After sampling and species identification, specimens were counted and analyzed by relative abundance and constancy using the equations described below. Species abundance can be expressed as the number of individuals at a given sampling point (Brower et al., 1989), and relative abundance as:

Relative abundance = (Species abundance/total number of individuals) x 100;

Species with less than 0.5% of the total number of individuals were considered rare.

Constancy index (C) for each species was calculated according Dajoz (1973), by the formula:

(C) = p. 100 / P, where p is the number of samples wherein the species occurred and P is the total number of samples taken. In this sense, species can be classified into three different categories: constant ($C \geq 50\%$), accessory ($25\% < C < 50\%$) and accidental ($C \leq 25\%$).

Community diversity (H') was estimated by Shannon-Wiener index, as well as its components: species richness through the Margalef index (d) and Piellou evenness (E), by depth range (200 to 600 m), time of day ("Day" and "Night") and latitudinal section (North/Center/South). Diversity indices were calculated in the R software (R Development Core Team, 2022) using the vegan package.

Distribution and relative abundance of crustaceans were also analyzed based on the number of individuals captured (total and suborders) and catch-per-unit-of-effort (CPUE), expressed in the number of individuals captured per trap (ind/trap), by depth stratum, latitudinal section and time of day. As the CPUE variation in the depth, position and time of day were not homogeneous, we used the Kruskal-Wallis (distributions by depth stratum and latitudinal section) and Mann-Whitney (for shift distributions) tests to assess the significance of the statistical differences. Analyzes were performed using the R program for estimates of abundance (CPUE), richness, and diversity, all at a significance level of 5%, and were plotted using ggplot2 (Wickham, 2016).

Results

Species Composition

During the research 38 surveys using baited bottom traps were carried out between depths comprising 218 m (Station 10) and 600 m (Station 18), with hauls located in the center area and during night (Table 1). A total of 690 individuals of class Malacostraca were collected belonging to the orders Decapoda (57.8%) and Isopoda (42.2%). The Decapoda had the biggest representation, with three infraorder: Brachyura (7.4%), Caridea (46.1%) and Anomura (3.6%), while isopods belonged to suborder Cymothoida (Table 2).

Table 1. Sampling point, latitude, longitude, depth, area and time of day of fishing hauls using baited bottom traps in the State of Pernambuco, Brazil.

Fishing set	Latitude (S)	Longitude (W)	Depth (m)	Area	Time of day
1	08° 11' 15,0"	034° 34' 26,0"	238	Center	Night
2	08° 11' 13,0"	034° 34' 09,0"	300	Center	Night
3	07° 59' 13,4"	034° 30' 16,9"	297	North	Night
4	07° 58' 49,6"	034° 30' 08,6"	300	North	Night
5	08° 12' 07,0"	034° 32' 59,0"	508	Center	Day
6	08° 11' 40,0"	034° 32' 52,0"	500	Center	Day
7	08° 11' 19,3"	034° 34' 07,6"	312	Center	Night
8	08° 11' 26,5"	034° 33' 33,5"	405	Center	Night
9	08° 20' 28,6"	034° 38' 32,6"	309	Center	Night
10	08° 19' 30,2"	034° 38' 26,1"	218	Center	Day
11	08° 30' 07,5"	034° 41' 37,7"	307	South	Night
12	08° 30' 18,2"	034° 41' 49,7"	290	South	Day
13	08° 14' 27,2"	034° 35' 40,2"	301	Center	Night
14	08° 31' 22,8"	034° 41' 54,9"	311	South	Night
15	08° 30' 14,3"	034° 41' 37,0"	319	South	Day
16	07° 50' 16,7"	034° 27' 22,9"	400	North	Night
17	07° 50' 01,6"	034° 27' 18,1"	395	North	Day
18	07° 47' 23,2"	034° 24' 36,5"	600	North	Night
19	08° 52' 30,0"	034° 47' 12,9"	500	South	Night
20	08° 43' 42,5"	034° 44' 57,3"	405	South	Night
21	08° 42' 35,8"	034° 44' 32,1"	418	South	Night
22	08° 41' 23,0"	034° 44' 15,5"	406	South	Day
23	08° 44' 13,8"	034° 44' 02,3"	382	South	Day
24	08° 36' 28,6"	034° 42' 56,1"	402	South	Night
25	08° 35' 48,4"	034° 42' 53,2"	395	South	Night
26	08° 31' 57,3"	034° 41' 38,1"	410	South	Day
27	08° 31' 20,6"	034° 41' 39,0"	380	South	Day
28	07° 49' 07,8"	034° 27' 02,7"	407	North	Night
29	08° 10' 09,6"	034° 33' 11,8"	402	Center	Night
30	08° 09' 44,1"	034° 33' 34,0"	300	Center	Night
31	08° 10' 28,5"	034° 34' 23,2"	300	Center	Day
32	08° 11' 12,2"	034° 33' 09,6"	300	Center	Night
33	08° 11' 03,7"	034° 34' 11,5"	270	Center	Night
34	08° 11' 54,7"	034° 34' 56,5"	256	Center	Day
35	08° 10' 52,6"	034° 34' 14,7"	225	Center	Night
36	08° 09' 12,0"	034° 33' 13,0"	324	Center	Night
37	08° 07' 11,0"	034° 32' 25,5"	367	Center	Day
38	08° 06' 13,3"	034° 32' 20,2"	311	Center	Night

