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Litter production in two mangrove forests along the coast of Ghana

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ABSTRACT

Litter production is an important component of mangrove primary productivity and has been widely used as a measure of productivity. During the past years, studies have been carried out on aspects of mangrove ecology and biodiversity in Ghana. These lay the foundations for surveys in ecological processes including productivity. This study was aimed at evaluating the production of litter within the mangrove forests at the Kakum and Pra estuaries. Four 0.25 ha study plots were demarcated in each mangrove forest, within which litter production and mangrove structural parameters were measured. Records on meteorological parameterss surrounding the study areas were obtained from Tutiempo Network. It was observed that annual litter production rate varied significantly ($t = 2.91$, $P < 0.05$) between the two mangrove forests - Kakum mangrove forest recorded 9.60 t ha^{-1} y^{-1} while Pra mangrove forest recorded 10.72 t ha^{-1} y^{-1}. Litter production also varied significantly within the sampling months and study plots ($P < 0.05$). Leaf litter accounted for 61.26–99.45% of litterfall in both forests. Mean DBH and height of mangrove trees per study plot ranged from 3.05 cm to 3.39 cm and 3.20 m to3.92 m respectively for the Kakum mangrove forest, while that of the Pra mangrove forests ranged between 3.12 cm and 4.06 cm, and 3.58m and 4.44 m respectively. It was observed that the meteorological and structural parameters explained very little of the litter variability within the two mangrove forests. Hence, other factors such as growth cycles, senescence and age might have influenced mangrove litter production more than those measured in this study. This calls for more studies into litter production in mangrove ecosystems in Ghana, to ascertain the various factors that contribute to litter production. This will help emphasise the importance of mangrove litter productivity and the need to restore and conserve our mangrove ecosystems.

1. Introduction

Mangrove forests are productive coastal ecosystems with relatively high productivity. The high productivity in mangrove forests is linearly related to the rapid litter production and effective recycling of nutrients [1]. Mangrove litter production or litterfall is the shedding of leaves and other vegetative and reproductive structures of mangroves. However, it has been opined that mangrove litter primarily consists of leaves, which become obtainable by consumers and decomposers [2,3].

Mangrove litterfall is a very important component of primary productivity of mangroves [4]. This is because mangrove litter production has been commonly used as a measure of productivity, due to the difficulty in measuring primary productivity directly with other methods in mangrove forests [5,6]. Additionally, productivity of mangroves is generally dependent on litter [7], hence litterfall

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is very important in the mangrove ecosystems.

Consequently, litterfall plays a significant role in ecosystem functioning, and provision of several ecosystem services, including nutrient cycling and carbon storage [8]. Litterfall is also essential for ecosystem processes on account of its importance in production of organic matter and sequence of decomposition [7,9], in addition to serving as the basis of detritus food chains [10]. Mangrove litterfall is also a primary source of organic matter which serves as food for a varied range of marine invertebrates and detritus-feeding organisms, that are found in the mangrove forests, the intertidal tidal flats and nearby shore waters [1,11]. Additionally, mangrove litter plays a critical role in carbon storage as well as carbon exchange to other adjoining coastal ecosystems [3,7,12]. For instance, it has been reported that organic carbon entered estuaries in the form of fallen reproductive and vegetative structures of mangroves, signifying mangrove forests as important sources of carbon in estuaries [13]. Hence, litter production is the most principal factor that controls the functions of mangroves in storing and cycling carbon and nutrients within the coastal ecosystem [2].

Litter production may be generally caused by natural factors such as withering, growth cycles, senescence, death and age, as well as environmental factors such as rainfall, wind and temperature [5,10,14]. Correlation between mangrove litter production and structural parameters including density of mangroves has also been reported [1,8,15]. All these indicate that mangrove litter production is governed by varying factors including environmental, natural and biological factors.

Seasonal and spatial variations occur in the quantity and composition of mangrove litter around the world [12,16–18], with the peak occurring in summer and the least during winter [16,18]. Also, estimates of litter production for mangrove forests are varied worldwide [9], ranging from 800 to 20300 kg ha^{-1} $year^{-1}$ (0.8–28.1 t ha^{-1} $year^{-1}$) [19]. These variations are caused by several factors such as type of species [19], tree height and anthropogenic activities [20], geographical location [6]. Others include type of forest, nutrient availability and fresh water drainage deposits [21].

For instance, seasonal litterfall patterns showed variations within the various forest types [14,21]. For a sub-tropical mangrove forest, peak litterfall occurred during the autumn season while the minimum occurred during winter [22]. For a tropical mangrove forest, however, litterfall was continuous all year-round and exhibited bimodal peaks [23]. This was confirmed by a study conducted in Cameroon and Ghana, where litterfall was recorded throughout the year, with the maximum litterfall occurring during the dry season whilst the minimum occurred in the wet season [15].

