International Journal of Environmental Sciences Vol. 3 No. 2. 2014. Pp. 51-59

Full Length Research Paper

Changes in Water Chemistry, Chlorophyll *a* Concentration (Phytoplankton Biomass) and Zooplankton Characteristics at a Mariculture Site in the Lagos Lagoon

*I. C. Onyema and Harris-Sanni, M. O.

Department of Marine Sciences, University of Lagos, Akoka, Lagos, Nigeria

**Corresponding Author: I. C. Onyema*

Abstract

The water chemistry, chlorophyll a and zooplankton diversity at a Mariculture site in the Lagos lagoon was investigated for 34 consecutive weeks (November, 2010 and June, 2011). Weekly variations in the physical and water chemistry parameters were more "brackish" in the dry season and "fresher" in the wet season, and linked with the tidal sea water incursion and flood water inputs from rainfall due to seasonal changes. For instance, the Salinity was low (0.11‰) at the beginning of the study and increased considerably into the dry season (20.4‰). Chlorophyll a values ranged between 3.2 and 13.2 µg/L, with a mean of 8.6 and standard deviation of ± 2.90. Chlorophyll a concentration were negatively correlated with nutrients (Nitrate r = -0.46, Sulphate r = -0.56, Phosphate r = -0.36), Rainfall r = -0.56, salinity r = -0.24 and pH r = -0.31. On the other hand, positive correlation was recorded with Water temperature r = 0.35, Silica r = 0.18, Biological oxygen demand r = 0.36 and Chemical oxygen demand r = 0.44. The Zooplankton biomass in terms of number of individuals were higher in the dry (weeks) season when Salinity values were higher. The Zooplankton spectrum consisted of two Phyla and eight juvenile stages. Whereas the Phylum Arthropoda recorded 57%, the Phylum Cnidaria reported 19%. The juvenile stages (24%) comprise of the Nauplii larva of Barnacle, Annelids and Bivalve larvae, Fish and Copepod eggs, Gastropod Zoea and Megalopa larva. The prevalent holoplankton species were Acartia clausii, Acartia discaudata, Cyclopina longicornis, Paracalanus parvus, Oithona rigida, and an unidentified Jelly Fish.

Keywords: *Water chemistry, Zooplankton, meroplankton, Physico-chemical, Chlorophyll a, Mariculture, Lagoon.*

Introduction

Aquaculture is now recognized as a viable and profitable enterprise worldwide and aquaculture technology has evolved various ways of production including cages. Cage culture involves the practice of rearing fish in cages and usually applies to existing water bodies that cannot be drained or seined and would otherwise not be suited for aquaculture (McGinty and Rakocy, 1989). When these operations are carried out in the marine environment, the practice is usually termed Mariculture.

Lagoons are fragile ecosystem susceptible to pollution effects from municipal, industrial and agricultural runoff (Odiete, 1999). Lagoons are important in water transportation, energy generation, exploitation and exploration of some mineral resources including sand, provide natural food (Onyema, 2009a) resources rich in protein, fish and fisheries farming or mariculture sites as well as sites for the disposal of both domestic and industrial wastes (FAO, 1969; Kirk and Lauder, 2000; Onyema *et. al.,* 2003, 2007; Chukwu and Nwankwo, 2004).

The phytoplanktons are the foundation of the food web in providing a nutritional base for zooplankton and subsequently to other invertebrates, shell and fin fish (Emmanuel and Onyema, 2007). Phytoplankton contains photosynthetic pigment known as chlorophyll *a*. Chlorophyll *a* concentration in an aquatic ecosystem is a quantification of phytoplankton biomass hence a reflection of primary productivity (Lee 2008). Ogamba *et. al.*, (2004) is of the view that Chlorophyll *a* concentration is an indicator of phytoplankton abundance and biomass in the aquatic ecosystems. Furthermore, Chlorophyll *a* can also be an effective measure of trophic status. However, elevated chlorophyll *a* concentrations often indicate poor water quality and low levels often suggest good conditions (Onyema and Ojo, 2008).

The phytoplankton and zooplankton are an important source of food for many aquatic organisms including fish and invertebrates in lagoons (Emmanuel and Onyema, 2007). Planktonic components have also been reported by investigators to reflect water chemistry status and changes, hence acting as bio-diagnostic tools that point to the health of the ecosystem (Onyema *et al*., 2003).

Phytoplankton production usually determines the amount of zooplankton present at any time (Castro and Huber, 2000). The diversity and the distributions of zooplankton components is strongly influenced by a combination of seasonal physical and water chemical characteristics (Onyema *et al.* 2007, 2010).