Table 2. Composition of malacostracan species collected in trap surveys, between 2014 and 2018, on the upper slope of the continental shelf of Pernambuco (Brazil), with data on relative abundance (RA) and constancy (C).

Order	**Suborder**	**Infraorder**	**Family**	**Scientific Name**	**n**	**RA**	***C***
Isopoda	Cymothoida		Cirolanidae	*Bathynomus miyarei*	289	41.88	35.56
				Bathynomus giganteus	1	0.14	2.22
				Bathynomus obtusus	1	0.14	2.22
Decapoda	Pleocyemata	Brachyura	Epialtidae	*Minyorhyncha crassa*	4	0.58	4.44
				Rochinia gracilipes	2	0.29	4.44
				Stenocionops spinosissimus	42	6.09	15.56
			Polybiidae	*Bathynectes longispina*	3	0.43	6.67
		Caridea	Pandalidae	*Heterocarpus ensifer*	16	2.32	4.44
				Plesionika edwardsii	307	44.49	20.00
		Anomura	Diogenidae	*Paguristes inconstans*	23	3.33	4.44
			Pylochelidae	*Mixtopagurus paradoxus*	1	0.14	2.22
			Parapaguridae	*Parapagurus* sp.	1	0.14	2.22
				Total	690	100.00	
				Species	12		

For the species collected, individuals of the Cymothoida belong to three species, all of the Cirolanidae Dana, 1852: *Bathynomus giganteus* A. Milne-Edwards, 1879, *B. miyarei* Lemos de Castro, 1978, and *B. obtusus* Magalhães and Young, 2003. The most representative in relation to the number of species collected was infraorder Brachyura (4), being three of family Epialtidae MacLeay, 1838, *Minyorhyncha crassa* A. Milne-Edwards, 1878, *Rochinia gracilipes* A. Milne-Edwards, 1875, and *Stenocionops spinosissimus* de Saussure, 1857, and one of family Polybiidae Ortmann, 1893, *Bathynectes longispina* Stimpson, 1871. Infraorder Caridea Dana, 1852, formed for shrimp, was represented by *Plesionika edwardsii* Brandt, 1851, and *Heterocarpus ensifer* A. Milne-Edwards, 1881, both belonging to the Pandalidae Haworth, 1825. Infraorder Anomura MacLeay, 1838, was represented by three species, all hermit crabs, distributed into three families: Diogenidae Ortmann, 1892, *Paguristes inconstans* McLaughlin and Provenzano, 1975; Pylochelidae Bate, 1888; *Mixtopagurus paradoxus* A. Milne-Edwards, 1880; and Parapaguridae Smith, 1882; *Parapagurus* sp. Smith, 1879 (Figure 3).

The species of *P. edwardsii* were the most numerous with 307 individuals captured (44.49% of the total in number). The second most abundant species was the deep-sea isopod *B. miyarei*, with 289 individuals, accounting for 41.88% of the captures in number.

This isopod species also showed greater capture constancy between sampling stations (35.56%), which is, in addition to its high abundance, more present in the sampled points.

