The hydrochemistry and biota of a thermal coolant water stressed tropical lagoon.

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Abstract: The effect of coolant or waste heat discharge on the water characteristics, phytoplankton, zooplankton and benthic macro invertebrate at the Egbin area of the Lagos lagoon were investigated from February to July, 2000 at three (3) stations. The water quality reflected the influences of coolant water introduction, net tidal seawater inflow in the dry season and freshwater incursions effects in the raining season. Whereas the phytoplankton recorded 83 species, the zooplankton recorded 23 species and the benthos five species. Comparatively higher cyanobacteria diversity for the phytoplankton, water temperatures, transparency coupled with reduced dissolved oxygen levels were recorded at station 1 throughout the study and possibly reflect the effects of coolant water introduction. Notable phytoplankton species recorded were *Aulacoseira granulata, A. granulata* var. *angstissima*, *Gonatozygon* and *Spirogyra aficanum* that marked the wet season. Similarly, *Acatia clausii, Paracalanus parvus* and *Cylops* sp were frequently occurring for the zooplankton and the benthos was notably represented by *Pachymelenia aurita, Tympanotonus fuscatus* and *Aloidis trigona*. Furthermore, whereas the phytoplankton was dominated by diatoms, copepods and gastropods dominated the zooplankton and benthos of the study area respectively. The effects of elevated temperature reduced as stations were increasing distant from the waste heat deposition site. Additionally, sand mining in the region may also have negatively affected the distribution of benthic fauna. [Nature and Science 2010;8(1):18-32]. (ISSN: 1545-0740).

Keywords: Coolant water, phytoplankton, zooplankton, benthos, macro invertebrate fauna, lagoon, thermal station

Introduction

The Lagos lagoon system is the largest of the four lagoon systems of the Gulf of Guinea (Chukwu, 2002). This aquatic ecosystem is habitat to a variety of biota which include the plankton, nekton and benthos in a complex trophic interrelationship (Emmanuel and Onyema, 2007). The Lagos lagoon environment apart from being sheltered from reduced hydrodynamics of the sea, serves for fishing, a seaport, recreation destination, nursery, feeding and spawning ground for a diverse number of fish and fisheries (Akpata *et al*., 1993; Chukwu, 2002; Onyema *et al*., 2003). There are a number of published work on the species spectrum distribution and aspects of the ecology of phytoplankton (Nwankwo 1988, 1996; Nwankwo *et al*., 2003), zooplankton (Olaniyan, 1969; Akpata *et al*., 1993; Onyema *et al*., 2003; 2007; Emmanuel and Onyema, 2007) and macro-invertebrate fauna (Onyenekan, 1988; Brown and Oyenekan, 1998; Brown, 1998; Ogunwenmo, 2002) of the Lagos lagoon.

In Nigeria, over 85% of all industries are located in the Lagos Metropolitan area (Odiete, 1999). These industries discharge their effluents through channels and drainage systems into nearby storm water drains and coastal waters (Nwankwo, 2004). Of particular interest are sewage outfalls, textile mills, woodwastes, breweries and chemical facilities located in several layouts of the metropolis. Also important in this regard are thermal plants used for electricity generation and which release waste heat into the aquatic environment (Ajao, 1996). A number of electricity generating power plants exist in Nigeria. These include plants in Ijora (Lagos State), Afarm-Imo river (Rivers State), Oji river (Enugu State), Ughelli (Delta State) and Egbin (Lagos State) which is the largest in the country with a generation capacity of 1320 Watts (Ukuoma, 1989). The Egbin thermal station accounts for a quarter of Nigeria's installed power capacity presently. However, the station is only able to generate between 350 and 800 Megawatts of electricity especially in the last few years which is below its installed capacity. This has been largely due to the consistent vandalisation of its gas supply pipelines and hence translates to under production and acute shortage of electricity. This scenario has been the bane of the national power industry in Nigeria.

Thermal plants are known to release coolant (hot) waters as a major waste fallout of the internal combustion process (Ajao, 1996; Odiete. 1999; Chukwu, 2002, 2006). With regard to the ecological effects of the introduction of such waste heat on the recipient aquatic environment it was needful to conduct a spatio-temporal study to investigate the species present and the impact of such elevated temperature conditions on the plankton and benthic spectra of the lagoon area.

Materials and Methods.

Description of study site.

The coast of South-western Nigeria is a meandering network of lagoons and many creeks, of which the Lagos lagoon with an area of 208 sq km is about central and important in terms of size (FAO, 1969; Nwankwo, 2004). The study site of this work (Egbin) with co-ordinates at about Longitude $3^{0}40$ and Latitude 6^{0}, 34'E is located to the east of the Lagos lagoon (Fig. 1). The lagoon is open all year round via the Lagos habour and experiences both tidal and salinity regimes. It provides the only opening to the sea for the lagoons of South-western Nigeria (Onyema, 2008). Sea water associated with semi-diurnal tidal regime and fresh water from adjourning wetlands are the two main factors that determine the physico-chemical parameters and biology of the lagoonal area (Nwankwo, 1996; Chukwu and Nwankwo, 2004; Onyema and Nwankwo, 2009). In the Lagos lagoon, there is a direct relation between the seasonal bimodal rainfall pattern, the environmental gradient and the biotal gradient. Owing to the dynamics of river inflow and seawater incursion, the Lagos lagoon experiences brackish condition that is more discernable in the dry season (Onyema *et al*., 2008). In the wet season, the increased river inflow creates freshwater and low brackish conditions in various parts of the lagoon. Most of the lagoon area are colonized by riparian mangrove swamp community. Some notable macro-floral species in the area include *Rhizophora racemosa, R. harrisoni, Paspalum vaginatum, Avicennia germinans, Phoenix reclinata, Raphia hookeri, Elaeis guineensis, Acrotiscum aureum* and *Cocos nucifera*.

