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The Impacts of Micro-Topographic Changes on Mangroves in the Lower Reaches of the Benin River, Niger Delta

[1, 2]Elijah I. Ohimain, [3]Joseph F. Bamidele and [3]Olumide O. Omisore
[1]Department of Natural Resources and Environmental Design,
School of Agriculture and Environmental Sciences,
North Carolina Agricultural and Technical State University, Greensboro NC 27411, USA
[2]Department of Biological Sciences, Niger Delta University, Wilberforce Island,
Amassoma, Bayelsa State, Nigeria
[3]Environquest Nigeria Limited, Resort House, 12 Boyle Street, Onikan, Lagos, Nigeria

Abstract: Oil exploration and related activities in coastal wetland areas created the need for dredging to construct navigable access. This study was carried out in the lower reaches of the Benin River to measure topographic profiles across five oil installations access canals. Soil chemical parameters and vegetation density and diversity were also studied at these sites. The results of the micro-topographic measurements of the abandoned spoils show that the elevations of the five spoil deposition sites ranged from 1.63-2.54 m above the lower low water spring tide datum (>LLWS), with a mean of 2.31 m>LLWS, whereas, within the control intact mangrove swamp, the elevation was 1.36 m>LLWS. Therefore, the abandoned spoil dumps were 95 cm higher than the control area. These micro-topographic changes coincided with soil chemical properties and vegetation changes leading to the emergence of upland and/or freshwater species in mangrove areas. The study concludes by affirming that the resultant spoils that are often abandoned as canal banks as a result of oil exploration related dredging activities, have caused micro-topographic changes in the Niger Delta leading to changes in soil chemical properties causing a shift in the vegetation pattern of the area.

Key words: Benin River, dredged spoil, dredging, mangrove, micro-topography, Niger Delta, wetland

INTRODUCTION

The surface topography of the soils and sediments of the Niger Delta is fast changing owing to dredging and abandonment of dredged spoils as a result of oil exploration and marine related activities in the region. The Niger Delta, which is located in the southern part of Nigeria bordering the Atlantic Ocean, is a wetland of over 70,000 km^2. The Niger Delta environment has been described as highly diverse and sensitive.

Being the home of the largest stands of mangroves in Africa (over 1 million ha) and the third largest in the world (Spalding *et al*., 1997), it is of both regional and global importance (Moffat and Linden, 1995). The delta is poorly serviced by roads and is made up of meandering creeks that are highly silted up, which made oil exploration and marine transport difficult. Overcoming the access difficulties requires dredging to create navigable canals. During dredging, sediments, soil, vegetation along the proposed canal are removed using hydraulic or mechanical dredgers and are typically dumped over bank and abandoned. Dredging in the Niger Delta has caused several impacts including algal bloom (Ohimain and Imoobe, 2003), impairment of benthic invertebrates (Ohimain *et al*., 2005) and destruction of zooplankton (Ohimain *et al*., 2002), vegetation dieback (Fagbami *et al*., 1988), water quality impairment (Ohimain *et al*., 2008a), alteration of soil and sediment physico-chemistry leading to acidification (Ohimain, 2004; Ohimain *et al*., 2004) and heavy metal pollution (Ohimain *et al*., 2008b).

The current dredging practices in the Niger Delta have double impacts, those resulting from the dredging activities itself and those resulting from the dumping and abandonment of dredged spoils. While the former have been described to be short-term (Ohimain *et al*., 2008a), the latter could be long-term. According to Van Dessel and Omoku (1994), the handling and management of the resultant dredged materials is of greater concern in the Niger Delta. Typically, the materials are placed adjacent to the canal being dredged, mostly upon fringing mangrove vegetation and then abandoned. The subsequent poor spoil management practices have led to a number of environmental impacts through direct burial and destruction of fringing mangroves and associated fauna,

Corresponding Author: Elijah I. Ohimain, Department of Botany, Faculty of Life Sciences, University of Benin, Benin, Nigeria

siltation of navigable canals, flooding and suffocation of mangroves, degradation of water quality, habitat fragmentation and alteration of vegetation and land use (Ohimain, 2003a, b) and alterations in the sediment distribution pattern along the coastline (Awosika *et al*., 1993, 2001). The cumulative effects of these impacts are the loss of wetlands (Turner and Streever, 2002). Dredging has also been associated with widespread hydrological changes (Ohimain, 2003a), which has been reported to be the cause of the observed coastal retreat (Eedy *et al*., 1994).

