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Response of Macrobenthic Invertebrate to Organic Carbon and Particle Size in Lagos Lagoon, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Macrobenthic fauna communities are important constituents of soft bottom marine ecosystems which inhabit the bottom environments playing a key factor in controlling structure and functioning of the aquatic environment. Lagos lagoon is the most exposed lagoon to anthropogenic influence in Nigeria coastal lagoon system. Bimonthly sampling was carried out in the Lagos lagoon from September 2014 - July 2016 for water and sediment in twenty – four stations to examine response condition of benthic communities to measures of water quality and sediment quality in Lagos lagoon in order to understand the benthic condition of the aquatic environment. A range of 9 – 91% for sand, 7 – 25% for silt, 0 – 73% for clay while a range of 0 – 4.77 was observed for TOC. The Diversity (H,) richness (d) and evenness (j) were positively correlated with the silt sediment particle size and. Kruskal-Wallis test showed that there was significant difference ($p<0.05$) between species richness and diversity at all sampling stations. Analysis of variance (ANOVA) showed no significant difference ($p>0.05$) in mean percentage particle sizes and TOC recorded at the stations but was significant ($p<0.05$) between TOC and macrobenthic invertebrates. The overall low

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diversity of macrobenthic fauna observed was attributed to anthropogenic activities majorly industrial dredging and local sand mining which altered the sediment characteristics of the aquatic ecosystem. Assessments of human induced stressors in the lagoon provided information useful for strict regulations and environmental policies to help prevent the aquatic environment from continuous deterioration hence, causing more loss of biodiversity. Responses of macrobenthic invertebrates to measured variables showed that there are high abundance and diversity of ecological groups of sensitive species majorly distributed around the slightly disturbed zones of the study area. In summary, variables examined in this study showed that the total organic content does not have a depleting effect on the abundance of macrobenthic invertebrates because the values are within permissible limits but the particle size characteristics present in this study showed good environmental indicator for evaluating macrobenthic invertebrate responses to stress pattern in water bodies along the coastal areas surrounded by various human activities.

Keywords: Anthropogenic; macrobenthic; species diversity; ecological groups; Lagoon.

1. INTRODUCTION

The benthic fauna is an important ecosystem component playing vital roles in nutrient cycling, detrital decomposition and food source for higher trophic levels, a consumer of primary producers and other first-order consumers. These communities are diverse and make up important constituents of soft-bottom marine ecosystems, exhibiting a high adaptability to their habitats [1]. They inhabit a wide range of environments, in which sediment conditions play a key factor in controlling their structure and functioning [2,3]. In addition, macrobenthic communities appear to be particularly sensitive to anthropogenic activities, such as sewage outfalls, oil spills, dredging and trawling [4–7]. These perturbations result in changes in the environmental conditions which modify the biogeochemical properties of the water and sediments characteristics thus, shaping the macrobenthic community biodiversity [8].

Few studies have statistically associated a variable with apparent impact on the benthos and the metrics could be a combination of chemical and physical environmental factors. Sediment composition or grain size, organic carbon, and dissolved oxygen [9–13] are key environmental factors that influence the diversity, species composition and distribution patterns of macrobenthic communities [3]. In coastal areas, a decrease of marine diversity can be reflected due to increased sewage outfalls which result in increases of organic supply and hypoxia of sediments in bottom waters [14].

Studies on the importance of different environmental factors in structuring benthic communities and species distribution in the Lagos lagoon have shown that food availability and hydrodynamic regime influence macrobenthic invertebrate distribution on various spatial scales. According to Pearson and Rosenberg [15] a model of the response of macrobenthic organisms to organic enrichment was proposed, which was also expanded for sediment contamination by Thompson and Lowe [16] The benthic response curve is a non-linear with intermediate concentrations resulting in elevated numbers - above reference values) of total taxa, abundances and tolerant taxa. These benthic metrics are assumed to respond positively as contaminant concentration increases until a biological threshold is reached. Conversely, sensitive taxa would begin to decrease as threshold values are exceeded. Above thresholds, levels of benthic metrics are expected to decline, eventually decreasing to zero survival in conditions of very high contamination, organic enrichment, or disturbance.

Benthic organism distribution is dependent on particle size, their important food source is organic matter in sediments and its excess can result in species reduction in abundance composition and richness due to oxygen depletion and toxic by-product build-up that is associated with materials breakdown. Hence, the present study is designed to examine associations between the condition of benthic communities, measures of water quality and sediment characteristics in Lagos lagoon.

2. MATERIALS AND METHODS

2.1 Study Area

The Lagos lagoon system is described as the largest of the four lagoon systems of the Gulf of

Guinea and serves as habitat to a variety of biota which includes the planktons, nektons and benthos in a complex trophic inter-relationship. It serves for fishing, a seaport, recreation destination, nursery, feeding and spawning ground for a diverse number of fish and fisheries. Owing to the dynamics of river inflow and seawater incursion into the lagoon, it experiences a brackish condition that is more discernible in the dry season while in the wet season, the increased river inflow creates freshwater and low brackish conditions in various parts of the lagoon. The study area is limited to a sizeable western part of the Lagos lagoon (Fig. 1) with twenty-four (24) selected georeferenced sampling stations using a handheld Garmin GPSmap 76 model (Table 1) and sampling was done bi-monthly between September 2014 to July 2016 for sediment and benthic macroinvertebrate fauna.