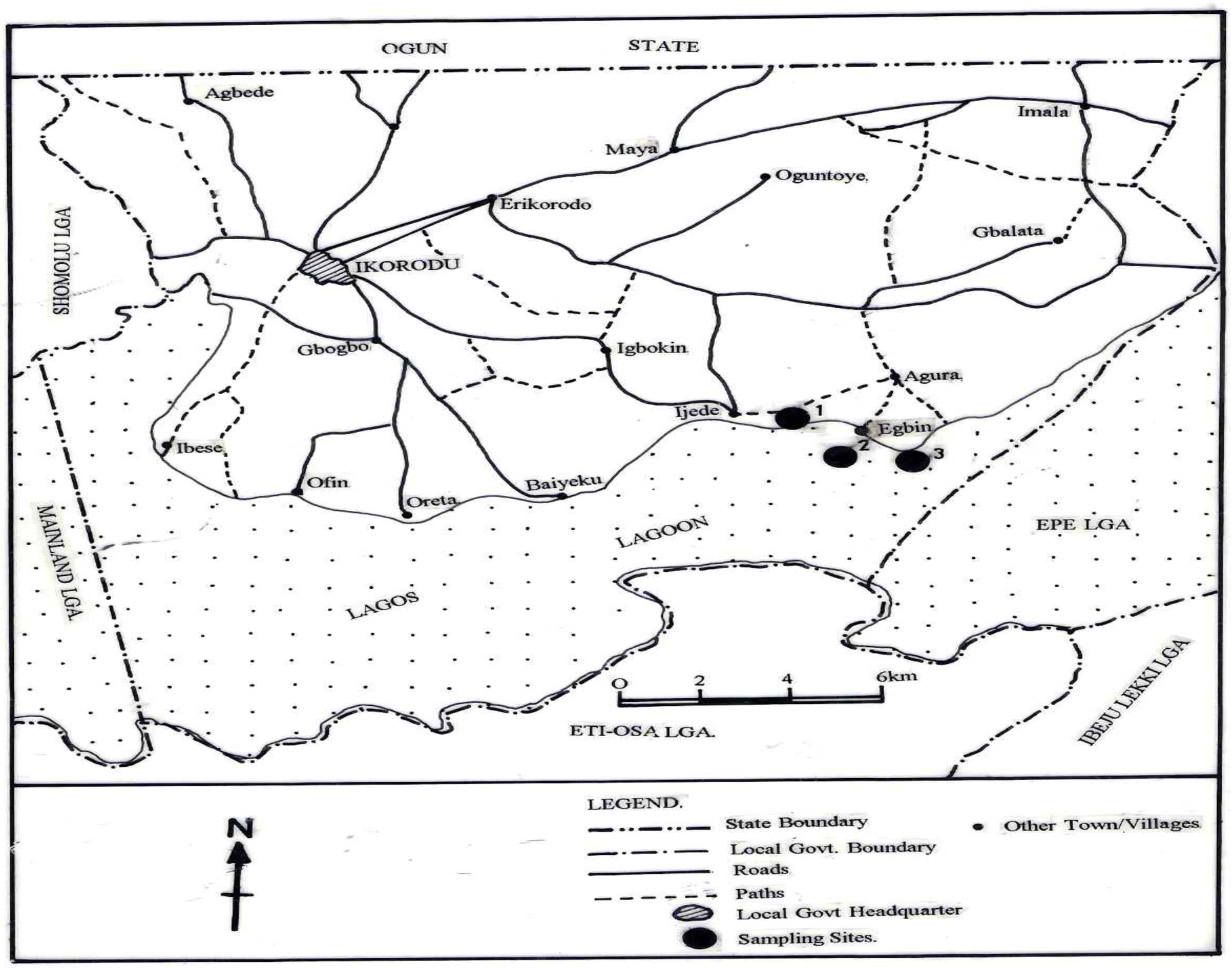

Fig 1: Part of the Lagos lagoon showing important town in the area including Egbin.

Collection of samples.

Monthly samples were collected over a period of six months between September, 2004 and February, 2005 for water chemistry analysis, phytoplankton, zooplankton and benthos. Samples were collected from three stations designated as stations 1, 2 and 3. Station 1 being the site closest to the facility and receives the discharged of coolant water from the thermal station, station 2 is located about 200m away from station 1. Furthermore, Station 3 is located downstream (200m) from station 2.

Collection of water samples

Surface water samples were collected for the survey for physico-chemical characteristics analysis using 1.5L plastic containers with screw caps. Collection of samples from the sites were between 10 and 15hr. Water samples were collected just a few centimeters below the water surface. The plastic containers were labeled appropriately and transported to the laboratory and stored in the refrigerator ($t \leq 5^0C$) prior to further laboratory analysis.

Collection of plankton samples.

Plankton sample were collected with a 55µm mesh size standard plankton net towed from a motorized boat for 5minutes at low speed (<4 knots) at the three sampling stations (1, 2 and 3). The net was then hauled in after this time and the plankton sample transferred into a 250ml well labeled plastic containers with screw cap. Samples were labeled aptly and preserved with 4% unbuffered formalin and stored in the laboratory prior to microscopic analysis of the plankton. This is after samples have concentrated to 10ml.

Collection of benthic samples

Sampling was carried out at three stations using a Van Veen grab ($0.1m^2$) from an anchored boat. Three grab hauls for benthic samples were also taken from each station, the collected material was washed through a 0.5mm mesh sieve in the field. Preservation of the residue in the sieve was with 10% formalin solution. These were then stored in labeled plastic containers and transported to the laboratory. The sediment samples collected at each station were placed in three different labeled polyethylene bags for physical and chemical analysis in the laboratory. The samples were stored in the fridge prior to analysis.

Physico-chemical analysis

Table 1 below tabulates the methods and reference used in the determination of some of the physico-chemical parameters.

Table 1: Summary of environmental factors and method/device used for their estimation for water samples.

	Parameter/ Unit	Method / Device	Reference
1	**Water temperature (^oC)**	Mercury – in – glass thermometer	Brown (1998)
2	**Transparency (cm)**	Secchi disc	Nwankwo (1984)
3	**Rainfall (mm)**	Acquired from NIMET, Oshodi, Lagos	
4	**Total Dissolved Solids (mgl^{-1})**	Cole Palmer TDS meter	
5	**Total Suspended Solids (mgl^{-1})**	Gravimetric	APHA (1998)
6	**pH**	Electrometric / Cole Parmer Testr3	
7	**Conductivity (µS/cm)**	Philip PW9505 Conductivity meter	
8	**Salinity (‰)**	HANNA Instrument	APHA (1998)
9	**Dissolved oxygen (mgl^{-1})**	Titration	APHA (1998)
10	**Nitrate – nitrogen (mgl^{-1})**	Colorimetric	APHA (1998)
11	**Phosphate – phosphorus (mgl^{-1})**	Colorimetric	APHA (1998)
12	**Sulphate (mgl^{-1})**	Turbidimetric	APHA (1998)
13	**Copper (mgl^{-1})**	Atomic Absorption Spectrophotometer Perkin Elmer 5000 AAS	Perhin Elmer Application methods (2002)
14	**Iron (mgl^{-1})**	Atomic Absorption Spectrophotometer Perkin Elmer 5000 AAS	Perhin Elmer Application methods (2002)
15	**Lead (mgl^{-1})**	Atomic Absorption Spectrophotometer Perkin Elmer 5000 AAS	Perhin Elmer Application methods (2002)

Sediment analysis

Total organic matter (Ash method).

