Spatial Patterns in Diversity and Distribution of Benthic Molluscs in a Weak Tidal Tropical Lagoon

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Abstract  Spatial patterns in diversity and distribution of benthic molluscs in a weak tidal tropical lagoon in south-west Nigeria were investigated from samples collected in eight study stations distributed along the stretch of the lagoon for two consecutive years. The study also investigated selected environmental conditions of overlying water and sediment of the lagoon to establish the roles played by environmental variables. There was a significant variation (p < 0.05) in salinity values along the study stretch which was predicated on the existing gradient in salinity of the lagoon. Higher values of mud and Total organic content (TOC) of sediment occurred in upstream compared to values observed in downstream stations. Mollusc communities were significantly influenced by the spatial gradient in salinity and variability in sediment parameters. The downstream stations had brackish conditions, while the upstream stations were typically freshwater, leading to differences in the composition and abundance of molluscs. The downstream stations recorded higher density and diversity of mollusc compared to upstream stations. Our results suggest that benthic molluscs in Epe Lagoon show spatial patterns related to differences in environmental parameters.

Keywords  Spatial patterns; Mollusks; Environmental variables; Weak tidal lagoon

Introduction  An evaluation of distribution patterns is the first step to understanding the set of processes that structure benthic communities, and thus to formulate predictive models (Atrill, 2002). Scale-dependent patterns of distribution may be particularly important in coastal areas, since they are characterized by variability in abiotic conditions (Neves et al., 2012). For benthic fauna, patterns of distribution are related to salinity (Atrill, 2002; Atrill and Rundle, 2002; Ysebaert et al., 2003), sediment characteristics (Teske and Wooldridge, 2003; Anderson et al., 2004) and other factors. Spatio-temporal variability in benthic macrofauna has been studied in coastal aquatic systems throughout the world (Morrisey et al., 1992; Ieno and Bastida, 1998; Biles et al., 2003; Giberto et al., 2004). This variability is dependent on physical and chemical factors and biological interactions. Salinity fluctuations in estuarine systems have a strong influence on temporal patterns and daily and inter-annual variations; sediment characteristics have more influence on the spatial structure of benthic assemblages (Neves et al., 2012). Other factors should not be disregarded, since they can act in synergy (Bemvenuti et al., 2005). Benthic macrofauna in estuarine systems forms a mosaic of patches, which are maintained by a variety of disturbances and other biotic and abiotic factors (Morrisey et al., 1992).

Molluscs constitute one of the largest phyla of invertebrates, in both numbers of living species and numbers of individuals (Gomes et al., 2004). Two classes; Gastropoda and Bivalvia are the best represented in benthic systems, and their species have been used to characterize benthic associations (Diaz and Puyana, 1994). This characterization could suggest means of sustainable exploitation and appropriate management of commercially exploited species (Silva et al., 2005), as well as providing important data for biodiversity evaluations.

Nigeria is endowed with about 853 km coastline inundated with different types of aquatic systems which are majorly estuarine in nature. Although several studies (Oyenekan, 1979, 1988; Oyenekan and
0.01‰ and 19.30 ‰ (Table 1). Salinity at the higher during the dry season with values ranging between 0.00‰ and 3.4‰ and relatively 19.72‰. Values were low during the wet season trend. Salinity values varied between 0.0
Values (2.4~10.5 mg/L) of DO show no particular with station 6 having significantly higher values. P < 0.05) in water temperature at the study stations recorded. There was significant difference (ANOV A,℃
Water temperature ranged from 23 °C to 43 °C. Relatively higher values of temperature were observed at station 6 where a range of 29°C to 43°C was recorded. There was significant difference (ANOVA, P < 0.05) in water temperature at the study stations with station 6 having significantly higher values. Values (2.4~10.5 mg/L) of DO show no particular trend. Salinity values varied between 0.00‰ and 19.72‰. Values were low during the wet season ranging between 0.00‰ and 3.4‰ and relatively higher during the dry season with values ranging between 0.01‰ and 19.30‰ (Table 1). Salinity at the study stations were significantly different (ANOVA, P < 0.05), with downstream stations (4, 5, 6, 7, 8) closer to the Lagos Lagoon having relatively higher salinity values than upstream stations (1, 2, 3).

