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MANGROVE ECOSYSTEM OF THE NIGER DELTA: DISTRIBUTION AND DYNAMICS

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ABSTRACT

Changes in species composition and distribution of macrobiota were studied during 1985-2004 in the Niger Delta system, Southern Nigeria. Two creeks were selected per estuary, two transects per creek, and two stations per transect for regular sampling of macrobiota. A total of 14 taxa of macrofauna comprising over 60 species were found in the region. Decapod brachyurans tended to decrease in mean densities from 35 individuals m^{-2} in 1985 to 21 and 18 individuals m^{-2} in 2000 and 2004 respectively. Phytoplankton and zooplankton decreased in species diversity, specie richness, and abundance in estuaries, notably Bonny, Qua Iboe, Brass, and Escravos where the THC contents of water were > 12 ppm emanating from minor oil spills. With the exception of Nypa palms, mangrove vegetation types displayed a general deterioration in numerical abundance and Nypa-rich vegetation were frequent in the more disturbed estuaries, replacing the indigenous mangroves as a type "A" invader.

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INTRODUCTION

The mangrove ecosystem of Nigeria, is the third largest in the world (World Bank, 1995) and occupies about 975,000 km^2 of the low-lying land fringing the coastal swamps of Southern Nigeria from Bakassi in the East to Badagry in the West (Figure 1). The ecosystem reaches its greatest extent in the Niger Delta where the swamp is extensively anastomosed by creeks and rivers, resulting in a considerable input of nutrients and organic matter. The primary producers utilize this rich nutrient-base to increase biomass. The vegetation consists of complex communities of plants which vary in height from 1-35 meters and consists of halophytic families of Rhizophoraceae, Avicenniaceae, Folieceae, Combretaceae, and Palmae. Also, associated with the mangrove swamp are other vegetation types, mostly of the families Leguminosae, Malvaceae, Euphorbiacea, Convolvulaceae, and Amarantheceae. The ecosystem is typically low in species richness of angiosperms due perhaps to the inability of floral species to withstand the "harsh" periodic salinity gradient typical of the environment. However, phytoplankton, microepiphytes, benthic microalgae, and macroalgae contribute to the plant groups of the mangrove ecosystem.

The Nigerian mangrove swamps harbor a great diversity of macro in- and epi-fauna of which crab and mollusc form the great majority in terms of biomass (Ewa-Oboho, 1988, 1994). The fauna are faced with severe problems of water and salt balance, siltation, desiccation, oxygen availability, weight, and temperature limitations especially when attempting to invade the adjacent and adjoining land.

Presently, few quantitative estimates of Niger Delta mangrove swamp fauna exist, perhaps due to the difficulty of sampling among thickets of mangroves, deep mud banks, and semi stagnant lagoons in addition to the difficulty of obtaining reliable estimates of fauna which spends much of their time in burrows or very active when on ground (Ewa-Oboho & Asuquo, 2006; Jones, 1984). In many cases, seasonal occurrence and distribution of most macro fauna in the swamp is related to the characteristic fluctuations in environmental parameter associated with the dry and wet seasons (Ewa-Oboho, 1988; Ewa-Oboho & Asuquo, 2006; Kwei, 1978; Sandison & Hill, 1966; Webb & Hill, 1958), as well as stress from anthropogenics. Besides, the influence of substratum on faunal species, distribution on the Nigerian mangrove swamp of Nigeria has been reported (Ekweozor, 1985; Ewa-Oboho, 1988; 1992; Ombu, 1986).

For over 2 decades, increased human activity in the region has resulted in intense infrastructural development of large areas of the swamp, with subsequent degradation and loss of rich and sensitive mangrove habitats in some areas. The region is not only petroleum rich, but also biologically productive, with many endemic species contributing to its large biodiversity. The entire area is a breeding and nursery ground for most juvenile marine fish species, being protected and sheltered from the adjacent marine turbulence and has a vast autocthonous source of nutrients production and recycling (detritus machine). A great diversity of macrofauna and mega fauna thus reside in these swamps. Few quantitative data exist on the dynamics of the Niger Delta mangrove swamp bio-components, particularly as they are affected by recent development in the region. Data acquisition is necessary not only for the sustainable utilization of the unique bioresources, but for making testable predictions about changes in community composition and structure overtime, taking into account the human developmental activities in the area. The present study presents a comparative analysis of the occurrence, distribution, and change in macrofauna and flora of the Niger Delta mangals in the last two decades of intense infrastructural development in the region.

MATERIAL AND METHODS

The Environment

The study area extents from the Cross River estuary (04° 32^{n}: 06°N and 08° 04^{n}: 46°. 03^{n}E), which is relatively less perturbed and therefore used as control swamp, to Takwa Bay in Lagos (06° 25: 47^{n}N and 03° 32. 51”E; Figure 1) approximately 870 km stretch and encompassing Imo River, Bonny River, Brass River, and Forcados and Escravos River estuaries.

The entire area is an extensive mudflat at low tide with many shallow water drainage creeklets and estuaries. Occasional sandy beaches which extend up the land and are only flooded during the highest spring tides are common features in the environment, especially along the ocean fronts. At high tides, the channels and creeks of all these estuaries are flooded, allowing access to the surrounding mangrove vegetation which consists of the following dominant species from the low water level to the high water level landward: *Rhizophora mangle, L, Rhizophora racemosa* G. F. W Meyer; Rhizophora harrisonii Leech man; *Laguncularia racemosa* (L), and *Avicennia africana* P. Beauv.

The tides are of mixed type, typical of the Atlantic spring and neap tides. The maximum tidal range recorded in the region is 2.4 m. During periods of heavy rains, normal limits may be greatly exceeded. Thus the extent and duration of exposure of littoral biota can be extremely variable. Rainforest climate prevails in the Niger Delta region and mean ambient temperature of 28°C with a diurnal variation of 2°C is a common feature. The temperature of the tidal water remains fairly constant at 28°C. However, at the mudflats and tidal pools, temperatures of 35°C to 48°C could be recorded. Tidal flats at mid-tide level (MTL) are drained for an average of 5.5 hours per cycle of 12.5 h. The sediments include a whole range of sediment types from almost pure fine sand (silt content below 1% and a median grain size 190 µm) at the more exposed stations to silty sand and mud (about 60% silt) and medium grain sand of about 63 µm, at the more sheltered areas.

