NOTES ON THE ECOLOGY OF BENTHIC MACROFAUNA COMMUNITY OF LAGOS LAGOON SYSTEM: A CRITICAL REVIEW OF THE ROLE OF SALINITY IN COMMUNITY ASSEMBLAGE AND DISTRIBUTION

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Abstract: The Lagos Lagoon system consists of many interconnected lagoons situated along the coast of southwest, Nigeria. The system is fed by numerous water bodies and is open all year round via the Lagos harbor and experiences semi-diurnal tidal regime. Sea water incursion and freshwater from adjourning rivers determine the salinity of the area. The system experiences freshwater, brackish and marine conditions depending on the season and distance from the harbor. Salinity values generally decreases inland, thereby establishing a salinity gradient. The variation in salinity has resulted in some level of zonation in the distribution of benthic macrofauna. This zonation follows the pattern exhibited by the salinity gradient in the lagoon system. This majorly accounts for the presence of freshwater benthic species in areas farther away from the sea where tidal saltwater influx is weak or absent and true brackish or euryhaline species occur majorly within the central portion of the Lagos Lagoon system. Existence of marine, brackish and freshwater conditions in different parts of the lagoon at different times of the year for long periods sufficient enough to allow temporary colonization by organisms, either from the sea or from the permanent freshwater of rivers and other adjoining water bodies, is a major factor regulating benthic species distribution. The extents to which marine or freshwater species penetrate the brackish area of the lagoon largely depend on their salinity tolerance.

Keywords: Benthic macrofauna zonation, ecology, Lagos Lagoon system, salinity gradient

Introduction

Salinity is one of the major factors determining the distribution of benthic communities (Webb & Hill, 1958; Longhurst, 1962; Olaniyan, 1975;Grzesiuk& Mikulski, 2006; Uwadiae, 2009a; b; Micheal& Hans, 2010).The effects of salinity on benthic invertebrates span through molecular, physiological, behavioral, life-history, morphological, population and community changes (Webb, 1958a, b). Salinity is an abiotic factor delineating the environmental optimum for most benthic fauna species. The range of optimal salt concentrations for freshwater species is 0 – 2‰ (Jeppesen*et al.,* 1994) and salt concentrations higher or lower than the optimal but, still within the tolerance rangeplay a role as stress factors capable of causing changes in physiology, behaviour, life history and morphology of benthos. In contrast to few species like lobsters, which can increase mobility as mechanism to leaving local patches of high salinity, most benthic fauna species are not known to possess any similar mechanism (Longhurst, 1958).

Life history processes can be affected by salinity, such parameters as life-span, growth rate, age and size at first reproduction, offspring size and number, all of which are crucial to fitness are dependent of salinity. Lethal salt concentrations differ among between the taxonomic groups. However, the effect of salinity can be modified by other abiotic factors, albeit with the pattern of these modifications varying. A strong interaction between effects of temperature and salinity on survival in *Daphnia magna* has been demonstrated, a high temperature compounding the harmful effect of the salinity (Ajao&Fagade, 1990). Even where it does not reduce lifespan, salinity may limit individuals' growthrates, with freshwater animals transferred to a brackish environment found to grow moreslowly (Teschner, 1995; Arner&Koivisto, 1993).

It is common for a stress factor influencing growth rate to have a knock-on effect on size and age at first reproduction. As animals grow more slowly where salt concentrations are higher, more time is needed for the optimal size for reproduction to be reached. Such delays in the onset of reproduction have been observed for salt-stressed horseshoe crabs *Limulus polyphemus*(L.) (Ehlinger&Tankersley, 2004). Salinity can cause both delayed maturity and a smaller size at first reproduction (Kikuchi, 1979; Kikuchi &Tinaka, 1976).

Freshwater animals release fewer neonates in a saline than in a freshwater habitat; this has been reported for *Branchipusschaefferi*Fisher, *Daphniamagna*(Arner and Koivisto, 1993; Teschner, 1995; Martinez-Jeronimo*et al.,* 2004, 2005), and *Moinahutchinsoni*Brehm (Martinez-Jeronimo& Espinosa-Chavez, 2005). Kikuchi (1979) reported that, the gills and digestive tracts of crustaceans are their basic osmo-regulatory organs, with changes in salinity capable of modifying gill morphology. These changes affect the so-called dark cells in particular, these being rich in mitochondria and possess an elaborate tubular system and modified cell membrane. An increased concentration of salt in water changes its physical characteristics, for example increasing density v and changing viscosity and flow characteristics (the Reynolds number). This ought to have consequences for optimal body shapes of animals and the structures of their filtering organs (Rubenstein &Koehl, 1977).