The zooplankton in waters of south-western Nigeria has not received enough attention. Published works on zooplankton include that of Olaniyan (1975), which reported on the plankton of lagoons of south-western Nigeria and that of Akpata *et. al.* (1993). Egborge (1994) considered the Salinity and distribution of rotifer zooplankton in the Lagos Harbour.

More recent studies include Onyema *et. al*. (2003), which studied the effect of plankton at a sewage disposal site and Onyema *et. al.* (2007) which considered the same group of organisms at two organically polluted sites of the Lagos lagoon. Emmanuel and Onyema (2007) investigated the plankton and fishes at a tidal creek in south-western Nigeria and also Onyema and Ojo (2008) investigated the zooplankton and phytoplankton biomass in a tropical creek in relation to water quality indices. Furthermore Onyema (2009b) reported on the zooplankton dynamics and chlorophyll *a* concentrations at the Tomaro creek in relation to water quality indices. Lawal-Are *et. al.,* (2009) investigated monthly variations in water quality parameters, chlorophyll *a* and zooplankton in an estuarine creek, Lagos. Furthermore, Onyema *et. al.,* (2010) investigated the water chemistry and plankton dynamics of a tropical high energy erosion beach in Lagos while Nkwoji *et. al.,* (2010) studied the wet season spatial occurrence of phytoplankton and zooplankton in the Lagos lagoon. At present, there is no report on the chlorophyll *a* concentration (phytoplankton biomass), zooplankton diversity in relation to water chemistry characteristics at a Mariculture site in the Lagos lagoon, especially weekly. Thus, the objective of this study was to investigate weekly variation in the level of primary production (Chlorophyll *a*) and zooplankton diversity in relation to water chemistry changes at a Mariculture site in the Lagos lagoon.

Materials and Methods

Description of study site

The Mariculture site is located on the eastern extreme and shoreline of the University of Lagos. It is situated within the Lagos lagoon. The Global Position System (G.P.S.) location of the site is about Latitude 6º31’038N and Longitude 3º24’261E. The Mariculture setup is located attached to a jetty adjoining the shoreline of the University of Lagos at its water front. The cages are placed on both sides of the jetty. It experiences similar environmental conditions like the rest of the lagoon, notably freshwater discharge from wetlands through the adjoining creeks, creeklets and rivers in the wet season and tidal sea incursion predominantly in the dry season. Sampling was carried out weekly for eight consecutive months in order to cover two key periods (dry and wet seasons).

The Lagos lagoon is a large, open, shallow and tidal coastal lagoon (Fig. 1) located in Lagos State, Nigeria. The Lagos lagoon is one of the ten lagoons in South-western Nigeria (Hill and Webb, 1958; Nwankwo, 2004; Onyema, 2009c, d). The Lagos lagoon covers an area of 208km^2 (Nwankwo, 1998) and an average depth of less than 2m (Ajao, 1996) except for areas that are often dredged for marine traffic. The Lagos lagoon is subject to semi-diurnal tide (Onyema, 2009a). A lag period of between 1hr 55mins and 2hrs occur between the time of tidal change at the mouth of the lagoon to the sea and the corresponding change off the University of Lagos Mariculture site and shoreline (Onyema, 2011). Owing to the dynamics of river inflow and seawater incursion, the Lagos lagoon experiences brackish condition that is more discernable in the dry season. In the wet season, the increased river inflow creates freshwater and low brackish conditions in various parts of the lagoon especially away from the harbour.

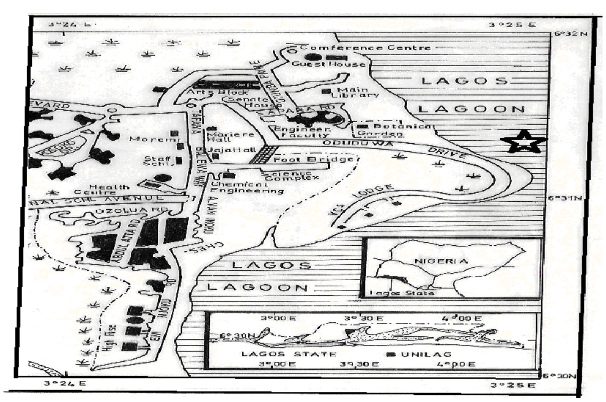

Fig. 1: The Lagos lagoon, University of Lagos Shoreline and the Mariculture site.

