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Research Article
Effect of Pollution and Seasonal Changes on Litter Fall and Accumulation in Mangrove Forest (*Rhizophora* Species) of the Niger Delta, Nigeria

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Abstract

Background and Objective: Hydrocarbon pollution and seasonal changes cause defoliation and litter fall, respectively. It is hypothesized that increasing pollution and rapid seasonal changes can cause increased litter fall. The objectives of the study were (1) To determine the annual litter fall of leaves, fruits and flowers, (2) To determine the total litter accumulation and (3) To determine the amount of litter fall in wet and dry season in highly and lowly polluted treatments. **Materials and Methods:** Litter fall data were collected monthly for three years at four 20×20 m plots in highly and lowly polluted plots and locations in the mangrove forests. A total of 1,440 litter samples were collected from litter traps randomly placed under mangrove trees. The litters were sorted into leaves, fruits and flowers. **Results:** There is a negative correlation between precipitation and litter fall (leaf r = - 0.68, fruit r = - 0.47, flower r = 0.31). Mean-monthly litter fall for leaves, fruits and flowers were 23.9 ± 1.3, 9.3 ± 0.8 and 2.8 ± 0.6 g m^{-2}/year, respectively. Total average litter fall was 66.5% leaf, 25.5% fruit and 8% flower. Total litter fall between locations and amongst plots did not vary significantly ($p>0.05$). But the 3 years cumulative litter fall was higher in highly polluted treatment (~4777 g m^{-2}/year) than in lowly polluted treatment (4077 g m^{-2}/year). Precipitation and season significantly influenced litter fall ($p<0.0001$). Dry season (November-January) had higher litter fall than wet season (February-October). **Conclusion:** This implies that pollution and season influence the rate of litter fall.

Key words: Hydrocarbon pollution, mangrove, *Rhizophora* species, seasonality, Niger Delta

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Litter fall energizes biological activities and influences nutrient distribution in mangrove forest. Mangroves are diverse, globally distributed and have long term growth. Mangrove litters fall on forest floor, accumulate and decompose to enrich the swamp[1]. Long term litter fall data is important to fully understand the dynamic of nutrient cycling. Mangroves of the Niger Delta are the largest in Africa and the Atlantic[2], but have few litter fall data in the literature to allow for proper assessment of their contribution to global carbon sequestration and storage. Mangroves are biodiversity-rich and a hot-spot for many aquatic, terrestrial and arboreal organisms. Mangroves play vital role in trophic energy distribution through litter production[3]. Litter is a major component of primary productivity in tropical rain forests[4], which is incorporated into the mangrove food web[5]. Decomposed litter on forest floors[1] enriches the mangrove soil and serves as food for crabs[6] and other organisms, which begins the process of nutrient cycling. Increased precipitation generates floodwater[7], which ferries and deposits litter in readiness for decomposition and nutrient cycling[8]. Increase in soil nutrients lead to luxuriant growth of mangroves, which in turn increase flowering and fruiting activities and results to increased litter fall[9]. Precipitation influences growth[10] and global distribution[11] of mangroves.

Seasonality is related to precipitation because it determines the wetness or dryness of an area. Wet condition facilitates the dispersal of mangrove propagules and litter from the ground to the river[12]. However, different species respond differently to seasons, for instance, flowering in *Avicennia germinans* occur during the dry season while flowering in *Laguncularia* occur during the wet season[13]. In dry conditions, upland run-off decreases leading to increased evaporation and increase saline absorption by plant leading to accelerated leaf senescence. Fruits and leaves are a small fraction of the above ground biomass and could have a weight range of 130-1870 g m^{-2}/year while below ground biomass makeup large part of mangrove biomass[14]. Site-specific factors cause differences in mangrove phenology[10]. The rate of litter fall varies according to the latitudinal gradients. The closer the area is to the equator, the higher the litter fall[15].