These fluctuations in abiotic conditions may cause major physiological problems for animals (Beadle, 1972; Odiete, 1999). Studies on pattern of salinity variation in estuaries have demonstrated that fluctuations may have major effects on growth, reproduction and ultimately survival because osmotic and thermal stresses cause changes in basal metabolic rate, which reduces surplus energy available for other activities (Odiete, 1999). These observations have led to the widely accepted concept that estuarine ecosystems are variable (or unstable) environments (Nybakken, 1988; Tait& Dipper, 1998; Catsro& Huber, 2005). This concept has played a fundamental role in estuarine ecology and constitutes one of the principal assumptions of several hypotheses that explain a whole range of observations. For example, fluctuation in salinity may constitute a major factor controlling the distribution of estuarine animals (Rejean and Julian, 1993). Burrowing in the sediment has been reported as an adaptation to reduce tidal salinity fluctuations.

Environmental variability may be responsible for the lower diversity of estuarine organisms compared to marine and limnitic environments, few species being adapted to tolerate rapid changes in abiotic conditions (Meire*et al*., 1991). Estuarine communities may be mainly 'physically controlled' in opposition to the biologically accommodated' communities found in areas where physical conditions are constant and uniform for long periods of time (Rejean& Julian, 1993). These hypotheses including others assume that estuarine animals are subjected to fluctuations in environmental conditions. The mechanism that generates environmental variability for animals in estuaries may be reduced to two components (Rejean& Julian, 1993). The first component corresponds to the presence of longitudinal and vertical gradients in physico-chemical parameters. The second component is dynamic: environmental variability resulting from the movement of animals against the spatial gradients. The speed and direction of this movement determine the rate and the direction of changes in abiotic conditions an individual experiences.

Most of the information available on the nature of environmental variability experienced by estuarine animals comes from studies of benthic organisms. This stems from the fact that these animals are affected by the periodic longitudinal displacement of the horizontal gradient in physico-chemical conditions caused by tides and freshwater discharge. Sessile animals are exposed to the whole range of fluctuations observed at one geographic point in the estuary, unless adaptations such as living in interstitial waters or in a shell reduce the range of fluctuations experienced by an individual (Odiete, 1999).

The coast of South-west Nigeria is inundated by a meandering network of lagoons and creeks. The lagoon system is open all year round via the Lagos harbor and experiences semi-diurnal tidal regime. Sea water incursion and fresh water from adjourning rivers constitute a major influence on the environment of the area especially with respect to salinity variations (Nwankwo, 1998). This dynamics of inflow of adjoining water bodieswith different salinity regimes establishes a salinity gradient that decreases inland (Hill & Webb, 1958; Nwankwo, 1998; Uwadiae, 2009a, b).The estuarine nature of the lagoon systemaccentuates the wide variations in physico-chemical characteristics especially salinity and other related variables, such as conductivity and concentration of total dissolved solids are associated (Nybakken, 1988; Tait& Dipper, 1998; Catsro& Huber, 2005).

Lagos Lagoon system has received a considerable research attention especially the central part of system known as the Lagos Lagoon, but inspite of the cardinal role of salinity in the ecology of the lagoon biota especially with respect to the benthic community, no attempt has been made to relate the pattern of distribution and diversity to the salinity variation. Although Uwadiae (2009b) reported on the Response of Benthic Macroinvertebrate Community to Salinity Gradient in a Sandwiched Coastal Lagoon (Epe Lagoon), his report did not cover the entire Lagos Lagoon system. In this present study a critical review of the role of salinity in the distribution and diversity of benthic macrofauna in the Lagos Lagoon system is presented.

Description of study area

The Lagos Lagoon system is shallow expanse of water that is generally < 2 m in average depth (Hill & Webb, 1958), although deeper waters are encountered in the Lagos Harbour owing to dredging. Like many coastal lagoons, Lagos Lagoon is a shallow brackish water body separated from the ocean by a barrier and connected to the open ocean through the Lagos Harbour. The lagoon is partially enclosed and this impedes water exchange between the basin and ocean and tends to dampen wave, wind, and current action (Hill & Webb, 1958).