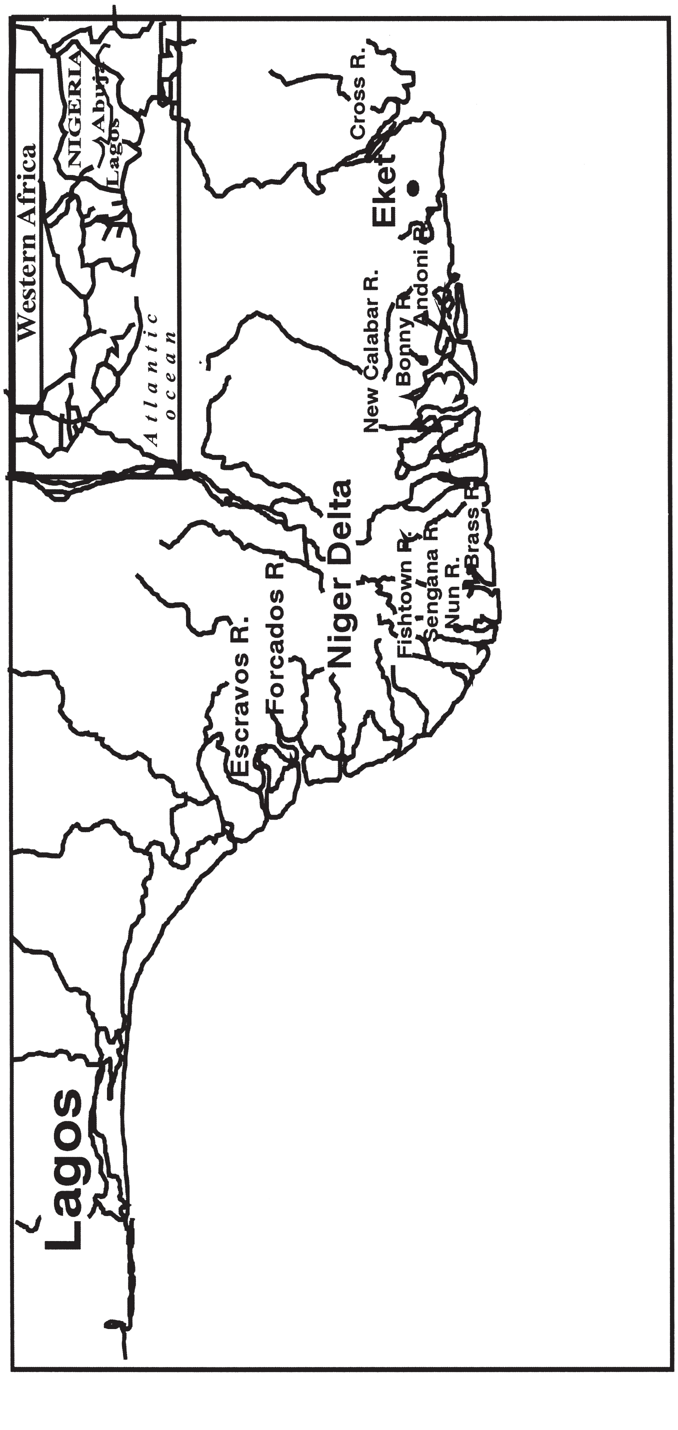

Figure 1. Map of Nigerian coastline showing the Niger Delta region.

Macrofaunal Studies

For macrofaunal studies, two creeks were selected per estuary, two transects per creek, and two stations per transect for sampling. At the sublittoral areas, samples were obtained from outboard engine boat using a 0.1 m^2 Van Veen grab. At low tide, samples were collected on the mud flats and other exposed areas using a 0.25 m^2 quadrat and sieved through 1 mm and 0.5 mm sieves for resident macrofauna, which were mostly dominated by brachyurans, polycheatous annelids, coelenterates, and molluscs. The mudflat decapods were sampled by counting the numbers of burrows per 0.25 m^2; this correlates very highly with the actual number of crabs inside them (Ekweozor, 1985; Ewa-Oboho, 1994, 1998; Ombu, 1986). Epibenthos was sampled by taking five random 1 cm^2 quadrat and macrobiota recorded as percentage cover, or counted where appropriate. Fauna were preserved in 5% formalin for identification and counting under a stereomicroscope. Only heads were counted for broken polychaetes. Average station values of abundance and biomass were used for analysis. Records from key species sheets were subjected to the following methods of analysis to compare estuaries and habitats (shore levels) based on species lists. These include principal component analysis based on species presence and absence data, covariance matrix, using species presence at more than two estuaries, hierarchical agglomeration (Cluster analysis) using Tanimoto and Kulazynki Indices (Ewa-Oboho & Asuquo, 2006; Jones & Richmond, 1992; Prena, 1996).

Phytoplankton

In each estuary, phytoplankton was sampled in 1 liter glass bottles, preserved before sedimentation with Lugol's solution and subsequently neutralized with 4% formalin. Counting and enumeration of phytoplankton cells were carried out by means of an inverted microscope of the Reichert Universal Kamara type at the Institute of Oceanography University of Calabar laboratory. To allow for comparison to previously published phytoplankton results (Nwankwo, 1992; Onwutiake, 1985), Shannon-Weaver Diversity Index was calculated for estuaries of intense petroleum activity from 2000-2005 and for the experimental control (CR). This index is biased toward the dominant species and is a gross measure of diversity (Ewa-Oboho, 1993; Washington, 1984). Species diversity estimates were arithmetic means calculated from 6 monthly samples, based on comparison of composites versus seasonal/yearly samples, the diversity result from 1985 (a period of less activities in the region) are comparable to the 1998-2004 data (characterized by intense development in the region).

Changes in community structure at the species level were assessed by correspondence analysis (CA; Statistical Analysis Software [SAS], 1990). Individual species biomass for six estuaries for each year was used. Mean species biomass estimates for Cross River were created by averaging the data into two blocks that represented different phases of development (i.e., different period of development). The two data sets combined, resulting in a matrix of 6 estuary-year by 128 species. Rare species created problems because they resulted in a large number of zeroes in the matrix. Only species that contributed > 1 % of the total biomass in at least 1 estuary-year were therefore retained for analysis (56 species). Biomass values were transformed by Log ([100* Biomass]+1). An accepted method (Hill, 1979) used in community ordination software CANOCO (terBrakk & Smilauer, 1998) was used to further down-weight rare species in the final correspondence analysis used. 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

$$f_i \left(\sum aij\right)^2 / \sum aij^2 \quad (1)$$

where aij = abundance of species j in sample i. If fi for species j is greater than Amax/5 then with weighing factor, is 1 otherwise it is fi/(Amax/5). Pearson correlation analysis (SAS, 1990) was used to test the significance of relationship between biological and chemical parameters viz total hydrocarbon content (THC; which is oil and grease), $N0^3 + N0^2$, conductivity, and DOC.

Chemical Analysis

Analytical procedures for water chemistry from the estuaries were as outlined by the Ontario Ministry of Environment and Energy (OMOEE) (1996). Water samples were taken at the same time as the phytoplankton from the integrated samples and measured using standard protocols (Asuquo, Ewa-Oboho, Asuquo, & Udo, 2004).

Zooplankton

Zooplankton was sampled from a scoop plastic bucket of 10 liter capacity. Subsurface water (approximately 5 m depth), was vertically collected with the bucket and filtered through a 100 µ mesh size of plankton net. Fifty scoop buckets of 10 liters capacity were filtered via the net. The net samples (representing 500 liter) were washed into 1 ml sample collecting bottles and fixed immediately in 2% formalin solution. After making up to 100 ml with distilled water, the samples were agitated and homogenized and 1 ml sub-samples placed in counting chamber for observation under 40-100× magnification. Organisms were identified based on Durand and Leveque (1980), Jeje and Fernando (1985) identification keys and enumerated for subsequent statistical computation.

Vegetational Studies

For mangrove plant studies, five populations were chosen from five estuaries (viz, Cross River (control) Bonny River, Brass River Forcados, and Qua Iboe

River) to represent different degrees of disturbance. All populations were vigorous and healthy at all sites when the study began in 1985. In each estuary, two permanent stations, 20 × 20 m each, were mapped out and labeled markers placed within each quadrat and mapped with the plants. At intervals of 4-6 months, all plants, within a quadrat, were mapped and the following features recorded for each seedling or established shoot status number damaged, the presence or absence of individuals, and their zonation patterns were also noted.

