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Epifauna diversity and ecology on intertidal flats in the tropical Niger Delta, with remarks on the gastropod species *Haminoea orbignyana*

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Here we report novel data on the ecology and diversity of West African estuarine biological communities, with emphasis on the opisthobranch gastropod, Haminoea orbignyana*. Macrofaunal samples were obtained from five intertidal flats within Bodo Creek in the lower Niger Delta during two years (May 2006–April 2008) to investigate diversity and community assemblages of epimacrofauna. A total of 601 individuals belonging to 18 species were recorded, with density varying between 4 ind.m^{-2} and 660 ind.m^{-2}. Gastropods (predominantly* Pachymelania aurita *and* H. orbignyana*) accounted for 92.3% of the community abundance, followed by malacostraca crustaceans (7.7%). Diversity varied (*$P < 0.05$*) between locations, with the mangrove swamp station having higher richness, diversity and evenness values than the open intertidal flat locations. The species* H. orbignyana *was only found on downstream sampling sites reaching a maximum density of 52 ind.m^{-2}. The species seems to recruit during November/December and likely attains a maximum life span of about 18 months.*

Keywords: Africa, Nigeria, coastal communities, epizoobenthos, biodiversity, management

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INTRODUCTION

The ecology and diversity of estuarine and coastal communities in West Africa are very understudied and the Niger Delta is no exception. Yet, the delta is simultaneously the hub of oil and gas production and the biodiversity hotspot of Nigeria, having a web of diverse biological communities and productive ecosystems (Zabbey, 2009). The Niger Delta has the fourth largest mangrove belt in the world (Spalding *et al.*, 1997; Nandy & Mitra, 2004), which together with extensive substrate-diverse adjacent tidal flats, constitute thriving habitat for many commercial and non-commercial faunal species. The mangroves of the Niger Delta and their associated productive open tidal flats are breeding and nursery grounds for, at least, 60% of commercial fish in the Gulf of Guinea (Bassey, 1999).

Human population grows faster in the Niger Delta (3.1% per year) than elsewhere in Nigeria (UNDP, 2006), mainly due to higher crude birth rate and influx of oil- and gas-related labour seekers. Impacts associated with oil and gas exploration, particularly reduction and fragmentation of habitat, conversion of biodiversity-rich and productive ecosystems for one form of development, and pollution constitute major threats to ecosustainability and biodiversity in the Niger Delta (Steiner, 2008; IUCN/CEESP, 2006; UNDP, 2006).

The situation will likely worsen with the conclusion of the Bodo–Bonny road and bridges project, presently under construction. This road will connect Bodo mainland (traversing Bodo Creek) to the industrial bustling island city of Bonny with its oil terminal and foremost liquefied natural gas plant in Nigeria. This city is presently only accessible by air and water and is already land 'saturated'. Littoral reclamation remains the only option to create the needed space for industrial expansion and thus, Bodo Creek banks are increasingly becoming very attractive for industrial settlement (Onwugbuta-Enyi *et al.*, 2008).

A search through the literature reveals incredibly a paucity of data on the ecology and biodiversity of Bodo Creek (Asia Phil-Fisheries Cooperation, 1981; Oliver, 1986; CORDEC, 1989; ARAC, 1990; Onwugbuta-Enyi *et al.*, 2008; Zabbey *et al.*, 2010). These data hardly include any information on macrozoobenthos, besides being limited in space and time of sampling.

Kio & Ola-Adams (1986) noted the urgency to collect baseline data on ecosystems. The lack thereof, undermines the validity of post-impact assessment conclusions (Snowden & Ekweozor, 1990). Macrobenthic fauna are amongst the most preferred bioindicators and biomonitors of aquatic environmental quality (Odiete, 1999; Moreno & Calisto, 2006; Zabbey & Hart, 2006). Longevity, relative largeness, high density, diversity, etc, are some of the features that make zoobenthos choice-animals for tracking spatio-temporal changes

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in hydrosystems (Jones, 1987; Odiete, 1999). The surface of intertidal sediments has long been recognized (Eltringham, 1971) as a difficult environment to live in due largely to the dehydrating aerial weather experienced during exposed low tide. Furthermore, the potential epifauna must be able to avoid or minimize the stresses of daily fluctuations between water–air environmental conditions (Nybakken & Bertness, 2005).

