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Research Article
Factors Determining Benthic Foraminiferal Distribution in the Shallow Water Coastal Environments of Southwest Nigeria Sector of the Gulf of Guinea

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Abstract
Background and Objective: The dominant factors influencing abundance and distribution patterns of foraminifera in shallow water coastal environments of southwest Nigeria sector of the Gulf of Guinea was undertaken. The objectives were to characterize benthic foraminiferal population in sediments and establish relationships of the identified fauna with depth, salinity, pH, pollutant metals and sediment texture. **Materials and Methods:** One hundred and thirteen surface-sediment samples were analyzed for common pollutant metal and foraminiferal contents and grain size composition. The depth of sediment-water interface, salinity and pH of water collected from selected stations were measured. **Results:** Organic matter enriched, dark-grey to black mud substrate enabled relatively large quantity of foraminifera at the Northwest portion of the lagoon despite the very low salinity that characterizes the micro-habitat. However, this habitat could only produce a monospecific assemblage whose total population is constituted by over 80% *Ammonia beccarii.* Few stations in Lagos Harbour were moderately polluted with Zn and are marked by low species diversity and abundance. Substrates seem to influence relative abundance of calcareous porcellaneous and agglutinated foraminifera at the Southwest and Eastern segments of Lagos Lagoon. **Conclusion:** Consequent upon the non-saline nature, specimens of foraminifera were not recovered from Badagry and Yewa creeks. Moderate pollution of sediments with Zn, Cd, Ni and Cr and the nature of substrates accounted for the disparity in foraminiferal species abundance, diversity and dominance in Lagos Lagoon. However, favourable pH, salinity and substrates facilitated high species variation and abundance in Lagos Harbour.

Key words: Foraminifera, salinity, sediment texture, Lagos Harbour, Lagos Lagoon, micro habitat

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The past five decades have witnessed many studies on benthic foraminiferal assemblages from different parts of the world in areas exposed to mixed continental-marine water[1-11]. These environments undergo stresses resulting from the drastic changes during flood and ebb tides producing changes in temperature, salinity, pH and oxygen content of the interstitial waters. Since large number of foraminifera can be collected in small sample volumes and living forms and tests of dead specimens are often preserved in sediments, comparison between anthropogenic and pristine conditions is possible. In the sedimentary record, interactions between meiofaunal and geochemical elements have made it possible to distinguish between unimpacted, pre-industrial intervals and sediments deposited in industrial periods[10]. Studies dealing with benthic foraminiferal assemblages in the Nigeria sector of the Gulf of Guinea coast have been carried out[12-19]. However, only few studies considered specifically, the influence of temperature, pH, salinity and depth on distribution of foraminiferal assemblages[12,13,18].

Benthic foraminifera occur in a wide variety of marine and brackish environments[20] and their abundance, spatial and temporal distribution in marine and marginal marine sediments make them valuable indicators. Ecological data on recent foraminifera is commonly used to draw conclusions on the adaptations of various fossil forms. These conclusions will be more accurate, if analogies are made between forms at the lower taxonomic levels. In order to determine the factors influencing abundance and distribution of foraminifera in the shallow water coastal environments of Southwest Nigeria, ecological factors such as water temperature, pH, salinity, depth and nature of substrates were considered. In addition to ecological factors, trace metal concentration was also considered as a likely influence on the distribution of foraminifera in the study area. Benthic foraminifera are more sensitive to industrial wastes containing heavy metals and also less tolerant to pollution when compared to ostracods and molluscs[21]. The adverse effects of metallic pollution on foraminiferal population and species diversity has also been reported[22,23]. It is important to note that all sediments contain some concentration of trace and toxic metals from natural sources, though usually low. These background levels can vary widely depending on a number of factors such as parent materials and sedimentation processes in water bodies. Unarguably, anthropogenic activities contribute much more to these metal load and consequently, pollution in sediments can rise to the point where they represent potential health or ecological risk. In order to ascertain the degree of pollution and possible influence on foraminiferal distribution and abundance in the study area, sediments were analysed for their common trace metal concentrations.

In coastal environments, depth may not directly influence foraminiferal abundance and distribution, but, may exert an indirect control on deep water column-muddy microhabitats which are usually turbid. The turbidity will limit light penetration or cuts off direct sunlight which could lead to decimation of foraminifera in symbiotic (e.g., Zooxanthellae), parasitic (e.g. Entosolenia) or commensal relationship with green algae. Mud dwelling foraminifera seem to be tolerant of turbidity as this is the main feature of their habitat (e.g., Ungerianus-pseudoungerianus). Consequent upon this, depth was considered as a factor in this study. Owing to a poor knowledge of the impact of natural variables on foraminiferal assemblages in this segment of the Gulf of Guinea coast, the use of bioindicators merit many more studies. Therefore, this study is aimed at characterizing the population of foraminifera in sediment samples and establish relationship(s) of identified benthic foraminifera with depth, salinity, pH, pollutant metals and sediment texture. The purpose is to improve the understanding of foraminifer's response to variables and enhance the existing knowledge on the degree of impact of changes in conditions on the faunal composition. This study is the first to cover a wide area of different conditions with a view to compare faunal composition, abundance and diversity across these environments. It is thus believed that the determination of parameters under consideration will also contribute to the resolution of the controversies on the degree of pollution in the area. The purpose of this study was to improve the perceptive of foraminifer's response to variables and enhance the existing knowledge on the degree of impact of changes in conditions on the faunal composition.

MATERIALS AND METHODS

A total of one hundred and thirteen surface sediment samples were collected from the various environments at the southwest Nigeria coast in April, 2013. Harbour, lagoon and creek samples were collected from boat using a 30×30 cm grab sampler constructed to hermetically close to prevent the surface of the sediment from being washed away during collection. This study considered only the uppermost layer of sediments (≈10 mm) scraped off and preserved in 5% formalin-seawater kept in various labelled plastic containers for harbour, lagoon and creeks investigated. Sampling of the uppermost layer of sediment does not give accurate representation of modern marsh foraminiferal assemblages[24]. This is true for living assemblages, which additionally need a continuous survey owing to seasonal changes. However, inaccurate results may be obtained for ecological zonation based on total faunas collected in a thick surface interval owing to different sedimentation rates and taphonomic processes in different areas. Hence, total faunas in a thin surface interval which provides less biased ecological information in this regard was considered. One hundred and twenty grams of oven-dried sample was used for sand size granulometry following the standard procedures[25]. Specifically, this method was used for Lagos Harbour as sediments are all composed of unconsolidated sand sized particles. The sediments from Lagos Lagoon and the creeks have quantifiable amount of mud contents hence standard pipetting method[26] for separation of silt and clay fractions was employed. This was done after the sand fraction has been removed from the samples by wet sieving through a 63 µm aperture sieve.

To obtain a good representation of foraminiferal species, separate 30 g each of dried sample was taken and washed over 63 µm sieve aperture size to remove mud. The samples were subsequently oven-dried at 45°C in the laboratory and cool in air before being stored in well labelled dispensing cellophane bags. The foraminiferal specimens were then picked, counted and identified based on qualitative morphological characteristics from relevant literature[27-30]. The relative abundance of specimens was defined using the limits: dominant >20%, common 10-20%, accessory 5-10% and rare <5%[31]. Only species of one occurrence of abundance in the analysed samples >5% were considered to build a matrix of data for sample weighted Q- mode cluster analysis employing Paleontological Statistics software[32]. The Q-mode was considered because trends in similarity of samples based on species composition in relation to the influencing environmental factors are of utmost interest. The algorithm used is the Un-weighted Pair Group method (UPGM) which supports missing data and ensures clusters are joined based on the smallest distance of all members in the 2 groups. Taxa weighted R-mode clusters were generated for Lagos Harbour but was difficult for the lagoon because of wide variation in foraminiferal species' composition and very low species variation. Scanning electron micrograph (SEM) was used to produce photographs of foraminiferal specimens at a macroscopic scale at the University College, London. The specimens recovered are presented in Fig. 1, 2 and 3. However, the SEM required urgent maintenance during this period and the remnant specimens were sketched as observed from the reflected light binocular microscope (Fig. 3). Determination of common trace metal concentrations in sediments was done using inductively coupled plasma-Optical emission spectrometer (ICP-OES) at the Activation Laboratories Limited, Ancaster, Ontario, Canada. Particle size analyses were carried out to establish the percentages of mud, sand and gravel fractions in the sediment samples. This will assist in the interpretation of hydrodynamic regime under which the zoogenous sediments were emplaced.

In order to determine water characteristics, bottom water was collected from the harbour, lagoon and creeks under investigation. These samples were kept in labelled plastic bottles indicating the various stations and on the spot measurements of temperature and pH were done. The pH was measured with pH meter (Hanna H 19625, Precision 0.01), temperature with a mercury thermometer and salinity was determined in the laboratory with a conductivity salinometer (WTWLF 325, Probe WTW Tetracon 325, Precision 0.1 g L^{-1}). The depth was measured using a calibrated rope to the end of which a lead weight was attached.

Consequent upon the high dissimilarity in mineralogical and chemical nature of substrates, influence from ebb and flood tides and hydrographic complexity, Lagos Lagoon was divided into 5 segments for comprehensive investigation[33]. The segments are southwest, west, northwest, central and eastern portions of the lagoon.

Environmental setting: The Gulf of Guinea coast is part of the tropical Atlantic Ocean which runs south-eastward from Cape Palmas in Liberia to Cape Lopez, a 55 km- long peninsula on the coast of west-central Africa in Gabon. The Cape Lopez is located at latitude 0°38'S and longitude 8° 42' E and separates the Gulf of Guinea from the South Atlantic Ocean. The Gulf lies south of the Dahomey Basin in the west, the Niger Delta Basin in the central and Douala Basin in the south. The Craton is further inland. Sedimentation in this region commenced in the Cretaceous in response to the separation of the South American and African land masses and the subsequent opening of the Atlantic Ocean. The continuous separation of the 2 continents produced easily recognizable margins and deep ocean provinces of transform faulting marked by numerous fracture zones[34]. Among the three main sedimentary basins within the Gulf of Guinea coastal region are Dahomey and Niger Delta occurring in the Nigerian sector. The Dahomey basin, under study is filled with Cretaceous to Quaternary sediments. The coastline consists of low-lying sandy beaches. Two suites of sediment strata (''Older'' and ''Younger'' suites) floor the Nigerian continental shelf [35]. The ''Older suites'' are of Pleistocene to early Holocene age, while deposition of ''Younger suites'' occurred along the shoreline and in open shelf region. Sand barrier ridges were built