The study area was predominantly sandy intermixed with varying proportions of mud in the stations sampled. The highest value of sand fraction (93.6%) occurred in station five, while the least (54.4%) was recorded in station three. The highest amount (44.6%) of mud in sediment was recorded at station three. Total organic content of sediment was highest (10.45%) in station three, while the lowest value (1.01%) occurred in stations 4, 6, 7 and 8. The trend displayed by TOC values shows higher values in upstream stations than downstream stations.

1.2 Mollusc assemblage
A total mollusc density of 174 680 ind./m² comprising 12 species belonging to seven families from two molluscan groups (Gastropoda and Bivalvia) were recorded. Twelve molluscan species made up of six gastropod species belonging to three families (Neritidae, Melaniidae, Potamididae) and six bivalve species belonging to four families (Tellinidae, Avicidae, Osteridae and Aloididae) were identified. Gastropod dominated in terms of population of individuals collected with a density of 119 200 ind./m² constituting 68.2% of the total population of mollusc in the study area, while bivalvia constituted 32.8% with a density of 55 480 ind./m². Most of the gastropods were widely distributed occurring in all study stations, except Pachymelania fusca var quadrata which was not found in stations one and three (Figure 1). The dominant species observed among the gastropod was P. aurita, which recorded total density of 78 520 ind./m² and constituted 45.05% of the molluscan population, the species ranked highest in abundance among the species of molluscs encountered and recorded 982 ind./m² as mean spatial density. Other gastropod species recorded in the study area include; Neritina kuramoesis (Density=13 290 ind./m²; mean spatial density = 1661 ind./m²; % contribution = 7.62%), N. glabarata (Density = 11 110 ind./m²; mean spatial density = 1389 ind./m²; % contribution = 6.37%), Tympanotonus fuscatus (Density=8 560 ind./m²; mean spatial density = 1 070 ind./m²; % contribution =4.91%), T. fuscatus var radula (Density=6912 ind./m²; mean spatial density = 864 ind./m²; % contribution = 3.96%) and P. fusca var quadrata (Density=810 ind./m²; mean spatial density=102 ind./m²; % contribution=0.5%). Among the bivalves collected from the study stretch, Macoma cumana dominated in terms of density and distribution. Of the total bivalve density of 55 480 ind./m² recorded, M. cumana contributed 51 170 ind./m², thereby constituting 29.35% of the total molluscan population. With mean spatial density of 6 396 ind./m², the animal ranked second in terms of abundance and constitutes another keystone species after the gastropod, P. aurita. Another major representative of the bivalve group was Aloidis trigona which recorded a total density of 2 440 ind./m², mean spatial density of 305 ind./m² and constituted 1.19% of the total molluscan population. Other bivalve species collected were; Tellina nymphalis (Density=1 240 ind./m², mean spatial density = 155 ind./m²; % contribution = 7%), Crassostrea gazar (Density=270 ind./m²; % contribution
=0.15%), *Mytilus perna* (Density=220 ind./m²; % contribution=0.13%), *Mytilus edulis* (Density=140 ind./m²; % contribution = 0.08%). Of the six bivalve species, only two (*M. cumana* and *T. nymphalis*) occurred in all the study stations, while three (*M. edulis*, *M. perna* and *C. gazar*) were restricted to station 7 (Figure 2).

