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PHYTOPLANKTON PRODUCTIVITY IN THE OKRIKA PORT HARCOURT SECTOR OF BONNY ESTUARY NIGERIA

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ABSTRACT

This study concerns the phytoplankton flora and primary productivity of the Bonny river estuary. The objectives of the study were to provide baseline information on the impact of the refinery effluent on the Bonny estuary – the recipient environment, to investigate the phytoplankton composition and abundance, and compare the water quality of the affected and unaffected stations. The studies on water quality and phytoplankton productivity were carried out from 1991 to 2001 at ten regular sampling stations of the Okrika arm (downstream), and the University of Science and Technology (U.S.T upstream), of the Bonny estuary of the delta area of Port Harcourt, Nigeria. Sampling program and techniques were such that spatio-temporal variations in the physico-chemical factors might be revealed. Primary productivity was highest upstream at the unaffected UST stations. Total productivity values temporal and spatial (column or depth variations) for the period under study were highest at UST stations. Productivity values ranged from 25.63mg C/m^3/hr $^{-1}$ to 193.13mg C/m^3/hr^{-1} in comparison to a range of 18.00mg C/m^3/hr^{-1} to 62.00mg C/m^3/hr^{-1} at the affected jetty stations. Biomass (Chlorophyll a) for the unaffected area was also highest, and ranged from 0.73 to 16.29mg/m^3: while that for the affected area ranged from 0.73 to 11.77mg/m^3. Gross production for all the stations or sample points around the jetty area was 317.98mg/m3 chlorophyll a , while gross production from the UST unaffected station was 849.07mg/m^3. The result was highly significant (P<0.01). Analysis of variance carried out for the four factors (River water, position, months and chlorophyll a) showed that there was significant difference for each of the single factors as well as some two- factor interactions and some three-factor levels. A systematic account of the phytoplankton flora consisted mainly of diatoms and which were sparse. Refinery effluent is toxic to natural phytoplankton population. Toxicity was however not reflected in the receiving water, as the levels of the various factors got diluted beyond detection limit. But with the volume of effluent discharge, and possible bioaccumulation process, the environment will pose a threat to the existence of aquatic life, especially as these water bodies are known to be nursery grounds for fishes and shrimps.

KEYWORDS: Phytoplankton, Okirika Port-Harcourt sector, Bonny estuary, Niger Delta, Nigeria.

INTRODUCTION

Studies have been carried out on petroleum effluent and related industries in Nigeria and European countries such as those of Sridhar (1982) Petpiroon and Dicks (1982) Singh *et al*, (1989) Onuoha (1980, 1986), Asuquo (1999), Chindah and Braide (2001) to mention a few.

The results of their studies showed that petroleum refinery and related industries contained the highest amount of dissolved solids, and ranked third in the levels of chemical oxygen demand (C.O.D) content, was considered important in evaluating the degree of water pollution. The refineries were also found to discharge large amounts of oils and grease, which substances were found to cause difficulties in sewage systems and receiving waters, such as the clogging of waste water conduits, interferences in biological processes, slower rate of degradation of these compounds and unsightly formulations at outfalls and in streams. The refinery effluent discharge caused considerable damages notably devegetation of the marshes, reduction in numbers of several shore species such as grazing gastropods (littorina) with corresponding increase in abundance of fucoid algae. Cyanophyta was found to be the dominant algal group in the effluent of Mathura oil refinery (1989) and its relative abundance decreased with the removal of the pollutants. There was gradual improvement in water quality downstream away from effluent discharge.

The Bonny River estuary like all estuaries is a brackish water environment noted for their high productivity. They are important nursery grounds for the young stages of many commercially important fish species such as peneid shrimps, mullets and others, which spend the early part of their life in the Bonny estuary where they feed on the abundant plankton and detritus before moving to off-shore waters, where they may be caught for food. The Bonny estuary for the same reason acts as a form of nutrient sink due to nutrient availability and "nutrient trap" produced by the mixing of waters of different salinity, and the favourable tidal transportation of nutrients, food and waste materials. The estuary is in particular being gradually transformed into industrial layouts and holiday resort, with the attendant pollution problems.

Primary production is the observed increase in the biomass of photosynthetic plant tissue over a period of time, plus possible processes such as excretion, respiration, tissue damage, death or grazing. Primary production is thus the total quantity of new organic compounds created by photosynthesis. The rate at which primary production takes place is called primary productivity. Most studies on aquatic primary production tend to be concerned with the phytoplankton (mainly algae), as they are naturally the dominant primary producers of the aquatic environment (sea, lakes, ponds, rivers) on which the rest of the biological community depend.

The production and productivity depend on the physico-chemical qualities of the environment as well as the community structure and biomass of the producers involved. Hence anything that can affect water quality for example, pollutants, will ultimately influence both the production and productivity, as there exists a correlation between fish yields and primary production. The specific objectives of this study are to investigate the following;1)to determine the phytoplankton composition and abundance at the Okrika arm of the Bonny estuary; 2) to investigate the primary production and productivity of the plankton flora; 3) to investigate the composition of the flora and their production and productivity as affected by the effluent discharge.

It is hoped that the results obtained will be useful in determining the extent of the impact of the refinery on the environment, especially in terms of the immediate environment of the Bonny estuary, after two decades of the operation and little or no information on the impact of the refinery on the estuary.

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MATERIALS AND METHODS

AREA OF STUDY

The Bonny River estuary is one of the numerous low coastal rivers of the Niger Delta complex or Niger Delta Basin. Information of the Niger Delta Basin is given by NEDECO (1961). The basin covers all land between latitudes 4^015^1 N and 5^035^1 N and longitudes 5^026^1 E and 7^037^1 E with a total area of 18,000 km^2. It extends from the Benin River in the West to the Bonny River in the East and encompasses the pre Niger Delta Basin and most parts of the Delta province of Edo State. With its characteristic extensive inter-connection of creeks, it is one of the finest examples of delta formation in the world. It is the most important drainage feature of the Niger-Benue rivers system and drains about 60% of Nigeria and about 34% of the entire West Africa, Adeniyi (1983). It covers only about 2% of the surface area of Nigeria.

Fig. 1 shows the sampling stations that were investigated along Bonny River estuary. The Bonny River estuary itself is located between latitude 4^025^1 and 4^050^1 North and longitudes 7^000^1 E and 7^015^1 East in the Rivers State of Nigeria. Like most of the other coastal rivers, it is very short, extending approximately 180km from its source to mouth. It is mainly brackish with very little freshwater discharge mostly from New Calabar River system, which joins it near the Port Harcourt end. It is bordered to the East by the tidal divides of Andoni basin, to the North-East and North by the coastal plain sands of the River Sombreiro drainage, to the West by the tidal waters of New Calabar River systems, covering a tidal swamp system of about 42,005.75 Ha (Pillay, 1973) or 59,973.57 Ha, NEDECO (1961).

The sampling stations comprise the effluent receiving sites of the Bonny estuary (Okrika arm), with ten study locations. Five of these were regular stations, which were sampled twice every month. Sites were selected at increasing distances on both sides of the discharge point, and on its opposite side towards the river edge (Port Harcourt end). The stations were about 100 meters apart from the effluent discharge point. These were the Jetty Head (point of effluent discharge), the Jetty head shore, the New jetty, The New jetty head shore, Ogoloma (Jetty complex downstream stations). For the non-effluent receiving water, five stations on the upper part of the Bonny estuary, along Elechi Creek- the University of Science and Technology Complex (U.S.T) were used as reference site for comparative purpose. The distance between the UST (upstream) stations and the Okrika or Jetty (downstream) stations is thirty kilometers. The two areas, effluent and non-effluent receiving waters of the Bonny Rivers are brackish water type. Both are mesohaline, having salinity of the range 14.4 to 19.1%0 with a mean of 17.0%o± 2.2. The stations along the Okrika arm lie between latitudes 4^048^1 North and longitude 7^005^1 East; while the U.S.T. sites lie between latitude 4^048^1 North and 6^029^1 East.