Blasco *et al*. (1996) reported that the mangroves of the Atlantic coast of West Africa particularly the Niger Delta, on account of their gentle gradient of sediment are sensitive to disturbance. Minor alteration (natural or anthropogenic) can result in a considerable change in the duration of inundation, thereby causing plant mortality, habitat alterations and impacts on fauna. The aim of this study was therefore, to assess the impacts of topographic changes arising from dredged materials abandonment on changes in soil physico-chemical properties and vegetation distribution.

MATERIALS AND METHODS

Topographic profiles of the study area were investigated at low tide using a Nikon automatic level model AE-7 with a beacon located at Escravos bar, Ugborodo, as a reference point. Measurements were made along three transects across the dredged canal starting from an undisturbed mangrove habitat through a dredged material heap (canal bank), across the dredged canal and terminating at an undisturbed mangrove swamp on the other side of the canal. Soil surface elevations were taken at 10 m intervals. The elevations of adjacent intact mangroves were taken as control.

Soil and dredged spoil samples were collected from the study area using soil sampling auger. The soil samples were dried at 28°C and analyzed for chemical parameters including pH, electrical conductivity, chloride, sulphate, phosphate, total nitrogen and organic carbon. USDA (1996) methods were used for the analysis of the samples for the various parameters. Electrical conductivity and pH were measured using Hach CO 150 conductivity/TDS meter and EC 20 pH m, respectively. Ten grams of the soil sample was the prepared into a 50 mL beaker. With an automatic pipetting machine 10 ml of distilled water added for a 1:1 (g vol^{-1}) ratio and was thoroughly mixed with a glass and before inserting the pre-calibrated pH and conductivity probes to take measurements. Sulphate was determined spectrophotometrically using turbidimetric method. Sulphate in the soil was extracted using $CaHPO_4$ before adding barium chloride and sulphate determined colorimetrically at 450 nm using Hach DR 2010. Chloride was analyzed using Mohr's argentometric titration method. This involved the direct titration of chloride with silver nitrate (0.0141 M) solution using potassium permanganate as the indicator. Phosphate was analyzed colorimetrically using ascorbic acid method, while total nitrogen was determined using Kjeldahl distillation method. One gram of the soil was weighed into 75.0 mL volumetric digestion tube and concentrated sulphuric acid (ρ = 1.84 kg L^{-1}) was added and the tube was placed in a heating mantle at 150°C for 30 min until the temperature rise to 350°C for 2 h or until samples are completely digested. The samples were removed from the heating mantle and allowed to cool under fume hood for 5-10 min. The total nitrogen and phosphorus in the sample were determined colorimetrically using Hach DR 2010 at 890 and 500 nm, respectively. Organic carbon was determined using Loss on Ignition (LOI) method. In the LOI method, 5 g of soil was dried at 150±5°C for 2 h to remove moisture. The dried samples was weighed and heated to 360°C in a muffle furnace for another for 2 h. The difference in weigh was used to estimate the organic carbon content.

Vegetation studies were carried out using quadrats along transects established within the plant community type. The quadrat for the determination of frequency of plants was 10×10 m for trees; 5×5 m for shrub and 1×1 m for herbaceous species. Plant species frequency was determined using the method outlined by Kershaw and Looney (1985).

RESULTS AND DISCUSSION

The results of the micro-topographic measurements of the abandoned spoils are shown in Table 1. The elevations of the five spoil deposition sites ranged from 1.63-2.54 m above the lower low water spring tide datum (>LLWS), with a mean of 2.31 m>LLWS, whereas, within the control intact mangrove swamp, the elevation was 1.36 m>LLWS. Therefore, the abandoned spoil dumps were 95 cm higher than the control area. This micro-topographic change had implications on the soil properties, ecology and vegetation of the area.

The control site is characterized by matured red and white mangroves (*Rhizophora* and *Avicennia* sp.) occurring in monospecific stands with traces of mangrove fern, *Acrostichum aureum* (Table 2). They range between 30-40 m in height. The vegetation cover is significantly different in areas covered by dredged spoils (along the canals), which are dominated by non-mangrove species. The canopy of the vegetation in areas with dredged spoils

Table 1: Micro-topographic measurements, hydrology, vegetation type and surface area covered by the dredged spoil

Location	Coordinate (Lat. /Long.)	Soil type	Hydrology/ drainage	Vegetation type	Spot height of dredged material (m)	Surface area of dredged materials
Control (intact mangrove)	5°39'05"/5°13'10"	Mangrove soil	Natural tidal drainage	Mangrove	1.36 m LLWS (n = 25)	Nil
Pipeline access canal	5°10'52"/5°37'48"	Dredged spoil	Altered drainage/rain fed	Non mangrove	2.36 m LLWS (n = 9)	Width = 25 m*
Flowstation 1 access canal	5°12'30/5°48'30	Dredged spoil	Altered drainage/rain fed	Non mangrove	2.49 m LLWS (n = 25)	30,000 m^2
Flowstation 2 access canal	5°08'37"/5°50'35"	Dredged spoil	Altered drainage/rain fed	Non mangrove	1.63 m LLWS (n = 16)	80,000 m^2
Oil well access canal	5°07'50"/5°51'36"	Dredged spoil	Altered drainage/rain fed	Non mangrove	2.52 m LLWS (n = 7)	19,000 m^2
Manifold access canal	5°12'59"/5°48'35"	Dredged spoil	Altered drainage/rain fed	Non mangrove	2.54 m LLWS (n = 21)	20,000 m^2

*Area covered by dredged spoil could not be estimated owing to distance

Table 2: Plant species distribution and percentage frequency of occurrence* around oil well heads and along canals

		Abandoned dredged spoil dumps				
Species names	Control site/ Intact mangroves	Pipeline access canal	Flow station 1 access canal	Flow station 2 access canal	Oil well access canal	Platform access canal
Acrostichum aureum	4	-	-	-	-	-
Rhizophora mangle	35	-	-	-	-	-
Rhizophora racemosa	59	-	-	-	-	-
Avicennia germinans	2	-	-	-	-	-
Axonopus compressus	-	3	-	-	-	-
Anthoclestia vogelii	-	12	-	-	-	12
Alchornea cordifolia	-	8	-	-	24	37
Carapa procera	-	6	-	-	8	5
Dalbergia ecastaphyllum	-	8	5	16	69	58
Ficus sp.	-	5	1	7	8	5
Machaerium lunatus	-	3	4	12	14	16
Paspalum vaginatum	-	14	16	25	16	23
Rhynchosphora corymbosa	-	-	8	6	18	13
Elaeis guineensis	-	4	-	-	6	3
Emilia sonchifolia	-	12	-	-	21	14
Memecylon blaikeiodes	-	2	-	-	-	-
Phoenix reclinata	-	3	-	-	-	1
Phragmites communis	-	2	-	6	-	-
Pteris vittata	-	3	-	4	-	5
Solanum torvum	-	1	-	-	-	6
Cyperus articulatus	-	-	12	-	-	5
Mariscus ligularis	-	-	-	9	25	15
Musa sapientum	-	-	-	1	-	2
Musanga cecropioides	-	-	-	2	3	8
Hallea ciliata	-	-	-	2	-	2
Chromolaena odorata	-	-	-	-	6	2
Cocos nucifera	-	-	-	-	4	-
Cyperus iria	-	-	-	-	23	8
Dissotis erecta	-	-	-	-	14	2
Paspalum orbiculare	-	-	-	-	5	6
Selaginella kraussiana	-	-	-	-	4	-
Syzygium guineense	-	-	-	-	-	10

*Note that the frequency of occurrence refers to the probability of sampling a particular species from the sites, it therefore do not add up to 100%

is generally open, while the reverse is the case for control sites. The plant species diversity in the dredged spoils is higher than the mangroves (Table 2). They include herbaceous types such as *Paspalum vaginatum*, *Emilia sonchfolia*, *Mariscus ligularis*, *Chromoleana odorata*, *Cyperus articulatus*, *Acrostichum aureum*, *Dissotis erecta*, *Cyperus iria* and *Axonopus compresus.* These species are pioneers on the spoil heaps. They are replaced by creeping/straggling legume, *Dalbergia ecastophyllum.* Where the spoil has been in place for a long time without repeated disturbance, tree species such as *Alchornea cordifolia*, *Ficus congensis*, *Harungana madagascariensis*, *Anthocleista* sp., *Elaeis guineensis* and *Alstonia boonei* become dominant. These species often form an association as opposed to consociation typical of the undisturbed control areas dominated by red mangroves. The majority of the species growing on the spoil heaps are non-halophytes (intolerant to high salinity). Their seeds were apparently buried within the soil and they germinate and grow in areas beyond tidal influence. The non-halophytes were confined to the abandoned dredged spoils. One of the direct impacts of canalization is the conversion of mangrove wetlands to spoil dumps or uplands (Turner and Streever, 2002).

The pH of the soils in the control site (mangrove) was higher (5.7) than those of the spoil dump (3.1-4.6) indicating that the spoils are more acidic than the mangrove soil (Table 3). The relatively lower pH of the

Table 3: Physico-chemical properties of soil/spoils in the study area

	Statistics	pH	Elec. Cond. (mS cm^{-1})	Chloride (mg kg^{-1})	Sulphate (mg kg^{-1})	Phosphate (mg kg^{-1})	Total nitrogen (%)	Organic carbon (%)
Control (n= 16)	Mean	5.7	8.3	8676.4	3527.6	224.4	0.3	15.4
	SD	0.3	0.6	1263.8	4121.1	149.8	0.4	10.1
	Max	5.8	8.8	10032.4	9675.9	370.9	0.8	21.9
	Min	4.1	7.4	7019.1	964.7	40.2	0.0	0.4
Pipeline access canal (n= 10)	Mean	4.3	1.2	516.2	559.6	299.6	0.1	7.0
	SD	0.6	0.7	186.0	92.9	118.4	0.1	0.5
	Max	5.4	2.4	828.2	621.5	449.7	0.2	8.0
	Min	3.7	0.5	283.6	429.0	172.8	0.0	6.6
Flowstation 1 access canal (n= 14)	Mean	3.3	0.9	340.3	1329.0	279.4	0.2	5.8
	SD	0.4	0.3	178.3	1219.3	109.1	0.0	3.0
	Max	3.9	1.2	602.7	3495.2	390.6	0.2	9.5
	Min	2.9	0.5	106.4	643.3	157.5	0.1	3.3
Flowstation 2 access canal (n= 7)	Mean	3.5	3.0	1282.1	2541.4	234.8	0.2	7.6
	SD	0.2	1.6	508.5	1526.4	159.4	0.2	6.0
	Max	3.8	6.0	1949.8	4665.6	434.8	0.4	17.8
	Min	3.4	1.6	531.8	865.8	2.1	0.0	0.3
Oil well head access canal (n = 8)	Mean	3.7	0.8	469.7	354.8	235.5	0.0	2.1
	SD	0.3	0.2	101.8	224.0	152.4	0.0	1.6
	Max	4.0	1.1	602.7	602.1	398.2	0.1	3.5
	Min	3.5	0.6	390.0	157.0	32.6	0.0	0.6
Manifold access canal (n = 5)	Mean	3.1	1.3	1715.8	4011.1	367.4	0.1	7.7
	SD	0.2	0.6	1852.3	3271.5	281.0	0.1	3.0
	Max	3.4	1.9	4254.0	8894.0	810.5	0.3	9.9
	Min	3.0	0.7	106.4	964.7	32.5	0.0	4.2

spoil suggests that acidification has set in. The exposure of the pyrites in the spoil to atmospheric oxygen causes their oxidation resulting in the formation of sulphuric acid, thus lowering the pH at the spoil dumps (Ohimain, 2004) The results of Electrical Conductivity (EC), chloride and sulphate exhibited similar pattern being several orders of magnitude higher in the control site relative to the abandoned spoil dumps. The high EC, chloride and sulphate concentrations clearly show that while the intact mangrove soil remains brackish due to continuous drainage by seawater, the abandoned spoils are at various stages of weathering and desalination resulting in their relatively becoming less saline, which then created favorable conditions for succession by invasive species. Also, the control site had higher levels of total nitrogen and organic carbon that the spoil dumps, while the phosphorus didn't exhibit any discernable pattern. Overall, the control sites had higher fertility than the abandoned spoils. Silts are usually carried by tide water and deposited in mangroves. The constant tidal inundation of the mangrove sites help to sustain their salinity unlike the abandoned spoils, which are elevated beyond tidal reach.

The results showed that abandonment of dredged spoils causes micro-topographic changes in the mangrove forest of the Niger Delta. The altered topography of the spoil dumps have resulted in a change in the hydrology, with subsequent effect on plant species diversity. There is also a change in vegetation structure. The altered soil properties creates suitable conditions for non mangroves to thrive. This change is possible since the ability of plants to grow in a place is determined, among other factors, by soil chemical properties such as pH, salinity and redox potential (Mckee, 1993; Komiyama *et al*., 1996). The reduced salinity has encouraged the growth of plants typical of the rain forest zone in Nigeria in preference to mangroves. Seedlings of mangroves were observed at the fringes of the canals. It has been reported that elevation difference of only 35 cm can affect seedlings survival. The survival rate of mangrove seedlings showed a clear relationship with the micro-topography, with the results that seedlings performed poorly at higher elevations (Komiyama *et al*., 1996). Topography has been reported to be spatially related to hydrology, hence slight modification in topography have been linked to important hydrological changes (Hughes, 1998; Hughes *et al*., 1998; Loftin *et al*., 2000; Mitsch and Gooselink, 2001). It therefore, follows that the physical change in soil topography is linked with the chemical and biological changes in the environment.

CONCLUSION

Oil exploration and coastal marine related activities created the need for dredging to create the navigable accesses. The resultant spoils that are often abandoned as canal banks have caused micro-topographic changes in the mangrove forest of the Niger Delta leading to changes in soil chemical properties. This subsequently leads to a shift in the vegetation pattern of the area.

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