Given the diversity of mangrove forests within tropical countries including Ghana, and different prevailing conditions, as well as the current trend in climate change, there is the need to study factors which account for litterfall in these forests. This is because measurement of mangrove litter production is very important for assessing productivity as well as functions of the mangrove forests [2]. Also, the rate of mangrove litter production indicates the health of the mangrove forests [10]. In spite of these, only one comprehensive work has been done on the mangrove litter production in a relatively well conserved mangrove ecosystem, Ada Songor Ramsar Site in Ghana [15]. There is no other published work on mangrove litter production in other mangrove ecosystems in Ghana.

This research therefore seeks to provide information on the litterfall patterns in two coastal mangrove forests along the western shore of Ghana by: 1) determining the rate of litter production within two mangrove forests; 2) assessing the spatial and temporal variations in litter production; and 3) evaluating the possible factors that govern litter production in the two mangrove forests. These

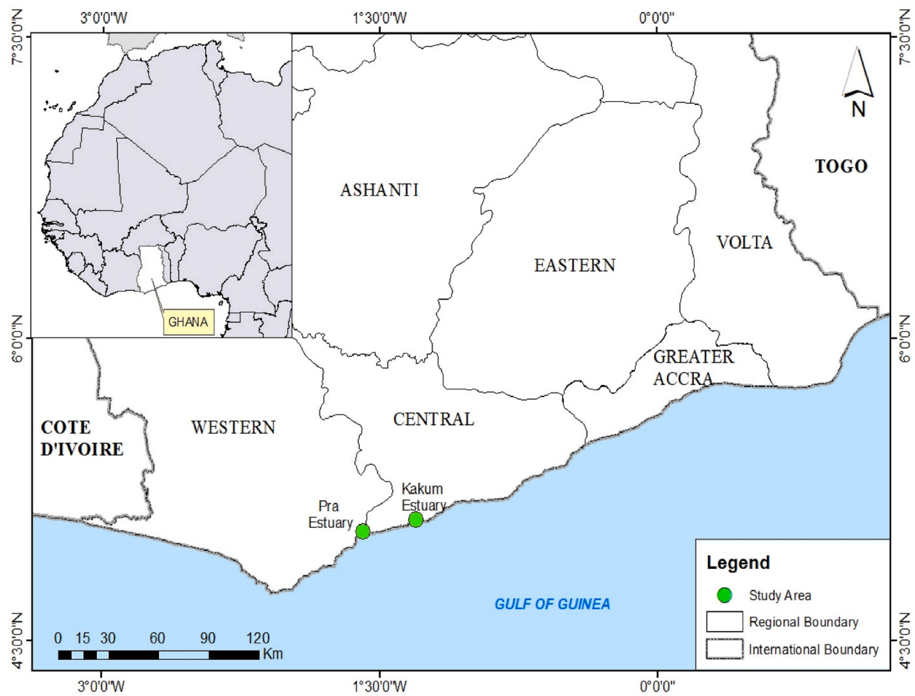

Fig. 1. Map of southern Ghana showing locations of the Kakum and Pra estuaries

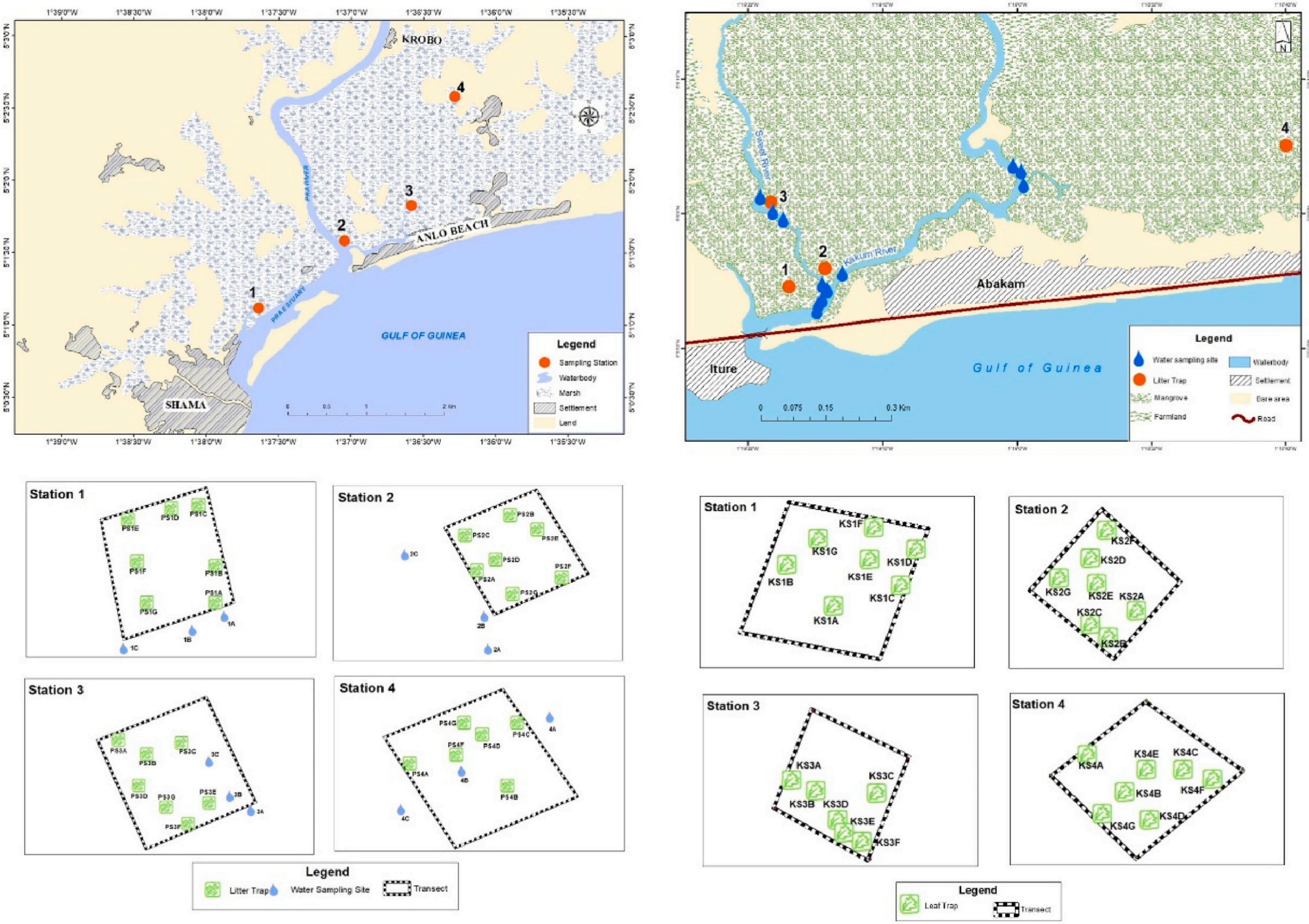

Fig. 2. Maps showing demarcated study plots and litter traps at the Pra and Kakum mangrove forests

two mangrove forests – Kakum and Pra, are important mangrove forests, but with contrasting conservation issues. The Pra mangrove forest has benefited from replanting of over 14,000 mangrove tree seedlings to help contribute to recovering more than 76 ha of lost mangrove cover [24]. However, though the Kakum mangrove forest is the most diverse mangrove forest in Ghana, there has never been any replanting efforts or programmes aimed at recovering mangrove cover lost.

Although these two mangrove forests are of great importance, nothing is known about litter production in these forests. This study will provide baseline information on mangrove litter production to researchers and policy makers towards mangrove conservation and restoration these neglected ecosystems. The outcome of the study will thus contribute to data on the health of mangrove communities in Ghana, towards the sustainability of these mangrove forests.