Mangrove litter fall is also influenced by oil pollution[16,17], which causes defoliation and yellowing of leaves[18]. This results to anomalous leaf drop leading to net loss of live canopy[19]. Similarly, prolonged exposure to toxic substances in mangrove causes deformities[20] that triggers litter fall. Litter fall as a result of seasonal and climatic influences such as wind, sunlight and rainfall and also hydrocarbon pollution is difficult to determine.

It is thus hypothesized that increased litter fall could signify increased pollution activity and rapid seasonal changes. The main goal of this study was, therefore, to determine the monthly, seasonal and cumulative litter fall in the study areas. Objectives were as follows: (1) To determine annual litter fall of leaves, fruits and flowers, (2) To determine total litter accumulation and (3) To determine the amount of litter fall during dry and wet seasons in highly and lowly polluted treatments i.e., plots and locations.

MATERIALS AND METHODS

Study areas: The Niger River Delta consists of a network of river tributaries and its delta is a flood plain that makes 7.5% of Nigeria's total landmass[21]. This area is rich in aquatic organism (e.g., tilapia, mudskipper, periwinkle, mussel, etc.), forests products (e.g., timber, firewood and medicinal herbs) and mineral resources (e.g., liquefied natural gas and crude oil). It has a tropical climate with rainfall occurring throughout the year, except in November, December and January[22]. The mean monthly temperature range is 26-30°C. The two seasons that prevail in the study area are the wet (February-October) and the dry (November-January) seasons with a break in August, known as the "August break". The study was undertaken in two towns namely: Buguma (4°45'N, 6°53'E) and Okrika (4°43'N, 7°05'E). Buguma is an island town, surrounded by fringe mangrove, part of whose forest had been cut, dredged and sand filled. This area has one oil well, but no major industrial activities, hence it is classified as lowly polluted location (Plots A and B). Plot A is closer to the river while plot B is situated upland and away from the river. Okrika sampling area is a host to a major oil refinery, a petrochemical industry and other subsidiary firms. The crude oil products are transported from the refinery to the evacuation jetty by ten giant pipelines (measuring between 8-10 inches) that pass through the mangrove forests. Because of oiling activities, this location has more oil spillages than the lowly polluted location, hence, it is classified as a highly polluted location (plots C and D). Plot C is closer to the river than plot D. The polluted location constantly has oil films on the water, which are carried along by tidal currents into nearby mangrove forests. The roots of the trees are usually embedded in the oil-soaked swamp.

Study species: The dominant mangrove species in both study locations are the Rhizophoraceae family. There were five species, three *Rhizophora* species (*R. racemosa*, *R. mangle* and *R. harrisonii*) plus *Avicennia germinans* and *Laguncularia racemosa*. The study was focused on *R. racemosa* Meyer, being the most dominant among the *Rhizophora* species in the Niger River Delta[23].Thus the litter traps were directly placed under the canopies of the *R. racemosa* trees.

Experimental design and site selection: The two study areas were 24.4 km apart from each other. These areas had similar geography and were both surrounded by vast mangrove forests. Four plots each measuring 20×20 m (400 m^2) were delineated, with two plots at each study location. This designation was done based on total hydrocarbon content analysis and characterization parameters developed in an earlier study[1,24].

In each plot, ten trees ranging from 1.8-6.1 m high were randomly selected and geo-referenced using Garmin GPS (USA). Large hand-weaved basket litter traps having a surface area of 0.15211 m^2 were attached to each tree with aluminum strings to prevent falling. The baskets were placed 1 m above the ground surface. The inner part of the trap was lined with soft cotton material to prevent bouncing off of litter from inside the trap. The basket was used in place of a plastic container in other to prevent edge effect, where falling litter will bounce off after hitting the edge of the container.