Haminoea orbignyana (Ferussac, 1822) is a shelled cephalaspidean opisthobranch gastropod with a shell shape distinct from all other eastern Atlantic species (Malaquias & Cervera, 2006). The species can attain maximum shell length of 20 mm (Talavera *et al.*, 1987). An ecological study on a coastal lagoon in southern Europe revealed that this species is an important member of the epifaunal communities and can be extremely abundant on seagrass tidal flats (Malaquias & Sprung, 2005). There are no reported accounts of *H. orbignyana* from the Niger Delta in published literature; however, a reference to this species was found in an unpublished EIA macrofauna checklist by C.B. Powell, and its presence in the Delta is now confirmed (present study).

This work reports the results of a two-year ecological survey (May 2006–April 2008), aiming to: (1) study the diversity, abundance, and ecology of intertidal macrozoobenthic epifaunal communities in Bodo Creek, Niger Delta, Nigeria; and (2) to provide pioneering baseline information that could be used as a reference in future predictive, biomonitoring, and population biology studies in the creek basin.

MATERIALS AND METHODS

General description of the study area

Bodo Creek is a network of brackish water creeklets flanking Bodo City on the upper reaches of the Andoni–Bonny River system (Figure 1). Bodo City is an Ogoni coastal community, administratively located in the Gokana Local Government Area of Rivers State, eastern Niger Delta of Nigeria. The creek configuration and hydrology have been described by Onwugbuta-Enyi *et al.* (2008). Two major channels conduct saline waters in and out of Bodo Creek: Dor Nwezor and Kpador. Seaward, these two main channels connect Bodo Creek to Opobo channel (an adjunct linking Andoni and Bonny Rivers), and to Bonny River respectively. Traditionally, Bodo Creek serves as a strong livelihood support base for the people of Bodo and their neighbours (Powell *et al.*, 1985). The creek provides ready incentives for capture fisheries, transportation, cassava fermentation, fuel wood production, domestic waste disposal, small-scale aquaculture, sand dredging (Onwubuta-Enyi *et al.*, 2008), and hitherto, crude oil exploitation and large-scale fish farming. In addition, the network of mangrove swamps within the creek basin provides the locals with ecosystem services such as shoreline protection, flood control, fish breeding ground, etc.

Access to bioresources within Bodo Creek is open to every person including migrant fishermen. There are no organized management structures in place to check and regulate exploitation rates in the creek basin beyond weak community-imposed regulations, which are grossly violated due to lack of enforcement (Zabbey *et al.*, 2010) and the erosion of respect for traditional authorities. However, the Sivibilagbara protected mangrove swamp (Figure 1) fringing Dor Nwezor channel stands out as a rare exception. Over thirty years ago, a highly respected communal moratorium was issued, declaring the Sivibilagbara mangrove block closed to entry and for any kind of resource removal.

This study was conducted at Sivibilagbara protected mangrove swamp and four open intertidal flats along Dor Nwezor channel of Bodo Creek; approximately between latitude 4°36′29.7″N 4°35′26.3″N and longitude 7°15″30.2″E to 7°16″50.9″E (Figure 1). Vegetation along the margins of the study area is dominated by red mangrove, *Rhizophora racemosa* with presence of the white mangrove, *Avicennia germinans*, black mangrove (*Laguncularia racemosa*), mangrove sedge (*Paspalum vaginatum*), and scanty pockets of nypa palm (*Nypa fructicans*). On the upper shore limits, vegetation is dominated by mosaic communities of near-shore plants like date palm (*Phoenix reclinata*), coconut (*Cocos nucifera*) and mango (*Mangifera indica*).

Sampling stations

For the purpose of this study, five sampling stations were established on intertidal flats fringing the Dor Nwezor main channel. The locations were chosen to cover the various biotopes available. The sampled locations were on isolated flats, which did not require artificial position fixing object for demarcation. Where, however, a tidal platform was too expansive (as in Stations 2, 4 and 5), the macrolocation for sampling was visually marked using existing landmark structures since the placement of artificial markers (such as driven post) attract molluscs collectors which may cause avoidable physical disturbances (Eleftheriou & Holme, 1984).

Station 1: the most upstream station located in the Sivibilagbara protected mangrove swamp (4°36′29.7″N 7°15′30.2″E; Figure 1). The vegetation of Sivibilagbara is homogeneously red mangrove (*R. racemosa*), with knitted structural architecture of prop roots and thick intertwined crowns. The swamp dimension is approximately 105 × 42 m (4410 m^2). The sediment type was peaty clay (dominated by silt and clay).

