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Effect of dredging on benthic-pelagic production in the mouth of Cross River Estuary (off the Gulf of Guinea), S. E. Nigeria

[1]I. Ewa-Oboho*,[2] O. Oladimeji & F. Emile Asuquo

[1] Department of Marine Biology, Institute of Oceanography,
University of Calabar, P.M.B. 1115, Calabar, Nigeria
[2] Department of Food Technology, Obafemi Owolowo University, Ile-Ife, Nigeria
[3] Marine Chemistry Department, Institute of Oceanography, University of Calabar, P.M.B. 1115, Calabar, Nigeria
* E-mail: ita_ewa_oboho2005@yahoo.co.uk

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The effect of high turbidity on benthic-pelagic production at the mouth of Cross River Estuary (South Eastern Nigeria) was investigated following the dredging of the river channel in 1998. Annual phytoplankton production in the estuary was higher (25.9g C/m^2/yr) before dredging than after (20.7g C/m^2/yr). The seasonal distribution of chlorophyll-a correlated positively with that of primary production before ($r = 0.82$, $P<0.001$) and after dredging ($r = 0.65$, $p <0.001$). Primary production values were higher in the rainy season than in the dry season. Reduction in chlorophyll-a concentration (primary production) shortly after dredging, could be attributed to the significant reduction in light penetration, the physical smothering of benthic algae and disruption of benthic habitats. The patterns of seasonal copepod densities closely paralleled that of algal biomass. The efficiency of energy transfer from primary production to copepod production was lower after dredging (8%) than before (15%). Copepod grazing rates were high and greater on larger phytoplankton species which had < 10 % of algal carbon needed for secondary production.

[**Key words:** Benthic-pelagic production, dredging, detritus, phytoplankton, Cross River Estuary, Nigeria.]

Introduction

Carbon sedimentation is a major controlling factor of benthic production in the marine environment. In deep water or open ocean areas, faecal pellets of marine forms provide the primary source of benthic carbon[1-3]. On the continental shelves, faecal contribution is uncertain[4] and thus detritus may be more important. In the mouth of the Cross River estuary off the Gulf of Guinea, South eastern Nigeria, rapid sedimentation of algal cells during the dry season may be influenced by-benthic production [5-7].

Sediment trapping, micro heterotrophic[8] and nanoplanktonic exploitation[9,10] are the various procedures of studying carbon flux in tropical waters. By measuring carbon flows within and between pelagic and benthic habitats in the mouth of the Cross River estuary (largest in Africa) before and after dredging, attempts have been made to explain the functioning of some local phenomena that could form the basis for some important generalizations not only for the local ecosystem, but also for the global carbon cycle[6]. The present study involves primary production estimates, and estimates of secondary benthic and pelagic invertebrate production one year before dredging and six months after dredging.

The aim of this study was to determine the impact of dredging on aquatic production as measured by the amount of carbon sedimentation from the photic zone, and to design a production inventory for the Cross River estuary which could be applied widely to similar marine environments in the tropics.

Materials and Methods

The Cross river system lies between latitudes 4° 00′ and 8° 00′N and longitudes 7° 20′ and 10° 00 E. (Fig. 1) It rises from the Cameroon mountains, from where it flows west wards into Nigeria and finally discharges into the Gulf of Guinea in the southern Nigeria. Major tributaries include rivers Calabar, Akpayafe, Mbo and the Great Kwa river. The rivers drain mainly through the tropical rain forest belt consisting of thick rain forest to the north and the freshwater and mangrove swamps to the south. It is the largest estuary in West Africa. The study area is characterized by two distinct seasons, the wet season (April – October) and the dry season (November – March). During the months of December–January, the

