Diversity of muddy-bottom benthos in a tropical estuarine ecosystem: Cross River estuary, off the Gulf of Guinea, southeastern Nigeria

I. Ewa-Oboho[*1], S. W. Petters[1], N. Essien[1] and E. Antai[2]

ABSTRACT

The community structure of soft-bottom fauna is described for the Cross River estuary, Gulf of Guinea, with special reference to relationship between diversity and tropical estuary. Of the 105 species of invertebrates collected in June 2004, polychaetes comprised 80% by number of species and 68.5% by number of individuals. Density ranged from zero to $4374m^{-2}$ with a mean of $634m^{-2}$ per station and biomass ranged from zero to $10.96gm^{-2}$ with a mean of $2.0gm^{-2}$. Numerical analysis indicated considerable faunal homogeneity characterized by polychaetes. From measures of diversity it is concluded that the soft-bottom community of the Cross River estuary is not rich for a tropical estuary. Physical processes (riverine run-off and frontal systems) mainly influenced community structure and function in the lower estuary whereas biological processes (predation) seemed to prevail in the middle reaches.

INTRODUCTION

The paper at hand focuses on the diversity of soft-bottom fauna of a marine habitat. Earlier studies on soft-bottom benthos were carried out by Sanders (1968) who, after comparative studies of several littoral soft-bottoms from a variety of marine habitats, was led to propose the stability time hypothesis. During the past decade, considerable progress has been made in describing structures of benthic communities particularly with regard to soft-bottom-marine ecosystem under stress (Rosenberg, 1975, Nichols-Driscoll, 1976). These results are consistent with provisions of the stability-Time hypothesis according to Sanders (1968).

However, Ewa-Oboho and Ukpong (2008) recorded diversity values (H') of 3.0 and 2.3 at a control station off the mouth of Calabar River estuary. These are low for a non-stressed tropical marine environment. According to Pielon (1977), H' measures the diversity per individual in a many-species population. The greater the population's diversity the greater the uncertainty in predicting the identity of a randomly selected individual from the collection. Nichols-Driscoll (1976) felt that it was incorrect to generalized about soft-bottom communities as containing high diversity; instead, he proposed that comparatively few communities attain the level of diversity typical of tropical estuaries. Clearly, more studies of diversity of soft-bottom infauna of tropical communities are needed for the reassessment of the stability-time hypothesis.

Examples of benthic studies of soft-bottom communities in the tropical regions include the Atlantic Ocean, Caribean sea, Africa, Australia, Indian Ocean, Central America and Malaysia. (Long hurst 1959; Aller and Dodge, 1974; Holm 1998; Ewa-Oboho, 2006, 2008). 1986), quantitative studies of soft bottom fauna of the Cross River estuary is peculiarly scanty. Therefore the purpose of the present study is to describe the community structure and diversity of soft-bottom infauna of Cross River estuary, the largest in Africa. Accordingly the present study will provide some of the first quantitative data on community structure of subtidal soft bottom benthos in the eastern West African tropics.

MATERIALS AND METHODS

From 10-24 June, 2004, benthic grab samples were taken at 29 stations located at various points in the Cross River System (Fig. 1) from the R. V. "Mudskipper". Two replicates were taken per station with a modified Van-Veen bottom grab (sample area = $0.16m^2$). A sediment sample was extracted and then each sample was immediately sieved through a 1000µm and then through a 500µm mesh screen. Materials retained on each sieve was placed in 7% $MgCl_2$ for approximately 15 min prior to fixation in 10% buffered formalin. In the laboratory, grab samples were rinsed with fresh water and placed in 70% ethanol. Samples were scanned under a dissection microscope, and organisms were sorted to major taxon. For broken polychaetes, only heads were counted. Excess moisture was dried by blotting specimens on toweling, and biomass (wet weight including skeletal parts, if any) was measured. Organisms were identified to species at each station per sieve type. Important references utilized for species identifications are cited in Ewa-Oboho et al. (2004).

*corresponding author. Email: ita_ewa_oboho2005@yahoo.co.uk
Manuscript received by the Editor July 3, 2007; revised manuscript accepted October. 19, 2007.
[1]School of Ocean Science & Technology, Akwa Ibom State University, Uyo, Nigeria.
[2]Institute of Oceanography, University of Calabar, P.M.B. 1115 ,Calabar, Nigeria.