Collection and analysis of Samples
The surface water samples were collected with 250ml plastic container with screw caps at the site between the hours of 9am and 12pm. Samples were then taken to the laboratory for water chemistry analysis. Plankton samples were collected using a 55µm mesh size standard plankton net and a 10L plastic bucket. At the station plankton samples was collected by filtering 100 litres of surface water through the plankton net. The filtered plankton was then emptied into a well labelled 250ml plastic container with a screw-cap. The plankton samples were stored in well labelled 250ml plastic containers with screw caps and preserved with 4% formalin. The plastic containers were labelled appropriately to reflect the date, name of site and contents.

Air and water temperatures were determined using a mercury-in-glass bulb thermometer. Rainfall data was supplied by Nigerian Meteorological Agency, Oshodi Lagos (NIMET). Other physico-chemical parameters were estimated as stated in APHA (1998).
For the extraction of chlorophyll *a*, 200ml of water sample was filtered through 0.45µm glass fibre membrane filter. The residue on the filter was transferred to a tissue blender and covered with 3ml 90% aqueous acetone and then macerated for 1min. the sample was transferred quantitatively with 90% acetone to a centrifuge tube. It was capped and allowed to stand for 2hours in the dark at 4ºC (in a refrigerator). Thereafter, it was centrifuged at 500g, for 20min. The supernatant was decanted, and the volume noted. The fluorometer was then calibrated with standard chlorophyll solutions (2, 5, 10 and 20µg chlorophyll a/L). The readings for each solution at ×1; ×3; ×10; ×30 sensitivity settings were noted. This is in accordance with APHA (1998).

Zooplankton samples were allowed to settle in the laboratory for a period of at least 48hrs and then decanted until a concentration of about 20ml was achieved. 5 mounts for each sample for each sample of 0.2ml (2 drops) were investigated under an Olympus binocular microscope. Zooplankton species were drawn where necessary to aid identification and micrographs taken using compound microscope with photographic attachment. Relevant identification texts were used to confirm the taxa.

Results
The data obtained for the water quality parameters exhibited distinct weekly/seasonal variations. Table I shows minimum, maximum, mean and standard deviation of weekly changes in chlorophyll *a* and physic-chemical parameter at the mariculture site.

Table 1: Minimum, maximum, mean and Standard Deviation of weekly changes in physical, chemical characteristics and Chlorophyll *a* at a Mariculture site in the Lagos lagoon (November, 2010 and June, 2011).

Parameter	Minimum	Maximum	Mean	± S.D
Air temperature (°C)	28	33	30.93	1.34
Water temperature (°C)	27.5	38	31.46	1.68
Total Suspended Solids (mg/L)	10	250	52.53	46.20
Total Dissolved Solid (mg/L)	135	23310	13881.21	8279.40
Rainfall (mm)	0	317.4	128.01	122.47
pH @ 25°C	6.82	7.96	7.59	0.34
Salinity (‰)	0.11	20.4	12.21	7.11
Chloride (mg/L)	45.6	12100	7363.03	4342.90
Conductuvity (µS/cm)	265	35300	22386.26	11937.08
Acidity (mg/L)	4	15.3	7.66	3.18
Alkalinity (mg/L)	11.1	139.2	71.89	43.62
Total Hardness (mg/L)	27	5600	2877.72	1928.05
Dissolved oxygen (mg/L)	0.2	5	4.32	0.81
Biochemical oxygen demand (mg/L)	2	260	24.09	44.97
Chemical oxygen demand (mg/L)	6	488	81.35	102.43
Nitrate (mg/L)	0.1	14	4.56	4.65
Phosphate (mg/L)	0.11	7.9	1.04	1.61
Sulphate (mg/L)	2	4500	1056.43	1180.75
Silica (mg/L)	1.6	3.8	2.96	0.41

Calcium (mg/L)	7.21	2228.9	308.24	383.95
Magnesium (mg/L)	1.9	1433.3	567.70	410.63
Copper (mg/L)	0.003	0.051	0.01	0.01
Iron (mg/L)	0.03	0.38	0.15	0.09
Zinc (mg/L)	0.0009	0.012	0.01	0.00
Cadmium (mg/L)	0.001	0.013	0.01	0.00
Lead (mg/L)	0.002	0.011	0.01	0.00
Chromium (mg/L)	0.01	0.01	0.01	0.00
Manganese (mg/L)	0.005	0.028	0.01	0.01
Nickel (mg/L)	0.003	0.014	0.01	0.00
Chlorophyll *a* (µg/L)	3.2	13.2	8.60	2.90

Chlorophyll *a* and zooplankton analysis

Chlorophyll *a* recorded high values at the beginning of the sampling but fluctuated as the sampling progressed. Values ranged from <1.0 to 13.2 µg/L. The highest value was recorded in week 2 in December, 2010 while the lowest value was recorded in week 34 in July, 2011. The mean value and standard deviation values were 8.6 and 2.9 respectively. Correlation between chlorophyll *a* and other physico-chemical parameters are shown in Table 2.