Station 2: this was located approximately 1280 m downstream from Station 1 (Figures 1 & 2) on an open, unvegetated tidal flat locally called Si Eeva. Facing downstream, the station lay to the left of Dor Nwezor main channel (4°36′12.7″N 7°16′08.1″E). The riparian vegetation of this station is mainly stunted red mangrove, and dwarf, aged and unproductive coconut trees at the edges of the supralittoral shores. The substratum was sandy mud.

Station 3: located approximately 956 m downstream from Station 2, on a right-flanked tidal platform. The station was sited opposite a sprawling fishing settlement called Kozo (4°35′55.3″N 7°16′33.8″E). The marginal vegetation is dominated by red mangrove (*R. racemosa*), with few stands of the white mangrove (*A. germinas*) and mangrove sedge (*P. vaginatum*) at the high intertidal zone. The palm (*P. reclinata*) and mango are amongst the mosaic admixture of plants at the supralittorial zone. The bottom was muddy sand.

Station 4: this was located 994 m downstream from Station 3, having expansive unvegetated intertidal flat (4°35′32.4″N 7°16′56.6″E). Predominantly black mangrove and few stands of red mangrove and nypa palm characterize the marginal vegetation. The sediment was sandy mud.

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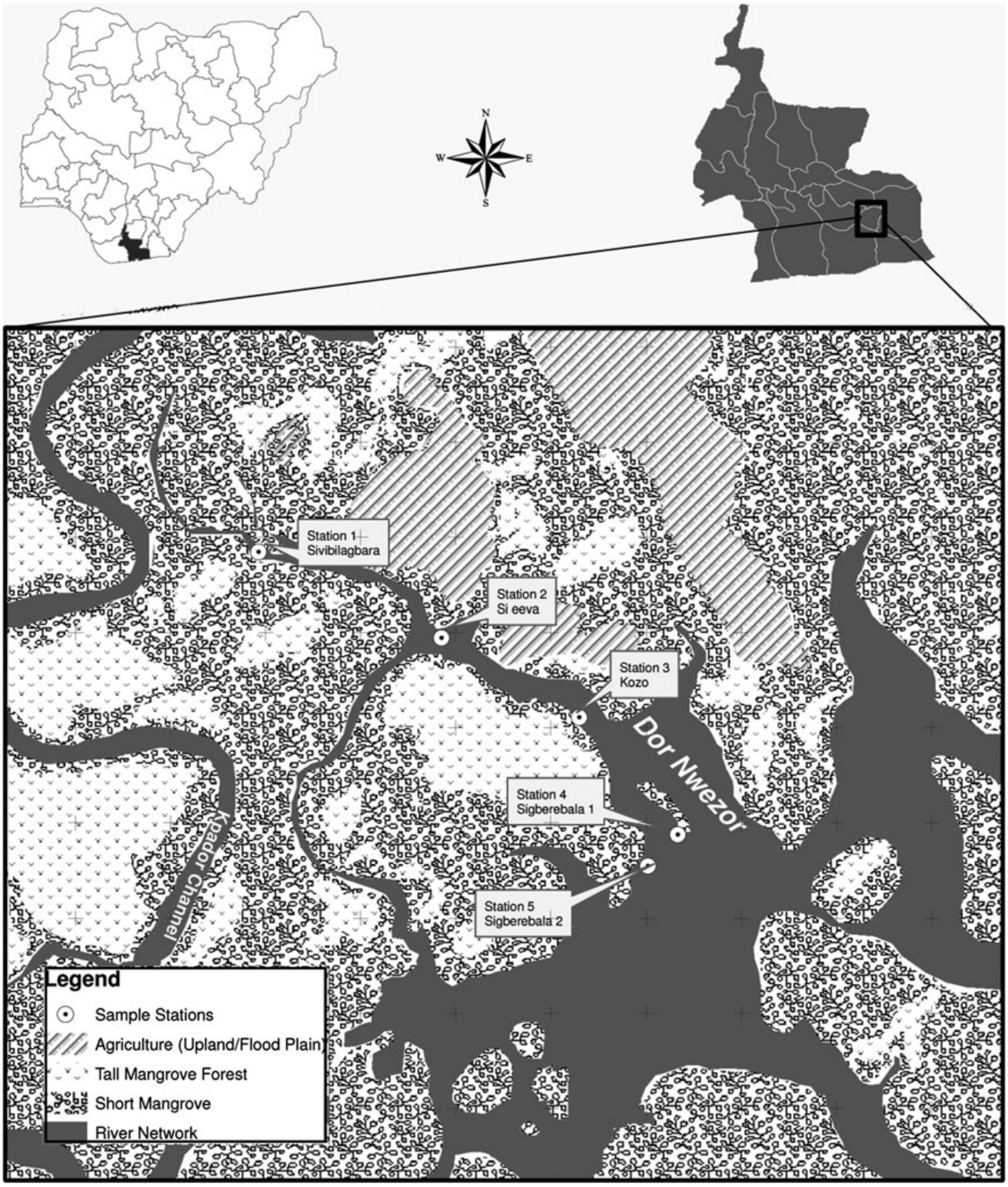