Figure 1 Spatial occurrence and variations in density of gastropod species

Figure 2 Spatial occurrence and variations in density of bivalve species

Figure 3 Variations in number of species of gastropod and bivalve recorded in the study stations
Figure 4 Variations in density of Gastropoda and Bivalvia in the study stations

Table 2 Summary of biotic metrics at the Study Stations

<table>
<thead>
<tr>
<th>Study stations</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total density (No. of ind./m²)</td>
<td>1090i</td>
<td>9940i</td>
<td>810i</td>
<td>33070a</td>
<td>35850a</td>
<td>31130a</td>
<td>24170a</td>
<td>38260a</td>
</tr>
<tr>
<td>Number of species</td>
<td>8</td>
<td>9</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>8</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>Shannon-Wiener index</td>
<td>0.33</td>
<td>0.37</td>
<td>0.17</td>
<td>0.52</td>
<td>0.52</td>
<td>0.43</td>
<td>0.58</td>
<td>0.53</td>
</tr>
<tr>
<td>Evenness</td>
<td>0.33</td>
<td>0.10</td>
<td>0.31</td>
<td>0.24</td>
<td>0.19</td>
<td>0.25</td>
<td>0.20</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Note: Lower case alphabets indicate no significant difference (P > 0.05), * Turkey’s test (P < 0.05).

1.3 Spatial patterns of ecological indices

Species representation of the two groups (Gastropod and Bivalvia) is depicted in Figure 3. Analysis of the variation in the density of molluscan species in the study stretch at the spatial scale indicates that there were great variations among the study stations (Table 2). Generally, stations downstream and close to the brackish water Lagos Lagoon recorded higher densities of molluscs than upstream stations. Station eight recorded the highest density (38 620 ind./m²), followed by station 5 (35 850 ind./m²). Densities of mollusc observed in other stations were; 33 070 ind./m² for station four, 31 130 ind./m² for station six, 24 170 ind./m² for station seven, 1 090 ind./m² for station one, 9 940 ind./m² for station two and 810 ind./m² for station three. Highest gastropod density (30 490 ind./m²) was recorded in station 6, and the lowest (190 ind./m²) was observed in station 1, whereas highest density of bivalvia occurred in station 8 (14 330 ind./m²) and the lowest (580 ind./m²) recorded in station 3 (Figure 4). Turkey’s test indicated that the densities of mollusc collected in the downstream stations were similar, higher than and significantly different from those in upstream stations (Table 2).

Number of species of molluscs recorded at the study stations ranged between 8 and 12 (Table 2). Highest number of molluscan species occurred in station 7, while the least number (8) was observed in stations 1, 3 and 6. Stations 2, 4, 5 and 8 recorded 9 species of molluscs each. The diversity of benthic mollusc as illustrated in Table 2, was highest (0.58) in station 7 and lowest (0.17) in station 3, while values of evenness varied between 0.1 (Station 2) and 0.33 (Station 1). There was a remarkable increase in density and diversity toward the downstream stations.

The cluster analysis presented in Figure 5 shows clearer separation of the study stations into groups with similar ranges of density of mollusc. Two main groups can be recognized from the dendogram, group I comprised stations 1, 2 and 3, while stations 4 to 8 occurred in the same group. At higher level of separation the analysis revealed that the density of mollusc in stations 4, 5, 6 and 7 were similar, while that of station 8 was relatively lower.
Table 3 Percentage representation of molluscan species in the study stations