Litter fall estimation: The litter samples were collected monthly for the duration of the study from June, 2010 to June, 2013. Samples were cleaned of dirt and water and placed under the sun to dry. Samples were sent to the laboratory of the Department of Animal and Environmental Biology, where they were sorted into leaves, fruits and flowers[25,26]. Fruits were referred to as buds, stipules and sepals while flowers are the reproductive parts that include corollas and petals. The sorted litter was weighed before and after oven-drying to a constant mass at 70°C for 48 h. The total dry weight of litter (g m^{-2}) in each litter trap with surface area of 0.15211 m^2 was calculated using Eq. 1 as follows:

$$\text{Dry weight of litter (gDW)} = \frac{\text{gDW m}^{-2}}{0.15211\text{ m}^{-2}} \qquad (1)$$

Then the rate of litter fall is calculated by dividing the dry weight of litter (gDW m^{-2}) by the number of days between each collection date as shown in Eq. 2:

$$\begin{array}{c}\text{Dry weight of}\\ \text{litter (gDW)}\end{array} = \frac{\text{gDWm}^{-2}\text{/day}}{\text{Number of days between each collection date}} \qquad (2)$$

$$\text{Percent litter fall} = \frac{\text{Litter fall (i.e., leaf, fruit, flower)}}{\text{Total litter fall}}\times 100 \qquad (3)$$

The result of the outcome is given in Table 1. Monthly precipitation for the duration of the study (i.e., 2010-2013) was retrieved from the database of the Meteorological Research and Training Institute, Nigerian Meteorological Agency, Lagos.

Statistical analyses: A non-parametric Spearman's rank correlation was used to determine the relationship between litter fall and precipitation. Similarly, relationship between average monthly precipitation and total litter fall was determined with Spearman's correlation. One-way ANOVA was performed to determine differences in litter fall between seasons, locations and plots followed by Tukey HSD *post hoc* test[27] at $p<0.001$. To ensure normality litter data (i.e., leaves, fruits and flowers) were log transformed and used for the analysis. Also bar graphs representing the pattern of litter fall was plotted where litter fall amount was the dependent variable and months, seasons and locations were regarded as the independent variables. All analyses were performed in R Statistical Environment, version 3.0.1[28].

Table 1: Sum total of annual cumulative litter fall (g m^{-2}/year) in traps from different plots in Buguma and Okrika for 1st year (Jul, 2010-Jun, 2011), 2nd year (Jul, 2011-June, 2012) and 3rd year (Jul, 2012-Jun, 2013) in the Niger River Delta, Nigeria

		1st year			2nd year			3rd year		
Locations	Plot	Leaf	Fruit	Flower	Leaf	Fruit	Flower	Leaf	Fruit	Flower
Buguma	A (high)	2696.3	1205.2	390.02	2398.9	750.9	149.6	3714.5	2037.7	145.4
Buguma	B (low)	2591.4	488.00	277.10	2657.2	1084.4	200.2	2837.5	757.7	80.5
Okrika	C (high)	3094.9	1217.6	926.80	2831.1	1613.4	369.5	2826.3	1484.7	266.2
Okrika	D (low)	3852.7	958.90	346.60	3522.4	918.4	322.2	2289.7	1163.6	634.2
*Cumulative (%)		Leaves (66.5)			Fruits (26)			Flowers (8)		

*Equation 3 for calculation of percent litter fall per plot

RESULTS

Effect of pollution on overall litter fall: The mean monthly litter fall in the mangrove forests for leaves, fruits and flowers were 23.9±1.3, 9.3±0.8 and 2.8±0.6 g m^{-2}/year, respectively. There was significant difference in monthly litter fall ($F_{1,70}$ = 12.6, p<0.0001). Highest litter fall was recorded in January and February while lowest litter fall was recorded in July and August (Fig. 1), which were peak of dry and wet seasons, respectively. Litter fall was relatively higher in highly polluted plot (Fig. 1a). During the second year (Fig. 1b), litter fall was slightly higher in lowly polluted plot while during the 3rd year (Fig. 1c), litter fall was clearly higher in highly polluted plot. Leaves were the most important contributors to the total litter fall followed by fruits and flowers for all locations and years sampled. The average percent of litter fall for Buguma is as follows: Leaves (69%), fruits (25%) and flowers (6%) and for Okrika, it is as follows: Leaves (64%), fruits (26%) and flowers (10%). Therefore, the average percent of litter fall for both locations include: Leaves (66.5%), fruits (25.5%) and flowers (8%).