2. Materials and methods

2.1. Study area

The study was conducted in the Kakum and Pra mangrove forests from May 2017 to July 2018. The Kakum mangrove forest is located between Cape Coast and Elmina in the Central Region of Ghana (latitudes 5° 05′ 01.4" N and 5° 03′ 56.3" N and longitudes 1° 18′ 48.3" W and 1° 19′ 19.9" W), along the Cape Coast - Takoradi trunk road, while the Pra mangrove forest (latitudes 5° 01′ 06″ N, 5° 02′ 14″ N and 1° 35′ 56″W, 1° 39′ 33″W), in the Western Region of Ghana (Fig. 1).

The Kakum River estuary is formed by two rivers - the Sorowie (Sweet) River and the Kakum River. The estuary discharges into the Atlantic Ocean at Iture. Mangroves fringe the banks of the estuary, forming the Kakum mangrove forest, which is reported to have the highest diversity of mangroves in Ghana [25,26].

The Pra estuary is the second biggest estuary in Ghana after Volta Estuary. The Pra has adjoining marshlands and floodplains of about 1000 ha [27]. The estuary and its related wetland is rich in biodiversity and has diverse ecosystems comprising swamps and mangrove forest [28] (Kankam & Robadue, 2013). The mangrove forest extends some kilometres fringing the banks of the estuary [27].

3. Demarcation of study plots

Within each of the two mangrove forests, four 50 m × 50 m study plots were demarcated. The four study plots at Kakum mangrove forest were demarcated as follows: Plot I was about 13 m from the mouth of the estuary; Plot II was at the confluence of River Kakum and River Sorowie, about 22 m from the mouth of the estuary; Plot III was along the arm of the River Sorowie, about 33 m from the mouth of the estuary; and Plot IV was along the arm of River Kakum, about 140 m from the mouth of the estuary (Fig. 2). At the Pra mangrove forest, the study plots were: Plot I was about 0.3 km from the mouth of the estuary and 0.4 km from Shama-Apo community; Plot II was about 1.7 km from the mouth, and 0.9 km from Anlo Beach community, along the arm of River Pra; Plot III was about 2.7 km from the mouth of the estuary, about 0.6 km from Anlo Beach community; and Plot IV was about 4.1 km from the mouth, about 1.8 km away from Anlo Beach community. Some of the factors considered during the demarcating the study plots included ecological sensitivity, accessibility, and avoidance of evidently disturbed areas.