*Corresponding author; Ph.: 234-080-33858365

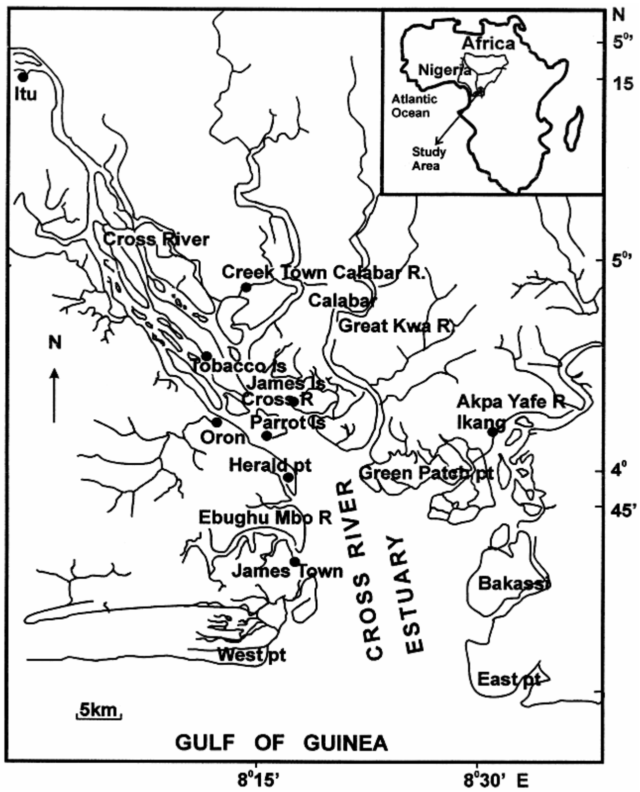

Fig. 1—Location map of the mouth of the Cross river estuary with Africa as inset.

climate is characterized by cold dry and dusty conditions brought about by the North East trade winds blowing from the Sahara desert. The south-west trade winds dominate the wet season. Temperatures are high and ranges between 22°C and 35°C. Relative humidity ranges from 60 – 90% while rainfall is of the order 800-1000 mm per annum. Current speed is 68 cm/sec maximum at ebb tide and 50.1 cm/sec at flood tide. The estuary is the largest source of inland fisheries in Nigeria with an annual fish production estimated to be 8000 tonnes[11]. The dredging activity extended over 30km from the Calabar Sea Port (middle reaches) to the lower reaches of the estuary. This activity was carried out to deepen the channel for large maritime/cargo vessels thereby facilitating the transportation of goods/services in and out of the Calabar international sea port.

For sestonic biomass and sedimentation rate studies over an average depth of 40 m, sampling was conducted monthly during January – September 1997 (before dredging which commenced from 8th October to 20th November 1997).

Two months after dredging, sampling was repeated monthly from January (dry season) to August 1998 (wet season) to assess possible changes in the ecosystem. Salinity and temperature of the water were measured at 10 m depth intervals using a calibrated Beckman RS5 salinity/temperature probe. Light intensity was measured with a LICOR, L1886 integrating photometer and the depth at which 1% of the surface light intensity was obtained defined the lower boundary of the euphotic zone in this study. Replicate water samples were collected at 1, 10, 20 and 40 m depths between 08:00 A.M and 12:00 noon using a Nansen water sampler. Aliquots for image analysis of algae, faeces and protozoans were fixed in a mixture of 0.5% Lugol's and 5% Bouin's solution. For chlorophyll a[12] and particulate organic carbon (POC) determination, water was kept refrigerated at 20°C pending laboratory analysis. Zooplankton samples were collected using vertical trawl with 64 – µm and 250 – µm mesh sizes.

Particulate sedimentation was measured using a floating sediment trap to which a current meter was attached to detect currents passing over the trap (3-5 $cm.sec^{-1}$). This range of current speeds indicate 90-100 % collection and retention efficiency of particles in the range of 3-800 µm. Traps were deployed to the lower end of the euphotic zone (10m) for 18-24 hrs. The cylinder contents of the traps were poured into 20-litre plastic containers and sub-sampled into fourlitre glass bottles and fixed with both 0.5% Lugol's and 5% Bouin's solutions. Samples in bottles were transferred to graduated cylinders and allowed to stand for 24 hrs before decanting. The remaining water collected by the trap was refrigerated for laboratory analysis.