Fig. 1. Map of Bodo Creek in the Niger Delta, Nigeria (for sampling sites coordinates see text).

Station 5: located on an expansive tidal mudflat (sandy mud) parallel to Station 4. The distance between Stations 5 and 4 is approximately 256 m and they are separated by the main creek channel (4°35′26.3″N 7°16′50.9″E). The vegetation is dominantly black mangrove.

Abiotic parameters

Samples were collected during low tide from the visually delineated stations once every month for 2 years (May 2006–April 2008). Interstitial water samples for assessment of physicochemical parameters were obtained from dugout holes created by a complementary infaunal study. Temperature of the pore water was measured *in situ* to the nearest 0.1°C with mercury-in-glass thermometer. Hydrogen ion concentration (pH) was determined with a Jenway 3015 model meter, conductivity was measured with Jenway 4010 meter, and salinity (psu) was measured with a refractometer (Atagos/miltE 0–100‰). Dissolved oxygen content (DO) (mg/l) was measured by the alkaline–azide modification of Winkler's method (APHA, 1998).

Sampling and identification

The epizoobenthos were sampled monthly quantitatively at the five sampling stations using a 50 × 50 cm quadrat randomly thrown three times (Sasekumar, 1974). All visible animals within the three replicated sample units (at each

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location) were collected, combined together to form a composite sample and preserved with 10% formalin for *ex situ* analyses. It was impossible to enumerate active mobile surface animals like mudskippers, which were recorded as site-seen and could not have been quantitatively assessed by burrow counts, since mudskippers might seek refuge in crab burrows when threatened by human invaders. The macrozoobenthos were identified to the lowest possible taxonomic level using appropriate taxonomic keys (Edmunds, 1978; Deekae, 1987; Badejo, 1998; Powell, unpublished data) and counted. Density was calculated as in Malaquias & Sprung (2005):

$$A = \frac{(\sum ni)1}{(n_{sq})A_{rsq}}$$

where ni is the total number of specimens found, n_{sq} is the number of squares (=3) sampled, and A_{rsq} is the area of each square (=0.25 m^2).

Species richness was calculated using the Margalef (1958) index:

$$d = \frac{S - 1}{\ln N}$$

where S is the total number of species, N is the total number of individuals and ln is the natural logarithm.

Community diversity was calculated using the Shannon–Wiener (Shannon & Weaver, 1963) information index:

$$H = \sum_{l=1}^{s} Pi \ln Pi$$

where Pi is the proportion of individuals found in the *ith* species (i.e. $Pi = ni/N$, N being the total abundance and ni = number of individuals of the *ith* species).

Dominance, a measure of the probability that two individuals drawn at random from a community belong to the same species, was calculated using the Simpson (1949) index:

$$D = \sum_{i=1}^{s} \frac{ni\ (ni - 1)}{N(N - 1)}$$

where ni = number of individuals in the *ith* species and N = total number of individuals.

Evenness (E) was calculated using the Pielou (1969) index:

$$E = \frac{H}{H_{max}} = \frac{H}{\text{Log } S}$$

where H = Shannon–Wiener value, S = number of species.

RESULTS

Physico-chemical parameters

Interstitial water temperature varied between 25 and 34°C. Mean temperature differed significantly ($P < 0.05$) between Stations 1 and all others (Table 1); the observed variation on mean water temperature between Stations 2 and 5 was minimal. pH varied (6.64–8.10) spatially except between Stations 4 and 5 which had similar mean values ($P > 0.05$) (Table 1). Conductivity values varied significantly between Stations 3 and 5 whereas others had similar ($P > 0.05$) mean conductance (3200–51000 μs/cm; Table 1). Salinity (psu) had similar ($P > 0.05$) mean inter-site values, ranging between 17.9 and 18.2 psu. Dissolved oxygen content (DO mg/l) varied significantly between the locations (Table 1). The least mean DO (0.655 mg/l) and maximum mean (3.224 mg/l) were recorded at Stations 1 and 3, respectively.