2.2 Chemical and Physical Variables

The chemical and physical variables used in this study are total organic carbon content of sediment and sediment particle size as stress indicators on the macrobenthic invertebrate species to determine their responses to the stress indicators.

2.3 Collection of Sediment Sample

Sampling of sediment was carried out from September 2014 – July 2016 at twenty-four sampling stations (Fig. 1). The sediment samples were taken from the bottom surface using a 0.1m^2 van Veen grab. At each station, triplicate sediments grab was taken, thoroughly homogenised. In the laboratory, these samples were air dried for further analysis.

2.4 Collection of Sediment Sample for Macrobenthic Invertebrate Fauna

A Grab sample was collected and washed carefully through 0.5 mm sieve by gentle agitation to avoid damage to infaunal organisms. The materials retained on the sieve were preserved in labeled jars and 10% formalin solution was added to prevent decay. Sorting of the species was carried out using a microscope. The cleaned, well-sorted macroinvertebrate fauna was stored in labeled jars and preserved in 10% formalin solution before they were identified and grouped into taxonomic groups of polychaetes, molluscs and crustaceans. These broad taxa were identified to genus or species levels as possible. Identifications were based on taxonomic guides and manuals [17].

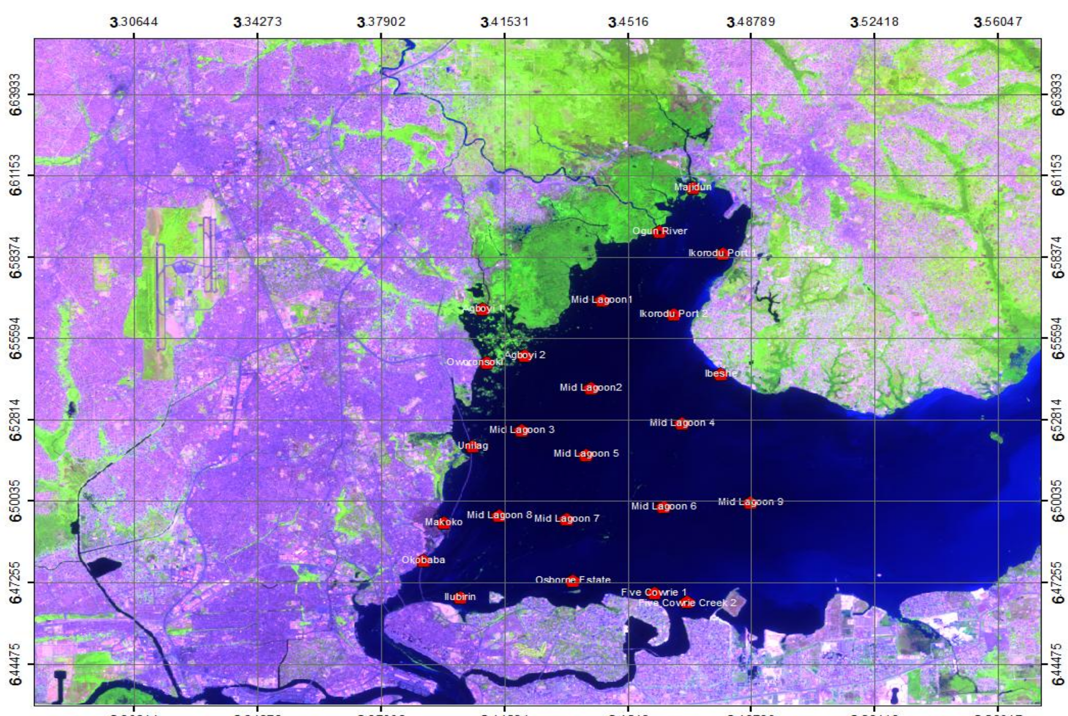

Fig. 1. Map of study area with selected sampling stations

Table 1. Study stations, locations, coordinates and approximate depths

Stations	Locations	Coordinates		Approx. depths (m)
		North	East	
1	Unilag	6.518995	3.406172	1.77
2	Mid lagoon 3	6.524607	3.420586	0.91
3	Oworo	6.547671	3.4409	1.13
4	Agboyi 1	6.565877	3.409078	1.25
5	Agboyi 2	6.55001	3.421475	2.62
6	Mid lagoon 1	6.568827	3.444125	2.53
7	Ogun River	6.592375	3.461128	4.48
8	Majidun	6.607325	3.470942	6.07
9	Ikorodu 1	6.584928	3.479678	2.68
10	Ikorodu 2	6.56418	3.465058	2.16
11	Ibese	6.55783	3.479133	2.49
12	Mid lagoon 2	6.538965	3.4409	3.66
13	Mid lagoon 4	6.526888	3.467548	3.08
14	Mid lagoon 5	6.516283	3.439303	3.57
15	Mid lagoon 6	6.49844	3.462253	3.2
16	Five Cowrie Creek 1	6.469097	3.459417	2.59
17	Five Cowrie Creek 2	6.466081	3.469043	2.14
18	Osborne	6.473108	3.435339	5.67
19	Ilubirin	6.467364	3.40237	8.29
20	Oko Baba	6.480163	3.391661	4.66
21	Makoko	6.493004	3.397506	1.16
22	Mid lagoon 8	6.49546	3.413878	2.4
23	Mid lagoon 9	6.50035	3.48789	2.1
24	Mid lagoon 7	6.494157	3.433819	2.4