<table>
<thead>
<tr>
<th>Study stations</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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</thead>
<tbody>
<tr>
<td>Neritidae</td>
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<td></td>
</tr>
<tr>
<td>N. glabarata</td>
<td>10^d</td>
<td>0.4^t</td>
<td>2.47^c</td>
<td>6.6^d</td>
<td>3.8^c</td>
<td>7.9^d</td>
<td>6^d</td>
<td>9^d</td>
</tr>
<tr>
<td>N. kuramoensis</td>
<td>2.75^c</td>
<td>0.2^r</td>
<td>2.47^c</td>
<td>2.7^c</td>
<td>6.2^b</td>
<td>12.8^d</td>
<td>6.4^d</td>
<td>11.9^d</td>
</tr>
<tr>
<td>Melaniidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pachymelania aurita</td>
<td>2.75^c</td>
<td>0.8^r</td>
<td>8.6^d</td>
<td>38.3^d</td>
<td>50.1^d</td>
<td>52.4^d</td>
<td>67.5^d</td>
<td>37.6^d</td>
</tr>
<tr>
<td>P. fuscavargradula</td>
<td>–</td>
<td>0.1^r</td>
<td>–</td>
<td>0.6^r</td>
<td>0.6^r</td>
<td>0.9^r</td>
<td>0.2^r</td>
<td>0.1^r</td>
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<tr>
<td>Gastropoda</td>
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<tr>
<td>Potamididae</td>
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<td></td>
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<tr>
<td>Tympanotus fusatus</td>
<td>0.92^r</td>
<td>1.0^r</td>
<td>3.7^c</td>
<td>1.7^c</td>
<td>3.8^c</td>
<td>0.2^r</td>
<td>1.9^c</td>
<td>2.9^c</td>
</tr>
<tr>
<td>T. fuscatusvargradula</td>
<td>0.92^r</td>
<td>0.2^r</td>
<td>11.1^d</td>
<td>8.2^d</td>
<td>3.4^c</td>
<td>6.5^b</td>
<td>1.3^c</td>
<td>1.3^c</td>
</tr>
<tr>
<td>Tellinidae</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Macomacumana</td>
<td>56.9^d</td>
<td>88.4^d</td>
<td>50.6^d</td>
<td>40.3^d</td>
<td>30.5^d</td>
<td>2^c</td>
<td>12.4^b</td>
<td>34.9^d</td>
</tr>
<tr>
<td>Tellinanymphalis</td>
<td>7.3^d</td>
<td>2.2^c</td>
<td>14.8^d</td>
<td>0.8^r</td>
<td>0.1^r</td>
<td>0.03^r</td>
<td>0.1^r</td>
<td>1.2^c</td>
</tr>
<tr>
<td>Avcidae</td>
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<tr>
<td>Mytilusedulis</td>
<td>–</td>
<td>–</td>
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<td>–</td>
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</tr>
<tr>
<td>Bivalvia</td>
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<tr>
<td>M. perna</td>
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<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>0.6^t</td>
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<tr>
<td>Ostreidae</td>
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<tr>
<td>Crassostrea gazar</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>1.1^t</td>
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<tr>
<td>Aloididae</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Aloidistrigona</td>
<td>18.3^d</td>
<td>6.9^d</td>
<td>6.2^d</td>
<td>0.7^r</td>
<td>1.3^c</td>
<td>–</td>
<td>1.6^c</td>
<td>1.0^c</td>
</tr>
</tbody>
</table>

Note: ≥ 15% = dominant (d); ≥ 5 to < 15 % = sub-dominant (sd); ≥ 1% to < 5% = common (c); < 1% = Rare (r)

Figure 5 Hierarchical cluster analysis based on total mollusc density in the study stations

1.4 Dominant, Subdominant, Occasional and Rare Species

The species representation analysis of mollusc in the study stations are presented in Table 3. *Macoma cumana* and *A. trigona* were dominant in station 1, while *N. glabarata* and *T. nymphalis* assumed subdominant position. Other species recorded occurred as common and rare species. In station 2 and 3, *M. cumana* was dominant, while *A. trigona* occurred as subdominant species in both stations. *Tympanotus fusatus* var radula and *T. nymphalis* were recorded as subdominant species in station three. *Pachymelania aurita* and *M. cumana* (except in stations 6 and 7) were dominant in stations 4–8. *Neritina glabarata* occurred as subdominant species in stations 4, 6, 7 and 8, whereas *N. kuramoensis* was recorded as subdominant species in stations 5, 6, 7 and 8. The overall species representation indicates that, *M. cumana* and *P. aurita* were the dominant species in Epe Lagoon while, *P. fuscus* var quadrissista, *M. edulis, M. perna,* and *C. gazar* occurred as rare species.