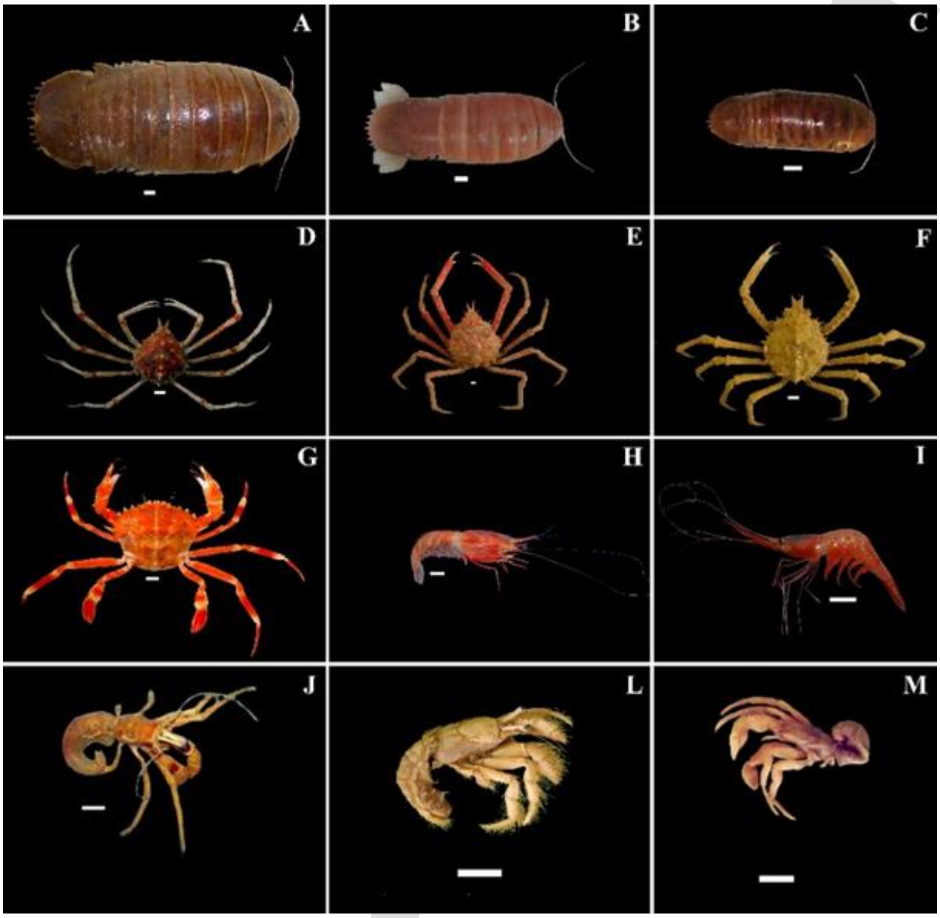

Figure 3. Deep-sea malacostracan species collected from the upper slope of Pernambuco state. A) *Bathynomus giganteus*; B) *B. miyarei*; C) *B. obtusus*; D) *Minyorhyncha crassa*; E) *R. gracilipes*; F) *Stenocionops spinosissimus*; G) *Bathynectes longispina*; H) *Heterocarpus ensifer*; I) *Plesionika edwardsii*; J) *Paguristes inconstans*; L) *Mixtopagurus paradoxus*; M) *Parapagurus* sp. Scales: 5 cm (H – I), 1 cm (J – M).

The tenspine spider crab *S. spinosissimus* was the third species with the highest relative abundance and constancy (AR = 6.09% and CO = 15.56%). Other species had a relative abundance below 1% and a constancy ranging between 2.22 and 6.67%, among them *B. longispina* obtained a higher constancy than the others.

In general, there are six species considered rare in the surveys: *B. giganteus*, *B. obtusus*, *R. gracilipes*, *B. longispina*, *M. paradoxus* and *Parapagurus* sp., that presented relative abundance below 0.5%. Regarding constancy, only *P. edwardsii* and *B. miyarei* were considered accessory, even with values very close to 50%, and all other species were classified in the accidental category (C ≤ 25%).

Diversity

The total richness observed reached 12 species, varying between 14.60 for the Chao sampler and 16.92 for the second order Jackknife, thus suggesting that between 71% and 82% of the fauna accessible to the collection methodology were recorded. Shannon's diversity index (*H'*) per depth stratum ranged between 0.00 and 1.43 and Pielou's equitability index (E) between 0.000 and 0.637. The depth range between 500 – 600 m had the highest richness and evenness index, while the range between 200 and 300 m had the highest diversity and evenness index (respectively, Shannon-Wiener *H'* = 1.026 and Pielou E = 0.637). The results suggest a well-defined pattern of decreasing diversity, evenness and species richness in the intermediate depth strata, between 300 and 500 m, increasing again in the deepest stratum.

There is a sharper drop in the indices from the third to the fourth depth stratum, rising again to 500 – 600 m, the richest zone. Although the number of individuals captured in the time of day "Night" was expressively higher when compared to those captured during the "Day", the ecological indices estimates were higher in the “Day”, with richness *d* = 1.828, evenness E = 0.704 and diversity *H’* = 1.464. In relation to the latitudinal section, the southern region had the greatest richness and greater diversity (Shannon-Wiener *H'* = 1.182), but with less evenness between sections (Pielou E = 0.476) (Figure 4).