2.5 Determination of Total Organic Carbon in Sediment

The determination of soil organic carbon was based on the Walkley-Black chromic acid wet oxidation method. Oxidisable matter in the soil was oxidised by 1 N $K_2Cr_2O_7$ solution. The reaction was assisted by the heat generated when two volumes of H_2SO_4 are mixed with one volume of the dichromate. The remaining dichromate is titrated with ferrous sulphate. The titer is inversely related to the amount of C present in the soil sample.

Two grams (2 g) of soil sample at each study location was weighed into a 250 mL conical flask and 10 mL of 1 N $K_2Cr_2O_7$ was added. Flask was swirled gently to disperse the soil in the solution. 20 mL of concentrated H_2SO_4 was added, swirled immediately until the soil and the reagent are mixed. A 200°C thermometer was inserted while swirling the flask and the contents on a hot plate for about 30 secs after which it was set aside to cool slowly on an asbestos sheet in a fume cupboard. Two blanks (without soil) were run in the same way to standardise the $FeSO_4$ solution. When cooled after 20–30 minutes, the solution was diluted to 200 mL with deionised water and titrated with $FeSO_4$ using 3-4 drops "ferroin" indicator. As the end point was approached, the solution takes on a greenish colour and then changes to a dark green. At this point, the ferrous sulphate was added drop-by-drop until the colour changes sharply from blue-green to reddish-grey.

Calculations:

$$\text{Organic Carbon (\%)} = 0.003\ \text{g} \times N \times 10\ \text{mL} \times (1\ T/S) \times 100 / ODW$$

$$= 3(1 - T/S)/W$$

Where:

N = Normality of $K_2Cr_2O_7$ solution
T = Volume of $FeSO_4$ used in sample titration (mL)
S = Volume of $FeSO_4$ used in blank titration (mL)
ODW = Oven-dry sample weight (g)

2.6 Sediment Grain Size Analysis

2.6.1 Grain size analysis – Mechanical method

2.6.1.1 Dry sieving

One hundred grams of the oven-dried cohesionless sample was weighed and poured into pre-arranged sieves with the larger size (2.36 mm) at the top and descending in decreasing order of sieve size. The nest of sieves was agitated by lateral motions for about 10 mins until no more material passes through each sieve then the retained material on each sieve was weighed and the amount recorded.

2.6.1.2 WET sieving

One hundred grams of the oven-dried sample was transferred into a dish. Sodium hexametaphosphate (100) mLs solution and 200ml of water was added to cover the soil mixture and allowed it to stand for about thirty minutes. The test sample was then transferred onto a 75 µm sieve with a receiver placed beneath the sieve and carefully washed using tap water until the water was clear. The residue was carefully poured into a pan for a short period till the top of the suspension becomes clear. The soil water suspension was placed in hydrometer shaker for 20 mins to determine the clay content.

The equivalent particle diameter D (in mm), was calculated from the equation:

$$D\ (mm) = 0.005531 \quad \sqrt{\Omega Ht / (\rho s - 1)\ t}$$

Where:

Ω = dynamic viscosity of water at the test temperature.
Ht = effective depth at which the density of the suspension is measured (mm).
ρs = particle size density (mg/m^3)
t = elapsed time (minute)
0.005531 = constant

2.7 Macrobenthic Invertebrate Community Structure

Macrobenthic organisms were classified into groups (groups I – V) based on their sensitivity and response to anthropogenic stress [18] with the groups defined as follows: I, sensitive species and present under unpolluted condition; II, species indifferent to enrichment; III, species tolerant to excess organic matter enrichment; and IV and V, first and second order opportunistic species.

Diversity indices were employed to calculate the relative abundance of species to show how each species is represented by individuals in a community. The diversity indices were calculated using Margalef's index to measure the evenness with which individuals are divided among the taxa present [19], Shannon-Wiener used to quantify the species diversity [20,21] Equitability [22] Menhinick's index and Simpson's Dominance Index employed to calculate the relative abundance of species and to show how each species is represented by individuals in a community. The significance difference in diversity of macrobenthic invertebrates of Lagos lagoon was tested using paleontological statistics (PAST 3.14) software.

