INTERNATIONAL JOURNAL OF NATURAL AND APPLIED SCIENCES (IJNAS), VOL. 2, NO. 1(2007); P. 29 – 36, 3 TABLES, 5 FIGS.

Phytoplankton community response to increase petroleum hydrocarbon in Niger delta estuaries, southern Nigeria.

I. Ewa-Oboho*[1], O. Oladimeji[2], F. E. Asuquo[1] and E. I. Oboho[1]

ABSTRACT

Phytoplankton communities from eight estuaries of the Niger delta (S. Nigeria) covering a range of oil and grease (total hydrocarbon content – THC) from 2.26 to 38.82 ppm, were studied during 1998-2000 and compared to data from experimentally (simulated) oiled estuarine embankment in Abonnema – near Port Harcourt, to assess recovery from oiling effects. Based on historical data, total Hydrocarbon Content levels have increased in several of the estuaries. Phytoplankton biomass did not correlate with total hydrocarbon content, but there was a high significant relationship between species richness and total hydrocarbon content. Recovery from oiling were observed in some estuaries, combining species diversity data from the present study with historical data. Correspondence analysis indicated that some of the estuaries that experienced increase total hydrocarbon content have shifted toward phytoplankton assemblages typical of non-oiled estuarine environment.

INTRODUCTION

The Niger delta region of southern Nigeria is a major oil producer in the world, and Exxon Mobil Idoho Platform, with production capacity of over 600,000bl of crude oil per day, is the region's biggest producer.

Pollution from oil activities have impacted estuaries along the Nigerian coastline particularly within the Niger Delta. In many instances the impacts are extreme and affect both biological communities and chemical cycle for example extirpation of sensitive invertebrates and fish species commonly consumed by the inhabitants. Some of the estuaries/water bodies are more prone to oiling as a result of greater intensity of oil activities undertaken in them. Estuaries of Bonny-Port Harcourt River, Brass, Forcados and Escravos Rivers and probably Qua River, are more susceptible to oiling than the Cross River Estuary, which is the reference (control) in the present study.

During 12 January – 28 January, 1998, oil from ruptured pipe at Idoho platform smeared most sections of the Nigerian coastlines as oil stranded ashore or entered the adjoining estuaries. The severity of the oiling and its effects on the benthos and some pelagic components have been reported (Ewa-Oboho, 1998, 1994, 1998, 2002, 2004, Akpan 1995, 1998; Antia 1998a, 1998b). Earlier reports on algae/planktonic community have been documented (Ewa-Oboho, 1993, Nwankwo 1998) for this region.

Although long-term impact and recovery are scantily documented, the region has been area of several short-term oiling effect and recovery studies (Asuquo et al, 2004; Ewa-Oboho, 2004). The recovery of these estuaries has elucidated changes that can be anticipated in other petroleum impacted tropical estuaries during the recovery.

The phytoplankton is one of the first biological communities to be affected by oiling (Nwankwo, 1998) and its species are likely to recover quickly because of their rapid turnover times (Findlay, 2003).Recovery of phytoplankton in simulated studies has been reported for near shore waters, over the past two decades. The phytoplankton population of estuaries along Nigerian coastal areas have been studied sporadically. Researchers (Nwankwo, 1992, 1994, 1998; Ewa Oboho, 1993, Akpan 1998) have concluded that estuaries with high petroleum hydrocarbon in the water had reduced species diversity and that their algal assemblage were dominated by petroleum hydrocarbon resistant species, such as *Bostrychia tenalla* sp, *Rhizoclonim* sp as well as dinoflagellates. The purpose of this paper is to present results for phytoplankton from oil stressed estuaries sampled during 1998-2000. The data are compared with historical data from 2 other estuaries less susceptible to oiling viz, cross River and River Andoni, and data from an experimentally oiled and recovered water body near Abonnema in Port Harcourt for evidence of recovery from oiling effects.

MATERIALS AND METHODS

Study area

The oiled coastal area is by the Gulf of Guinea, along the coast of Nigeria and includes the following estuaries Fig.1: Cross River (CR 4^0.43' N,$8^0$9'E);

*Corresponding author. Email: ita_ewa_oboho2005@yahoo.co.uk
Manuscript received by the Editor September 4 , 2006; revised manuscript accepted July 20, 2007.
[1] Department of Marine Biology, University of Calabar, P.M.B 1115, Calabar, Nigeria
[2]Department of Food Technology, Obafemi Awolowo University, Ile-Ife, Nigeria

Qua Iboe , (QIT 4⁰32'N,7⁰.59E), Imo River (IMO 4⁰.30'N,7⁰36E), Andoni (AD 4⁰.27'N,7.18'E), Bonny River (BON 4⁰28'N,7⁰10'E), Forcados (FCD 5⁰.23'N,5⁰22'E), Escravos River (ESC 5⁰36'N,5⁰12'E) and Brass River (BRS 4⁰18'N,6⁰13'E).