RESULTS

Macrofaunal Distribution and Abundance

Table 1 is a list of the more abundant species with their average abundances. The preponderance of polychaetes in the upper ranks can be seen, with *Capitella capitata, Chaetozone setosa,* and *Magelona filiformis* dominating. *Echinocardium* was ranked 65th with a density of 5/m^2. The coefficient of variation for each species is also presented in Table 1. This index (standard deviation ÷ mean density) indicates the spatial evenness in the abundance of the species; numbers much less than 1 being indicative of a uniform distribution.

Table 2 shows the changes in macro faunal standing crop from 1985 to 2005. A total of 14 taxa were found in the Niger Delta estuaries, although the macro faunal taxa such as Foraminifera, Major Nematoda, Copepoda, and Ostracoda were also collected but are not included in the final analysis. The Porifera, Ectoprocta, and the Cnidaria were always encrusted in their occurrence, this made enumeration as individuals difficult. The total number of species occurring through the sample series was enumerated only for polychaetes, bivalves, and decapods (Figure 2). Apart from polychaetes, abundances of macrofauna deceased from 1985 to 2004 in the region. Many studies have shown that some species are sensitive to environmental perturbations, particularly with regard to organic pollutants. This is particularly the case with larval forms of macro invertebrates of this region.

Polychaetes showed a steady increase in terms of numerical abundance during the period from 1985 to 2004, though species abundance did not show any significant change during this time (Table 2; $p \leq .01$; t-test by one-way ANOVA). While the Decapods and Scaphopods showed significant reduction in standing crop from 268 ind./m^2 and 73 ind./m^2 in 1985 to 162 ind./m2 and 35 ind./m^2 respectively in 2004, the groups Echnioidea and Amphipoda displayed little fluctuation from period to period during 1985-2004. Figure 2 shows the changes in four most dominant taxa in the major estuaries in the Niger Delta. Cross River estuary was considered to be the most pristine in terms of anthropogenic disturbance from intense development in this study. Rivers Qua Iboe, Bonny–Port Harcourt, Brass, and Forcados are more infused with activities varying from petroleum related to timbering and transportation reclamation etc.

Table 1. Rank and Abundance of Dominant Macro Benthic Fauna in the Niger Delta Mangrove Ecosystem during 1985-2005

Rank	Specimen	No/m^2	Coefficient of variation
1	*Capitella capilata*	62	0.20
2	*Chaetozone setosa*	56	0.26
3	*Megalona filiformi's*	45	0.32
4	*Exogone lebes*	41	0.46
5	*Nemetina*	38	0.54
6	*Abra alba*	25	0.42
7	*Uca tangeri*	21	0.85
8	*Ampellisca*	18	0.83
9	*Nematoda*	16	0.67
10	*Nephthys sp*	15	0.64
11	*Glycera*	9	0.38
12	*Scoloplos armiger*	8	0.62
13	*Polydora sp*	7	0.56
14	*Turritella communis*	6	0.63
15	*Notomastus filiformis*	5	1.08
16	*Cirratulus cirratulus*	5	1.1
17	*Neries sp*	5	0.68
18	*Marphysa belli*	4	1.32
19	*Hydrobia*	4	0.52
20	*Tellina sp*	3	0.86
30	*Pectinaria*	5	0.65
35	*Pchygrapsus gracillis 5*	5	0.72
40	*Sesamaelegans*	15	0.68
48	*Sesarina alberti*	12	0.65
55	*Metagrapsus curratus*	12	0.65
60	*Littonia sp*	2	1.21
62	*Mya areneria*	1	1.02
65	*Echinocardium sp.*	1	1.23

Mean densities of dominant/macrofauna showed variation with species. While polychaetes increased in number from 75 ind./m^2 in 1985 to 122 and 149 ind./m^2 in 2000 and 2004 respectively, densities remain fairly constant from year to year in Cross River estuary where marine or other activities in the adjoining urban city (Calabar) is less.

The decapods, which are mostly beach and mudflat dwelling crabs, had little variation in period mean densities in Cross River estuary (Figure 2; $p > 0.05$ *t*-test by one-way ANOVA). However, in Qua Iboe, Bonny–Port Harcourt, Brass, and Forcados river estuaries abundances tended to decrease with period from mean values of 35 ind./m^2 in 1985 to 21 and 18 ind./m^2 in 2000 and 2004 respectively. Single Factor ANOVA test showed significant difference ($p < 0.05$) in the abundance of Niger Delta bivalves survey from 1985 to 2004 which may not only be due to environment perturbation but to intense predation by higher vertebrates including human.

Phytoplankton Composition and Biomass

A total of 58 species from six taxonomic groups (Cyanophyceae, Chlorophyceae, Bacillariophyceae, Dinophyceae, Cryptophyceae, and Chrysophyceae) represented the phytoplankton communities of the Niger Delta region.

Total phytoplankton Biomass from 1998-2004 ranged from 30 mgm^{-3} to 632 mg m^{-3}. Low biomass values were recorded in Qua Iboe, Bonny, Escravos, and Forcados Rivers than Cross River and Imo River which probably are less stressed with anthropogenic input. Correlation of biomass, THC, DOC, and $N0^3 + N0^2$ vary from estuary to estuary and from species to species (Table 3).

Plankton, Species Diversity, and Richness

Changes in phytoplankton community assemblages of the Niger Delta estuarine ecosystem were reflected in species diversity and number of species present (a measure of richness). Species richness was significantly correlated with THC (Figure 3, Table 3).

Species diversity (D1) using Shannon-Weaver Index was also significantly correlated with THC. A linear regression analysis based on a subset of three estuaries combining 1984 historical data and data from 1998-2004 resulted in a significant relationship between THC and diversity (Figure 3), an obvious transition in species occurred from 1984 to 2004 in Bonny Brass and Qua Iboe estuarine as THC increased due to oiling activities over time.

Community Structure

The first four axes of the CA accounted for 14.4%, 7.8%, and 4.1% respectively of the total inertia (1.652, $\chi^2 = 24108$, *df* 10246; Figure 4). Axis 1 was significantly correlated with THC ($r^2 = 0.68$, $p = 0.0001$), while Axis 2 was correlated with

Table 2. Macro Faunal Composition and Standing Crop in 50.25 m^2 Box Corers from the Niger Delta Estuarine Ecosystem during 1985-2005

Macro faunal Taxa	Year											
	1985	1988	1990	1995	1997	2000	2003	2005	Total	Total No. m^{-2}	Total No. of sp.	Total No. of sp/m^2
Porifera												
No. Ind.												
No. sp.	3	3	3	2	1	1	2	2	17		17	68
Cnidaria												
No. Ind.												
Polychaeta												
No. Ind.	486	524	389	425	608	890	878	689	4,889	19,559		
No. sp.	15	18	12	11	1	9	10	12	8			
Nemertina												
No. Ind.	48	42	56	32	45	28	35	31	317	1,268		
No. sp.	3	3	2	5	3	3	4	3	2	2		
Isopoda												
No. sp.	158	185	231	196	162	136	101	123	1,292	5,168		
Nos	6	8	8	12	9	6	5	5	59	9	59	236
Amphipoda												
No. Ind.	24	39	54	31	46	32	21	25	272	1,088		
No. sp.	7	8	8	5	5	6	4	4			47	188

