Assessment of benthic macroinvertebrate fauna as bio-indicator and physicochemical characteristics in the Gulf of Guinea off western Nigerian shore

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Abstract

Benthic macroinvertebrates are helpful bio-indicators providing better understanding of modified and perturbed aquatic ecosystems. This study seeks to determine the ecological status and diversity of the macroinvertebrate community in relation to environmental variables in western Nigerian offshore waters within the Gulf of Guinea. Macroinvertebrate samples were collected from five (5) sampling stations using a Van-veen grab following standard protocols. Water samples were collected and the physico-chemical parameters measured onboard using a multi-parameter checker, HORIBA-U53. The physico-chemical parameters of the water varied significantly ($p<0.05$) between stations. *Macoma litoralis* (13.71%), *Tellina gilchristi* (13.71%), and *Tellina trilateri* (11.71%) were the dominant macroinvertebrate species, while *Nassarius cuvierii*, *Oxystele tigrina Tritia lanceolata Turritella communis*, *Turritella communis* and *Orbinia angrapequensis* (0.33% each) were the least abundant. Axis 1 (63.73%) and axis 2 (22.32%) of the Canonical Correspondence Analysis (CCA) explained macrobenthic fauna-environmental variables association. Gastropoda showed strong relationship with salinity, silicate, sulphate, TDS and conductivity in Stations 1, 2 and 3. Bivalvia and Scaphopoda showed strong relationship with pH, BOD, water temperature, phosphate and nitrate in Stations 4 and 5. The AZTI Marine Biotic Index (AMBI, 0.85), multivariate AZTI Marine Biotic Index (M-AMBI, 0.80), Bentix Index (5.46) and Biotic Index (BI, 1.00) showed that this section of the Gulf of Guinea is undisturbed.

Keywords: Macroinvertebrates, bio-indicators, water quality, western Nigerian offshore waters, Gulf of Guinea

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Introduction

Benthic macroinvertebrates are organisms associated with sediment that make up the bottom of an aquatic ecosystem, such as streams, lakes, rivers, lagoons, seas, and oceans. They provide valuable ecosystem services such as supporting ecosystem functioning, nutrient cycling, leisure and recreation, and inspiration for artistic expression (Liu *et al* 2013). They are responsible for sediment bioturbation and secondary productivity, and are commonly used as bioindicators to detect pollution impacts on aquatic ecosystems (Smith *et al* 2001) because of their exclusive and unique characteristics. They are abundant, easy to collect and have diverse representatives from different phyla utilizing many different habitats and feeding strategies (Little 2000). These assemblages respond predictably to pollution because they are sedentary in nature and integrate the stress over the years as great sentinels (Sarker *et al* 2016). Soft-bottom macrobenthic communities respond to environmental stressors via different adaptive strategies. Some basic information vis-à-vis the ecological attributes of benthic macrofauna is still largely lacking for subtropical and tropical regions (Muniz *et al* 2005).

Using macroinvertebrates as bioindicators of ecosystem health requires proper understanding of their response to changes in the environment, especially quantitatively. Therefore, several biotic indices such as the Biotic Index (BI: Grall and Glemarec 1997), AZTI Marine Biotic Index (AMBI: Borja *et al* 2000; Borja and Muxika 2005), Bentix Index (BENTIX: Simboura and Zenetos 2002), Benthic Quality Index (BQI: Fleischer *et al* 2007), Community Disturbance Index (CDI: Flaten *et al* 2007) and most recently the multivariate AZTI marine biotic index (M-AMBI: Muxika *et al* 2007) have been developed for effective utilization of macroinvertebrates to evaluate ecosystem health. These indices are designed to establish the ecological quality of aquatic ecosystems

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that explore the response of soft-bottom communities to natural and man-induced changes in water quality, integrating long-term environmental conditions.

The study of biodiversity of benthic macroinvertebrate communities is pertinent because these organisms play vital link roles between trophic levels and serve as indicator species for water pollution assessment. Therefore, this study aims to ascertain the ecological quality status of the western Nigerian offshore waters within the Gulf of Guinea using the abundance and diversity of the benthic macroinvertebrate community and some environmental variables.