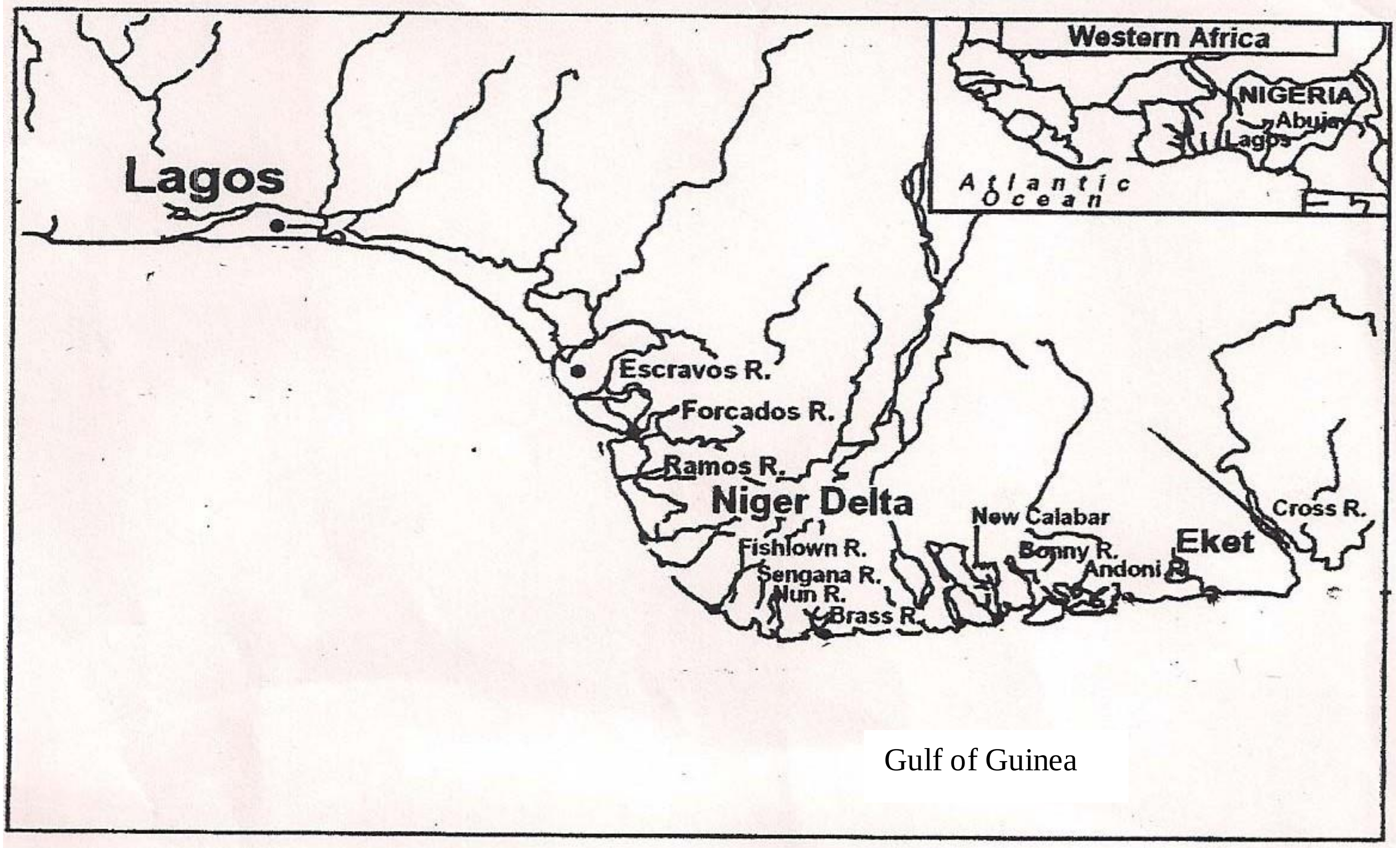

Fig. 1.The oiled coastal area of the Gulf of Guinea

The area has the equatorial climate that is influenced by the monsoon, which brings rain during April – October, and the North East Trade winds, accompanied by the dusty "Hammattan", during December – January and dominates in the dry season (November – April).

The tides are of the mixed type typical of the Atlantic spring and neap tides, and depending on the beach profile, tidal height range from 1.08m – 2.5m. Along the ocean front sediments are mostly sandy, but become clayey and muddy from the lower reaches to the middle reaches of the estuaries.