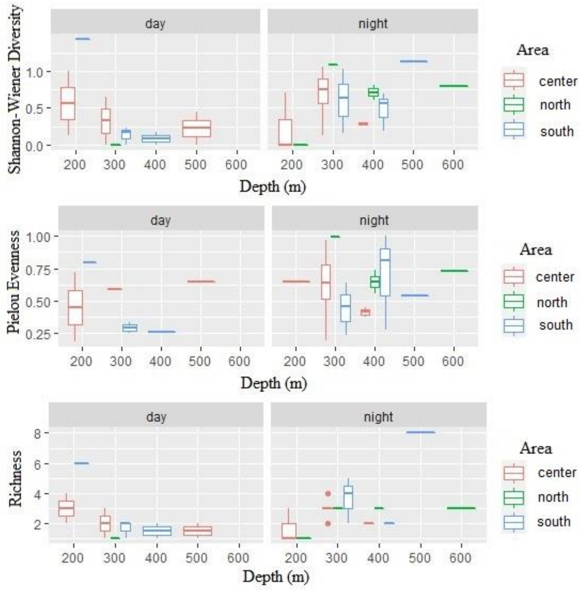

Figure 4**.** Shannon-Wiener, Pielou's evenness and Richness diversity indices obtained by latitudinal section, time of day and depth stratum of captured malacostracan from the upper slope of Pernambuco state, Brazil.

Bathymetric distribution

Anomura dominated the shallower strata, between 200 and 300 m, while Brachyura species were found in all depth strata. Caridea were more frequent in isobaths close to 300 m, with records of *Plesionika edwardsii* at 500 m depth. Among the species of the Brachyura, *Bathynectes longispina* was more frequent at depths between 400 and 500 m, *Rochinia gracilipes* had a uniform distribution between 200 and 500 m, *Minyorhyncha crassa* was collected only at a depth of 500 m, and *Stenocionops spinosissimus* between 200 and 400 m, predominantly in the 300 m isobath. The isopods (Cirolanidae) dominated the deepest strata, between 400 and 500 m, with records between 300 and 600 m (Figure 5).

Brachyura and isopods were well distributed, while the Anomura had its distribution restricted to the South section. The species of Caridea had the highest abundance between the Center and North sections. In general, the soldier striped shrimp *P. edwardsii* and the isopod *B. miyarei* were the most abundant species along the bathymetric distribution.

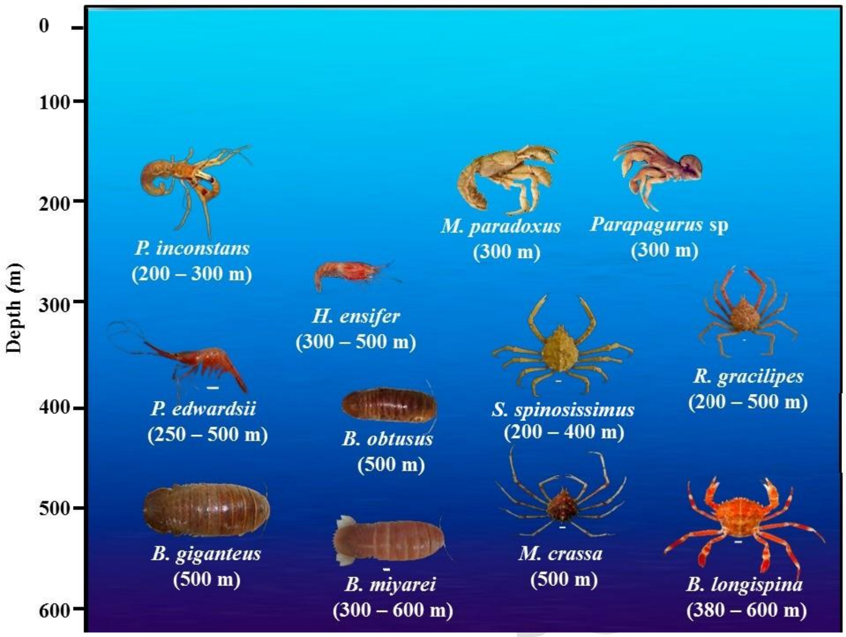

Figure 5. Vertical distribution of deep-sea malacostracan species from the upper slope of Pernambuco state, Brazil.

The overall nominal CPUE of the 38 fishing sets ranged from 0.00 to 50.00 ind/trap, with the highest values found for *P. edwardsii* (44.67 ind/trap) followed by *B. miyarei* (30.33 ind/trap). The highest CPUE per latitudinal section was observed in the south coast with 10.26 ind/trap against 4.26 ind/trap in the center and 2.61 ind/trap in the north (average 5.71 ± 4.02 ind/trap) (Figure 6; Table 3).