Decapoda												
No. Ind.	286		269	316	282	205	187	156	162	1,863	7,452	
No. sp.	13	13	12	12	12	10	10	10			93	372
Bivalvia												
No. Ind.	102	116	91	128	84	92	81	56	750	3,000		
No. sp.	9	10	9	10	6	7	8	5			64	256
Gestropoda												
No. Ind.	56	41	48	51	38	48	56	38	376	1,504		
No. sp.	5	3	3	4	4	3	3	3				
Scaphopoda												
No. Ind.	73	85	12	10	15	12	10	10	10	89	356	
No. sp.	1	2	2	2	3	2	2	1			15	60
Holothuroidea												
No. Ind.	4	6	4	5	4	4	3	3	33	132		
No. sp.	1	1	1	2	1	1	1	1			9	36
Ectoprocta									8	32	10	
No. Ind.	2	2	1	3	—	—	—	—				32
No. sp.	2	2	1	3	—	—	—	—	2	8		40
Ascidiacea												
No. Ind.	5	2	3	4	—	—	—	—	14	56		
No. sp.	3	1	1	2	1	—	—	—			8	32
Nematode	608	504	625	662	456	401	512	486	43	14		
Copepoda	55	36	38	45	22	31	21	18	266			
Ostracoda	—	—	13	15	12	18	10	8	76			

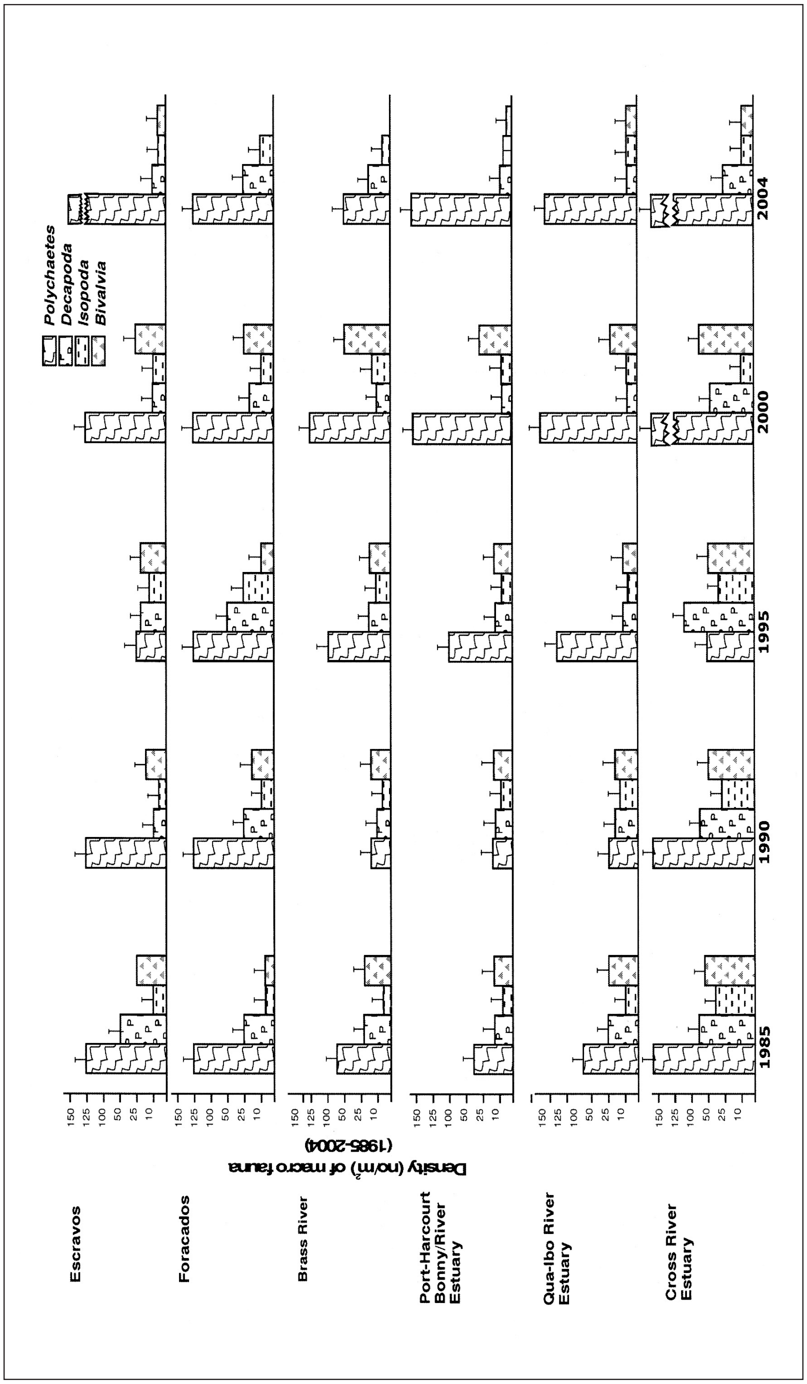

Figure 2. Periodic changes in four most dominant macrofauna in Niger Delta estuaries.

Table 3. Result of Pearson Correlation Analyses Using Chemical and Biological Parameters from the Studied Estuaries from 1988-2004

	THC		Conductivity		$NO_3 + NO_2$		DOC	
	Oiled Bonny River	Cross River	Oiled Bonny River	Cross River	Bonny River	Cross River	Bonny River	Cross River
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	0.002	< 0.01	0.001	< 0.01	0.8
Shannon-Weaver Index	r. 0.36	0.68	0.05	–0.05	–0.31	–0.62	0.00	
	p. 0.0056	0.0001	0.662	0.001	0.021	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 Biomass	r. 0.35	–0.38	0.01	0.06	–0.65	0.19	< 0.02	
	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
		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

The correlation coefficient (*r*) and the second row is the probability $p = < 0.05$ is considered significant.

