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Environmental Influence on the Diversity and Composition of Benthic Macrofauna of Asarama Estuary at Adoni Flat in the Niger Delta

Abdul-Rahman Dirisu[1,*], Nsirim L. Edwin-Wosu[2]

[1]Department of Animal and Environmental Biology, Faculty of Life Sciences University of Benin, Benin City, P.M.B. 1154, Nigeria
[2]Department of Plant Biology and Biotechnology, College of Sciences, University of Portharcourt, Rivers State, Nigeria
*Corresponding author: dedonrahman10@yahoo.com

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Abstract Asarama estuary is an inter-tidal system characterised by a number of freshwater influxes, mud flat at low tide and associated with mangrove and nipa ecosystems. The biodiversity of Asarama estuary at Andoni flat in the Niger Delta of Nigeria was surveyed in the wet and dry seasons of 2016/17. Benthic macrofauna samples were collected during the sampling period, including the analyses of sediments for selected parameters. The results for the environmental chemistry showed relatively high concentrations in values for the parameters in sediments which is a normality in most tropical aquatic environments. The sediments pH concentrations were at slightly acidic state (≥ 6) across the stations, likewise a few parameters such as pH, total hydrocarbon content and nutrients, recorded slightly high concentrations during the wet season than the dry season. Biodiversity analyses revealed three groups of benthic macrofauna (Mollusca constituted - 69.67%, crustacea - 22.95% and Annelida - 7.37%). Amongst these groups; crustaceans and molluscans had more abundance in the wet season than the dry season. Species diversity was low for macrobenthos while, indiscriminate harvest of fisheries, unregulated navigations and illegal activities of crude oil products pose major challenge to the biotic communities. Indiscriminate human exploitation of its living resources coupled with transportation activities pose some threats to the estuary sustainability.

Keywords: *Andoni flat, Mangrove, Macrofauna, sediment, tide*

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1. Introduction

Asarama estuary in Andoni flat of the Niger Delta, is a brackish ecosystem with a network of freshwater influx. The estuary housed over 200 years old mangrove forest called Aso-forest which is a biodiversity hotspot for crustaceans-decapods, molluscans, reptiles, insects, ichthiofauna, and birds which depend on the primary and secondary producers therein. It was asserted [1] that the mud flats are very sensitive ecological zone which constitute an integral part of the Andoni River, thus exposes the estuary to both natural factors and human exploitation activities on daily bases.

Estuaries are notably very highly productive environments where many species of commercial importance nest, reproduce and grow. They are also essentially the feeding and resting grounds to several migratory species such as marine mammals, sea turtles, shore birds, fishes and so forte, besides they are very rich in nutrients [2,3]. An understanding of species and functional diversity in coastal sedimentary environments is therefore crucial to evaluate linkages between catchments and coastal seas. Furthermore, assessing benthic communities is an important step for the protection of coastal wetlands and planning of Marine Parks [4,5,6]. This is specifically relevant in an area like the Niger Delta inclusive of Asarama estuary where wetlands are subjected to a range of environmental pressures [7,8].

The Niger Delta of Nigeria has been described as the zone of the fastest ecological alteration and degradation, perhaps in the Gulf of Guinea (GoG) coast due to the intense offshore and onshore industrial activities. Meanwhile oil and gas pollution, coastal erosion, siltation, navigation, dredging and of course sea level rise coupled with flooding of inland water channels through the distributaries as well as the mangal deforestation, are the major cause of hazards [9,10]. Consequently, this has necessitated several research studies on environmental and water quality, plankton, macrobenthos and ichthiofauna resources of the domain [1,10-15]. Elsewhere in the North America, dredging of navigational channels which increases their exposure to wave actions have been reported. Furthermore, many estuaries have been completely wiped out due to reclamation and their rivers mouths completely blocked [2] and similarly in the Western Europe [16].

Most studies in the Niger Delta have focused on the plankton and benthos or some aspect of benthic macrofauna of some rivers, creeks and lagoons [16,17,18,19]. While others were conducted in the Bonny estuary [20,21,22]. However, one available work on Asarama estuary was the literature by Ansa and Francis [1] on the sediment physicochemistry.

It was asserted [10] that studies on the benthic macrofauna of Nigeria brackish aquatic environments, have been very scanty due to the difficulty by ecologists to assess the terrain of creeks, creeklets and estuaries. Besides, research works on Asarama estuary and the adjoining creeks have been greatly discouraged by militancy and pirates' activities which have strongly affected the choice of studies therein.

This study is the first major work on the benthic fauna of Asarama estuary based on records from existing publications and was aimed to assess the human-derived impacts on the macrobenthic fauna in relation to sediment physicochemistry. Therefore, the objectives were to examine the diversity, composition and community structure of the macrobenthic fauna in relation to physicochemistry by comparing other stations with stations 1 and 2 which were far less disturbed and to create baseline data for subsequent studies. Thus, we used Multimeric approach such as canonical correspondence analysis (CCA) including diversity indices to analyse the data.