Table 3. Mean values of CPUE, latitudinal section, depth range grouped by suborders/infraorder and species

	Total Average	**Time of day**		**Area**			**Depth stratum**							
		Day	**Night**	**North**	**Center**	**South**	**200 - 250**	**250 - 300**	**300 - 350**	**350 - 400**	**400 - 450**	**450 - 500**	**500 - 550**	**550 - 600**
Total average	**6.05 (± 11.77)**	**1.18**	**8.59**	**2.61**	**4.26**	**10.26**	**2.11**	**2.50**	**8.90**	**0.13**	**5.81**	**0.00**	**13.22**	**5.33**
Suborder/infraorder														
Brachyura	0.45	0.23	0.56	0.39	0.30	0.69	0.33	0.25	0.90	0.13	0.07	0.00	0.56	0.33
Caridea	2.83	0.31	4.15	0.17	1.58	5.90	0.00	1.67	7.26	0.00	0.00	0.00	2.22	0.00
Anomura	0.22	0.59	0.03	0.00	0.32	0.18	1.78	0.58	0.05	0.00	0.00	0.00	0.00	0.00
Cymothoida	2.55	0.05	3.85	2.06	2.07	3.49	0.00	0.00	0.69	0.00	5.74	0.00	10.44	5.00
Species														
Bathynomus miyarei	2.54	0.05	3.83	2.03	2.07	3.44	0.00	0.00	1.13	0.00	6.46	0.00	10.22	5.00
Bathynomus giganteus	0.01	0.00	0.01	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00
Bathynomus obtusus	0.01	0.00	0.01	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00
Plesionika edwardsii	2.69	0.31	3.93	0.17	1.58	5.49	0.00	0.74	11.67	0.00	0.00	0.00	0.78	0.00
Heterocarpus ensifer	0.03	0.00	0.21	0.00	0.00	0.41	0.00	0.00	0.13	0.00	0.00	0.00	1.44	0.00
Stenocionops spinosissimus	0.37	0.09	0.47	0.33	0.28	0.51	0.22	0.11	1.46	0.00	0.08	0.00	0.00	0.00
Minyorhyncha crassa	0.04	0.00	0.05	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.00
Rochinia gracilipes	0.02	0.03	0.01	0.00	0.02	0.03	0.11	0.00	0.00	0.00	0.00	0.00	0.11	0.00
Batyhynectes longispina	0.03	0.03	0.03	0.06	0.00	0.05	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.33
Paguristes inconstans	0.32	0.54	0.03	0.00	0.32	0.13	1.78	0.19	0.08	0.00	0.00	0.00	0.00	0.00
Mixtopagurus paradoxus	0.01	0.03	0.00	0.00	0.00	0.03	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Parapagurus sp.	0.01	0.03	0.00	0.00	0.00	0.03	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00

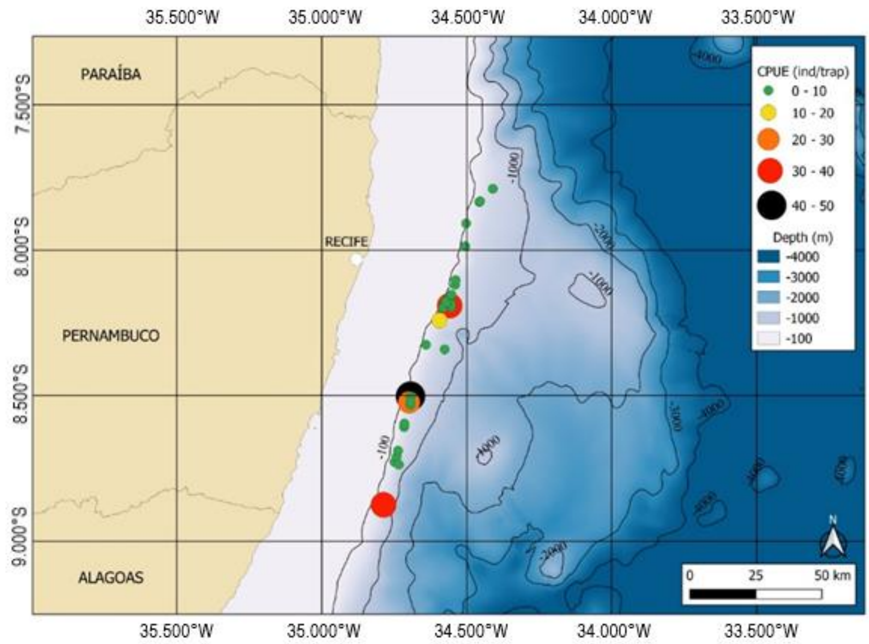

Figure 6. Abundance distribution (ind/trap) of malacostracan from the upper slope of Pernambuco state, Brazil.