Epifaunal macrozoobenthos

A total of 601 individuals belonging to 18 species were recorded; the number excludes the actively mobile mudskipper fish. Community assemblages, inter-site distribution patterns, and community diversities are presented in Table 2. The gastropod, *Neritina glablata* (Sowerby) was recorded only at Station 4. Decapods, *Sesarma huzardi* (Desmarest), *S. elegans* (Herklots), *S. alberti* (Rathbun), *Gionopsis pelli* (Herklots) and *Pachygrapsus gracilis* (De Saussure) were encountered only at Station 1. The mud crab, *Panopeus africanus* (A. Milne-Edwards) was recorded at Stations 1 and 5. The swimming crab *Callinectes amnicola* (De Rochebrune) was represented at Stations 2, 4 and 5, while the opisthobranch gastropod, *Haminoea orbignyana* was recorded at Stations 4 and 5. Epifaunal densities varied from 4 ind.m^{-2} to 660 ind.m^{-2}. The gastropod *Pachymelania aurita* (Müller) had the highest densities; this was particularly notorious at Station 3 with a minimum density of 44 ind.m^{-2} throughout the study period. *Haminoea orbignyana* was the second

Table 1. The mean, range and standard deviation of physico-chemical parameters at Stations 1 to 5 of Bodo Creek interstitial water (May 2006–April 2008).

Station	pH		Temperature (°C)		Salinity (psu)		Dissolved oxygen(mg/l)		Conductivity (μs/cm)	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
1	7.46 ± 0.34^{b}	6.64–7.90	28.17 ± 1.50	25.00–30.00	18.23 ± 1.42	12.00–26.00	0.66 ± 1.27	0.00–3.50	16032.3 ± 10360.51	6980–44300
2	7.58 ± 0.56^{a,b}	6.70–8.30	30.08 ± 2.58	25.30–34.00	18.18 ± 4.68	12.00–26.00	2.22 ± 2.21	0.40–7.60	16324.5 ± 10519.43	7800–45600
3	7.57 ± 0.44^{a,b}	6.74–8.10	30.41 ± 2.71	25.30–34.00	17.91 ± 6.12	5.00–26.00	3.22 ± 1.48	0.60–5.60	15449.5 ± 10953.19	5260–44800
4	7.62 ± 0.52^{a}	6.73–8.40	30.09 ± 2.40	25.40–33.00	18.18 ± 5.20	11.00–27.00	2.23 ± 1.84	0 –6.40	16301.4 ± 114577	7920–48550
5	7.60 ± 0.58^{a}	6.67–8.60	30.22 ± 2.49	25.40–32.00	18.23 ± 4.57	7.00–28.00	2.69 ± 1.57	0–4.80	16454.5 ± 12092.65	3200–51000

$^{a-c}$, means with the same superscript in the same column are not significant ($P < 0.05$).

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Table 2. Diversity, distribution, and relative abundance (combined annual data) of surface fauna on intertidal flats of Bodo Creek (May 2006–April 2008).

Higher rank	Species	Station				
		1	2	3	4	5
Gastropoda						
Naticidae	*Natica* sp.				15	6
Melaniidae	*Pachymelania aurita*		1	439	3	2
	P. fusca			1		
Potamididae	*Tympanotonus fuscatus*	3	11	3		5
Neritidae	*Neritina glablata*				1	
Galeodidae	*Semifusus morio*					1
Littorinidae	*Littorina angulifera*	1				
Haminoeidae	*Haminoea orbignyana*				6	50
Malacostraca						
Grapsidae	*Pachygrapsus gracilis*	4				
	Sesarma huzardi	3				
	S. elegans	3				
	S. alberti	2				
Gecarcinidae	*Gionopsis pelii*	4				
Portunidae	*Callinectes amnicola*		1		1	1
Panopeidae	*Panopeus africanus*	1				1
Diogenidae	*Clibanarius africanus*	11	1	11	2	2
Bivalvia						
Arcidae	*Anadara senilis**			2	1	1
Polychaeta						
Nereidae	*Platynereis* sp.*		1			
	Margalef diversity (d)	2.308	1.477	0.490	1.501	1.883
	Shannon–Wiener H	0.844	0.412	0.074	0.578	0.489
	Pielou index of evenness	0.884	0.590	0.122	0.742	0.513
	Simpson's dominance	0.182	0.556	0.936	0.352	0.526

*, infauna fortuitously recorded at the surface.

species with higher density, ranging between 4 and 52 ind.m^{-2}.