Lagos Lagoon is located on a lowlying coasts and oriented parallel to the shore.The overall physical, biological and chemical features of the Lagos Lagoon system is a reflection of the basin morphometry as determined by human habitat alteration, marine and watershed influences, as well as in-basin hydrological processes (Olatunji&Abimbola, 2010). The size and configuration of tidal inlets, expanse and development of bordering watersheds, amount of freshwater input, water depth, and wind conditions greatly influence the physicochemical processes occurring within the lagoonal water bodies (Hills & Web, 1958; Longhurst, 1962). Variations in precipitation and evaporation, surface runoff, and groundwater seepage, together with fluxes in wind forcing, account for large variation in the physic-chemical characteristics of the system.

Due to the protracted water residence times brought about by the restrictive enclosure of depositional barriers, the system is susceptible to nutrient and other pollutants, various anthropogenic drivers, hydrological modifications, as well as the vagaries of climate change (e.g., changes in storm frequencies and intensities, floods, droughts, and warming).

The lagoon system is open all year round via the Lagos harbor (Fig. 1) and experiences semi-diurnal tidal regime which is limited to areas affected by tidal water incursion. Sea water incursion and fresh water from adjourning rivers determine the environment of the area (Nwankwo, 1998). Owing to the dynamics of inflow of river and sea water incursion, the Lagos lagoon experiences brackish condition that is more discernable in the dry season (Hill & Webb, 1958; Nwankwo, 1998) and decreases inland, thereby establishing a salinity gradient (Uwadiae, 2009a, b).

The estuarine nature of the lagoon system is responsible for the wide variations in physico-chemical characteristics especially salinity and other related variables. The area is characterized by the presence of a longitudinal gradient in salinity with which other gradients in physico-chemical parameters, such as conductivity and concentration of total dissolved solids are associated (Nybakken, 1988; Tait& Dipper, 1998; Catsro& Huber, 2005).The salinity is weak upstream areas of Lekki and Epe Lagoons and very high downstream, up to 30 ppt around the Lagos Harbour and in parts of the Lagos Lagoon. Although, the salinity condition may fluctuate at any point according to displacements of the longitudinal gradient induced by factors such as tides and river discharge (Webb, 1958a, 1958b; Rejean& Julian, 1993).

Storm and wind surges, overwash events, inlet reconfigurations, land reclamation, construction bars, as well as channel dredging events, are important drivers of hydrological change in these lagoons. Seasonal changes in river inflow may also cause marked shifts in salinity structure in these lagoons. Local meteorological conditions are known to strongly influence the physicochemical parameters in the lagoon system and are very responsive to meteorological conditions, notably air temperature, because they are very shallow. The lagoons are heavily influenced by waves than by tides, with microtidal conditions predominating in many of these systems (Hill & Webb, 1958). Wind direction and speed are key elements of wave genesis in these systems. Wave effectiveness increases as the tidal range decreases (Longhurst, 1962).

A substantial volume of sediment enters the lagoons during storm surge and over wash events (Hill & Webb, 1958). The breaching of barriers and formation of wash-overs deliver sediments from the ocean and back-barrier areas. Aside from these sources, sediments accumulate in the lagoonal basins from rivers draining the mainland, runoff of tidal marsh and other habitats bordering the basin, and internal processes (i.e., organic carbon production, chemical precipitation, as well as erosion and resuspension of older sediments). As noted by Longhurst (1962), coastal lagoons are net sediment sinks, but changes in the volume of river inflow, frequency of storms, and in-basin wave and current action all contribute to considerable variation in the rate of biogenic activity and sediment accumulation in these shallow systems.

Salinity variation in Lagos Lagoon system

Hill & Webb (1958a) gave a detailed account of the salinity and pattern of salinity variation in the Lagos Lagoon complex. The authors reported that, the water in the Lagos Lagoon System and Habour is derived partly from the sea by salt water entering the harbor in the rising tide and partly from freshwater from rivers entering the lagoons, the salinity displays both a diurnal fluctuation due to tidal effects and much greater seasonal changes caused by the influx of freshwater during the rainy season. On the falling tide, water flows from the lagoon system into the harbor. With the rising tide the direction of the currents is reversed. The influx of salt water from the sea gives rise to brackish conditions in the lagoon.

Salinity in the lagoon system is usually higher during the dry months from January to May. In June and July, the salinity falls, but rise in August and September and falls again in October and November. The onset of the rains in the rainy months is not usually followed by a significant fall in salinity until about 8 to 10 weeks later, but in August the resumption of the rains after the short dry period cause a fall in salinity in only 2 to 4 weeks, while cassation of rains was reflected in a salinity rise after 2 weeks. It is clear therefore that when the ground was saturated the rain water from the drainage area took an average of 2 to 4 weeks to reach the lagoon. After the dry season, however, much of the early rains was evidently absorbed by ground and never reached the lagoons, and it was not until sufficient rain had fallen to give an appreciable run-off that the rivers began to flow and the salinity in the lagoon was affected. This phenomenon thus caused a lengthening of the period for which marine conditions prevailed in the harbor, the salinity being continuously high for 5 months from mid-December to mid-may as compared with a dry season of only 3 months.