2. Materials and Methods

2.1. Study Area

Asarama estuary at Adoni land in Rivers State of Nigeria is located within the coordinates (04° 30´ 37´´N, 007° 27´ 05´´E and 04° 31´ 35´´N, 007° 28´ 44´´E). It is a semi-diurnal tidal estuarine system and the area is known for two major communities viz; Ataijong and Amaubong which are separated by a major road (Figure 1). Both communities have common boundaries at the eastern fringe which links the Andoni coastal communities with Ogoni hinterland region. The communities also share common shoreline boundary at the southern flank with mangroves wetlands, Nipa palm, mud, sandy beach, marshy land, creeks, rivers and rivulets, and salt water from the Atlantic coast which provide rich habitat for aquatic life. Artisanal fishing is the main traditional occupation of the people and it is carried out by both the men and women.

The Asarama by the rivers and several creeks that provide the communities with aquatic resources. The mangrove swamp covers about 3 square kilometers of Ataijong and Amaubong communities respectively. The mangrove ecosystem in the two communities has been overtaken by Nipa palm (*Nypa fruiticans*) and the situation is direr. This has led to the loss of fisheries and their spawning grounds and other aquatic resources and has also hindered navigation in some of the infested areas. The area has an equatorial climate characterised by two main seasons: the rainy season from March to October and the dry season from November to February.

The major human activities in the locality include land and water transportations using cars, motor-bikes and boats, fishing with fish nets, gears and fish traps. Mariculture of Oysters (*Castrostrea* sp) and Periwinkles (*Tympanotonus fuscatus* Var. *Radular*) were predominant. At low tides particularly between 08:30 and 10:00 hr, some of the locals were seen engaged in picking periwinkles indiscriminately without regulations. Illegal local refinery of petroleum products was observed far upstream off the estuary at the north-western bank. *Manihot* sp farms were seldomly seen on the banks. Farming and agricultural activities in these communities are on a subsistence level and crops such as *Musa paradisiaca* (plantain) and *Musa sapientum* (banana), *Manihot esculenta* (cassava), *Elaeis guineensis* (oil palm) and vegetables such as *Telfairea occidentalis* (fluted pumpkin) *Talinium triangulare* (water leave) and *Vernonia amygdalina* (bitter leave) are the major crops besides root and tuber crops.

The sampling stations were fixed by using a hand-held Global Positioning System (GPS) and were maintained throughout the study period. All samples were collected at high tide between 11:00 am and 2:00 pm, of which water depths were significantly greater than 1 m but less than 1.5 m across the stations. Besides, the samples were collected within the littoral zone throughout the study.

At station 1, is located a forest of mangroves named; Aso mangrove forest which is over 200 years old (personal communication 2016). The forest is a host to several species of birds, monkeys, reptiles, bees and insects as observed during field studies. Stations 2 is rich in mangroves as well. Decapods and bivalves were commonly seen on mangrove branches here. Stations 3 is characterised by an admixture of white mangrove and nipa palms. The sediment was mostly muddy and silty, and contained a lot of dead decaying organic matter like woods, leaves and dead shells of molluscs. Station 4 is located far downstream after the bridge by the fishing wooden traps. The substratum was a mixture of muddy-sandy bed. A film of soot from an illegal local petroleum refinery was observed on the water surface throughout this study. Station 5 is equally located downstream of station 4. A lot of nipa palms were found here with so much decomposition activities of the palm fronds and seeds. The substratum was mostly muddy at the upper reaches.

2.2. Sediment Sampling and Analyses

Ten sediment cores were collected for physico-chemical analyses across the study stations. The samples were preserved where applicable and analysed in the laboratory according the methods [23,24,25]. Hydrogen Ion Concentration (pH) was determined in-situ using the pH-Conductivity meter (Hach pH-meter, sense ion 2 model). Electrical Conductivity (EC) was equally measured in-situ using the pH-Conductivity meter as above. Nitrate and Sulphate were analysed in the laboratory using the methods [23]. Phosphate - phosphorus was extracted from the sediment sample using extracting solution of 0.03 M NH_4F and 0.025 M HCL. Total Hydrocarbon Content (THC) was determined in sediment sample with extraction/photometric method using the Hach Spectrophotometer (UV/VIS Model DR/2000. Particle size was determined in the laboratory using the modified pipette method. 20g of sediment sample was weighed and placed in a 1000ml cylinder. 5ml of Hydrogen peroxide (H_2O_2) was added to the content ensure the removal of organic matter, about 20ml of hydrogen peroxide was further added to allow complete oxidation of the content. The sample was then air dried on a hot plate and 40ml of Calgan (sodium hexametaphosphate) solution was added. The content was shaken for 2 hrs which was there after sieved through a mesh size of 0.053mm; the sample was then washed into a 1 L measuring cylinder until the water coming out becomes clear. It was assumed that the silt and clay would have passed through 0.05mm sieve leaving the sand fraction behind. The content was shaken vigorously and the colloidal solution was allowed to stand for 3 hrs for sedimentation. The sand left in the sieve was oven dried and the weight was noted.