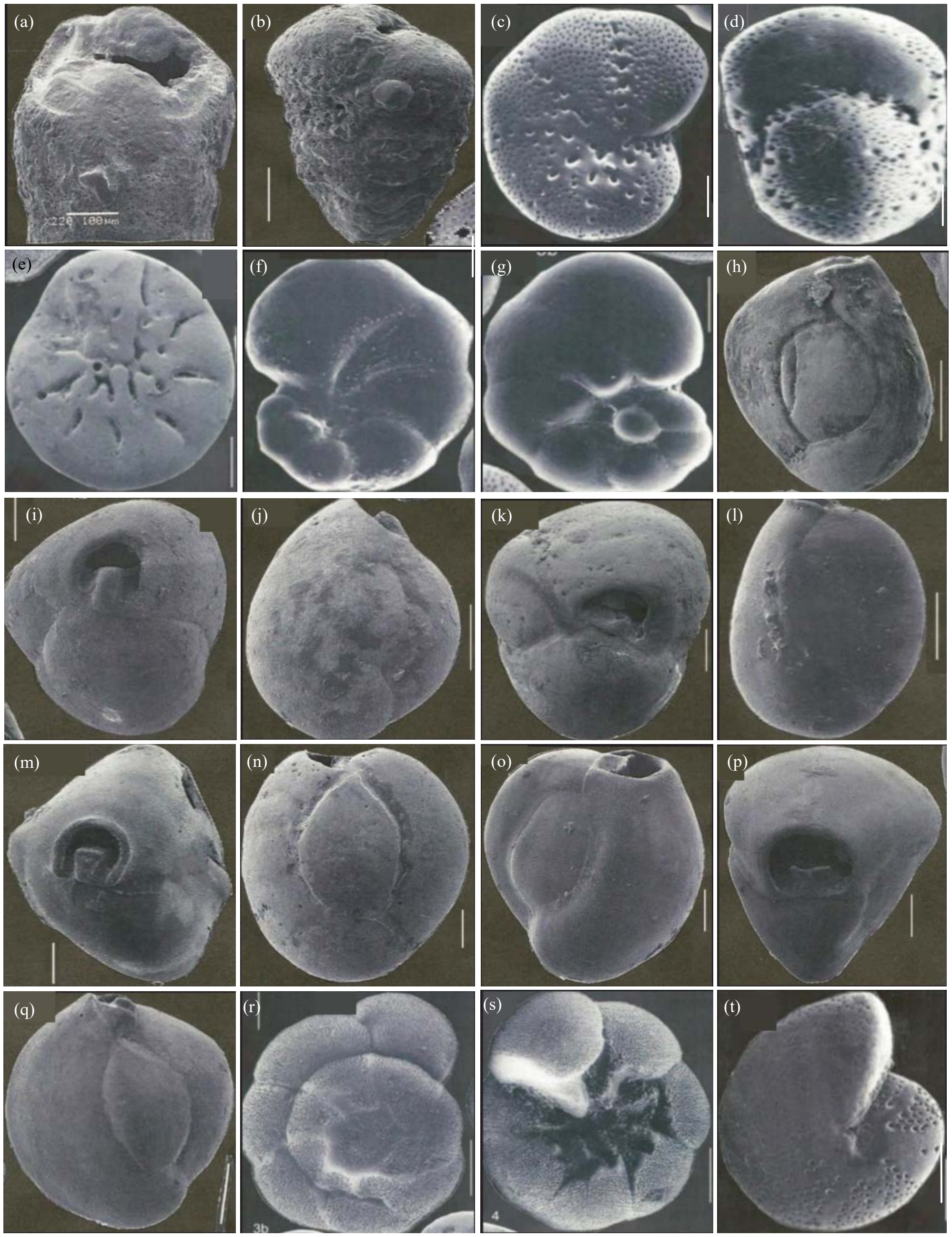

Fig. 1(a-t): (a) *Textularia sagittula* Defrance, Apertural view (X220, scale 100 μm), (b) Lateral view (X230, scale 100 μm), (c) *Cribroelphidium semistriatum* (d'Orbigny) dorsal view (X230, scale 100 μm), (d) *Cribroelphidium semistriatum* (d'Orbigny) apertural edge view (X230, scale 100 μm), (e) *Eponides cribrorepandus* (Asano and Uchio) dorsal view (X150, scale 100 μm), (f) *Hanzawaia boueana* (d'Orbigny) ventral view (X180, scale 100 μm), (g) Dorsal view (X180, scale 100 μm), (h) *Quinqueloculina seminulum* (Linné) front view (X220, scale 100 μm), (i) Apertural view (X270, scale 100 μm), (j) *Quinqueloculina vulgaris* d'Orbigny, dorsal view (X220, scale 100 μm), (k) Apertural view (X140, scale 100 μm), (l) *Quinqueloculina padana* (Perconig) front view (X240, scale 100 μm), (m) Apertural view (X350, scale 100 μm), (n) *Quinqueloculina oblonga* (Montagu) front view (X120, scale 100 μm), (o) *Cruciloculina triangularis* d'Orbigny, posterior view (X130, scale 100 μm), (p) Apertural view (X130, scale 100 μm), (q) *Quinqueloculina bicarinate* d'Orbigny front view (X200, scale 100 μm), (r) *Ammonia beccarii* (Linné) dorsal view (X220, scale 100 μm), (s) Ventral view (X180, scale 100 μm), (t) *Melonis padana* (Perconig) dorsal view (X180, scale 100 μm)

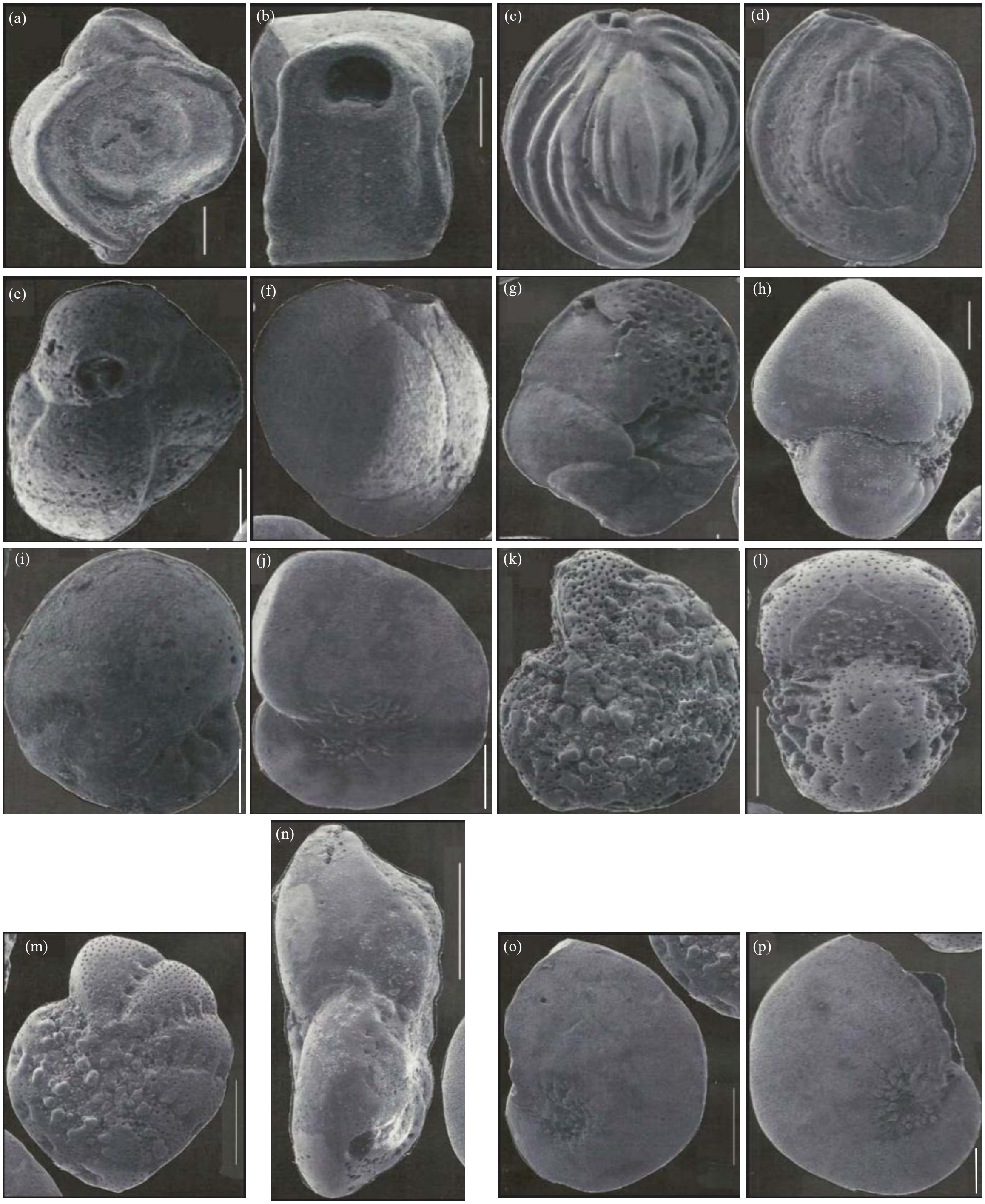

Fig. 2(a-p): (a) *Spiroloculina depressa* d'Orbigny front view (X220, scale 100 µm), (b) Apertural view (X400, scale 50 µm), (c) *Quinqueloculina* sp. front view (X190, scale 100 µm), (d) *Sigmoilopsis schlumbergeri* (Solvestri) front view (X220, scale 100 µm), (e) *Quinqueloculina agglutinans* d'Orbigny apertural view (X240, scale 100 µm), (f) Posterior view (X220, scale 100 µm), (g) *Cancris auriculus* (Fichtel and Moll) apertural edge view (X270, scale 100 µm), (h) Apertural edge view (X270, scale 100 µm), (i) Dorsal view (X220: scale 100 µm), (j) *Florilus atlanticus* (d'Orbigny)umbilical view (X220, scale 100 µm), (k) *Cribroelphidium decipiens* (Costa) dorsal view (X250, scale 100 µm), (l) Apertural edge view (X250, scale 100 µm), (m) *Elphidium advenum* (Cushman) dorsal view (X250, scale 100 µm), (n) Apertural edge view (X230, scale 100 µm), (o) *Florilus boueana* (d'Orbigny) dorsal view (X200, scale 100 µm) and (p) ventral view (X200, scale 100 µm)

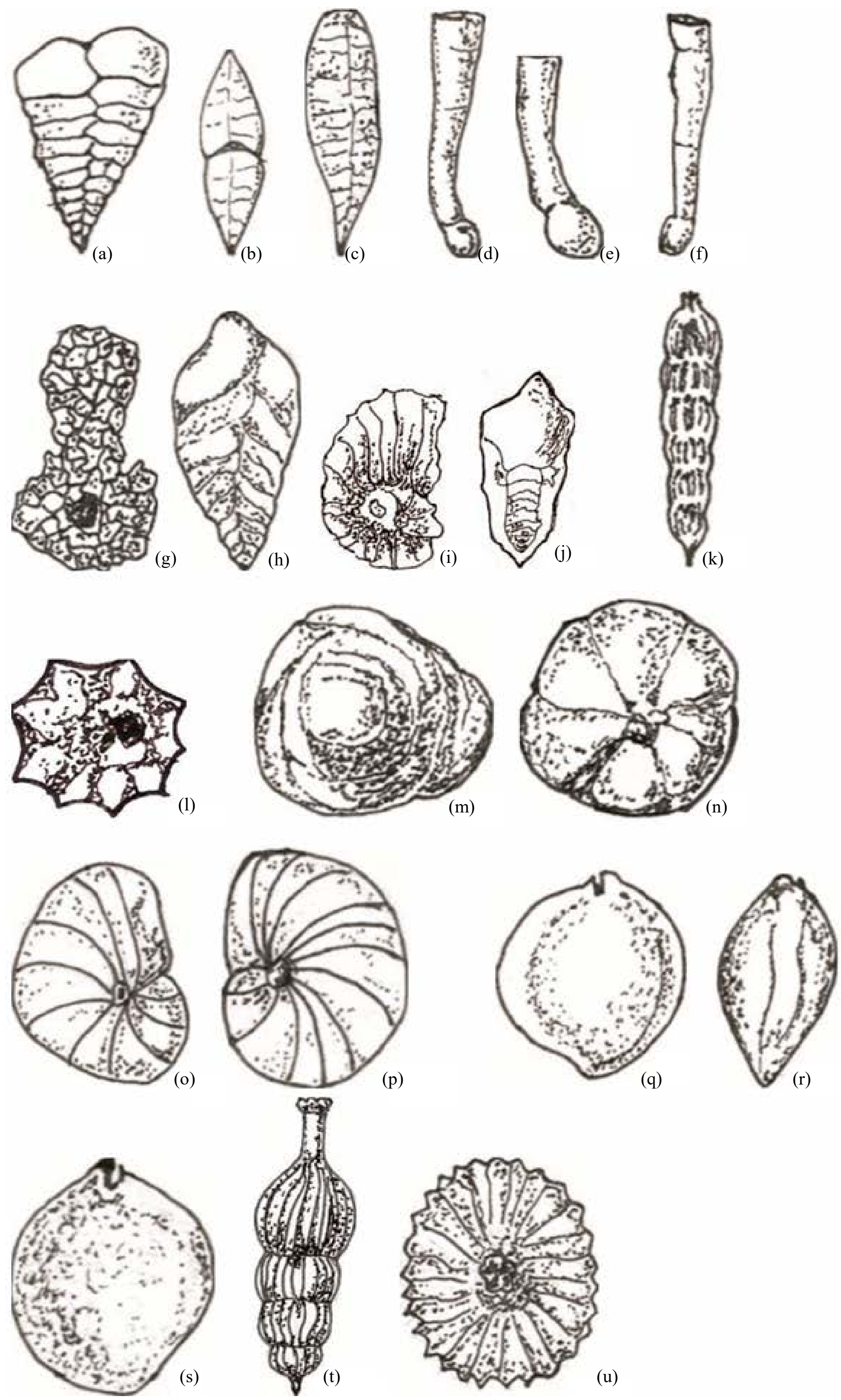

Fig. 3(a-u):(a) *Poritextularia panamensis* Loeblich and Tappan front view (X80), (b) Edge view (X80), (c) Spiral view (X80), (d) *Tubinella inornata* Brady front view (X80), (e) Posterior view (X80), (f) Dorsal view (X80), (g) *Ammobaculites agglutinans* (d'Orbigny) front view (X100), (h) *Bolivina spathulata* d'Orbigny -front view (X100), (i) *Zeaflorilus parrii* (Cushman) ventral view (X80), (j) Apertural view (X120), (k) *Nodosaria raphanus* (Linné) front view (X100), (l) Apertural view (X220), (m) *Neoeponides schreibersii* (d'Orbigny) apical-dorsal view (X100), (n) Ventral view (X100), (o) *Nonion depressulum* (Walker and Jacob) dorsal view (X100), (p) Ventral view (X100), (q) *Sigmoilina sigmoides* (Brady) ventral view (X150), (r) Posterior view (X100), (s) Dorsal view (X100), (t) *Amphicoryna scalaris* (Batsch) front view (X160) and (u) Apertural view (X240)