A portion of the sediment stored in plastic containers in the freezers was oven dried at 500°C after allowing the frozen samples to thaw. The drying process continued until a constant weight of the sample was obtained. 5 g of the dried sample was placed in a pre-weight crucible and kept in a muffle furnace for 8hours at 6000°C. It was then cooled. The crucible and its content were re-weighted and the total organic matter (T.O.M.) was calculated as a percentage of the original weight.

$$T.O.M. = \frac{\text{Loss of weight on ignition (Xg)}}{\text{Initial weight}}$$

Where X (g) = A1 (g) - A2 (g)

A1 = Initial weight of sample

A2 = Final weight of sample

Sediment texture

The sediment collected for all the stations during the study were separated into different textures. This was done with the aid of a measuring cylinder. Water was added into the measuring cylinder and was thoroughly shaken for 2minuetes after which the cylinders were left to settle down for 24hours. After 24hours the sediment had separated into different fractions mainly sand, clay and silt, and the percentage of each texture was determined using the formula:

$$\% \text{ Sediment texture} = \frac{\text{Height of sample}}{\text{Total height of sediment}} \times 100$$

Plankton analysis.

In the laboratory five drops of the concentrated sample (10ml) were investigated at different magnifications (50X, 100X and 400X) using a Wild II binocular microscope with calibrated eye piece and the average recorded. The drop count method described by Lackey (1938) was employed. Since each drop is 0.1ml the results on abundances were multiplied accordingly to give the values as numbers of organisms per ml which is the standard unit. Appropriate materials were used to aid identifications. The final data were presented as number of organisms per ml (cells, filaments, colonies).

Appropriate texts were used to aid identification (**Phytoplankton**-Hendey 1958, 1964; Wimpenny, 1966; Patrick and Reimer, 1966, 1975; Whitford and Schmacher, 1973; Vanlandingham, 1982; Nwankwo, 1990, 1995, 2004; **Zooplankton**- Newell and Newell, 1966; Olaniyan, 1975, Barnes *et al.,* 1993 and Waife and Frid, 2001).

Benthic sample analysis.

Preserved benthic samples were washed with tap water to remove the preservative and any remaining sediment in order to make sorting easier. The animals were sorted on a white tray into taxonomic groups (Phyla, class, families, species) using suitable texts (Olaniyan, 1975; Oyenekan, 1975; Edmunds, 1978; Schreider, 1990; Barnes *et al*., 1993) as identification guide. The number of species and individuals for each station were counted and recorded.

Community structure analysis

The following diversity indices were used for biological data analysis.

Species Richness Index (d)

The Species richness index (d) according to Margalef (1951) is a measure of diversity and was used to evaluate the community structure. The equation below was applied and results were recorded to two decimal places.

$$d = \frac{S - 1}{\ln N}$$

Where:

d = Species richness index

S = Number of species in a population

N = Total number of individuals in S species.

Menhinick's Index (D) (Ogbeibu, 2005).

$$D = \frac{S}{\sqrt{N}}$$

S = Number of species in a population

N = Total number of individuals in S species.

Shannon and Wiener diversity index (Hs)

Shannon and Wiener (1963) diversity index (H) Hs = ∑ Pi 1n Pi

Where

Hs = Diversity Index

i = Counts denoting the ith species ranging from 1 – n

Pi = Proportion that the ith species represents in terms of numbers of individuals with respect to the total number of individuals in the sampling space as whole.

Species Equitability (j).

$$j = \frac{Hs}{\log_2 S}$$

Where

j = Equitability index

Hs = Shannon and Wiener index

S = Number of species in a population

Simpsons dorminance index (C) (Ogbeibu, 2005).

$$C = \Sigma (n/N)^2$$

Where n = the number of species in the ith species.

N = the total number on individuals.

Correlation Coefficient Values (r)

The Pearson correlation coefficient (r) (Ogbeibu, 2005) for the relationship between water quality characteristics, and biotic component at the different stations were obtained using the formula:

$$r = \frac{n(\Sigma XY) - (\Sigma X)(\Sigma Y)}{\sqrt{(n(\Sigma X^2 - (\Sigma X)^2] [n\Sigma Y^2 - (\Sigma Y)^2}}$$

Where

r = Coefficient of correlation

X and Y = Variables under consideration

RESULT

Physico-chemical parameters

Results of the various water quality characteristics are presented in Table 1. Water temperature recorded at the sampling stations were between 27 and 40^0C . The highest water temperature value (40^0C) was recorded in May at Station 1, while the lowest value (27^0C) was recorded in February, June and July at Station 3. Furthermore, temperature values recorded the highest estimates at Station 1 throughout the study. Transparency values were higher in the dry months than the wet months. Values were between 66 and 196cm. The highest value (196cm) was recorded in February at Station 1, while the lowest (66cm) was recorded in June at Station 2. Measurable difference was recorded between total suspended solid values in the dry and wet months. An estimate of 450 mgl^{-1} (highest value) occurring in July at Station 1 while the lowest was in April at Station 2 and 3 respectively. The total dissolved solids content was higher in the dry months than the wet months. Values were between 394 mgl^{-1} (July at Station 3) and 12546 mgl^{-1} (March at Station 2). The pH values were between 6.23 (May at Station 3) and 6.96 (May at Station 2). Conductivity values were higher in the dry months than wet months and ranged between 7.9 x 10^{-4} and 2.5 x 10^{-2} Scm^{-1} during the study period. Dissolved Oxygen values during the study period were between 3.2 (May at Station 1) and 5.7 mgl^{-1} (June at Station 3). Furthermore, values were comparatively lower in Station 1 than other stations for the study.

Salinity was between 1.1 (July at Stations 1 and 3) and 12.1‰ (March at Station 2). The nitrate-nitrogen values were higher in the wet months. Values were between 0.12 (July, Station 3) and 3.98 mgl^{-1}(March at Station 2). Low phosphate-phosphorus values were recorded throughout the study period. The highest value (0.640mgl^{-1}) was recorded in March at Station 2, with the lowest (0.019 mgl^{-1}) in July at Station 3. Sulphate estimate was higher in the dry months than in the wet months and ranged between 35.5 (July at Station 3) and 1135 mgl^{-1} (March at Station 2). Heavy metal levels were high throughout the study, however higher levels were recorded in the dry than wet season. The highest Lead content (0.978 mgl^{-1}) was obtained in February at Station 2, while the lowest value (0.011 mgl^{-1}) occurred in May at Station 2. The highest value recorded for Copper (3.618 mgl^{-1}) occurred in March at Station 1, whereas the lowest value (0.006 mgl^{-1}) was in May at Station 2. The range of value recorded for Iron was between 0.06 mgl^{-1} in June at Station 2 and 3.618mgl were recorded in March at Station 1, respectively. The values for oil and grease obtained in samples collected during the dry months were higher than the values obtained during the wet months. A range of between 9.0 (occurring in March at Station 1) and 1.0 mgl^{-1} (in July at Station 3) was recorded.

