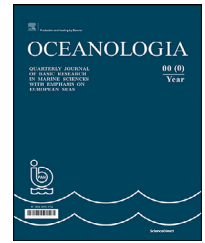




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ORIGINAL RESEARCH ARTICLE

Low abundance and high patchiness of decapod fauna sampled with van Veen grab on the West African continental margin (Gulf of Guinea, Ghana)

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Abstract Sixty morphospecies of Decapoda (Malacostraca: Crustacea) representing 34 families were recorded in the material collected in 2012 from 265 van Veen grab (0.1 m²) samples, from the nine transects distributed along the coast of Ghana in the 25–1000 m depth range. The examined material was dominated by the Diogenidae, Panopeidae, Leucosiidae, Pilumnidae and Xanthidae families. Species accumulation curves showed undersampling of the studied area and a large number of the morphospecies comprised singletons and doubletons. *Panopeus africanus* was the most frequent morphospecies in the analysed material (9.1% of all samples). We observed a substantial decrease of diversity (Shannon Index) and abundance along a depth gradient. Species richness also decreased with depth, starting from the highest number of morphospecies – 38 at 25 m depth, then 33 at 50 m, 17 at 100 m, 11 at 250 m, 8 at 500 m and ending with 1 morphospecies at 1000 m bottom depth. Higher diversity was observed on the continental shelf (25–250 m – 57 morphospecies), while on the slope (500–1000 m) only eight morphospecies were recorded. Numerous factors of natural and anthropogenic origin may

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affect decapod communities on the coast of Ghana. Since our material was collected using a sampler collecting material at a very small scale, the observed patterns might be affected by the sampling method.

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1. Introduction

Decapods belong to the most important macro and mega epibenthic marine invertebrates (Boudreau and Worm, 2012; Wolfe et al., 2019). They are a significant element of marine trophic webs and represent a wide range of feeding modes, including predators, detritivores and scavengers (Boudreau and Worm, 2012). Moreover, decapods are characterized by high species richness (Appeltans et al., 2012; Ateş et al., 2006; Coelho et al., 2008; Muñoz et al., 2012; Rosa et al., 2012), represent high functional and morphological diversity (Boudreau and Worm, 2012; Carvalho et al., 2017; Sahlmann et al., 2011) and are a significant component of benthic biomass (Cartes and Sardà, 1992; Thurston et al., 1994). These crustaceans are also associated with a great variety of microhabitats and can be found from the intertidal zone, down to the hadal depths (Cartes et al., 2014; Fanelli et al., 2007; Jamieson et al., 2009; Pajuelo et al., 2015; Rosa et al., 2012). All those features make them important for the functioning of marine ecosystems, including processes such as the decomposition of organic matter, nutrient cycling and benthic-pelagic coupling (Agnetta et al., 2019; Boudreau and Worm, 2012).

Studies analysing depth-related changes in the abundance and diversity of decapod crustaceans demonstrated substantial differences between the investigated regions (Company et al., 2004 and references therein). Some analyses from the Mediterranean Sea showed an increase in biodiversity from shelf to bathyal (Fanelli et al., 2007), and a similar pattern was observed in the waters of Guinea-Bissau (Muñoz et al., 2012). In the central-eastern Atlantic, the highest diversity was recorded on a lower shelf and upper slope, and the lowest diversity on a lower slope (Pajuelo et al., 2015). Those discrepancies emphasize the importance of local conditions on the distribution of decapods along a depth gradient, and the need for further studies since similar questions occur also in the analysis of more general distribution patterns of the benthic macrofauna. For example, one of the common assumptions in marine biology states that the diversity of the benthos increases along a depth gradient, reaching its maximum at the bathyal zone (Levin and Dayton, 2009; Rex and Etter, 2010). Therefore, the continental slope is often considered to be the major diversity hotspot of benthic marine diversity (Danovaro et al., 2009). This opinion is rationalized by high habitat heterogeneity resulting from geomorphological variability (e.g. steep bottoms, presence of canyons) and high dynamics of environmental conditions, e.g. differences in sediment structure, changes of the hydrostatic pressure and decrease in food availability (Levin and Dayton, 2009). Nevertheless, it was already suggested by Gray (2001) and fur-

ther supported in later studies by Levin and Sibuet (2012), that this pattern is not universal. Results may differ depending on the taxonomic groups studied or between regions, for example in areas characterized by the presence of oxygen minimum zone or as a result of differences in food availability between shelf and slope (Brandt et al., 2009; Levin, 2003; McCallum et al., 2015).

One such area is the Gulf of Guinea. It is a large marine ecosystem (LME) characterized by the presence of natural oxygen minimum zones between 200 and 500 m, the high dynamic of water masses, and differences in productivity (Djagoua et al., 2011; Guiavarc'h et al., 2009; Levin, 2003). At the same time, knowledge about the diversity and distribution patterns of benthic communities of this basin is still very scarce and mostly restricted to shallow shelf areas. The marine waters of Ghana are among the most scarcely sampled areas of the East Atlantic, and most of the studies there were performed over 40 years ago (Bassindale, 1961; Buchanan, 1958), except for some recent studies on *Lophelia* reefs (Buhl-Mortensen et al., 2017), and coastal shallows (Olomukoro and Dirisu, 2019), as well as studies on Tanaidacea (Józwiak et al., 2022), Cumacea (Stępień et al., 2021), Polychaeta (Sobczyk et al., 2021, 2023) and higher taxa (Pabis et al., 2020) along a depth gradient. There is almost no data about the distribution patterns and ecology of the decapod fauna of the Ghanaian shelf and slope. Previous studies mainly focused on taxonomy or provided only species lists (Bassindale, 1961; Bayer, 1966; Forest, 1956; Forest and Guinot, 1966; Gauld, 1960; Guinot, 1966; Monod, 1956) and generally, our knowledge about the decapod fauna associated with the whole western continental margin of Africa is scanty. The majority of studies concern taxonomy (e.g. Emmerson, 2016; Kensley, 1980; Macpherson, 1988), although there are also some studies analysing the zoogeography (Matos-Pita et al., 2016) and diversity of crustaceans from various parts of African continental margin, like South Africa (Kensley, 2006), Côte-d'Ivoire (Le Loeuff and Intès, 1999), Namibia (Macpherson, 1991) or Canary Current LME (García-Isarch and Muñoz, 2015). Decapods were also analysed as part of the demersal communities in Angola (Bianchi, 1992a), as well as in Congo and Gabon (Bianchi, 1992b). Only the studies from Guinea-Bissau (Muñoz et al., 2012) and Mauretania (García-Isarch et al., 2017; Moctar et al., 2020) included analysis of decapod communities at a wider depth range, down to the slope depths.

In this study, we aimed to analyse distribution patterns, diversity and abundance of the decapod fauna of the Ghanaian marine waters from six different bottom depths ranging from 25 up to 1000 m. This will fill a substantial knowledge gap, as there have been no decapod studies conducted in Ghana for over half a century.