Fixed water samples from both bottle-cast and sediment trap collections, were sized and species partitioned using an image analysis system (made available at Nigerian National Petroleum Corporation Laboratory). The system consisted of a Leitz inverted microscope, a Hitachi high resolution video camera and monitor, and a SAC Graf/Pen digitizer interfaced with an IBM-PC computer. Measurements were converted to the closest approximate geometric volume, and from volume to carbon content for faecal pellets[13], algal cells[14]and for protozoans[15]. Where appropriate, these relationships were calibrated on separated samples digitized as above and then processed for carbon content in a park in Elmer Model 240 CHN analyzer. Based on morphology, faecal pellets were partitioned into 'green', 'brown' and 'red' types. Calculation of particle flux measured by the sediment trap were made for background concentration. All copepodite stages and adults were calculated either from P/B ratio base on water or from the number of generations per year calculated either from P/B ratio base on water or from the number of generations per year calculated from Belebrahdek's function[16]. Copepod grazing rates were also measured[17]. Macrobenthos production was calculated by multiplying the biomass value of each species by estimate P/B values and summing for all species at the station [18,19].

Water for chlorophyll and POC analysis were filtered within 5hrs of collection with a filtration vacuum not greater than 180 mm Hg. Duplicate samples were filtered through a 20 µm mesh to divide sample into net-plankton (>20 µm) and nonaplankton (< 20 µm). Then they were filtered through Whatman GF-F filters (0.45 µm) and immediately frozen in Telfon-capped test tubes for chlorophyll analysis. Chlorophyll-a concentration was measured fluorometrically[12]. Particulate organic carbon was measured by combustion of the suspended (SPM) filtered in a Coleman analyzer and compared with wet oxidation methods[20].

Results

The surface salinity was generally low at ebb tides and high at high water levels. Maximum values were recorded in the months of January and February (28 $^{o}/_{oo}$) which corresponded to the dry season when seawater temperature reached an average of 26°C. (Fig. 2). The lowest surface salinity (18 $^{o}/_{oo}$) was recorded in July when the region experienced the heaviest (980 mm) rainfall, and the lowest temperature (22° C), leading to seawater dilution in the area. Temperature and salinity showed no significant differences at 40 m and the surface 0-5m depth (Fig. 2).

Before dredging of the channel, the mean monthly production ranged from a low 0.2 gC/m^2 in January 1997 to high of 0.5 gC/m^2 in August 1997 (Fig. 3) Production tended to increase during July and August when two peaks were obtained. Similarly, after dredging, a low value of 0.l2 gC/m^2 and a peak of 0.184 gC/m^2 were recorded in January and July 1998 respectively, (Fig. 3).

Maximum chlorophyll concentrations were recorded from 0 -1 m of water column before and after the dredging activities. However, after dredging, mean concentration ranged from <1mg/m^3 in February to 1.8 mg/m^3 in August and 2 mg/m^3 in July (Fig. 3). In general, the seasonal profile of surface chlorophyll approximated that of seasonal primary production data before and after dredging. Most of the chlorophyll in the light zone was contained in algal cells < 20 µm in diameter (Fig. 4). In July, about 98% of algal cells present were < 20 µm in size before dredging and about 80% were < 20µm after dredging. In April however about 10% of algal cells were < 20µm before dredging and about 8% after dredging activities. There was a substantial increase in flagellates towards the dry seasons. The peak in chlorophyll-a in July (mid rainy season) coincided with the peak in algal standing crop both before and after dredging the estuary (Fig. 3). Copepod mean densities (Table 1) though higher in the dry season (2,600 individuals/m^3) than in the rainy season (2850 individuals/m^3), were not significantly different before dredging. Similarly, mean densities of 1565 and 1800 individuals/m^3 were recorded for dry and rainy seasons respectively after dredging. Generally, mean densities of copepods which were predominantly adults or later copepodites stages of *Acartia* and *Paracalanus roma* were significantly higher before the dredging activities ($P < 0.05$ F-test by ANOVA).

Correspondingly, grazing rates which ranged from 126-520.mgC/m^2 (3-10%) were more in the dry season than the rainy season, and significantly different before and after dredging ($P < 0.05$ t-test) (Table 1). In July, the copepod density increased with algal bloom resulting perhaps in higher grazing before (421-443 mgC/m^2) than after (126-248 mgC/m^2) dredging respectively, and leading correspondingly to a reduction of the percentage of primary production grazed from 10% to 6% and from 8% to 3% before and after dredging respectively.