Sediment.

Table 2 shows the Total organic matter of sediment (%) at the study area. Total organic matter for the study was between 0.1 and 0.3% which translates to 2 – 6% dry weight. With regard to percentage sediment texture composition, where as sand content varied from 49 to 97%, clay ranged between 0 and 28% and silt between 0 and 21%.

Total hydrocarbon content ranged between 0.14 and 0.32 mgl^{-1} for station 1, 0.03 and 0.21 mgl^{-1} for station 2 and 0.1 and 0.43 mgl^{-1} for station 3 throughout the study (Table 3). The percentage sediment profile for each station during the study period is shown in Table 3. Station 1 was predominantly sandy (78 – 97%); clay, 1 – 13%, and silt; 3 – 21%. Station 2 was mixture of and clay, sand (56-79%), clay (21-33%) and silt (0-19%). Station 3 however had more of clay (49-90%) sand (4-36%) and silt (1-15%).

Table 2: Physico-chemical parameters in the Lagos Lagoon at Egbin (February to July, 2000).

	Feb			March			April			May			June			July		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Water temperature (^0C)	36	32	27	37	34	29	38	36	29	40	38	30	38	34	27	35	34	27
Transparency (cm)	196	189	184	190	190	184	167	145	148	186	184	168	85	66	78	91	89	83
pH	6.57	6.53	6.45	6.74	6.62	6.69	6.5	6.4	6.6	6.23	6.96	6.93	6.32	6.8	6.83	6.93	6.81	6.47
Total Suspended Solids (mgL^{-1})	2	16	20	6	28	26	32	0	0	0	276	90	82	106	106	450	390	334
Total Dissolved Solids (mgL^{-1})	6496	7074	8082	11130	12546	1964	10036	9228	8960	9416	9080	8060	564	1198	798	402	410	394
Conductivity (Scm^{-1})	0.013	0.0141	0.0162	0.022	0.025	0.0039	0.020	0.0039	0.018	0.019	0.018	0.016	0.011	0.0024	0.0016	0.00080	0.00082	0.00079
Salinity ($^0/_{00}$)	6.5	6.7	7.7	10.1	12.1	7	9.3	7	7.4	7	6.7	7	1.4	1.4	1.4	1.1	1.2	1.1
Dissolved Oxygen (mgL^{-1})	3.6	4.3	4.7	3.7	5.1	5.4	4.7	4.9	5.5	3.2	4.7	5.3	4.8	5.3	5.7	5	5.1	5.4
Phosphate (mgL^{-1})	0.33	0.36	0.42	0.57	0.64	0.12	0.528	0.517	0.476	0.48	0.468	0.414	0.039	0.067	0.042	0.025	0.022	0.019
Nitrate (mgL^{-1})	2.1	2.94	3.25	3.92	3.98	0.86	3.61	3.58	3.28	2.99	2.88	2.57	0.19	0.38	0.28	0.15	0.14	0.12
Sulphate (mgL^{-1})	628	715	745	1008	1135	179	922	184	817	852	821	735	51	108	72	36	37	35.5
Oil and grease (mgL^{-1})	6	6	7	8	9	4	4	6	6	3 ND	ND	ND	6	2	4	2	5	1
Lead (mgL^{-1})	0.874	0.978	0.699	0.455	0.438	0.843	0.164	0.183	0.466	0.178	0.011	0.008	0.1581	0.513	0.301	0.489	0.618	0.776
Iron (mgL^{-1})	7.443	7.866	8.644	12.618	10673	6.114	6.646	5.758	0.917	4.618	0.102	0.619	2.688	2.316	0.778	8.643	16.481	10.165
Copper (mgL^{-1})	1.564	1.956	1.688	3.618	2.768	2.768	0.926	0.914	0.886	0.631	0.06	0.67	0.883	0.716	0.967	0.913	0.996	0.878

Table 3: TOTAL ORGANIC MATTER OF SEDIMENT (%) AT EGBIN THERMAL STATION

Parameter	**February**			**March**			**April**			**May**			**June**			**July**		
STATIONS	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Wt. Before ignition (g)	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Wt. After ignition (g)	4.9	4.9	4.9	4.8	4.8	4.9	4.9	4.9	4.7	4.9	4.9	4.7	4.9	4.7	4.7	4.7	4.8	4.8
Difference	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.3	0.1	0.1	0.3	0.1	0.1	0.3	0.3	0.2	0.2
%	2	2	2	4	4	2	2	2	6	2	2	6	2	2	6	6	4	4

Table 4. PERCENTAGE SEDIMENT TEXTURE OF SEDIMENT AT EGBIN THERMAL STATION

	February			**March**			**April**			**May**			**June**			**July**		
	1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Sand	83	79	94	94	74	75	96	68	68	78	78	65	95	83	49	97	66	83
Clay	12	21	0	0	23	24	0	25	29	1	15	28	5	13	36	0	15	13
Silt	4	0	6	6	3	1	4	7	3	21	7	7	0	4	15	3	19	4

Biological characteristics.

Phytoplankton

A total of 83 phytoplankton species from 43 genera were recorded for this survey (Table 4a). Whereas the diatoms recorded 50 species from 22 genera, the cyanobacteria recorded, 24 species from 13 genera, the green algae,7 species from 6 genera and the euglenoids were represented by 2 species from a sole genus. For the diatoms (bacillariophyceae) the pennate forms (32 Species) were more important than the centric forms (18 Species) in terms of species number. *Aulacoseira grannulata* and *A. granulata* var. *augustissima* were notable species in the wet season and recorded high numbers. Other notable species were *Melosiira moniliformi, Coscinodiscus centralis, Coscinodiscus eccentricus, Biddulphia aurita, Terpsinoe musica, Thalassionema fraunfeldii, Gyrosigma balticum, Pinnularia major, Pleurosigma angulatum,Synedra crystallina, Pinnularia major* and *Pleurosigma angulatum*.