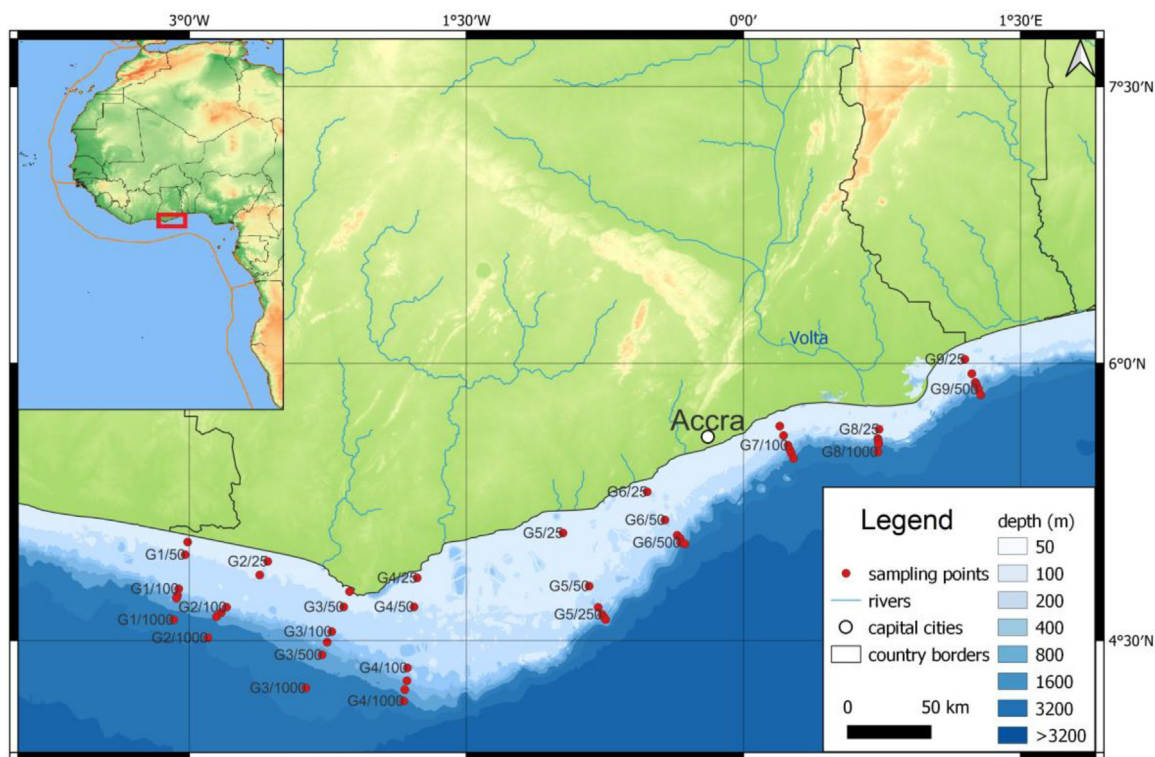


Figure 1 Distribution of transects (G1–G9) and sampling points along the coast of Ghana. The auxiliary map in the top left corner presents Western Africa with the area of LMEs delineated by an orange line and the study area outlined by a red rectangle.

2. Material and methods

2.1. Study area

The Gulf of Guinea is a large embayment on the Atlantic coast of Africa (Ukwe et al., 2003). Marine ecosystems of the tropical and subtropical part of the East Atlantic African coast are shaped by a very dynamic and diverse set of factors. The Gulf of Guinea is influenced by the Guinea, the Benguela, and the South Equatorial Counter Currents (Ukwe et al., 2006), oxygen minimum zones (Levin, 2003), coastal erosion (Ukwe et al., 2003) and upwellings (Djagoua et al., 2011). The total length of the coast of Ghana is 565 km. The River Volta is the only large river system on the Ghanaian coast (Humphries et al., 2014). The marine ecosystem of the Gulf of Guinea is also affected by numerous threats of anthropogenic origin, including urban pollution, the dyeing industry in the coastal areas and the oil industry (Scheren et al., 2002). Growing industrialization as well as gas and oil extraction results in increasing risk of disturbance, not only in the coastal zone but also in the deep sea (Acquah, 1995; Boadi and Kuitunen, 2002).

2.2. Sampling

The material was collected from onboard the *r/v Dr Fridtjof Nansen* in October and November 2012 along the nine transects located along the whole coast of Ghana. Altogether 265 van Veen grab (0.1 m²) samples were collected. The

use of Video Assisted Monitoring System (VAMS) allowed us to monitor the sampling process. When sediment penetration by the grab was inappropriate (e.g. partially opened grab), the samples were discarded from further analysis. Sampling points were distributed from shallow shelf areas down to bathyal depths. Six points were sampled along each transect: 25 m, 50 m, 100 m, 250 m, 500 m and 1000 m (Figure 1). Five samples were collected at each sampling point. The material was sieved using 0.3 mm mesh sieves and fixed in formalin (40% solution of formaldehyde). The methodology was consistent with the recommendations of the Oil Spill Prevention, Administration and Response Fund (OSPAR) (Coit and Ball, 2012).

2.3. Environmental data

Temperature, conductivity, and oxygen concentration were measured using Seabird 911 CTD Plus and SBE 21 Seacat thermosalinograph from each sampling point. The sediment was mixed with water (solubilized) and sieved through 0.063 mm mesh size sieve and Endecott sieves to analyse sediment grain size. The formulae of Blott and Pye (2001); Buchanan (1984) and Folk and Ward (1957) (GradiStat 4.01) were used. Total organic matter was determined as the weight loss in a 2–3 gram dried sample (dried at 105°C for 20 hours) after two hours of combustion at 480°C. Petroleum hydrocarbon content (GC/FID) analysis of the extracts was obtained as described in the Report of the Intergovernmental Oceanographic Commission on its activities during 1980–1982 (Intergovernmental Oceanographic Commission, 1983). Metal concentrations (Ba, Cd, Cr, Cu, Pb,

Zn, Hg) were determined by Inductively Coupled Plasma – Atomic Emission Spectrometry (ICP – AES), apart from mercury, which was determined by Cold Vapour Atomic Emission Spectrometry (CVAAS). Full details of the analysis of environmental factors can be found in [Pabis et al. \(2020\)](#); here we only summarize the most important data that are of relevance to this study ([Table 1](#)).

2.4. Data analysis

The material was identified to the morphospecies level ([Horton et al., 2021](#); [Sigovini et al., 2016](#); [Wägele, 2005](#)) using a stereoscope Opta-tech, based on morphological traits, among others carapace shape, proportions and shape of particular sections of appendages, using appropriate taxonomic literature (e.g. [Fransen, 2014a,b](#); [Ingle, 1996](#); [Manning and Holthuis, 1981](#); [Mavridis et al., 2009](#); [McLaughlin, 1980](#); [Poore, 2004](#); [Tan, 2007](#)). If necessary for identification purposes, certain specimens were dissected. After identification, the specimens were kept separately in vials and preserved in 96% ethanol. However, the previous preservation in formalin excludes the possibility of molecular analyses.

If identification was possible to the genus or family level, we used the open nomenclature abbreviations: “sp.” for morphospecies from a particular genus (e.g. *Dardanus* sp.) and gen. sp. for morphospecies representing higher taxonomic units (e.g. Porcellanidae gen. sp.), according to the latest taxonomical recommendations ([Horton et al., 2021](#); [Sigovini et al., 2016](#)). If there were more morphospecies representing a given family or genus, these were numbered continuously (e.g. Callianassidae gen sp. 1, Callianassidae gen. sp. 2). If we were able to assign the given morphospecies to an already described species, we used the full taxonomic name (e.g. *Panopeus africanus* A. Milne-Edwards, 1867). Part of the material was identified only to a higher taxonomic level due to the poor condition of the material, and such specimens were excluded from the diversity and morphospecies richness analyses to avoid potential errors in the calculation of diversity indices and cluster analysis.

Mean density, richness (S – number of morphospecies per sample) and Shannon index ($\log_e$) ([Magurran, 2004](#)) were calculated with standard deviation for each depth: 25 m, 50 m, 100 m, 250 m, 500 m and 1000 m (for each depth samples from all sampling points were used). Differences between the depths were tested using the Kruskal-Wallis test. Post hoc testing was performed using Dunn’s test in the Statistica 13 package. Chao 1 and Chao 2, as well as Jackknife 1 and Jackknife 2 estimators of species richness ([Canning-Clode et al., 2008](#)), were calculated using Primer package ([Clarke and Gorley, 2015](#)). Frequency of occurrence (F – percentage (%) of samples where a morphospecies was found out of the total number of samples) was calculated for each morphospecies, in each depth zone and also for the whole material ([Table 2](#)).

Rare morphospecies, defined as singletons, doubletons and tripletons (morphospecies represented by only one, two or three individuals in the whole material, respectively), as well as uniques, duplicates and triplicates (morphospecies found in one, two or three samples, respectively), were also counted ([Table 3](#)).