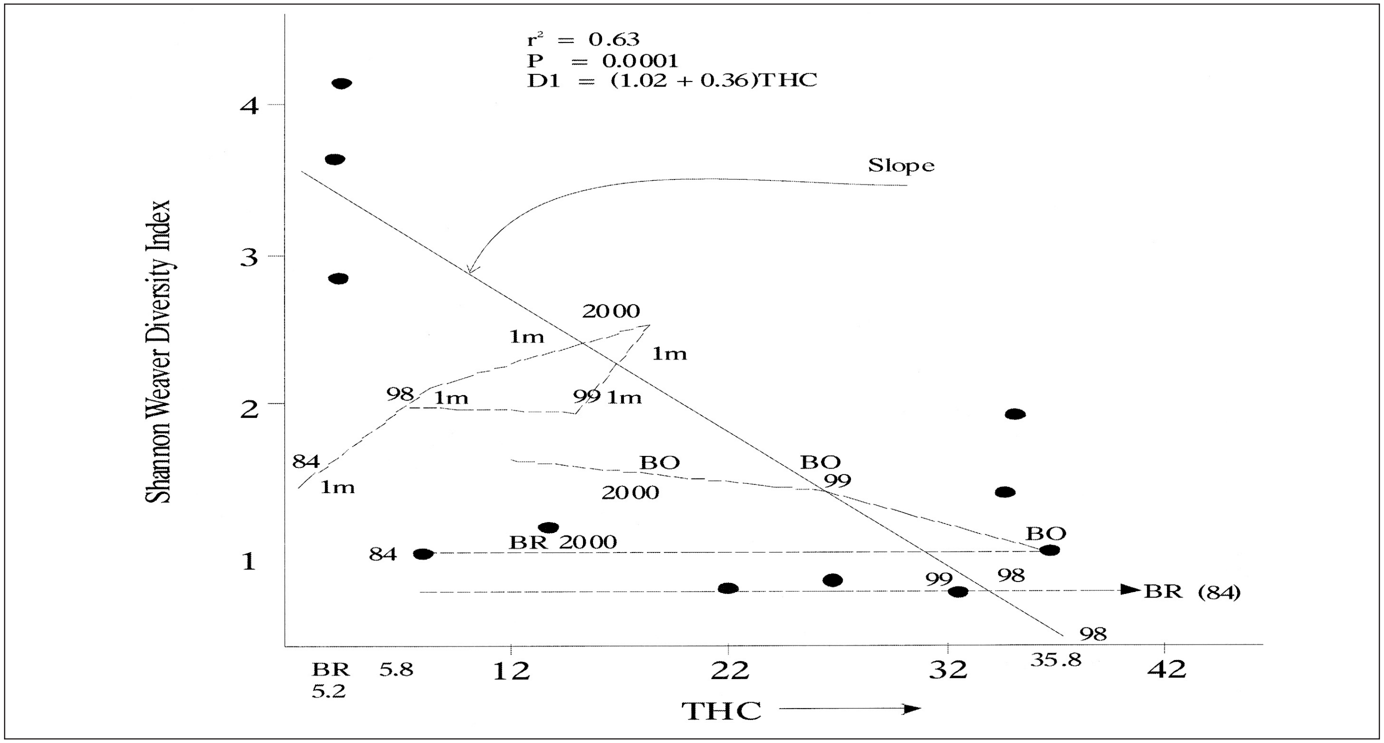

Figure 3. Linear regression of Shannon-Weaver Index (DI) on THC for a subset of Niger Delta estuaries, containing data for 1984. BO = Bonny, BR = Brass, IM = Imo estuaries. The number following estuary Code is the year, diversity decreased as the THC increased.

chrysophyte (r^2 = -0.48, p = 0.001) and cryptophyte (r^2 = 0.33, p = 0.005). Species scores (Figure 4) generated from the CA apply to all estuary-years and can be overlaid on them. The CA analysis revealed some interesting features. First, the 10 estuaries separated into two 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 to the lower right quadrant in 1999-2000. The phytoplankton assemblages for these estuaries were represented by dinoflagellates (*Peridinium excentricum, Gymnodinium splendens, G. polykrikos*) and chrysophytes (*Dinobryon sociale, Nitzchia filiformis, Chrysochromulina sp, Podosira sp*). 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 embarkments (ABPH), which shifted from the left quadrant to the extreme lower right as it was experimentally oiled to THC 38 ppm and shifted back to 5.62 ppm near-before experimentally oiled level of 6.1 ppm as THC decreased during recovery.

Zooplankton

Table 4 shows the percentage composition of the major taxonomic forms of zooplankton in the Niger estuarine ecosystem during 1984-2004. Total zooplankton (2857) was dominated at all times by the copepoda (76.2%), followed by Rotatoria (12%) and Cirripedes (1.5%). The economic larvae, such as larvae of crab (zoea) and fish put together, accounted for about 3.2%.

Mangrove Vegetation: Distribution and Occurrence

In 1985, at the start of the study, the vegetation showed a distinct pattern characterized in Figure 5 in terms of percentage cover of species present. Total numbers of mangrove species varied greatly between site (estuary), but all sites displayed similar seasonal/periodic change. Differences in numbers of seedlings were detected between sampling periods and sites reflecting seedling influx. There was no significant difference between sites however (ANOVA F = 1.14, $p > 0.30$). Figure 6 shows the periodic distribution of mangrove vegetation types in the delta region. Over 2 decades, the number of shoots in each species decreased markedly (between 4.35 to 41%). However, *Nypa fructican* displayed progressive increase within this period, reaching a maximum of 40.6% mean percentage cover over the other species.

In Figure 7, the periodic sequence of mean percentage cover of plant species in various estuaries are shown. At the relatively undisturbed Cross River mangal

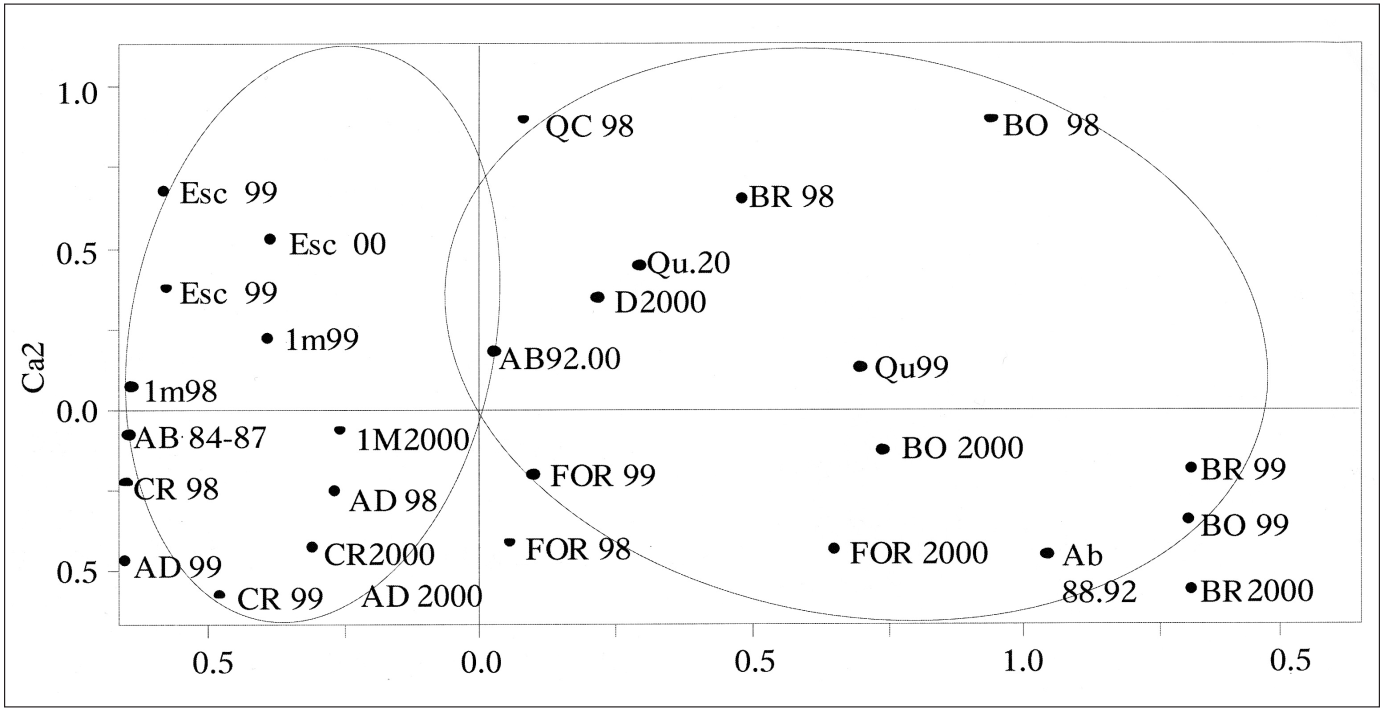

Figure 4. Estuary-year score results of a correspondence analysis of Abonnema Experimental water body (AB) and the eight Niger Delta estuary phytoplankton communities from 1998-2000. The ellipses are visual groupings. Ab = Abonnema Experimental, Ad = Andoni, Bo = Bonny, BR = Brass, CR = Cross River, Esc = Escravos, FOR = Forcados, IM = Imo River, Qu = Qua Iboe River.