For the cyanobacteria (cyanophyceae) the hormogones (15 Species) were better represented than the chroococoid forms (9 Species). Station 1 was better represented in terms of number of species and abundance than other stations for the cyanobacteria. Species represented were *Pseudanabaena galeata, Microcystis flos-aquae, Lynbgya martensiana, Aphanocapsa* sp., *Calothrix coenfervicola, Phormidium uncinatum, Schizothrix fasciculate, Oscillatoria formosa* and *Oscillatoria minima.*

For the green algae (Chlorophyceae) redorded 7 Species *Gonatoaygon* and *Spirogyra* spp were the two important green algae species recorded in terms of numbers. These species were recorded only in the wet season. Other were *Cladophora glomerata, Cladophora* sp., *Oedogonium* sp. and *Rhizoclonium* sp. The phytoplankton community structure parameters (bio-indices) are presented in Table 4b. These bio-indices values showed both spatial and temporal variations.

Zooplankton

A total of 21 zooplankton species were recorded for the study (Table 5a). Copepods, Cladocerans, Amphipods, Mysids, Chaetognahs and Cnidarians were represented. Of the lot, the Copepods (11 Species) particularly the calanoid copepods (9 Species) were the more diverse and frequently occurring species at all three (3) stations. *Paracalanus parvus* was the singular more important species recorded in terms of frequency and number. Other copepod species recorded include *Acartia clausii, Centropage typicus, Diaptomus* sp, *Isias claripes, Pseudocalanus elongates, Temora longicornis* (Calanoid copepod) *Cyclops* sp., and *Oithona nana* (Cyclopoid copepod). The cladocerans comprised of 4 species. They were *Diaphanosoma* sp., *Daphnia* sp., *Chdorus* sp, and *Bosmina* sp. The Amphipods were represented by *Gammarus sp., Hyperia galba*, the Mysids were represented by *Mysis oculata*, the Chaetognahs were represented by *Sagitta enflata* and the Cnidarians were represented by *Chysaora melanaster* and *Sarsia eximia* . The zooplankton community structure parameters (bio-indices) are presented in Table 5b. These bio-indices values showed both spatial and temporal variations.

Benthos

A total of 5 species of macro-invertebrate were recorded for the sample area (Table 6a). All species belonged to the Phylum Mollusca. Whereas the Gastropods recorded 3 species (*Pachymelania aurita*, *Tympanotonus fuscatus* and *Neritina glabrata*), the bivalve recorded 2 species namely (*Iphigenia truncata* and *Aloidis trigona*). *Pachymelania aurita* and *Tympanotonus fuscatus* var. *radula* were the more important species with regards to occurrence and number, followed by *Aloidis trigona*.

The benthic invertebrate community structure parameters (bio-indices) are presented in Table 6b. These bio-indices values showed both spatial and temporal variations.

DISCUSSION

Higher than previously documented temperature for the region was recorded for the Egbin area and this could be attributed to waste heat (hot water) discharged from the thermal facility. The temperature ranged between 27 and 40^0C. Water temperature reduced as the stations were further away from the thermal plant. The variation in the other physical and chemical characteristics of the lagoon water especially at station 3 recorded known trends and ranges for the Lagos and Epe lagoon areas (Nwankwo, 1986, 1996, 1998; Onyema *et al.*, 2003). Some of the impact of temperature on water physico-chemistry and benthic organisms has been well documented (Pandey, 1983). There was a low dissolved oxygen level particularly at Station 1 which recorded the highest temperature. Dissolved oxygen levels were higher at stations 2 and 3 with associated lower temperatures than station 1. Similarly, higher transparency was recorded for station 1 than 2 and 3 throughout the study. These differences are also possibly linked with the effect of the coolant water introduction from the thermal facility.

Generally however, the higher transparencies for the three stations in the dry season may be due to dilution of particulates by sea water incursion (Onyema *et al*., 2008). High transparencies have been reported by previous authors (Olaniyan, 1969; Yoloye, 1976; Nwankwo, 1996; Chkwu and Nwankwo, 2004) especially in the dry season. According to Ajao (1996) for the Lagos lagoon the Egbin thermal plant serves as a point source of pollution in the lagoon because apart from impacting the lagoon with heated waste water, it also introduces metals, oil and grease to the lagoon environment. Quite high heavy metals levels were estimated especially in the dry season. The hydrogen ion index (pH) ranged between 6.23 and 6.96, hence acidic. pH changes can drastically affect the structure and function of the ecosystem both directly and indirectly. It could lead to increasing concentration of heavy metals in water through increased leaching from sediments (Oyenekan, 1988; Odiete, 1999).

Salinity was high throughout the study at all stations, except in June and July where it fell probably due to the rainfall and associated dilutions from floodwaters. Furthermore, the high salinity values recorded earlier could additionally be due to the effluent from the facility since thermal stations are known to discharge high saline waters in addition to heat as a result of evaporative concentration (Odiete, 1999). Salinity values were higher in the dry season at all stations. This period for the Lagos lagoon is known to experience reduced rain events and increased sea water incursion leading to higher salinity records (Brown and Kusemiju, 2002; Chukwu and Nwankwo, 2004; Nwankwo, 2004; Onyema, 2008; Onyema *et al*. 2008). The reduction in the nitrate – nitrogen, phosphate – phosphorus and sulphate values as well as the increase in total suspended solids (TSS) values observed in June and July may be due to dilution from floodwater and the introduction of allochtonous material. According to Dance (1981), the transportation of particulate matter in streams is a physical process while the transportation of particulate organic matter is positively related to precipitation and flow conditions. Evaporation and reduction of river inflow leading to concentration could have been responsible for the higher levels of nutrients in the dry season. With regard to biota and heavy metals Nwankwo (1993) was of the opinion that the levels of some heavy metals particularly zinc have increased well above the background level in the Lagos lagoon and may have produced inhibitory effects or the formation of complexes which may have placed some nutrients beyond the reach of the Cyanobacteria population. High copper values well above the FEPA (1991) limitation guidelines of less than $1 mgL^{-1}$ were recorded for the Egbin area.

According to Nwankwo (1988), *Aulacoseira granulata* and *A. granulata* var. *angstissima* were prominent in the eastern zone of the lagoon which is primarily fresh or associated with low salinity values. Similar floral spectrum was observed in this study but with another sub-dominant species, a desmid, *Gonatozygon* sp. This community has also been recorded by Onyema (2008) for the Iyagbe lagoon. These species could be regarded as possible indicators of fresh water / very reduced salinity conditions within the lagoon. Indicators of high brackish water conditions observed were *Biddulphia aurita, B. laevis, Gyrosigma balticum, Melosira moniliformis, M. nummuloides* while possible Cyanobacteria bloom species recorded were *Microcystis aureginosa* and *M. flos-aquae* (Nwankwo 1986; Nwankwo, 2004; Onyema *et al*., 2003). These cyano-bacteria have also been previously reported in South-western Nigeria (Nwankwo *et al*., 2003; Onyema, 2008). According to Onyema *et al*., (2003) the high densities of *Aulacoseira granulata* and *A. granulata* var. *angstissima* recorded during the rains may have been recruited from the fresh eastern extremes of the lagoon where they are known to bloom. As floodwater increases the volume of these eastern lagoons swell and gravitate to the lower Lagos lagoon with their planktonic content. The Agboyi and Majidun creek to the norther axis of the Lagos lagoon are also possible recruitment areas of the Aulacoseira community.