The actively mobile mudskippers fish sighted on the mangrove shaded tidal flat of Station 1 were only enlisted in the checklist, as the species monthly density was not determined. Of the 601 studied individuals, gastropods contributed 92.3% while malacostraca crustaceans accounted for 7.7% of the community abundance. On the basis of specific contribution to overall community, the periwinkle *Pachymelania aurita* accounted for 74.9%, followed by *H. orbignyana* (9.4%) and hermit crab *Clibanarius africanus* (Aurivillus) (4.2%). Some specimens of the infaunal bloody-cockle (*Anadara senilis* Linnaeus) and the polychaete worm, *Platynereis* sp., were unusually found on the tidal flats of Stations 2, 3 and 4, and Station 2 respectively. The species richness and diversity (Table 2) decreased according to the following pattern: Station 1 > 5 > 4 > 2 > 3 and Station 1 > 4 > 5 >2 > 3, respectively. The animals were also more evenly distributed at Station 1, but Simpson's dominance value was highest for Station 3, followed by Station 5 which had a relatively high proportion of *H. orbignyana*.

DISCUSSION

Shade provided by the thick mangrove canopy of Station 1 limited the influence of sun-heating on the sedimentary floor. The mangrove microclimatic thermal conditions regulate the aerial temperature, which consequentially modulated interstitial temperatures at the location. The direct relationship between air temperature and the temperature of tidal flats has long been noted (Eltringham, 1971; Kennedy *et al.*, 1974). Temperature of exposed (low tide) interstitial water may rise too high when the sun is shining or fall abruptly in the rains. Though, temperature varied minimally between the open, unvegetated mudflats (Stations 2–5), there was no marked trend of increasing values downstream. Instead, mean temperature peaked at the mid-location (Station 3) due to its relative elevation and hence, longer emersion and exposure to sunlight.

In tidal flats mean values of abiotic parameters (like those measured here) may vary substantially during tidal cycles and along the year. Though, this variation is unlikely to have ecological effects because tidal organisms are adapted to them (Nybakken & Bertness, 2005). Salinity gradient of the tidal flats deviated from the usual situation of most brackish waters whereby salt concentration increases downstream due to the inflow of oceanic waters and the decreasing influence of river- and runoff-derived freshwater (McLusky, 1989). Station 1, the most upstream location, had an equivalent mean salinity value to Station 5, the most downstream site; in spite of the long inter-site distance (approximately 3.5 km) between both locations. Salinity also peaked at both locations (see Table 1), but generally showed no obvious trend. The relatively higher salt concentrations consistently recorded at Station 1 could be explained by the ecological role of mangroves in water quality preservation, particularly salt maintenance (Ronnback, 1999).

Tide, localized freshwater seepages, and salinity were the determinants of conductivity in the study area. For instance, conductivity was highest at Station 5 and least at Station 3 (Table 1), where salinity was lowest. Underground freshwater seepages contributed to decreased conductivity values at Station 3. However, the conductivity of Bodo Creek interstitial waters constantly remained within the range of brackish waters. Dissolved oxygen peaked at Station 3, and could be attributable to freshwater seeps at the locality, which also resulted in the low salinity and low conductivity recorded at the station.

Generally, intertidal epifaunal communities are comparatively poor in species and diversity since not many benthic taxa can withstand the inherent environmental vagaries of such unstable habitat (Eltringham, 1971; Nybakken & Bertness, 2005). Notwithstanding the unavoidable consequences of natural environmental fluctuations, the cumulative number of surface fauna reported here is apparently low considering the number of sites studied and the duration of the investigation. The unvegetated flats (Stations 2–5) are notable bloody-cockle beds in Bodo Creek. Exploitation of cockle disturbs surface sediment (see harvest technique described below). The consistent physical disturbances and work-burial risk associated with cockle collection arguably contribute to the numerical poverty since trampling is considered an important factor that impacts on macrozoobenthos diversity and recruitment (Rossi *et al.*, 2007).