The Zooplankton biomass in terms of abundance were higher in the dry months when Salinity was higher, the Zooplankton spectrum consisted of two phyla and eight juvenile stages. The zooplankton phyla identified were phylum Arthropoda and phylum Cnidaria, the juvenile stages comprise of the Annelids larva, Bivalve larva, Fish eggs, Gastropod eggs, Gastropod larva, Megalopa larva, Nauplii larva of Barnacle and Zoea larva. The prevalent species were *Acartia clausii, Acartia discaudata, Cyclopina longicornis, Paracalanus parvus, Oithona rigida*, and Unidentified Jelly Fish.

Table 2: Pearson correlation co-efficient between Chlorophyll a and physic-chemical characteristics at the Mariculture site (November, 2010 – June, 2011).

Parameters	(r)	Parameters	(r)	Parameters	(r)
Air temperature (^{0}C)	0.09	**Total Hardness (mg/L)**	-0.48	**Magnesium (mg/L)**	**-0.29**
Water temperature (^{0}C)	0.35	**Dissolved Oxygen (mg/L)**	-0.24	**Zinc (mg/L)**	**0.33**
Rainfall (mm)	-0.56	**Biological Oxygen demand$_5$ (mg/L)**	0.36	**Iron (mg/L)**	**0.29**
Total Suspended Solids (mg/L)	0.19	**Chemical Oxygen Demand (mg/L)**	0.44	**Copper (mg/L)**	**0.51**
Total Dissolved Solids (mg/L)	-0.23	**Chloride (mg/L)**	-0.36	**Cadmium**	**0.45**
pH @ 25°C	-0.31	**Nitrate (mg/L)**	-0.46	**Lead**	**-0.20**
Conductivity (úS/cm)	-0.35	**Sulphate (mg/L)**	-0.56	**Chromium**	**-5.90**
Salinity ($^0/_{00}$)	-0.24	**Phosphate (mg/L)**	-0.36	**Manganese**	**0.16**
Acidity (mg/L)	0.20	**Silica (mg/L)**	0.18	**Nickel**	**0.69**
Alkalinity (mg/L)	**-0.24**	**Calcium (mg/L)**	**-0.28**	**Chlorophyll *a* (µg/L)**	**1.00**

Discussion

According to Onyema *et. al.* (2003) and Emmanuel and Onyema (2007), the salinity regime in the Lagos lagoon is seasonal with high salinities reported from December to April and low salinities observed from May through November. In agreement with this, the salinities were lower in week 1 to 3 (November), 2010 and higher from week 9 (January). Hence hydro-meteorological forcings are implicated in the control of the water quality conditions of the Lagos lagoon, namely freshwater associated with rains and seawater incursion. Various authors have reported that the dynamic interplay between tidal seawater incursion and flood water inflow from adjoining rivers and creeks are the key factors governing the hydrodynamics of the Lagos lagoon (Hill and Webb 1958, Nwankwo 1990, Onyema 2013).

Salinity recorded greater values (brackish) as the dry season progressed (Dec. 2010 – May 2011). The high salinity values recorded during the dry season of the investigation period may be attributed to low rainfall, high evaporation rate coupled with low humidity, increased tidal seawater incursion, reduced flood water and water inflow from associated rivers and creeks. These impacted the physico-chemistry of the marticulture site.

Increase in zooplankton abundance corresponded with increase in salinity. The pH values were essentially alkaline due to the buffering effects of the sea water from tidal influences. Similar views have been reported by Oyewo (1998) Nwankwo (1996), Ajao (1990) and Nkwoji *et.al*, (2010). Similarly, conductivity during sampling period was relatively high during the dry months. This could be due to low incidence of rainfall, which must have given rise to marine condition as sea water inflow affected the lagoon environment. According to Nwankwo (1988), Dissolved oxygen decreases with increase in temperature and biological oxygen demand due to increased metabolic activities of most species.