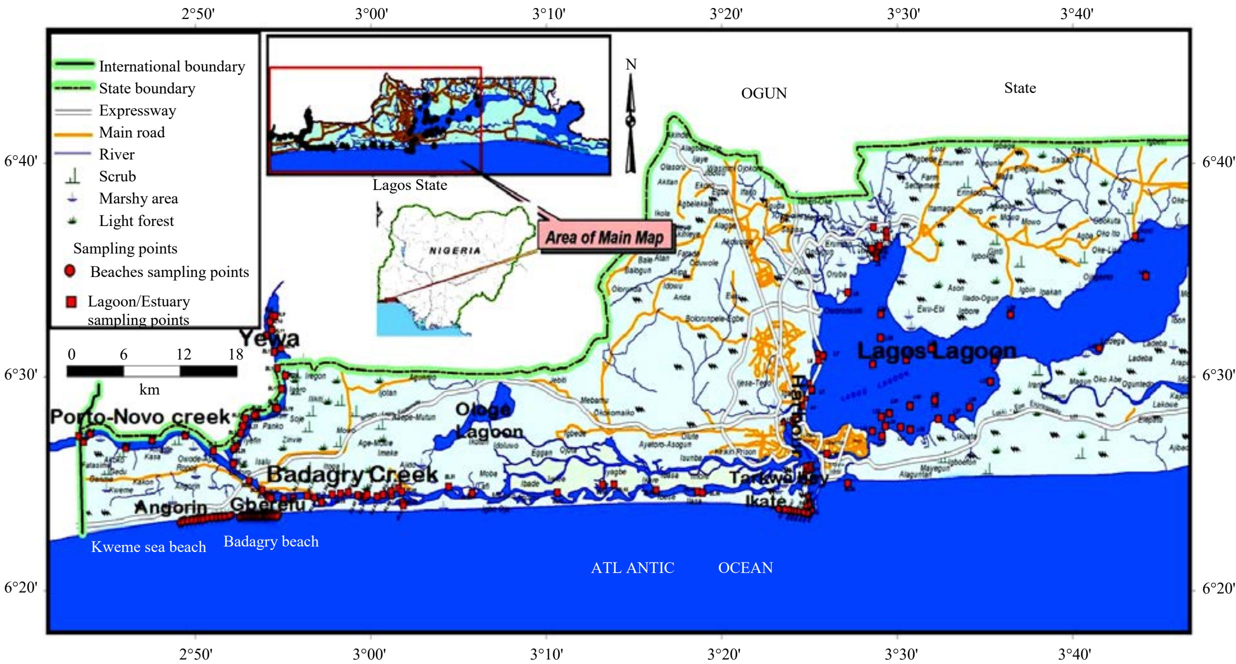

Fig. 4: Map showing location of study area with the sampled stations in southwest Nigeria sector of the Gulf of Guinea coast

outward and aligned to the shoreline trend at the time of their formation. The sand materials which constitute the ridges are progressively sorted from gravelly coarse-grained sand at the Badagry beach to the fine sands of the Lighthouse beach, west of Lagos Harbour. They protect the moles, which are structures erected between 1908 and 1912, to stop the silting of the Commodore channel being the main entrance to Lagos sea ports. This interrupted the west-east longshore sediment transport leaving the relatively older, white sands at the down drift Bar beach-Kuramo end of the moles around Victoria Island, extending to Ebute-Lekki end of Lagos shoreline. Estuaries on the western flank were blocked by the development of beach ridges trapping the waters of the rivers behind them to form the Lagos-Lekki-Lagoon system. Fine sand and mud have been accumulating since impoundment. Some of the social-economic activities that are regular in this region are tourism, sand mining, farming, gas flaring, oil exploration and transportation (involving ship and various categories of boat).

Study area: The study area covers Badagry and Yewa creeks, Lagos Harbour and Lagos Lagoon in southwest Nigeria. The channels west of Lagos City (towards Benin Republic border) are linked together at several locations (Fig. 4). After construction of the breakwaters (Lagos Harbour moles) in the previous century, the beach in front of Victoria Island retreated arising from the decrease in sediment supply. A network of old mostly dried up channels is visible in a brighter green colour of which the shape suggests it was part of an old estuary of various drainage channels much larger than could be expected to be the result of just rainwater run-off was observed at the north of Badagry creek[36]. It is therefore likely that in a previous period of high sea level, a similar lagoon system existed in this area, bounded by beach ridges which are now the elevated areas on which a large part of Lagos Mainland is built. The Southern branch of Badagry creek shows a meandering main channel and several dead-end channels. Only relatively small rivers and streams discharge via Badagry creek as the inlet at Cotonou offers a direct link to the ocean for water discharged by Queme river in Republic of Benin. Badagry creek flows across the boundaries of the Federal Republic of Nigeria and the Bénin Republic between the longitudes 2°42'E and 3°29'E and latitudes 6°23'N and 6°28'N. The sources of water into this creek include Lagune de Porto-Novo in Bénin Republic and in Nigeria, Yewa and Owo rivers and Ologe and Lagos Lagoons. The creek is shallow with an average water depth of 3.5 m in addition to the irregular topography being displayed[37]. The largest of the four-lagoon system in the Gulf of Guinea is Lagos Lagoon. It is connected to Atlantic Ocean by Commodore channel in Lagos and receives freshwater from important rivers like Yewa, Ogun, Ona and Osun. Badagry, Ikate, Elegushi, Oniru, Lekki and Kuramo beaches among others form the land-sea interface of this coastal system.

The region in which the study locations fall extends for over 250 km from Cotonou in Republic of Benin eastwards and lies between latitudes 06° 21'N and 06° 38'N and longitudes 02° 43'E and 03° 45'E (Fig. 4).

RESULTS

Data on ecological factors

Data on ecological factors in Lagos Harbour: Almost all samples collected from relatively deeper portions of the harbour are unconsolidated fine grained sediments, whereas, medium grained sediments constituting approximately 28.57% dominate the shallow areas (Table 1). The measured temperature ranges from 23.7-24.1°C. Salinity and pH values vary from 33.40-34.80% and 7.73-8.05, respectively. The slight influence of rivers entering the Lagos Lagoon which is connected to the harbour is noticeable in the stations except H4 and H14 which have almost sea water salinity (34.80%). Depth varies from 0.9 m near Tarkwa bay (H13 and H14) to a maximum of 9.0 m around Oke Ogbe (H5).

Data on ecological factors in Lagos Lagoon: Muddy sand dominated in approximately 42.5% of the stations in Lagos Lagoon and sand and sandy mud dominated in 40% and 17.5% of the remaining stations, respectively. The sediments of southwest and eastern segments are overwhelmed by sand sized fraction whereas, sandy mud are prevalent in 5 out of thirteen stations at the northwest segment (Table 2). Muddy sand and sand are in equal abundance at the centre of the lagoon. The temperature recorded varies between 26.4°C (L1and L2) and 29.0°C (L20 and L27) (Table 2). The water is slightly alkaline and the values recorded for pH ranged from 7.75 (L1) to 8.46 (L12a) throughout the entire lagoon.

The depth varies from 0.4 m close to the centre of the lagoon to a maximum of 11.5 m near the entrance of the sea. Almost 62% of the sampled stations recorded the depth of 3 m and below. Although, depths of 9.0 and 8.8 m at the eastern and southwest segments respectively, were recorded for this lagoon, most stations are between 0.4 and 5.0 m. Noteworthy is the maximum depth of 11.5 m recorded at the entrance of the lagoon (L1) that communicates with the sea. About 82% of the sampled stations have very low salinity, ranging from 0.00-15.00%. The stations (Southwest segment) that are not far from the harbour are hyposaline to moderately marine (16.00-32.10%).

Data on ecological factors in Badagry creek: The surficial sediments found in this area in order of decreasing abundance are muddy sand, sand, sandy mud and mud (Table 3). Temperature of water in this creek ranges from 25.5-29.4°C and the pH recorded varies from 7.00-7.30. Most stations have salinity between 0.00 and3.00%. The stations from BL52 to BL59 represent the portion of Badagry creek mostly influenced by backwater from Lagos Harbour and possess the pH of typical coastal water (7.70-8.10). This is complemented by the values recorded for salinity (3.00-22.00%).

The depths recorded range from 0.9-4.0 m for 70% of the sampled stations (Table 3).

Data on ecological factors in Yewa creek: Sandy mud characterized the sediments of Yewa Creek except station Y9 which is dominantly muddy sand. This creek is marked by slightly acidic (pH = 6.9) to slightly alkaline (pH = 8.8) water environment (Table 4). The salinity recorded ranges from 0.00-1.00% and the depth of water is anomalously shallow i.e., 1.0 m at the centre of the creek reaching a maximum of

Table 1: Data on ecological factors obtained from Lagos Harbour, Southwest Nigeria

Sample stations	Depth (m), Sediment-water surface	pH	Salinity (%)	Temperature (°C)	Coordinates Longitudes (East)	Latitudes (North)	Sediment description
H1	4.6	7.74	33.40	23.9	3.397817	6.400033	Fine sand, well sorted, strongly fine skewed, platykurtic
H2	1.5	7.73	33.90	23.9	3.397650	6.401070	Fined sand, very poorly sorted, strongly fine skewed, platykurtic
H3	3.9	7.93	34.20	23.9	3.395367	6.399667	Fine sand, moderately sorted, fine skewed, platykurtic
H4	5.6	8.05	34.80	23.7	3.399867	6.395700	Fine grained size moderately sorted, strongly fine skewed, platykurtic
H5	9.0	7.89	34.30	23.8	3.396088	6.406867	Fine sand, moderately sorted, strongly fine skewed, platykurtic
H6	2.6	7.87	34.00	23.8	3.396850	6.418180	Fine sand, poorly sorted, strongly fine skewed, extremely very leptokurtic
H7	1.9	7.80	34.00	24.1	3.399100	6.427450	Fine sand, poorly sorted, strongly coarse skewed, very platykurtic
H8	1.2	7.89	34.00	23.8	3.396110	6.405830	Fine sand, very poorly sorted, coarse skewed, platykurtic
H9	1.0	7.88	34.00	23.8	3.397050	6.400583	Medium sand, moderately well sorted, fine skewed, very leptokurtic
H10	1.0	7.86	34.10	23.9	3.396450	6.417983	Medium sand, poorly sorted, strongly fine skewed, very leptokurtic
H11	1.0	7.87	34.10	24.1	3.392717	6.423817	Fine sand, poorly sorted, strongly fine skewed, mesokurtic
H12	1.1	7.79	33.90	24.0	3.397780	6.428890	Medium sand, poorly sorted, strongly fine skewed, very leptokurtic
H13	0.9	7.80	34.10	24.0	3.395280	6.426670	Fine sand, poorly sorted, strongly fine skewed, mesokurtic
H14	0.9	8.01	34.80	23.8	3.394017	6.399200	Medium sand, well sorted, strongly fine skewed, platykurtic

Table 2: Data on ecological factors obtained from Lagos Lagoon, Southwest Nigeria