Materials and method

Study site

The study area is the Gulf of Guinea off Western Nigerian shore. The map of area was generated using ArcGIS 10.5 (Figure 1). The Gulf of Guinea is regarded as one of the world's most important oil and gas producing region and fishery capture hotspots. Exploration and development activities in the region have increased significantly following the discovery of enormous oil reserves (Oduntan 2009) and the extent of impact of these activities is relatively unknown. Samples for this study were collected from five sites on the Gulf during an exploration on board RV-BAYAGBONA research vessel on October, 2021.

Sampling

At each sampling station, triplicate water samples were collected at different depths using Niskin bottle. Water temperature, transparency, total suspended solids (TDS), dissolved oxygen (DO), pH, alkalinity, and salinity were measured onboard using a multi-parameter checker-HORIBA-U53. Some parameters (such as temperature, conductivity and density) were profiled using mini CTD cast. Samples for Biochemical oxygen demand (BOD) were collected in amber and transparent bottles from the different stations, incubated in the Department of Biological Oceanography laboratory for 5 days at 25°C and the BOD values determined according to APHA (2012). The nutrients (nitrate, phosphate, silicate and sulphate) were determined using UV spectrophotometer at optical densities of 880nm, 543nm, 420nm and 430nm, respectively (APHA 2012).

Sediment samples were collected from the five stations using a 0.1m^2 van-Veen grab and GPS (embedded within the Automatic Identification System (AIS) transmission). This was also used to determine the coordinates of each sampling station. Contents of the grab were washed with seawater through a sieve of 0.5mm mesh size (Plate 1). Benthic macroinvertebrates recovered from the sieve were preserved with 10% formalin in labelled jars for further analysis. In the laboratory, the preserved macroinvertebrates were washed with tap water through a 0.5mm sieve to remove the preservative and other fine sediments. The retained organisms were sorted and identified to species level, where possible using the following identification guides: (Edmunds 1984; Barnes 1994; FAO 1998; Branch and Branch 1992).

Table 1: GPS coordinates of sampling stations

Stations	Latitude	Longitude
1	6°13'.897"N	4°07'.172"E
2	6°13'.290"N	4°10'.087"E
3	6° 13'.182"N	4°13'.801"E
4	6° 01'.358"N	4°34'.339"E
5	6° 10'.989"N	4°27'.218"E

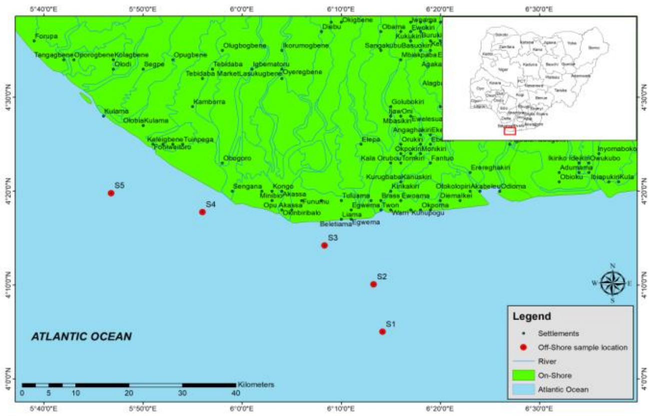

Figure 1. Sampling stations offshore Nigerian waters within the Gulf of Guinea

Diversity and ecological indices

Macroinvertebrate species richness and diversity were computed using Shannon-Wiener (H), Simpson's dominance (D), Menhinick, Margalef (d) and Simpson's indices using paleontological statistical software tool (PAST 4.10) (Hammer *et al* 2001). The AZTI Marine Biotic Index (ABMI), multivariate-AMBI (M-AMBI), Biotic and BENTIX indices (Simboura and Zenetos 2002; Cardoso *et al* 2012; Sany *et al* 2015) were used to determine the ecological quality status (EcoQs) of the Nigerian offshore waters. Macrobenthic assemblages were grouped into five (5), which includes sensitive species (%GS), which is the relative abundance of %Group I and %Group II) and tolerant species (%GT), which is the relative abundance of %Group III, %Group IV, and %Group V) as shown in Table 2. The BENTIX index was calculated using the equation below:

$$\textbf{Bentix Index} = (\mathbf{6} \times \%\mathbf{GS}) + (\mathbf{2} \times \%\mathbf{GT})/\mathbf{100}$$