The low dissolved oxygen levels recorded during the wet period coupled with very high biochemical oxygen demand levels within the lagoon are indicators of severe pollution stress within the Lagos lagoon. The higher the amount of pollution, the lower the levels of dissolved oxygen usually estimable (Onyema, 2009a). This could be attributed to the high organic content, mainly human faeces, decayed plant and animal materials and domestic effluents flushed into the lagoon from different land-based sources and areas. On the other hand, the increased dissolved oxygen content of the lagoon during the dry period may be as a result of high transparency and increased productivity by both the macrophyte vegetation and phytoplankton algae. Increased aquatic photosynthesis gives rise to moreoxygen released as by-product.

It is important to note that higher chlorophyll *a* levels were recorded in the dry season known for hydrological stability and the existence of environmental gradients within the lagoon. This is not withstanding the comparatively reduced level of nutrients at this time. Hence, hydrological stability and increased resident time of water within the mariculture site may be "more important' to primary productivity than nutrient levels (Fig. 2). This may allow the colonization and development of the phytoplankton community as against the flushing out to sea especially during the wet season.

Most tropical waters have low nutrients values, a feature considered common for natural and polluted waters, but the level of sulphates and nitrates recorded during the study is suggestive of both chemical and organic pollution and nutrient enrichment. Nutrient (nitrate – nitrogen and phosphate – phosphorus) recorded higher values during the study period probably due to the high amount of organic wastes, which enters the lagoon through run-offs while the high values of sulphate and silicate recorded may be a reflection of the high amount of bio-degradable waste discharges in the region and reduced dilution effects from floodwaters. This is in agreement with Ajao (1990) who observed that the nutrient levels obtained in Lagos lagoon were mainly governed by suspended sediments transportation with the fresh water influx, and this usually occurs during the wet seasons. Olaniyan (1969) while working on the lagoons of southern Nigeria revealed that the variation in the nutrients content was related to the pattern of rainfall.

Onyema (2011) is of the view that it is possible that the fish feed introduction and consequent deterioration and disintegration of uneaten feed in the Mariculture site did not impact the water measurably as would have been expected. This is probably because the area is tidal and flow conditions change semi-diurnally. This could have ameliorated the prospective effect of the introduction of the fish feed and wastes to the endemic plankton species. The increase in available nutrients coupled with reduced current speed causes an increase in phytoplankton population and hence an increase in zooplankton (Onyema, 2009a).

The pattern of variation of chlorophyll *a* values observed during this study is in agreement with Kadiri (1993). Chlorophyll *a* values were observed to be moderately high throughout the study period but higher in the dry months than in the wet months confirming earlier observations by Kadiri (1993) and Ogamba *et. al., (*2004). This may be attributed to high light intensity, reduced cloud cover and more stable conditions which permitted maximum use of available nutrients by the phytoplankton, hence an increase in biomass (Onyema and Emmanuel, 2009).

Generally, zooplankton diversity was higher in the dry than in the wet period. More stable conditions including water flow characteristics, light penetration, reduced rainfall and increased salinity conditions experienced in the dry season could have encouraged the development of a richer zooplankton spectrum within the site, while freshwater conditions during the wet months reduced zooplankton abundance.

Similar observations have been made by Kusemiju *et. al*. (1993), Onyema (2009a), Onyema and Nwankwo, (2009) in similar environment in the region. The high species abundance and diversity, recorded in week 19 (March), 2011 may be associated to the increased nutrients during the dry period. The zooplankton community was dominated by calanoid copepods mainly *Arcatia clausii* and *Paracalanus parvus* confirming earlier reports by Onyema *et. al.,* (2003, 2007) and Onyema and Ojo (2008). The abundance of an array of developmental stages in the zooplankton spectrum especially crustaceans of known estuarine and migratory fauna may point to the suitability of the site as a nursery and breeding ground. This observation is in consonance with reports of Nwankwo and Gaya (1996) and Solarin and Kusemiju (2003). According to Onyema *et. al.* (2007), the occurrence of fish eggs, larvae and juvenile stages of known marine forms may confirm suggestions that the Lagos lagoon is populated by immigrant forms from the sea particularly during the dry season.

More zooplankton taxa (11) were observed in week 21 and week 25. An increase in abundance (295 individuals per ml) was observed in week 19 when chlorophyll *a* concentration decreased from 11 to 9µg/L). Increasing zooplankton population corresponded with rise in salinity in the dry season only i.e. zooplankton abundance had a positive correlation with salinity. It is possible that increasing tidal inflow in the dry season allow for the recruitment of more marine plankton (Onyema, 2009a). According to Holden and Green (1960), the low plankton number in the wet months was due to flood water which diluted the plankton and other important chemical content. Zooplankton species and abundance increased with season. Sea water incursion increases salinity, recruits euryhaline species and changes the biotic spectrum of the Lagos lagoon (Nwankwo, 1996, Nwankwo *et al*., 2004). According to Onyema *et. al*., (2007) the occurrence of euryhaline copepods may be indications of incursion of marine forms.