Table 4. Spatial Percentage Composition of Major Zooplankton in the Niger Delta Estuarine Ecosystem during 1985-2004

	Estuarine				
Taxa	Qua Iboe	Bonny	Brass	Forcados	Cross R
Copepoda	76.2	72.5	80.3	76.8	78.2
Rotatoria	12.6	14.5	9.6	13.2	15.3
Cirripeda	2.6	1.2	4.6	1.1	3.1
Chaetognath	0.2	0.1	0.5	0.2	0.8
Economic larvae	3.0	4.8	1.3	5.1	10.5
Total zooplankton	427	466	435	562	965

systems, species of *R. racemosa, R. mangle,* and *Avicennia* displayed gradual reduction trend from 1985 to 2005. In contrast, the populations at the highly disturbed estuaries (viz. Bonny and Brass) showed much smaller percentage cover values (Figure 7) and faster reduction rate. Analysis of variance showed a difference in size among the four mangrove vegetation populations examined in the four estuaries ($F = 9.68$, $p < 0.001$) and a subsequent Student–Neuman–keuls test distinguished the vigorously growing Nypa populations in all the estuaries as the single unique group. In Cross River Calabar river channel *Nypa* sp showed a consistent growth increment from 1985 to 2005 when most parts of the estuary were covered with Nypa population and less mangrove.

In Qua Iboe River estuary, Avicennia species displayed a gradual reduction from 1995 reaching 1/3 of its initial cover value in 2005. While species of *Rhizophora racemosa* and *R. mangle* tended to stabilize in 1995-2005, *Nypa fructican* had consistently high cover values since 1985, and between 1995 to date it has out grown the mangrove plant species to their complete exclusion. Cover values of 25% as against 15 and 10% of dominant mangrove species were displayed in Qua Iboe River estuary, probably due to overcrowding *Nypa* sp. Plants tended to take to yellow coloration.

Since 1985, the vegetation standing crop and cover values has been low in Bonny and Brass estuaries. While the cover values and relative densities of *R. racemosa* are high (> 35%) in Cross River and Qua Iboe river estuaries in 1985, densities were low in Bonny and Brass rivers (< 18%) for this mangrove vegetation type. Significance of difference existed between ($F = 12.96$, $p < 0.01$) cover values of vegetation types between 1985 and 2005 in contrast. While *Avicennia* sp like *R. racemosa* and *R. mangle* diminished in size steadily, *Nypa* palm displayed some periodic increment in Bonny and Brass River but tended to stabilize with lower cover values in Bonny river estuary (Figure 7).

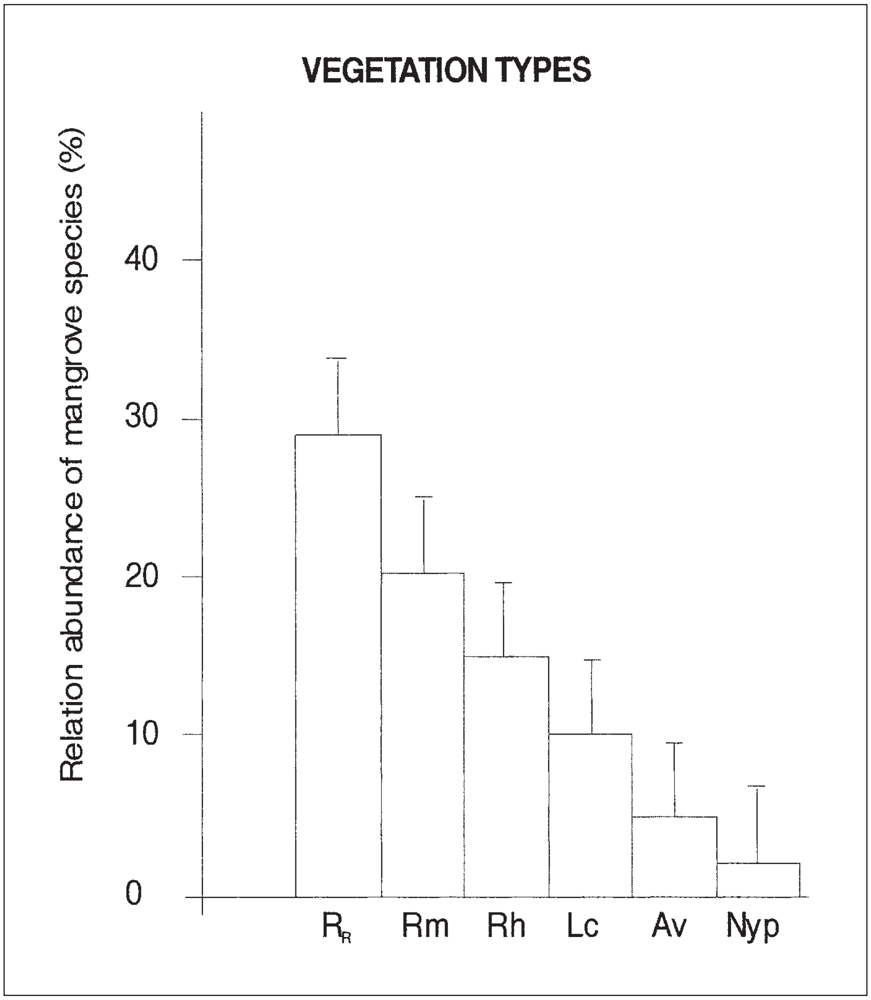

Figure 5. Mean percentage cover of the most abundant mangrove vegetation estuaries in the Niger Delta, cover values are based on five 20 × 20 m^2 quadrats positioned within each population in each estuary. Vertical bars represent one standard error. Species include *Rhizophora racemosa* (RR) *Rhizophora mangle* (Rm), *Rhizophora harrisonii* (Rh), *Laguncularia racemosa* (Lc), *Avicennia* (Av), and *Nypa fructican* (*Nyp*).

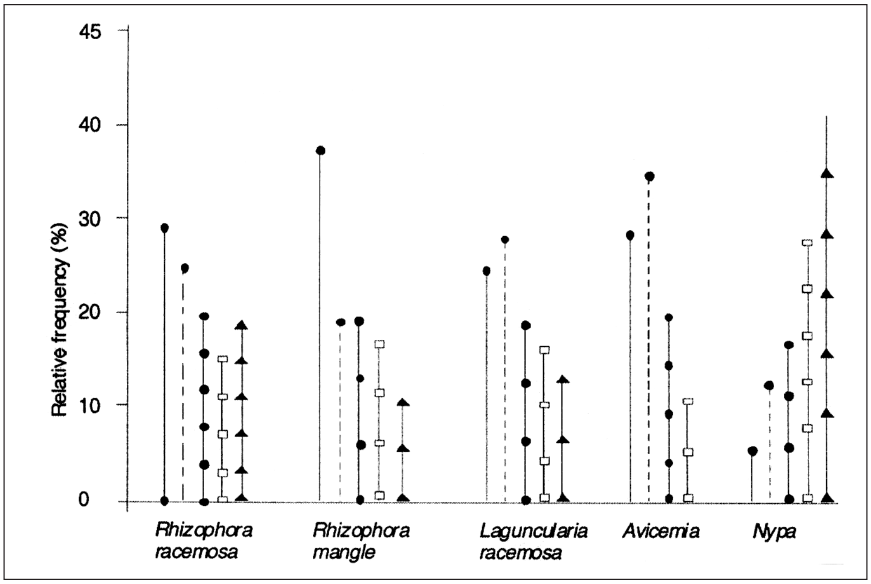

Figure 6. Relative frequencies of the Niger Delta mangrove vegetation types in 1985, •—•; 1990, •- - -•; 1996, •–•–•; 2000, □—□; and 2005, ▶–▶–▶.