Based on the pattern of species representation, two parallel community assemblages of epifauna were delineated at the study area. Gastropoda dominated the open unvegetated mudflats (Stations 2–5) while the mangrove site (Station 1) had a malacostraca dominant community (Table 2). Distribution of the epifaunal assemblages may have been regulated by synergy of the ability of each taxon to withstand physical (desiccation) stress, food availability and predation pressure as well as other unclear interrelated habitat factors. All the surface faunas exhibited irregular inter-site distribution, with the exception of the hermit crab *Clibanarius africanus*, that showed a wide distribution in the study area, likely because its major habitation incentive (empty shells) was readily available in the study area due to high abundance of washed shells of periwinkles and other snails. Hermit crab mode of life is characterized by intermittent protrusion out of the shell to feed mainly on tidal flats rather than in shallow waters (Ajao & Fagade, 2002), and shows responsive retraction to threats.

The periwinkles, especially *P. aurita* were the dominant epifauna at the adjacent open mudflat stations (Table 2), most likely, due to their heat-protective shells. According to Ajao & Fagade (2002), gastropods and bivalves are relatively tolerant to physical and chemical variations of the environment and are present in a broad range of habitats. The gastropods *Pachymelania* and *Tympanotonus* are amphibious in nature, showing preference for mudflats of mangrove swamps and open mudflats at low tide where the annual salinity fluctuation is between 2 psu and 25 psu (Oyenekan, 1979; Egonmwan, 1980). The salinity in the tidal flats (interstitial waters) varied mainly between 5 psu and 25 psu; occasionally rising to 28 psu on very sunny days of summer (dry season) springtide. The periwinkles (*Pachymelania* and *Tympanotonus*) are of economic importance, featuring prominently in native soups in the Niger Delta and other Nigerian coastal communities (Gabriel 1981; Powell *et al.*, 1985; Deekae, 1987). Empty shells of these gastropods are locally preferred materials for improvising mixed aggregates (for building foundation, decking and flooring). The relatively high density of *P. aurita* encountered at Station 3 could be explained by the fact that the snail is able to withstand the physical challenges of the intertidal surface, find food resource (epibenthic algae), and space readily abundant. According to Eltrigham (1971), the surface of intertidal mud and sand is not an easy environment for animals and they are characterized by a paucity of species but a great number of individuals.

Specimens of the cockle, *A. senilis*, and the polychaete, *Platynereis* sp., occasionally recorded in the surface fauna samples at Stations 2–5 (Table 2) are naturally infaunal zoobenthos that live buried in subsurface sediment. Human activities may have caused the specimens to be dislodged and stranded at the surface. Paddling in the shallow intertidal waters especially during neap or ebb tide can destabilize sediments and dislocate the polychaetes and cockles, which remain exposed at low tide. Some cockles can fall off from the harvesters or may be ignored by the collector, after being uncovered by the fishing gear blade. At Bodo Creek, the intertidal cockle collectors (predominantly women) employ the use of L-shape metallic gear locally called *cuvegeh*, meaning curved knife. The longer handle is about 15 cm while the short cockle-detecting blade is around half the handle. The cockles are uncovered or their presence detected by clanking sound following forth-and-back scraping of the sediment surface with the exploring blade. The sizes of hand-picked cockle are a preserve of the harvester.

Swimming crabs, *Callinectes amnicola*, encountered on the surface shores of Stations 2, 4 and 5 (Table 2) were not unusual residents of exposed intertidal flats, particularly mudflats. Though, the crab naturally inhabits bottoms of shallow sub-tidal waters (Chindah *et al.*, 2000), the juveniles and subadults can be marooned in shallow depressions in mudflats, which remained water-filled when the tide recedes. Tide pools may also contain shrimps (Eltringham, 1971) and fish fry (Ansa, 2004). *Callinectes amnicola* trapped in inhospitable tide pools (i.e. in terms of drastic temperature and salinity fluctuations) continue to deposit-feed within the geolimits of the confined pool until flooding (personal observation by first author). The crabs respond to intruder threats by burying themselves superficially in the soft substratum after making complicated zigzag sideways races to create masking turbidity.

Comparatively, species richness and community diversity peaked at the forested location (Table 2) due to shade-effect conferred by the mangrove canopies. This regulates the habitat microclimate against abrupt fluctuations in temperature at low tide, reducing the thermal and osmotic shocks of dehydration (Odiete, 1999). It also minimizes *in situ* salinity fluctuation (see discussion above). Kumar (1995) recorded rich diversity and abundance of macrobenthos in the mangrove ecosystem of Cochin, south-west coast of India, and attributed the rich biodiversity to conducive, supportive conditions such as availability of suitable substrate for attachment, and dense shade-canopy of the mangroves which protect the animals from desiccation.