Conclusion

The weekly water chemistry, chlorophyll *a* and zooplankton diversity at a Mariculture site in the Lagos lagoon were investigated. The physical and water chemistry parameters were more “brackish” in the dry season and “fresher” in the wet season, and linked with the tidal sea water incursion and flood water inputs from rainfall. Chlorophyll *a* concentration were negatively correlated with nutrients. The Zooplankton was higher in the dry (weeks) season when Salinity values were higher. Juvenile stages suggested a breeding and nursery aquatic ecosystem.

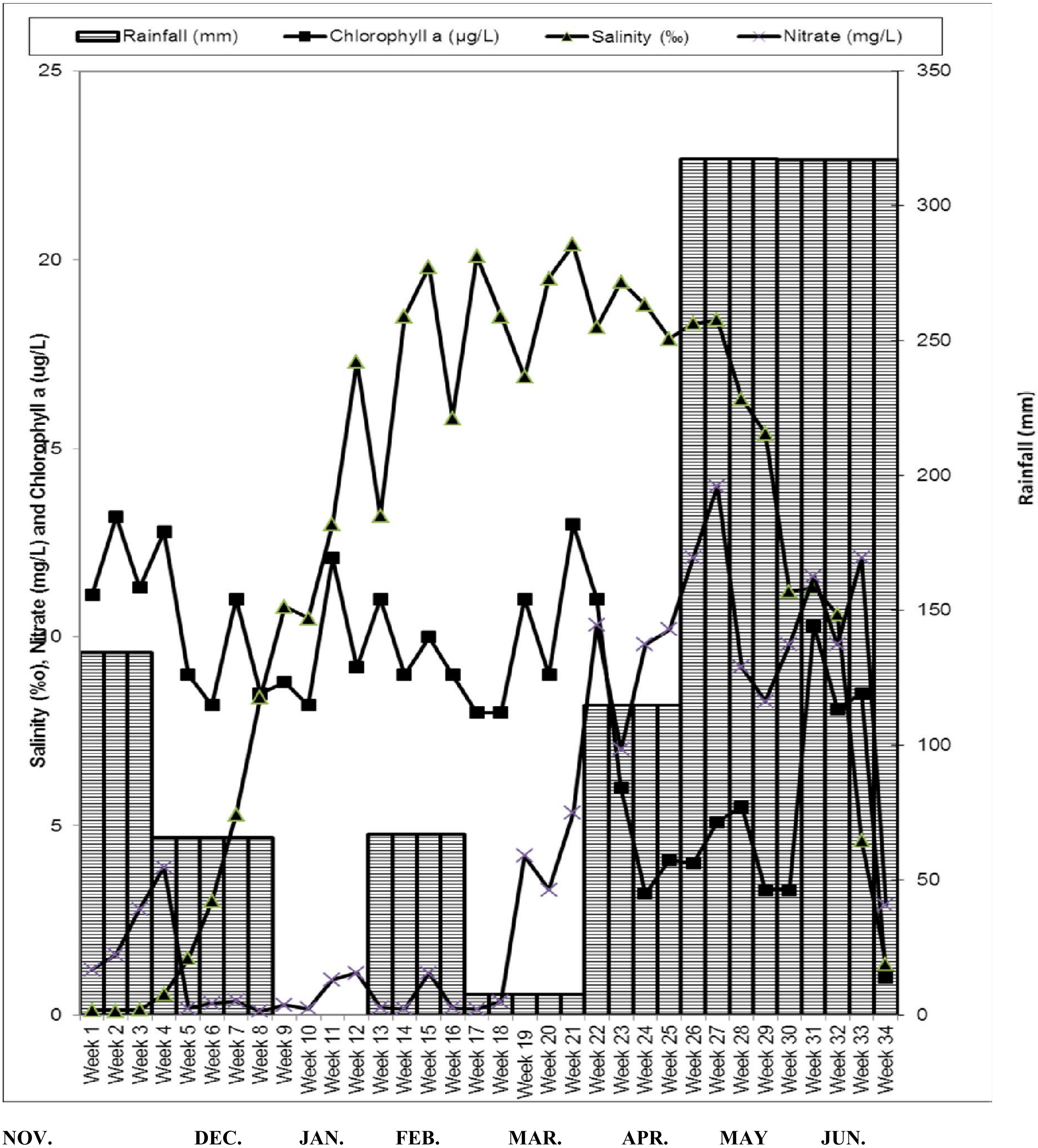

Fig. 2: Weekly variations in chlorophyll *a*, Salinity, Nitrate and Rainfall at the Mariculture site, Lagos lagoon

References

Ajao E.A. (1990).The influence of domestic and industrial effluents on populations of sessile and benthic organisms in Lagos Lagoon. PhD Thesis, University of Lagos. 411p.