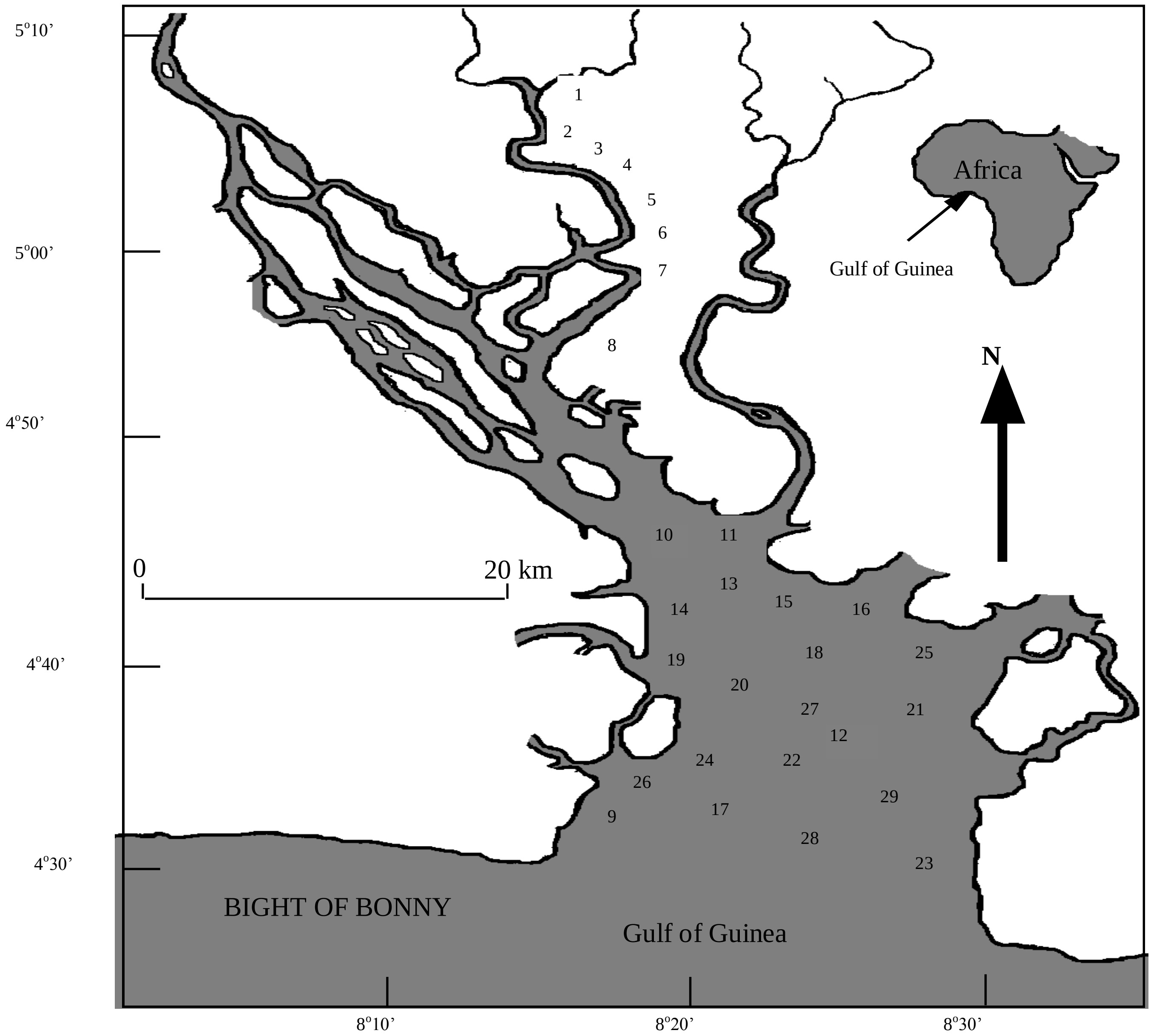

Fig. 1. Location map of the study area showing sampling stations 1-29 along the Cross River estuary.

Salinity, oxygen and temperature of surface water and subsurface water were measured in conjunction with bottom-grab samples. Water for temperature and salinity measurements was collected by hydrocast using a Niskin bottle. Temperature and salinity were determined on deck with a Beckman RS 5-3 Salinometer. Oxygen content was measured *insitu* by hydrocast using a YSI Model 51 B oxygen meter.