3. RESULTS

3.1 Characteristics of Environmental Variables

The summary of variations in the dissolved oxygen, total organic carbon in the sediments and the macrobenthic invertebrate fauna abundance at the 24 study stations is presented in Fig. 2. The lowest spatial mean total organic carbon (0.72 ± 0.19%) was recorded at station 3 while the highest mean total organic carbon (1.31 ± 0.34%) was recorded at station 10. Analysis of variance (ANOVA) between TOC and macrobenthic invertebrates was significantly different ($p<0.05$) between the stations.

3.2 Macrobenthic Richness and Diversity

A total of 30 species comprising of phylum Mollusca with two classes (Bivalvia and Gastropoda) having 29 species and phylum Arthropoda one class (Hexanauplia) with only one specie were recorded from the sampling stations during the period of study.

The spatial variations in the diversity indices {Margalef's (d), Sahnnon-Wiener (Hs), Equitability (j), Menhinick's (D) and Simpson dominance (C)} based on the bi-monthly collection of macrobenthic invertebrates at different stations of Lagos lagoon is presented in Fig. 3 Margalefs indices ranged from 0 – 2.232 while the values of Shannon-Wiener ranged from 2.056. Equitability values ranged from 0 – 0.987, Menhinick index ranged from 0 – 1 and Simpson dominance index ranged from 0 – 0.803. All the indices were highest at station 22 and lowest at station 7. Kruskal-Wallis test showed that there was significant difference ($p<0.05$) between species richness and diversity at all sampling stations.

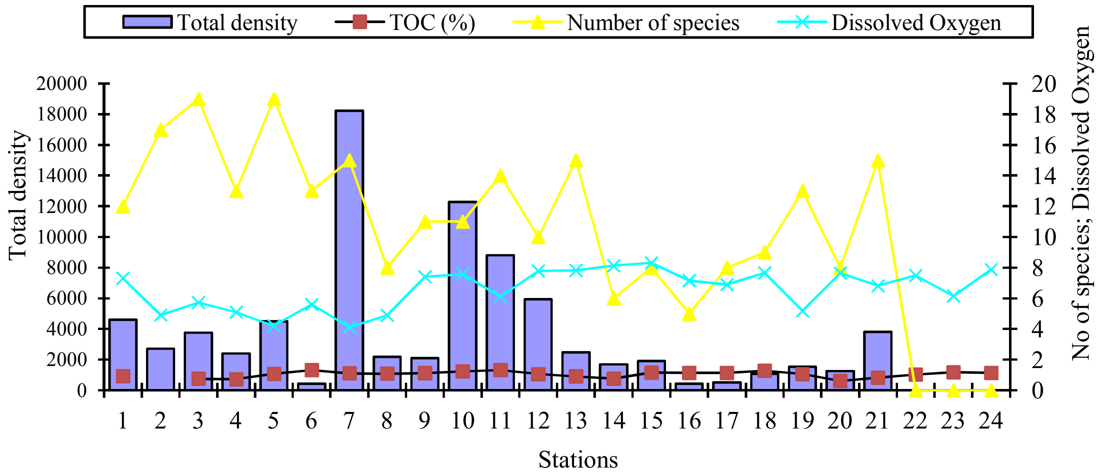

Fig. 2. Spatial variations in the density of macrobenthic invertebrates, number of species and total organic carbon (TOC) at the study stations in Lagos lagoon during the study

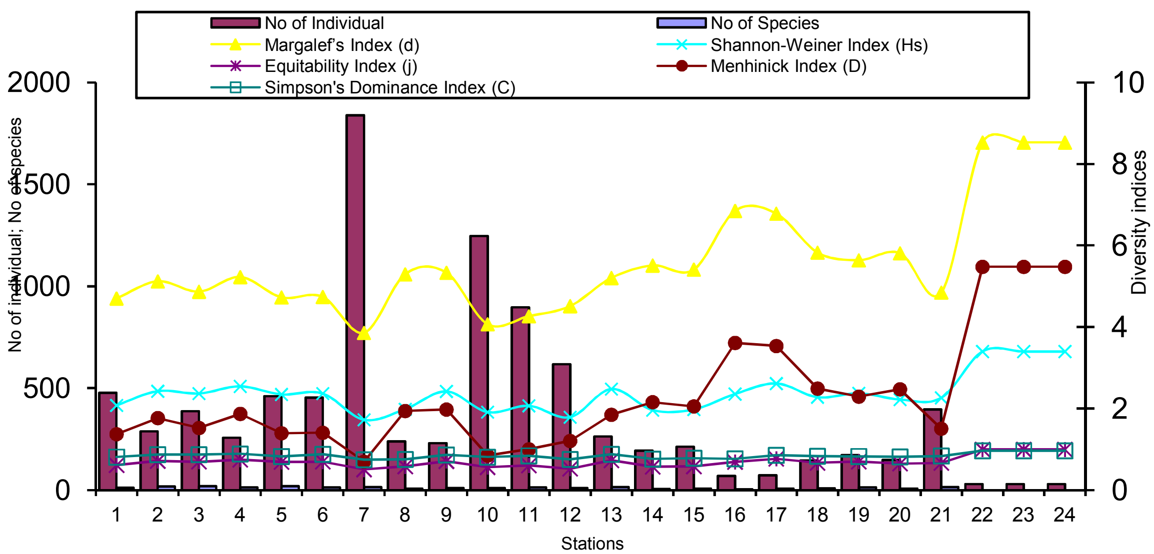

Fig. 3. Spatial variations in the overall diversity indices of macrobenthic invertebrates at the study stations in Lagos lagoon during the study

3.3 Macrobenthic Composition

A total of 8,688 macrobenthic invertebrates were recorded from the sampling stations during the period of study and the percentage dominant composition is given only for those species comprising 6% at all stations ad species which account for less than 0.3% of total abundance over all study stations [23]. Individual species of bivalve constituted 63.33% of the total abundance followed by the gastropoda 33.33% and the hexanaupli 3.34%.