Where GS is sensitive species and GT is tolerant species

Statistical analysis

The spatial distribution of the physico-chemical parameters was graphed using Surfer 23 software. Analysis of variance (ANOVA) was used to test the difference in the physico-chemical parameters between the stations using SPSS version 25. The relationship between the physico-chemical parameters and benthic organisms was evaluated by canonical correspondence analysis (CCA) using PAST 4.10 software (Hammer *et al* 2001). Ecological Indices were analysed using AZTI's AMBI version 6.0 software (Borja *et al* 2000; Muxika *et al* 2007).

Plate 1. Deployed and retrieved van Veen Grab and sieving of macroinvertebrate samples

Table 2: Ecological indices with scales and classifications

AMBI	M-AMBI	Biotic index	BENTIX	EcoQs	Dominant ecological group	Disturbance classification
0.0 < AMBI ≤ 1.2	≥ 0.77	0-1	4.5-6.0	High	I and II	Undisturbed
1.2 < AMBI ≤ 3.3	0.53-0.77	1.1-3	3.5-4.5	Good	III	Slightly disturbed
3.3 < AMBI ≤ 4.3	0.39-0.53	3.1-4	2.5-3.5	Moderate	IV-V	Moderately disturbed
4.3 < AMBI ≤ 5.5	0.2-0.39	4.1-6	2.0-2.5	Poor	V	Heavily disturbed
5.5 < AMBI ≤ 7.0	<0.2	≥7	0-2.0	Bad	Azoic	Extremely disturbed

Results

Physico-chemical parameters

The mean water temperature was 30.1±0.07°C with range of 29.88-30.2°C, pH values ranged from 8.02 to 8.29 with mean value of 8.14±0.05, conductivity values ranged from 39.3 to 43.6mS/cm and TDS values ranged from 24 to 26.6mg/l (Figure 2a). Salinity ranged from 24.9 to 28.01‰ with mean value of 26.7±0.55‰, DO values ranged from 8.91 to 11.63mg/l with mean value of 10.4±0.56mg/l (Figure 2b). The BOD values ranged from 3.41 to 8.03mg/l with mean value of 6.14±0.86 mg/l. The nitrate values ranged from 0.12 to 1.36mg/l with mean value of 0.60±0.24mg/l. The sulphate values ranged from 1700 to 2050mg/l with mean value of 1833.3±60.42 mg/l. The phosphate values ranged from 0.19 to 0.26mg/l with mean value of 0.21±0.01mg/l. The silicate values ranged from 1 to 2 mg/l with mean value of 1.33±0.20mg/l. Analysis of variance (ANOVA) showed that the physico-chemical parameters varied significantly ($p<0.05$) across all the stations.

Composition, abundance and diversity indices

The benthic macroinvertebrate fauna identified belong to two (2) Phyla – Mollusca (98.33%), which was represented by 36 species and Annelida (1.67%), with 3 species (Table 3). Bivalvia (69.9%) were predominant while Polychaeta was the least abundant Class (Figure 3). Thirty-nine (39) species were recorded across the five stations. *Macoma litoralis* (13.71%), *Tellina gilchristi* (13.71%), and *Tellina trilateri* (11.71%) were the most abundant species, while the least were *Nassarius cuvierii*, *Oxystele tigrina Tritia lanceolata Turritella communis, Turritella communis* and *Orbinia angrapequensis* with 0.33% each.