The annual flux of POC was distributed between detritus, algae and faecal matter: 22 gC/m^2/yr before and 17.4 gC/m^2/yr after dredging for detritus, 25.9 gC/m^2/yr before and 20.1 gC/.m^2/yr respectively. The algal components which were more prominent in the rainy months of May to August averaged about 40% of the total flux (Table 2). After dredging however, detrital contribution to the total POC was significantly higher than either algal or faecal components (Table 2, Fig 5). Small proportions (26 and 31%) of the total carbon flux (67.15gC/m^2/yr and 53.29 gC/m^2/yr) were contributed by faecal pellets during pre-and post-dredging respectively. On the contrary, detritus comprised more than 90% of the standing organic carbon biomass before and after dredging (~93% and 97% respectively).

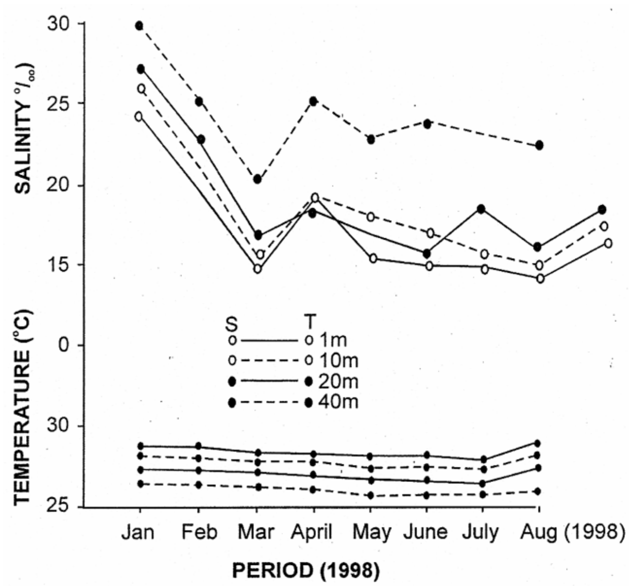

Fig. 2—Seasonal salinity and temperature profiles in the water column of the study area.

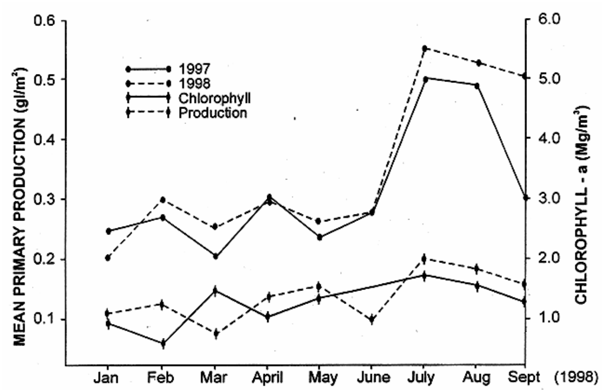

Fig. 3—Average monthly primary production data(-) and monthly surface chlorophyll-a concentration (—) at the study site, before dredging 1997 (*) and after dredging 1998 (-o).

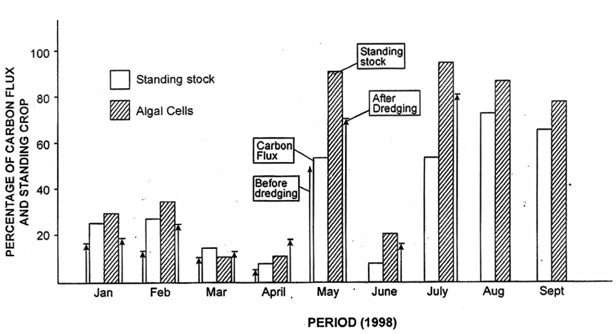

Fig. 4—Percentage carbon flux of algae (□) and standing crop (Ⓢ) in 20 μI algal size fraction for each month sampling in the mouth of Cross river estuary. The horizontal strokes on the sides of bars represent average values of the corresponding variable after dredging read off horizontally from the x-axis.

Approximately, 35 - 40% of the algal standing crop (as chlorophyll-a) sedimented out of the light zone before dredging, with 70% of the cells being < 02 μm in size (Fig.4). However, more algal cells were found to sediment out of the light zone after dredging activities. Also, a higher percentage of carbon flux was measured after dredging (Fig. 4).