Hierarchical agglomerative clustering was performed using the Bray-Curtis formula (non-transformed data, group

average method) to assess faunistic similarity between the samples. Since there were no strong disproportions in the abundance of particular morphospecies, and generally the abundance per sample was low, the data were not transformed. The SIMPROF test with a 1% significance level was performed ([Clarke and Gorley, 2015](#)). The SIMPROF routine confirms statistically significant evidence of genuine clusters, and therefore the determination of groupings. It provides objective stopping rules for the dissection of the dendrogram into groups ([Clarke and Warwick, 2001](#); [Clarke et al., 2008](#)). Such clusters are indicated on the dendrogram using dotted lines.

3. Results

Environmental factors changed along the depth gradient ([Table 1](#)). The highest oxygen concentrations were recorded on the shelf and decreased in the 250–500 m depth range. Shelf sediments were characterized by higher heterogeneity (from silt clay to coarse sand) compared to slope sampling points, which were homogenous and characterized by silt clay fractions. Total organic matter content was highest on the slope. At the same time, 500–1000 m bottom deposits were characterized by the highest concentrations of barium and other metals, as well as the highest hydrocarbon concentrations.

Altogether 60 morphospecies of Decapoda, representing 34 families (613 individuals), were recorded ([Table 2](#)). The most speciose families were Hexapodidae and Inachidae, with four morphospecies recorded, followed by the Diogenidae, Epialtidae, Majidae, Parthenopidae, Portunidae and Xanthidae families (each represented by three morphospecies). The majority of morphospecies were rare and patchily distributed. Thirty-two morphospecies (53.3% of all morphospecies) were recorded from less than four samples (20 uniques, 5 duplicates, 7 triplicates). Twenty-eight morphospecies (46.7% of all morphospecies) were represented by one to three individuals (18 singletons, 6 doubletons, 4 tripletons) ([Table 3](#)). The most abundant morphospecies, with 63 individuals, was *Dardanus* sp. (Diogenidae), although 25 of these were found from a single sample. The highest frequency of occurrence (9.1% of samples, only 24 out of 265 samples) in the whole material was recorded for *Panopeus africanus* (Panopeidae) and *Dardanus* sp. (Diogenidae) ([Table 2](#)). The general frequency of occurrence of Decapoda in the whole material was low, as they were recorded from 132 samples (49.8% of all collected samples).

Diversity, morphospecies richness and abundance of decapods decreased along a depth gradient ([Figure 2](#)). The mean number of morphospecies (S) per sample and mean values of the Shannon index were low. The highest values (mean $\pm$ SD, max) were recorded at 25 m (S : 2.9 ± 2.8 , max=10.0; Shannon Index: 0.7 ± 0.7 , max=2.1), while the lowest values were found at 1000 m (S : 0.0 ± 0.2 , max=1; Shannon Index: 0.0 ± 0.0 , max=0.0). A similar pattern was found for mean densities. The highest abundance was found at 25 m (6.8 ± 9.3 ind./0.1 m², max=44) and the lowest at 1000 m (0.1 ± 0.5 ind./0.1 m², max=3). Differences in diversity, morphospecies richness and density were statistically significant between shelf and slope depths ([Figure 2](#))

Table 1 Mean values of environmental parameters at individual depth samples (standard deviations omitted for clarity). FLU – fluorescence concentration as a measure of the level of chlorophyll *a*. Percentages of Silt, Sand and Gravel show the percentage of individual sediment fractions in the samples.

Depth (m)		Temperature	Salinity	Oxygen	FLU	As	Ba	Cd	Cr	Cu	Ni	Pb	Zn	Hg	THC	PAH	NPD	TOM	Silt	Sand	Gravel	Pressure
		(°C)	(PSU)	(ml/l)	(µg/l)	(µg/g)								(ppm)	(µg/g)	(µg/g)	(%)	(%)			(at)	
25	mean	28.0	35.1	4.2	0.2	44.8	11.5	0.1	38.8	3.2	10.7	7.5	35.1	0.01	5.3	40.7	21.3	4.5	32.8	57.5	9.7	22.7
25	min	26.2	34.7	3.7	0.1	4.6	3.4	0.0	12.2	0.5	2.4	1.4	6.2	0.01	1.1	4.6	4.1	0.9	1.1	18.8	0.0	18.0
25	max	28.9	35.3	4.6	0.4	109.5	23.1	0.1	90.9	10.5	23.1	24.0	84.2	0.03	10.3	204.0	64.1	8.4	81.3	94.0	30.2	24.0
50	mean	26.9	35.5	4.1	0.2	31.4	21.0	0.1	46.7	5.3	15.9	6.3	46.7	0.01	6.2	142.2	48.5	5.1	44.9	51.5	3.6	46.3
50	min	24.1	35.4	3.2	0.1	6.8	11.4	0.0	27.8	2.4	7.9	2.8	29.2	0.01	3.1	6.7	12.5	0.9	19.8	14.4	0.0	43.0
50	max	28.9	35.5	4.5	0.3	185.8	32.6	0.4	62.9	9.7	29.5	19.8	99.5	0.04	11.7	1117.1	229.6	9.1	85.0	72.5	12.6	48.0
100	mean	25.2	35.8	2.5	0.1	11.0	29.1	0.1	41.6	7.4	17.5	4.3	42.9	0.01	6.6	23.6	25.5	7.2	52.9	45.4	1.6	96.4
100	min	17.1	35.7	2.1	0.1	4.7	14.7	0.1	31.1	4.1	11.0	2.5	30.7	0.01	4.0	9.9	12.3	5.1	29.5	2.7	0.0	93.0
100	max	28.9	35.9	2.8	0.1	34.8	51.0	0.3	59.9	17.7	30.3	8.9	54.5	0.02	10.4	66.9	52.7	10.8	97.3	68.8	4.3	99.0
250	mean	23.6	35.4	1.5	0.0	21.5	28.5	0.2	63.9	7.5	19.7	5.3	68.9	0.01	7.1	23.3	28.9	7.5	48.8	50.4	0.8	248.3
250	min	13.3	35.3	1.2	0.0	6.9	15.0	0.1	42.6	4.4	13.3	2.8	47.2	0.01	3.7	8.4	14.4	5.4	18.5	2.2	0.0	240.0
250	max	28.9	35.5	1.7	0.1	66.9	51.5	0.2	89.2	14.6	26.7	9.1	102.0	0.02	14.5	72.7	69.6	9.5	97.9	79.2	2.3	267.0
500	mean	22.1	34.6	1.9	0.0	10.6	87.8	0.2	64.5	12.4	27.2	4.8	59.9	0.02	17.4	47.8	48.8	9.8	80.8	19.2	0.1	500.9
500	min	6.2	34.1	1.7	0.0	5.8	27.5	0.1	46.4	4.5	16.0	2.5	47.9	0.01	3.5	12.0	13.4	6.7	42.2	1.1	0.0	492.0
500	max	28.7	34.8	2.2	0.1	18.8	185.6	0.3	94.6	20.1	38.8	8.9	74.5	0.02	59.2	109.9	94.5	12.2	98.9	57.8	0.5	528.0
1000	mean	15.9	34.7	3.6	0.0	10.4	188.8	0.2	60.2	18.1	34.7	6.2	64.9	0.02	13.0	53.4	44.2	12.0	95.1	4.9	0.0	1060.8
1000	min	4.2	34.6	3.2	0.0	5.9	100.9	0.2	54.2	12.5	26.6	3.9	57.5	0.02	5.1	26.9	20.7	9.8	87.4	0.5	0.0	970.0
1000	max	28.2	34.8	4.0	0.0	21.6	363.3	0.3	64.3	22.6	43.2	9.2	76.6	0.04	19.4	86.7	67.1	17.6	99.5	12.6	0.1	1226.0

Table 2 List of Decapoda morphospecies recorded at the six depths along the nine transects in the Gulf of Guinea. N – total number of individuals; F – frequency of occurrence, i.e. percentage (%) of samples where the morphospecies was present.