Sampling Program for Biological Parameters

Trawl samples of plankton were collected, biweekly from the Jetty Head Stations (area of discharge), that is affected stations (effluent – receiving water) and from U.S.T. stations (non-effluent receiving water) along with the sampling of physico-chemical parameters.

A 2.0 liter hydro-bios water sampler was used to collect water samples monthly from the stations. All the samples were analyzed for phytoplankton and chlorophyll a pigment. One liter each of the water samples from the sampling stations of the affected river was sedimented by adding Lugol's iodine and 4% formalin in measuring cylinders of I liter capacity. They were left to stand for forty-eight hours after which the supernatant was siphoned out to obtain 50 mls of the sedimented algal material. One ml. Of properly homogenized sub-sample was transferred on to a Sedge-wick rafter counting chamber, using Stempel pipette For each sample, 3 replicates of the concentrate were examined under the Lietz Wetzel binocular microscope using the scanning, low power and high power objectives at 100-200x, and 100-400x magnifications.

The identification of the composite taxa was done with the aid of keys, description and illustrations given by Durand et Leveque (1980), Prescott (1984), APHA (1985).

Estimation of Production (Biomass)

A. **Cell count:** Three horizontal columns each with fifty squares were counted so that out of 1000 fields of vision in the counting chambers, a total of one hundred and fifty fields were counted and total cells were obtained by multiplying by 50 (sedimented volume). The total number divided by 2 (2.0L water sampler used) provided the total number of cells per liter.

B. **Chlorophyll Extraction:** Pigment filtration, extraction and measurements of optical extinction (O.D.) were carried out according to Golterman *et al* (1978) and APHA (1985). Extraction was carried out with refrigerated 90% acetone solution (10 mls). The O.D. reading at 750 nm served as a correction for turbidity. This reading at 750nm was always subtracted from each of the pigment O. D. values of the other wavelengths before they were used for calculations. The concentrations of the chlorophylls were calculated by inserting the corrected optical densities in the following equations.

a) $C\underline{a} = 11.64D_{663} - 2.16D_{645} + 0.10D_{630}$
b) $C\underline{b} = 20.97D_{645} - 3.9D_{663} + 3.66D_{630}$
c) $C\underline{c} = 54.22D_{630} - 14.81D_{645} + 5.53D_{663}$

Where $C\underline{a}$, $C\underline{b}$, $C\underline{c}$, = concentrations of Chlorophylls a, b, c, respectively in the extract (mg/1), and D_{663}, D_{645}, D_{630} = Optical densities (with 1 cm light path) at the respective wavelengths.

When the concentration of pigment in the extract has been determined, the amount of pigment per unit volume of sample was calculated as follows:

$$\text{Chlorophyll } \underline{a} \text{ mg/m}^3 = \frac{\text{Ca x vol. of extract,1}}{\text{Vol. of sample. m}^3}$$

Chlorophyll b and c mg/m^3 were similarly calculated for the extracts.

C. **Estimation of Primary Productivity**
The "Light and Dark bottle" incubation technique was used for measurement of primary productivity (Vollenweider,1974) and the Gross photosynthesis or gross production, net production and respiration calculated from the following formulae after Vollenweider (1974).

$$= \frac{LB - DB}{T\ (Hrs)} \times 0.375 \times 1000\ mgC/m^3/hr^{-1}$$

$$\text{Net Production} = \frac{LB - IB}{T\ (Hrs)} \times 0.375 \times 1000\ mgC/m^3/hr^{-1}$$

$$\text{Respiration} = \frac{IB - DB}{T\ (Hrs)} \times 0375 \times 1000\ mgC/m^3/hr^{-1}$$

Where: T = Incubation period for primary productivity
0.375 = Ratio of weight of carbon to oxygen.
1000 = liters in m^3
IB, LB, DB = Initial bottle, light bottle and dark bottle respectively.

D. Treatment of Data and Statistical Analysis

Total cell counts for the months for each genus were made for the two study areas. Statistical analysis included similarly index calculations in order to determine the degree of similarity between the communities in the two areas, using similarly indices of Gleason (1926), Bray and Curtis (1957), and Czekanowski in Hellawell, (1978). A correlation matrix of phytoplankton abundance was calculated to show interrelationship between species and habitats. Three indices were used to obtain the estimate of species diversity,species richness, S or number of species present in a simple (Shannon – Weiner, 1963), equitability or evenness according to Buzas and Gibon's equation (Sen Gupta and Kilbourne, 1974). The correlation coefficients were used to plot dendogram of the phytoplankton population in the area. A two – way analysis (AOV) was also computed to analyze the relationship between the sampling stations on the basis of frequency of occurrence of algal genera in the study areas. The operation was performed using the information on the diatoms (bacillariophyceae), blue-greens (Cyanophyceae) and the dinoflagellates (Pyrrophyceae). Multiple linear regression was then used to estimate the relationship between gross primary productivity, biomass (standing crops in terms of cell count, chlorophyll a) and physico-chemical factors of the Bonny estuary.

T – tests were then calculated to determine if there were any significant differences between the affected and unaffected stations using the means of the Shannon – Weiner diversity index values, the taxa composition and evenness of distribution.

RESULTS

Table 1 shows a checklist of the phytoplankton flora of Bonny estuary. The planktonic algae recorded belong to the following divisions – the chlorophycophyta, the chrysophycophyta, the cyanophycophyta, and the pyrrophycophyta. Thirty-one genera of the total planktonic algae were recorded, although some of them were poorly represented. The diatoms constituted about 72% of the total algae and was represented by 26 genera in the phytoplankton of Bonny estuary, the cyn\anophyceae (blue-green) constituted about 15% of the total algae; the dinoflagellates constituted about 8%, while the greens constituted about 4% and others about 2%. Peak occurrence was in April and May but they were generally abundant throughout the months from February to August, along the Jetty Stations, including the area of discharge. The cell counts ranged from 667 to 24, 012 cells/1 to a total of 18,343 to 79,041 cell/1 for the period of study showing effluent effect. The mean cell density during the dry period was 31,831 cells/1, while mean cell density during the rainy period was 17,512 cells/1. The cell densities however for the jetty stations were not as high as those of the unaffected stations of the U S.T.

Table 1: Checklist of Phytoplankton Flora of Bonny Estuary.
DIATOMS

A. **Centrales: Coscinodiscales:**
Coscinodiscus radiatus
Coscinodiscus rothii
Coscinodiscus lineatus (Ehrenberge)
Coscinoditus excentricus
Cyclotella meneghiana spp
Stephanodiscus
Melosira granulata (Ehrenberg)

Rhizosoleniales:
Rhizosolenia spp

Biddulphiales:
Biddulphia sinensis
Biddulphia mobiliensis
Biddulphia aurita
Chaetoceros spp

B. Pennales:
Asterionella spp
Corethron
Stauroneis
Cymbella
Diploneis
Gomphonema
Laudena
Leptocylindricus
Navicula
Nitzchia
Pinnularia
Plankotonella
Pleurosigma

Checklist of Blue - Green algae
Anabaena
Chroococcus
Dactyllococcopsis
Merismopedia

Oscillatoria
Phormidium

Figs. 2 and 3 illustrate the phytoplankton abundance at sample stations of both the effluent receiving waters and non-effluent receiving waters of Bonny estuary. Fig. 2. illustrates the phytoplankton abundance at the effluent receiving stations of the Okrika Jetty area. The abundance of phytoplankton indicate normal distribution in the stations with peak abundance in April/May with the exception of station 3 which had its peak abundance in March. The taxa (genera composition) of the jetty area ranged from 20-31 for the sampling period.

Stations 6 and 7, that is, jetty head opposite shore, Ogoloma and Ogoloma upstream, had fewer species composition of 20,23 and 21 respectively. The area of discharge, station 1, station 2 (jetty head midstream), station four and five-New Jetty and New Jetty downstream had 30, 25 and 25, species composition respectively.

Fig. 3 shows the phytoplankton abundance at the non-effluent receiving stations. It can be seen that phytoplankton peaks showed almost the same pattern of distribution with peaks in April/May, with the exception of stations 4 and 5 that had two peaks in March and May. The taxa composition varied from 19 – 26 with the least number of nineteen in the first station (Agip), and highest composition of 26 in the 4th station, UST. The second, third and fifth stations (Rumuolu, Imueme, and UST creek) had a composition of 24, 21 and 24 genera respectively.