Sample stations	Depth (m), Sediment-water surface	pH	Salinity (%)	Temperature (°C)	Coordinates Longitudes (East)	Latitudes (North)	Sediment description Sand (%)	Silt (%)	Clay (%)	Remarks
L1	11.5	7.75	32.10	26.4	3.398267	6.430950	92.75	5.20	3.05	Sand: Sample from Southwest (SW) segment of the Lagoon
L2	2.2	8.05	27.70	26.4	3.394367	6.430133	93.76	3.85	2.39	Sand: Sample from SW segment of the Lagoon
L3	8.8	8.10	31.80	27.4	3.381767	6.465533	59.30	19.50	21.20	Muddy sand: Sample from SW segment of the Lagoon
L4	5.1	8.22	26.00	27.45	3.390650	6.477367	96.56	3.01	0.43	Sand: Sample from SW segment
L5	2.8	8.15	16.00	27.42	3.399583	6.489917	94.80	3.20	2.00	Sand: Sample from SW segment
L6	2.8	7.82	7.30	27.42	3.406483	6.512967	91.79	6.09	2.12	Sand: Sample from Western (W) segment
L7	0.9	7.79	1.60	27.45	3.410533	6.516583	89.66	8.76	1.58	Muddy sand: Sample from W segment
L8	1.5	8.11	0.70	28.0	3.433867	6.565933	94.44	5.04	0.52	Sand: Sample from W segment of the Lagoon
HL1	1.5	8.10	26.00	27.2	3.372900	6.464380	67.81	18.98	13.32	Muddy sand: Sample from W segment of the Lagoon
HL2	4.8	8.05	24.50	27.4	3.384900	6.470130	88.52	7.10	4.36	Muddy sand: Sample from W segment of the Lagoon
HL3	1.8	8.15	20.50	27.4	3.393870	6.483070	74.08	18.00	7.92	Muddy sand: Sample from W segment of the Lagoon
HL4	0.8	7.82	16.00	27.6	3.397330	6.495030	97.35	2.60	0.05	Sand: Sample from W segment of the Lagoon
HL5	2.0	7.90	15.00	27.6	3.405050	6.518220	24.09	7.61	68.30	Sandy mud: Sample from W segment of the Lagoon
L9	6.0	8.08	0.10	28.2	3.461100	6.592967	80.74	11.20	8.06	Muddy sand: Sample from Northwest (NW) segment
L10	3.2	7.99	0.00	28.8	3.460383	6.596233	59.73	14.27	26.00	Muddy sand (Dark grey): Sample from NW segment
L11	7.0	8.33	0.10	28.7	3.458767	6.597467	26.05	11.90	62.05	Sandy mud (Dark-grey to black): Sample from NW segment
L12A	5.6	8.46	0.00	28.8	3.457783	6.599317	30.00	10.20	59.80	Sandy mud: Sample from NW segment
L12B	5.2	8.51	0.10	28.5	3.457500	6.599100	53.09	20.05	26.86	Muddy sand: Sample from NW segment
L13A	4.8	8.15	0.00	28.8	3.456100	6.599917	71.09	17.61	11.30	Muddy sand: Sample from NW segment
L13B	5.0	8.21	0.10	29.0	3.456717	6.599167	39.98	10.64	49.56	Sandy mud: Sample from NW segment
L14	1.2	8.44	0.30	28.5	3.462600	6.599167	84.44	7.39	8.17	Muddy sand: Sample from NW segment
L15	0.9	8.45	0.50	28.9	3.463100	6.601283	41.18	9.19	49.63	Sandy mud: Sample from NW segment
L16	2.2	7.90	0.40	26.5	3.464483	6.601917	51.87	18.83	29.30	Muddy sand: Sample from NW segment
L17	5.6	7.94	0.10	27.0	3.470950	6.608933	75.17	13.05	11.76	Muddy sand: Sample from NW segment
L18	3.1	8.30	0.20	26.8	3.470300	6.613450	88.16	7.00	4.84	Muddy sand: Sample from NW segment
L19	1.1	8.20	0.50	27.5	3.414067	6.440167	20.05	9.45	70.50	Sandy mud: Sample from NW segment
L20	9.0	8.10	9.00	27.1	3.458433	6.616567	94.50	5.00	0.50	Sand: Sample from Eastern (E) segment of the Lagoon
L21	7.5	8.00	8.00	27.4	3.466450	6.453900	91.75	6.55	1.70	Sand: Sample from E segment of the Lagoon
L22	1.0	8.40	6.00	27.2	3.469517	6.461700	93.76	5.92	0.32	Sand: Sample from E segment of the Lagoon
L23	0.6	8.10	5.00	27.4	3.569381	6.496319	96.25	3.70	0.05	Sand: Sample from E segment of the Lagoon
L24	0.8	8.00	4.00	27.6	3.484083	6.460867	93.88	6.12	0.00	Sand: Sample from E segment of the Lagoon
L25	7.0	7.90	5.00	27.6	3.493333	6.458767	55.57	14.43	30.00	Muddy sand: Sample from E segment of the Lagoon
L26	3.8	7.90	7.00	28.5	3.519983	6.467300	92.02	7.05	0.93	Sand: Sample from E segment of the Lagoon
L27	2.3	8.00	1.00	29.0	3.533017	6.467533	64.02	7.48	28.50	Muddy sand: Sample from central portion of the Lagoon
L28	2.0	8.20	1.00	28.2	3.549600	6.647583	74.43	18.00	7.57	Muddy sand: Sample from central portion of the Lagoon
L29	2.5	8.20	1.00	28.1	3.516550	6.481833	92.74	6.01	1.25	Sand: Sample from central portion of the Lagoon
L30	2.0	8.20	0.20	28.0	3.493017	6.477217	96.25	3.05	0.70	Sand: Sample from central portion of the Lagoon
L31	0.4	8.00	4.00	27.0	3.473317	6.471350	93.88	4.85	1.27	Sand: Sample from central portion of the Lagoon
L32	2.5	8.30	5.00	27.0	3.465800	6.469050	72.24	9.76	18.00	Muddy sand: Sample from central portion of the Lagoon
L33	7.5	7.90	13.00	26.7	3.457217	6.457733	18.79	10.61	70.60	Sandy mud: Sample from central portion of the Lagoon

Table 3: Data on ecological factors obtained from Badagry Creek, Southwest Nigeria

Sample stations	Depth (m), Sediment-water surface	pH	Salinity (%)	Temperature (°C)	Coordinates Longitudes (East)	Latitudes (North)	Sediment description Sand (%)	Silt (%)	Clay (%)	Remark (s)
BL1	1.1	7.00	0.00	25.5	2.703459	6.453677	13.08	7.62	79.30	Sandy mud: Sample from the boundary between Nigeria and Republic of Benin
BL2	2.8	7.10	1.00	25.5	2.708146	6.449552	5.90	13.40	80.70	Mud: Sample from Western (W) segment
BL3	2.0	7.30	1.00	25.8	2.714333	6.455739	8.60	4.40	87.00	Mud: Sample from W segment
BL4	2.7	7.20	1.00	25.6	2.748082	6.444490	4.88	9.112	86.00	Mud: Sample from W segment
BL5	3.6	7.00	1.00	25.5	2.773207	6.450677	1.59	12.01	86.40	Mud: Sample from W segment
BL6	2.3	7.00	0.00	25.5	2.804518	6.454052	47.82	6.18	46.00	Sandy mud: Sample from W segment
BL7	1.9	7.10	0.00	25.5	2.831330	6.442240	34.17	15.47	50.36	Sandy mud: Sample from W segment
BL27	1.6	7.90	0.00	26.7	2.850329	6.432313	84.95	8.76	6.29	Muddy sand: Sample from Eastern (E) segment
BL28	5.2	7.80	0.00	26.5	2.865201	6.419220	83.42	8.93	7.65	Muddy sand: Sample from E segment
BL29	5.1	7.90	0.00	27.6	2.877531	6.411848	89.70	8.00	2.30	Muddy sand: Sample from E segment
BL30	3.6	7.90	1.00	27.5	2.882996	6.406636	64.24	18.50	17.26	Muddy sand: Sample from E segment
BL31	4.1	7.80	1.00	27.2	2.886301	6.405492	69.31	10.64	30.05	Muddy sand: Sample from E segment
BL32	4.7	7.80	1.00	27.2	2.8982494	6.4049839	84.47	8.70	6.83	Muddy sand: Sample from E segment
BL33	3.2	7.80	1.00	28.5	2.9072742	6.4057466	72.54	16.46	11.00	Muddy sand: Sample from E segment
BL34	3.1	7.8	1.00	28.3	2.9202394	6.4072719	26.55	20.00	53.45	Sandy mud: Sample from E segment
BL35	6.3	7.80	1.00	28.8	2.9274846	6.4058737	41.68	9.97	48.35	Sandy mud: Sample from E segment
BL36	3.0	7.90	2.00	29.1	2.9342214	6.4025689	90.47	6.05	3.48	Sand: Sample from E segment
BL37	3.2	7.80	2.00	29.4	2.9442630	6.4085430	97.07	2.90	0.03	Sand: Sample from E segment
BL39	0.9	7.90	3.00	29.0	2.9595162	6.4100683	97.62	2.38	0.00	Sand: Sample from E segment
BL40	2.3	8.00	2.00	29.0	2.9684138	6.4076532	93.32	4.68	2.00	Sand: Sample from E segment
BL41	2.5	8.00	2.00	28.8	2.9756591	6.4065092	78.97	6.03	15.00	Muddy sand: Sample from E segment
BL42	4.2	8.00	2.00	29.0	2.9774386	6.4082888	67.28	15.74	16.98	Muddy sand: Sample from E segment
BL43	1.0	7.90	2.00	28.6	2.9868447	6.4065092	16.40	10.60	73.00	Sandy mud: Sample from E segment
BL34	3.1	7.80	1.00	28.3	2.9202394	6.4072719	26.16	14.00	59.84	Sandy mud: Sample from E segment
BL44	1.6	7.90	2.00	28.6	2.9926917	6.4081617	85.58	10.90	3.52	Muddy sand: Sample from E segment
BL46	4.8	7.90	1.00	28.4	3.0003183	6.4110852	95.51	4.49	0.00	Sand: Sample from E segment
BL47	7.5	7.80	1.00	28.5	3.007182	6.413246	95.76	3.50	0.74	Sand: Sample from E segment
BL48	2.2	7.00	1.00	28.2	3.010487	6.410577	99.92	0.08	0.00	Sand: Sample from E segment
BL49	4.6	7.80	1.00	27.6	3.010868	6.401933	87.00	9.00	4.00	Muddy sand: Sample from E segment
BL50	3.8	7.80	1.00	26.5	3.011885	6.399645	96.61	3.39	0.00	Sand: Sample from E segment
BL51	3.1	7.90	0.00	26.8	3.054848	6.414263	96.02	3.72	0.26	Sand: Sample from E segment
BL52	4.1	8.10	5.00	26.5	3.077220	6.409306	91.28	6.35	2.37	Sand: Sample from E segment
BL53	4.0	8.10	6.00	26.5	3.158061	6.409941	97.08	2.92	0.00	Sand: Sample from E segment
BL54	2.7	8.10	3.00	26.4	3.200897	6.416043	96.52	3.08	0.40	Sand: Sample from E segment
BL55	4.5	8.00	4.00	26.2	3.211828	6.416170	93.95	3.05	3.00	Sand: Sample from E segment
BL56	2.3	7.90	11.00	26.2	3.251868	6.411848	89.04	7.06	3.90	Muddy sand: Sample from E segment
BL57	5.2	7.90	20.00	26.0	3.291399	6.410704	14.63	15.37	70.00	Sandy mud: Sample from E segment
BL58	1.3	8.00	22.00	26.0	3.295975	6.409941	73.57	8.49	18.00	Muddy sand: Sample from E segment
BL59	3.1	7.70	19.00	26.2	3.434016	6.417059	62.41	10.09	27.50	Muddy sand: Sample from E segment

Table 4: Data on ecological factors obtained from Yewa Creek, Southwest Nigeria

Sample stations	Depth (m), Sediment-water surface	pH	Salinity (%)	Temperature (°C)	Coordinates: Longitudes (East)	Coordinates: Latitudes (North)	Sediment description: Sand (%)	Silt (%)	Clay (%)	Remark (s)
Y1	1.9	6.90	0.00	27.7	2.887191	6.547982	18.01	11.99	70.00	Sandy mud: Sample from Northern (N) segment of the creek
Y2	1.6	8.80	1.00	27.6	2.889733	6.547474	25.42	20.08	54.50	Sandy mud: Sample from N segment of the creek
Y3	1.1	7.90	0.00	27.7	2.885030	6.542771	15.05	14.70	70.25	Sandy mud: Sample from N segment of the creek
Y4	1.6	7.60	0.00	27.1	2.886683	6.536415	44.28	6.72	49.00	Sandy mud: Sample from N segment of the creek
Y5	1.0	8.00	0.00	28.0	2.881725	6.531966	24.00	26.00	50.00	Sandy mud: Sample from N segment of the creek
Y6	1.1	8.10	0.00	28.0	2.888970	6.519510	13.86	6.10	80.04	Sandy mud: Sample from N segment of the creek
Y7	1.9	7.90	0.00	28.1	2.895580	6.522433	30.61	20.09	49.30	Sandy mud: Sample from N segment of the creek
Y8	1.2	8.40	0.00	28.2	2.892148	6.506799	46.59	3.00	50.41	Sandy mud: Sample from N segment of the creek
Y9	1.7	8.20	0.00	28.1	2.899648	6.501206	77.15	8.85	14.00	Muddy sand: Sample from N segment of the creek
Y10	1.8	7.80	0.00	27.8	2.896343	6.490529	23.83	21.07	55.10	Sandy mud: Sample from N segment of the creek
Y11	2.9	8.20	0.00	27.8	2.889987	6.476165	37.67	20.33	42.00	Sandy mud: Sample from Southern (S) segment of the creek
Y12	2.0	8.00	0.00	27.8	2.892021	6.475403	37.82	20.00	42.12	Sandy mud: Sample from S segment of the creek
Y13	3.0	8.00	0.00	28.0	2.872192	6.470954	48.75	10.00	41.25	Sandy mud: Sample from S segment of the creek
Y14	2.6	8.40	1.00	28.0	2.870158	6.469810	9.50	10.30	80.20	Mud: Sample from S segment of the creek
Y15	2.8	7.80	0.00	28.2	2.861769	6.467649	9.35	11.00	79.65	Mud: Sample from S segment of the creek
Y16	1.9	7.90	0.00	28.2	2.859608	6.461421	4.00	10.50	85.50	Mud: Sample from S segment of the creek
Y17	2.0	8.20	1.00	28.0	2.857447	6.456082	65.55	13.00	21.45	Muddy sand: Sample from S segment of the creek
Y18	2.6	7.80	0.00	27.6	2.853126	6.445913	19.00	10.25	70.75	Sandy mud: Sample from S segment of the creek
Y19	3.0	7.80	0.00	27.7	2.850711	6.444007	19.50	11.00	69.50	Sandy mud: Sample from the entrance of Yewa creek from Badagry creek

Table 5: Concentration of selected trace metals in sediments of Lagos Harbour, Southwest Nigeria and reference values

Common trace metals	Maximum detection limit (ppm)	Concentration (ppm) of trace metals in sediments of Lagos Harbour: Sampled stations H1	H3	H4	H6	H8	H9	H10	H14	EPA reference values (Prater and Anderson, 1977) Range	Status	Olatunji and Abimbola on lagos lagoon sediments (2010) Range	Status
Mo	1.0	<1	<1	<1	<1	<1	<1	<1	<1	-	-	<1.0-28.0	MP
Cu	1.0	3	2	1	5	2	<1	1	2	<25.0	NP		
										25.0-50.0	MP		
										>50.0	VP	3.0-241.0	VP
Pb	3.0	9	<3	4	8	<3	5	7	5	<40.0	NP		
										40.0-60.0	MP		
										>60.0	VP	2.0-146.0	MP
Zn	1.0	24	143	19	107	6	9	123	13	<90.0	NP		
										90.0-200.0	MP		
										>200.0	VP	9.0-366.0	MP
Ni	1.0	11	9	4	10	5	5	5	8	<20.0	NP		
										20.0-50.0	MP		
										>50.0	VP	3.0-49.0	MP
Co	1.0	9	6	3	9	2	3	2	5	-	-	1.0-23.0	NP
Cd	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	6.0	VP	0.5-3.7	MP
V	1.0	31	26	13	21	13	16	9	23	-	-	4.0-124.0	NP
Cr	1.0	32	29	15	37	19	19	16	26	<25.0	NP		
										25.0-75.0	MP		
										>75.0	VP	6.0-87.0	Few stations are MP-VP

NP: Non-Polluted, MP: Moderately polluted, VP: Very polluted

3.0 m where it opens into the confluence between Yewa and Badagry creeks. The recorded temperature values are fairly constant, approximately 28.0°C (27.6-28.2 °C).