Morphospecies	25 m		50 m		100 m		250 m		500 m		1000 m		Total	
	N	F	N	F	N	F	N	F	N	F	N	F	N	F
Anomura														
Family: Diogenidae														
<i>Dardanus</i> sp.	39	15.6	20	28.3	4	8.9	-	-	-	-	-	-	63	9.1
<i>Clibanarius</i> sp.	4	4.4	2	4.4	3	4.4	-	-	1	2.3	-	-	10	2.6
Diogenidae gen. sp.	5	6.7	8	10.9	-	-	-	-	-	-	-	-	13	3.0
Family: Galatheidae														
Galatheidae gen. sp.	-	-	1	2.2	-	-	-	-	-	-	-	-	1	0.4
<i>Galathea</i> sp.	26	17.8	8	8.7	1	2.2	-	-	-	-	-	-	35	4.9
Family: Munididae														
Munididae gen. sp.	-	-	-	-	-	-	-	-	3	4.7	-	-	3	0.8
Family: Paguridae														
Paguridae gen. sp.	-	-	2	2.2	-	-	-	-	-	-	-	-	2	0.4
Family: Porcellanidae														
Porcellanidae gen. sp.	1	2.2	-	-	-	-	-	-	-	-	-	-	1	0.4
<i>Petrolisthes</i> sp.	7	6.7	1	2.2	-	-	-	-	-	-	-	-	8	1.5
Axiidea														
Family: Callianassidae													26	4.2
Callianassidae gen. sp. 1	4	4.4	22	19.6	-	-	-	-	-	-	-	-		
Callianassidae gen. sp. 2	-	-	-	-	-	-	3	6.8	2	4.7	-	-	5	1.9
Brachyura														
Family: Atelecyclidae														
<i>Atelecyclus rotundatus</i> (Olivi, 1792)	-	-	1	2.2	-	-	-	-	-	-	-	-	1	0.4
Family: Calappidae														
<i>Acanthocarpus brevispinis</i> Monod, 1946	-	-	-	-	-	-	2	4.6	-	-	-	-	2	0.8
<i>Calappa pelii</i> Herklots, 1851	-	-	1	2.2	-	-	-	-	-	-	-	-	1	0.4
Family: Dorippidae														
<i>Phyllodorippe armata</i> (Miers, 1881)	1	2.2	-	-	-	-	-	-	-	-	-	-	1	0.4
Family: Epialtidae														
<i>Herbstia rubra</i> A. Milne-Edwards, 1869	12	11.1	-	-	-	-	-	-	-	-	-	-	12	1.9

(continued on next page)

Table 2 (continued)

Morphospecies	25 m		50 m		100 m		250 m		500 m		1000 m		Total	
	N	F	N	F	N	F	N	F	N	F	N	F	N	F
<i>Pisa carinimana</i> Miers, 1879	12	11.1	3	6.5	3	6.7	1	2.3	-	-	-	-	19	4.5
<i>Pisa</i> sp.	-	-	1	2.2	-	-	-	-	-	-	-	-	1	0.4
Family: Ethusidae														
<i>Ethusa mascarone</i> (Herbst, 1785)	1	2.2	-	-	-	-	-	-	-	-	-	-	1	0.4
<i>Ethusa rosacea</i> A. Milne-Edwards & Bouvier, 1897	1	2.2	-	-	1	2.2	-	-	2	4.7	-	-	4	1.5
Family: Geryonidae														
<i>Chaceon affinis</i> (A. Milne-Edwards & Bouvier, 1894)	-	-	-	-	-	-	1	2.3	2	4.7	-	-	3	1.1
Family: Goneplacidae														
<i>Goneplax barnardi</i> (Capart, 1951)	-	-	-	-	-	-	1	2.3	-	-	-	-	1	0.4
Family: Grapsidae														
<i>Geograpsus lividus</i> (H. Milne Edwards, 1837)	-	-	-	-	1	2.2	-	-	-	-	-	-	1	0.4
Family: Hexapodidae														
Hexapodidae gen sp.	-	-	1	2.2	-	-	-	-	-	-	-	-	1	0.4
<i>Parahexapus africanus</i> Baiss, 1922	1	2.2	-	-	-	-	-	-	-	-	-	-	1	0.4
<i>Pseudohexapus platydactylus</i> Monod, 1956	21	15.6	3	6.5	-	-	-	-	-	-	-	-	24	3.8
<i>Theoxapus buchanani</i> (Monod, 1956)	1	2.2	1	2.2	-	-	-	-	-	-	-	-	2	0.8
Family: Inachidae														
<i>Achaeus cranchii</i> Leach, 1817	2	2.2	-	-	4	6.7	-	-	-	-	-	-	6	1.5
<i>Achaeus</i> sp.	1	2.2	-	-	-	-	-	-	-	-	-	-	1	0.4
<i>Calypsachaeus calypso</i> (Forest & Guinot, 1966) ()	2	2.2	2	4.4	-	-	-	-	-	-	-	-	4	1.1
<i>Macropodia macrocheles</i> (A. Milne-Edwards & Bouvier, 1898)	1	2.2	-	-	2	4.4	-	-	-	-	-	-	3	1.1
Family: Leucosiidae														
<i>Ebalia</i> sp.	2	4.4	7	15.2	8	15.6	-	-	-	-	-	-	17	6.0
<i>Ilia</i> sp.	2	4.4	1	2.2	5	8.9	23	22.7	-	-	-	-	31	6.4

(continued on next page)

Table 2 (continued)

Morphospecies	25 m		50 m		100 m		250 m		500 m		1000 m		Total	
	N	F	N	F	N	F	N	F	N	F	N	F	N	F
Family: Majidae														
<i>Eurynome aspera</i> (Pennant, 1777)	-	-	3	6.5	2	4.4	-	-	-	-	-	-	5	1.9
<i>Eurynome</i> sp.	-	-	1	2.2	-	-	-	-	-	-	-	-	1	0.4
<i>Micippa</i> sp.	3	6.7	1	2.2	-	-	-	-	-	-	-	-	4	1.5
Family: Panopeidae														
<i>Panopeus africanus</i> A. Milne-Edwards, 1867	26	26.7	1	2.2	22	22.2	1	2.3	-	-	-	-	50	9.1
Family: Parthenopidae														
<i>Distolambrus maltzami</i> (Miers, 1881)	2	4.4	5	8.7	1	2.2	-	-	-	-	-	-	8	2.6
<i>Parthenopoides massena</i> (Roux, 1830)	2	4.4	2	4.4	-	-	-	-	-	-	-	-	4	1.5
<i>Spinolambrus notialis</i> (Manning & Holthuis, 1981)	-	-	4	8.7	-	-	-	-	-	-	-	-	4	1.5
Family: Pilumnidae														
<i>Pilumnus</i> sp.	20	15.6	5	6.5	21	22.2	1	2.3	-	-	-	-	47	7.9
Family: Pinnotheridae														
<i>Nepinnotheres pinnotheres</i> (Linnaeus, 1758)	-	-	-	-	-	-	1	2.3	-	-	-	-	1	0.4
<i>Pinnotheres</i> sp.	-	-	1	2.2	-	-	-	-	-	-	-	-	1	0.4
Family: Plagusiidae														
<i>Plagusia depressa</i> (Fabricius, 1775)	1	2.2	-	-	-	-	1	2.3	-	-	-	-	2	0.8
Family: Portunidae														
<i>Achelous inaequalis</i> (Miers, 1881)	2	4.4	-	-	-	-	-	-	-	-	-	-	2	0.8
<i>Callinectes amnicola</i> (de Rochebrune, 1883)	5	8.9	-	-	-	-	-	-	-	-	-	-	5	1.5

(continued on next page)

Table 2 (continued)