During November, December and January, the salinity rises and in February, harbour salinity reaches that of the open sea and may remained at this range until middle of April. In areas of the lagoon, close to the harbor such as the Five Cowrie Creek, the salinity during the dry season at high tide equals that of the harbor, but at low tide the salinity falls.Towards the end of the dry season and at the beginning of the wet season, the salinity falls rapidly at low tide within the lagoon system, but more slowly at high tide in the harbor and its environs. Although the diurnal fluctuation in the lagoon was negligible, that in the harbor and its environs may be great and may remain so throughout the period of the rains except when the flow of freshwater was so great that influx of salt or brackish water from the sea at high tide was prevented. Expectedly values of salinity and its fluctuation reduce with increasing distance from the harbor mouth until lagoon water remain fresh at most times at 20 miles away from the seas.

Aside tidal and freshwater influx, salinity changes in the Lagos lagoon systems have also been related to waste occasionally breaking over the beach and salt water flows into the lagoon thereby increasing the salinity at high tide in rough weather. Seapage of salt water into the lagoon from the sea through beach sand is another likely source of salt water. Evaporation of water from the surface of the lagoon was also pinpointed as another source contributing to rise in salinity. The drainage of rain water from local storms is known to be contributing significantly in the reduction in salinity of the lagoon during the wet season.

In the harbor, the seasonal salinity pattern is a simple cycle determined by rainfall regime. Maximum value occurred in March at the end of the dry season, and the minimum recorded at the end of the wet season between August and September. According to Olaniyan (1969), the seasonal fluctuations in salinity of the Lagos Lagoon system correlated positively with the volume of water draining the Lagoon from rivers. The author also observed that the salinity and salinity variation in the Lagos Lagoon complex become progressively less with increasing distance from the sea, and suggested that, values recorded at the harbor will be the highest at any given time.

Similar pattern was reported for Epe by Uwadaie (2009a, b), the author observed that there was a salinity gradient in the study stretch and values recorded were significant difference (ANOVA, $P<0.05$) in salinity values at the study stations in Epe Lagoon (Fig. 2). The salinity at the upstream stations A to F were similar (DMRT, $P<0.05$) and significantly lower than those at downstream stations (G and H) which had similar (DMRT, $P<0.05$) salinity.