Trace metal concentrations in sediments: In sediments of Lagos Harbour, the concentrations in part per million (ppm) recorded for Mo and Cd in all stations are below detection limits of <1 and <0.5, respectively, whereas, Cu ranged from <1-5, Pb<3-8, Zn 6-143, Ni 5-11, Co 2-9, (<0.5), V 9-31 and Cr 15-37 (Table 5). However, there are much higher concentrations of these trace metals in sediments of Lagos Lagoon, Yewa and Badagry creeks.

Of note are the much higher than the background concentration of Cr (>25 ppm) which was obtained from almost all the stations sampled in Lagos Lagoon, high concentrations of Ni (>20 ppm) and Cd (>0.5 ppm) in some of these stations and Zn (>90 ppm) in few places (Table 6). Three stations at the northwest (L10, L15 and L17A) and 2 of the 3 stations analyzed (HL3 and HL5) in the western portions of Lagos Lagoon were marked by high values for concentrations of Cu (>25-35 ppm) whereas, high concentrations of Zn (>110-145 ppm) were documented for a total of three stations from the central portion and 2 each from the West and Northwest portions of the lagoon.

The most polluted in the Badagry creek is the Western- half (BL1-BL7) where there is a sequential decrease from the Porto-Novo creek at the Bénin Republic-Nigeria border down to the Central half of the Badagry creek (Table 7). The concentrations of Cu, Zn, Ni, Co, Cd, V and Cr in these sediments are highly consequential due to a relatively much higher than the background values recorded. Generally, the concentrations of Mo in the creek sediments are below detection limit in almost all the stations.

The concentrations of Pb (3.0-12.0 ppm), Cu (2.0-19.0 ppm) and Mo (<1.0 ppm) are within their background values in the sediments of Yewa Creek. Also, the Zn (31-239 ppm), Ni (20-28 ppm) and Cd (0.5-4.0 ppm) contents of this creek have revealed that these metal loads surpass their natural background values (Table 8).

Anomalously high contents of Zn (239.0 ppm) was recorded for sediment at station Y5 (Table 8) near the boundary between Ogun and Lagos states. Also, Yewa and western end of Badagry creeks, northwest and western portions of Lagos Lagoon recorded high concentrations of cadmium (>1.0-<1.7 ppm). Generally, the trace metal concentrations in sediments near the confluence of Badagry and Yewa creeks are much higher than that at the Northern segment of Yewa Creek.

Table 6: Concentration (ppm) of selected trace metals in sediments of Lagos Lagoon, Southwest Nigeria

Sample station	Analyte Fe (%) MDL 0.01	Mo (1)	Cu (1)	Pb (3)	Zn (1)	Ni (1)	Co (1)	Cd (0.5)	V (1)	Cr (1)
L1	2.97	2	14	25	60	15	08	0.6	36	43
L2	3.51	2	15	20	68	17	10	0.7	37	48
L9	5.71	2	22	17	67	26	24	0.8	50	47
L10	3.89	2	27	37	113	22	17	1.3	50	49
L11	4.16	2	23	30	77	28	14	0.9	57	59
L13	3.30	<1	20	16	81	19	24	<0.5	51	42
L14	4.09	1	24	18	99	20	26	0.5	54	44
L15	3.49	<1	31	14	70	30	29	0.7	57	52
L16A	3.03	1	14	16	63	17	12	0.8	37	43
L16B	2.30	<1	15	13	51	13	17	<0.5	40	32
L17A	2.85	<1	27	13	66	29	33	<0.5	58	47
L17B	4.38	1	20	12	56	21	32	<0.5	48	36
L18	3.68	1	22	21	79	20	25	<0.5	56	49
L22	1.35	2	7	9	34	13	5	<0.5	17	26
L23	1.18	1	3	<3	76	8	4	<0.5	11	19
L26	3.88	2	21	14	70	19	14	<0.5	58	63
L27	3.80	<1	21	19	142	18	15	<0.5	73	63
L28	3.82	<1	14	11	65	18	20	<0.5	43	45
L29	6.31	1	15	13	98	22	23	<0.5	41	46
L30	6.81	2	15	13	88	25	28	0.6	41	43
L33	3.93	2	20	15	92	22	12	0.7	52	58
HL2	4.09	2	24	30	140	22	16	1.1	50	55
HL3	4.54	2	29	31	144	22	16	1.0	45	52
HL4	5.33	1	20	18	63	22	18	1.1	59	53
HL5	4.53	1	34	30	139	22	16	1.5	49	53

Values in () represent concentration

Table 7: Concentration (ppm) of selected trace metals in sediments of Badagry Creek, Southwest Nigeria

Sample station	Analyte Fe (%) MDL 0.01	Mo (1)	Cu (1)	Pb (3)	Zn (1)	Ni (1)	Co (1)	Cd (0.5)	V (1)	Cr (1)
BL1	4.37	1	27	15	68	29	24	1.3	54	59
BL2	5.05	<1	26	15	73	30	25	0.9	61	66
BL3	4.72	1	25	16	69	28	22	0.8	58	61
BL4	5.03	<1	27	16	81	30	26	1.0	65	67
BL5	4.94	<1	26	15	75	29	24	0.6	65	57
BL6	7.63	<1	21	9	82	27	33	1.1	57	56
BL7	4.92	<1	21	13	69	26	23	0.6	52	51
BL27	5.22	<1	15	11	55	22	24	1.1	37	40
BL28	5.00	<1	17	13	63	24	25	<0.5	47	47
BL29	2.38	<1	1	<3	14	5	9	<0.5	12	13
BL30	4.67	<1	22	12	60	26	27	<0.5	51	46
BL33	2.07	<1	7	7	30	11	13	<0.5	22	21
BL34	7.17	<1	12	7	47	20	21	<0.5	24	36
BL41	1.86	<1	3	<3	21	10	9	0.7	14	20
BL51	2.24	<1	6	7	26	9	11	<0.5	19	21
BL52	2.34	<1	7	6	27	12	11	<0.5	21	27
BL53	3.65	<1	2	5	31	10	15	1.6	16	20
BL54	1.58	<1	1	<3	13	5	6	<0.5	11	14
BL56	2.92	<1	11	14	45	14	11	<0.5	29	31

Values in () represent concentration

Table 8: Concentration (ppm) of selected trace metals in sediments of Yewa

Sample station	Analyte Fe (%) MDL 0.01	Mo (1)	Cu (1)	Pb (3)	Zn (1)	Ni (1)	Co (1)	Cd (0.5)	V (1)	Cr (1)
Y3	7.11	<1	11	7	88	21	26	0.6	21	34
Y4	4.95	<1	14	6	65	28	32	4.0	42	40
Y5	5.77	<1	15	11	239	21	25	<0.5	28	36
Y7	6.29	<1	15	6	52	20	19	<0.5	24	37
Y8	6.61	<1	12	8	55	23	28	1.1	22	38
Y9	2.11	<1	2	3	31	17	28	1.2	9	20
Y10	5.77	<1	13	12	55	20	23	<0.5	25	32
Y12	7.03	<1	10	10	48	22	26	0.8	26	33
Y15	6.68	<1	14	10	53	22	26	0.5	26	37
Y17	7.85	<1	16	8	72	21	31	<0.5	41	42
Y19	7.25	<1	19	9	77	24	29	1.1	43	49

Values in () represent concentration

Foraminiferal data acquired: Sediments from Yewa and Badagry creeks are barren except 3 stations at the extreme eastern end of Badagry creek characterised by weak tidal currents from Lagos Harbour. A specimen each, was recovered from these stations.

The deepest station (H5) in Lagos Harbour is greatly enriched in agglutinated, calcareous imperforate and calcareous hyaline forms. The calcareous hyaline forms (rotalids) are most abundant (Fig. 5) and the highest frequency percentage of *Hanzawaia boueana* was recorded for this microhabitat next to station H6 (Fig. 6). This study has identified 25 foraminiferal species in sediments of Lagos Harbour (Table 9). In this study, foraminiferal species were assigned to the suborders Textulariina, Miliolina and Rotaliina, 8 superfamilies, 11 families and 19 genera (Table 10). The total foraminiferal number (TFN g^{-1}) of dry sediment varies from 0.6 g^{-1} (18/30 g) to 45.8 g^{-1} (1374/30 g). Few broken tests of foraminifera and ostracods were noticeable in the samples from H3, H6 and H10. Noteworthy are the very low total foraminiferal counts in stations H3, H5, H6 and H10 where coincidentally, high concentrations of Zn were recorded. This environment is characterized by the preponderance of rotaliids (67.50%) and common occurrences of miliolids and textulariids with percentage composition of 14.6 and 17.90%, respectively (Fig. 5). The foraminiferal species' composition showed that the representative benthic foraminiferal assemblage in sediments of Lagos Harbour is constituted by *Hanzawaia boueana* (26.89%), *Textularia sagittula* (16.87%), *Florilus atlanticus* (14.25%) and *Melonis padana* (11.84%) in decreasing order of abundance (Fig. 6). Also, rare occurrences of *Fluorilus boueana* (4.32%), *Eponides cribrorepandus* (4.30%), *Quinqueloculina seminulum* (4.23%), *Quinqueloculina oblonga* (2.39%) and *Poritextularia panamensis* (1.03%) were recorded.

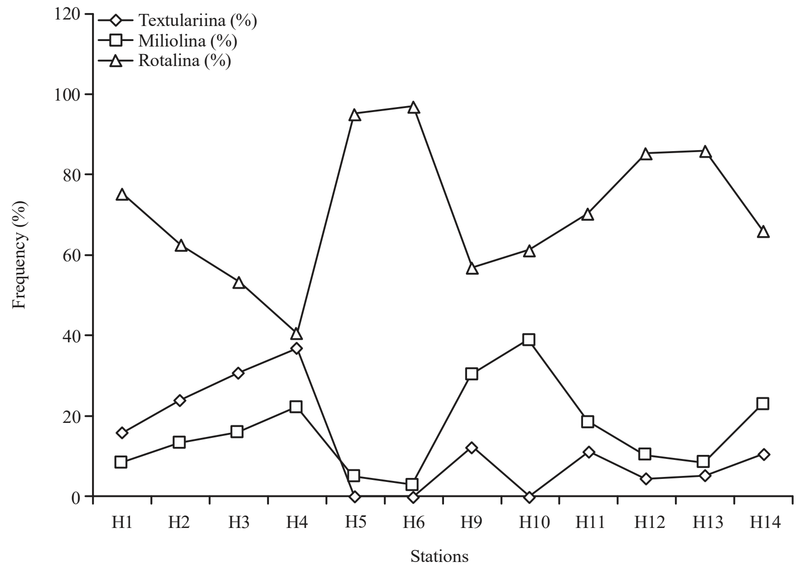

Fig. 5: Percentage frequency composition of textulariina (agglutinated), miliolina (Porcellaneous) and rotalina (calcareous hyaline) in Lagos Harbour