Morphospecies	25 m		50 m		100 m		250 m		500 m		1000 m		Total	
	N	F	N	F	N	F	N	F	N	F	N	F	N	F
<i>Cronius ruber</i> (Lamarck, 1818)	3	6.7	-	-	-	-	-	-	-	-	-	-	3	1.1
Family: Raninidae														
<i>Ranilia constricta</i> (A. Milne-Edwards, 1880)	-	-	1	2.2	-	-	-	-	-	-	-	-	1	0.4
Family: Xanthidae														
<i>Monodaeus rouxi</i> (Capart, 1951)	27	8.9	3	4.4	-	-	-	-	-	-	-	-	30	2.3
<i>Paractaea</i> sp.	4	6.7	-	-	-	-	-	-	-	-	-	-	4	1.1
<i>Paraxanthias eriphioides</i> (A. Milne-Edwards, 1867)	5	6.7	-	-	-	-	-	-	-	-	-	-	5	1.1
Caridea														
Family: Alpheidae														
<i>Alpheus</i> sp.	25	11.1	-	-	-	-	-	-	-	-	-	-	25	1.9
Family: Crangonidae														
Crangonidae gen. sp.	-	-	-	-	-	-	-	-	1	2.3	-	-	1	0.8
Family: Ogyrididae														
<i>Ogyrides</i> sp.	3	4.4	-	-	1	2.2	-	-	-	-	-	-	4	1.1
Dendrobranchiata														
Family: Luciferidae														
<i>Belzebub faxoni</i> (Borradaile, 1915)	11	17.8	9	13.0	-	-	-	-	-	-	-	-	20	5.3
Luciferidae gen. sp.	-	-	-	-	-	-	-	-	1	2.3	-	-	1	0.4
Family: Penaeidae														
<i>Parapenaeopsis</i> sp.	9	13.3	16	8.7	-	-	-	-	-	-	-	-	25	3.8
Family: Processidae														
Processidae gen. sp.	-	-	2	2.2	-	-	-	-	-	-	-	-	2	0.4
Family: Sergestidae														
<i>Sergia</i> sp.	-	-	-	-	-	-	5	11.4	11	18.6	3	2.4	19	5.3
Gebiidea														
Family: Upogebiidae														
Upogebiidae gen. sp.	11	13.3	17	26.1	7	8.9	-	-	-	-	-	-	35	8.3

Table 3 The number of rare morphospecies: singletons, doubletons and tripletons (morphospecies represented by only one, two or three individuals in the whole material, respectively), uniques, duplicates and triplicates (morphospecies present in one, two or three samples, respectively) recorded at the six depths (25–1000 m) along the nine transects in the Gulf of Guinea.

Morphospecies	Depth (m)						All depths
	25	50	100	250	500	1000	
singletons	9	13	5	7	3	0	18
doubletons	7	5	2	1	3	0	6
tripletons	3	4	2	1	1	1	4
represented by more than three individuals	19	11	7	2	1	0	32
uniques	11	15	5	7	3	1	20
duplicates	8	4	3	1	4	0	5
triplicates	6	4	2	1	0	0	7
present in more than three samples	13	10	6	2	1	0	28
Total	38	33	16	11	8	1	60

(Kruskal-Wallis test, Dunn's test, $p < 0.05$). The species accumulation curves did not reach the asymptote (Figure 3).

Total number of morphospecies also decreased with depth (25 m – 38 morphospecies, 50 m – 33 morphospecies, 100 m – 16 morphospecies, 250 m – 11 morphospecies, 500 m – 8 morphospecies, 1000 m – 1 morphospecies). Some morphospecies were common to different depth zones (Figure 4). However, there were substantial differences in morphospecies number between the shelf (25–250 m – 57 morphospecies) and the slope (500–1000 m – 8 morphospecies). Only two morphospecies (i.e. *Clibanarius* sp. and *Ethusa rosacea*) were found in the shallows (25–100 m) and on the upper slope (500 m). Three other morphospecies (i.e. Callianassidae gen. sp. 2, *Chaceon affinis* and *Sergia* sp.) were recorded on the lower shelf (250 m) and upper slope (500 m).

The highest number of species unique to a given depth zone was found at 25 m (12 morphospecies) and 50 m (11 morphospecies), while the number of unique morphospecies recorded deeper was lower, e.g. one (*Geograpsus lividus*) at 100 m, three (*Acanthocarpus brevinispinis*, *Geograpsus barnardi*, *Nepinnotheres pinnotheres*) at 250 m, and three morphospecies (Muninidae gen. sp., Crangonidae gen. sp. and Luciferidae gen. sp.) at 500 m. No unique decapod morphospecies were identified from a depth of 1000 m. The frequency of occurrence of the majority of morphospecies in particular depth zones was very low. Only *Panopeus africanus* was relatively frequent (26.7%) in samples collected at 25 m. At 50 m, *Dardanus* sp. and Upogebiidae gen. sp. were the most frequent morphospecies, with frequencies of 28.3% and 26.1%, respectively (Table 2).

Cluster analysis yielded seven groups, although the majority of these were on a low or very low level of similarity (Figure 5). The clearest pattern is the separation of the more diverse shallow water shelf communities from shelf break and slope samples, which were species-poor. There was no pattern associated with the distribution of transects. All the groups were characterized by the constant presence of only one to three morphospecies (Figure 5) and all of those morphospecies had low abundances (mostly one or two individuals per sample).

4. Discussion

4.1. Overall species richness

Virtually all of our current knowledge of the decapod fauna of the Ghanaian coast is the result of a single survey (Bassindale, 1961), although information about the species number of decapods from the intertidal zone and shallow sublittoral of the Gold coast has been reported by Bassindale (1961); Forest (1956); Gauld (1960); Monod (1956). The list of 109 species (54 from the intertidal zone) presented in those studies were the result of 90 dredging samples and Agassiz Beam trawl exploring a narrow depth range from 7 to 64 m, while in our studies there were 50 morphospecies found in 67 samples from 25 to 50 m. A short species list was also provided in the study of Buchanan (1958).

Those restricted studies which used only trawling samples to assess decapod diversity along the coast of Ghana hamper reliable comparison with our quantitative results. Nevertheless, the total number of species collected during other Atlantic surveys was very variable. For example, Muñoz et al. (2012) collected 122 (including at least 21 pelagic and nectobenthic) decapod species from a 20 to 1000 m depth range in 98 trawls in the waters of Guinea-Bissau, while in the waters of Angola, Bianchi (1992a) collected only nine decapod species in 163 samples at depths ranging from 20 to about 500 m. Fariña et al. (1997) found 40 species in 293 samples collected on shelf and upper slope (100–500 m) along the Galician coast of Spain, while Moctar et al. (2020) collected 100 species (including 37 swimming) from 95 sampling points distributed along the coast of Mauritania. Similar results were recorded in an earlier study of Mauritanian waters at an 81–1825 m depth range (García-Isarch et al., 2017). Even in the Mediterranean Sea – one of the diversity hot spots for the decapod fauna – total species number in various surveys based on trawling samples was variable, e.g. 97 species in 113 trawls at 1–200 m depth range (Ateş et al., 2007), 53 species in 46 samples at 10–700 m depth range (Fanelli et al., 2007), 42 species in 109 samples at 140–730 m depth range