The cumulative litter fall for the three years sampled indicates that the highly polluted location had higher litter fall and litter accumulation than the lowly polluted location (Table 1). The average overall litter accumulation for both locations showed that there was variation between locations, plots and years (Table 1).

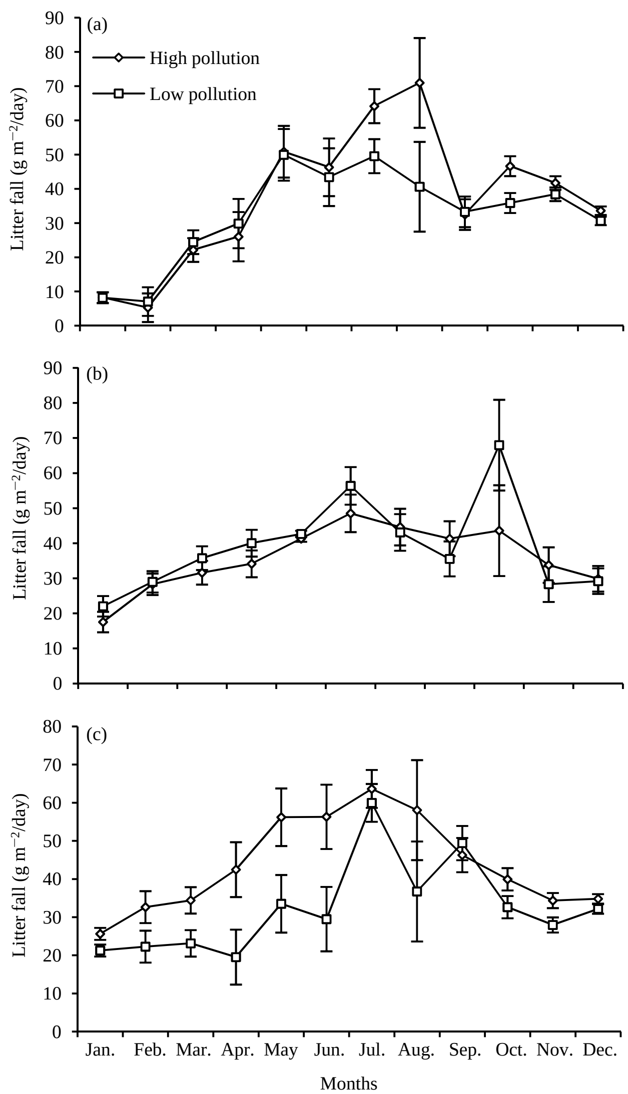

Fig. 1(a-c): Mean litter fall (±SE) per month in lowly and highly polluted plots in (a) 2010-2011, (b) 2011-2012 and (c) 2012-2013
Three years litter fall showing monthly variation and seasonal phenology in highly and lowly plot in Buguma and Okrika, Nigeria. Low represents low polluted plot and high represents high polluted plot