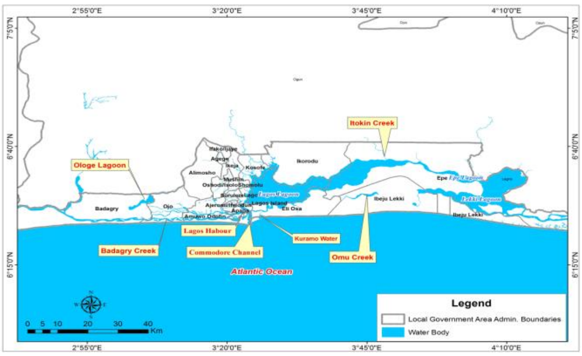

Fig. 1: Map of study area

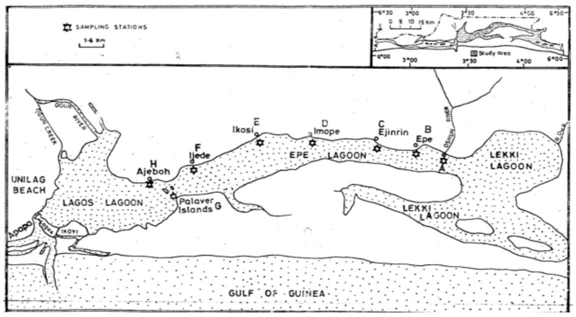

Fig. 2: Epe Lagoon showing study points

Benthic communities of the Lagos Lagoon system

Owing to the variations in salinity, only species with the specialized adaptations can survive in these lagoons. The salinity variation has resulted in some level of zonation in the distribution of benthic macrofauna (Olaniyan, 1975; Uwadiae, 2009a; Brown, 1998; Brown, 2000). This zonation follows the pattern exhibited by the salinity gradient in the lagoon system and majorly accounts for the presence of freshwater benthic species in areas farther away from the sea where tidal saltwater influx is weak or absent. These areas; Lekki, Epe and Iyagbe Lagoons (Figs. 1 and 2) are mainly freshwater environments. Benthic fauna of the Lagos lagoon system vary from animals with low salinity tolerance such as the freshwater animals to those with tolerance for wide variation in salinity changes, the euryhaline species (Tables 1 and 2). The freshwater species are common in Lekki, Epe and Iyagbe Lagoons. Majority of the animals occur as phytomacrofauna (Table 2) attached to floating aquatic macrophytes such as water hyacinth (Uwadiae*et al*., 2011). The seasonal distribution of floating macrophytes especially water hyacinth limits the spread of these organisms. As a freshwater plant, water hyacinth does not usually occur in the central areas of the Lagos lagoon system during the dry season due to rising salinity conditions.

Table 1: Composition of benthic macoinvertebrates in Epe Lagoon

Phylum	Class	Family	Species
Annelida	Polychaeta	Capitellidae	***Capitellacapitata*Fabricius, 1780.
			***Capitellahermaphrodita*Boletzky and Dolile,1967.
			**Heteromastus filiformis* (Laparède, 1864.
			**Notomastushemipodus*Hartman, 1945
		Lumbrineridae	**Lumbrineridescingulata* Ehlers, 1897
			**Lumbrineriopsisparadoxa*Saint-Joseph, 1888
		Nereidae	***Nereis lamellose* Linnaeus, 1758.
			***Nereissuccinea*Leuckart, 1847.
			***Nereisdiversicolor*MÜller, 1776.
	Oligochaeta	Lumbriculidae	**Lumbriculusvariegatus* Müller, 1774.
		Naididae	**Nais eliguis*Müller, 1774.
Arthropoda	Crustacean	Gammaridae	**Gammarusfasciatus*Say, 1818
		Corophidae	***Corophiumvolutator* Pallas, 1766
		Penaeidae	***Penaeusnotialis*Pérez Farfante, 1967
			***Palaemonetesvulgaris* Say, 1818
		Ocypodidae	***Ocypoda cursor*
			***Ocypoda*Africana
			***Ucatangeri*Eydoux, 1835.
		Sesarmidae	***Sersamahuzardi*(Desmarest, 1825.
		Clibanaridae	***Clibanariusafricanus*, Aurivillus,1898
			***Clibanariussenegalenses*Chevreux&Bouvier, 1898
			***Clibanariuschapini*Schmitt, 1926.
	Insecta	Chironomidae	**Chironomusplumosus*Linnaeus, 1785.
		Gomphidae	**Gomphusvulgatissimus*Linnaeus 1758.
		Libellulidae	**Libellulavibrans*Fabricius, 1793.
		Baetoidae	**Baetismuticus*Linnaeus, 1758.
		Tenthredinidae	**Kaliofenusaulmi*
Chordata	Leptocaridia	Branchiostomidae	***Branchiostomanigeriense* Webb, 1955
Echinodermata	Holothuroidea	Cucumariidae	***Cucumariaconicospermium*Stepanov, 2001
Mollusca	Gastropoda	Neritidae	***Neritinaglabarata*Sowerby, 1849.
			***Neritinakuramoensis*Yoloye&Adegoke, 1977
		Melaniidae	***Pachymelaniaaurita* Muller, 1776.
			***Pachymelania*fusca*quadriseriata*Gray, 1831.
		Potamididae	***Tympanotonusfuscatus* Linnaeus, 1758.
			***Tympanotonusfuscatus*var radula Linnaeus, 1758.
	Bivalvia	Tellinidae	***Macomacumana*O.G. Costa, 1829.
			***Tellinanymphalis* Lamarck, 1818.
		Avcidae	***Mytilusedulis* Linnaeus, 1758
			***Mytilusperna*Linnaeus, 1758
		Ostreidae	***Graphaegasar*Dautzenberg
		Aloididae	***Aloididistrigona*. Hinds
Nermertina	Hoplonemertea	Otonemeridae	**Lineuslongissimus*Gunnerus, 1770.
			**Lineusruber*Müller, 1774
Porifera	Demospongiae	Chalinidae	***Tetillamonodii* Burton, 1929

* = Freshwater species; ** = Brackish water species

Source: Uwadiae (2009, 2010, 2013)