Total carbon sedimentation increased from approximately 0. 05 gC/m^2 in January after dredging to 0.l2 gC/m^2 in September. Before dredging values of 0 19 gC/m^2 were obtained in January with a peak in June (0.29 gC/m^2) and July (0.25 gC/m^2). These values were significantly higher than values after dredging ($P < 0.05$, F- test on ANOVA).

Detritus accounted for over 70% of sedimenting carbon during the entire study period before and after dredging (Fig. 5) The contribution of faecal matter to total carbon sedimentation increased from about (10-12%) before and after dredging in January to about 20-25% in March and May. Again, percentage values were higher after dredging than before dredging. The percentage values of algal carbon in the total POC flux in the months of May, June and August were higher before dredging, and also higher in the rainy than in the dry months. Percentage monthly values recorded 12 months before dredging

Table 1—Periodic copepod densities, grazing rates and percentage primary production grazed in the Cross River estuary, 1997-1998.

Period	Copepod density (no/m^2)	Grazing rate mgC/m^2	Primary production (%)
1997			
Rainy Season	2850	421-433	90
Dry season	2600	362-520	6
1998			
Rainy season	1800	126-248	82
Dry season	1560	163-330	30

Table 2—Annual organic carbon flux, standing crop and proportion of major ecosystem component of carbon flow

Component	Annual flux $gC/m^2/yr$	Flux (%)	Standing crop gC/m2	Biomass (%)
Detritus	22.45	33	15	92
	(17.42)	(38)	(18)	(97)
Phytoplankton	25	40	0.014	6
	(20)	(30)	(0.672)	(1)
Fecal pellets	26	25	0.046	0.95
	(20)	(31)	(0.39)	(0.72)
Total	67	-	16	
	(53)		(18)	

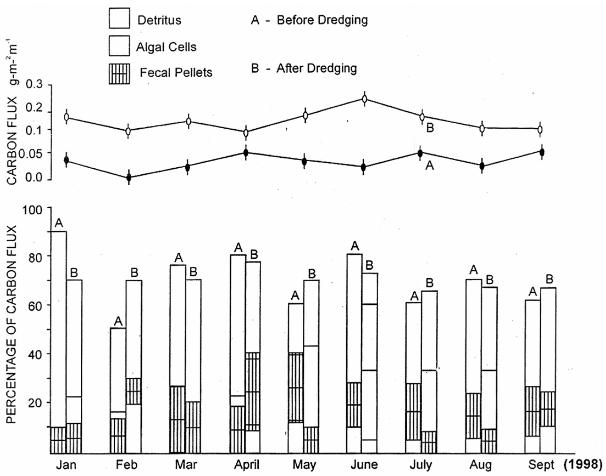

Fig. 5—Monthly total carbon sedimentation and proportion of carbon flux as detritus: (□), algal cells (Ⓢ), and faecal pellets, before (B) and after (A) dredging.

Table 3—Two-way ANOVA of mean annual flux (POC) for ecosystem component 1 month before and 1 month after commencement of dredging in the Cross River Estuary.

Ecosystem component	Sources of variation	df	SS	MS	F-value
Detritus	Total	9			
	Sampling period	1	0.2131	0.1256	82.6**
	Site	4	0.0015		3.2
	Error	4	0.0015		
Phytoplankton	Total	9			
	Sampling period	1	0.1320		
	Site	4	0.0017	0.052	41.8**
	Error	4	0.0003	0.081	7.2*
Fecal pellets	Total	9			
	Sampling period	1	0.2031	0.102	65.6**
	Site	4	0.0036	0.083	5.1
	Error	4	0.0008		
* P< 0.05,	**P< 0.01				

showed no significant difference (P > 0.05 F-test on ANOVA) temporarily. However, to demonstrate the impact of the dredging activities on the aquatic system, data obtained one month before and after dredging were compared for same stations. The source of variation (sampling period) showed marked differences for the three ecosystem components tested (Table 3). Sampling station (site), as the source of variation showed significant difference (P < 0.05) in station by station data for phytoplankton.