After sedimentation period, all the silt was completely settled at the bottom of the measuring cylinder leaving clay particles suspension. The supernatant was thus discarded and silt was oven dried, and the weight was noted.

The weight of silt is given thus:

$$\frac{\text{Total Volume}}{\text{Volume Taken}} X \textit{ the initial weight}$$

$$\textit{Calculation}: \ \% \ \textit{Sand}$$

$$= \frac{\text{Weight of Oven dried sand}}{\text{Total weight of sample}} X100$$

$$\textit{Calculation}: \% \ \textit{Silt}$$

$$= \frac{\text{Weight of Oven dried silt}}{\text{Total weight of sample}} X100$$

$$\textit{Calculation}: \% \ \textit{Clay}$$

$$= \frac{\text{Weight of Oven dried clay}}{\text{Total weight of sample}} X100$$

2.3. Benthic Fauna Sampling, Laboratory Analyses and Identification

We used a van Veen grab (0.1 m^2) operated by hand which is designed for shallow water with an attached polypropylene rope, to sample the sediment for benthic fauna. A total of thirty sediment cores (i.e., three per station per season) were collected from the littoral zone across the study stations within the estuary stretch and were processed for macrofauna throughout the study. The trapped contents were introduced into a plastic bow, and the samples were processed on-board with benthos sieve of mesh size 0.5 mm [10]. Larger faunal such as molluscs and crabs were handpicked from the sediment cores before processing and both the processed specimens, and the handpicked were thereafter introduced into the benthos sample bottles and preserved with about 10 ml of 10 % formalin solution in-situ. Identification of specimens to taxonomic species level where possible; was aided with some manuals [26,27,28] as well as making confirmations from the available specimens in Prof. A.B.M. Egborge's Museum in the University of Benin, Benin City.

2.4. Data Analyses

Macrobenthic fauna results were subjected to some basic measurement of central tendency while, the physicochemical data were tested for Analysis of Variance (One-way ANOVA) using SPSS (version 16.0). Canonical Correspondence Analysis (CCA) was performed with the aid of Paleontological Statistics (PAST software version 1.99) [29] to test for relationships between the physicochemical characteristics and macrobenthic fauna. PAST was also used to test for any variation amongst species diversity, species richness, evenness and dominance across the study stations.

3. Results

3.1. Sediment Quality

Physicochemical conditions in the sediments showed increasing concentrations across the study stations (Table 1 and Table 2). There were significant differences amongst electrical conductivity, total dissolved solids, total hydrocarbon content, sulphate and amongst particle size distribution ($P<0.05$) across the study stations. However, pH, total hydrocarbon content and nutrient significantly recorded higher concentrations during the wet season.

Table 1. Summary of the Mean and Standard Deviation of the Physicochemical Condition in Sediments of Asarama Estuary Across the Study Stations (Between August, 2016 and March, 2017).

Parameters	Station 1 $\bar{x}$±SD	Station 2 $\bar{x}$±SD	Station 3 $\bar{x}$±SD	Station 4 $\bar{x}$±SD	Station 5 $\bar{x}$±SD	Significant
pH	6.50±0.42	6.35±0.35	6.55±0.49	6.30±0.71	7.30±0.71	0.464
Electrical Conductivity($mSCm^{-1}$)	4.24^{b}±120.21	4.66^{a}±43.13	3.31^{c}±84.85	1.23^{d}±0.00	1.06^{d}±206.48	0.000
Total Dissolved Solids ($mgKg^{-1}$)	2156.40^{a}±60.95	2454.30^{a}±0.57	1737.50^{b}±21.21	1233.25^{c}±3.18	712.20^{d}±325.13	0.000
Total Hydrocarbon Content ($mgKg^{-1}$)	557.55^{b}±178.54	190.45^{b}±27.65	1157.40^{a}±176.35	512.25^{b}±121.69	510.40^{b}±124.31	0.007
Nitrate ($mgKg^{-1}$)	1.27±0.21	1.06±0.05	1.88±0.78	1.07±0.06	1.19±0.23	0.308
Phosphate ($mgKg^{-1}$)	49.06±0.00	48.75±9.12	73.00±26.87	50.23±6.97	35.15±2.33	0.209
Sulphate ($mgKg^{-1}$)	810.00^{cd}±56.57	1251.00^{a}±69.30	1045.00^{b}±77.78	938.00^{bc}±56.57	654.25^{d}±79.13	0.002
Total Clay (%)	49.50^{b}±0.71	50.00^{b}±0.00	0.00^{d}±0.00	67.00^{a}±0.00	51.00^{b}±1.41	0.000
Total Silt (%)	48.00^{a}±0.00	48.00^{a}±0.00	3.50^{c}±2.12	31.00^{b}±0.00	47.00^{a}±1.41	0.000
Total Sand (%)	2.50^{b}±0.71	2.00^{b}±0.00	96.50^{a}±2.12	2.00^{b}±0.00	2.00^{b}±0.00	0.000

Significant < 0.05 – Significant difference; Superscript – Denotes the source of significant variation.