The number of species (S) recorded ranged between 9 (Station 1) to 23 (Station 4), while numerical abundance ranged from 16 (Station 1) to 130 (Station 4) as shown in Table 4. Shannon-Wiener Index (H) ranged from 2.05 to 2.77, while Dominance Index (D) was between 0.08 and 0.15. Menhinick Index values ranged from 1.40 to 2.53, Margalef Index (d) values ranged between 2.29 to 4.52, evenness ranged between 0.69 and 0.86, and Simpson's diversity Index ranged between 0.85 and 0.92 (Table 4). Ecological indices of benthic macrofauna

The ecological quality status using benthic macrofauna as bioindicators of pollution in Nigerian offshore waters are presented in Table 5. The highest AMBI (1.20), M-AMBI (0.98) and BENTIX (6.00)

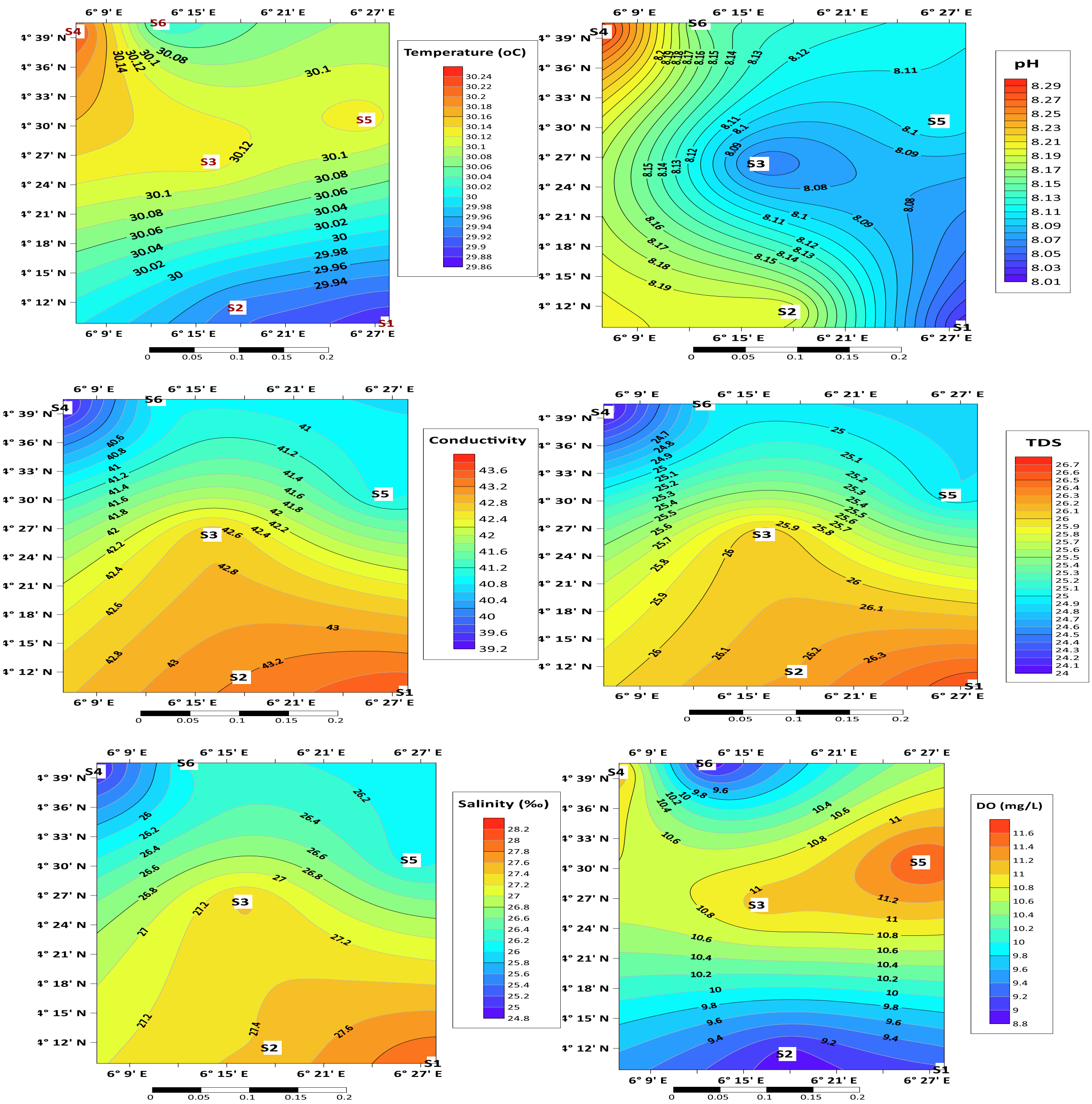

Figure 2a. Spatial variation of water temperature, pH, conductivity, TDS, salinity and D in the Gulf of Guinea of Western Nigeria shore

were recorded at Stations 2, 4 and 5, respectively (Table 5). Table 6 and Figures 3(a-c) show that the benthic community was dominated by Ecological Groups I and II (15-77.4%; sensitive species) and Ecological Group III (0-32.5%; tolerant species).