In the laboratory, sediment samples were washed through a 62µm mesh screen to separate the silt and clay portion of the sediment (<62µm) from sand fraction. Silt and clay fractions were determined by pipette analysis. A portion of the sediment sample was taken for analysis of organic content. The loss of weight upon ignition at 400^0 to 500^0C was taken as the organic content of the sediment. Species diversity was measured per station using the Shannon-Wiener function (H'), evenness (J'), Species rich-ness (SR) and number of species (N) (Pielon, 1977). McNaughton's (1967) dominance measure (DI) and the biological index value (BIV) were also calculated according to McCloskey (1970). Distribution patterns were analyzed with cluster analysis. Normal classification (site groups) and inverse classification (species groups) were produced following Clifford and Stephenson (1975). The data matrix was reduced by elimination of rare species which occurred as only a single individual at a single station (50 species). Biomass and sediment characteristics for each station were also clustered. Data were transformed $\log_e x(N+1)$ prior to generation of the euclidean distance resemblance (similarity) measure. A flexible clustering strategy with a beta of -0.25 was used. To determine whether there were any quantitative relationships between biotic and environmental measured, Peterson's correlation coefficient (R) was computed. Prior to compulation, data were transformed as above or by the arcsine transformation. The log transformation was selected to make the variances of counts independent of the mean, and the arcsine transformation is especially appropriate for percentages and proportion (% silt-clay, % sand) according to Sokal and Rohlf (1969).

RESULTS

Environmental conditions

Surface and bottom salinity were slightly higher in the dry season than the rainy season (Table 1.) The largest differences occurred at the month of the Cross River estuary where values of only 2 to 5% were recorded. Dissolved oxygen values were higher on the surface than in the bottom. Moreover, surface values in the dry season were markedly higher than surface values in the rainy season. During both seasons, there was a marked reduction in percent oxygen saturation between 20 and 25km distance seaward (Table 1).

Table 1. Characteristics of surface and bottom water along a transect down axis of the Cross River estuary during dry and rainy seasons. Distance seaward is from Calabar River beach towards the ocean.

Nd= no data.

Distance seaward (km)	Depth (m)	Temperature -(%)		Salinity (%$_0$)		Dissolved O_2 (% saturation)	
		Dry	Rainy	Dry	Rainy	Dry	Rainy
0	Surface	28.8	28.8	5.3%	3.0	98	76
	5	28.8	28.5	5.3	3.0	86	75
10	Surface	28.0	28.0	5.3	3.1	98	80
	10	28.0	27.9	5.4	3.0	76	74
15	Surface	27.5	27.5	6.5	5.8	101	98
	15	27.5	27.2	6.6	6.2	75	92
20	Surface	28.1	n.d	8.5	7.6	87	86
	18	28.0	n.d	8.8	7.8	73	75
25	Surface	28.2	28.1	10.6	9.8	78	71
	20	23.0	26.0	10.9	9.9	48	42

At km 25, percent saturation on the bottom in the dry and rainy seasons were 48 and 42% respectively.

Based on numerical analysis sediment distribution in the estuary was grouped into three general categories (Ewa-Oboho,1992): (1) the upper estuary and shallower stations (76 to 90% silt-clay); (2) off Parrot island (44 to 60% sand), and (3) at the mouth of the estuary close to Oron town (8 to 30% sand). The mean value of silt-clay per station was 63.6%. Sediment with high silt-clay content contained high organic carbon content (R=0.78). This indicated that sediment in the Guinea Gulf area could represent an important source of food for sediment-feeding benthos.

Benthic survey

A total of 105 species of fauna were collected polycheates dominated by number of species, comprising 58.5% (60 spp.) of macrofauna; crustaceans constituted 23.5% (2.5 spp.), molluscs 10.7% (11 spp), sipunculids (2.4% (3 spp.), echinoderm 2.0% (2 spp.) and miscellaneous (anthozoan, rhynchocoel, brachiopod, enteropneust, cephalochordate and pyenogonid) 3.9% (4 spp.). A total of 2345 organisms were collected in the survey. Polycheates and crustaceans again dominated the fauna by number of individuals, comprising 68.1% and 22.2% respectively, of the macrofauna. They were followed by miscellaneous taxa with 5.6% (132 individuals), molluses 3.7% (82 individuals), echinoderms 1.6% (38 individuals) and sipunculids 1.2% (28 individuals). Several measures of community structure were generated to characterize the benthos of the Cross River estuary. Density and biomass ranged from zero to 4374m^{-2} with a mean of 634m^{-2} and from zero to 10.967gm^{-2} with a mean of 2.012gm^{-2}, respectively. In regard to diversity, the number of species ranged from zero to 31 per station with a mean of 18.9. A more formal measure of species richness (SR) ranged from zero to 9 with a means of 4 and the Shannon-Wiener function (H') varied from zero to 3.09 with a mean of 1.91. The evenness component of diversity (J) ranged from zero to 1.0 with a mean of 0.76. This indicated that the number of individuals was relatively evenly distributed among the number of species. Dominance index (DI), which is usually inversely related to evenness, supported this. The DI ranged from zero to 100% with a mean of 51.4% (Table 2).