The highest CPUE indices per depth stratum, in turn, were found between 500 – 550 m (13.22 ind/trap), mainly reflecting the captures of the isopod *B. miyarei* (10.22 ind/trap), followed by the range between 300 – 400 m (8.90 ind/trap), due to the high relative abundance of the shrimp *P. edwardsii* (11.67 ind/trap). Regarding the time of day, the "Night" period presented a CPUE index (8.59 ind/trap) much higher than the "Day" period (1.18 ind/trap). Hermit crabs were captured exclusively in the "Day", while the shrimp *H. ensifer*, the crab *M. crassa* and the isopods *B. giganteus* and *B. obtusus* were captured exclusively in the "Night" (Figure 7).

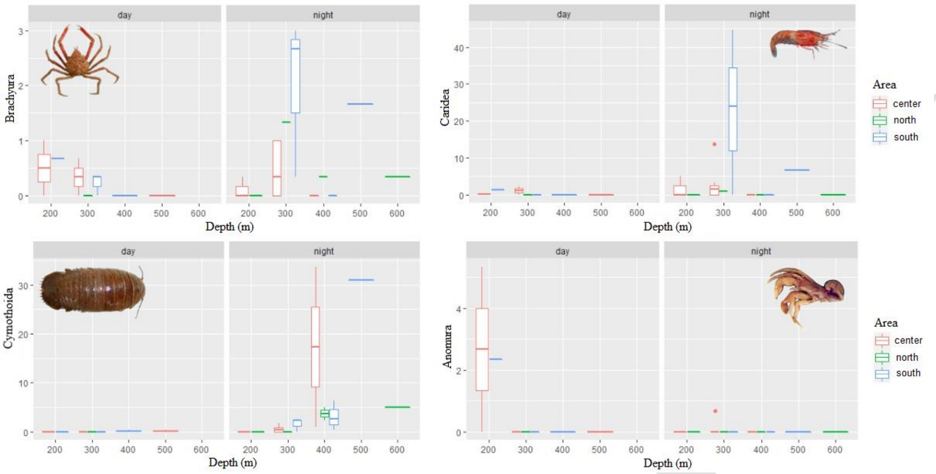

Figure 7. CPUE distributions by time of day of malacostracan catch from upper slope of Pernambuco state.

There was no statistically significant difference in the total average of CPUE by set (KW p = 0.429), by depth (KW p = 0.134) or by latitudinal section (KW p = 0.933). The mean time of day "Night" CPUE, however, was significantly higher than the "Day" (MW p = 0.009). The distributions of Caridea and Cymothoida were significantly different by depth range (respectively, KW p = 0.008; KW p = 0.005), whereas those of Brachyura and Anomura did not diverge statistically (respectively, KW p = 0.132; KW p = 419). For average CPUE distributions per time of day, there was a significant difference for Cymothoida species (MW p = 0.004), while for Brachyura, Caridea and Anomura no significant differences were found (respectively, MW p = 0.300; MW p = 0.259; MW p = 0.564). None of the differences found for the mean CPUE per latitudinal section for Brachyura, Caridea, Cymothoida, or Anomura were significant (respectively, KW p = 0.659; KW p = 0.473; KW p = 0.482; and KW p = 0.713) (Figure 8).

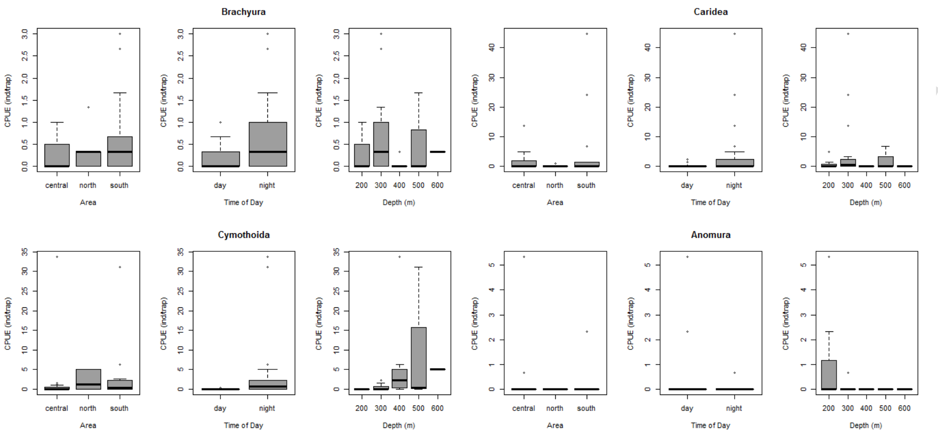

Figure 8. Distribution of malacostracan CPUE values from the upper slope of Pernambuco state: by latitudinal section, time of day and depth.