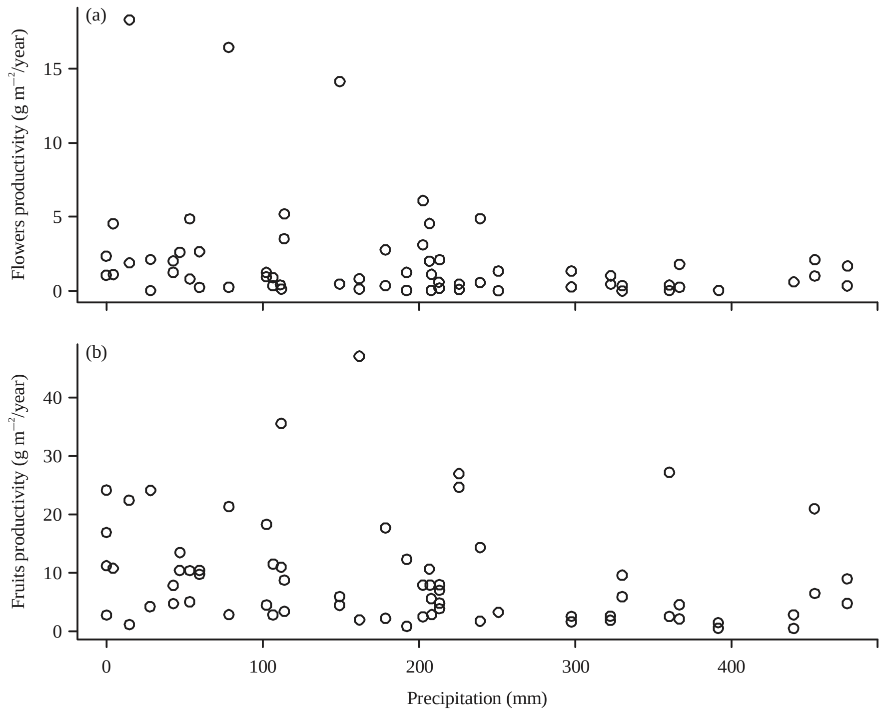

Fig. 2(a-b): (a) Flowers and (b) Fruits productivity as a function of the amount of precipitation
Seasonal multi-modal variation pattern in the mangroves. Dots represent the monthly mean of precipitation for study areas in the Niger River Delta, Nigeria from 2010-2013

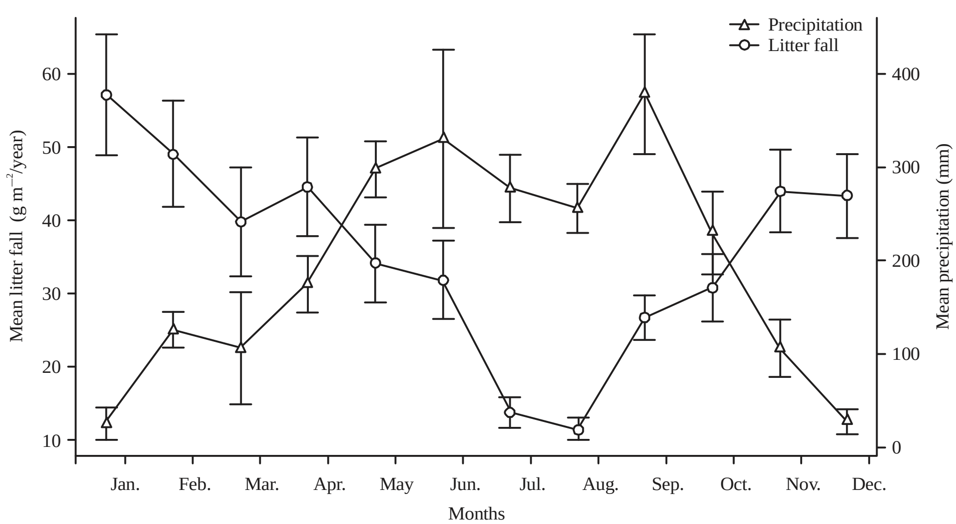

Fig. 3: Mean values (±SE) of litter fall of *R. racemosa* and monthly precipitation for three years in the Niger River Delta, Nigeria
Dotted line is mean precipitation and thick line is mean litter fall

Effect of precipitation on litter fall: Precipitation influenced total litter fall ($F_{1,70}$ = 21.3, p = 0.0001) and there was a strong negative correlation between total litter fall and precipitation (r = -0.539, p = 0.0001) for flowers (Fig. 2a) and fruits (Fig. 2b) productivity. This means that during periods of high precipitation, the rate of litter fall dropped while during periods of low precipitation the rate of litter fall increased (Fig. 3).