There were eighteen dominant species identified namely *Turritella ungulina, Turritella meta, Atactodea striata, Macomopsis cumana, Natica marochiensis, Tivela tripla, Tympanotonus fuscatus, Tympanotonus fuscatus* var. *radula, Pachymelania aurita, Brachyodontes puniceus,* and *Perna perna Aloidis trigona, Clithon glabratum*, *Austromacoma nymphalis, Crassostrea tulipa, Mytilopsis africana, Nerita senegalensis* with a range from 40 at station 17 to 1,795 at station 7. Station 7 supported the largest number of individual dominant taxa and the next two stations with high occurring dominant taxa is found at stations 10 and 11.

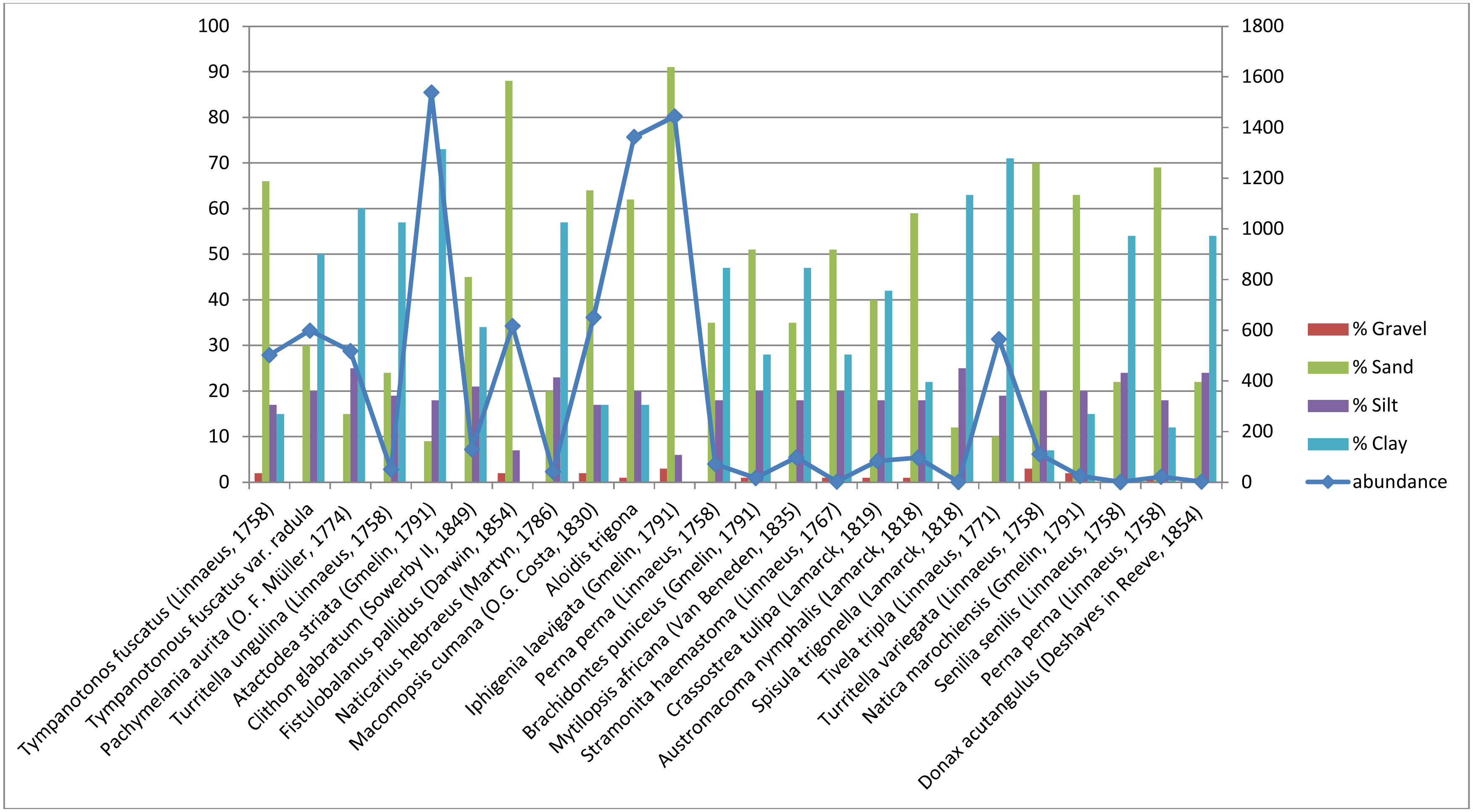

Fig. 4. Summary of particle size distribution of sediment and macrobenthic invertebrates during the study period