Table 2. Summary of measures of benthic community structure, June 2004, Cross River estuary (data based on 52 samples). H': species diversity; J': evenness; S. R. species richness; DI: dominance index.

	No of animals	No of species	Density (no.m^{-2})	Biomass (gm^{-2})	H'	J'	SR	DI
Maximum	787	61	4374	10.967	3.09	1.0	9.0	100
Minimum	0	0	0	0	0	0	0	0
Mean	114.2	18.9	1269	2.01	1.91	0.76	4.0	51.4
SD	166.2	16.4	1845.4	2.80	0.87	0.23	2.51	23.9
SE	25.9	2.57	288.2	0.43	0.13	0.03	0.39	3.74

Numerical analysis indicated that the relative abundance of characteristic species close to the mouth of the estuary was different from the remaining portion of the estuary sampled in this survey. However, the species composition throughout the survey area showed considerable overlap from station to station.

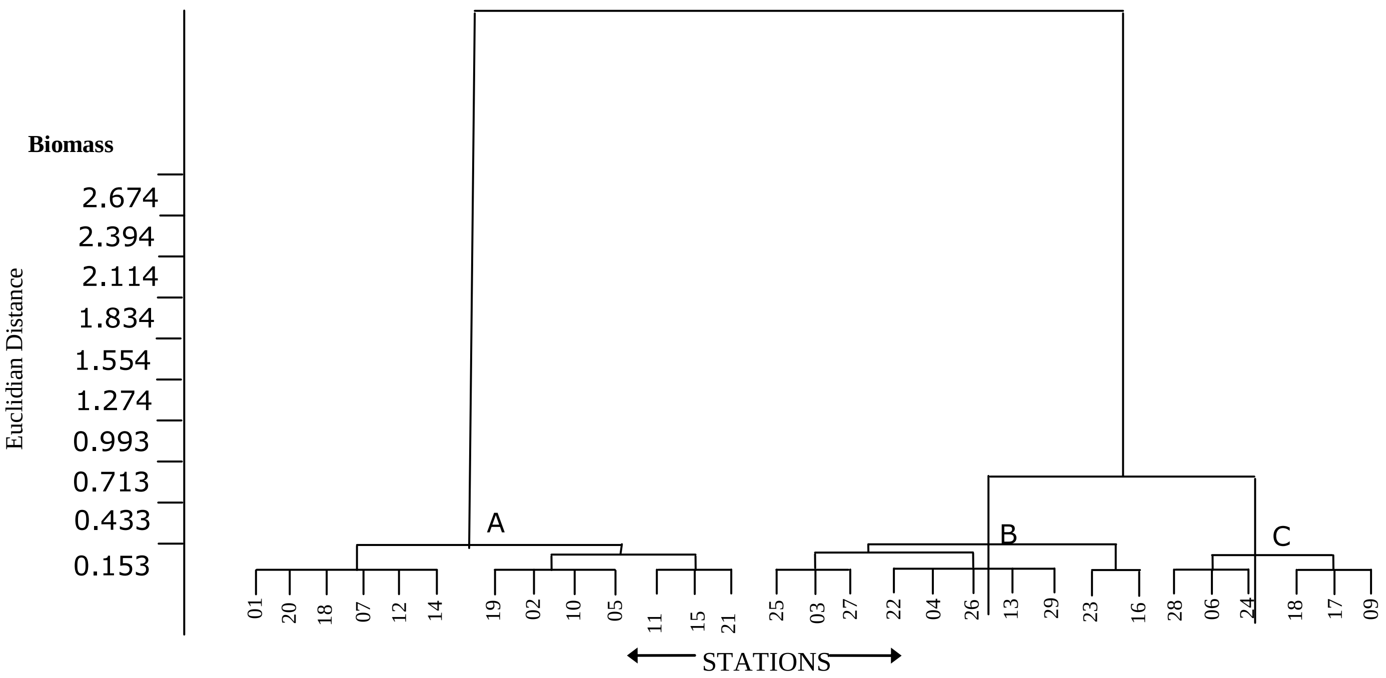

Fig. 2. Cluster diagram of similarity of biomass between stations in Cross River estuary.