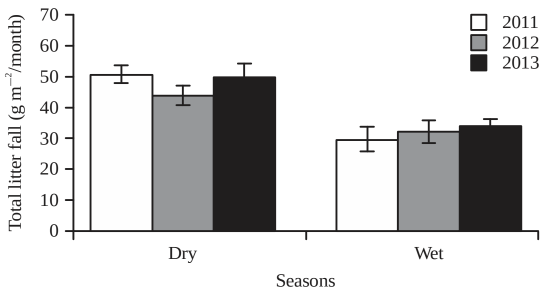

Fig. 4: Mean (±SE) total litter fall of mangrove during dry and wet seasons for three years (i.e., 2011, 2012 and 2013) in the Niger River Delta Nigeria

There was no significant difference within seasons but there was significant difference between seasons ($p<0.001$) for the three years analyzed

Similarly, there was significant individual correlations between precipitation vs. leaf ($r = -0.684$, $p<0.001$), precipitation vs. fruit ($r = -0.465$, $p<0.001$) and precipitation vs. flower ($r = -0.306$, $p<0.01$).There was also a multi-modal monthly variation of mean litter fall and mean precipitation at both study locations (Fig. 3)[29].

Effect of seasons on litter fall: There was a significant effect of seasons on total litter fall ($F_{1, 70} = 21.3$, $p<0.001$, Fig. 4[29]). Data on litter fall were grouped into seasons as follows: Dry season (November-January), associated with little or no rainfall and wet season (February-October) associated with light to heavy rain fall. Total litter fall was higher in dry season than in wet season (Fig. 4). According to the Tukey HSD *post hoc* test, January and February were the peak litter fall periods in both locations and in all the years sampled.

Effect of location on litter fall: There was no significant difference in total litter fall between study locations ($F_{1,70} = 2.4$, $p>0.05$) and within plots A, B, C and D ($F_{1, 70} = 2.5$, $p>0.05$, Fig. 5), but there were slight differences in total litter fall and litter fall accumulations in both study locations (Table 1). Highly polluted location had higher total litter accumulation than the lowly polluted location. Similarly, the amount of litter fall from trees close to the river (i.e., A and C) was slightly higher than the amount of litter fall from trees that are upland or away from the river (i.e., B and D).

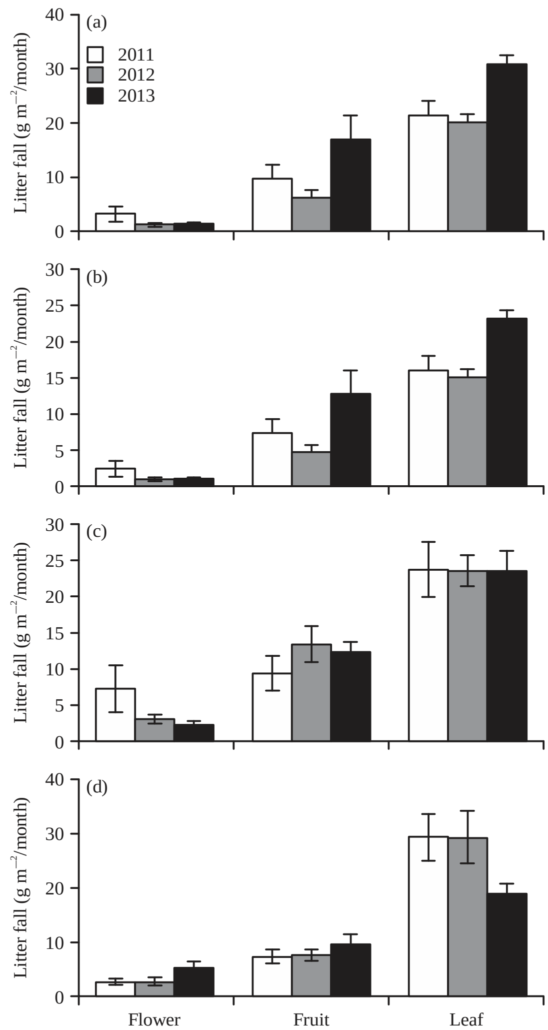

Fig. 5: Mean (±SE) flower, fruit and leaf litter fall in Buguma (a) High polluted, (b) Low polluted; in Okrika, (c) High polluted and (d) Low polluted in the Niger River Delta, Nigeria