Canonical correspondence analysis (CCA)

The CCA exhibited strong relationships between the physico-chemical parameters of surface water and the distribution of benthic macrofauna as shown in Figure 4. Axes 1 and 2 of CCA, respectively accounted for 63.73% and 22.32% of macroinvertebrate-physico-chemical parameter association. Gastropoda distributions were more influenced by salinity, silicate, sulphate, TDS and conductivity in Stations 1, 2 and 3. Bivalvia and Scaphopoda showed strong relationship with pH, BOD, water temperature, phosphate and nitrate in Stations 4 and 5.

Discussion

The physico-chemical characteristics of any aquatic ecosystem determines the productivity and biodiversity of the biota (Anyanwu *et al* 2019; Jonah *et al* 2020). The relatively high DO values observed across all stations may be due to high water clarity and photosynthesis activities within the western Nigerian offshore waters as suggested by Kale (2016). Alkaline pH observed across the stations could be attributed to low anthropogenic activities at this section of the Nigerian offshore waters as suggested by Amah-Jerry *et al* (2017) and Jonah *et al* (2020). Water quality is essential for species abundance and distribution in an aquatic ecosystem. In water of premium quality, aquatic organisms such as macroinvertebrates can proliferate and render essential ecosystem services such as recycle nutrients, energy relay and serve as carbon sources that support higher trophic levels in many ecosystems (Quintino *et al* 2006). However, when the water quality declines, these essential services are distorted as macroinvertebrates respond to critical changes in the environment (Idowu and Ugwumba 2005; Iyiola 2015).

Assessment of the diversity and distribution of benthic macroinvertebrates provides essential information on the water quality of most water bodies, including marine waters (Bassey *et al* 2020). In this study, the physico-chemical variables significantly influenced the abundance and diversity of benthic macroinvertebrates as evidenced by the CCA. Similar, observations were made by Varner (2001) and Jonah *et al* (2020). Benthic macroinvertebrates are essential aquatic fauna that contribute to nutrient cycling processes between sediments and the water column through bioturbation (Quintino *et al* 2006). Their consistent response to environmental changes, especially to physical and chemical stressors affects the sediment and secondary production (Quintino *et al* 2006). However, when the water quality declines, these essential services are distorted as macroinvertebrates respond to critical changes in the environment (Idowu and Ugwumba 2005; Iyiola 2015).