1.5 Environmental influence on molluscs

Spearman’s correlations between biotic and environmental variables in the study area (Table 4) indicates that water salinity correlated positively and significantly with overall mollusc diversity (rs = 0.0857, p < 0.01) and gastropod density (rs = 0.762, p < 0.5). Total organic content of sediment correlated negatively and significantly with density of mollusc (rs = 0.738, p < 0.5) and gastropod species richness (rs = 0.756, p < 0.5). The amount of sand fractions in sediment also correlated negatively and significantly with density of bivalves (rs = 0.958, p < 0.01). In the overall relationship, salinity, TOC and percentage of sand in sediment had strong effects on the benthic molluscan assemblage in the study stretch.
Table 4 Spearman's correlations between biotic and environmental parameters in the study area

<table>
<thead>
<tr>
<th></th>
<th>Salinity</th>
<th>TOC</th>
<th>Sand</th>
<th>Mud</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Diversity</td>
<td>+**</td>
<td>ns</td>
<td>ns</td>
<td>+ns</td>
</tr>
<tr>
<td>Gastropod Density</td>
<td>+**</td>
<td>ns</td>
<td>ns</td>
<td>+ns</td>
</tr>
<tr>
<td>Species richness</td>
<td>+ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Bivalvia Density</td>
<td>+ns</td>
<td>-</td>
<td>-ns</td>
<td>ns</td>
</tr>
<tr>
<td>Species richness</td>
<td>+ns</td>
<td>+ns</td>
<td>+ns</td>
<td>+ns</td>
</tr>
</tbody>
</table>

Note: +: positive correlation; -: negative correlation; ns: no significant correlation; p > 0.01/0.05; *: significant correlation; p < 0.01; **: significant correlation; p < 0.05

2 Discussion

The result of this study suggest that the observed spatial pattern in diversity and distribution of benthic molluscs were majorly controlled by the salinity gradient and sediment characteristics of the lagoon, although the localized effect of elevated temperature in station six is also worthy of note. The importance of salinity and sediment characteristic in the distribution of benthic organisms is widely recognized. This assertion agrees with results of studies carried out in Nigeria (Wbb, 1958; Webb and Hill, 1958; Sandison, 1966) and in other parts of the world, such as Guanabara Bay (Van Der Ven et al., 2006; Mendes et al., 2007; Santi and Tavares, 2009); and South American estuaries (Paranagua’ Bay: Boehs et al., 2004; Patos Lagoon: Bemvenuti et al., 1992; Todosos Santos Bay: Venturini et al., 2004; Samborombon Bay: Ieno and Bastida, 1998; Rio de la Plata Estuary: Gilberto et al., 2004), where salinity gradient and sediment type strongly influenced the spatial distribution and diversity of benthic fauna.

The molluscan community recorded in this study was majorly euryhaline species, occasioned by the low and fluctuating salinity of the study area resulting from weak tidal salt water incursion experienced in the lagoon. This observation fulfills the predictions of Olaniyan (1975) who noted that, although the bottom fauna of Epe Lagoon has not been studied, it is very likely to consist of animals which can tolerate low salinity, and low fluctuations in salinity. Epe Lagoon is sandwiched between two lagoons, the brackish water Lagos Lagoon and the freshwater Lekki Lagoon (Figure 6), and is weakly influenced by tidal water input through the Lagos Lagoon. Higher salinities values occurred in study stations close to the Lagos Lagoon than those located towards Lekki Lagoon and the discharge points of Oshun and Oni Rivers. Mollusc diversity followed the salinity gradient, with the highest diversity in the downstream stations which were mostly influenced by marine intrusion, and decreasing towards upstream. Community composition gradually changes according to the salinity gradient of the lagoon, a trend similar to those reported in Gaston et al (1998) and Giberto et al (2004). Species (M. edulis, M. perna and C. gazar) known to be intolerant of wide fluctuations in salinity were restricted to station seven where a higher and relatively stable salinity was recorded, this observation has also been reported in other estuarine systems (Oyenekan, 1988).