DISCUSSION

Though difficult, it was possible to compare recent results, especially quantitative ones, with older data. The sampling stations are mostly the same, and the methods have not changed; besides, the same team carried out the investigations. Hence, some general features of the situation at the present time can be compared with observations from the past.

Macrofaunal Distribution and Abundance

The general faunal composition at estuaries in the Niger Delta is fairly typical of the shallow water mud/muddy–sand habitats throughout the Atlantic coast of West Africa (Edmond, 1978; Ekweozor, 1986; Ewa-Oboho, 1988; Ombu, 1987; Thorson, 1957). The fauna contains several species characterizing the tropical mangrove muddy–sand association. The significant differences in population densities of macrofaunal species between estuaries may be due in part to difference in composition of the substratum which was muddy in the inner sections of the estuaries and sandier in the more exposed sites. The larval forms of most deposit-feeding macro benthic fauna require fine sediment in which to burrow. In addition, the greater quantity of organic matter present in this

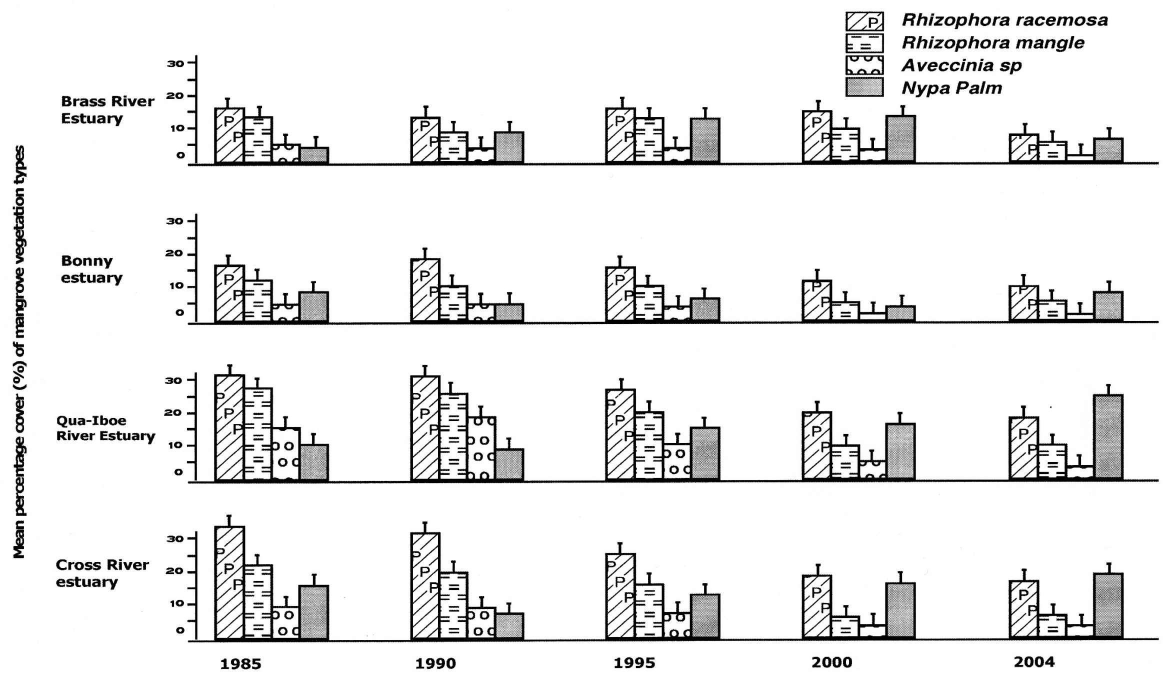

Figure 7. Mean percentage cover of the four most abundant species of mangrove vegetation types at four estuaries in the Niger Delta S. Nigeria. Cover values are based on five 20 × 20 m^2 quadrats positioned within each estuary mangrove vegetation population. Vertical bars represent one standard error.

part of the estuaries (Ewa-Oboho, 1988), is probably instrumental in decreasing the compactness of the sediment, thereby facilitating burrowing of larval forms of polychaetes, Decapods, and Isopods which were the dominant macrofauna in number of individuals and species. The numerical dominance of the polychaetes was due to two Capitelidae *Capitella capitata* Fabricus and *Chaetozone setosa* averaging from 56 and 162/m^2. Both species are suspension feeders with a capacity for indirect feeding on deposit (mud). The preponderance of suspension/deposit feeders in communities inhabiting mangrove soft substrata is well documented (Ekweozor, 1986; Ewa-Oboho, 1988; Ombu, 1987). Species are either affected numerically by the differences in sediment composition between estuaries or by pollution effects (Ewa-Oboho, 1999).

Response of polychaetous organisms have been known to vary with species (Ewa-Oboho, 1994; Ombu, 1987). *Capitella capitata* and *Polydora* have been found to show marked increase in numerical abundance following organic infusion into the environment. This is probably one of the reasons for the consistent relatively high abundance of polychaetes in these estuaries which is continuously polluted by organic materials from urban runoffs or from point-source discharge by industries. The low abundance of benthic fauna in Bonny and Brass River estuaries in 1985 and 1990 can be attributed to the many times of dredging and channelization activities in these rivers. This has the ecological effects of increased turbidity which tends to clog delicate feeding and respiratory structures of invertebrates. Dredge spoil tends to bury in fauna and alters the bottom substrate and smother benthic algae against primary productivity. Bonny, Brass, Forcados, and recently Qua Iboe river estuaries have for the past 2 decades, been under stress of anthropogenic input from petroleum and petroleum-related activities. Previous studies have shown various levels of species exterminated by oil spillages or introduction of alien or opportunistic species, thus adding to indigenous species of the area. Most of the later has been linked to the discharge of ballast water and associated sediments from ocean-going vessels.

Gastropods are deposit/detritus feeders and the predominant silt/clayey sediment (> 80%) characteristic of the delta estuaries (Ewa-Oboho, 1992, 1994) offers abundant food for their apparent proliferation. Though pollutants are retained for a longer period in this muddy sediment type (Asuquo et al., 2004; Ewa-Oboho, 2004), gastropods can stand high concentrations of bioaccumulated toxic pollutants that enter the environment from time to time. Dredging of channels, which is a very frequent activity in estuaries of Bonny Brass and Imo Rivers, has been shown in previous studies to result in low benthic production through burial of benthic algae by the spoil and also the sedimentation of fine suspended particles on the benthos, thus representing a major source of carbon loss to the benthos. Low benthic production could also be ascribed to excessive carbon loss by tidal transport of detrital material or microbial cells. These further reduce benthic secondary production observed after dredging activities in these estuaries (Ewa-Oboho, in press).

Plankton

The period between 1985 to 2005 has witnessed a tremendous hike in the total hydrocarbon content (THC) of the Niger Delta estuaries, particularly Brass, Bonny, Qua Iboe, and Imo Rivers where petroleum activities are at their peaks. The effects of this increase has been documented (Akpan, 1998; Ewa-Oboho, 2004).

In estuaries where the THC of water is > 12ppm, species diversity, species richness, and the abundance of diatom, cyanophytes, and cryptophytes decrease, while dinoflagellate abundance tends to increase (Ewa-Oboho, 2004). Documented 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 factors since most of the estuaries have different rates of fresh water in flow from land runoffs (Cole, 1965). Estuary-order may be a factor influencing water renewal NO_3 and P loading since the estuaries do not have same width and therefore same volume of water flow (Antia, 1998).