Results of numerical analysis of benthic stations using biomass as attributes are shown in Fig. 2. Cluster A, was the largest group of 14). These stations were generally low in biomass ranging from 0.005 to 0.779gm^{-2} (Ewa-Oboho, 2004). Clusters B consisted of stations on the middle reaches of the estuary (stations 10, 25, 21, 13, 26, 29, 16). These stations contained intermediate values of biomass ranging from 1.700 to 2.700gm^{-2} Cluster C consisted of stations near the month of the estuary opening to the Gulf of Guinea Atlantic Ocean (stations 28, 24, 17, 18, 09). These stations contained the biological index value (BIV) of these species are presented in Table 3. as a measure of dominance. Seventeen species accounted for 1410 individuals or 65% of the fauna by number. Polychaetes comprised 9 species or 70% of the top species. Rank by abundance or occurrence offered different impressions of dominance. When abundance and occurrence were combined in the BIV, dominants changed stations and consisted of those stations on eastern end of the estuary close to Calabar Town (stations 1, 20, 18, 07, 12, highest values of biomass, ranging from 6 to 10gm^{-2}. A few stations from Biomass Clusters B and C were similar in species abundance. These data indicated that region influence by the out flow of the Cross river may be of major importance to the Gulf of Guinea ecosystem.

Dominant species

Species containing more than 10 individuals per sample were extracted from station counts. The abundance, occurrence and accordingly. For example when *Marphysa belli* and *Cheatozone setosa* were ranked by abundance, they were 3 and 16 respectively (Table 3). However, when ranked by the BIV, *M. belli* ranked 1 and *C. setosa* ranked 5. This indicated that *C. setosa* occurred more frequently but in fewer numbers than *M. belli*. The same followed with other species (Table 3).

Table 3. Abundance (Ab), occurrence (Oc) and biological index value (BIV) of top' (> 10 individuals per sample) species, June 2004, Cross River estuary.

Species	Abundance	Ab Rank	Occurrence	Oc Rank	BIV	BIV Rank
Notomastus	231	1	19	4	339	4
Mediomastus	153	2	21	2	361	2
Marphysa belli	150	3	20	1	423	1
Synelmis albini	116	4	9	10	132	13
Branchiostoma	98	5	12	8	187	8
Tympanotomus fuscata	84	6	4	161	63	18
Triodos sp	82	7	2	20	34	20
Ostracod sp	73	8	9	9	163	9
Chone sp	70	9	9	10	162	10
Heteromastus filiformis	62	10	21	2	349	16
Nebalia sp	60	11	4	16	74	16
Neris diversicolor	57	12	2	20	27	21
Magelona sp.	43	13	9	9	151	10
Phyllochaetopterus	42	14	14	6	215	6
Alpheus sp	36	15	4	16	57	19
Chaetozone setosa	27	16	14	6	214	15
Callinaessa sp.	26	17	9	9	135	12

Ecological relationships

Characteristically, the number of marine species tend to reduce toward the head of estuaries and increases towards the sea. The ecological significance of this pattern is usually interpreted as a response of stenohaline species to reduced salinity. In the Great Cross River estuary, the salinity gradient from the middle reaches (at Calabar) Town to the mouth was very small, even in the dry season (Table 1). As a result, reduction in marine species would not be expected to be marked up the estuary. However, when the number of species was plotted against distance from the mouth of the estuary, there was a significant (α=0.05) reduction (R=0.59). In addition, density, biomass and diversity (H') also declined significantly from the mouth of the estuary (R=-0.35, R=-42, R=-52). In shallow estuaries where benthic predation is conspicuous, extension of prey species into deeper water can serve as a refuge.

In the Cross River estuary an extensive fish fauna and large vagile invertebrates can exert remarkable grazing pressure on benthic organisms (Maurer et al; 1978, 1980, Ewa-Oboho, 2006, 2008). Population response to this pressure would be a shift towards deeper water. Benthos in estuary showed this trend as the number of species, density, diversity (H') and species richness (SR) significantly increased with increasing depth (R=0.42, R=0.49, R=0.36). Associated with this response to depth was that the number of species significantly increased with increases in bottom oxygen (R=0.45). Generally, there was a marked sediment-animal relationship among soft-bottom benthos in the estuary. The number of species, density, biomass and diversity (H') and species richness (SR) increased significantly with increasing percentage of sand in the sediment (R=0.48, R=0.56, R=0.42, R=0.38, R=0.46). No significant association between biotic measures and temperature or salinity was ascertained.