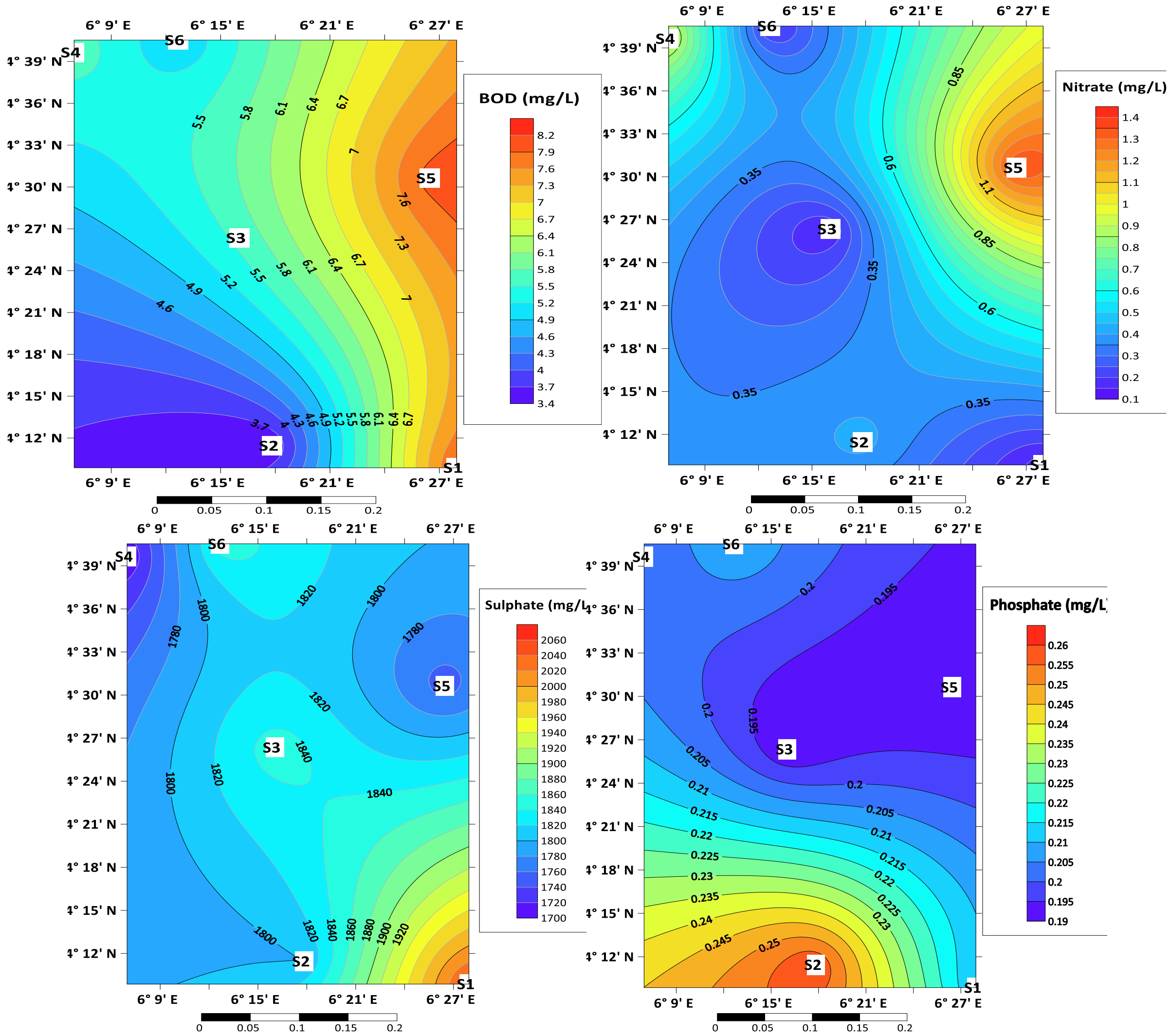

Figure 2b. Spatial variation of nitrate, sulphate and phosphate in the Gulf of Guinea of Western Nigeria shore

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The Shannon-Wiener diversity index values (2.05 to 2.77) of this study are similar to that reported by Singh and Sharma (2020) in high altitude wetland Dodi Tal and Garhwal Himalaya (2.43 to 3.66). Shannon–Wiener diversity index (H') > 3 represents unpolluted regions, H' < 1 represents polluted status and 1 < H' < 3 represents moderate pollution status (Brraich *et al* 2017). The other indices estimated in this study (dominance, evenness etc) corroborated the Shannon-Weiner values and show that the studied environment was relatively unpolluted. Pawar and Said Al-Tawaha (2017) stated that dominance index

Table 3: Species composition and distribution of macroinvertebrate fauna community