Table 2 gives the summary of phytoplankton population abundance at sample stations of effluent and non-effluent receiving water of Bonny estuary. It shows that the phytoplankton population was more abundant at the unaffected area.

Table 3 provides the Shannon Weiner diversity index values of the phytoplankton population at the study area. Shannon – Weiner diversity index values (means) ranged from 2.21 to 2.86, 2.00 to 2.33 for the affected and unaffected stations respectively. Some stations however had very high values showing preponderance of certain genera over the others. Evenness also ranged from 0.71 to 0.84, and 0.66 to 0.68 for the affected and unaffected stations also. The diversity index was high during the early dry period for the affected area, but was lower in the unaffected area. The t-test of the taxa composition of the two study areas showed no significant difference ($P > 0.01$). The analysis variance "ANOVA" of regular phytoplankton species at sampled stations showed significant differences ($P<0.01$, Table 4). Fig. 4 and 5 show the dendograms – average linkage method and Wards method respectively. When directly computing the distance from the phytoplankton data using all available objects, Fig. 4 contains 5 clusters while fig. 5 contains 9 clusters. The fifth cluster contains the largest number of species. The sixth cluster has a large cluster also. The seventh cluster comes next with a large number of species. The clustering is done according to stations. The 6th and 7th are important clusters, related to an early grouping and also appear to have seasonal influence due to the fact that the samples are mainly from dry months.

Table 2: Summary of phytoplankton abundance at sample stations of Element-receiving and non-effluent receiving waters of Bonny estuary (Cells/l). February to August 1999.

Serial No.	Stations	Feb.	March	April	May	June	July	Aug.	Grand Total
1.	Jetty Head	2,670	6.673	27,931	52,366	19,347	10,009	19,347	138,343
2.	Jetty Head (Mid-Stream)	4,004	6,838	26,017	47,694	21,679	11,341	7,430	124,913
3.	Jetty Head (Opposite shore)	17,844	134.236	34,687	30,651	16,679	17,345	20,014	271,456
4.	New Jetty	10,522	25,018	33,023	33 354	23 350	13,676	18,347	157,290
5.	New Jetty (Downstream)	1,668	6.004	16,343	23,349	22,014	9,673	11,673	90,724
6.	Ogoloma	6,005	15,345	32,687	45,025	29,019	5,338	19,680	153,099
7.	Ogoloma (Upstream)	4,003	9,339	20,680	55,698	24,013	14,009	23,016	150 758
8.	Agip	12,342	15,342	343507	73,373	16,677	13,341	18,348	492 930
9.	Rumuolu	11,676	16 011	21,012	40,357	22,013	31,018	11,675	154,096
10.	Imueme	9,340	26,682	73;205	64,701	26,348	21014	7,339	228,629
11.	UST	12,342	53,031	9 672	49,029	38,022	24,015	39,357	225,468
12.	UST Creek	12,676	51 362	36,187	62 370	29 018	24,349	14,010	229,972

Table 3: Shannon – Weiner Diversity Index of Phytoplankton population at Study area (Feb – August) 1999. Number of Taxa (S), Shannon – Weiner's Diversity Index (DI), Evennes (J),

Months	Diversity	Effluent-receiving (Affected Stations)							Non-effluent - receiving (Non-affected Stations)				
1983	Index	1	2	3	4	5	6	7	1	2	3	4	5
February	Summation H	2.16	2.59	2.58	2.39	0.97	2.39	1.21	2.70	1.80	2.70	2.71	2.81
	Evennes 'J'	0.93	0.92	0.78	0.80	0.80	0.80	0.60	0.85	0.64	0.90	0.86	0.84
	Number of Taxa (S)	30	26	20	31	25	23	21					
March	Summation H	2.66	2.45	2.05	3.14	2.25	3.54	1.83	1.75	2.51	1.96	2.27	2.09
	Evenness 'J'	0.89	0.82	0.52	0.83	0.80	0.89	0.71	0.75	0.79	0.69	0.63	0.66
April	Summation H	2 87	2.37	2.67	2.86	2.90	3.00	2 27	0.20	1.11	1.04	1.04	0.85
	Evennes 'J'	0 87	0.09	0.77	0.73	0.87	0.79	0 68	0.07	0.43	0.33	0.65	0.27
May	Summation H	3 05	2.85	2.45	2.84	2.97	2.41	2.98	2.06	2.66	2.87	1.90	2.32
	Evenness 'J'	0 73	0.75	0.74	0.75	0.74	0.65	0 74	0.65	0.74	0.78	0.55	0.63
June	Summation H	3.16	3.13	3.36	3.57	2.95	3.29	1.87	2.56	2.79	2.59	2.59	2.39
	Evenness 'J'	0.86	0.87	0.91	0.87	0.85	0.80	0.67	0.85	0.81	0.82	0.82	0.67
July	Summation H	2.83	2.60	1.95	2.78	2.71	2.75	2.22	1.82	2.76	2.36	3.15	2.89
	Evenness 'J'	0.82	0.78	0.62	0.80	0.90	0.92	0.74	0.70	0.75	0.75	0.83	0.84
August	Summation H	2.82	2.28	2.23	2.42	2.61	2.28	3.07	2.88	2.69	2.11	2.27	2.89
	Evenness 'J'	0.81	0.76	0.70	0.70	0.87	0.72	0.81	0 78	0.81	0.75	0.63	0.83
Shannon Weiner D.IX		2.79	2.61	2.47	2.86	2.48	2.81	2.21	2.00	2.33	2.33	2.28	2.32
Values Evennes		0.84	0.80	0.72	0.78	0.83	0.80	0 71	0.66	0.71	0.72	0.71	0.68

Table 4: Two way AOV of Regular phytoplankton species at sample stations.

Names of Species	Source/DF	SS	MS	F	Probability level of significance
Coscinodiscus	Total 83	68.5			
	Rows 11	18.8	1.7	2.4	$\leq$ 0.01
	Cols 6	3.4	0.6	0.8	
	Errors 66	46.3	0.7		
Chaetoceros	Total 83	171.8			
	Rows 11	6.5	1.6	0.3	$\leq$ 0.01
	Cols 6	48.2	8 0	4.5	
	Errors 66	117,1	1 8		
Cyclotella	Total 83	173 5			
	Rows 11	17 1	4.3	2 6	$\leq$ 0.01
	Cols 6	18 9	3.2	1.9	
	Errors 66	107 5	1.6		
Ditylum	Total 83	177 3			
	Rows 11	59.6	5.4	3.2	$\leq$ 0.01
	Cols 6	7.0	1.2	0.8	
	Errors 66	110.7	1.7		
Navicula	Total 83	121.4			
	Rows 11	17 3	1 6	1.2	$\leq$ 0.01
	Cols 6	20.9	3.5	2 8	
	Errors 66	83.3	1 3		
Nitzchia	Total 83	205.3			
	Rows 11	94.2	8.6	7 9	$\leq$ 0.01
	Cols 6	39.2	6 5	6 0	
	Errors 66	71 0	1 1		
Oscillatoria	Total 83	198 8			
	Rows 11	16 1	1.5	0 8	$\leq$ 0.01
	Cols 6	66.0	11 0	6 2	
	Errors 66	116 7	1 8		
Pleurosigma	Total 83	31 0			
	Rows 11	6 3	0 6	2 2	$<$ 0 01
	Cols 6	7 9	1.3	5 2	
	Errors 66	16.8	0.3		

Table 7: Monthly variation in chlorophyll values mg/m³ at New Jetty Station of the receiving water of the Bonny estuary.