Sediment type is a limiting factor for the spatial occurrence and abundance of benthic organisms (Ysebaert and Herman, 2002; Bemvenuti et al., 1992), and can be important in the structure of benthic communities (Teske and Wooldridge, 2001; Ysebaert and Herman, 2002). Sediment characteristics (Percentage of sand particles and TOC) strongly affected the mollusc community in the study area (Table 4). Organic matter in sediment strongly influenced the density and species composition of molluscs. The lowest density (810 ind./m²) of mollusc was recorded in station 3 which was characterized by high mud and TOC. Although, organic matter is important as food for benthic species (Newell et al., 2002; Arrighetti and Penchasazadeh, 2010), induced sedimentation resulting from high organic matter can smother benthic molluscs, both at their adult and planktonic stages. Increased turbidities arising from the presence of large amount of organic matter may heighten the formation of pseudofeces and decrease the amount of water that is pumped by molluscs during feeding and respiratory activities (Hart and Fuller, 1979). Higher percentage of organic matter recorded in station 3 compared to other stations was caused by the large quantity of organic debris from a farm located at the bank of the lagoon, this may have accounted for the low density and diversity of benthic molluscs recorded in the station. In general, values (2.1%~10.45%) of organic matter in the upstream stations were higher than those (1.01%~7.5%) recorded for downstream stations, this may have contributed to the variation in density and diversity of mollusc observed. The lower deposition rate of organic matter in the downstream stations results from...
the circulation pattern that favored efficient water renewal and higher energy because of seawater intrusion and the absence of nearby sources of organic matter (Uwadiae, 2009).

This study observed that mollusc densities showed nearly the same trend related to the influence of environmental gradients on dominant bivalve and gastropod. Density of mollusc decreased towards the upstream stations just as the occurrence of *P. aurita* and *M. Cumana*. The spp. were most numerous in stations with relatively higher salinity values with poor representations in upstream stations. Lowest densities of the two spp. occurred in station three (for *M. cumana*) and station one (for *P. aurita*) whereas highest densities were collected station eight (for *M. cumana*) and station five (for *P. aurita*). The peak in density (30 490 ind./m²) of gastropods in station six, where a relatively higher water temperature was recorded due to the discharge of heated water from the Egbin Thermo-Electric power plant, agrees with the observations of Hart and Fuller (1979), who reported that, in the more tropical regions, many animals are living near their upper thermal limits, and few degrees increase in temperature may be fatal or result in the interruption of the normal maturation and spawning cycles. Molluscs are geared towards a cycle of growth and build-up of reserves to be converted to gamete and subsequent spawning. A continuous production of gametes occurs, which would result in little or no growth because all energy is used for producing the gametes. Shell growth of hard clam (native to New York) when transplanted to Florida waters, was reported to have ceased when the temperature reached about 27°C (Hart and Fuller, 1979). Warm water might cause spawning when the needed kind of phytoplankton food is not present in sufficient abundance, or the larvae might be carried by the currents to colder water, which would be detrimental to them (Hart and Fuller, 1979). The specimens of gastropods collected from this station were relatively smaller than those of other stations (Uwadiae, 2009) and among the bivalves, only two species were recorded in station six, suggesting that the high temperature recorded in this station may have affected the molluscs (Teske and Wooldridge, 2001) of the lagoon adversely.

The salinity gradient and sediment characteristics of Epe Lagoon greatly influenced the species diversity and density of molluscs. The downstream stations provided a seemingly more favorable environmental condition such as relatively higher proportion of sand in sediment with low organic matter. The observed pattern of diversity is consistent with the distributional pattern proposed by Sanders (1958), which describes the dominance of filter feeders or suspension feeders on sandy sediments (Rhoads and Young, 1970), this explains the dominance of the estuarine filter feeder, *P. aurita* and suspension feeder, *M. cumana* in the study stretch.

The present findings have important consequences for studies of the distribution of benthic organisms in estuarine ecosystems, including those concerned with environmental monitoring. Although the diversity and distributional pattern of molluscs in Epe Lagoon seems to be related mainly to the natural estuarine gradient and sediment characteristics, anthropogenic factors indirectly may also influence molluscan communities (Oyenekan, 1979; Clements, 1997; Wiegener et al., 2003; Goto and Wallace, 2010), especially in areas with multiple sources of human stressors (Hewitt et al., 2005), where the dominance of few species may indicate systems subjected to organic enrichment and contaminated sediments (Gray and Mirza, 1979; Dauer, 1993; Azrina et al., 2006). Epe Lagoon is an estuarine system with a history of pollution (Nwankwo, 1998; Nwankwo and Onitiri, 1992), therefore, monitoring programmers relating to significant long-term changes in molluscs communities (species disappearance, and shifts in composition, densities and frequencies) will serve as invaluable tools for the assessment of the impact of human activities in the lagoon.