Phytoplankton sampling and enumeration

During September 1998 – August 2000, monthly phytoplankton samples were obtained from the deep station on each estuary using polyvinyl chloride (PVC) tube (Stokes and Yung, 1986). Samples were taken to a depth of 8 meters, which was approximately 2 times the secchi disk visibility and fixed with lugol's solution. At the end of the sampling season, 10ml aliquots from each monthly sample were removed and combined to create one seasonal composite sample for each estuary. Historical samples from 1984 (Owutuiake, 1985) for 3 of the 8 estuaries in the study area (Andoni, Cross River and Imo), were sampled using the same method, but the monthly samples were analyzed individually and values reported were calculated arithmetic means. Abonnema Port Harcourt experimental estuary was sampled for phytoplankton every four weeks form 1998 – 2000. Water samples were obtained from the deep region of the estuary using an integrated sampler (Shearer, 1978). The validity of comparing a calculated means seasonal value to a value from a single composite was checked by creating a composite sample from Abonnema – Port Harcourt monthly samples using the same protocol and for the 8 estuaries composites.

Total biomass, number of species, diversity of diatom, chrysophyte and dinoflaellate were similar for the two estimates (Table 2). Although they contributed less than 15% of the total biomass, chlorophyte, cryptophyte and cyanophyte biomass showed great variation. Samples for the 8 oiled estuaries (1998 – 2000) and for Abonnema – Port Harcourt water body were analyzed using the same protocol and by the same scientist. Aliquote samples (10ml) were gravity settled for 24hrs. With the aid an inverted microscope at magnification of 125x and 400x and a phase contrast illumination at 1200x, cells were counted using the utermohl technique (Rott, 1981). Cell counts were converted to wet weight biomass by approximating cell volume. Estimates of cell volume for each species were obtained by measurement of up to 50 cells of an individual species and applying the geometric formular best fitted to the shape of the cell (Rott, 1981). A specific gravity of 1 was assumed for cellular mass.

Analysis of community change

To allow for comparisons to previously published phytoplankton results (Nwankwo, 1992, Onwutiake, 1985), Shannon – Weaver diversity index was calculated for the 8 oiled estuaries from 1998 – 2000 and for the experimentally controlled Abonnema – Port Harcourt water body (ABPH). This index is biased towards the dominant species and is a gross measure of diversity (Washington 1984). Species diversity estimates reported in the 1984 historical investigation (Owutiake 1985), were arithmetic means calculated from 6 monthly samples. Based on comparison of composite vs seasonal samples presented in Table 2, the diversity result from 1984 (before intense oiling activities in the region) are comparable to the 1998 – 2000 data for the 8 estuaries. Changes in community structure at the species level were assessed by correspondence analysis (CA) (SAS, 1990). Individual species biomass obtained from composite sample from each of the 8 estuaries for each year (1998 to 2000) were used. Mean species biomass estimates for Abonnemah – Port Harcourt (ABPH) water bodies were created by averaging the data into 2 blocks that represent the different oiling phase (Table 1). The two data sets were combined, resulting in a matrix of 11 estuary-years by 128 species. The species data for 1984 historical survey were not readily available. Rare species create problems because they result in a large number of zeroes in the matrix. Therefore only species that contributed > 1% of the total biomass in at least 1 estuary – year were retained for analysis (86 species). Biomass values were transformed by log ([100* biomass]+1). Preliminary analysis showed that result were still highly influenced by rare species and final CA included a further down weighing of rare species by an accepted method (Hill, 1979) used in the community ordination software CANOCO (Terbrakk & Smilaver 1998). In brief, if Amax was the frequency of the most common species, then the abundances of species rarer than Amax/5 were reduced in proportion to their frequency. Frequency of species j is operationally defined as

$$f_i = (\sum a_{ij})^2 / \sum a_{ij}^2$$

where $_{aij}$ = abundance of species j in sample i. If $_{fj}$ for species j is greater than Amax/5 then its weighting factor is 1, otherwise it is fj/(Amax/5). Pearson correlation analysis (SAS 1990) was used to test the significance of relationships between biological and chemical parameters. The analysis was based on THC, conductivity, No_3 and DOC.

Table 1. Ranges of total hydrocarbon (THC) (values for 1984, Owutiake 1985 are in parentheses), number of species, Shannon – Weaver diversity index and total phytoplankton biomass for the study area (1998 – 2000) and experimental estuarine embarkments in Abonnema Ab 1, 2 and 3 (1985 – 2000)

Estuary	THC oil and grease (ppm)	Number of species	Diversity	Biomass (mgm^{-3})
Cross River	1998-2000 2.41-2.26	38 – 44	3.21-3.62	485-632
Qua Iboe River	28.16-8.66	20-21	2.105-3.07	20-46
Andoni River	12.58-13.86	33-42	2.80-3.98	201-324
Bonny River	35.58-18.24(5.86)	12-14	1.25-1.94	30.49
Forcados River	28.15-12.39	16-18	1.80-2.41	76-386
Escravos	22.62-8.86	20-22	1.19-2.52	65-142
Brass River	38.85-12.63(5.22)	10-15	0.78-0.87	147-285
Abonnema Ab 1	1985-1986 6.1-4.68	Before simulated spills 35-40	3.32-3.96	266-280
Abonnema Ab 2	1987-1988 36.82-32.18	After simulated spill 38-12	2.16-1.65	150-183
Abonnema Ab 3	*1990 – 2000* 8.86-5.62	Recovery 32-36	1.89-3.32	400-568