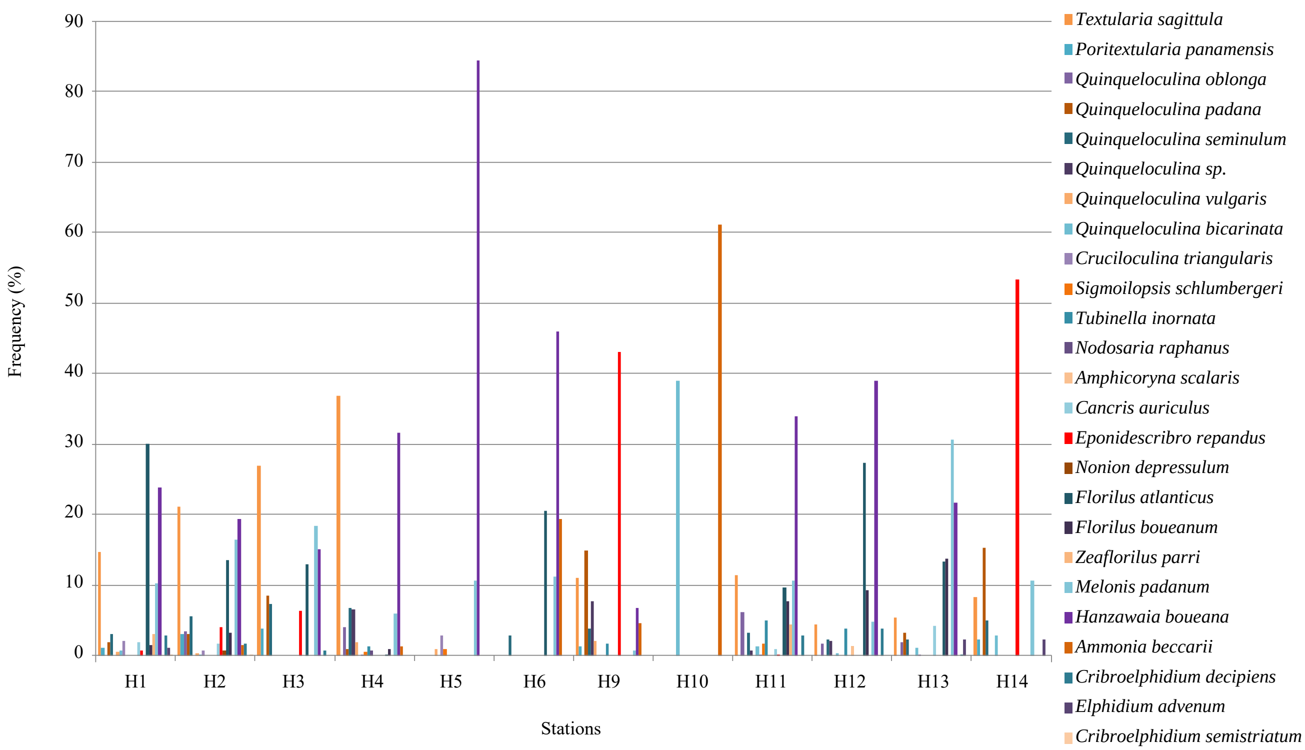

Fig. 6: Frequency percentage of the benthic foraminiferal species identified in sediments of Lagos Harbour, Southwest Nigeria

Station L20 at the eastern segment of Lagos Lagoon is characterized by significant population of porcellaneous, agglutinated and calcareous hyaline forms in increasing order (Fig. 7). Also, the species variation is remarkable in comparison to other stations in the lagoon (Fig. 8). Twenty eight out of forty samples were foraminifera bearing. Two specimens of *Quinqueloculina seminulum* are with patches and scars at station HL2 and *Ammonium beccarii* with sutural scars at the dorsal view were also identified at station HL5. Few test fragments of *Ammonia beccarii* were observed in addition to

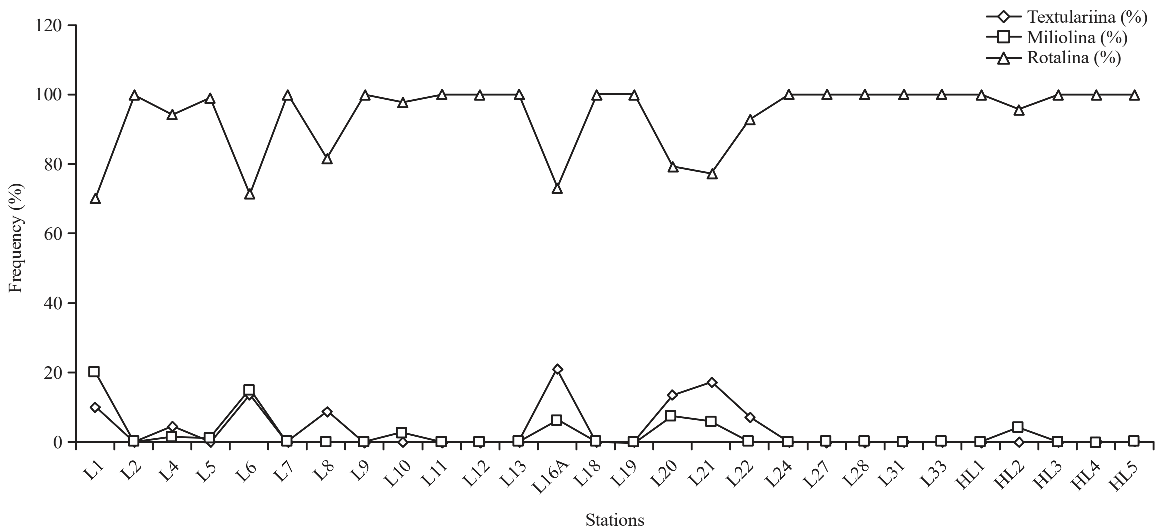

Fig. 7: Percentage frequency composition of Textulariina, Miliolina, Rotalina in Lagos Lagoon

Table 9: Absolute number and distribution of total benthic foraminiferal species identified in sediments of Lagos Harbour, Southwest Nigeria

	Sample stations												
Species	H1	H2	H3	H4	H5	H6	H9	H10	H11	H12	H13	H14	Total
Textularia sagittula	182	286	98	505	-	-	31	-	93	46	39	18	1298
Poritextularia panamensis	15	41	14	-	-	-	4	-	-	-	-	5	79
Quinqueloculina oblonga	-	46	-	55	-	-	-	-	51	18	14	-	184
Quinqueloculina padana	25	41	31	14	-	-	42	-	-	-	23	33	209
Quinqueloculina seminulum	38	77	27	92		5	11	-	26	23	16	11	326
Quinqueloculina sp.	-	-	-	91	-	-	22	-	6	22	-	-	141
Quinqueloculina vulgaris	6	4	-	27	1	-	6	-	-	-	-	-	44
Quinqueloculina bicarinata	10	1	-	-	-	-	-	7	11	4	8	6	47
Cruciloculina triangularis	27	11	-	3	3	-	-	-	1	-	1	-	46
Sigmoilopsis schlumbergeri	-	-	-	8	1	-	-	-	14	-	-	-	23
Tubinella inornata	-	-	-	18	-	-	5	-	41	39	-	-	103
Nodosaria raphanus	-	-	-	9	-	-	-	-	-	-	-	-	9
Amphicoryna scalaris	-	-	-	-	--	-	-	-	-	13	-	-	13
Cancris auriculus	23	22	-	-	-	-	-	-	8	-	31	-	84
Eponides cribrorepandus	10	55	23	-	-	-	127	-	1	-	-	115	331
Nonion depressulum	-	11	-	-	-	-	-	-	-	-	-	-	11
Florilus atlanticus	371	183	47	2	-	35	-	-	79	283	96	-	1096
Florilus boueanum	18	43	-	14	-	-	-	-	63	95	99	-	332
Zeaflorilus parri	39	-	-	-	-	-	-	-	37	-	-	-	76
Melonis padanum	126	223	67	83	11	19	2	-	87	49	221	23	911
Hanzawaia boueana	293	263	55	434	87	78	19	-	279	403	157	-	2068
Ammonia beccarii	-	21	-	19	-	33	13	11	-	-	-	-	97
Cribroelphidium decipiens	35	23	3	-	-	-	-	-	23	39	1	-	124
Elphidium advenum	14	-	-	-	-	-	-	-	-	-	17	5	36
Cribroelphidium semistriatum	1	3	-	-	-	-	-	-	-	-	-	-	4
Total	1233	1354	365	1374	103	170	282	18	820	1034	723	216	7692

complete specimens of this species in the near barren station HL5. Also, 18 specimens of *Elphidium advenum* were recovered, among which 6 were with different patches and scars from station L27. The relatively high abundance of foraminifera is found in stations L11, L2, L22 and L5 in decreasing order of abundance, whereas, near-barren samples were collected from L27, L28, L18, L7, L24, L32, HL5, L18, L7 and L12 in increasing order of barrenness (Table 11). Nineteen benthic species were recovered and classified into 3 suborders, 9 super families, 11 families and 14 genera (Table 12). The rotaliids overwhelmingly dominated this lagoon with the percentage frequency of 94.27%, whereas, rare occurrences of miliolids (2.19%) and textulariids (3.54%) were recorded (Fig. 4). *Ammonia beccarii* (65.25%) and *Florilus atlanticus* (18.52%) are the species among others that registered dominant and common occurrences in relative

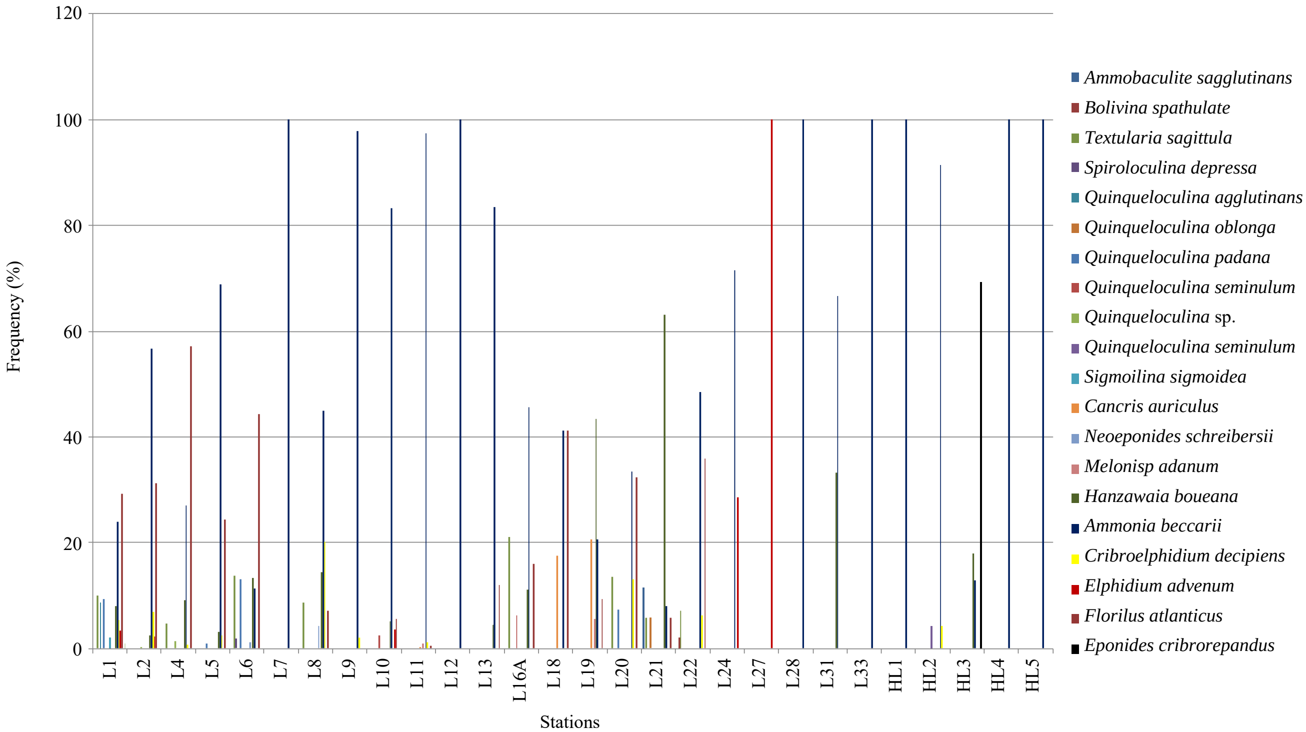

Fig. 8: Frequency percentage of the benthic foraminiferal species identified in sediments of Lagos Lagoon, Southwest Nigeria

Table 10: Suborders, superfamilies and genera of foraminifera identified from Lagos Harbour sediments, Southwest Nigeria

Group	Suborder	Superfamily	Family	Genus
Benthic	Textulariina	Lituolacae	Textularidae	*Textularia*
				Poritextularia
	Milliolina	Miliolacea	Spiroloculinidae	*Spiroloculina*
			Hauerinidae	*Quinqueloculina*
				Cruciloculina
				Sigmoilopsis
				Tubinella
	Rotalina	Nodosariacea	Nodosauridae	*Nodosaria*
			Vaginulinidae	*Amphicoryna*
		Chilostomellacea	Gavelinellidae	*Florilus*
		Discorbacea	Bagginidae	*Cancris*
				Eponides
		Nonionidae	Nonionidae	*Nonion*
				Zeaflorilus
				Melonis
		Chilostomellacea	Gavelinellidae	*Hanzawaia*
		Rotaliacea	Rotalidae	*Ammonia*
			Elphidiidae	*Cribroelphidium*
				Elphidium

order (Fig. 8). Noteworthy, is the dominance of *Florilus atlanticus* in stations L1, L4 and L6, *Hanzawaia boueana* (L19 and L21) and *Eponides cribrorepandus* which is only contained in sediment obtained from station, HL3 (Table 11). The eastern portion where agglutinated foraminifera are most abundant, is mainly marked by sand grade substrates (L20, L21 and L22). It is pertinent to note that *Textularia sagittula* was only recovered in sand dominated lithofacies throughout the study area (Stations L1, L4, L6, L8, L16, L20, L21 and L22). The only three foraminifera bearing samples (L20, L21 and L22) from the eastern portion contain 49.1% of the total specimens of *Textularia sagittula* recovered from Lagos Lagoon. Nevertheless, *Ammonia beccarii* and *Hanzawaia boueana* are overwhelming in this micro-habitat.