Discussion

Deep water benthic communities are among the most limited communities of the world in terms of food availability (Smith et al., 2008), and therefore, in most regions, have low biomass and productivity (Rex et al., 2006; Rowe et al., 2008). Tropical continental shelves, especially the Brazilian one, are considered unproductive, with low efficiency in the energy transfer between trophic levels, oligotrophic waters, high energy expenditure with breathing and lower rates of physical disturbances (Lana et al., 1996). Its diversity, however, is among the highest on Earth (Hessler and Sanders, 1967; Snelgrove and Smith, 2002; Kitahara, 2009), showing a decreasing trend with depth, in addition to high uniformity.

On the northeast coast of Brazil, most of the studies developed on deep water species deal with distribution and taxonomic aspects and there is still a great deficit of bioecological aspects. In the current paper, was possible to contribute a substantial with the knowledge about occurrences, abundance and distribution across spatial trends of deep-sea crustaceans off upper slope of Pernambuco State. The genus *Bathynomus*, strongly registered in this research, is easily recognized from the other ones of the Cirolanidae due to its large size and deep-water habitat. The genus *Bathynomus* contains 24 described species, three of them recorded from Brazilian waters: *Bathynomus giganteus*, from Amapá, Espírito Santo and Rio de Janeiro (Lemos de Castro, 1978; Cintra et al., 1998; Soto and Mincarone, 2001; Magalhães and Young, 2003), *B. miyarei*, with discontinuous distribution off Brazilian coast from Amapá, Ceará, Rio Grande do Norte and Rio Grande do Sul (Lemos de Castro, 1978; Cintra et al., 1998; Soto and

Mincarone, 2001), indicating these are probably distributed throughout the whole Brazilian coast, and *B. obtusus*, a relatively new species of *Bathynomus* described only from Bahia and Espírito Santo state (Magalhães and Young, 2003). The specimens collected in this work confirmed the *B. obtusus* presence in Pernambuco waters, therefore consisting of the northernmost record in South Atlantic, expanding its distribution.

Shallow-water species of Anomura are well known and studied in Brazil, but deep species knowledgment are even more scarce. *M. paradoxus* was previously reported from western Atlantic, off northern Caribbean to Brazil (off Amapá) at depths between 194 to 371 (Coelho Filho, 2004; Coelho Filho and Freitas, 2004), with this record expands its distribution to northeast Brazil. *Paguristes inconstans* was recorded from western Atlantic from Florida to Venezuela at depths between 36 to 338 m (Poupin and Corbari, 2016), being the first record of *P. inconstans* to south Atlantic. Species of *Parapagurus* must be analyzed for specialists to correct identification at specie level, although they are distributed along Atlantic and Pacific Ocean. The findings of *P. inconstans*, *M. paradoxus*, and *Parapagurus* sp. in Pernambuco waters illustrates the need for more intensive studies at greater depths.

Anomura is a group with high significance among marine crustaceans, popularly known as hermit crab (McLaughlin and Holthuis, 1985; McLaughlin et al., 2010). *Paguristes* Dana, 1851 is one of the most species-rich genera among Paguroidea and the first in number of species in the Diogenidae family, with 132 species being 34 species currently assigned in western Atlantic (WORMS, 2022). *Paguristes inconstans* can be readily distinguished from other western Atlantic congeners by the presence of red spots on meri of chelipeds and live coloration with blue corneas (Poupin and Corbari, 2016). The sampling difficulties can be considered one of the main factors responsible for the lack of knowledge of many important biological and ecological features of deep water species, including distribution.

From the new records, the occurrence of *P. inconstans*, previously restricted to the Caribbean Sea (Felder and Camp, 2009), is now also indicated for the south Atlantic. *Bathynomus obtusus* distribution, a relatively new species described only from Bahia and Espírito Santo states (Magalhães and Young, 2003), was expanded with the northernmost record in the south Atlantic. *Mixtopagurus paradoxus* has distribution in the western Atlantic from North Carolina to São Paulo slope, Brazil, and no species of *Parapagurus* genus had been recorded so far off the coast of Pernambuco. *Bathynomus miyarei* is an endemic Brazilian species recorded from the Amazon Continental shelf to Rio Grande do

Sul slope, Brazil, and *B. giganteus* have a wide geographical distribution, found in the Indian, Pacific and western Atlantic oceans (Soto and Mincarone, 2001). The last two species were also recorded for the first time off the coast of Pernambuco.