Table 2. Total biomass, taxonomic group biomass, (mgm^{-3}) number of species and Shannon Weaver diversity index from experimental estuary, 2001 monthly samples, compared to a composite sample created from monthly samples. The seasonal means are an arithmetic means of the monthly values. Percent difference (% diff) is the difference between the seasonal mean and the composite.

Taxonomic group	2 May	20 June	25 July	28 Aug.	16 Sept	20 Oct	Seasonal Mean	Composite (%)	% diff
Diatom	18	12	55	130	40	28	48	42	-7.3
Chlorophyte	28	115	27	22	25	55	46	73	37.2
Cyanophyte (Blue-green algae)	3	2	8	18	12	112	28	20	-38.8
Cryptophyte	191	501	486	650	986	186	826	806	-3.2
Chrysophyte	625	62	8	30	131	135	162	134	-20.5
Dinoflagellate	252	396	268	236	286	108	308	339	12.6
Total Biomass	1117	1088	812	1386	1480	2304	1418	1414	0.9
No. species	30	38	46	44	32	38	38	43	12.2
Shannon Weaver	3.33	3.16	3.82	3.56	3.25	3.01	3.37	3.86	13.2

Chemical analysis

Water chemistry during 1998 – 2000 for the water bodies was measured in July and December. The july samples were representative of well mixed rainy season sample while the December samples which represented the dry season samples, were integrated using a 5-m tube. Only July water chemistry and THC data were used in the analysis because this was most representative of the chemical environment of the phytoplankton. Analytical procedures for water chemistry from the study estuaries were as outlined by OMOEE (1996). Samples from experimental estuarine embankment of Abonnema, were taken at the same time as the phytoplankton from the integrated sample sample and measured using standard protocols (Asuquo, 2004).

RESULTS

Phytoplankton composition and biomass

Total phytoplankton biomass in the Niger Delta estuaries from 1998 to 2000 ranged from 20mg m^{-3} (Table 1). The lowest biomass occurred in Qua Iboe River ($20mgm^{-3}$ and the highest in Cross River (632mg m^{-3}) both of which had THC values < 10mg 1^{-1}. Biomass and THC were not significantly correlated (Table 3). However, total biomass was correlated with DOC and N. In the contrary, total phytoplankton biomass in experimental embankment (ABPH) was significantly correlated with THC as well as DOC and N. (Table 3).

A total of 108 species from 5 taxonomic groups (cyanophytes, chlorophytes chrysophyte, diatoms and dinoflagellates) represented the phytoplankton communities in the 8 Niger Delta estuaries. Of the 6 taxonomic groups, diatoms were strongly correlated with THC while chlorophytes and cryptophytes were weakly correlated (Table 3). The experimental water body phytoplankton community was represented by 189 species within the 6 taxonomic groups. Similar to the study estuaries, diatom and cyanophytes were correlated with THC, however the strongest correlation with THC in ABPH was with dinoflagellates (Table 3).

Table 3. Results of Pearson Correlation Analyses using Chemical and Biological Parameters from the studied Estuaries from 1998-2000 and Abonnema – Port Harcourt (ABPH) embarkment from 1984-2000.
The first row is correlation coefficient ® and the second row is the probability; p is < 0.5 is considered significant.

		THC		Conductivity		$No_3 + N0_2$		Doc	
		Oiled	**Expt**	**Oiled**	**Expt**	**Oiled**	**Expt**	**Oiled**	**Expt**
Number of species	r	0.80	0.76	0.36	-0.58	-0.51	-0.62	0.61	0.58
	p	0.001	0.001	<0.01	0.00.2	<0.01	0.001	<0.01	0.8
Shannon Weaver	r	0.36	0.68	0.05	-0.05	-0.31	-0.62	0.00	
Index	p	0.0056	0.0001	0.662	0.001	0.02	0.003	1.0	
Chlorophyte Biomass	r	0.42	-0.28	0.21	0.18	-0.38	0.38	0.39	
	p	0.0066	0.256		0.8	0.01	0.16	<0.01	
Chryptophyte	r	0.35	-0.38	0.01	0.06	-0.65	0.19	<0.02	
Biomass	p	0.0028	0.1081	0.092	0.65	<0.02	0.51		
Chrysophyte Biomass	r	0.16	0.52	-0.08	-0.51	-0.36	-0.69	0.18	-0.32
	p	0.1586	0.0326	0.86	0.001	<0.01	0.05	0.15	0.1
Dinoflagellate	r	-0.22	-0.92	-0.36	0.82	-0.16	0.76	0.06	0.008
	p	0.1686	0.001	0.04	0.006	0.28	<0.002	0.54	
Total Biomass	r	0.24	-0.78	-0.06	0.55	-0.48	0.76	0.62	-0.64
	p	0.0821	0.0007	0.62	0.03	<0.01	<0.001	<0.01	0.003