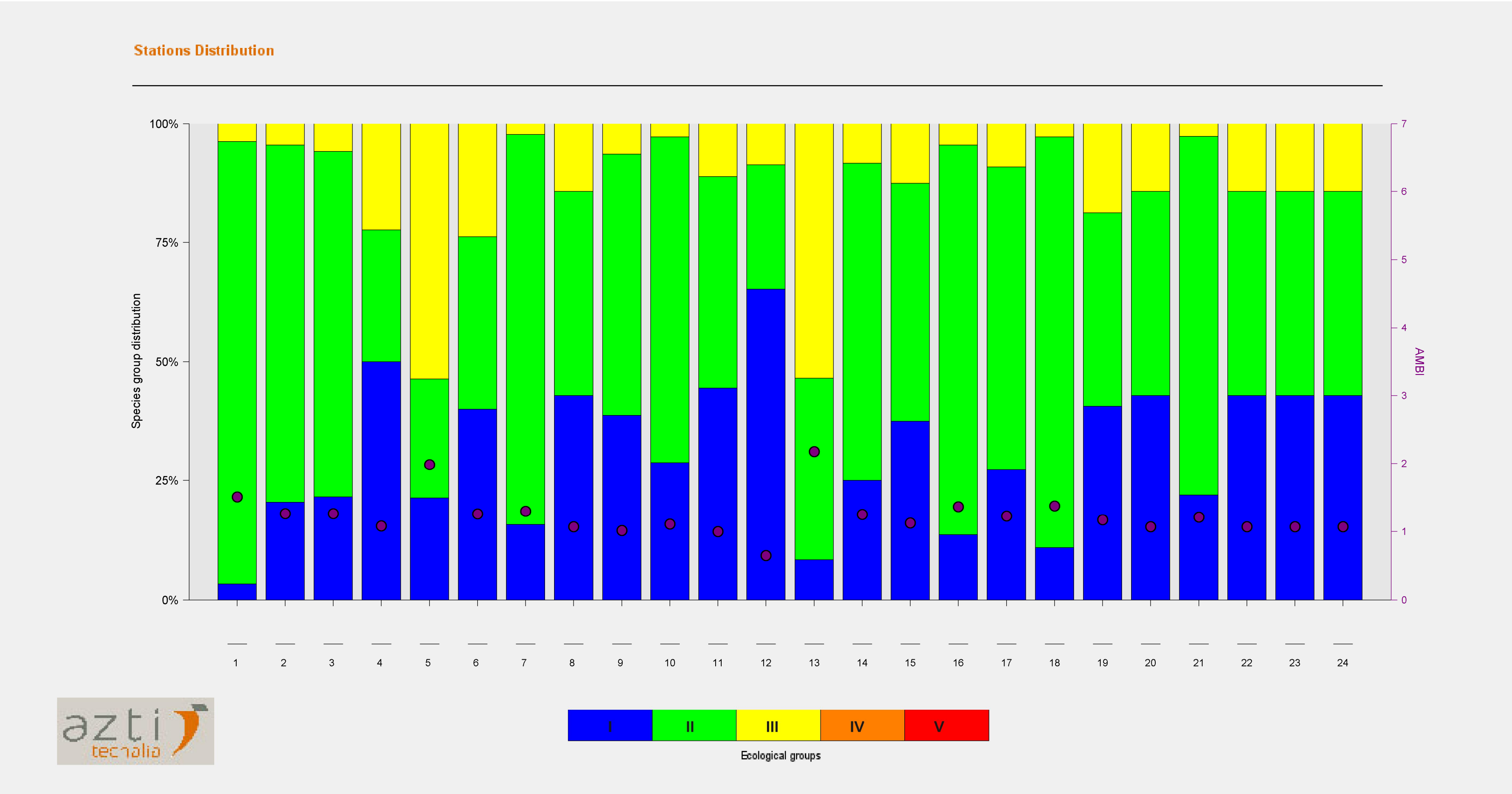

Fig. 5. Spatial distribution of observed macrobenthic invertebrates in response to relative proportion of sensitivity classifications