3.1. Measurement of litter production

Nylon fabric of mesh size of 1 mm × 1 mm was used to make litter traps. Each trap was made in the form of a basket, 75 cm deep, with an opening of 0.25 m^2. Within each of the study plots, seven traps were randomly suspended on tree branches of mixed stands, about 1 m above the ground to prevent flooding by tidal water. In this study, it was not possible to measure litter on species basis because of the mixed strands at the two mangrove forests , as well as the monospecific nature of some portions of the Kakum mangrove forest. The traps were emptied monthly from May 2017 to July 2018, and the litter was kept in labelled polythene bags and sent to the Fisheries Research laboratory of the Department of Fisheries and Aquatics Sciences, University of Cape Coast for analyses. In the laboratory, litter from respective traps were wrapped in aluminium foil and oven dried at a temperature of 105 °C to constant weight. The dried litter was sorted into four parts - leaves, flowers (including other reproductive parts), fruits (and propagules) and twigs, and the weight of each component was recorded.

Rate of monthly litter production was calculated per litter trap (surface area of 0.25 m^{-2}), for each mangrove forest as:

$$\text{Monthly Litter production}\left(g\ m^{-2} month^{-1}\right) = \frac{Dry\ Weight\ of\ monthly\ litter\ (g)}{0.25\ m^2}$$

Data on air temperature, relative humidity, rainfall and wind speed around the study areas were retrieved online [29]and used to assess the relationship between each of these factors and litter production.

The main limitations of the methods used in the data are the inability to measure mangrove litter production per species and the inability to measure the meteorological factors directly on the field. These limitations however, did not affect the outcome of the study. This is because, litter production could be measured on community levels, comprising of different species or mixed stands. This kind of method had been used by other workers [5,30]. Also, although meteorological parameters were not measured *in situ*, this approach of obtaining meteorological or climatic data from recognised institutions had been used by several earlier workers [3,14,30,31].

3.2. Determination of structural parameters of mangrove trees

Mangrove trees with diameter greater than 2 cm at breast height (1.3 m above ground level) were measured within each of the study plots. While a vernier caliper was used to measure the diameter of smaller trees, the girths (circumferences) of large trunks trees were measured using a tape measure, from which diameter (D) of each tree was calculated as $D = C/\pi$. Measurements of DBH of mangrove trees with irregularities were done following standard procedures [32]. The height of each tree was also measured using a graduated pole and a clinometer, where applicable. Additionally, the number of individuals of each of the mangrove tree was also recorded. The density of each mangrove species was then calculated as follows:

$$\textbf{Density}\ (\textbf{ha}^{-1}) = \frac{\text{Number of individuals of a mangrove species}}{\text{Area sampled}}$$

4. Results

4.1. Litter production in the Kakum and Pra mangrove forests

The variations in average rate of monthly litter production for both the Kakum and Pra mangrove forests are shown in Fig. 3. The rate of litterfall varied between 50.35 ± 6.24 g m^{-2} $month^{-1}$ and 105.40 ± 12.04 g m^{-2} $month^{-1}$, and 63.84 ± 5.88 g m^{-2} $month^{-1}$ and 128.51 ± 15.29 g m^{-2} $month^{-1}$ for the Kakum and Pra mangrove forests respectively. In the Kakum mangrove forest, litter production peaked in April 2018, whilst that of the Pra mangrove forest peaked in July 2018. The rates of annual litterfall were 959.96 g m^{-2} y^{-1} for the Kakum forest and 1071.51 g m^{-2} y^{-1} for the Pra mangrove forest. T-test analysis showed a significant difference between the rate of litter production from the two mangrove forests ($t = 2.91$, $P < 0.05$). ANOVA also indicated that litterfall varied significantly within the study plots and sampling months ($P < 0.05$).

4.2. Composition of litterfall in the mangrove forests

The percentage compositions of litter in the Kakum and Pra mangrove forests are presented in Fig. 4. The principal components of the litterfall in both forests were leaves, which ranged between 61.26% (in April 2018) and 97.85% (in September 2017) for the Kakum mangrove, and 75.87% (in August 2017) and 99.45% (in March 2018) for the Pra mangrove forest. Twigs were the least represented in litterfall in both mangrove forests and ranged from 0.28% in December 2017 to 6.294% in May 2018 for the Kakum mangrove forest, and 0.21% (November 2017) to 3.22% (May 2017) for the Pra mangrove forest. Results of ANOVA showed that the composition of the various parts of litter within the sampling months differed significantly, ($p < 0.05$).

4.3. Meteorological parameters in the Kakum and Pra forest areas

There were variations in meteorological parameters around the Kakum and Pra forest areas during the study period (Fig. 5). Variations in average monthly air temperature around both study areas were minimal and ranged from 24.9 °C to 29.1 °C and 25.1 °C to28.6 °C respectively for the Kakum and Pra mangrove forests. For both mangrove forests, while the least air temperatures were recorded in August 2017, the highest air temperatures occurred in April 2018 at the end of the dry season. Air temperatures of the two mangrove areas did not differ significantly ($t = -0.23$, $p > 0.05$).