Species diversity and richness

Changes in phytoplankton community assemblages of ABPH and the study estuaries were reflected in species diversity and number of species present (a measure of richness) (Fig 2). Species richness in the ABPH and the 8 study estuaries (1998 – 2000) was significantly correlated with THC (Fig 2, Table 3). Species diversity (DI), using the Shannon-Weaver Index, in both data sets was also significantly correlated with THC but the relationship was much stronger in ABPH (Table 3). A linear regression analysis based on a subset of the 3 Delta estuaries, combining the 1984 historical data and data from 1998 2000, resulted in a significant relationship between THC and diversity (Fig 3). An obvious transition occurred from 1984 to 2000 in Imo, Bonny and Brass estuaries as THC increased overtime Fig 3).

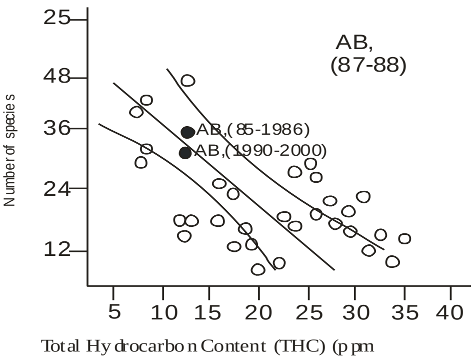

Fig.2. Linear regression of the number of species present and the THC in the 8 Niger Delta estuaries (1998-2000) and the experimental ABPH. Water body (19884-2000)

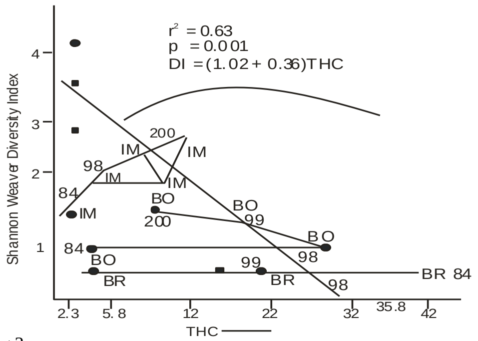

Fig.3. Linear regression of Shannon-Weaver Index (DI) on THC for a subset of Niger Delta estuaries containing data for 1984.
Bo = Bonny estuary
BR = Brass Estuary
IM = Imo Estuary. The number following estuary - code is the year. Diversity decreased as THC increased.

Community structure

The first 4 axes of the CA accounted for 14.4%, 7.8% and 4.1% respectively of the total inertia (1.652, X^2 = 24108, df = 10246) (Fig. 4). Axis 1 was significantly correlated with THC (r^2 = 0.68, p =0.001) while Axis 2 was correlated with chrysophyte (r^2 = -0.48, p = 0.001) and cryptophyte (r^2 = 0.33, p = 0.005). Species scores (Fig. 5) generated from the CA apply to all estuary – years and can be overlaid on them. The CA analysis revealed some interesting features. First, the 8 estuaries separated into 2 groups along axis 1, which was significantly correlated with THC. Estuaries with high THC were positioned in the right quadrants and estuaries with low THC (Cross River, Imo River, Andoni) were located on the left quadrants. They indicated very little change in the THC from 1998 – 2000. Their phytoplankton assemblages were largely represented by chlorophyte, diatoms, and chrysophyte. The more oiled estuaries tended to locate in the upper right quadrant in 1998, shifted downward t o the lower right quadrant in 1999 – 2000 (Fig. 4). The phytoplankton assemblages for these estuaries were represented by dinoflagelates (*Peridinium spp, Gymnodinium splendens, G. polykrikos*) and *chrysophytes (Dinobryon sociale, Nitzchia filitformis, Chrysochromulina sp, Podosira spp*). From 1998 to 2000, none of the estuaries shifted significantly from quadrants represented by high THC assemblages to quadrants describing low THC assemblages. In contrast a recovery trajectory can be seen for Abonnema experimental embankments, (ABPH) which shifted from the left quadrant to the extreme lower right as it was experimentally oiled to THC 38ppm and shifted back to 5.62ppm near-before experimentally oiled level of 6.1ppm as THC decreased during recovery.