DISCUSSION

Diversity

The purpose of the present study, stated at the outset, involves the relationship between diversity of soft-bottom infauna and a tropical estuary such as Cross River estuary. Generally, in tropical estuaries, environmental factors contributing to stressed conditions involve high-temperatures, high turbidity, low dissolved oxygen, high H_2S, and fluctuating salinity (Wade, 1972; Rosenberg, 1975; Nichols-Driscoll 1976; Dungan et al. 2003; Bolam and Fernandes 2002; Dungan et al, 2003). Based on ranges of temperature, salinity and oxygen (Table 1) and general occanogrphic processes, encountered in the study/area, the area mainly covered in this study cannot be characterized as a stressed estuary. The stability-time hypothesis (Sanders, 1968), would predict that the soft-bottom fauna in the non-stressed tropical Cross River estuary be characterized as species-rich community. However, comparison of diversity with other estuaries revealed the following trends. Compared to a total of 105 species recognized in the present study there were comparably large numbers of species reported for the following temperature communities. 334 in Scotland, 276 in Norway, 250 in Southern Australia, 224 in Block Island, New York; 168 in Delaware Bay and 163 in Chesapeak (Lie, 1978; Pearson and Eleftherion, 1991; Rainer 1982).

Similarly, in subtropical and tropical communities, the following large numbers of species have been reported: 430 in North Australia, 380 and 298 in Africa, 153 in Jamaica, 139 in China and 130 in Florida (Field, 1971; Wade, 1972; Day, 1974; Stephenson et al., 1974; Shin and Thompson, 1982; Ewa-Oboho, 1993; Ekweozor, 1985; Ombu 1986). The number of species recorded from the Cross River estuary falls in the middle of values recorded for subtropical and tropical estuaries and is lower than several values recorded for several temperature estuaries. Regardless, diversity in the soft-bottom component was low compared to world-wide studies using similar collecting gear.

This result findings added support to Rosenberg (1975) who concluded that there is to date no proof that tropical and subtropical deep sea communities are more diverse than other communities from environmentally stable areas.

Faunal assemblages

Since Cross River estuary contains a variety of habitats (sand, mangroves, mud and head lands) and the bottom type change rapidly particularly in the mid and low reaches, it would be expected that several distinct faunal assemblages would have been identified. The soft-bottom fauna of Cross River estuary was characterized, according to cluster analysis in earlier studies (Nawa, 1982) and supported by the present study, as broadly occurring species, fluctuating in abundance with change in depth and bottom type. Faunal assemblage is perhaps, a polychaete dominated one. Probably, samples from deeper portions or from a tighter collecting grid would provide further basis to distinguish a variety of faunistic assemblages.

Density and biomass

Reduction of benthic density and biomass in low latitudes compared to middle and higher latitudes has been reported earlier (Saila, 1976). In the present study density and biomass ranged from zero to 4374m^{-2} with a mean of 634m^{-2} and from zero to 10.967gm^{-2} with a mean of 2.0gm^{-2}, respectively. These values compare with 3055m^{-2} and 3.7gm^{-2} dry weight in Scotland, ca 6000m^{-2} and 13.7gm^{-2} AFDW (ash-free dry weight) in Spain, 3114m^{-2} and 158gm^{-2} wet weight in Block Island, 22780m^{-2} and 2.85gm^{-2} dry weight in Nova Scotia for middle and high latitudes (McIntyre and Eleftheriou, 1968 and Levings, 1975), Comparison of density and biomass from the Cross River estuary with studies from lower latitudes showed 320m^{-2} and 7.131gm^{-2} dry weight in Florida, 240m^{-2} and 3.5gm^{-2} dry weight in Jamaica 30 to 40gm^{-2} wet weight off the Cango, 10gm^{-2} wet weight off the Malabar Coast, India., 115m^{-2} and 19.3gm^{-2} wet weight off West Africa and 101m^{2} and 35.2gm^{-2} wet weight off Hong Kong (Shin and Thompson, 1982). These values support the contention of reduced density and biomass in the tropics and so the density and biomass estimates for the Cross River estuary were consistent with this pattern.