Table 2. Mean Values of the Investigated Parameters in Sediments across Wet and Dry Seasons during the Study

Parameters	Wet Season $\bar{x}$±SD	Dry Season $\bar{x}$±SD	Significant
pH	6.98±0.47	6.22±0.36	0.021
Electrical Conductivity ($mSCm^{-1}$)	2.83±1689.76	2.96±1666.95	0.907
Total Dissolved Solids ($mgKg^{-1}$)	1617.84±788.57	1699.62±619.14	0.860
Total Hydrocarbon Content ($mgKg^{-1}$)	666.68±398.18	504.54±309.81	0.493
Nitrate ($mgKg^{-1}$)	1.48±0.55	1.10±0.13	0.171
Phosphate ($mgKg^{-1}$)	57.64±20.62	44.83±7.70	0.229
Sulphate ($mgKg^{-1}$)	965.26±263.78	914.04±194.45	0.736
Total Clay (%)	43.40±25.35	43.60±25.44	0.990
Total Silt (%)	35.40±20.07	35.60±18.53	0.987
Total Sand (%)	21.20±42.93	20.80±41.48	0.488

Significant < 0.05 – Significant difference.

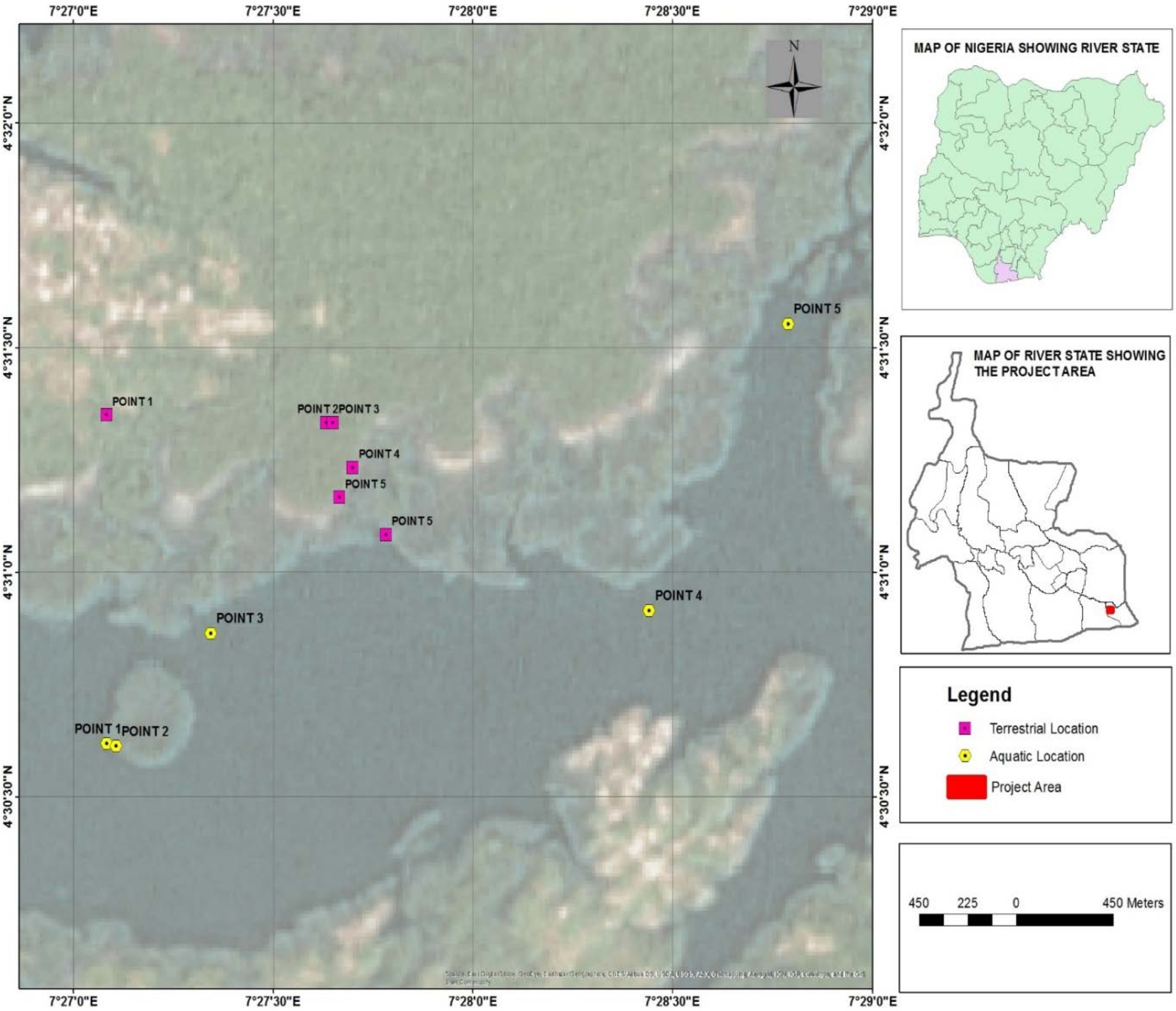

Figure 1. Map of the Study Area

The mean seasonal concentrations of pH in the sediments were in a slightly acidic condition throughout. The values ranged between 6.22 in the dry season and 6.98 in the wet season, while the mean seasonal concentrations across the study stations were between 6.30 at station 4 and 7.30 at station 5. Electrical conductivity concentrations recorded fairly high values across the study stations. The mean seasonal concentrations were not less than 1056.00 $\mu S\ cm^{-1}$. High mean value of 466.50 $\mu S\ cm^{-1}$ was recorded at station 2. Likewise, total dissolved solids concentrations in the sediments were equally high. Mean seasonal values were 1617.84 $mgkg^{-1}$ in the wet season and 1699.62 $mgkg^{-1}$ in the dry season. In the sediments total hydrocarbon recorded high concentrations of values. The mean seasonal concentration was lowest at station 2 (190.45 $mgkg^{-1}$) and was highest at station 3 (1157 $mgkg^{-1}$). The highest mean value recorded in the wet season was 666.68 $mgkg^{-1}$ and in the dry season (504.54 $mgkg^{-1}$). Nutrient's concentrations were higher during the wet season than in the dry season.