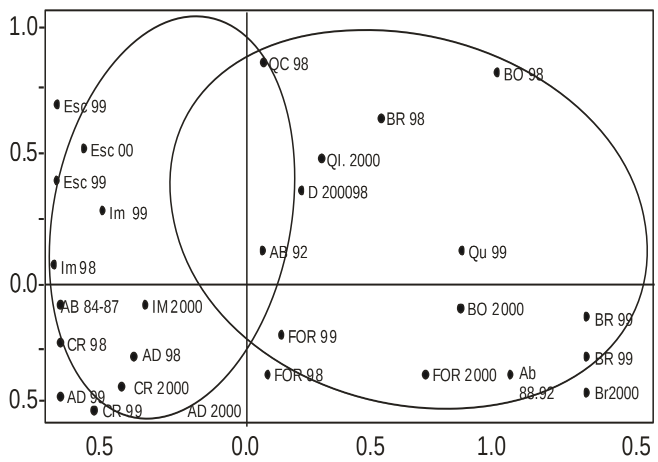

Fig. 4. Estuary-year score results of a correspondence analysis of Abonnema Experimental water body (AB) and the Niger Delta estuary phytoplankton communities from 1998 – 2000. The ellipses are visual groupings. Ab – Abonnema (simulated), Ad – Andoni. Bo – Bonny. Br – Brass, Cr – Cross River, Esc – Escravos,

For – Frocados, Im – Imo River, Qu – Qua Ibo River

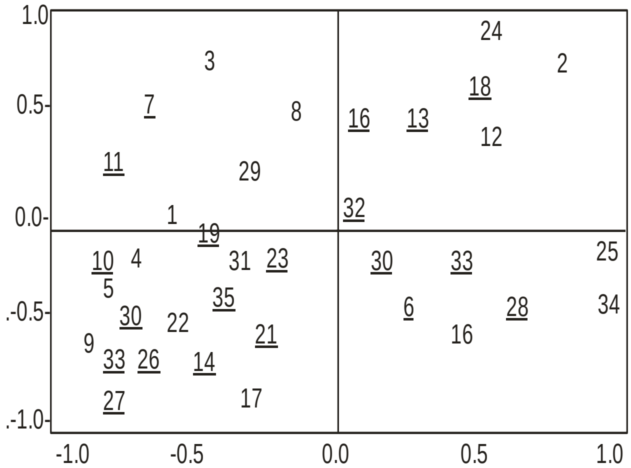

Fig. 5. Species score results of a correspondence analysis of Abonema Port Harcourt embankment (ABPH) and the Niger delta estuaries for phytoplankton communities from 1998 – 2000. To reduce congestion, only species that have a quality of representation greater than 25% on the first 3 axes are shown

Chlorophytes

1. *Oscillatoria limnetica*
2. *Holopedium irregulare*
3. *Cyanodictyon sp*
4. *Anabaena spirioides*
5. *Microcystis aeruginosa*

Chlorophytes

6. *Chlamydomonas spp*
7. *Sphaerocystis schroeteri*
8. *Staurodesmus sp*
9. *Ankistrodesmus falcatus*
10. *Cosmariums triolatum*
11. *Scenedesmus falcatus*

Chrysophyte (Bacillariophytes

12. *Dinobryon sociale*
13. *Dinobryon sertularia*
14. *Chrysococcus sp*
15. *Sydedra sp*
16. *Cyclotella sp*
17. *Chrysochromulina longispin*
18. *Podosira sp*
19. *Nitzchia filiformis*
20. *Chromulina sp*
21. *Coscinodisus*
22. *Pinnularia borealis*

Chryptophytes

23. *Sryptomonae erosa*
24. *Cryptomonae rostratiformis*
25. *Cryptomonae ovata*
26. *Chilomonas paramecium*

Dinoflagellates

27. *Gymonodium sp*
28. *Ceratium horridum*
29. *Codium sp*
30. *Gyrodinium*
31. *Peridinium pusillum*
32. *Peridinium conicoides*
33. *Peridinium inconspicuum*

DISCUSSION

The effects of oiling on phytoplankton communities in Niger Delta estuaries have been well documented. (Akpan 1998, Nwankwo, 1998). In estuaries with THC of water > 12pmm, species diversity, species richness and the abundance of diatoms, cyanophytes and cryptophytes decrease, while dinoflagellate abundance tends to increase. Documentated responses of the relationship between level of oiling and biomass are contradictory and appear to be more estuary specific with NO_3 and P loading possibly being important factor since most of the estuaries have different rates of fresh water in flow from land runoffs. Estuary – order may be a factor influencing water renewal and NO_3 and P loading since the estuaries do not have same width and therefore same volume of water flux.

The 8 Niger Delta estuaries span a wide Total Hydrocarbon content (THC) range, and between the study period (1998 – 2000) there was significant increase in Total Hydrocarbon Content levels observed in the estuaries. However historical Total Hydrocarbon Content data indicate that some of the estuaries (Brass, Bonny and Imo) have become more oiled over the last 2 decades despite stringent measures put in place by NGO, States and Federal Governments to prevent oil pollution in the region. These estuaries had initial Total Hydrocarbon Content levels around 3ppm that over time rose to 38ppm. Estuaries in rivers that were more oiled (Total Hydrocarbon content> 10ppm) have exhibited greater increase in total Hydrocarbon Content between 1985 – 2000.