The true brackish or euryhaline species occur majorly within central portion of the Lagos Lagoon system (Oyenekan, 1975; 1979; 1983; 1988; Egonmwan&Odiete, 1983; Oyenekan, 1984; Oyenekan&Bolufawi, 1986; Oyenekan&Adeniran, 1987; Oyenekan, 1988; Ajao&Fagade, 1991; Brown, 1998; Brown &Oyenekan, 1998; Brown, 2000; Ogunwemimo&Osuala, 2004; Edokpayi*et al*., 2004; Egonmwan, 2007). Prominent among these are the hermit crabs (Olaniyan, 1975; Oyenekan&Adeniran, 1987) which inhabit the shells of two common gastropods groups *Pachymelania*sppand *Tympanotonus* spp. Other lagoon crabs you easily found crowding intertidal area at low tide include *Ucatangeri*, *Seasarmahuzardii* also known as the mangrove crab found on the roots of mangroves, *Cardiosomaarmatum* often seen at night some distance from water and the swimming lagoon crab *Callinecteslatimanus* (Olaniyan, 1975).

The annelid *Mercierellaenigmatica* and *Bankia*spp are common tube dwelling organisms found in the lagoon mostly on red mangrove, floating objects and shells of other animals. The gastropod *Littorinaangulifera* and bivalve *Graphaeagasar* inhabit the root of mangrove. The bivalve *Brachyodonyesniger* has also been collected from the surface of rocks and other hard surfaces. *Egeriaparadoxia* is another bivalve recorded in the lagoon. It occurs on sandy sediment. Other common benthic fauna found in areas with high salinity variability are the lancelet *Brachiostomanigeriae* and the bivalves *Anadarasenelis*, *Macomacumana*, *Tellinanymhalis*and the gastropods, *Neritinaglabarata*and *N. kuramoensis*.

Table 2: Checklist of benthic phytomacrofauna associated with water hyacinth in Iyagbe Lagoon (November, 2013 – May, 2014)

Phylum: ANNELIDA
Class:Polychaeta
Family:NEREIDAE
*Nereisindica*Kinberg, 1866
*Nereissuccinea*Leuckart, 1847
Family:NEPHTYIDAE
Nephtyshombergii Lamarck, 1818
Family:CAPITELLIDAE
Notomastuslobatus Hartman, 1947
Phylum:ARTHROPODA
Class: Insecta
Family:CHIRONOMIDAE
*Chironomusplumosus*Linnaeus, 1758
Family:CERATOPOGONIDAE
*Culicoidesimpunctactus*Goetghebuer, 1920
Family:GOMPHIDAE
*Paragomphuslineatus*Selys, 1850
Family:CORDULEGASTRIDAE
Cordulegasterdorsalis Leach, 1815
Family:PHILOPOTAMIDAE
Dolophilodesdistinctus Walker
Family:PSEPHENIDAE
*Psephenusfalli*Casey, 1893
Family:GYRINIDEA
*Gyrinusnatator*Linnaeus, 1758
Family:ELMIDAE
*Stenelmiscanaliculata*Gyllenhal, 1808
Family:CYBAEIDAE
Agyroneta aquatic Clerck, 1757
Class:CRUSTACEA
Family:AMPHILOCHIDAE
*Amphilochusneapolitanus*Della Valle, 1893
Family:PENAEIDAE
Penaeusnotalis Perez Fanfante, 1967
Family:CIROLANIDAE
*Eurydice pulchra*Leach, 1815
Family:IDOTEIDAE
*Idotea*sp
Family: SESARMIDAE
*Sesarmahuzardii*Desmarest 1825
Phylum: MOLLUSCA
Class: Gastropoda
Family:NERITIDAE
*Neritinaglabrata*Sowerby, 1849
*Neritinakuramoensis*Yoloye and Adegoke, 1977
Family: Eulimidae
Eulimafisceri
Family: Planorbidae
*Gyraulusparvus*Say, 1817
Family:MELANIDAE
Pachymelaniaaurita Muller, 1776
*Pachymelaniafuscaquadriseriata*Gray,1831
Family:POTAMIDIDAE
Tympanotonusfuscatus Linnaeus, 1758
*Tympanotonusfuscatus*var. *radula* Linnaeus, 1758
Class: Bivalvia
Family: Tellinidae
*Tellinanymphalis*Lamarck, 1818
*Macomacumana*O.G. Costa, 1829

Source: Uwadiae 2017-In press

It is important to note that it is becoming quite difficult to state with certainty the pattern of distribution of the Lagos lagoon benthic community. This is because apart from the primary roles of variation in salinity and sediment, the increasing rate of anthropogenic activities has continued to alter natural conditions that favoured the original bioeconosis of the lagoon.