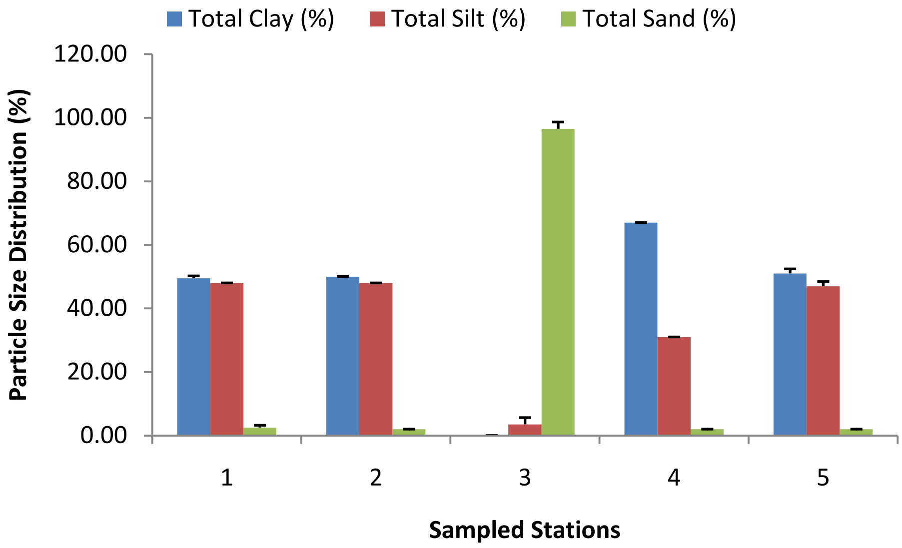

Figure 2. Particle Size Distribution in Sediments of Asarama Estuary

There was high significant difference (P<0.000) in the particles size distribution of the wet and dry seasons samples across the stations. However, clayey and silty sediments were the dominant proportion at stations 1, 2, 4 and 5. Sandy–sediment was predominant at station 3 with over 80% composition (Figure 2).

3.2. Benthic Fauna Composition and Community Structure

A total of 66 individuals of macrobenthic fauna comprising one species each of Polychaeta, Oligochaeta and Hiruidinea; 5 species of Decapoda, I species of Bivalvia and 2 species of Gastropoda were encountered in this study. These benthic macrofauna were distributed into three major taxonomic phyla of Annelida, Crustacea and Mollusca. The Molluscan group constituted - 69.67%, Crustacean - 22.95% and Annelid - 7.37% (Figure 3). Amongst the Molluscans – the members of the class Gastropoda were the dominant and constituted a total of 90.59% while, Bivalvia had 9.41%. For Annelida; the group Polychaeta constituted a total of 77.78%, Oligochaeta and Hirudinea had 11.11% each. The total density of individuals recorded for the macrobenthic fauna was 124 m-^{2}. Only one species was each represented for the three classes of Annelida recorded. Decapoda was represented by five species and Mollusca with three species (Table 3).

Macrobenthic fauna never recorded any individual amongst the eleven taxa throughout station 4 except with the species *Tympanotonus fascutus* (Gastropod-Mollusca). Likewise, the distribution of all other taxa across the sampled stations were mostly and randomly encountered at stations 1, 2, 3, and 5.