Ajao, E.A. (1996). Review of the state of pollution of the Lagos lagoon. NIOMR Tech. Paper No. 106. 19pp.

Akpata, T. V. I., Oyenekan, J. A. and Nwankwo, D. I. (1993). Impact of organic pollution on the bacterial, plankton and benthic populations of Lagos lagoon, Nigeria. *International Journal of Ecology and Environmental Sciences*. **17:** 1-10.

American Public Health Association. (1998). *Standard Methods for the Examination of Water and Waste Water*. 20th ed. APHA New York. 1270pp.

Chukwu, L. O. and Nwankwo, D. I. (2004). The impact of land-based pollution on the Hydrochemistry and Macrocommunity of a Tropic West Africa creek. *The Ekol.*, **2:** (1-2): 1-9.

Egborge, A. B. M. (1994). Salinity and the distribution of rotifers in the Lagos Habour – Badagry creek system, Nigeria. *Hydrobiologia*. **272**: 95 – 104.

Emmanuel, B. E. and Onyema, I. C. (2007). The plankton and fishes of a tropical creek in South-western Nigeria. *Turkish Journal of Fisheries*. **7:** 105-113.

F.A.O. (1969). "Fisheries Survey in the western and mid-western regions of Nigeria". FAO/SF.74/NIR 6, 142p.

Hill, W. B. and Webb, J. E. (1958). The ecology of Lagos lagoon II. The topography and physical features of Lagos Harbour and Lagos lagoon. *Philosophical Transactions of the Royal Society of London.* **241**: 307-419..

Holden, M. J. and Green, J. (1960). The hydrology and plankton of Sokoto River. *Journal Animal Ecology*. **29**: 65-84.

Kadiri, M. O. (1993). Seasonal changes in the phytoplankton biomass of a shallow Tropical reservoir. *Nigerian Journal of Botany.* **6**: 167 – 175.

Kusemiju, K., Nwankwo, D. I. and Bamisaye, R. B. (1993). The Hydrobiology and Fishes of Opobo Channel, Rivers State, Nigeria. *Journal of Scientific Research and Development 1(1):* 74 – 79.

Kirk, R. M. and Lauder, G. A. (2000). Significant coastal lagoon systems in the South Island, New Zealand. Coastal processes and lagoon mouth closure. *Science for conservation*.**146:** 47 p. Kjerfve, B. (Ed.) 1994: *Coastal lagoon processes*. Elsevier Oceanography Series 60. Elsevier, Amsterdam. 577p.

Lawal-Are, A. O., Onyema, I.C. and Akande, T. R. (2009). The Water Chemistry, Crustacean, Zooplankton And Some Associated Faunal Species Of A Tropical Tidal Creek In Lagos, Nigeria. *Journal of American Science*. **5**(7):81-90.

Lee, R.E. (1999). *Phycology.* 4th Edition. Cambridge University Press, New York. 547pp.

McGinty, A. S. and Rakocy, J. E. 1989. Cage culture of Tilapia. SRAC Publication No. 281. 4pp.

Nkwoji, J. A., Onyema, I. C. and Igbo, J. K. (2010). Wet Season spatial occurrence of Phytoplankton and Zooplankton in Lagos lagoon. *Science world Journal.* **2**(5): 214 - 218.

Nwankwo, D.I. (1988). A preliminary checklist of planktonic algae in Lagos lagoon Nigeria. *Nigeria. Journal of Botanica l Applied Sciences..* **2**: 73-85.

Nwankwo, D. I. (1990). Contributions to the Diatom Flora of Nigeria 2. Diatom of Lagos lagoon and adjacent sea. *Nigeria Journal of Botany.* **3:** 53-70.

Nwankwo, D.I. (1988). A preliminary checklist of planktonic algae in Lagos lagoon Nigeria. *Nigeria. Journal of Botanica l Applied Sciences..* **2**: 73-85.

Nwankwo, D. I (2004). The Microalgae: Our indispensable allies in aquatic monitoring and biodiversity sustainability. University of Lagos Press. Inaugural lecture series. 44p.