Ecology

The infauna in Cross River estuary showed a considerable station-to-station variability in biomass and density. The lower estuary forms a deep sand-silt shelf which contrast with the shallower muddy middle and upper reaches of the Cross River estuary. During the rainy season, rivers and creeks of the Cross River System provide greater run off into the estuarine system, introducing more detrital materials and nutrients. It appears that soft-bottom benthos, mainly polychaetes, gastropod and amphipods benefit from these materials.

In turn, there is a heavy concentration of penaeid shrimp in this area (Enin, 1989, Nwosu, 2006), which is consistent with small crustaceans and polychaetes together with micro-and meiofauna commonly associated with detritus as the prime food source of penacids (Edwards, 2000; Mariarty and Barday, 2001).

In addition, there is a riverine plume producing a frontal system off the mouth of the Great Kwa River, a tributary of the Cross River System. Frontal systems concentrate nutrients (Sick et al., 1998) and often augment primary and secondary production in the lower reaches of the Cross River. In the middle estuary close to Calabar town, we speculate that biological processes may be more important in affecting structure and function of soft-bottom benthos than physical processes. This is based primarily on inferences from distribution of finfish and vagile invertebrates. High biomass of bottom feeding fish are often sampled from the middle estuary (Enin, 1989). Several species of large, bottom-feeding brackish water fish characterize this area. In addition reptantian decapods increase significantly up estuary with large populations of *Callinectes sp.* occurring in the upper reaches. The interaction of bottom fish and portunid crabs could represent considerable predation pressure on the soft-bottom benthos of Cross River estuary.

ACKNOWLEDGEMENT

We thank Prof. Enyenihi for providing the facilities needed for the study: Special thanks go to Evang. H. Ukpabio for great moral support. Bassey Job played a major role in field collection, laboratory processing and identifications and provided sources for taxonomic information. We gratefully acknowledge Dr. N. Abby-Kalio and the anonymous reviewers who criftiqued earlier drafts.

REFERENCES

Aller, R. C. and Dodge, R. E. (1974). Animal-sediment relations in a tropical lagoon, Discovery bay, Jamica. *J. Mar. Res. 32*:209-232.

Bollica, D.C. (1988). Animal-Sediment relations in a tropical lagoon, Discovery bay, Jamaica. *J. Mar. Res.* 32: 232-244.

Bolam, S.G. and Fernandez F.F. (2002). The effect of macro-algal cover on the spatial distribution of invertebrates: the effect of macro-algal morphology. *Hydrobiologia* 475/476: 437 – 448.

Castra, M. H., Dela, R . Sanchez – Mata, A.G. and Lopez J., (2006). Ecology of exposed beaches in northern Spain. environmental factors controlling macro -fauna communities. *J. Sea Res.* 55. 128 140.

Clifford, H.T.and Stephenson,W.(1975). An introduction to numerical Classification. Academic Press, New York, 229 pp.

Day, J. H. (1974). The ecology of Morrembene estuary, Mocambique. *Trans. Res. Soc. S. Africa. 41:* 43 – 97

Dungan, J.E., Hubbard, D.M., McCrary, D.M.and Pierson M.O.O.(2003). The response of macro fauna communities and shore birds to macrophyte wrack subsidies on exposed breaches of Southern Califonia. Estuary. *Coast. Shelf. Sci* 585:133 -148.

Edwards, R.C. (2000). The fishery and fisheries biology of penaeid shrimp on the Pacific coast of Mexico. *Oceanogr. Mar. Biol. A. Rev.* 86: 145 – 180.

Enin U. (1989). The artisanal in shore fisheries of Cross River estuary, *Fish by the* :76 – 10.

Ekweozor, I.K.E. (1985). Baseline survey for the monitoring of pollution in Bonny estuary. M. Phil. Thesis, University of Science and Technology, Port Harcourt,Nigeria, 281 pp.

Ewa-Oboho I. (1988).Effect of Bonny light crude oil on benthic organisms of the upper Bonny estuary. M. Phil. Thesis, University of Science and Technology, Port Harcourt. 268 pp.

Ewa-Oboho I. (1993). Substration preferences of two estuaries macrozoobenthos. *Tympanotomu tuscata and Uca tangeri. Hydrobiologia* 271:119-127.

Ewa-Oboho I. (2006). Basis of allometric relationships in juvenile brachyura: data from a West African mangrove swamp crab population. *West Africa Jour. of Applied Ecology* 10:35-45

Ewa-Oboho I.and Ukpong S.(2008).Impact of crude oil on recruitment of epbenthic organisms in Cross River estuary, S.E. Nigeria. *Global Journal of Pure and Applied Sceince* 15(2): 205 – 210.