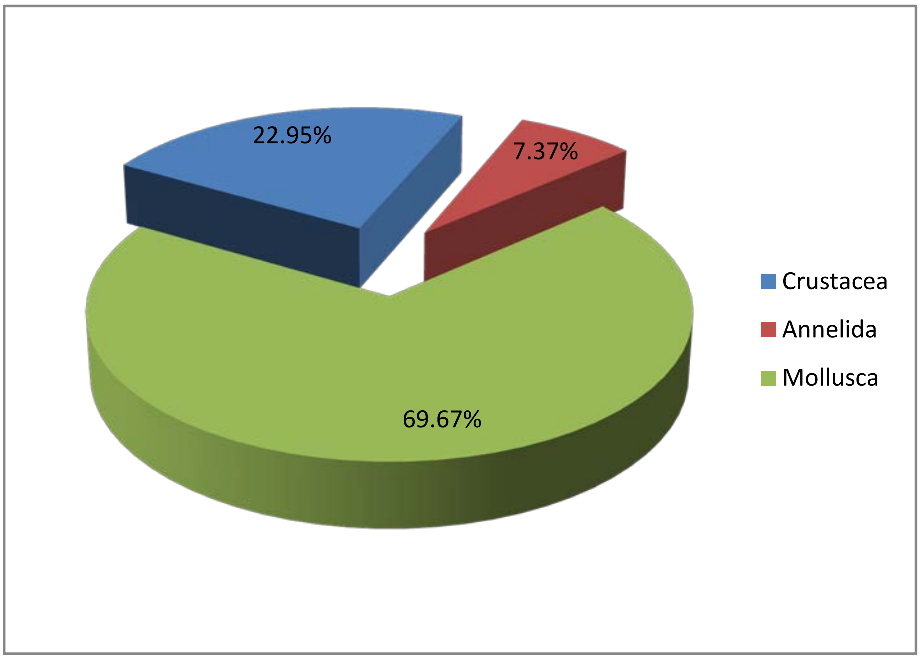

Figure 3. Percentage Composition of the Major Macrofauna Groups

Table 3. Summary of Benthic Macrofauna of Asarama Estuary across the Sampled Seasons (Wet Season, 2016 and Dry Season, 2017) in the Study Area

Taxonomic Group	STN 1	STN 2	STN 3	STN 4	STN 5	Total
ANNELIDA						
Polychaeta						
Nereis sp**.** (Neridae)	1	1	2		3	**7**
Oligochaeta						
Oligochaeta sp.		2				**2**
Hirudinea						
Haemopsis sp.	1					**1**
CRUSTACEA						
Decapoda						
Amphipoda sp**.**		3	1			**4**
Ocypode africana (Ocypodidae)		3	1			**4**
Uca tangeri (Ocypodidae)	3		3		1	**7**
Goniopsis pelli (Grapsidae)	7					**7**
Sesarma angolensis (Grapsidae)	1	1	4			**6**
MOLLUSCA						
Bivalvia						
Pitar tumens (Juveniles)(Tellinidae)		2	3		3	**8**
Gastropoda						
Thais coronate (Muricidae)	3	4	5			**12**
Tympanotonus fuscatus (Potamididae)	5	18	21	1	21	**66**

3.3. Biodiversity Indices for Macrobenthic Fauna

Though the occurrence of macrofauna was poor, species richness was fairly high between stations 1 and 4 except at stations 5. Species evenness were highest at stations 1 and 4 majorly. Dominance values for species composition was highest at stations 4 and 5 respectively (Table 4).

3.4. Canonical Correspondence Analysis (CCA) for Macrobenthic Fauna

Strong positive associations were observed for macrofauna along axis 2 of the plot (Figure 4). Nitrate, THC and total clay were strongly positively correlated with *Uca tangeri* (Decapoda). Meanwhile, *Pitar tumens* showed strong negative association with pH and total sand.

Table 4. Macrobenthos Diversity Index

Description	STN 1	STN 2	STN 3	STN 4	STN 5
Taxa_S	7	8	8	1	4
Individuals	21	34	40	1	28
Dominance_D	0.2154	0.3183	0.3163	1	0.5867
Shannon_H	1.699	1.558	1.551	0	0.8134
Simpson_1-D	0.7846	0.6817	0.6837	0	0.4133
Evenness_e^H/S	0.7811	0.5935	0.5897	1	0.5639
Margalef	1.971	1.985	1.898	0	0.9003