Nwankwo, D. I. (1996). Phytoplankton diversity and succession in Lagos lagoon, Nigeria. *Archiv fur Hydrobiologie.* **135** (4): 529-542.

Nwankwo, D.I. and Gaya, E.A. (1996). The Algae of an Estuarine Mariculture Site in South-Western Nigeria. *Tropical Fresh Water Biology.* **5**: 1-11.

Nwankwo, D.I., Onyema., I.C, Labiran, C.O., Otuorumo, O.A.; Onadipe, E.I.;, Ebulu, M.O. and Emubaiye, N. (2004). Notes on the observations of brown water discolouration off the light house beach, Lagos, Nigeria. *Discovery and innovation*. **16** (3). 111 – 116.

Odiete, W. O (1999). *Environmental Physiology of Animals and Pollution.* Diversified Resources Ltd., Lagos. 261p.

Ogamba, E. N., Chindah, A. C., Ekweozor, I. K. E. and Onwuteaka, J. N. (2004). Water quality of phytoplankton distribution in Eledu creek complex of the Niger delta. *Journal of Nigerian Environmental Society*. **2**(2):121-130.

Olaniyan, C. I. O. (1969). The seasonal variation in the hydrology and total plankton of the lagoons of Southwestern Nigeria. *Nigerian. J. of Sci*. **3**(**2**): 101-129.

Olaniyan, C. I. O (1975). *An Introduction to West African Ecology*. Heinemann Education Books Ltd., London. 170p.

Onyema, I.C. (2009a). *Pollution and the ecology of coastal waters of Nigeria:* . Dolps and Bolps Investment Limited, Lagos, Nigeria. 216pp.

Onyema, I.C. (2009b). Zooplankton dynamics and chlorophyll a concentrations at the Tomaro creek in relation to water quality indices. *Report and Opinion*. **1**(6): 51 – 64.

Onyema, I. C (2009c). Notes on the existence of an additional lagoon in South-western Nigeria: Apẹṣẹ Lagoon. *Journal of American Science*. **5**(4):151-156

Onyema, I.C. (2009d). The Water Chemistry, Phytoplankton Biomass (Chlorophyll *a*), Episammic and Periphytic Algae of the Apese Lagoon, Lagos. *Report and Opinion*. **1**(5): 31 – 40.

Onyema, I. C. (2011). The Water chemistry and Periphytic Algae at a Cage culture site in a Tropical open lagoon in Lagos. *Journal of life and physical sciences. actaSATECH.* **4** (1): 53-63.

Onyema, I.C. (2013). The Water Quality Changes And Phytoplankton Of An "Acadja" System In A Tropical Estuarine Lagoon In Lagos. *Res. J. Pharm. Biol. Chem. Sci*., **4**(1):1132-1143

Onyema, I. C., Otudeko, O. G. and Nwankwo, D. I. (2003) The distribution and composition of plankton around sewage disposal site at Iddo, Nigeria. *Journal Science Research Development* **7**: 11-24.

Onyema, I. C., Okpara, C. U., Ogbebor, C. I. Otudeko, O. and Nwankwo, D. I. (2007) Comparative studies of the water chemistry characteristics and temporal plankton variations at two polluted sites along the Lagos lagoon, Nigeria. *Ecology, Conservation and Environment*. **13**(1): 1-12

Onyema, I. C and Ojo, A. A. (2008). The zooplankton dynamics and chlorophyll *a* concentration of a tropical tidal creek in relation to water quality indices. *Life Science Journal*. **5** (4): 7 – 14

Onyema, I. C and Emmanuel, B. E (2009). Fishing impairment and *Spirogyra africanum* (Fruda) in a freshwater lagoon. *Estonian Journal of Ecology*. **58** (1): 1 – 7.

Onyema, I. C and Nwankwo, D. I (2009). Chlorophyll a dynamics and environmental factors in a tropical estuarine lagoon. Academia Arena. 1(**1**): 18 – 30.

Onyema, I. C., Nkwoji, J. A. and Eruteya, O. J. (2010). The water chemistry and plankton dynamics of a Tropical high energy erosion beach in Lagos. *Journal of American Science*. (**6**): 1. 122p.

Oyewo, E. O (1998). Industrial Sources and Distribution of Heavy Metals in Lagos Lagoon and Biological Effect on Estuarine Animals. PhD Thesis. University of Ibadan. 279p.

Solarin, B.B. and Kusemiju, K. (2003). Fish shelters as fisheries enhancements techniques Lagos lagoon, Nigeria. *Nigerian Journal of Fisheries.* 1: 57 – 61.