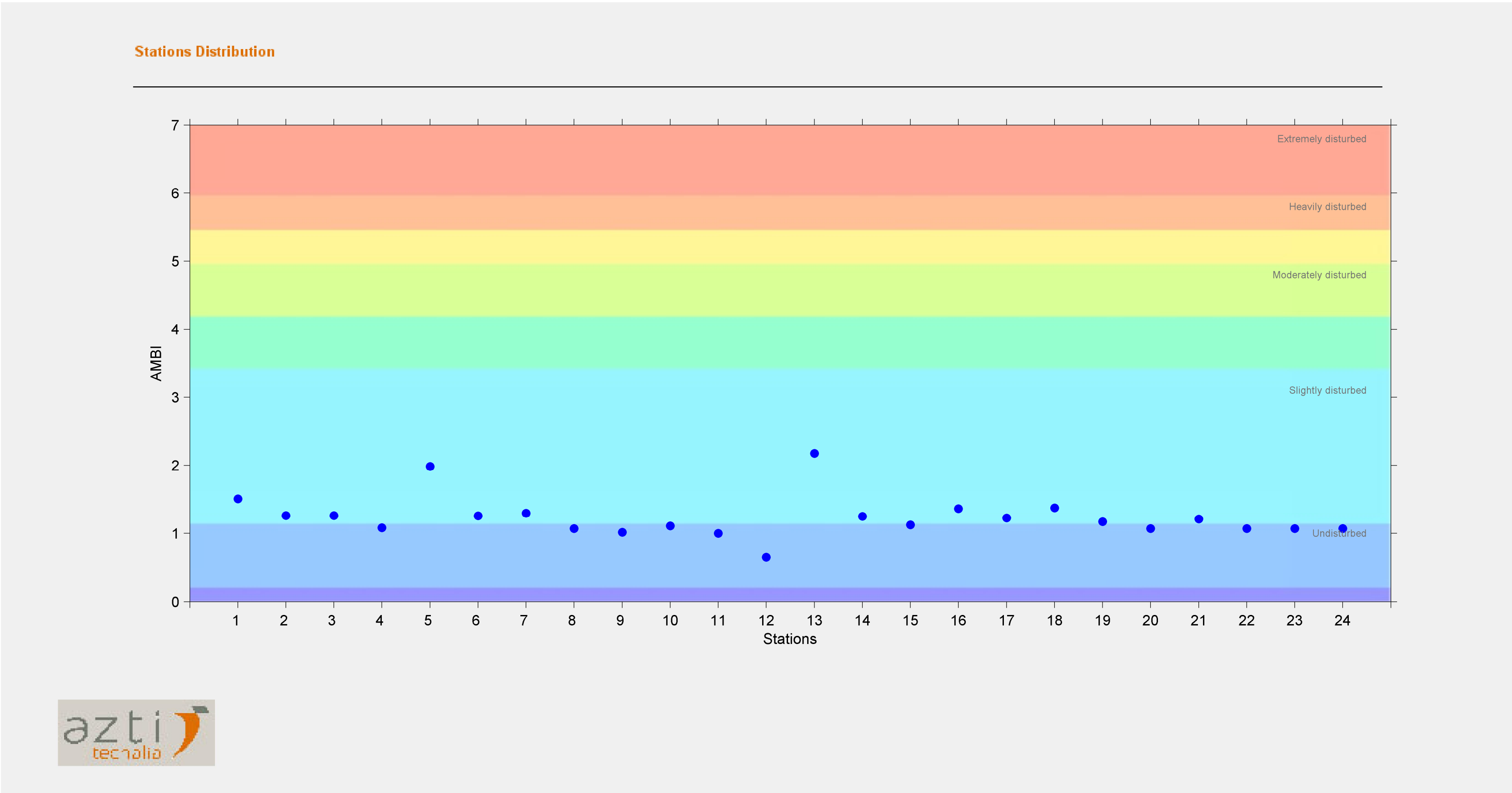

Fig. 6. Time series distribution of observed macrobenthic invertebrates in response to relative proportion of environmental disturbance

Table 2. Pearson correlation matrix of physico-chemical parameters and benthic diversity during the study period

	Gravel	**Sand**	**Silt**	**Clay**	**Toc**	**Dissolved oxygen**	**Margalefs**	**Shannonweiner**	**Equitability**	**Menhinicks**	**Simpson**
Gravel	1										
Sand	.700**	1									
Silt	-.547**	-.708**	1								
Clay	-.738**	-.956**	.608**	1							
Toc	-.095	.194	-.162	-.157	1						
Dissolved oxygen	.029	.142	.296	-.235	.071	1					
Margalefs (D)	-.297	-.229	.413*	.318	.099	.302	1				
Shannon weiner diversity (H)	-.274	-.239	.409*	.334	.019	.086	.880**	1			
EQUITABILITY (J)	-.274	-.239	.408*	.334	.019	.085	.880**	1.000**	1		
Menhinicks (d)	-.289	-.205	.387	.299	.114	.293	.999**	.883**	.883**	1	
Simpson (C)	-.158	-.133	.363	.206	-.059	.039	.653**	.919**	.919**	.658**	1

***. Correlation is significant at the 0.01 level (2-tailed).*

**. Correlation is significant at the 0.05 level (2-tailed)*

The spatial variations in the particle size sediment distribution and macroinvertebrate abundances are as illustrated in Fig. 4. The clay particle size characterises the presence of *Clithon glabratum*, *Pachymelania aurita*, *Atactodea striata Crassostrea tulipa*, *Mytilopsis africana*, *Perna perna* and *Tivela tripla*, the sand particle size recorded the *Tympanptonus fuscatus*, *Tympanotonous fuscatus* var. *radula*, *Clithon glabratum*, *Fistulobalanus pallidus*, *Macomopsis cumana*, *Aloidis trigona*, *Iphigenia laevigata*, *Austromacoma nymphalis*, *there* was only *Turritella ungulina* specie recorded in the silt sediment particle size (Fig. 4). Statistical analysis of the variations in the density of macrobenthic invertebrates recorded at each station using Kruskal-Wallis test showed significant difference ($p<0.05$) in the number of species recorded at each station.