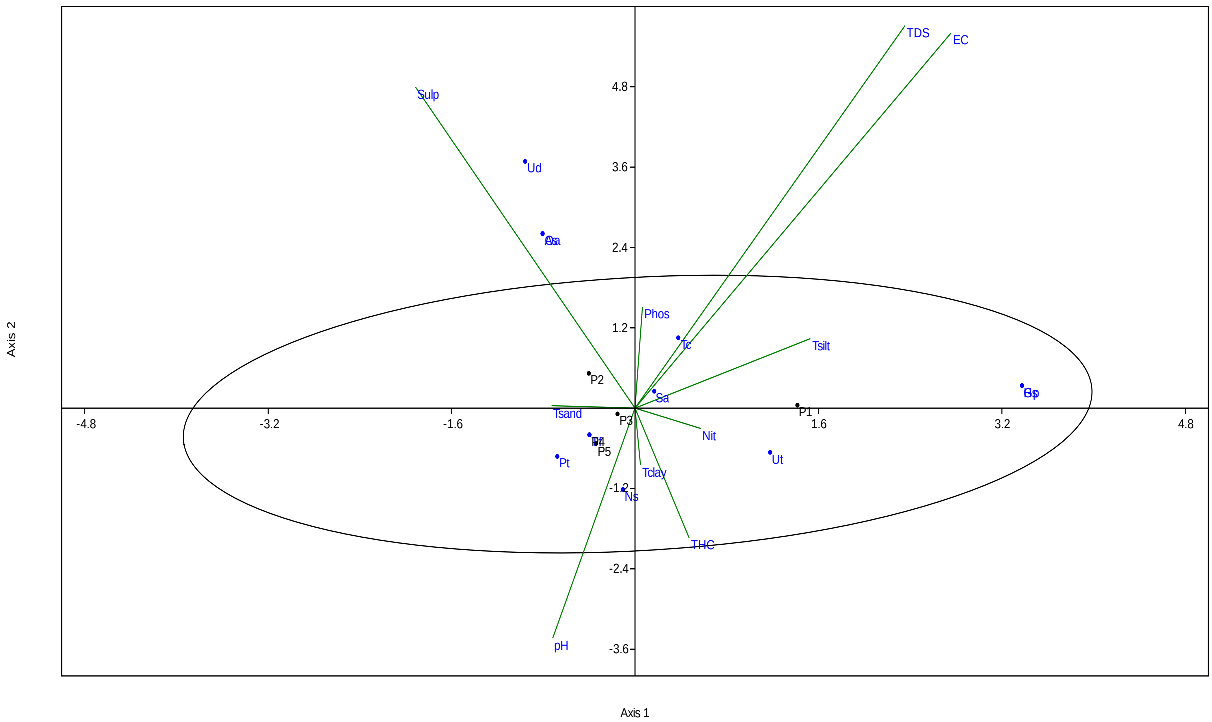

Figure 4. Canonical Corresponded Analysis for Macrobenthos

4. Discussion

A major challenge of this study was the lack of documented data on the macrobenthos of Asarama estuary (except for Ansa and Francis [1], on the sediments) for the purpose of results comparison and perhaps for interpretation. Although, limited literatures are available on the neighboring Bodo creek, Bonny estuary and a few Rivers [30]. Comparably to elsewhere in the tropics, a number of estuarine and lagoonal ecosystems studies have been carried out in Brazil extensively, particularly dwelling on the benthic macrofauna community and diversity [3,31,32].

The macrobenthic fauna result was low in diversity and typical of some coastal environments characterised by tidal action across the globe [8,10] which is evident upon the dominance of muddy/silty sediments. The macrofauna were composed of three major phyla viz; Annelida with species distributed within three classes (polychaeta, oligochaeta and hirudinea), Arthropods (represented by crustacean-decapoda) and Molluscs which were distributed in two classes (bivalvia and gastropoda respectively). This finding was similar to what was reported [32] for Trapandé Bay in southern Brazil in terms of phyla composition though, with much less population density. The dominance of molluscans in the sediment of most coastal environments in Nigeria was discussed [10,33] but was contrary to the report by de Souza et al. (2013) in which molluscans were amongst the sub-dominant groups. Mollusca was the dominant group by 69.67% of which *Tympanotonus fuscatus* (Var. *radular* - Gastropoda) had very high abundance in the study area particularly at stations 2, 3 and 5 despite the indiscriminate harvesting by the locals at low tides in the mud-flat. Between stations 1, 2 and 3; there were a lot of dead mollusc shells which were mostly bivalves and gastropods, mariculture of oyster (*Castrostrea* sp, mollusca-bivalvia) adjacent station 2 was a common practice in the estuary. Conversely, the dominance of *T. fuscatus* in brackish water within the Niger Delta was earlier reported [33] for Ekpan creek at Warri.

The composition and diversity of members of the phylum Annelida as encountered in this study were extremely poor when compared with the report [10,32]. The study by the former worker showed that Polychaeta-Annelida had more of the occurrences at the Escravos domain and offshore stations, with a similar finding by the latter authors, implying that their occurrences in the shallower depths as in the case of Asarama estuary may be very unlikely. Only one species of the family Neridae (*Nereis* sp) was encountered across the stations except at station 3. *Haemopsis* sp was the only taxa and member of the group Hirudinea that was recorded at station 1. This species is known to inhabit fresh and mostly brackish waters [34]. The individual was encountered on leaves littered muddy/silty sediment and this restriction could not be better explained. The study on Sado estuary [16] in western coast of Portugal, reported some contrary observations in terms of high species diversity which include temperate and Mediterranean worms. The variations are attributed to its temperate climatic and sub-Mediterranean environmental differences contrary to the tropical estuarine and lagoonal ecosystems [32].