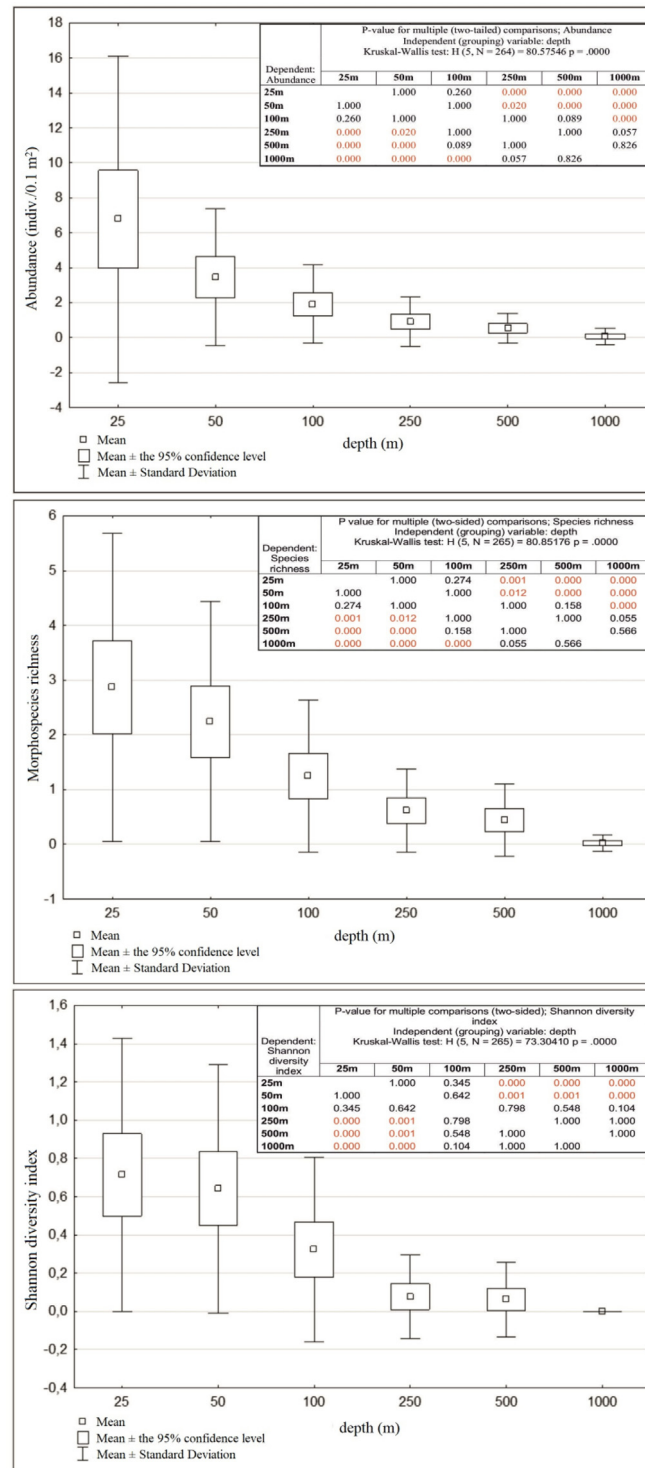


Figure 2 Abundance, species richness and Shannon diversity index calculated for each depth.

(Cartes et al., 1994), 23 species in 32 samples at 800–1500 m depth range (Follesa et al., 2009) and 40 species in 67 samples at 550–2200 m depth range (Cartes and Sarda, 1992). Despite the very high efficiency of trawling in terms of abundance—even up to 200 000 individuals in one survey—the number of recorded species was not much higher than in the present study (García-Isarch et al., 2017;

Muñoz et al., 2012). Moreover, morphospecies accumulation curves (Figure 3) indicated undersampling of the studied area. It is probably partially related to a type of sampling gear used in combination with a highly patchy distribution of decapods. Based on our morphospecies list, we suggest the undersampling, especially regarding highly mobile taxa, such as Dendrobranchiata and Caridea (Poore et al., 2015).

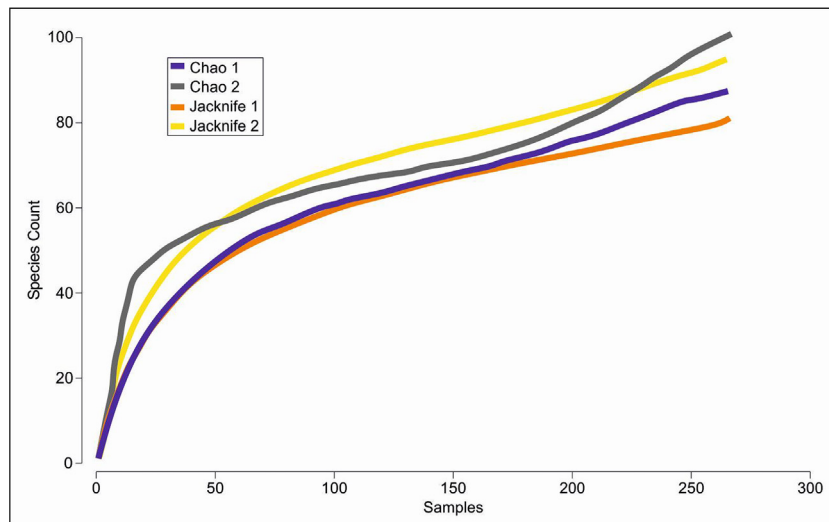


Figure 3 Species accumulation curves (Chao and Jackknife) for the material examined in the study area (excluding non-identifiable individuals).

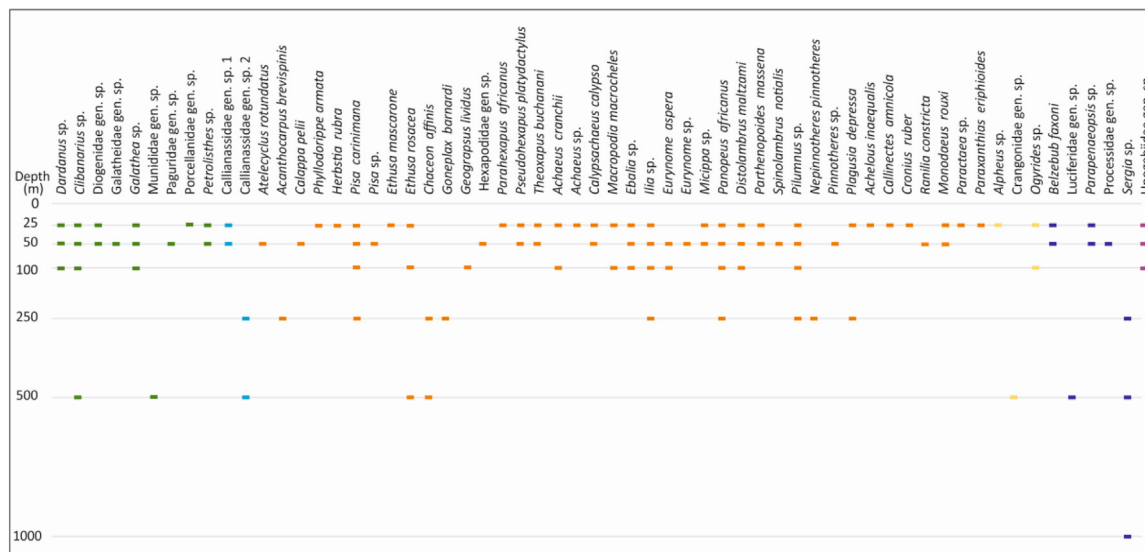


Figure 4 Bathymetric distribution of decapod morphospecies collected at six depths along the nine transects in the Gulf of Guinea. Groups of Decapoda can be distinguished by colours of plots: green – Anomura; blue – Axiidea; orange – Brachyura; yellow – Caridea; dark blue – Dendrobranchiata; purple – Gebiidea.

Thus, we can expect significantly higher diversity and morphospecies richness of those taxa than we report in our study.

The lack of other more comprehensive decapod studies from the West African continental margin makes comparisons of species composition difficult. Only a few species recorded in the Guinea-Bissau were also found in our study, including typical benthic species, such as *Atelecyclus rotundatus*, *Acanthocarpus brevispinis*, *Goneplax barnardi* or genera like *Pisa*, *Ilia* and *Chaceon* (Muñoz et al., 2012). *Calappa pelti* was an important element of communities in the water of Mauritania (Moclar et al., 2020). In the case of the brachyuran fauna, our results confirm available zoogeographic data (Gauld, 1960; Matos-Pita et al., 2016). One of the more frequent morphospecies in samples collected in shallow waters of Ghana was *Panopeus*

africanus, a common crab with wide geographic distribution in the African waters that was found mainly in shallow shelf sites (estuaries and lagoons) up to 140 m depth (Manning and Holthuis, 1981; Rodriguez et al., 1997). In our material, it was also the most abundant morphospecies in shallow waters, although the species was also recorded at a depth of 250 m. However, this species was not recorded in the study of Muñoz et al. (2012). Contrastingly, some taxa, such as *Acanthocarpus brevispinis* or highly mobile brachyurans (such as Portunidae), were very abundant in the Guinea-Bissau survey (Muñoz et al., 2012) but extremely rare in our material. Those differences might also reflect the advantages and disadvantages of different sampling methods (grabs and corers vs. trawls, dredges and sledge), which we discuss at the end of this study.