Field, J.G. (1971). Numerical analysis of changes in the soft-bottom fauna along a transect across False bay, South Africa. *Jour. exp. Mar. Biol,* 7:215 – 253.

Holm, R. F. (1998). The community structure of a tropical marine lagoon. *Estuar. Estl Mar. Science.* 7 :329-345.

Levings,C. D.(1975).Analyses of temporal variation in the structure of a shallow-water benthic community in Nova Scotia. *Int. Revue ges. Hydrobil.* 60:449 – 470.

Lewes, D.(1979). University of Delaware, Collage of Marine Studies. *Progress Report Intenational Sea Grant Program.*

Lie, V. (1978). The quantitative distribution of benthic macrofauna in Fanafjorden, Western Norway. *Sarsia 63*:305-316.

Longhurst, A. R. 1959. Benthos densities off tropical *West Africa. J. Cons. Perm. Int. Explor. Mer 25*: 21-28.

Mc Closkey, L.R. 1970. The dynamics of the community associated with a scleractinian coral. *Int. Revue ges. Hydrobiol.* 55:13 -18.

Maurer, D; Epifanio, C. and Price, K.S. (1980). Ecological assessment of finfish and megabenthic invertebrates as indicators of natural and impacted habitats in the Gulf of Nicoya, Cost Rica, 305 pp.

Maurer, D, Watling, P. Kinner, W and Wether, C. (1978). Benthic invertebrate assemblages of Delaware Bay. *Mar. Biol.* 48: 65 – 78.

Mc Intyre, A.D. and Eleftherion, A. (1968). The bottom fauna of a flat fish nursery ground. *Jour. Mar Biol. Ass. U.K.* 48 :113 – 142.

Moriarty, D.J. and Barday, M.C.(2001). Carbon and nitrogen contents of food and the assimilation efficiencies of penaaeid prawns in the Gulf of Carpentaria. *Austr. Jour. Mar. Freshwat. Res*. 32:245 –251.

McNaughton, S. J. (1967). Relationships among functional properties of California grassland. *Nature*. 216:168 – 169.

Nawa, I. G. (1982). The ecology of Cross River estuary, Ph.D. Thesis, University of Kiel. F. R. Germany, 162pp.

Nichols –Driscoll, J.(1976). Benthic invertebrate communities in Gulfo Duke, Costa Rica *Revta – Biol*. 24:281 – 298.

Nwosu, F. M. (2006). Population dynamics of the giant African river prawn, *Macrobranchium vollenhovenii* (Crustacea, Palaemonidae) in the Cross River estuary, Nigeria. *West African Jour. of Appl. Ecology* 9:1-18.

Ombu E. (1986). The effect of Okrika oil terminal on the ecology of the upper Bonny estuary. M. Phil Thesis, University of Science and Technology, Port Harcourt,128 pp.

Pearson, T. H. and Eleftheriou, A. (1991). The benthic ecology of Sullom Voe. *Proc. R. Soc. Edinb* (Sect. B). 80:241-269.

Pielon, E. C. (1977). Mathematical ecology.,2nd edition. John Wiley and Sons, New York, 385 pp.

Rainer, S. f. (1982). Trophic structure and production in the macrobenthos of a temperate Australian estuary. *Estuar. Cstl Shelf Sci. 15:*423-441.

Rosenberg, R. 1975. Stress tropical benthic fauna in a Swedish fjord subsequent to the closure of a sulphite pulp mill. *Oikos* 24: 244 – 258.

Siala, S. B. (1976). Sedimentation and food resources animal – sediment relationships. In: Marine sediment transport and environmental management.(D.J. Stnadkey and D.J.P. Swift. Eds.). John Wiley and Sons, New York: 479 -497.

Sanders, H.L. (1968). Marine benthic diversity: a comparative study. *Am. Nat* 102:243 – 282.

Shin, P.K. and Thompson, G.B. (1982). Spatial distribution of the in faunal benthos of Hong Kong. *Mar ecol. Prog. Ser*. 10:37 – 47.

Sokal, R.R. and Rohlf, F.J. (1969). Biometry: the principles and practice of statistics in biological research, W.H. Freeman and Co, San Francisco,776pp.

Sick, L.V. Engel R .and Johson, C. A.(1978).Trace metal enhancement in the biotic and abiotic components of an estuarine tidal front. *Jour. geophys. Res.* 83 :4157-4667.