According to Nwankwo (1984) algal productivity in the Lagos lagoon is high and principally dominated by diatoms as was observed in this study. A mixture of fresh and marine species present at the study sites may be an indication that they were recruitment from adjoining freshwater and high brackish zones respectively. The prevalence in most samples of pennate forms might indicate their recruitment from the phytobenthos community (Nwankwo and Akinsoji, 1989; Onyema, 2007). According to Onyema and Nwankwo (2006) frequently occurring pennate forms in plankton samples could be a reflection of the mixing of the shallow Lagos lagoon and the phytobenthic community by tides and floodwaters at various seasons.

Generally the fluctuations in the water chemistry and microalgal flora at the different stations of the Lagos lagoon at Egbin were similar especially for stations 2 and 3. This may be due to their control by similar factors. Whereas salinity was the dominant factor during the dry months, rainfall associated with fresh water inflow dominated the wet months. More importantly, temperature was a key factor in both the dry and wet season especially at station 1. According to Nwankwo and Akinsoji (1989) there is the existence of an environmental gradient linked with rainfall pattern in the Lagos lagoon. There is yet to be a report of fish poisoning around the area. However ciguatera – marine fish poisoning has been reported as a possible consequence of thermal pollution in tropical seas, (De Sylva and Hine, 1972). It is caused by the spread of blue – green algae as a result of elevated temperature. The planktonic algae is eaten first by small browsing and grazing fishes and invertebrates, then by large predatory fishes such a Barracudas, Snappers, Grouper and jacks and finally by man. Nwankwo (1993), Nwankwo *et al.* (2003), Onyema (2008) have already reported potential harmful algae especially with regard to bloom condition in the region. Furthermore the cyanobacteria group which had a marked representation at station 1 are known to produce a variety of potent toxin which are responsible for animal poisoning and human health problems worldwide. Additionally, the composition and abundance of cyano-bacteria was strong and positively correlated with increasing temperature (r = 0.68) at station A. According to Odiete (1999) the cyanobacteria are tolerant and become dominant in temperatures above 32^0C. Kadiri (2000) also reported a higher diversity of cyanobacteria in a warm spring than in a cold spring within the same area at Ikogosi, Nigeria.

According to Onyema *et al*., (2003) in the Lagos lagoon, diatoms for the phytoplankton and copepods for the zooplankton dominate the plankton spectrum. A similar situation was been documented for this study. Similar finding have been noted by other authors (Olaniyan, 1975; Akpata *et al*., 1993; Emmanuel and Onyema, 2007; Onyema *et al*. 2007, 2008). Zooplankton diversity and abundance was higher in the dry months possibly due to increases in salinity and hydrological stability (Onyema *et al*, 2007) hence recruitment from the more brackish and western parts of the Lagos lagoon. There is evidence to show that the brackish conditions of the dry season caused the recruitment of marine species. For example, *Sagitta* sp a well known marine species of the Nigerian coastal waters was recorded at Egbin in February and March. The abundance of juvenile forms probably indicates that the water quality was relatively suitable for their habitation. The low zooplankton population recorded in May could be due to the sharp drop in salinity caused by rainfall. According to Nwankwo (1996) sharp drops or sharp rises in salinity is catastrophic to lagoon biota. The prevalence of copepods in the Lagos lagoon at Egbin confirms observations by Olaniyan (1975) that the copepods are taxonomically the most important zooplankton group in the Lagos lagoon. This present investigation also confirms earlier report (Nwankwo, 1990) that life in the lagoon is subject to vagaries of seasonal fluctuation from fresh water to brackish or marine conditions and only species showing a high degree of salinity tolerance are able to survive for sufficiently long periods.

The organic matter distribution in the Lagos lagoon has been attributed to anthropogenic inputs and to the sedimentation or depositional nature which is governed by the current flow and the fluxes due to the rising and falling of tide in the lagoon (Ajao *et al*., 1996). The Total organic matter of the stations was generally low. Station 3 recorded the highest value of 6%. Bader *et al*., (1970) as stated by Oyenekan (1981) suggested that the Total organic matter could be used as an index of the amount of food available to benthic animals. Station 3 with higher organic matter would be expected to support a greater composition and abundance of benthos than Stations 1 and 2. On the contrary, this was not the case. According to Brown and Oyenekan (1998) and Ajao and Fagade (1991) benthic invertebrates in the Lagos lagoon are sediment type specific. Water chemistry also of the overlying waters according to them could also act as a key factor. The benthic macro fauna of the study area was numerically dominated by the gastropod - *Pachymelania aurita*. at all stations. Gray (1979) showed that chances in community structure were correlated with environmental disturbances notably pollution. Loss of biodiversity in the study area can therefore be linked to thermal pollution. For instance increases in temperature have been found to increase fish metabolic rate, spawning and also causes changes in the toxic action of various substances upon fish (Nikoslky, 1963).

Large numbers of dead shells of these species were observed at all stations. Sediment structure and stability are important factors in benthic fauna distribution. Sand mining which is also common in the area may also constitute deleterious effects to benthic life. The benthic community in the area is arguably the Pachymelania community described by Oyenekan (1988) as being the dominant macrofauna community of the Lagos lagoon. Other key members of this community recorded for the present study were *Tympanotonus fuscatus, Iphigenia truncata, Aloidis trigona* and *Neritina glabrata.*

The values for community composition parameters of the biota encountered at Egbin varied in tandem with species diversity and abundance at the different stations. Generally, the low species diversity recorded for the three categories of organisms studied maybe a reflection of prevailing unfavorable conditions especially when compared to species diversity and density of similar studies in South-western Nigeria (Nwankwo, 1988, 1996; Oyenekan, 1988; Brown and Oyenekan, 1998; Onyema *et al*., 2003, 2007).