Impact of salinity on the diversity and distribution of benthic macroinvertebrates

Environmental variability may be responsible for the lower diversity of estuarine organisms compared to marine and limnitic environments, few species being adapted to tolerate rapid changes in abiotic conditions (Meire*et al*., 1991). The mechanism that generates environmental variability for animals in estuaries may be reduced to two components (Rejean& Julian, 1993). The first component corresponds to the presence of longitudinal and vertical gradients in physico-chemical parameters. The second component is dynamic: environmental variability resulting from the movement of animals against the spatial gradients. However, the former appears to be more relevant witin the context of this review as longitudinal and vertical gradients in sanility expose benthic organisms physiological stresss, but environmental variability resulting from the movement of animals may not apply since many of these oragisnms are sessile.

Benthic invertebrates are affected by the periodic longitudinal displacement of the horizontal gradient in salinity caused by tides and freshwater discharge. They are exposed to the whole range of fluctuations observed at one geographic point in the estuary, unless adaptations such as living in interstitial waters or in a shell reduce the range of fluctuations experienced by an individual (Odiete, 1999).

A close examination of the benthic macrofauna communities in the different lagoons comprising the Lagos Lagoon system shows that, differences in abundance, composition and diversity are majorly controlled by variations in salinity (Sandison and Hill, 1966; Oyenekan, 1975; 1979; Brown, 2000; Uwadiae, 2009a, b). Sandison& Hill (1966) described the epifauna*Balanuspallidus*Darwin, *Grapheagazar*Dautzenburg, *Mercierellaenigmatica*Linneaus and *Hydroidesuncinata*L. and their distribution in relation to seasonal salinity changes. They reported that the two salinity regimes in the Lagos lagoon affected the distribution of the benthos. Salinity has also been reported to affect the life cycles of *Ballanuspallidus*(Sandison, 1966) and *Tympanotonusfuscatus*var*radula* (Egonmwan and Odiete, 1983). The community types described in this study are both freshwater species (e.g.insect larvae) and marine/brackish water species (e.g.*Brachiostomanigeriense*). The sizes of the brackish water species recorded in this study were smaller than those encountered in the Lagos lagoon (Ajao&Fagade, 1990).

According to Uwadiae (2009a, b), in a total of 576 samples collected from Epe Lagoon, there were 17,712 specimens belonging to 45 taxa. Molluscs constituted the highest percentage (98.43%) of the animal population, followed by Annelida (1.16%), Arthropoda (0.32%), Nermertina (0.04%), Chordata and Porifera (0.02%), respectively, and Echinodermata (0.005%). There were strong similarities in the values obtained for monthly fauna abundance, species richness, diversity and evenness for wet and dry seasons, indicating no strong seasonal influence. However, the benthic macroinvertebrate abundance and distribution suggested strong influence by the salinity gradient. The values of benthic macroinvertebrate abundance were higher in locations with mean salinity >0.34 ‰ while low abundance occurred in areas with mean salinity <0.09‰. The highest number (33) of taxa was observed in station G (Fig. 2) which had the highest mean salinity (3.44‰) (Tables 3 and 4).

This gradation in salinity has also resulted in benthic macrofauna distribution pattern (Uwadiae,2009a, b). The Lagos lagoon system is subject to various degrees of changes in salinity. In order to survive therefore, benthic fauna must have some degree of tolerance to salinity changes and some powers of adaptation to water of varied salinity regimes. The degree of change they can withstand and the limits of salinity in which they can survive are important factors determining their ability to colonize new grounds and the extent to which they can be distributed in a particular area.

Many benthic fauna species die when placed in salinity conditions, different from their natural salinity tolerance. The powers of osmoregulation are not the same in benthic organisms. Webb & Hill (1958) in their study of the reactions of *Brachiostomanigerience*to its environment noted that, the lower threshold for both larva and the adult of the organism was 13 ‰. They observed that, adults survive in salinities up to 58.9 ‰. According to the result of their experiment, adults of *B. nigerience* can withstand diurnal fluctuations of salinity within a range as high as 14.5 to 31 ‰. It was also revealed that the rate of adjustment of lancelets to salinity change indicate that lancelets transferred from 25 to 13‰ underwent a process of accommodation to lower salinity which became critical at 14 to 20h from the time of transfer. Lancelets returned to the high salinity water at this time died while other returned earlier or later, or remaining at the low salinity recovered.