	Chlorophyll a mg/m³		Chlorophyll b mg/m³		Chlorophyll c mg/m³		Total Chlorophylls
Dates	New Jetty	New Jetty Downstream	New Jetty	New Jetty Downstream	New Jetty	New Jetty Downstream	mg/m³
25/2/99 February	2.12	9.58	0.94	13.37	2.84	33.88	62.73 $\bar{x}$ 10.46 ±12.46
18/3/99 March	11.77	0.75	4.32	3.07	13.62	7.33	40.86 $\bar{x}$ 6.81 ± 5.06
17/4/99 April	8.62	4.57	12.03	8.78	30.49	15.46	79.95 $\bar{x}$ 13.33 ± 9.17
30/5/99 May	8.83	15.74	10.30	17.93	26.55	46.33	125.68 $\bar{x}$ 20.95 ± 13 94
17/6/99 June	2.87	5.75	4.01	8.02	10.16	20.33	51.14 $\bar{x}$ 8.52 ± 6.36
20/7/99 July	2.13	3.83	0.58	5.35	8.26	13.53	33.70 $\bar{x}$ 5.62 ± 4.71
28/8/99 August	1.92	5.48	2 67	8.02	6.78	20.33	45.20 $\bar{x}$ 7.53 ± 6.69
Σx	38.26	45.70	34.85	64.54	98.70	157.21	439.26
x	5.47	6.53	4.98	9.22	14.10	22.46	
Std. Dev.	±4.14	±4.84	±4.48	±4.98	±10.44	±13.33	

Table 8: Monthly variation in chlorophyll values mg/m^3 at UST stations of Bonny estuary. (Non-effluent- receiving station).

	Chlorophyll a mg/m^3					Chlorophyll b mg/m^3					Chlorophyll c mg/m^3					Total Chlorophyll
Dates	Agip	Rumuolu	Imueme	UST	UST CrK	Agrip	Rumuolu	Imueme	UST	UST CrK	Agrip	Rumuolu	Imueme	UST	UST CrK	mg/m^3
26/2/99 February	1.91	9.58	2.12	0.73	0.75	3.04	13.37	0.94	2.70	3.07	1.35	33.88	2.84	12.28	7.33	- 95.89 $\bar{x}$ 6.39 ± 8.68
19/3/99 March	0.74	0.96	0.98	3.30	2.12	3.43	1.34	0.61	0.18	0.94	1.91	3.39	14.23	7.70	2.84	- 44.67 $\bar{x}$ 2.98 ± 3.63
18/4/99 April	5.01	3.82	5.76	9.46	4.80	4.59	5.71	7.66	4.74	6.32	18.42	8.13	25.75	20.15	22.36	- 152.68 $\bar{x}$ 10.18 ± 7.47
30/5/99 May	2.87	2.87	2.87	11.39	16.29	4.01	4.01	4.01	27.13	22.73	10.16	10.16	10.16	47.48	57.60	- 233.74 $\bar{x}$ 15.58 ± 10.82
18/6/99 June	1.92	5.75	4.79	1.92	1.92	2.67	8.02	6.69	2.67	2.67	6.78	20.33	16.94	6.78	6.78	- 96.63 $\bar{x}$ 6.44 ± 5.43
29/7/99 July	2.13	1.92	1.93	1.70	1.91	0.58	2.67	2.31	4.77	3.04	8.26	6.78	12.20	5.30	1.35	- 56.85 $\bar{x}$ 3.79 ± 3.17
29/8/99 August	0.97	2.13	1.48	5.74	0.96	0.77	0.58	6.87	8.39	1.34	8.81	8.26	3.81	14.91	3.39	- 68.61 $\bar{x}$ 4.57 ± 4.16
Σx	15.55	27.03	19.93	34.24	28.75	19.29	35.7	29.09	50.58	40.11	55.69	90.93	85.93	114.6	101.65	749.07
$\bar{x}$	2.22	3.86	2.85	4.89	4.11	2.76	5.10	4.16	7.23	5.73	7.96	12.99	12.28	16.37	14.52	
Std. Dev.	±1.42	±2.96	±1.78	±4.14	±5.53	±1.49	±4.45	±2.96	±9.13	±7.69	±5.73	±10.61	±7.88	±14.67	±20.26	

Table 9: Time –depth Monthly variation in the gross primary productivity mgC/m^3/hr^{-1} at Ogoloma station of the effluent receiving water of Bonny estuary.

Water Depth (cm)	February	March	April	May	June	July	August	Temporal Summary
0	25.63	77.50	103.13	78.13	103.13	0	76.88	66.34 ± 39.03
50	12.50	51.25	65.00	65.00	65.00	77.50	25.63	51.70 ± 23.85
100	25.63	12.50	51.25	65.00	77.25	0	51.88	40.54 ± 28.46
150	13.13	25.63	25.63	38.75	38.75	51.88	0	27.68 ± 17.40
200	13.13	25.63	25.63	51.25	25.63	0	12.50	21.97 ± 16.06
Total	90	192.51	270.64	298.13	309.76	129.38	166.89	208.23
X	18.00	38.50	54.13	59.63	61.95	25.88	33.38	41.65 ± 17.99
Column	±6.97	±25.94	±32.21	±15.05	±30.83	±36.57	±31.00	

Table10: Time-depth month variation in the gross primary productivity mgC/m^3/hr^{-1} at Jetty Head Station of effluent – receiving water of Bonny estuary.

Water Depth (cm)	February	March	April	May	June	July	August	Temporal Summary
0	26.25	51.25	39.38	39.39	64.38	12.50	38.75	38.84± 16.63
50	38.75	25.63	51.88	38.75	64.38	25.63	64.38	47.86 ± 14.34
100	38.75	38.75	25.63	38.75	51.25	0	51.25	34.91 ± 17.71
150	38.75	38.75	83.75	64.38	51.25	0	25.63	36.78 ± 20.25
200	25.63	38.75	38.13	26.25	25.63	51.25	12.50	31.16± 12.54
Total	168.13	193.13	238.77	207.52	256.89	89.38	192.51	189.55
$\bar{x}$	33.63	38.63	47.75	41.50	51.38	17.88	38.50	37.91 ± 6.12
Column	±6.27	±6.12	±9.29	±13.92	±15.82	±21.45	±20.45	

Table 11: Time-depth month variation in the gross primary productivity mgC/m^3/hr^{-1} at UST Station of non-effluent – receiving station of Bonny estuary.

Water Depth (cm)	February	March	April	May	June	July	August	Temporal Summary
0	90.63	77.50	116.25	193.13	167.50	25.00	51.88	103.13± 60.49
50	64.38	65.00	102.50	155.00	155.00	51.25	65.00	93.93 ± 44.60
100	77.50	90.63	51.25	76.88	116.25	38.75	65.00	73.75 ± 25.57
150	51.88	64.38	25.63	77.50	90.00	25.63	77.50	58.93 ± 25.66
200	26.25	26.25	39.38	77.50	51.25	25.63	65.00	44.47± 20.83
Total	310.64	323.76	335.01	580.01	580	166.26	324.38	374.21
X	62.13	64.75	67.00	116.00	116.00	33.25	64.88	74.84 ± 24.19
Column	±24.73	±24.06	±40.02	±54.67	±42.52	±11.60	±9.06	