Taxa	ST 1	ST 2	ST 3	ST 4	ST 5	% Occurrence
MOLLUSCA						
Gastropoda						**20.73**
Genota mitriformis				2		0.67
Marginella capensis		4		4		2.68
Nassarius capensis		2	5			2.34
Nassarius cuvierii	1					0.33
Nassarius denticulatus		5	8	4		5.69
Nassarius incrassatus,				6		2.01
Nassarius sp			4		3	2.34
Oxystele tigrina		1				0.33
Tritia lanceolata,	1					0.33
Turris sp				2	4	2.01
Turritella acropora				2	3	1.67
Turritella communis				1		0.33
Bivalvia						**69.90**
Arca geissei					4	1.34
Cardium costatum				4		1.34
Cardium kobelti	2			3		1.67
Cardium ringens				2	2	1.34
Cuspidaria sp			2		3	1.67
Donax lubricus	3			4		2.34
Flexopecten sp				1		0.33
Lithophaga aristata		2				0.67
Macoma litoralis	4	3	10	15	9	13.71
Mactra glabrata				13		4.35
Pecten flexuosus	1	1	2			1.34
Pecten hyalinus var succinea				7	2	3.01
Pecten sp		1	3	1		1.67
Perna perna		6				2.01
Sunetta contempta bruggeni	2					0.67
Tellina gilchristi		2	11	10	12	11.71
Tellina trilateral		4	5	22	10	13.71
Tivela tripla			1	11		4.01
Trachycardium flavum				9		3.01
Scaphopoda						**7.69**
Dentalium oerstedii				2		0.67
Dentalium plurifissuratum		4		3	2	3.01
Dentalium regulare		2			1	1.00
Dentalium strigatum		2		2	2	2.01
Paradentalium hexagonum		3				1.00
ANNELIDA						
Polychaeta						**1.67**
Nephyts sp	1	1				0.67
Orbinia angrapequensis,	1					0.33
Pseudonereis variegata		2				0.67

Table 4: Diversity indices of macroinvertebrate fauna offshore Nigerian waters in the Gulf of Guinea

Indices	ST 1	ST 2	ST 3	ST 4	ST 5
No of taxa(S)	9	17	10	23	13
No of individuals	16	45	51	130	57
Dominance(D)	0.15	0.08	0.14	0.08	0.12
Simpson(1-D)	0.85	0.92	0.86	0.92	0.88
Shannon-Wiener(H)	2.05	2.69	2.09	2.77	2.30
Evenness(e^H/S)	0.86	0.86	0.81	0.69	0.77
Brillouin	1.52	2.23	1.83	2.51	2.00
Menhinick	2.25	2.53	1.40	2.02	1.72
Margalef	2.89	4.20	2.29	4.52	2.97
Equitability(J)	0.93	0.95	0.91	0.88	0.90
Fisher_alpha	8.51	9.95	3.72	8.11	5.26
Berger-Parker	0.25	0.13	0.22	0.17	0.21
Chao-1	12.33	17.86	10.00	23.43	13.00

Table 5: Ecological indices of benthic macrofauna response to pollution in Nigerian offshore waters

Stations	AMBI	M-AMBI	BENTIX	BI	Disturbance classification
ST 1	1.03	0.67	5.51	1	Undisturbed
ST 2	1.20	0.86	4.70	1	Undisturbed
ST 3	1.05	0.69	5.36	1	Undisturbed
ST 4	0.61	0.98	5.75	1	Undisturbed
ST 5	0.34	0.80	6.00	1	Undisturbed

Table 6: Ecological groups of benthic macrofauna at the Nigerian offshore waters

Stations	EG I (%)	EG II (%)	EG III (%)	EG IV (%)	EG V (%)
ST 1	43.8	43.8	12.5	0	0
ST 2	52.5	15	32.5	0	0
ST 3	46	38	16	0	0
ST 4	65.8	27.9	6.3	0	0
ST 5	77.4	22.6	0	0	0