Diversity indices revealed that macrofauna diversity and abundance were highly reduced at stations 4 and 5. Consequently, species richness and general diversity (Shannon-wiener diversity) were equal zero. The reason why no single species of the phylum Annelida and the class Crustaceans were not recorded at station 4 despite the high proportion of muddy-silty sediment which is predominant at the stations could be attributed to the intense perturbation of the habitat induced by fishing, transportation of good and services and coupled with the periodic exposure of the estuary bed at low tides. The effects of environmental perturbation on species composition and abundance have been reviewed [3,35]. Meanwhile, Simpson diversity and species richness had their highest values of occurrence at station 2 most importantly which serve as the control station alongside station 1. We attribute this to the abundance of food such as the secondary producers and moderate nutrients in the habitats. This assertion was earlier acclaimed [10] in their work within the Niger Delta coast and the Gulf of Guinea (GoG). However, the use of biotic indices has limitations in tropical and sub-tropical regions, where information on the ecological characteristics of soft-bottom benthic communities still remains scarce [3,36,37].

Crustacean-decapoda diversity and abundance were relatively high in this study. Meanwhile, the performance of canonical correspondence analysis (CCA) showed a positive association between *Uca tangeri* (a typical coastal and mangrove swamp Crab) and nitrogen as well as with total clay and total hydrocarbon content at plot 2. This implies that as THC, nitrogen and clayey sediments stabilises so crustacean taxa flourished in the environment. Estuarine environments characterised by mangrove ecosystems are known to greatly support the ecology of Decapoda (particularly crabs) in that the numerous species feed on plant materials [37,38,39] and including aquatic snails [40,41]. We attribute the restriction of members of the families; Grapsidae (*Goniopsis pelli*), *Sesarma angolensis*) and Ocypodidae (*Ocypode africana*, *Uca tangeri*) to stations 1, 2 and 3 to be due to the presence of mangroves and nipa palms which they feed on alongside crustaceans and Annelids [41] and essentially their habitat types [33]. For instance, Sediments with higher organic matter contents are likely to present higher abundances of deposit-feeder species such as polychaetes and/ or early colonizing species [32]. Capitellid polychaetes are a good example of opportunistic species, characteristically found in areas with heavy input of organic matter [32,42,43]. At stations 1 and 2 (i.e., within the mangrove forests), a number of crabs were regularly seen climbing mangroves and perhaps feeding on the leaves as long as silence was maintained within the habitats. No crab species was sampled or collected from station 4 which was devoided of mangroves or nipa palms, although the station was very rich in muddy sediments (>60 %) and silty (>30 %) (Figure 3) suggesting a good habitat for burrowers a like. Comparably, the dominance of silty sediment (particle size between 22 – 93.5%) was reported for Sado estuary in the western coast of Portugal in a similar study [16] and for a study in tropical areas in Northeast Brazil [3].

We considered the concentrations of total hydrocarbon content (THC) and nutrients (phosphate, sulphate and nitrate) as high enough to cause some deleterious effect to infauna and epifauna of the Asarama Estuary. Likewise, the pH values were at slightly acidic state between stations 1 and 4 but at slightly alkaline condition at station 5. During the study, we observed the deposition of soot at stations 4 and 5 from an illegal local modular refinery at far upstream of station 1. Besides, transportation of petroleum products and unauthorised bunkering impacted the water which could have increased the concentrations of THC in the matrixes. Our finding in terms of the concentrations for pH, particle distribution and electrical conductivity in the sediments of Asarama estuary was contrary to the report [1]. They recorded higher pH values (4.09 – 5.04) at the mudflat of Andoni and clayey sediment had the least particle size as well as very high conductivity values (>1000 µScm^{-1}).

One very important observation during this study was the high rate of predators such as the white and black cattle egrets preying on the macrofauna including molluscs and stranded juvenile fishes in the mud flat at low tides in which the mud flat is exposed for about six hours. Besides, the harvest of periwinkle by the locals almost on daily basis, does greatly negatively impact on the macrofauna assemblage as they step on the exposed marshy river bed (mud-flat). This phenomenon certainly contributed to the low macrofauna density particularly at stations 4 and 5 when compared to stations 1 and 2 in particular. Although predatory activity was mostly observed around stations 1 and 2 which were less impacted by human induced activities.

5. Conclusion

Only three major divisions were collected and the groups were considered important indicators of perturbed ecosystems or as indicators of rapidly degrading environment. Conversely, the diversity of macrofauna was rather low. Taxa density were mostly confined to the mangroves and/ or the nipa palms habitats of stations 1, 2, 3 and 5 respectively within the littoral zone.

Meanwhile, the indiscriminate harvesting of fisheries, effect of transportation of goods and services with wooden boats/canoes and the illegal activities of crude oil products pose major challenge to the stability of macrobenthic communities.

However, the effect of predictors during low tides has severe impact on the macrofauna density coupled with the sediment types particularly at stations 4 and 5. A more detailed study on the biota is strongly required in future which will help governmental and non-governmental organisations to formulate policies for the effective management of the estuary and the sustainable exploitation of the resources.

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Conflict of Interest

The corresponding author states that there is no conflict of interest.

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