The times of appearance and disappearance of some benthic organisms in a particular area is governed by the salinity tolerance of the organisms for example, the times of appearance and disappearance of *B. nigerience* in the Lagos Harbour and Lagos lagoon are related to salinity tolerance of the animal (Webb & Hill, 1958).

Webb & Hill (1958) further opined that, salinity fluctuations from a high to a low salinity or in the reverse direction is known to cause stoppage of the ciliary beat in larval and adult lancelet gills for a period dependant upon the magnitude of the change and the salinity range in which it occurs. A salinity of 20 ‰ was shown to be critical in this respect as fluctuations involving passage across this salinity in either direction caused prolonged cessation of the ciliary beat as compared with others of equal magnitude within a range either above or below 20 ‰. In addition, they reported that periodic interruptions in the ciliary feeding mechanism due to salinity fluctuations in the range above 20 ‰ was mainly responsible for the slow rate of growth of lancelets in the Five Cowries Creek from January to May as compared with those in Lagos lagoon. According to them, Five Cowries Creek at this time had mean salinity of 25‰ and fluctuation is considerable, whereas in the Lagos lagoon the mean salinity is19‰ and fluctuation is slight.

Table 3: Summary of the benthic macroinvertebrates' metrics at the study stations in Epe Lagoon (Sept. 2004 – Aug. 2006)

Metric	Stations							
	A (Mouth of Oshun River)	**B (Epe jetty)**	**C (Ejirin)**	**D (Imope)**	**E (Ikosi)**	**F (Egbin Power station)**	**G (Palava Island)**	**H (Ajebo)**
Number of samples	72	72	72	72	72	72	72	72
Number of taxa	23	23m	11	12j	18k	12m	32k	18j
Number of individuals	191h	1045h	87h	3312i	3611i	3120i	2489i	3855i
Margalef's Index of species richness (*d*)	4.37d 3.	30c	2.46c	1.60d	2.32d	1.37c	4.09	2.18d
Shannon-wiener diversity index (H')	1.06f 0.	34f	0.77	0.61g	0.60g	0.62f	0.60	0.66g
Evenness (E)	0.33a	0.10a	0.31	0.24a 0.	19a	0.25a	0.20a	0.22a

Lower case alphabets indicate no significant difference (P>0.05) *DMRT (P<0.05)

Source: Uwadiae (2009a, b)

Table 4: Percentage composition of benthic macrofauna phyla at the sampling stations in Epe lagoon) (Numbers in parenthesis represents the actual number of individuals in the phylum)

Phylum	Sampling station							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Annelida	35.44(68)	4.0(42)	3.44(3)	0.09(3)	0.51(18)	0.14(5)	1..52(41)	0.7(27)
Nemertina	0.52(2)	-	-	-	-	-	0.20(5)	
Arthropoda	7.28(15)	0.83(9)	3.45(3)	0.06(2)	0.23(8)	-	0.84(21)	-
Mollusca	56.77(109)	96(994)	93.1(81)	99.8(330 7	99(3585)	99.8(3113)	97(2417)	99(3826)
Porifera	-	-	-	-	-	0.03(1)	0.04(1)	0.03(1)
Echinodermata	-	-	-	-	-	-	0.04(1)	-
Chordata	-	-	-	-	-	-	0.12(3)	0.03(1)

Source: Uwadiae (2009a, b)

In an experiment to determinethe effect of salinity on survival and growth of blue crab, *Callinectesamnicola* from Lagos Lagoon, Lawal-Are &Kusimiju (2010) reported that crabs tolerated a salinity range of 5 to 25 ‰. The tolerance rate of the crabs was monitored after abrupt transfer tovaried salinities from acclimatization tanks. According to the report, the percentage survival was recorded at 15 and 20 ‰ salinities and 50% survival at5 and 25 ‰. Twenty five percent survival rate was observed at 0 ‰, while 10 %survival rate was recorded when salinity was 30 ‰ and 5 % survival rate occurred in 35 ‰ salinity. They also observed that, the medium used for the experiment was hypertonic to thecrab. However, 75% survival rate was recorded when salinity was10 ‰. The percentage of survival decreased gradually at 35 ‰, and from the second week, no specimens survived. At 0 ‰, none of the crabs survived by Week 10. At 10 ‰, survival rate dropped to 95 % between Weeks 1 and 2, however, between Weeks 3 and 10 therewas 90% survival. At 5, 20 and 30 ‰ salinities survival rate were 40, 50 and 15% respectively from Weeks 7 to 10.

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