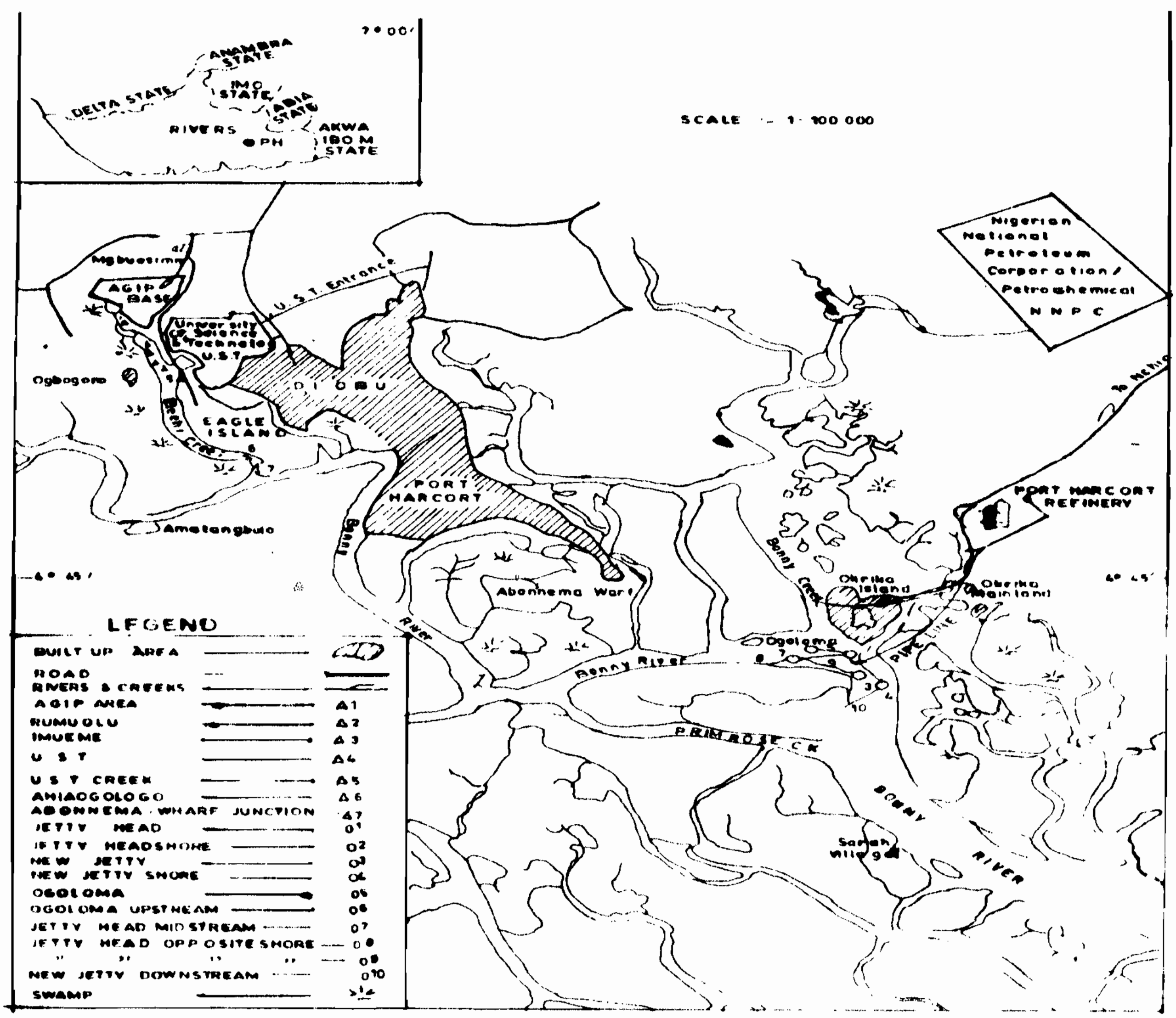

Figure 1: Map of Bonny River Showing Sampling Stations

Fig. 6 illustrates the 3 – way PCA solution of dominant genera of the phytoplankton data. The figure suggests that stations 1, 2, 3 (Jetty head, New Jetty and Ogoloma) are somewhat different from the rest of the stations. The three stations are distinguished from the others by the dominance of genera I, VII, VIII, IX, X, a further remarkable fact is constituted by isolated position.

Phytoplankton Biomass Chlorophyll a

At Ogoloma station of the jetty area, total chlorophyll production was highest in April with value of 90.31 mg/m^3 followed by February with a value of 67.98mg/m^3 Gross total for Ogoloma study area was 300.63 mg/m^3. Quantities of chlorophyll b and c especially c was highest.

The maximum chlorophyll production of 73.86 mg/m^3 were obtained in March for Jetty head stations, while the minimum of 17.7 mg/m^3 was obtained also in February and July. Total Chlorophyll a, b, c, (gross production) for all the sample points around the jetty was 317.98 mg/m^3. At new Jetty Station, maximum value of 15.74 mg/m^3 chlorophyll a and the minimum of 0.75 mg/m^3 were obtained in May and March respectively. Total production of chlorophyll was highest in May with a value of 33.70 mg/m.^{3} Gross total for the month was 439.26 mg/m^3 chlorophyll(Tables 5, 6,7).

At UST stations, total production was highest in May with a value of 233.74 mg/m^3 and a minimum of 44.67 mg/m^3 in March. Total chlorophyll production was highest here at the unaffected study area. The gross total produced from this study area was 849.07 mg/m^3, showing that the highest production was upstream at the unaffected area. The area of discharge had less production but the opposite shore and midstream of the area of discharge had a little more production(Table 8).

Primary Productivity

The mean monthly gross productivity values for Ogoloma station ranged from 18.00 mgC/m^3/hr $^{-1}$ $\pm$ 6.97 to 62.00 mgC/m^3/hr $^{-3}$ $\pm$ 30.84 with highest production in June. The productivity value of 103.13 mgC/m^3/hr^{-1} was higher at the subsurface than at the 100cm – 200 cm depths. The 150cm and 200cm depths had lower productivity values of 27.68mgC/m^3/hr $^{-1}$ $\pm$ 17.40 and 21.97 mgC/m^3/hr $^{-1}$ $\pm$ 16.06 respectively. The values for jetty head station for the period of study ranged from 12.50 to 64.38 mgC/m^3/hr ^{1} +.16.63 with a mean value of 31.16 mgC/m^3/hr ^{1} $\pm$ 12.54. The 50cm depth had maximum productivity. Mean monthly productivity for the same jetty head ranged from 17.88 mgC/m^3/hr $^{-1}$ $\pm$ 21.46 to 51.38 mgC/m^3/hr $^{-1}$ $\pm$ 15.82. The total productivity values temporal and spatial (column or depth variations), for the period under study were highest at UST stations. The gross primary productivity values ranged from 35.63 mgC/m^3/hr $^{-1}$ to 193.13 mgC/m^3/hr $^{-1}$, the depth variation values ranged from 33.25 mgC/m^3/hr ^{1} $\pm$ 11.60 to 116.00 mgC/m^3/hr $^{-1}$ $\pm$ 54.69. (Tables 9,10,11). While the primary productivity peaks for the stations were unimodal, the chlorophyll a peaks were bimodal.