3 Material and Methods

3.1 Study area

Epe Lagoon (Figure 6) is located in Lagos State. It lies between latitudes 3°50'~4°10' N and longitudes 5°30'~5°40' E. It has a surface area of about 243 km² (Kusemiju, 1988). The lagoon which has an average depth of about 2.45 m is fed by the waters of adjoining rivers and creeks. It is connected to the Atlantic Ocean through the Lagos Harbour via the Lagos Lagoon and tidal influence is relatively weak especially in the upstream of the lagoon. The effects of the tides is more in the dry season, and decreases
inland resulting in the characteristic environmental and biological gradients associated with the lagoon (Uwadiae, 2009).

Figure 6 Part of Lagos Lagoon system showing Epe Lagoon and study stations

The local climate is tropical, with two major seasons differentiated by the amount of rainfall as rainy and dry seasons. The rainy season experiences higher amount of rainfall and extends from April/May to November, while the dry season which depicts a period of relatively lower amount of rain begins in December and ends in March. Epe Lagoon is sandwich between two lagoons Lekki and Lagos Lagoons (Figure 6) and is surrounded by rural areas with poor and unorganized waste management systems.

Human impacts on the lagoon and the surrounding environment include dumping of untreated domestic wastes, fishing, sand mining, transportation of people and goods using motorized boats and the transportation of logs of timber in the water. A Thermal Electric Power station is located in the study stretch where this study was carried out precisely at station six. A major feature of the lagoon is the overwhelming preponderance of water hyacinth which has been linked to the degradation of the lagoon ecosystem (Nwankwo, 1998).

3.2 Data collection and laboratory analyses

Eight study stations were chosen based on accessibility; stations were distributed throughout the length of the lagoon. Twenty-four monthly samples were taken during two consecutive years from 2004 to 2006. Water temperature was measured with a graduated thermometer while salinity and dissolved oxygen were evaluated by the chlorinity and Winkler methods respectively (APHA, 1998).

From each station, samples of benthic macrofauna were taken in three replicates with a van Veen grab having a surface area of 0.1 m². Samples were washed through a sieve of 0.5 mm mesh size and organisms retained by the sieved were preserved with 10% formaldehyde solution in situ. The upper portion of the third replicate of the grab samples for each station were carefully taken and placed in labeled polyethylene bags for sediment analyses in the laboratory. The samples were stored in the refrigerator prior to analysis. In the laboratory preserved benthic samples were washed with tap water to remove the preservative and any remaining sediment for easy sorting. The molluscs animals were sorted into different taxonomic groups using suitable identification manuals including Buchanan (1954), Edmunds (1978), Barnes (1987), Yankson and Kendall (2001). The numbers of taxa and individuals for each station were counted and recorded for all the sampling months. Molluscs were counted and their density calculated for each study station throughout the two-year period of study.

For the sediment samples 100 g fresh weight was collected to determine the total organic matter content (TOC) in the sediment. The latter was calculated from the weight loss after ignition at 500°C for 4 hours, after previously drying for 48 hours at 60°C (APHA, 1998). Sediment was categorized by major fraction (mud/sand), based on procedures outlined in APHA (1998).

3.3 Statistical analysis

One-Way analysis of variance (ANOVA) was used to determine variations in environmental conditions at the study stations. When significant variations are detected, a post hoc test using Duncan New Multiple Range Test (DMRT) in the case of physico-chemical variables and Turkey’s Test in the case of biotic variables were performed to determine the locations of significant differences.

The following ecological parameters were assessed to describe the structure and composition of molluscs; density = number of individuals per 0.1 m² (ind./m²), mean spatial density of species = total density of species/number of study stations, % representation = percentage contribution of species, taxa richness (S) = total number of taxa per station); taxonomic diversity
expressed in Shannon–Wiener index (H') (Shannon, 1948) and Pielou’s evenness (J) (Pielou, 1974).