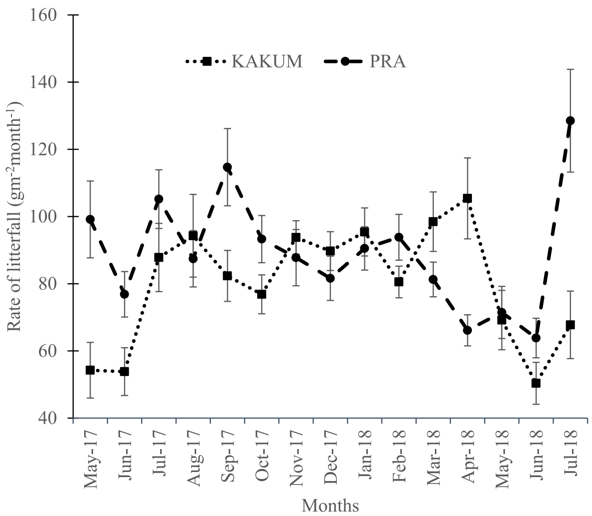

Fig. 3. Variations in monthly litter production in the Kakum and Pra mangrove forests.

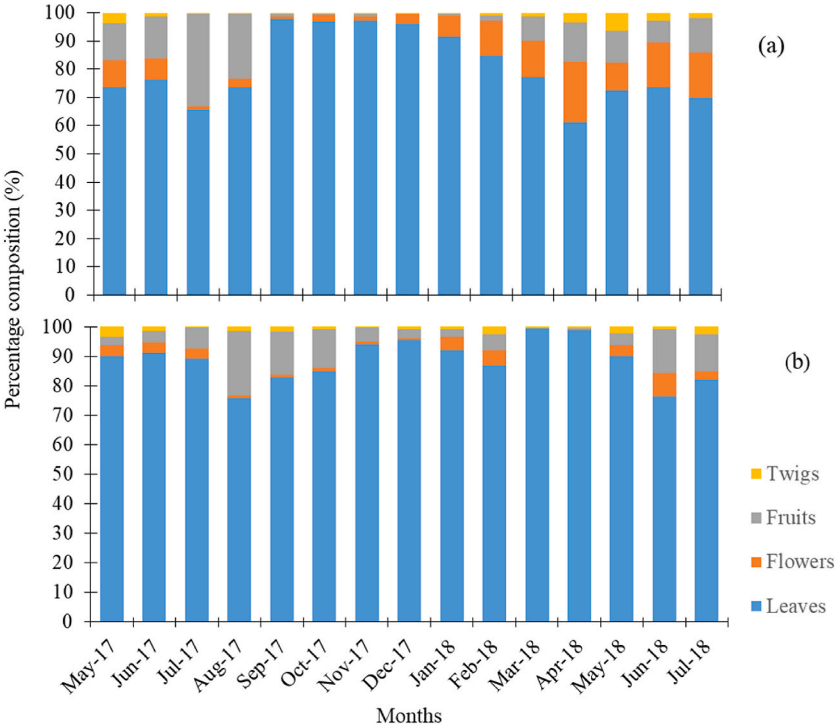

Fig. 4. Percentage composition of litterfall in Kakum (a) and (b) Pra mangrove forests.

Mean relative humidity was fairly constant at both study sites for the entire study period. Relative humidity was highest for both study sites in July 2018 - Kakum had 92.1% whilst Pra had 90.0%. However, generally, the Kakum area had marginally higher relative humidity than the Pra area, except for April 2018. Statistically, no significant difference was observed in relative humidity between the two mangrove areas, ($t = -0.23$, $p < 0.05$).

Notably, there were variations in monthly total rainfall pattern at both study areas, with the Kakum area recording lower amounts of rainfall (0.0–144.14 mm) than the Pra area (0.0–270.25 mm). Rainfall was highest in June and October 2017, with a smaller peak in May 2018, within the Kakum mangrove forest area. The highest amount of rainfall recorded for the Pra mangrove forest area occurred in May–June 2017, with a significant peak in May 2018. However, statistically, the amount of rainfall did not differ around the two forests, $t = -1.87$, $p > 0.05$.

Monthly variations in wind speeds ranged from 3.9 Km/h to 7.3 Km/h around the Kakum mangrove forest area, and between 6.0 Km/h and 11.7 Km/h around the Pra mangrove forest area. Clearly, higher wind speeds prevailed at the Pra area than the Kakum area. The highest wind speeds occurred in April 2018 for both study sites. The wind speeds differed significantly between the two mangrove areas ($t = -6.46$, $p < 0.05$).