With regards to ameliorative measures, the amount of waste heat discharged to the lagoon can be reduced by improving the efficiency of the station, and by making productive use of heat or by using cooling towers, cooling ponds or spray ponds. There is therefore the need for treatment of the coolant water before discharge into the lagoon to forestall conditions of dire ecological damage to the ecosystem. In an experience carried out on the thermal waters for agricultural purposes (Gunderson and Bienfary, 1975), it was found that it is possible to convert a thermal waste discharge problem into an environmental benefit at a cost effective return. Such similar projects can be embarked on also in Nigeria, and the major goal will be to protect the recipient environment.

Although the effects of elevated temperatures on the physical, chemical and biological factors at the site cannot be dispensed with, the effect of fresh water discharge from rivers, creeks storm water channels from the adjoining wetlands areas and tidal sea water incursion were also acting as modifying factors to determine the presence or absence of biota in the Egbin area.

Table 5: The phytoplankton around a coolant water discharge area at Egbin, Lagos state.

PHYTOPLANKTON
DIVISION: CYANOPHYTA
CLASS: CYANOPHYCEAE
ORDER 1: CHROOCOCCALES
Anabaena constricta (Geitler)
A. torulosa Hagerhen
Anabaena sp.
Aphanocapsa sp.
Gleocapsa sp.
Microcystis auriginosa (Kutzing)
M. flosaquae Kirchner
Microcystis sp.
Pseudanabaena galeata (Bocher)

ORDER II: HORMOGONALES
Calothrix sp.
Cylindrospermum major (Maigs)
Lyngbya mantensiana Meneghini
L. limnetica Lemmerman
Lyngbya sp.
Oscillatoria formosa Bory
O. limnosa Agardh
O. margardifera Kutzing
O. minima Gicklhorn
O. tenuis C.A. Agardh
Oscillatoria sp.
Plectonema sp.
Phormidium uncinatum Gomont
Schizothrix fasciculate Gomont
Tolypothrix sp.

DIVISION: CHLOROPHYTA
CLASS: CHLOROPHYCEAE
ORDER I: CLADOPOPHERALES
Cladophora glomerata (L) Kutzing
Cladophora sp.
Rhizoclonium sp.

ORDER II: OEDOGONIALES
Oedogonium sp.

ORDER III: ULOTRICHALES
Microspora flocca (Vaucher) Thuret

ORDER IV: ZYGNEMATALES
Gonatozygon sp.
Spirogyra africana Fritsch Cruda

DIVISION: EUGLENOPHYTA
CLASS: EUGLENOPHYCEAE
ORDER: EUGLENALES
Lepocinclis fusiformis (H.J. Carter) Lemm.
Lepocinclis sp.

DIVISION: BACILLARIOPHYTA
CLASS: BACILLARIOPHYCEAE
ORDER: CENTRALES
Aulacoseira granulata Ehrenberg (Ralfs)
A. granulata var. *angstissima* Muller
Biddulphia aurita (Lyngbye) Brébisson
B. laevis Ehrenberg
Cerataulina bergoni Per-. agallo;
Coscinodiscus centralis Ehrenerg
C. eccentricus Ehrenberg
C. lineatus Ehrenberg
C. radiatus Ehrenberg
C. sub-bulliens Jorg
Cyclotella meneghiniana Kutzing
C. stelligera Cl. and Grum
Cyclotella sp.
Melosiira moniliformi Agarth
M. nummuloides Agarth
Melosira sp.
Terpsinoe musica (Boul) Ralfs
Podosira sp.

ORDER II: PENNALES

Cymbella affinis Kutzing
Epithamia sp.
Fragillaria cylindricus Grun.
F. striatula Lyngb.
Fragillaria sp.
Gomphonema sp.
Gyrosigma balticum (Ehr.) Rabenhorst
Navicula cuspidata Kutzing
N. cryptocephala (Kutz) Hustedt
N. mutica Kutzing
N. rhynchocephala Kutzing
Navicula sp.
Nitzschia brebissomi W. Smith
N. closterium Ehrenberg
N. palea (Kutzing)
N. sigmoidea (Nitzsh)
Nitzschia sigma Grunow
Pinnularia cardinalis (Ehrenb.) W. Sm.
P. major (Kutzing) Rabenh
P. nobilis Ehrenberg
Pinnularia gibba Ehrenberg
Pleurosigma angulatum (Quekett)
P. aestuarii Brebisson
P. elongatum Wm Smith
Pleurosigma sp
Surirella ovata Kutzing
S. splendida Wm. Smith
S. quantimalensis Ehrenberg
Synedra crystalina Kutzing
S. ulna (Nitzsch) Ehrenberg
Thalassiosira dicipens (Grun)
Thalassiothrix fraunfeldii Cleve & Grunow

Table 6: The zooplankton around a coolant water discharge area at Egbin, Lagos state

CLASS: CRUSTACEA
SUB-CLASS: COPEPODA
ORDER I: CALANOIDA
Acartia clausii Giesbrecht
Paracalanus parvus (Claus)
Centropage typicus Dana
Diaptomus sp.
Eurytemora sp.
Isias claripes Boeck
Microcalanus sp.
Pseudocalanus elongates Boeck
Temora longicornis M. H. Doall

ORDER II: CYCLOPOIDA
Cyclops sp.
Oithona nana (Grisbrecht)

SUBCLASS: BRANCHIOPODA
ORDER: CLADOCERA
Bosmina sp.
Chdorus sp.
Daphnia sp.
Diaphanosoma sp.

SUBCLASS: MALASCOSTRACA
ORDER: AMPHIPODA
Gammarus sp.
Hyperia galba (Mont.)

ORDER: PARACARIDA
SUBORDER: MYSIDACEA
Mysis oculata (Fabricius)

PHYLUM: CHAETOGNATHA
Sagitta enflata Vogt

PHYLUM: CNIDARIA
CLASS: HYDROZOA
ORDER: SIPHONOPHORA
Chysaora melanaster Brandt
Sarsia eximia (Atlman)

Table 7: The benthic invertebrates around a coolant water discharge area at Egbin, Lagos state.

	FEB			MAR			APRIL			MAY			JUNE			JULY		
BENTHIC INVERTEBRATES	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
CLASS: GASTROPODA																		
ORDER:ARCHEOGASTROPODA																		
FAMILY I: POTAMIDAE																		
Tympanotonus fuscatus	9	276	15	16	1	0	164	14	5	23	59	48	40	7	9	15	5	42
FAMILY II: MELANIDAE																		
Pachymelania aurita	8	338	12	25	24	15	22	47	7	32	28	14	220	8	12	21	21	24
FAMILY III: NERITIDAE																		
Neritina glabrata	-	-	-	-	-	-	-	-	-	-	2	-	4		2	-	-	1
CLASS: BIVALVIA																		
ORDER: HETERODONTIDAE																		
FAMILY I: DONACIDAE																		
Iphigenia truncata	-	-	-	-	-	-	-	-	1	-	-	2	-	-	1	-	-	2
FAMILY II: ALOIDIDAE																		
Aloidis trigona	-	-	30	-	-	1	2	12	14	-	8	10	-	9	9	-	9	9
Total number of Species (S)	**2**	**2**	**3**	**2**	**2**	**3**	**3**	**3**	**4**	**2**	**4**	**4**	**3**	**3**	**5**	**2**	**3**	**5**
Species Abundance (N)	**17**	**614**	**57**	**41**	**25**	**16**	**188**	**73**	**27**	**55**	**97**	**74**	**264**	**24**	**33**	**36**	**35**	**78**

Table 8: Phytoplankton community composition parameters around a coolant water discharge area at Egbin, Lagos state.