The method of Slack et al (1979) was used to determine dominant, subdominant, occasional and rare species. Taxonomic groups comprising 15% or more of the total number of individuals collected were considered dominant, those comprising at least 5% of the total number of individuals were considered subdominant group, and those comprising at least 1% of the total number of individuals were considered common while those comprising less than 1% were considered the rare group.

Cluster analysis was applied to determine the stations with similar densities of mollusc. Spearman’s Rank Correlation Test was used to determine the relationship between environmental parameters and biotic variables (density, diversity, species richness and evenness).

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Table 1 Summary of environmental characteristics of the study stations in Epe lagoon

<table>
<thead>
<tr>
<th>Study stations</th>
<th>Max</th>
<th>Min</th>
<th>Mean ± SD</th>
<th>Max</th>
<th>Min</th>
<th>Mean ± SD</th>
<th>Max</th>
<th>Min</th>
<th>Mean ± SD</th>
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<th>Mean ± SD</th>
<th>Max</th>
<th>Min</th>
<th>Mean ± SD</th>
<th>Max</th>
<th>Min</th>
<th>Mean ± SD</th>
</tr>
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<tbody>
<tr>
<td><strong>Water temperature (°C)</strong></td>
<td>34</td>
<td>24</td>
<td>31±2.67</td>
<td>35</td>
<td>24</td>
<td>32±3.03</td>
<td>35</td>
<td>24</td>
<td>32±3.34</td>
<td>36</td>
<td>24</td>
<td>33±4.00</td>
<td>36</td>
<td>23</td>
<td>32±3.61</td>
<td>38</td>
<td>23</td>
<td>32±3.35</td>
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<tr>
<td><strong>Salinity (‰)</strong></td>
<td>0.35</td>
<td>0.00</td>
<td>0.06±0.08</td>
<td>0.24</td>
<td>0.00</td>
<td>0.07±0.08</td>
<td>0.28</td>
<td>0.00</td>
<td>0.09±0.08</td>
<td>1.77</td>
<td>0.01</td>
<td>0.34±0.69</td>
<td>3.62</td>
<td>0.01</td>
<td>0.39±0.74</td>
<td>8.37</td>
<td>0.01</td>
<td>1.70±2.25</td>
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<tr>
<td><strong>DOnGL-1</strong></td>
<td>9.8</td>
<td>3.7</td>
<td>5.1±1.36</td>
<td>5.9</td>
<td>3.7</td>
<td>4.8±0.57</td>
<td>7.5</td>
<td>3.5</td>
<td>4.8±1.00</td>
<td>13</td>
<td>3.2</td>
<td>5.5±2.32</td>
<td>14</td>
<td>2.4</td>
<td>5.8±3.04</td>
<td>10.5</td>
<td>4</td>
<td>5.7±1.75</td>
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<tr>
<td><strong>Sand (%)</strong></td>
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<td>79</td>
<td>83.8±16.27</td>
<td>87.4</td>
<td>61.4</td>
<td>82.3±4.29</td>
<td>89.4</td>
<td>54.4</td>
<td>78.0±9.98</td>
<td>85.4</td>
<td>65.4</td>
<td>81.0±3.36</td>
<td>93.6</td>
<td>73.5</td>
<td>80.5±5.00</td>
<td>89</td>
<td>65.8</td>
<td>81.0±6.08</td>
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<tr>
<td><strong>Mud (%)</strong></td>
<td>21</td>
<td>7.8</td>
<td>13.5±3.74</td>
<td>28.6</td>
<td>7.5</td>
<td>17.3±4.29</td>
<td>44.6</td>
<td>11.4</td>
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<td>27.6</td>
<td>2.6</td>
<td>18.7±1.93</td>
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<td>11</td>
<td>19.2±5.06</td>
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<tr>
<td><strong>TOC (%)</strong></td>
<td>8.61</td>
<td>2.1</td>
<td>5.91±1.96</td>
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<td>4.3±1.54</td>
<td>6.1</td>
<td>1.0</td>
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