4.4. Relationships between litter production and meteorological parameters

The relationships between monthly litter production and meteorological parameters were generally weak for both mangrove forests (Tables 1 and 2). In the Kakum mangrove forest, air temperature and wind speed correlated positively with litter production, however, these relationships were not significant ($r = 0.034$, $p > 0.05$ and $r = 0.129$, $p > 0.05$ respectively). There was negative correlation between litter production, and rainfall and relative humidity ($r = -0.221$, $p < 0.05$ and $r = -0.134$, $p < 0.05$ respectively). While the correlations between litter production and relative humidity and wind speed, were positive at Pra mangrove forest, only relative humidity showed significant correlation, $r = 0.169$, $p < 0.05$. Rainfall and air temperature both correlated negatively with litter production, but only that with air temperature was significant ($r = -0.176$, $p < 0.05$).

4.5. Litter production, DBH and height of mangrove species within study plots

Mean litter production, DBH and height of mangrove species within each study plot are presented in Table 3. At the Kakum mangrove forest, mean litter production varied significantly within the four study plots, with Plot 1 recording the highest mean production of 3.67 ± 1.30 g m^{-2} $month^{-1}$ while Plot 4 recorded the least litter production of 1.66 ± 1.25g m^{-2} $month^{-1}$. Plot 1 and Plot 2 recorded the highest mean DBH and height of 3.39 ± 1.02 cm and 3.39 ± 1.19 cm respectively, while the highest mean height of 3.92 ± 1.21 was recorded for Plot 1, followed by Plot 2 which recorded a mean height of 3.69 ± 1.42 m.

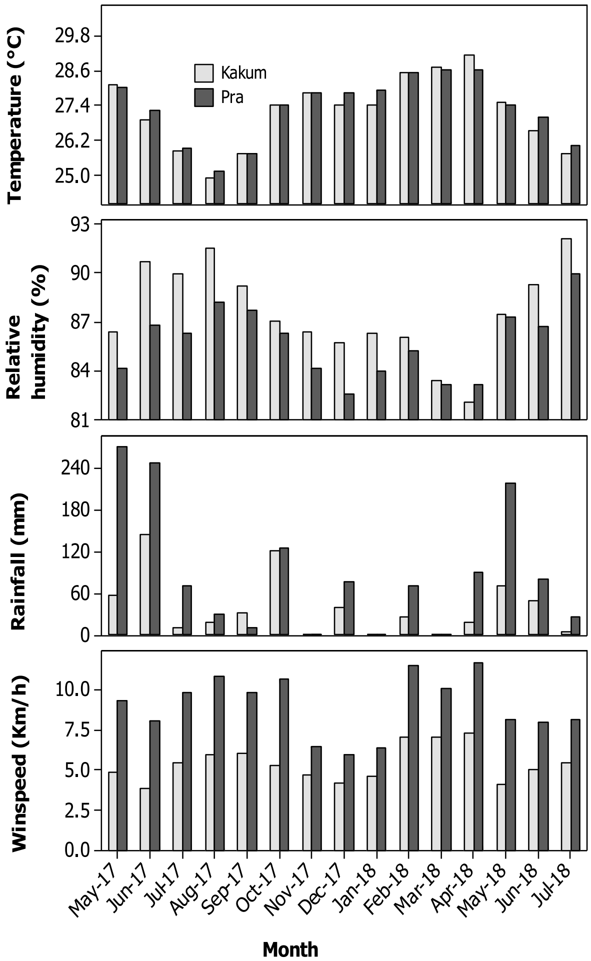

Fig. 5. Variations in meteorological parameters within the Kakum and Pra mangrove areas
Source: Tutiempo Network (2018).

Table 1
Correlations of litter production with contributing factors at Kakum mangrove forest.

	Litter	Air temperature	Relative Humidity	Rainfall	Wind speed
Litter	1				
Air temperature	0.034	1			
Relative Humidity	−.132**	−.909**	1		
Rainfall	−.221**	0.011	.203**	1	
Wind speed	.129**	.229**	−.356**	−.463**	1

*p < 0.05, **p < 0.01, ***p < 0.001.

Table 2
Correlations of litter production with contributing factors at Pra mangrove forest.

	Litter	Air temperature	Relative Humidity	Rainfall	Wind speed
Litter	1				
Air temperature	−.176**	1			
Relative Humidity	.169**	−.805**	1		
Rainfall	−.096*	.181**	.029	1	
Wind speed	.019	−.038	.125*	.041	1

*p < 0.05, **p < 0.01, ***p < 0.001.

Table 3
Mean litter production, DBH and Height of species within study plots.

Study plots	Litter production (SD) ($g\ m^{-2}\ month^{-1}$)		DBH (SD) (cm)		Height (SD) (m)	
	Kakum	Pra	Kakum	Pra	Kakum	Pra
1	3.67 ± 1.30[a]	3.22 ± 1.66[a,b]	3.39 ± 1.02[a]	3.24 ± 2.94[b]	3.92 ± 1.21[a]	4.19081[c]
2	2.90 ± 1.17[b]	2.52 ± 1.49[c]	3.39 ± 1.19[a]	4.06 ± 5.17[a]	3.69 ± 1.42[b]	4.44 ± 1.11[a]
3	2.28 ± 1.38[c]	2.69 ± 1.39[b,c]	3.06 ± 1.11[c]	3.22 ± 0.99[b]	3.29 ± 0.86[c]	3.58 ± 0.80[d]
4	1.66 ± 1.25[d]	3.51 ± 1.58[a]	3.23 ± 1.26[b]	3.12 ± 0.95[b]	3.20 ± 1.01[c]	4.32 ± 0.97[b]

Means for groups in homogeneous subsets are displayed.
SD mean Standard Deviation.