	FEB			MAR			APRIL			MAY			JUNE			JULY		
	A	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Total phytoplankton diversity (S)	**17**	**12**	**16**	**7**	**11**	**8**	**10**	**13**	**7**	**14**	**8**	**14**	**8**	**13**	**7**	**10**	**9**	**17**
Total phytoplankton abundance (N)	1460	870	540	560	890	600	1080	540	240	470	180	910	4410	1150	41520	43620	370	35080
Log of Species diversity	1.23	1.08	1.20	0.85	1.04	0.90	1.00	1.11	0.85	1.15	0.90	1.15	0.90	1.11	0.85	1.00	0.95	1.23
Log of phytoplankton abundance	3.16	2.94	2.73	2.75	2.95	2.78	3.03	2.73	2.38	2.67	2.26	2.96	3.64	3.06	4.62	4.64	2.57	4.55
S hannon-Wiener Index (Hs)	1.06	0.88	1.12	0.72	0.82	0.57	0.77	0.92	0.67	0.98	0.82	1.02	0.64	0.93	0.50	0.49	0.74	0.47
Menhinick Index (D)	0.44	0.41	0.69	0.30	0.37	0.33	0.30	0.56	0.45	0.65	0.60	0.46	0.12	0.38	0.03	0.05	0.47	0.09
Margalef Index (d)	2.20	1.63	2.38	0.95	1.47	1.09	1.29	1.91	1.09	2.11	1.35	1.91	0.83	1.70	0.56	0.84	1.35	1.53
Equitability Index (j)	0.86	0.81	0.93	0.85	0.78	0.64	0.77	0.82	0.80	0.86	0.90	0.89	0.71	0.83	0.59	0.49	0.78	0.38
Simpson's Dominance Index (C)	0.11	0.17	0.09	0.23	0.21	0.39	0.22	0.17	0.28	0.14	0.19	0.11	0.28	0.15	0.34	0.40	0.24	0.42

Table 9: Zooplankton community composition parameters around a coolant water discharge area at Egbin, Lagos state

	FEB			MAR			APRIL			MAY			JUNE			JULY		
	A	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Total species diversity (S)	**8**	**5**	**5**	**7**	**4**	**5**	**5**	**3**	**5**	**3**	**1**	**3**	**8**	**6**	**3**	**5**	**6**	**3**
Total zooplankton abundance (N)	280	260	190	340	100	100	70	50	90	50	10	30	180	150	50	90	130	30

Log of Species diversity	0.90	0.70	0.70	0.85	0.60	0.70	0.70	0.48	0.70	0.48	0.00	0.48	0.90	0.78	0.48	0.70	0.78	0.48
Log of zoplankton abundance	2.45	2.41	2.28	2.53	2.00	2.00	1.85	1.70	1.95	1.70	1.00	1.48	2.26	2.18	1.70	1.95	2.11	1.48
Shannon-Wiener Index (Hs)	0.64	0.39	0.59	0.60	0.52	0.65	0.64	0.46	0.62	0.41	0.00	0.48	0.84	0.70	0.46	0.64	0.74	0.48
Menhinick Index (D)	0.48	0.31	0.36	0.38	0.40	0.50	0.60	0.42	0.53	0.42	0.32	0.55	0.60	0.49	0.42	0.53	0.53	0.55
Margalef Index (d)	1.24	0.72	0.76	1.03	0.65	0.87	0.94	0.51	0.89	0.51	0.00	0.59	1.35	1.00	0.51	0.89	1.03	0.59
Equitability Index (j)	0.71	0.55	0.84	0.70	0.86	0.93	0.92	0.96	0.89	0.86	0.00	1.00	0.93	0.90	0.96	0.91	0.95	1.00
Simpson's Dominance Index (C)	0.36	0.56	0.30	0.36	0.34	0.24	0.27	0.36	0.28	0.44	1.00	0.33	0.16	0.23	0.36	0.26	0.20	0.33

Table 10: Marco invertebrates' community composition parameters around a coolant water discharge area at Egbin, Lagos state

	FEB			**MAR**			**APRIL**			**MAY**			**JUNE**			**JULY**		
	A	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Total species diversity (S)	**2**	**2**	**3**	**2**	**2**	**3**	**3**	**3**	**4**	**2**	**4**	**4**	**3**	**3**	**5**	**2**	**3**	**5**
Total abundance (N)	17	614	57	41	25	16	188	73	27	55	97	74	264	24	33	36	35	78
Log of Species diversity	0.30	0.30	0.48	0.30	0.30	0.48	0.48	0.48	0.60	0.30	0.60	0.60	0.48	0.48	0.70	0.30	0.48	0.70
Log of abundance	1.23	2.79	1.76	1.61	1.40	1.20	2.27	1.86	1.43	1.74	1.99	1.87	2.42	1.38	1.52	1.56	1.54	1.89
Shannon-Wiener Index (Hs)	0.30	0.30	0.44	0.29	0.07	0.10	0.18	0.39	0.49	0.30	0.41	0.42	0.22	0.47	0.59	0.29	0.41	0.48
Menhinick Index (D)	0.49	0.08	0.40	0.31	0.40	0.75	0.22	0.35	0.77	0.27	0.41	0.46	0.18	0.61	0.87	0.33	0.51	0.57
Margalef Index (d)	0.35	0.16	0.49	0.27	0.31	0.72	0.38	0.47	0.91	0.25	0.66	0.70	0.36	0.63	1.14	0.28	0.56	0.92
Equitability Index (j)	1.00	0.99	0.93	0.96	0.24	0.21	0.38	0.82	0.81	0.98	0.68	0.70	0.46	1.00	0.84	0.98	0.85	0.68
Simpson's Dominance Index (C)	0.50	0.51	0.11	0.52	0.92	0.88	0.77	0.45	0.10	0.51	0.45	0.46	0.72	0.20	0.21	0.51	0.38	0.39

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