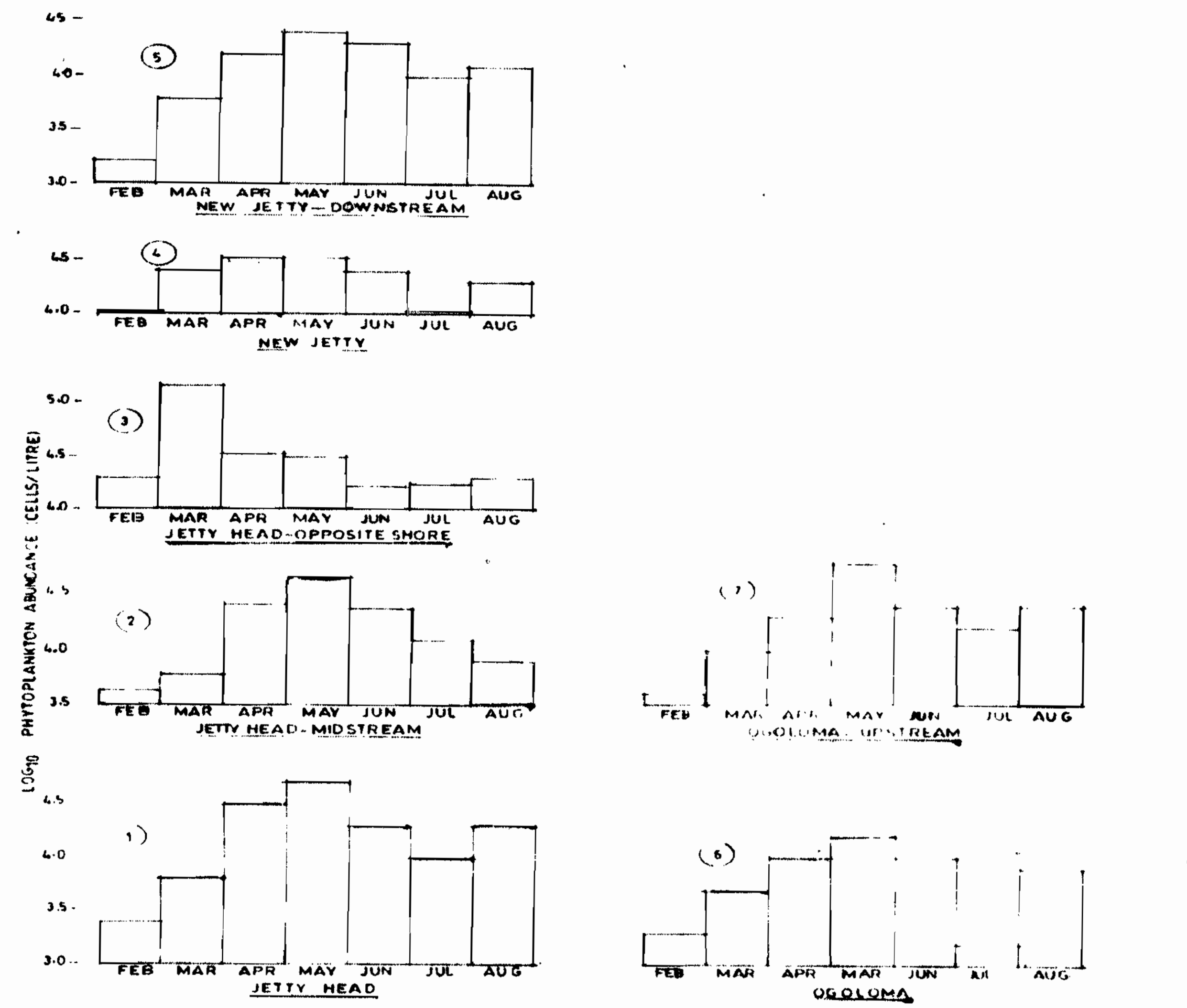

FIG 2 PHYTOPLANKTON ABUNDANCE(CELLS PER LITRE)AT EFFLUENT RECEIVING STATIONS OF BONNY RIVER FEB-AUG 1991

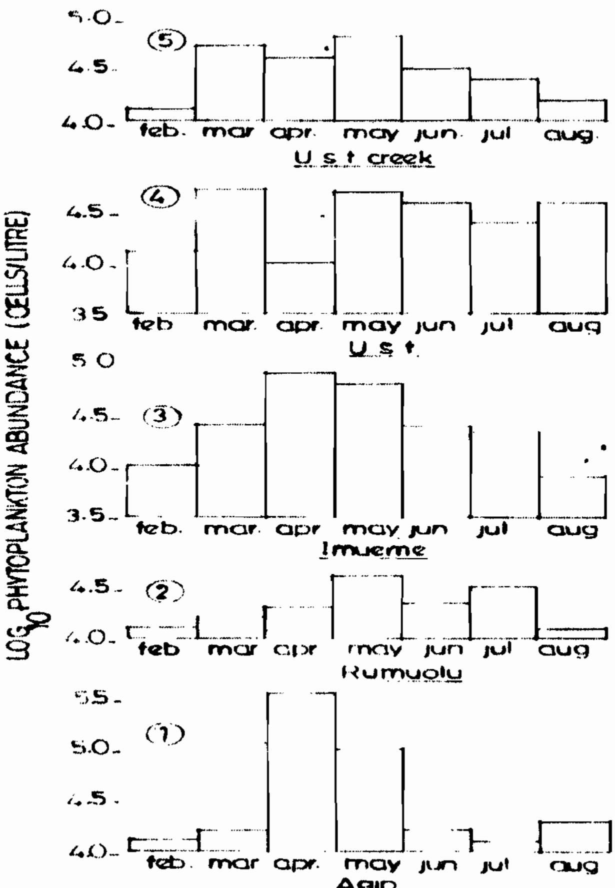

FIG 3 PHYTOPLANKTON ABUNDANCE (CELLS/LITRE) AT NON EFFLUENT RECEIVING STATIONS OF BONNY RIVER FEB - AUG 1991

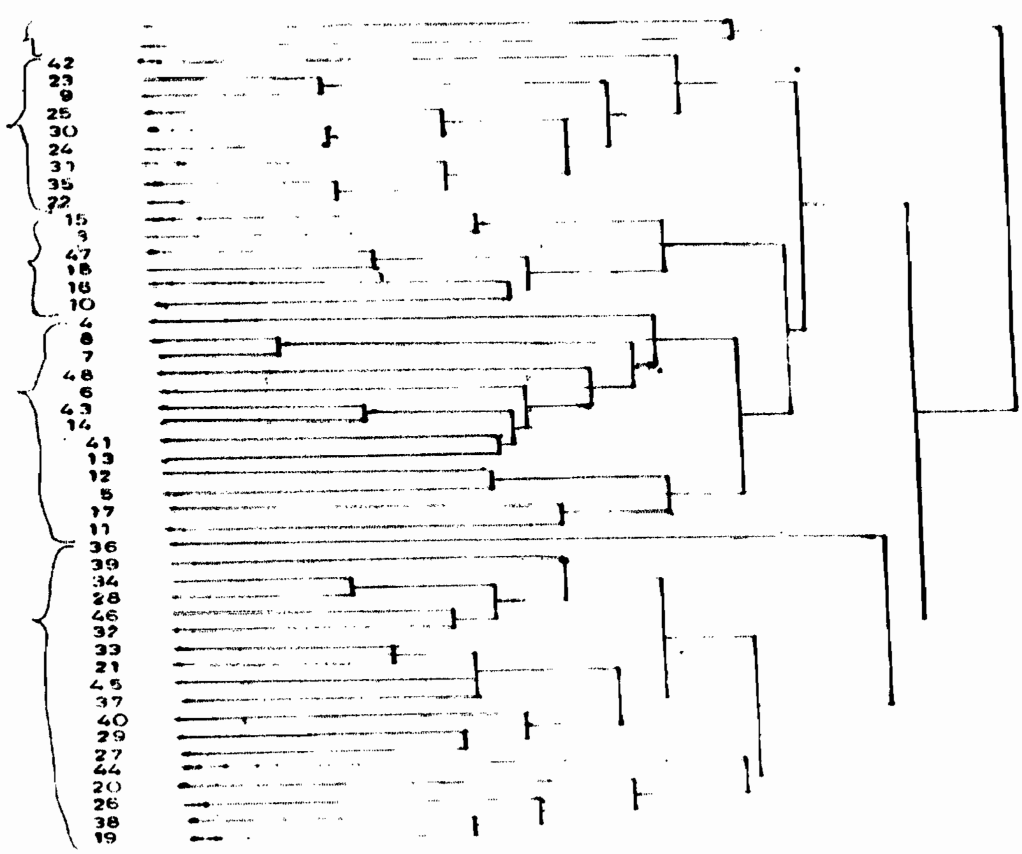

Figure 4: Hierarchical Cluster Analysis. Dendrogram of Phytoplakton Simples from Study Stations (Czekanowski's Coefficients)