Defining what constitutes recovery is a major difficulty in assessing ‘recovery’ of biological communities from petroleum pollution in aquatic systems (Findlay, and Kasian, 1996). For the present study, recovery is defined by the return of an algal community to its previous natural state, based upon species composition, diversity and richness, with allowances for local temporal changes as measured by comparisons with other estuaries. The experimental oiling and recovery of the Abonnemah embarkments is a good example of defining the recovery of an impacted aquatic system.

In its natural state it was similar to other reference systems within the area. As Total Hydrocarbon Content increased species richness declined and dinoflagellate become dominant. During the recovery phase, as Total Hydrocarbon Content decrease the species richness increased. However not until Total Hydrocarbon Content level reached 5.6ppm did the community shift back almost to its previous natural state.

There are several studies that describe the algal communities for some of the Niger Delta Estuaruies at time when there were mostly oiled during accidental oil pollution. Bonny (1986) and Brass (1985 – 1988) (Ewa-Oboho 1998, Owetwake, 1983) estuaries had total Hydrocarbon Content values that seasonally ranged from 13 – 38ppm and were dominated by dinoflagellates and chrysophytes typical of oil greasy aquatic environments. During the study (1998 – 2000) Total Hydrocarbon Content in the estuaries had increased substantially in the CA analysis (Fig. 4) Imo River and Escravos in 1998 – 2000 are positioned within a cluster, as Brass and Bonny showing no recovery from oiling effects on phytoplankton communities. On the other hand, Forcados and Qua Iboe Rivers were moderately oiled (Total Hydrocarbon Content 15ppm) in the 1980s but by 1998 – 2000 Total Hydrocarbon Content has decreased to < 6ppm. Based on the CA where the phytoplankton assemblages of both water bodies are positioned in the cluster, which indicates that they have experienced little or no change.

Previous studies of estuaries in the Niger Delta Region have documented highly significant relationships between species richness and oil levels, and species diversity and oil levels (Ewa-Oboho, 1994). These relationship exist for the 8 estuaries (Fig. 2 and 3). Several studies, based on the recovery of experimentally oiled estuaries have documented recovery trajections for benthic algae and phytoplankton communities using diversity indices (Ewa-Oboho 1992). During the 16 year study of Abonnema, (experimental site) a recovery trajectory was observed as species diversity decreased during high Total Hydrocarbon Content levels and increased as Total Hydrocarbon Content decreased, suggesting species diversity is recoverably as estuary become less oily. (Ewa-Oboho, 1988, 1994).

A similar recovery trajectory is apparent for three estuaries (Brass, Bonny and Imo Rivers) where historical species diversity data are combined with data from the present estuarine sites. The sampling and analytical methods for the 2 studies were the same and the comparison between seasonal means versus a composite mean (Table 2) shows the methods yield similar results. Biological recovery of oiled Delta estuaries was documented to have lagged chemical recovery. Based on the phytoplankton rapid turnover times, dispersion to new habitats is generally not an issue and estuarine sediments are an enormous seed bank for species, one would thus expect these populations to recover rapidly. Several factors may impede the rapid recovery of phytoplankton result from the estuaries (1998 – 2002) partial recovery appears to be progressing. It has been hypothesized that an aquatic region that undergoes long-term stress may become species impoverished thus impacting on the ability of the water bodies to recover their natural diversity (Vinebroke et al, 2002). However, plankton species composition in several water bodies in the Niger Delta that had increased in Total Hydrocarbon Content over the past decade, had similar communities to estuaries that were unaffected by recent incessant minor oiling in this region.

This would suggest that the phytoplankton pool for the Niger Delta estuaries was not impoverished. Some Niger Delta estuaries also have significant input of toxic metal associated with industrial activities in the region (Asuqwo et al 2004) and this may impede phytoplankton communities recovery.

During the recovery phase of the experimentally oiled Abonnemah embarkments which were stressed only by increased Total Hydrocarbon Content, it took 2 – 5 years of Total Hydrocarbon Content below 6ppm before the phytoplankton population appeared to have recovered and corresponds with the time frame documented for estuaries in different parts of the tropics (Sears 1998).

The phytoplankton sp. that dominated at areas high Total Hydrocarbon Content level filled a niche and because they were so robust, could survive as Total Hydrocarbon Content decreased. Not until these petroleum hydrocarbon – tolerant species diminished could natural chrysophyte species become dominant. The oiled estuaries that have reduced Total Hydrocarbon Content levels below 10ppm appear to show similar sign of recovery.