Discussion

The observed significant difference (P < 0.05) in the spatial distribution of phytoplankton could be attributed to the patchy nature of plankton distribution in such systems. Interestingly, the annual phytoplankton production (25.9 $gC/m^2/yr$) of the estuary before dredging was significantly (P < 0.05) higher than after dredging (20.7 $gC/m^2/yr$). This corroborates the positive correlation observed in the seasonal distribution of chlorophyll-a with that of primary production both before and after dredging (r = 0.82, P < 0.01) peaking in the rainy season and lower in dry months. It is possible that the impact of radiant energy phase[19] on algal production was delayed in the estuary until July-August when marked increase in production and biomass were observed. The significant reduction in concentration of chlorophyll-a and primary production in the system shortly after dredging could be ascribed to reduced depth of light penetration as a result of increased turbidity[21].

Definitely, the patterns of seasonal copepod densities closely; parallels that of algal biomass. Large number of copepods did not appear until July-August when *Paracalarids* dominated, particularly in 1997 before the dredging. A similar pattern was observed after dredging, though with significantly (P < 0.05) reduced copepod densities. The efficiency of energy transfer from primary production and to copepod production was lower after dredging (> 10%) than before dredging (> 15%) and its ratio is comparable with that elsewhere[21].

A large number (70%) of algal cells measured from chlorophyll-a were < 20 µm in diameter. However, over 90% of algal carbon estimated from size to volume conversion, was in the form of autotrophic microflagellates (< 10 µm in diameter). Since the copepod grazing rates were high and there was probably more grazing on larger phytoplankton than the smaller sized groups, the energy requirement of zooplankton was in effect, not met by larger phytoplankton[13]. This suggest that other direct (e.g. detritus and coprophagy) and indirect sources must have contributed to the high secondary production. Detrital feeding by copepods has been extensively studied[22,23]. Coprophagy has been shown to contribute significantly to the energetics of the estuaries[12], and is responsible for a decrease in faecal pellets with depth.

Evidence from this study indicates that before dredging, the relative contribution of different particles to downward organic carbon flux was dependent upon the season and that on an annual average detritus, faeces and algae contribute almost equal amounts of carbon to this flux. In both the rainy and the dry seasons, detritus is the major contributor of organic carbon flux to the benthos derived from a combination of local mangal inputs and resuspended materials due to strong tidal mixing at the mouth of the estuary. Resuspension of particles was particularly marked soon after he dredging activities. This led to high water turbidity and therefore low light penetration, high degree of algal sedimentation and reduced phytoplankton production. Benthic algae production was also hampered by the smothering effects of resuspended materials soon after dredging.

Faecal pellets and phytoplankton, on the average, contribute more particulate organic carbon to the benthos than detritus. An increase in copepod density is accompanied by an increase in faecal pellet contribution to carbon flux.

The mean total POC flux was highest in the rainy months of June and July when algae and zooplankton (copepod) densities were highest. However, after dredging, the total POC flux showed lower values in the months of June and July 1998 corresponding to the decrease in algal and copepod densities. One possible explanation is the depression of vertical copepod migrations related to the degree of reduction of the euphotic zone due to high turbidity, soon after dredging. As floating sediment traps were deployed at the base of the euphotic zone, the measured rate of sedimentation would be reduced by such a depression in vertical migration.

Out of over 4000 KJ/m^2/yr energy flux obtained from the light zone, only an estimated 436 KJ/m^2/yr was produced by benthic production in the Oron location before dredging[23]. Macrozobenthos near Oron and Calabar areas of the estuary are primarily deposit feeders[18] and do not appear to be efficient at converting the sedimenting carbon into production. Production was lower after dredging because most of the benthic algae were buried by dredge spoil and also by sedimentation of fine suspended particles on the benthos. This represents a major source of carbon loss to the benthos, (as much as 1-3% annual phytoplankton crop may be retained within the sediment). Low benthic production soon after dredging could also be ascribed to excessive carbon loss by tidal transport of detrital materials or microbial cells[24].

The pelagic fish production, largely sardines, tilapia and *Polydactylus* sp. in the area was also low possibly as a result of other anthropogenic disturbances such as minor oil spills and sewage discharges that led to reduced pelagic food sources[11].

In conclusion, the significant reduction in the proportion of secondary production within water column and benthos after dredging can be attributed to the effect of siltation associated with dredging of the channel.

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