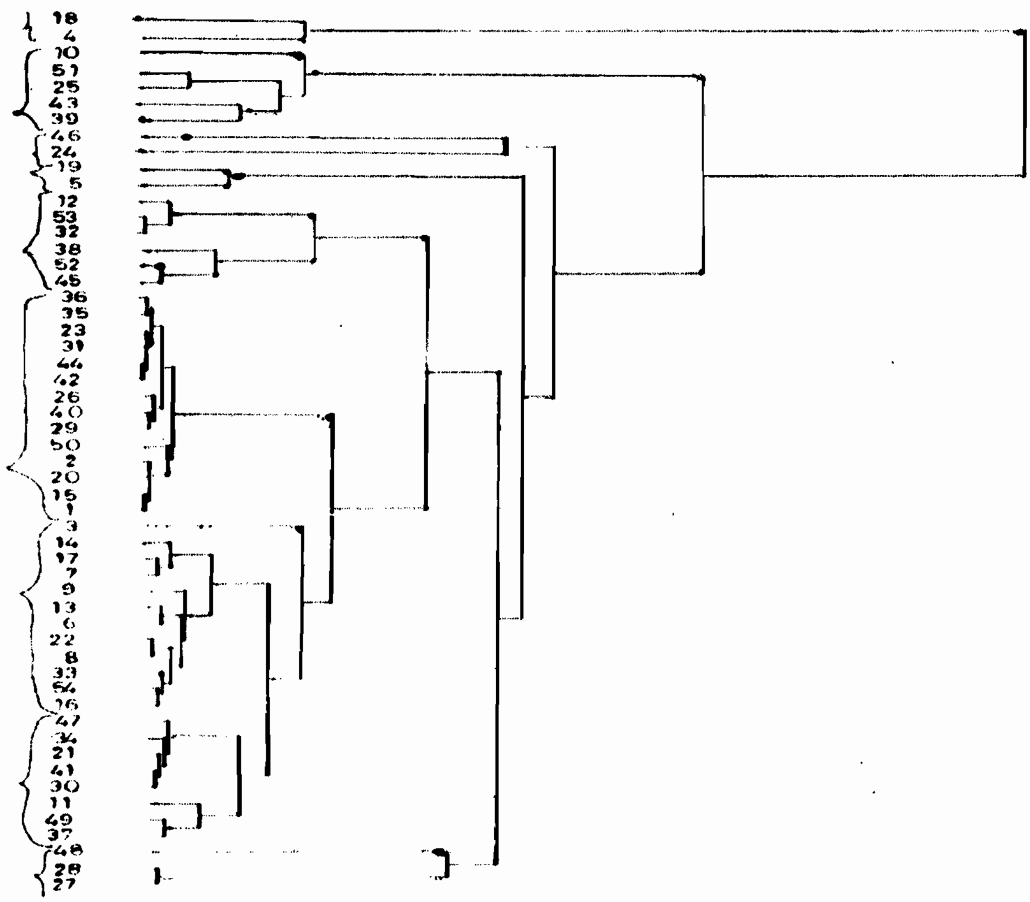

Figure 5: Dendrogram (Ward & Method) of Phytoplanton Samples from Study Staions

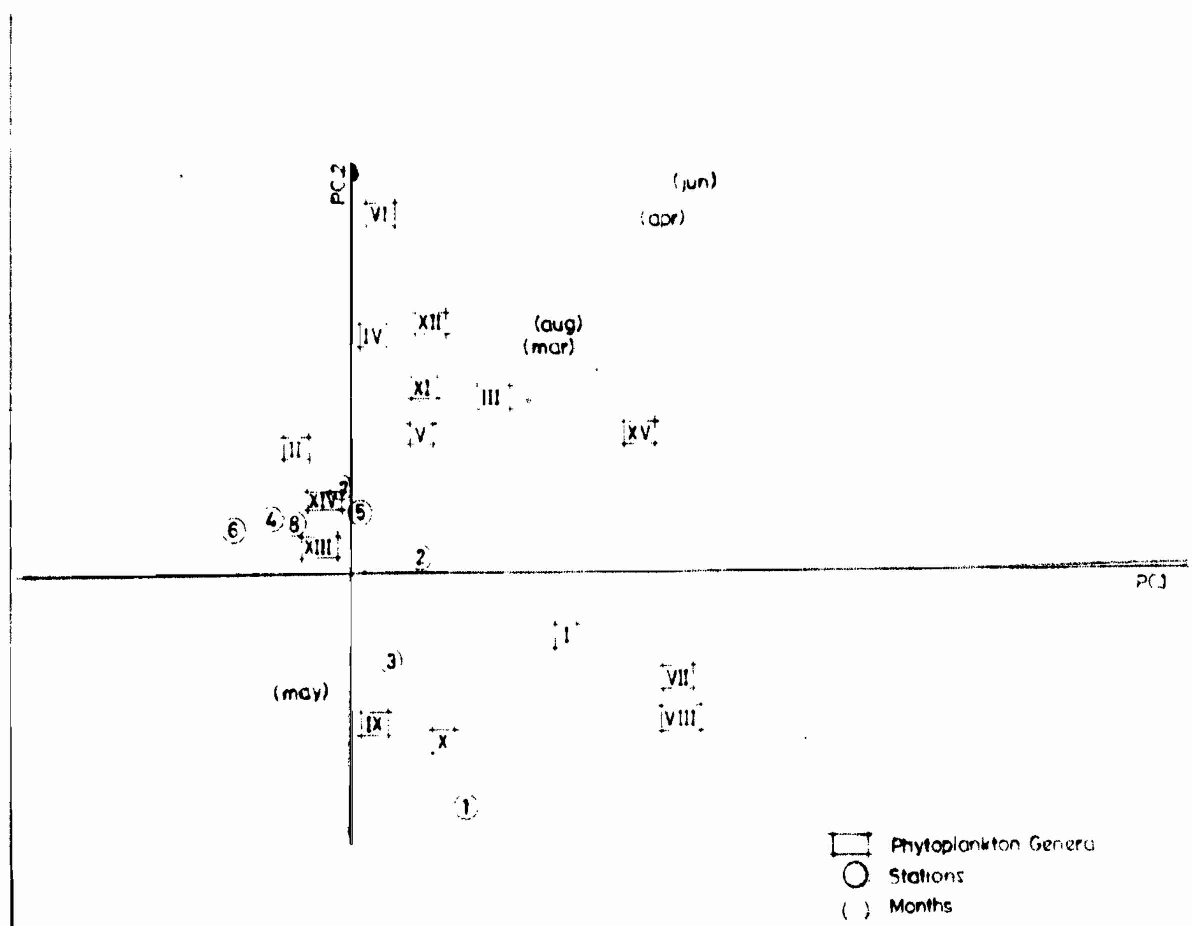

Figure 6: 3 way PCA Solution of Dominant Genera of Phytoplankton Data

DISCUSSION

Adeniyi (1978) stated that much more work has been done on the phytoplankton and primary productivity of African Lentic environments such as the freshwater lakes and reservoirs in Africa than in the Lotic Systems. The results obtainu were dominant in the lake than the diatoms. The brackish water of the Bonny River system showed diatoms as the dominant group while the greens and blue-greens occurred sparsely. Dangana (1985) stated that low occurrence of the cyanophyta in number and diversity may be partly due the fast flowing nature of the rivers, since these organisms thrive best in slow flowing to stagnant water bodies. These blue-greens were dominant in channel of the contractors gate because the water body was stagnant. It is often used as index of aquatic pollution (Trivedy and Khatavkar,1996).

In terms of phytoplankton genera identified, it can be seen that 28 genera exist in the Bonny/New Calabar River. During this study the following species *Chaetoceros, Biddulpha, Coscinodiscus and Piuerosigma* were obtained. The Diatom group was predominant; confirming the earlier findings of RPI/NNPC (1986). In terms of succession among phytoplankton, the *Cosicinodiscus cyclotella* dominated community was present in the polyhaline zone of the effluent – receiving water, while *Pleurosigma, Nitzchia* and *Navicula,* dominated the community of the UST (non-effluent receiving water), which is the *Mesohaline* community. *Pleurosigma* was very abundant at both study areas. The frequency of the benthic genera such as *Pleurosigma, Navicula, Nitzchia* and *Triceratium* sp were most probably because they were stirred up into the water column by the fast moving currents associated with spring tides. This is consistent with the frequency of their occurrence in plankton samples, and their high cell number during the spring tides. For the year 1983, May had the highest number of sunshine hours, with a total of 1‾1 1 hours and a mean of 5.5 hours per day followed by April which had a total of 144.4 sunshine hours and a mean of 4.8 hours. August was the month with the highest number of sunshine hours of 62.9 hours with a mean of 2.0 hours. The period of sunshine hours must have contributed to the productivity and biomass of the phytoplankton at these periods. Kalu (2004) similarly obtained very few species (a total of 6 species) of phytoplankton, higher density of the plankton was also obtained in May, which had the highest sunshine hours 5.8 hours during the period of study. He stated that the trend could be attributed to the heavy rainfall (highest rainfall 436.3mm) in that month, which increased the flow rate and subsequently facilitated the scoring of the bottom layer of the river resulting into re-suspension of nutrients and heavy metals in sediment and associated algae that are involved in the utilization of such nutrients (Chinda and Braide, 2001). With regards to species diversity, the composition of the phytoplankton at the Okrika area of the Bonny estuary can be described as poor. This why the primary production and productivity of the phytoplankton flora there is low. On the other hand, the phytoplankton diversity was higher at the unaffected stations, although species diversity was low. The spatial variation was no doubt related to both geographical influences and the influence of the pipeline discharge, which brought in oil and grease. The low phytoplankton density and diversity recorded confirms earlier investigations such as *Hess et al* (1985), IPS (1987); Powell and Chindah (1986), Adeniyi (1986), Chindah and Pudo (1991), Onuoha (1980) had ealier reported on the low density (29 genera) of the phytoplankton in Bonny River, attributing it oil pollution. Nevertheless the general reduction in species diversity must be seen as evidence of the polluting effects of the oil industry on the phytoplankton. Nwigwe (2000) also confirmed this statement that environmental stress tends to reduce the phytoplankton community to smaller number of species that are able to tolerate a wide range of conditions.