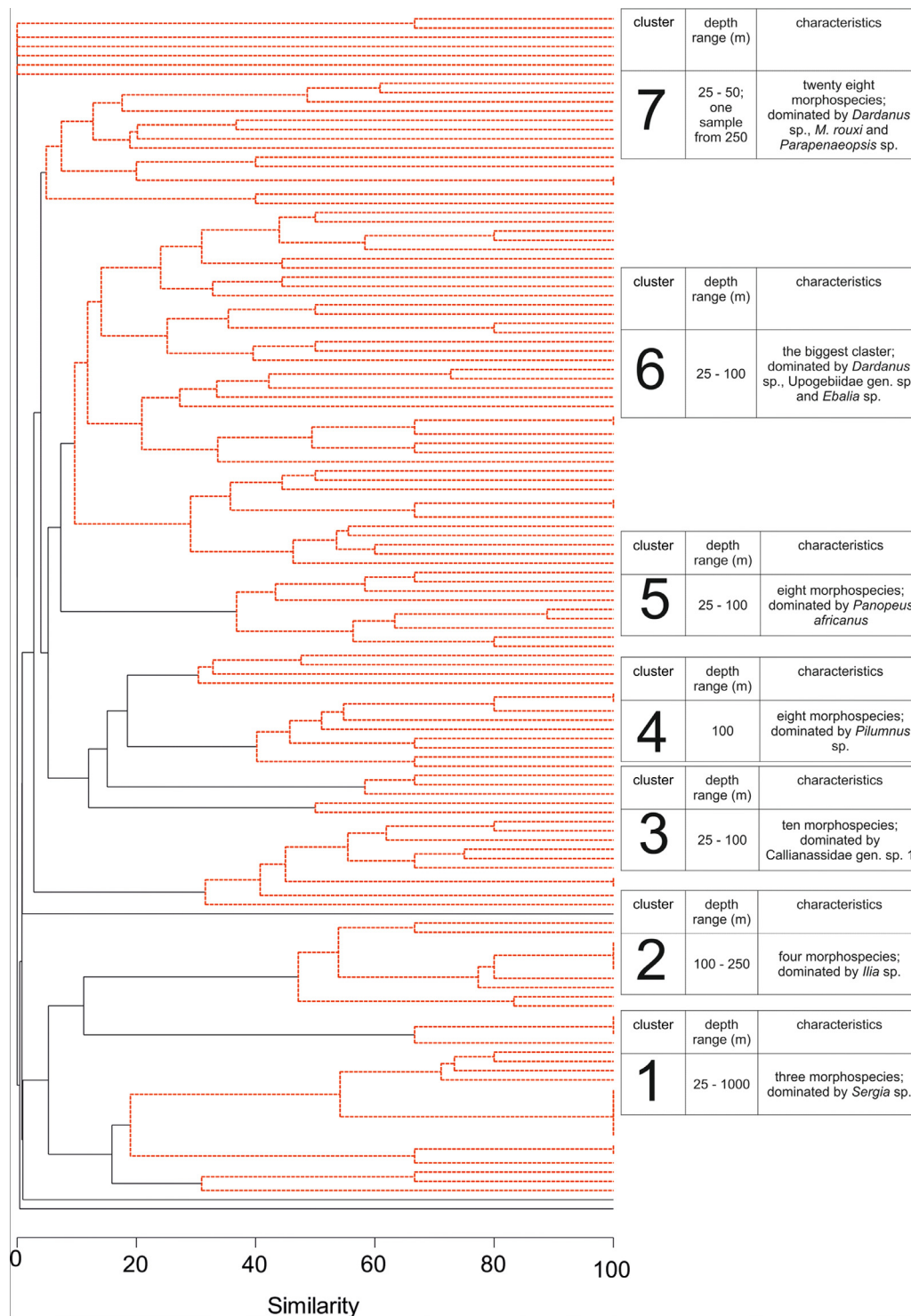


Figure 5 Dendrogram of decapod samples collected in the study area (Bray-Curtis similarity, group average method, non-transformed abundance per 0.1 m²). Dashed red lines indicate the samples that cannot be significantly differentiated by SIMPROF.

4.2. Diversity and distribution along a depth gradient

Our study demonstrated a substantial decrease in abundance, species richness and diversity along a depth gradient. There were almost no species associated only with deeper bottom areas. Clear differences between the shelf

and slope were observed also in Guinea-Bissau (Muñoz et al., 2012) and in other surveys (Abelló et al., 1988; Cartes et al., 1994; Fanelli et al., 2007; García-Isarch et al., 2017; Macpherson, 1991; Moctar et al., 2020; Pajuelo et al., 2015). Although, decapod abundance increased along a depth gradient in Guinea-Bissau, reaching the highest values on the upper slope, a clear zonation of fauna was

observed. Diversity on the Ghanaian slope sampled with the van Veen grab was low. Earlier observation has also shown that the distribution of decapods along a depth gradient can be very variable depending on the region being studied (Company et al., 2004). Some studies suggest that bathyal communities are often diversity hotspots for the decapod fauna (Company et al., 2004; Follesa et al., 2009; Maynou and Cartes, 2000) because of higher habitat heterogeneity and stability of environmental variables (especially temperature and oxygen concentration), resulting in co-occurrence of nectobenthic and benthic species (e.g. Abelló et al., 1988; Fanelli et al., 2007; Muñoz et al., 2012). Those earlier observations were also in agreement with a commonly held hypothesis that bathyal is a major diversity hotspot of benthic fauna (Danovaro et al., 2009; Levin and Dayton, 2009). However, Cartes and Sardà (1993) reported decapod fauna impoverishment on deep slopes, below 1200 m, and linked this pattern with lower food availability and degradation of organic matter. Moreover, McCallum et al. (2015) reported that a general pattern of higher slope diversity is not universal and may vary depending on the region. Food availability is also important for the distribution of decapods and might influence diversity and abundance, both on the slope and in the shallow shelf waters (Cartes and Sardà, 1993; Woolley et al., 2016). Values of total organic matter (TOM) increased along a depth gradient on the coast of Ghana but the highest levels of hydrocarbons and some toxic metals were found at the 500 and 1000 m sampling points (Table 1). Those factors affect polychaete and peracarid communities (Jóźwiak et al., 2022; Sobczyk et al., 2021, 2023; Stępień et al., 2021) and probably also affect decapod distribution. A recent study of depth-related changes in total macrozoobenthic abundance based on the same set of samples also showed a decrease in mean densities along a depth gradient, while cluster analysis separated disturbed sampling sites from unaffected bottom areas (Pabis et al., 2020). Contrary to our results, Jóźwiak et al. (2022) showed the highest Tanaidacea species richness on the slope. In the case of Cumacea, the highest number of species was recorded in the 25–50 m depth range and on the slope (Stępień et al., 2021), while polychaetes followed the pattern observed for decapod fauna, both in terms of species richness and abundance (Sobczyk et al., 2021, 2023).

Cluster analysis did not reveal any clear patterns besides the difference between shelf (morphospecies rich) and slope (morphospecies poor) (Figure 5). The results demonstrated seven, most probably incidental groupings. It seems that mobile decapods do not form stable, evenly distributed faunal assemblages, but only temporary patches, most probably associated with food availability, which was already observed for Decapoda (Boada et al., 2018). Mobility is an important feature of decapods (Florko et al., 2021), which allows them not only to actively search for food (Gomes et al., 2019), but also, at least to some point, avoid various types of disturbances or unpreferred environmental conditions (Attrill and Thomas, 1996; Felder et al., 2014).