DISCUSSION

The study showed that increased litter fall was facilitated by seasonal changes attributed to high or low precipitation during wet and dry seasons, respectively. Similarly, defoliation as a result of hydrocarbon pollution contributes to increase litter fall. Seasonal change in the tropics is controlled primarily by changes in precipitation than changes in temperature[30]. However, other studies indicate that leaf and stipule litter falls were linked to monthly sunshine hour, mean air temperature and relative humidity[31]. The level of precipitation is usually higher during the wet season than during the dry season (Fig. 2-4). It was, therefore, thought that wet conditions as a result of high rainfall would facilitate increased litter fall, but this study revealed the contrary. This is because higher litter fall occurred during the dry season, which indicates that dry conditions had more influence on increased litter fall than wet conditions[32,33]. There was higher litter fall during the dry season because it coincides with the reproductive period of the mangroves, which occur between November and March (Fig. 1a-c) in all years sampled. Similarly, other studies had revealed that seasonality pattern show only in the production of reproductive materials[34]. Results from the present study indicates that four factors contributed to increased litter fall, they are reproductive activities of mangroves during the dry season (Fig. 1a-c), crab herb ivory, which spiked during flowering and fruiting season. This is because the crabs were observed to feed on the propagules during the flowering and fruiting seasons, oil spillages, which has more impact on mangroves in highly polluted plots and locations leading to more defoliations than lowly polluted plots and locations (Table 1) and harmattan winds, which mainly occur during the dry season from December-February. Reproductive activities lead to the expulsion of flowers and fruits while harmattan winds blow down litter during the dry season. Further evidence indicates that litter traps placed on trees close to the river had slightly higher litter fall (Fig. 5a, c) than litter traps placed upland (Fig. 5b, d). The simple explanation to higher litter fall at the sea side is as a result of edge effect and sea breeze or coastal energy[35]. Other studies had shown that wind contributed to litter fall especially at coastal areas[35,36]. Wind pressure around coastal areas accelerates litter fall during the dry season. In addition, increased saline uptake into leaves facilitates leaf senescence. Rapid leaf loss is also a defensive mechanism by mangroves not only to eliminate diseased leaves, but also to expel polluted leaves to prevent the death of the trees. In contrast, other researchers have found out that heavy rains lead to increased litter fall[18,37-40]. Inter-species differences and climatic conditions too can influence litter fall. For instance, in Florida *Rhizophora mangle* had peak litter fall in summer because of the need to prevent excess transpiration, while *Avicennia germinans* had peak litter fall in winter[3] because of freezing conditions. Other factors that contribute to litter fall are tidal regime, sea current[8], wind energy and salt sprays[41] .The dominance of leaf litter in the overall litter fall in this study agrees with results of other researchers[4,36]. But the average litter accumulation in this study (>36 g m^{-2}/year) exceeded the results obtained from other regions such as in East Kalimantan, Indonesia where litter accumulation was 5.78 g m^{-2}/year[4]. This shows that more litter accumulated in the Niger River Delta mangrove forest as compared to other regions. This means that the mangrove ecosystem is a major global carbon sink and biodiversity hot-spot. The implication of this study is that increased biotic activity in mangrove forest is as a result of increased litter fall from hydrocarbon pollution and seasonal activities.

CONCLUSION

This study provides important litter fall data of mangroves in the Niger Delta, an area with little or no data in the literature. The study indicates that hydrocarbon pollution and seasonal changes are the two key factors that contributed to high litter fall in the area. Similarly, there was an increase in reproductive activity during the dry season (i.e., November-March), which had the highest litter fall. Hydrocarbon pollution influenced litter fall and litter accumulation, which may affect decomposition and trophic activities in the forest. Though further studies are needed to investigate the other causes of litter fall in mangrove forest in the Niger Delta.

SIGNIFICANCE STATEMENT

The study discovers that hydrocarbon pollution cause a spontaneous spike in litter fall activity, which may have a beneficial effect on decomposition and nutrient cycling in mangrove forest. This study will help researchers to uncover the role of pollution in litter production. Thus a new theory of litter productivity as a determinant factor of pollution may be achieved.

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