The gastropod *H. orbignyana*

The opisthobranch gastropod *H. orbignyana* was known from the Gulf of Biscay in Europe southwards to Cape Verde (Malaquias & Cervera, 2006) and its presence is here confirmed in Nigeria. The population and trophic ecology of this species were previously studied within its northern geographical limits (Malaquias *et al.*, 2004; Malaquias & Sprung, 2005). This study reports the first ecological data for the species in Africa and establishes a baseline for comparison with the European population.

Along Bodo Creek the species was found restricted to the most downstream locations (Stations 4 and 5), with the latter having markedly more representatives than the former (9 times higher). Habitat cannot explain the sharp difference of abundances, as both locations shared similar physical, chemical and community diversity conditions. The similarity and close inter-site proximity will potentially eliminate the possibility of site-fidelity related to habitat quality. Site-fidelity is not unique to sessile and less mobile fauna, but also observable amongst mobile animals (Willis *et al.*, 2003), and may arise due to recruits being positively attracted by chemical exudates of resident adults (Eltringham, 1971). It remains to be investigated whether or not larval settlement in *H. orbignyana* is governed by adult–larvae chemical attractants.

An alternative hypothesis could be the variability in the quality and quantity of food available; specimens of *H. orbignyana* were observed gliding over the sediment surface, presumably grazing on epibenthic algae that they are known to feed upon (Garcia *et al.*, 1991; Chester, 1993; Sprung, 1994; Malaquias *et al.*, 2004). Epibenthic algal quality/quantity was not assessed to determine whether or not differences could account for the disproportionate abundance *of Haminoea* specimens, but we regard this as unlikely due to the similarities between both sites.

The comparatively lower abundance of the species in Bodo Creek with a maximum density of 52 ind.m^{-2} is also striking (Station 5) compared with 341 ind.m^{-2} at the intertidal flat studied by Malaquias & Sprung (2005) in southern Portugal. The higher abundances detected by Malaquias & Sprung (2005) are likely due to exceptional good conditions for the survival of this species in the Ria Formosa coastal lagoon, but a density of 52 indiv.m^{-2} sampled in Bodo Creek cannot be considered low, particularly for a snail of about 10 mm in shell length. Both tidal flats (Stations 4 and 5) where *H. orbignyana* was exclusively recorded are bloody-cockle beds, which attract cockle collectors. Thus, anthropogenic disturbances may account for the lower densities at Bodo Creek.

The distribution of the predatory gastropod *Natica* sp. was the opposite of *H. orbignyana* with more individuals of the former at Station 4 than at Station 5. *Natica* snails are known to predate on gastropods and bivalves living a typical circular hole-mark on their shells (e.g. Berry, 1982); however no reports of predation of *Haminoea* by *Natica* are known and here we also did not find clear evidence of these attacks. Nevertheless, this cannot be completely disregarded because *Haminoea* shells are very fragile and any attempt at predation by *Natica* would likely result in the destruction of the whole shell.

During this survey, *H. orbignyana* was conspicuously absent in the February and September samples. Specimens collected in May were very large (maximum length H = 11 mm), while small specimens (H = 3.0 mm; recruits) made up the collections in January. It is hard to give reasons why no individuals occurred in the composite samples in February and September. A holistic mortality of the recruits cannot explain the absence of the species during February since they were found again in the following months. Malaquias & Sprung (2005), found a similar absence with individuals absent during August after recruitment in June. These authors attributed the unusual finding to adverse environmental conditions (August is when atmospheric and water temperatures in the studied intertidal flat were higher) that may have forced the animals to migrate elsewhere in the vicinity of the sampling area searching for favourable conditions. We speculate that something similar may occur at the creek; perhaps animals undertake horizontal or vertical movements when the environmental conditions at the intertidal flats become unbearable. We cannot completely reject the hypothesis that the low density of the species may have precluded the specimens from the samples.

The smallest individuals of *H. orbignyana* (H = 3.0 mm) sampled in this study were larger than the 0.5–1 mm recruits found by Malaquias & Sprung (2005) in southern Portugal. Assuming an average growth rate of 1 mm.month^{-1} (based on data from Malaquias & Sprung, 2005), it is conceivable that recruitment occurs in Bodo Creek during November/December. Consequently, it is likely that the largest specimens found during May resulted from a recruitment that took place two winters before implying that life span of the species in the Niger Delta can reach a maximum of approximately 18 months, which is in line with findings reported by Malaquias & Sprung (2005).

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