REFERENCES

Akpan A. W. (1995). Limnology and net plankton periodicity of a tropical freshwater in Uyo (Nigeria). *Tropical Fresh water Biology,* 4:65-81

Akpan A. W. (1998). Post impact assessment of january 1998 *Idoho – QIT 24,* Pipeline oil spill, Final Report for Mobil Producing Nigeria. 400pp

Antia, E. E. (1998a). Oil Spill sensitivity ranking of Nigeria coastal waters. International Seminar on the Petroleum Industry and the Nigerian Environment, Abuja 30th November – 3rd December, 1998.

Antia, E. E. (1998b). Post impact assessment of January 1998 Idoho – QIT 24" pipeline oil spill Final Report for Mobil Producing Nigeria Unltd. 400pp.

Asuqwo E. F. Ewa-Oboho, I. O., Udo P. J. (2004). Organisms used as biomarker for heavy metal and petroleum hydrocarbon contamination for Cross River, Nigeria. *The Environmentalist* 24: 29-37.

Ewa-Oboho, I. O. (1998). Effect of simulated crude oil spills on the ecology of a mangrove swamp in Bonny estuary. m. phil. Thesis, University of Science and Technology, Port Harcourt, Nigeria. 105pp.

Ewa-Oboho, I. O. (1994). Effect of simulated oil exposure on benthic organisms in tropical estuarine ecosystem. *Ecotoxicology and Environmental* Safety 28: 232 – 234.

Ewa-Oboho, I. O. (1993). Seasonal variation and community structure of benthic algal in a tropic estuarine ecosystem. *Tropical Ecology* 26: 21-238

Ewa-Oboho, I. O. (1998). Post impact assessment of January 1998 Idoho – QIT 24 "pipeline rapture, Final Report, Mobil Producing Nigeria Unlimited : 400pp.

Findley, D. L. (2003). Response of phytoplankton communities of acidification and recovery in killarney part and the Experimental Lakes, Area, Ontario. *Ambio* 32: 1990 – 1995.

Findley, D. L. and Kasian, S. M., (1996). Phytoplankton community response to incremental pH recovery of Lake 223. *Can. J. Fish Aquat. Sci,* 53: 856 – 864

Hill, M. O. (1979). DECORANA: A Fortran program for detrended correspondence analysis and reciprocal averaging. *Ecology and Systematic*, Cornell University, Ithaca, New York.

Jerbrakk, J. F., and Smilauer P. (1998). CANOCO reference manual and user's guide to Canaco for Windows: Software for Canonical Community Ordination (Version 4). Microcomputer Power (Ithaca, New York, 352pp.

Nwankwo, D. I. (1992). Periphyton algal on fish fences "ACADATA" in a tropical open lagoon. *International Journal of Ecology and Environmental Sciences 17:1 - 10*

Nwankwo, D. I. (1994). Hydrochemical properties and bottom-dwelling diatoms of a Lagos lagoon sewage disposal site, *Polskie Archicolling Hydrobiologie* 41 (1): 35 – 47.

Nwankwo, D. I. (1998). Phytoplankton diversity and succession in Lagos lagoon. Nigeria *Archiv Fur Hydrobiologie.* 135 (4): 529 – 542.

OMOEE (1996). 1995 Performance Report, Water Quality Analyses Section. Ont., Min. Environ. Energy Rep. Toronto: 332pp .

Owutiake, E. F. (1985). Diversity of phytoplankton species in Bonny Port Harcourt River, *Journal of Environ Sci.* 32 (3): 22 – 30.

Owutiake, E. F. (1983). On the distribution and abundance of phytoplankton waters. *Environment* 46 (13): 36 – 42.

Rott, E. (1981). Some results from phytoplankton intercalibrations. *Scheweiz Z. Hydrobiol.* 43:43 – 62.

SAS Institute Inc. (1990). SAS user's guide: statistics, Version 6 Edition, SAS Institution Inc. Cary, NC.

Shearer, J. A. (1978). Two devices for obtaining water samples integrated over depth. *Can Fisah. Mar Srv. Tech. Rep.* 772: 13

Stokes, P. M.N. And Yung, Y. K. (1986). Phytoplankton in selected la Cloche (Ontario), lakes pH 4.2-7.0 with special reference to algal as indicators of chemical characteristics. In: Diatoms and Lake Acidity, (Smol. J. P. Battarbee, R. W. Davis R. B, and Merilainen, J. eds), Junk Publishers Dordrecht. : 57 – 72.

Vinebrok, R. D. Graham, D. D. Findlay, D. L. and Turner, M. A (2002). Compositional stability of epilithic algal assemblages in experimentally recovering acidified lakes. *Ambio* 32: 196-202

Washington, H. G. (1984). Review: diversity, biotic and similarity indices. A Review with special relevance to aquatic ecosystems. *Water Res*. 186: 652-694.