Within the Pra mangrove forest, although the highest and least mean litter production of 3.51 ± 1.58 g m^{-2} $month^{-1}$ and 2.52 ± 1.49 g m^{-2} $month^{-1}$ respectively occurred in Plots 4 and 2, there were overlaps within the study plots. In terms of DBH, the mean highest DBH of 4.06 ± 5.17 cm was recoded for Plot 2, however, there were overlaps within the other study plots. With regard to mean height, there were significant differences among the heights of the mangroves within the study plots, with the highest occurring in Plot 2 (4.44 ± 1.11 m) and least occurring in Plot 3 (3.58 ± 0.80 m).

4.6. Densities of mangrove species within study plots

The density of each of the mangrove species within each study plot is given in Table 4. At the Kakum mangrove forest, *Rhizophora* had the highest density of 2680 ha^{-1} within Plot 1, while in Plot 4, *Avicennia* had the highest density of 7384 ha^{-1}. While *Avicennia* dominated Plot 2 with a denisty of 4640 ha^{-1} at Pra mangrove forest, *Laguncularia* had the highest density of 4456 ha^{-1} in Plot 1 and *Rhizophora* dominated Plot 4 with density of 3768 ha^{-1}.

5. Discussion

5.1. Litter production in the Kakum and Pra mangrove forests

Litter production of mangroves is directly linked to net primary production and global biogeochemical cycles since litterfall plays an essential role of carbon storage as well as nutrient supply within the ecosystem and to adjacent coastal ecosystems [3]. Globally, the rate of litter production for mangrove forests is estimated to range from 100.0 to 2030 g m^{-2} y^{-1} [19]. In this study, the rates of annual litter production at the Pra mangrove forest was higher (1071.51 g m^{-2} y^{-1}) than the rate recorded for Kakum mangrove forest (959.96 g m^{-2} y^{-1}), although both rates fell within the global range. A higher total annual litter production of 3030 g m^{-2} $y^{-1}$was reported for the mangrove forest at Ada Songor Ramsar Site in Ghana [15]. The difference in litter production between the two studies could be possibly due to the restricted access to the Ramsar site which might have enhanced high productivity. That is, the lower rates of productivity recorded in this study could be attributed to the ongoing destruction of these mangrove forests.

Litter production was significantly different between the two mangrove forests and within the sampling months (Fig. 3) and this is in line with several reports on spatial and seasonal variations in mangrove litter production [4,19,30,31,33]. The litter production peaked during the dry and wet seasons in the Kakum and Pra mangrove forests respectively. The peak litterfall in mangrove forests in the wet seasons has been reported in other studies elsewhere [18,34,35]. Nonetheless, peak litterfall was also reported in the dry season [15,23], as recorded for the Kakum mangrove forest. Peak litterfall during the dry season could be attributed to response of the mangrove species to water stress [12]. Given that Kakum and Pra mangrove forests are found within similar equatorial climatic conditions, the difference in litterfall could be due to differences in species composition of mangroves within the study sites. Whilst the Pra mangrove forest contained only *Avicennia germinans, Laguncularia racemosa* and *R. racemosa*, the Kakum mangrove forest was characterized by two additional species - *R.mangle* and *R. harrisonii* [36]. Also, the replanting exercises might have contributed to the higher litter production at the Pra mangrove forest.

Table 4
Densities (ha^{-1}) of species within study plots.

Mangrove forest	Mangroves	Study plots			
		1	2	3	4
Kakum	*Avicennia*	516	700	3924	7384
	Laguncularia	1172	1568	1104	**0**
	Rhizophora	2680	1452	944	**0**
	Total	***4368***	***3720***	***5972***	***7384***
Pra	*Avicennia*	3104	4640	888	92
	Laguncularia	4456	388	2624	1528
	Rhizophora	1168	2224	2896	3768
	Total	***8728***	***7252***	***6408***	***5388***

Leaf litter formed the principal component of the litter production in both forests, ranging from about 61 to 99% of litterfall. This is in line with numerous studies that indicated the leaf as a major component of litter production [9,12,19,23,37]. This finding confirms that leaves are the primary constituents of mangrove litter [2]. Generally, the litter component was in the decreasing order of leaves, reproductive parts (flowers, fruits and propagules) and twigs. This outcome is similar to that of earlier studies [12,12,38,38]. It also supports a recent study that provided the composition of mangrove litter as leaves, flowers, propagules (and/or fruits) and twigs [3]. The highest percentage production of fruits and propagules in both forests, occurred in the wet season. This is in agreement with the findings of other studies that reported highest fruit production during wet seasons [18,35]. This can be related to the phenology of mangroves, whereby fruiting and flowering occurred in the wet season. This supports the findings that indicated that rainfall influenced the production and release of mature fruits and propagules of mangrove species in the Sundarbans, since they are only released when the environmental condition is favourable for their dispersal [3]. Hence, it can be deduced that the wet season is the suitable period for release of propagules and fruits in mangrove forests.