3.4 Correlation Matrix

The correlation between the diversity index, sediment characteristics and chemical parameter of water revealed that dissolved oxygen (DO) had no correlation with particle size characteristics, total organic carbon (TOC) while the Diversity (H,) richness (d) and evenness (j) was positively correlated with silt sediment characteristic (Table 2).

3.5 Macrobenthic Responses to Environmental Variables

The relative proportion of sensitivity classification at each station as shown in Fig. 5 showed the relative proportion of sensitivity classification at each station. Above 50%, species group distribution at station 4 and station 12 were dominated by high abundance and diversity of ecological group I (sensitive species and present under unpolluted condition) while stations (1 – 3, 7, 10, 14, 6 – 18 and 21) were dominated by high abundance and diversity of ecological group II (species indifferent to enrichment). The ecological group III (species tolerant to excess organic matter enrichment) was only recorded in high abundance and diversity at stations 5 and 13. The ecological group IV and V were not recorded during the study period. Furthermore, the time series distribution showed that most of the recorded organisms in terms of disturbance level are majorly in the slightly disturbed stations of the study area with the exceptions of stations 4, 9-12, and 20 – 24 (Fig. 6).

4. DISCUSSION

The environmental evaluation using total organic carbon as a variable is very important because it is proportional to total organic matter which serves as primary food source for macrobenthic organisms and when it is in excess, it can lead to oxygen depletion in the sediment and overlying water eventually, the benthic and fish communities. In this study, It was observed that the obtained total organic content across the sampling stations was not significantly different across the study period but the differences in the results of the total organic carbon (TOC) values obtained at station 10 (highest TOC content) when compared with each other stations and these values were within permissible limits thus, did not have a depleting effect on the available dissolved oxygen and the abundance of macrobenthic invertebrates in the sediment of the study area. In contrast, the abundance of macroinvertebrate fauna increased at the station with moderate TOC and decreased at the station with high TOC.

Reports of researchers who observed that environmental variables such as organic carbon, dissolved oxygen concentration correlated with the abundance, distribution and diversity of macrobenthic fauna in coastal waters [24,25] and this present study also showed similar patterns as earlier reported. It also revealed that the overall diversity of benthic macroinvertebrate fauna were low which may be attributed to the continual impacts of surrounding anthropogenic activities that have changed the nature of the bottom substratum thus affecting the distribution of the macrobenthic invertebrates.

The distribution by the number of the observed dominant species showed that there are two faunal assemblages in this study; one majorly found in the sand sediments while the other are in the clay sediments. It is usual to describe the benthic communities of Lagos lagoon into five communities as described by Oyenekan [26] based purely on the sediment characteristics. These communities are venus community, mangrove community, pachymelania community, estuarine rock community and estuarine amphioplus community. From the dominant species observed in this study, four of the five communities were well represented with the exception of the estuarine amphioplus community which recorded only one species *Donax acutangulus* present only once throughout the entire study.

The abundances of *Naticarius hebraeus*, *Brachidontes puniceus*, *Stramonita haemastoma*, *Spisula trigonella*, *Natica marochiensis*, *Senilia senilis* and *Perna perna*, were low which may be as a result of a change in the sediment characteristics in the study area due to diverse surrounding anthropogenic activities altering preferred sediment characteristic of concerned macrobenthic organisms. It, therefore, appears that two sediment criteria, of fine sand and a well-sorted sample, are well correlated with large populations of macrobenthic communities observed in this study. This is in relation to sediment type preference of the observed macrobenthic species is in consonance with the reports that organism distribution is dependent on the sediment characteristics of the observed environment.

5. CONCLUSION

Sediment particle size varied considerably at the study site, and the total organic carbon values recorded in this study indicate little change in the composition and functioning of the benthic community in the Lagos lagoon during the study. This indicates the presence of a diverse benthic community that appears to efficiently metabolise organic matter and prevent its accumulation in bottom sediments.

In summary, the overall low diversity of macrobenthic fauna observed is attributed to the anthropogenic activities along the coasts of the lagoon which is majorly dredging. Dredging activities observed at some of the selected study stations is a physical stress disturbance causing an intense change in the sediment characteristics enough to reduce the abundance of macrobenthic organisms eventually, the ecosystem stability.

Therefore, organic carbon (TOC) and particle size characteristics examined in this study showed that they are good environmental indicators for evaluating macrobenthic invertebrate responses to stress pattern in water bodies along the coastal areas surrounded by various human activities. Hence, information useful for strict regulations and environmental policies is provided to help prevent the aquatic environment from continuous deterioration and loss of biodiversity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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