Previous studies of estuaries in Nigeria have documented high significant relationships between species richness and oil levels and species diversity and oil levels (Ewa-Oboho, 1988, 1994). During a simulated oil spill study (Ewa-Oboho, 1988), a recovery trajectory was observed as species diversity decreased during high THC levels and increased as THC decreased, suggesting species diversity is recoverable as estuary becomes less oily (Ewa-Oboho, 1988, 1994). Dredging activities within most of the estuaries impact the environment. After dredging of Bony, Imo, and some parts of Brass and Calabar River estuaries, production are particularly lower shortly after dredging than before (Ewa-Oboho & Oladimeji, 2004). Resuspension of particles often observed during and soon after dredging leads to high water turbidity and therefore low light penetration, low degree of algal sedimentation, and reduced phytoplankton production. Benthic algal production is also hampered by the smothering effects of resettling of mass of resuspended materials soon after dredging.

Zooplanktonic forms respond similarly to disturbance in the estuaries environment as the phytoplanktons. Activities resulting in oiling of the estuaries during accidental spills and point discharge of industrial effluents and dredging result in the general decrease in zooplanktonic species diversity and abundance. These activities, which have peaked off in recent times compared with their intensity 2 decades ago, have resulted perhaps in zooplankton species impoverished state of the estuaries. Spilled oil has been found to hinder metabolism in copepods (Rosenthal & Alderic, 1976) shrimp larvae (Broderson et al., 1977; Mecklenburg et al., 1977; Rice, 1986) and Teleostei eggs (Kuhnhold, 1978; Sharp et al., 1979). This probably explains the low species diversity and abundance in the delta estuaries in general. Oily surface prevent larval forms from settling and developing to adult stages hence die shortly before metamorphosis (Edung, 2001).

The acute toxicity of petroleum hydrocarbons to marine organisms varies considerably among species, developmental stage, and routes of exposure. Although precise interspecific comparison is difficult at any one time, differential sensitivity of various phylogenetic groups is related to hydrocarbon bioavailability, capacity for hydrocarbon biotransformation, and the metabolic consequences of hydrocarbon exposure. Sublethal effects due to incessant minor spills elicit effects on planktonic larvae which are dependent on the duration of exposure to toxic concentration and compensatory mechanisms available for recovery following exposure.

Responses of planktonic larval stages to low levels of hydrocarbon exposure could manifest in delayed development (Cucci & Epifanio, 1979; Katz, 1973; Laughlin & Neff, 1979; Wells, 1972), reduced feeding (Johns & Pechenik, 1980), reduced growth (Johns & Pechenik, 1980; Linden, 1976; Tatem, 1980), inhibit molting in larval crustaceans (Cucci & Epifanio, 1979; Laughlin & Neff, 1979), morphogenic abnormalities (Linden, 1980), inhibition of yolk utilization (Linden, 1980), and the presence of abnormal intermediate larval stages (Laughlin & Neff, 1979; Wells & Sprague, 1976).

Mangrove Vegetation

Several major features of the Niger Delta mangrove vegetation are discernible after more than 2 decades of observation. First, the mangrove plants may be regarded as long-lived perennial shrubs of shallow muddy and sheltered marine habitats. Within this brief, however, species show enormous latitude in demographic features depending on local conditions in the different parts of the Niger Delta mangrove swamps. Populations of mangrove vegetation type examined here conformed to similar schedules of growth, but differed perhaps in the scale of recruitment which showed variation with time (Botkin, Janak, & Wallis, 1992; Faroque, 1989).

Quantitative differences in numerical abundance of vegetation types between estuaries imply variation in control on a very local scale (Faroque, 1989). While frequent links have been drawn between demography of isolated populations and proximal environment factors (Ewa-Oboho, 2004; Grime, Mason, Gurtis, & Shaw, 1981; Harper, 1977; Harper & White, 1984; Holzlohner, Akpan, & Nwosu, 2003; Leck & Graveline, 1979; Matlack, 1987), causation has rarely been demonstrated experimentally. The danger of this is apparent: correlations may not indicate direct causation, but may arise through more complex interactions, or may be spurious. In the present study, experimental field studies have been used to assess the impact of human caused disturbance on mangrove vegetation populations in different estuaries in the Niger delta. The assessment of plant size was difficult because individuals vary greatly in the proportion of their stem which was above the ground.

Mangrove vegetation types (species) display markedly different demography at the estuaries and appear to remain a feature of the vegetation for 2 decades and probably longer, indicating a degree of success in each. Although there was a general deterioration in numerical abundance in the estuaries with time except for *Nypa* sp., in periodically eroded areas, *Rhizophora racemosa* and probably *R. mangle* seemed to be a narrow endemic with low migratory potential, living in permanently young habitats usually at the waterfront in the swamps. Erosion of channel and creek banks are caused mostly by exposing the banks to tidal currents and waves from passing trucks and vessels. Apart from use for construction and fuel wood, mangroves are cleared extensively in Bonny, Brass, and Qua Iboe swamps for channelization, rig and flow station construction, oil and gas pipe laying, and the establishment of human settlements which have all contributed immensely to the diminishing trend of mangrove vegetation in the region.

The distribution pattern and composition of the vegetation changed in a non-random way during the study period. The *Rhizophora*-rich vegetation types shrunk in area from 38% to less than 8%. In 2000 to 2005, the vegetation types of each estuary, not excluding Cross River estuary (control), was clearly associated with the disturbances of the ecosystem during 1985-1999. During this period, incidents of oil spills, large-scale mangrove deforestation for construction, and dredge spoil dumping on adjacent swamp areas were common features in the Niger Delta mangrove swamps.

The Nypa-rich vegetation types were more frequent than expected in the more disturbed estuaries, replacing indigenous mangroves in vast areas of the swamp. *Nypa* has become a biological invader and has exhibited a full range of impact and abundance in the Niger Delta mangals especially in disturbed systems of Qua Iboe, Bonny, Brass, and Forcados Rivers. *Nypa* "Success" is speculated to be associated with any one or a combination of the following: biological, chemical, and physical factors. Experiments to establish causation is currently on, though *Nypa* sp seem to fall into the pattern "A" type of marine invasion (GESAMP, 1997). Here species may become extraordinarily abundant in the early part of its invasion history, and then become less abundant in subsequent years. The reasons for this pattern are often speculative, but have been linked to an increasing "balance" between the invader, its food resources, and decreasing predation upon the invader by native species (GESAMP, 1997). Pattern "B" invasion, which is not likely exhibited by *Nypa*, is the natural fluctuations undertaken by the invader (ranging from blooms to uncommon to rare) within its native range. Distinguishing between these two patterns to explain *Nypa* abundance in the Niger Delta, especially within the first 2 decades of invasion, is very difficult.

In many ways, however, *Nypa* fits classical models of successful invaders (Drake, Mooney, Groves, & Williamson, 1989; Mooney & Drake, 1986). *Nypa* is susceptible and amenable to transport, it is a species of broad reproductive and physiological capabilities, and has invaded an environment (West Africa mangrove ecosystem). As a rapidly-reproducing self-fertilizing simultaneous hermaphrodite (Faraque, 1989), it possess an ideal reproductive strategy for a colonizing species. Finally, the disturbance regimes of the Niger Delta mangroves combined with its low floral diversity have lately made the delta mangrove swamp environment susceptible to invasion by *Nypa,* inoculated probably from ballast water from South Asia.

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