Changes in weather and environmental conditions have influence on mangrove productivity [33]. In this study, however, only moderate to weak correlations existed between litter production and meteorological parameters within both mangrove forests. Wind speed was the common meteorological parameter that showed positive correlation with litter production in both mangrove forests, although its correlation in the Pra mangrove forest was not significant. Rainfall and air temperature correlated negatively but significantly with litter production in Kakum and Pra mangrove forests respectively. This could be the reason why litter production peaked during the dry and wet seasons respectively in Kakum and Pra mangrove forests. In the course of the dry season, higher air temperatures raise cellular metabolism, which in turn activates more litter production to enable mangroves to cope with the higher salt concentration [33]. Also, availability of water has a positive effect on litterfall, which results in higher litterfall in the wet season, whereas in the dry season, higher litterfall occurs as a response to decrease evapotranspiration [4,30]. Thus, variation in the seasonality of peak litter production in the two mangrove forests is acceptable.

Besides climate and structure, site fertility and adequate nutrient have also been cited as factors contributing to litter production [35], as well as species composition [39] and location. In this study, litter production varied significantly among study plots. At the Kakum mangrove forest, the highest mean production recorded for Plot 1 could be attributed to the fact that the plot was close to the mouth of the estuary, that is, more seaward. Besides, the place is highly inaccessible and fairly undisturbed. This is because besides the fact that residents had to cross the river in order to access that place, the place was also dark, marshy, smelly and full of mosquitoes. The extraordinary strong smell at that place could be attributed to hydrogen sulphide and anoxic conditions in deeper sediments [40, 41]. In a similar study conducted in Indonesia, higher litterfall was recorded in seaward than landward, due to environmental conditions including salinity, dissolved oxygen and temperature [7]. In addition to these factors, Plot 1 again recorded both the highest mean DBH and height of species (Table 4), hence, the large sizes and the heights of the mangrove trees might have contributed to the high litter production in Plot 1. Strong correlation between litter production and tree height was also reported in an earlier study [16]. Again, Plot 1 was dominated by *Rhizophora* and this conforms to other studies that reported that *Rhizophora* dominated areas produced higher litter than areas dominated by other mangrove species [35]. Plot 4 which recorded the least litter production was monospecific, only *Avicennia* was present and this might have contributed to the low litter production there. This is because monospecific mangrove forests are known to produce less litter than mixed forests [12]. Also, other studies recorded *Avicennia* to be the mangrove species that produced the least mangrove litter [35,38].

Unlike the trend of litter production observed in the Kakum mangrove forest, within the Pra mangrove, there were overlaps among the study plots, although the production varied among the study plots. The highest production occurred at Plot 4 and this could be attributed to the high density of *Rhizophora* in the study plot, as well as the distance of the plot from the communities, hence, less human disturbances. This supports the finding that anthropogenic activities have been identified to have reduced litter production [20].

It can be inferred from the results of the analyses that different and various factors influenced mangrove litter production within the two mangrove forests. The meteorological parameters comprising air temperature, relative humidity, rainfall and wind speed explained very little of the litter variability. It was concluded in a similar study that the pattern of litter production was influenced by the distinctiveness of each mangrove forest, because a particular factor could be the most significant factor for a given mangrove forest but less influential in another mangrove [35]. The trends for litter production reported in this study therefore, calls for more studies into litter production in mangrove ecosystems in Ghana, taking into consideration different factors that might contribute to litter production.

6. Conclusion

The rates of annual litter production recorded in this study were moderate and far less than the rates recorded for a reserved mangrove ecosystem in Ghana. This indicates that these mangrove forests are under stress and there is a need to conserve these forests for improved litter production, which will serve as bases for food for our marine environments. There were significantly spatial and temporal variations in the rates of litter production, which could be attributed to the type of forest and seasonality. The spatial variations in litterfall showed a higher litterfall for the Pra mangrove forest than the Kakum mangrove forest. All the meteorological and structural parameters that were evaluated had minimal effects on the rates of litter production in the two mangrove forests. This calls for more studies into mangrove litter production to establish the factors that have more control or influence on litter production in the mangrove ecosystems in Ghana. This will help not only to understand the dynamics of litter production, but also emphasise the importance of litter productivity and the need to restore and conserve our mangrove ecosystems.

Author contribution statement

Gertrude Lucky Aku Dali: Conceived and designed the fieldworks and experiments; Performed the experiments; Analyzed and interpreted the data; Contributed materials, analysis tools or data; Wrote and reviewed the paper.

Data availability statement

Data associated with this study has been deposited at University of Cape Coast Institutional Repository https://ir.ucc.edu.gh/xmlui/.

Declaration of competing interest

The author declare that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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