EG – Ecological group

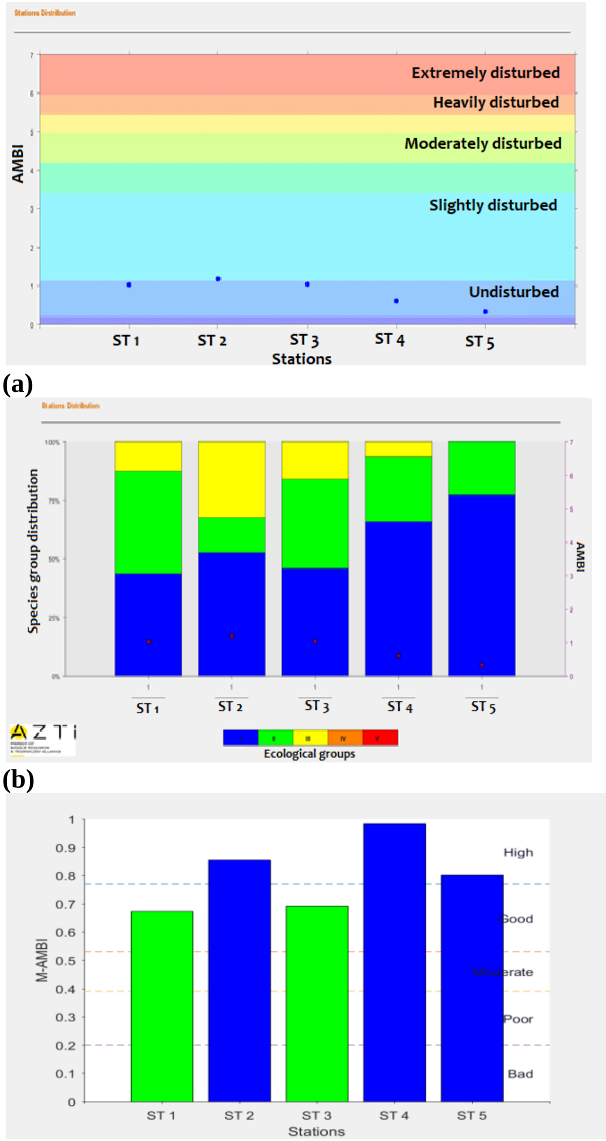

Figure 3. (a) Ecological quality status per station (b) Ecological Groupings of macroinvertebrates assemblage per station (c) M-AMBI status per station in Nigerian offshore waters

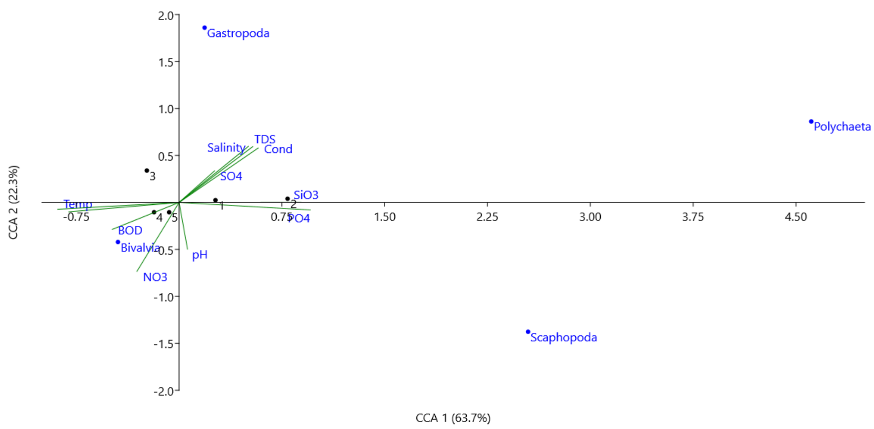

Figure 4. CCA of environmental variables-macroinvertebrate community at the Nigerian offshore waters

with values near zero indicates highly diverse or heterogeneous ecosystems and values near one indicate homogenous ecosystems. Thus, dominance index values (0.08 to 0.15) revealed a diverse ecosystem, which incidentally contained mostly sensitive and few tolerant species within the Nigerian offshore waters.

Generally, the AMBI and M-AMBI values of this study showed a stable and healthy environmental condition (undisturbed marine environment) for the benthic macrofauna. This is in agreement with the findings of Muniz *et al* (2005) that first tested AMBI in the tropical Atlantic Ocean. Furthermore, majority of the macroinvertebrates encountered in this study belonged Ecological Group I (sensitive species), which is a further testimony that this section of the Gulf of Guinea is unpolluted and is minimally influenced by anthropogenic activities.

Conclusion

The study explicitly showed that benthic macroinvertebrates are useful bio-indicators, which were critical in establishing the ecological quality status of the Nigerian offshore. AMBI, M-AMBI, BENTIX and Shannon-Wiener indices provided critical information that enhanced understanding of changes in the environmental conditions of the studied stations. It is essential that this important ecosystem be monitored regularly to maintain the unpolluted status in order to sustain macroinvertebrate diversity and the essential ecological services derived from them.

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