Table 11: Absolute number and distribution of total benthic foraminifera species identified in sediments of Lagos Lagoon, Southwest Nigeria

	Sample stations																		
Species	L1	L2	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L16A	L18	L19	L20	L21	L22	Total
Ammobaculites agglutinans	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	10
Bolivina spathulate	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12	12
Textularia sagittula	15	-	7	-	22	-	6	-	-	-	-	-	34	-	-	35	5	41	165
Spiroloculina depressa	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Quinqueloculina agglutinans	13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13
Quinqueloculina oblonga	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	5
Quinqueloculina padana	14	-	-	5	21	-	-	-	-	-	-	-	-	-	-	19	-	-	59
Quinqueloculina seminulum	-	-	-	-	-	-	-	-	5	-	-	-	10	-	-	-	-	-	15
Quinqueloculina sp.	-	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Sigmoilina sigmoidea	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Cancris auriculus	-	-	-	-	-	-	-	-	-	1	-	-	-	3	11	-	-	-	15
Neoeponides schreibersii	-	-	-	-	2	-	3	-	-	-	-	-	-	-	-	-	-	-	5
Melonis padanum	-	-	-	-	-	-	-	-	-	9	-	-	-	-	3	-	-	-	12
Hanzawai abouehna	12	18	14	16	23	-	10	-	10	-	-	5	18	-	23	-	55	-	204
Ammonia beccarii	36	411	41	349	18	10	31	282	164	962	2	91	74	7	11	86	7	274	2856
Cribroelphidium decipiens	8	51	1	13	-	-	14	6	-	11	-	-	-	-	-	34	-	36	174
Elphidium advenum	5	17	-	-	-	-	-	-	7	-	-	-	-	-	-	-	-	-	29
Florilu satlanticus	44	227	87	123	71	-	5	-	11	5	-	13	26	7	5	83	5	203	915
Total	150	725	152	506	160	10	69	288	197	988	2	109	162	17	53	257	87	566	4498

Species	L24	L27	L28	L31	L33	HL1	HL2	HL3	HL4	HL5	Total
Quinqueloculina seminulum	-	-	-	-	-	-	7	-	-	-	7
Eponidescribro repandus	-	-	-	-	-	-	-	27	-	-	27
Hanzawai aboueana	-	-	-	7	-	-	-	7	-	-	14
Ammonia beccarii	5	-	11	14	47	28	151	5	102	5	368
Cribroelphidium decipiens	-	-	-	-	-	-	7	-	-	-	7
Elphidium advenum	2	18	-	-	-	-	-	-	-	-	20
Total	7	18	11	21	47	28	165	39	102	5	443

Grand total: 4498+448 = 4941

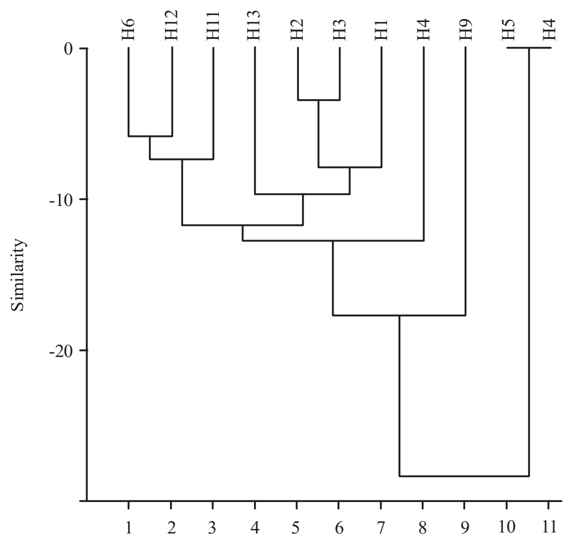

Fig. 9: Dendrogram of Q-mode cluster analysis of sediments of Lagos Harbour, Southwest Nigeria (Euclidean similarity measure used)

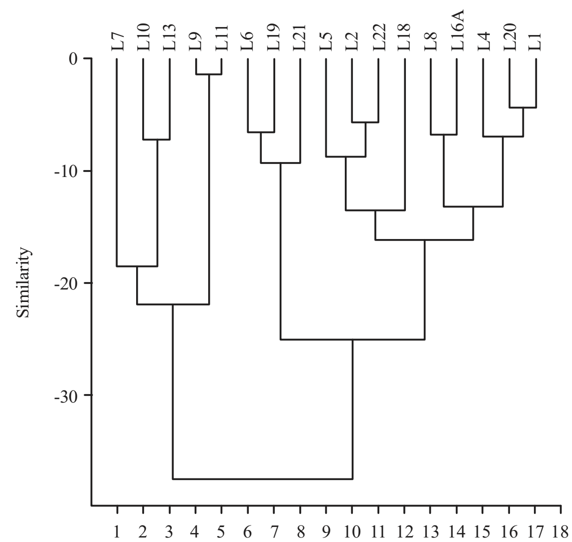

Fig. 11: Dendrogram of Q-mode cluster analysis of sediments of Lagos Lagoon, Southwest Nigeria (Euclidean similarity measure used)

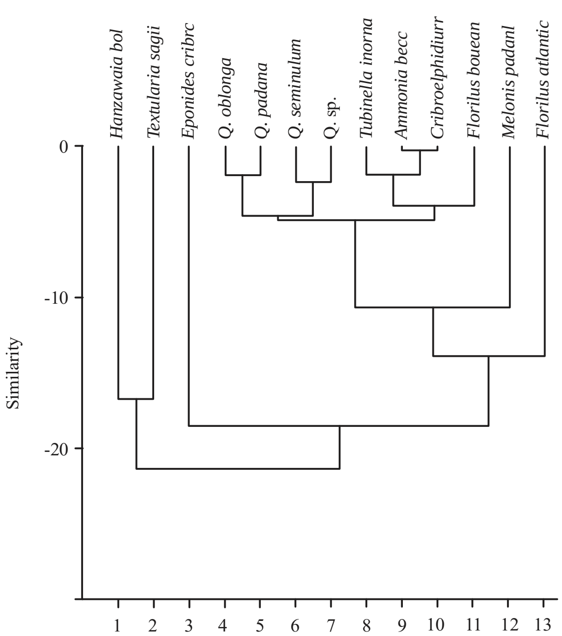

Fig. 10: Dendrogram of R-mode cluster analysis of species contained in sediments of Lagos Harbour, Southwest Nigeria (Euclidean similarity measure used)

There is relatively higher species diversity in areas with lower concentrations of the common trace metals: L22 (5 species present), L20 (5 species), L1(9 species) and L4 (5 species). The specimens of *Ammobaculites agglutinans* recovered are all from station L21 and the highest counts for *Textularia sagittula* was recorded at L22 (Table 11). The highest foraminiferal number recorded for the entire open lagoon was at the northwest (L11) 32.9 g^{-1} (988/30 g), though constituted by 97.92% *Ammonia beccarii* (Fig. 8).

Cluster analysis: Sample weighted cluster (Q-mode) was generated to allow comparison among sediments characterised by foraminiferal species from the various coastal environments investigated. It is believed that this will give insights into the similarity in assemblages across the various micro-habitats.

It has been observed that salinity, nature of substrate and operating hydrodynamic regime largely determined the foraminiferal component of the assemblages. The multivariate statistical software produced the dendrograms for the various clusters for sample weighted Q-mode and taxon weighted R-mode where possible (Fig. 9, 10 and 11).

The Q-mode hierarchical classification (Fig. 9) identified similarities in samples collected from stations H5 and H14 in Lagos Harbour based on closeness in proportional abundances of *Melonis padana* (10.68 and 10.65% respectively) and only one dominant species i.e., *Hanzawaia boueana* (84.49%) and *Eponides cribrorepandus* (53.24%) in relative order. Also, other components in these two samples are in rare occurrences. Samples from stations H6 and H12 are similar in that they have two to three abundant species with close percentage frequency of occurrence of *Florilus atlanticus* and *Quinqueloculina seminulum.* Euclidean similarity measure has also joined station H11 to these 2 stations based of

Table 12: Suborders, superfamilies and genera of foraminifera identified from Lagos Lagoon sediments, Southwest Nigeria

Group	Suborder	Superfamily	Family	Genus
Benthic	Textulariina	Lituolacea	Lituolidae	*Ammobaculites*
		Textulariacea	Textulariidae	*Textularia*
	Milliolina	Miliolacea	Spiroloculinidae	*Spiroloculina*
			Hauerinidae	*Quinqueloculina*
				Sigmoilina
	Rotaliina	Discorbacea	Bagginidae	*Cancris*
		Orbitoidacea	Discorbidae	*Neoeponides*
		Nonionacea	Nonionidae	*Melonis*
		Chilostomellacea	Gavelinellidae	*Hanzawaia*
				Florilus
			Elphidiidae	*Cribroelphidium*
				Elphidium
		Bolivinacea	Bolivinidae	*Bolivina*
		Rotaliacea	Rotalidae	*Ammonia*

closeness in percentages of dominant occurrence of *Hanzawaia boueana* (Fig. 9). Three to four species are in abundance occurrence with closely similar percentage frequencies for *Textularia sagittula*, *Hanzawaia boueana, Florilus atlanticus* and *Poritextularia panamensis* and *Eponidescribro repandus* which are in rare occurrences in stations H2 and H3 clustered.

Sediment samples from Lagos Lagoon with only one species are discarded for the convenience of grouping. The taxon weighted cluster (R-mode) could not be obtained probably as a result of many missing data arising from fluctuation in species abundance and wide variation in species' composition. There is predominance of *Ammonia beccarii* though, few species dominated in some stations e.g. *Florilus atlanticus* (L1, L4, L6 and L18) and *Hanzawaia boueana* (L19 and L21). *Cribroelphidium decipiens* is also common in some of the stations and together with these species may constitute the assemblage of the lagoon. The Q-mode cluster (sample weighted) grouped the samples into 2 assemblages (Fig. 11). Assemblage I is constituted by L7, L10, L13, L9 and L11, these samples are showing similarity based on species dominance arising from relatively high frequency of occurrence in the sampled stations. In these stations *Ammonia beccarii* dominates, hence can be referred to as *Ammonia beccarii* biofacies I (frequency value >83.0%). The second major assemblage has 3 biofacies units:

A = L6, L19 and L21, here we have *Florilus atlanticus* and *Hanzawaia boueana* biofacies (Table 11)

B = L5, L2, L22, L18 refer to *Ammonia beccarii* biofacies II (frequency value>41.0%)

C = L8, L16A, L4, L20, L1 refer to *Florilus atlanticus* and *Ammonia beccarii* biofacies (frequency value of *Ammonia beccarii* 24.00-45.68%)

DISCUSSION

Exemptions to the values recorded for Yewa and Badagry creeks, the measured water temperature and pH values are similar to that of coastal waters[38]. The documented temperature range of 20-30°C is conducive for foraminifera to thrive[39]. Arising from this, the measured water temperature range in the investigated environments has indicated their suitability for foraminiferal survival. In consonance with literature[40], the general alkaline state at the harbour and some parts of Lagos Lagoon may be largely adduced to the strong influence of seawater as the range of values recorded is similar to pH of seawater. Corollary to this, a low pH could cause decalcification of calcareous tests of foraminifera[18]. The pH below 7.50 could cause disappearance of calcareous hyaline and porcellaneous forms even where all other factors are favourable[41]. Although, the tolerance limit of benthic forms is very wide and quite distinct for different species, a threshold exists where they are adversely impacted. This explains why brackish and hypersaline are known to be habitable to only few tolerant species.

In a study of Christchurch Harbour in England, an abundant living benthic foraminiferal population could flourish in waters whose salinity ranged[42] from 0-34%. This implies that foraminifera could survive the entire range of mixohaline (brackish) conditions between 0.5-30.0%. The salinity recorded for Lagos Harbour (33.40-34.80%) is normal marine because the environment derive water mostly from the sea. Yewa and western Badagry creeks are non-saline (0.00-1.00%), whereas, the long eastern portion of Badagry creek is mostly mixohaline with few locations being non-saline.