The most abundant species during explorations in deep waters off the coast of Pernambuco State was the soldier striped shrimp *P. edwardsii*. This species is target of fishing in Mediterranean and NE Atlantic archipelagos (González et al., 1992; Vafidis et al., 2005). Many aspects of its ecology and biology were studied, elucidating, for example, a bigger-deeper trend in response to seasonal changes and segregation by reproductive condition and the brood size variation as a function of female body (Triay-Portella et al., 2017). To Brazilian northeast slope, Oliveira et al. (2014) based on samplings carried out during the REVIZEE, also highlighted the high abundance of *P. edwardsii* and suggested its potential for economic exploitation, perhaps underdeveloped due to the high costs involved in deep water fishery.

Bathynomus miyarei, the second most abundant species found during this study, is a giant deep-sea isopod. Although *Bathynomus* species is not a target species for fishing (Poore and Bruce, 2012), individuals of this genus are recognized as common bycatch in several fisheries, like in blackfin goosefish (*Lophius gastrophysus*) fishery in southern Brazil, Golden deepsea crab (*Chaceon fenneri*) fishery in the northern Gulf of Mexico and hagfish (*Eptatretus* spp.) trap fishery in Taiwan (Soong and Mok, 1994; Harper et al., 2000; Perez and Wahrlich, 2005). In general, the genus *Bathynomus* plays a fundamental role in the cycling of organic matter from the upper water layers, acting as scavengers, necrophagus and serving as food for other species. They are also capable of prey on impaired, slow-moving, or sessile animals (Barradas-Ortiz et al., 2003), making the study of this genus essential for a better understanding of the functioning of the food web of deep-sea demersal communities.

On the northeastern coast, Coelho-Filho (2004), analyzing the macrozoobentic of the continental shelf found mean abundance values of 4.60 ind/L, while Oliveira et al. (2014) comment that the average CPUE of *P. edwardsii* collected in the south of Pernambuco obtained the highest indices in the strata between 100 – 200 and 200 – 300 m (with CPUEs, respectively, equal to 8.91 and 9.00 ind/trap), corroborating the present research, which found a total CPUE for deep-sea crustaceans equal to 6.05 ind/trap and the highest index at a depth of 307 m, station 11, South section. This pattern in the spatial variability of yields per haul is observed for any data combination analysis associated with variables related to depth stratum, latitudinal section and time of day, suggesting that the distribution of deep-sea crustaceans off the coast of Pernambuco is not uniform and there may be higher point yields probably associated with other environmental and/or biological variables (eg. water temperature, salinity, reproductive cycle, body size and topography).

In addition to food availability, depth variation is one of the factors that most influence the distribution of benthos in slope and continental shelf areas (Pires-Vanin, 1993; Sumida, 1994; Boos et al., 2021). A unique feature of deep-sea ecosystems is the lack of usable photosynthetic light below ~200 m. In the absence of photosynthesis, energy supply depends on foods that sink from the euphotic zone, favoring heterotrophic diversity. According to Wilson and Hessler (1987) the diversity of marine scavengers isopods is remarkably high in oligotrophic environments.

The distribution of diversity of deep-sea crustaceans may also be related to temperature, with species ascending or descending in depth following their preferred isotherms (Boschi, 2000), biotic relationships of competition and predation (Barradas-Ortiz et al., 2003; Alves et al., 2012). Results obtained regarding the distribution of species in depth strata reflect the same sequence observed in the continental margins (Coelho, 2006) and indicate remarkable depth fidelity of the species, despite small vertical excursions. For the upper slope of Pernambuco this depth fidelity was also observed, where five new occurrences were recorded, with a large part of the catch has been concentrated in the deeper strata.

Faced with the growing scarcity of resources exploited by traditional fisheries on the continental shelf, deep-sea fishing has been seen as an alternative to fishing resource for the human population, resulting in an accelerated development of new technologies aimed to capture (Pezzuto et al., 2006; Oliveira et al., 2007; Serejo et al., 2007; Arana et al., 2013). Along with fishing, other activities such as maritime transport and oil spills intensified the impact on this environment, before the resilience capacity or even the occurrence of such species were properly measured.

In this way, this work contributes to the understanding of the occurrence, distribution and abundance of deep-sea crustaceans on the Pernambuco slope. Data provided here also have the potential to contribute to impact assessments produced from the implementation of deep-sea fishing in the region. Finally, we expect new studies be carried out transcending the exploratory approach, mainly investigating biological and ecological patterns exhibited by deep water species, their connection with environmental variables and seasonal changes in surface waters.

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Conflict of Interest

Declaration of interests

☒The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: