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Carbon credits assessment in a mixed mangrove forest vegetation of Cross River Estuary, Nigeria

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ABSTRACT

The relative contributions of a mixed mangrove forest vegetation comprising Nypa fruticans Wurmb. Arecaceae, Rhizophora racemosa GFW May. Rhizophoraceae, Avicennia germinans var. africana P. Beauv. Avicenniaceae) of the Great Kwa River, in the Cross River estuary were studied. Litter production and composition along tidal gradients (low, mid, high) were measured over a 12 month period using litter traps. The average monthly litterfall was 37.43g dwt m^{-2} ($\simeq$ 449.2g m^{-2} y^{-1}). Leaves constituted 64%, wood 13% and "miscellaneous" litter (propagules and stipules) 23%. The average monthly litter biomass on the forest floor was 13.38g dwt m^{-2} ($\simeq$160.56g$m^{-2}y^{-1}$). This constituted 35.75% of the litter produced. Litterfall and litter biomass varied significantly ($P<0.001$) temporally and spatially (across tidal gradients). The average monthly litterfall at low, mid and high tide levels were 21.90, 42.80 and 47.53 (g dwt m^{-2}) with leaf litter constituting 58, 64 and 65%, wood litter 18, 15 and 12% and "miscellaneous" litter 26, 21 and 23% respectively. Similarly litter biomass was 7.43, 16.08 and 16.72 (g dwt m^{-2}) with leaf constituting 56, 65 and 64%, wood litter 21, 15 and 13% and "miscellaneous" litter 23, 20 and 23% respectively. Litterfall and litter biomass were observed to exhibit seasonality. Litterfall had bimodal response peaking during rainy (August) and dry (February) season while litter biomass was low during the rainy season (June to September). Litterfall and litter biomass increased generally across tidal gradients towards the high tide level. The periodicity, amount and fate of litter in this mixed mangrove forests have implications in the understanding and prediction of patterns of accumulation and distribution of mangrove litter. This provides insight into carbon storage potentials of the mangrove ecosystems in Nigeria.

Keywords: Litterfall, Cross River estuary, litter biomass, tidal gradients.

INTRODUCTION

There is a gradual estimated worldwide loss of mangrove ecosystems at 1-2% y^{-1} [1, 2] due to exploitation, degradation and unsustainable management practices. Nigeria has the most extensive natural stands of mangrove in Africa with large portion of it in the Niger Delta of the country [3] and the fifth largest mangrove stands in the world [4]. In this part of the world, mangrove ecosystems are still considered as eyesores and wastelands instead of wealth by the populace. Mangroves are halophytic trees that dominate the intertidal zone along coastlines, estuaries and islands in tropical and sub-tropical regions of the world where they exist under conditions of high salinity, extreme tides, strong winds, high temperature and muddy, anaerobic soil [5, 6]. They form distinct communities called mangrove forests or mangroves covering riverbanks, estuaries, sea coasts, as well as carbonate sands and coral rubble islands especially in the tropics and sub-tropics [7]. They are best developed in tropical estuaries which receive evenly distributed heavy rainfall throughout the year [8]. Mangroves are extremely important to the nutrient budgets of adjoining estuaries and other coastal waters because of their high productivity.

Mangrove primary production is generally discussed in terms of litterfall. The mangrove litterfall is the most important source of organic carbon in biogeochemical cycles in the mangrove ecosystem and a valuable indicator of mangrove productivity [9]. Litterfall is a useful index of mangrove productivity since it is a component of net primary production and an important element in the calculation of energy and nutrient fluxes in mangrove ecosystems [10, 11, 9, 12, 13]. The dynamics of mangrove litter, including rates of production, and export, is essential for the assessment of the productivity of the ecosystem as a whole and its relevance for food webs in coastal environments [14, 12, 15, 16]. Litter production varies among ecological types of mangrove ecosystems which may be associated with the different geophysical energies, and hydrological dynamics such as tides, river flow and winds in association with distinct geomorphological types of coastal environments [17, 18]. Litter production rates are also affected by pollution, salinity, altitude, season, species, and structural morphology of the forest and sediment nutrient availability [19, 20, 21]. Several studies have been carried out to estimate litterfall production of mangrove forests in different parts of the world [22, 23, 24, 25, 26, 27]. Litterfall is a perennial process in tidal mangrove forests, with its accumulation being more common in the shoreline mangrove habitat. Part of the litter production is tidally exported into the adjacent estuaries and coastal waters [11, 28]. There is variation in litter production in mangrove stands among morphological parts and between seasons with leaves dominating [29, 30, 22]. The different production pattern in litter quality and quantity among different species is in relation to the phenological spreads and prevailing unique hydrological conditions [22, 25].

Mangrove vegetation or mixed mangrove forests have been reported to have greater litter fall rates than monospecific stands while litterfall magnitude has been found to be greater in mangrove than that in upland forests [31, 25]. The rate of primary productivity is high in mangrove forests, producing organic carbon in excess of the ecosystem's requirements and contributing significantly to the global carbon cycle as a major source of dissolved organic carbon (~10%) to the oceans [32]. Mangroves also play a major role for dissolved organic matter exchange between continents and oceans via detritus loading, providing basis for food chain and exporting dissolved organic carbon to the oceans which act as one of the largest carbon pools on earth.

The assessment of the productivity of a mangrove ecosystem requires an understanding of the key processes of production and composition of mangrove litter. The quantification of litterfall and composition of mangrove species in the riverine mangrove forests vegetation of the Cross River estuary is important for estimating the productivity of the system and its relevance for food webs in the estuary and thus important in developing management strategies for sustainable use of the mangroves. Therefore the rapid decline of mangroves may have already reduced the flux of terrestrial dissolved organic matter to the ocean with potential consequences for global carbon cycle and climate [33]. The biological productivity of the Cross River estuarine water and its controlling factors has been studied [34, 35, 36, 37, 38]. However, information on the productivity of the fringing mangrove forests vegetation of the estuary, and material flow within the ecosystem remain largely unstudied. Thus, the significance of the mangrove forests in the overall biological productivity of this estuary remains underestimated. A study of litter production and composition will give insight into the rates of productivity (litter fall) in the mangrove ecosystem. This study aims at evaluating carbon credits through litter production, and specifically investigating the effects of temporal and spatial variation on litter production and composition of mangroves along a tidal gradient, comparing the results obtained with those of other tropical mangrove ecosystems in other regions of the world. This study is therefore important in rehabilitation / regeneration of the mangrove ecosystem in Nigeria with special attention to the scope of biodiversity conservation

MATERIALS AND METHODS

2.1. *Geo-morphological description of the study area*

The study area covered is the mangrove forest vegetation of the Great Kwa River, east of the Cross River estuary which flows into the Gulf of Guinea. This area lies within latitudes 04^{o} 45′ and 04^{o} 15′ North of the Equator and longitudes 008^{o} 15′ and 008^{o} 30′ East of Greenwich Meridian along the eastern border of the University of Calabar. Geomorphologically, the area is characterized by silty clays, peaty clays commonly called "*Chikoko soil*", saline sands and mud flat benthic sediment. These edaphic structures are intermittently inundated by the ebbing and up-rising tidal flow of hydrological regimes and also characterized by a sulphate odour, which becomes more intensive at a high temperature and ebbing tide. More conspicuous with mycoflora and cyanophyta (blue-green algae) at the ebbing tide. The mangrove forest vegetation in this region occurs in clear zonation pattern along a tidal gradient with *N. fruticans* forming the outermost zone towards the water front, followed by either pure stands of *R. racemosa* or mixed stands of *R. racemosa* and *N. fruticans*. These zones are followed by pure stands of *A. africana*. Climate in this region is equatorial and is characterized by a pattern of alternating wet and dry seasons. The wet season extends from April to September and the dry season from October to March with maximum temperature and relative humidity.

2.2. *Species assessment*

Three sites were established along a tidal gradient within the mixed mangrove forest. The study sites chosen represent the zonation along the tidal gradient and include the low tide level (LTL) dominated by *N. fruticans*, the mid tide level (MTL) dominated by *R. racemosa* and the high tide level (HTL) dominated by *A. africana*. A two factor experimental design (species, and tidal level) was employed [39]. Field investigations were carried out along transects taken parallel to the shoreline and within the tidal levels indicated (LTL, MTL, HTL). Litterfall measurements were made using litter traps ($1m^2$) constructed of wooden frame with 1mm nylon mesh [40]. The nylon mesh was shaped into a bag-like receptacle to prevent vegetative structures from bouncing out or being washed out by high wind and tide.

In order to investigate spatial variation in litterfall 5 traps were randomly placed along a 200m transect taken parallel to the axis of flow, in each study site (LTL, MTL and HTL) [40]. Traps were securely fastened to branches such that they could stay above water level at high tide. To investigate temporal changes in litterfall, trap contents were collected over a period of 12 months (April 2008 to March 2009). The contents of each trap were emptied into clean labelled polyethylene bags at monthly intervals to minimize leaching or decomposition of leaves within the traps [41]. The collected litter was taken to the laboratory where it was rinsed with deionized water to remove excess salt, sorted into three categories: leaves, wood and miscellaneous (propagules / reproductive parts) and dried to constant weight at 80^oC for 12 hours in a Gallenkamp (England) drying oven. After drying, the samples were weighed to the nearest 0.1g [40]. The biomass (standing crop) of litter was determined by placing three quadrats ($1m^2$) on the forest floor near the litter traps at each of the sampling tidal levels. The litters within the quadrats were collected from the surface of the forest floor at monthly intervals. The litters collected were processed as previously described for litterfall samples.

2.3. *Data analysis*

Litterfall and litter biomass (standing crop) are presented in the form of graphs, with the x-axis representing time (months) and the y-axis the rate of litterfall in (g m^{-2}) [40]. A repeated measures analysis of variance (ANOVA) by Sullivan [42] was used to evaluate total litterfall and litter biomass and their individual components. Turnover rates of litter were evaluated using the equation by Nye [43].

$$K_t = \frac{L}{X_{ss}} \qquad (1)$$

Where

L = litterfall

X_{ss} = steady state of litter on the forest floor

K_t = litter turnover rate

RESULTS

Litterfall

Average monthly rates of litterfall in g dry weight (dwt) m^{-2} across tidal gradients (low, mid and high) including leaf, wood and 'miscellaneous' (stipules and reproductive products) components were analysed and presented graphically (Fig 1). The mean monthly litterfall for the period was 37.43 ± 1.02 g (dwt) m^{-2} with leaves contributing 63.53%, wood 14.27% and 'miscellaneous' litter 23.03% (Table 1). Litterfall varied in composition and amount temporally and spatially (over time and across the tidal gradient) (Fig.1a,b). The average monthly litterfall was highest at high tide level (47.53 ± 1.03), followed by the mid tide level (42.85 ± 0.93) and lowest values at the low tide level (21.90 ± 1.09) (Fig. 1b). The contribution of leaf fall to the total litter across the tidal gradients at low, mid and high tidal levels was 58.87% , 64.32% and 65.03% respectively, while that of wood fall was 18.72%, 14.77% and 11.74% respectively and that of 'miscellaneous' fall was 26.76%, 20.93% and 23.23% respectively (Fig.1b). Leaf was a dominant component of litterfall throughout the year. Leaf fall was highest in the month of February with lower peaks in April and November. The highest average production of leaf litter was at the high tide level (30.91±0.87) and lowest at the low tide level (12.88±0.66); 'miscellaneous' litter was highest in the months of

August and September with the highest average production at the high tide level (11.04 ± 0.78) and lowest at the low tide level (5.86 ± 1.18). Wood litter, however, was highest in the month of December with the highest average production at the mid tide level (6.33 ± 0.51) and lowest at the low tide level (4.10 ± 0.46) (Figs.1 a,b). A two- way analysis of variance (ANOVA) with repeated measures revealed highly significant differences ($P < 0.001$) in the rate of litterfall at different months of the year and in litterfall over different tidal levels (low, mid and high) (Table 2). The partitioning of litter into leaf, wood and 'miscellaneous' components also varied significantly ($P < 0.001$) within and across the tidal levels. There was significant interaction effect ($P < 0.001$) between monthly litterfall and tidal levels for total litter, leaf, wood and 'miscellaneous' litters (Table 2).

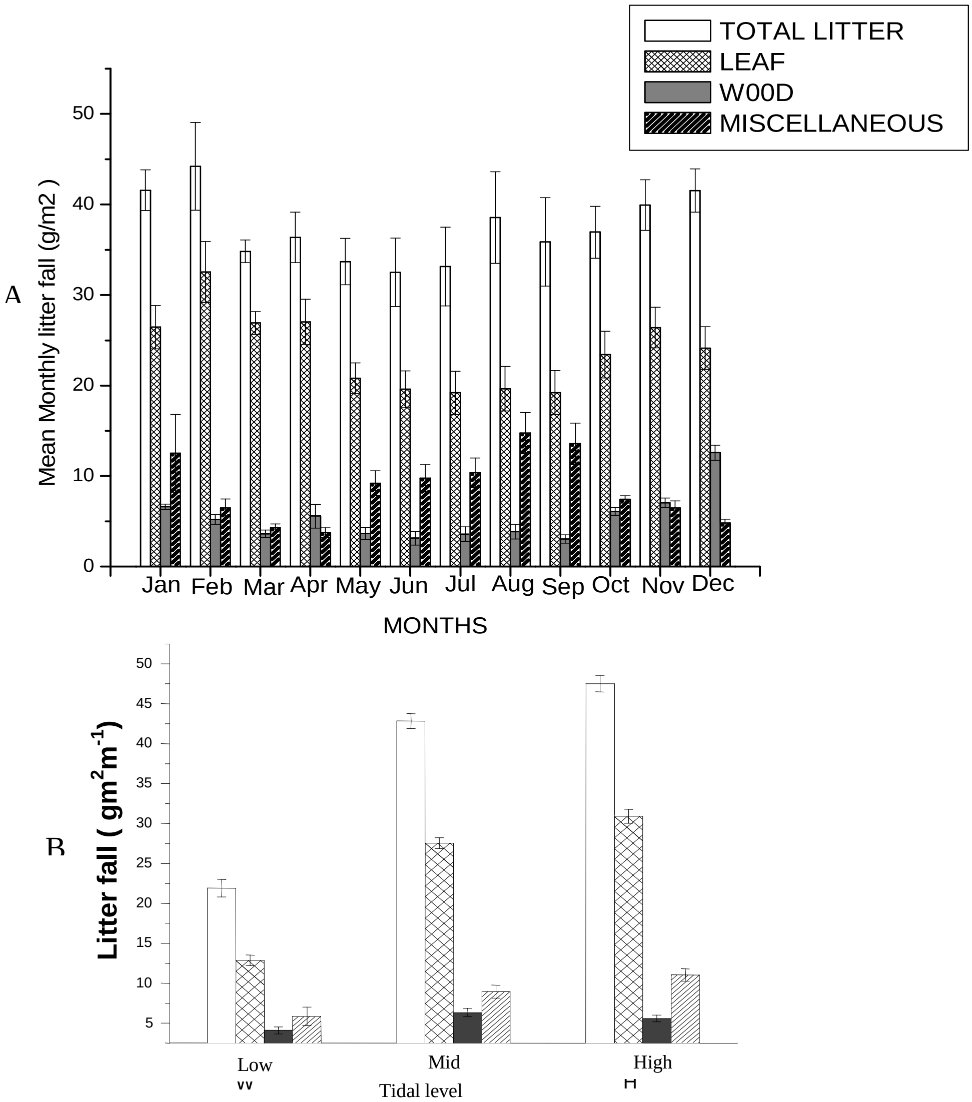

FIG. 1: Litterfall (mean ±SE, dry weight) in a mangrove forest vegetation (*Nypa fruticans, Rhizophora racemosa* and *Avicennia africana*) at Esuk Mba of the Great Kwa River of Cross River estuary, Nigeria (April 2008 – March 2009) (a) monthly average across tidal gradients for 12 months (b)monthly average within tidal gradients (low, mid, high)

Table 1: Mean monthly litterfall (g m^2 dry weight, ± litter biomass along tidal gradients (low, mid, high) in a mangrove forest vegetation (*Nypa fruticans, Rhizophora racemosa, Avicennia africana*) at Esuk Mba, east bank of Great Kwa River, Cross River estuary, Nigeria (April 2008 – March 2009)

Parameter	Months	Low	Mid	High	LSDS	Parameter	Months	Low	Mid	High	LSDS
	Apr	25.42±2.5	38.76±3.03	45.0±4.12			Apr	5.26±2.10	3.68±1.60	7.8±2.91	
	May	23.16±0.79	34.5± 3.96	43.3±1.65			May	3.4 ±0.38	5.02±1.92	2.76±0.47	
	Jun	13.5±1.32	40.68±2.54	43.26±2.55			Jun	1.0±0.19	5.8±1.82	2.62±0.39	
Total litter	July	11.20±1.57	45.08±1.97	43.14±3.14			July	1.06±0.33	6.28±1.62	3.38±0.27	
	Aug	11.78±0.99	54.08±2.07	49.0±2.18	1.4606	Wood	Aug	1.40±0.17	7.61±1.52	3.38±0.27	
	Sept	10.68±1.11	47.24±2.38	49.64±1.82	5.0697	Litter	Sept	1.08±0.31	4.84±0.56	3.22±0.38	0.6823
	Oct	23.1± 1.45	43.34±1.99	44.42±2.89			Oct	4.54±0.36	7.46±0.57	6.2±0.44	2.3637
	Nov	29.5±2.23	37.80±2.06	52.54±2.11			Nov	8.08±0.75	4.76±0.40	8.32±0.4	
	Dec	31.22±2.17	43.64±2.03	49.74±2.34			Dec	11.20±1.04	16.52±1.53	11.02±0.78	
	Jan	30.92±1.66	44.90±1.95	48.9±1.56			Jan	6.76±0.85	6.46±0.39	6.6±0.37	
	Feb	20.58±0.91	47.98±0.80	64.12±1.13			Feb	2.54±0.23	5.90±0.17	7.18±0.26	
	Mar	30.84±1.72	36.26±2.53	37.38±1.06			Mar	3.0±0.94	3.18±0.15	4.72±0.45	
Average		**21.90±1.09**	**42.85±0.93**	**47.53±1.43**	**37.43±1.02**	**Average**		**4.10±0.46 (18.72%)**	**6.38±0.51 (14.77%)**	**5.58±0.42 (11.74%)**	**5.34±0.20 (14.26%)**
	Apr	16.32±1.59	31.56±2.33	34.18±2.51			Apr	4.84±1.28	3.52±0.48	2.92±0.77	
	May	12.86±1.60	29.0±1.09	26.58±1.06			May	7.2±1.93	6.48±1.97	13.96±1.70	
	Jun	9.48±1.36	24.82±0.94	26.72±0.85			Jun	3.06±0.51	12.3±1.68	13.92±1.75	
Total litter	July	7.32±1.39	24.82±0.94	25.5±1.85			July	2.82±0.42	13.98±1.97	14.26±1.51	
	Aug	7.36±0.98	26.66±1.36	24.94±1.76	1.0479		Aug	3.02±0.46	18.58±1.62	20.06±1.14	
	Sept	7.50±1.08	23.82±2.37	26.36±1.45	3.6301	**'Miscellaneous'**	Sept	2.1±0.33	18.58±1.82	20.06±1.14	0.7281
	Oct	11.6±1.89	28.68±2.82	30.0±2.33		Litter	Oct	6.86±0.29	7.2±0.58	8.22±1.08	2.5223
	Nov	16.06±0.89	28.78±2.18	34.4±1.72			Nov	5.82±0.91	4.26±0.78	9.82±0.51	
	Dec	14.20±1.41	24.4±0.98	33.82±2.61			Dec	5.82±0.91	3.73±0.34	4.92±0.74	
	Jan	14.82±1.85	3.58±1.93	46.22±0.92			Jan	9.54±1.0	6.86±0.47	9.14±0.58	
	Feb	16.16±0.65	36.20±1.15	46.22±1.04			Feb	1.88±0.13	6.88±0.58	10.72±0.45	
	Mar	22.08±0.77	29.64±2.47	29.0±0.84			Mar	5.76±0.99	3.44±0.38	3.66±0.17	
Average		**12.88±0.66 (58.81%)**	**27.56±0.89 (64.32%)**	**30.91±0.87 (65.03%)**	**23.70±0.73 (63.53%)**	**Average**		**5.86±1.18 (26.93%)**	**8.97±0.81 (20.93%)**	**11.04±0.78 (23.23%)**	**8.62±06 (23.03%)**

TABLE 2: Repeated measures ANOVA for mangrove litterfall (g/m^2, dry weight) across tidal gradients (low, mid, high) in mixed mangrove forest (*Nypa fruticans, Rhizophora racemosa* and *Avicennia africana*) at Esuk Mba of the Great Kwa River of Cross River estuary, Nigeria (April 2008 – March 2009)

Source of variation		Total litter			Leaf litter			Wood litter			'Miscellaneous' litter		
	df	**MS**	**F**	**P**	**MS**	**F**	**P**	**MS**	**F**	**P**	**MS**	**F**	**P**
Month (m)	11	71.11	8.38	0*	89.12	19.98	0*	30.08	18.10	0*	67.97	7.40	0*
Error (m)	48	8.49			4.46			1.66			9.18		
Tidal level (t)	2	10827.90	422.80	0*	5517.06	411.71	0*	967.21	120.45	0*	408.90	14.32	0*
Error (t)	96	2.60			13.40			8.03			28.56		
M x T	22	232.60	9.08	0*	46.30	3.45	0*	47.94	5.97	0*	140.87	4.93	0*
Error (M x T)	96	25.60			13.40			8.03			28.56		

* = *Significant difference ($P < 0.001$)*
df = *Degrees of freedom*
MS = *Mean squares*
F = *Variance ratio*
P = *Level of probability*

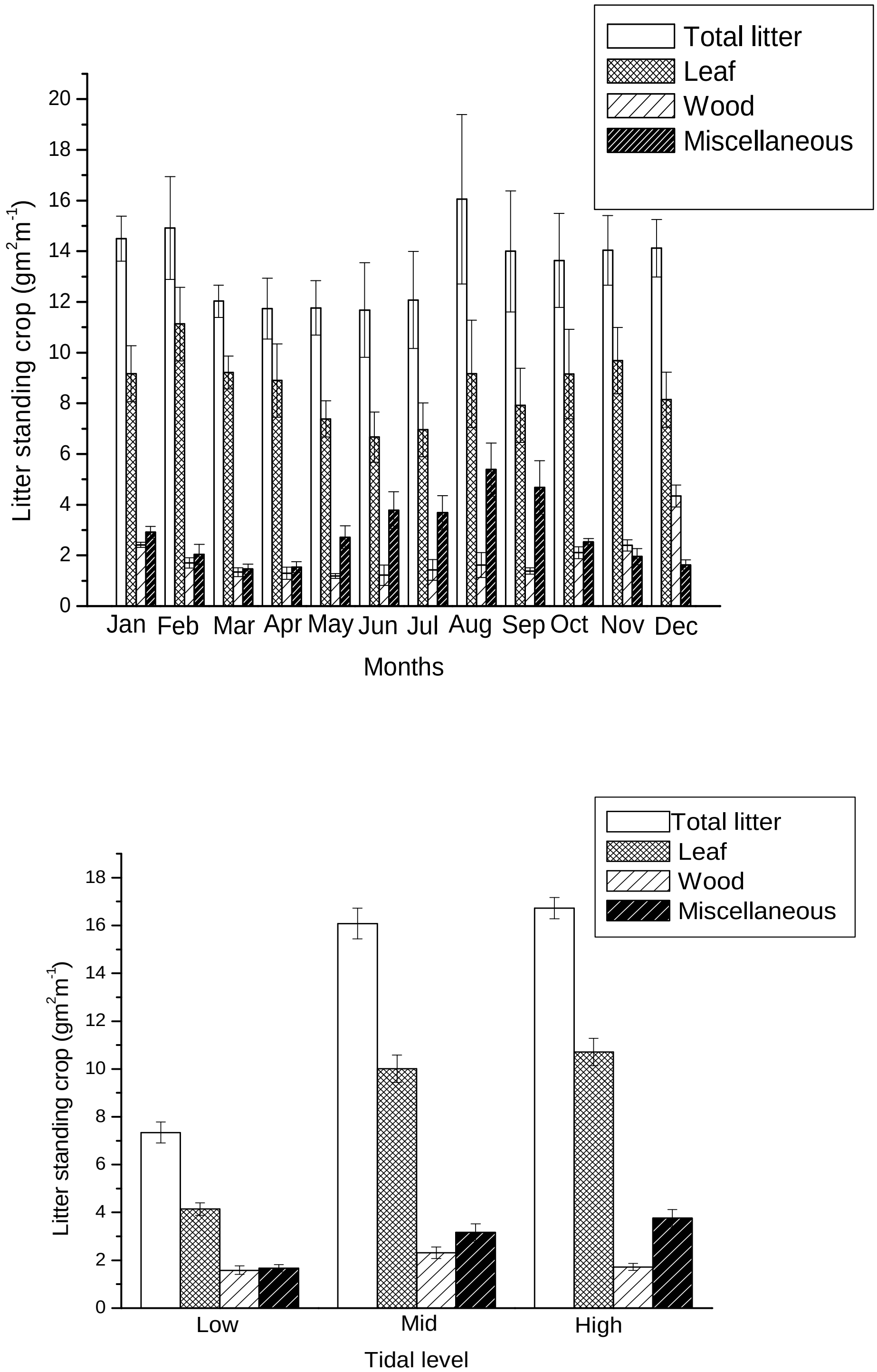

FIG. 2: Litterfall Biomass (mean ±SE, dry weight) in a mangrove forest vegetation (*Nypa fruticans, Rhizophora racemosa* and *Avicennia africana*) at Esuk Mba of the Great Kwa River of Cross River estuary, Nigeria (April 2008 – March 2009) (a) monthly average across tidal gradients for 12 months (b)monthly average within tidal gradients (low, mid, high)

Table 3: Mean monthly litter fall (g m^2 dry weight, ± litter biomass along tidal gradients (low, mid, high) in a mixed (*Nypa fruticans, Rhizophora racemosa, Avicennia africana*) mangrove forest at Esuk Mba, east bank of Great Kwa River, Cross River estuary, Nigeria (April 2008 – March 2008)

Parameter	Months	Low	Mid	High	LSDS	Parameter	Months	Low	Mid	High	LSDS
	Apr	7.43±0.05	14.0±0.32	13.67±1.77			Apr	1.93±0.38	0.9±0.25	1.07±0.41	
	May	7.57±0.15	12.6±0.80	13.78±0.57			May	1.23±0.13	1.33±0.09	1.0±0.23	
	Jun	4.37±0.47	14.8±0.55	15.83±0.81			Jun	0.33±0.07	2.40±0.87	0.93±0.16	
Total litter	July	4.53±0.27	15.5±0.61	16.2±0.66			July	0.50±0.06	2.63±0.91	1.17±0.12	0.2472
	Aug	3.90±0.15	26.33±2.28	17.93±0.35	0.5175	Wood	Aug	0.47±0.03	3.20±0.95	1.17±0.17	0.8565
	Sept	4.67±0.58	20.0±0.84	17.33±0.64	1.7927	Litter	Sept	1.23±0.12	1.73±0.29	1.20±0.12	
	Oct	7.07±0.30	14.1±0.30	19.77±0.78			Oct	1.77±0.23	2.77±0.24	1.63±0.003	
	Nov	10.07±0.97	13.23±1.07	18.83±0.91			Nov	3.0±0.21	1.67±0.22	2.53±0.24	
	Dec	9.90±0.82	16.4±0.57	17.07±0.66			Dec	3.5±0.55	5.70±0.65	3.84±0.38	
	Jan	11.1±0.40	16.78±0.59	16.50±0.30			Jan	2.7±0.15	2.33±0.15	2.23±0.2	
	Feb	7.27±0.52	16.19±0.17	20.97±0.43			Feb	0.93±0.12	2.0±0.06	2.20±0.06	
	Mar	10.27±0.95	13.0±1.21	12.63±0.37			Mar	1.23±0.50	1.13±0.09	1.67±0.12	
Average		**7.43±44**	**18.09±1.26**	**16.72±0.44**	**13.38±0.51**	**Average**		**1.59±0.18 (21.66%)**	**2.32±0.24 (14.43%)**	**1.72±0.15 (10.29%)**	**1.87±0.12 (13.98%)**
	Apr	3.33±0.12	11.73±0.10	11.63±1.32			Apr	2.17±0.27	1.37±0.09	0.97±0.3	
	May	4.83±0.75	8.40±0.57	8.93±0.38			May	1.50±0.55	2.87±0.86	3.80±0.23	
	Jun	2.90±0.31	7.77±0.33	9.37±0.44	0.533		Jun	1.13±0.24	4.70±0.72	5.53±0.55	
Total litter	July	2.80±0.15	8.5±0.5	9.57±0.27	1.8443		July	1.23±0.12	4.37±0.59	5.47±49	0.2862
	Aug	2.20±0.32	16.8±2.70	9.50±0.31			Aug	1.23±0.15	7.33±0.37	7.27±0.23	0.9914
	Sept	2.73±0.35	11.73±1.84	9.30±0.70		**'Miscellaneous'**	Sept	0.70±0.5	6.53±1.10	6.83±0.39	
	Oct	3.0±0.17	8.70±0.26	15.43±0.44		Litter	Oct	2.30±0.15	2.63±0.12	2.70±0.32	
	Nov	5.40±0.29	10.10±1.25	13.57±0.41			Nov	1.17±0.38	1.47±0.32	2.73±0.55	
	Dec	4.43±0.48	8.53±0.32	11.47±1.13			Dec	1.97±0.38	1.17±0.12	1.77±0.35	
	Jan	4.93±0.82	11.37±0.67	11.20±0.17			Jan	3.47±0.38	2.20±0.15	3.07±0.18	
	Feb	5.63±0.28	12.37±0.10	15.40±0.42			Feb	0.70±0.15	2.07±0.27	3.37±0.18	
	Mar	7.03±0.18	10.73±1.04	9.90±0.29			Mar	2.0±0.50	1.13±0.13	1.27±0.07	
Average		**4.13±0.26 (56.27%)**	**10.01±0.57 (62.25%)**	**10.71±0.57 (64.06%)**	**8.29±0.38 (61.96)**	**Average**		**1.67±0.15 (22.75%)**	**3.16±0.36 (19.65%)**	**3.76±0.36 (22.49%)**	**2.87±0.19 (21.45%)**

TABLE 4: Repeated measures ANOVA for mangrove litter biomass (g/m^2, dry weight) across tidal gradients (low, mid, high) in a mixed mangrove forest (*Nypa fruticans, Rhizophora racemosa* and *Avicennia africana*) at Esuk Mba of the Great Kwa River of Cross River estuary, Nigeria (April 2008 – March 2009)

Source of variation		Total litter			Leaf litter			Wood litter			'Miscellaneous' litter		
	Df	**MS**	**F**	**P**	**MS**	**F**	**P**	**MS**	**F**	**P**	**MS**	**F**	**P**
Month (m)	11	15.46	10.09	0*	4.79	7.31	0*	2.39	14.46	0*	4.93	26.23	0*
Error (m)	24	1.53			0.66			0.16			0.19		
Tidal level (t)	2	1231.52	350.10	0*	551.53	286.61	0*	5.45	15.28	0*	41.58	85.89	0*
Error (t)	48	3.52			1.92			0.36			0.48		
M x T	22	76.61	21.78	0*	12.32	6.40	0*	1.56	4.38	0*	7.13	14.73	0*
Error (M x T)	48	3.52			1.92			0.36			0.48		

* = *Significant difference (P < 0.001)*
df = *Degrees of freedom*
MS = *Mean squares*
F = *Variance ratio*
P = *Level of probability*

TABLE 5: Estimates of mean litter turnover across tidal gradients in (low, mid and high) in a mixed mangrove forest (*Nypa fruticans, Rhizophora racemosa* and *Avicennia africana*) at Esuk Mba of the Great Kwa River of Cross River estuary, Nigeria (April 2008 – March 2009)

Tidal level	Component	Litterfall (LF) / g m^{-2}(dwt)	Litter biomass (LB) (g m^{-2}dwt)	Turnover rate (K_t) (LF/LB)	Residence time ($1/K_t$)(days)	Half-life (T_{50}) (In $2/K_t$)
Low	Total litter	21.90	7.34	2.98	0.34	0.23
	Leaf litter	12.88	4.13	3.12	0.32	0.22
	Wood litter	4.10	1.59	2.58	0.39	0.27
	“Miscellaneous” litter	5.86	1.67	3.51	0.29	0.20
Mid	Total litter	42.85	16.08	2.67	0.38	0.26
	Leaf litter	27.56	10.01	2.75	0.36	0.25
	Wood litter	6.33	2.32	2.73	0.37	0.25
	“Miscellaneous” litter	8.97	3.16	2.87	0.35	0.24
High	Total litter	47.53	16.72	2.84	0.35	0.34
	Leaf litter	30.91	10.71	2.89	0.35	0.24
	Wood litter	5.58	1.72	3.24	0.31	0,21
	“Miscellaneous” litter	11.04	3.76	2.94	0.34	0.23
Mean	Total litter	37.43	13.38	2.80	0.36	0.25
	Leaf litter	22.78	8.29	2.75	0.36	0.25
	Wood litter	5.34	1.87	2.86	0.35	0.24
	“Miscellaneous” litter	8.62	2.87	3.00	0.33	0.23

K_t = Turnover rates calculated as litter fall relative to litter biomass by Nye (1961)
T_{50} = Time required for the decomposition of half the initial material

Litter biomass

The mean monthly biomass of litter on the forest floor for the period under study was 13.38 ± 0.51 g , (dwt) m^{-2} with leaf litter contributing 61.96%, wood litter 13.98% and 'miscellaneous' litter 21.5% (Table 3). The litter biomass varied in composition and quantity temporally and spatially (across the tidal levels; Figs. 2a, b). Litter biomass was highest in August on the forest floor with the average quantity higher at the mid tide level (18.09± 1.26) than at the high tide level (16.72 ± 0.44) and at the low tide level (7.34 ± 0.44). The peaks of leaf litter contribution to the biomass were in February and October. The highest average contribution of leaf litter to biomass was at the high tide level (10.71 ± 0.44) and lowest at the low tide level (4.13 ± 0.26). 'Miscellaneous' litter contribution to biomass was highest in August in the forest floor. The highest quantity of 'miscellaneous' litter to biomass was at the high tide level (3.76 ± 0.36) and lowest at the low tide level (1.67 ± 0.15). The contribution of wood to the biomass was highest in December with the highest average contribution at the mid tide level (2.32 ± 0.24) and lowest at the low tide level (1.59 ± 0.18) (Figs. 2a,b). The composition of the biomass also varied across the tidal gradient. The leaf litter contributed 56.27%, 62.25% and 64.62%, wood litter 21.66%, 14.43% and 64.62% and 'miscellaneous' litter 22.75%, 19.65% and 22.49% across the tidal gradients low, mid and high respectively (Table 3). The results of the repeated measures ANOVA revealed a highly significant difference ($P < 0.001$) for the litter biomass over time (months), and the litter components (leaf, wood and 'miscellaneous'). There were also highly significant differences ($P < 0.001$) in litter biomass across the tidal gradient including the litter components (Table 4). There was also a significant interaction effect ($P < 0.001$) between monthly litter biomass and tidal levels for total litter, leaf, wood and 'miscellaneous' litters (Table 4).

Litter turnover

The turnover rates of mangrove litter were estimated using the method by Nye [43]. The estimates were based on the relative measure of litterfall to litter on the forest floor at each of the tidal levels. The results show that the litter turnover rates differed across the tidal gradients with the low tide level having the highest turnover rate and the mid tide level having the lowest turnover rate (Table 5). There were also variabilities in estimated turnover rates of different components of the litter across the tidal gradients. Leaf and 'miscellaneous' litter had the highest turnover rate at the low tide level, while wood litter had the highest turnover rate at the high tide level (Table 5).

DISCUSSION

The composition of litter fall with leaves accounting for 58 – 64%, wood for 11 – 18% and 'miscellaneous' (reproductive products and stipules) for 14 – 23% of the total litter (Table 1) is comparable to litter composition in other tropical mangrove systems [44, 17, 11, 45, 29, 22, 24]. Litterfall exhibited seasonality with a bimodal response peaking during rainy (August) and dry (February) seasons. This is the general litterfall pattern exhibited in the tropics [46, 26]. These litterfall peaks may be partly attributable to the phenology of mangroves where sequential diversion of resources into flowering likely culminates in loss of old inefficient leaves as litterfall. Also, the seasonal increases in substrate salinity during the dry season, especially at elevated sites, may lead to eventual loss of leaves [46]. The mean monthly litterfall rate of 37.43g dwt m^{-2} (~1.25g $m^{-2}d^{-1}$) is low compared to those recorded for other tropical mixed mangrove forests [47, 17, 11, 48]. However, the highest mean monthly litterfall of 47.53g dwt m^{-2} (~ 1.58g $m^{-2}d^{-1}$) recorded at the high tide level (landward) and composed mainly of *A. africana* lies within the range of litterfall values reported for *Avicennia* species in the tropics (1.49g $m^{-2}d^{-1}$ to 6.0g $m^{-2}d^{-1}$) [48, 24]. The overall low mean rates of litterfall recorded in this study may be related to the species composition of the forest. This may be partly due to the fact that the mangrove species, which dominates the low tide level of the forest, *N. fruticans*, rarely contributes to leaf fall due to the architectural palm nature of its leaf [49, 5, 50]. Other contributing factors to low litterfall production may include geophysical processes such as tides, river flow and winds associated with the environment [17], temperature and salinity [51, 52]. The average monthly litter biomass found on the forest floor (13.38g dwt m^{-2}, Table 3) constituted 35.75% of the litterfall indicating possible retention of litterfall. The litter biomass was generally lowest at the low tide level (7.43g dwt m^{-2}) especially during the rainy season (June to September). This low amount of litter biomass on the forest floor compared to the amount of litterfall (21.90g dwt m^{-2}, Table 1) may be associated with greater export due to the effects of tides on the transport of litter from the forest floor [53]. The litter biomass increased generally across the tidal gradients, towards the high tide level where tidal effects are much reduced. This pattern of litterfall relative to litter biomass in this mangrove forest is similar to global patterns in mangrove forests in different environmental settings. This pattern is consistent with the conceptual model of leaf litter dynamics by Twilley *et al*. [53]. The model suggests that geophysical energies such as tides and river discharge that influence the structural attributes of mangrove ecological types, can also control the fate of litter, with riverine mangroves having the highest litter turnover rates compared to fringe and basin mangroves. These have implications for organic matter dynamics and fisheries in the estuary. Knowledge of the mechanisms controlling organic matter provides insight into carbon storage potential [54] and biogeochemical cycles of nutrients [55].

The annual total litter production in this mangrove forest for the period of April, 2008 to March 2009 is estimated to be approximately 449.2g dwt $m^{-2}y^{-1}$ based on the obtained result of 37.43gdwt m^{-2} m^{-1}. If this value is applied to the total estimated mangrove area (1950km^2) of the Cross River estuary, [56] the figure would become approximately 4.22^{11}g dwt y^{-1}. If this value is applied to the total area (7,356km^2) of mangroves in Nigeria, Spalding *et al*., [4], what an enormous amount of litter is produced by mangroves, all year round. Out of the estimated 37.43g dwt m^{-2} monthly litter produced, only 13.38g dwt m^2 (35.8%) was found as litter biomass accumulating in the forest floor. The low decomposition rates and litter biomass recorded in this study may imply a maximal export of litter from this mangrove system [57, 11]. Thus the enormous amount of litter which is produced throughout the year in the mangrove ecosystem may partly be transferred through tidal waters to nearby coastal waters forming an additional major support for off-shore biological production [28]. Those retained in the system directly increase benthic primary production within the environment [5].

Coastal forests play important role in maintaining the ecology of estuarine and inshore marine ecosystems [58, 59]. Coastal forest streams gather materials such as nutrients, energy and matter from the coastal forests and concentrate them in estuaries at the land-sea ecotone. The inputs of energy source through the mangrove litterfall and its export have profound effects on the biodiversity resources in mangrove systems.

CONCLUSION

The periodicity, amount and fate of litter in this mixed mangrove or mangrove forest vegetation studied are comparable to mixed mangrove forests in other tropical locations. This is the first study of litter production and composition in a riverine mangrove system of the Cross River estuary. The findings from this study have implications for understanding and predicting patterns of productivity and distribution of litter in Nigerian mangrove wetlands. Knowledge of the mechanisms controlling litter production and distribution provides insight into carbon storage potential and biogeochemical cycles of the system. These findings can be used to bridge the gap in the knowledge of the ecology of mangrove ecosystems in Nigeria and create awareness on the importance of sustainably managing, conserving, restoring or rehabilitating, rather than removal of mangroves for economic and aesthetic reasons.

REFERENCES

[1] Farnsworth, E. J.; Ellison, A. M. *Ambio*, **1997**. 26:328-334.
[2] Alongi, D. M. *Environmental Conservation*, **2002**. 29:231-349.
[3] Kinako, P.D.S. *Ecology and conservation of natural resources*. Belk publishers, Port Harcourt. Pp145. **1989**.
[4] Spalding, M.; Kainuma, M.; Collins, L. World *Atlas of Mangroves*. The International Society for Mangrove Ecosystems (ISME), Okinawa, Japan Earthscan Limited, Washington DC. 319pp. **2010**.
[5] Hogarth, P. J. *The Biology of Mangroves*. Oxford University Press. 272pp. **1999**.
[6] Middleton, B. A.; McKee, K. L. *Journal of Ecology*, **2001**. 89:818-828.
[7] Ellison, A. M.; Farnsworth, E. J. Mangrove communities. In: Bertness, M. D., Gaines, S. D.; Hay, M. E. (Eds). *Mangrove Community Ecology*, (432 – 442). Sinauer Associates, Sunderland, Massachetts, U. S. A. **2001**.
[8] Rey, J. R.; Rutledge, C. R. Mangroves. http://edis.ifas.ufi.edu/in195. **2005**. Retrieved 16/02/06.
[9] Clough, B. F. *Mangroves – Salt Marshes*, **1998**. 2:191-198.
[10] Li, M. S. *Estuarine, Costal and Shelf Science*, **1997**. 45:463-472.
[11] Wafar, S.; Untawale, A. G.; Wafar, M. *Estuarine, Coastal and Shelf Science*, **1997**. 44:111-124.
[12] Lee, S. Y. *Australian Journal of Ecology*, **1999**. 24:355-366.
[13] Clough, B. F.; Tan, D. T.; Phuong, D. X.; Buu, D. C. *Aquatic Botany*, **2000**. 66**:**311-320.
[14] Dawes, C.; Siar, K.; Marlett, D.. *Mangroves and Salt Marshes*, **1999**. 3:259-267.
[15] Manson, F. J.; Loneragan, N. R.; Harch, B. D.; Skileter, G. A.; Williams, L. *Fisheries Resources*, **2005a**. 74:69 – 85.
[16] Manson, F. J.; Loneragan, N. R.; Skileter, G. A.; Phinn, S. R. *Oceanography and Marine Biology Annual Review*, **2005b**. 43:483-513.

[17] Twilley, R. R.; Pozo, M.; Garcia, V. H.; Rivera-Monroy, V. H.; Zambrano, R.; Bodero, A. *Oecologia*, **1997**. 111:109-122.
[18] Feller, I. C.; Whigham, D. F.; O'Neill, J. P.; McKee, K. L. *Ecology*, **1999**. 8:2193-2205.
[19] Day Jr., J. W.; Coronado-Molina, C.; Vera-Herrera, F. R.; Twilley, R.; Rivera-Monroy, V. H.; Alvarez-Guillean, H.; Day, R.; Conner, W. *Aquatic Botany*, **1996**. 55:39-60.
[20] Slim, F. J.; Hemminga, M. A.; Ocheing, C. A.; Jannick, N. T.; Gocheret de la Moriniere, E.; Vander Velde, G. *Journal of Experimental Marine Biology and Ecology*, **1997**. 215:35-48.
[21] Silver, C. A. R.; Lacerda, L. D.; Ovalle, A. R.; Rezende, C. E. *Mangroves Salt Marshes*, **1998**. 2:149-157.
[22] Gwada, P.; Kairo, J. G. *South African Journal of Botany*, **2001**. 67 (3): 443- 449.
[23] Ross, S. M.; Ruiz, P. L.; Telesnicki, G. J.; Meeder, J. F. *Wetlands Ecology and Management*, **2001**. 9:27 – 37.
[24] Ocheing, C. A.; Erflemeijer, P. L. A. *Trees*, **2002**. 16:167-171.
[25] Cattiano, J. H.; Anderson, A. B.; Rombold, J. S.; Nlepstad, D. C. *Revista Brasileira de Botanica*, **2004**. 25:419 - 430.
[26] Mfilinge, P. L.; Meziane, T.; Bachok, Z.; Tsuchiya, M. *Estuarine, Coastal and Shelf Science*, **2005**. 63:301-313.
[27] Imgraben, S.; Dittmann, S. *Journal of Sea Research*, **2008**. 59:83-93.
[28] Alongi, D. M. *Coastal Ecosystem Processes*. *Boca Raton*. CRC Press, 419pp. **1998**.
[29] May, J. D. *New Zealand Journal of Marine and Freshwater Research*, **1999**.33:163-172.
[30] Bunyavejchewin, S.; Nuyim, T. *Silvicultural Research Report*, **2001**. 17:18-25.
[31] Saenger, P.; Snedaker, S. C. *Oecologia*, **1993**. 96:293 – 299.
[32] Dittmar, T.; Hertkorm, N.; Kattner, G.; Lara, R. J. Mangroves, a major source of dissolved organic carbon to the oceans. *Global Biogeochemical Cycles*, **20**, GB 1012. *doi:1029/2005GB0025*. **2006**.
[33] Dittmar, T.; Lara, R. J.; Kattner, G. *Marine Chemistry*, **2001**.73:253-271.
[34] Ibianga, M. S. Management objectives for mangrove forests in Nigeria. In: Wilcox, B. H. R.; Powell, C. B. (Eds). *The mangrove ecosystem of the Niger Delta, Nigeria*. (88-93). University of Port Harcourt Press, Port Harcourt, Nigeria. **1985**.
[35] Akpan, E. R. *Seasonal variation in phytoplankton biomass in relation to physiochemical changes in the Cross River estuary, South Eastern Nigeria*. Ph.D Thesis, University of Calabar, Nigeria. 269pp. **1994**.
[36] Akpan, E. R. *Nigeria Tropical Freshwater Biology*, **1998**. 7:53-61.
[37] Akpan, E. R. *Tropical Journal of Environmental Research*, **2000**. 2 (182):107-111.
[38] Holzloehner, S.; Nwosu, F. M.; Akpan, E. R *African Journal of Environmental Pollution and Health*, **2002**.1(2): 76-87.
[39] Obi, J. U. *Statistical methods of determining differences between treatment means and research methodology issues in laboratory and field experiments*. Enugu: SNAAP Press. 717pp. **2002**.
[40] Brown, M. S. Mangrove litter production and dynamics. In: Snedaker, C. S.; Snedaker, J. S. (Eds). *The mangrove ecosystem. Research methods monograph on oceanographic methodology*, (231-238). UNESCO, Paris. **1984**.
[41] Ukonmaanaho, L.; Starr, M. *Environmental Monitoring Assessment*, **2001**. 60:129-146.
[42] Sullivan, L. M. *Circulation*, **2008**. 117:123 -143.
[43] Nye, P. H. *Plant Soil*, **1961**. 13:333 – 346.
[44] Mackey, A. P.; Smail, G. *Aquatic Botany*, **1995**. 52:133-142.
[45] Mokolensang, J. F.; Tokuyama, A. *Bulletin of College of Science, University of Ryukyus*, **1998**. 65:73-79.
[46] Clarke, P. J. *Australian Journal of Botany*, **1994**. 42**:**37 – 48.
[47] Hadiwinoto, S.; Makasugei, T.; Igarashi, T. *Research Bulletins of the College Experiment Forests, Hokkaido University*, **1989**. 4 (3): 577-594.
[48] Shonula, J. P.; Whittick, A. *Estuarine, Coastal and Shelf Science*, **1999**. 49:51 – 54.
[49] Tomlinson, P. B. *The Botany of Mangroves*. New York, USA. Cambridge University Press. 419pp. **1994**.
[50] Duke, N. C. *Australia's mangroves: the authoritative guide to Australia's mangrove plants*. University of Queensland, Brisbane. Melbourne, CSIRO Publishing, 200pp. **2006**.
[51] Medina, E.; Francisco, M. *Estuarine, Coastal and Shelf Science*, **1997**. 45:337– 344.
[52] Saenger, P. *Mangrove Ecology, Silviculture and Conservation*. Dordrecht. Kluwer Academic Publishers 360pp. **2002**.
[53] Twilley, R. R.; Lugo, A. F.; Patterson – Zucca, C.. *Ecology*, **1986**. 67:670 - 683.
[54] Fujimoto, K.; Imaya, A.; Tabuchi, R.; Kuramoto, S.; Utsugi, H.; Murofushi, T. Blowground carbon storage of Micronessian mangrove forests. *Ecological Research*, **1999**. 14:409 – 413.
[55] Chen, R.R.; Twilley, R. *Biogeochemistry*, **1999**. 44:93-118.

[56] ENPLAN. *Feasibility Report on Cross River Basin*. Federal Government of Nigeria Publication, Lagos 3976pp. **1974**.
[57] Lee, S. Y. *Hydrobiologia*, **1997**. 295:203-212.
[58] Polis, G. A.; Hurd, S. D. *American Nature*, **1996**. 147:396 – 423.
[59] Wu, J. P.; Calvert, S. E.; Wong, C. S. *Estuarine, Coastal and Shelf Science*, **1999**. 48:193-203.