The Shannon – Weiner diversity index ranged from 2.21 to 2.86 for the effluent receiving station and 2.00 to 2.33 for the non-effluent receiving station. This is quite high because from the result obtained by Kalu (2004), Day (1981) in other relatively rich systems, free from contamination, the number of phytoplankton species exceed 406, while values of Shannon – Weiner range between 3.0 and 5.0. In his study of the composition of phytoplankton at Aba River, Kalu (2004) came up with values of Shannon – Weiner diversity index which ranged from 0.91 to 1.3.

The quality of the contamination at the effluent-receiving stations might be the cause of the high diversity index since it is oil in water dispersion. At the non-effluent-receiving stations (upstream), it is possible that the current is so fast that it washes away most of the algae.

REFERENCES

Adeniyi, F. I., 1983. The general features, climate, nature and sources of water Pollution in the Niger Delta Basin of Nigeria. Final Report on the Environmental Pollution Monitoring of the Niger Delta Basin of Nigeria Submitted to the Niger Delta Development Authority, 171 pp.

Adeniyi, F. I., 1986. The ecology of Bonny estuary. The chemical composition of the river and creeks. A paper presented at the man and Biosphere 5 (MAB5) UNESCO International Conference on Nigerian wetlands. 31 pp.

Adeniyi, F J, 1978. Studies on the physico – chemical factors and the planktonic algae of Lake Kainji. Vols. 1 & 2 Ph.D. Thesis. University of Ife, Ile – Ife. Nigeria, 597 pp.

American Public Health Association (APHA)., 1985. Standard Methods for the Examination of Water and Wastewater, Washington, D. C. 15th ed. 1195pp.

Asuquo, F E, 1999. Physico-chemical characteristics and anthropogenic Pollution of the surface waters of Calabar River, Nigeria. Global journal of Pure and Applied Sciences, 5 (4): 595 – 600

Bray, J. R. and Curtis, C. T., 1957. An ordination of the upland forest communities of Southern Wisconsin. Ecol. Mono. Ser. 27: 325 – 49: In: Ecological Methods by T.R.E Southwood.

Chinda, A C and Pudo, J. K., 1991. A preliminary checklist of algae found in plankton of Bonny river in Niger Delta, Nigeria Fragm. Flor. Geobot. 36 (1): 117 – 126.

Chinda, A C. and Braide, S. A, 2001 Crude oil spill and the phytoplanktoncommunity of a swamp. African Journal of Environmental Studies 12 1: 1 – 8

Dangana, L B, 1985. Hydro – geomorphological control of the mangrove Environment in parts of the Rivers State. Paper presented at the Mangrove Workshop, University of Port Harcourt, Nigeria. 6-25pp.

Day, J H.(ed.)., 1981. Estuarine Ecology. A.A.Balkema. I Rotterdam.411pp.

Durand, J, R. et Leveque, C., 1980. Flora et fauna aquatiques de L' Afrique Sahelo-Soudanienne Tome I Paris 389 pp.

Gleason, H. A., 1926. The individualistic concept of plant association, Torrey Botanical Club Bulletin 53: 7 – 26.

Golterman, H. L, Clymo, R. S. and Ohnstad, M. A. M., 1978, IBP Handbook No. 8 2nd ed. Methods for physical and chemical analysis of freshwaters. Blackwell Scientific Publishers, London. 215 pp.

Hellawell, J. M., 1978. Biological surveillance of rivers. A biological monitoring Handbook. Water Research Centre, Elderway, Stevenage, England, 332. pp.

Hess, S. P., Duncan, P. and Powell, C. B., 1985. Plankton of the Niger Delta. Paper Presented at the Nigeria National Petroleum Company Conference, Kaduna 15pp.

Institute of Pollution Studies (IPS)., 1987. Biological Baseline data acquisition at NNPC Installations Technical Report No. 11, RSUST/IPS/87/03. 241 PP.

Kalu, M., 2004. Effect of industrial effluent and domestic sewage discharges on the water quality and flora of Aba River. M.Sc. Thesis, Michael Okpara University of Agriculture, Umudike, 101 pp.

NEDECO., 1961. (2nd edition). Waters of the Niger Delta. Netherlands Engineering Consultants. The Hague P. 201 – 235.

Nwigwe, H. C., 2000. Effect of drilling mud on the plankton community of an experimental lacustrine system. Aquatic Sciences Proceedings of the 16th Annual Conference/International Workshop of Nigeria Association of Aquatic Sciences 134 – 144.

Onuoha, G. C., 1980. Phytoplankton production and oil pollution in the Niger Delta M.Sc. Thesis. University of Port Harcourt. 69 pp.

Onuoha, G. C., 1986. Primary Productivity and phytoplankton of Okrika sector of Bonny River estuary, in relation to petroleum refinery effluent discharge, Paper presented at the Man and Biosphere 5 (M.A.B.5) UNESCO International Conference, Port Harcourt, Nigeria. 10pp.

Petpiroon, S. and Dicks, B., 1982. Environmental effects (1969 – 1981) of a refinery effluent discharged into Little Wick Bay, Milford Haven. Field Studies 5: 623 – 641.

Pillay, T.V. R., 1973. Report to the Government of Nigeria on the investigations of the possibility of Brackish-water fish culture in the Niger Delta. Rep.FAO/EPTA 52 PP.

Powell, C. B. and Chinda, A. C., 1986. Phytoplankton communities and densities along the middle and upper reaches of the Bonny estuary. Paper presented at the man and Biosphere 5 (MAB5) UNESCO International Conference, Port Harcourt. 6pp.

Prescott, G. W., 1984. How to know the fresh water algae. 3rd ed W.M.C.Brown/Company Publishers, IOWA 293 pp.

RPI/NNPC., 1986. Environmental Baseline studies for the establishment of Control criteria and standards against petroleum – related pollution in Nigeria. Final report submitted to the Petroleum Inspectorate, NNPC Lagos.

Sen Gupta, B. K. and Kilbourne, R. T., 1974. Diversity of benthic foraminifera on the Georgia continental shelf. Geological Society of America Bulletin, 85:969-972.

Shannon, C. E. and Weiner, W., 1963. The Mathematical theory of Communication. Univ. of Illinois Press, Urbana, U. S. A. 125pp.

Singh, A. K. and Gaur, J. P., 1989. Algal epilithon and water quality of a stream receiving oil refinery effluent, Hydrobiologia 184 (3): 193 – 199.

Sridhar, M. K. C., 1982. A field study of estuarine pollution, Madras, India Mar. Poll, Bull, 13 (7): 233 – 236.

Trivedy, R. K. and Khatavkar, S. D., 1996. Phytoplankton ecology of the river Krisha in Maharashtra with reference to bio-indicators of pollution, Mmishru, S. R. Nangia, S. B.(eds.) for APH publishing corporation, New Delhi. 299 – 328.

Vollenweider, R. A., 1974. A manual of methods for measuring primary production in aquatic environments. IBP Handbooks No. 12 ed. R. Vollenweider 2nd ed. Blackwell Scientific Publication. 225 pp.