In comparison to other stations, high foraminiferal species diversity characterizes stations H5 and L20, where the highest depth values were recorded for Lagos Harbour and Lagos

Lagoon, respectively. This implies that depth is not a disadvantage as the two micro-habitats are basically sand with insignificant mud fractions that could cause turbidity or haziness of water. The textural, chemical and mineralogical nature of substrate may contribute to the pattern of distribution and abundance of benthic foraminifera[43]. Marked preferences have been observed between certain species and the grain size distribution and presented that only those species that live firmly attached to their substrates seemed to be influenced by grain size[44]. Meanwhile, other investigators have concluded that substrate has little or no influence on the distribution of foraminifera[45].

The dynamics of tidal currents and the hydrographic nature of Lagos Lagoon, produced different sediment facies and influenced the abundance and distribution of foraminifera. Being accessible to network of rivers entering at different velocities and activities of flood and ebb tides, sediments' texture are influenced, hence foraminiferal composition are determined by the prevailing conditions in the various microhabitats. For instance, Lagos Harbour are mostly fine sand, deposited under relatively low energy hydrodynamic conditions without much influence of river incursion, recorded the highest total foraminiferal number (TFN) and species variation. Also, in Lagos Lagoon, the highest foraminiferal specimens/g of sample was recovered in sand grade sediments of the Southwest segment. This may not be unconnected with the fact that this segment is the least polluted and salinity is favourable. The black to dark-grey organic rich sandy-mud (Station L11) greatly favoured the abundance of *Ammonia beccarii* as others could not probably withstand the prevailing very low salinity condition. The highest TFN in the entire lagoon was recorded here probably because of availability of food. Agglutinated foraminifera are abundant in all sand substrates as evident in Lagos Harbour, southwest and eastern segments of Lagos Lagoon. Examples are the preponderance of *Ammobaculites agglutinans* and *Textularia sagittula* in sand substrates at the eastern segment (L20, L21, L22) of Lagos Lagoon. In addition, *Textularia sagittula* is abundant in sand enriched station L6 at the western segment (Table 2 and 11). It is equally important to note that, Miliolids are relatively abundant in Lagos Harbour and only sand enriched substrates in Lagos Lagoon yielded specimens of Quinqueloculina (Fig. 2 and 5). Rotalids dominate the mud substrates and in most cases constitute opportunistic species and form a monospecific assemblage (Table 11, Fig. 4).

The concentrations of the selected pollutant metals in sediments, which were determined in part per million (ppm) are near the background values for Mo (<1.0-2.0) in all the environments investigated (Table 5, 6, 7 and 8).The reference values for some elements by the Environmental Protection Agency (EPA) of United States of America[46] were used to draw inferences on pollution status of these sediments (Table 5). The relatively high concentrations of Zn in the harbour may have been a contribution from municipal waste water discharges, antifouling paints from boats or secondary products of petroleum through leakage or during repairs of boats' engines. Elevated Zn concentration of just 94 ppm in sediments of Maina Harbour, Baltic Sea has been reported to have impacted snails after controlled experiments undertaken for a period of 1 year[47]. The effect may have been pronounced because of limited water exchange with the sea. In the present study, in spite of the fact that the Zn concentrations at stations H3, H6 and H10 of Lagos Harbour have not reached the threshold to be regarded as highly polluted, the lowest TFNs (0.6-12.2 g^{-1}) were recorded, whereas, TFN for other stations in the same environment ranges from 27.3-45.8 g^{-1}. However, foraminifera being sensitive to ambient environmental changes are already indicating pollution in the moderately polluted stations where mostly rotaliids were recovered with the attendant low TFN record. Heavy metal analysis and subsequent evaluation of the trace metal contents of Lagos Lagoon sediments[48] revealed that Pb, Cd, Bi, Ti, W and Zn have exceeded their background level in most of the sediments (Table 5). Contrastingly, moderate pollution with Ni, Cd and Zn were only found in few places and Pb poses no threat to the lagoon as all concentrations can be attributed to natural background level (<3-37 ppm) in the present study. The moderate pollution with Cr in almost all sediments of this lagoon deserves attention. Also, the northwest, west and central portions of the lagoon ecosystem are moderately polluted with Zn, Cu and Ni. It is thus, important that the resultant influence of this pollution on foraminiferal abundance and dominance should not be deprecated.

The concentration of trace metals increases sequentially from Porto-Novo Creek at the Benin Republic-Nigeria boundary down to the central half of Badagry creek. Such metals as Zn, Cu, Ni, Co, Cd and Cr, though, have moderately polluted this creek but their concentrations in sediments are highly consequential. The only station in the entire study area with very polluted status (VP) was discerned at the upper reach of Yewa Creek, where Zn concentration was anomalously high (Station Y5: 239 ppm).

There is enough documentation that creek and river sediments do host foraminifera. Chaturvedi *et al.*[49] investigated Kharo creek sediments at West India Coast and recovered 47 foraminiferal species of which 44 are benthic and 3 are planktic. Such favourable factors like salinity

(31.13-38.4%), organic carbon contents (0,166-0.0299%), suspended load (71.93-104.28 mg L^{-1}) and temperature (22.80-24.66°C) made this creek highly inhabitable for foraminifera. It has also been reported that South Alligator River in northern Australia contained considerable quantity of benthic foraminifera in its sediments[6]. It was explained that tidal influence mainly contributed to transportation and deposition of these zoogenous materials in some part of the river where salinity is within the tolerance limit. The transport of foraminiferal tests in estuaries has been widely reported from macrotidal to semi-diurnal mesotidal estuaries with strong tidal flows e.g. Humber Rivers in United Kingdom[50], Elbe River in Germany[51] and Yangtze Rivers in China[52]. However, the comparison of Yewa and Badagry creeks to Kharo creek and South Alligator River has made it obvious that tidal influence is consequential to inhabitability of an environment for foraminifera. This also explains the non-saline to extremely low salinity conditions imposed as a result of overwhelming fluvial forcings. Therefore, the non-recovery of foraminiferal specimens in sediments of coastal creeks of southwest Nigeria is adducible to mainly the non-saline nature of the environment. Therefore, the unfavourable pH in most stations, depth, fairly polluted substrates and the favourable temperature were consequently not considered as factors determining abundance and distribution of foraminifera in these creeks. The high species abundance recorded for Lagos Harbour may be connected with favourable salinity, pH and the prevailing low energy hydrodynamic condition under which the substrate-sediments were deposited. The over whelming fine sand substrates (Table 1) emplaced in this environment suggest by logical inference significant dissipation of energy of transport during sedimentation. Inferring from the premise of abundance (Fig. 2) and similarity measure that produced the R-mode cluster, the representative assemblages in decreasing order of abundance for Lagos Harbour are presented as *Hanzawaia boueana*, *Textularia sagittula*, *Florilu satlanticus, Melonis padanum*, *Florilus boueanum*, *Eponidescribro repandus* and *Quinqueloculina seminulum*. Though samples for stations H7 and H8 that are barren were not analysed for their trace metals, the possibility that Zn pollution could have impacted the micro-habitat beyond tolerance limit for foraminifera is high. For example, the representative sample for station H10 is moderately polluted with Zn (123 ppm) and near barren considering its total foraminiferal number (TFN) of 0.6 g^{-1}. Taking all the ecological factors being considered into account, most part of the harbour could be regarded as highly habitable for foraminifera. Morphological abnormalities are not obvious in the impacted stations but responses are characterized by disappearance of some species, most especially the agglutinated species (Stations H6 and H10), high species dominance and very low species diversity (H10). Since this environment only indicated incipient pollution, the response may be poor test development (e.g. weak and thin tests) that could be badly damaged and transported away from source. This may explain the large number of fragments of foraminifera and ostracods identified during sample analysis. High organic matter contents has been inferred as a result of dark grey to black mud substrate. This high organic matter must have favoured the increase in the number of test of the *Ammonia beccarii* as pollution is still moderate[53]. In stations (L10, L14, L27, L29, L3, HL3, HL5) where there is relatively higher concentrations of Zn, Ni, Cd usually associated with >15% mud contents in these sediments, foraminifera are rare and are marked with high dominance of *Ammonia beccarii*.

The sample barrenness documented for L15 and L17 may be an indication of response by foraminifera in these stations to higher concentrations of Zn, Cd, Ni and Cr. There is no morphological abnormality visible enough for photographic/ micrographic capture. The most significant response to the mild pollution encountered in Lagos Lagoon is the severe abnormalities brought about by mechanical trauma[54]. *Quinqueloculina seminulum* with patches and scars in station HL2 and *Ammonia beccarii* with sutural scars at the dorsal view (station HL5) have attested to the higher than background concentrations of these trace metals. The southwest portion of the lagoon possess the highest foraminiferal counts and least remarkable dominance. Species variation is well marked but still low and the assemblage could be regarded as oligospecific. Fluctuation in salinity arising from the diurnal changes in the flood and ebb tides could have contributed to low species variation and abundance. This is possible because very sensitive species may have been destroyed significantly as a result of the sudden changes in salinity which could even espouse shifting of substrates. The southwest segment is dominated by *Ammonia beccarii* and *Florilus atlanticus*. *Florilus atlanticus* dominated where *Hanzawaia boueana* and *Textularia sagittula* are in common occurrences in 3 of the 4 samples analysed for the southwest portion of this Lagoon (L1, L4 and L5). Also, Zn (144 ppm) being the only metal above background concentration indicating moderate pollution seemed not to have adversely affected foraminiferal abundance at station HL3 of the western portion. Slightly above background concentration of Zn (142 ppm) and the highest concentration of vanadium (73 ppm), still within the background level, were recorded in the sample from station L27 of the central portion. It is thus believed that the vanadium must be bioavailable to the biota despite background concentration as adverse impact was produced on this micro-habitat (station L27).This is because only specimens of *Elphidium advenum* were recovered, implying *Elphidium advenum* is an opportunistic species here. Scars and patches found on few specimens of *Elphidium advenum* in this station becomes consequential as the fairly high concentration of Zn could not produce the same influence at station HL3 (western segment).The decimation of *Ammonia beccarii* in station HL5 and disappearance of other species could be consequent upon moderate pollution by Cr and Cu in the mud enriched micro-habitat. Here, the enrichment of mud may have favoured the adsorption of these metals unto its surface and are retained, thereby making a high dosage of the metals available. The foraminifera assemblages identified in this open lagoon strongly contrast the proliferation of the calcareous imperforate (Miliolids) in lagoons protected from influences of open sea from the Egyptian Red Sea shore[55]. The lagoons from the Red Sea are hypersaline and protected, whereas, Lagos Lagoon communicates with the Atlantic Ocean and network of rivers through different entrances, hence, it is open and hyposaline. This explains the strong influence of salinity on the distribution and abundance of foraminiferal suborders different in their tests' wall composition and microstructure.

The R-mode cluster has a complementary evidence that the outliers *Hanzawaia boueana* and *Textularia sagittula* have the highest frequency of occurrence and are widespread in Lagos Harbour (Fig. 7). *Florilus atlanticus* and *Melonis padana* are in common occurrences with moderate spread, hence clustered. The dendrogram derived from Q-mode cluster has also shown that *Hanzawaia boueana* shows its highest dominance in station H5 and *Eponidescribro repandus* in station H9 complementing the percentage frequency of occurrence (Fig. 3). The sample weighted cluster (Q-mode) for foraminiferal data acquired from Lagos Lagoon based on species dominance arising from relative frequency of occurrence, identified two major assemblages. These assemblages are principally differentiated according to sample similarities as defined by their foraminiferal species' composition.

CONCLUSION

Non-recovery of foraminiferal specimens in the sediments of coastal creeks of southwest Nigeria has been attributed to mainly the non-saline nature of the environment. The high foraminiferal population in sediments of Lagos Harbour has been adduced to favourable substrates, pH, temperature and salinity. Foraminiferal species abundance, diversity and dominance are strongly influenced by moderate pollution of sediments with Zn, Cd, Ni and Cr and the nature of substrates. Salinity seems not to dominate the factors influencing foraminiferal distribution at the West, East, Northwest and central portions of Lagos Lagoon where salinity is very low and organic matter enrichment and metal pollutants played significant roles.

SIGNIFICANCE STATEMENT

This study discovered large disparity in foraminiferal species composition and abundance in the micro-habitats of Lagos Lagoon, giving evidence of the high dissimilarity in the hydrographic setting and mineralogical and chemical nature of substrates. There is no available literature that has thoroughly considered the variation in assemblages of foraminifera across the various segments in spite of being an open lagoon. This study has not only identified the factors strongly influencing the abundance and distribution of foraminifera, but, characterized foraminiferal assemblages across the various shallow water coastal environments of the southwest Nigeria segment of the Gulf of Guinea. Furthermore, future variation of the present assemblages may help researchers to localize and clarify changes in the impact of natural and anthropogenic variables in the investigated environments.

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