It is difficult to study the ecological diversity of decapod fauna in Ghanaian waters since there is only scanty knowledge about the biology or habitat preferences of particular species. Nevertheless, the shelf fauna was ecologi-

cally diverse. We have recorded a group of species associated with sandy or muddy bottoms, including *A. rotundatus*, *E. rosacea*, *G. barnardi*, and *M. macrocheles*, species associated with shell debris or gravel, including *C. pelii* and *A. brevispinis*, and species with wide habitat preferences, recorded from mud and sand, shell debris and solid rock, such as *D. maltzami*, *E. aspera* and *S. notialis* (De Matos-Pita et al., 2016). These results confirm high microhabitat diversity, which has also been reported from polychaete studies (Sobczyk et al., 2021, 2023) and are congruent with sediment characteristics of the studied area (Pabis et al., 2020). Moreover, the majority of these species have a wide bathymetric range from the shallow shelf down to the slope depths (De Matos-Pita et al., 2016), which was also confirmed in our results. Part of our results is also confirmed by historical data from the Gulf of Guinea. This includes the presence of the genus *Dardanus* on the shelf (Bayer et al., 1966). Such taxa as *Dardanus* and *Goneplax* were also found on the shelf in Mauritanian waters, while such genera as *Sergia* occurred in the deep sea, though many species had a wide bathymetric distribution (García-Isarch et al., 2017).

The availability of organic matter was high on shallow shelf stations (Pabis et al., 2020) which is important for such taxa as Galatheididae or Porcellanidae (Nicol, 1932). Moreover, many decapods, e.g. crabs are generalists which may feed on algae or prey on small crustaceans and molluscs (Sant'Anna et al., 2015). The 25–50 m depth range was also characterized by high diversity and abundance of polychaetes (Sobczyk et al., 2023) and peracarid crustaceans (Jóźwiak et al., 2022; Stępień et al., 2021), and generally high macrofaunal abundance (Pabis et al., 2020), and therefore, variety of potential prey for omnivorous or predatory decapods like *Ebalia* (Schembri, 1981). Decapods sampled on the Ghanaian shallow shelf represent high ecological and functional diversity, similarly to polychaetes (Sobczyk et al., 2021) and suggest that the Ghanaian shelf is a diverse system characterized by a high variety of ecological interactions associated with high habitat heterogeneity compared to deeper bottom areas (Pabis et al., 2020; Sobczyk et al., 2023). Heterogeneity was evident in the character of the bottom deposits, which were diversified on the shelf, and homogenous on the slope (dominated by silt clay fractions) (Table 1).

4.3. van Veen grab in decapod sampling

Quantitative samplers (van Veen grabs or box corers) are not perfect for collecting large and motile decapods (Frutos et al., 2022). Underestimation of mobile epifauna might be associated with the bow wave effect and closing mechanism of the grab (Eleftheriou and McIntyre, 2005; Lozach et al., 2011). On the other hand, broadly used trawling or dredging devices are excellent for assessing diversity or benthic zonation, though they preclude detailed quantitative analysis and/or reliable estimation of rarity, patchiness and small-scale distribution patterns (Frutos et al., 2022; García-Isarch et al., 2017). Trawling or dredging also facilitates the collection of pelagic and nectobenthic decapods (Fanelli et al., 2007; Furlan et al., 2013; Moctar et al., 2020; Muñoz et al., 2012), which are only sporadically recorded in van Veen grabs. Large sampling efforts, such as that of the present study, might to some

point minimise the underestimations associated with the use of quantitative samplers which collect the fauna at a very fine spatial scale, although it is worth mentioning that decapods were found only in 49.8% out of 265 collected samples. Nevertheless, the van Veen grab has already been used in studies of benthic decapods (e.g. Ateş and Katağan, 2008; Fanelli et al., 2007) and some decapod taxa have been mostly (or exclusively) sampled via grabs or corers (Dworschak, 2015). Generally, each of those two sampling protocols may sample different, unique fauna (Jóźwiak et al., 2020). Grab samples permit quantitative analysis, assuming that the level of underestimation is similar for all of the samples (Eleftheriou and McIntyre, 2005), especially when we use monitoring like VAMS which allows us to discard poor samples. Moreover, in the case of trawling, it is almost impossible to link the data on abundance and diversity with environmental variables that are collected using samplers like grabs and corers (if collected at all) and do not describe the microhabitat diversity sampled during trawling (Eleftheriou and McIntyre, 2005; Frutos et al., 2022; Pabis et al., 2015; Sobczyk et al., 2023). For example, our results demonstrated that decapods in Ghana form small temporary patches. Those conclusions are supported by our analysis of video recordings from ROV (Remote Operated Vehicle), performed at the same sampling sites (Jóźwiak P., Podwysocki K., Pabis K. unpublished data). Such evidence of patchiness is only collected when using samplers like van Veen grab, and is usually lost in the case of trawling samples, which tend to mix materials from large bottom areas, and various microhabitats (Eleftheriou and McIntyre, 2005; Frutos et al., 2022). In the case of slope fauna results from Remote Operated Vehicle (ROV) movies (Jóźwiak P., Podwysocki K., Pabis K. unpublished results) partially confirmed results based on analysis of van Veen grab samples. Only at 500 m depth from three transects, i.e. G2, G3 and G6, we have recorded large aggregations of Caridea (up to 400 individuals on several square meters).

The very low frequency of decapods occurrence in van Veen grab samples, together with the almost complete absence of those crustaceans in the 250–1000 m depth range, precludes meaningful cluster analysis or detailed analysis of depth-related changes in diversity and abundance against a background of environmental conditions, e.g. modelling or Canonical Correspondence Analysis (Reiss et al., 2015). It is a general problem of many deep-sea studies of benthic macrofauna (Jóźwiak et al., 2022 and references therein). An attempt to perform such analysis resulted in lack of clear patterns, low eigenvalues and a low percentage of explained variability, therefore, it was impossible to interpret such not informative results, and they were not included in the manuscript according to Occam's razor principle. Comparisons of our results with the above-mentioned studies show the importance of using combined approaches in decapod sampling. Trawling allows for describing more general spatial patterns, while grabs or corers allow for studying small-scale variability. It is also worth mentioning that earlier studies of quantitative sampling efficiency suggest that box corers are more useful in the deep-sea studies than in shelf sampling (Eleftheriou and McIntyre, 2005). On the African coast, such an approach was used by Eisenbarth and Zettler (2016) and van Veen grab was used only down to

300 m depth, while deep-sea sampling was conducted using a box corer. The use of VAMS is also important because the problems are associated mostly with the closing mechanisms and appropriate sediment penetration of the grabs in the deep-seabed. Results may also differ depending on the region studied, especially the type of sediment sampled, which may affect the functioning of the grab-closing mechanism (Eleftheriou and McIntyre, 2005).

4.4. Concluding remarks

Earlier studies on other taxonomic groups (Jóźwiak et al., 2022; Sobczyk et al., 2021, 2023; Stępień et al., 2021) demonstrated that the coast of Ghana is under the influence of numerous interacting environmental factors, of both natural (e.g. oxygen minimum zones, productivity, upwellings) and anthropogenic (heavy metals and THC) origin, and those factors might affect decapods, especially in the larval stage (Felder et al., 2014; Katz, 1973), resulting in changes in abundance of adults. Further studies using different sampling protocols are needed to fill the knowledge gaps of decapod biodiversity in the area studied. Although, it is worth mentioning that previous studies on decapods sampled with more efficient equipment, such as trawls in most cases, were not supplemented with detailed knowledge about relevant environmental factors (e.g. Cartes and Sardà, 1993; Fariña et al., 1997; Follesa et al., 2009; Muñoz et al., 2012), therefore, documented mostly depth-related trends. Therefore, despite some limitations of van Veen grab, our study conducted on a wide depth range in the tropical Eastern Atlantic still stands out from earlier similar decapod research. It also showed the great need for applying different types of sampling methods in studies on decapods.

Declaration of competing interest

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.

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